OCEAN DRILLING PROGRAM

Wireline Logging Manual

Volume 1

The Basic Physical
Principles of Well Logging

Borehole Research Group
Lamont-Doherty Geological Observatory
Columbia University
Palisades, New York 10964

SEPTEMBER, 1990

TABLE OF CONTENTS: Volume 1

The Basic Physical Principles of Well Logging

Chapter 1. The Basic Physical Principles of Well Logging

The major problem we face in the Ocean Drilling Program (ODP) is the use of downhole tools designed to detect hydrocarbons for something quite different: subsurface geology. Geology has little in common with either hydrocarbons or water confined within the pore space of a rock., and the tools themselves do not detect oil, gas or water directly. Consequently, combinations of different tools are necessary to determine either the lithology or the type of fluid in the formation. It is very important to always keep in mind the physics behind each type of logging tool because we must understand what these tools are actually measuring when they are lowered into the ODP's unusual environments such as basalts with under 10% porosity or sediments with over 60% porosity.

Density and Neutron Porosity Logs

In order to test how much of the physics of downhole measurements we really understand consider a standard set of logs: gamma ray, bulk density and neutron porosity (Figure 1). The density tool uses a cesium source to bombard the formation with gamma rays; these are scattered through the rock and gradually losing energy. The tool measures the energy level of the gamma rays returned to a NaI crystal with a photo multiplier, which measures flashes of light emitted as each gamma ray impacts the crystal. A simple geiger-counter does the same thing, except that it emits a "click" rather than storing the energy level. The drop in gamma ray energy occurring during the scattering process through water, rock matrix, and hydrocarbons, is strictly related to the electron density of the formation and in turn to the bulk density of the rock. Thus, the physical measurement made by the density tool does not discriminate the density of the rock matrix from that of the pore fluid. Therefore, other measurements are necessary to detect the differences among water, oil, and gas in the pore space of the rock.

The neutron porosity tool employs a chemical source (Am-Be) to bombard the borehole and the formation with neutrons. Neutrons collide with the molecules in formation and lose energy with each collision, just as gamma rays do. But neutrons lose energy most effectively when they hit something their own size. Neutrons are closest in size to hydrogen atoms present in the fluid and rock. In order to better understand this physical principle consider the case of a cue ball hitting the snooker ball versus the bowling ball. If your neutron (the cue ball) hits a hydrogen atom (the snooker ball) which is the same size, significant energy transfer occurs. If a neutron hits any other element in the formation or fluid (a bowling ball), the neutron loses less energy. In conclusion, the response of the neutron tool depends on the hydrogen concentration in the formation, and because water and hydrocarbons have different hydrogen indexes, the neutron porosity device allows us to discriminate among the types of fluid in the rock.

Water is densely packed with hydrogen atoms. Hydrocarbons are complex organic molecules of very large size, thus hydrocarbons do not ordinarily have as much hydrogen per unit volume because the molecules are much larger than H_2O molecules. If the pore fluid is a heavy oil, it could have almost as many hydrogens as water but if it is a light oil, or gas, it will have a lower hydrogen index.

In the sandstone reservoir from 2500 to 2550 feet in Figure 1 gas, oil, and water can be discriminated by using both density and neutron logs. While the neuron log yields a very different response for the three types of fluid (with the typical crossover to low density-low porosity in the gas-bearing interval), the density log exhibits similar low density values over the gas and oil zones, thus indicating the presence of a very light oil.

In the example of Figure 1 the neutron log exhibits the highest values over clay-rich zones (shale). These high porosity readings, however, are only apparent; in fact, because of its sensitivity to all the hydrogens present in the formation. The neutron tool "sees" the bound water associated with clay minerals, and translates it into additional porosity. The amount of bound water varies with the clay type, and is inversely related to its hydrogen index. Corrections based on the volume of clay present and on the response to the clay type in the formation are required to estimate the "true" porosity of the rock.

Natural Gamma Ray Log

The addition of a measure of the natural radioactivity of the formation further contributes to the ability to find oil and gas. Natural radioactive decay from potassium, uranium and thorium produces gamma rays that can be measured by a NaI scintillation detector. In sedimentary formations the gamma ray log reflects the shale content of the formation, because radioactive minerals concentrate in clays. Igneous rocks can also exhibit high radioactivity levels, due to the presence of potassium-rich minerals. In the example in Figure 1 the gamma ray log allows us to recognize the shales from the "clean" sandstone intervals.

While potassium is chemically bound into the shale, uranium is electrically attracted to slots occupied by oxygen in the clays. If millions of years after burial the shale is swept by an oxygenated ground water, the uranium will be leached away and deposited elsewhere. The concentration of uranium in the sediments will be controlled by depositional environment and diagenetic processes, thus adding information on the geologic history of the well.

Acoustic Logs

Another useful physical measurement is acoustic velocity. While this measurement can be effectively used for gas identification (where it corresponds to a large reduction in compressional velocity) it does not provide any help when we try to separate oil and water. If we bang a hammer on a table, the acoustic energy travels through the table, regardless of the presence of fluid on the top. The velocity measurement is thus primarily made to separate the matrix from the fluid. If both shear and compressional velocities are measured, then we can describe the elastic parameters of the rock

Of course, another important reason to measure sonic velocities is that the well was sited based on seismic reflection profiling. Velocity times density gives seismic impedance which is used to generate synthetic seismograms to tie well-depths to seismic times.

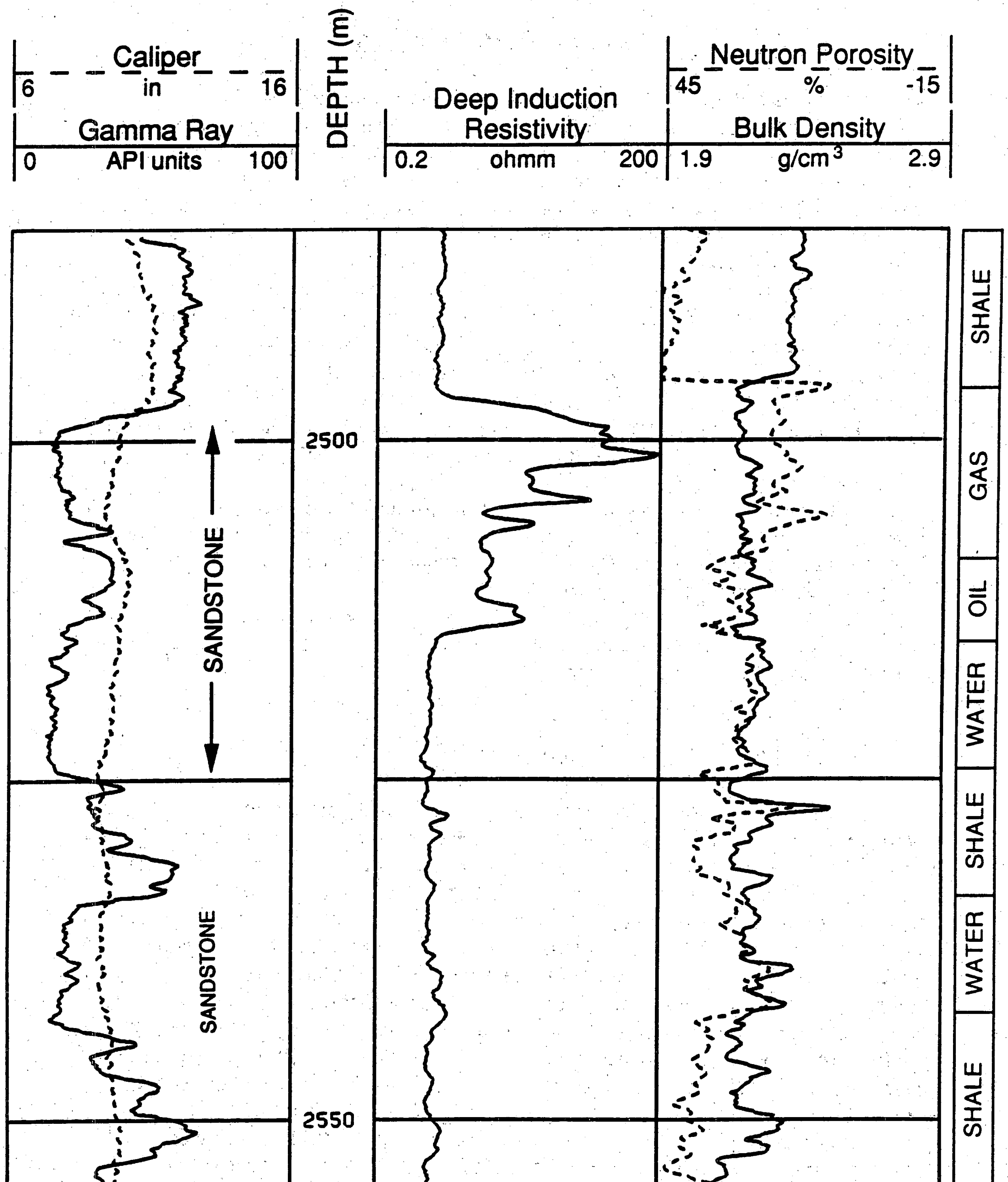


Figure 1. Example of the typical response of standard logs in a sandstone gas- and oil-bearing reservoir.

Electrical Resistivity Logs

The resistance of a rock to the passage of an electrical current provides significant help in determining the pore fluid composition. The transmission characteristics of an electrical current are the opposite of those of an acoustic wave; unlike sound energy, an electrical current moves primarily through the pore fluid. Water is the most conductive fluid; its conductivity is directly proportional to salinity and, to a lesser degree, to temperature. In fact, the presence of Na^+ and Cl^- ions promotes the flow of electrons, while a temperature raise increases their mobility.

One of the major problems in reservoir analysis based on well logs is that clays can greatly contribute to an increase of the conductivity of a reservoir; in fact, all clays have negative charges because of electrostatically unbalanced substitutions within their lattice or of broken bonds on the edges of the silica-alumina units. These charges are partially balanced by absorption on the clay surfaces of counter-ions, which are exchangeable with other cations in aqueous solutions. The amount of this cations is called cation exchange capacity (CEC) and is responsible for the additional conductivity observed, for example, in shaley sands.

Hydrocarbons have low conductivity (high resistivity) because they do not contain many free ions within their huge, complex organic molecules. In the sandstone of Figure 1 the hydrocarbons are recognized by the high resistivity values between 2495 and 2515 ft, with gas being more resistive than oil.

Table 1 summarizes the typical responses to gas, oil, water, and shale of the logs commonly used in the oil industry. See Volume 2 for more detail about how these geophysical logs are used in oil exploration.

Geochemical Logs

The measurement performed with the geochemical logging tool (GLT) is more complicated than that of physical properties such as bulk density or porosity. It uses a pulsed-neutron accelerator , called a "minitron" to bombard the formation with fast neutrons. The "minitron" was developed by NASA to measure the chemical composition of the moon by remote sensing. The Apollo capsule shot neutrons at the surface of the moon and measured the energy level of gamma rays returned from the surface. The gamma rays emitted by interaction of the fast neutrons with the nucleii in the formation are measured in the geochemical logging tool by a spectrometer consisting of a NaI detector and a 256-channel analyzer. Each gamma ray that randomly hits the NaI crystal (similar to that employed in the natural gamma ray spectrometry tool) makes a flash of light of a certain "color" which is a function of the energy of the gamma ray that has just collided with the crystal.

Unlike the GLT, gamma ray spectroscopy experiments carried out in a laboratory utilize a germanium crystal. This is not used for logging because it must be maintained at cryogenic temperatures; in fact these crystals are clear at temperatures near -270°C, whereas they become "cloudy" at room temperature. The advantage in using a germanium

Table 1. Response of well logs commonly used in oil/gas detection.

	Gamma Ray	Resistivity	Neutron Porosity	Density
GAS	low (1)	high	low	low
OIL	low	high	medium-high (2)	medium-high (3)
WATER	low	low	medium-high	medium-high
SHALE	high (4)	low	high	high

(1) assuming a "shale-free" reservoir
(2) depending on the oil hydrogen index
(3) depending on the oil density
(4) assuming K-rich shales

crystal is an enhanced sharpness in the "color" of the flash of light, though the brightness is slightly lower. On the other hand, the sodium iodide crystal works at temperature as high as 150°C, above which it also becomes "cloudy".

The geochemical logs of the well displayed in Figure 2 provide the elemental abundances of iron, silica, calcium, and aluminum from induced gamma ray spectroscopy, as well as the concentration of thorium, uranium, and potassium from natural radioactivity. The combination of these chemical curves allows for a precise definition of lithology. In the example of Figure 2 two sandstone intervals, separated by a "shale" layer, can be identified between 2300 and 2500 ft. They are characterized by high silicon content, and low concentration in the radioactive elements. The lower interval exhibits an increase in iron and aluminum, which might be related to the presence of abundant feldspars. The shales are seen by their high aluminum, iron, potassium, uranium, and thorium content. Also, they display lower silicon content than the sandstones above. The calcium curve in Figure 2 leaves no doubt about the presence of two limestone layers at 2750 and 2900 ft.

The Ocean Drilling Program

> "The Ocean Drilling Program is the world's largest and most successful multi-national earth science research effort. By drilling deep beneath the sea floor, scientist can reconstruct the fundamental mechanisms that have led to formation of ocean basins, island chains, and mountain ranges. The ODP provides researchers with data essential to understanding the history and structure of the earth's slowly changing surface, and the evolution of its climate" (from "A record of our changing planet", Joint Oceanographic Institution).

The program employs a 143-meter long drilling ship, the JOIDES Resolution, to drill holes in waters as deep as 4-5,000 meters. Drilling is routinely performed with one way fluid circulation, (no return of fluid and cuttings to the surface), by lowering the drill pipe freely through the water column (Figure 3). At the beginning of some holes a re-entry cone is drilled into place and cemented with a short casing string. This allows scientists to re-enter the hole during subsequent legs by using a television camera, located at the bottom tip of the pipe. Unlike the oil industry, where selected hole intervals are sampled by sidewall coring, continuous coring is a standard practice in the Ocean Drilling Program. However, in most of cases continuous coring does not result in 100% core recovery; well logs are effectively used to fill these gaps.

When discussing logging within the ODP, it is very important to always keep in mind the basic physical principles behind each measurement, because the logging tools are used in scientific environments very different from those encountered in oil exploration (see above). Several improvements of tools and techniques have been necessary to solve some problems related to the unusual ODP logging environment for example, ship's heave. Because there is no "riser" connection to the sea floor the ship's heave is transmitted as movement onto the logging cable, thus affecting all measurements to various degrees. To solve the problem, L-DGO-BRG contracted Schlumberger to design a wireline heave motion compensator (WHC) for the logging cable. After an independent engineering report

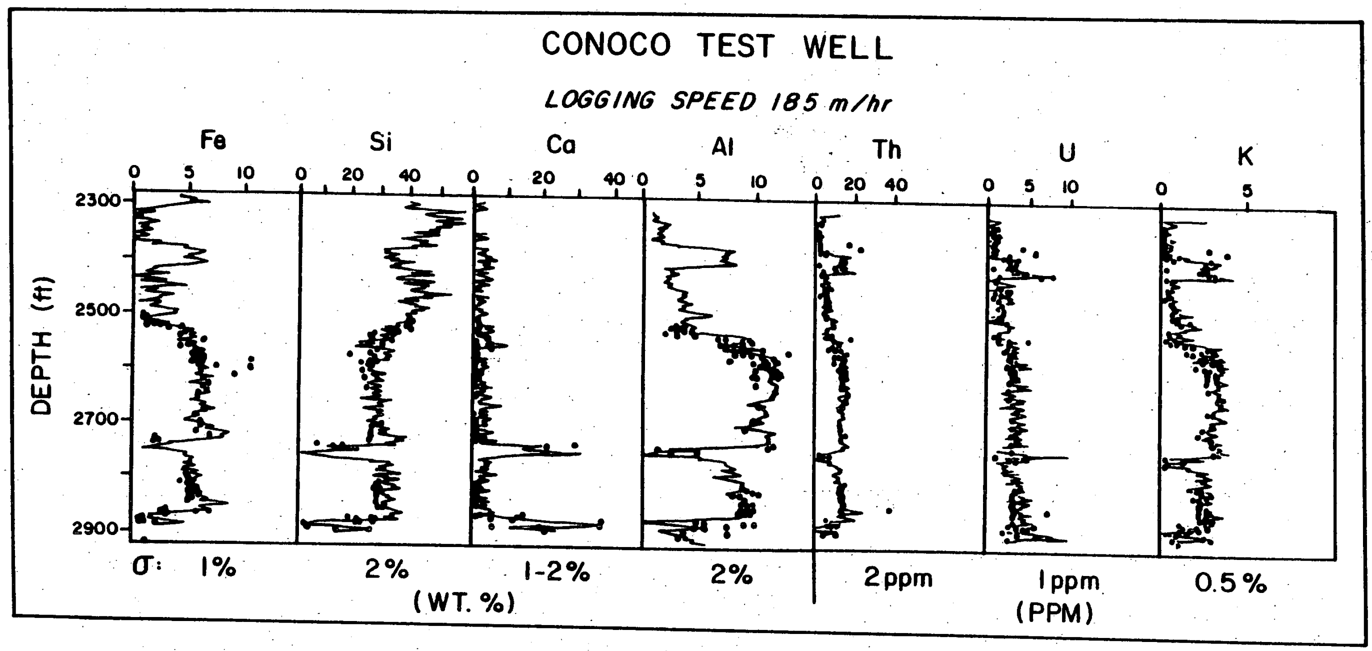


Figure 2. Geochemical logging results compared with analyses made on sidewall core samples from the Conoco Test Well in the Anandarko Basin. Standard deviations between core and log results are shown at bottom.

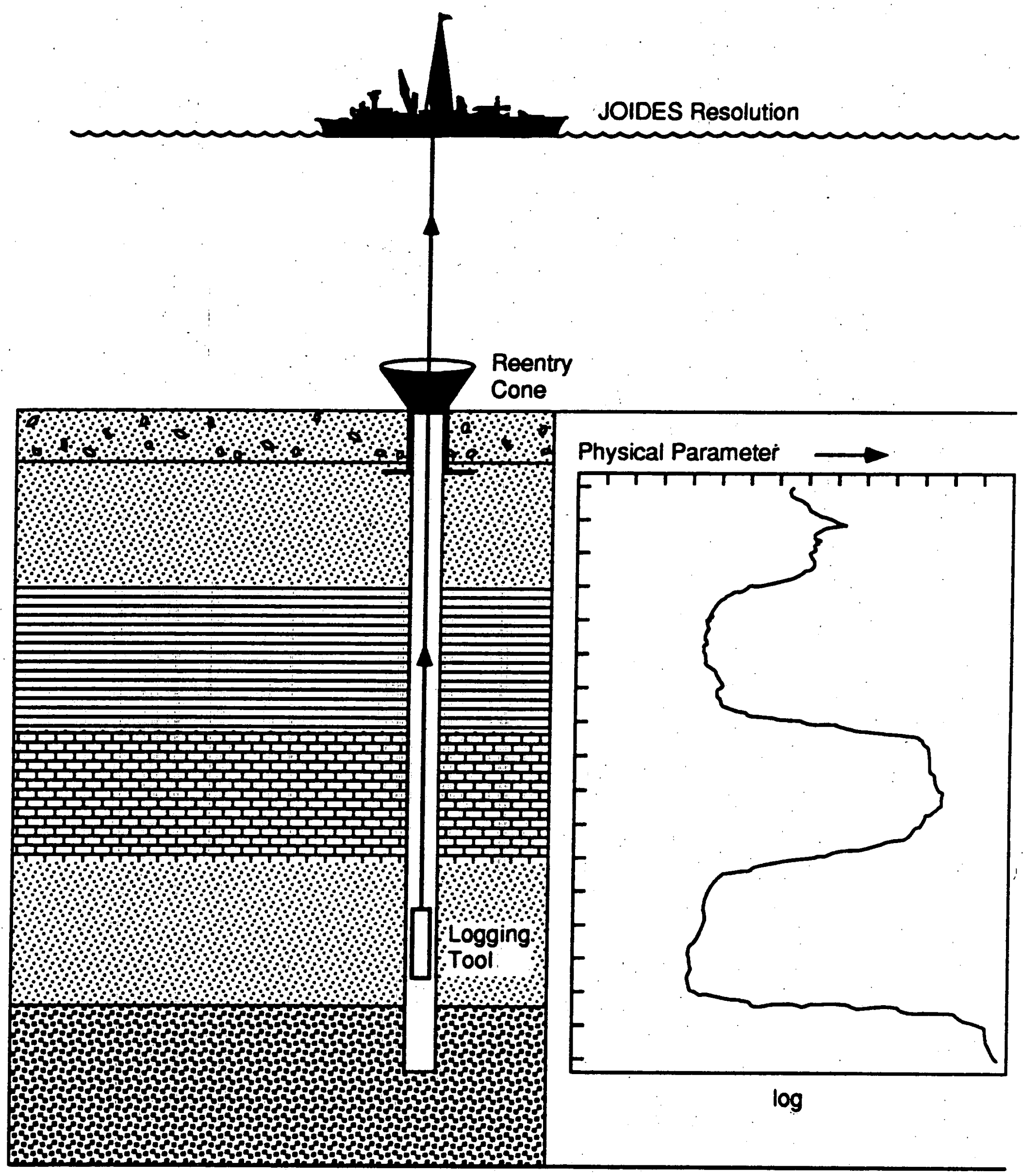


Figure 3. Schematic drawing of logging operation on the JOIDES Resolution.

determined that the design was effective, the compensator was installed on the starboard side of the winch cab. During logging operations the logging cable is run from the winch to the rig floor, then back through a piston-mounted sheave on the heave compensator, and back again to the rig floor. As the piston extends, the length of cable between the winch drum and the rig floor is reduced by twice the amount of extension. The ship's heave is sensed by an accelerometer mounted near the rig floor, and the signal is transmitted to a computer which computes the effective motion. The piston-mounted sheave is then driven in or out to compensate for vertical motions of the drilling vessel. Tests of this system on ODP legs indicated that in operation the heave compensator improved log quality and reduced the primary components of ship's heave by more than 50%.

Another major problem encountered when logging for the Ocean Drilling Program is the bad hole conditions, mainly caused by the use of seawater as drilling fluid. In soft sediments seawater causes clays to swell, thus producing bridges that have often limited or prevented the logging program in the well. Besides the introduction of additives such as KCl or, less often, bentonite in order to inhibit clay swelling, we have adapted a part of the oil industry's horizontal logging capabilities called a Sidewall Entry Sub (SES). The drill pipe is first lowered into the hole and then the logging tool is lowered into the top of the drill pipe through the SES. The logging cable travels from the winch outside the drill pipe to the SES, where it passes inside the pipe to connect to the logging tool. This SES is then lowered with the drill pipe; the logging tool is pushed through the bottom of the drill pipe: and the tool and pipe are pulled upward simultaneously during logging. As you might guess, communication and coordination are difficult, and ODP has lost two logging tools so far using this technique. On the other hand, many ODP wells have been logged successfully with this technique.

Conclusions

Table 2 summarizes the major differences between ODP and oil industry data acquisition cultures. In the oil industry, sidewall coring is carried out solely in the hydrocarbon-bearing intervals, and only selective analyses are performed. Neglecting the rest of the hole means missing important information about the geology of the well (for example about the aquifer and the water replacement system of a reservoir delivering oil or gas to the surface).

In the ODP, we continuously core by wireline and have an extensive sampling and analysis program, both on the ship and on shore. A full array of measurements is routinely carried out on board (e.g. X-ray fluorescence and diffraction, pore fluid analysis, physical and magnetic properties, and biostratigraphy).

Finally, as you will see in the following volumes, the logging suites run in the Ocean Drilling Program are more complete than those run in in the oil industry. In fact, logging for the Ocean Drilling Program is the most technically complete downhole measurement program operated on a routine basis in the world. In succeeding volumes of this logging manual, the methodology for scientific well logging will be presented in more detail.

Table 2. Comparison of data acquisition cultures.

OIL INDUSTRY	ODP
SELECTIVE CORING	CONTINUOUS CORING
VERY SELECTIVE ANALYSIS	VERY RIGOROUS ANALYSIS
ONLY RESERVOIR ANALYSED	ALL MATERIALS ANALYSED
GENERALLY MORE LIMITED LOGGING SUITES	VERY DIVERSE LOGGING SUITES

OCEAN DRILLING PROGRAM

Wireline Logging Manual

Volume 2

Exploration Well Logging:
A Historical Perspective

Borehole Research Group
Lamont-Doherty Geological Observatory
Columbia University
Palisades, New York 10964

SEPTEMBER, 1990

TABLE OF CONTENTS: Volume 2

Exploration Well Logging: A Historical Perspective

Exploration Well Logging: A Historical Perspective

Within the Ocean Drilling Program (ODP), there is often confusion as to what benefits will come from having an arsenal of downhole measurements run in a well when one could use the rig time to obtain more core material. One of the basic differences between ODP and the oil industry is that the ODP cores continuously. The oil industry's primary method for finding oil in a well is wireline logging, and consequently, it tries to minimize core because it is very expensive. Within ODP, the situation is reversed; because obtaining cores is your primary objective, there is a certain amount of reticence to use precious rig time for logging. But most ODP scientists now appreciate the added value of logging:

1) logging measurements are made at *in situ* conditions,
2) logging measurements are made on a continuous basis throughout the well with no missed section, and
3) logging sample size is many times larger than cores.

These are the distinct advantages of downhole measurements within the ODP, as well as in the oil industry. Below, we will review the development of exploration well logging from the oil industry perspective. A perspective of where logging came from may help the scientist to better realize the strengths and weaknesses of logging when used to solve strictly geological problems. At the end of this volume, we should be to the point where the jargon, definitions, and perspective are out of the way so that subsequent volumes can discuss how to apply well logs to scientific objectives.

The Early Logs

The very first well log was an electrical log run in 1927 by the Schlumberger brothers in the Paris basin, France (Figure 1). In those days, the first logs were done in stationary mode: that is, the cable was stopped for several minutes at fixed points in the well in order to make the measurement (logs are now run continuously uphole).

The simplest of the early logging tools, which emerged in the early 1930's, and which is still part of the standard logging suite today, is the self potential (SP) log. The SP log is basically a single electrode pulled up the hole. It measures the "natural voltages" in the subsurface through an earth return. These "natural voltages" are, in fact, completely unnatural because they would not exist if the hole was not there. But the SP is still useful because it gives information about permeable zones. Electrochemical cells are established at boundaries between sands and shales, assuming that there is a salinity contrast between the borehole and the formation fluids. The SP log provides a very qualitative picture of the permeability in the formation.

The normal resistivity device, which came into use around 1932, is still offered today by a number of contractors and is used widely in other industries, for example for water resource evaluation. It was the first continuous measurement of the resistivity of the

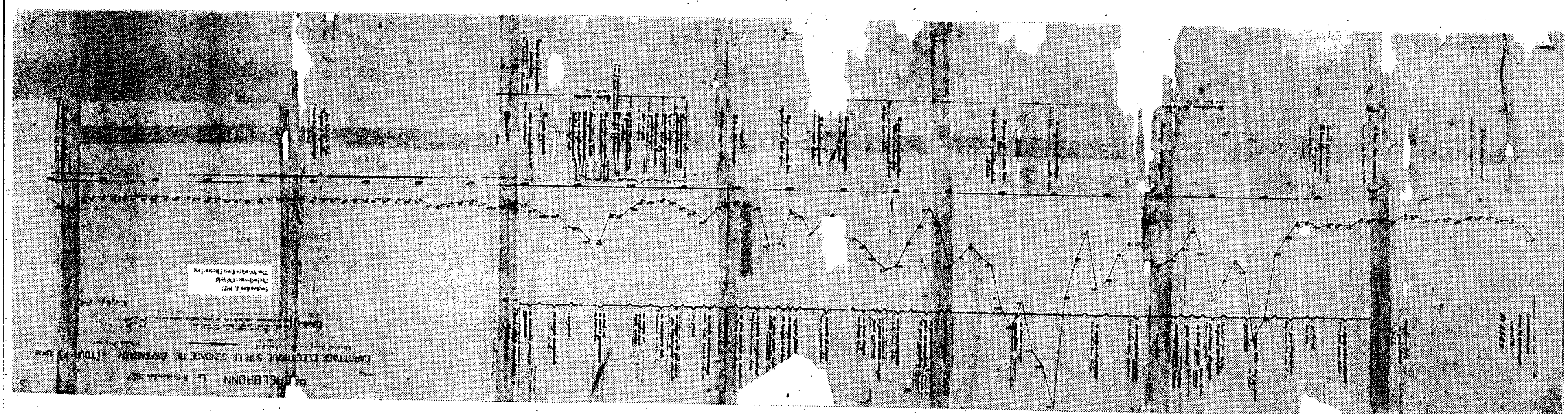


Figure 1. The first log was an electrical log recorded by the Schlumberger brothers in 1927.

subsurface. These electrical logs could be used to determine bed thickness because resistivity changes from one bed to another. Also, high resistivity gave indication of the presence of hydrocarbon-bearing zones.

As we entered the era just before the Second World War, the practice of formation evaluation using downhole measurements was simply of correlating these electrical logs between wells and of trying to locate permeable zones with the SP log.

Archie's Law

This qualitative approach was dramatically changed in 1941 by the work of Gus Archie from Shell, who put together the "formation factor" concept from work of a number of previous investigators (in fact, the formation factor concept, now called "Archie's Law" was introduced by a Swede, Karl Sundberg, in 1932). Archie's Law (Table 1) contains the basic quantitative definitions of how to find hydrocarbons using resistivity logs. Basically, Archie put different electrolites into the pore system of a rock in the laboratory and observed that the ratio of R_o (the resistivity of a rock 100 % saturated with water) to R_w (water resistivity) remained nearly constant for resistivity of the electrolite <1 Ωm. Therefore, the ratio was not a factor of the fluid; it was a factor of the formation. Called the "formation factor", Archie developed this into the partially saturated domain by observing that the more you de-saturated the rock, the more resistive it became. The ratio of R_o to R_t (formation resistivity), called the "water saturation index" (S_w; Table 1), was intuitively linked to the amount of water versus hydrocarbon in pores. These two equations (formation factor and S_w) have become known as the first and second Archie's laws.

Archie's first law, which related formation factor to porosity was essentially empirical (he observed that there was a logarithmic relation, Figure 2). He called the gradient "m" the "cementation factor" or the cementation indicator. These days people use it as a pore geometry exponent. The second law relates the resistivity index to the water saturation - the fraction of the pore space that is actually filled with electrolite as opposed to fluids such as gas or oil. Again these were found to be exponentially related. The gradient "n" was called "saturation exponent." The first law has never been proved theoretically, though it has been established empirically in the laboratory in numerous formations, including basalts and other fractured media. It is used extensively within the ODP to calculate porosity from resistivity.

Interpretation Philosophy - 1945

If we move to 1945, we can begin to see modifications made to Archie's Law. We are already approaching the philosophy of log evaluation as it is today in the oil industry.

Resistivity logging tools of 1945 measured R_t and R_w, allowing the formation factor to be calculated from Archie's first law. Measurement of formation resistivity from sidewall cores would then allow the calculation of porosity. If you didn't know "m", you would assume it to be equal to two. But there was no way of separating the porosity effects

Table 1. Archie's Laws (1942) for clean (no clay present) sands.

$$\varnothing = \left(\frac{a}{F}\right)^{1/m} = \left(\frac{R_w}{R_o}\right)^{1/m}$$

$$S_w = \left(\frac{1}{I}\right)^{1/n} = \left(\frac{FR_w}{R_t}\right)^{1/n}$$

$\varnothing$ = porosity
F = formation factor
m = cementation factor
a = empirically determined constant
R_w = formation resistivity (100% water-saturated)
R_o = formation water resistivity
R_t = formation resistivity
S_w = water saturation (% of pore space occupied by water)
I = resistivity index
n = saturation exponent

soft formations:	a = 0.62	m = 2.15
	a = 0.81	m = 2
hard formations:	a = 1	m = 2

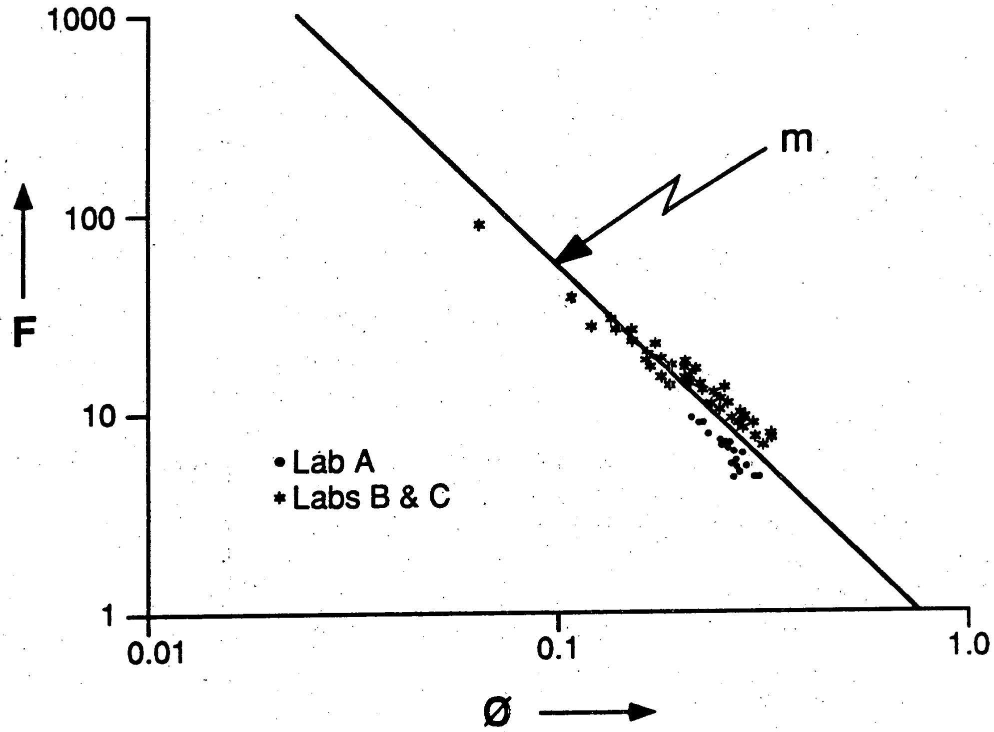


Figure 2. Formation resistivity factor - porosity correlation from different laboratories (after Hook, 1983).

caused by lithology changes from those created by the occurrence of the hydrocarbons, so the practice was to assume constant porosity throughout the possible reservoir intervals. That is, you could measure porosity in the water zone through this new empirical facility of Archie, but you couldn't find it in the hydrocarbon zone. If you then measured the formation resistivity of the hydrocarbon zone, R_w from a sample of water, and the formation factor of the water zone, then you could calculate a resistivity index (I; Figure 3). If you measured the value of "m" (and if you did not know it, you assumed 2 again), you could then calculate S_w from Archie's second law. The relationship between I and S_w is shown in Figure 4. Combined with the bed thicknesses, S_w told you the total amount of recoverable hydrocarbons in the well.

Tool Developments - 1945-1970

By the end of the Second World War, the quantitative approach in well log interpretation was established, but some important technical and interpretation problems were still waiting for a solution. Among them, the need of resistivity tools with different depth of investigation, able to provide a measurement in both the shallow "flushed" zone (invaded by the drilling mud filtrate) and the deep "virgin" zone, unaffected by the mud filtrate. Such tools would provide a key to a better estimate of the porosity (allowing for a correction for the effect of hydrocarbons), of water saturation, and of movable and irremovable hydrocarbons.

So the tool development of the next twenty five years was directed at filling these gaps (Table 2). First we saw the emergence of the microlog, a pad-device consisting of two switchable arrays of electrodes several centimeters apart. Because they are sensing resistivity variations only very close to the hole, they are very much influenced by the mudcake. The mudcake forms when the formation is permeable; if there is no mudcake, we presume there is no permeability because there has been no mud filtrate invasion. Where the mudcake is thick, the two microlog electrodes respond differently and the measured resistivity curves separate.

Because of its very shallow investigation, the microlog was not the answer to the porosity problem (Figure 4). In the early 1980's, Schlumberger tried to withdraw it from the market, but there was pressure from oil industry customers to maintain it because it provided unambiguous information about the location of permeable zones.

In response to the porosity problem several non-electrical porosity measurement tools were designed in this period, such as the neutron porosity, gamma ray density and continuous velocity tools. There are now algorithms relating the responses of all these tools to porosity. In the latter two cases, the algorithms are conceptual, while in the former, they are empirical.

The other major developments during this time were the deep sensing resistivity logs. These focused tools were specifically designed to investigate the virgin zone, that is the zone uninvaded by the mud filtrate. The development of electrical induction devices, guard logs, and laterologs allowed for the first time a precise measurement of the bulk resistivity of the formation.

At this point we saw the emergence of the same interpretation philosophy that is in use today (Figure 5). We could now measure porosity from nuclear logs and the resistivity of

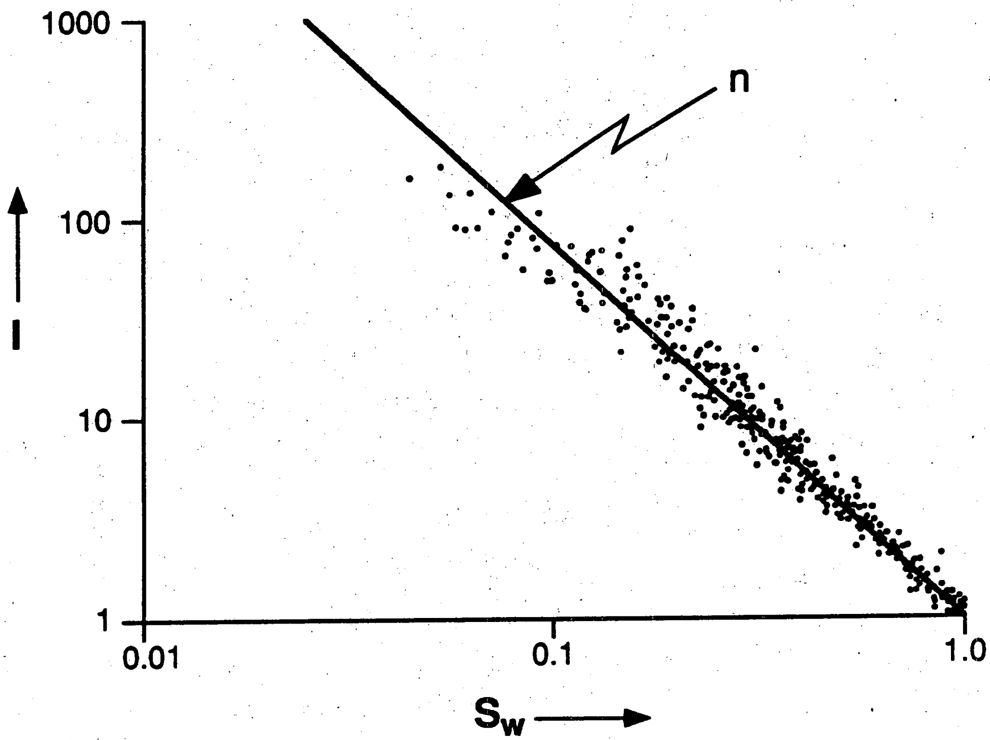


Figure 3. Resistivity index - water saturation correlation (after Hook, 1983).

Table 2. Tool developments in the 1945-1970 period.

Microlog	• **Micronormal**
	• **Microinverse**
<u>Porosity</u>	• **Neutron–Neutron Log**
	• **Continuous Velocity Log**
	• **Gamma–Gamma (Density) Log**
Deep Resistivity	• **Induction Log**
	• **Guard Log**
	• **Laterolog**

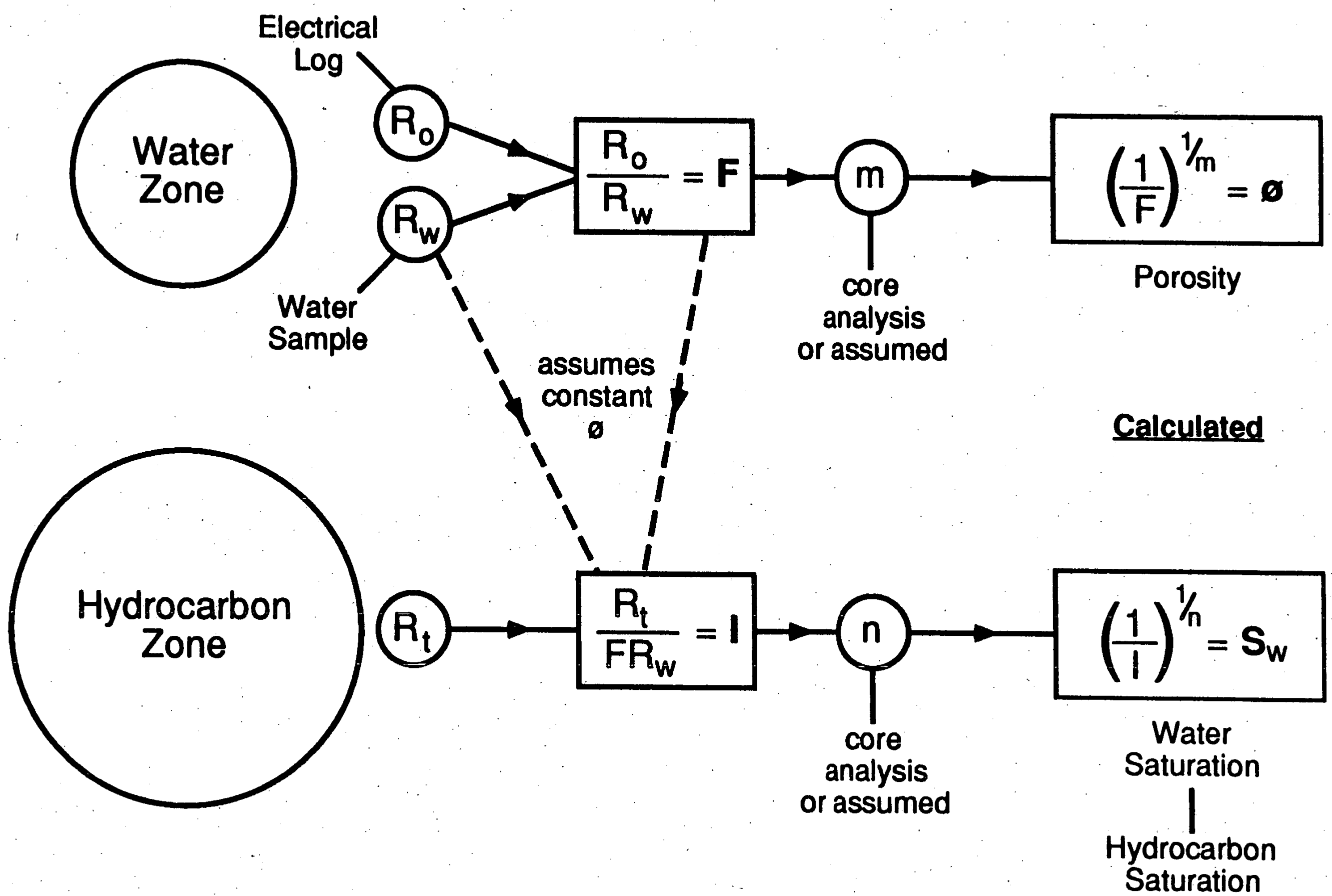


Figure 4. 1945 interpretation philosophy in clean unconsolidated formations.

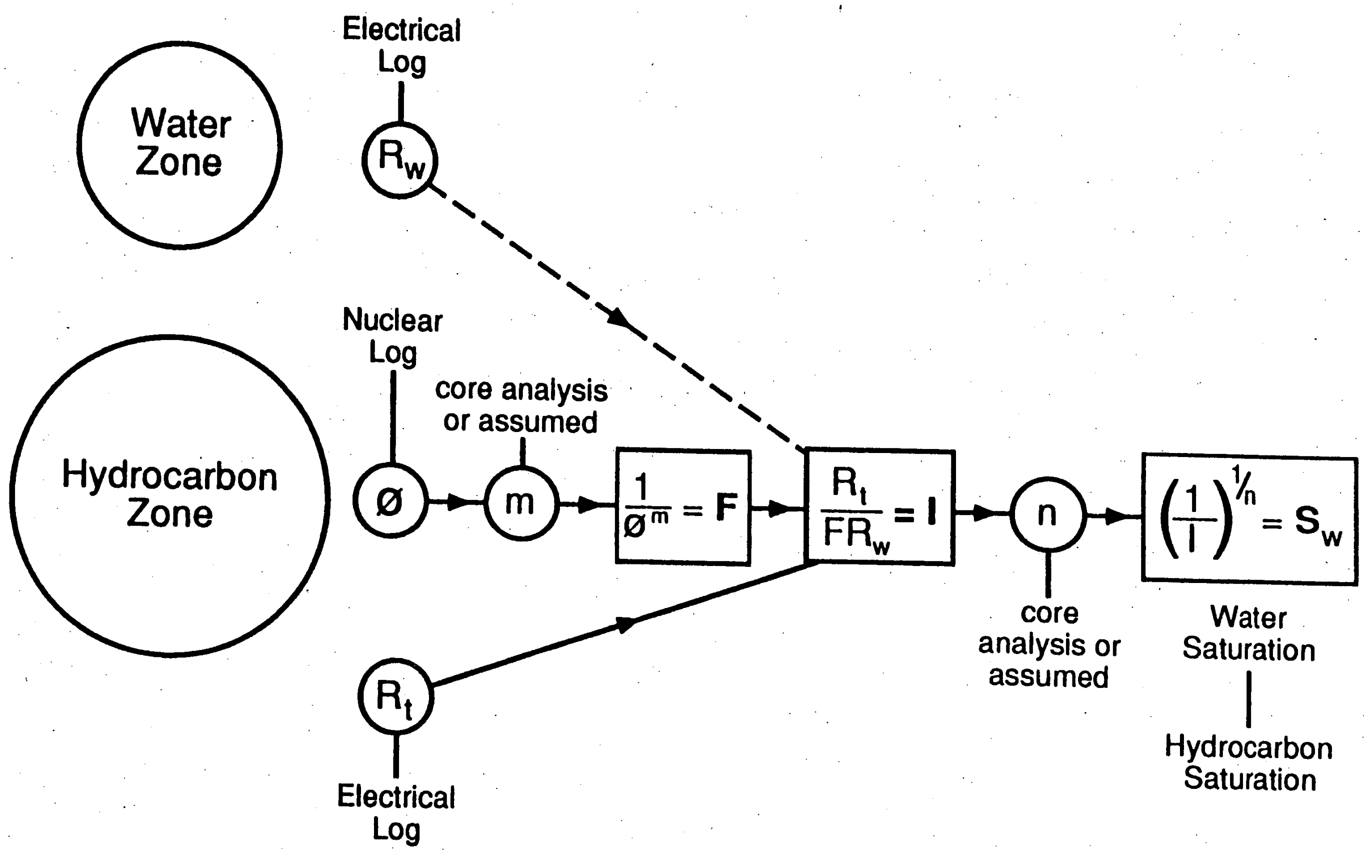


Figure 5. 1945-1970 interpretation philosophy in clean formations.

the rock in both flushed and virgin zones. Note that in Figure 5 Archie's first law is now being used backwards. The original intention of Archie was to move from resistivity to porosity, and then to hydrocarbon concentration. What happened by 1955 was that we measured neutron and density porosity in the hydrocarbon zone and used that to calculate a formation factor independent of resistivity. It's in this reversal of Archie's law that the shaley sand problems of the 1960's became evident (see below).

The basic problem is that shaley sands with water in the pore space look very much like oil-bearing reservoir rocks (Figure 6), and as such it remains one of the major technical difficulties that the oil industry faces today. Shaley sands are sandstones that contain intermixed clay minerals. In a shaley sand, the resistivity values are lower than what you would expect from the electrolite distributed in the rock pore space (Figure 7). This effect is caused by the surface interaction between clay minerals and the electrolite in the pore fluid; whenever clay mineral surface conduction effects are present, they have an impact on the determination of resistivity-derived porosity.

In terms of the ODP, there are also clear situations where data have been misinterpreted because clay mineral products over altered zones produce the same effects on resistivity data as in oil reservoirs. One must be careful that Archie's law not be applied indiscriminately. Archie said, "My law only works for clean situations" (Journal of Petroleum Technology, 1953).

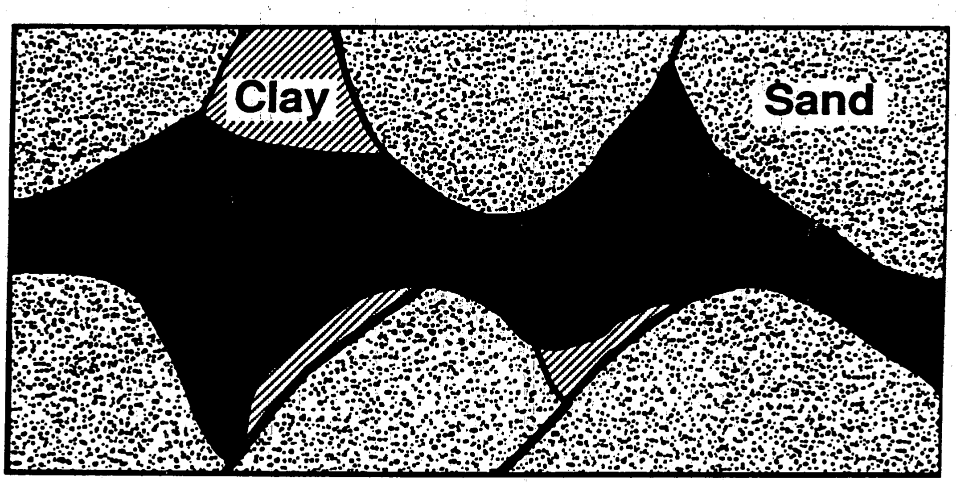
After 1960, we moved into the era of the logging tools as we know them today. Dual and multi detector tools started to be developed in order to overcome some of the problems related to the borehole environment (such as mudcake). Also, many realized that perhaps Archie's original experimental assumptions were not quite as valid as were thought of at the time. In fact, Archie had specified quite clearly that the relationship was valid for limestones and sandstones with very little clay-mineral content and high salinity, and that his "law" was applicable only over certain ranges of porosity. If you look at the shaley-sand literature, it appears that in 1951 clay minerals suddenly began growing in abundance in the reservoir rocks, only to stop in 1960 when another generation of logs was introduced.

The Interpretation Philosophy into the 1970's

In shaley-sands, the formation factor (R_t/R_w) drops fairly steeply as the volume of clay increases. To take this into account the literature now offers 50 different equations (see Appendix II) that all attempt to evaluate this extra conductivity, called "X" in Figure 8. For Archie's original laws, there are now correction factors for each term. Unfortunately, each equation provides a different answer. However, a way to test which equation is most appropriate for a specific situation is to check the value of water saturation (S_w) in the water-bearing zone (dashed line in Figure 8), where it should be equal to 100%.

New Technologies of the 1980's

The standard logging suite in the oil industry in the 1970's consisted of caliper, gamma ray, sonic, density, neutron porosity, and various resistivity logs, each with different



Δt_{sh} ρ_{sh}
Clay Bound Water } Porosity

R_{sh}
Electrochemical Effects (CEC) } Resistivity

Δt_{sh} = shale transit time
ρ_{sh} = shale bulk density
R_{sh} = shale resistivity

Figure 6. Problems of shaley sands.

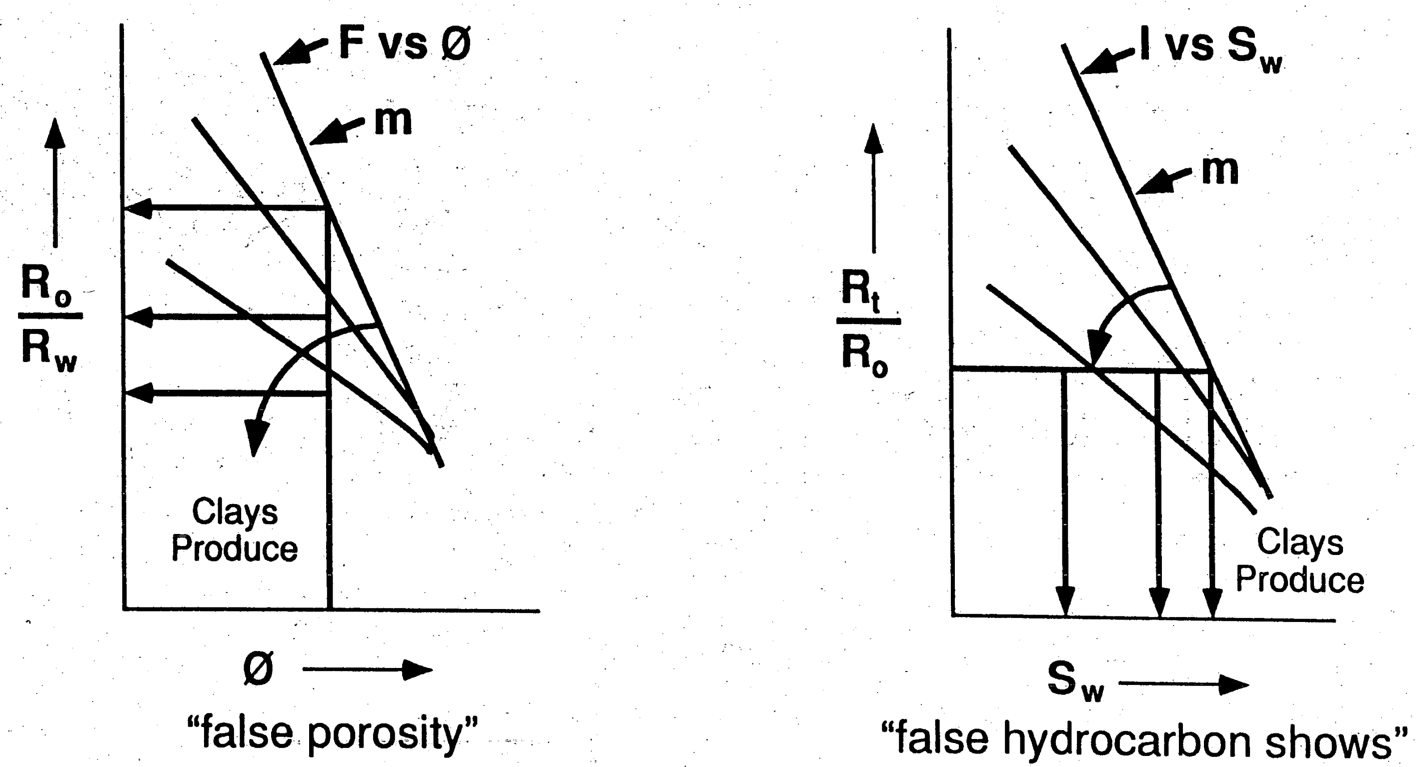


Figure 7. Effect of shaliness upon Archie's relationships.

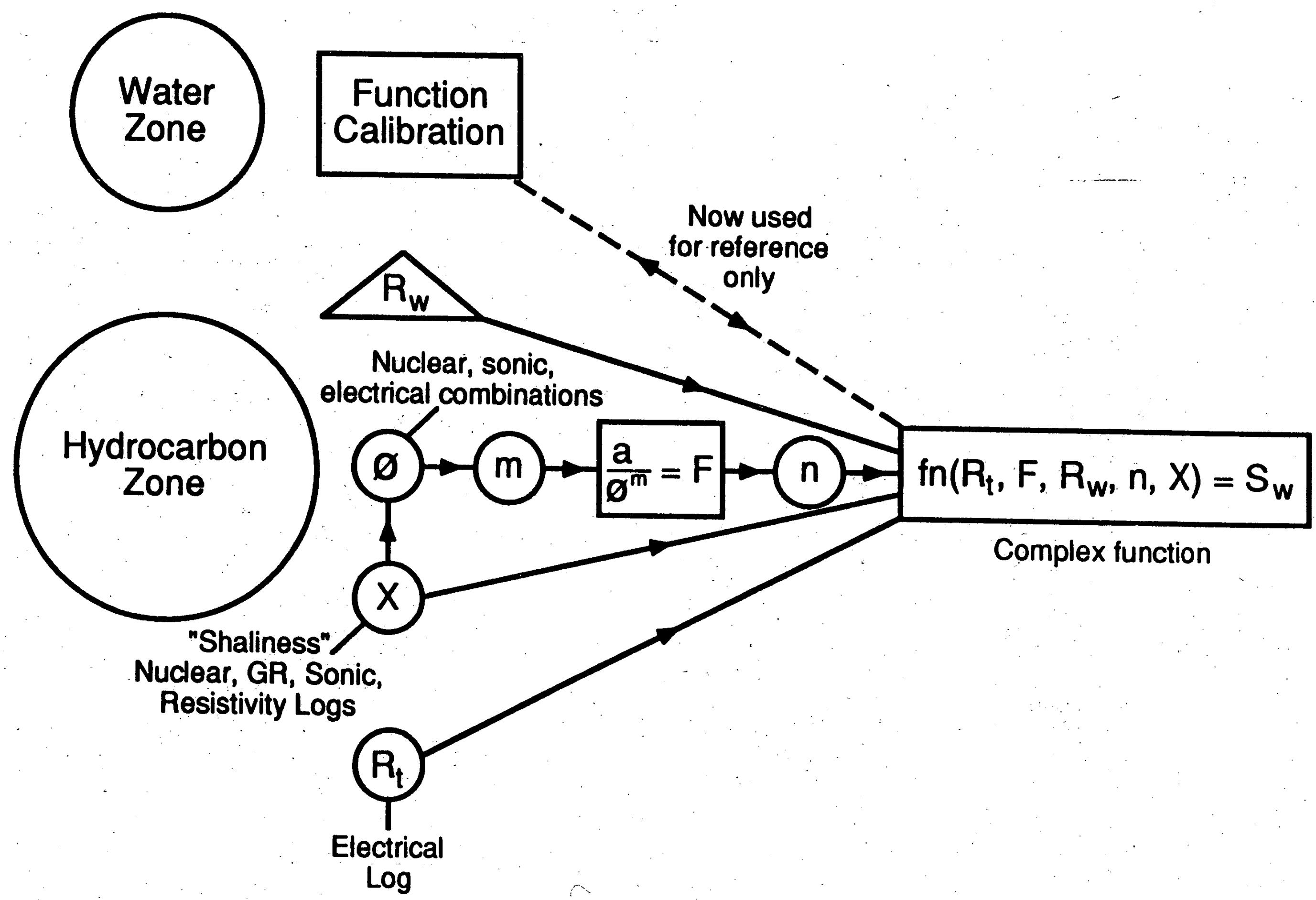


Figure 8. 1970 interpretation philosophy in shaley formations.

depths of investigation. This set of measurements, integrated with laboratory measurements, allowed us to solve the porosity and water saturation problems.

Things have dramatically changed since then because of a technological revolution. Because of the complexity of the function in Figure 8, there have been efforts to bypass the calculation of S_w and measure oil directly. For example, high frequency dielectric tools have been developed to measure the difference in dielectric constant between oil and water, but they have limited depth of investigation. They investigate the flushed zone only, that is the portion around the borehole where the hydrocarbons are displaced by the mud filtrate. Carbon-oxygen tools have been constructed that use the bombardment of fast neutrons to directly measure the carbon-to-oxygen ratio in the formation. But these tools have been shown to have uncertainties as big as the range of S_w error.

Advances in digital data acquisition and processing, both downhole and uphole, have allowed for downhole computers that could transmit data digitally to the surface. By the end of the 1970's the introduction of digital computers at the well site made it possible to look at the raw logging data in real-time, providing better quality control, calibration, and more efficient operation.

Enormous advances in pulse electronics, high data rate sensors, and multiple telemetry systems opened the door to a new generation of logging tools:

Natural Gamma Ray Spectroscopy Log

Instead of the gamma ray tool which was developed in 1939, a natural gamma ray spectroscopy tool was introduced that measures the three most abundant components of the natural radioactivity of the rocks, K, U, and Th. The reason for separate determination of K, U and Th was to provide greater insight into lithology identification and clay typing. Charts like that in Figure 9 which maps clay mineral variations by relating thorium versus potassium, have been heavily criticized because they are too simplified. This correlation is likely to break down if you look in detail at the complex compositions of different clay-types but it pointed the way to better quantitative understanding of the geology of a well.

Lithodensity Log

At the beginning of the 1980's the lithodensity tool replaced the old density tool. The new generation of tools added a diagnostic capacity for detecting lithology to the density log, by measuring the so-called "photoelectric absorption index". Unlike the old tool, they measure the entire gamma ray spectrum (Figure 10), including the low-energy region where the tool response is a function of the lithology. Originally, low-energy gamma rays were not taken into account because the primary objective was to obtain information about the density of the formation, not the lithology. The photoelectric absorption index allows for a better identification of the lithology and therefore a better quantification of the clay content; this, in turn, yields a more precise estimate of the porosity and water saturation in the formation.

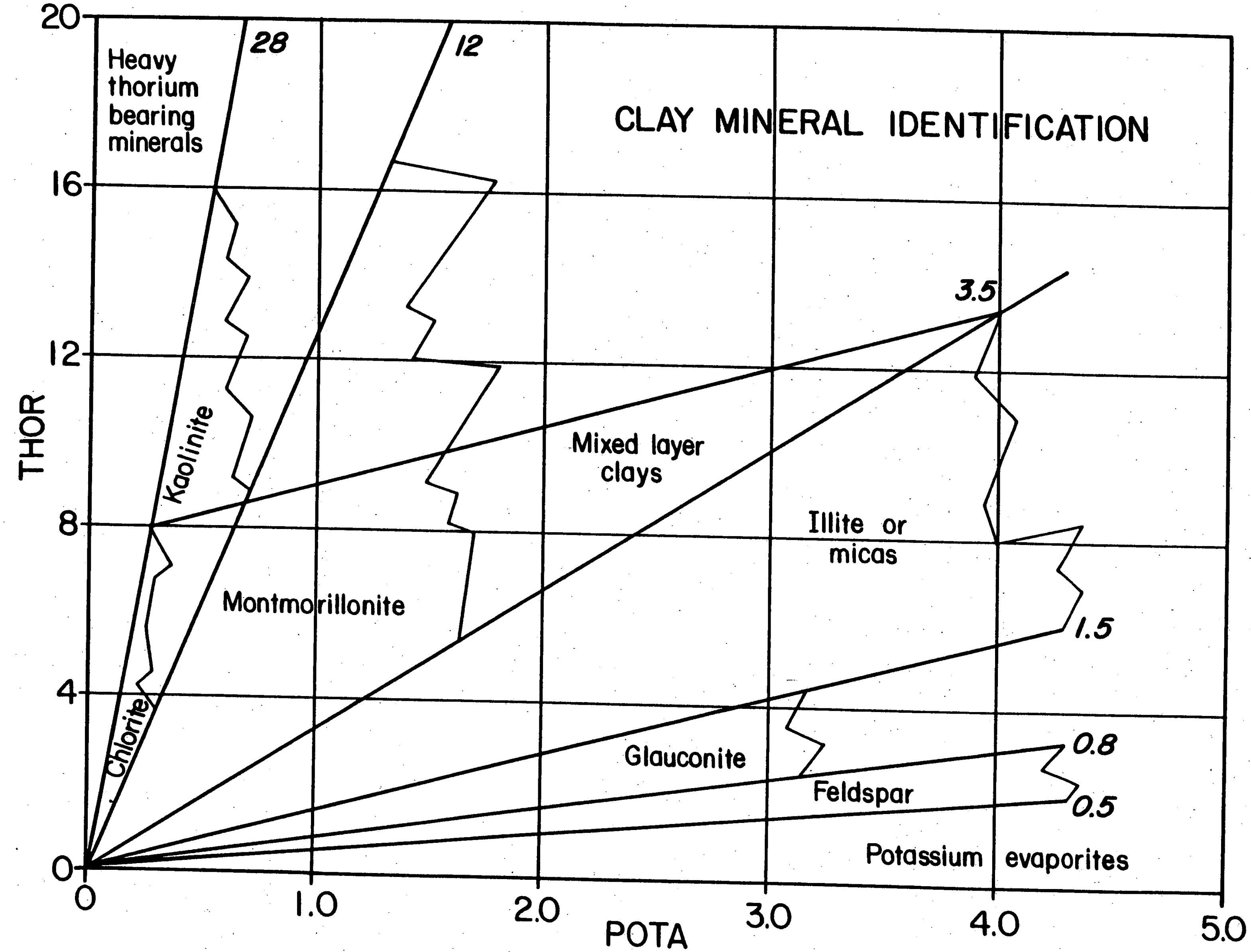


Figure 9. Thorium versus potassium can be used to classify radioactive minerals via spectral gamma ray. Because of the variability of the thorium and potassium content of clay minerals, this plot should be used as a guide, not as a definitive interpretation to the possible clay minerals present on the rock.

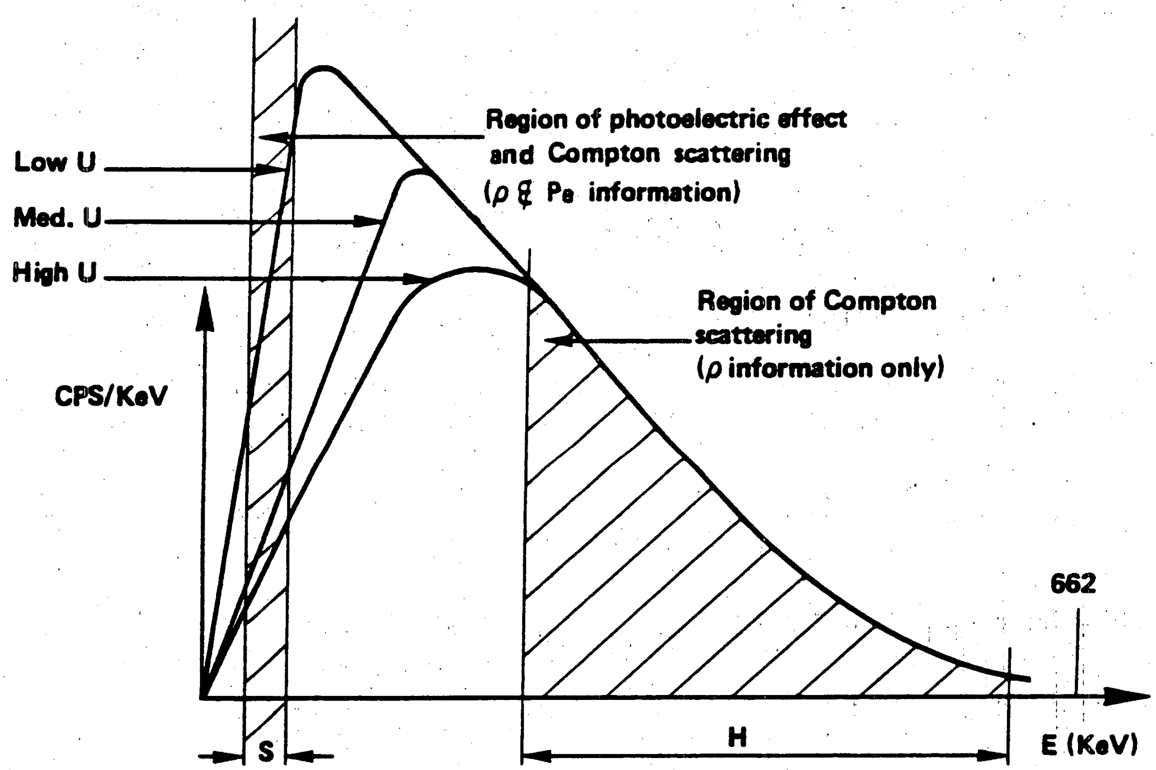


Figure 10. Gamma ray detection in the low and high energy region of the spectrum recorded by the the lithodensity tool.

Induced Gamma Ray Spectroscopy Tool

The determination of lithology was raised to an entirely new level with the development of pulsed-neutron tools. They record the full spectrum (256 energy channels) of the gamma rays emitted by capture of the bombarding neutrons by individual nucleii in the formation. Through a comparison of the recorded spectrum with a library of standard responses for different elements it is possible to calculate the actual elemental composition of the formation around the borehole.

Multichannel Sonic Log

Another exciting development was the emergence of sonic waveform measurement, instead of just measuring the compressional wave velocity. Waveform recording gives us the ability to calculate amplitude, frequency and velocity of shear as well as compressional waves, which provide useful information about the elastic properties of the rocks, and indirectly, about the lithology. One of the biggest drives in the industry now is the integration with surface seismic reflection profiling. Everybody is talking of the need to integrate data from downhole with that from the surface to build a complete description of the reservoir.

Logging in the Ocean Drilling Program

One very important point differentiates the scientific logging done by the Ocean Drilling Program from that used in the oil industry. The oil industry is very conservative and, surprisingly, does not like risk. Drilling requires risk, thus the industry does not add to those risks by using technology which is not well established. The industry will be ready to adopt new technologies only when they have been sufficiently tested in different situations. In the ODP this problem is not addressed, because we use the most recent logging technology and take the inevitable risks related to tool failure and to the different logging conditions. Taking these risks has brought the Ocean Drilling Program considerable advancement in logging techniques, such as geochemical logging.

The package of logs routinely used in the Ocean Drilling Program and the so-called specialty tools go some way beyond the logging suites that are commonly used in the oil field. In acoustics, we provide sonic waveform measurements and ultrasonic acoustic imaging from the borehole televiewer. In terms of electrical measurements, a wide array of tools is available: the phasor induction, the dual laterolog, the spherically focused log, and the Formation MicroScanner (in the four pad form specifically developed for ODP use). Only very recently have four pad FMS's become available in the oil industry as well. Borehole magnetics figure prominently in ODP, whereas they are hardly used in exploration. In terms of mechanical measurements, major thrusts within ODP are sampling good pore fluids, and conducting permeability measurements through wireline packer tests (another tool designed for ODP). As to nuclear measurements geochemical composition, density, and porosity are provided by pulsed-neutron, neutron-porosity, and lithodensity tools. Thermodynamics measurements are represented by an accurate pressure and temperature logging tool (again designed for ODP) which can be attached to the bottom of both Schlumberger and specialty tools for multiple temperature runs. In summary, only optics are missing from the ODP logging arsenal; optical borehole television systems are available on the market, but none of them has yet been used within ODP.

The way these different logging tools are combined for each lowering in the well is summarized in Figure 11 (also see Volume 3, Chapter 2 for further details). The quad-tool logging string consists of: a) sonic waveform log; b) dual induction and spherically focused log; c) the natural spectral gamma ray log; d) lithodensity log for density and lithology determination; e) neutron porosity log, and f) caliper log to determine hole size.

The biggest departure between ODP and oil industry logging is that instead of a tool combination which traditionally looks at fluids (water and movable and irremovable hydrocarbons) we run a geochemical tool string (Figure 11). This string has three components: a) an induced gamma spectral tool operated in capture mode to give us elemental analysis of nine elements (Si, Fe, Ca, S, Ti, Gd, K, H, and Cl); b) an aluminum activation tool which provides a measurement of the aluminum content in the formation, and c) the natural gamma spectral tool, which measures the concentrations of potassium, thorium, and uranium, in addition to the natural radioactivity of the rock.

The third tool string is the Formation MicroScanner, which is combined with a gamma ray tool for depth correlation.

New Directions in Logging in the 1990's

The problem areas to be faced in the near future concern parameters, algorithms, and environment. In terms of parameters, despite the new arsenal of logging tools, we still do not know how to handle complex lithologies. A complex lithology is a rock other than a sandstone, limestone, and dolomite (which are the only three lithologies on the Schlumberger logging charts).

In terms of algorithms, we are still investigating Archie's law, as we are facing more and more situations where it is not directly applicable (i.e., oceanic basalts). We have learned a great deal about how to make resistivity measurements on the recovered cores, but we still have to find a way to keep the core structure intact before it gets into the laboratory. We must find a way to sample lithologies such as unconsolidated sands so that the pore geometry remains undisturbed; a possible solution, freezing the cores at the wellsite, raises the question of how to defrost them in the laboratory without bursting the liner, and altering the pore structure.

There has been a tendency to extrapolate algorithms well established in one geographic area to others as well. For example, the Indonesia formula, an algorithm devised to overcome a particular problem of shaley-fresh-water sands in Indonesia , has been indiscriminately used around the world.

Finally, in terms of environment, despite the fact that a fair amount of attention has been paid to improving the resolution of logging tools, we do not have a uniform approach to enhance the resolution in finely laminated reservoirs. Also, we still cannot measure the invasion profile. Logging in pressured zones is a very important safety issue, and logging of deviated wells is an interesting area in its own right. A deviated well introduces the question of anisotropy; anisotropy has been shoved under the carpet for years, and the

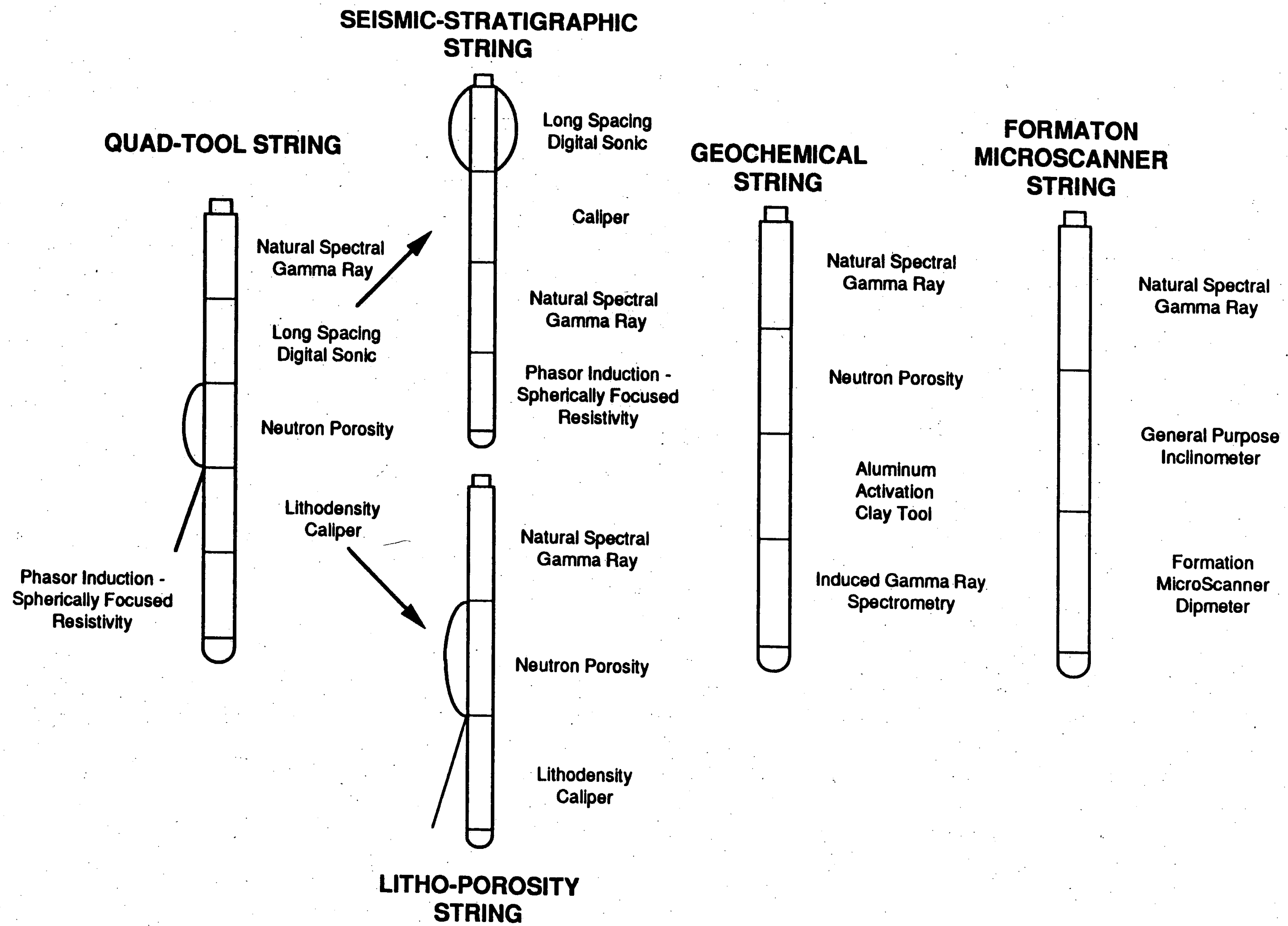


Figure 11. Schematic configurations of the Schlumberger tool strings operated in the Ocean Drilling Program

geophysicists with their seismic interpretations are as bad as log analysts in pretending that the problem does not exist. But times are changing now, and we will probably see more people paying attention to quantitative solutions of the problems introduced by formation anisotropy.

Conclusions

As far as well logs are concerned, we use them because they provide a continuous and *in situ* characterization of a larger volume of the subsurface than cores. We see them as complementing the cores, and therefore we must use use both intelligently.

Logging is beginning to appear in all the geosciences, such as continental drilling, hydrology, and climate change research. Whereas in the oil industry the logs provide a commercial legacy (and actually have a dollar trading value), we try to see them within the Ocean Drilling Program as a scientific legacy. Suppose we don't fully understand the logging results from a certain well. In a few years somebody may come back to the same area with a fresh understanding and say: "Aren't there any continuous *in situ* data in this area that I could now look at?". Consultants in the United States make very good livings by looking at old logs and finding oil that wasn't seen at the time because we didn't fully understand the measurements.

As you will see in the other volumes of this Logging Manual, logs have already provided a strong scientific input to the Ocean Drilling Program. But the full potential of this input has not yet been realized. Data integration is going to be the hallmark of the geosciences in the 1990's, and people who allow themselves to concentrate only in special fields without looking outside are going to miss an important piece of information. There is no room for isolationists in the 1990's, and that goes for academic and government scientists as well as for those in the industry.

Finally, - remember that "too much data poorly understood is often worse than not enough data". We have tried to get this message across in the Ocean Drilling Program as well. We feel that fewer holes studied thoroughly are better than more holes studied imperfectly. Also, it is too easy to catch the enthusiasm of the latest technology and neglect the basics. If the industry is going anywhere, it is to return now to ask questions about some of the basic physics and chemistry that are not totally understood. All the major logging tool developments that will be used in the next decade are available to us now, so we have the possibility of trying to understand more fully what logging data are telling us about subsurface geology.

OCEAN DRILLING PROGRAM

Wireline Logging Manual

Volume 3

The Logging Service

Borehole Research Group
Lamont-Doherty Geological Observatory
Columbia University
Palisades, New York 10964

SEPTEMBER, 1990

Introduction

Lamont-Doherty Geological Observatory, as the prime logging contractor for the Ocean Drilling Project, provides JOIDES scientists with a full suite of geophysical and geochemical services which involve the acquisition, processing, and presentation of *in-situ* logging measurements . Our charge is to supply state-of-the-art logging customized to the scientific needs of JOIDES scientists, plus certain specialty logs which are of particular usefulness to scientific logging. We also provide data interpretation and dissemination services so that JOIDES scientists can use the logs to help solve their particular scientific problems.

To direct us in these duties, the JOIDES Planning Committee has designated the Downhole Measurements Panel to plan long-term tool and services development, to assist in the identification of new technology and in recruiting scientific logging scientists to participate in each ODP leg, and to coordinate and integrate the L-DGO logging services with other downhole measurements programs planned for ODP legs.

Volume 1 of this Wireline Logging Manual is subdivided into three chapters. The first chapter provides an overview of shipboard operations and of the responsibilities of the logging personnel. The next section acquaints the reader with the various types of logging measurements by describing the physics behind each measurement, the form in which the preliminary data is displayed, and its primary applications. The final chapter discusses logging times and provide equations for their estimate.

TABLE OF CONTENTS: Volume 3

Chapter 1. The Logging Service

Chapter 2. Logging Tools

Chapter 3. Logging Time Estimates

Chapter 1. The Logging Service

Structure of the Logging Service

The Borehole Research Group at Lamont-Doherty consists of the personnel and management structure shown in Table 1-1. In our research effort we are involved in a wide array of scientific logging investigations on the continents, as well as with the Ocean Drilling Program. This broad scientific scope benefits JOIDES logging services in two direct ways. First, tools and techniques developed throughout the logging industry are examined for their applicability to ODP needs often long before they become commercial products. Consequently, the JOIDES RESOLUTION is presently equipped with the most advanced multi-element geochemical logging technology, high Resolution borehole imaging, and multi-channel sonic logging capability. Secondly the land program provides us the crucial opportunity to field-test tools and processing techniques before they become operational on the JOIDES RESOLUTION.

As the prime logging contractor for ODP we subcontract Schlumberger, the industry leader, to supply and operate their state-of-the-art logging tools on every leg of ODP. In addition, we provide some specialty tools such as the Borehole Televiewer and the Multichannel Sonic tools, which are operated by Borehole Research Group personnel. Also, we have recently developed a self-contained temperature tool that can be attached to the bottom of a host drilling string. Each year, we hope to bring on-line a new specialty tool to add to the scientific logging capability aboard the ship. Finally, a log analysis center at Lamont-Doherty has computer processing, log analysis and interpretation services ready for the ODP scientists' use after leaving the ship. This center is designed to provide the JOIDES scientist with the interpretive skills and tools to solve his/her geological problems with the assistance of *in-situ* measurements.

Data Acquisition Overview

In the Ocean Drilling Program, geophysical log data are recorded using probes which are lowered on the end of a wireline into the previously drilled borehole. The depth at which the measurements are made is determined primarily by measuring the length of cable run into the hole. Small but significant errors in this depth measurement can result from cable stretch, small horizontal offsets of the ship and wave motion. Because much of the analysis of wireline logs depends on the ability to compare at each depth the results from different lowerings of the various tool combinations, each tool string includes a measurement of the natural radioactivity of the formation. In general, different logging runs can be depth-shifted using this common measurement. Once the depths have been corrected to a common point, identifiable horizons such as the sediment/basement contact or the

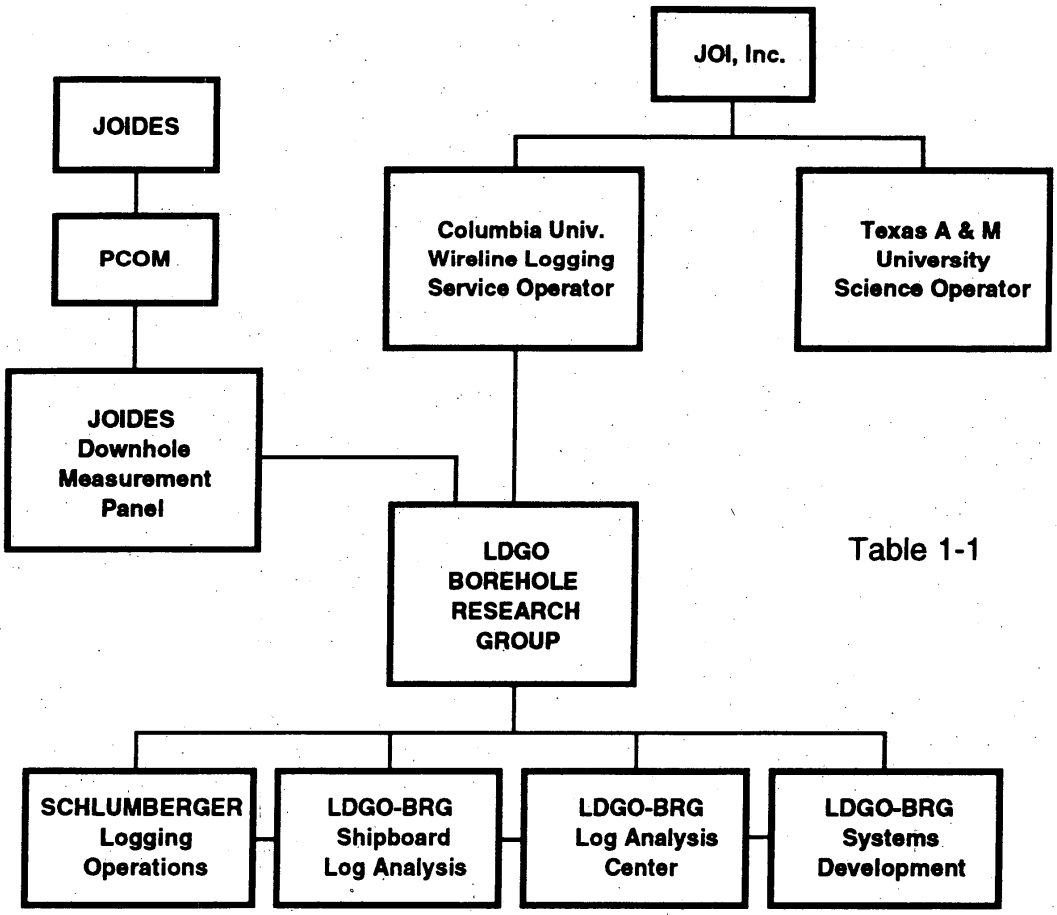


Table 1-1

BOREHOLE GROUP PERSONNEL

Director of Operations: Dr. David Goldberg
Overall responsibility of BRG operations and ODP logging.

Chief Scientist: to be named
Long-term planning of ODP logging program in cooperation with ODP planning structure.

Project Scientist: Dr. Peter DeMenocal
Interpretation and evaluation of ODP logs; paleoclimatic interpretation.

Project Scientist: Dr. Chuan Yin
Development of scientific applications and interpretation of ODP logs.

Program Manager: Ms. Katherine Rodway
Management of LDGO-BRG operations and ODP contracts and subcontracts.

Database and Log Analysis Manager: Ms. Cristina Broglia
Supervision of database and data distribution, and of shore-based log analysis.

Log Analyst: Ms. Elizabeth L. Pratson
Geochemical and FMS processing and interpretation.

Database and Log Analysis Assistant: Ms. Debbie Barnes.
Database implementation and data distribution.

Computer Systems Manager: Mr. Michael Hobart
Design and maintainance of computer systems operated by the BRG on the ship and on shore.

Manager of Technical Operations: Mr. Frank Filice
Supervision of downhole systems operations and development.

Logistics Coordinator: Mr. Larry Sullivan
Procurement, shipping, and inventory management of ship and shore operations.

Research Engineer: Mr. Alex Meltzer
Downhole systems design, electrical and computer engineering.

Secretary: Ms. Janice Gittings

Graduate Students: Mr. Gilles Guerin, Mr. Craig Wilkinson.

bottom of the drill pipe can be used to relate the log depth to the drilling depth. As the length of the logged section is usually small compared to the water depth, slight residual cable stretch will not degrade the correlation between log and drill depth. Because core recovery is seldom 100%, however, the exact relationship between core samples within a given coring run and log data recorded over the cored interval is ambiguous. The correlation can be improved by running a gamma-ray or velocity log on the core before sampling.

Two types of logging tools are currently operated in the Ocean Drilling Program: Schlumberger tools and specialty tools. Each of these tools is described in some detail in the next chapter. Unlike specialty tools, Schlumberger tools can be stacked so that each type of measurement does not require a separate lowering. Log data are recorded whenever the logging sonde is moving in the open hole. Downgoing logs are recorded both to ensure that the tool string has not stopped at a hole constriction (to prevent tangling of the logging cable) and to ensure that if the tool fails during its ascent some data will have been recorded. Data recorded uphole, however, are more reliable, as tool motion is less erratic. An exception to this is temperature logging, which must be done on the down-going pass.

All logging tools operate continuously, but the data can be recorded and averaged only in discrete steps, in the Schlumberger logs at half-foot (0.1524-m) intervals. An exception is represented by the Formation MicroScanner, whose sampling rate is every 0.1 in (3 mm). However, if data need to be sampled as a function of time (for instance, to invert tool motion data to monitor the performance of the heave compensator) slow logging speeds increase the length of time between samples. For example, a logging speed of 300 feet/hour yields data points at one-minute intervals.

Shipboard Operations

Shipboard Personnel

To carry out the program at sea, there are three persons on each ODP leg: a logging scientist from the JOIDES scientific community, a Schlumberger field engineer to operate the tools, and a L-DGO-BRG logging scientist to assist the co-chiefs and co-chief scientists in the design, implementation and subsequent interpretation of the logging program on each leg. The JOIDES logging scientist is selected by Texas A & M, from applicants approved by the Downhole Measurements Panel.

The L-DGO-BRG logging scientist oversees the operate of the Schlumberger engineer to ensure that the log data are properly recorded. He/she also works with the JOIDES logging scientist to prepare a logging plan for each borehole, and attends the pre-cruise meeting to present the co-chiefs a description of the log measurements and the logging plan with time estimates, to allow the logs to be integrated into the overall cruise plan. The L-DGO-BRG logging scientist also operates the Lamont specialty tools and the logging computer. Postcruise data archiving, distribution, and display for the ODP Proceedings volumes Initial Reports Volume is the responsibility of the L-DGO-BRG database and log analysis personnel, in cooperation with the logging scientist on that cruise.

The JOIDES logging scientist is the person on the ship who is primarily responsible for the dissemination of the logging results to the scientific party, scientific log interpretation, and, in concert with the LDGO-BRG logging scientist, for the preparation of the logging chapters of the shipboard and later scientific reports.

Equipment Used During Logging Operations

Logging operations on the JOIDES RESOLUTION depend on a wide variety of equipment. Figure 1-1 shows the location on the ship of the primary components of the logging system. The logging winch, the Schlumberger logging cabin, and the wireline heave compensator are located at the end of the pipe racker. The Downhole Measurements Lab, (DML) just forward of the rig floor on top of the lab stack, houses the L-DGO logging computer, electronics lab, and tool storage. Space in the DML is shared with the re-entry tools. Specialty logs brought on board by individual scientists are staged from this area, and the logs themselves are run from a lab which provides a window looking over the rig floor. Due to space constraints, Schlumberger logging tools are stored on the roof of the lab stack, from which they are easily moved for logging operations. The nuclear sources used during Schlumberger logging are stored in shielded containers below the pipe racking system and are installed in the tools just before they are run into the hole.

Logging Winch

The logging winch system is the responsibility of SEDCO. It contains almost 10 km of 7-conductor logging cable. The cable is terminated with a torpedo connection which can be quickly connected to pigtails terminated with a variety of logging heads. The Schlumberger engineer maintains pigtails for connection to his tools. Pigtails terminated with a Gearhart-Owen $1^{1/2}$ in. 7-conductor logging head are provided for the specialty logs and for wireline re-entry. In theory, this method allows the use of any cable-head which can be connected to a 7-conductor cable. However, no other termination schemes are currently supported on the JOIDES Resolution.

The winch can operate at any speed between about 100 m/hr and the safe maximum working limit set by the ODP Operations Manager. Depth in the hole is determined by measuring the length of cable run into the hole. The Schlumberger depth counter transmits 120 pulses per foot and is used during standard and L-DGO specialty operations. The TAMU depth counter delivers 500 pulses per foot and is used primarily for reentry.

The upper end of the cable is terminated at the TAMU winch cab. A connection panel there allows the signals to be transmitted either to the Schlumberger cab, the DML or the Underway Geophysics Lab. A second patch panel in the DML reroutes the signals to different areas of that lab or to the dynamic positioning shack above the bridge. Each of these connections is made using a Schlumberger A-K connector.

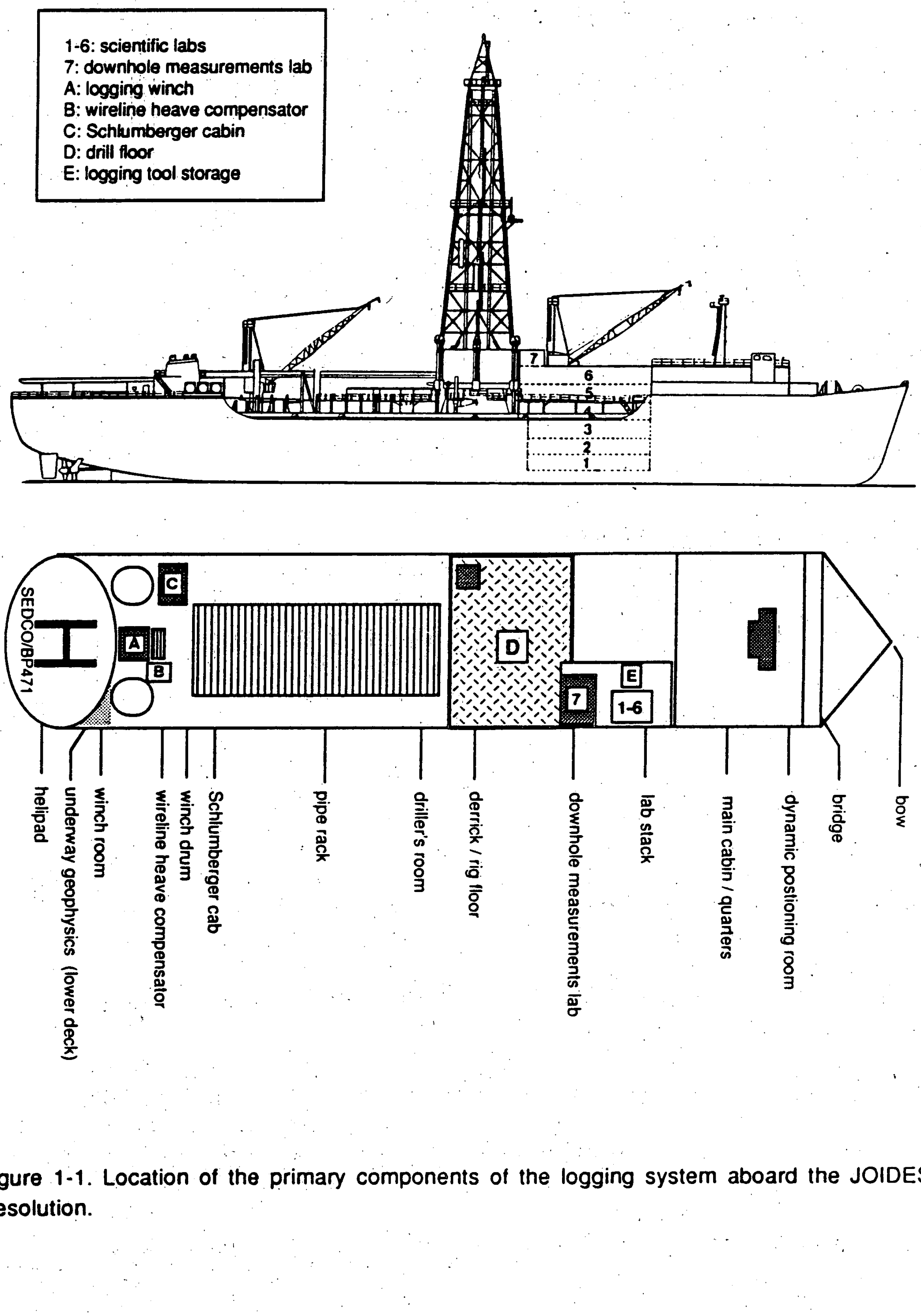


Figure 1-1. Location of the primary components of the logging system aboard the JOIDES Resolution.

Schlumberger Cyber Service Unit (CSU)

The Schlumberger cabin houses a wellsite digital computer system called Cyber Service Unit. This system overcomes many of the problems related to the stacking of many measurement sensors into one logging string, and expedites some field operations such as tool calibration. The CSU contains two complete computer systems each with CPU, 4 Mb RAM memory, and hard disk in order to make sure that there is always a functional system available during the logging run. The data are recorded on magnetic disk and then played back on magnetic tape for archiving and transfer to other computer systems. Selected data can be printed out on a thermal printer during the logging runs, so that logs can be made available for immediate examination. Additional logs are played back to the film recorder or to a graphic printer after the run. The CSU is powered by a 12 Kva generator.

In 1991, the present CSU will be replaced by MAXIS (Multi Task Acquisition and Imaging System). In addition to being directly connected to the other computers on the ship, MAXIS will allow for interactive computer graphics on two color terminals for both logging engineer and scientist, color display and printed output, integration of Formation MicroScanner data with standard logging curves, and log quality control and printing while logging.

Weight indication

Line weight is determined by a load cell which measures the tension on a sheave mounted on the rig floor. Using the line weight indicator, the winch operator can usually determine whether the probes are sticking during descent or ascent. Line weight, however, varies with ship heave which complicates this determination. As a matter of ODP policy TAMU has decided that all logging tools must weigh at least 200 lbs. (90 kg) if they include bowspring centralizers. Most lighter tools can be run by adding an above-tool sinker bar that is available on the ship.

Wireline Heave Compensator

Experience during DSDP demonstrated that ship heave can seriously degrade the quality of logging measurements. Although the relationship between ship motion and the motion of a downhole instrument is not simple, a significant amount of heave was being transmitted to the logging probe. Therefore, L-DGO contracted Schlumberger to design a heave motion compensator for the logging cable. After an independent engineering report determined that the design was effective, the compensator was installed on the starboard side of the winch cab.

During logging operations the logging cable is run from the winch to the rig floor, then back through a piston-mounted sheave on the heave compensator, and back again to the rig floor. As the piston extends, the length of cable between the winch drum and the rig floor is reduced by twice the amount of extension. Ship's heave is sensed by an accelerometer mounted near the rig floor, and the signal is transmitted to a computer which computes the effective motion. The piston-mounted sheave is then driven in or out to compensate for vertical motions of the drilling vessel. Tests of this system on ODP legs indicated that in operation the heave compensator improved log quality and reduced the primary components of ship's heave by more than 50%.

Sidewall Entry Sub

Bridges within soft sediments have been a constant problem. The amount of logged hole in Eocene or younger sediments was consistently less than 50% of the cored depth prior to our adapation of horizontal hole logging technologies to ODP use. A special Sidewall Entry Sub (SES) was designed which attaches to the drill-pipe to allow the cable to be run outside the pipe (see Figure 1-2). This sub is installed with the open end of the pipe above the top of the interval to be logged, and tools are then run into the hole as usual with the cable passing through the SES. The pipe is run back to total depth. Open hole logs are recorded as pipe is simultaneously pulled back up and hole is exposed. This significantly improves the recovery of logs in soft sediments. A TAMU-designed second-generation SES with improvements based on operational experience was installed on the ship in 1990.

Communications

Communications between the Downhole Measurement Lab, winch cab, Schlumberger cab, and the rig floor are accomplished by a special intercom system not connected to the shipboard telephones. Thus critical communications between these areas are not affected by standard telephone traffic. Good intercoms do not insure good communications, however. It is imperative that these areas communicate well with each other during logging operations.

Shipboard Computers and Log Analysis Facilities

Preliminary log analysis is routinely undertaken on board the JOIDES RESOLUTION, followed by the full complement of log analysis after each cruise. Also, interactive computer work stations at Lamont are available for post-cruise log analysis by interested scientists. As further analysis techniques are developed, these are implemented and tested first at Lamont and then incorporated into the shipboard log analysis system.

Figure 1-3 provides an overview of the shipboard computers and log analysis facilities described in the text.

The computer systems available in the Downhole Measurements Laboratory (as of the fall of 1990) are a Masscomp MC-5500 Unix-based system, a Digital VAXStation 3200 running the VMS operating system, an Apple Macintosh SE, and a Compaq Portable running the MS-DOS operating system. *Various enhancements to these systems are being planned, so interested scientists should contact the Borehole Research Group for the latest information.*

Numerous additional computers are available for use on the JOIDES RESOLUTION as part of the support and operational facilities provided by ODP/TAMU. These include several Digital VAXes operated in a VAXCluster configuration, numerous Apple Macintosh computers, numerous MS-DOS computers, several Digital DECPros, two

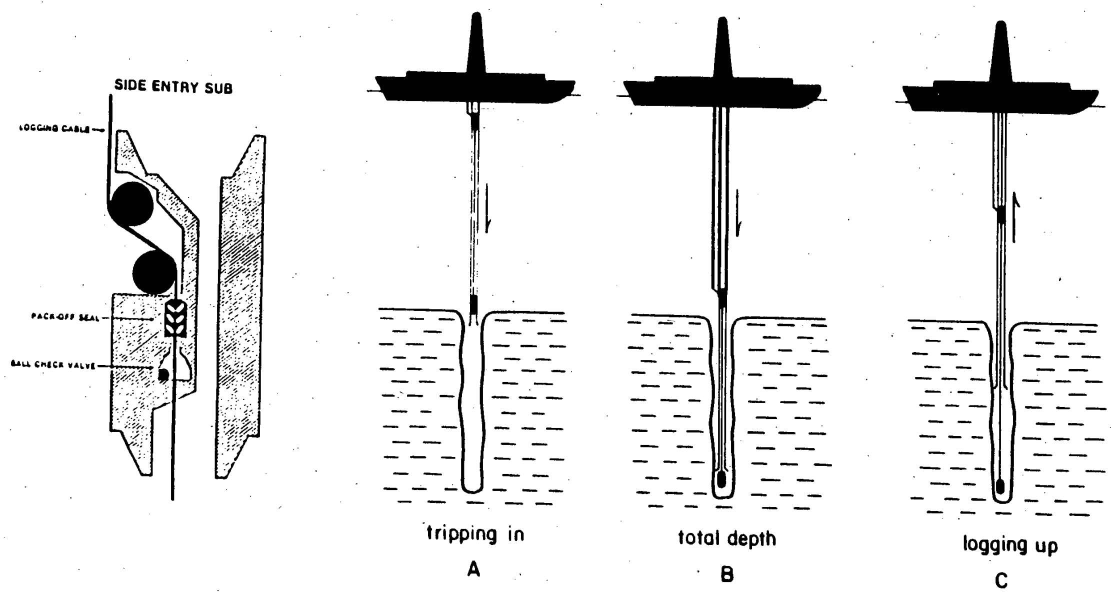


Figure 1-2. Sidewall entry sub (a) installed with the open end of the pipe just above the top of the logging interval; (b) with the pipe run to total depth along with the logging tool; and (c) recording open hole logs as pipe is simultaneously pulled up and hole is exposed.

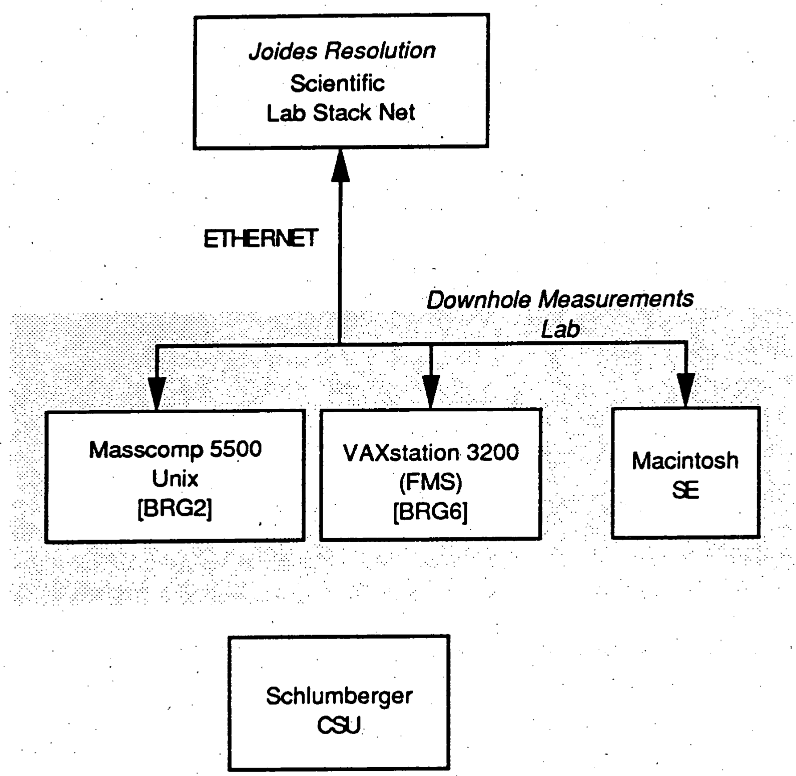


Figure 1-3. Sketch of the ship logging computer facilities.

additional Masscomps, and others. Contact the computer support staff at ODP/TAMU for further details on the current computers which they support on board ship.

MASSCOMP MC-5500 (Figure 1-4)

L-DGO-BRG specialty logs (BHTV, MCS) acquired on the ODP drillship are controlled by and recorded on a MASSCOMP 5500 data acquisition and display system. The MC-5500 is a 32 bit Unix-based minicomputer system designed specifically to facilitate real-time operations. The computer has 3 Mb of RAM memory, a high-Resolution graphics display, and 85 Mb and 165 Mb hard disk drives. Two 1600 bpi 9-track tape drives are available (they are ONLY capable of 1600 bpi, there are NO facilities on the ship to read 6250 bpi tapes). An Ethernet controller is installed and TCP/IP and NFS software packages are installed. Three RS-232C serial ports are available, though one of them is almost always in use with the Macintosh SE. An independently controlled subsystem performs the data acquisition tasks, and a separate graphics processor simultaneously displays the acquired data in real-time. In addition, an integral array processor/floating point processor combination enhances computational performance, enabling the MC-5500 to compute Fast Fourier Transforms quickly and to handle the sophisticated image processing required for interpretation of BHTV images. Hard-copy output of the results of these calculations is provided by a Versatec V-80F electrostatic plotter.

As mentioned above, programs have been developed to run the MCS and BHTV logs, as well as general-purpose data acquisition routines to record the data from a wide variety of experimental logs. These include a continuous logging program and programs to record data from hydraulic fracturing experiments and flow tests. The primary reason for installation of the MC-5500 in the downhole measurement lab is to provide a general-purpose, flexible system which can be used to record data from any experiment which can be run from a wireline. For this purpose, we expect to be able to work closely with scientists interested in running unique experiments which would benefit from the real-time capabilities of the MASSCOMP system.

As the MC-5500 is fully programmable in Fortran or C, additional analysis routines can be developed easily while on the ODP drill ship. With adequate advanced warning, a specific applications package including data acquisition, display and analysis can be developed before the ship sails for any specialty experiment.

<u>Terralog Log Analysis System</u>

TERRALOG is an interactive system of log analysis routines which operates in real-time, using a menu-driven approach. It is a proprietary commercial product developed by TerraSciences, Inc. As with any log analysis system, it has immediate application to the petroleum industry, but it can also be used effectively in the evaluation of other subsurface problems for which borehole geophysics provides useful information. Even though TERRALOG has been designed to operate with geophysical logs, other data, such as geochemical measurements or core analyses can be handled. The package can import and

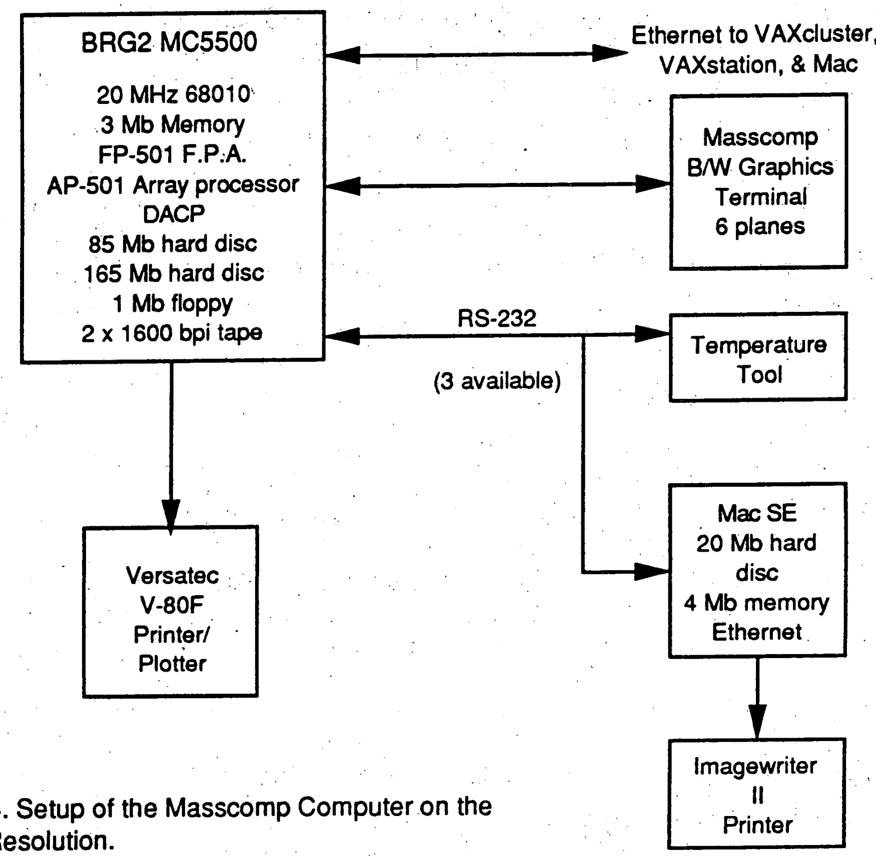


Figure 1-4. Setup of the Masscomp Computer on the JOIDES Resolution.

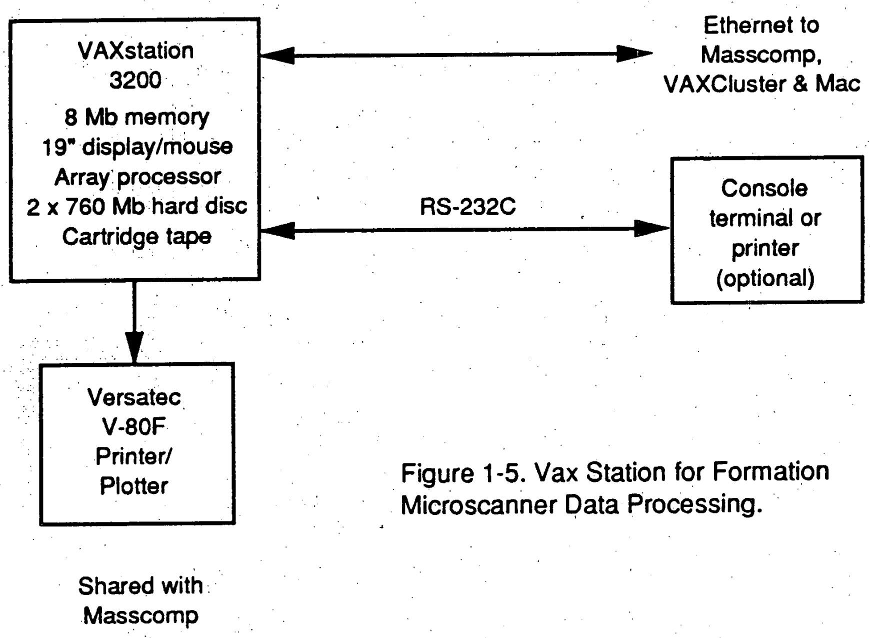


Figure 1-5. Vax Station for Formation Microscanner Data Processing.

export data in ASCII format, in addition to importing the various standard log data formats. The programming language is Fortran, in order to allow the user to modify and/or add routines (although this is not normally done due to the complexity of the package.)

TERRALOG is installed on the Masscomp and utilizes a Versatec V-80F for tape mapping and graphic display. The Macintosh SE is often used as a graphics display terminal with TERRALOG, since it supports Tektronix compatible graphics terminals or terminal-emulation programs.

The data are loaded from Field Edit tapes prepared by the Schlumberger engineer in the Cyber Service Unit. Once a data tape has been loaded onto the system the L-DGO and JOIDES scientists perform the preliminary analyses and interpretation needed for the preparation of the logging chapter of the shipboard report.

Corpac Data Correlation Package

The CORPAC data correlation package developed by Doug Martinson at L-DGO has been installed on the Masscomp MC-5500. This package allows the correlation of different logs, time series, core data sets, and the description of their correlations via transfer functions. It has many features and extensive built-in contextual help. It is run from the Macintosh or other graphics terminal since it does not directly support the Masscomp native graphics mode.

Specialty Log Processing

The specialty log processing is accomplished using programs developed at L-DGO and Stanford University which are run on the MASSCOMP logging computer. For the BHTV these include the calculation of a 3-D caliper log, a hole volume log (useful for analysis of slug-type permeability), a surface roughness log, and an oriented ellipticity log, which can be used to determine the orientation of the horizontal principal stresses acting on a borehole. Image enhancement techniques to improve the BHTV images and to quantitatively determine fracture properties are also available. For the MCS log, analysis and display software includes calculations of compressional, shear and Stoneley velocities using a modified semblance technique, estimations of energy and frequency content for the primary borehole modes, and frequency-domain and slowness filtering to enhance particular arrivals. Estimates of amplitude and frequency content of the arrivals can be obtained which can be related to fracturing and attenuation near the wellbore.

The range of analysis techniques is limited only by the scientific interests of the shipboard party. Cross-correlation of the Schlumberger logs with borehole televiewer fracture, void and bedding information and the multi-channel sonic data allow identification at sea of such geological targets as over- and under-pressure zones, fault zones, dip changes, geophysical boundaries such as reflector horizons imaged by surface multi-channel seismic profiling, etc.(see other volumes of this manual).

Schlumberger Cyber Service Unit (CSU)

This computer is designed primarily for data acquisition and display of all primary Schlumberger log curves (as discussed above). In addition, it can run preliminary analyses of the data to obtain a "quick look" at computed values.

VAXStation 3200 (Figure 1-5)

A Digital VAXStation 3200 has been put on the ship to process data acquired by the Formation MicroScanner (FMS) Tool. It runs Digitals VMS operating system (version 5.3 as of the summer of 1990) and uses DECWindows (DEC's version of X-Windows) on its' 19" grey scale display. The system has 8 Mb of main memory, two 760 Mb hard disc drives, an Ethernet interface, and a TK-50 cartridge tape drive with 95 Mb capacity. DECnet software is installed to permit communication with the ODP/TAMU VAX computers and TCP/IP software is installed to permit communication with the Masscomp and the Macintosh. NFS server software is also installed on this system. An array processor is attached to the system to speed computations and a Versatec interface is installed to permit it to use the V-80F printer/plotter described above.

The primary analysis software on this computer is the proprietary Schlumberger Log Operating System (LOGOS) package. ODP/TAMU computer technicians are being trained to operate this package for the routine processing of FMS data. This will avoid the problems caused by having to train a new person in the use of this package for each leg. The Lamont and JOIDES loggers can instead concentrate on the scientific analysis of the data.

Macintosh SE

An Apple Macintosh SE along with an Apple Imagewriter is provided in the Downhole Measurements Laboratory. This is normally connected to the Masscomp MC-5500 as an additional terminal. An Ethernet card is installed along with TCP/IP software for high-speed data transfer and communications. The Macintosh has a 20 Mb hard disk and 1 Mb of RAM memory (as of the summer of 1990, an upgrade to 4 Mb of RAM memory is planned for the fall of 1990). Various standard word-processing, data-analysis, and data-presentation packages are installed on the computer.

Numerous additional Macintoshes are available on the ship, as are several Apple Laserwriter printers and an Apple Scanner.

Compaq PC

A Compaq portable PC running MS-DOS is available in the lab. (Actually there are two of these machines, but one is sometimes back at L-DGO). These are primarily intended for use with the Wireline Packer tools, but are otherwise available for use. They have 640 kB of RAM memory. One has a 10 Mb hard disk and the other has a 20 Mb hard disk. Various standard utilities are installed, but not a wide selection, since these are primarily intended to be dedicated machines for use with the specialty tools.

Numerous PC and PC/AT style MS-DOS machines are available on the ship and are supported by ODP/TAMU. Several of these have AppleTalk cards installed so that they can use the Apple Laserwriters.

A more advanced PC style machine will be added to the lab to support the new German Digital Borehole Televiewer system. Contact the Borehole Research Group for further details on what will be included and when it will be available on the JOIDES Resolution.

On-shore Computers and Log Analysis Facilities

Masscomp computer systems and the software described above are also available on shore at the Borehole Research Group laboratory at L-DGO. There are also two dedicated log analysis systems, one developed by Energy Systems, Incorporated, and the other by Schlumberger.

Energy Systems

The Energy Systems' package is a user-friendly, menu driven, interactive graphic system which provides an accurate analysis of the logging data. Data can be entered via tape, digitizer or manually (core data); they can be interactively adjusted for errors occurring during logging operations, depth shifted, and corrected for environmental conditions. Because the system was designed for the oil industry, it also offers a selection of analysis programs to estimate porosity, shaliness, and fluid saturation of a formation. Finally, the system provides the user with the capability of developing his own programs by using a simple programming language which combines features of Fortran and Pascal. We are running version 4.1L of this software (see below).

The equipment used at L-DGO-BRG consists of the following components: a DEC PDP-11/23 processor, a Kennedy 9800 dual density (800 and 1600 bpi) tape drive, a Calcomp 9000 digitizer, a Versatec V-80F printer/plotter, a Tektronix 4696 color printer, and two Tektronix 4107 color terminals. An RS-232C link to the Masscomp computers has been installed. Primary data storage consists of a 96 Mb hard drive with a 16 Mb cartridge drive. *It is likely that this system will be upgraded to a MicroVAX II based system in the fall of 1990. This will be accompanied by a major upgrade in the software.*

Energy Systems is largely used for editing, depth shifting, displaying for the ODP Proceedings, and for data distribution.

Schlumberger Elite 1000 Workstation

All Schlumberger software available to any oil industry client also resides at the BRG in the form of a CLIC (Client Log Interpretation Center).and is run on a small VAXCluster. The primary unit of the VAXCluster is a MicroVAX II computer which has all of the disk storage and input/output devices attached to it. A diskless VAXStation 3100 is also part of the cluster (see below). A second diskless VAXStation 3100 will be added to the cluster in the fall of 1990.

The MicroVAX II has 16 Mb of RAM memory, along with two 380 Mb and three 760 Mb hard disks. Input and output are accomplished with a 1600 bpi 9-track tape drive, a TK-50 cartridge tape drive, and a Benson (now Oce) B-90 printer/plotter driven by a Versatec interface. A Tektronix 4105 terminal is attached to the system, and it shares the Tektronix 4696 printer with the Energy Systems' system described above. It can also utilize the Energy Systems' or the Masscomp's Versatec V-80F as an output device. An auxiliary array processor is attached to the system.

The operating system is VMS (version 5.3 as of the summer of 1990) and the system supports DECwindows, though there are no graphics devices directly installed in the MicroVAX II. DECnet software is used to communicate within the VAXcluster. TCP/IP and NFS (server/client) software will be installed in the fall of 1990.

The proprietary Schlumberger Log Operating System (LOGOS) is the main data analysis package on the system. The MicroVAX II is primarily used to reduce and interpret the geochemical logs.

VAXstation 3100

A VAXstation 3100 has been added to VAXcluster for land-based FMS log data reduction and analysis. This system has a 19" color monitor running DECwindows and has 16 Mb of local memory. It does not have a local disk and is linked via ethernet to the MicroVAX II.

A similary diskless system will be added in the fall of 1990 to provide more processing power for the geochemical log analysis.

Other Computer Systems

There are various other computer systems available to aid in the analysis of the logging data. Our goal is to link as many of these systems together via Ethernet, TCP/IP and NFS as possible. The Borehole Research Group has several Apple Macintosh and Macintosh II computers linked together on an AppleTalk net along with a laser printer and an AppleTalk-Ethernet gateway. An 386SX, color graphics, MS-DOS computer will be added in the fall of 1990 with a CD-ROM drive so that the NGDC (National Geophysical Data Center) CD-ROMS of DSDP data and their associated programs can be used. Additional Masscomp computers with greater processing power and larger disk storage than the shipboard system are available in the BRG. A system which is similar to the shipboard system is maintained in our logging truck. An IBM PC/RT system with the Landmark Graphics software system is located in the BRG building and is linked into the net via an Ethernet connection. This has extensive 3-D graphics capabilities, a large digitizer, and an 800/1600/3200/6250 bpi tape drive.

The computer network in the BRG building is linked into the Lamont-Doherty network via a fiber-optic cable link. There are numerous other computers available at Lamont-Doherty, including Sun machines. The Lamont-Doherty net is linked to the Columbia University campus and to the NSFNET via a T1 class connection. Internet electronic mail, telnet services, and ftp file transfer are available through these connections. Direct modem dialup is also available worldwide.

Please contact us for further information about logging onto and using our computer facilities, and for updates to the facilities when they become available.

Data Distribution

All logging data acquired on each leg of the Ocean Drilling Program are available to each member of the scientific party. Practical limits to data distribution on board are such that some time is required to process, correct, and display the data in a form appropriate for preliminary science.

Once the data are returned to L-DGO, they are archived and composite logs are prepared for distribution to the members of the shipboard party. They also receive a form to request additional analog and/or digital data (the latter usually become available about 2 months after the end of the leg). When requests are received, the zdata are plotted or copied to magnetic tape in the desired format and sent to the individual scientist. Schlumberger data are available on tape in either LIS (Log Information Standard) or ASCII format, with density of 800 or 1600 bpi., on 3.5" diskettes in ASCII format , or in MS-DOS format. Schlumberger sonic waveforms and well seismic data are both available in LIS format; the former are available in binary format as well.

Multichannel Sonic data are available in BRG or binary format (1600 bpi); a guide to reading the former will be provided along with the data. Borehole Televiewer data are available in analog form only (photographs).

As per ODP data distribution policy the rest of the scientific community has access to the logging data from each leg beginning one year from the sailing date of that leg. In addition, certain other data distribution occurs after one year. The National Geophysical Data Center receives data tapes from each leg after one year, and logging tapes are deposited with the appropriate agencies in JOIDES non-U.S. member countries. For more information contact Dr. Mike Lovell at the University of Leicester, United Kingdom.

Chapter 2. Logging Tools

This chapter provides a description of the physics behind each logging measurement, the form in which the data is generally presented, and its primary applications. Table 2-1 presents a complete list of the Schlumberger and specialty logging tools currently used in the Ocean Drilling Program. As mentioned before, all logging tools operate continuously, but the data can be recorded and averaged only in discrete steps, at half-foot (0.1524-m) intervals in the Schlumberger logs (Table 2-2). An exception is represented by the Formation MicroScanner, whose sampling rate is every 0.1 in (3 mm). If data needs to be sampled as a function of time (for instance, to invert tool motion data to monitor the performance of the heave compensator) slow logging speeds increase the length of time between samples. For example, a logging speed of 300 feet/hour yields data points at one-minute intervals.

Table 2-2 provides a list of the sampling rates and vertical resolutions of most of the logging tools used in the Ocean Drilling Program. It is defined as intrinsic vertical resolution the thinnest bed in which the logging tool can provide a true reading. This depends mostly on the sonde geometry: for example, the closer the source and the detector in a nuclear tool, the higher the vertical resolution. In general, the vertical resolution is also inversely related to the depth of investigation. The vertical resolution reported by the log, instead, is a function of the tool's intrinsic vertical resolution, the sampling rate and data averaging at the well site.

Schlumberger Tools

The Schlumberger logging tools are the tools most commonly run in the Ocean Drilling Program. They are combined into multiple-tool strings for efficiency of operations (see Table 2-1 and Figure 2-1). Due to the stacking process and the finite separation between individual measurement points, however, a few meters at the very bottom of the hole cannot be logged completely. The maximum length of hole for which data is lost is different for each measurement and depends on the position of the tool in the logging string (Table 2-3).

We presently operate the following three tool combinations: the quad-tool string, the geochemical string and the Formation MicroScanner string. Sometimes, however, a seismic-stratigraphic and a litho-porosity combination are run instead of the quad-tool string. Each logging run includes a measurement of the natural radioactivity of the formation, which can be used later to depth-shift the logs to a common point. An additional sonde component which measures vector magnetic field, hole azimuth, and hole deviation can be run with each of the tool strings.

Most Schlumberger tools can be run in boreholes with pressure and temperatures as high as 20,000 psi (1400 bars) and 350 °F (175 °C) respectively. The temperature rating for the gamma spectrometry tool (GST) is 300 °F (150 °C).

Table 2-1. Shipboard Logging Tools and their Applications (1)

TOOL	ACRONYM	PRINCIPLE	Usable Through Pipe	Combinable	Synthetic Seismogram (2)	Lithology Mineralogy (3)	Porosity	Geochemistry Elements	Other
Sonic	LSS/SDT BHC/SDT	travel time of sound (2 receivers)	N	1	G	F	G		
Resistivity									
shallow	SFL	focused current	N	1	F	F	VG		
medium	ILM	induced current	N	1	F	F	VG		
deep	ILD	induced current	N	1	F	F	VG		
Caliper	MCD	hole diameter	N	1		P			(4)
Dual Laterog	DLL	resistivity to current	N		F	F	VG		
Neutron Porosity	CNTG	absorption of bombarding neutrons	Y	1/2	P	F	VG	H	
Spectral γ-ray	NGT	natural γ-ray emissions	Y	1/2/3/4	P	VG		K, Th, U	
Bulk Density	HLDT	absorption of bombarding γ-rays	N	1/2/3	G	G	G		
Induced γ-ray Spectroscopy	GST	capture of bombarding neutrons	Y	3	F	VG	F	Ca, Si, Fe,S, Ti, Gd, H, Cl	
Aluminum Clay Tool	ACT	absorption of bombarding neutrons	Y	3	P	F	P	Al, Mn	
General Purpose Inclinometer	GPIT	oriented magnetic field including inclination	N	1/2/3/4	P	F			(5)
Formation Microscanner	FMS	focused micro-current	N	4	P	P	G		(6)
12-Channel Sonic	MCS	travel time of sound (12 receivers)	N		VG	F	G		(7)
Borehole Televiewer	BHTV	travel time + reflectivity of borehole wall	N		P	F			(8)
Temperature	TLT	formation temp.	Y	1/2/3/4					

(1) usefulness of tool for application: VG=very good; G=good; F=fair; P=poor
(2) logs other than sonic and density can be converted to pseudosonic/density, based on known log responses to lithology and porosity
(3) percentages of minerals with abundance > 3% are determined from simultaneous inversion of several logs
(4) quality control for other logs
(5) magnetic reversals, stratigraphy, fault zones
(6) detailed mapping of fractures, faults, foliations, and formation structures; analysis of depositional environments; formation dip
(7) shear velocity, apparent attenuation
(8) stress directions, fracture orientation, structural dip, formation morphology

Table 2-2. Tool Sampling Intervals and Vertical Resolutions
(modified after Schlumberger, 1988)

MEASUREMENT	INTRINSIC VERTICAL RESOLUTION	SAMPLING INTERVAL	VERTICAL RESOLUTION ON THE LOG
Phasor Induction			
Medium	5-6 ft / 1.5 m	0.5 ft / 15 cm	5-6 ft / 1.5 m
Deep	7-8 ft / 2 m	0.5 ft / 15 cm	7-8 ft / 2 m
Spherically Focused Log	2.5 ft / 76 cm	0.5 ft / 15 cm	2.5 ft / 76 cm
Dual Laterolog	2 ft / 61 cm	0.5 ft / 15 cm	2 ft / 61 cm
Digital Sonic Tool	2 ft / 61 cm	0.5 ft / 15 cm	2 ft / 61 cm
Borehole Compensated Sonic Tool	2 ft / 61 cm	0.5 ft / 15 cm	2 ft / 61 cm
Compensated Neutron Tool	1.25 ft / 38 cm	0.5 ft / 15cm	1.5 ft / 46 cm
High Temperature Lithodensity Tool	1.25 ft / 38 cm	0.5 ft / 15 cm	1.5 ft / 46 cm
Natural Gamma Ray Tool	0.75-1 ft / 20-31 cm	0.5 ft / 15 cm	1.5 ft / 46 cm
Gamma Ray Spectrometry Tool		0.5 ft / 15 cm	1.5 ft / 46 cm
Formation MicroScanner (1)	0.2 in / 5 mm	0.1 in / 2.5 mm	0.2 in / 5 mm
Stratigraphic High Resolution Dual Dipmeter	0.4 in / 1 cm	0.1 in / 2.5 mm	0.4 in / 1 cm
12-Channel Sonic Tool	0.5 ft	0.5 ft / 15 cm	5.5 ft / 1.68 m
Borehole Televiewer			0.5 in / 1.27 cm

(1) acceleration and magnetometer data acquired every 1.5 in. (3.8 cm)

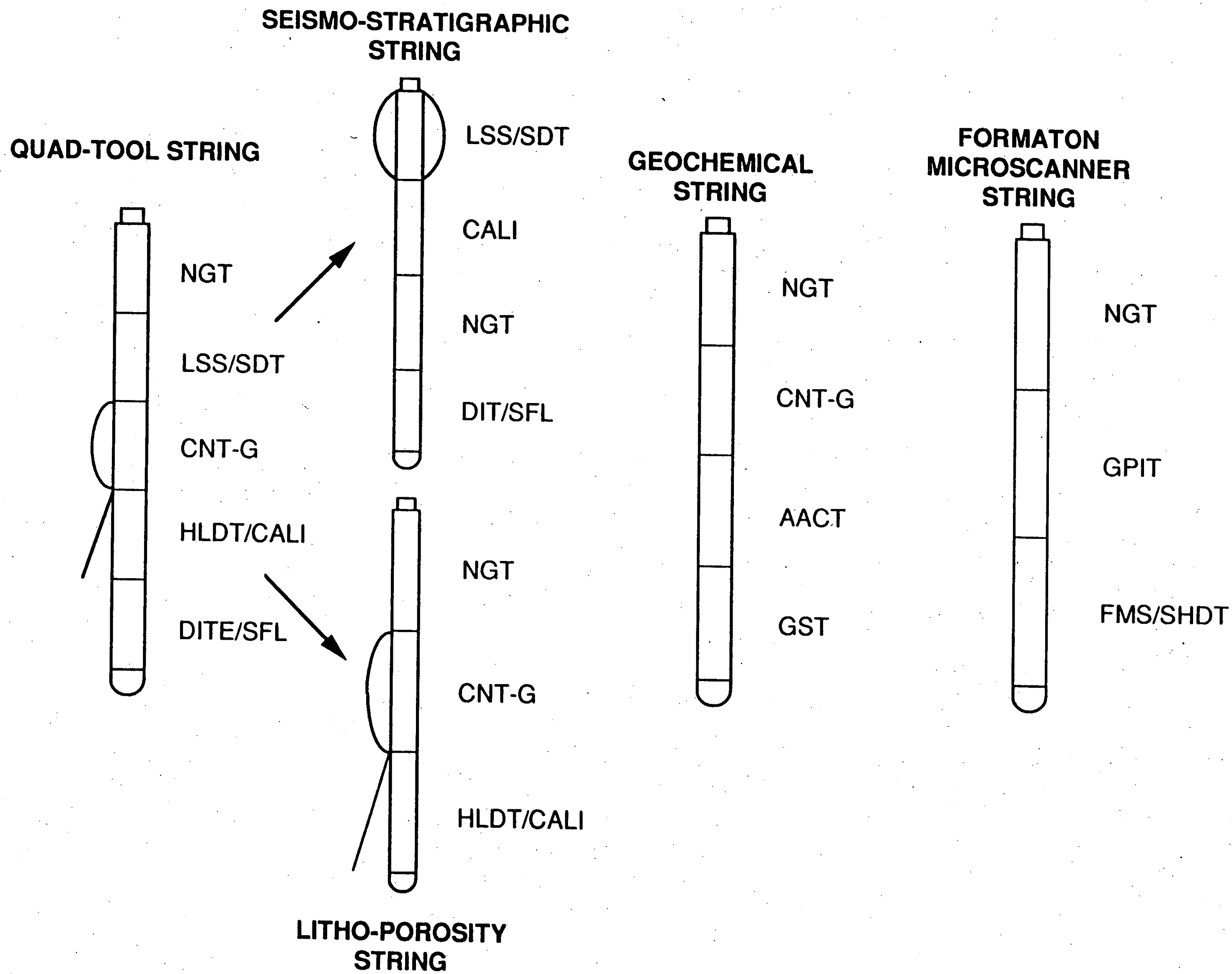


Figure 2-1. Schematic configurations of the Schlumberger tool strings operated in the Ocean Drilling Program. For the exact location of the measure point of each tool sensor refer to Table 2-3.

Table 2-3. Sensor Measure Points of the Schlumberger Tools (height above bottom of tool string) (1)

STRING	TOOL	SENSOR MEASURE POINT (in m)
Quad-tool combination	NGT	30.61
	LSS/SDT	
	CNTG	17.30 (E), 17.81 (T) (2)
	HLDT	10.36 (N), 10.49 (F) (3)
	CALI	10.31
	DIT (deep)	2.90
	SFL	1.98
	DIT (medium)	1.83
Geochemical	NGT	16.87
	CNTG	12.04 (E), 12.55 (T)
	AACT	10.57
	GST	2.84
Formation Microscanner	NGT	9.83
	CALI	0.33
	GPIT	0.33
	FMS/SHDT	0.33
Seismo-stratigraphic	LSS/SDT	17.73 (N), 18.03 (F) (3)
	CALI	13.08
	NGT	11.79
	DIT (deep)	2.90
	SFL	1.98
	DIT (medium)	1.83
Litho-porosity	NGT	13.08
	CNTG	8.77 (E), 8.26 (T) (2)
	HLDT	0.64 (N), 0.79 (F) (3)
	CALI	0.81

(1) if a temperature tool is attached to the bottom of the tool string add 1.52 m
(2) E=epithermal detectors, T=thermal detectors
(3) N=near detector, F=far detector

Quad-Tool String (Figure 2-2)

When the logging plan does not allow any time for extra logging runs this string permits the runnning of five tools in one lowering (from top to bottom): Natural Gamma Ray (NGT), Long Spacing Sonic (LSS) with a cartridge from the Digital Sonic Tool (SDT), Compensated Neutron Porosity (CNT-G), High Temperature Lithodensity (HLDT) with Caliper, and Phasor Dual Induction (DIT) tool (Figure 2-2). With the quad-tool combination, however, the sonic tool response recorded in real-time is often unreliable, due to the lack of centralization. Because a hole size reading is now provided by the caliper mounted on the lithodensity tool (eccentered), the three-arm caliper originally located above the sonic tool has been eliminated, along with the centralization of the tool itself. As a consequence, the sonic pulse does not radiate symmetrically, and the measurements do not come from all sides of the hole simultaneously. On the other hand, the neutron porosity tool needs to be eccentralized and in contact with the borehole wall in order to reduce the attenuation of the signal by the borehole fluid. Routinely, the eccentralization is accomplished by a bow spring which is not used on the quad-combo because it would increase the risk of getting stuck in the 5-inches diameter pipe. In conclusion, in order to obtain good quality sonic and neutron porosity data, the quad-tool combination is sometimes separated into two logging runs (Figure 2-1), the seismic-stratigraphic and the litho-porosity combinations (see below), which meet the requirements for a proper sonic and neutron recording.

Geochemical String (Figure 2-3)

This string utilizes three modes of gamma ray spectroscopy to obtain a detailed elemental analysis of the formation. Natural (no nuclear source) spectroscopy with the Natural Gamma Ray tool (NGT) yields the concentration of the naturally occurring radionucleides in the formation K, Th, and U. Neutron-induced activation analysis performed with the Aluminum Activation Clay tool (AACT) provides an absolute measurement of Al concentration. Finally, induced capture spectroscopy measurements made with the Gamma Spectroscopy tool (GST) can be used to determine the concentration of Si, Ca, Fe, S, H, Cl, Ti, and Gd.

Formation MicroScanner String (Figure 2-4)

The Formation MicroScanner (FMS) provides oriented, two-dimensional, high-resolution images of the variations in microresistivity around the borehole wall. The string also includes a general purpose inclinometer tool (GPIT) which allows for the orientation of the microresistivity measurements from accelerometry measurements and from the declination and inclination components of the earth's magnetic field vector. The FMS also provides precise measurements of the borehole diameter in two orthogonal directions, while a natural gamma ray measurement permits correlations with other logging runs.

Among the applications of the FMS are the following: correlation of coring and logging depth; orientation of cores and location of the cored sections when recovery is less than 100

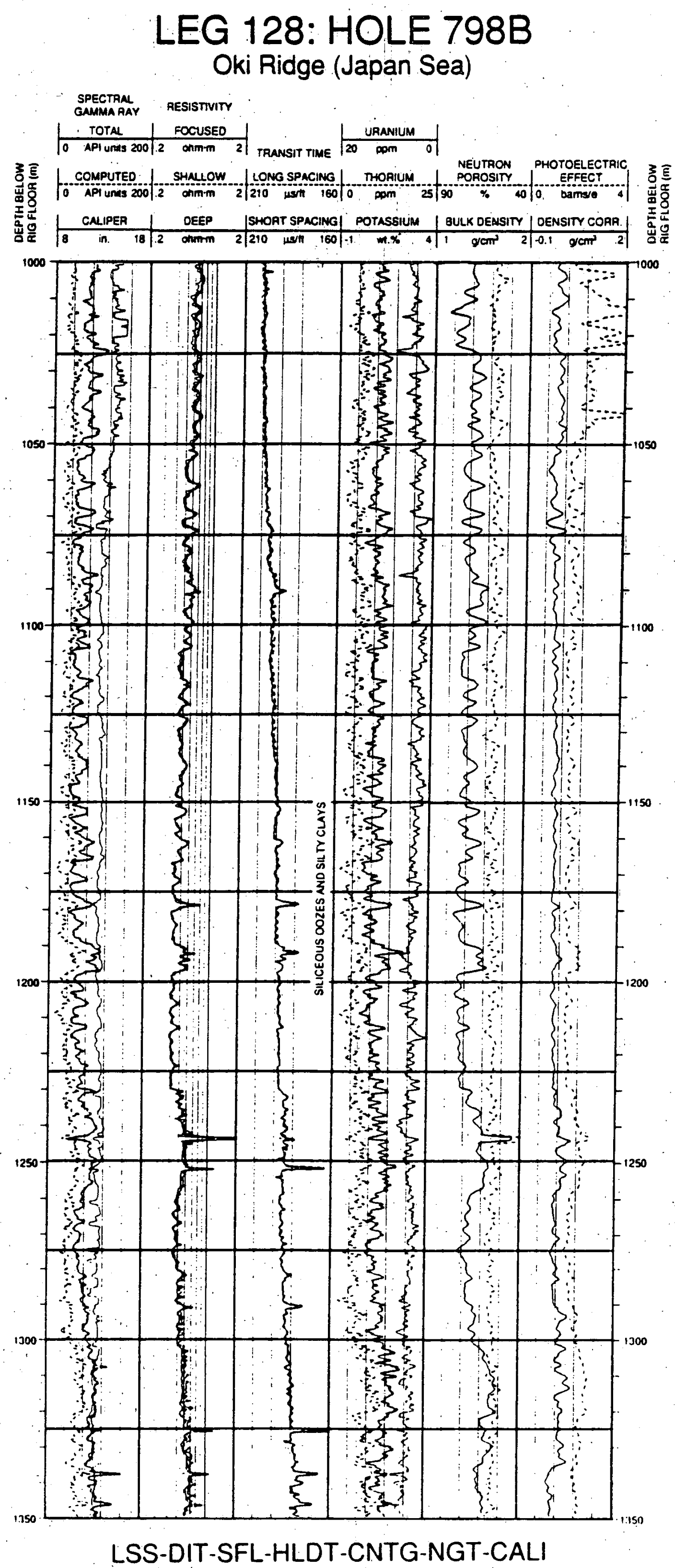
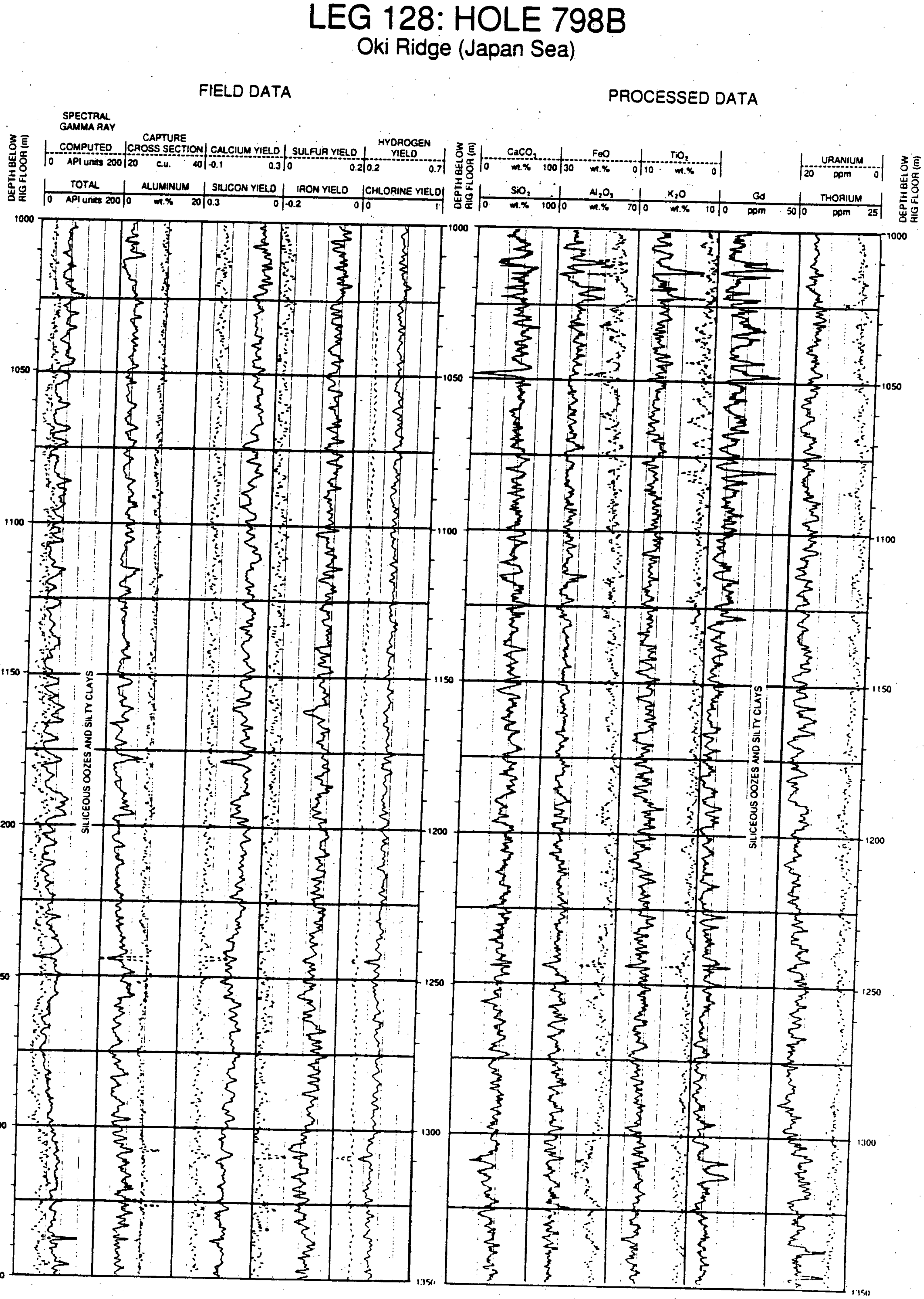


Figure 2-2. Typical log dataset recorded with the quad-tool string.



ACT-GST-NGT

Figure 2-3. Example of logging dataset recorded with the geochemical tool string. Both the original and processed data are displayed. Because in this section of the hole the sediments consist almost entirely of siliceous oozes and the $CaCO_3$ measured on cores is less than 1%, the computation of $CaCO_3$ from the logs was omitted, as it would introduce noise into the other estimates.

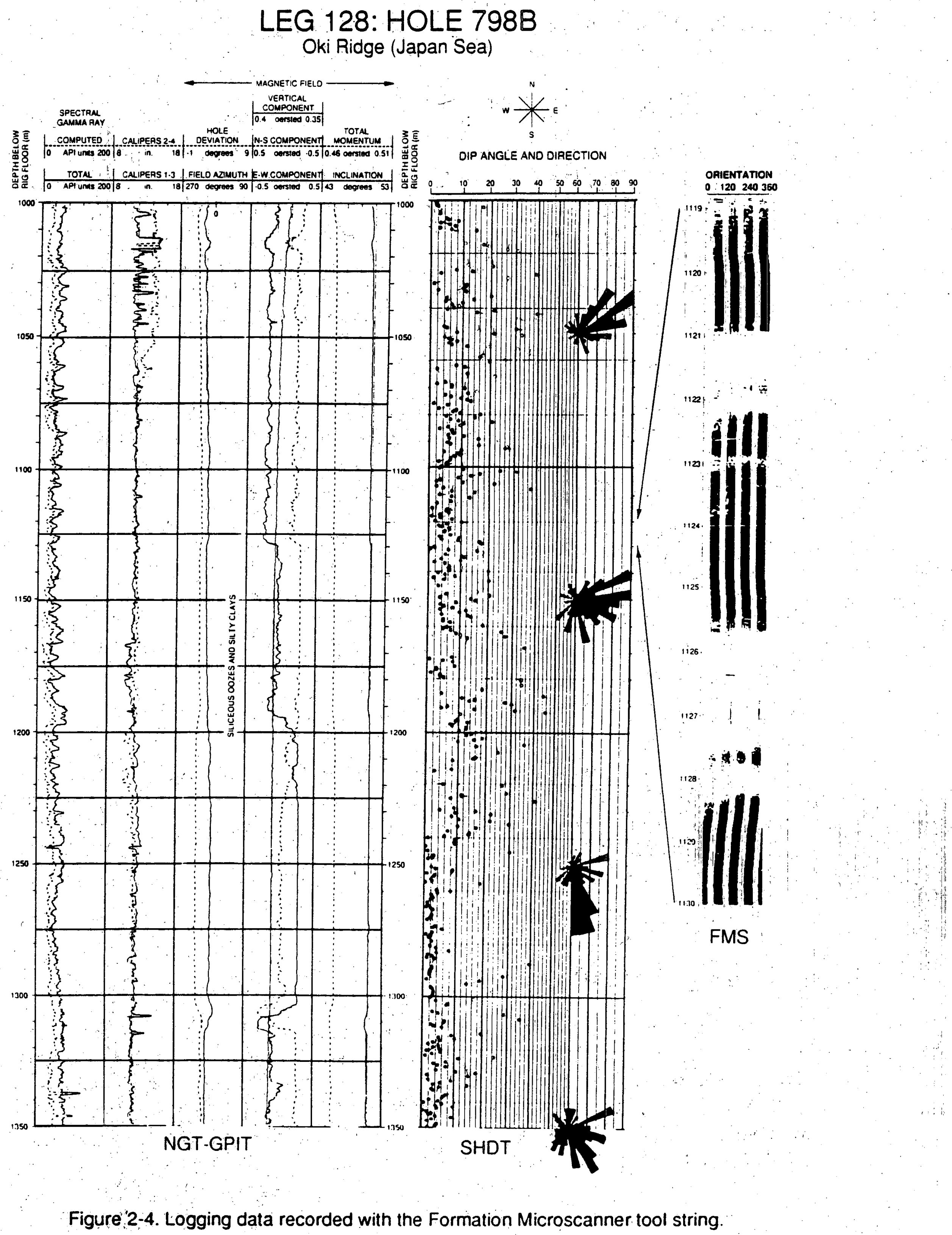


Figure 2-4. Logging data recorded with the Formation Microscanner tool string.

%; mapping of fractures, faults, foliations, and formation structures; analysis of depositional environments; definition of stress directions.

Seismic-Stratigraphic String

The seismic stratigraphic combination includes the Long Spacing Sonic (LSS) with a cartridge from the Digital Sonic Tool (SDT), the Phasor Dual Induction (DIT), the Natural Gamma Ray (NGT), and the 3-arm caliper (MCD) tools. The Borehole Compensated Sonic tool (BHC) is also on the ship as backup tool, to replace the Long Spacing Sonic in case of tool malfunction. The value of this combination to seismic stratigraphy is that it directly measures compressional wave sound velocity and indirectly measures the two variables that most often affect velocity: porosity and clay mineral content.

Litho-Porosity-Gamma Ray String

This combination includes Natural Gamma Ray (NGT), High Temperature Lithodensity (HLDT), caliper, and Dual Porosity Compensated Neutron (CNT-G) tools. It provides measurements of formation porosity and density as well as an estimate of the proportions of the primary radioactive elements (U, K, and Th).

Dual Laterolog

Resistivity induction logging probes do not produce reliable results in highly resistive formations such as oceanic basalts. To record these data we must run in a separate pass the Schlumberger Dual Laterolog (DLL). This tool can be combined with the NGT (Natural Gamma Ray) tool.

Well Seismic Tool

The WST is a wellbore clamped single-component geophone used to record vertical seismic profiles in a borehole. It provides a measure of formation velocity at seismic frequencies by measuring the travel-time between a surface seismic shot and the wellbore geophone. Estimates of depths to reflectors below the total depth can be made with this experiment. These data are useful in depth correlating reflectors on nearby seismic lines. The WST is not routinely aboard the JOIDES Resolution but is available for individual legs.

Calibration of Schlumberger Tools

Schlumberger standard logging tools are calibrated for optimum response in sedimentary rocks. In order to verify operation in other lithologies, the ODP Schlumberger density, neutron, spectral gamma, resistivity, and sonic tools were run in hard rock test pits at the Denver Federal Center of the United States Geological Survey. All log responses were within the range of core measurements. The data recorded with the geochemical tools can be calibrated at each site using core measurements.

Specialty Tools

The Borehole Research Group at LDGO provides three types of logging tool, the Borehole Televiewer (BHTV), Multichannel Sonic (MCS), and the temperature tool (TLT) which are operated by the L-DGO-BRG logging scientist. While the temperature tool is virtually run on each logging run, the BHTV and MCS are run on selected legs only, after time is approved by the Downhole Measurements Panel and ODP Planning Committee.

Specialty Tools by Shipboard Scientists

A wide variety of other measurements have been made in boreholes on land. Many of these have also been obtained on the JOIDES Resolution by members of the scientific party during various legs. These include: large scale resistivity (leg 102, 109, and 128), precision temperature (leg 109, 111, and 118), magnetic susceptibility (leg 102, 109, and 118), 3-axis magnetometer (leg 102, 109, 111, 118, 120, 123, and 125), vertical seismic profile (leg 101, 102, 104, 111, 118, 123, and 129), and drillstring packer (leg 102, 109, 111, 118, and 123) to mention some. Measurements that have been made on land but have not yet been recorded in ODP boreholes include non-linear complex resistivity, induced polarization, and circumferential acoustic logs.

There are several restrictions which should be noted by prospective logging investigators. These include the TAMU minimum weight restriction (100 lbs. floating for uncentralized tools and 200 lbs. floating for tools with centralizers), the limitations in cable speed (100 m/hr lower limit), the specifications of the cable (7 conductors, 170 Ω line resistance, G-O cable-head or your own pigtail), the determination of depth (500 pulls per foot quadrature signal), the amount of space available for tool storage and setup, and the computer space to record and process the data (severely limited).

Phasor Dual Induction - Spherically Focused Resistivity (DITE-SFL)

The Phasor Dual Induction - Spherically Focused Resistivity tool provides measurements of spontaneous potential (SP) and three different resistivity values: IDPH (deep induction), IMPH (medium induction) and SFLU (shallow spherically focused resistivity). Since the solid constituents are orders of magnitude more resistive than pore fluids in most rocks, resistivity is controlled mainly by the conductivity of the pore fluids and by the amount and connectivity of the pore space. The spontaneous potential is a measure of the streaming potential generated by differences between borehole and pore fluid electrical properties; these result in both membrane and liquid junction potentials due to differences in the mobility of ions in the pore and drilling fluids. As such,it has generally been assumed to be uninteresting in ODP boreholes; recent results, however, suggest that it may be responding both to the presence of fractures and to the electromagnetic properties of basalts.

The induction sonde consists of a series of transmitter and receiver coils mounted on the sonde axis. To facilitate the principle understanding Figure 2-5A considers a simplified sonde with only one transmitter and receiver coil. The high frequency, alternating current of constant intensity sent through the transmitter coil produces an alternating magnetic field which in turns induces currents in the formation around the borehole. These currents flow in circular ground loops coaxial with the sonde and because the alternating current sent by the transmitter coil is of constant frequency and amplitude, they are directly proportional to the formation conductivity. They also produce a magnetic field which induces a voltage in the receiver coil, which is in turn proportional to the ground loop currents and therefore to the resistivity of the formation. The operating frequency of the induction arrays can be selected at 10 kHz, 20 kHz, or 40 kHz, but the default frequency is 20 kHz. Because the signal from an element of formation increases with the square of the transmitter frequency, operation at 40 kHz yields fourv time the signal that operation at 20 kHz, thus improving the signal-to-noise ratio at high resistivities. In addition to the usual inphase (R-signal) induction measurement, the Phasor Induction Tool provides a high quality measurement of the induction quadrature signal (X-signal). The combination of these two signals along with improvements in signal processing provide higher vertical resolution logs, fully corrected for shoulder and borehole effects.

The resistivity measured by the induction log is quite accurate for low resistivities, but in formations with resistivity higher than 100 Ωm the error can be as high as 20%. In these rocks the Dual Laterolog (see page 2.7) produces more reliable results.

In the spherically focused resistivity sonde the measure (i_o) and focusing currents (i_a) are sent into the formation from electrode A_o (Figure 2-5B). The former returns to the cable armor while the latter return to electrodes A_1 and A'_1 on the sonde. The focusing currents are adjusted so that the potential between M_o and the midpoint between M_1 and M_2 is constant; thus, i_a flows into the borehole and i_o into the formation. This system produces two equipotential spheres around the sonde which are 9" and 50" away from the current electrode, while a constant 2.5 mV potential is maintained between the two surfaces; the

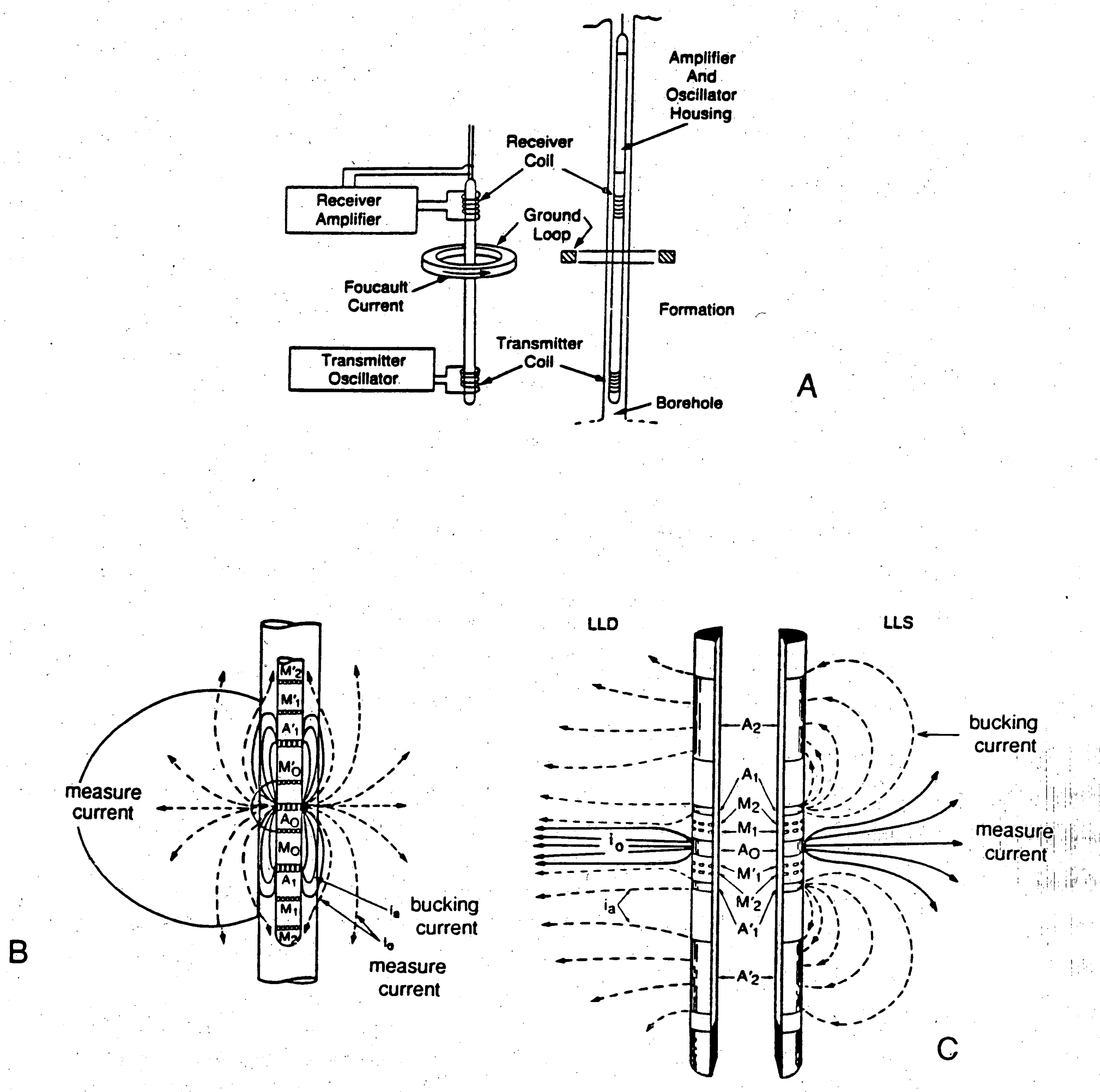


Figure 2-5. Sketch of the resistivity devices used in the Ocean Drilling Program: (A) Dual Induction Tool (DIT), (B) Spherically Focused Resistivity Tool (SFL), and Dual Laterolog (DLL; courtesy of Schlumberger).

intensity of the current flowing through the volume between these two spheres is inversely proportional to the resistivity of the formation.

Depth of Investigation and Vertical Resolution

In homogeneous formations with resistivity higher than 100 Ωm the average radial depth of investigation is about 5 ft (1.5 m) and 2.5 ft (76 cm) for the deep and medium induction curves respectively, and 1.25 ft (38 cm) for the SFL. This drops to 4 ft (122 cm) and 2.2 ft (66 cm) at 0.1 Ωm resistivities.

Thanks to an enhanced signal processing technique and to a real time correction for the effect of adjacent formations (shoulder effect) the thin bed resolution over a full range of formation conductivities has been greatly improved. Vertical Resolution is 5-6 ft (1.5 m) and 7-8 ft (2 m) for the medium and deep induction and 2.5 ft (76 cm) for the spherically focused log.

Log Presentation

Deep (ILD or IDPH) and medium induction (ILM or IMPH), and spherically focused resistivity (SFLU) are usually plotted in Ωm on a logarithmic scale along with caliper, gamma ray, and sonic data (Figure 2-6).

Environmental Effects

The Phasor Dual Induction tool provides a set of corrections for different environmental effects, which can be performed in real time during logging. These include corrections for adjacent formations, borehole signal, and invasion. In general, invasion is not a problem in the boreholes logged in the Ocean Drilling Program, because seawater is used as drilling fluid, but can occur in land wells. In fact, depending on the type of drilling mud used and on the permeability of the formation, invasion of the mud filtrate into the formation adjacent to the borehole can lead to differences in the response of shallow and deeper resistivity devices. On the other hand, invasion can provide useful information about formation permeability and pore fluid electrical conductivity. Differences in the temperature of drilling fluid compared to undisturbed formation temperatures can also generate this effect, as conductivity in ionic fluids such as seawater is strongly temperature dependent.

Principal Applications

- ❑ porosity estimate. In sediments which do not contain clay or other conductive minerals, the relationship between resistivity and porosity has been quantified by Archie's Law, which relates the resistivity to the inverse power of porosity. This relationship has also been used to estimate an apparent porosity in oceanic basalts.

- ❑ density and velocity reconstruction. Archie's equation has been used effectively to create "pseudodensity" and/or "pseudovelocity" logs from porosity over intervals where no such logs were recorded or were totally unreliable. In some instances velocities derived from resistivity logs can be used to depth-tie seismic reflectors.

LEG 107: HOLE 651B
Sardinian Margin (Mediterranean Sea)

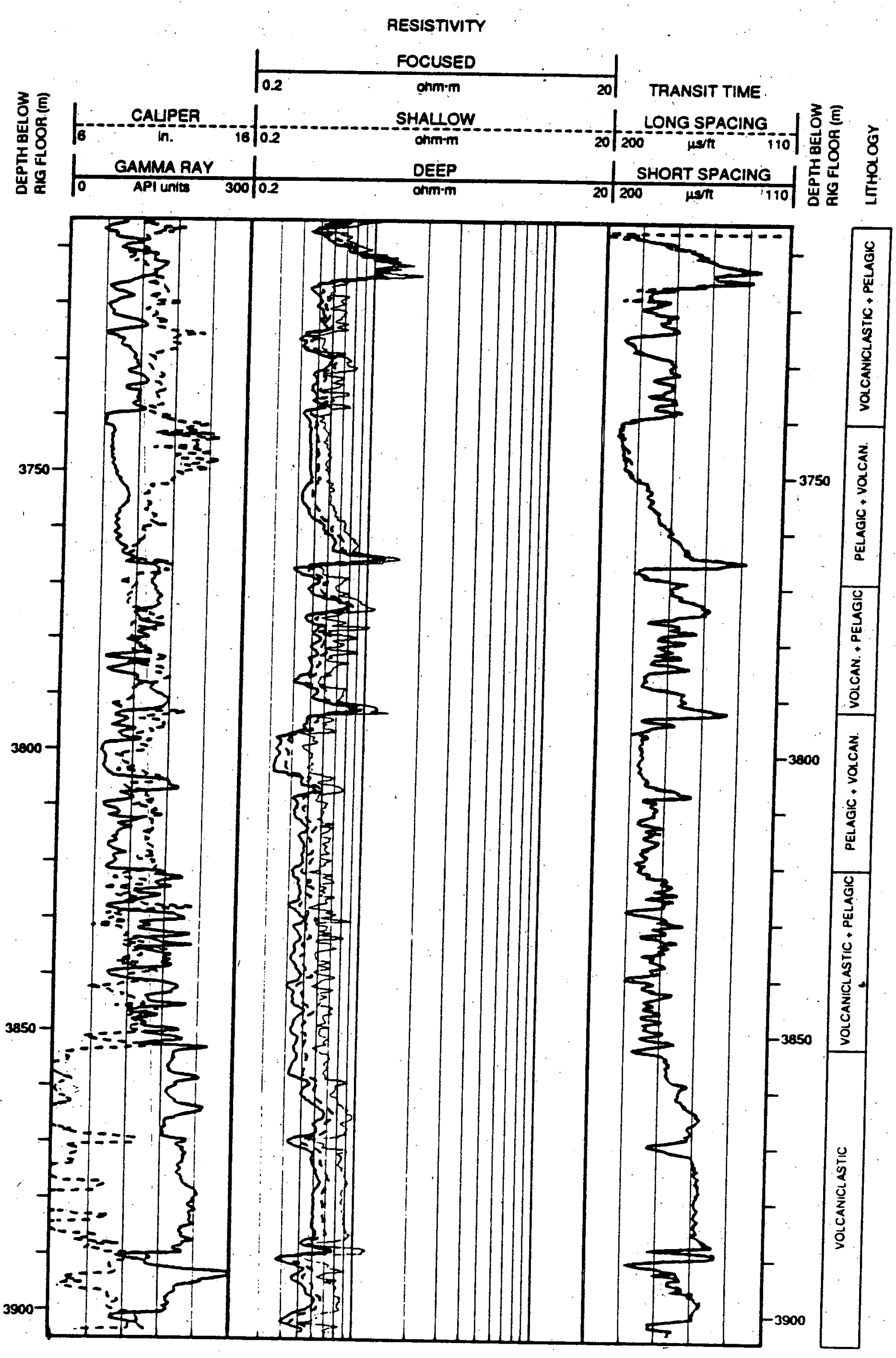


Figure 2-6. Typical display of resistivity data (ILd, ILm, SFLU) along with acoustic data (DT and DTL), gamma ray (GR), and caliper (CALI). Both resistivity and transit time were used to define lithologic boundaries where core recovery was poor and to detect grain size variations, (e.g. the fining-upward sequence between 3770 and 3740 mbrf). The difference between the three resistivity measurements is due to invasion by drilling fluid less saline that formation water; only the deep resistivity device "sees" the true formation resistivity.

- lithologic boundary definition and textural changes. Resistivity, along with acoustic and velocity logs, is a very valuable tool in defining lithologic boundaries over intervals of poor core recovery, as shown in Figure 2-6. Also, in this example, the decrease in resistivity towards the top of the unit at 3740-3770 mbrf, coupled with a decrease in velocity, allows one to interpret this unit as as a fining-upward sequence in mostly carbonatic sediments. Similar saw-tooth patterns in the resistivity response can also be observed in oceanic basalt units where they are related to porosity changes towards the top of each unit (Volume 6, Figure 3-9).

Dual Laterolog (DLL)

The Dual Laterolog provides two resistivity measurements with different depths of investigation into the formation: deep (LLd) and shallow (LLs). In both devices, a current beam 2 ft-thick (A_0) is forced horizontally into the formation by using focusing (also called bucking) currents (A_1-A_2, A'_1-A'_2 in Figure 2-5C); two monitoring electrodes (M_1, M_2, M'_1, M'_2) are part of a loop that adjusts the focusing currents so that no current flows in the borehole between the two electrodes. For the deep measurement both measure and focusing currents return to a remote electrode on the surface; thus the depth of investigation is greatly improved, and the effect of borehole conductivity and of adjacent formations is reduced. In the shallow laterolog, instead, the return electrodes which measure the bucking currents are located on the sonde, and therefore the current sheet retains focus over a shorter distance than the deep laterolog.

The Dual Laterolog response ranges from 0.2 to 40,000 Ωm, thus permitting a good characterization of highly resistive rocks such as oceanic basalts and gabbros.

The DLL is usually run in combination with the Natural Gamma Ray Tool (see below).

Depth of Investigation and Vertical Resolution

The depth of investigation of the laterolog depends on the resistivity of the rock and on the resistivity contrast between the zone invaded by the drilling fluid and the virgin (uninvaded) zone. The vertical resolution of both LLd and LLs depends on the geometry defined by the focusing electrodes: this is about 2 ft (61 cm).

Log Presentation

The LLd and LLs curves are displayed on a resistivity logarithmic scale on tracks 2 and 3, along with the gamma ray log on track 1 (Figure 2-7, left).

LEG 111: HOLE 504B
Costa Rica Rift (Pacific Ocean)

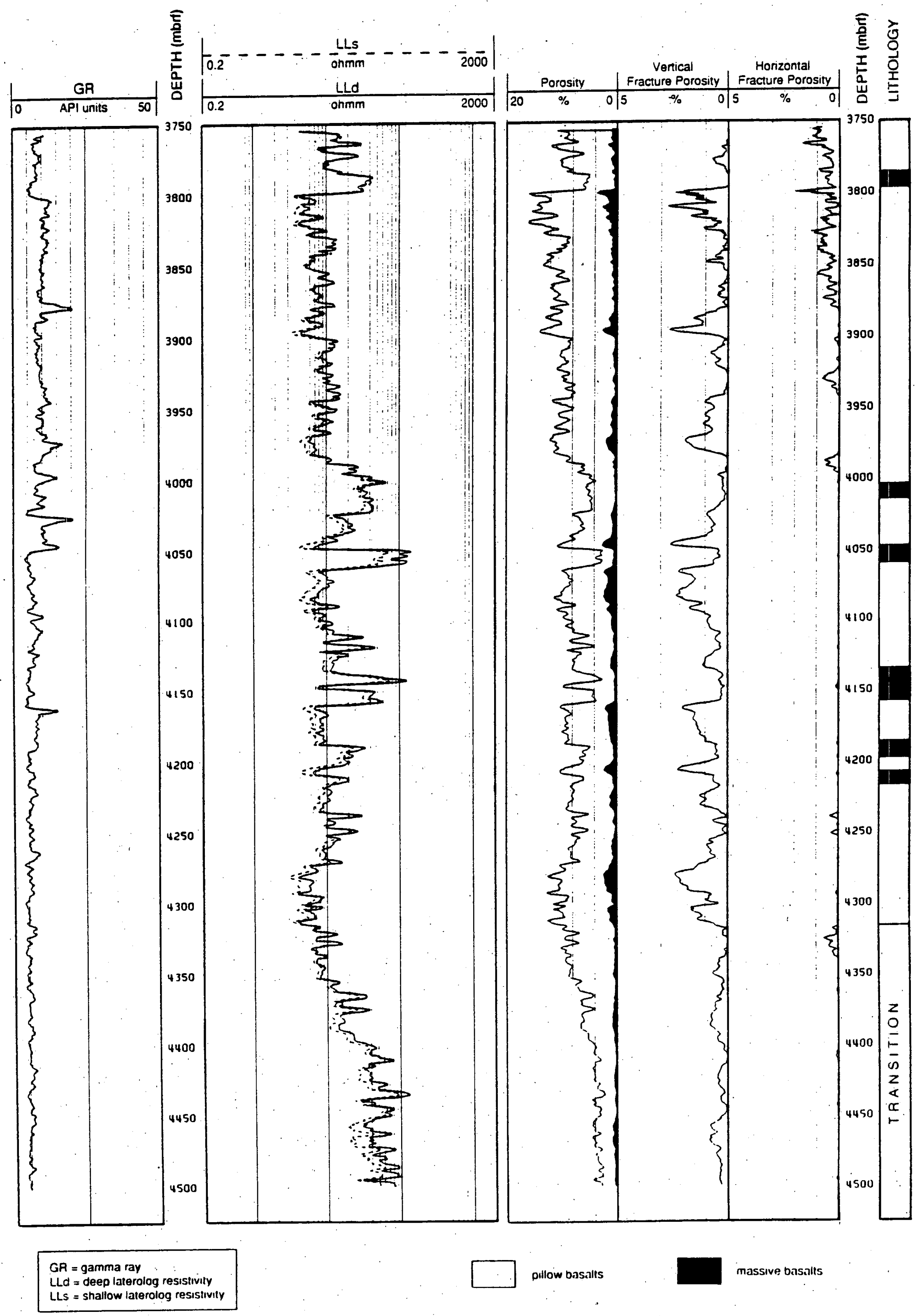


Figure 2-7. Estimate of total porosity and fracture distribution using the Dual Laterolog. LLd > LLs because of predominance of vertical fractures.

Environmental Effects

For the LLd the borehole effect is small for hole diameters up to 16 in, while the LLs provides good readings in holes not exceeding 12 in. Corrections are available for holes up to 20" in diameter.

Principal Applications

- porosity estimate. Because of the inverse relationship between resistivity and porosity, the dual laterolog can be used to estimate the porosity of the rock from Archie's equation if the sediments/rocks do not contain any clay or if the contribution of surface conduction to the signal is negligible.

- fracture porosity estimate. This can be estimated from the separation between the deep and shallow measurements based on the observation that the former is sensitive to the presence of horizontal conductive features only, while the latter responds to both horizontal and vertical conductive structures (Figure 2-7, right).

Natural Gamma Ray Tool (NGT)

The NGT utilizes a sodium-iodide scintillation detector to measure the natural gamma ray radiation of the formation and 5-window spectroscopy to resolve the detected spectrum into the three most common components of the naturally occurring radiation: potassium, thorium, and uranium. The high-energy part of the spectrum is divided into three energy windows, each covering a characteristic peak of the three radioactivity series. The concentration of each component is determined from the count rates in each window. Because the high-energy region contains only 10 % of the total spectrum count rates, the measurements are subject to large statistical variations, even using a low logging speed. The results are considerably improved by including the contribution from the low-energy part of the spectrum. Filtering techniques are used to further reduce the statistical noise by comparing and averaging counts at a certain depth with counts sampled just before and after. The final outputs are the total gamma ray (SGR), a uranium-free gamma ray measurement (CGR), and the concentrations of potassium (POTA, wt. % or decimal fraction), thorium (THOR, ppm), and uranium (URAN, ppm).

Depth of Investigation and Vertical Resolution

The radius of investigation depends on several factors: hole size, mud density, formation bulk density (denser formations display a slightly lower radioactivity), and on the energy of the gamma rays; (a higher energy gamma ray can reach the detector from deeper in the formation). The vertical resolution on the log is about 1.5 ft (46 cm; Table 2-2).

Log Presentation

The NGT log is routinely recorded with each logging string for correlation between logging runs. To this purpose SGR and CGR are usually displayed along with other curves (resistivity, sonic, density etc.; Figure 2-2, 2-3, 2-4). A full display of the data, with SGR and CGR in track 1, and THOR, URAN, and POTA on track 2 and 3 is usually provided separately (Figure 2-8).

Environmental Effects

The NGT response is affected by borehole size, mud weight, and by the presence of bentonite or KCl in the mud. In ODP boreholes KCl is often added to the mud to stabilize fresh-water clays which tend to swell and form bridges. This procedure takes place before logging operations start, and even though KCl is probably diluted by the time the tool reaches total depth, it can still affect the tool response.

All the above effects are accounted for during the processing of the NGT data on-shore.

Principal Applications

- Clay typing. Potassium and thorium are the primary radioactive elements present in clays; because the result is sometimes ambiguous, it can help combining these curves or the ratios of the radioactive elements with the photoelectric effect from the lithodensity tool.

- Mineralogy. Carbonates usually display a low gamma ray signature; an increase of potassium can be related to an algal origin or to the presence of glauconite, while the presence of uranium is often associated with organic matter (see Volume 3, Figure 5-3).

  In sandstones with very low potassium signature sudden rises in thorium and uranium can be indicative of heavy mineral concentrations (which may be confirmed by the occurrence of positive kicks on the lithodensity log) or of feldspars mixed into terrestrial sands.

  In igneous rocks the combination of potassium with the SiO_2 weight fraction from the GST tool and/or bulk density and photoelectric effect logs provides an easy determination of the rock type (Figure 2.9). Generally, the content of thorium and uranium decreases from acidic to ultrabasic rocks . In oceanic basalts an increase in potassium may be related to the presence of voids and fractures filled with K-bearing alteration minerals formed by interaction of basalt with seawater (see Volume 4, Figure 3-11).

LEG 121: HOLE 752B
Broken Ridge (Indian Ocean)

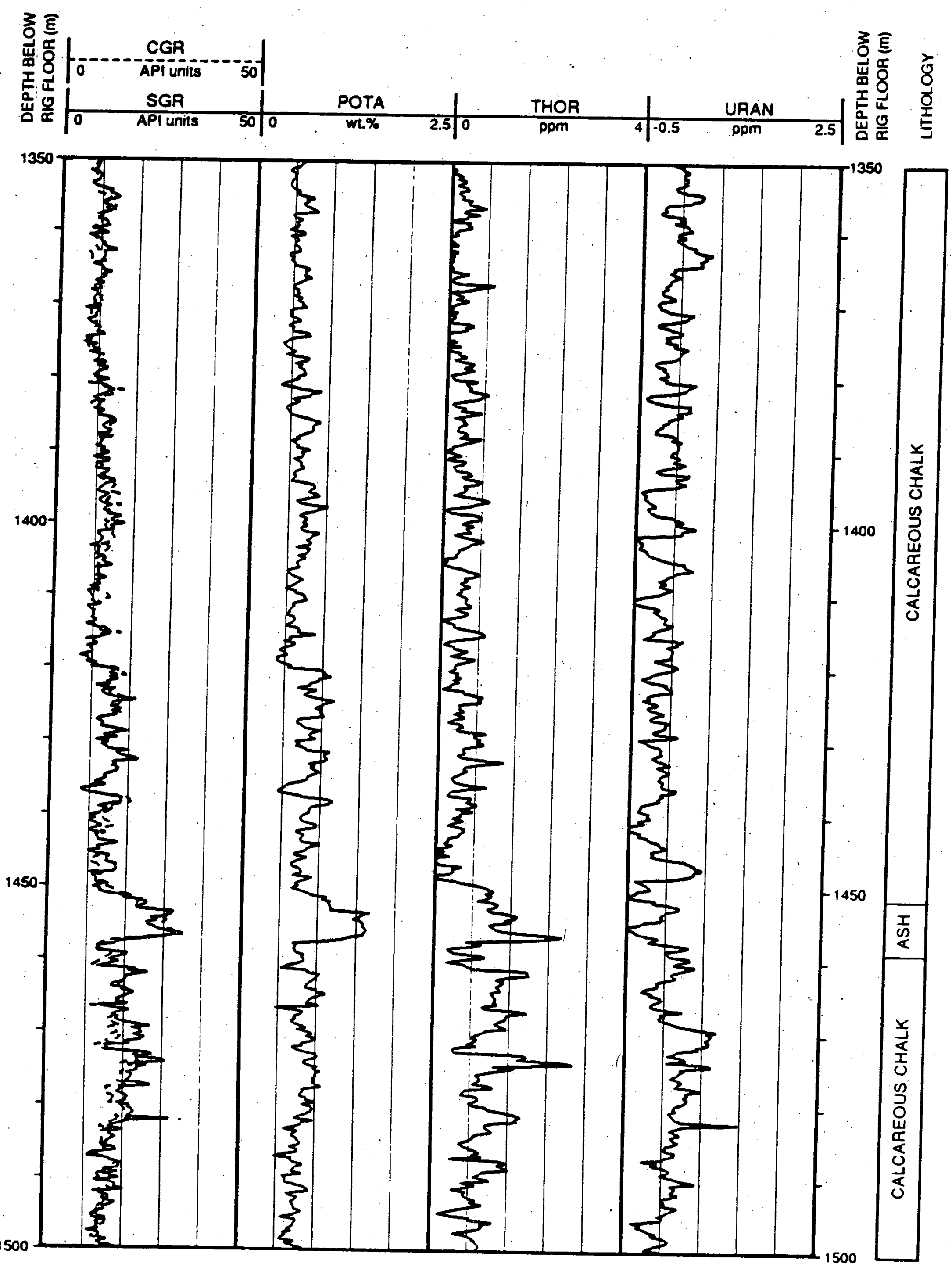


Figure 2-8. Typical display of natural gamma ray data recorded with the Natural Gamma Ray Spectrometry Tool (NGT).

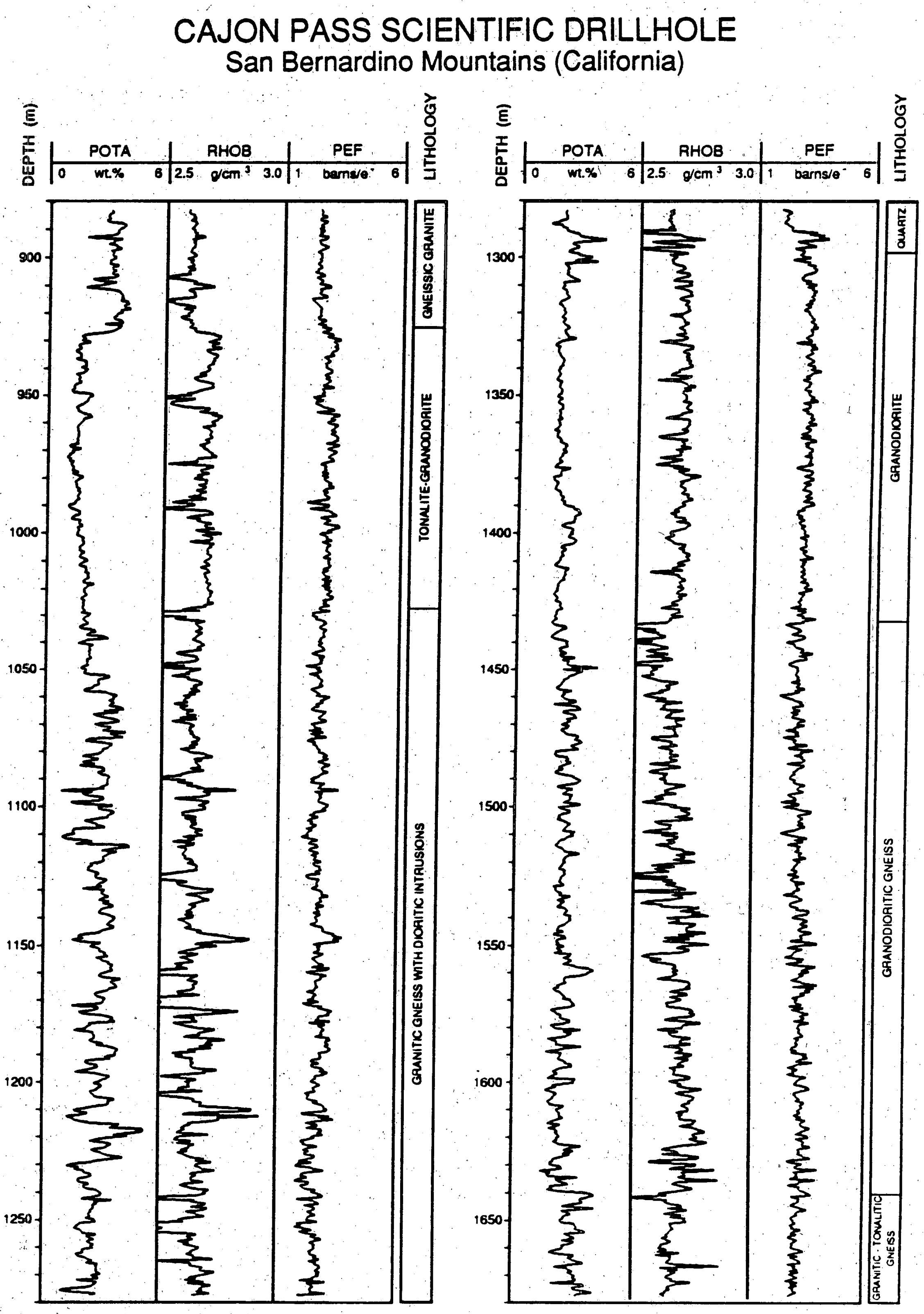


Figure 2-9. The potassium concentration (POTA) measured by the Natural Gamma Ray Tool, along with the bulk density (RHOB) and photoelectric effect (PEF) measured by the Lithodensity Tool have been effectively used to identify the different lithologies drilled at the Cajon Pass Scientific Drillhole.

Long-Spacing (LSS/SDT) and Borehole Compensated (BHC) Sonic Tools

Sonic tools are designed to measure the elastic compressional-wave velocity of the formation surrounding the borehole. In essence the sonic tool can be thought of as a miniature seismic refraction experiment carried out within the cylindrical borehole. The tool is centered in the hole by means of centralizers, and contains one or more sources and receivers. A source fires acoustic energy which is transmitted into the borehole fluid. When the wavefront impinges on the borehole wall, a refracted compressional wave is generated. If formation shear velocity is higher than the acoustic velocity of the fluid, a refracted shear wave will also be generated. The refracted waves travel along the borehole wall, re-radiating energy into the fluid. Energy arrives at receivers on the logging tool at a time which is linearly proportional to their offset from the source. Thus formation elastic-wave velocities can be determined by differencing the arrival times at two receivers a known distance apart.

The Borehole Compensated Sonic tool (BHC) consists of an upper and lower transmitter arranged symmetrically on either side of two pair of receivers (Figure 2-10, left). The spacing T_1-R_1 and T_1-R_3 are 3 and 5 apart as well as the spacings T_2-R_4 and T_2-R_2. The transit time of the compressional wave in the formation, measured in microseconds per foot is given by

$$\Delta t = 1/2\ (T_1R_3 - T_1R_1 + T_2R_2 - T_2R_4).$$

The Long Spacing Sonic sonde (LSS), which utilizes a cartridge from the Digital Sonic Tool (SDT) contains two acoustic sources spaced two feet apart located eight feet below a pair of receivers also spaced two feet apart (Figure 2-10, right). This provides source-receiver offsets of 8, 10, 10, and 12 feet. The measurement relies on the "depth derived" borehole compensation principle. Compensation is achieved by memorizing the first Δt reading and combining it with a second Δt reading measured after the sonde has been pulled the appropriate distance along the borehole. The symmetry of the sources and receivers allows travel-time measurements for 8 combinations of sources and receivers. Four of these are reversed by source-receiver reciprocity.

The tool needs to be run centralized in order to obtain reliable readings: the upper centralizing spring provides the hole diameter using a linear potentiometer to measure bowspring extension.

The LSS tool records the full waveform for each source-receiver pair, in addition to its automatic determination of arrival time. The sonde can be run in two modes to either correct downhole gains for variations in amplitude or to maintain a fixed gain As arrival-time is determined automatically using a threshold detector, the variable gain mode often produces better travel-time logs, although the waveforms will no longer be at fixed gain.

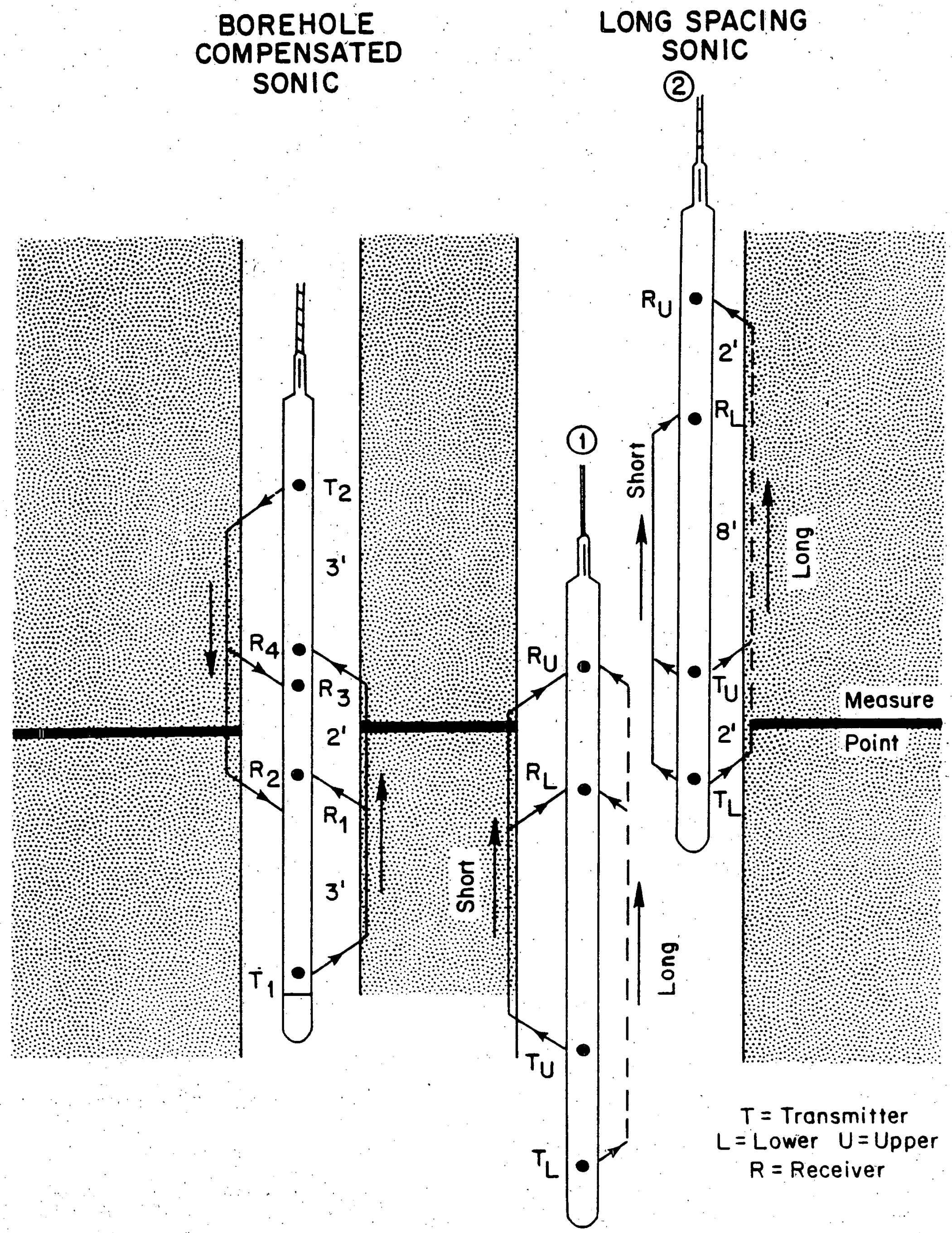


Figure 2-10. Sketch of the Schlumberger acoustic devices used in the Ocean Drilling Program: Borehole Compensated Sonic (BHC; left) and Long Spacing Sonic (LSS; right).

Depth of Investigation and Vertical Resolution

The depth of investigation cannot be easily quantified: it depends on the spacing of the detectors and on the petrophysical characteristics of the rock such as rock type, porosity (granular, vacuolar, fracture porosity), and alteration. For source-detector spacings of 3-5", 8-10", and 10-12" the depth of investigation ranges from 2" to 10" (altered/invaded and undisturbed formation, respectively), 5" to 25", and 5" to 30". The vertical resolution is 2 ft (61 cm).

Log Presentation

DT and DTL are interval travel-times in microseconds per foot for the near and far receiver pairs, respectively (Figure 2-6). In very slow formations DTL provides the only valid measurement, as the refracted wave is not seen at the near receivers. The sonic waveforms can also be displayed alongside the travel-time curves, and the individual travel-time measurements in microseconds (TT1 to TT4) are also available. Pips on the log plot indicate integrated travel-time to depth for crude seismic correlations.

Environmental Effects

One common problem is cycle skipping: a low signal level, such as that occurring in large holes and soft formations, can cause the far detectors to trigger on the second or later arrivals, causing the recorded Δt to be too high. This probem can also be related to the presence of fractures.

Transit time stretching appears when the detection at the further detector occurs later because of a weak signal. Finally, noise peaks are caused by triggering of detectors by mechanically induced noise, which causes the Δt to be too low.

Reprocessing programs that can eliminate the aberrations described above are available both at sea and on-shore.

Principal Applications

- ❑ porosity and "pseudodensity" log. The sonic transit time can be used to compute porosity by using the appropriate transform (Figure 2-11), and to estimate fracture porosity in carbonatic rocks. In addition, it can be used to compute a "pseudodensity" log (Figure 2-11) over sections where this log has not been recorded or the response was not satisfactory.

- ❑ seimic impedance. The product of compressional velocity and density is useful in computing synthetic seismograms for time-depth ties of seismic reflectors (Figure 2-12).

- ❑ sonic waveforms analysis. If a refracted shear arrival is present, its velocity can be computed from the full waveforms, and the frequency content and energy of both compressional and shear arrivals can also be determined.

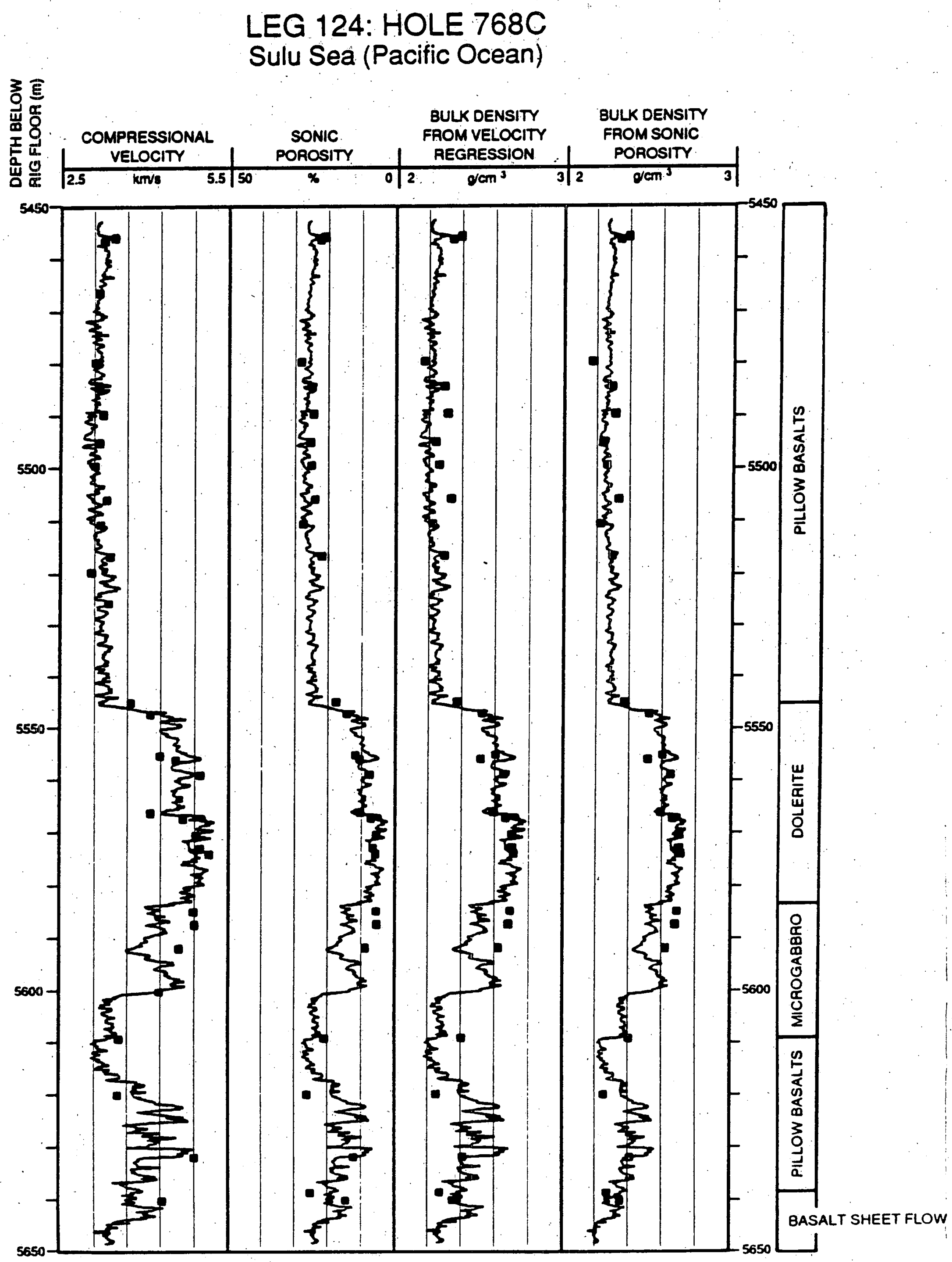


Figure 2-11. Estimate of porosity and pseudo-density logs from acoustic data recorded in basaltic crust. Note the good agreement with core measurements (solid squares).

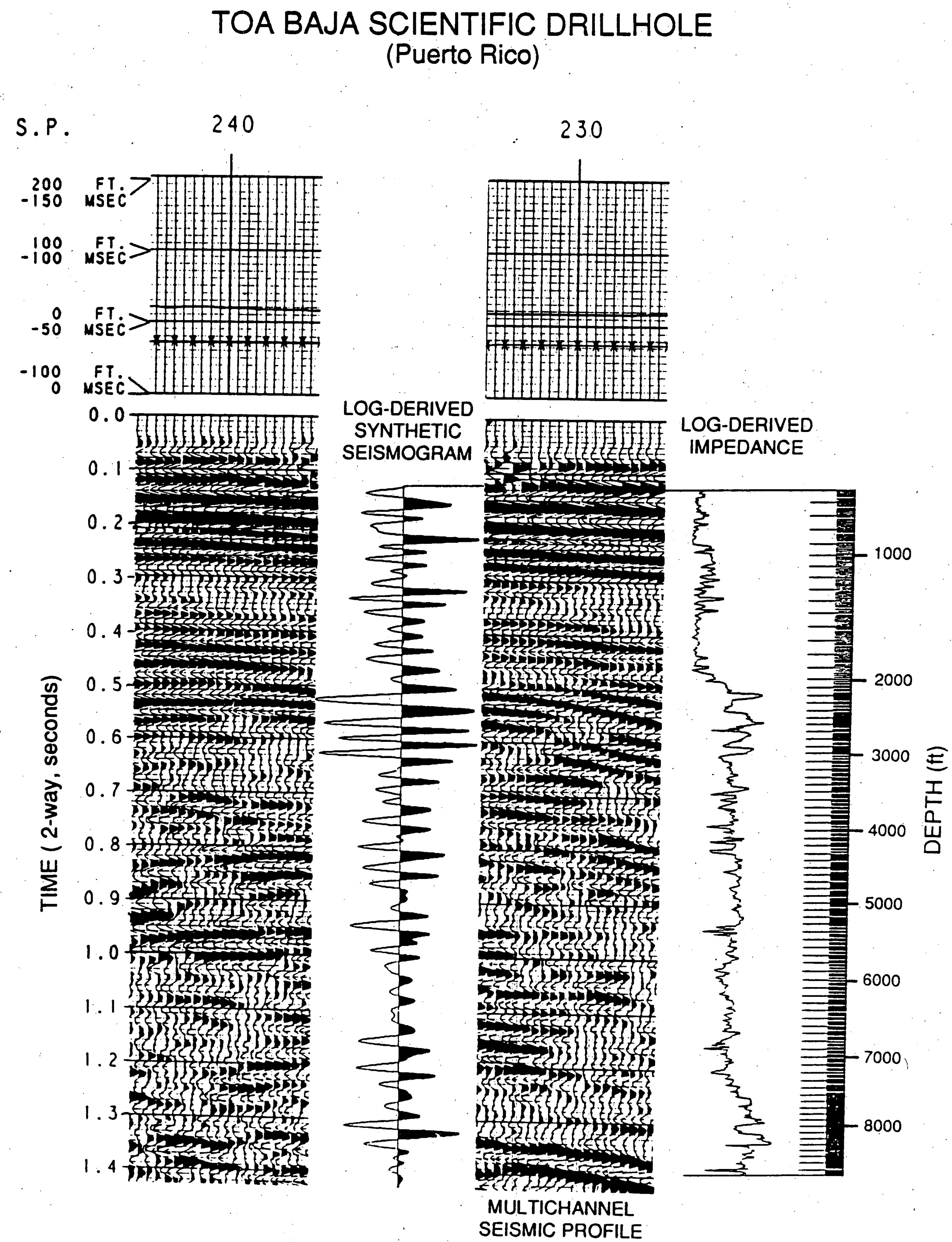


Figure 2-12. Impedance curve and synthetic seismogram computed from density and velocity data.

- fracture porosity. Variations in energy and frequency content are indicative of changes in fracture density, porosity, and in the material filling the pores. In some cases compressional-wave attenuation can also be computed from the full waveforms.

Lithodensity Tool (HLDT)

The HLDT consists of a Ce^{132} radioactive source and two detectors mounted on a shielded skid which is pressed against the formation by a hydraulically-activated eccentering arm (Figure 2-13). The 662 keV gamma rays emitted by the source into the formation experience two types of interaction with the electrons in the formation: Compton scattering and photoelectric absorbtion. The former is an elastic collision by which energy is transferred from the gamma ray to the electrons in the formation. This interaction forms the basis of the density measurement; in fact, because the number of scattered gamma rays which reach the detectors is directly related to the the number of electrons in the formation, the tool responds to the electron density of the rocks, which is in turn related to the bulk density.

Photoelectric absorption, instead, occurs when the gamma rays reach a low energy (< 150 keV) level after being repeatedly scattered by the electrons in the formation. The photoelectric effect index is determined by comparing the counts from the far detector in the high energy region, where only Compton scattering occurs, with those in the low energy region, where the count rates depend on both reactions. The far detector is used because it has a greater depth of investigation. The response of the short-spacing detector, which is mostly influenced by mudcake (not present in ODP boreholes where a seawater-based drilling fluid is used) and borehole rugosity is used to correct the density measurement for these effects.

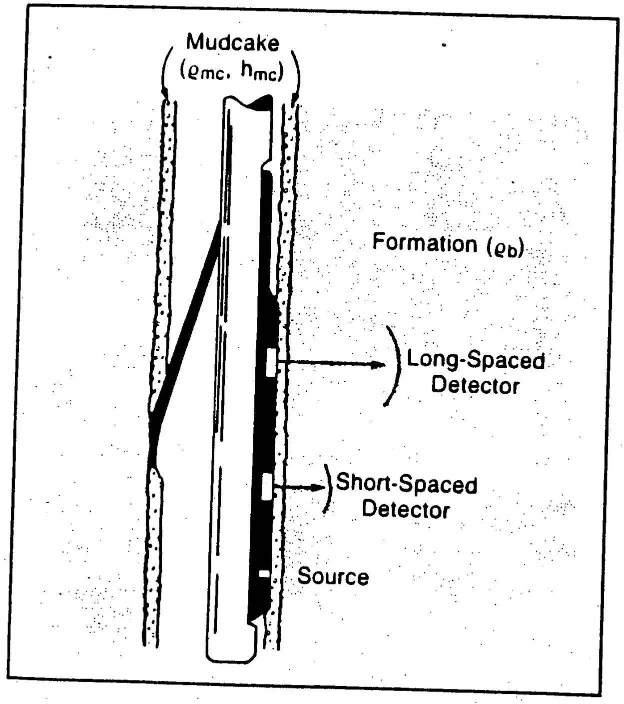
Depth of Investigation and Vertical Resolution

Like in the case of the sonic tool, the depth of investigation of the lithodensity tool cannot be easily quantified; it is in the range of tens of centimeters, depending on the density of the rock. In highly permeable formations the lithodensity tool may only investigate the zone invaded by the drilling fluid.

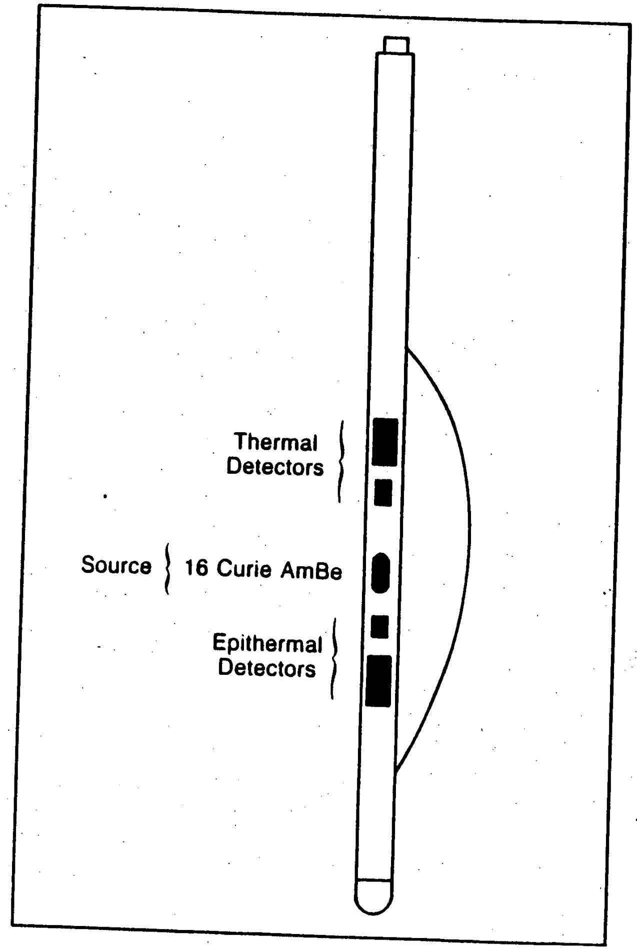
The vertical resolution is 16 in (38 cm).

Log Presentation

The primary curves are: bulk density (RHOB, in g/cc), photoelectric effect (PEF, in barns/electron) density correction (DRHO, in g/cc), and caliper (CALI, in in); Figure 2-14). They are usually displayed along with the neutron porosity curve NPHI. Also, DPHI (density porosity) can be computed and displayed by assuming a constant grain density of



HIGH TEMPERATURE
LITHODENSITY TOOL



COMPENSATED NEUTRON LOG

Figure 2-13 Schematic drawing of the density and porosity devices used in the Ocean Drilling Program (courtesy of Schlumberger).

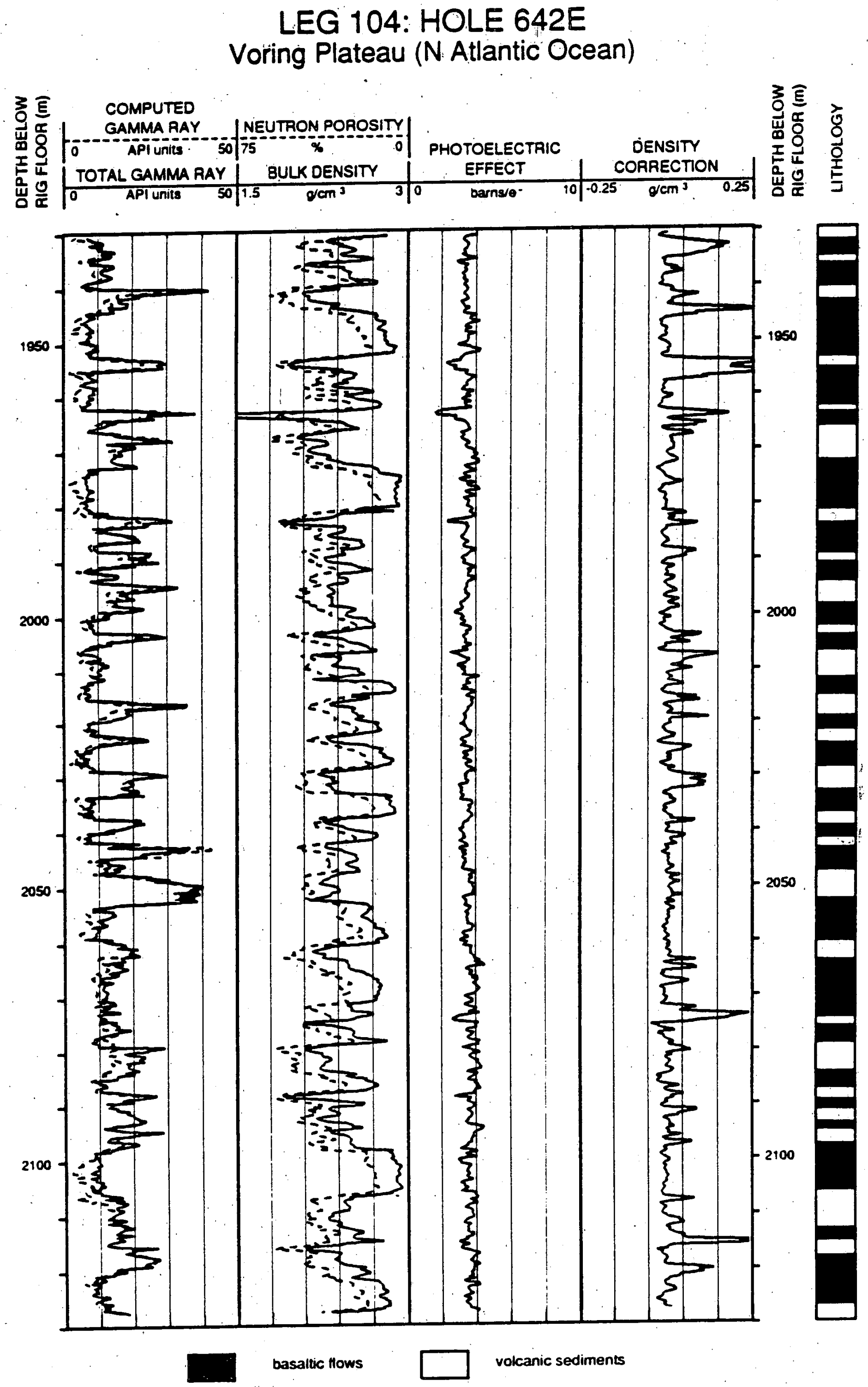


Figure 2-14. Typical display of bulk density, photoelectric effect and neutron porosity data. At this site, density, porosity and gamma ray data complemented the cores for a precise definition of the thickness of the basaltic flows versus the interbedded volcaniclastic sediments.

the matrix. DRHO is useful for quality control of the data; if the tool is operating correctly it should be less than 0.1 g/cc.

Environmental Effects

A reliable density measurement requires good contact between pad and formation. Because a caliper measurement is made during the recording, it is possible to check the quality of the contact. In the lithodensity tool the presence of mud cake and hole irregularities are automatically accounted for using a "spine and ribs" chart based on a series of laboratory measurements. The "spine" is the locus of the two counting rates (short and long spacing) without mudcake and the "ribs" trace out the the counting rates for the presence of mudcake at a fixed formation density. The short and long spacing readings are automatically plotted on this chart and corrected for their departure from true value.

Principal Applications

❑ porosity estimate. If grain density is relatively constant, porosity can be calculated from the density log. Alternatively, porosity and density logs can together be used to calculate grain density.

❑ seismic impedance calculation. The product of velocity and density can be utilized as input to synthetic seismogram computations.

❑ lithology and rock chemistry definition. In combination with the neutron porosity log, the density log allows for the definition of the lithology and of lithologic boundaries (Figure 2-14). Because each element is characterized by a different photo-electric factor, this can be used, alone or in combination with other logs, to determine the lithologic type (Figure 2-9). Both density and photoelectric effect index are input parameters to some of the geochemical processing algorithms used on-shore.

Compensated Neutron Dual Porosity Tool (CNT-G)

The CNT-G tool employs a chemical source (Am-Be) to bombard the borehole and the formation with fast neutrons (4.5 MeV) and two pairs of sensors to detect the number of neutrons (count rates) in the epithermal (100 eV-0.1 eV) and thermal energy range (< 0.025 eV; Figure 2-13). In the scattering process the neutrons interact elastically with the atoms in the formation, are slowed down, and loose part of their kinetic energy at each collision; when they reach the thermal energy level, they are absorbed by the surrounding nucleii. The amount of energy lost by the neutrons depends on the relative mass of the nucleii with which they interact. Because the greatest energy loss occurs during the collision with hydrogen atoms - which have a mass almost equal to that of neutrons - the slowing-down and capture processes are mainly controlled by the hydrogen concentration in the formation. By taking the ratio of count rates at each pair of detectors, a measurement of the porosity of the formation, compensated for borehole parameters, is provided.

The response at the thermal detectors can be greatly affected by elements with large thermal neutron capture cross section, such as chlorine, boron, gadolinium, and samarium; these are usually present in very small quantities in the borehole fluid or in clay or alteration minerals, yet they can cause the porosity of the formation to be overestimated. The epithermal detectors, instead, are less sensitive to these neutron absorbers and provide a more reliable measurement of the true porosity of the formation over clay-rich intervals. Because the epithermal neutron count rate is about one order of magnitude less than that for the thermal neutrons, the detectors are placed closer to the source in order to improve statistical variations.

Depth of Investigation and Vertical Resolution

The depth of penetration of the neutrons is inversely related to the porosity of the formation, but also depends on the source-detector spacing. In general we can say that for porosity ranging from 0 to 30 % the depth of investigation varies from 2 ft (61 cm) to about 6" (15 cm).

The vertical resolution is 1.5 ft (46 cm).

Log Presentation

The CNT-G provides and epithermal (ENPH) and thermal neutron porosity (NPHI) measurement. The porosity curves are presented either in decimal units or in percents along with the bulk density.

Environmental Effects

Eccentralization of the tool by a bow spring is the most important requirement to obtain reliable porosity measurements. The lack of contact of the tool with the borehole wall during the recording results in the attenuation of the formation signal by the borehole fluid and, in turn, the overestimate of the true porosity of the formation.

Hole size also affects the neutron log response; the formation signal, particularly for the epithermal count rates, tends to be masked by the borehole signal with increasing hole size.

In liquid-filled holes the influence of the borehole fluid depends on its salinity - chlorine is a strong neutron absorber - and density: the addition of weighting additives such as barite will yield a lower porosity reading.

In the Ocean Drilling Program, the neutron tool is sometimes recorded through the drilling pipe and the bottom hole assembly. Because iron is a strong neutron absorber, the effect will be of an increased porosity reading depending on the thickness of the pipes.

Principal Applications

- <u>porosity</u>. In reservoir engineering its importance is quite evident; in the study of the volcanic rocks that make up the upper oceanic crust, a good *in-situ* porosity

measurement is most important to the correct understanding of the crustal structure. First, because it samples both the small-scale (microcrack, vesicle) porosity seen in the cores and the large-scale fractures not sampled by drilling, and secondly because other properties such as density, seismic velocity, and permeability, depend strictly on porosity variations and on the geometry of the pore space.
In the presence of clays or hydrous alteration minerals a correction is required to account for the presence of bound water (Figure 2.15).

- lithologic determination. Because the hydrogen measured by the tool is present not only as free water but also as bound water in clay minerals, the porosity curve, often combined with the density log, can be used to detect shaly intervals, or minerals such as gypsum, which has a high hydrogen index due to its water of crystallization. Conversely, the neutron curve can be used to identify anhydrite and salt layers (which are both characterized by low neutron readings and by high and low bulk density readings respectively).

Geochemical Tool String: Natural Gamma Ray (NGT)-Gamma Ray Spectrometry (GST)-Aluminum Activation Clay (AACT) Tool

The geochemical tool string was originally developed by Schlumberger to measure all the major elements needed in determining clay mineralogy. However, because these elements are among the major constituents of most of the minerals forming sedimentary and igneous/volcanic rocks, geochemical logging has proven to be a very powerful complement to the traditional X-Ray Fluorescence (XRF) measurements obtained from cores.

A sketch of the geochemical tool string is shown in Figure 2-16.The tool string is configured with a Natural Gamma Ray tool (NGT) at the top that measures the gamma ray spectrum of Th, U, and K before the formation is activated by the neutron and gamma spectroscopy tools. Next, the neutron porosity tool (CNTG) is used as a source carrier for a Ca^{252} source. Californium is used instead of the conventional AmBe source because its spectrum has a much lower energy (2 MeV instead of 4.5 MeV), thus reducing the number of fast neutron reactions which would interfere with the aluminum activation measurement. Aluminum activation is caused by thermal neutron capture by Al^{27} and produces an Al^{28} nucleus. This decays with a half life of 2.3 minutes and emits 1.78 MeV gamma rays.

The Aluminum Activation Clay tool (AACT) is a modified NGT - the spectrometer includes three more windows for a more detailed analysis of the spectrum - which measures the gamma ray spectrum of the activated formation. By combining this measurement with that from the NGT tool, a reading of the formation Al concentration is obtained.

Finally, a Gamma Ray Spectrometry tool (GST) is located at the bottom of the string. The GST measures the relative contribution (yield) of gamma rays resulting from the interactions of neutrons emitted by a source with the elements present in the formation. The

LEG 118: HOLE 735B
SW Indian Ridge (Indian Ocean)

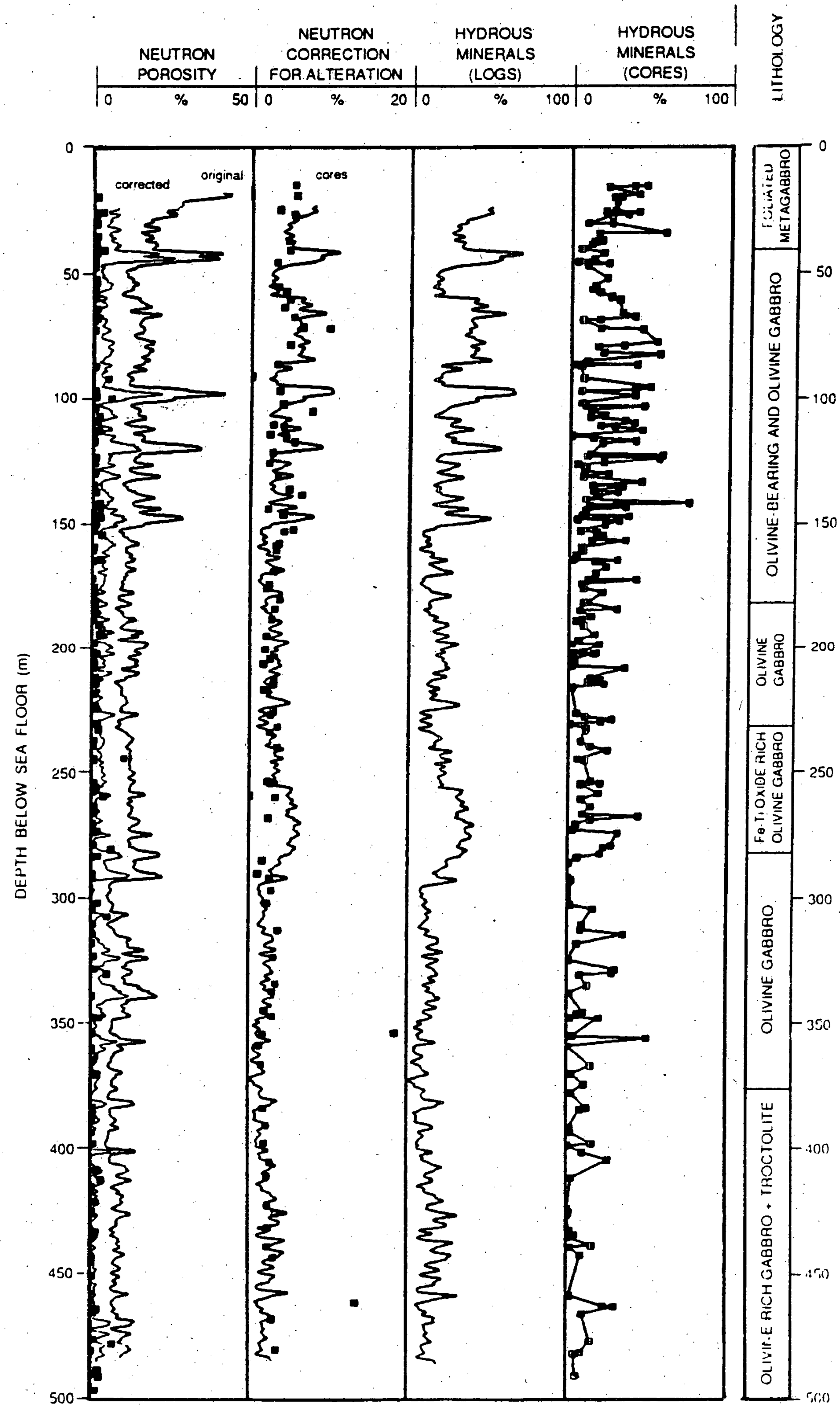


Figure 2-15. At ODP Site 735 the neutron porosity data were corrected for the abundant hydrous alteration minerals present in the gabbroic rocks. This yielded a corrected porosity value which is in good agreement with core measurements. The results from different tools (Borehole Televiewer, Multichannel Sonic) confirm that discrepancies between the two are probably related to the presence of fractures not sampled by coring.

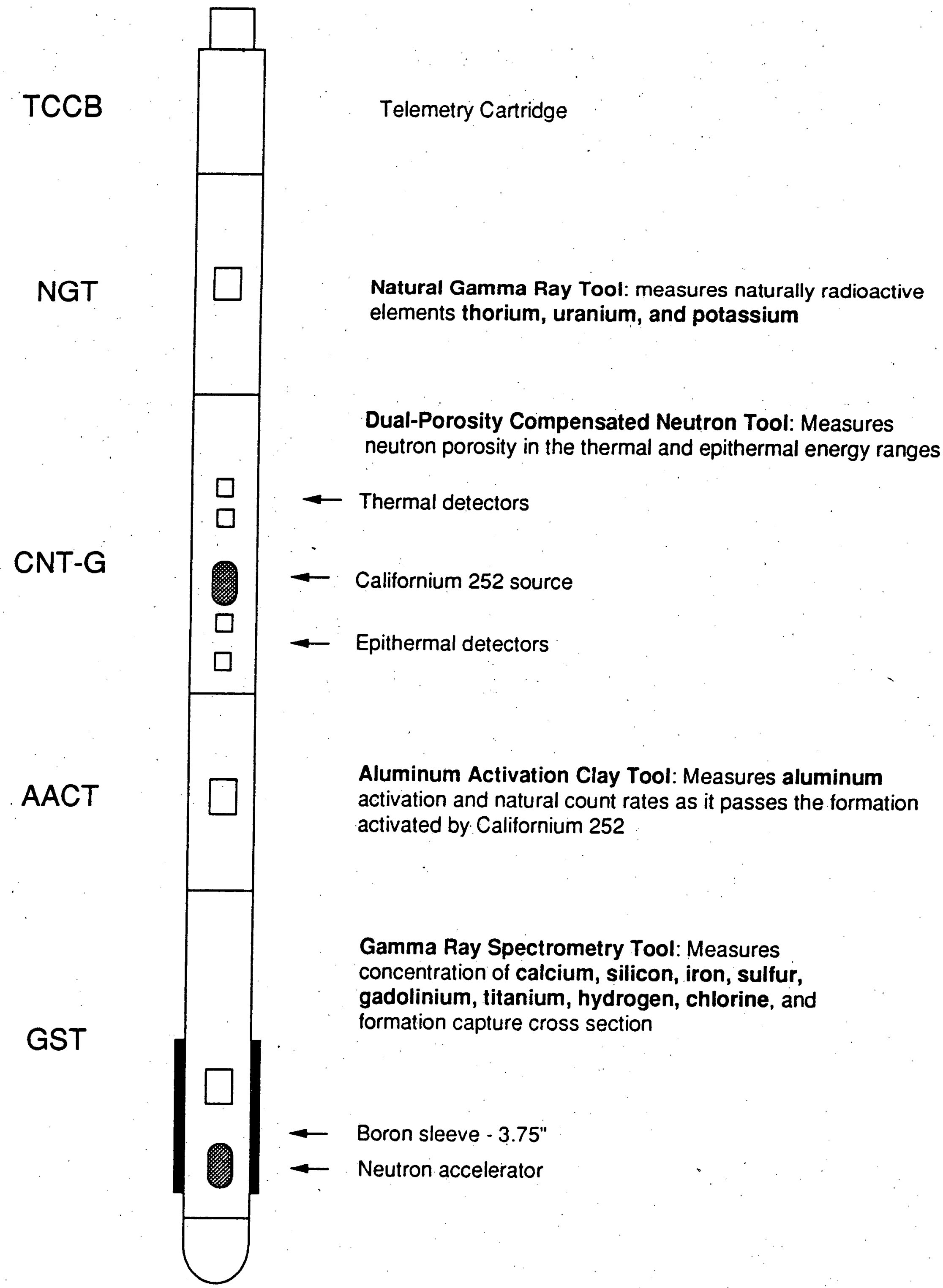


Figure 2-16. Configuration of the geochemical logging string operated on the drillship JOIDES Resolution..For the exact position of each tool sensor see Table 2-3.

source consists of a pulsed neutron accelerator which generates 14 MeV neutrons. Through scattering interactions with the atoms in the rock surrounding the borehole, the neutrons progressively lose energy until they reach the thermal energy level in which they can be captured by elemental nucleii in the formation. When this occurs, the nucleus emits a γ-ray of charcteristic energy. The emitted gamma rays are measured by a spectrometer consisting of a sodium iodide detector and a 256-channel analyzer. Because each element has a unique emitted spectrum, the comparison of the spectra recorded downhole with a library of standard spectra provides an estimate of the elemental composition of the formation. The GST can operate in two timing modes: inelastic, which mainly measures the neutron reactions in the high energy range, and capture-tau mode, in which the capture gamma ray emissions are detected. In ODP wells the GST is run in a capture-tau mode, which allows the calculation of the elemental proportions of six elements: Ca, Cl, Si, Fe, H, and S. The measurement accuracy is largely determined by statistics; the slower the logging speed the more accurate the results. The GST can be run inside the logging pipe, but corrections for the effect of the pipe are not always conclusive. The data, however, can be used from a qualitative point of view, and offer useful information about the formation geochemistry in holes that otherwise could not be logged due to well-bore instability.

Log Presentation

The standard presentation of the geochemical logging string data includes the elemental yields (CCA, CSI, CSUL, CFE, CHY, CCHL) along with the formation capture cross section (CSIG), and the aluminum counts (ALUM) from the Aluminum Activation Clay tool (Figure 2-3). Also displayed are the ratios of the elemental yields: IIR (iron indicator ratio), PIR (porosity indicator ratio), LIR (lithology indicator ratio), SIR (salinity indicator ratio), and AIR (anhydrite indicator ratio) in anhydrite or gypsum-bearing formations.

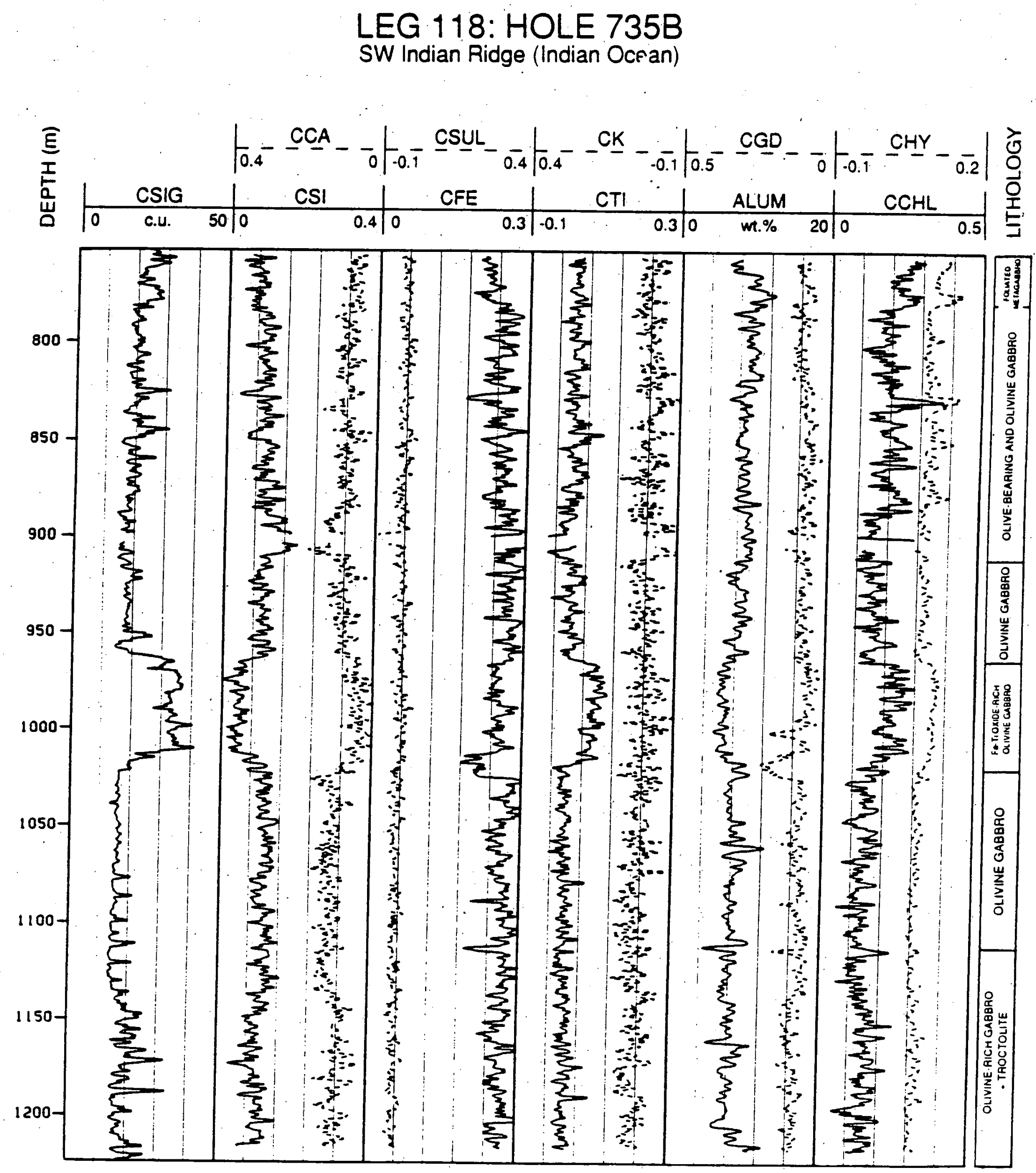
Environmental Effects

Since the GST investigation depth is rather limited (12.7-20.3 cm in capture mode) attention must be paid to invasion and borehole effects. Invasion affects the salinity readings; this effect is negligible in cased holes in which case the iron yield will be affected.

Principal Applications

- ❑ geochemistry. Because the elemental yields represent the relative contribution to the measured signal of some of the major elements present in the rocks, a complex processing technique, which requires data recorded with the natural gamma ray and aluminum activation clay tool as well, is routinely used on-shore to compute new elemental yields (that include titanium, potassium and gadolinium; Figure 2-17) and finally absolute dry weight fractions of the major oxides (Figure 2-18).

- ❑ mineralogy. The oxide concentrations can be inverted using a correlation matrix to estimate the volumes of the main mineralogical constituents of the rock (see Volume 5, Figure 3-17).



CSIG = capture cross section
ALUM = aluminum
CSI = silicon yield
CCA = calcium yield
CFE = iron yield
CSUL = sulfur yield
CTI = titanium yield
CK = potassium yield
CGD = gadolinium yield
CCHL = chlonne yield
CHY = hydrogen yield

Figure 2-17. Example of recomputed geochemical yields in gabbroic rocks.

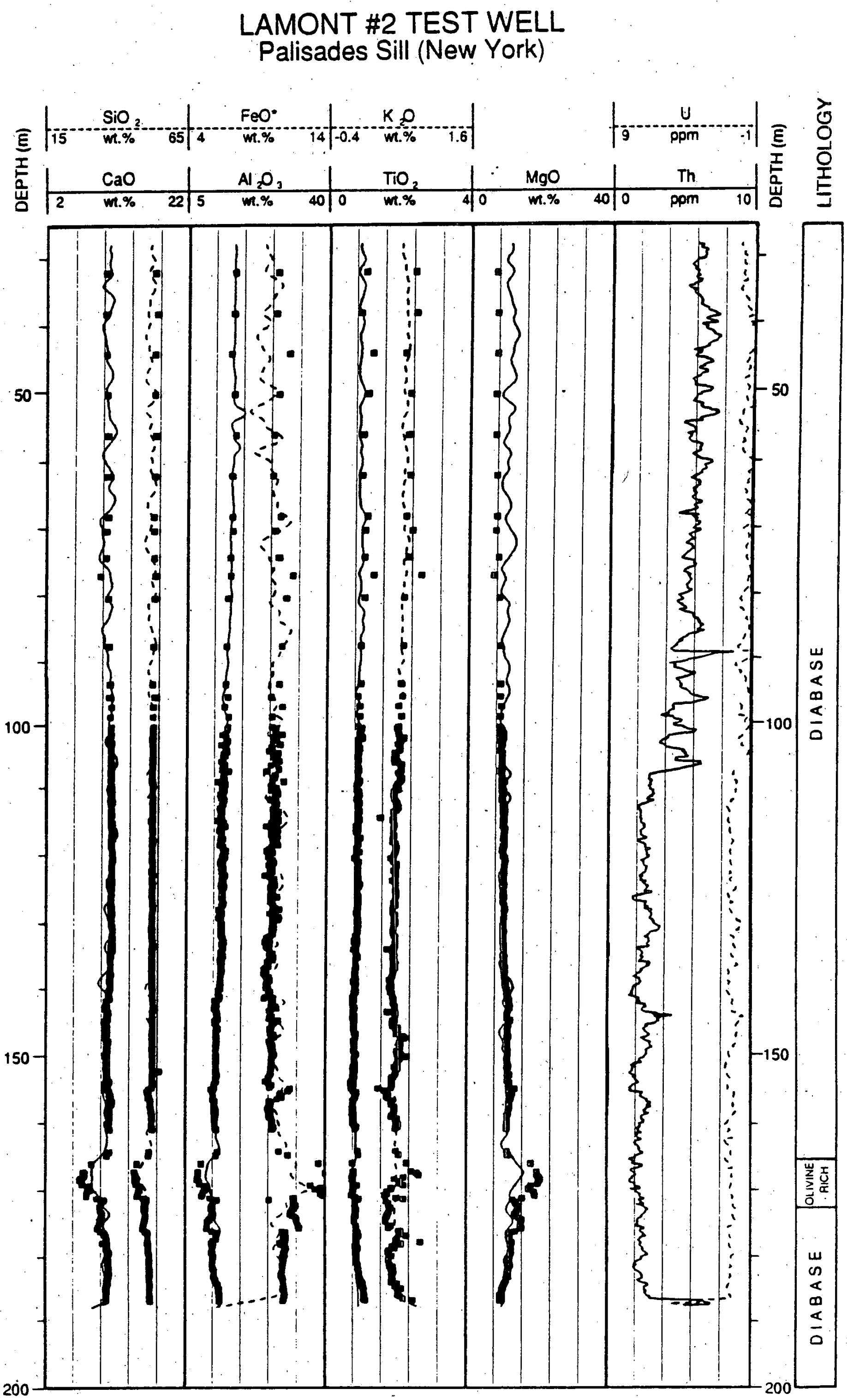


Figure 2-18. Comparison between log-computed oxides and core measurements from the Palisades Sill. Th and U from the NGT tool are also displayed.

- lithologic determination. It is possible to perform a preliminary analysis of the data at the well site simply using the ratios of the elemental yields (see Volume 6, Figure 6-2) and/or the Al measurement. The analysis of GST results in sediment is relatively straightforward, as elemental concentrations vary markedly with lithology. The variations in the lithology indicator ratio (LIR) and/or in the Al curve can be correlated with the calcium carbonate values routinely measured on-board, (Figure 2.19) or with some of the mineral proportions estimated from the smear slides (clays, siliceous/nannofossil oozes, calcite). The iron indicator ratio can help detect Fe-rich clay intervals (see Volume 6, Figure 6-2), whereas the presence of sulfur can be related to the occurrence of anhydrite and/or gypsum. Also, K, Th, and U concentrations form the NGT tool can help in clay-type characterization.

- porosity, salinity. The porosity indicator ratio shows porosity variations, whereas the chlorine/hydrogen ratio yields an estimate of the salinity of the borehole and formation fluids (see Volume 5, Figure 5-4).

- lithologic boundaries. In basement, variations in elemental concentrations will help delineate flow boundadries, characterize alteration vein-filling, and provide an extension of the core analyses to the entire (continuous) logged section.

Elemental Yield Ratios Mnemonics

Si/(Si + Ca)	lithology indicator ratio	LIR
Fe/(Si + Ca)	iron indicator ratio	IIR
S/(Si + Ca)	anhydrite/gypsum indicator ratio	AIR
H/(Si + Ca)	porosity indicator ratio	PIR
Cl/H	salinity indicator ratio	SIR

Formation MicroScanner (FMS)

The Formation MicroScanner sonde consists of four orthogonal imaging pads each containing 16 microelectrodes which are in direct contact with the borehole wall during the recording (Figure 2-19). The tool also includes a General Purpose Inclinometry Cartridge (GPIT) which provides accelerometer and magnetometer data which allow one to define the tool position and spatial orientation during the recording. The button current intensity is sampled every 0.1 in (2.5 mm), while the two-arm caliper, magnetometer, and acceleration measurements are sampled every 1.5 in (3.8 cm). The tool works by emitting a focused current from the 4 pads into the formation. The current intensity variations are measured by the array of buttons on each of the pads.

Processing transforms the current intensity measurements which reflect the microresistivity variations of the formation into high resolution grey or color images of variable intensity. Black and white (darkest or lightest color) indicate low and high microresistivity respectively. In Figure 2-20 (left), the interface between a silt layer and the silt/sand layers below is a sharp change from black (silt) to the alternate banding of dark

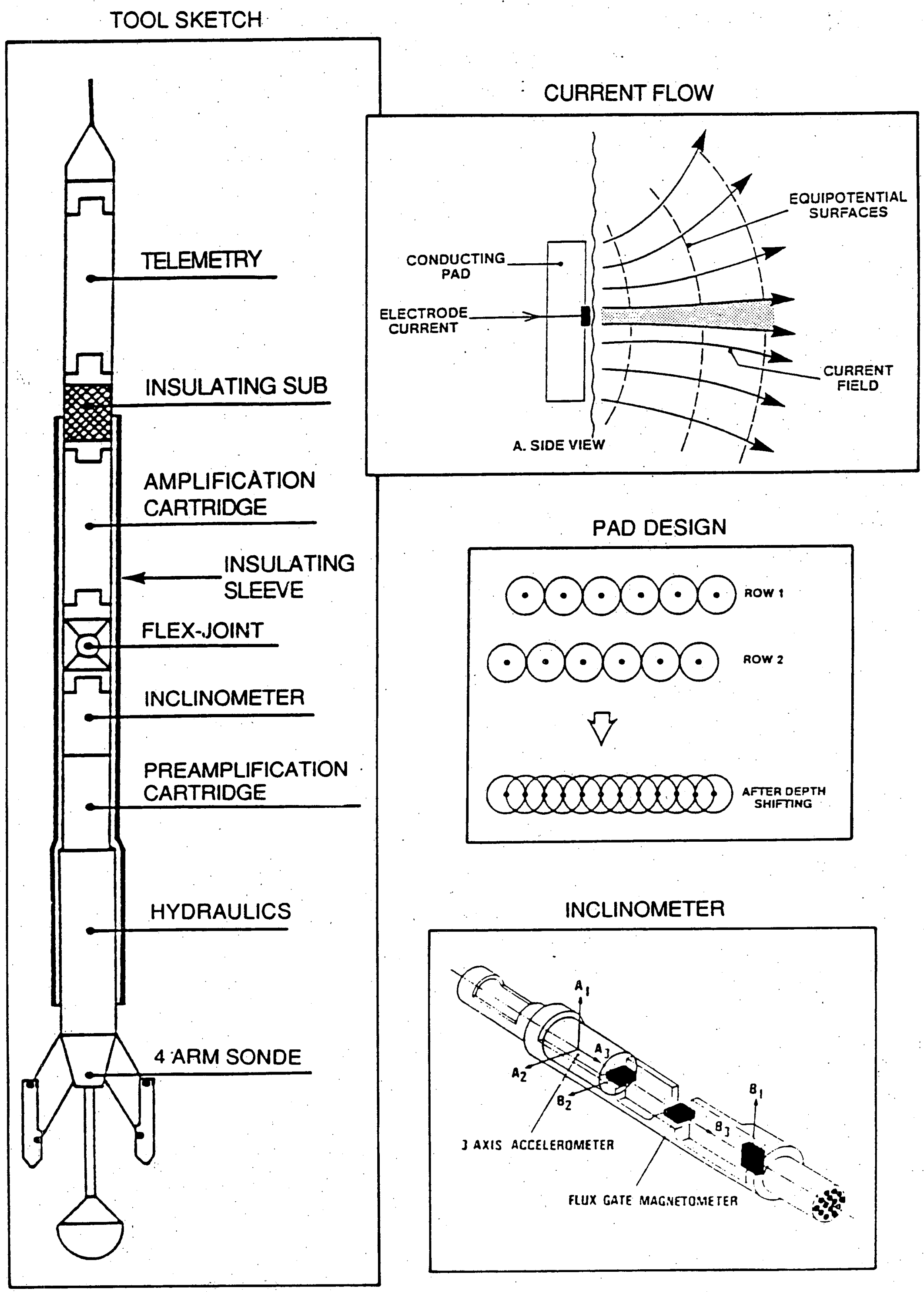


Figure 2-19. Sketch of the four-pad Formation Microscanner sonde redesigned for use in the Ocean Drilling Program (modified after Ekstrom et al., 1986).

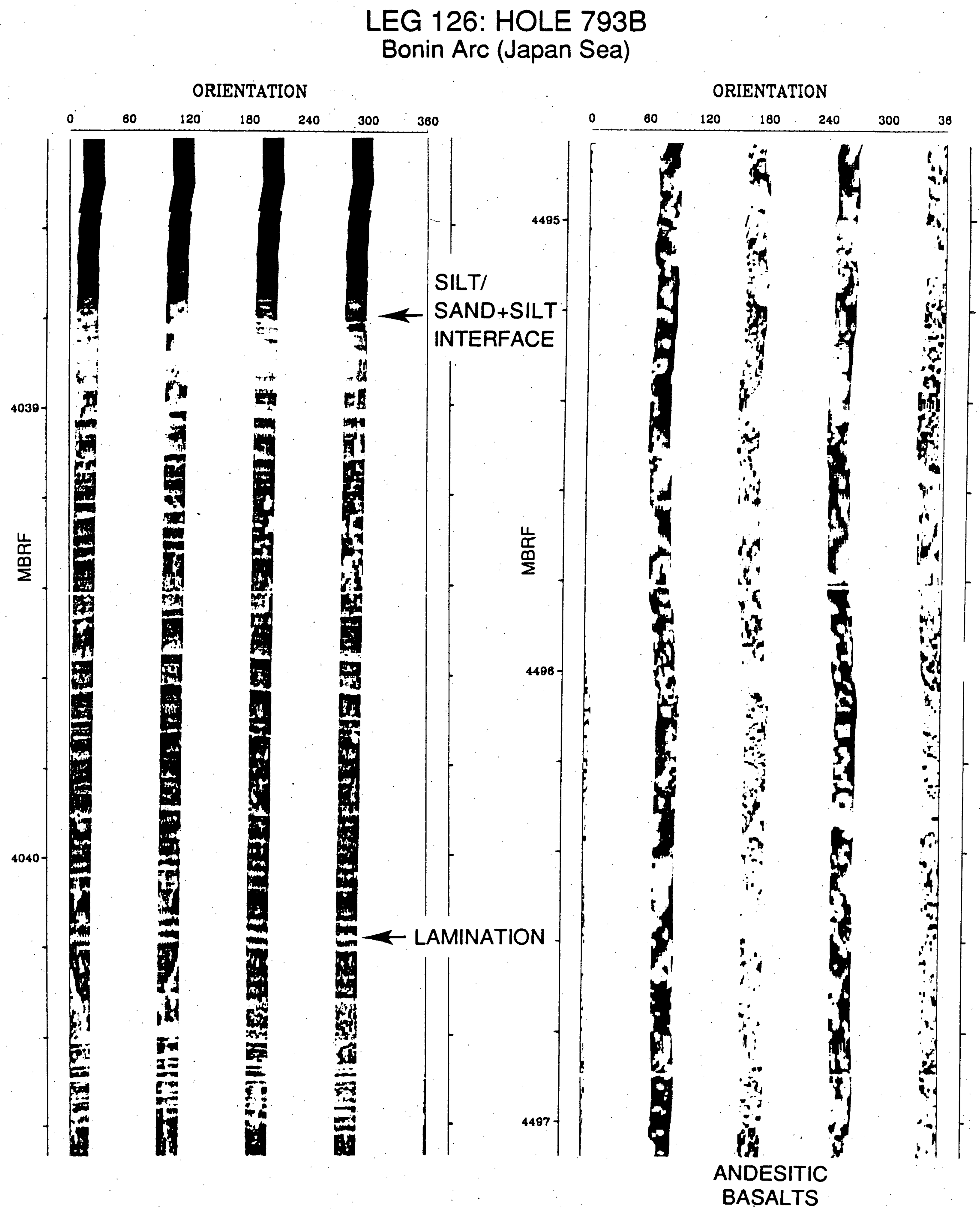


Figure 2-20 Display of Formation Microscanner images in a silt/sand sequence (A) and in an andesite breccia (B) from the basement section of ODP Hole 793B.

(silt) and light (sand). The mottled black and white image of Figure 2-20 (right) is an FMS image of andesite breccia.

Depth of Investigation and Vertical Resolution

In smooth boreholes with very homogeneous bedding the depth of investigation is about 10 in (25 cm). The vertical resolution is 0.2 in (5 mm).

Log Presentation

FMS images are commonly plotted with identical vertical and horizontal scales to see features without exaggeration. To display the images, we use an oriented plot, also called an azimuthal plot, because the images are positioned according to their orientation in the borehole with N in the center and S on both edges. Images from two passes of the tool can be merged and plotted together (Figure 2-21). The calipers can be plotted alongside the images as well.

With an additional processing step on the VAXstation, dipmeter plots can be generated. Standard dipmeter plots consist of borehole drift, calipers, dip angle and direction (tadpoles), azimuth frequency plots, and pad traces (Figure 2-21).

Environmental Effects

To produce high-quality FMS images, the pads must be pressed firmly against the borehole. The maximum extension of the caliper arms is 15.0 inches. In holes with a diameter larger than 15 inches, the pad contact will be inconsistent and the FMS images will be blurred. The maximum borehole deviation that can be recorded with this tool is 10°, although the tool itself works well in horizontal wells with the Schlumberger Tough Logging Condition (TLC) system.

Principal Applications

- detailed correlation of coring and logging depths.
- precise positioning of core sections where core recovery is less than 100 %.
- core orientation.
- mapping of fractures, faults, foliations, and other formation structures and dip determination.
- analysis of depositional environments.
- identification of stress directions.

LEG 128: HOLE 794D
Yamato Basin (Japan Sea)

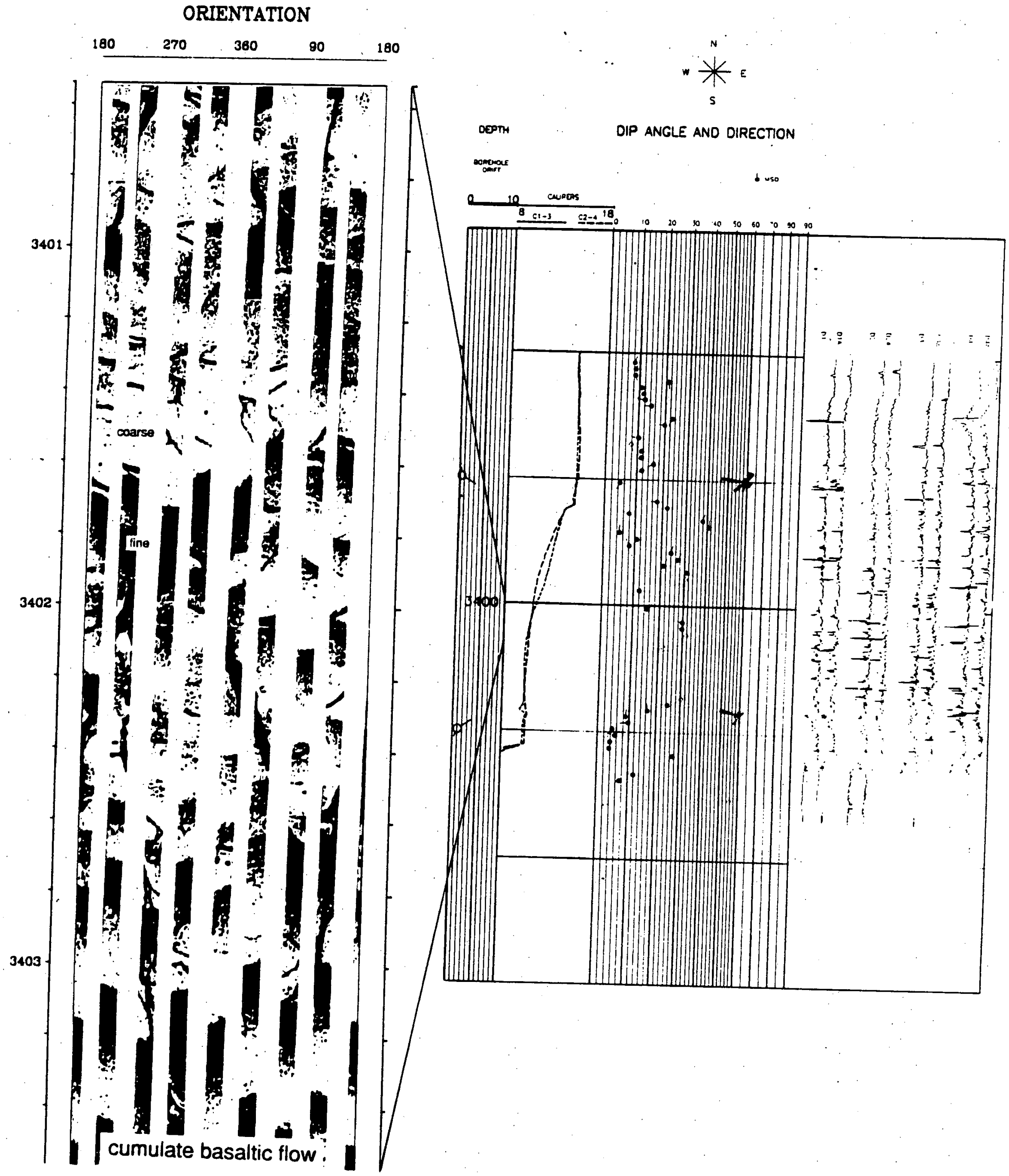


Figure 2-21 Two passes of the Formation Microscanner tool have been merged and both sets of images are plotted together (left) along with a dipmeter plot (right).

Well Seismic Tool (WST)

The WST measures seismic velocities by recording the time required for a wavelet generated by a seismic source hung outside the ship to reach a sidewall clamped geophone located at a series of depths within the hole (Figure 2-22). The anchoring system includes two multi-spiked arms which are opened and retracted by an hydraulic system. The electrical signals produced by the geophones are amplified and transmitted to the surface instrumentation. The waveforms arriving from the downhole equipment are sampled, digitized and stored in the computer memory. Source time is determined using a surface hydrophone. The geophone and hydrophone signals are displayed on a screen where the complete waveform can be checked and stacked. The stacking technique allows a number of shots to be combined, in order to reduce any random noise and to increase the signal-to-noise ratio.

Log Presentation

A wellsite preliminary processing can provide correction of measured depths and transit times for well geometry, acquistion configuration, and formation characteristics. Also, it can produce the following types of display of the data (Figure 2-23):

- WST shot and stack plots. Stacked shots at each levels are displayed with amplitude and transit time. Upon request, the corrected, stacked data can be converted to a standard SEG-Y format for further processing.
- two-way time plot of stacked data, corrected to the surface reference datum and to true vertical depth
- WST depth versus time and time versus depth velocity curve.

Further processing can provide a vertical seismic profile of the well surroundings.

Principal Applications

- <u>sonic log calibration</u>. The calibrated sonic log becomes the basic seismic reference and allows a surface seismic section to be scaled to depth.
- <u>determination of depth of seismic reflectors.</u> Interval velocities, and characteristics of the formation through reprocessing of full VSP surveys can be be obtained using standard seismic techniques.

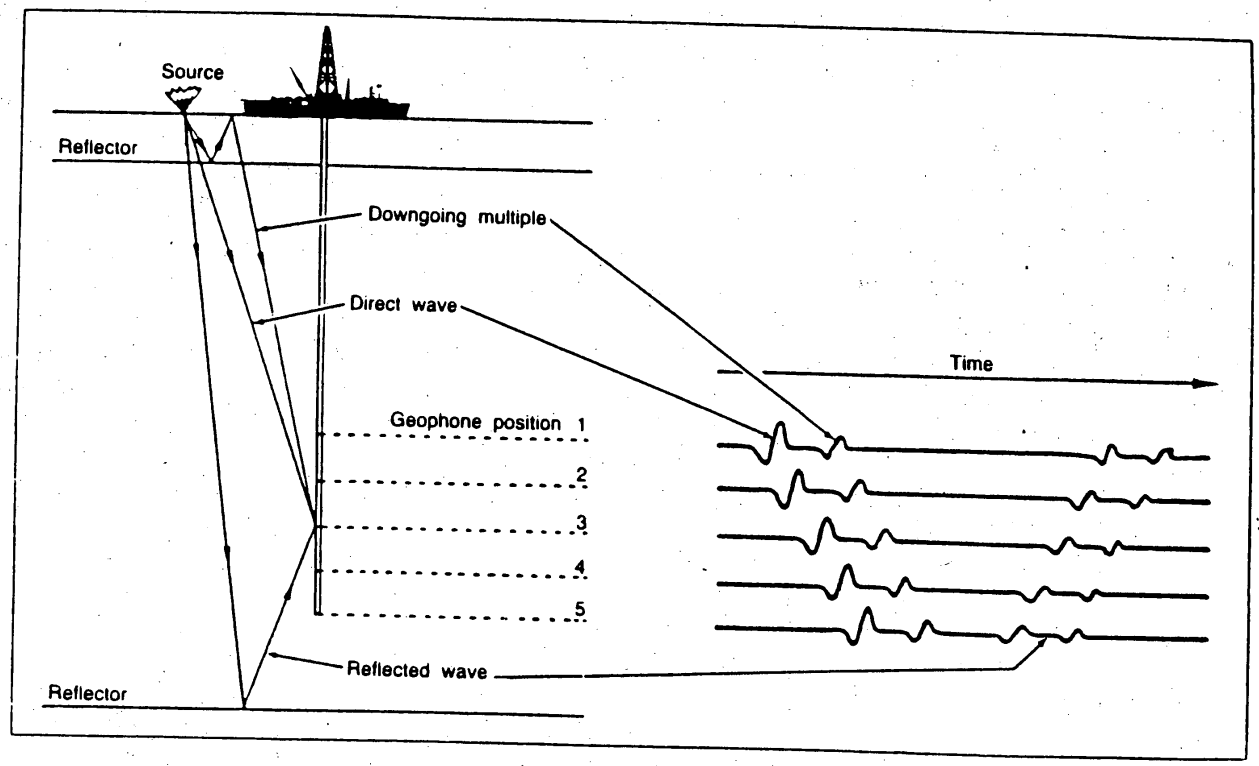
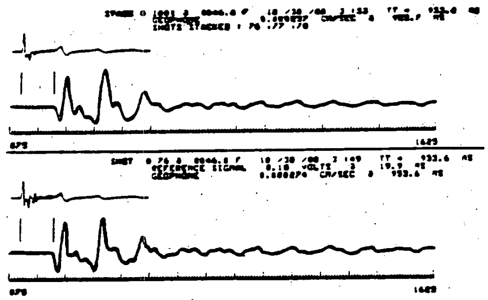
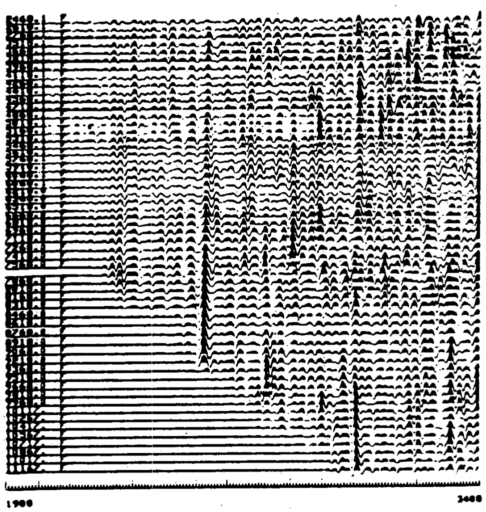


Figure 2-22. In the Well Seismic Tool, a sidewall-clamped geophone located at different depths in the wellbore records the arrivals of an acoustic wave generated by a seismic source towed by the ship.

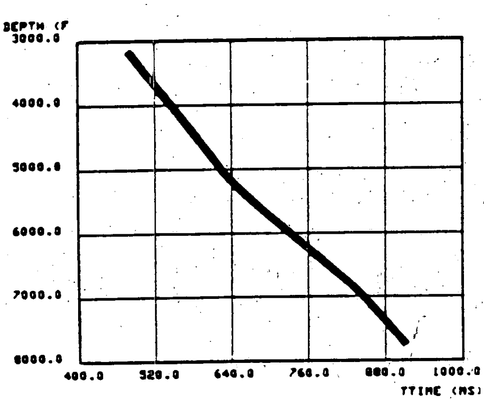
WSS Shot and Stack Plots



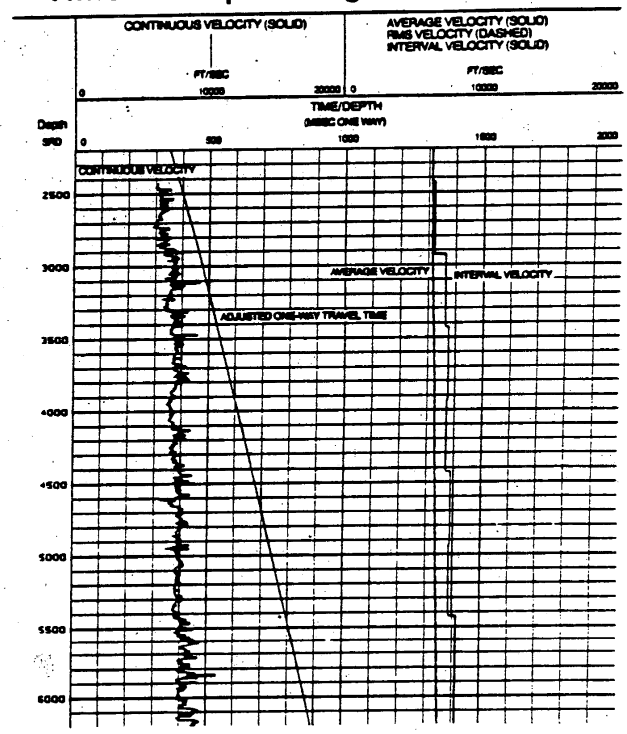
Two - Way Time Plot



WST Depth vs. Ttime Curve



Time / Depth Log - Velocities



Time - Depth / Interval Velocity Log

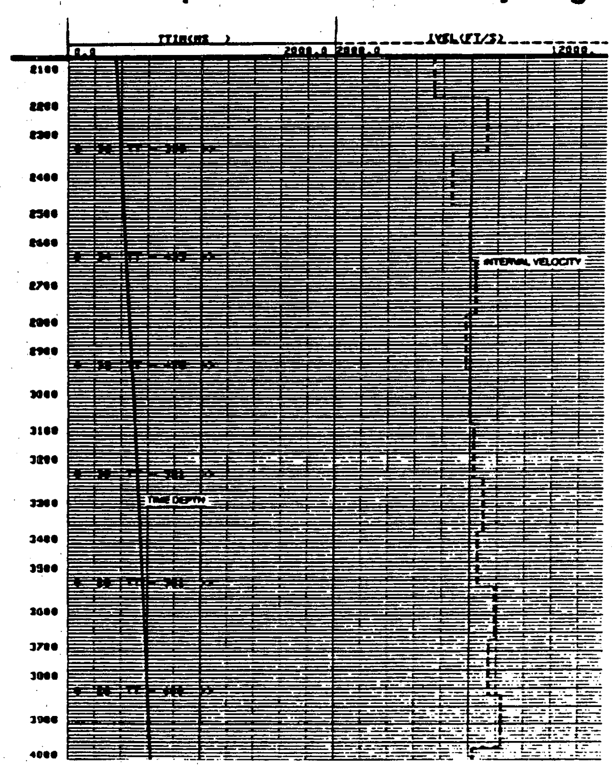


Figure 2-23 Different types of display available for the data recorded with the Well Seismic Tool (courtesy of Schlumberger).

Mechanical Caliper Devices (MCD)

Caliper is a measure of wellbore size. The Schlumberger 3-arm caliper log is run at the top of the seismic stratigraphic combination and also serves to centralize the sonic tool. Three bow-springs are mounted 120 degrees apart, and the extension of these moves a contact along a potentiometer. Changes in resistance of the potentiometer are linearly proportional to hole size. In case of elliptical holes, the measurement provided by this caliper is intermediate between the short and long axis. The caliper has a maximum extension of 16 inches, so larger diameter "washouts" are not measured accurately.

Log Presentation

The caliper trace (CALI) is usually displayed in the left-hand track with a scale from 6 to 16 inches. Often, bit size is also plotted for comparison.

Principal Applications

- log quality control and borehole correction.The caliper curve indicates the portions of bad hole where other logs may read inaccurately, and is used to correct the logs whose response is sensitive to hole size even when variations are less severe

- indication of lithologic variations. For instance, in zones with swelling clays, hole constrictions are observed where caliper reads less than the bit size. Also, as hole conditions are in general a consequence of rock properties, variations in hole size may correlate with lithologic changes.

Borehole Televiewer (BHTV)

The borehole televiewer (BHTV) is an acoustic device which scans the wall of a borehole, producing an image of the reflectivity of the rock surrounding the wellbore as a function of depth and azimuth. The BHTV is manufactured by SIMPLEC under license from Mobil Oil Corp., and is operated on the ODP drill ship by the L-DGO logging staff.

Details of BHTV mechanical design and operation are shown in Figure 2-24. The BHTV log is obtained while logging uphole at a rate of approximately 1.5 meters/minute with the sonde centered in the hole by means of bowspring centralizers. A piezoelectric transducer mounted on a central shaft rotates 3 times per second and transmits a high-frequency acoustic pulse 600 times per revolution. Two transducers are mounted on this shaft, allowing the operator to select either a 1.3 MHz or a 400 kHz source pulse. While the

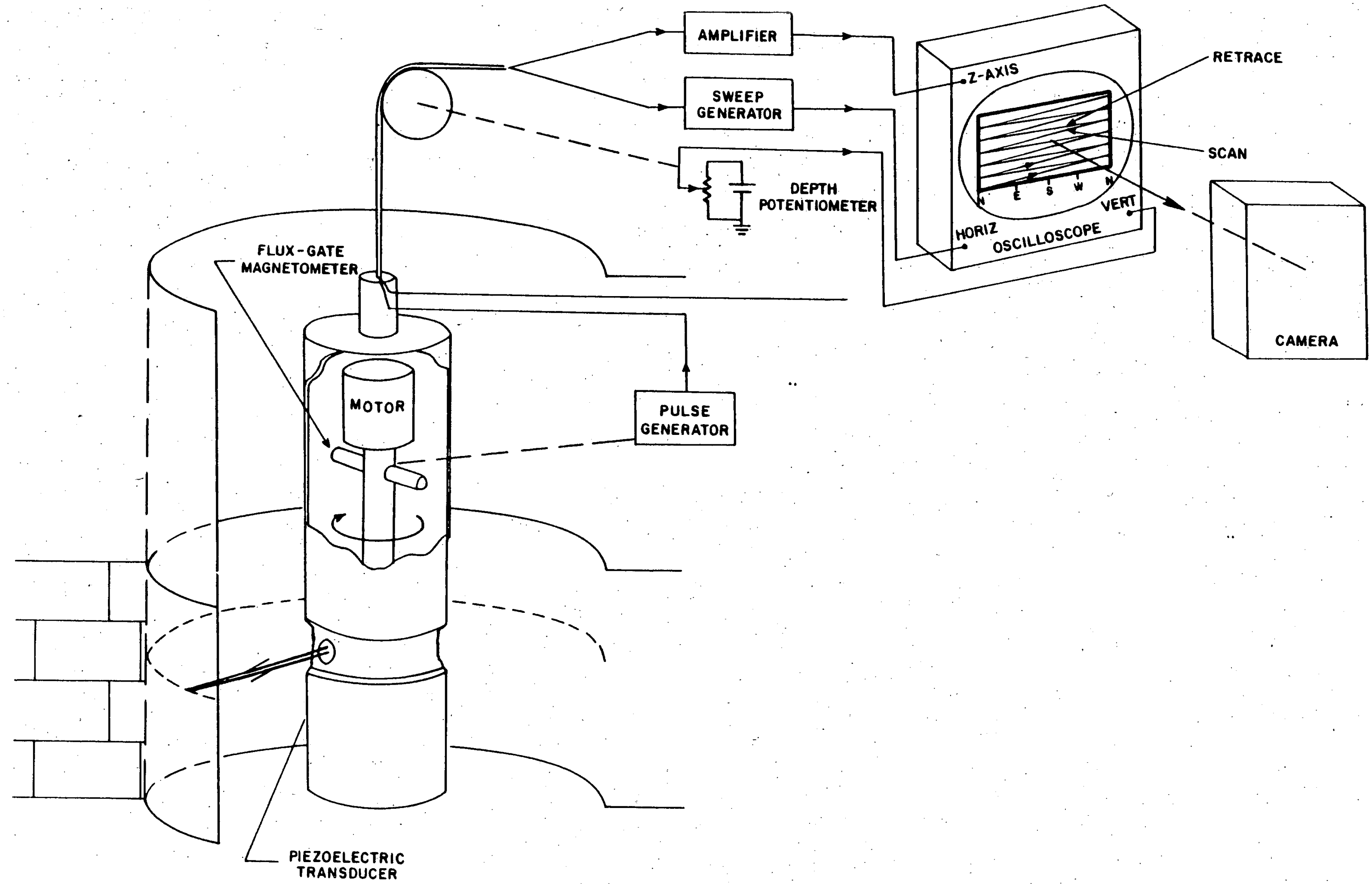


Figure 2-24. Block diagram of the Borehole Televiewer logging system (after Zemanek et al., 1969).

higher frequency source reveals more of the details of the wall surface, the lower frequency source has better penetration and can produce a cleaner image if the surface of the borehole is rough. When the source pulse is transmitted, it travels through the borehole fluid, reflects from the borehole wall and returns to be received at the transducer. This returning signal is transmitted uphole and recorded on a specially-formatted video cassette recorder and its amplitude is simultaneously displayed as brightness on a the z-axis of an oscilloscope. The oscilloscope image is thus an acoustic picture of the reflectivity of the borehole wall, where the azimuth varies along the horizontal axis and depth varies along the vertical axis (Figure 2-25). A film of the oscilloscope screen is exposed which is aligned (along the left-hand edge) with magnetic north using a sweep generator triggered by a downhole fluxgate magnetometer. This film exposure can be adjusted to compensate for reflectivity (amplitude) variations due to changes in hole size or opacity of the borehole fluid, such as from suspended cuttings, to show the fine-scale detail of the interior of the borehole wall (Figure 2-26).

In addition to obtaining a film image of the borehole reflectivity, the signal recorded on video cassette can be digitized by the L-DGO MASSCOMP computer and processed in a variety of ways to enhance the image and improve the results. These digital televiewer logs can be analyzed quantitatively, where previous analyses of BHTV images were at best only qualitative. For example, the BHTV data can be processed to obtain a picture in which the image intensity is proportional to the travel-time of the reflected pulse. Figure 2-26 shows two processed intervals which have high angle fractures (dark sinusoidal lines) intersecting the borehole. Such travel-time information can also be processed to create a three-dimensional wire mesh image of the shape of the borehole (Figure 2-27). As shown here, the borehole size can be presented as a function of depth and azimuth in the well, and from three different perspectives, which can be very useful for fracture identification and interpretion. The fracture shown in Figure 2-26 is dipping 50 degrees W-NW with apparent offsets due to tool sticking.

Principal Applications

- <u>location and orientation of fractures intersecting the wellbore</u>. Structural features such as bedding in sediments, and the character and distribution of pillow basalts in the ocean crust can be determined from oriented amplitude images of the borehole wall.

- <u>measurement of borehole diameter</u>. Wall surface roughness and ellipticity, the characteristics of borehole breakouts, and the orientation of the principle horizontal stress from cross-sectional images of the borehole dimensions are measured.

Although the BHTV log has wide applications, it does have some limitations, which should be considered before recommending its use in a given situation. First, as the BHTV log is effectively a point measurement, ship heave often results in jerky tool motion and a degradation of the images (Figure 2-26). Even operating with a heave motion compensator in moderate seas, this motion may prove to be a problem. Second, severe borehole deviation or ellipticity will degrade the image, because the acoustic beam is no longer perpendicular to the borehole wall at all azimuths. Usually, this effect can be recognized

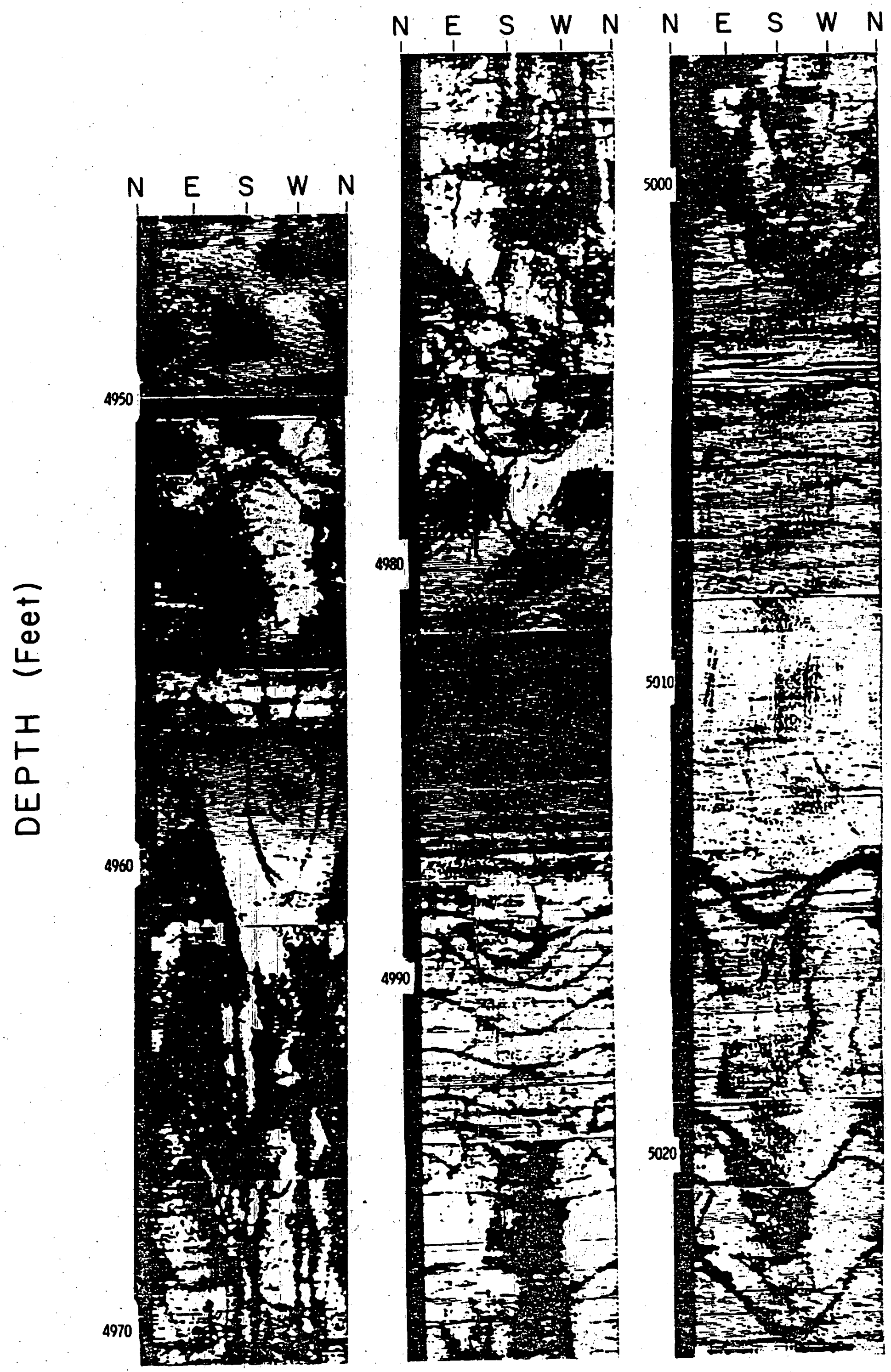


Figure 2-25. Borehole Televiewer log recorded in fractured West Texas Precambrian formation (Zemanek et al., 1969).

LEG 118: HOLE 735B
SW Indian Ridge (Indian Ocean)

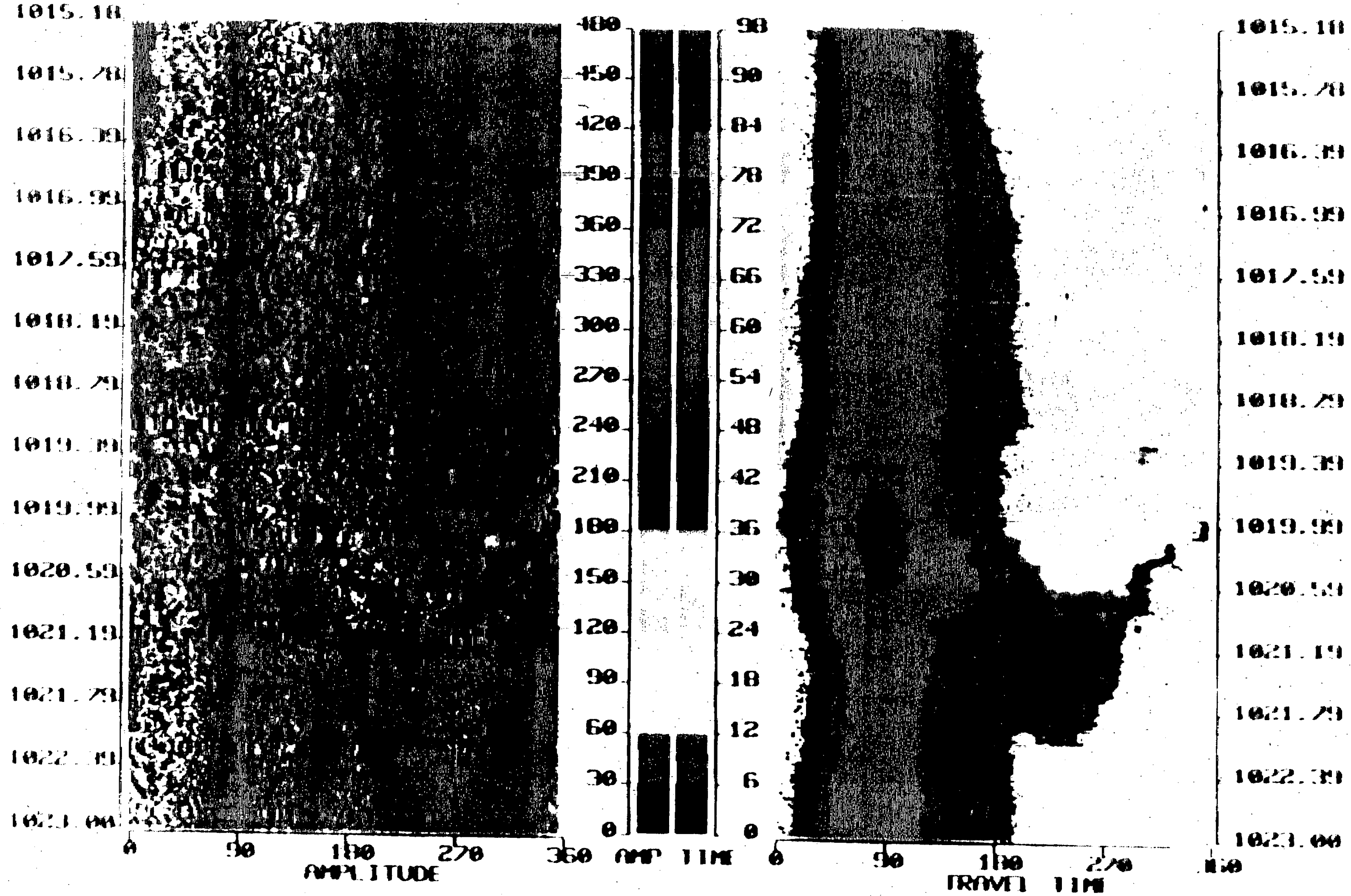


Figure 2-26. Digitally processed BHTV amplitude (left) and travel time (right) images. Tool decentralization appears as diffuse vertical banding (right). An isolated fracture at 1020 mbrf shows up as a dark sinusoidal band that dips about 73° west-southwest.

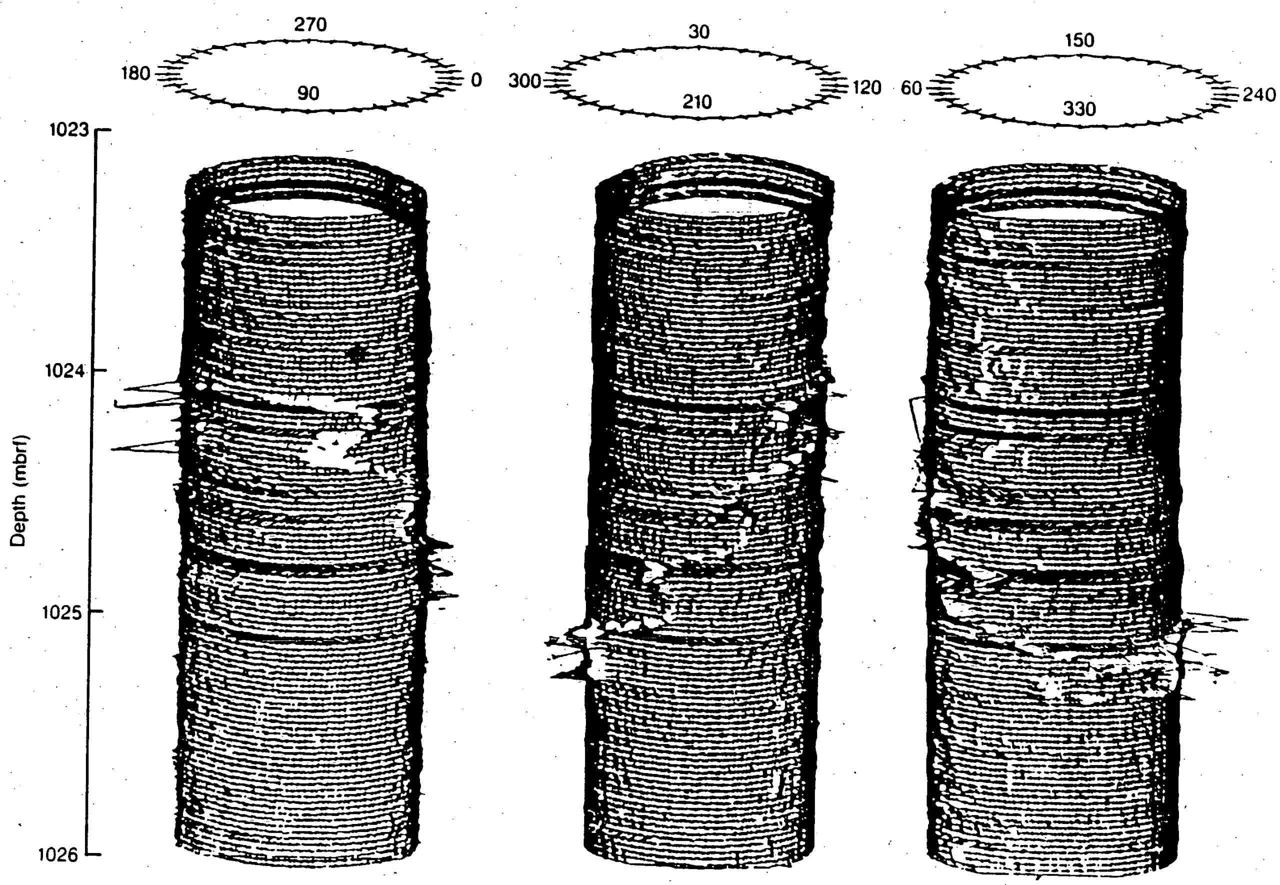


Figure 2-27. Cylindrical net projections at three viewing angles (90, 210, and 330) showing the intersection of a dipping fracture with the borehole at 1024.5 mbrf.

and corrected in the time-domain image (Figure 2-25). Third, the BHTV cannot recognize features which do not affect either the roughness, reflectivity, or radius of the borehole. Hence, subtle sedimentary variations usually will not be detectable.

Multi-Channel Sonic (MCS)

The multi-channel sonic log (MCS) is a multi-receiver, single-source sonic logging tool which records 12 sonic waveforms at each recorded depth. The MCS tool is configured with a magnetostrictive source above the receiver string, separated by a variable-length spacer assembly (Figure 2-28). The receivers are spaced 15 cm apart, resulting in a 1.65-m receiver array, and form a vertical geometry analogous to a surface refraction survey. The energy which ultimately arrives at the receiver array travels from the source as a compressional pulse in the borehole fluid, refracts at the borehole wall, propagates through the wall rock, and refracts back into the borehole fluid. While logging, the MCS tool must be centered in the borehole by means of bowspring centralizers to insure simultaneous arrival of the signal around the tool. Additional guided modes are typically produced in the borehole environment, and their propagation is controlled largely by the coupling of energy between the formation and the fluid-filled borehole.

The MASSCOMP computer controls the tool during logging, allowing the operator to select the depth increment between recorded source firings as well as the number of receivers to be used. MCS waveforms are digitized by the MASSCOMP and recorded on magnetic tape during the logging run. The MCS log is usually recorded while logging uphole at a rate of about 3 m/min, although the rate depends on the depth increment and number of receivers selected. Typically, 0.3-m depth increment and 12 receivers per source depth are used providing data at each source depth like that shown in Figure 2-29 (top).

MCS waveforms, such as in Figure 2-28, can be analyzed at each source depth to yield compressional, shear and Stoneley wave velocities in moderate to hard formations. The MCS log output includes the various velocity logs and full waveform displays, both plotted using a Versatec (Figure 2-29, bottom). In addition, variations in frequency content and amplitude of the individual wave modes can be computed from MCS data and used for fracture evaluation.

Principal Applications

❑ <u>lithology and Poisson's ratio</u> can be determined from compressional and shear wave velocities.

❑ <u>porosity and pore aspect ratio</u> can be estimatied from Vp/Vs and theoretical models.

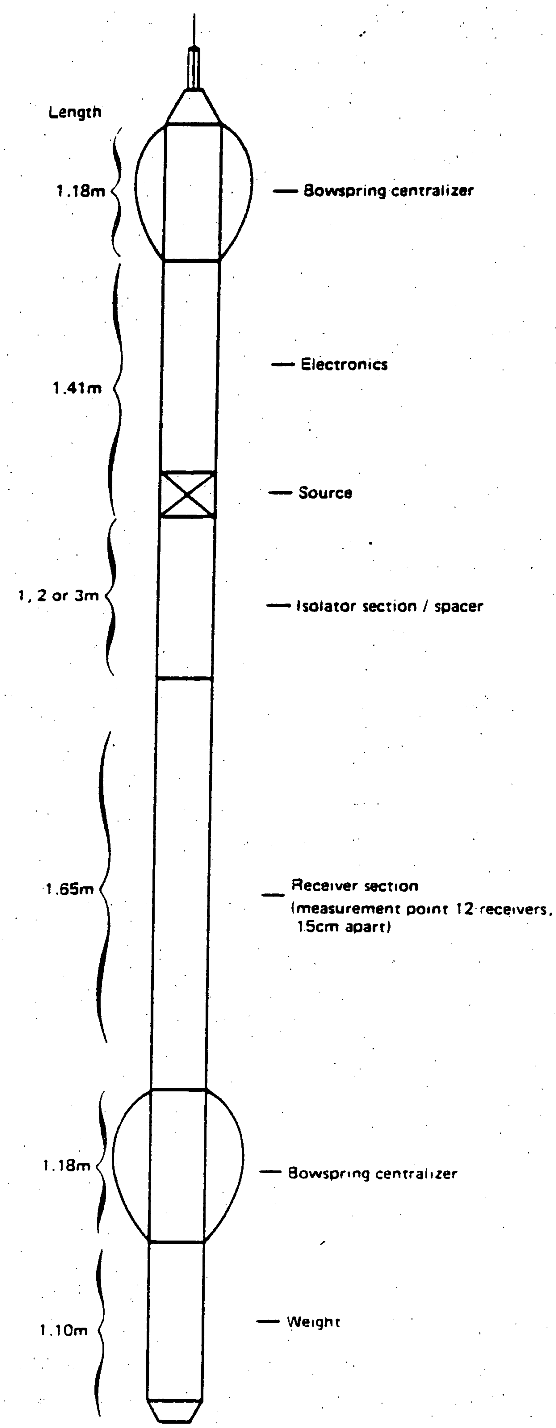
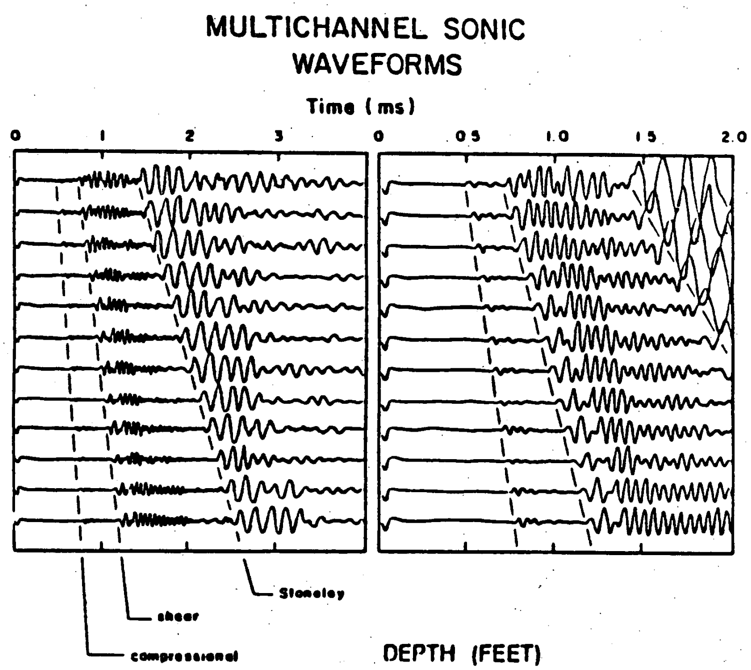


Figure 2-28. Schematic drawing of the Multichannel Sonic Tool.



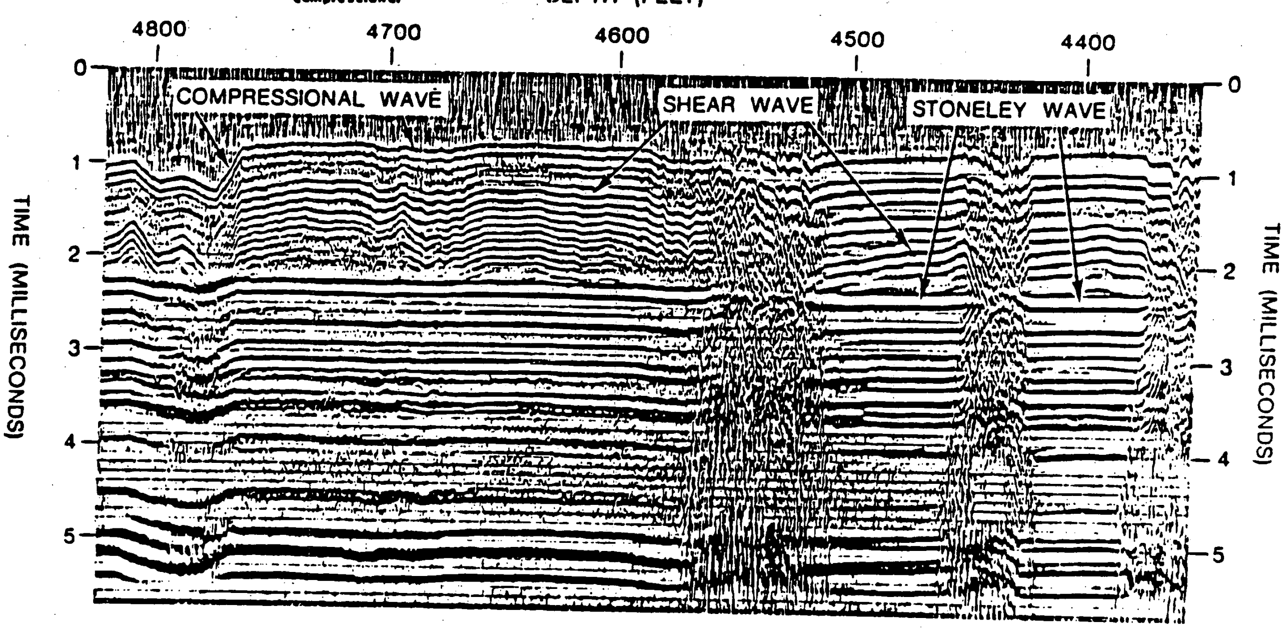


Figure 2-29. Multichannel Sonic waveform display. Top: 12-channel array recording in a diorite formation at Kent Cliffs, NY. On the left, compressional, shear, and Stoneley wave modes are displayed and noted; on the right, the compressional and shear arrivals are shown in greater detail at an expanded time scale. Bottom: Variable Density Log (VDL) for one receiver recording over 450' in a shale-limestone sequence in Oklahoma. Compressional, shear, and Stoneley wave modes are observed as coherent arrivals with varying arrival times in each formation.

- <u>structural analysis and fracture location</u> can be obtained by amplitude and frequency evaluation of MCS data

Although the standard Schlumberger sonic logs can provide accurate compressional velocities, the additional information available from the MCS log enables determination of the elastic properties of the formation and a qualitative estimate of fracture transmissivity. As MCS logging requires an additional pass, adequate time must be allocated only when information beyond that provided by the Schlumberger sonic log is desired. With recent advances, the MCS log can be adapted for use with a multipole source which enables accurate shear wave velocities to be measured in all formations.

Temperature Tool

Because of the high cost of operation time on the JOIDES Resolution, a separate logging run dedicated solely to heat flow measurement is not economically feasible. To solve this time constrâint problem the Borehole Research Group at LDGO has designed a self contained tool that can be attached to the bottom of any of the Schlumberger strings or to the specialty tools from BRG. Fast and slow response thermistors measure the temperature every 1 and 2-5 seconds respectively, while pressure is measured every 3.5 seconds by a transducer. The pressure transducer also turns on the tool when the recording depth (100 m above the mudline) is reached, thus preventing battery drain. The data are recorded and loaded at a 9600 baudrate by an onset tattletale data logger which operates in a TTBASIC language. The tattletale has a memory capacity of 132 Kb which allows logging for up to nine hours.

The power supply comes from two lithium batteries which power the electronics cartridge and the pressure transducer.

Soon after the logging operations the data is dumped from the tool memory onto the Masscomp to be processed. Data processing first involves extracting the data from a raw data file and then converting it into readable temperatures and pressure as a function of time. Further processing, such as converting hydraulic pressure into depth, or merging temperature versus time with time versus depth data from Schlumberger logs, is needed to produce temperature logs (Figure 2-30).

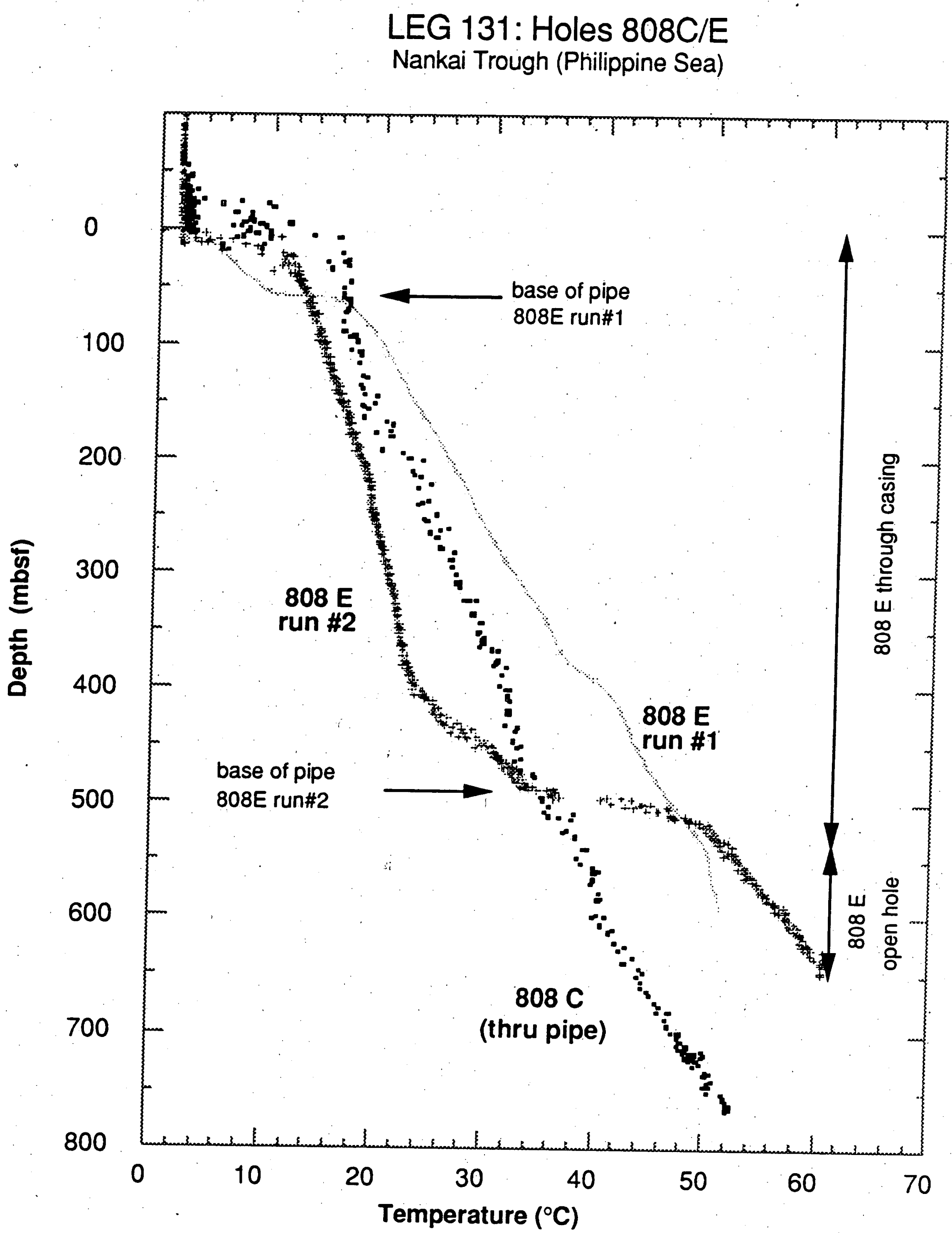


Figure 2-30. Temperature data versus depth. The temperature tool was run through pipe at Hole 808C and through casing and openhole at Hole 808E.

Chapter 3. Logging Time Estimates

The following logging time estimates were written in November, 1989. You may wish to depart significantly from the steps and times shown in Table 3-2 (e.g. the Operations Superintendent may want to do a different hole preparation; the tool string is run more slowly to collect better data; through-pipe logging requires slower logging speeds than openhole logs). It is advisable that you prepare an estimated time breakdown (Table 3-1) and keep track of whether you are ahead of or behind schedule; this can influence operational decisions.

Total logging time at any site includes not only the time for collecting data but also time for hole preparation, logging tool rig-up, and other logging-related activities (Tables 3-2 and 3-3). Based on previous ODP logging operations, most aspects of logging can be estimated with reasonably good accuracy. Total logging time depends primarily on four variables: the tools to be run, whether or not the sidewall entry sub (SES) is used, water depth, and subbottom depth of the hole.

The logging tools that are routinely available on the JOIDES Resolution are listed in Chapter 2 of this volume, Table 2-1. The first 14 log types listed in the table are Schlumberger logs, run by the Schlumberger engineer. The last three logs are ODP specialty logs, run by the LDGO logging scientist. In order to save logging time, many of the tools are run at the same time, in tool combination strings, as explained in the previous chapter.

Two "standard" Schlumberger tools strings are run at virtually every logged hole: the quad-tool and geochemical combinations. The former includes the sonic, resistivity, gamma ray, lithodensity, neutron, and caliper tools. The geochemical combination includes the natural spectral gamma ray, induced gamma ray spectroscopy, and aluminum clay tools. Table 3-2 lists all logging operations times involved in hole preparation and running both standard Schlumberger combinations. To improve the quality of the recording sometimes the tools of the quad-tool combination are separated into two logging strings, the seismo-stratigraphic (sonic-resistivity-gamma ray) and the litho-porosity (density-neutron porosity-gamma ray) strings. Logging times for the lithoporosity and seismo-stratigraphic combinations are not specifically shown in either Table 3-2 or 3-3, but they are approximately equal to the times listed there for the multichannel sonic tool.

One additional Schlumberger strings is also often run. The Formation MicroScanner (FMS) string includes the FMS (a high-resolution dipmeter), general purpose inclinometer, and spectral gamma ray tools. Logging times for the FMS are shown in Table 3-3. Table 3-3 also lists the times required to run the borehole televiewer, magnetometer / susceptometer, wireline packer, and dual laterolog. Note that these times for the six tools assume that the standard Schlumberger logs of Table 3-2 have been run, so Table 3-3 does not include hole preparation and general rig-up/rig-down times that are already included in Table 3-2.

The geochemical combination is the only tool string that collects useful data through drill pipe. Normally, the pipe is pulled to a depth of 50-100 mbsf prior to logging, so that nearly the entire drilled interval can be logged open-hole. In the calculations that follow, we assume that pipe ends at 75 mbsf. Variations from this 75 mbsf assumption cause very minor changes to total logging time. Most times in Tables 3-2 and 3-3 are functions of either pipe length or openhole length, and of either tool speed or pipe pulling speed. For example, the time to run the tool down to base of pipe when using the SES (Table 3-2) is (WD+75)/2200, that is a distance equal to water depth plus 75 m at a speed of 2200 m per hour.

Prior to Leg 112, the major uncertainty in logging time estimates involved delays associated with bridges. A bridge is a constricted-hole interval that the logging tool may not be able to get past, while the tool is on its way down through open hole. Nearly all ODP bridges are found in sedimentary sequences and are caused by clay swelling after drilling. Bridges can also form in heavily fractured formations, but these have been much rarer. Deep basalt holes virtually never exhibit bridging. Bridging is very difficult to predict before a leg begins. Even after drilling and before logging, the likelihood of bridges cannot always be estimated reliably.

In the past, one only had two choices if a bridge was encountered that stopped the logging tool. First, one could just log the interval above the bridge and cancel plans to log beneath the bridge. Second, one could pull the logging tool out of the hole and up onto the ship, set pipe through the bridge, then lower the logging tool again. Nearly always, the much heavier drill pipe can punch through bridges that had stopped the lighter logging tool. This second option requires about 3-4 hours for each bridge, in addition to the logging times shown in Tables 3-2 and 3-3 in the column "Time, no SES."

To-date, more than half of the ODP sediment holes have encountered bridges. To prevent lost time or lost logs associated with bridges, the JOIDES Resolution now has the capability of using a sidewall entry sub (Figure 1-2) during logging. The SES was tested successfully on Leg 108 and a new, streamlined design has been built for Leg 132. When inserted into the drill string, it allows one to add or remove drill pipe while a logging tool is downhole. The SES strategy is to lower pipe to near the bottom of the hole, lower the logging tool into open hole just beneath the pipe, then log up while simultaneously pulling pipe at the same speed. In this way open hole logs are obtained without allowing enough time between pipe removal and logging for bridges to form. Even though one usually hopes not to need the SES, it is prudent to estimate logging assuming that it will be used. If the SES is planned for but not needed, logging operations will take 1-12 hours less than planned at a site. Tables 3-2 and 3-3 include separate logging time estimates for programs with and without SES.

In order to estimate the logging time for a site, it is not necessary to use Tables 3-2 and 3-3 The times required for the many steps for each logging run can be combined into a

Table 3-1 - Site 731 Operations

Estimated Time	Actual Time	Operation
1600	1610	rig-up
1700	1655	RIH (run into hole) seismo-strat. combo.
1800	1750	resistivity calibration & down log
1915	1904	log up
2115	2102	POOH (pull out of hole)
2215	2155	change tools
2315	2319	RIH
0015	0011	downlog*
0215	0230	GST calibration
0245	0250	main log
0745	0930	repeat section*
1000	0953	POOH
1100	1100	rig-down
1200	1140	end

* available for reduced time if necessary

Table 3-2 - Logging Times (hrs) for "Standard" Schlumberger Logs (Quad-tool and Geochemical Combinations)

OPERATION	TIME USING SES	TIME, NO SES
Circulate mud	2	2
Wiper trip	1 + 2(SD-75)/667	1 + 2(SD-75)/667
Release bit	1	1
Pull up to 75 mbsf	1 + (SD-75)/667	1+ (SD-75)/667
Rig up (WHC, seismo-strat. combo, possible SES)	5	1.5
Run tool down to base of pipe	(WD + 75)/3000	(WD + 75)/3000
Log down to T.D.	-	(SD - 75)/1000
Lower pipe and tool to T.D., reaming bridges	(SD - 75)/600	-
Exit pipe with tool (probably using circ. head) and position for logging	0.5	-
Log up (while pulling pipe if SES used)	(SD - 75)/300	(SD - 75)/300
Run tool up pipe to ship	(WD - 25)/3000	(WD + 75)/3000
(slow last 100 m)	100/200	-
Rig down seismo-strat. combo and rig up geochemical. combo	2	0.5
Run tool down to open hole	(WD + 75)/3000	(WD + 75)/3000
Test and calibrate tool	0.5	0.5
Run tool down to T.D.	-	(SD - 75)/1000
Lower pipe and tool to T.D.	0.5 + (SD - 75)/600	-
Log up (while pulling pipe if SES used)	(SD - 75)/200	(SD - 75)/200
Log up through pipe	85/50	85/150
Move pipe 5 m, lower tool to open hole	0.5	0.5
Log up through pipe	85/150	85/150
Run tool up pipe to ship	(WD - 110)/3000	(WD - 10)/3000
(slow last 100 m)	100/200	-
Rig down (WHC, geochemical. combo possible SES)	3.3	1.5

TD = total depth (m); WD= water depth (m); SD = sub-bottom depth (m)
SES = sidewall entry sub

Table 3-3 - Logging Times (hrs) for Other Logs

OPERATION	TIME USING SES	TIME, NO SES
Rig up tool	1	0.5
Run tool down to base of pipe	(WD + 75)/3000	(WD + 75)/3000
Run tool down to T.D.	-	(SD - 75)/1000
Lower pipe and tool to T.D.	0.5 + (SD - 75)/600	-
Log up (while pulling pipe if SES used)		
borehole televiewer	LI/90+(SD-75-LI)/1500	LI/90+(SD-75-LI)/1500
magnetometer/susceptometer	LI/300+(SD-75-LI)/1500	LI/300+(SD-75-LI)/1500
Formation MicroScanner (FMS)	(SD-75)/500	(SD-75)/600
wireline packer	8 + (SD - 75)/500	8 + (SD - 75)/1000
multichannel sonic or temp. log	(SD - 75)/180	(SD - 75)/180
dual laterolog	(SD - 75)/500	(SD - 75)/1600
Run tool up pipe to ship	(WD - 25)/3000	(WD + 75)/3000
(slow last 100 m)	100/200	-
Rig down tool	1	0.5

TD = total depth (m); WD = water depth (m); SD = sub-bottom depth (m)
LI = length of interval to be logged (m); SES = sidewall entry sub

single equation. Table 3-4 lists these equations derived from the previous two tables. To estimate total logging time for a site, follow these simple steps:

1. decide whether or not the sidewall entry sub is likely to be used (probably, yes)
2. calculate the total logging time for each logging tool (or tool string) planned, by inputting water depth and subbottom depth of penetration into the equation for that tool
3. add the times for the various runs.

For example, suppose that the standard Schlumberger (seismic stratigraphic and geochemical combinations) and FMS tool strings are to be run at a site in 3000 m water depth, with 1000 m subbottom penetration, and that the SES will be used. The time for hole preparation and running the "standard" Schlumberger logs is

$$19.2 + .00147 \times 3000 + .0178 \times 1000 = 41 \text{ hours}$$

The additional time for the FMS is

$$3.0 + 00073 \times 3000 + .004 \times 1000 = 9 \text{ hours}$$

Thus, all logging operations at this site require about two days and obtain almost all of the logs shown in Table 1-2, or about 30 different types of log curves.

Table 3-4, as well as Tables 3-2 and 3-3, generally assumes that the entire interval below 75 mbsf is logged, with some exceptions. The times for the geochemical combo include not only the openhole interval but also two logging passes through pipe for the uppermost 75 mbsf. The borehole televiewer and magnetometer/susceptometer are normally run over only part of the hole (e.g. basement). Thus the equations for these two tools include a third variable: length of interval to be logged. The wireline packer is a station tool rather than a continuous logging tool. At each station, packers are inflated and a formation fluid sample is taken. The wireline packer times shown in Tables 3-3 and 3-4 assume one wireline packer trip and four fluid samples, but this tool is so new to ODP that the times are only very rough estimates.

The logging time equations in Table 3-4 are good working estimates, but they do not include four contingencies:

1. time required to punch through bridges or change to the sidewall entry sub if one starts logging without the SES
2. for reentry holes in which it is not permissible to drop the bit at the bottom of the hole, time to pull the drill string, take off the bit, and reenter the hole
3. time beyond 1 hour to drop the bit, due to problems with the bit release
4. tool or cable breakdown, which occurs at about 10% of sites and requires 1-3 hours extra to deploy a backup tool or cut off faulty cable.

The preceding discussions of logging times consider all logging tools that are routinely available on board the JOIDES Resolution. For individual legs, scientists may bring

Table 3-4 - Logging Time Equations

Using SES	
"Standard" Schlumberger	t = 19.2 + .00147 x WD + .0178 x SD
Formation MicroScanner	t = 3.0 + .00073 x WD + .004 x SD
Dual Laterolog	t = 3.0 + .00073 x WD + .004 x SD
Wireline Packer	t = 11.8 + .00073 x WD + .004 x SD
Multichannel Sonic or Temp. Log	t = 2.7 + .00073 x WD + .0079 x SD
Borehole Televiewer	t = 3.1 + .00073 x WD + .0026 x SD + .0114 x LI
Magnetometer/susceptometer	t = 3.1 + .00073 x WD + .0026 x SD + .0029 x LI
Without SES	
"Standard" Schlumberger	t = 10.5 + .00146 x WD + .0163 x SD
Formation MicroScanner	t = 0.9 + .00073 x WD + .0029 x SD
Dual Laterolog	t = 1.0 + .00073 x WD + .0018 x SD
Wireline Packer	t = 9.8 + .00073 x WD + .0022 x SD
Multichannel Sonic or Temp. Log	t = 0.6 + .00073 x WD + .0072 x SD
Borehole Televiewer	t = 1.0 + .00073 x WD + .0018 x SD + .0114 x LI
Magnetometer/susceptometer	t = 1.0 + .00073 x WD + .0018 x SD + .0029 x LI

t = total logging times (hrs); WD = water depth (m); SD = sub-bottom depth (m)
LI = length of interval to be logged (m); SES = sidewall entry sub

their own logging tools (e.g. magnetometer, vertical seismic profile tool). Estimation of logging times for these tools requires consultation with those scientists.

OCEAN DRILLING PROGRAM

Wireline Logging Manual

Volume 4

Scientific Logging (1989-1990)

Borehole Research Group
Lamont-Doherty Geological Observatory
Columbia University
Palisades, NY 10964

SEPTEMBER, 1990

TABLE OF CONTENTS: Volume 4

Chapter 1. Introduction to Scientific Uses of Wireline Logging

Chapter 2. New Logging Technologies in the Ocean Drilling Program

Chapter 3. Cyclicity in Logs and Paleoclimate

Chapter 4

Chapter 5

Moos, D., and Zoback, M.D., Utilization of Observations of Well Bore Failure to Constrain the Orientation and Magnitude of Crustal Stresses: Application to Continental, Deep Sea Drilling Project,and Ocean Drilling Program Boreholes.

Chapter 1. Introduction to Scientific Uses of Wireline Logging

Wireline logging within the Ocean Drilling Program (ODP) provides fundamental observations of the physical and chemical state of the Earth's crust by making *in situ* acoustic, electrical and nuclear measurements in ODP boreholes. The combination of core samples returned to the surface and downhole measurements adds a new dimension to the pursuit of global geoscience problems into the 1990's.

As defined by the JOIDES COSOD I, and particularly, II documents, the major geological thematic objectives of the ODP are listed in Table 1-1, with examples of the contributions of wireline logging to the solutions of problems within these themes. Below, we present recent examples from Legs 123-131 of logs used to solve problems from this thematic list. Further, more extensive ODP examples of the utility of logging data directed at the solutions to these thematic problems are given in Volume 5 (covering ODP Legs 111-121) and Volume 6 (covering ODP Legs 101-111).

Paleoenvironment

The geophysical and geochemical logs recorded in ODP boreholes provide the only continuous record throughout the well from which to examine the impact of climatic changes on the sedimentological record of the past. Consider, for example, the variations in natural radioactivity (natural gamma-ray emissions from the decay of potassium, uranium, and thorium) of the sediments from Hole 798B (Leg 128) in the Japan Sea (Figure 1-1). The cyclicity observed in the gamma ray log is caused by the variation of the wind-blown, continentally-derived dust component of the sediments called loess (see detailed discussion in Chapter 3, below), as can be seen from the correlation of zones with high natural gamma-ray emission and high aluminum content recorded by the geochemical logging tool. The continentally-derived loess contains clays and feldspars that are abundant in both radioactive elements and aluminum. These wind-blown deposits are massively eroded during major dry periods in Asia, and deposited in the Sea of Japan. When the climate of Asia becomes wet, the major deposition in the Japan Sea comes from local, river-bourn sources that are much lower in radioactive elements and aluminum. The period of the gamma ray log caused by this climatic variability agrees nicely with the 41,000 year variation in the Earth's orbital tilt predicted by Milankovitch (Figure 1-1).

Because the continuous nature of logs allow them to be treated as time-series, it is possible to define the periods of the cyclicity information they contain. The power spectrum of the gamma-ray log can be precisely calculated (Figure 1-2); the gamma-ray log tuned to the orbital tilt driving function produces a dramatic spectral peak at 41,000 years. This "tuning" predicts the fine-scale sedimentation rate changes that would be required to bring the logging cycles into complete agreement with an orbital tilt driving function for the signal observed in the log. These sedimentation rates are then observed to be consistent with, but

Table 1-1.

MAJOR ODP THEMES AND LOGGING CONTRIBUTION TO EACH

PALEOENVIRONMENT

a. Cyclicity
b. Geologic connection to orbital parameter changes

BIOSTRATIGRAPHY

a. Sedimentation rate
b. Ties to sequence stratigraphy from surface seismics

PHYSICS AND CHEMISTRY OF THE OCEANIC CRUST

a. Geochemical reference holes and mass balance during subduction
b. Chemical exchange during hydrothermal alteration
c. Geophysics of normal and back-arc basin crust

STATE-OF-THE STRESS IN THE EARTH'S CRUST

a. Direction of maximum horizontal compression
b. Thermal versus driving forces
c. Stress distribution in subduction zones
d. Plate rotation

MILANKOVITCH CYCLICITY IN GEOCHEMICAL LOGS JAPAN SEA LEG 128, HOLE 798B

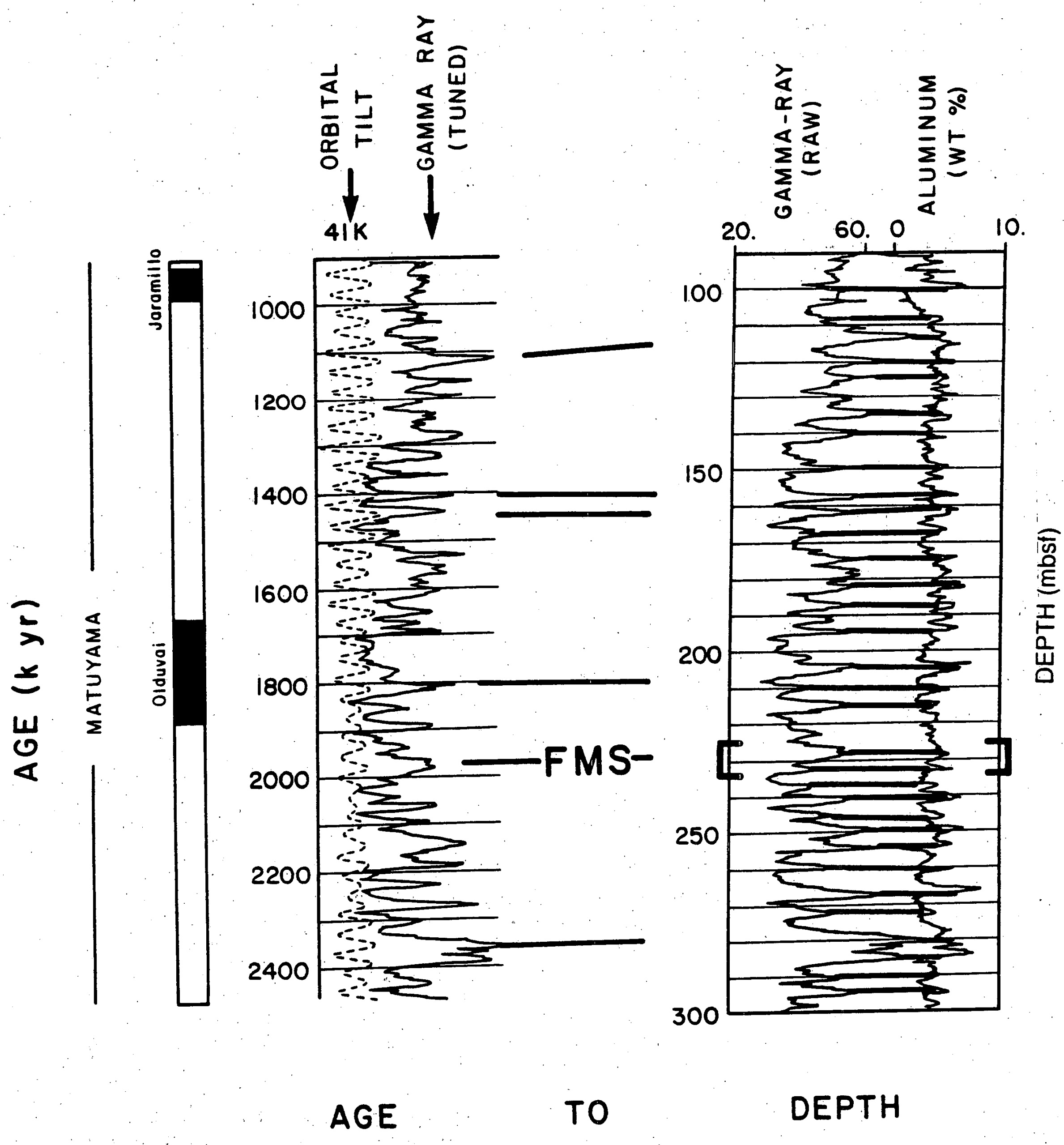


Figure 1-1.Correlation of gamma ray logs from the Japan Sea with (left) the magnetic reversal time scale (left), the 41,000 year period of changes in the earth's orbital tilt (center), and the aluminum log showing increases caused by terrigenous sedimentation (right).

much more detailed than either paleomagnetic or biostratigraphic datums derived from the core recovered from this site (Figure 1-2). Note that the 23,000 year Milankovitch cycle is too fine-scale at these sedimentation rates for the gamma-ray log to detect, because this logging tool does not have sufficient vertical resolution. The observation of one Milankovitch cycle in the log predicts the locations of other detectable periods and there is considerable power in the proper location for the 100,000 year cycle seen in Figure 1-2 (again, see Chapter 3, next).

The gamma-ray log from the only hole yet to penetrate Jurassic sediments (Leg 129, Hole 801B; Figure 1-3) also shows cyclical variations in natural radioactivity that are related to Milankovitch climate cycles. Because the sedimentation rates are very low (approximately 10 m/Ma), only the 106,000 and 410,000 year Milankovitch periods are evident in spectral analyses of the gamma-ray log from Hole 801B. The Formation MicroScanner images of the fine-scale resistivity variations promise to reveal the shorter period sedimentological responses to Jurassic climate change, but these have yet to be analysed. This illustrates a powerful contribution of logs to paleoclimatic determinations because they record the variations in physical and chemical properties of the sediment, regardless of its age. The variations in the relative contributions of the various orbital parameters to past global climates are poorly understood far into the past.

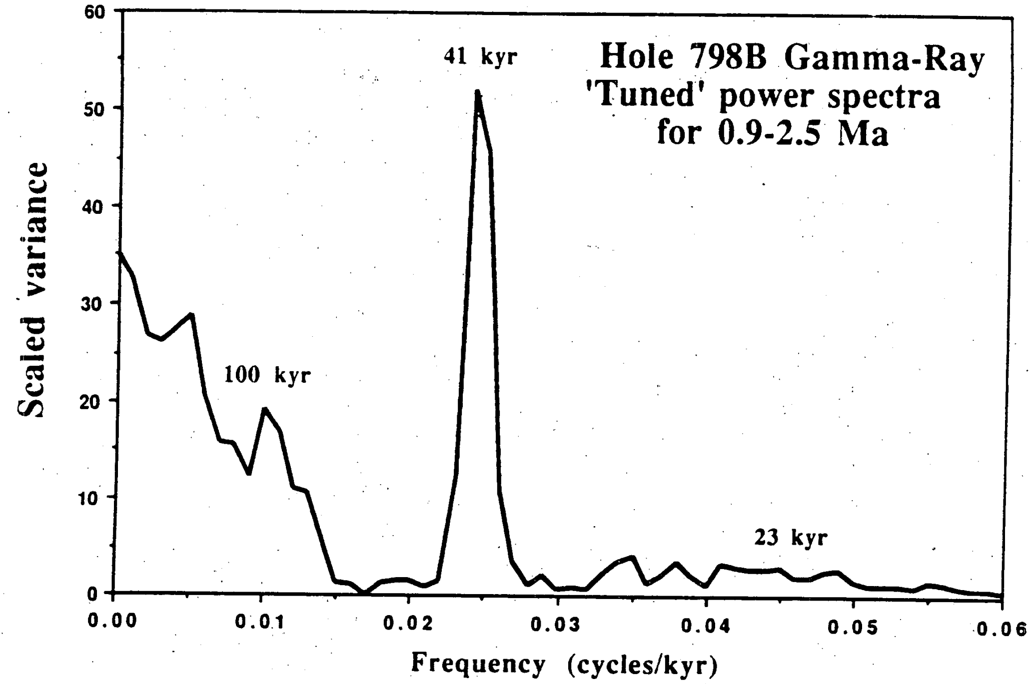
Biostratigraphy

Well logs provide a record of the stratigraphic impact of major sequence changes caused by not only short-period climatic variations, but also longer period, sea-level and tectonic changes that allow for the fine-tuning of age-depth relations in ODP boreholes. The "tuning" of the gamma-ray log to adjust sediment ages to precise 41,000 cycles, allows for the determination of a sedimentation rate curve (Figure 1-2) that is considerably more accurate than that determined from biostratigraphy of the limited core recovered from this site. A new nuclear magnetic resonance logging tool for sediments that is to be tested on Leg 134 offers further hope of age-identification capabilities from logs. We have never before had the ability to determine absolute ages that will come from the tie to the magnetic reversal time-scale, but the determination of climatic periods is already giving us relative age determinations.

One important result of such age determinations is that precise ties to the "Vail" sea-level curve can be made between logs and seismic sequences derived from surface reflection profiling. Further examples of the age-dating and sequence correlation capabilities of logs are given in Chapter 3 of this volume.

Physics and Chemistry of the Oceanic Crust

Geochemical logs are the only continuous record of the chemical variations in the crust. (see Chapter 4). The usefulness of such a complete record can be seen from an examination of the geochemical logs from the Java Trench "geochemical reference site" in the Indian



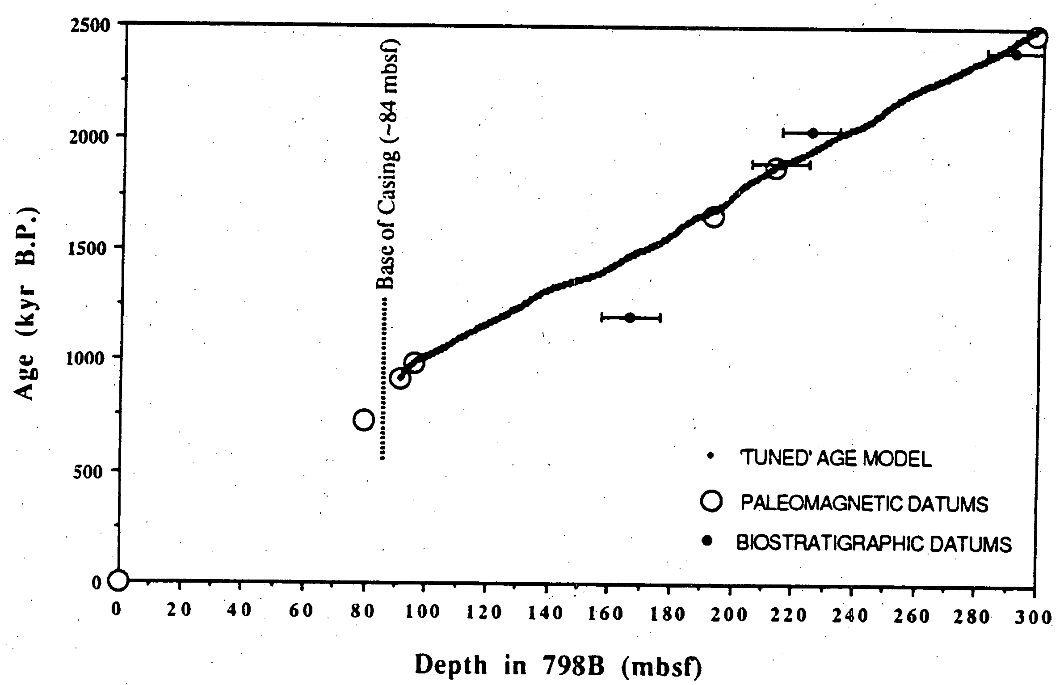


Figure 1-2. Continuous correlation ("tuning") between the gamma ray log of Figure 1-1 and orbital obliquity variations provides very high-resolution data in the entire logged interval (bottom), consistent with but much more detailed than paleomagnetic and biostratigraphic datums. The biostratigraphic datums are determined from core-catcher samples, and therefore have a 9.5 m spread (error bar) in either direction. The relatively minor sedimetation rate changes resulting from "tuning" the gamma ray log to the orbital time series dramatically increase the 41,000 year power (top).

Leg 129, Hole 801B
Milankovitch climate cycles in Jurassic sediments from the Western Pacific

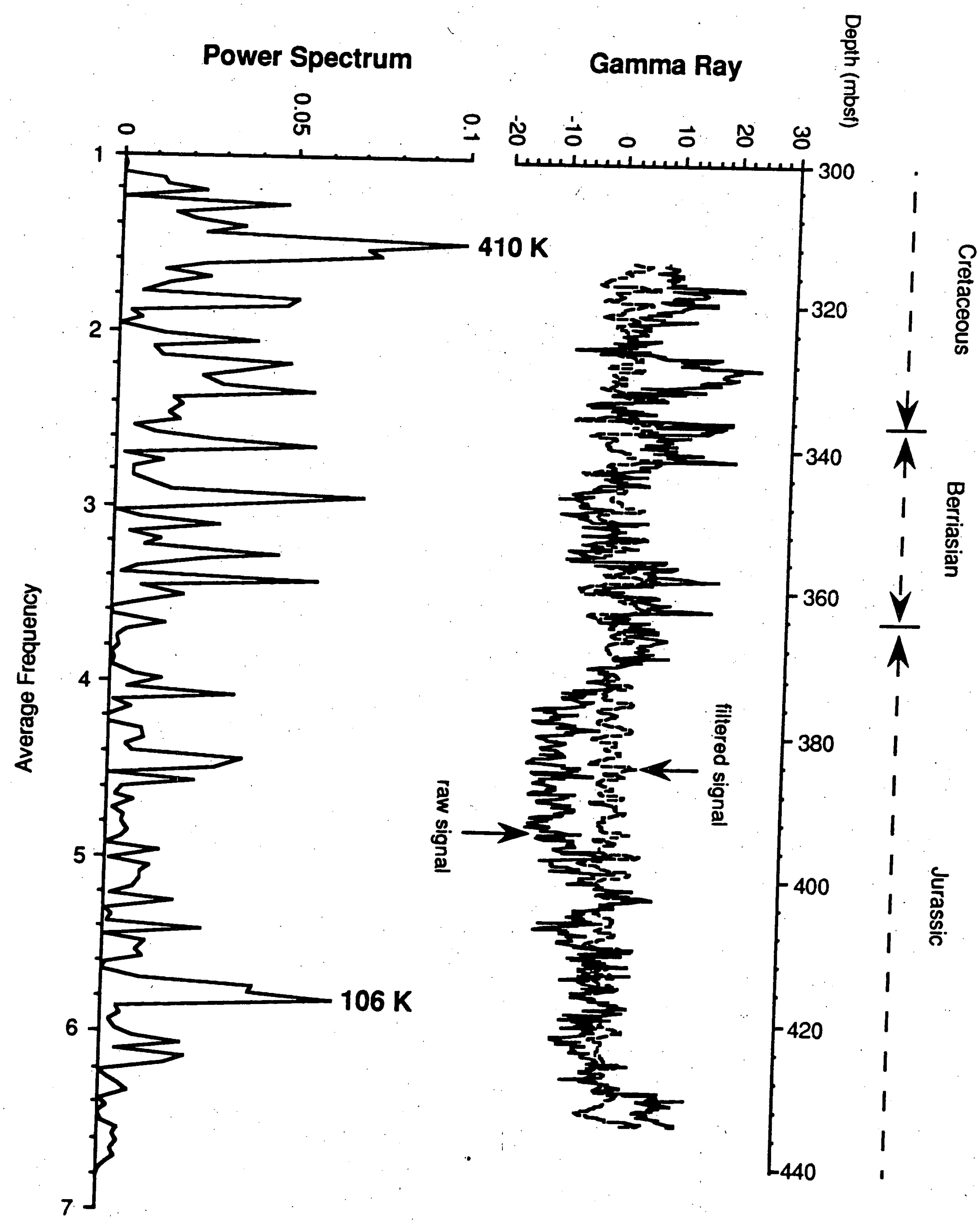


Figure 1-3. Cyclical variations of the gamma ray log recorded in the Jurassic sediments of Hole 801B appear to have detected the Milankovitch eccentricity periods of about 410,000 and 106,000 years.

Ocean, Hole 765D (Leg 123; Figure 1-4). The chemical composition of the upper 1.5 km of the crust in the Argo Abyssal Plain of the eastern Indian Ocean provides bounds for the composition of crust being subducted beneath the Java Trench to the north.

The compositional variability of the sediments and crust being subducted must be known before the volcanic processes active in the Island Arcs behind the subduction zone can be fully understood. For example, the amount of to potassium to be subducted when this crust moves north in the near future is generally low in the upper 500 m of the sedimentary section and throughout the basement. However, an increase in the abundance of aluminum-rich clays (particularly in a layer found from 580 to 640 mbsf) raises the potassium content of the lower 500 m of the sedimentary column. The horizontal and vertical extent of this interval, with its >5 % K_2O, would obviously influence the amount of potassium available for incorporation into island-arc magmas after subduction.

The compositional variability of these island-arc volcanics is poorly known, so that the discovery of high potassium andesites beneath 700 m of high mafic-content boninites in the Izu-Bonin forearc at Hole 786B (Leg 125; Figure 1-5) was a big surprise. These andesites are compositionally variable, with high silica magmas containing virtually no iron (true ryolites) overlying dacites with similar silica contents to the ryolites, but with higher iron contents. These silicic rocks contain about 5% K_2O. Thus, a significant source for potassium must have been subducted beneath the Bonin Trench within the last 5 Ma. The source for this abundant potassium could be from the subduction of an extensive area of clay-rich sediments similar to those found in the lower sedimentary column in the Argo Abyssal Plain.

Geophysical logs provide the benchmark observations with which to integrate fine-scale core analyses with large wavelength, remote sensing techniques, such as seismic reflection, gravity, and magnetic mapping of the upper oceanic crust. The most extensive set of geophysical and geochemical logs into back-arc basin crust was recorded during Leg 124, at Holes 768C in the Sulu Sea and Hole 770C in the Celebes Sea (Figure 1-6). The true back-arc basin crust found in the Sulu Sea Hole 768 contains a magnetic reversal at 1068 m below the sea floor. Both pillow basalts and massive flow units below this boundary are reversely polarized. The trapped normal MORB oceanic crust from the Celebes Sea Hole 770C was found to contain a single reversely polarized sill within the otherwise normally magnetized pillow basalts of the rest of the hole.

State-of-Stress in the Earth's Crust

Logs provide the only mechanism for routine measurement of the orientation and magnitude of the tectonic stresses that drive the surface plates of the Earth. Both the Borehole Televiewer (BHTV) and the Formation MicroScanner (FMS) record the direction of maximum horizontal compressive stress by imaging the orientation of wellbore breakouts, failure caused by hoop stresses along the wall of the newly cut hole. Extensive wellbore failure produced the acoustically absorptive (black) stripes observed in the BHTV logs from Hole 765D in the Argo Abyssal Plain (Figure 1-7). The least compressive

LEG 123: HOLE 765D

Argo Abyssal Plain (Indian Ocean)

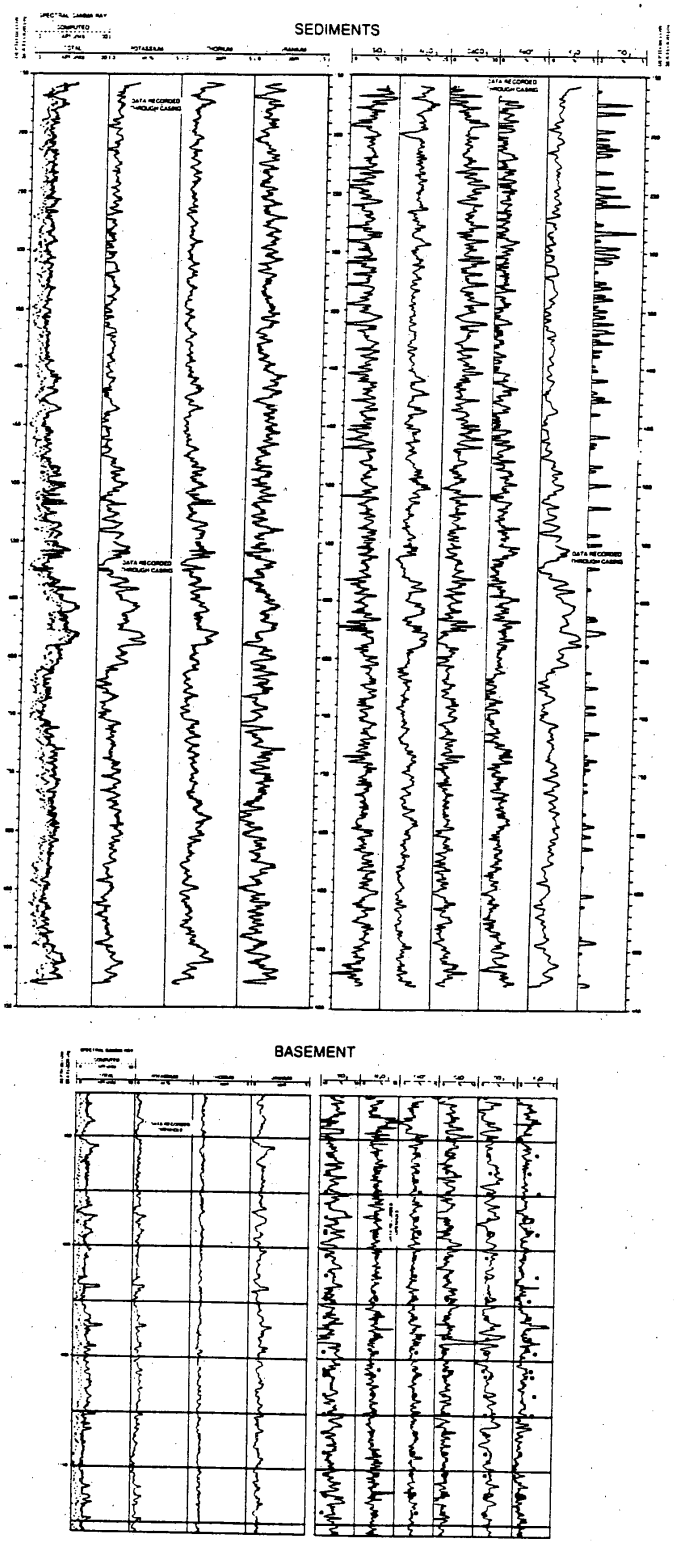


Figure 1-4. Geochemical logs from Hole 765D were obtained through casing in the sedimentary section of the hole and openhole in the basaltic basement. Geochemical logging allows for the determination of the total geochemical budget in ODP boreholes, a critical ingredient for geochemical reference holes such as Hole 765D.

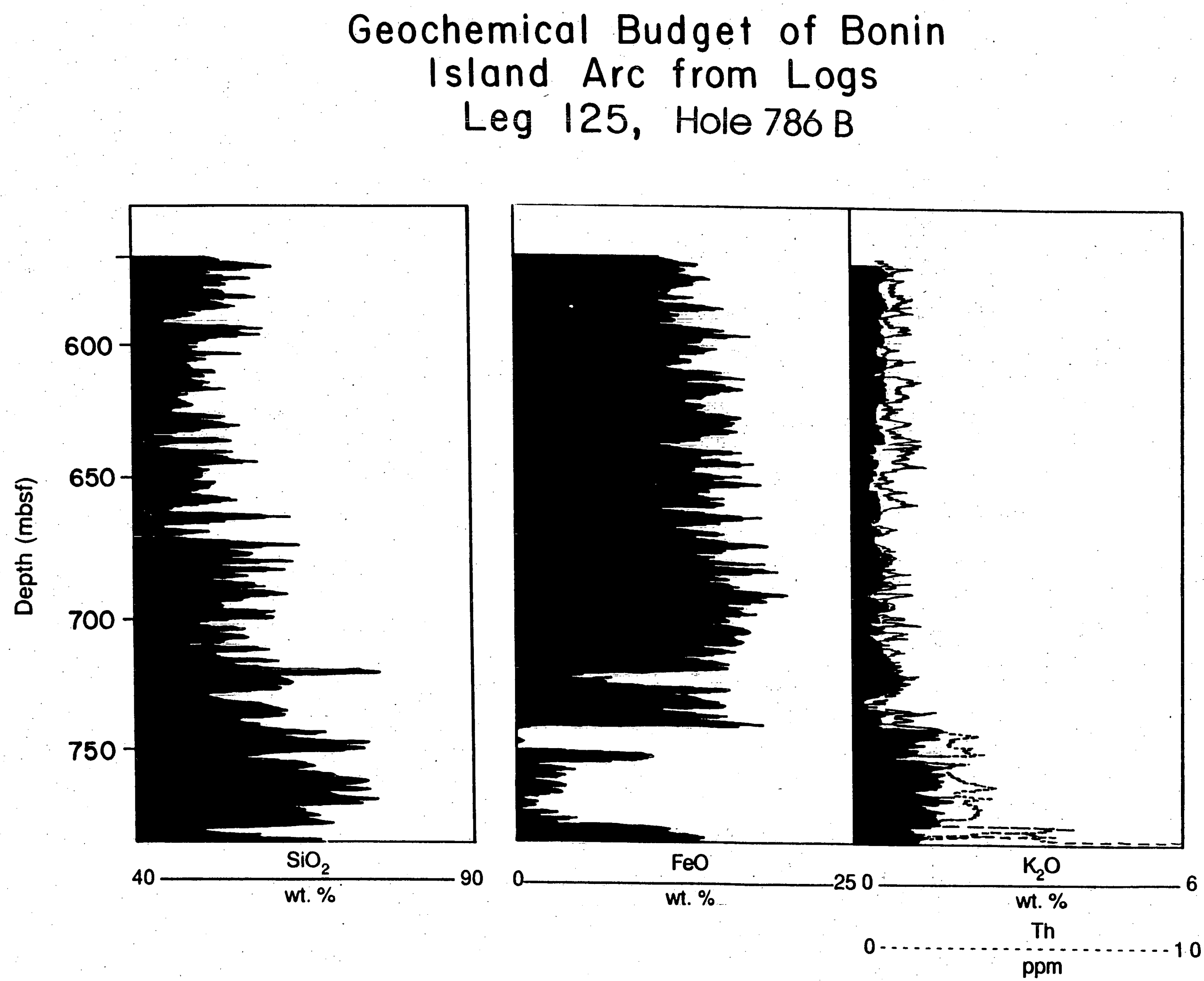


Figure 1-5. Four of the geochemical logs obtained for the island-arc volcanics of Hole 786B. One aspect of geochemical reference holes is a comparison of geochemistry between subducted materials and arc volcanism. The major geochemical change at the bottom of the hole could reflect a change in composition of subducted sediments.

GEOPHYSICAL PROPERTIES OF BACKARC CRUST LEG 124

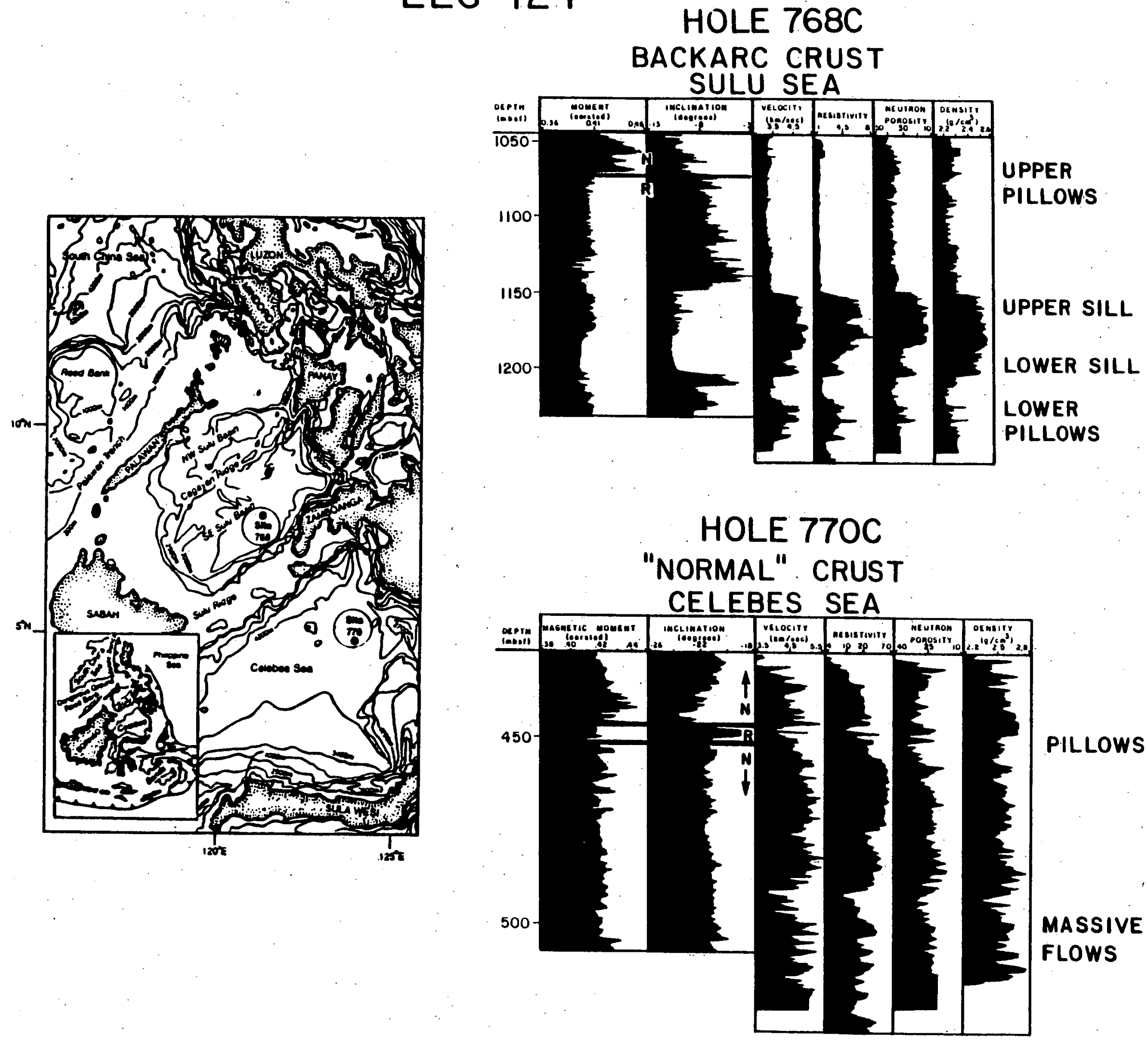
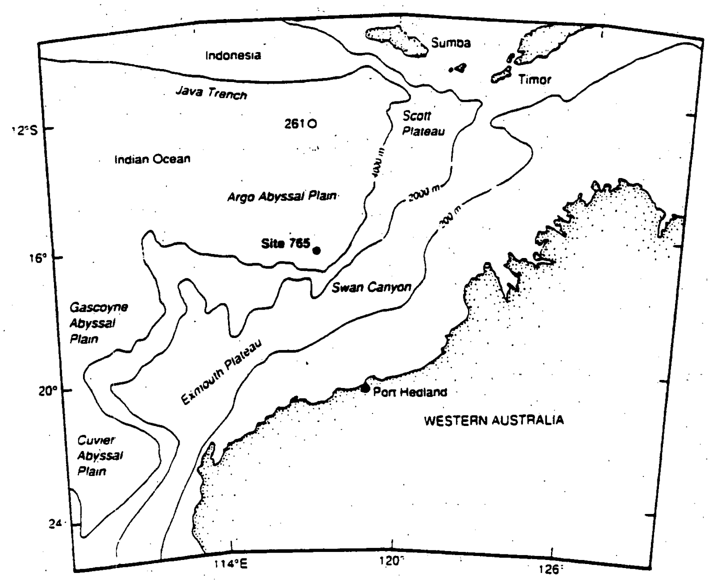


Figure 1-6. Geophysical logs from two back-arc basins near the Philippines. The geophysical properties of back-arc crust at Hole 768C are actually more like those of typical oceanic crust than are the anomalously dense properties of "normal" crust trapped in the Celebes Sea at Hole 770C. At both sites magnetic reversals are evident in the magnetic logs.

MINIMUM COMPRESSIVE STRESS DIRECTION FROM BOREHOLE TELEVIEWER LEG 123, HOLE 765D



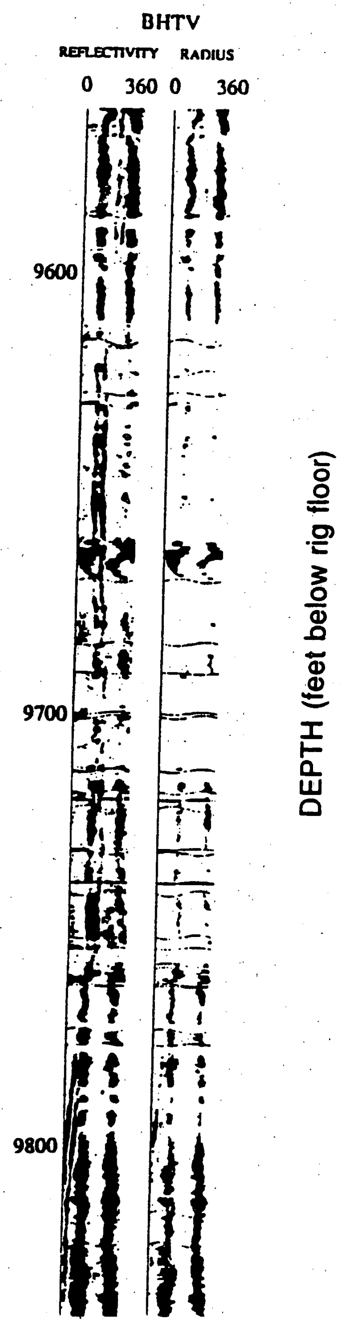


Figure 1-7. Borehole televiewer record of basement at Hole 765D shows strong and consistent pattern of breakouts indicating approximately E-W minimum compressive stress seaward of the Java Trench.

horizontal stress direction in the Argo Abyssal Plain is east-west, indicating that the maximum compressive stress direction is north-south. This direction is consistent with predictions from plate driving force models of the Indian Plate based upon an evaluation of the relative importance of the pulling force of the Java Trench, the pushing force of the Southeast Indian Ridge, and the resistive force of the collision of India with Asia.

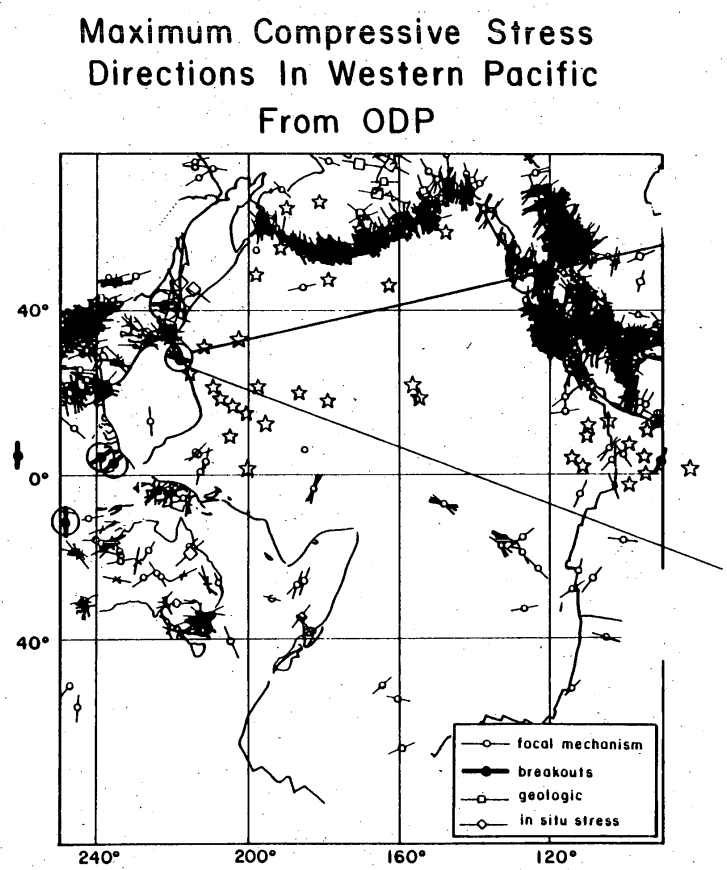
Stress directions were recorded at a total of eight sites in the Western Pacific during Legs 123, 124, 126, 127, and 128 (Figure 1-8). Compression oriented perpendicular to the subduction zone was found in all these sites. However, four stress directions that were recorded within a small area of the Bonin Fore-Arc indicate that the local stresses near the trench are more complex than previously thought. The maximum compressive stress direction rotates from 020° in FMS images from Hole 792E to 040° in BHTV logs from Hole 786, to 065° in FMS images from Hole 793B, to 090° implied by structural constraints in the newly rifting Bonin back-arc at Site 790 (Figure 1-8).

These present-day rotational forces within the fore-arc landward of the Bonin trench were also present in the past, as can be seen from the 90° rotation found in middle Oligocene sediments from Holes 792E and 793B (Figure 1-9). Here, viscous magnetization directions from normally polarized sediments from Hole 792 agree with paleomagnetic measurements from reversely polarized core oriented by the FMS log at Hole 793B. Both indicate that sediments now oriented east-west have been rotated by movement of the Philippine plate since the Oligocene. Such rotational forces are just now being recognized as important deformational processes in continental as well as oceanic plate boundaries (c.f., the England and Molnar and McKenzie articles in the March 12, 1990 issue of *Nature* on the rotation of eastern Tibet).

Further discussions of the determination of plate stresses from well logs are given in Chapter 5.

Summary.

Below, we detail new logging technologies recently added to the ODP arsenal of downhole measurements and show examples of how they can be used to do science (Chapter 2). We then describe in considerable detail how to use well logs 1) to do paleoclimate research with well logs (Chapter 3), 2) to determine the chemical exchange that has occurred between the oceanic crust and the ocean during hydrothermal alteration (Chapter 4), and 3) to map intraplate stresses within the oceanic lithosphere (Chapter 5).



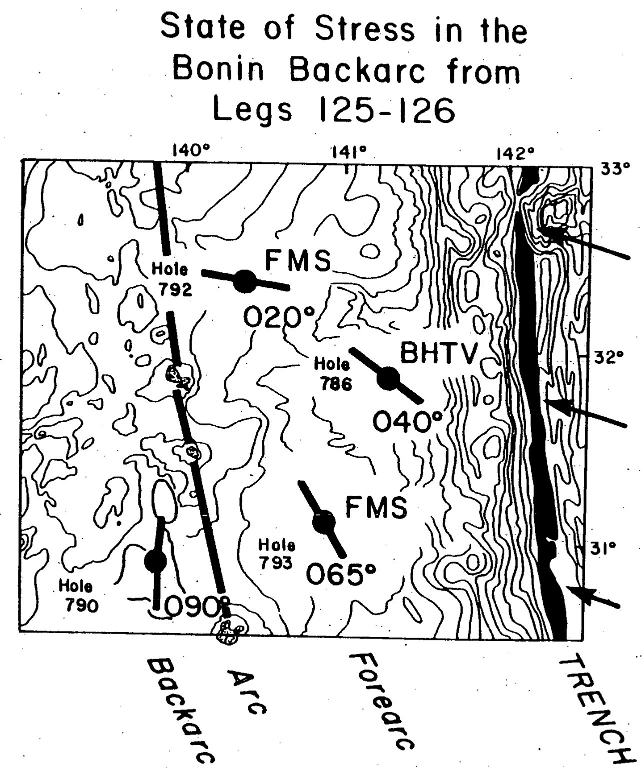


Figure 1-8. Some of the first intraplate stress directions from the Western Pacific (circled at left and blown-up for the Philippine Plate at right), from FMS and televiewer breakouts, show unexpected lateral gradients in stress direction. Stars on the map of Pacific stress orientation data show the locations of possible CEPAC ODP sites; stress information from these "targets of opportunity" would clearly fill large gaps in our knowledge of broad intraplate stress patterns.

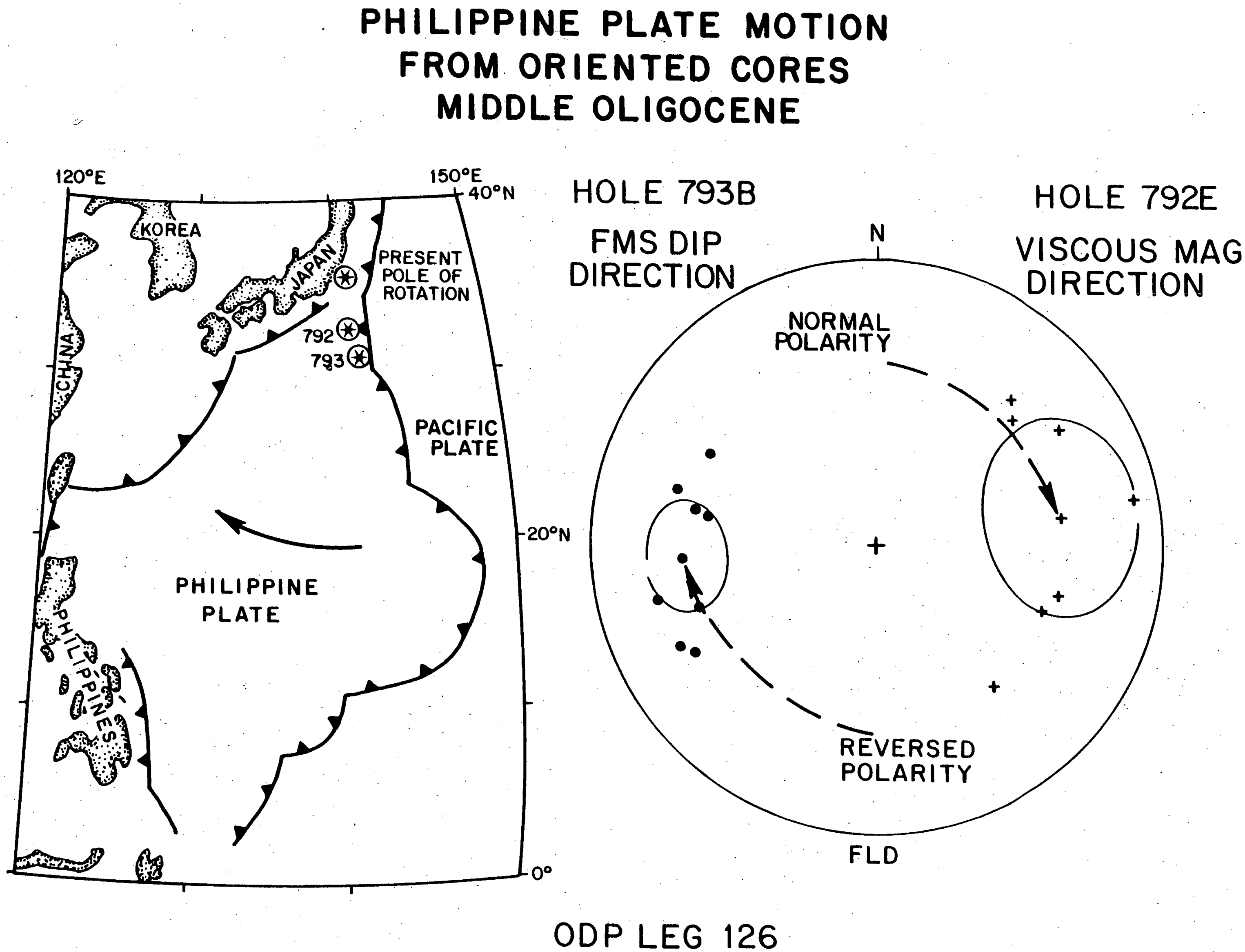


Figure 1-9. Paleomagnetic studies of oriented ODP cores have the potential for solving a long-outstanding problem of rotation of the Philippine Plate. Cores from Hole 793B could be oriented by comparing structural dips within cores to the *in situ* dip direction from the FMS. Paleomagnetism of these oriented cores indicates a clockwise rotation of about 90°; a similar but less reliable result was obtained by viscous magnetization orientation at Hole 792E.

Chapter 2. New Logging Technologies in the Ocean Drilling Program

Recently, the wireline logging program has made major technological improvements in the measurements made in ODP holes that have significantly advanced our ability to achieve a greater understanding of the mechanisms that affect the thematic processes outlined above in the oceans.

Formation MicroScanner

The most important addition to the ODP logging program is the deployment of the electrical Formation MicroScanner (FMS), a four-pad dipmeter with 16 resistivity-measuring electrodes per pad (see text and Figure 2-19 in Volume 3 for further detail). This tool gives oriented, high-resolution images of the electrical conductivity variations along the wellbore wall, and allows for the first time the exact location-in-depth and orientation of the cores recovered in ODP wells. FMS data are acquired at logging speeds that are the fastest of the entire Schlumberger suite (about 900 m/hour), whereas the other ODP imaging tool, the Borehole Televiewer (BHTV), acquires data at the slowest speed (100 m/hr). The eventual combination of BHTV and FMS images in each ODP well will yield acoustic and electrical images of comparable resolution to optical images of recovered core. The three imaging techniques are complementary since color (optical), reflectivity (acoustic), and conductivity (electrical) are each controlled by different physical and chemical processes in the rocks.

The FMS provides vertical resolution of about 5 mm, allowing the imaging of features of the wellbore wall that are more than three orders of magnitude finer than from any other logging tool except the ultrasonic Borehole Televiewer. For example, the images from the turbidite sequence drilled in Leg 126, Hole 793B (Figure 2-1), show the fine-scale layering and gradual grain size changes that can be observed only from core and in outcrop, on land. It is reassuring to see from the comparison of the FMS images and the more traditional induction log that the long wavelength peaks and troughs characteristic of the poorer vertical resolution of the induction log can be seen clearly in the FMS logs, as well. The combination of significant core recovery and continuous FMS logs allowed the construction of the most complete sedimentary description of this hole yet achieved within ODP (Figure 2-2). Laminations, cross-bedding, fluid-escape pillars, cobbles and pebbles, were imaged and used to locate the precise depths of core within the turbidite sequence.

As of September, 1990, the FMS has been deployed in 14 ODP wells in the Western Pacific, with about 6 km of cumulative log recorded. The images, as well as strike and dip of resistive beds in the formation, are oriented using a downhole, 3-component, fluxgate magnetometer. As shown by dipmeter results from Leg 128, Hole 798B in the Japan Sea (Figure 2-3), the strike of beds dipping 5-20° is predominantly to the northeast above a

FMS IMAGE FROM BONIN FORE-ARC COMPARED TO STANDARD RESISTIVITY LOG, Leg 126 - Site 793

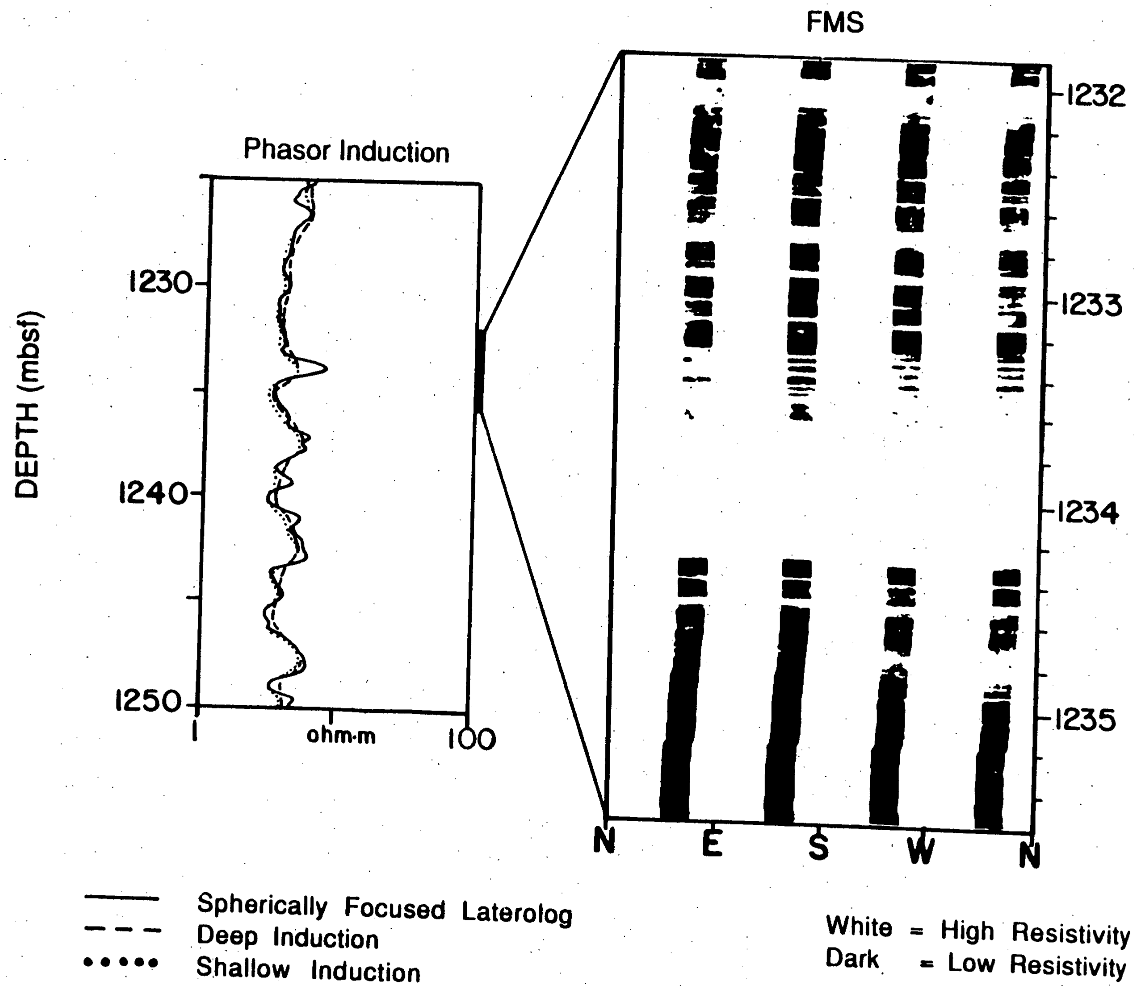


Figure 2-1. Formation MicroScanner images allow the identification of several turbiditic sequences at Hole 793B. The high resolution image is compared to the conventional resistivity log; the high resistivity layer detected by standard logs at 1234 mbsf consists of thin beds visible on the FMS image.

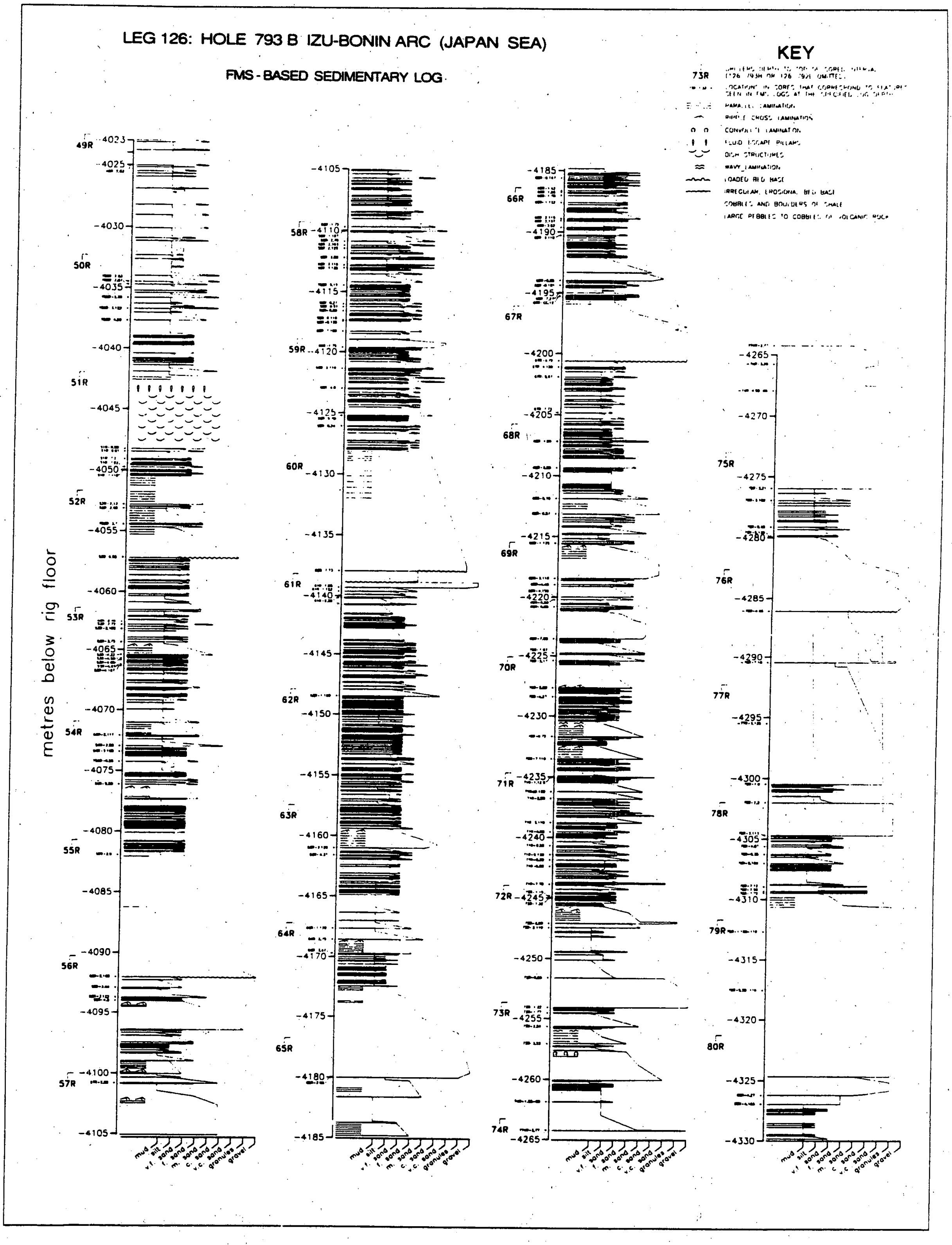


Figure 2-2. Preliminary version of the sedimentary log derived from the combination of FMS data and cores from a turbiditic sequence at Hole 793B (after Hiscott et al., 1990).

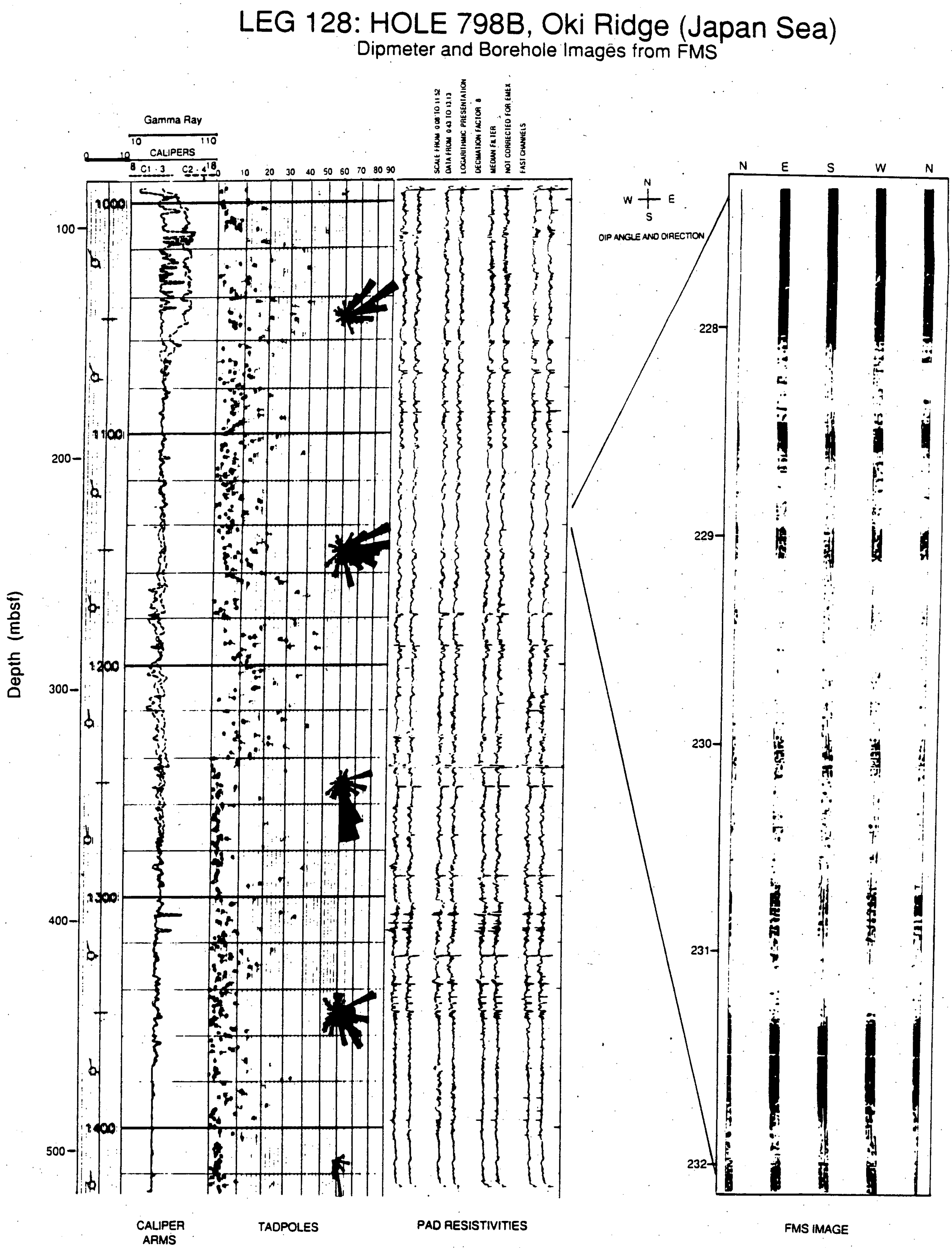


Figure 2-3. Example of the information provided by the Formation MicroScanner. From left to right: hole deviation as a function of depth (shown as open-headed tadpoles); caliper measurements along two perpendicular directions (used to detect stress-induced breakouts); tadpole plots of local dip magnitude and direction (used to determine sedimentary facies and structural dip); resistivity logs (used to determine porosity variations); and a small portion of the FMS images.

subtle unconformity at 340 m subbottom, whereas the beds below strike south-southeast and dip from 0 to 10°. The hole ellipticity recorded by the four-arm caliper from 100 to 160 m subbottom indicates a maximum compressive horizontal stress striking east-west (orthogonal to the least compressive stress direction that causes the ellipticity of the wellbore).

The FMS provides much more than dipmeter information, however. The fine-scale images from 224 to 229 m show low resistivity (black) to high resistivity (white) cyclicity that varies with a 41,000 year period (4 m cycles), and with <1 m cycles (Figure 2-3). Even finer-scale laminations, fractures, and features directly recognizable in the core recovered from this same depth interval allow the core's location in true-depth, and more importantly, the orientation of the core to be determined.

The usefulness of the FMS images in basalts from the oceanic crust can be seen from Leg 127, Hole 794 in the Japan Sea (Figure 2-4). Two passes of the borehole wall produce extended coverage from the FMS, allowing the observation of resistive 'banding' caused by cumulate layering within a massive flow unit in the upper basaltic crust. Extensive fracturing of the basalt is also evident. The strike and dip of the layering and the imaging of the fractures allows the basaltic core to be oriented at this site, as well. Pillow basalts were also successfully imaged in Leg 130, Hole 807 on the Ontong Java Plateau (Figure 2-5).

Boron Sleeve for Geochemical Logging Tool

Another major improvement in ODP logging has been the introduction of a boron sleeve onto the Geochemical Logging Tool (see text and Figure 2-16 in Volume 3), which allows further isolation of borehole effects and subsequent improved sensing of formation chemical changes. Because the Schlumberger boron sleeve is >5 inches in diameter, we designed a slim-hole version which would fit in ODP boreholes.

The added sensitivity of the Geochemical Logging Tool allowed the recording of variations in elemental abundances of the sediments surrounding the frontal thrust of the Nankai Trench off southern Japan in Leg 131, Hole 808C (Figure 2-6). At this site the hole conditions were so bad that the drillpipe itself was in considerable jeopardy. Open-hole logging was therefore impossible, and the logs shown in Figure 2-6 were recorded through the drillpipe; as a result, the signal is greatly attenuated. By using elemental ratios to enhance the geochemical variations (Figure 2-7), both the frontal thrust and several surrounding intervals were found to be zones with high clay content. The abundant hydrogen, aluminum, potassium and thorium abundances relative to that of silica, and the high thorium and uranium concentrations are characteristic of the presence of clay minerals.

The combination of FMS imaging and geochemical logging provides geophysical and geochemical characterization of the formation never before possible from logs. Consider for example the diagenetic changes found in Leg 127, Holes 794B and 797C in the Japan Sea (Figures 2-8 and 2-9). Geophysical logs record major physical property changes related to the opal-A/CT and CT/Quartz phase transitions that occur in the laboratory at 36-55° and 49-64° C, respectively (Figure 2-8). The aluminum weight percent log from the Geochemical Logging Tool indicates an increased clay content across these reaction fronts

FORMATION MICROSCANNER IMAGE OF CUMULATE LAYERING WITHIN BASEMENT

LEG 127, HOLE 794B

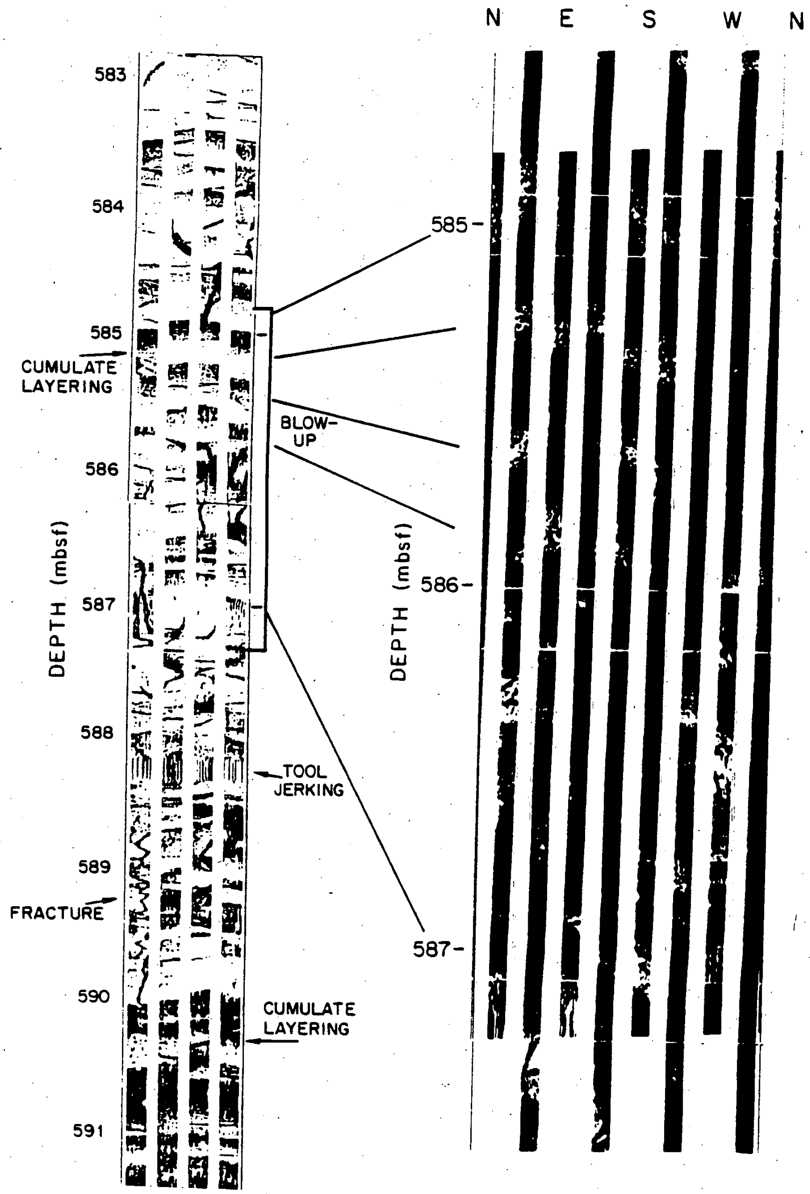


Figure 2-4. Raw (left) and processed (right) FMS images of basement rocks at Hole 794B. Though these black and white display provide only a small fraction of the information contained in the many gray-level s of the original images, fracturing and the sinusoidal pattern of dipping cumulate layers are still evident.

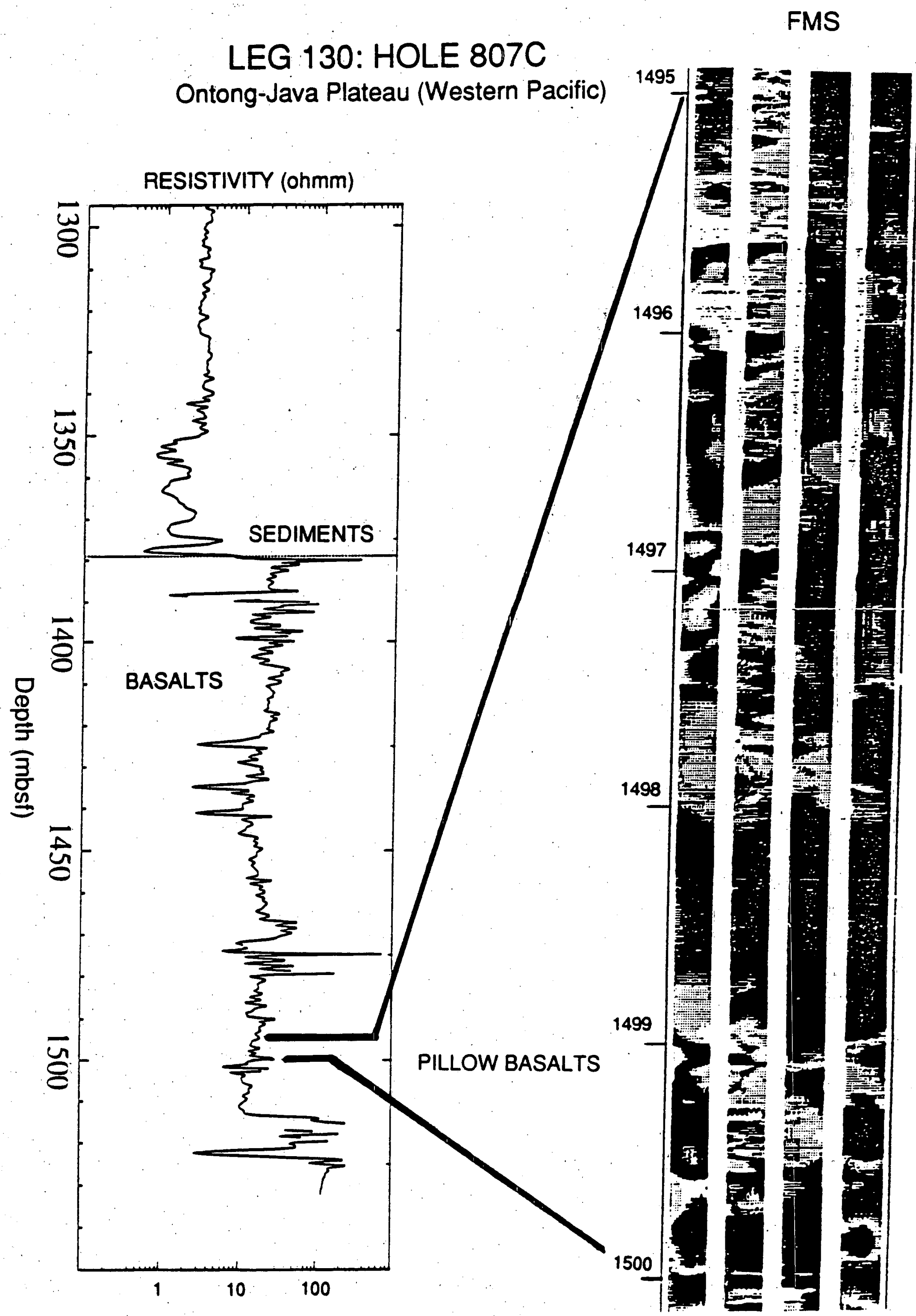


Figure 2-5. Pillow basalts at Hole 807C. FMS images and electrical resistivity logs in the pillow basalts of Hole 807C, Leg 130, Ontong Java Plateau.

Nankai Trough LEG131 HOLE 808C

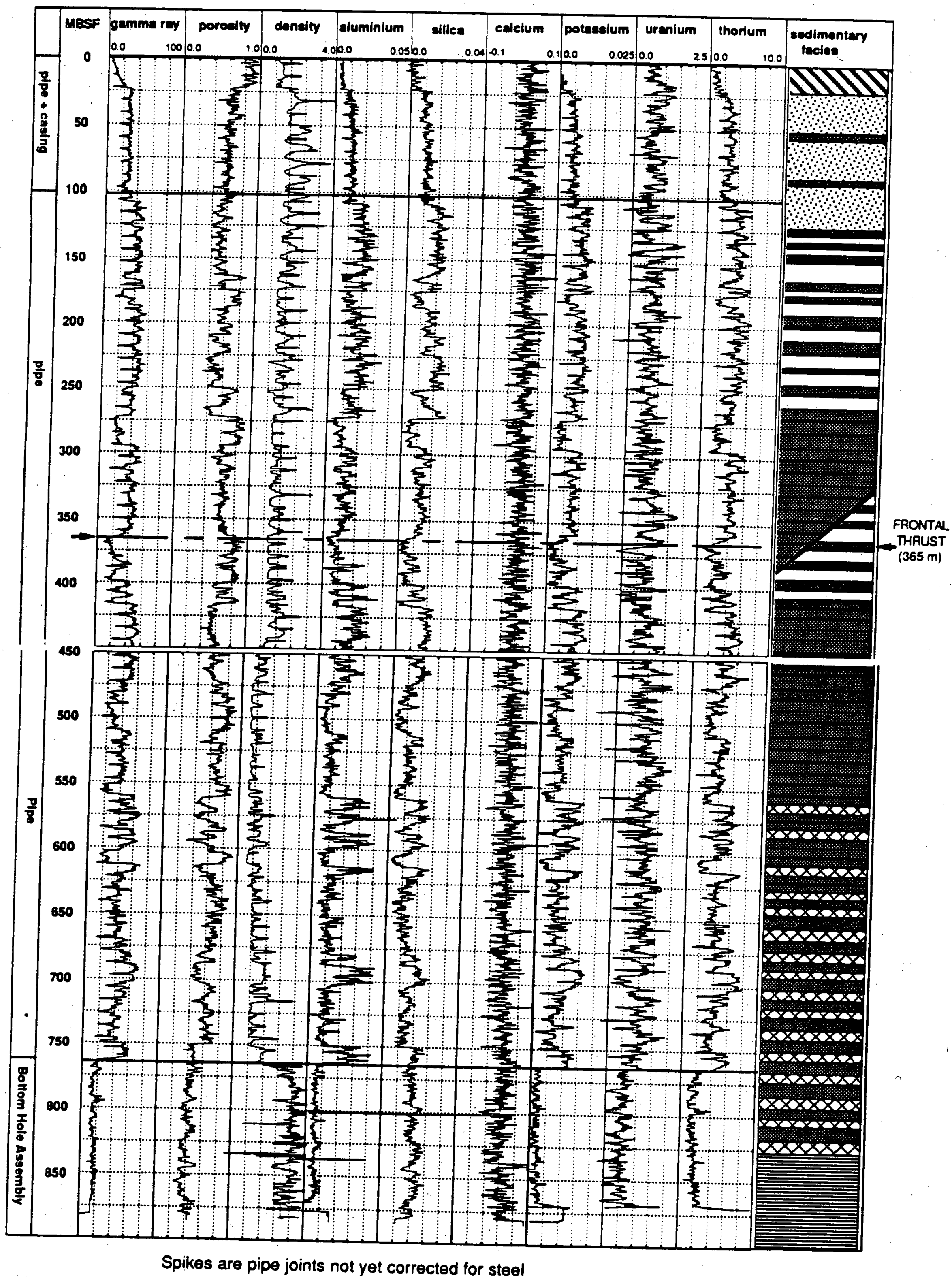


Figure 2-6. 808C. Geochemical logs recorded through drillpipe from the Nankai acrretionary prism, Hole 808C, Leg 131.

LEG 131 HOLE 808C Nankai Trough

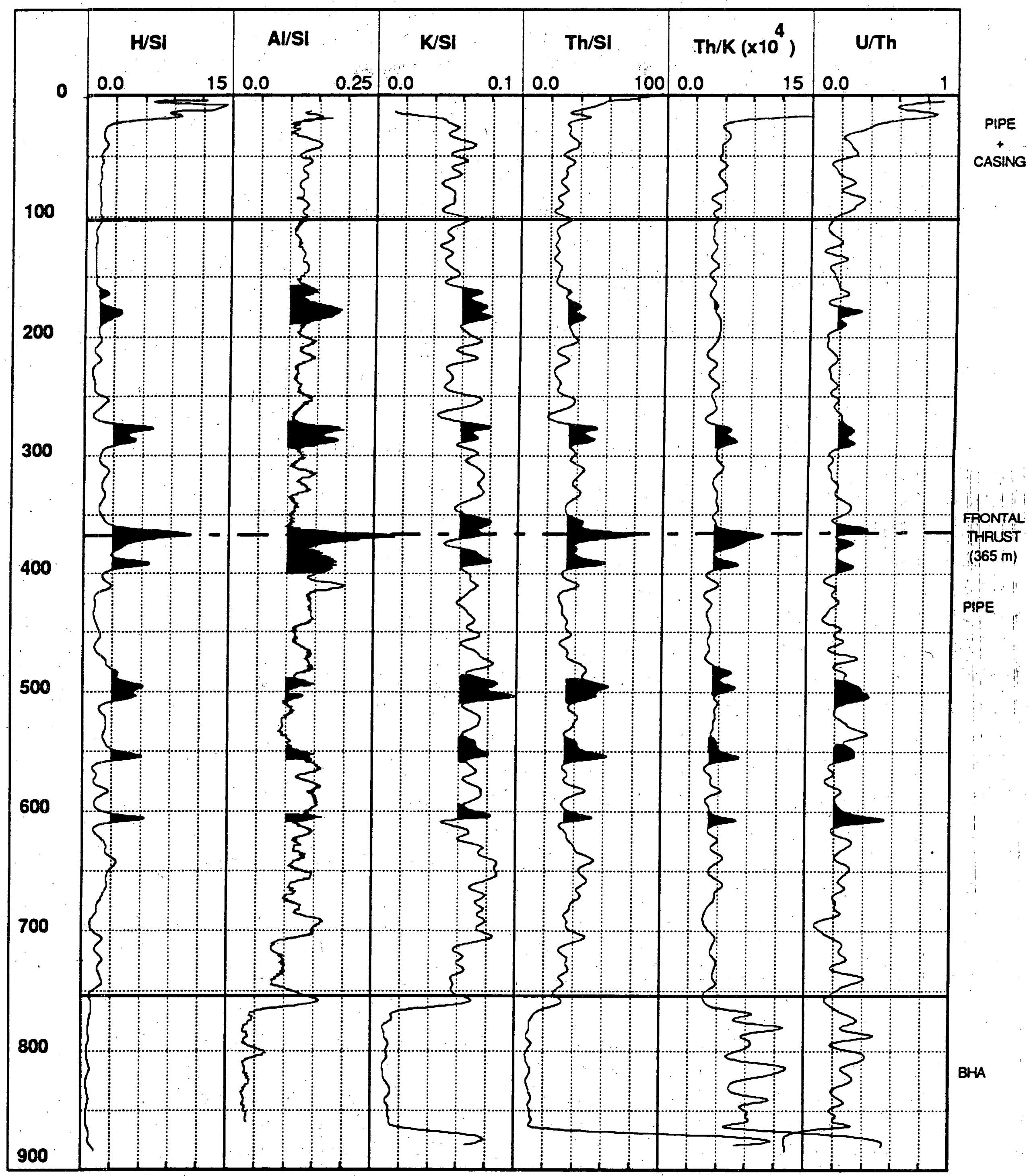


Figure 2-7. Hole 808C. Elemental ratios from geochemical logs (see Figure 2-6) from the Nankai Trough, Leg 131. Blackened peaks are clay-rich zones..

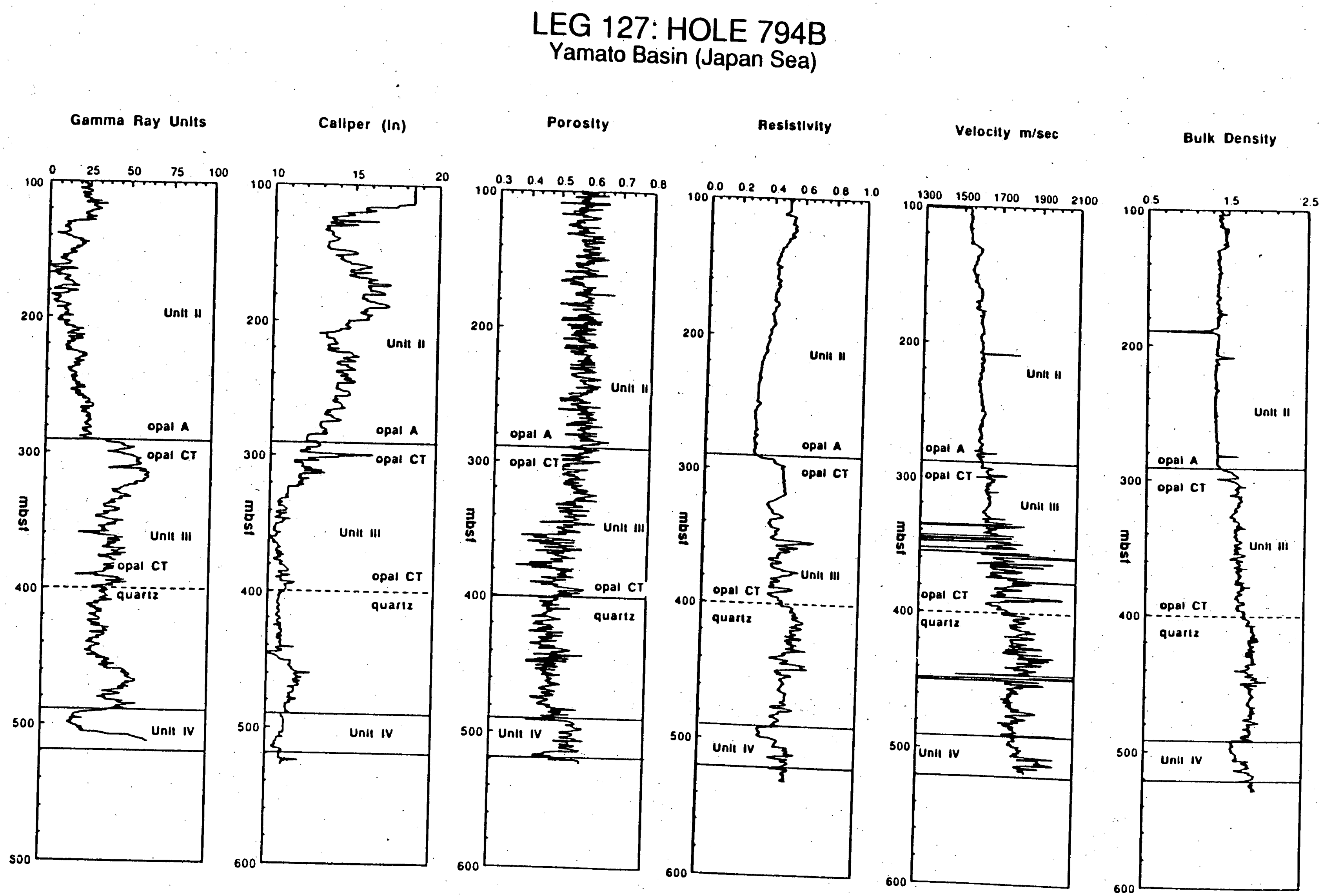


Figure 2-8. Diagenetic boundaries were logged by a complete geophysical suite in Hole 794B in the Japan.

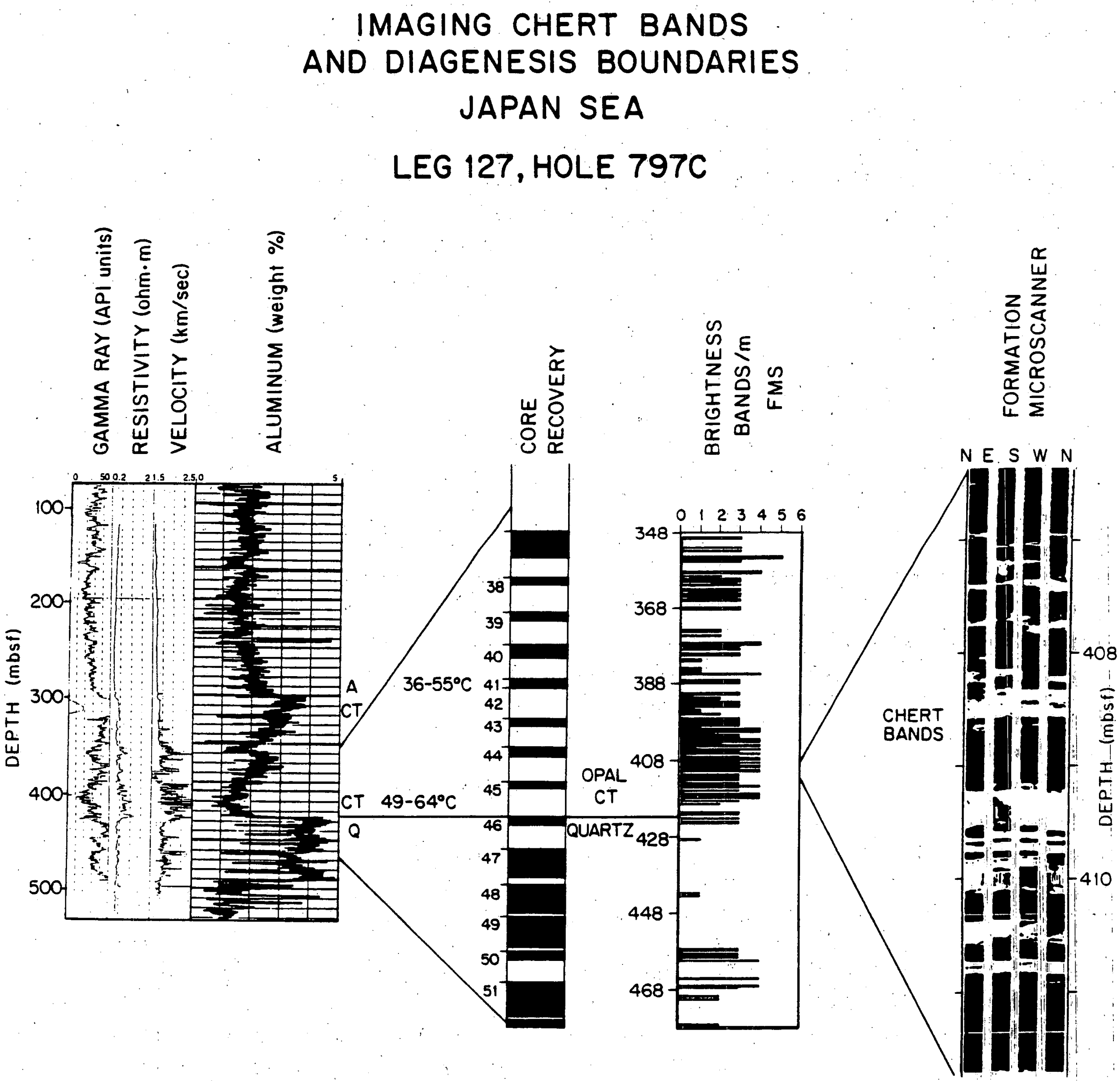


Figure 2-9. A wealth of diagenetic information was obtained from a single fully-logged hole such as Hole 797C, whether one looks at geophysical versus geochemical log variations at a broad scale (left), core recovery versus log-based lithology at a scale of tens of meters (center), or laminations at a scale of centimeters (right).

as well, and brightness bands from the FMS images identify chert bands forming within the opal-rich horizons (Figure 2-9). Core recovery was clearly affected by these chert bands.

Lamont Temperature Tool

The use of the Lamont Temperature Tool on the bottom of each Schlumberger tool string run into ODP holes has now become routine (see Volume 3). Multiple runs allow for the precise mapping of fluid flow disturbances, as well as the calculation of changes in heat flow in ODP wells. At Hole 792E (Leg 126), the fault zone encountered just above the sediment/basement contact (Figure 2-10) would have gone undetected without the observation of borehole cooling from the loss of drilling fluid into the highly permeable fault zone.

Wireline Packer/Fluid Sampler

The Wireline Packer-Fluid Sampler is in the final stages of testing prior to deployment on the drillship (Figure 2-11). The WLP inflates two straddle packers against the formation, then draws fluid through a test chamber using a powerful downhole pump. Pressure, temperature, chlorinity, pH, sodium, and calcium content of the tested fluid is displayed in real-time at the surface. When the operator is satisfied that borehole fluid has been flushed and formation fluid is being sampled, four sample bottles can be filled. These fluids are then delivered to the surface under pressure. We anticipate full operational use of the tool for the drilling in the eastern pacific in 1991.

WBK Digital Borehole Televiewer

The BHTV has, with the advent of the wireline heave compensator, acquired excellent data in hard sediment and basement rocks. Among their scientific applications, these data provide delineation of formation contacts, fractures, and intraplate stress directions (See Chapter 5). The borehole televiewer will hopefully be transformed from our least reliable tool to one that realizes its full potential with the replacement of our obsolete analog tool with digital BHTV's leased from the German WBK. These state-of-the-art ultrasonic imaging tools send a digital record of the reflectivity and precise size of the borehole at 600 points per rotation within the borehole. One of the new BHTV's will be able to operate at the relatively high-temperature of 250° C.

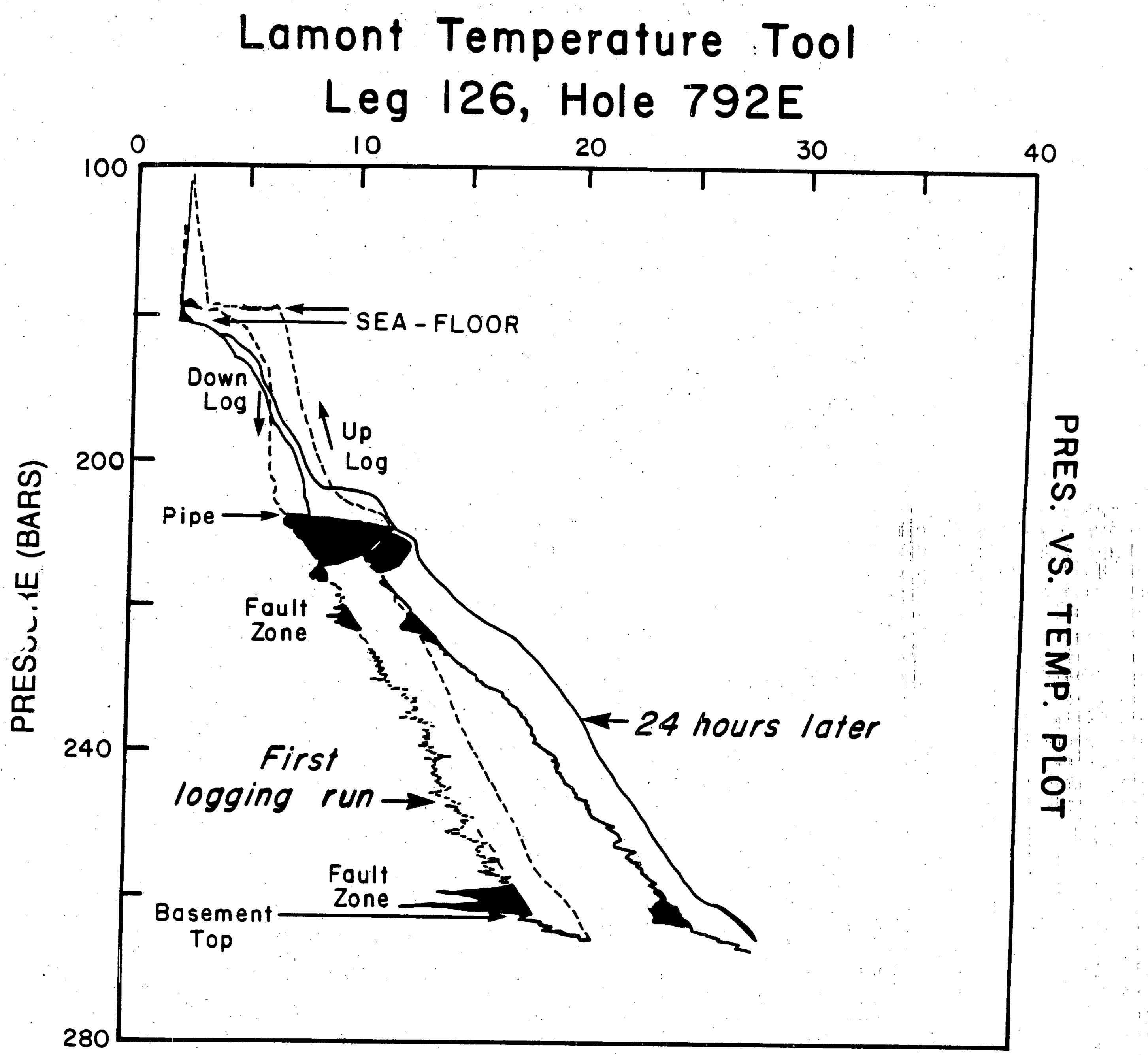


Figure 2-10. Down- and up-going temperature logs are now routinely obtained on most ODP logging runs, thus providing information on both thermal gradients (broad trends) and fluid flow (local anomalies). This example shows the comparison between two runs at Hole 792E (Leg 126). The steeper thermal gradient of the second run was obtained after the hole had approached thermal equilibrium. In both runs anomalously low temperatures were recorded at an inferred fault zone just above the top of the basement.

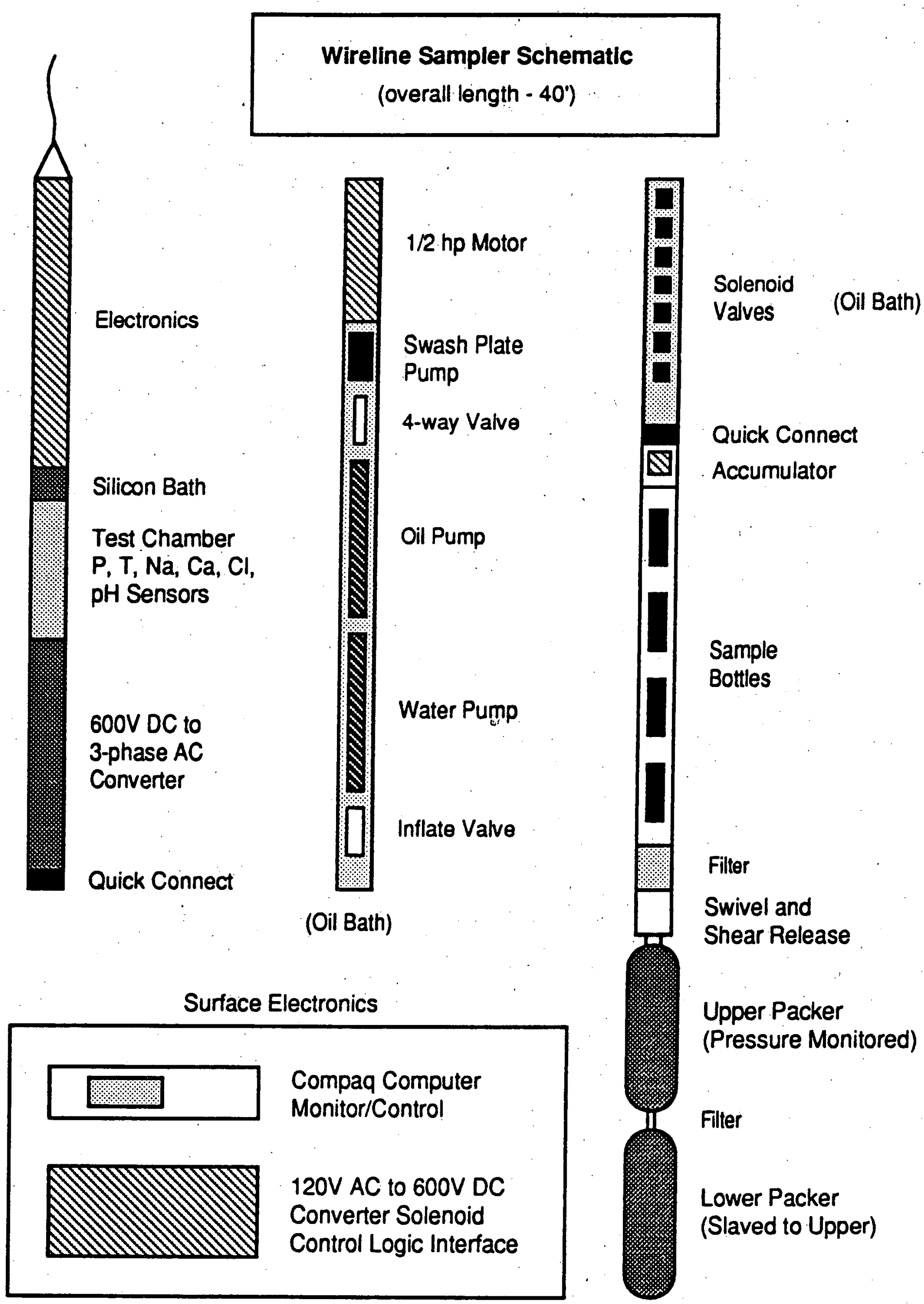


Figure 2-11. Schematic drawing of the three connecting portions of the wireline packer. Inflation of the upper and lower packer (bottom right) isolates a short interval of borehole; *in situ* fluids from this interval are sucked through the filter (bottom right) first into a test chamber (center left) for real-time transmission to the surface, and then into sample bottles (middle right) for later laboratory analysis.

High Temperature Slim-Hole Logging

Among the slim-hole logging tools identified by the JOIDES Panels for deployment in the high temperatures of the East Pacific drilling programs which use the Diamond Coring System (DCS) are temperature, fluid resistivity, and fluid sampling. ODP must develop a high-temperature, slim-hole logging capability in the near future. Options are to lease a temperature, fluid pressure, flowmeter tool from JAPEX, or to procure this tool and a fluid sampler from Sandia National Laboratories, where their Office of Continental Drilling has developed capabilities to make temperature logs and fluid samples in wells with temperatures up to 400° C.

In addition, there are longer-term requirements within ODP for a full, conventional logging capabilities for the high-temperature, DCS holes. The double dewering of electrical resistivity, and then possibly gamma-ray and sonic logging tools (assuming new crystals and transducers are not required) will be attempted in 1991. Prior to their deployment in ODP wells these repackaged slim-hole tools will be evaluated in land wells in order to test the accuracy of their measurements versus that of conventional, larger diameter tools,.

Summary

Below, we go into more detail about the scientific applications of these new technologies. In subsequent volumes of this logging manual you will find that significant new insights have already been made utilizing these tools within ODP. Their use, along with the enhanced drilling and station-keeping capabilities of the JOIDES Resolution, are the major technical advance from the Deep Sea Drilling Project to the Ocean Drilling Program.

Chapter 3. Cyclicity in Logs and Paleoclimate

Introduction

Cycles in the Earth's climate have been known for hundreds of years. The causes must be derived from variations in the energy input the earth receives from the sun. It is not likely, however, that the sun itself has flickered, or in other ways wavered in its energy output, particularly over periods of tens- to hundreds-of-thousands of years that appear to have been driving climatic changes such as glacial cycles. Milankovitch first recognized that it was changes in the Earth's orbital parameters themselves that have caused the energy input to vary periodically over our geological past. It is still unclear how the ellipticity of the Earth's orbit, the obliquity of that orbit to the sun, or the precession of the Earth's tilt axis have changed in relative importance as driving forces of the Earth's climate far into the geological past.

In order to fully understand the ultimate causes of climatic variation, we must also determine the geological responses to that climatic change. The effects of climatic change do not have to be either linear or the same everywhere on the Earth's surface, and their ties to external energy input may not be clear. For example, a major shift in the locations of the continents caused by plate tectonic movements likely cooled the high latitudes, producing the last ice ages, with or without orbital variations. We must first understand the geological responses to climatic change and then determine the effects such change might have on logging data before we can address fundamental questions of the long term variations in the paleoclimate of the earth.

As a result of such an understanding, logs may be used to identify variations in porosity or elemental abundances that are caused by climatic periodicities. These log-derived cycles can then be used for quick age-control, particularly when core recovery is poor. Sedimentation rates, unconformities, and ages themselves can be determined from logs for the first time using this correlation to the Earth's climatic variations.

Climate Cycles and Milankovitch Orbital Parameter Variations

First, the earth does not spin around its axis with a perfect spiral. It wobbles slightly on its axis, because of the gravitational pull of the sun and moon on the equatorial bulge of the earth. The axis precesses; it moves slowly around a circular path and completes one revolution every 19,000-23,000 years. Second, the angle of tilt of the earth, called obliquity, changes with a period of 41,000 years. Third, the orbit of the earth varies from about 5% eccentric, to just about a perfect circle with a period of about 100,000 years. The obliquity and precession signals are modulated by the eccentricity variation with periods of approximately 400,000 years (Figure 3-1). Therefore, there are significant variations in the amplitude of the energy flux as well as in the period of the changes.

These orbital variations must be integrated to determine the energy flux at any time in the past. At present, the earth is closest to the sun at winter solstice. 5,500 years ago, the Earth's tilt was 9 degrees from vertical. 11,000 years ago, the closest approach to the sun was at the summer solstice. Then, a larger amount of solar energy was entering the northern hemisphere in the summer.

The energy flux is also dependent upon latitude, as we all know. The flux at the highest latitudes is dominated by the obliquity cycle, whereas at low latitudes, the precession cycle is more important because it is closer to the sun in the summer. This orbital variation in energy flux at any given latitude is only about 10%, however, because even though the amplitude is higher at lower latitudes, the mean is also much higher. Though 10% appears small, it was enough of a change to bring the ice sheets down over the entire northern United States only 18,000 years ago.

In fact, increasing the areal cover of ice on the Earth's surface reflects more solar energy, amplifying the effect. Complex feedback mechanisms clearly are of great importance. Also, the degree of change in the orbital parameters over the geological past is poorly known. The day has been lengthening through time because of the drag of the moon's tide on the earth. Both tilt and precession have been changed by this slow movement of the moon away from the earth, and we know of few methods for tracking the change in eccentricity back in time. The hope is that logging results from the Ocean Drilling Program will provide an entirely new data set to track the variations in these fundamental orbital parameters back into the Mesozoic.

Log Responses to Climatic Change

Orbital parameter variations produce periodic changes in the overall climate of the earth resulting in local climatic changes that can be observed as mineralogy or porosity changes in a drillhole (Table 3-1). For example, clay type and abundance can be affected by aridity and humidity cycles; grain size, mineral type and abundance can be related to wind pattern changes; and biogenic abundance and compositional changes can be caused by ocean temperature and upwelling variations.

As a case study, consider the log responses recorded during Leg 128 at Hole 798B on the Oki Ridge in the Sea of Japan (Figure 3-2). The Sea of Japan is interesting because of what's happening upwind. The stippled region in Figure 3-2 indicates the extent of Chinese loess deposition. Loess is a silty soil deposited over vast regions of the Chinese plateau by winds carrying silt and clay released by the drying up of glacial streams. The chinese loess deposits contain a 3 million year record of glacial aridity from mainland Asia. These deposits are cyclical in China, where they appear as a repeated loess-soil sequence. The loess represents glacial times and the soil represents humid interglacial times. Very good magnetic stratigraphy exists in the Chinese deposits, with the Matuyama/Gauss, the Olduvai, the Jaramillo, and the Brunhes/Matuyama reversals clearly evident in these samples. This sequence of loess/soil alternation correlates very well with the marine oxygen-isotope record over a period of 41,000 years (Figure 3-3), leading to the inference that the loess deposits are a continental record of ice development in Asia.

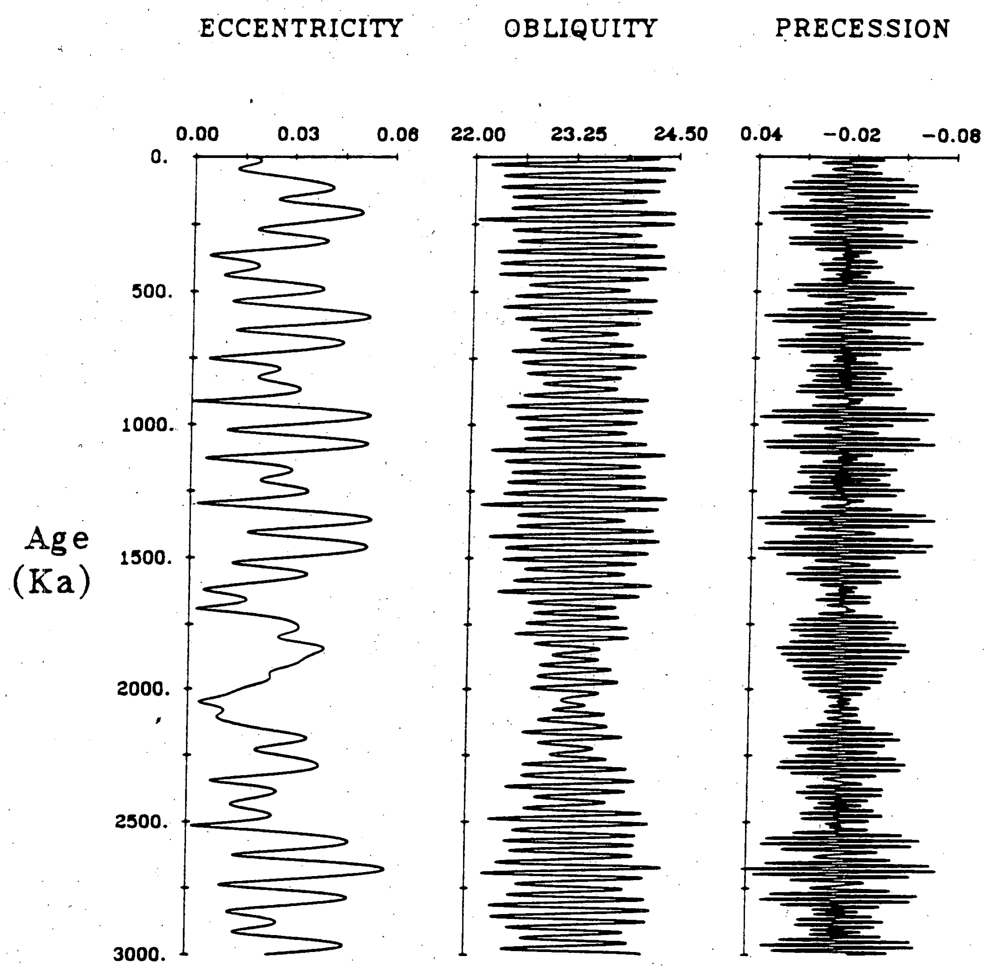
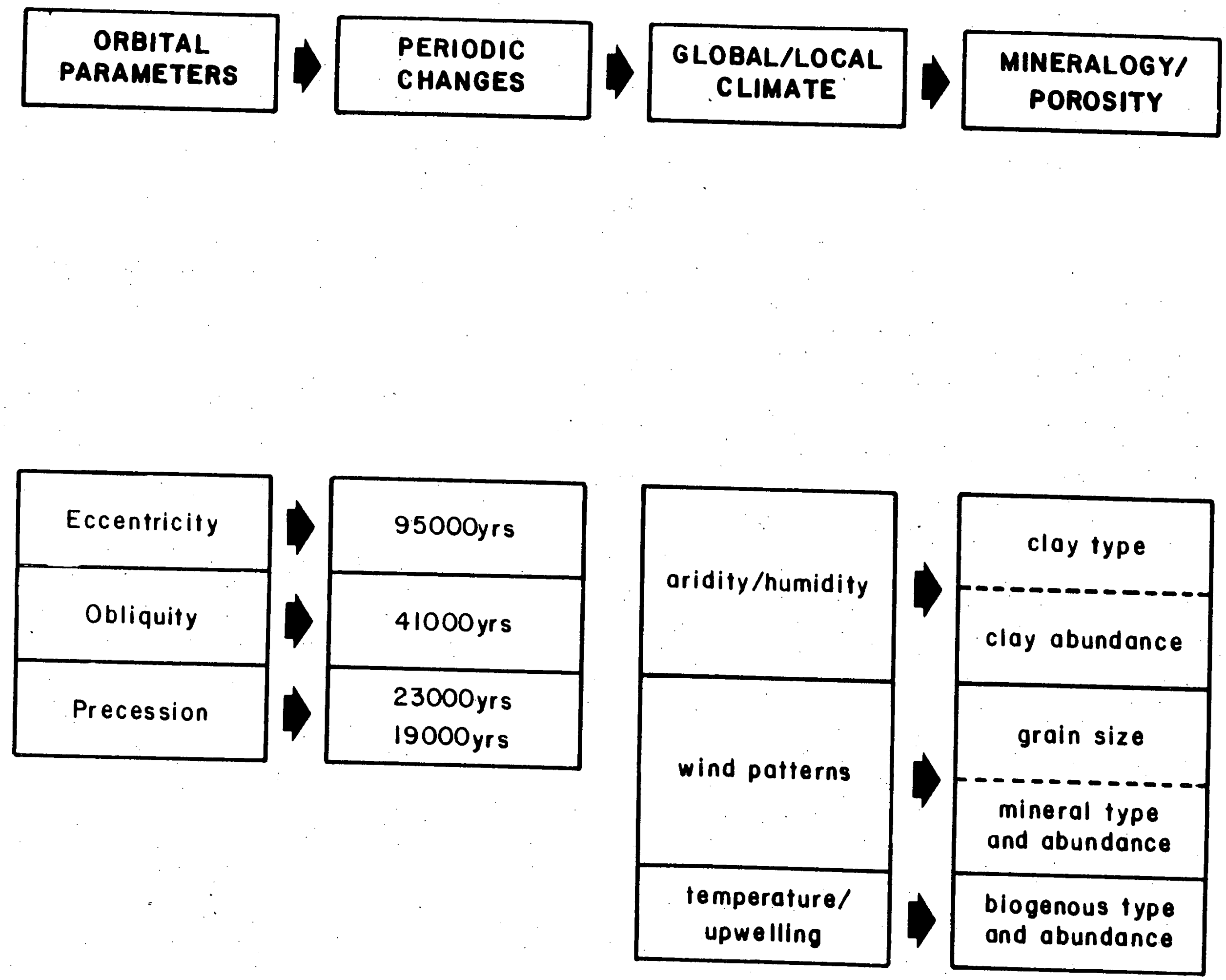


Figure 3-1. Variations over the last 3 m.y. of the three major component of the Earth's orbit around the sun: eccentricity, obliquity, and precession. Precession is shown as the precessional index (e *sin* w), which incorporates the modulating effect of eccentricity.



	Sonic	Resistivity	Gamma Ray	Spectral Density	Neutron	Natural Gamma Spectral	Aluminium Activation	Induced Gamma Spectral
clay type						●	●	●
clay abundance			●	●	●	●		
grain size	●	●		●	●		●	●
mineral type and abundance	●	●	●	●		●	●	●
biogenous type and abundance	●	●	●	●	●	●	●	●

Table 3-1. The sequence of cause-and-effect between Milankovitch orbital parameter changes and log responses. Changes in eccentricity, obliquity, and precession cause changes in the amount of the Sun's energy to hit the planet. This, in turn, causes cycles in aridity/humidity, wind and ocean current patterns, and sea-surface temperatures. These changes cause cycles of clay type and abundance, grain size, mineralogy, and composition and abundance of organisms that die to form deep sea sediments. The logs respond differently to several of these changes producing a complex interaction of geophysical and geochemical responses to climate change.

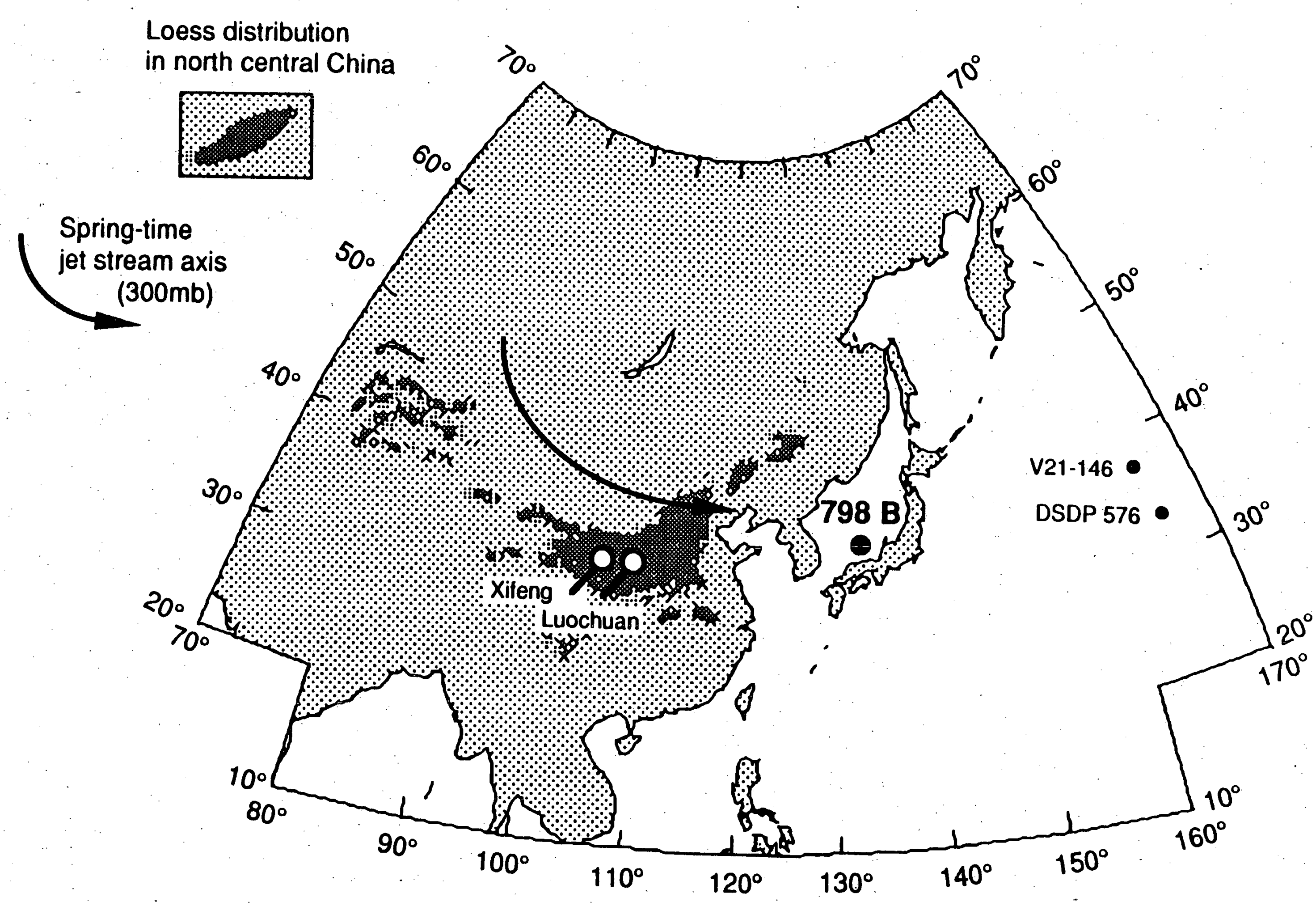


Figure 3-2. Location of Hole 798B, drilled and logged during ODP Leg 128 in the Japan Sea.

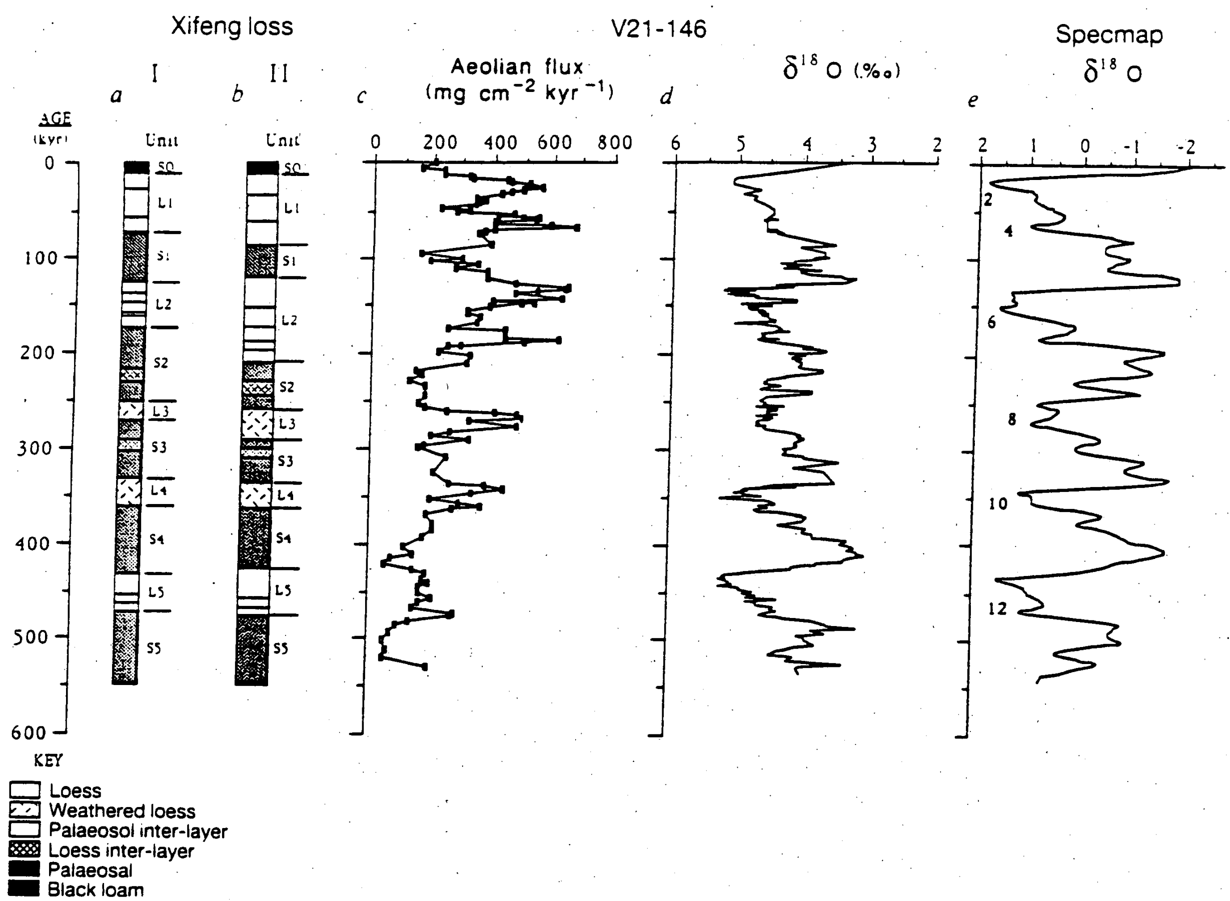


Figure 3-3. Correlation of Xifeng loess deposits to marine record (core V21-146). a) Lithologic column 1 uses susceptibility model to define time scale of loess deposition, b) Column II shows refined ages of loess sedimentation based on correlation to aeolian flux record, c) Aeolian flux record of the North Pacific, d) $\delta^{18}O$ stratigraphy of core V21-146, and e) $\delta^{18}O$ stratigraphy of Specmap global record.

The Oki Ridge in the Sea of Japan is like an inverted cup which collects sediments that are not subjected to down slope transport. The sedimentation rates are extremely high (about 12 centimeters per thousand years) and the sediments have very good paleomagnetic stratigraphy, as well as several thick ash layers that can be used for depth control.

There are two main benefits from the use of logs for paleoclimate work. Paleoclimate studies in general are based on measurements made on discrete samples taken from whatever core material is available. Also, you are limited by the number of samples you can actually process in a resonable amount of time. Logs are continuous and quick.

The sediments sampled at Hole 798B on the Oki Ridge are composed of only two components: a) about 20 to 40% opal in diatomaceous clay, and b) silt and clay size, loess-like terrigenous material. From a visual inspection of the core, there are cycles about every 4 meters from dark layer to light layers. The dark layers are organic-rich, opal-rich sediment with organic carbon content of up to 5%. Ash layers as little as 3 centimeters thick were both cored and imaged by the Formation MicroScanner, and they proved critical for establishing core-log correlations. The Formation MicroScanner image of that interval also shows a 4 meter wavelength variation in the electrical resistivity of the formation in Hole 798B (Figure 3-4). Dark indicates conductive, opal-rich units while light corresponds to the more resistive, terrigenous-rich units. The core recovery, which looks relatively good in Figure 3-4, is deceiving. One of the problems with having organic-rich sediment is that the gas exploded little bits of mud all over the rig floor, so that the core recovery is fragmented, and the section is expanded and disturbed.

Cyclicity is apparent in all the logs from Hole 798B (Figure 3-4). Increases of gamma ray are interpreted as reflecting terrigenous content; increases in bulk density are reflecting the fact that terrigenous material is denser than opal because opal tends to enhance porosity and decrease density; and increases in resistivity reflect the fact that the terrigenous-rich levels are less porous than the opal-rich intervals. These sympathetic variations in all three logs can be correlated with the amount of terrigenous material observed in the cores (Figure 3-5).

We can then use the paleomagnetic stratigraphy to assign age levels to the logging data. Then the logs can be directly compared to the $\delta^{18}O$ record from the oceans, a very high resolution indicator of variations in northern hemisphere ice volume (Figure 3-4). Both the logs and the $\delta^{18}O$ record have monotonic, 41,000 year variation. Even the fine-scale variations in the $\delta^{18}O$ record are duplicated by the logs. Just above the Matuyama/Gauss boundary, the sharp increase in oxygen isotope values, which documents the inception of northern hemisphere glaciation, is seen in the gamma ray curve as a decrease in radioactivity.

Variations in the supply of terrigenous material to the Sea of Japan are reflecting variations in aeolian dust which has its source in the loess deposits in China. When accumulating loess on a Chinese plateau, some of it is also being blown by the westerlies in the Sea of Japan, which is what happens today. Loess is a health hazard in Korea and Japan. Logs have provided a remote sensing method of detecting past variations in Asian aridity from marine sediments.

Downhole Logging: Leg 128, Hole 798B Oki Ridge, Sea of Japan

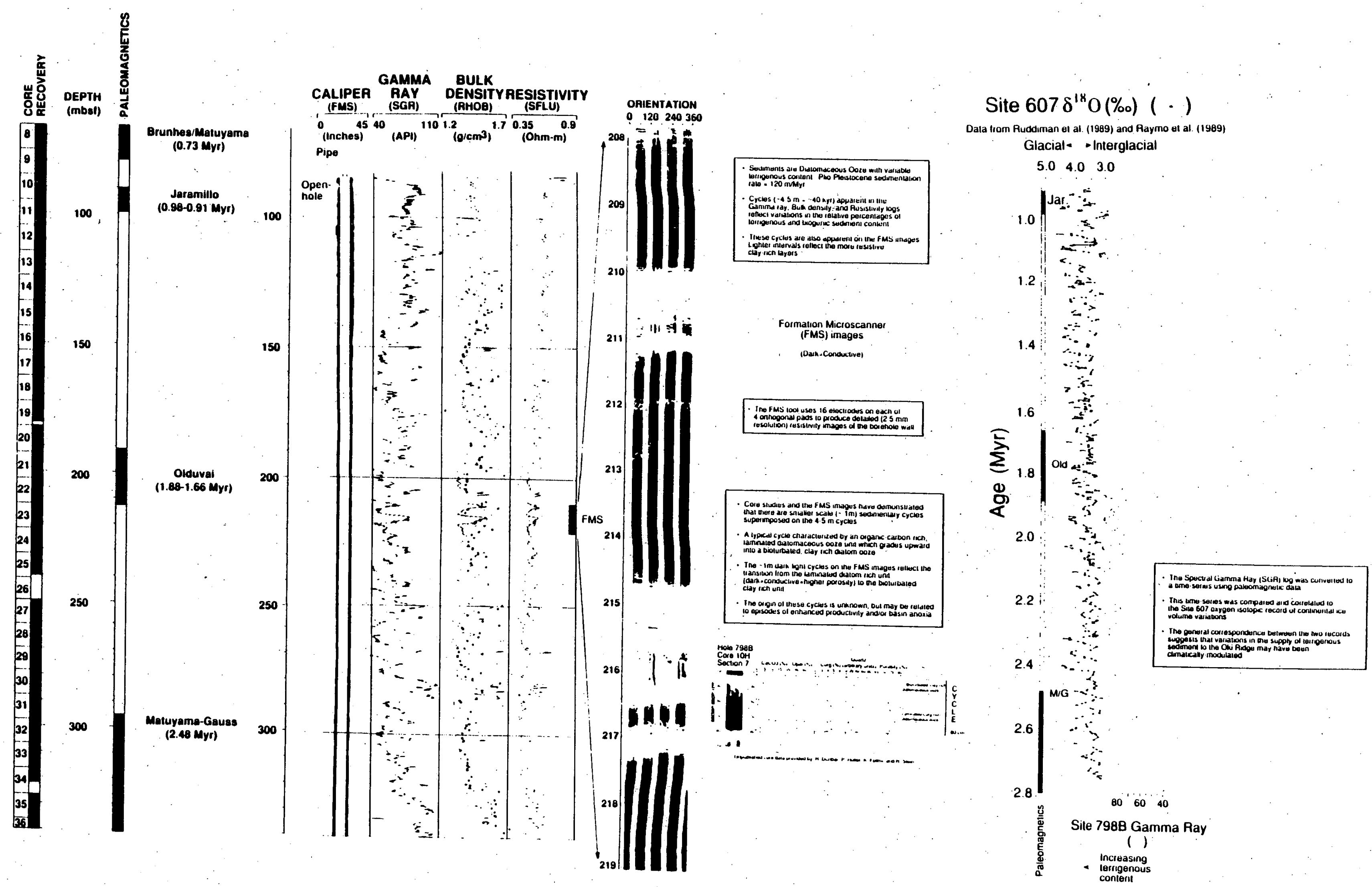


Figure 3-4. Downhole logging at Hole 798B. Logs and paleomagnetic time scale correlation shown at left. See for details of correlation between FMS and core (center) and gamma ray logs versus oxygen isotopes (right).

ODP LEG 128: Hole 798B, Oki Ridge (Japan Sea)

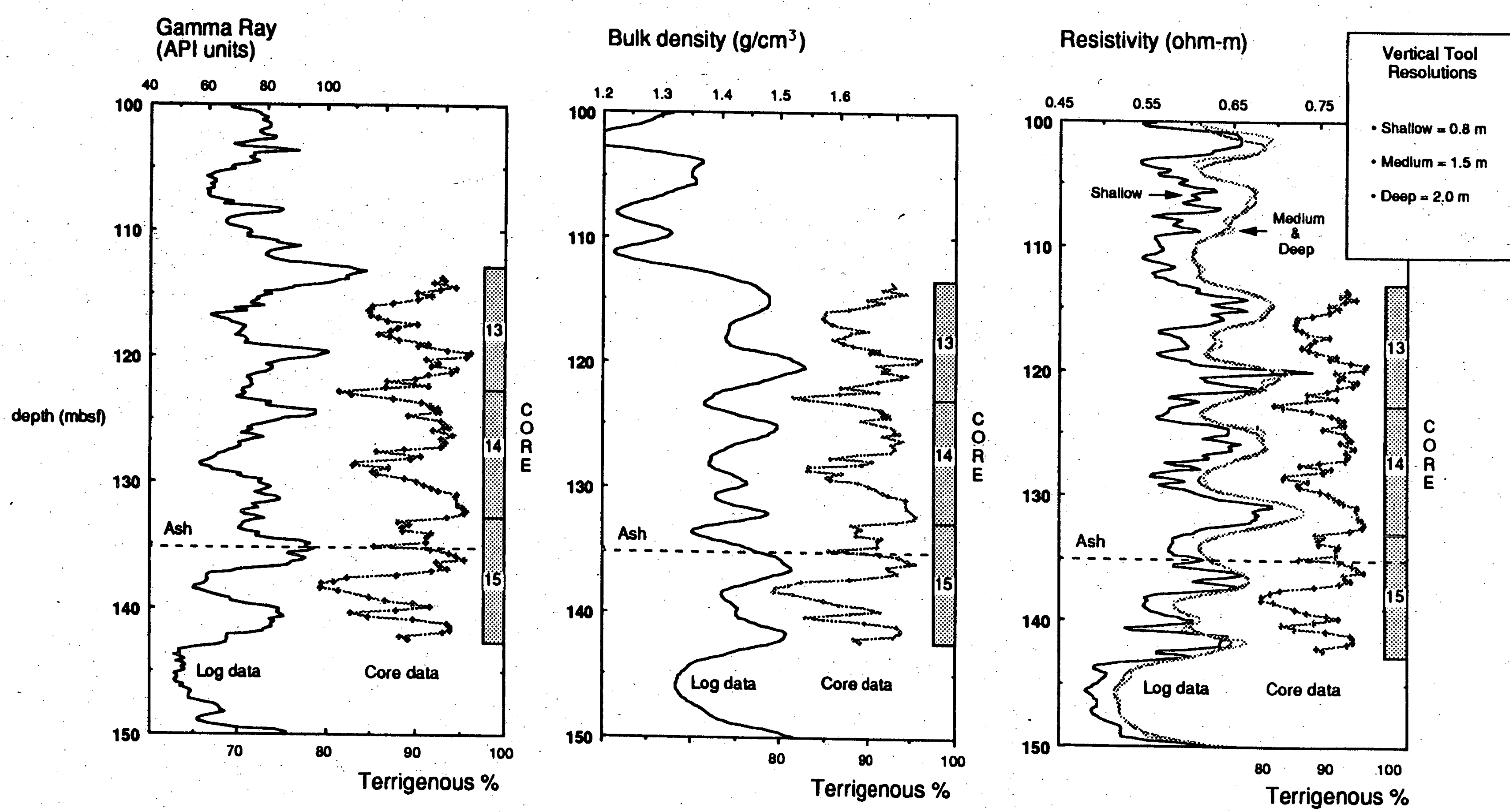


Figure 3-5. Gamma ray, bulk density, and resistivity logs compared to terrigenous content of cores at Hole 798B, ODP Leg 128.

Determination of Sedimentation Rate

As the above example has shown, periodic changes in depositional environments due to Milankovitch astronomical-climate cycles can cause cyclic patterns in sediment properties as recorded by logging data. Spectral analysis of logging data can identify these regular cycles and be related to the known Milankovitch periodicities, thereby providing actual sedimentation rates. Where accumulation rates are variable, application of a close-spaced series of sliding windows through the logging signal can detect variations and discontinuities in rates of sedimentation.

Sedimentation rates are generally determined by estimating the elapsed time between biostratigraphic events identified in the section. This procedure requires an absolute time scale and will generally yield a minimum sedimentation rate due to the difficulty of compensating for hiatuses. However, sediments contain an internal "clock" created by the systematic variation of depositional facies in response to periodic changes in the Earth's climate. These periodic climatic cycles are commonly recorded in sediments as variations in clastic grain size and abundance, biogenic constituents, organic carbon preservation and sedimentary structures; later diagenesis can enhance these variations. As we have seen above, resolution and separation of periodic components requires a spectral analysis of the *temporal* variation of some sedimentary factor, such as the clay content, gamma ray variation or oxygen-isotope ratio.

Spectral analysis of a time-series is a common technique in geophysics: high-pass and low-pass filters are applied to the signal to remove long-period trends and high-frequency noise. A "window taper" is applied to eliminate discontinuities across the ends of the signal interval. Fourier transforms of this processed signal are then displayed as spectral plots of the amplitudes of this constituentfrequency components.

The response of depositional environments to Milankovitch climatic cycles is periodic in time. In contrast, the observed sedimentary record is a function of depth. If a sediment has a relatively constant long-term rate of accumulation, then the variation of its constituents with depth (expressed as cycles/meter) will approximate their variation with time (expressed as cycles/million years). In such cases, spectral analysis of the depth-series will detect temporal cycles. This may be done in either of two ways. In the example from the Sea of Japan, we estimated the periods of the sediment cycles by applying a sedimentation rate estimated from the available magnetostratigraphic and biostratigraphic data. The computed periods were similar to those of climate cycles, so the corresponding Milankovitch periods were used to "tune" the sedimentation rate.

An alternate technique is to compare the ratios of the observed sediment cycle wavelengths to the ratios of Milankovitch time-periods. For example, if the spectral analysis of a formation displays three main cycles having ratios of wavelengths nearly identical to the ratios of the 413-123-95 k.y. set of major eccentricity cycles, then these cycles are probably a reflection of those eccentricity cycles. This ratio technique requires neither precise biostratigraphy nor a tie to an absolute time scale. Often these two methods must be combined, so that the available biostratigraphic data as a constraint on the interpretation of the Milankovitch orbital periodicities, because some ratios are not unique (the ratio of the 123/95 k.y. eccentricity cycles is very similar to that of the 23 /19 k.y. precession set).

The ability to detect Milankovitch cycles within logging data depends on the resolution of the tool and spacing of measurements relative to the sedimentation rate -- to detect cyclicity using Fourier analysis of such signals requires at least two points per cycle. Therefore, a resistivity-log signal having a 1-meter resolution requires a sedimentation rate of at least 20 m/m.y. to detect the suite of eccentricity cycles (95, 123, 413 k.y.) or at least 100 m/m.y. to detect precession cycles (23-19 k.y.). The natural gamma-ray logging tool has a resolution of 0.3 m, and therefore can detect the eccentricity cycles if the sedimentation rate is greater than 6 m/m.y. The Formation MicroScanner, with resolution down of 1 millimeter, should provide the ultimate cycle-detection logging tool.

Geophysical and geochemical logs of Ocean Drilling Project (ODP) holes have been used to identify periodic lithologic changes corresponding to Milankovitch climatic cycles in many sedimentary sequences from ODP boreholes. For example, sonic, resistivity and U/Th logs indicate fluctuations in porosity and clay content induced by bottom-water currents in the Labrador Sea and Baffin Bay (Leg 105), responding to Milankovitch cycles during the Pleistocene. Geochemical logging of Meteor Rise (Leg 114) detected obliquity and possibly eccentricity cycles . Obliquity and eccentricity cycles were also observed in gamma-ray, resistivity and sonic logs of upper Tertiary sediments on the Antarctic continental margin (Leg 113).

Sliding-Window Spectral Analysis to Compute Sedimentation Rate Curves

Sedimentation rates are rarely constant over multi-million year intervals, and therefore the vertical wavelengths of periodic sedimentary cycles will shift. However, if those cycles are reflections of Milankovitch orbital cycles, then the relative spectral ratios of power peaks within those wavelengths will remain constant. If spectral analysis were applied to the entire depth-series signal from a log from such a location, the result would either be broadband peaks or inconclusive cyclicity. Therefore, if subsets ("windows") of this depth-signal were analyzed, the individual results might display well-defined cyclicity, but there would be a consistent relative displacement of the peak-wavelengths between windows. Such displacements would be an indication of changing sedimentation rates, provided the spectral ratios of peak-wavelengths remain constant.

This sliding window comparison of spectral peak ratios is also a valuable supplemental technique to demonstrate the presence of Milankovitch cyclicity. If the windows yield shifting peaks which do not retain a constant ratio, then it is possible that the cyclicity may be due to non-Milankovitch-related variations such as diagenetic segregation, turbidite frequency or other sedimentary phenomenon.

Window size is adjusted according to the approximate spacing of the longest-period cycles of interest. A smaller window is more accurate for determining sedimentation rate variations, but will have poorer resolution of cycles. Use of narrow windows can also result in aliasing of the spectra; a problem that can be partially reduced by application of multiple window tapers.

Spectral analysis of overlapping windows can also be used to precisely determine the depth where discontinuities in sedimentation rate occur. A sharp change in sedimentation rate will result in the replacement of one set of peaks by another set with different wavelengths, which retain the same ratio among wavelengths. The level at which a discontinuity or rapid change in sedimentation occurs can be approximated from the depth of the window in which the amplitudes of the "underlying" and the "overlying" sets of peaks are nearly equal.

High-speed workstations provide the ability to slide a selected window at close-spaced intervals through the logging signal and display the series of spectral analysis results as a three-dimensional plot of depth vs. cycle-wavelength vs. peak-intensity. An example of sliding-window spectral analysis applied to a gamma-ray log of Upper Jurassic-Lower Cretaceous radiolarian mudstones of Pacific ODP Hole 801B (Figure 3-6) is shown in Figure 3-7 to illustrate the progressive shifting of peaks. The spectra from the logs can be used to locate the sedimentation rate change even more precisely by increasing the number of windows chosen across the boundary (Figure 3-8). Splitting from one peak as the new peak is formed across the disconformity can be observed.

The final sedimentation rate curve computed by this sliding-window procedure for these radiolarian mudstones is displayed in Figure 3-9. The major discontinuity in sedimentation rate corresponds to a sharp change in the chert/clay ratio, which was also observed in geochemical and Formation MicroScanner logs. The available radiolarian biostratigraphy, coupled with low core recovery, did not enable resolution of this discontinuity.

Summary

Many types of marine and continental sediments record periodic changes in depositional environments caused by Milankovitch climate cycles. Spectral analysis of logging data of these sediments can enable resolution of Milankovitch climatic cycles, thereby providing rates of sedimentation. It is important to verify that the ratios of the wavelengths of such cycles are the same as the ratios of the periods of the corresponding Milankovitch cycles; and preferably at least three such cycle periods should be identified and correlated. Plots of a series of such spectral analyses generated from overlapping sliding windows can be used to identify both gradual changes and sudden discontinuities in sedimentation rates. As sedimentation rate changes, the locations of spectral peaks shift, but the relative ratios within each spectra must remain constant. Use of Milankovitch cycles to compute sedimentation rates removes the need for precise biostratigraphic control for detailed age correlation in marine sediments.

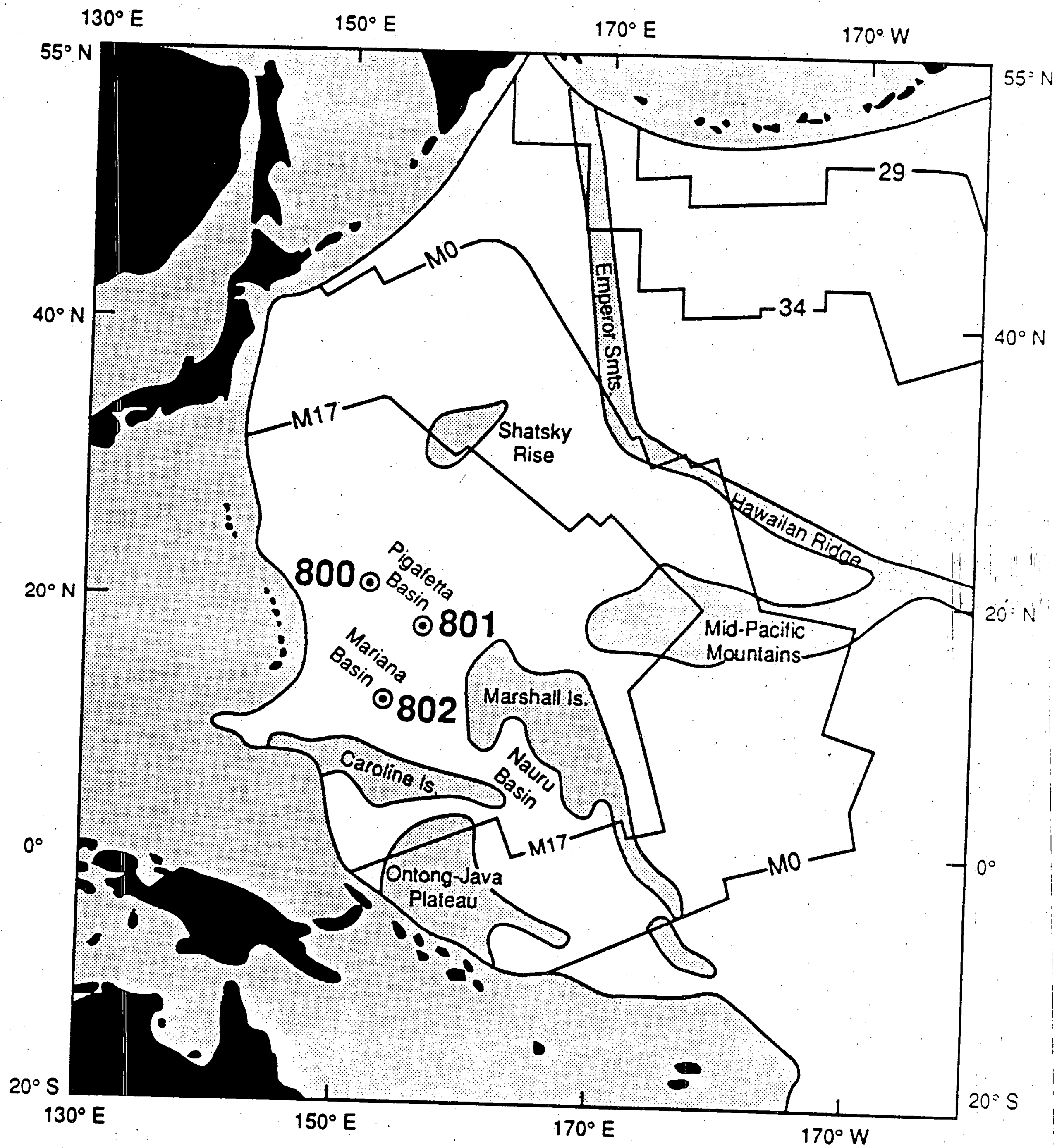


Figure 3-6. Location of Hole 801B drilled and logged during ODP Leg 129 in the Western Pacific.

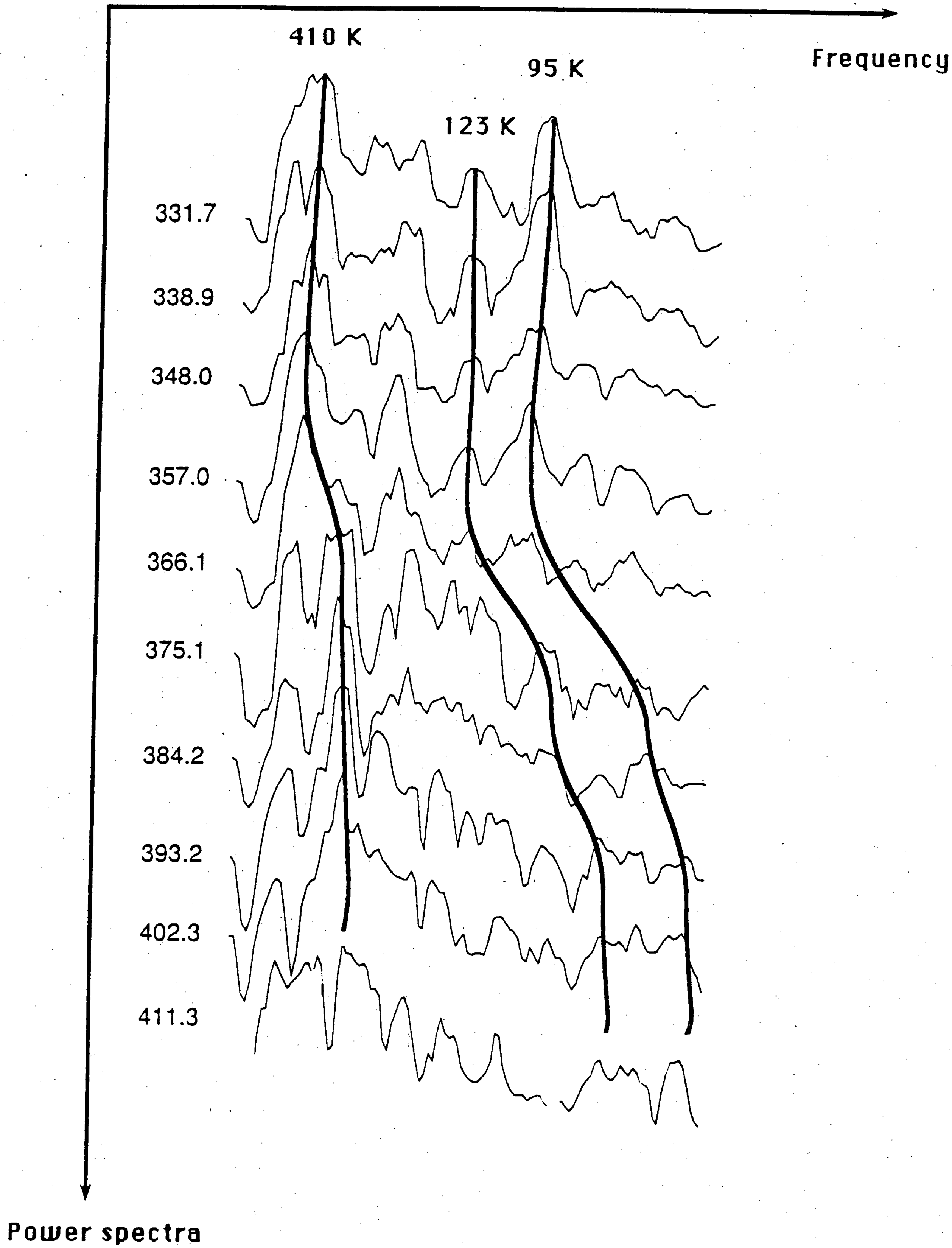


Figure 3-7. Selected spectra as a function of depth (in meters below seafloor) for Upper Jurassic-Lower Cretaceous radiolarian mudstones of the Equatorial Pacific (ODP Site 801B). Trends and rapid changes or discontinuities in sedimentation rates are indicated by shifts in the wavelengths of eccentricity cycles.

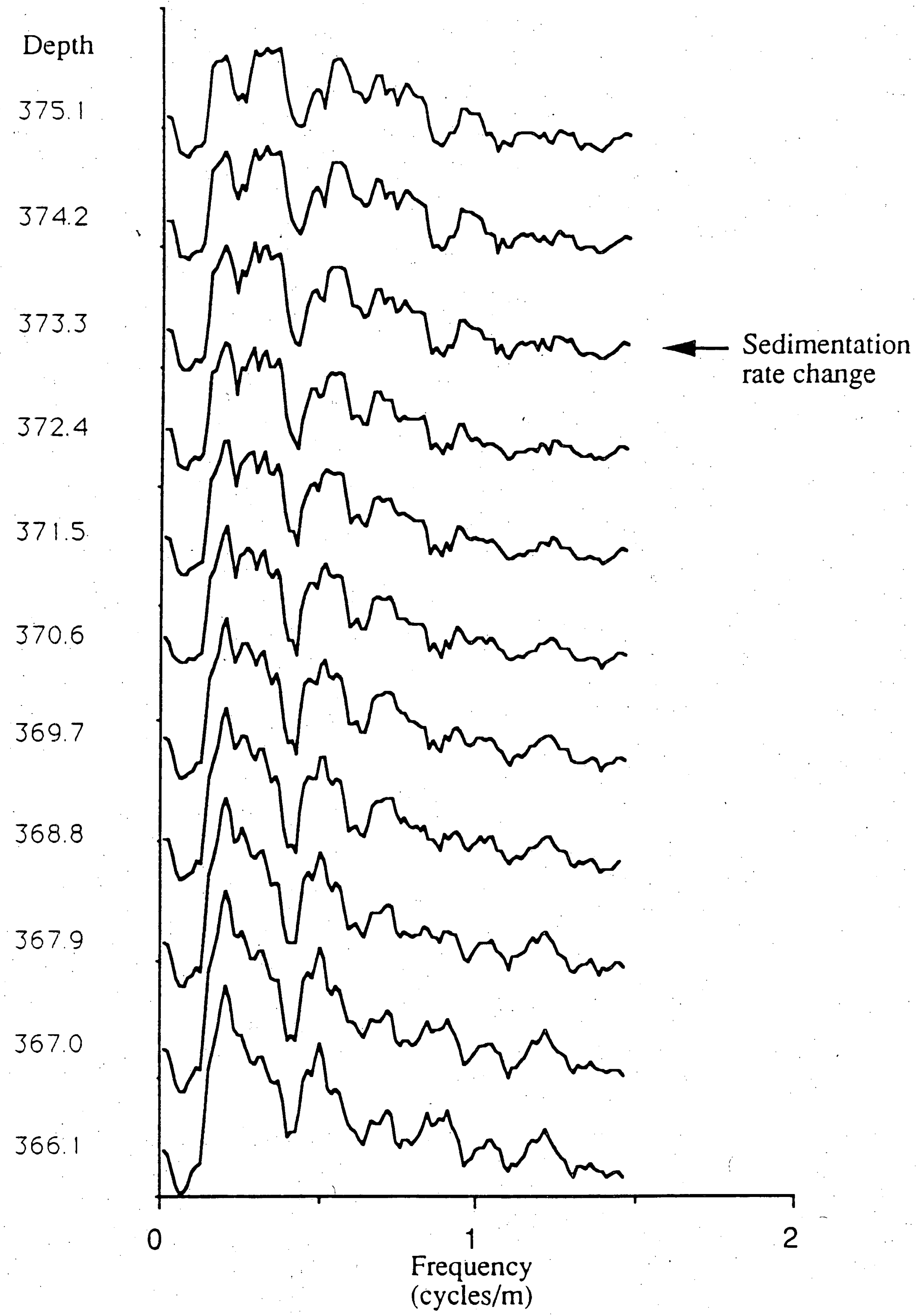


Figure 3-8. Much finer step-interval of 1.1 m used to calculate spectra of gamma ray log across the postulated unconformity. The peak-splitting of the spectra indicates equal energy of old and new peaks at 373.3 m, thus determining the precise depth of the unconformity.

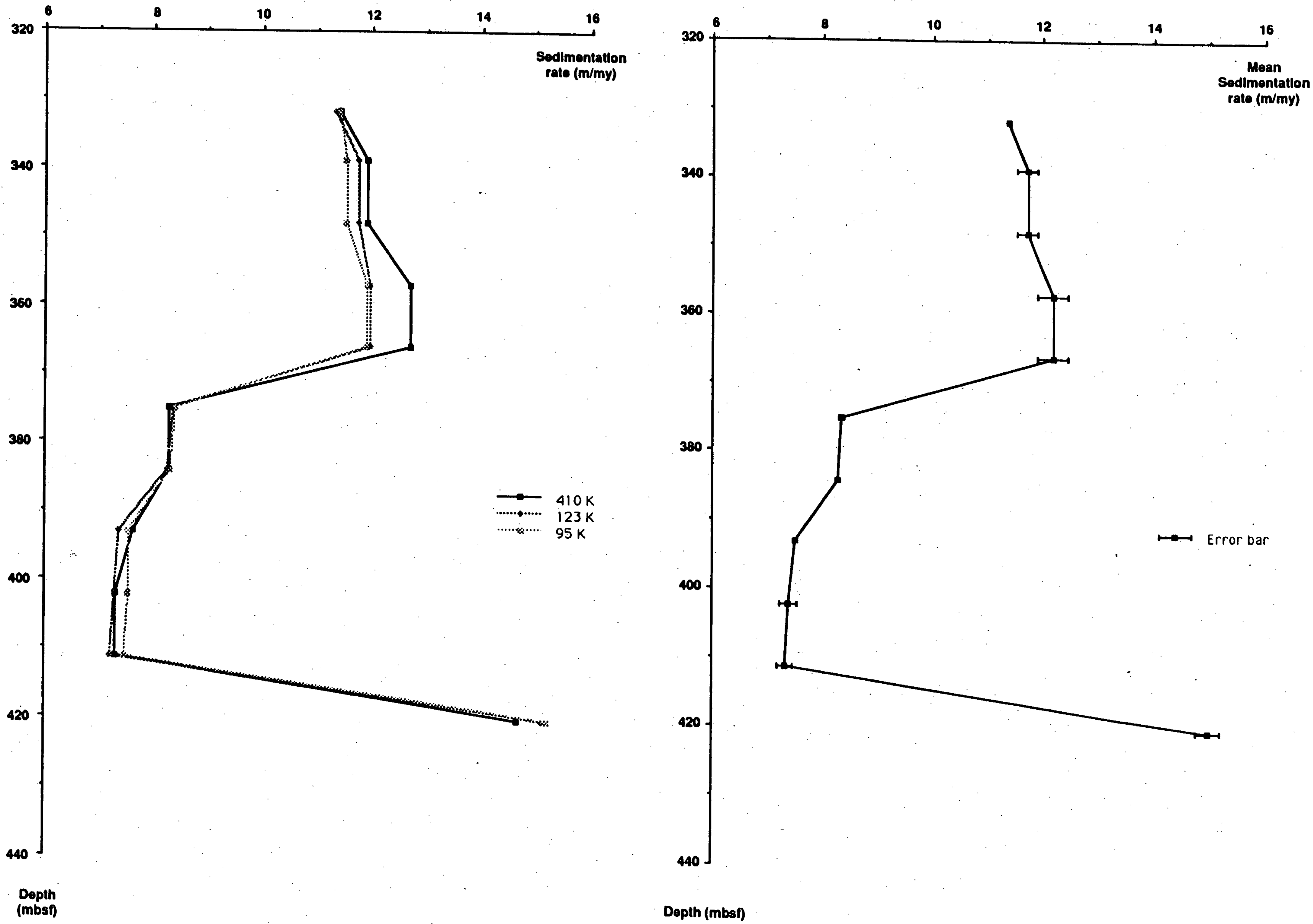


Figure 3-9. Computed sedimentation rates over the Lithologic Unit IV interval of Hole 801B and relative errors between the 413-123-95 k.y. cycle sets.

Chapter 4

Geochemical Well Logging in Basalts: the Palisades Sill and the Oceanic Crust of Hole 504B

Roger N. Anderson [1], Jeffrey C. Alt, [2] John Malpas [3], Michael A. Lovell [4], Peter K. Harvey [4], and E. Lewis-Pratson [1]

[1] Borehole Research Group of Columbia University, Palisades
[2] Dept. of Geological Sciences, University of Michigan, Ann Arbor
[3] Earth Sciences Dept., Memorial University, St. John's, Newfoundland, Canada
[4] Dept. of Geology, University of Leicester, Leicester, United Kingdom

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 95, NO. B6, PAGES 9265–9292, JUNE 10, 1990

Geochemical Well Logging in Basalts: The Palisades Sill and the Oceanic Crust of Hole 504B

ROGER N. ANDERSON,[1] JEFFREY C. ALT,[2] JOHN MALPAS,[3] MICHEAL A. LOVELL,[4] PETER K. HARVEY,[4] AND E. LEWIS PRATSON[1]

Geochemical well logging provides a continuous record of the variations in elemental abundances of the major rock-forming oxides of Si, Al, Ca, Fe, Ti, and K, as well as S, Gd, U, Th, and the H and Cl in the formation and pore fluid. Through the additional measurement of the photoelectric capture cross section of the rock, the sum of Mg + Na can also be estimated. Though not as accurate as laboratory analyses of recovered core samples, the log-derived abundances are precise enough to define the degree and extent of alteration, to identify igneous lithostratigraphy, and to calculate integrated chemical exchange between the oceanic crust and seawater. In this paper, the elemental yields from geochemical logging in basalts are calibrated against extensive XRF analyses of cutting samples from the Lamont 2 test well into the diabases of the Palisades Sill, New York. Accuracy and precision of the log-derived analyses are determined in the lower part of the well, and calibration equations are derived, which are then tested against core-derived "standards" from the upper part of the well. The calibrated, log-derived, elemental analyses are within one standard deviation of the core-derived results (except for the Mg + Na curve, which is somewhat noisier). These calibrations are then applied to geochemical logs from the oceanic crustal basalts of Ocean Drilling Program hole 504B, where core recovery was less than 20% of the section. The accuracy and precision of the calibrated, log-derived elemental abundances are tested against core-derived standards from seven dike and sill intervals. Then the corrected elemental analyses are used to derive a mineralogy model for hole 504B that shows the oceanic crust to contain secondary mineralization in the form of celadonites and smectites in the pillow basalts and chlorites in the dikes that are largely confined to fracture and breccia zones. Cyclicity in the Al and other elemental logs was found to vary with the abundances of these alteration products and with eruption and intrusion event boundaries. The geochemical logging data are then used to estimate the integrated chemical exchange resulting from hydrothermal alteration of the oceanic crust that has occurred over the last 5.9 m.y. in hole 504B. The primary change is from Ca loss and Mg gain caused by the reaction of basalt with seawater. A large Si increase found in the transition zone between the pillows and dikes is attributed to precipitation of quartz during mixing of hot, upwelling hydrothermal fluids and cold, downwelling seawater at what was once a major permeability discontinuity. The present low-to-high permeability transition in hole 504B is found 500 m shallower. The K budget requires significant addition to the uppermost pillow basalts both from high-temperature depletion in the lower pillows and dikes and from low-temperature exchange with seawater. The geochemical logs further document that the total chemical exchange between the oceanic crust and seawater is as important to the long-term composition of the oceans as is the chemical input carried by rivers. Integrated "water/rock ratios" are then derived for the mass of seawater required to add enriched elements and the mass of hydrothermal fluid required to remove depleted elements in the oceanic crust of hole 504B. Whereas Ca, Mg, and K require relatively low water/rock ratios, high values for Si, Al, and Fe suggest that off-axis, ridge-flank exchange is as important to the total cation exchange budget as are ridge-axis processes.

INTRODUCTION

The exploration of the Earth's crust has increasingly involved the direct testing of geophysical and geochemical models of structure, stratigraphy, and tectonic evolution by the drilling of wells. Successful scientific drilling requires a more complete description of the well bore rock and pore fluid than is required for economic drilling. These scientific drilling projects often involve coring programs that attempt to recover continuous samples of rock. As the Ocean Drilling Program (ODP) and its predecessor, the Deep Sea Drilling Project (DSDP), have all too well found, continuous coring does not result in continuous core recovery. And even when all the rock section is returned to the surface, it is not possible to analyze even a small percentage of the recovered core, particularly for geochemical variations. Consequently, geophysical well logging, in which a measurement device is placed directly into the well to make continuous in situ measurements of the electrical, nuclear, and acoustic properties of the rock, occupies an even more important role in scientific drilling than in industrial drilling.

A major addition to the in situ investigation of sedimentary basin well bores has recently been made with the invention of geochemical well logging, in which the elemental abundances of major and certain trace elements are determined continuously in a well in real time through the use of gamma ray spectroscopy. This promising new geochemical logging technology must be calibrated and tested carefully in environments other than the sedimentary basins for which it was designed before it can be fully utilized in scientific drill holes. In this paper, we first develop and test calibration equations for geochemical logging in basalts through comparisons with extensive laboratory analyses of cutting samples from a test

[1]Borehole Research Group, Lamont-Doherty Geological Observatory, Columbia University, Palisades, New York.
[2]Department of Geological Sciences, University of Michigan, Ann Arbor.
[3]Earth Sciences Department, Memorial University, St. John's, Newfoundland, Canada.
[4]Department of Geology, University of Leicester, Leicester, England.

Paper number 90JB00563.
0148-0227/90/90JB-00563$05.00

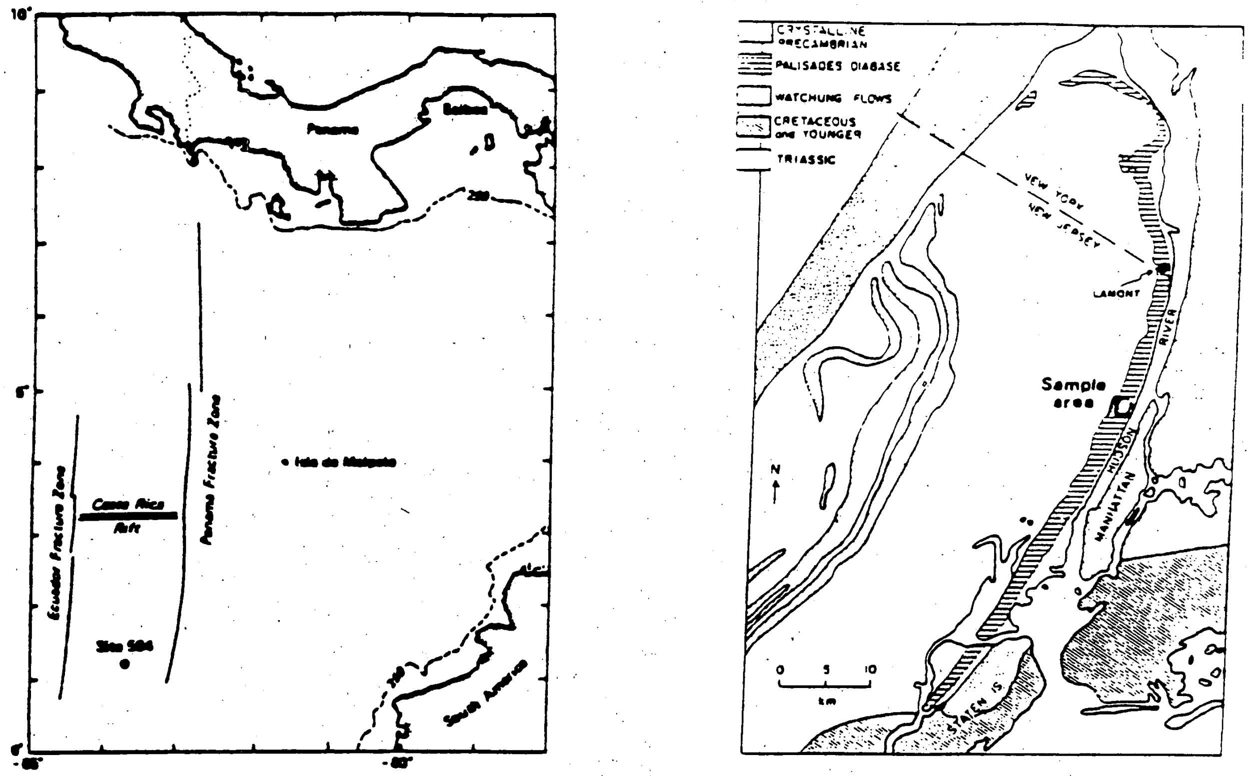


Fig. 1. Location maps for Hole 504B on the southern flank of the Costa Rica Rift (left) and the Lamont 2 well into the Palisades Sill in southeastern New York (right). The location of outcrop samples from near the George Washington Bridge in New Jersey also indicated [*Shirley*, 1987].

well into the diabases of the Palisades Sill, New York. Then we establish standards to correct log-derived elemental abundances from ODP hole 504B in the eastern equatorial Pacific. Once we have determined the accuracy and precision of the new geochemical logging technology in each well, we interpret variations in log-derived elemental abundances in terms of the lithostratigraphy and alteration state of the crust at each site.

The Palisades Sill Well and ODP Hole 504B

In order to evaluate the accuracy and precision of geochemical log-derived elemental analyses in basalts, it is necessary to first calibrate the logging method in relatively fresh basalts of uniform composition and in a well for which extensive, precisely located samples exist for laboratory analyses and intercomparison. We use the intensely sampled lower portion of the Lamont 2 test well into the Palisades Sill to derive general calibration equations for geochemical logging in basalts. We then test these calibrations against "standards" from the upper portion of the well.

In the course of the log calibration experiment, useful geochemical information is derived for the lithostratigraphy of the Palisades Sill itself. The Palisades Sill, which outcrops along the western cliffs of the Hudson River along the northern New Jersey and southern New York borders (Figure 1), consists of more than 350 m of diabase (medium- to coarse-grained, basaltic igneous rock) that was intruded into the Triassic sandstones and shales of the Newark Basin Group approximately 200 Ma, during the rifting of North America away from Africa. The Palisades Sill is a classic example of closed-system, basaltic magma differentiation [*Bowen*, 1928], and as such, the chemical variation of the sill has been extensively studied [e.g., *Walker*, 1940; *Walker*, 1969; *Shirley*, 1987].

The geochemical logging technique is then extended to the poorly sampled oceanic crust, where the continuous nature of these observations can add significant new information to interpretations of the geology of the upper lithosphere. ODP hole 504B, which was drilled into the Nasca plate on the southern flank of the Costa Rica Rift (Figure 1), is the deepest penetration into the oceanic crust to date. As such, its structure, stratigraphy, alteration state, and composition form the standards for comparison to geophysical and geochemical models of the oceanic crust. Also, the core recovery in hole 504B has been less than 20% of the drilled section, with less than 12% of the deepest dikes recovered. Consequently, geochemical logging in this hole promises to yield much needed additional information.

Great emphasis has already been placed during DSDP legs 69, 70, 83, and 92 and ODP leg 111, upon geophysical logging to identify structure and stratigraphy and to locate the recovered rocks within their proper geological framework. The log-derived, physical properties of this young oceanic crust (5.9 Ma) which was generated at moderate spreading rates (3.3 cm/yr), have already yielded fundamental information about the formative mechanisms of mid-ocean ridges [e.g., *Cann et al.*, 1983; *Anderson et al.*, 1985; *Becker et al.*, 1988].

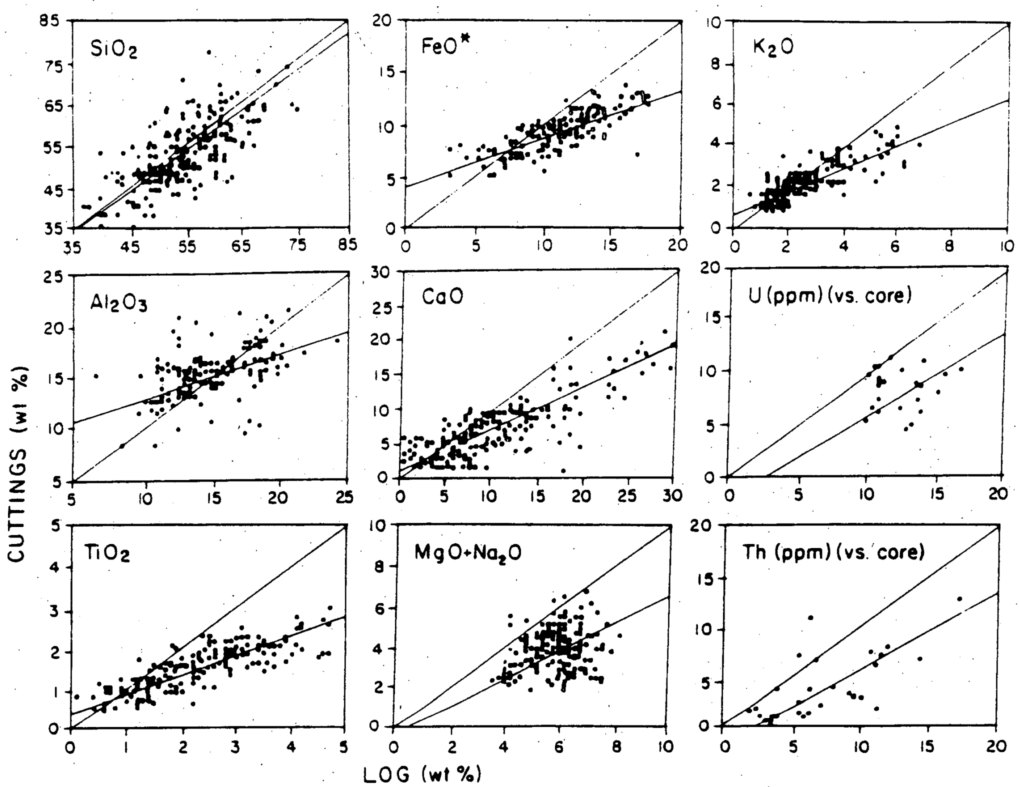


Fig. 6. Geochemical log-derived elemental abundances and XRF analyses of cuttings from the upper 500 m of the KTB pilot hole in the Oberpfalz metamorphic rocks of the Federal Republic of Germany [*Draxler and Hanel*, 1989]. Open circles are selected core plug analyses. Best fit linear regressions have slopes less than 1 : 1 because seven elements are forced to sum to 100% at each depth. (Figure courtesy of H. Draxler, R. Hanel. S. Havercamp, and R. Emmermann. Core data analyses from A. Stroh and M. Tapfer, KTB field laboratory.)

derived results are reasonably accurate and precise, as claimed by Schlumberger. That is, all elemental abundances derived from the geochemical logs appear to be normally distributed about the means from the core analyses (accuracy), and the standard deviations are within the ranges quoted above (precision). In fact, Fe, Al, and K are somewhat more and Ca and Si are somewhat less noisy than the averages from all the field tests in sediments.

The Continental Deep Drilling Program of the Federal Republic of Germany (Kontinentale TiefBohrprogramm der Bundesrepublik Deutschland (KTB)) has completed the pilot hole for their ultradeep penetration of the European continental crust. A significant part of the experiments carried out in the pilot hole was the calibration of the geochemical logs in the metamorphic rocks of the Oberpfalz thrust belt of northwestern Bavaria [*Draxler and Hanel*, 1989]. The large variations of major elemental compositions between the highly foliated gneisses, amphibolites, and metabasites encountered in just the upper 500 m of the pilot hole provide an excellent environment within which to calibrate the geochemical log-derived results (Figure 6). Cuttings were retrieved from the KTB well in an unusually effective manner because of the rapid circulation system, small borehole annulus, and thick isotropic drilling mud employed in this technically advanced drilling project. Cutting samples were collected over 1-m intervals and measured by XRF in the field laboratory adjacent to the well.

The calibration experiment in the KTB well shows that the correlation between log- and core-derived elemental abundances is linear for all the elements analyzed (Figure 6). Since the oxide abundances calculated from the geochemical logging measurements are forced to total 100% at each depth, slopes of core versus log-derived cross-plots are almost always less than 1 : 1. Thus it is necessary to calibrate geochemical log-derived measurements to "standards" derived from laboratory analyses of samples from each well in order to produce quantitatively accurate major elemental analyses. However, relative changes between elements (ratios) are reasonably accurate even in wells without such calibration information.

CALIBRATION IN BASALTS OF THE PALISADES SILL

The direct application of geochemical well logging to igneous rocks is not straightforward, however. The distributions of oxygens are different in igneous rocks versus those in sediments, particularly in carbonate versus silicate lithologies. Consequently, we have modified the oxygen distribution coefficients of *Hertzog et al.* [1987] from their CO_3-based, sedimentary system to a silicate-based, igneous system, in order to produce accurate oxide determinations from geochemical logging in basalts.

Theoretically, elemental abundance calculations consistent with an igneous oxide model should produce measurements from the geochemical logging tool that standup well in comparison to chemical analyses of samples of basalts. The

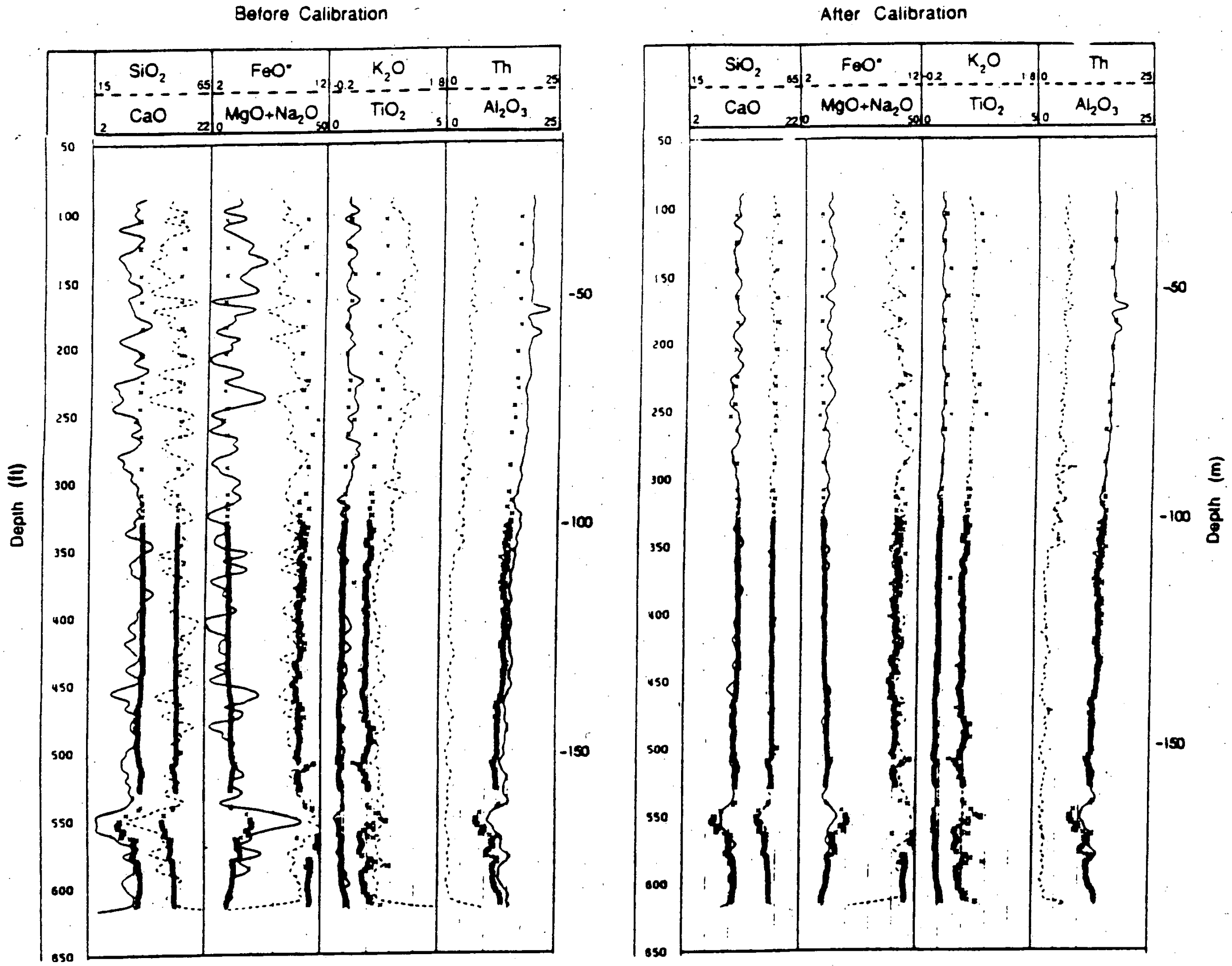


Fig. 7. Elemental analyses (in dry weight percent oxides, except where indicated) from geochemical logs in the Lamont 2 test well into the basal diabases of the Palisades Sill before (left) and after (right) calibration (see text), are plotted with XRF analyses (crosses) from cutting samples taken every foot over the lower 90–200 m interval and more sparsely from 30 to 90 m. Note the boundary between intrusion events marked by the increase in potassium, aluminum and thorium, at approximately 100 m depth, and the famous olivine-rich layer at 175–180 m.

comparisons below must assume that there are no errors in the depths assigned to either the core or log sample locations and that heterogeneities in rock composition do not make core measurements unrepresentative of the larger volume of the logging measurement [*Grau et al.*, 1990]. We will also ignore measurement uncertainties of the core analyses done in the laboratory.

Geochemical logs were recorded in the Lamont 2 test well, which penetrates more than 200 m of the basal portion of the diabases of the Palisades Sill, so that the log-derived elemental abundances could be compared to XRF analyses of cuttings collected from the same well (this study) and from samples taken from outcrops farther south along the cliff face [*Shirley*, 1987] (Figure 1). The Lamont 2 well offers the almost perfect logging conditions of a shallow, cylindrical well bore of a 6-inch diameter throughout, with fresh water used as the drilling fluid and rapid sample collection from high-velocity circulation using an air hammer drilling technique.

The geochemical logging tool induces the emission of gamma rays from the formation that come from a considerably larger volume of rock than that represented by individual rock cuttings. Consequently, we have collected virtually continuous cutting samples over the lower half of the Lamont 2 test well. These were then mixed into 1-foot (0.3 m) samples for shipment to the University of Nottingham, where XRF analyses were performed.

Elemental analyses from the geochemical logging tool were calculated both with and without the Mg + Na curve from the PEF measurement. In the latter case, the cutting-derived analyses of Mg + Na were input into the otherwise wholly log-derived oxide calculations, in order to produce a "lowest-noise-level-possible" data set (Figure 7). The degree of additional noise introduced throughout the major elemental suite by the PEF-differencing scheme is shown in histograms of the elemental oxides derived with, versus without, the PEF-produced Mg + Na curve (Figure 8). The means and normal distributions of the oxide abundances are not disturbed, but the standard deviations are increased. Elemental weight percentages of Al and K are measured

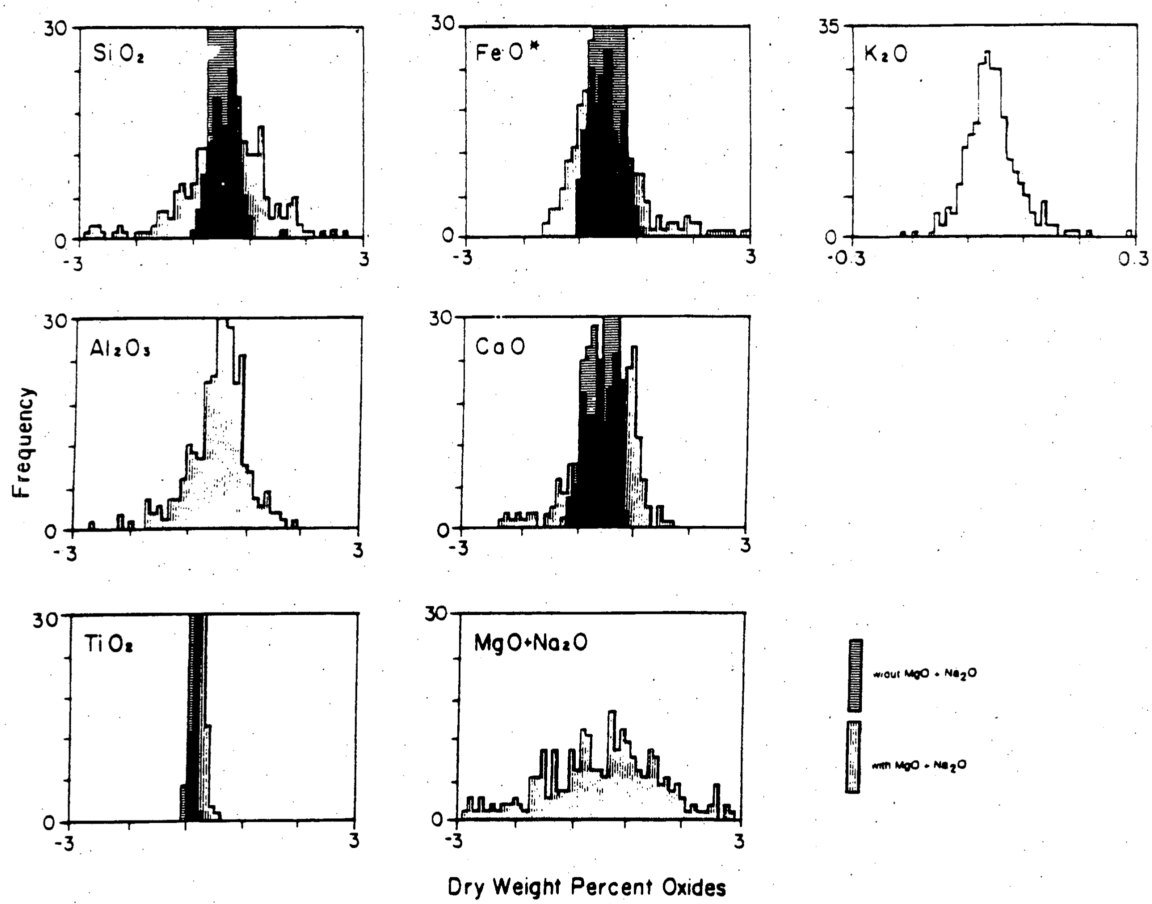


Fig. 8. Histograms of the elemental abundances from XRF analyses from cuttings minus that from geochemical logs from 300 to 500 feet (90 to 160 m) in the Lamont 2 well in the Palisades Sill (Figures 1 and 7). Note the increase in the scatter when Mg + Na are added to the calculation from the PEF curve (vertical versus horizontal hatching), yet the means are not significantly changed and the data remain normally distributed. Abundances of Al and K are measured directly, so the calculations with versus without Mg + Na do not affect these analyses.

directly by the logging tool, so their abundances are not affected by the inclusion of the Mg + Na curve. Though more noisy, the elemental abundances that are derived with the Mg + Na curve are of greater value to rock characterization studies because they present almost a complete major elemental oxide analysis at every 0.15 m throughout the well.

The calibration strategy which we will follow is analogous to XRF standardization procedures performed in the laboratory. We will first calibrate the instrument (the logging tool) by analyzing standards (the 90–200 m interval that was most intensely sampled). We will then apply corrections to the log analyses from throughout the well and test the calibrated abundances against samples of known composition from elsewhere in the well (the 30–90 m interval).

The comparison of the raw analyses from the geochemical log versus core-derived measurements within the 90–200 m interval show that though there are significant differences between laboratory and log-derived results, the correlations appear to be linear (Figure 9). Linear calibration equations to correct each element to values consistent with the core-derived results are easily calculated (Figure 9). The applications of these calibration corrections produce log-derived data that, though of considerably larger scatter than the laboratory analyses (less precise), are of sufficient accuracy to be of clear worth in determining the variations in chemical properties of the basalts of the Palisades Sill, as can be seen from the improvement in the fit of core- to log-derived abundances in the 30–90 m interval (Table 2 and Figures 7 and 10). The corrected, log-derived abundances from the 30–90 m interval are within one standard deviation of the core measurements for all elements except Mg + Na (Figure 10). The fact that this curve is reading so much higher than the lab analyses in this interval (11 versus 8% in Figure 7) suggests that large capture cross section, minor or trace elements that interfere with the PEF residual calculations may be more abundant in this portion of the well.

The calibration equations derived from the log-versus-laboratory intercomparison in the Palisades Sill well are proposed to be generally applicable to geochemical logs in basalts from scientific wells drilled under less favorable conditions. Of course, calibration tests with core "standards" from each well are required, but such are not always easy to locate to true depth in poor core recovery wells (as with most ODP wells). If such calibrations prove successful, geochemical well logging will add greatly to the chemical reconnaissance capabilities within basaltic drill holes, be-

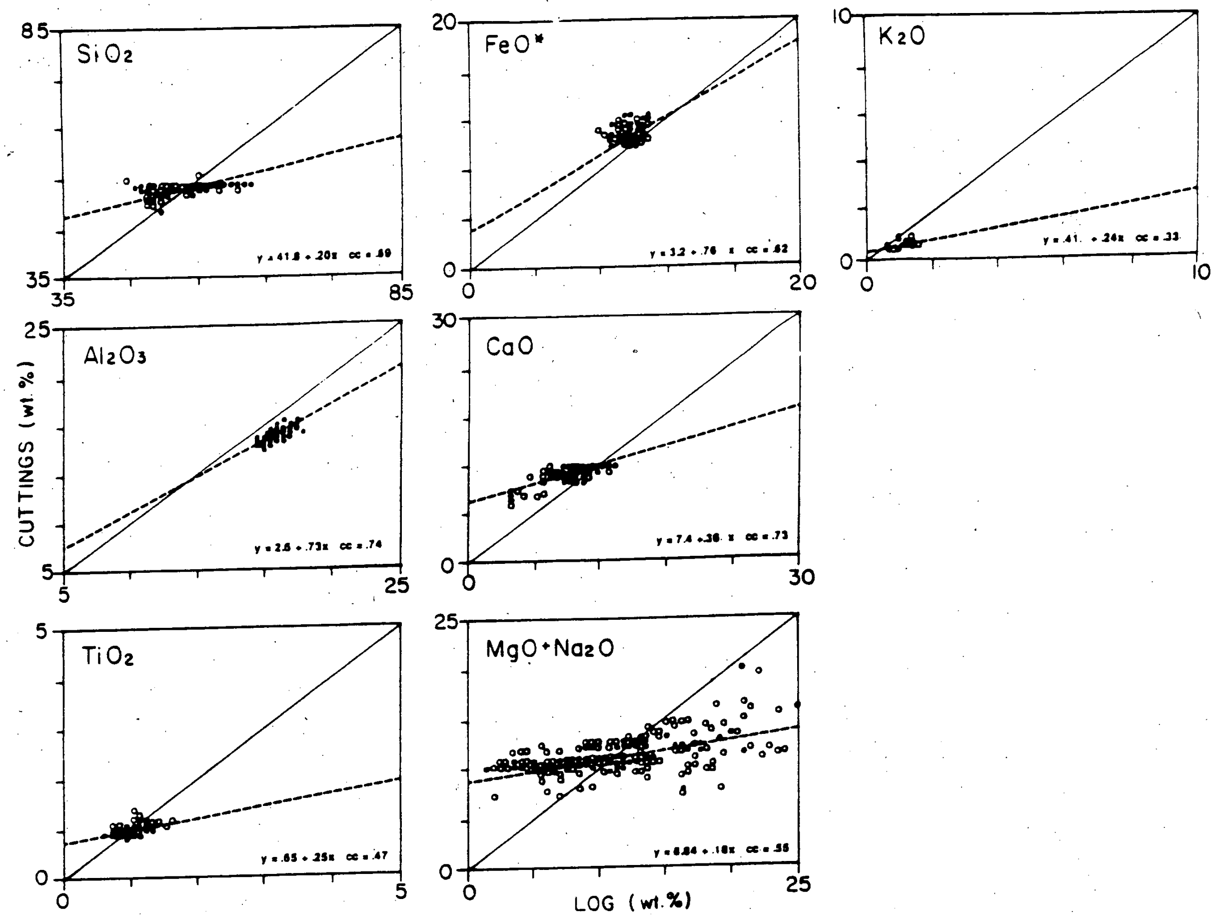


Fig. 9. Cross plots of XRF-derived versus geochemical log-derived elemental abundances in the 90–200 m calibration-interval of the Lamont 2 well into the diabases of the Palisades Sill (Figures 1, 7, and 8). The best fit linear regressions for each element are proposed as standards for calibrating geochemical well logs in basaltic composition drillholes because the geochemical logs were obtained under optimal experimental conditions at the Lamont 2 well. Solid dots are locations of more than one data point. CC is correlation coefficient.

cause the logs provide analyses that are fast and continuous with depth.

Geochemistry of the Diabases of the Palisades Sill

The Palisades Sill is most famous for the existence of a sharply defined, olivine-rich layer located just above the lower contact of the sill and for a steady increase in Al content upward from this basal layer, both of which were caused by differentiation within the magma of the newly forming sill [*Walker*, 1940, 1969]. The heavy olivine crystals sank to the bottom of the Sill as lighter plagioclase crystals floated toward the top. Abrupt increases in thorium content upward within the sill were used by *Shirley* [1987] to establish the existence of at least three distinct magmatic intrusion events that formed the sill. The Lamont 2 well is within the lowermost two of these intrusions.

The geochemical log-derived elemental abundances clearly locate both the olivine-rich layer at 550 feet (175–180 m) and the increase in Al content upward in the well (Figure 7). The olivine-rich layer is observed on all major elemental logging curves, with Fe and Mg increasing and Si, Ca, and Al decreasing. The increase in Al content upward in the hole was also recorded (Figure 7). The Al and thorium logs both display an abrupt increase at the appropriate stratigraphic height for the second intrusion. These changes, coupled with increases in log-derived gadolinium and potassium abundances and a decrease in uranium content, suggest a contact between intrusive events at approximately 100 m above the base of the sill.

The calibrated log analyses demonstrate that these differences are real and resolvable within the accuracy of the logging tool measurements (Figure 10). The average compositions of Al, Ti, and K are more than 1 standard deviation higher, and the Ca and Mg + Na are lower above versus below this contact (Table 2). The analyses from outcrop samples from 12 miles (19 km) to the south [*Shirley*, 1987] corroborate the existence of this boundary and place this intrusive contact at 90 m above the base of the sill. This small difference in depth can be accounted for by the increased stratigraphic dip of the sill at Lamont versus to the south.

The continuous nature of the geochemical log-derived analyses provides useful additional stratigraphic information, even when abundant samples can be taken from cut-

In addition, the location of hole 504B near the equator has resulted in the early deposition of a thick, relatively impermeable sedimentary blanket that has mostly sealed the crust to hydrothermal interchange with the ocean at an unusually early age [*Anderson and Hobart*, 1976; *Hobart et al.*, 1985; *Langseth et al.*, 1988]. The alteration recorded within the hole is from chemical reactions within a convective system which is in the process of sealing itself through deposition and precipitation of various zeolite, greenstone, and greenschist products [*Alt et al.*, 1986*a*]. Only the uppermost pillow units remain highly permeable to hydrothermal circulation at this time [*Anderson and Zoback*, 1982; *Anderson et al.*, 1985*a*; *Becker et al.*, 1989]. Geochemical logs from hole 504B, when properly calibrated, will provide the first continuous description of the variations in chemical composition versus depth that resulted from the volcanic emplacement and subsequent alteration of this oceanic crust.

THE GEOCHEMICAL WELL LOGGING TECHNIQUE

Geochemical well logging (mark of Schlumberger Well Services) was recently developed for use in sedimentary basins by the oil industry and is only just beginning to be used for scientific investigations in drill holes through igneous and metamorphic rocks [*Anderson et al.*, 1988*a*, *b*, 1990; *Draxler and Hanel*, 1989]. The geochemical logging tool string (Figure 2) is lowered into a well to make in situ, gamma ray spectroscopy measurements of the relative concentrations of 11 major and minor elements. In turn, continuous elemental and dry weight percent oxide abundances are derived at 0.15-m intervals throughout the well. As shown below and by *Anderson et al.* [1988*a*, *b*, 1989], the precision of geochemical log-derived measurements within a basaltic well is as good as that in sediments, although the accuracy is somewhat less than X ray fluorescence (XRF) analyses made on core or cutting samples in the laboratory, as expected.

The geochemical logging tool is, in fact, four different nuclear logs combined into one tool string for lowering into the well bore. First, a natural gamma spectroscopy (NGT) tool measures the abundances of the naturally occurring radionucleiides potassium (K, in weight percent), uranium, and thorium (U and Th, in parts per million) by detecting naturally decaying gamma ray particle energy in the 180 keV

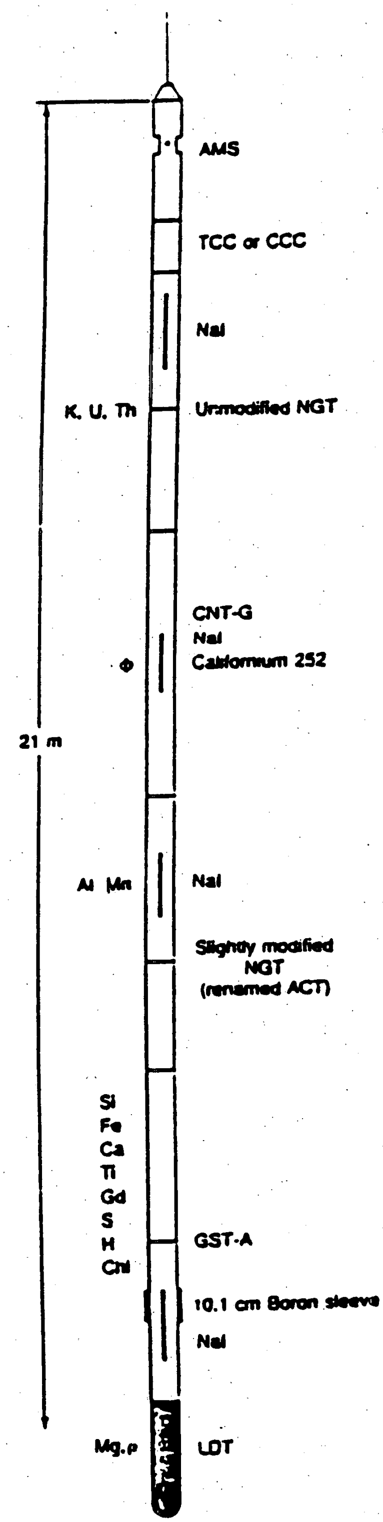


Fig. 2. (opposite) Configuration of the geochemical logging tool (mark of Schlumberger) used in this study. At the top are the auxiliary measurement sonde (AMS), which determines temperature and cable tension), and the TCC or CCC (both of which telemeter digital information to the surface much as a complex telephone modum works). Potassium, uranium, and thorium are measured by the natural gamma ray spectrometer (NGT). The compensated neutron tool (CNT-G) measures porosity and activates aluminum with a californium 252 source. The aluminum clay tool (ACT) follows to measure Al concentration. The induced gamma ray spectrometer tool (GST) uses a nuclear accelerator as a source for controlled "bursts" of neutrons, then collects emitted gamma rays with a NaI crystal, scintillation detector for the determination of the concentrations of silicon, iron, calcium, titanium, gadolinium, sulfur, hydrogen, and chlorine. A lithodensity tool (LDT) then either follows, as in the Ocean Drilling Program, or is lowered separately, as on land, to measure density and photoelectric capture cross section (PEF) using a cesium source. Magnesium plus sodium is calculated as a residual abundance from the difference between the measured PEF and that calculated from the abundances of all the other elements measured above.

to 3 MeV range, using a six-channel, NaI scintillation counter. Below this tool, a californium chemical source is carried within a compensated neutron tool (replacing the traditional americium beryllium source). This high-neutron-flux source of relatively low-energy neutrons (2.35 MeV) is used to activate aluminum in the formation (Al clay tool, ACT). Another natural gamma spectroscopy tool is then passed across the borehole wall to capture gamma rays emitted by Al activation with particle energies from 180 keV to 2 MeV. Then, an induced gamma spectroscopy tool (GST) carries a "minitron" neutron accelerator that emits gain-controlled bursts every 100 μs that total 10^{7-9} neutrons/s at energies higher than the Cf source (14 MeV) in order to activate iron, calcium, silicon, titanium, the rare earth element gadolinium, and sulfur in the rock, and the hydrogen and chlorine in the borehole and pore fluid (Fe, Ca, Si, Ti, Gd, S, H, and Cl). A 256-channel spectral analyzer then records the energy levels from emitted gamma rays with particle energies ranging from 1.5 to 7.5 MeV which impact a large NaI crystal within the tool. The gamma ray spectrum is summed over repeated burst intervals, and digitally transmitted to the surface at 0.15-m intervals.

In order to add an estimate of the amounts of magnesium and sodium (Mg + Na) present in the rock (the only major elements not measured by the geochemical logging tool), a new interpretation technique is then applied to the density tool, which bombards the formation with gamma rays from a cesium source. Not only is bulk density recorded, but a photoelectric absorption factor (PEF) is also measured which can be indirectly related to the weight percentage of Mg plus Na in the rock. The PEF of each major element has been measured in the laboratory, and therefore the theoretical PEF of a formation can be calculated as the sum of the elemental components measured by the geochemical logging tool. The difference between the logged PEF curve and that calculated based upon the abundance of elements recorded by the geochemical logging tool can then be used to estimate the abundance of the sum of these two missing elements (Mg + Na). This calculation is only as accurate as the PEF measurement itself in the well bore, and since often the tool cannot be padded solidly against rugose boreholes common in basaltic drilling, the Ma + Na derivation becomes the most "noisy" component of the elemental abundance computation.

ERRORS IN THE GEOCHEMICAL LOGGING TECHNIQUE

The gamma ray spectroscopy measurements made in the well detect a fraction of the total spectrum for each activated element which is linearly proportional to the concentration of that element within the volume of the measurement. The geochemical logging tool produces neutrons that penetrate rock up to 1 m^3 away from the sources, but the tool's scintillation counters are detecting emitted gamma rays in that rock a few seconds after the source passes the locale of each burst (since the crystals are below each source and logging is done upward in the hole at rates of approximately 100 m/h. Consequently, rock near the borehole wall provides more detected gamma rays than rock far from the well bore. The relative yields from each depth are used to calculate elemental abundances which are, in turn, forced to sum to 100% at each sampling point. The variations in dry weight percent of the major elemental oxides are estimated by assuming that approximately 50% of all rock is oxygen by weight [*Herron*, 1986; *Hertzog et al.*, 1987].

TABLE 1. Comparison Between Calculated Uncertainties and Measured Standard Deviations for 7.5-s Accumulation Times

Element	$F\Delta Y/S$*	ΔW_c†	ΔW_m‡
Si	3.67	2.75	2.76
Ca	2.52	2.37	2.29
Fe	0.46	2.37	2.29
Ti	0.19	0.19	0.19

Values are in absolute weight percent. From *Grau et al.* [1990].
*Uncertainties from induced gamma ray only (no Al, no K)
†Calculated uncertainties.
‡Measured standard deviations.

A significant contributor to the noise of induced gamma ray spectroscopy logging comes from the statistical variation in gamma ray counts returning to the crystals after each burst of neutrons. This statistical uncertainty caused by the logging measurements themselves can be calculated by beginning with W_i, which is the weight fraction of an element i measured through thermal neutron capture [*Grau et al.*, 1990]. W_i is related to the total spectrum Y_i by a sensitivity coefficient S_i and a depth-varying normalization parameter F_i that is applied to all the elements (i.e., $W_i = FY_iS_i$). Aluminum and potassium weight fractions are calibrated directly from their measurement peak heights and so are not subject to the same uncertainties. *Grau et al.* [1990] showed that individual elemental uncertainties are essentially independent of the values of Y_i by simulating 2000 spectra, each repeatedly perturbed by the application of statistical noise. Each was then analyzed as if it were an independent measurement. The standard deviations of the "measured" elemental concentrations were then used to estimate the statistical error for each measurement (ΔW_m). The calculated elemental uncertainties (ΔW_c) were then compared to these measured standard deviations. The estimated relative errors of both the standard deviations and the elemental uncertainties were found to be less than 2%. These results, in absolute weight percentages, are shown in Table 1, together with an estimate of the uncertainty from just the induced gamma ray spectroscopy elements, shown as $F\Delta Y/S$. The latter calculation ignores the effects of the forced closure relationship in going from spectral yields to elemental concentrations. The calculated uncertainties are in excellent agreement with the standard deviations from the simulated spectra for each element, though the statistical errors for Si and Ca are considerably larger than those for Fe and Ti. Typical statistical uncertainties under normal logging conditions are between 2 and 3 wt % for Si and Ca and a few tenths of 1 wt % for Fe and Ti.

It is important to consider what happens to the measurement accuracy when borehole conditions deviate from the ideal. Considerable tool standoff from the borehole wall can occur when washouts force the 21-m-long, excentered tool string away from the borehole wall. This standoff increases the number of gamma rays detected from the borehole fluid and decreases the number from elements in the rock (Figure 3). Even for the most extreme case yet analyzed by *Grau et al.* [1990], where the borehole is repeatedly washed out from 8 inches (20 cm) to as much as 18 inches (46 cm), the measured elemental concentrations are all equally affected,

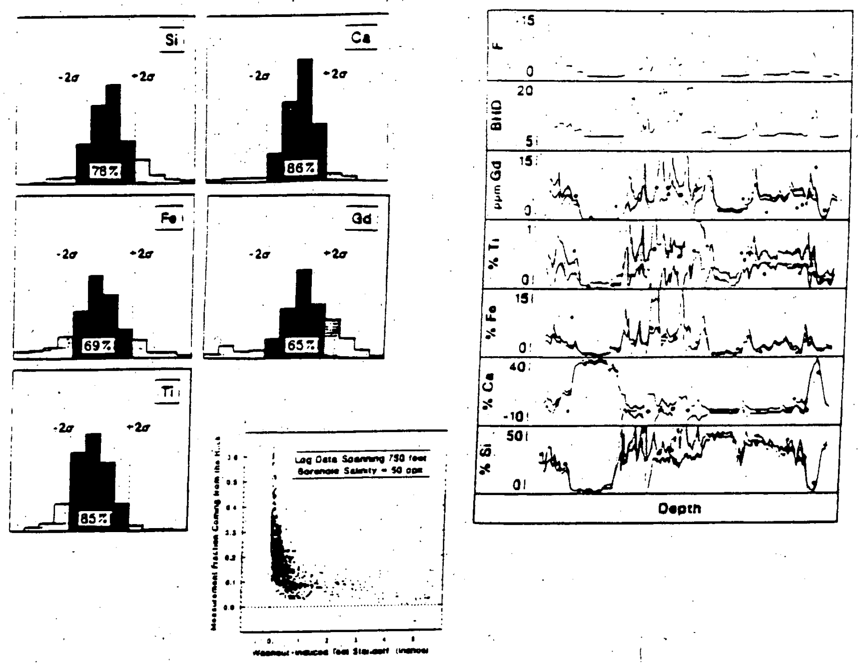


Fig. 3. The effects of bad hole conditions on the induced gamma ray spectroscopy-derived elemental abundances are illustrated by this example from *Grau et al.* [1990]. The geochemical logs from a 100-foot (30 m) depth interval of a sedimentary basin well are shown at the right. Shading is the ±1 standard deviation variation of the elemental abundances. Dots are XRF analyses of side wall cores. *F* is the depth-varying normalization parameter that compensates for bad hole conditions. BHD is borehole diameter in inches. Major elemental concentrations are in dry weight percentages. At left are histograms comparing the log-derived and core-measured elemental concentrations in units of calculated uncertainties. Black represents the percentage of log-derived observations falling within two standard deviations of the core-derived abundances for each element. In the center, the effects of washout-induced tool standoff on the yields of induced gamma rays from the rock are displayed. Counting interval of 7.5 s represents an interval of 0.15 m at standard logging speeds. Borehole salinity slightly greater than seawater (33 ppk). Whereas the increase in borehole standoff drops the overall gamma ray flux (the signal) and increases the noise, gamma rays from all elements are equally affected.

as can be seen from the increases in the standard deviations of each element (Figure 3). Compensation by the normalization parameter *F* still produces good agreement to core-derived analyses. In the example, we can see that the washouts are confined to shale intervals (abundant Fe and Ti) within the more intact sand unit (high Si). The Ca log shows that the best borehole is in the limestones above and below the sand/shale unit (Figure 3).

Calibration in Sedimentary and Metamorphic Rocks

Although the elements measured by gamma ray spectroscopy make up almost all of the significant major oxides comprising most rocks, the technique was developed and calibrated in sediments which have very large differences in major elemental compositions between different lithologies. That is, a carbonate is easily distinguished from a sandstone or a shale based upon major element compositional variations (cf. Figure 3). Metamorphic rocks also have large differences in major elemental compositions among different lithologies because of the chemical variability of the hydroxyl-bearing alteration products they commonly contain. Before we test the applicability of the geochemical logging technique in basalts that have much smaller differences in major elemental compositions, we review the accuracy and precision of the geochemical logging tool in sedimentary and metamorphic rocks.

Several major oil companies have conducted independent field tests which collectively demonstrate that the geochemical logging tool measures elemental yields that can be accurately converted to dry weight percent oxides in sediments from a wide variety of geological and borehole environments [*Hertzog et al.*, 1987; *Grau et al.*, 1989; *Herron and Herron*, 1989]. ARCO [*Pasternack and Herron*, 1989], Chevron [*Everett and Riek*, 1989], Conoco [*Hutchinson and Petersen*, 1989], Exxon [*Wendlandt and Bhuyan*, 1989], and Statoil [*Flolo*, 1989] have each conducted comparisons between measurements made by the geochemical logging tool and laboratory analyses from side wall cores from wells in the Anadarko Basin, Gulf Coast, Basin and Range, and North Slope of the United States, the North Sea, and the Middle East. The standard deviations of measurements from these field tests range from 1.6 to 6.5 wt % for Si (compositional ranges of 0–50%), 1.0 to 5.9 wt % for Al (0–15% range), 0.7 to 3.1 wt % for Ca (0–40% range), 0.2 to 0.6 wt % for Fe (0–10% range), and 0.1 to 0.3 wt % for K (0–5% range).

Consider, for example, the calibration results from the Exxon Production Research Sego Canyon 2 well in Utah [*Wendlandt and Bhuyan*, 1989]. XRF measurements were

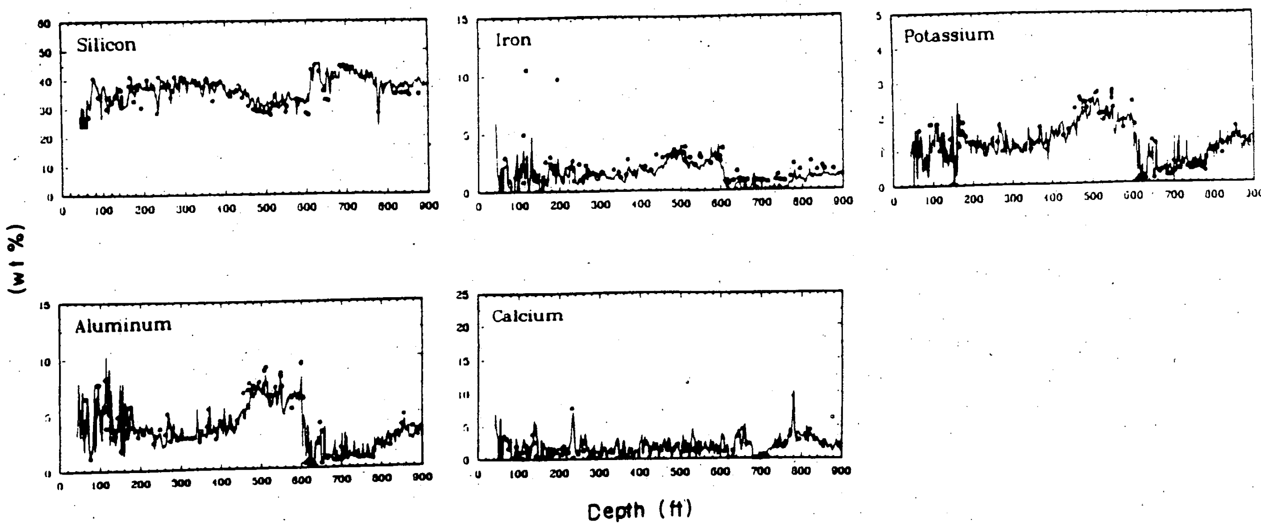


Fig. 4. Major elemental abundances from geochemical well logs in a sand/shale sequence from the United States' Basin and Range province in Utah (the Exxon Production Research Sego Canyon 2 well) are displayed with XRF analyses of side wall cores (dots) taken from the same well [*Wendlandt and Bhuyan*, 1989].

made on side wall cores taken in a sand-shale sequence to test the accuracy and precision of the geochemical logging tool's elemental abundance determinations (Figure 4). The sandstones at 100–400 and 600–800 feet (30–122 and 183–244 m) are distinguished by high Si contents and low Al, Fe, Ca, and K abundances. The shales at 400–600 feet (123–183 m) are high in Al, Fe, and K, and somewhat lower in Si contents. These elemental variations describe the stoichiometry of the clay minerals that make up the shales within this interval of the well. More subtle differences are also apparent in Figure 4. The 100–400 foot (30–122 m) sandstones have significant feldspars present, as can be seen from the higher Al, Fe, and K contents than in the clean sandstones found at 600–800 feet (193–244 m). Thin limestone stringers are found at 140, 220, and 780 feet (43, 67, and 238 m), as can be seen from the spikes of abundant Ca that correlate with the troughs of low Si content.

Histograms of the differences between core analyses and log-derived elemental abundances at each depth (core-minus-log values in Figure 5) demonstrate that the log-

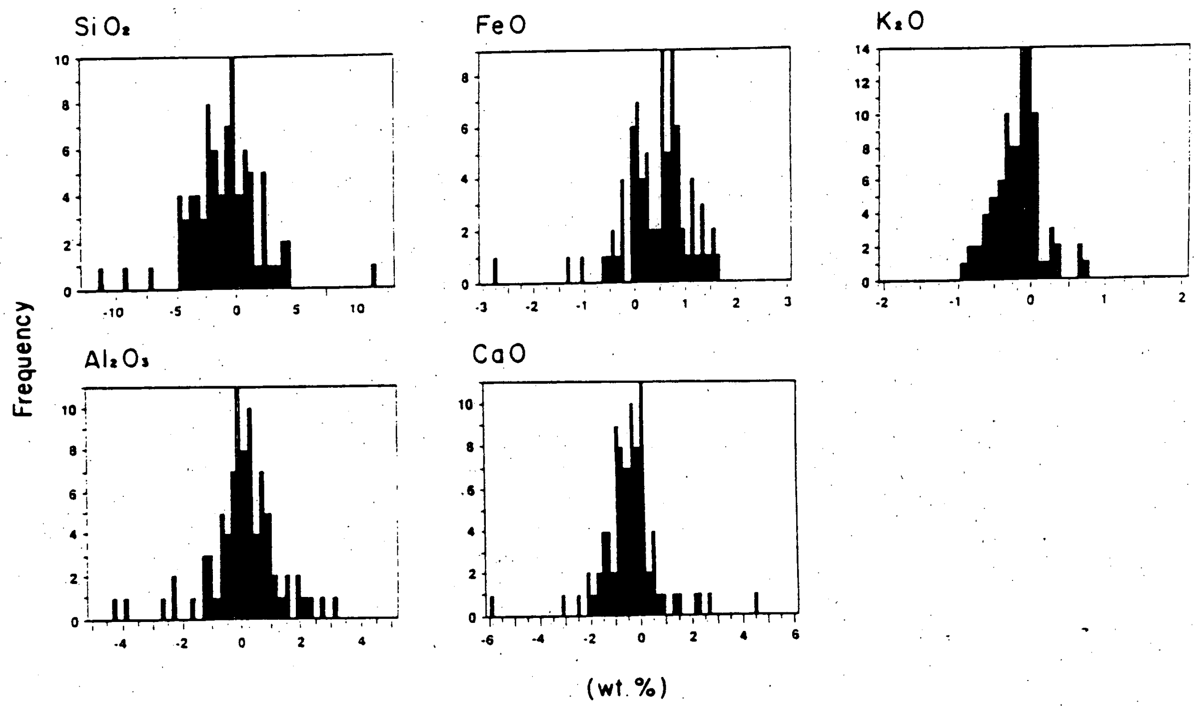


Fig. . Histograms of the differences between core and geochemical log-derived elemental analyses in the Exxon Sego Canyon 2 well, Utah (Figure 4).

TABLE 2. Geochemical Analyses of Palisades Sill Lamont 2 Well

	Outcrop Analyses*		Cuttings		Geochemical Logs			
					Before Calibration		After Calibration	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
			Calibration at 90–160 m					
SiO_2	53.27	1.49	52.85	0.28	54.80	1.33	52.60	0.80
TiO_2	0.98	0.21	0.86	0.05	0.96	0.14	0.89	0.03
Al_2O_3	13.33	1.88	13.67	0.72	14.04	0.85	13.77	0.55
FeO*	10.93	0.97	10.15	0.26	9.79	0.44	10.39	0.40
MgNaO	10.67	2.33	10.42	0.79	9.49	2.86	10.54	0.87
CaO	10.57	1.28	11.10	0.27	10.36	1.33	10.97	0.48
K_2O	0.73	0.35	0.58	0.05	0.76	0.11	0.60	0.02
Total number of samples	22		284		140		140	
			Test of Calibration at 30–90 m					
SiO_2			53.09	0.29	49.67	2.39	51.73	1.07
TiO_2			1.05	0.11	1.15	0.19	0.93	0.04
Al_2O_3			15.91	0.58	18.62	0.83	16.19	0.60
FeO*			10.58	0.45	8.88	0.82	9.95	0.62
MgNaO			7.63	0.57	11.73	2.86	10.95	1.05
CaO			10.37	0.33	8.79	1.48	10.56	0.53
K_2O			0.75	0.07	1.12	0.1[illegible]	0.68	0.02

*Shirley [1987].

tings and outcrop. For example, there appears to be stratification within the olivine-rich layer, because the major peaks in Mg and Fe abundances occur at different depths than the major trough in the silica curve (i.e., the Fe peak is 2 m higher than the Si trough in Figure 7). Also, there is little doubt that the base of the sill is in contact with a very radioactive shale. K and Th increase dramatically at the very bottom of the logged interval (Figure 7). Also, there is a clear increase in the amplitudes of the logging curves in the upper segment of the well, possibly from increased stratification within the sill (evident in Si, Ca, Fe, and Mg + Na curves, in particular; see Figure 7). Unfortunately, the core analyses do not corroborate this increased variability because of the sparse sampling interval in this part of the well. The discrete spike in the Al curve at 55 m appears real, as well, and is likely from the abundant occurrence of an Al-rich mineral at this depth in the sill.

GEOCHEMICAL LOGGING IN HOLE 504B

The correlation between core- and log-derived chemical analyses is considerably better in the Palisades Sill well than can be expected for hole 504B because of the more difficult logging conditions and poorer hole quality. The main differences are (1) the lack of a boron sleeve to isolate the formation from borehole fluid effects in hole 504B (used in the Palisades Sill well, but only after leg 125 in the ODP) will cause changes in the total induced gamma ray flux that will correlate with hole size determined by the caliper log (compare Figure 3), (2) the use of seawater as the drilling fluid will add Na cations from the borehole fluid to the measured major elemental abundances (since Cl from the fluid is also measured but is not present in the rock, it is easy to correct for this effect), (3) the larger hole diameter of hole 504B will lower the rock-derived gamma ray flux and increase the borehole fluid-derived flux (9+ inches (23 cm) versus 6 inches (15 cm) for the Palisades Sill well), and (4) the uncertainty of depth locations for the limited amount of core recovered from hole 504B will make the calibration more difficult. The cumulative effects should produce a decrease in the precision (increased noise) of the geochemical logs from hole 504B. On the other hand, the extensive metamorphic alteration of the basalts in hole 504B produces much stronger major elemental contrasts (more signal) than within the relatively fresh diabases of the Palisades Sill.

Below, we correct the log-derived elemental abundances from hole 504B using the calibration equations for basalts derived from the Palisades Sill analyses. Then we compare these corrected abundances with the laboratory XRF analyses from core recovered in seven of the best sampled and lithologically distinct portions of hole 504B (our "standards"). Major elemental variations observed from these corrected geochemical logs are then interpreted in terms of alteration and structural changes encountered in the well.

STRUCTURAL AND STRATIGRAPHIC SETTING OF HOLE 504B

Hole 504B penetrates over 1.25 km of 5.9-m.y.-old oceanic crust on the southern flank of the Costa Rica Rift in the eastern equatorial Pacific Ocean, easily the deepest ocean crustal section yet drilled. The geophysical logging suite [*Anderson et al.*, 1985*b*, *Becker et al.*, 1988] reveals three distinct zones within the basement: (1) an uppermost, 150-m-thick pillow basaltic section of very low sonic velocity and resistivity and high porosity that perhaps corresponds to the seismic layer 2A, (2) a lower pillow basaltic layer of increasing sonic velocity, slightly higher resistivity, and somewhat lower porosity that may represent seismic layer 2B, and (3) a deeper zone of high sonic velocity and resistivity and low porosity that is composed of basaltic dikes thought to be the upper part of seismic layer 2C (Plate 1). The basalts in this young crust are highly altered, as can be seen from the contrast between total and fracture porosities determined from shallow- versus deep-penetrating electrical resistivity logs (Plate 1) [*Pezard*, this issue]. Long spacing resistivity

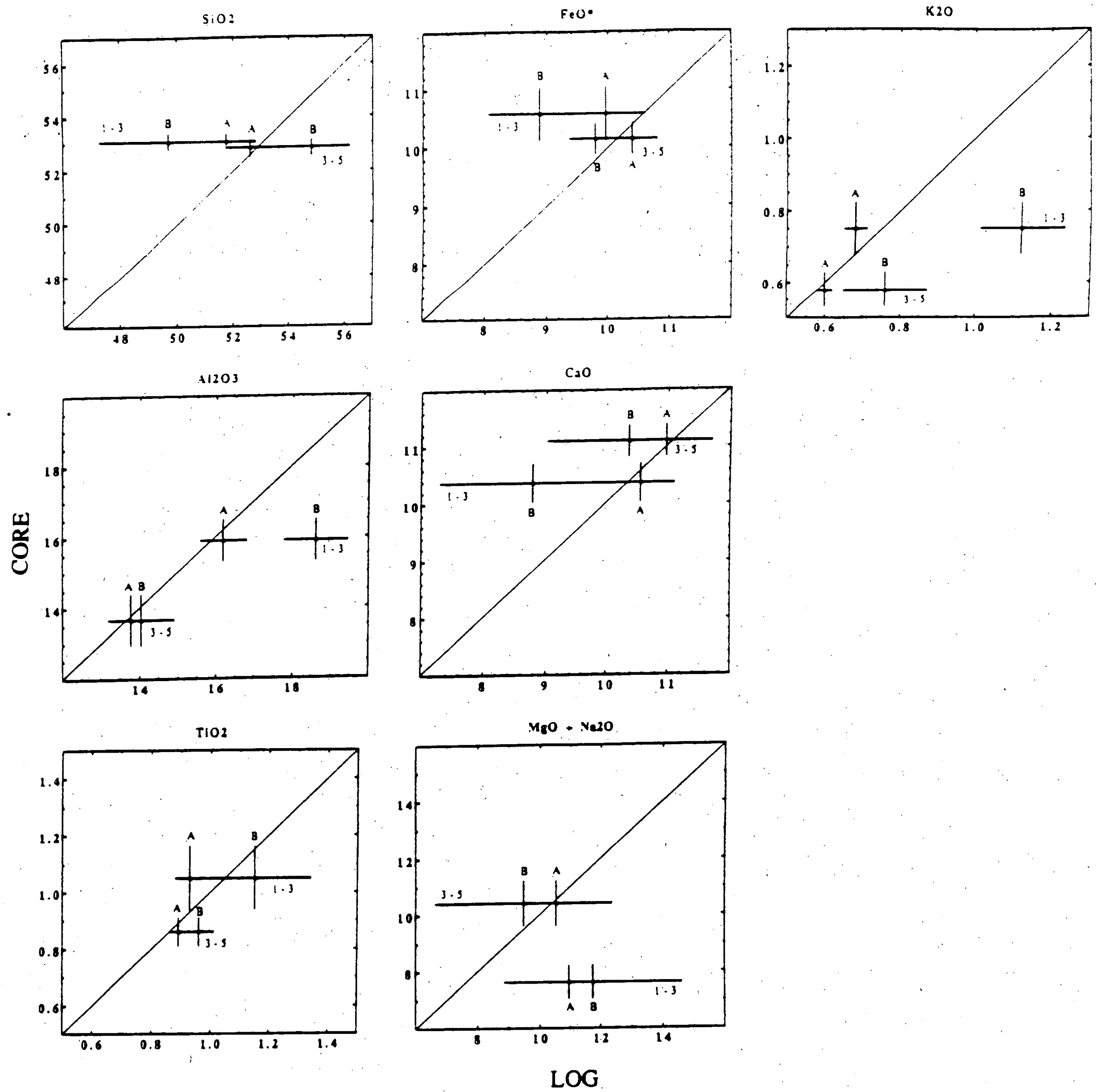


Fig. 10. Means and standard deviations of log- and core-derived elemental analyses (Figure 7) from 90–160 m (3–5) and 30–90 m (1–3) depth intervals before (B) and after (A) calibration within the Palisades Sill (Figure 9). Except for Mg + Na, the corrected, log-derived means are within one standard deviation of the core analyses (Table 2).

measurements show that the "apparent" porosity of the formation drops from 15 to 0.3% from the upper pillows to the dikes, whereas the actual porosity varies from 5 to <1% [*Becker*, 1985]. (Fracture porosity is thought to more correctly record the true porosity structure of the crust, with the difference between fracture and total porosity curves being "apparent" porosity caused by cation exchange capacitance of clays present in the formation [*Becker et al.*, 1989; *Pezard*, this issue].)

Permeability measurements, as well, indicate that the dikes are much tighter, lower permeability rocks than the pillows [*Anderson et al.*, 1985*a*; *Becker*, 1989]. Flow and pulse test measurements using hydraulic packers demonstrate that the permeability is high in the upper pillows but is constant and low within the lower pillows even though the "apparent" porosity is high [*Becker et al.*, 1989]. This drop in permeability is also thought to be the result of the precipitation of clays that have clogged the plumbing system of the lower pillows.

Three stratigraphic zones of chemical alteration were defined in hole 504B, based upon the occurrences of secondary minerals in cores recovered from the well [*Alt et al.*, 1985, 1986*a*]: (1) the upper half of the pillow section was altered by low-temperature (approximately 0°C, oxidizing, seafloor weathering; (2) the lower half of the pillow section was altered by low-temperature (<100°C), reducing reac-

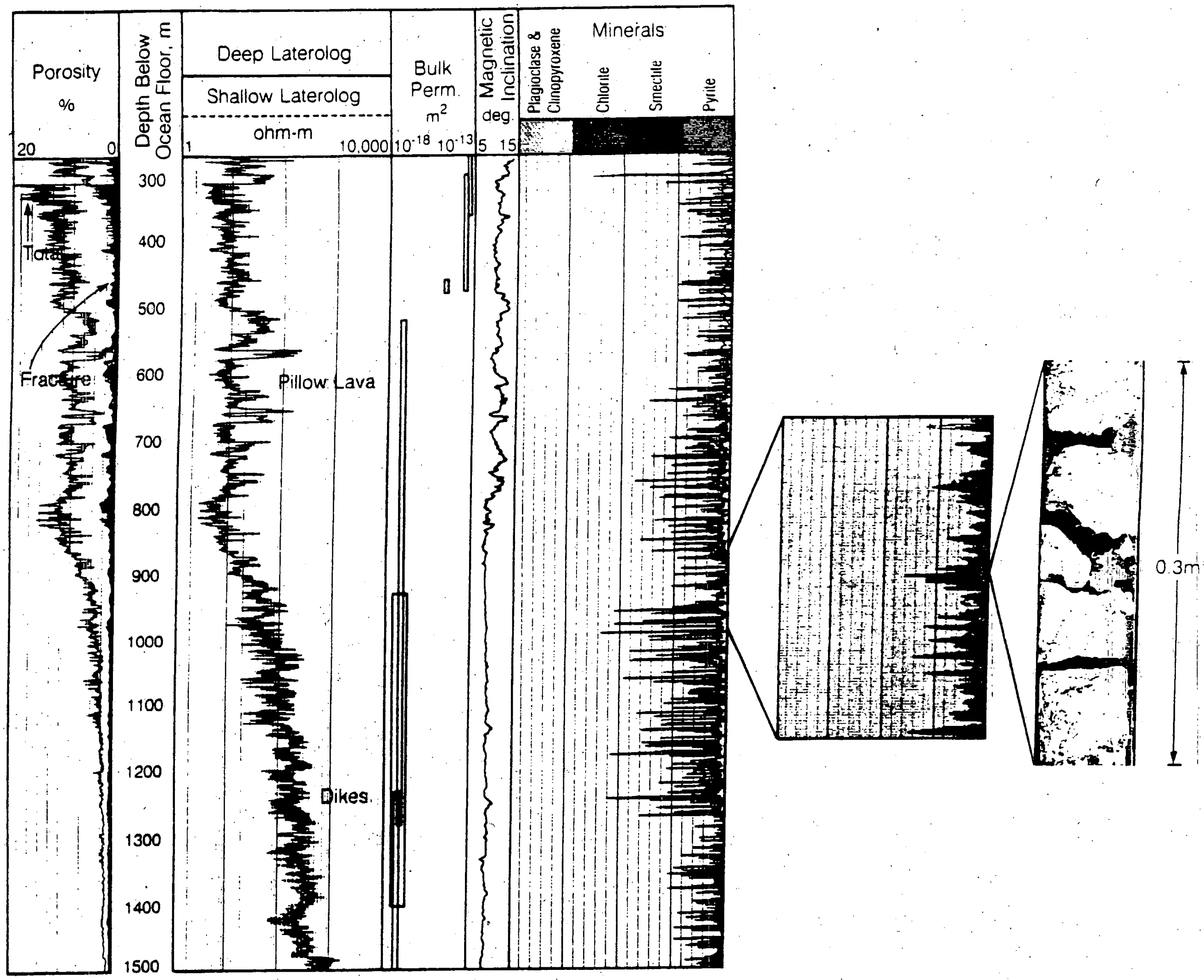


Plate 1. Geophysical and geochemical logs from hole 504B (Figure 1). Depths are in meters below the seafloor. At left, total-porosity and fracture-porosity derived from dual laterolog electrical resistivity measurements (left center) [*Pezard*, this issue]. "Apparent" porosity is the difference between these two porosities and is largely caused by cation exchange capacitance of clays that have been precipitated during hydrothermal alteration of the oceanic crust. Center, mineralogy model derived from geochemical logs (Table 5), with blowup of stockwork mineralization zone to right. Chemical alteration progresses from low temperature, oxidative celadonite precipitation (white mineral in color plot) above 550 m, to smectites (orange) which are abundant to 900 m, and then to chlorite-rich greenschist metamorphism (green) in the dikes below 900 m. Far right, photo of core from stockwork located at 925–950 m. The stockwork is characterized within the mineralogy model by the abundance of pyrite (yellow) from the log and core (centimeter-sized crystals of which are evident in the core photo at far right) [*Anderson et al.*, 1988*b*]. Bulk permeability was measured by impulse testing across packed-off intervals shown (center) [*Anderson and Zoback*, 1982; *Anderson et al.*, 1985*a*; *Becker et al.*, 1988]. Magnetic inclination was measured with a three-component, flux gate borehole magnetometer by H. Kinoshita (as cited by *Becker et al.* [1988]). (Reprinted with permission from *Oilfield Review*.)

tions; and (3) the dike section was altered by greenschist-grade, hydrothermal metamorphism occurring at high temperatures (>250°C).

Within the pillow-dike transition zone at 925 m, a stockwork of sulfide mineralization was cored during leg 83 (Plate 1). Porosity shows an abrupt change across this zone [*Becker*, 1985]. Hot, upwelling, mineralized hydrothermal fluids once mixed with cold seawater at this depth in the crust to deposit the stockwork [*Honnorez et al.*, 1985]. The mixing and precipitation likely occurred at the ridge axis as part of an axial hot spring system.

Comparison of Corrected Logs With Core Standards

The geochemical logs recorded in the basement of hole 504B, once properly calibrated, will allow the determination of the chemical variability of the oceanic crust, including the accumulated, bulk rock chemical changes caused by hydrothermal exchange between the oceanic crust and circulating seawater. The geochemical logs record the bulk chemistry of both the altered basalts and the secondary minerals filling fractures, pore spaces, and breccia zones, and they provide

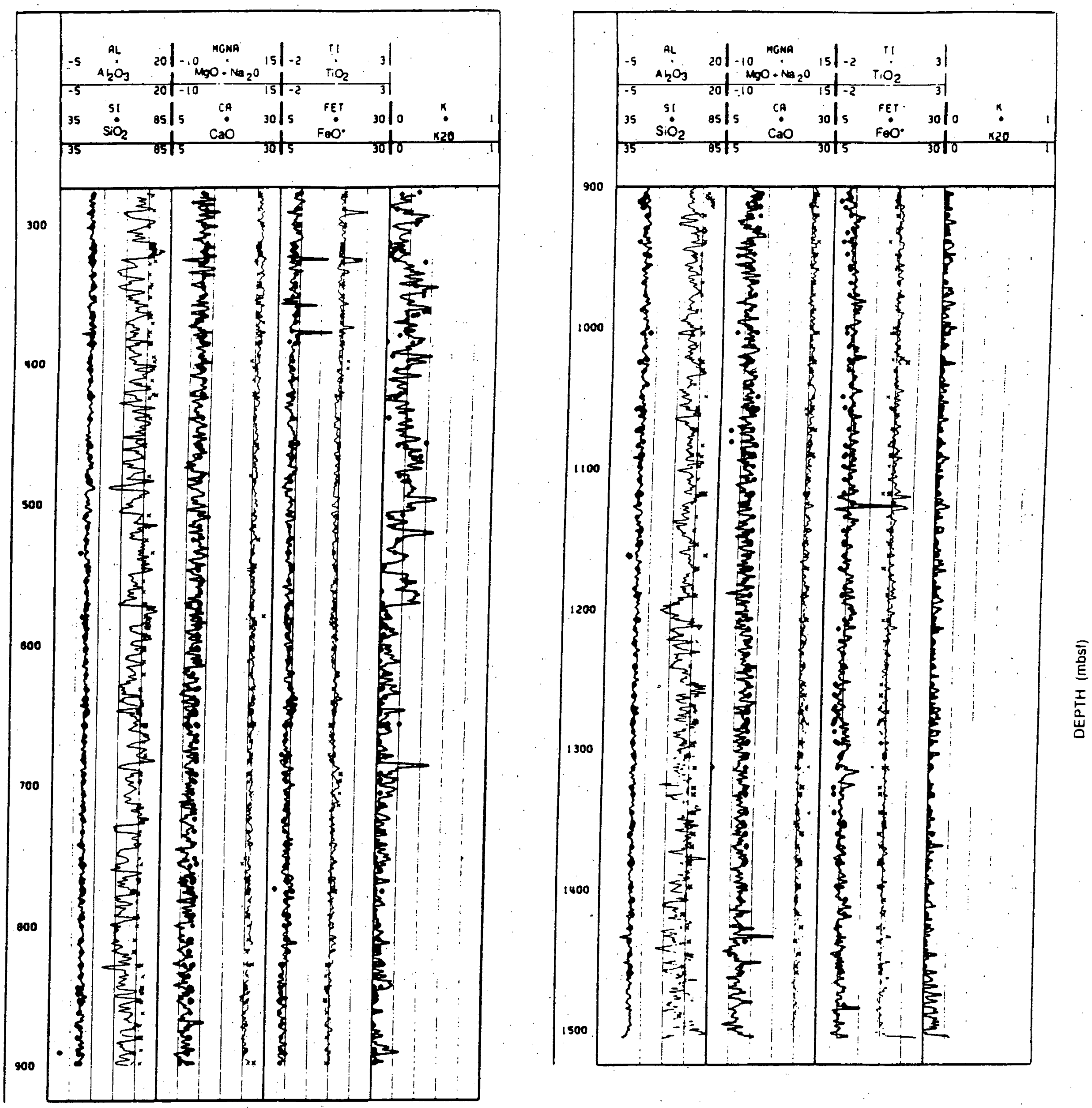


Fig. 11. Dry weight percent oxide concentrations of (from left to right) silica, aluminum, calcium, magnesium plus sodium, iron, titanium, and potassium from geochemical logs in hole 504B. Basaltic calibration corrections from the Palisades Sill (Figure 9) have already been made. Symbols are from core analyses by XRF. Depth given in meters below seafloor.

an integrated measurement of the compositional changes in the oceanic crust that have occurred over its 5.9-m.y. lifetime.

In spite of the complex alteration history encountered in hole 504B, it is possible to find examples in the recovered core samples of horizons where a considerable amount of primary basaltic rock still exists, including well-preserved chill margins of pillow basalts. These rocks have been taken as most representative of the primary composition of the basalts at hole 504B [*Alt and Emmermann*, 1985]. Several coherent flow units are found within the pillow basalts of the upper crust. These intervals have distinctively high electrical resistivities within the much lower resistivities of the altered pillow basalts (Plate 1). They are also some of the best recovered intervals within the pillow section of the well. Below, we use XRF analyses from cores from three of these internally coherent and well-sampled sills, along with four dike intervals with constant electrical resistivity, as "standards" for calibration of the corrected, geochemical log-derived analyses.

Comparisons between log- and core-derived analyses within the "standards" intervals are thought to be more

TABLE 3. Core to Log Calibration Analysis of Hole 504B Freshest Basalts

	Core Mean	Core s.d.	Log Mean	Log s.d.
		305–325 m		
SiO_2	49.54	0.05	49.42	0.58
TiO_2	0.87	0.01	0.93	0.12
Al_2O_3	15.96	0.15	14.27	0.83
FeO*	8.64	0.05	8.91	0.23
MgNaO	10.30	0.22	10.80	0.33
CaO	13.15	0.05	12.95	0.49
K_2O	0.08	0.02	0.13	0.04
		530–550 m		
SiO_2	49.21	0.33	49.55	0.43
TiO_2	0.91	0.02	0.74	0.06
Al_2O_3	16.03	0.14	16.55	1.87
FeO*	8.62	0.09	8.55	0.29
MgNaO	10.72	0.47	10.52	0.35
CaO	12.72	0.58	13.05	1.17
K_2O	0.14	0.03	0.08	0.06
		675–685 m		
SiO_2	49.64	0.43	49.89	0.37
TiO_2	0.88	0.06	0.09	0.03
Al_2O_3	15.75	0.53	15.45	0.70
FeO*	9.21	0.69	8.89	0.07
MgNaO	10.80	0.46	10.60	0.16
CaO	12.22	0.15	11.68	0.75
K_2O	0.08	0.07	0.01	0.03
		1075–1125 m		
SiO_2	49.18	0.76	49.02	0.71
TiO_2	0.89	0.09	0.94	0.07
Al_2O_3	14.71	0.92	14.70	0.74
FeO*	9.15	0.63	9.61	0.52
MgNaO	10.72	0.46	10.86	0.28
CaO	11.80	1.61	12.70	0.95
K_2O	0.02	0.01	0.01	0.02
		1275–1325 m		
SiO_2	48.90	0.21	49.48	0.61
TiO_2	0.75	0.05	0.96	0.09
Al_2O_3	16.16	0.20	13.76	1.33
FeO*	8.19	0.33	10.37	0.80
MgNaO	11.03	0.43	10.43	0.35
CaO	13.12	0.13	11.95	0.82
K_2O	0.01	0.01	0.02	0.05
		1325–1400 m		
SiO_2	49.48	0.38	49.44	0.5
TiO_2	0.89	0.09	0.88	0.06
Al_2O_3	15.68	0.75	16.30	1.33
FeO*	9.28	0.90	9.30	0.37
MgNaO	10.38	0.47	10.33	0.34
CaO	13.04	0.25	12.70	0.84
K_2O	0.02	0.01	0.01	0.05
		1450–1485 m		
SiO_2	49.65	0.33	49.10	0.48
TiO_2	0.91	0.06	0.95	0.09
Al_2O_3	15.31	0.43	15.80	1.45
FeO*	10.15	0.31	9.17	0.50
MgNaO	10.70	0.56	10.61	0.34
CaO	12.26	1.28	13.13	1.04
K_2O	0.01	0.01	0.03	0.04

representative of the true accuracy of the geochemical logs than over the entire depth of the well because although the pillow and upper dike intervals are clearly affected by the alteration and mineralization zones, only a few of these intervals were fully recovered by the coring operations. Either coring operations selectively sample only the least altered basalts in the well or, more likely, the recovered rocks reflect the appropriate compositions of the basalts and alteration products, but they do not properly represent the relative abundances of basalts versus secondary mineralization filling fractures, pore spaces, and breccia zones.

Dry weight percent abundances of major elemental oxides were calculated from geochemical logging measurements in hole 504B. Then corrections were applied using the calibration equations derived for basalts from the Palisades Sill study, and the results compared to all of the core-derived analyses from hole 504B (Figure 11). The success of the geochemical log analyses in determining major elemental abundances were then tested by comparing and correcting to the "standards" from the seven relatively fresh sills and dikes in hole 504B (Table 3 and Figure 12).

The comparisons with the "standards" demonstrate that the log-derived abundances can be corrected to within one standard deviation of the core-based analyses for most depth intervals tested (Figure 12). The relative precisions of the log-derived analyses are displayed as histograms of core-minus-log-derived values (Figure 13). The scatter is normally distributed, and surprisingly, the standard deviations of the hole 504B analyses are similar to those observed in sedimentary rocks and in the Palisades Sill study (compare Figures 3, 5, 8, and 12) (also compare Tables 1, 2, and 3). It is clearly possible to derive representative elemental analyses from geochemical logging in oceanic basalts when core "standards" are available for calibration within that well.

ALTERATION OF THE OCEANIC CRUST OF HOLE 504B

The geochemical logging results show quite different trends when compared to core analyses from throughout hole 504B as opposed to just from the "standards" intervals. Cross plots show that systematic discrepancies clearly exist between the overall log- and core-derived analyses (Figure 14). For example, there is a general decrease in the log-derived values of Ca upward in the hole, which is thought to be the result of depletion in the crust caused by cation exchange with seawater during chemical alteration [*Seyfried and Bischoff*, 1979; *Seyfried and Mottl*, 1982]. The corresponding Mg increase consistent with Ca-Mg exchange observed during experimental seawater-basalt reactions at various temperatures is also present, though somewhat complicated by the fact that Mg + Na is measured by the logs.

Core analyses, in fact, show the opposite: a Ca increase and a Mg decrease upward in the hole [*Alt et al.*, 1986*a*]. *Alt et al.* [1986*a*] interpreted these changes in the core analyses to reflect slight compositional variations of the freshest basalts which were preferentially sampled by the coring operations at hole 504B.

Systematic borehole size changes may accompany changes in the degree of alteration in hole 504B. If alteration minerals are confined to relatively soft breccia and fracture zones, the borehole may become more washed out in these areas. We have previously seen that such washout zones would lower the precision of the geochemical logging results but would not affect the accuracy of the measurements. Also, *Francis* [1982] determined that hole size changes observed in hole 495B in the Mariana Trough were caused by

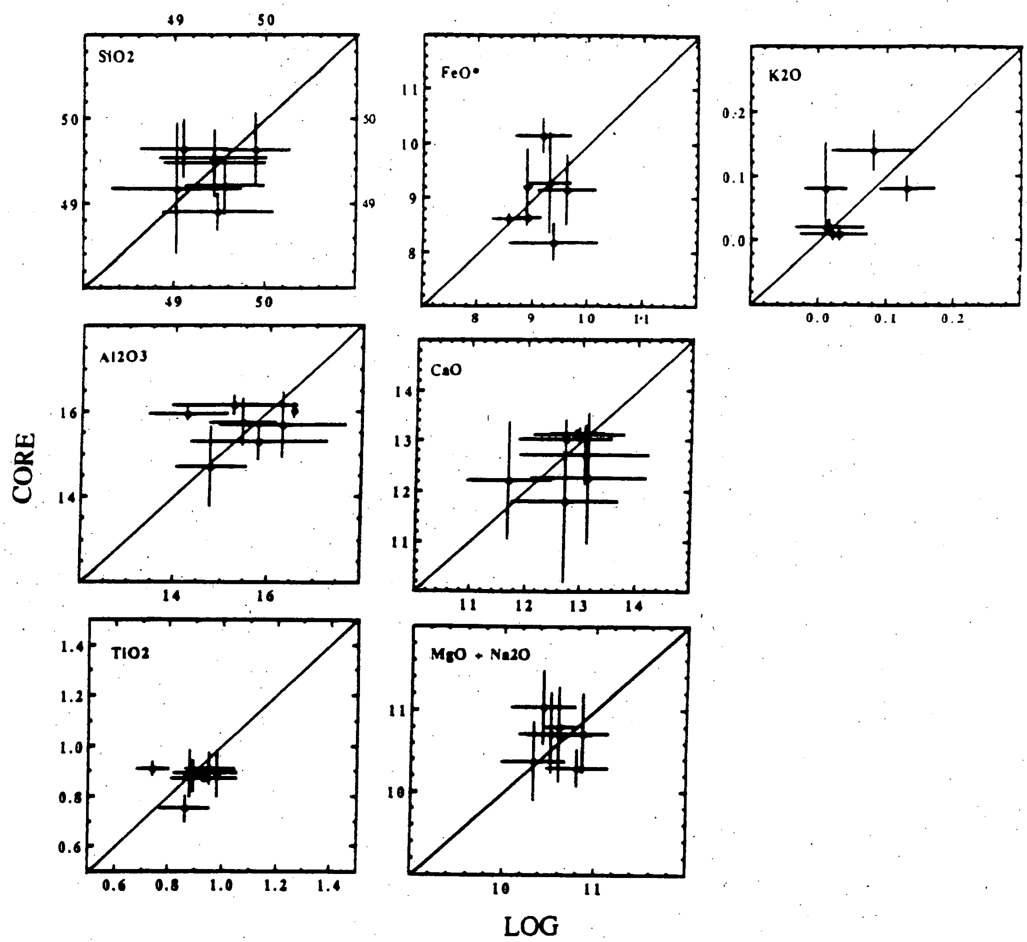


Fig. 12. Cross plots of the means and standard deviations of corrected, geochemical log-derived elemental abundances versus core-derived XRF analyses (standards) averaged over seven sill and dike intervals with both adequate sampling density and relatively fresh basalt in hole 504B. See Table 3.

rhythmic drilling processes. Though these too would presumably be attributable to soft versus hard drilling conditions, they too could produce significant borehole size changes in hole 504B.

We can test whether elemental variations in hole 504B are related to any such physical changes in borehole size by calculating the correlation coefficients between all the various combinations of geochemical and geophysical logs within 200 m overlapping intervals throughout the well (Figure 15). The variations in these correlation coefficients between the various elemental abundance curves, porosity, and the caliper log recorded by the borehole televiewer and multichannel sonic logging tools (much more accurate than traditional mechanical arm calipers) show that there is no systematic correlation between borehole size and elemental abundances (Figure 15). In fact, large borehole size intervals correlate with zones of increased porosity (softer rock) and with increases in some elemental abundances (e.g., Si and Mg + Na), but with decreases in others (Al and Ca). In addition, an inverse correlation exists between Si content and the other elements (when Si abundances are high, all other elemental abundances are proportionally lower). Al correlates negatively with Mg + Na but positively with Ca. Fe is positively correlated with Ti.

These correlations are caused by the chemical changes accompanying the alteration of basalts to clays and the cementation of cracks by clays, which in turn, cause changes in the "apparent" porosity in the well. This relationship can be seen particularly well in the lower pillow units where variations in the abundances of alteration products correspond with changes in the porosity curve determined from the electrical resistivity log (Figure 16). Increased Si and Mg + Na and decreased Al and Ca correlate quite clearly with porosity because the plumbing system is clogged with alteration products, as can be seen from both the low permeability, but high "apparent" porosity and the correspondence between elemental abundance changes and the porosity curve (Figure 16). These elemental variations reflect the changes in stoichiometry accompanying the alteration of basalts to smectites and chlorites within pore spaces, fractures and breccia zones. Consider for example, XRF analyses of core samples of adjoining basalt and breccia zones which show similar elemental changes between fresh and altered basalts over very short distances in the well (Table

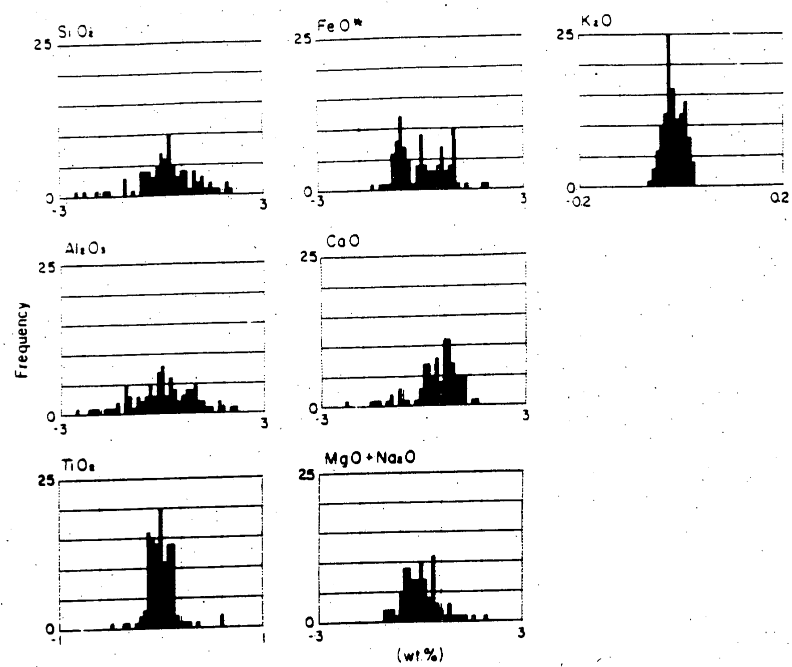


Fig. 13. Histograms of differences between core-derived and corrected, log-derived elemental abundances in hole 504B dikes from 925 to 1346 m depth interval. Comparisons to histograms from two sediment wells (Figures 3 and 5) and the Palisades Sill diabases (Figure 8) show that precisions are similar in the four wells.

4). Mg increases and Ca decreases with increased porosity (Figure 16) mirroring the alteration of dikes to breccias (Table 4).

Cyclicity in the Oceanic Crust in Hole 504B

One of the puzzles revealed by previous geophysical logging in hole 504B was the detection of cyclicity down the well bore not correlated with borehole size changes. These cycles affect all the geophysical logs, including velocity, resistivity, and borehole televiewer images [*Newmark et al.*, 1985]. Cyclicity can also be seen in the elemental abundances recorded by the geochemical logging tool, particularly in the Al variation (Figure 17).

A spectral analysis of Al abundance and resistivity logs provides a quantitative measure of the variation with depth (Figure 17). The Al abundance cyclicity is found to have predominant periods of 10 and 20 m in the upper pillows, decreasing to 5 and 9 m in the lower pillows, then increasing to 12–30 m in the dikes (Figure 17). While the short-wavelength energy might be from noise inherent in the geochemical logs (compare Figure 7), there is considerably more long-wavelength energy in the dikes than in the pillow units, (probably because of the vertical drill hole penetrating the nearly vertical dikes versus subhorizontal pillows and flows). This long-period cyclicity can be converted to an average thickness for individual dikes of 2–3 m if we assume an average dip for the dikes of 86°.

While the wavelengths of the lithostratigraphic units observed from core do not correspond exactly to those from the Al log, the frequency of changes observed in the core suggests a cause for the Al variability (Figure 17). *Adamson* [1985] (as cited by *Becker et al.* [1988]) was able to discriminate three phyric and one aphyric lithostratigraphic units (Figure 17). The compositional differences are associated with different lithostratigraphic units within the basalts. In fact, *Emmermann* [1985] identified changes in Al content between lithostratigraphic units that are at least as abrupt as similar changes observed in the Al log. However, the Al contents of adjacent lithostratigraphic units sometimes do not vary significantly, even though the phenocryst assemblages (upon which the units are distinguished) do change (compare 1270–1350 m, Figure 17). Therefore cycles derived from a single element (Al) cannot distinguish all the lithostratigraphic boundaries in hole 504B. Some Al units would appear thicker than the lithostratigraphic units, perhaps explaining the observed discrepancies in the lower portion of the hole (Figure 17).

The extrusion of relatively thin and geochemically distinct volcanic units within pillow basalts and the intrusion of individual dikes during the primary volcanic construction of the upper oceanic crust likely account for the primary cyclicity found not only in the Al log but also in the other geophysical and geochemical logs from the upper portion of hole 504B. That is, extrusions building the upper oceanic crust at hole 504B consisted of many thin flow units fed by intrusive dikes, some of which are of variable composition. Subsequent precipitation of alteration products along unit boundaries certainly enhanced the amplitudes of the observed cycles.

A Mineralogy Model for Hole 504B

The elemental abundances from the geochemical logs at hole 504B can be inverted using a correlation matrix to determine the distributions and abundances of alteration minerals that are present in the well [*Hertzog et al.*, 1987]. In the hole 504B case, six mineral compositions were input as

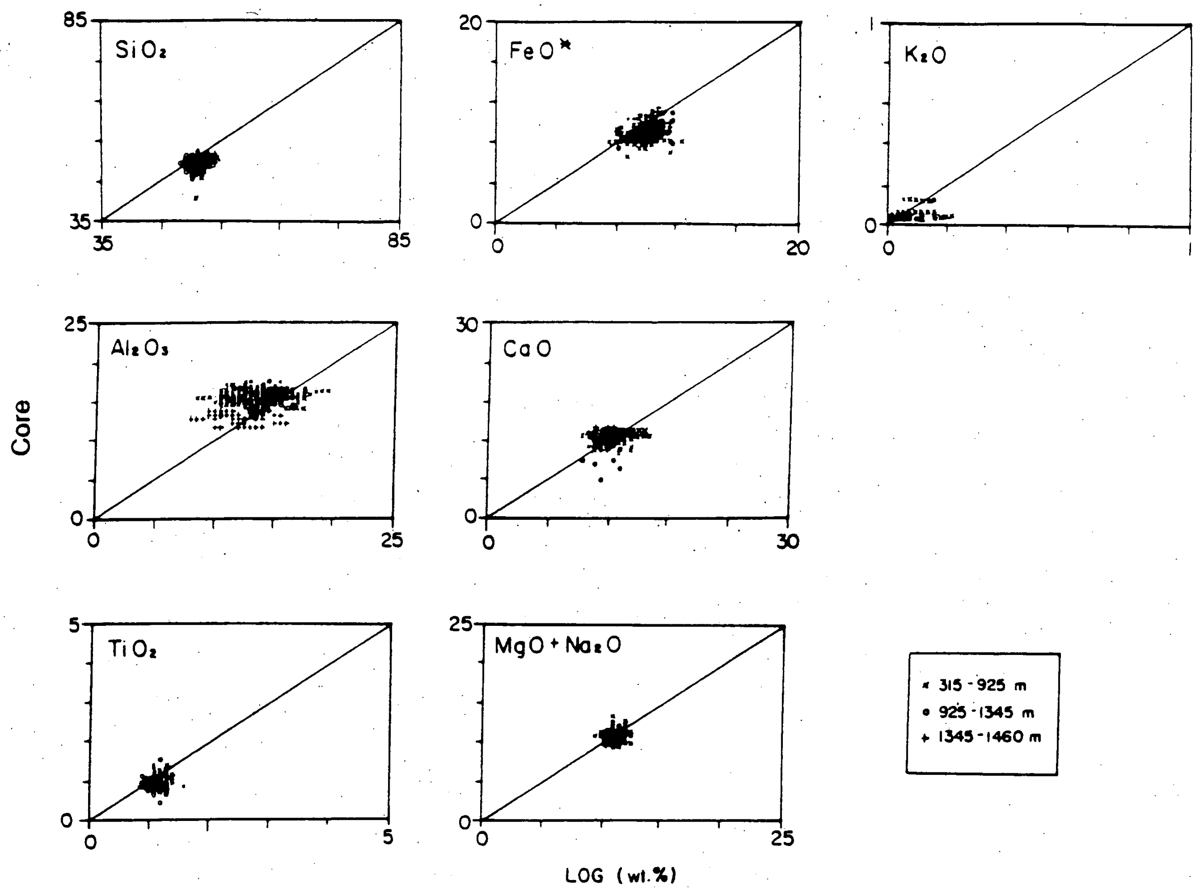


Fig. 14. Cross plots of corrected, log-derived elemental abundances and core-derived XRF analyses from throughout hole 504B (Figure 11). Symbols indicate depth intervals as in legend. Compare ranges (including altered basalts) with those from "standard" calibration intervals (freshest basalts) in Figure 12.

end-members into an inversion matrix with the dry weight percent oxide compositions of Si, Al, Fe, Ca, K, Na + Mg, and S from the geochemical logs (Table 5). Only six minerals were used because the number of constraining elements available for the matrix inversion in hole 504B is seven. Ideal compositions of plagioclase (An_{70}), clinopyroxene, smectite, chlorite, celadonite, and pyrite were chosen to be representative of the mineral suite found in the core. Other minerals recovered from the well but not included in the model, such as olivine, palagonite, and anhydrite, can be safely excluded because nearly all the olivine is altered to smectite and chlorite, anhydrites and other sulfides are rare relative to pyrite, and palagonite can be approximated by the smectite composition (see Table 5 for sources of microprobe analyses used to select the appropriate composition of each mineral going into the model).

This ELAN (mark of Schlumberger) calculation is essentially a "cluster analysis," in that the chemical analysis at each depth is fit within a seven-axis volume (one for each input element). The six ideal minerals form separate clusters within this volume. A serial calculation is performed to locate the nearest mineral clusters to each input of elemental abundances at the depth point. In much the same way that normative mineralogies are computed, the correlation matrix selects the amount of each ideal mineral that, when added together, would occupy a space closest to the elemental data within the volume. The amount of sulfur decides the amount of pyrite, the potassium is partitioned between celadonite and smectite, etc., as in Table 5.

Elements that have little contrast in abundance between ideal minerals (such as iron in Table 5), will have little influence on the mineral selection process, whereas those with large differences (such as aluminum in Table 5) will be very important. All errors propagate through the calculations as in normative analyses. However, at the end, reconstructions are created of the elemental abundances predicted by the mineral distribution chosen by the model. Comparisons are then made between this "best fit" elemental reconstruction and the original input analyses to estimate error.

The mineralogy model calculated for hole 504B, as limited as it is, still indicates that two major compositional components are present within the hole (Plate 1). Plagioclase and clinopyroxene form the bulk of the formation (this is the fresh basalt itself, in blue in Plate 1). A second component appears as large "spikes" of (1) K-rich celadonites (white) in the upper pillow basalts, (2) smectites (orange) in the upper and lower pillows, and (3) chlorites (green) in the dikes. The geochemical log-derived, mineral variations (Plate 1) agree nicely with those observed in core by *Alt et al.* [1986*a*] (compare our Plate 1 and *Alt et al.*'s [1986*a*] Figure 2). For example, the chlorite appears only below 600 m depth in

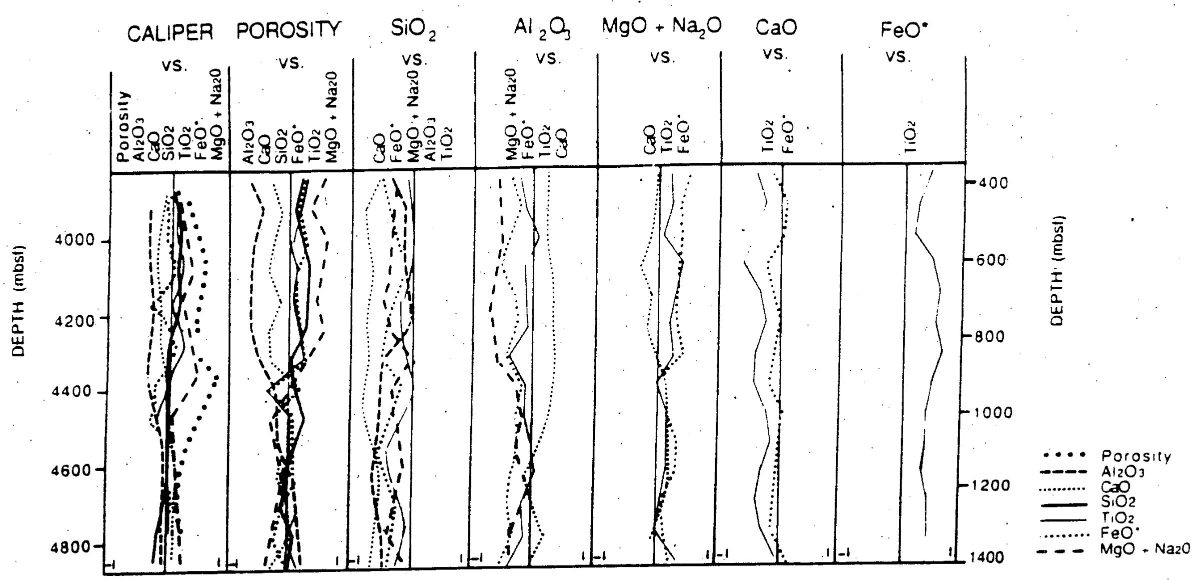


Fig. 15. Correlation coefficients in hole 504B calculated for 200 m intervals overlapping every 100 m among each of the corrected, log-derived elemental abundance curves (center to right), the caliper curve of hole size (left) and the total porosity curve (including "apparent porosity from Plate 1). Caliper size and porosity correlate with clay content in the lower pillow basalts, as can be seen from their correlation with the various stoichiometric components of clays. In the dikes, neither the caliper nor the porosity curves correlate with any geochemical curves.

both the core samples and in the log-derived mineralogy model.

A pattern is evident in the abundances, as well as the compositions, of minerals present in hole 504B. Volume percentages of high temperature chlorites present in the dikes average 10%, whereas lower temperature smectites fill up to 15% of the volume of the lower pillows. Celadonites and smectites fill only 5% of the upper pillow section in hole 504B.

The mineralogy model shows that abundant clay-rich fracture and breccia zones are found along the contacts of the lithostratigraphic units discussed above, (the characteristic spikes in Plate 1, see blowup). These elemental variations reflect smectite and chlorite precipitation in pore spaces within fracture and breccia zones found along the contacts between the lithostratigraphic units in hole 504B.

INTEGRATED CHEMICAL FLUXES IN HOLE 504B

Chemical reactions within submarine hydrothermal systems result in significant fluxes of elements between seawater and the oceanic crust, both at the ridge axes [e.g., *Edmond et al.*, 1979; *Jenkins et al.*, 1978; *Von Damm et al.*, 1983] and on ridge flanks [*Maris et al.*, 1984]. A volume of seawater equivalent to that of the entire oceans is thought to circulate through the ridge axes in approximately 7 Ma [*Sleep and Wolery*, 1978]. Concomitant chemical exchange with basalts not only alters the crust but affects the composition of the oceans as well. For the mass budgets of many elements in seawater, hydrothermal exchange is as important as river-input to the maintenance of a stable composition for the oceans over geologic time [e.g., *Thompson*, 1983].

Hot (~350°C), hydrothermal fluids exit the ridge axis at "black smokers," providing us with a view of active metallogenesis as metals, derived from reactions between seawater and basalts, are deposited as sulfides directly onto the seafloor [e.g., *Ballard and Francheteau*, 1983]. Helium 3 and methane gases that escape with the hydrothermal fluids provide chemical tracers with which to map the deep circulation patterns of the oceans [*Lupton and Craig*, 1983]. On the flanks of mid-ocean ridges, cold water circulation continues the chemical exchange between the oceans and the crust for several tens of million years [*Anderson and Hobart*, 1976; *Anderson et al.*, 1977]. Moreover, the interaction of seawater with the oceanic crust produces secondary minerals that, when subducted, release fluids into the overlying mantle affecting volcanism above downgoing plates [e.g., *Anderson et al.*, 1980].

Chemical fluxes between seawater and the oceanic crust have been calculated for many elements based upon the compositions of fluid samples taken directly from effluents. Hydrothermal vent fluids, sampled at several locations along the axial rifts, provide the most accurate estimates of axial fluxes to date [e.g., *Edmond et al.*, 1979; *Von Damm et al.*, 1983; *Hekinian et al.*, 1983; *Bowers et al.*, 1988]. Despite continued exploration of mid-ocean ridges and discoveries of additional high-temperature axial hydrothermal vents, problems still remain with quantification of chemical fluxes in seafloor hydrothermal systems. For example, *Morton and Sleep* [1983] estimate that only about one sixth of the convective heat loss from young oceanic crust occurs in high temperature, axial circulation systems, whereas the remainder occurs during lower temperature convection that occurs off-axis. Low-temperature, off-axis hydrothermal fluids have been sampled from pore waters of "hydrothermal mounds" at the Galapagos Spreading Center [*Maris et al.*, 1984; *Bender*, 1983] and the Mariana Back-Arc Basin [e.g., *Leinen et al.*, 1988], but only a primitive understanding of the chemical fluxes from these ridge flank systems presently exists.

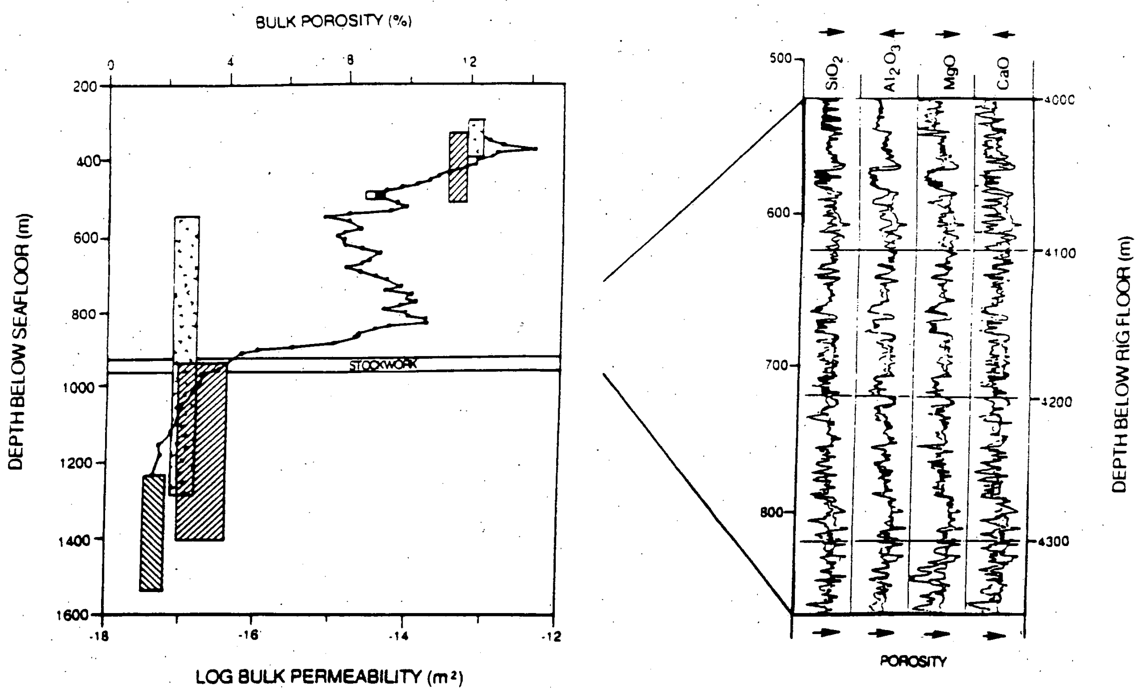


Fig. 16. (Left) Total porosity from an Archie's law interpretation of the large-scale electrical resistivity measurements in hole 504B [*Becker*, 1985] and bulk permeability measurements (shaded with various patterns) using packers [*Anderson and Zoback*, 1982; *Anderson et al.*, 1985*a*; *Becker et al.*, 1988; *Becker*, 1989] (see also Plate 1). The zone of high porosity but low permeability from 525 to 900 m is thought to be the result of "apparent" porosity from cation exchange capacitance from extensive clay mineralization that plugs the plumbing system of the interval. (Right) Total porosity (including "apparent" porosity, increasing to the right, as indicated by arrows at bottom) plotted in each panel against major element oxide abundances (increasing as in arrows at top). Black shading if logs less than porosity, stippled if porosity less than logs. Horizontal scales are arbitrary, and overlay of curves with different units is only meant to show correlation, which is positive for Si and Mg (really Mg + Na curve) and negative for Al and Ca.

Analyses of another source of direct sampling, sediment pore fluids, often indicates that basalt-seawater exchange has continued far off-axis, but again insufficient information is available from these data to place constraints upon the overall chemical mass balance [*Mottl et al.*, 1983, 1985; *Becker et al.*, 1989].

An alternative approach to the determination of the chemical exchange between seawater and the oceanic crust is to measure changes in rocks dredged and drilled from the seafloor and to estimate the distribution of the various alteration types [*Staudigel and Hart*, 1983; *Thompson*, 1983; *Alt et al.*, 1986*a*]. This method has an advantage over the direct fluid sampling in that the rocks integrate the mineralogical and chemical effects of alteration processes that have affected the rocks throughout their residence time on the seafloor [e.g., *Humphris and Thompson*, 1978]. However, the problem remains of extrapolation of the processes observed in dredged and cored rocks to those occurring throughout the subsurface.

Exposures of ophiolites on land allow complete sections of the old oceanic crust to be collected. However, conclusions from analyses of ophiolites are complicated by the often occurring overprint of metamorphism that accompanied emplacement and by variations in tectonic setting between

TABLE 4. X Ray Fluorescence Analyses of the Elemental Abundances of Core Samples From Breccias and Dikes in Hole 504B

	Leg 83				Leg 111, Core 142	
	Core 100-1		Core 101-1			
	83–87 cm	109–114 cm	134–139 cm	110–114 cm	110–114 cm	6–8 cm
Depth, m	1075	1076	1091	1090	1354	1353
SiO_2	50.20 ↑	48.25	50.00 ↑	49.20	45.50 ↓	50.20
Al_2O_3	13.20 ↓	16.20	13.90 ↓	15.10	14.70 ↓	15.10
Fe_2O_3	12.40 ↑	9.40	10.60 ↑	9.96	14.40 ↑	10.70
MgO	7.78 ↑	7.30	8.01 ↓	8.72	9.62 ↑	7.73
CaO	7.61 ↓	12.40	10.60 ↓	12.80	9.26 ↓	12.60
	breccia	dike	breccia	dike	breccia	dike

Arrows indicate the direction of change from dikes to breccias. Up is enrichment; down is deletion.

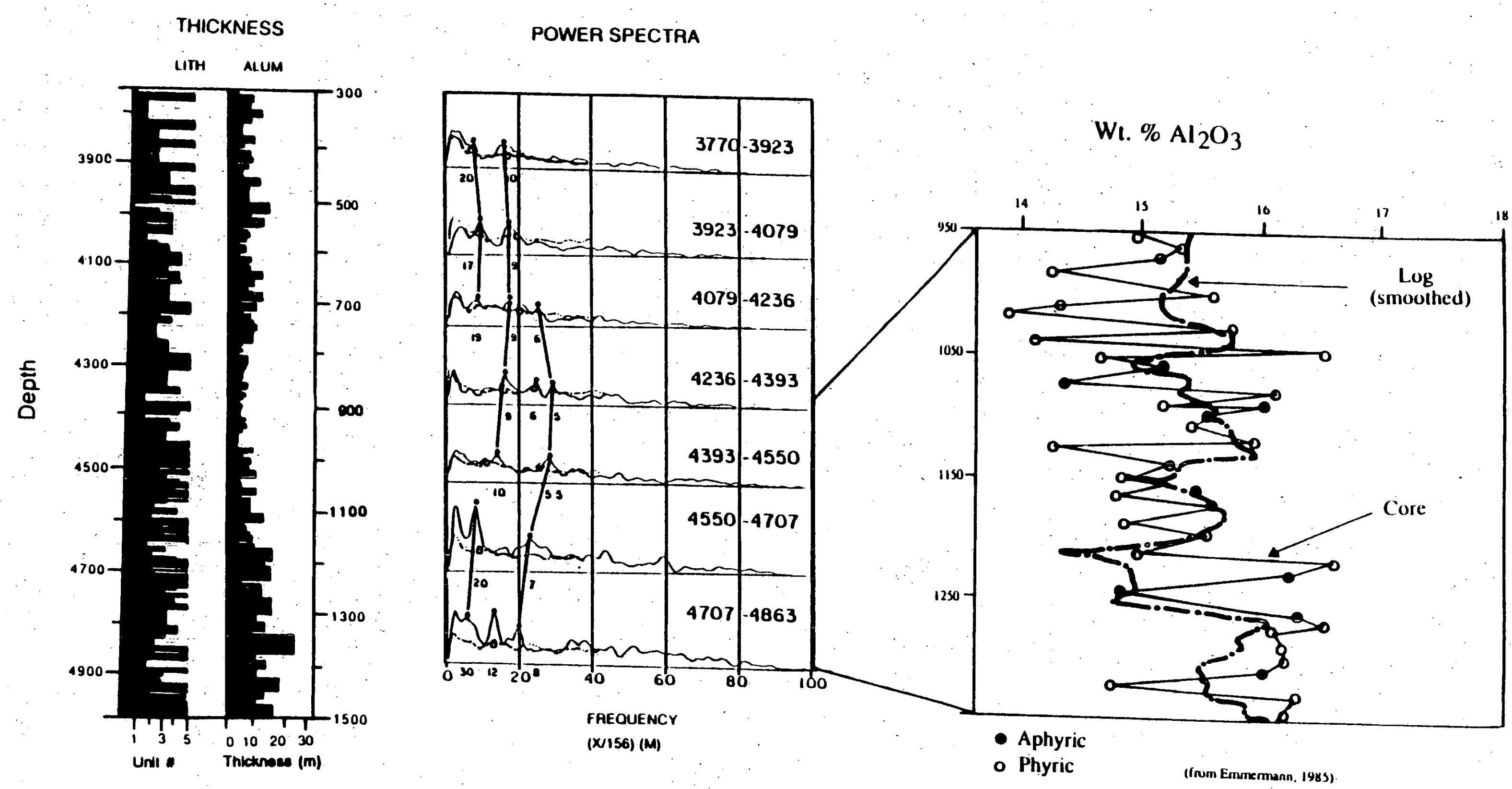


Fig. 17. (Left) Cyclicity in Al logs from hole 504B shown by variations in thicknesses of major units determined by abrupt changes in Al content and compared to lithostratigraphic unit thicknesses determined from phenocryst variations between cores (*Adamson* [1985], as cited by *Becker et al.* [1988].) Lithostratigraphic basalt types are 1, plagioclase-olivine phyric; 2 and 3, plagioclase-olivine-clinopyroxene phyric; 4, olivine-plagioclase phyric; and 5, aphyric. (Center) Power spectra of the Al log (solid line) and resistivity log (dashed curve) over depth intervals indicated. Solid circles identify prominent wavelengths (indicated in meters) of coherent power in the Al log, open circles are peaks in the resistivity spectra. (Right) Core-derived (dots connected by solid line) and log-derived (dot-dashed curve) Al variations both show changes in composition between adjacent lithostratigraphic units in the oceanic crust.

TABLE 5. Mineral/Element Abundance Matrix Used for Mineralogy Model of Plate 1, Hole 504B

	Plagioclase[a]	Clinopyroxene[b]	Celadonite[c]	Chlorite[d]	Smectite[e]
SiO_2	49.0	52.0	49.5	28.0	50.0
TiO_2	0	2.0	0	1.0	3.0
Al_2O_3	28.0	3.0	2.0	20.5	5.0
FeO	2.0	20.0	20.0	16.0	15.0
$MgO+Na_2O$	5.0	18.0	8.0	22.0	27.0
CaO	12.0	18.0	1.0	0	1.0
K_2O	0	0	8.0	0	2.0

[a] *Kempton et al.* [1985, Table 3].
[b] *Kempton et al.* [1985, Table 1].
[c] *Honnorez et al.* [1983, Table 3B].
[d] *Alt et al.* [1985, near the average composition, Table 12].
[e] *Kempton et al.* [1985, Table 9].

different exposures [e.g., *Gillis and Robinson*, 1985; *Honnorez et al.*, 1985].

Additional information about the variability and evolution of the chemical fluxes between oceanic crust and seawater can be gained from samples and measurements from drillholes within the oceanic crust [e.g., *Staudigel et al.*, 1979; *Alt et al.*, 1986*a*]. Because the compositions of the basaltic glasses and the freshest rocks are remarkably uniform throughout hole 504B [*Natland et al.*, 1983; *Alt and Emmermann*, 1985], the geochemical log-derived elemental abundances can be used to calculate integrated fluxes that resulted from the exchange of cations between these basalts and seawater.

CHEMICAL FLUXES IN HOLE 504B

As noted above, the crustal section at hole 504B contains evidence of at least three different alteration processes that dominate separate stratigraphic intervals; seafloor weathering in the upper pillow basalts, low-temperature, reducing alteration in the lower pillows, and high-temperature, greenschist metamorphism in the dikes. Moreover, the rocks from throughout the section record the effects of time-varying alteration processes; from high-temperature processes at the ridge axis to low-temperature, off-axis hydrothermal circulation that has proceeded to the present time [*Alt et al.*, 1986*a*]. In order to determine the integrated cation exchange between basalts and seawater from these different alteration processes, we must characterize the changes in elemental abundances between the freshest basalts (found in the deepest dikes) of hole 504B, and the crust that is more heavily altered (i.e., contains secondary mineral precipitates). By calculating the integrated cation exchange from the bottom to top of hole 504B, we do not intend to imply either that no exchange has affected the lowermost basalts (our "datum" composition) or that only the uppermost oceanic crust contributes to the overall crustal exchange with seawater. We simply have no geochemical logs from either deeper in the section or from any significant distance away from this well bore, yet.

The elemental variations caused by alteration cannot be estimated simply by comparing the oxide weight percentages in the altered rock to those in our chosen protolith (the freshest, most unaltered dikes at the bottom of hole 504B). Either a constant-volume assumption must be made for the rock during alteration (a common assumption), or a constant mass must be assumed for an immobile element such as gadolinium throughout the hole. Data for heavy rare earth elements similar in chemical behavior to Gd indicate that these elements are immobile during both seafloor weathering to zeolites and greenschist metamorphism [*Ludden and Thompson*, 1979; *Humphris et al.*, 1978]. Below, we make estimates of integrated chemical fluxes based upon both assumptions and interpret the differences between the two assumptions to be a fair representation of the error inherent in the method.

The first method used below to calculate the integrated chemical fluxes in the oceanic crust in hole 504B will be to assume that to the first-order, no volume change occurs during the alteration process. We begin by smoothing the log-derived, elemental oxide curves, then normalizing to the protolithic composition of the freshest dikes at the bottom of the hole. We use the average composition of log values found in the 1450 to 1485 m depth interval from our "standards" analysis (Figure 18 and Table 3). This depth interval corresponds to rocks with the highest resistivity and density, the lowest porosity and potassium content, and presumably, the freshest basalts recovered by the coring operation (also identified as the visibly least altered by J. Sparks and S. Uhlig (as cited by *Becker et al.* [1988]). We use the log-derived rather than the core-derived composition over this interval since it is the log-derived differences at other depths that are of interest. We recognize that any systematic errors between the log-derived elemental abundances and the true composition of the protolith will produce errors in the integrated cation fluxes which increase or decrease continuously with depth (the vertical, zero lines in Figure 18 would be moved to the left or right). The disadvantage of using the less accurate, log-derived elemental abundances for the calculation of elemental fluxes is more than offset by the advantage that these geochemical logging measurements are made continuously throughout the well.

CHEMICAL EXCHANGE IN HOLE 504B

To quantify the total chemical exchange that has occurred in hole 504B between basalts and seawater, a correction must be made for "apparent" volume changes that accompanied alteration (assuming first that we have constant volume in hole 504B). As noted above, a significant percentage of the porosity of the well measured by electrical resistivity logs is, in fact, "apparent" porosity caused by the added cation exchange capacity of alteration products [*Pezard*, this issue].

From *Lesher et al.* [1986], after *Gresens* [1967], the total integrated mass flux (F_i) of each element i over the depth interval of the basement section of the well (dz) is then

$$F_i = \int \rho_b (X_i^b - X_i^a)[(1 - \phi_b)/(1 - \phi_a)]\, dz \qquad (1)$$

where X_i^b is the weight fraction of element i in the altered rock (b), and X_i^a is that in the fresh basaltic protolith (a). Dry bulk density (ρ_b) is measured at each depth by the geophysical logs [*Anderson et al.*, 1985*b*]. The constant-volume correction is estimated as the difference between the total porosity (ϕ_b) and the porosity of fresh basalt (ϕ_a) at each depth in the well (from *Pezard* [this issue], as indicated above). Integrated fluxes are shown in Figure 18.

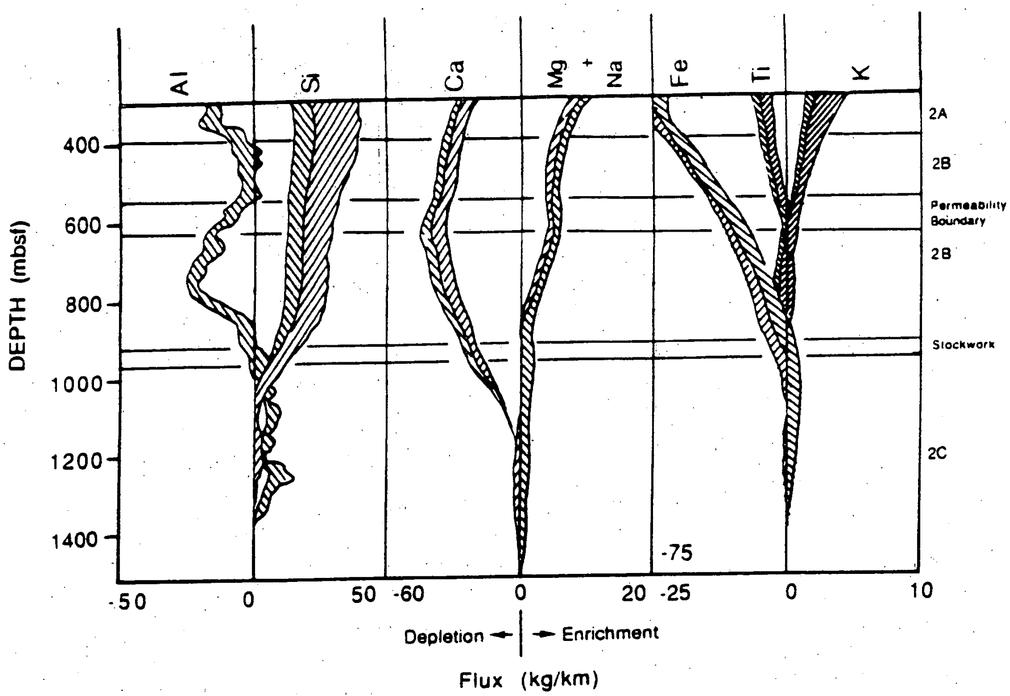


Fig. 18. Integration of the mass fluxes of the elements from the bottom to top of hole 504B (Fi from equation (1) in text). The total integrated mass flux of Figure 19 is found at the top of the hole. The center curves are corrected to constant volume for all reactions, and are for protolithic basalts of the composition found from 1425 to 1460 m (Table 3). The maximum fluxes (right diagonal hatching) are corrected to constant gadolinium at each depth, instead of to constant volume (Fi from equation (2) in text). The minimal flux estimates (left diagonal hatching) assume the protolith composition to be the average throughout the dikes (925–1500 m). There is no net flux from throughout the dikes for this case. Seismic layers indicated at right. Error estimates calculated by varying the standard protolithic basalt composition by two standard errors fall within the ranges from these other error estimates. Errors caused by the logging curve uncertainties (standard deviations in Table 3) would cause each curve to be rotated about a pivot at the bottom of the hole. The relative locations of changes in the fluxes indicate where within the section chemical exchange has occurred (e.g., quartz precipitation near the stockwork increases the enrichment of Si in this depth interval).

Error is introduced into the integrated flux calculations from two different assumptions. First, the protolith composition may be incorrectly determined by the geochemical logs. This introduces an error which rotates each accumulated flux-versus-depth curve in either the enrichment or depletion directions from a "pinned" beginning point at the bottom of the hole in Figure 18. The most extreme change in protolithic composition that we believe reasonable comes from selection of the average, log-derived, elemental composition for the entire dike interval (from 925 to 1500 m), instead of that for the basal dikes (from 1450 to 1485 m). This error in the flux calculations is indicated as the lower bound for each element in Figure 18, since significant alteration is clearly included within the "protolith."

The other assumption which introduces error into the integrated flux calculation is the constant volume assumption itself. Consequently, we have also calculated integrated fluxes based upon the assumption of immobility of Gd:

$$F_i = \int \rho_b (X_i^b - X_i^a)(I_b / I_a)\, dz \qquad (2)$$

The integrated flux calculations for each cation based upon immobile Gd are displayed as the maximum error estimates in Figure 18. I_b/I_a is the ratio of the concentration of Gd in the altered rock versus that in the protolith. The assumption of constant Gd in a protolithic composition given by the log-derived Gd value in the lowermost dikes does not quite produce no Gd flux when equation (2) is calculated for Gd itself. Therefore a further correction was made at each depth to force the total Gd flux to zero throughout the well. This produces the most extreme fluxes of Figure 18.

A compilation of experimental and total rock fluxes of Ca and Na versus Mg by *Mottl* [1983] can be used to estimate the relative contributions of Na and Mg to the log-derived Mg + Na flux. *Mottl* [1983] found an approximate −1 molar relationship between Ca and Mg, and an inverse-linear relation between Na and Mg. Given the measured Ca flux of −9 to −11 g/100 g of basalt, the observed Mg + Na flux of 3.6-4.9 g/100 g can be separated into a Mg flux of 5.9-7.2 g/100 g and a Na flux predicted to be −1 to −2 g/100 g. Such an estimate will obviously add additional error to estimates of the cation fluxes in the crust.

Implications of the Integrated Chemical Flux Calculations

There have been significant mass fluxes of all the major cations within hole 504B (Figure 18) (total fluxes of the elements per 100 g of basalt available in hole 504B are shown in Figure 19). The major fluxes observed in hole 504B are Mg gain above 900 m and Ca loss from 1100 to 600 m (Figure 18). This Mg increase and Ca decrease is caused by the exchange

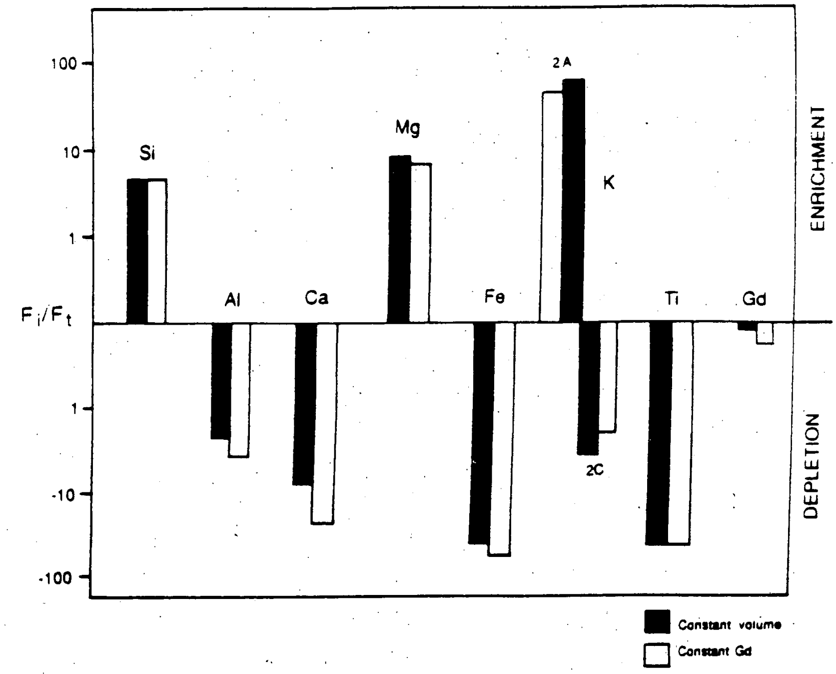


Fig. 19. Ratio of total integrated mass flux (Fi) to total of each element available (Ft) in hole 504B in percent or g/100 g of basalt.

of cations during chemical reactions between seawater and basalt [*Bischoff and Seyfried*, 1978; *Mottl et al.*, 1979].

The observed Si enrichment in the crust from 1100 to 800 m (Figure 18) is corroborated by observations from core samples from within this depth interval, where abundant quartz was found filling fractures (particularly from 850 to 1050 m) [*Alt et al.*, 1986*a*].

The Fe loss from the pillows may be due to reactions occurring during low-temperature, off-axis fluid circulation, such as those causing the Fe-rich hydrothermal deposits of the Galapagos [*Bender*, 1983] and Mariana mounds [*Leinen et al.*, 1988]. Alternatively, a relative increase in the Fe content of the dikes over that in the fresh basaltic composition may have been caused by the addition of chlorite to the bulk rock chemistry measured by the geochemical logs. In that case, the Fe flux (Figure 18) should be rotated to the right to indicate more enrichment in the dikes (since most of the chlorite is found in the dikes), rather than depletion in the pillows.

Still another alternative for the Fe flux can be seen in its covariance with the Ti loss (Figure 18). These elements generally covary in igneous processes, with Fe and Ti becoming enriched in the melt as tholeiitic magmas evolve or become more fractionated. Since Ti is thought to be much more difficult to move by hydrothermal processes than Fe, the complementary Fe and Ti loss may reflect primary igneous compositional changes relative to the protolithic composition.

The large K gain in the upper pillows becomes even more evident when viewed in percentage terms, because there is not a large amount of potassium in basaltic systems (Figure 19). It appears that almost 10% of the K is missing from the dikes, whereas almost 50% more K (than that in fresh basalt) resides in the upper pillows. The transfer of K from both the dikes (accounting for the K loss there) and cold seawater is required to balance the increase observed in the upper pillows.

The magnitude of the Al loss is surprising, particularly since very little Al is found in black smoker hydrothermal fluids egressing at the ridge crest. While some Al can be leached from basalt by hydrothermal fluids, most is thought to be reprecipitated locally as clays (or epidote, chlorite, and actinolite in the greenschist facies section of the hole). *Staudigel and Hart* [1983] estimate that whereas 1.3 g/100 g of Al are released during the alteration of fresh basaltic glasses, 0.6 g/100 g are retained in smectites.

The presence of significant amounts of Al-rich precipitates in some seafloor massive sulfide deposits [*Alt et al.*, 1987] and of hydrothermal Al-hydroxide precipitates coating basalts at mid-ocean ridges [*Howard and Fisk*, 1988] both indicate that Al mobility can occur on the scale of meters to tens of meters in the oceanic crust and that significant amounts of Al have been released through hydrothermal vents. Most of the Al loss in hole 504B occurs from 800 to 1000 m (Figure 18), which could be a "passive" loss caused by the cementation of breccias by Al-poor smectites in this zone. The smectites are also Ca-poor and Mg- and Si-rich in this zone (where the "apparent" porosity, or smectite content increases significantly) (Figure 16). Thus the Al loss could be related to Mg and Si gain through the filling of pore spaces with smectite, causing a dilution of Al and Ca. The constant-Gd assumption should eliminate any such passive chemical changes, however, and the decrease in Al is present in this calculation as well.

There is another possible explanation for the Al flux, in that the Al variation in Figure 18 might be a long wavelength change in the lithologic cyclicity discussed above. Al loss would appear in units with less primary Al than the protolith at 1450–1485 m and would be caused by primary compositional variations of the basaltic units themselves. The depth interval from 800 to 1000 m would simply have a greater number of Al-poor lithologic units than the protolith composition. The Gd and constant volume normalizations would both show this effect since both are normalized to the same fresh interval. Using the entire dike section as the protolith should reduce this effect, and it does (Figure 18). However, the core analyses from the lower pillow section do not support such a lower Al content than the dikes [*Alt et al.*, 1986*a*], so we interpret this as a real crustal Al loss. In any event, caution should be used when normalizing to constant Al, as is often done in the oceanic crust. In most cases, such a normalization is probably reasonable, but given the evidence for Al fluxes from the geochemical logs, together with the above mentioned hydrothermal evidence for relatively large-scale mobility of Al, appropriate caution should be used with such normalizations.

If we assume that the observed fluxes in hole 504B are representative of the entire oceanic crust, we can calculate the overall chemical exchange between seawater and the oceanic crust. Though the crust is mostly sealed at a younger age in hole 504B than elsewhere [*Anderson and Hobart*, 1976; *Hobart et al.*, 1985; *Langseth et al.*, 1988], heat flow studies indicate that it is possible that all crust is eventually sealed because of hydrothermal precipitation [*Anderson et al.*, 1977]. A calculation for fluxes in the entire, worldwide ridge system shows that the Si and Mg enrichment in the crust is of the same order of magnitude as the supply coming down all the rivers of the world [*Thompson*, 1983], as previously concluded by *Humphris and Thompson* [1978], *Stakes and O'Neil*, [1982], and *Bowers and Taylor* [1985]. As much Ca is supplied to the oceans by the crustal alteration mechanism as is carried by rivers, and about the same amount of K is needed to account for the enrichment of the upper pillows as is supplied by rivers. More important than the absolute magnitudes of these changes is the fact that the geochemical logs locate the sites of elemental sources and sinks within the crust (Figure 18).

INTEGRATED WATER/ROCK RATIOS

"Water/rock ratios" are frequently used by geochemists to quantify the amount of material that has reacted in hydrothermal systems [e.g., *Mottl*, 1983]. The geophysical meaning of such "water/rock ratios" in the oceanic crust is problematic, however. Geophysical fluid flow models describe convection of water through a rock matrix in terms of velocity, permeability, and buoyancy forces. The "water/rock ratio" actually represents the reactivity of the fluid-rock system and hence is a function of flow rates and reaction rates.

To examine the possible implications of the log-derived, integrated chemical fluxes in hole 504B, we have calculated "water/rock ratios" in two ways. For the calculation of "water/rock ratios" of Si, K, and Mg into the crust, we have assumed that all cations come from seawater of the composition given by *Rosenbauer and Bischoff* [1983] (Figure 20). The calculated "water/rock ratios" are then the volumes of seawater required to completely supply Si, K, and Mg cations to basalt to account for the total addition of these elements to the crust observed in the geochemical logging results.

For fluxes of Al, Ca, and Fe leaving the crust, we have assumed the extreme case that they exited as "black smoker" hydrothermal vent fluid. Again using compositions given by *Rosenbauer and Bischoff* [1983], we can calculate the "water/rock ratios" required to remove the missing cations in hole 504B (Figure 20). Here, we assume a beginning composition for the hydrothermal fluid of seawater, so that there are only two sources for the cations, seawater and the alteration of basalt. "Water/rock ratios" calculated in these ways might be considered minimal values because the effects of reaction kinetics are not considered. That is, all cations are assumed to be available for exchange with basalt. Offsetting this effect, however, is the fact that alteration of basalts is the sum of several episodes of circulation [*Alt et al.*, 1986*a*]. In each such episode, the "water/rock ratio" is likely to be less than that calculated for our "single-pass" assumption.

In any event, low water/rock ratios are found for Ca, Mg, and K (Figure 20). That is, reactions with only small volumes of hydrothermal fluid are required to account for the integrated mass fluxes of these elements observed in hole 504B. These observations agree with the results from basalt-seawater experiments [e.g., *Mottl*, 1983] and from oxygen isotopic data from the hole 504B dikes [*Alt et al.*, 1986*b*]. Local centimeter-sized chloritized zones in the dikes, however, require much greater water/rock ratios of around 65, and oxidation states of Fe indicate higher water/rock ratios in the pillow section, ranging up to 100 [*Alt et al.*, 1986*b*]. The discrepancies between the log-derived and core-based water/rock ratios can be attributed to the nature of the measurements. Logs yield bulk crustal measurements integrated for the entire 504B section, whereas the core measurements provide fine-scale local information. On a large scale, the log-derived ratios indicate that the locally high water/rock ratios detected by the core measurements are offset elsewhere by fresh, unreacted rock.

Large water/rock ratios were found to be required to explain the log-derived fluxes of Si, Fe, and Al in hole 504B. The explanation of an unusually high "water/rock ratio" for Si is likely that our assumption of a seawater source for the quartz precipitated from 800 to 1000 m depths is incorrect. Instead, the source of Si may be Si-rich hydrothermal fluids from deeper in the crust than the bottom of hole 504B; lateral transport is also possible. A correspondingly lower "water/rock ratio" would then result. The deepening of hole 504B that is planned for the next round of eastern Pacific drilling in 1992 should shed further light on these uncertainties in the source of the Si flux.

Not enough Al is present in "black smoker" hydrothermal fluids to account for even the small mass missing from hole 504B basalts. Over 1200 volumes of "black smoker" hydrothermal fluid must have exited the crust to remove the missing Al. Alternatively, off-axis convection at 40 cm/yr for the entire 5.9-m.y. evolution of hole 504B crust would be required to account for the missing Al. These large numbers suggest that at least part of this "loss" is primary igneous differences, as discussed above. Correspondingly, the high "water/rock ratios" for Fe imply some primary igneous differences, as well. These "water/rock ratios" provide an excellent cross check of the flux calculations, since a realistic mechanism for the exchange observed by the geochemical logs must also be available.

SUMMARY

The new geochemical logging data, though significantly less accurate than laboratory analyses, are extremely useful

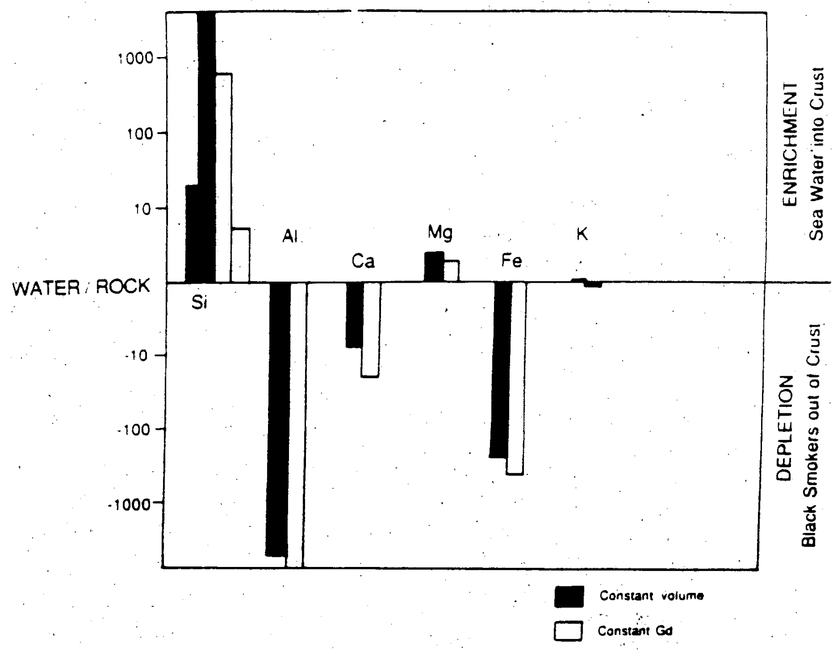


Fig. 20. Total integrated water/rock ratio over the last 5.9 m.y. in hole 504B, calculated from the assumption that the source for cations going into the crust is from bottom seawater and the output from the crust is a fluid of the composition of "black smoker" hydrothermal vent fluid. Very large numbers for Si, Fe, and Al mean that large volumes of fluid are required to enrich Si and deplete Fe and Al in the crust because little Si is going into the crust from seawater and little Fe and Al is leaving in black smoker fluids. Other sources and sinks are likely; silica from deeper in the crust (see smaller water/rock ratio calculated for black smoker source for Si precipitated as quartz also shown above), and Fe and Al loss in low-temperature, ridge-flank convection systems. Alternatives for large Al and Fe sinks are primary igneous variations within the original basalts in the crust.

for two reasons: (1) the continuity of the data allows for the quantification of elemental variations in all rock in a well, not just that recovered by core, and (2) the vertical extent of the data allows for variations to be examined as a function of depth in the crust. We have calibrated the geochemical logging technique against an extensive set of rock analyses from the Palisades Sill. An olivine-rich layer and more subtle intrusive contacts were easily identified in the corrected, log-derived analyses. To demonstrate the usefulness of geochemical logs in the oceanic crust, we have first corrected the log-derived measurements of the bulk chemistry of hole 504B using "standards" from relatively well-recovered sills and dikes. We have then demonstrated that the geochemical logs record the chemical signature of multiple, volcanic extrusion and intrusion events and the integration of all subsequent alteration processes that have acted upon these basalts.

In the future, the rapid accumulation of geochemical logging data for a wide variety of oceanic and continental crustal drill holes will allow studies of the intrusive origin, alteration history, and integrated mass fluxes throughout the crust to be carried deeper and farther back in time than would be possible from surface or core sampling alone.

Acknowledgments. The scientific parties of DSDP legs 68, 69, 70, 83, 92 and ODP leg 111 made this work possible with their incredible case study that is hole 504B. The operational staffs from Scripps and Texas A&M were exceptional, as well. In particular, the co-chief scientists of ODP leg 111, Keir Becker and Hiroshio Sakai, recognized the importance of the geochemical logging program and provided the time to do the experiments properly; Captain Jon Marvel provided invaluable assistance in the acquisition of the geochemical logging data at hole 504B; and Glen Foss, as Texas A&M operations manager, supervised the logging program and provided helpful assistance. We thank Carl Steefel of Yale for help with the methodology for calculating mass fluxes. Excellent and constructive reviews were received from Joe Cann, Charles Langmuir, Keir Becker, and Hubert Staudigel. We wish to thank Joe Cann, in particular, for repeated, time-consuming efforts to assist us in shaping this paper into the proper form within which we might convince the geochemical community of the importance of this new technology. This work was supported by the National Science Foundation through the Joint Oceanographic Institutions, Inc. These and all other geochemical and geophysical logging data collected by the Ocean Drilling Program are available to any scientist, beginning one year after termination of each leg of the D/V Joides Resolution. Please write to the Borehole Research Group, Lamont-Doherty Geological Observatory for data request forms.

REFERENCES

Adamson, A. C., Basement lithostratigraphy, Deep Sea Drilling Project hole 504B, *Initial Rep. Deep Sea Drill. Proj.*, *83*, 121–127, 1985.

Alt, J. C., and R. Emmermann, Geochemistry of hydrothermally altered basalts: DSDP hole 504B, leg 83, *Initial Rep. Deep Sea Drill. Proj.*, *83*, 249–262, 1985.

Alt, J. C., C. Laverne, and K. Muehlenbachs, Alteration of the upper oceanic crust: Mineralogy and processes in Deep Sea Drilling Project hole 504B, leg 83, *Initial Rep. Deep Sea Drill. Proj.*, *83*, 217–248, 1985.

Alt, J. C., J. Honnorez, C. Laverne, and R. Emmermann, Alteration of a 1-km section through the upper oceanic crust, DSDP Hole 504B: The mineralogy, chemistry, and evolution of basalt-seawater interactions, *J. Geophys. Res.*, *91*, 309–335, 1986*a*.

Alt, J. C., K. Muehlenbachs, and J. Honnorez, An oxygen isotopic profile through the upper kilometer of the oceanic crust, DSDP hole 504B, *Earth Planet. Sci. Lett.*, *80*, 217–229, 1986*b*.

Alt, J. C., P. Lonsdale, R. Haymon, and K. Muehlenbachs, Hydrothermal sulfide and oxide deposits on seamounts near 21°N. East Pacific Rise, *Geol. Soc. Am. Bull.*, *98*, 157–168, 1987.

Anderson, R. N., and M. A. Hobart, The relation between heat flow, sediment thickness, and age in the eastern Pacific, *J. Geophys. Res.*, *81*, 2968–2989, 1976.

Anderson, R. N., and J. Skilbeck, Oceanic heat flow, in *The Sea*, vol. 7, edited by C. Emiliani, pp. 489–523, Wiley-Interscience, New York, 1982.

Anderson, R. N., and M. D. Zoback, Permeability, underpressures, and convection in the oceanic crust near the Costa Rica Rift, *J. Geophys. Res.*, *87*, 2860–2868, 1982.

Anderson, R. N., and M. D. Zoback, The implications of fracture and void distribution from borehole televiewer imagery in DSDP holes 501 and 504B, *Initial Rep. Deep Sea Drill. Proj.*, *69–70*, 255–270, 1983.

Anderson, R. N., M. G. Langseth, and J. G. Sclater, The mechanisms of heat transfer through the floor of the Indian Ocean, *J. Geophys. Res.*, *82*, 3391–3409, 1977.

Anderson, R. N., S. E. Delong, and W. M. Schwartz, Dehydration in the downgoing slab, *J. Geol.*, *88*, 445–451, 1980.

Anderson, R. N., M. D. Zoback, S. H. Hickman, and R. L. Newmark, Permeability versus depth in the upper oceanic crust: In situ measurements, in Deep Sea Drilling Project hole 504B, eastern equatorial Pacific, *J. Geophys. Res.*, *90*, 3659–3669, 1985*a*.

Anderson, R. N., H. O'Malley, R. L. Newmark, Use of geophysical logs for quantitative determination of fracturing, alteration, and lithostratigraphy in the upper oceanic crust, Deep Sea Drilling Project, holes 504B and 556, *Initial Rep. Deep Sea Drill. Proj.*, *83*, 443–478, 1985*b*.

Anderson, R. N., et al., *Initial Reports of the Deep Sea Drilling Project*, vol. 83, U.S. Government Printing Office, Washington, D. C., 1985*c*.

Anderson, R. N., R. Dove, C. Broglia, L. Silver, E. James, and B. Chappell, Elemental and mineralogical analyses from geochemical logs from the Cajon Pass scientific drillhole, and their preliminary comparison with core analyses, *Geophys. Res. Lett.*, *15*, 969–972, 1988*a*.

Anderson, R. N., R. Jarrard, R. Dove, P. Pezard, and C. Williams, Logging for science, *Tech. Rev.*, *36*, 4–12, 1988*b*.

Anderson, R. N., R. E. Dove, and E. Pratson, The calibration of geochemical well logs in basalt, granite, and metamorphic rocks; and their use as a lithostratigraphic tool, *Spec. Publ. Geol. Soc. London*, *48*, 177–194, 1990.

Ballard, R. D., and J. Francheteau, Geological processes of the mid-ocean ridge and their relationship to sulfide deposition, in *Hydrothermal Processes at Sea Floor Spreading Centers*, edited by P. Rona et al., pp. 17–27, Plenum, New York, 1983.

Becker, K., Large-scale electrical resistivity and bulk porosity of the oceanic crust, DSDP hole 504B, Costa Rica Rift, *Initial Rep. Deep Sea Drill. Proj.*, *83*, 419–428, 1985.

Becker, K., et al., *Proceedings of ODP, Initial Reports*, vol. 111, Ocean Drilling Program, College Station, Tex., 1988.

Becker, K., et al., Drilling deep into young oceanic crust at hole 504B, *Rev. Geophys.*, *27*, 79–103, 1989.

Bender, M., Geochemistry of pore fluids from the Galapagos mounds, *Initial Rep. Deep Sea Drill. Proj.*, *69–70*, 365–380, 1983.

Bischoff, J. L., and W. E. Seyfried, Hydrothermal chemistry of sea water from 25 to 250°C, *Am. J. Sci.*, *278*, 838–860, 1978.

Bowen, N. L., *The Evolution of Igneous rocks*, Princeton University Press, Princeton, N. J., 1928.

Bowers, T. S., and H. P. Taylor, An integrated chemical and stable isotope model of the origin of mid-ocean ridge hot spring systems, *J. Geophys. Res.*, *90*, 12,583–12,606, 1985.

Bowers, T., A. C. Campbell, C. I. Measures, A. J. Spivack, M. Khadem, and J. M. Edmond, Chemistry of hydrothermal fluids from the black smokers of the eastern Pacific, *J. Geophys. Res.*, *93*, 4522–4536, 1988.

Cann, J. R., et al., *Initial Reports of the Deep Sea Drilling Project*, vol. 69–70, U.S. Government Printing Office, Washington, D. C., 1983.

Draxler, J., and R. Hanel, The Continental Deep Drilling Program of the Federal Republic of Germany (KTB)—First logging and evaluation results, in *Proceedings of the International Spectroscopy and Geochemistry Symposium*, edited by J. S. Schweitzer, pp. Q1–11, Schlumberger Educational Services, Houston, Tex., 1989.

Edmond, J. M., et. al., Ridge crest hydrothermal activity and the balances of the major and minor elements in the ocean, *Earth Planet. Sci. Lett.*, *46*, 1–18, 1979.

Emmermann, R., Basement geochemistry, hole 504B, *Initial Rep. Deep Sea Drill. Proj.*, *83*, 183–200, 1985.

Everett, R. V., and B. A. Riek, Geochemical logging in a cased hole: Field example, in *Proceedings of the International Spectroscopy and Geochemistry Symposium*, edited by J. S. Schweitzer, pp. X1–2, Schlumberger Educational Services, Houston, Tex., 1989.

Flolo, L. H., Improved reservoir description by use of induced gamma spectroscopy, in *Proceedings of the International Spectroscopy and Geochemistry Symposium*, edited by J. S. Schweitzer, pp. H1–17, Schlumberger Educational Services, Houston, Tex., 1989.

Francis, T. J. G., Large-scale resistivity experiment at DSDP hole 459B, *Initial Rep. Deep Sea Drill. Proj.*, *60*, 841–852, 1982.

Gillis, K. M., and P. T. Robinson, Low temperature alteration of the extrusive sequence, Troodos ophiolite, Cyprus, *Can. Mineral.*, *23*, 431–441, 1985.

Grau, J. A., and J. S. Schweitzer, Elemental concentrations from thermal neutron capture gamma-ray spectra in geological formations, in *Proceedings of the International Spectroscopy and Geochemistry Symposium*, edited by J. S. Schweitzer, pp. B1–9, Schlumberger Educational Services, Houston, Tex., 1989.

Grau, J. A., J. S. Schweitzer, D. V. Ellis, and R. C. Hertzog, A geological model for gamma-ray spectroscopy logging measurements, *Nucl. Geophys.*, *3*, 351–359, 1989.

Grau, J. A., J. S. Schweitzer, and R. C. Hertzog, Statistical uncertainties of elemental concentrations extracted from neutron-induced gamma-ray measurements, in *1989 Nuclear Science and Power Symposium Proceedings*, Institute of Electrical and Electronics Engineers, New York, in press, 1990.

Gresens, R. L., Composition-volume relationships of metasomatism, *Chem. Geol.*, *2*, 47–65, 1967.

Hekinian, R., et al., Hydrothermal deposits on the East Pacific Rise near 13 N: Geological setting and distribution of active sulfide chimneys, in *Hydrothermal Processes at Sea Floor Spreading Centers*, edited by P. Rona et al., pp. 17–27, Plenum, New York, 1983.

Herron, M. M., Minerology from geochemical well logging, *Clays Clay Mineral.*, *34*, 204–213, 1986.

Herron, M. M., and S. L. Herron, Geological applications of geochemical well logging in *Proceedings of the International Spectroscopy and Geochemistry Symposium*, edited by J. S. Schweitzer, pp. A1–15, Schlumberger Educational Services, Houston Tex., 1989.

Hertzog, R., L. Colson, B. Seeman, M. O'Brien, H. Scott, D. McKeon, P. Wraight, J. Grau, J. Schweitzer, and M. Herron, Geochemical logging with spectrometry tools, *SPE Pap. 16792*, 21 pp., Soc. of Pet. Eng., Dallas, Tex., 1987.

Hobart, M. A., M. G. Langseth, and R. N. Anderson, A geothermal and geophysical survey on the south flank of the Costa Rica Rift, *Initial Rep. Deep Sea Drill. Proj.*, *83*, 379–404, 1985.

Honnorez, J., Clay mineral composition, *Initial Rep. Deep Sea Drill. Proj.*, *69–70*, 285–296, 1983.

Honnorez, J., J. C. Alt, B.-M. Honnorez-Guerstein, C. Laverne, K. Muehlenbachs, J. Ruiz, and E. Saltzman, Stockwork-like sulfide mineralization in young oceanic crust: Deep Sea Drilling Project hole 504B, *Initial Rep. Deep Sea Drill. Proj.*, *83*, 263–278, 1985.

Howard, K. J., and M. R. Fisk, Hydrothermal alumina-rich clays and boehmite on the Gorda Ridge, *Geochim. Cosmochim. Acta*, *52*, 2269–2279, 1988.

Humphris, S. E., and G. Thompson, Hydrothermal alteration of oceanic basalts by seawater, *Geochim. Cosmochim. Acta*, *42*, 107–125, 1978.

Humphris, S. E., M. A. Morrison, and R. N. Thompson, Influence of rock crystallization history upon subsequent lanthanide mobility during hydrothermal alteration of basalts, *Chem. Geol.*, *23*, 125–137, 1978.

Hutchinson, M. W., and M. D. Petersen, Three log comparisons of geochemistry and minerology in *Proceedings of the International Spectroscopy and Geochemistry Symposium*, edited by J. S.

Schweitzer, pp. F1–6, Schlumberger Educational Services, Houston, Tex., 1989.

Jenkins, W. J., J. M. Edmond, and J. B. Corliss, He-3 and He-4 in Galapagos submarine hydrothermal waters, *Nature, 272*, 156–158, 1978.

Kempton, P. D., L. Autio, J. Rhodes, M. Holdaway, M. Dungan, and P. Johnson, Petrology and geochemistry of basalts from hole 504B, *Initial Rep. Deep Sea Drill. Proj., 83*, 129–164, 1985.

Langseth, M. G., M. J. Mottl, M. A. Hobart, and A. Fisher, The distribution of geothermal and geochemical gradients near Site 501/504: Implications for hydrothermal circulation in the oceanic crust, in *Proceedings of ODP, Initial Reports*, vol. 111, edited by K. Becker et al., pp. 23–34, Ocean Drilling Program, College Station, Tex., 1988.

Leinen, M., R. McDuff, J. Delaney, K. Becker, and P. Schulteiss, Off-axis hydrothermal activity in the Mariana Mounds Field, *Eos Trans. AGU, 68*, 1531, 1988.

Lesher, C. M., H. L. Gibson, and I. H. Campbell, Composition-volume changes during hydrothermal alteration of andesite at Buttercup Hill, Noranda District, Quebec, *Geochim. Cosmochim. Acta, 50*, 2693–2705, 1986.

Ludden, J. N., and G. Thompson, An evaluation of the behavior of the rare earth elements during the weathering of seafloor basalts, *Earth Planet. Sci. Lett., 43*, 85–92, 1979.

Lupton, J. E., and H. Craig, Excess helium-3 in the ocean above the East Pacific Rise, in *The Sea*, vol. 7, edited by C. Emiliani, pp. 640–665, Wiley-Interscience, New York, 1983.

Maris, C. R. P., M. L. Bender, P. N. Frolich, R. Barnes, and N. A. Luedtke, Chemical evidence for advection of hydrothermal solutions in the sediments of the Galapagos mounds hydrothermal field, *Geochim. Cosmochim. Acta, 48*, 2331–2346, 1984.

Morton, J., and N. Sleep, Hydrothermal circulation at mid-ocean ridges, in *Hydrothermal Processes at Sea Floor Spreading Centers*, edited by P. Rona et al., pp. 9–17, Plenum, New York, 1983.

Mottl, M. J., Hydrothermal processes at seafloor spreading centers, in *Hydrothermal Processes at Sea Floor Spreading Centers*, edited by P. Rona et al., pp. 199–210, Plenum, New York, 1983.

Mottl, M. J., H. D. Holland, and R. F. Corr, Chemical exchange during hydrothermal alteration of basalt by sea water, I, *Geochim. Cosmochim. Acta, 42*, 1103–1115, 1978.

Mottl, M. J., H. D. Holland, and R. F. Corr, Chemical exchange during hydrothermal alteration of basalt by sea water, II, *Geochim. Cosmochim. Acta, 43*, 869–884, 1979.

Mottl, M. J., J. Lawrence, and L. Keigwin, Elemental and stable-isotope composition of pore waters and carbonate sediments from DSDP sites 501-504 and 505, *Initial Rep. Deep Sea Drill. Proj., 69–70*, 461–473, 1983.

Mottl, M. J., et al., Chemistry of hot waters sampled from basement at Hole 504B, *Initial Rep. Deep Sea Drill. Proj., 83*, 479–510, 1985.

Natland, J. H., et al., A compositionally nearly steady state magma chamber at the Costa Rica Rift: Evidence from basalt glass and mineral data, *Initial Rep. Deep Sea Drill. Proj., 69–70*, 811–858, 1983.

Newmark, R. L., R. N. Anderson, D. Moos, and M. D. Zoback, Sonic and ultrasonic logging of Hole 504B and its implications for the structure, porosity, and stress regime of the upper 1 km of the oceanic crust, *Initial Rep. Deep Sea Drill. Proj., 83*, 479–510, 1985.

Pasternack, E., and M. M. Herron, A comparison of GLT log data with conventional log and core data from an arkosic sand, in *Proceedings of the International Spectroscopy and Geochemistry Symposium*, edited by J. S. Schweitzer, p. G1, Schlumberger Educational Services, Houston Tex., 1989.

Pezard, P. A., Electrical resistivity and the structure of the oceanic crust at hole 504B, eastern equatorial Pacific, *J. Geophys. Res.*, this issue.

Rosenbauer, R. J., and J. L. Bischoff, Uptake and transport of heavy metals by heaTed sea water: A summary of the experimental results, in *Hydrothermal Processes at Sea Floor Spreading Centers*, edited by P. Rona et al., pp. 177–198, Plenum, New York, 1983.

Seyfried, W. E., and J. L. Bischoff, Low temperature basalt alteration by seawater: An experimental study at 70 and 150°C, *Geochim. Cosmochim. Acta, 43*, 1937–1947, 1979.

Seyfried, W. E., and M. J. Hydrothermal alteration of basalt by seawater under seawater-dominated conditions, *Geochim. Cosmochim. Acta, 46*, 985–1002, 1982.

Shirley, D. N., Differentiation and compaction in the Palisades Sill, New Jersey, *J. Petrol., 28*, 1987.

Sleep, N. H., and T. J. Wolery, Thermal and chemical constraints on venting of hydrothermal fluids at mid-ocean ridges, *J. Geophys. Res., 83*, 5913–5922, 1978.

Stakes, D., and J. O'Neil, Mineralogy and stable isotope geochemistry of hydrothermally altered oceanic rocks, *Earth Planet. Sci. Lett., 57*, 285–304, 1982.

Staudigel, H., and S. R. Hart, Alteration of basaltic glass: Mechanisms and significance for the oceanic crust-seawater budget, *Geochim. Cosmochim. Acta, 47*, 337–350, 1983.

Staudigel, H., and S. R. Hart, Dating of oceanic crust hydrothermal alteration: strontium isotope ratios from hole 504B carbonates and reinterpretation of Sr isotope data from DSDP sites 105, 332, 417, and 418, *Initial Rep. Deep Sea Drill. Proj., 83*, 297–304, 1985.

Staudigel, H., F. A. Frey, and S. R. Hart, Incompatible trace element geochemistry and Sr isotope ratios in basalts and corresponding glasses and palagonite, *Initial Rep. Deep Sea Drill. Proj., 53*, 1137–1143, 1979.

Thompson, G., Basalt-sea water interaction, in *Hydrothermal Processes at Sea Floor Spreading Centers*, edited by P. Rona et al., pp. 225–278, Plenum, New York, 1983.

Von Damm, K. L., B. Grant, and J. M. Edmond, Preliminary report on the chemistry of hydrothermal solutions at 21 degrees north, East Pacific Rise, in *Hydrothermal Processes at Sea Floor Spreading Centers*, edited by P. Rona et al., pp. 369–390, Plenum, New York, 1983.

Walker, F. R., Differentiation of the Palisades diabase, New Jersey, *Geol. Soc. Am. Bull., 51*, 1059–1106, 1940.

Walker, K. R., The Palisades Sill, New Jersey: A reinvestigation, *Spec. Pap. Geol. Soc. Am., 111*, 226 pp., 1969.

Wendlandt, R. F., and K. Bhuyan, Estimation of lithology and mineralogy from geochemical logging measurements, in *Proceedings of the International Spectroscopy and Geochemistry Symposium*, edited by J. S. Schweitzer, pp. W1–20, Schlumberger Educational Services, Houston, Tex., 1989.

Williams, C. F., T. N. Narasimhan, R. N. Anderson, M. D. Zoback, and K. Becker, Convection in the oceanic crust: Simulation of observations from Deep Sea Drilling Project hole 504B, Costa Rica Rift, *J. Geophys. Res., 91*, 4877–4889, 1986.

J. Alt, Department of Geological Sciences, University of Michigan, Ann Arbor, MI 48109.

R. N. Anderson and E. L. Pratson, Borehole Research Group, Lamont-Doherty Geological Observatory, Palisades, NY 10964.

P. K. Harvey and M. A. Lovell, Department of Geology, University of Leicester, Leicester, LE1 7RH, England.

J. Malpas, Earth Sciences Department, Memorial University, St. John's, Newfoundland, Canada.

(Received March 3, 1989;
revised February 20, 1990;
accepted March 1, 1990.)

Chapter 5

Utilization of Observations of Well Bore Failure to Constrain the Orientation and Magnitude of Crustal Stresses: Application to Continental, Deep Sea Drilling Project, and Ocean Drilling Program Boreholes

Daniel Moos and Mark D. Zoback

Dept. of Geophysics
Stanford University
Stanford CA

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 95, NO. B6, PAGES 9305–9325, JUNE 10, 1990

Utilization of Observations of Well Bore Failure to Constrain the Orientation and Magnitude of Crustal Stresses: Application to Continental, Deep Sea Drilling Project, and Ocean Drilling Program Boreholes

DANIEL MOOS AND MARK D. ZOBACK

Department of Geophysics, Stanford University, Stanford, California

The conditions necessary for compressive and tensile failure of well bores drilled into crystalline rock can be adequately represented by simple elastic failure criteria, and analysis of well bore failure can provide constraints on the magnitudes of in situ stresses if the strength of the rock is known. When applied to several boreholes drilled into continental crust where there is relatively complete knowledge of stress magnitudes, these criteria enable us to predict the depth at which compressive failure of the well bores is observed. In oceanic crust, breakouts have been observed at depths below 700 m below sea floor in Deep Sea Drilling Project (DSDP) hole 504B, drilled into 5.9 Ma crust south of the Costa Rica Rift, and near the bottom of DSDP hole 395A, drilled into 7.3 Ma crust west of the Mid-Atlantic Ridge. In both cases the azimuth of maximum horizontal compressive stress is roughly perpendicular to the ridge axis. As the unconfined compressive strengths of basalt samples from DSDP hole 504B are generally above 200 MPa (Bauer and Handin, 1985), the existence of breakouts in DSDP holes 395A and 504B requires a highly compressional stress state, where $S_{\mathrm{hmin}} \sim S_v$ and $S_{\mathrm{Hmax}} \geq 100$ MPa at about 500 m subbasement. These results are consistent with the state of stress inferred from compressional (strike-slip and reverse faulting) earthquake focal mechanisms in young oceanic crust. As ridge push forces are relatively small in young oceanic crust, we concur with previous suggestions that the high horizontal compressive stresses result from the thermoelastic effects of a convectively cooled upper crustal layer overlying a conductively cooling lithosphere.

INTRODUCTION

Determination of the magnitude and orientation of in situ stress in the continents and oceans is important to understand lithospheric deformation and to evaluate models of a wide variety of plate tectonic processes. While many aspects of crustal deformation and plate tectonics can be adequately addressed from a kinematic perspective, data on the forces acting within plates are needed to provide constraints on the physical processes causing and resisting plate motion and deformation.

Compilations of stress orientation and relative magnitude data have become increasingly more complete over the past 10 years, and tectonic stress orientation can be reliably mapped in many parts of the world. In total, over 3400 reliable indicators of tectonic stress are now available to define global patterns of intraplate stress [*Zoback et al.*, 1989]. The remarkable improvement in the quantity and distribution of in situ stress orientation data makes it possible to utilize such data to interpret tectonic processes in a number of important ways. However, there are still some very large data gaps in the stress maps, and there is almost a complete absence of stress magnitude data from depths greater than about 1 km [e.g., *Rummel*, 1986]. The lack of data on stress orientation and magnitude is especially severe in the oceans. While earthquake focal plane mechanisms help constrain the orientations and relative magnitudes of oceanic crustal stresses [e.g., *Okal et al.*, 1980; *Okal*, 1984; *Bergman and Solomon*, 1984; *Wiens and Stein*, 1984; *Bergman*, 1986], intraplate events are rare, no direct measure of stress magnitude is obtained, and measurements of stress direction from a single earthquake focal mechanism are complicated by the fact that the earthquakes often occur on preexisting faults [*McKenzie*, 1969; *Raleigh et al.*, 1972]. *Newmark et al.* [1984] and *Morin et al.* [this issue] determined stress directions in oceanic crust from analysis of well bore breakouts. In this paper we expand on these two studies and consider the more general problem of utilization of well bore failure for evaluating stress magnitudes, with the potential for studying the state of stress throughout the ocean basins.

In general, borehole failure can occur as a result of either compressive or tensile stress concentrations around the well bore. Compressive stress failures at the azimuth of the least principal horizontal in situ stress (where the compressive stress concentration is greatest) are termed stress-induced well bore breakouts [*Bell and Gough*, 1979, 1983; *Gough and Bell*, 1981; *Cox*, 1983; *Zoback et al.*, 1985] and have proven to be a reliable measure of stress orientation on land in many areas [*Bell and Gough*, 1979; *Zoback and Zoback*, 1980; *Plumb and Cox*, 1987; *Zoback et al.*, 1987; *Mount and Suppe*, 1987; *Zoback et al.*, 1989]. In this paper we show the range of conditions under which breakouts occur in both continental and oceanic boreholes and the manner in which information about stress magnitude can be obtained from the breakouts. Tensile failures around the well bore form at the azimuth of the greatest principal horizontal in situ stress (where the stress concentration around the well is least compressive). Tensile fractures may form adjacent to the well bore because of the localized stress concentration, and thermally induced tensile stresses due to cooling of the borehole wall by circulation of relatively cold drilling fluids also promote tensile failure. In these cases the fractures cannot propagate significant distances away from the well

Paper number 90JB00495
0148-0227/90/90JB-00495$05.00

bore unless the well bore fluid pressure exceeds the least principal in situ stress [cf. *Stock et al.*, 1985]. As is the case for well bore breakouts, observations of tensile failure of the well bore provide information about both stress orientation and magnitude. Our overall goal is to illustrate the simple fact that the presence (or absence) of compressive and/or tensile failure at the well bore can provide useful information about the magnitudes of in situ stresses.

Frictional Strength of the Crust

As suggested by *Sibson* [1974] and *Brace and Kohlstedt* [1980], we assume that the ratio of the maximum to minimum effective stress cannot exceed that required to cause motion on preexisting faults that are optimally oriented to the principal stress field. We also assume that principal stresses (S_1, S_2, and S_3) in the upper few kilometers of the Earth's crust generally act in the vertical direction, corresponding to the weight of the overburden (S_v) and in two orthogonal horizontal directions (S_{hmin} and S_{Hmax}, corresponding to the least and greatest horizontal principal stresses). The validity of this assumption is borne out by the very small number of intraplate crustal earthquake focal mechanisms in which neither the P nor the T axis is observed to be within 10°–15° of horizontal or vertical [e.g., *Zoback et al.*, 1989]. If these assumptions are correct, the limiting stress ratio can be written [after *Jaeger and Cook*, 1979] as

$$(S_1 - P_0)/(S_3 - P_0) = [(1 + \mu^2)^{1/2} + \mu]^2 \qquad (1)$$

where μ is the coefficient of friction of the preexisting plane of weakness and P_0 is the pore pressure. Thus the stress can range from lithostatic (in the absence of tectonic forces, [*McGarr*, 1988]) to the limit defined by (1).

A large number of in situ stress measurements in seismically active areas have shown this to be generally correct [*McGarr*, 1980; *Brace and Kohlstedt*, 1980; *Zoback and Healy*, 1984]. As we are applying these results to the upper part of the crystalline crust, we assume that pore pressure is approximately hydrostatic, which is borne out from a number of drilling experiments in both continental crystalline crust [*Kozlovsky*, 1984; *Rummel*, 1986; *Coyle and Zoback*, 1988] and oceanic crust [*Anderson and Zoback*, 1982; Hickman et al., 1984*a*; *Shipboard Scientific Party*, 1985].

Figure 1 illustrates the range of allowable values for horizontal principal stresses in the earth's crust for normal-, reverse-, and strike-slip-faulting environments using (1) and *Anderson*'s [1951] theory of faulting. For reference the figure is shown for a depth of 5 km in continental crust (average density of 2600 kg/m^3 and μ = 0.8) and for a depth of 1 km into basalt in 4 km of water for the oceanic crust (rock density of 2800 kg/m^3 and μ = 0.8). We choose these depths for illustration simply because they are within the depth range of scientific boreholes within the continents and oceans. By definition, the fact that $S_{\mathrm{hmin}} \le S_{\mathrm{Hmax}}$ requires all stress states to be above the line of unit slope in Figure 1. The vertical and horizontal lines corresponding to S_v separate the fields of normal (NF), strike slip (SS), and reverse (RF) faulting as defined by Anderson. The vertical line constraining the lowest value of S_{hmin} is the failure bound for normal faulting (i.e., (1) with $S_1 = S_v$ and $S_3 = S_{\mathrm{hmin}}$). The horizontal line constraining the greatest allowable value of $S_{H\mathrm{max}}$ is the failure bound for reverse faulting (i.e., (1) with $S_1 = S_{\mathrm{Hmax}}$ and $S_3 = S_v$). The inclined line is the limit of the allowable stress states for strike-slip faulting (i.e., (1) with $S_1 = S_{\mathrm{Hmax}}$ and $S_3 = S_{\mathrm{hmin}}$). In cases of incipient fault activity (a case that may be true of much of the upper crust) the expected stress state is found along one of these three limiting lines, depending on the style of faulting. It is clear in Figure 1 that principal stress magnitudes are appreciably lower in the oceanic crust than in the continental crust for the depths chosen. This has an important impact on the likelihood of well bore failure at the depths reached by drilling within the oceans. For reference to several specific cases the circles shown in Figure 1 correspond to simultaneous strike-slip and normal faulting, where $S_v = S_{\mathrm{Hmax}} = S_1$ and $S_{\mathrm{hmin}} = S_3$.

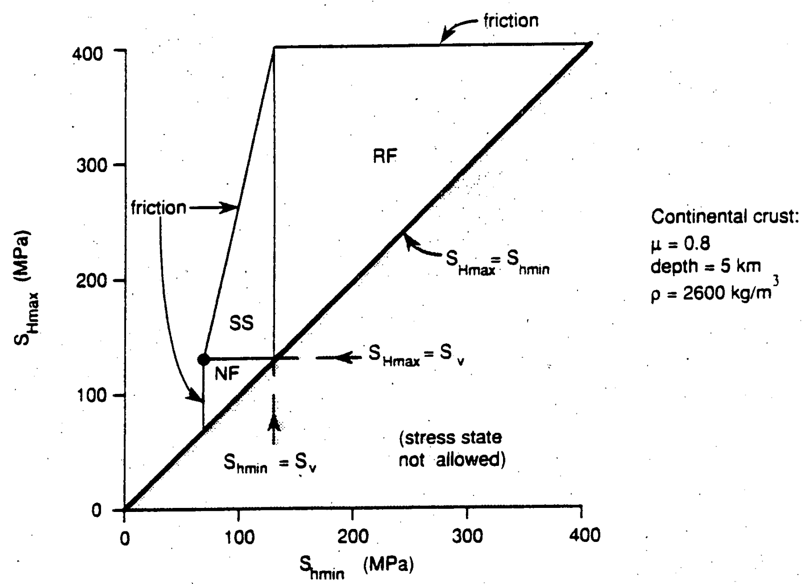
Stresses Around a Borehole

In the following discussion we continue to assume that the vertical stress is a principal stress, and we further assume that the well bore is drilled in the vertical direction and that the rock behaves elastically. We will present equations describing the magnitudes of the vertical, radial, and circumferential elastic stresses as a function of azimuth at the well bore; of the principal stresses; of fluid pressure differences between the well bore and the surrounding rock; and of the effects of temperature changes induced by the drilling fluid. These equations can be generalized for arbitrary stress and borehole orientations [e.g., *Fairhurst*, 1968; *Mastin*, 1988].

For a cylindrical hole in a homogeneous, isotropic elastic plate subjected to effective minimum and maximum far-field principal stresses (S^*_{hmin} and S^*_{Hmax}), the effective radial (σ_{rr}), circumferential ($\sigma_{\theta\theta}$), and tangential shear ($\tau_{r\theta}$) stresses described by *Kirsch* [1898] reduce at the borehole wall to

$$\begin{aligned}
\sigma_{rr} &= \Delta P \\
\sigma_{\theta\theta} &= S^*_{\mathrm{Hmax}} + S^*_{\mathrm{hmin}} - 2(S^*_{\mathrm{Hmax}} - S^*_{\mathrm{hmin}}) \cos 2\theta - \Delta P \\
\sigma_{zz} &= S^*_v - 2\nu(S^*_{\mathrm{Hmax}} - S^*_{\mathrm{hmin}}) \cos 2\theta \\
\tau_{r\theta} &= 0 \\
\tau_{zr} &= 0 \\
\tau_{z\theta} &= 0
\end{aligned} \qquad (2)$$

where ΔP is the difference between the well bore fluid pressure and the pore pressure in the rock, σ_{zz} is from *Fairhurst* [1968], and ν is the static Poisson's ratio. Theta (θ) is measured from the azimuth of the maximum horizontal stress. The circumferential stress is greatest at the azimuth of S^*_{hmin} and smallest at the azimuth of S^*_{Hmax}. Figure 2 shows the variation in $\sigma_{\theta\theta}$, the circumferential stress, and σ_{zz}, the vertical stress, as a function of azimuth at the well bore for the stress states indicated by the circles in Figure 1. It is important to note the wide range of circumferential stresses for this stress state. For the case at 5 km depth in the continents, $\sigma_{\theta\theta}$ varies from a point on the borehole at the azimuth of S^*_{hmin} where the circumferential stress is quite compressive ($3S^*_{\mathrm{Hmax}} - S^*_{\mathrm{hmin}} \approx 220$ MPa) to a point where, for the case shown, the well bore is in tension ($3S^*_{\mathrm{hmin}} - S^*_{\mathrm{Hmax}} \approx -25$ MPa) at the azimuth of S^*_{Hmax}. For the oceanic crust at 1 km below sea floor, $\sigma_{\theta\theta}$ ranges from about 50 MPa to −5 MPa. The vertical stress has the same θ dependence as the circumferential stress. However, the range in vertical stress in crystalline rock is considerably less than the far-



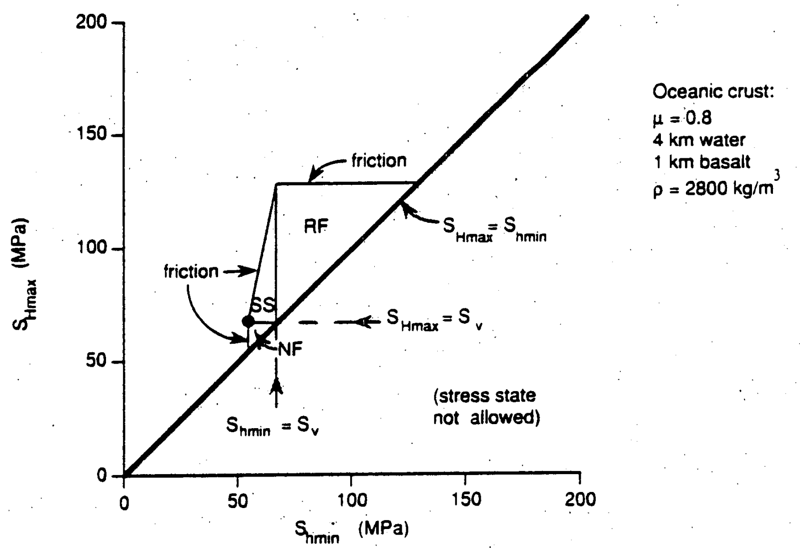


Fig. 1. Allowable stress conditions based on the frictional strength of favorably oriented fault planes, assuming $\mu = 0.8$, for continental crust at 5 km depth and for oceanic crust at 1 km below seafloor. (Note the different scales.) S_v is calculated from the weight of overburden, and pore pressure is assumed to be hydrostatic. The stress state is constrained to lie inside the polygon, because $S_{Hmax} \geq S_{hmin}$, by definition, and the ratio $(S_1 - P_0)/(S_3 - P_0)$ is bounded by friction (equation (1)). For reverse faulting, $S_1 = S_{Hmax}$ and $S_3 = S_v$, defining a maximum bound on S_{Hmax}. For normal faulting, $S_1 = S_v$ and $S_3 = S_{hmin}$, defining a minimum bound on S_{hmin}. For strike-slip faulting, friction bounds the ratio $(S_{Hmax} - P_0)/(S_{hmin} - P_0)$. The circle represents in each case the stress state $S_{Hmax} = S_v$, with S_{hmin} constrained by the frictional strength of normal or strike-slip faults.

field stress difference for static Poisson's ratios <0.25 [e.g., *Carmichael*, 1982].

Effect of Temperature Changes on Borehole Stresses

Additional stresses are applied to the rock at the borehole wall if the well bore fluid is at a significantly different temperature than the rock. These stresses can be compressive or tensile depending on whether the temperature of the fluid is higher or lower, respectively, than the ambient temperature. The effect of temperature is time-dependent, in the sense that the longer the rock is in contact with the well bore fluid, the further away from the hole the temperature perturbation will propagate. *Coussy* [1990] presents a complete treatment of the problem for a Biot coupled thermo-poroelastic material, which requires for its solution detailed knowledge of rock properties such as permeability. However, if one assumes that the material is impermeable with no thermoelastic coupling, simpler integral equations can be written for the magnitudes of $\sigma_{\theta\theta}$ and σ_{rr} as a function of

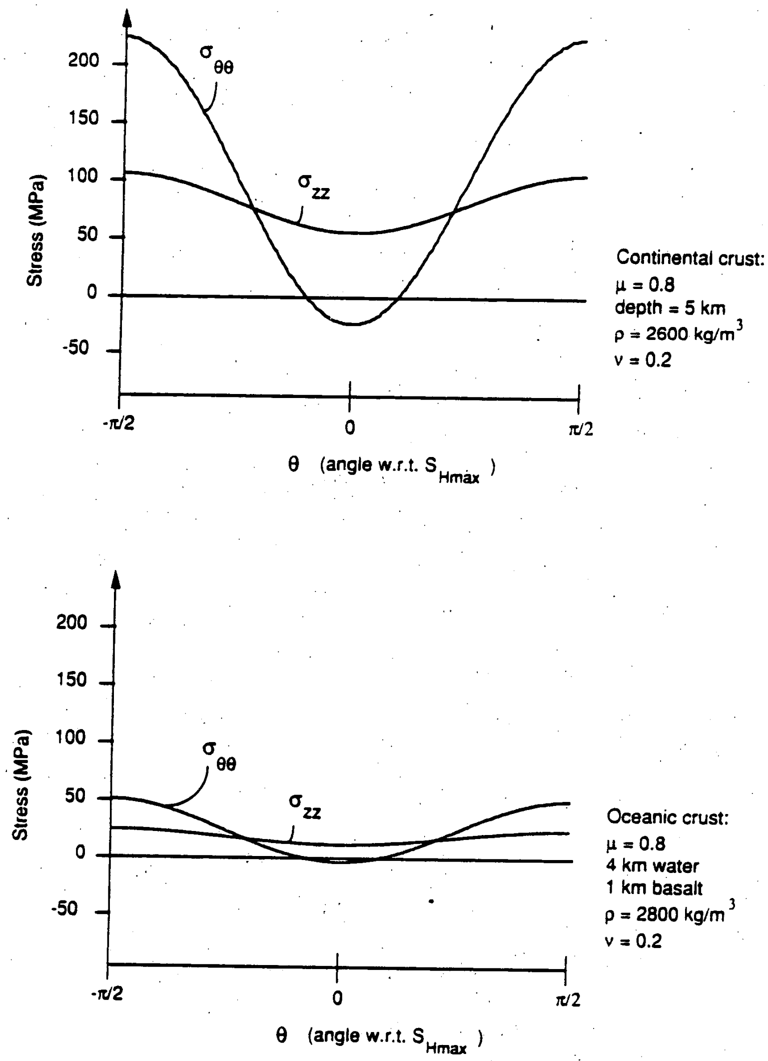


Fig. 2. The distribution of circumferential and vertical stresses around a well bore for the stress states defined by the circles in Figure 1. Note that for these strike-slip-faulting cases the well bore wall is in tension because of the circumferential stress concentration at the azimuth of S_{Hmax}.

radial position r and time t (see, for example, *Stephens and Voight* [1982]). Although the exact solution for the temperature distribution near a constant-temperature well bore is a series expansion [*Ritchie and Sakakura*, 1956], solutions which approximate the temperature using the first two terms of the expansion give sufficiently accurate results close to the hole, and the stresses become

$$\sigma_{\theta\theta} = [\alpha E \Delta T/(1-\nu)]\{[1/(2\rho) - \tfrac{1}{2} - \ln \rho] I_0^{-1} - [\tfrac{1}{2} + 1/(2\rho)]\} \quad (3)$$

$$\sigma_{rr} = [\alpha E \Delta T/(1-\nu)]\{[-1/(2\rho) + \tfrac{1}{2} - \ln \rho] I_0^{-1} - [\tfrac{1}{2} - 1/(2\rho)]\}$$

where

$$I_0^{-1} = \frac{1}{2\pi i} \int_{-\infty}^{0^+} \frac{e^{(4\tau/\sigma^2)z}}{z \ln z}\, dz$$

Here α is the coefficient of thermal expansion; E is the static Young's modulus; ΔT is the temperature difference between the well bore fluid and the rock surrounding the borehole; ν is the static Poisson's ratio; $\sigma = e^{\gamma}$; γ is Euler's constant; ρ is radial position normalized by the well bore radius R; and the parameter $\tau = \kappa t/R^2$ is the Fourier number. Here κ is the thermal diffusivity, and t is the time during which the well bore fluid temperature is perturbed.

If the well bore fluid is colder than the rock, the thermally induced stresses are extensional. This will generally be true where drilling fluids exit the pipe, particularly in Ocean Drilling Program (ODP) and Deep Sea Drilling Project (DSDP) drill holes, as in situ temperatures are generally higher than the temperature of the drilling fluid. However, drilling fluids returning to the surface from greater depths may be somewhat warmer than the undisturbed temperature of the rock and thus may induce compressional thermal stresses. For the purposes of this paper we will consider only the case of the effect of cooling the rock at the drill bit.

Equation (3) is plotted in Figure 3 for various values of time, assuming a 15-cm borehole radius and a coefficient of

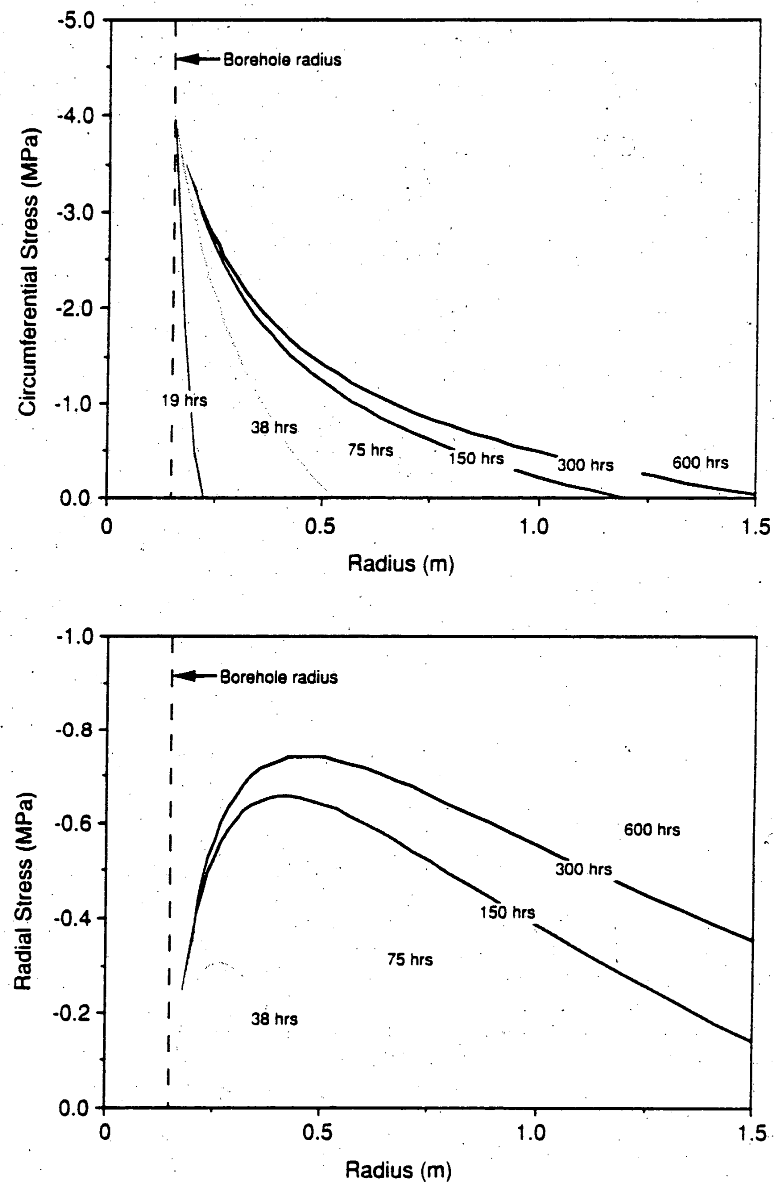


Fig. 3. Radial and circumferential stresses generated by a decrease in well bore fluid temperature of 10°C as a function of time, for a 15-cm-radius borehole drilled through basalt. Plotted as a function of radial distance from the center of the borehole, the lines correspond to pumping times of 19, 38, 75, 150, 300, and 600 hours. After 19 hours the radial stress perturbation is imperceptible at the scale of this plot. As the pumping time increases, the stress perturbations move away from the borehole wall.

thermal expansion of 5.4×10^{-6} °C^{-1} (values appropriate for DSDP and ODP boreholes penetrating oceanic crustal basalts). For these values and a thermal diffusivity $\kappa = 10^{-6}$ m^2/s the curves illustrate the effect of maintaining a 10°C temperature reduction within the well bore for 19, 38, 75, 150, 300, and 600 hours (from less than 1 day to 25 days). For this case, well bore cooling applies 4.1 MPa of circumferential tension at the borehole wall. The thermally applied stress decreases rapidly with radial distance, and after 19 hours of circulation is confined to less than 1 borehole radius. As circulation time increases, the stress anomaly progresses further away from the well bore but even after several weeks of cooling is insignificant beyond about 10 borehole radii (1.5 m). The thermally induced radial stress is zero at the well bore, attains a most tensile value a short distance away from the hole, and decreases at greater distances. The peak of the radial stress anomaly migrates away from the well bore as circulation is maintained for longer times, but as in the case of the circumferential stress, the effect is still confined to within a few borehole radii. Times shorter than 19 hours are not accurately modeled by the simplified (3) above but have a similar form.

WELL BORE FAILURE

In this section we consider the role of tectonic stress, applied fluid pressure and well bore temperature changes in terms of the stresses required to cause compressive and tensile failure.

Conditions for Breakout Formation

As first suggested by *Gough and Bell* [1981] and *Bell and Gough* [1983], breakouts are spalled regions centered on the azimuth of the least horizontal far-field stress and are formed by compressive shear failure due to the large difference between the radial stress and the circumferential stress at that point. *Zoback et al.* [1985] extended this model to account for the shape of the breakout region, using a modified Mohr-Coulomb criterion for shear failure. They showed that breakout shapes are generally consistent with those predicted by the Mohr-Coulomb theory and proposed that information about the shape of breakouts could allow estimates of the horizontal stress ratio. This technique was successfully applied by *Barton et al.* [1988]. It is not our intent in this paper, however, to utilize breakout shape information to constrain the stresses.

In the simple elastic Mohr-Coulomb analysis, compressive failure will occur at the well bore wall due to differences between the circumferential and the radial stress when the stress concentration exceeds C, the strength of the rock, i.e.,

$$\sigma_{\theta\theta} = S_{\text{Hmax}} + S_{\text{hmin}} - 2(S_{\text{Hmax}} - S_{\text{hmin}}) \cos 2\theta - 2P_0 \geq C \tag{4a}$$

for failure due to differences between circumferential and radial stresses, and

$$\sigma_{zz} = S_v - 2\nu(S_{\text{Hmax}} - S_{\text{hmin}}) \cos 2\theta - P_0 \geq C \tag{4b}$$

for failure due to differences between the vertical stress and the radial stress. Because $\sigma_{rr} \sim 0$ (when $\Delta P \sim 0$) and $\sigma_{\theta\theta}$ and σ_{zz} are both nonzero, the stress state around the well bore is polyaxial. In general, rock is stronger under polyaxial conditions than under uniaxial conditions, and as described by *Wiebols and Cook* [1968], the appropriate rock strength when one principal stress is zero is between the uniaxial strength (where $\sigma_2 = 0$) and the biaxial plane strength (where $\sigma_2 = \sigma_1$). Wiebols and Cook relate the biaxial plane strength to the uniaxial strength C_0 through the formula $C_b = C_0(1.0 + 0.6\mu_f)$, where μ_f is the coefficient of sliding friction on microcracks. For reasonable values of μ_f ($\sim$0.6 [*Byerlee*, 1978]), $C_b = 1.36C_0$. Therefore the strength of interest for well bore failure lies within the range $C_0 \leq C \leq 1.36C_0$. In the remainder of the paper we will assume that this range of values is appropriate for the study of breakouts.

Zheng et al. [1989] present a different model for breakout formation by extensional cracking (spalling) parallel to the well bore. As their spalling process requires some microcrack sliding to initiate the tensile cracks, the stresses necessary to initiate breakouts in their model are those required to promote sliding on favorably oriented microcracks. Thus the far-field stress magnitudes are similar to those necessary to cause compressive shear failure in the model of *Zoback et al.* [1985] using the *Wiebols and Cook* [1968] failure criterion. Laboratory results [*Mastin*, 1984; *Haimson and Herrick*, 1986, 1989] show that breakout formation generally occurs at stresses consistent with the Mohr-Coulomb criterion for shear failure as modified to include the effect of the intermediate stress, and although *Haimson and Herrick* [1989] observed features within breakouts that mimic spalling, the stress state for which the breakouts formed was similar to that of the *Zoback et al.* [1985] model. *Vardoulakis et al.* [1988] suggest an alternative failure criterion, based on a rigid plastic pressure sensitive dilatant rheology, and a bifurcation analysis to define failure development. This results both in a modification of the stress concentration at the well bore and a more complicated failure criterion. Unfortunately, this analysis has not yet been developed for unequal stresses acting perpendicular to the well bore and cannot be utilized for interpretation of field observations.

We now consider the in situ stress conditions under which (1) breakouts do not occur, (2) breakouts occur only near the azimuth of S^*_{hmin}, and (3) breakouts occur everywhere around the well bore. The boundaries between these three "fields" in horizontal stress space are determined by the strength of the rock and the differences between the far-field total stresses. In general, it is not necessary to evaluate the conditions for compressive failure due to the vertical stress, as in the region of the well bore the maximum circumferential stress ($3S_{\text{Hmax}} - S_{\text{hmin}} - 2P_0$) is generally greater than the maximum vertical stress ($S_v + 2\nu(S_{\text{Hmax}} - S_{\text{hmin}}) - P_0$), for reasonable values of the static Poisson's ratio ($\leq$0.25), except in the case of normal faulting where the two horizontal stresses are approximately equal ($S_v \gg S_{\text{Hmax}} \approx S_{\text{hmin}}$). For the present we assume that $\Delta P = \Delta T = 0$, but from the discussions above one can see that it is straightforward to vary these parameters and incorporate their effects.

In Figure 4 the fields in which breakouts do and do not occur are shown for an assumed rock strength $C = 200$ MPa for the same depths and conditions as Figure 1. As discussed below, $C \approx 200$ MPa is somewhat high for many crystalline rocks but comparable to the strength of basalt. The allowable stress states defined by the frictional strength of the crust that are shown in Figure 1 are also shown in Figure 4. The breakout fields in the figure are defined using (4a) by $S_{\text{Hmax}} \geq \frac{1}{3}(C + S_{\text{hmin}} + 2P_0)$, for failure only at the azimuth of S_{hmin}, and $S_{\text{hmin}} \geq \frac{1}{3}(C + S_{\text{Hmax}} + 2P_0)$, for failure occurring everywhere around the hole. For a strength of 200 MPa it is clear that at a depth of 5 km on land, breakouts are to be expected under nearly all stress conditions except those of normal faulting, and in a highly compressive tectonic stress state, breakouts would be expected to occur nearly everywhere around the well bore. Conversely, at a depth of 1 km in the ocean crust, breakouts would only occur at relatively high values of S_{Hmax} and a large horizontal stress difference, a reverse/strike-slip stress regime.

Breakouts have been found in many wells drilled on land, and the frequency of breakouts (and the likelihood that breakouts would be encountered) in a given well increases with depth. This can be understood by simply considering limits on the horizontal stresses in reverse-, strike-slip-, and normal-faulting regimes (where the values of S_1 and S_3 are limited by (1) and the coefficient of friction μ) and the criteria for breakout formation due to the circumferential stress concentration (Equation (4)). The relationship between the rock strength and the minimum depth of breakout occurrence from these equations is illustrated in Figure 5. In this figure the vertical stress S_v is equal to the weight of overburden, pore pressure is hydrostatic, and well bore fluid pressure is equal to the pore pressure. The value of the intermediate stress is conveniently defined in terms of a

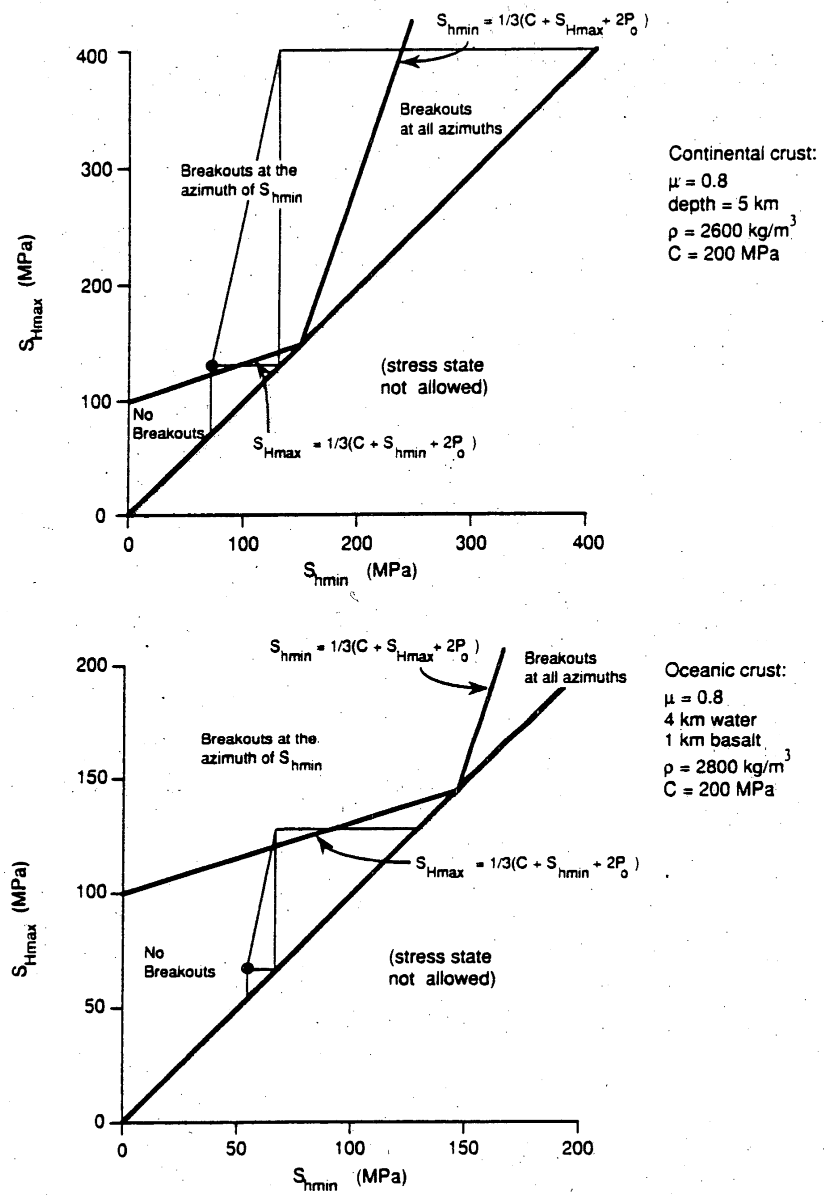


Fig. 4. Schematic illustration of the type of compressive well bore failure (breakout) possible for stress conditions as defined in Figure 1, for a rock strength of 200 MPa. As in Figure 1, the stress state must lie within the bounds imposed by friction and the definition that $S_{Hmax} \geq S_{hmin}$. Note that at 5 km depth in the continents, breakouts will occur for any stress state except a low-stress strike-slip one, whereas at 1 km into oceanic crust, breakouts will only occur if the horizontal stresses are quite high.

parameter ϕ, where $\phi = (S_2 - S_3)/(S_1 - S_3)$ [*Angelier*, 1979]. The figure shows, for the stress states defined by the respective faulting regimes and the value of ϕ, the depth at which breakouts would form for a given strength. As seen in this figure, breakouts develop at much shallower depths in a reverse-faulting regime than in a normal-faulting regime, for a given rock strength. For example, for a rock strength of 200 MPa and $\phi = 0.5$, breakouts would occur below a depth of approximately 1.2 km in a reverse-faulting environment, but in a normal-faulting environment they are not expected until depths of more than 9 km.

Figure 6 presents an analysis similar to Figure 5 for the oceanic crust assuming a water depth of 4 km. In this case, breakout formation occurs roughly at the same depth below the seafloor as below the ground surface on the continents, for the same tectonic stress and rock strength. Unfortunately, wells penetrating more than a few hundred meters of the oceanic crust are extremely rare, and breakouts would be expected only if the level of compressive stress was quite high and the rocks were anomalously weak.

Borehole Televiewer Observations of Well Bore Breakouts

The borehole televiewer (BHTV) is an acoustic logging device which scans the interior wall of a borehole, as first

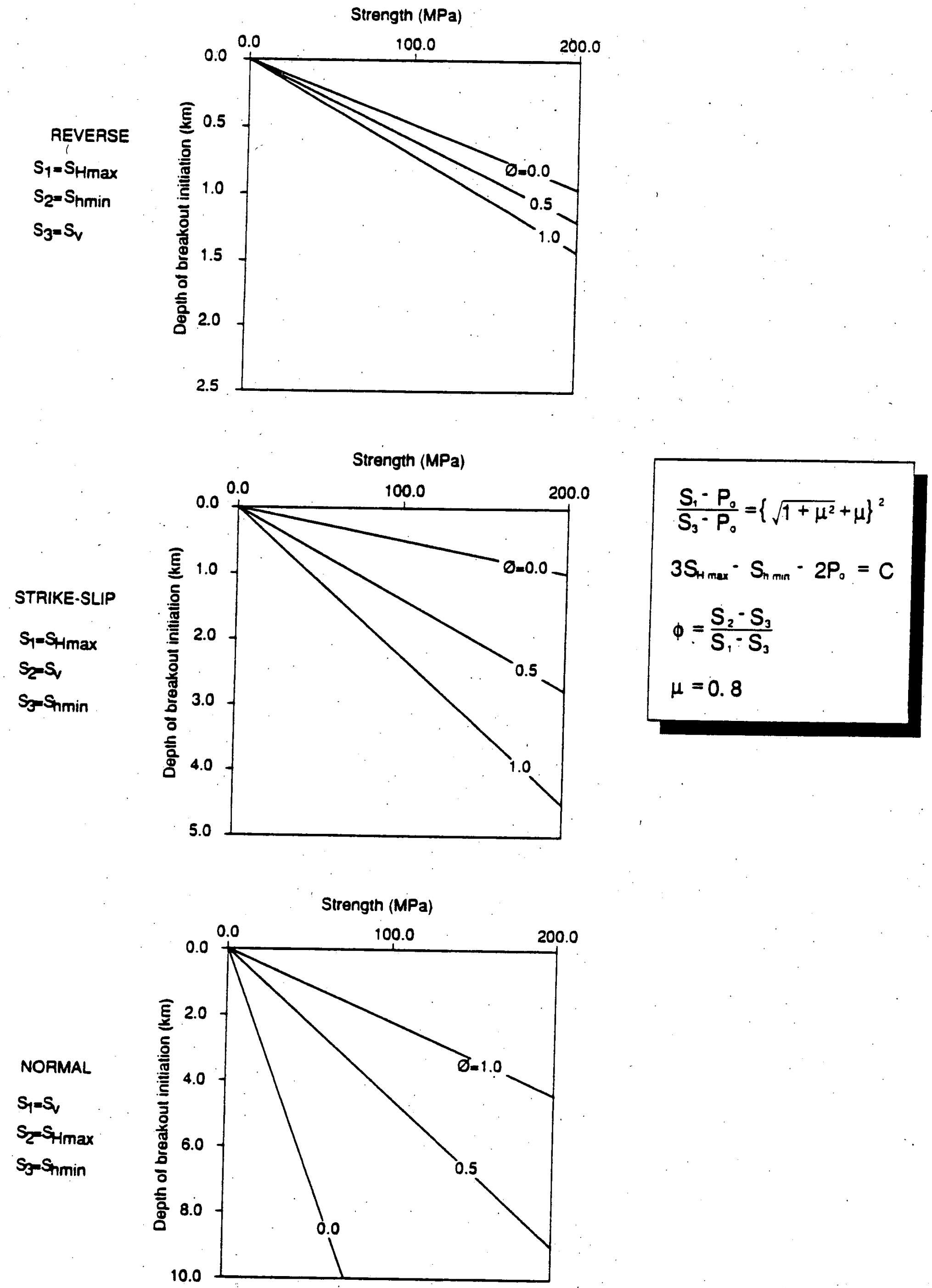


Fig. 5. Minimum depth of breakout formation due to the circumferential stress concentration around a well drilled into continental crust, plotted as a function of rock strength. For each stress state the stresses are at the limit constrained by a coefficient of friction $\mu = 0.8$ on favorably oriented fault planes.

described by *Zemanek et al.* [1970], to produce a magnetically oriented image of the reflectivity of the borehole wall as a function of depth and azimuth in the hole. *Zoback et al.* [1985] demonstrated that breakouts could be imaged with the BHTV and produced the first detailed study of breakout cross sections. Since that time, considerable improvement has been made in the analysis of borehole televiewer data [*Barton*, 1988], and travel times determined from digitized data are now used to determine borehole shape [e.g., *Shamir et al.*, 1988; *Morin et al.*, this issue].

Plate 1*a* shows breakouts imaged with the BHTV in the Cajon Pass research well [*Shamir et al.*, 1988]. The images

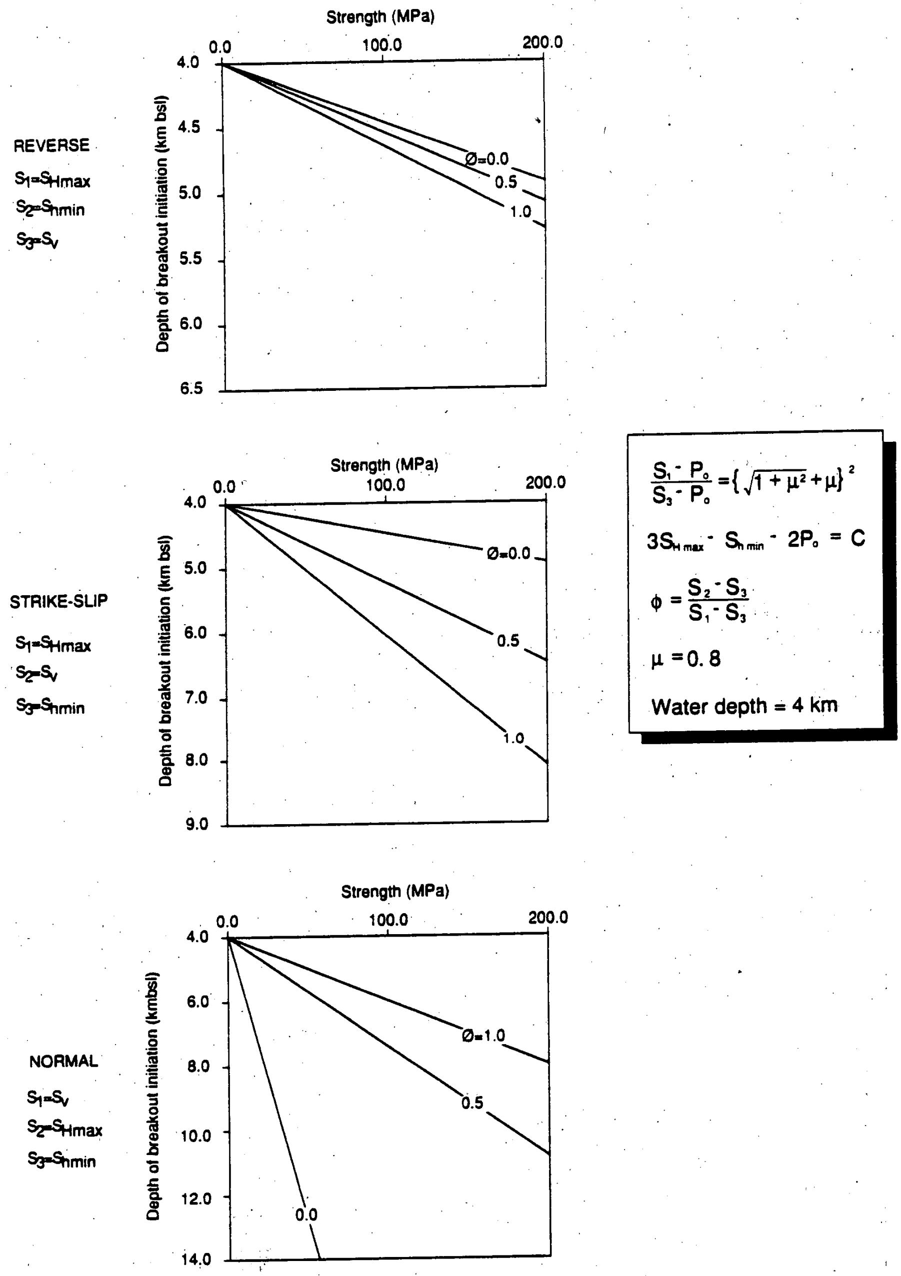


Fig. 6. Minimum depth of breakout formation in kilometers below sea level due to the circumferential stress concentration around a well drilled into oceanic crust overlain by 4 km of water, plotted as a function of rock strength. For each stress state the stresses are at the limit constrained by a coefficient of friction $\mu = 0.8$ on favorably oriented fault planes.

on the left are borehole radius as a function of depth and azimuth. On the right, cross sections of the borehole are shown at various depths. Each cross section involves superposition of three transducer scans (spanning approximately 10 cm vertically). The breakouts appear in cross section as smooth enlargements on opposite sides of the borehole. The amplitude of the reflected signal is lower within the breakout, due to the rougher surface and the fact that the reflection within the breakout is scattered away from the transducer because of nonnormal incidence of the acoustic pulse. As a result, one finds that often a reflection is returned only from the back of the breakout. In the images on the left side of the figure the breakouts appear as irregular vertical bands spanning several meters along the borehole.

Conditions for Tensile Failure

The conditions for tensile failure have been discussed extensively in the context of hydraulic fracturing. In typical

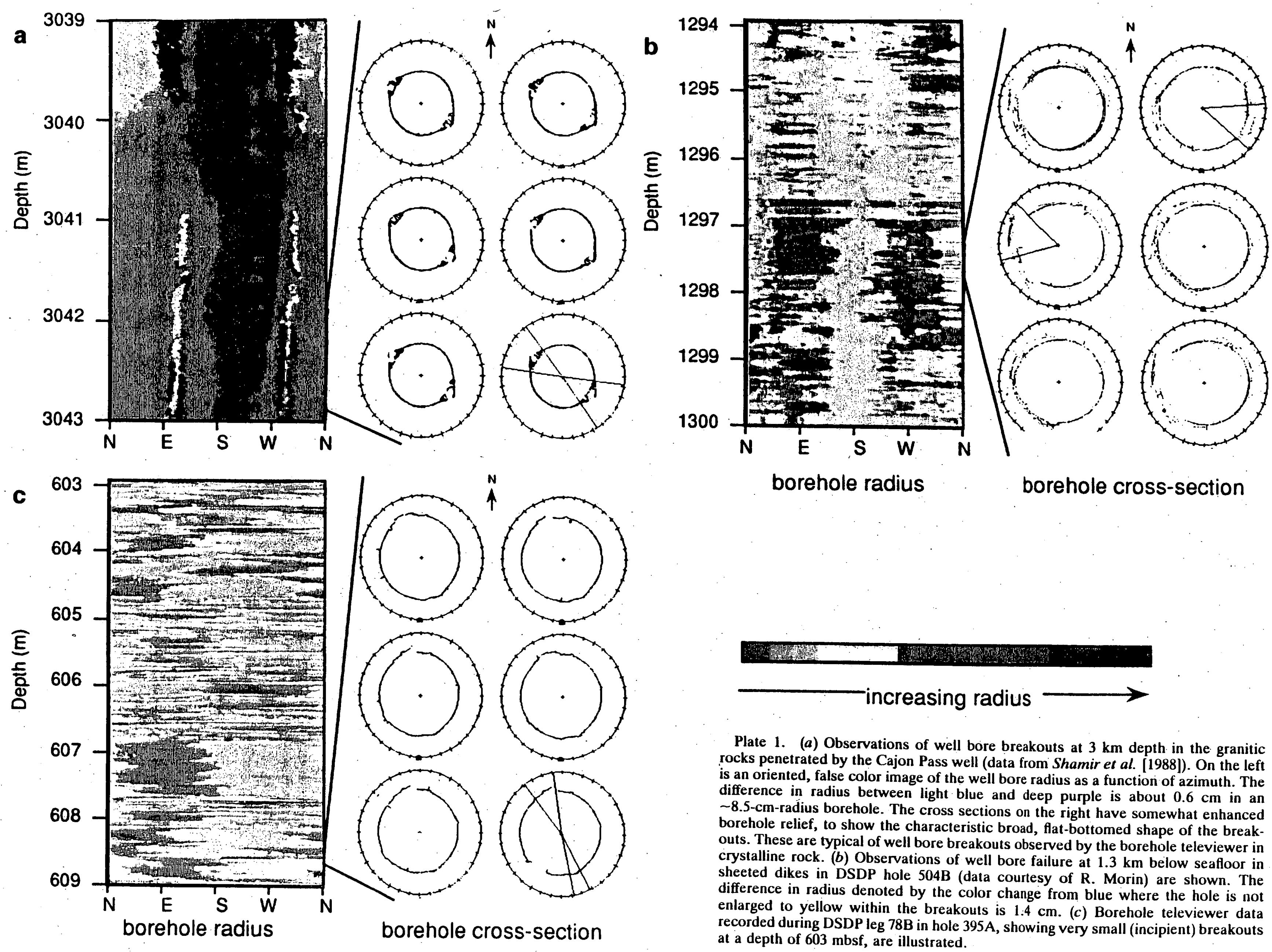
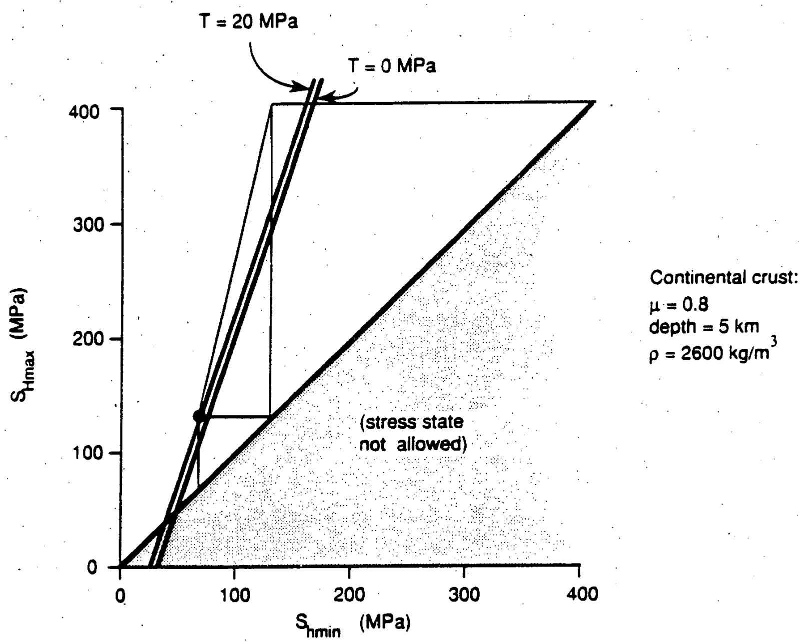


Plate 1. (*a*) Observations of well bore breakouts at 3 km depth in the granitic rocks penetrated by the Cajon Pass well (data from *Shamir et al.* [1988]). On the left is an oriented, false color image of the well bore radius as a function of azimuth. The difference in radius between light blue and deep purple is about 0.6 cm in an ~8.5-cm-radius borehole. The cross sections on the right have somewhat enhanced borehole relief, to show the characteristic broad, flat-bottomed shape of the breakouts. These are typical of well bore breakouts observed by the borehole televiewer in crystalline rock. (*b*) Observations of well bore failure at 1.3 km below seafloor in sheeted dikes in DSDP hole 504B (data courtesy of R. Morin) are shown. The difference in radius denoted by the color change from blue where the hole is not enlarged to yellow within the breakouts is 1.4 cm. (*c*) Borehole televiewer data recorded during DSDP leg 78B in hole 395A, showing very small (incipient) breakouts at a depth of 603 mbsf, are illustrated.



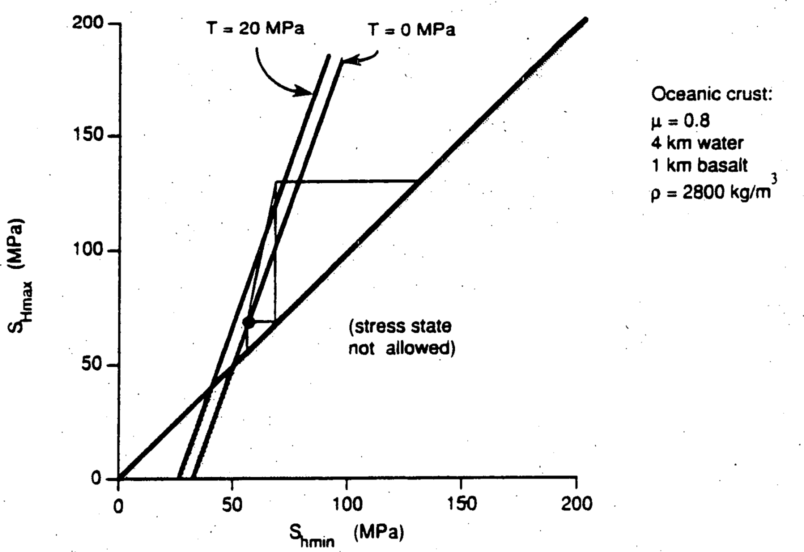


Fig. 7. Stress conditions necessary to cause tensile fracturing at the azimuth of S_{Hmax}, for the stress conditions defined in Figure 1. The lines illustrate the stress values necessary to cause tensile failure for the given values of tensile strength, if the well bore fluid pressure is equal to the ambient pore pressure (i.e., $S_{Hmax} = 3S_{hmin} - 2P_0 + T$). Tensile failure can occur under normal drilling conditions where the lines intersect the polygon constraining the stress state. For example, the stress state indicated by the circle will cause tensile failure if the tensile strength is zero, as shown also in Figure 2.

hydraulic fracturing operations, increasing the fluid pressure in the well bore induces tensile failure in a vertical well bore at the azimuth of the greatest far-field horizontal principal stress. Hydraulic fractures will be produced when the pressure in the well bore exceeds the sum of the tensile strength and the circumferential stress concentration. Written in terms of the total stresses and the pore pressure, this condition [after *Hubbert and Willis*, 1957] is

$$P_b = 3S_{hmin} - S_{Hmax} - P_0 + T \quad (5)$$

where P_b is termed the breakdown pressure and T is the tensile strength.

Under certain tectonic stress conditions, however, tensile failure occurs during drilling simply because of the pressure of the fluid column in the borehole resulting in "drilling-induced" hydrofracs. At the Nevada Test Site (NTS), where

TABLE 1. Relationship Between Observed and Predicted Breakout Depths

Well Name	C_0, MPa	C, MPa	Measured ϕ	Stress Regime	Depth of Breakout Initiation, km	Predicted Depth of Initiation, km	Predicted Range of ϕ
Moodus	>105*	>105–143	0.5	R	~1.1	0.90–1.22	>0.25
NTS	15–120†	15–163	0.35–0.6	N	~1.1	0.50–5.45	>0.3
Cajon Pass	100–150*	100–204	1.0	N/SS	~2.7	2.30–4.47	>0.9
Fenton Hill	124–176‡	124–240	1.0	N/SS	2.9	2.88–5.58	>0.85

*C_0 inferred from tensile strengths measured using the Brazilian test and the relationship between tensile and uniaxial compressive strength $C_0 \sim (8–12)T_0$.
†*Price and Bauer* [1985].
‡T. Dey (personal communication, 1987) [after *Barton et al.*, 1988].

the ambient pore pressure is appreciably subhydrostatic, the water used to fill the well bore during drilling frequently caused hydraulic fractures to occur [*Stock et al.*, 1985].

Figure 7 illustrates the range of stresses that could lead to tensile failure at the well bore, if the well bore fluid pressure is equal to the ambient pore pressure. Tensile failure can occur for a given value of tensile strength if the stress state lies to the left of the indicated line. Drilling-induced hydrofracturing can occur whenever the horizontal stress ratio is close to the limit constrained by the strength of strike-slip faults (i.e., where the ratio of the effective principal horizontal stresses is about 3). In some cases, as a consequence of the excess pumping pressure required to lift cuttings, the pressure at the bottom of a well during drilling can exceed the pressure due to the static fluid column by as much as 10 MPa. This is equivalent to reducing the "effective" tensile strength and would shift the lines of constant tensile strength to the right, making tensile failure more likely. Nevertheless, it is clear that the presence of drilling-induced hydraulic fractures would still constrain the possible stress state to be close to that associated with incipient strike-slip faulting.

Tensile failure at the well bore can also be induced by the thermal stresses associated with well bore cooling. *Allison and Nielson* [1988] observed features in four-arm caliper (dipmeter) logs in geothermal wells which may be due to tensile fractures developed because of well bore cooling. Similarly, tensile fractures were produced during drilling in geothermal fields in France and are suggested to have formed in the KTB (German deep drilling project) pilot hole (L. Mastin, written communication, 1989). The effect of thermal stresses is equivalent to that of the excess well bore pressure. Cooling the well would induce tensile thermal stresses, lower the apparent tensile strength, and promote tensile failure. Depending on the magnitude of the thermal stress, this could lead to failure within the oceanic crust even if the rock is fairly strong.

Thus although the presence of tensile cracks requires a large ratio of effective horizontal stresses and a strike-slip-faulting regime, it does not generally differentiate between cases in which $S_v \approx S_{Hmax}$ (strike-slip and normal faulting) and $S_v \approx S_{hmin}$ (strike-slip and reverse faulting). Distinguishing between these cases requires observations related to compressive failure (breakouts).

Application to Continental Crust

Over the past 5 years a number of wells have been studied in sufficient detail that data are available on the magnitude of in situ stresses, distribution of well bore breakouts, and compressive strength of the rock. This makes it possible either to utilize all of the data that are available from these wells to test the overall validity of the analysis, or to utilize only a portion of the available data in an attempt to place constraints on stress magnitudes simulating the general approach that we are suggesting for cases in which relatively complete information from a given well is not available.

Table 1 summarizes the key information from several wells in which the state of stress was found to be consistent with that predicted from the frictional strength of well-oriented faults (that is, in accordance with (1)) and for which information is available on the distribution of well bore breakouts and rock strength. Note that these four cases involve normal, normal/strike-slip, and reverse-faulting environments. Relatively continuous breakouts were observed in each case from the shallowest depth to the total drilled depth.

Utilizing (4*a*) and the information on strength and stress magnitudes in Table 1, we can calculate the range of depths below which "relatively continuous" breakouts would be expected in each well. The term relatively continuous refers to the fact that we want to consider failure of the well bore at representative stresses and rock strength values, not isolated and discontinuous breakouts that might be observed only in selected sections of the well bore where locally the rock might be unusually weak. We compare the observed depth below which breakouts are relatively continuous with the calculated depths. In each case the depth below which relatively continuous breakouts were observed is within the range predicted by the calculation. However, one must keep in mind the fact that the strength values are poorly constrained by laboratory measurements, particularly where unconfined compressive strength is calculated, rather than measured directly. In fact, the largest range of predicted depth (at NTS) is the one for which the largest range of strengths were assumed. The NTS wells were drilled into imbricated tuffs, for which the strengths depended on the degree of imbrication, which varied greatly from unit to unit. In general, breakouts were only observed in the weaker units, consistent with the known stress state. Aside from this case the depth of initiation observed is close to the lowest calculated value, suggesting that the appropriate strength is closer to C_0 than to C_b.

Alternatively, one can use the depth of breakout initiation to constrain the stress state. Table 1 shows the range of ϕ values predicted on the basis of the breakout distribution if the vertical stress and one limiting stress are known. In all cases the vertical stress was measured, and the stress magnitudes are at failure equilibrium; therefore (1) is valid for these data. The comparison between the calculated range of ϕ and the measured values illustrates our ability to predict one of the three principal stresses simply from knowledge of

TABLE 2. Physical Properties of Oceanic Basalts

Parameter	Value
Tensile strength T	23–34 MPa
Unconfined compressive strength C_0	170–224 MPa
Poisson's ratio ν	0.17–0.25
Young's modulus E	50–70 GPa
Thermal expansion coefficient α	$5.4 \pm 1 \times 10^{-6}$ °C^{-1}
Thermal diffusivity κ	1×10^{-6} m^2/s

the depth range of compressive well bore failure and of the other two stresses. In each case the predicted range includes the known value of ϕ. The power of the method lies in its ability to restrict ϕ and hence to place one bound (either a lower or an upper bound) on the intermediate stress. For example, for Moodus, where ϕ was measured to be 0.5, the analysis constrains ϕ to lie above 0.25. For NTS, where ϕ is between 0.35 and 0.6, the analysis requires ϕ to be greater than 0.3. At Cajon Pass and Fenton Hill, where ϕ is close to 1, the analysis also predicts very large values for this ratio.

All of these results are limited by our knowledge of the appropriate value of rock strength. The large range of values for ϕ result from the large range of possible values for C. These uncertainties will persist until laboratory strengths can be determined for rock from within these wells both in intervals which contain breakouts and in those which do not.

Application to Oceanic Crust

Although a large number of boreholes have been drilled into oceanic basement during the DSDP and ODP, only a small number of these have been logged with the borehole televiewer, and none have been tested by hydraulic fracturing. As described above, the presence of breakouts allows the determination of the orientation of the principal horizontal stresses and places a lower bound on the stress difference, whereas the absence of breakouts provides an upper bound on the stress difference. If tensile cracks are present, a further constraint can be placed on the ratio of the effective principal horizontal stresses.

We make the following assumptions in this analysis. First, we can reasonably assume that the in situ pore fluid pressures are close to hydrostatic. In fact, measured pore pressures in hole 504B [*Anderson and Zoback*, 1982], hole 395A [*Hickman et al.*, 1984*a*], and hole 597C [*Shipboard Scientific Party*, 1985] indicate that pore pressures are within 1 MPa (2.5%) of hydrostatic. We also assume that S_v is a principal stress and is equal to the weight of the overlying rock and seawater.

To place constraints on the stresses necessary for well bore failure, we need to know the properties of the basalts. Table 2 shows typical values for the parameters necessary for these calculations [*Clark*, 1966; *Carmichael*, 1982]. With the exception of one anomalously low-strength sample, *Bauer and Handin*'s [1985] measurements of E and C_0 of basalts from DSDP hole 504B lie within the range presented in this table.

There is considerable scatter in these data, particularly for the tensile and unconfined compressive shear strengths. The constraints presented below should therefore be considered in light of this fact and will have to serve until better information concerning the strength of specific oceanic basalts is available. For the purpose of this paper we will use the following (average) values of the properties tabulated above: $T = 28.5$ MPa, $C_0 = 200$ MPa, $\nu = 0.2$, $E = 60$ GPa, $\alpha = 5.4 \times 10^{-6}$ °C^{-1}, and $\kappa = 1 \times 10^{-6}$ m^2/s.

DSDP Holes 504B and 501

Hole 504B was drilled over a succession of DSDP and ODP legs to a total depth of 1562 m below seafloor (mbsf) in 3460 m of water and penetrates over 1200 m of 5.9-Ma oceanic crust south of the Costa Rica Rift (Figure 8). Pillows and minor flows were encountered in the uppermost 571.5 m of basement, below which was a 209-m transition zone followed by sheeted dikes and massive units [*Becker et al.*, 1989].

In hole 504B, *Newmark et al.* [1984] observed stress-induced well bore breakouts in the section of the hole drilled on legs 69 and 70. *Morin et al.* [this issue] digitized both the televiewer data from the leg 83 log and from a log recorded during leg 111. The digitized data cover a depth range from 440 mbsf to 1525 mbsf. The uppermost 170 m of basement could not be studied, as no data were recorded on tape during the log of this interval on leg 83. *Morin et al.* [this issue] identify a bimodal distribution of hole enlargements throughout the interval from about 700 mbsf to total depth and attribute the predominant azimuth of enlargement (117.5° ± 20°) to compressive failure (breakouts) and the secondary mode (about 27°) to tensile failure. The breakouts become nearly continuous below about 1.2 km below seafloor. The maximum compression direction inferred from these data (N27.5°E) agrees with the P axes of focal plane mechanisms of nearby earthquakes [*Bergman*, 1986].

Plate 1*b* presents a short section of digitized televiewer data from leg 111. The leg 111 data contain clearly imaged well bore enlargements, over the interval 1294–1300 mbsf, within the intrusive section of sheeted dikes. Hole enlargements occur at 90° and 270° here, within the range of scatter of the measurements presented by *Morin et al.* [this issue]. Although the breakouts are not as regular or as well imaged in data from hole 504B as they are in holes such as Cajon Pass (Plate 1*a*), the fact that enlargements occur on both sides of the hole, and at a generally consistent azimuth, suggests that they are stress-induced.

DSDP hole 501 was drilled 400 m west of hole 504B through 264 m of sediments and penetrated 73 m of basement. Core recovery was moderate and indicated a mixed assemblage of pillows and massive units. Televiewer data were recorded in the uppermost 25 m of basement only, but data were recorded in almost the entire sedimentary section [*Zoback and Anderson*, 1982]. We analyzed these data in detail and found no breakouts, either in the sedimentary section or in the basement interval.

The presence of breakouts within the depths penetrated by hole 504B demonstrates that high horizontal stresses must exist at a relatively shallow depth of less than 1 km into young oceanic crust. To illustrate this, we present in Figure 9 schematic plots of two possible stress states at sites 501 and 504. In these figures we calculate S_v from the weight of the overlying rock and seawater. In Figure 9*a* we assume that the stress regime is extensional, with $S_1 = S_v = S_{\mathrm{Hmax}}$, and allow S_{hmin} to range between that value and the value limited by a coefficient of friction $\mu = 0.8$. In Figure 9*b* we assume the stress regime is compressional, with $S_3 = S_v = S_{\mathrm{hmin}}$, and allow S_{Hmax} to range between that value and the

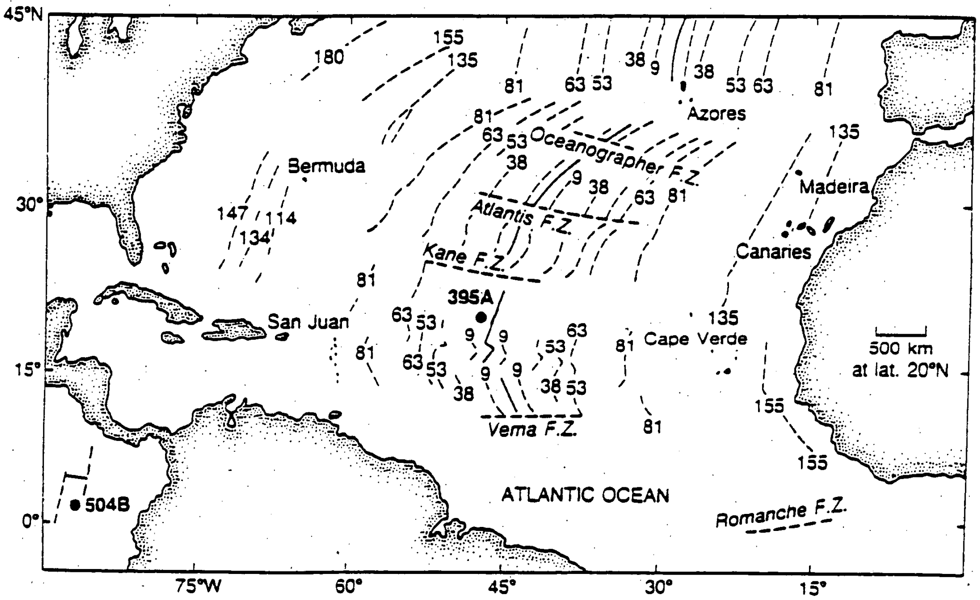


Fig. 8. Map [after *Hyndman and Salisbury*, 1984] showing the locations of DSDP hole 504B and of DSDP hole 395A. Hole 501 is within the area covered by the circle at site 504. The orientations of nearby spreading centers and transforms are also shown.

value limited by a coefficient of friction $\mu = 0.8$. In each case, setting one horizontal stress equal to S_v is equivalent to the most favorable stress state for the formation of breakouts. Lines are shown illustrating the value of rock strength (C) below which breakouts would occur for a given value of the unknown principal stress. It is evident in Figure 9*a* that breakouts cannot occur in an extensional stress environment at the depths penetrated by DSDP hole 504B unless the rock strengths were less than 75 MPa. This is a factor of 3 smaller than the average value of C_0 of more than 200 MPa measured by *Bauer and Handin* [1985]. We see in Figure 9*b*, however, that for a rock strength of between 200 and 272 MPa ($C_0 \leq C \leq 1.36C_0$), nearly continuous breakouts would be expected to occur at depths of about 1 km below seafloor, but only if the maximum horizontal stress was at the limit imposed by the strength of reverse faults and $\phi = 1$ (or $S_{hmin} = S_v = S_3$).

As illustrated in Figure 9, *Morin et al.* [this issue] report relatively continuous breakouts in hole 504B below about 1.2 km below seafloor. Therefore S_{Hmax} must be quite high (close to the limit constrained by the frictional strength of the crust), and S_{hmin} must be equal to S_v. Short intervals with breakouts which occur above that depth can be explained simply by localized sections of the hole with lower than average compressive strength. *Morin et al.* [this issue] also report the presence of tensile failure in DSDP hole 504B. We can develop a similar set of criteria for tensile failure, to constrain the ratio of the horizontal stresses. However, in this instance the thermal stress and therefore the temperature difference due to pumping cold fluid into the well bore must be known.

Calculating the thermal effect of circulation is quite difficult as pumping rate, rotation rate, fluid viscosity, and the temperature profile outside the pipe all influence the heat transfer among the drilling fluid, the fluid outside the pipe, and the rock surrounding the hole. Furthermore, although drilling fluids exiting the bit may cool the bottom of the hole, returning fluids may warm shallower sections. However, estimates of the minimum temperature perturbation can be obtained from temperature logs run shortly after circulation ceased. Temperatures within hole 504B were recorded a number of times, either shortly after drilling or after the well bore had equilibrated during legs 69, 70, 83, 92, and 111 [*Becker et al.*, 1989]. On the basis of the results of these measurements, drilling and circulating within hole 504B resulted in a minimum of 40°C cooling of the bottom of the well bore. During each circulation phase, shallower sections of the hole may have been warmed somewhat. As suggested by *Morin et al.* [this issue], temperatures were most strongly perturbed at the points where the fluid exited the pipe and for the periods during which the hole was deliberately cooled prior to logging. On the basis of 40°C cooling, the rock properties in Table 2, and (3), the minimum additional circumferential tensile stress applied during circulation within hole 504B is 16.4 MPa. Figures 10*a* and 10*b* are similar to Figures 9*a* and 9*b* and illustrate the stress conditions necessary to cause tensile failure at the borehole wall if well bore fluid pressure is equal to the in situ pore fluid pressure. The additional stresses generated by well bore cooling can be considered simply by reducing the tensile strength by the magnitude of the tensile thermal stress. In other words, a tensile strength of 20 MPa and a tensile thermal stress of 20 MPa are equivalent to a zero effective tensile strength. For the assumed average tensile strength of 28.5 MPa and a 40°C decrease in well bore temperature, the effective tensile strength is 12.1 MPa. For this strength and the reverse/strike-slip stress regime required for breakouts, tensile failure could occur at almost any depth below the top of basement. Thus the stress state required to produce breakouts would also produce tensile failure by well bore cooling, and it is therefore not surprising that such features were observed by *Morin et al.* [this issue].

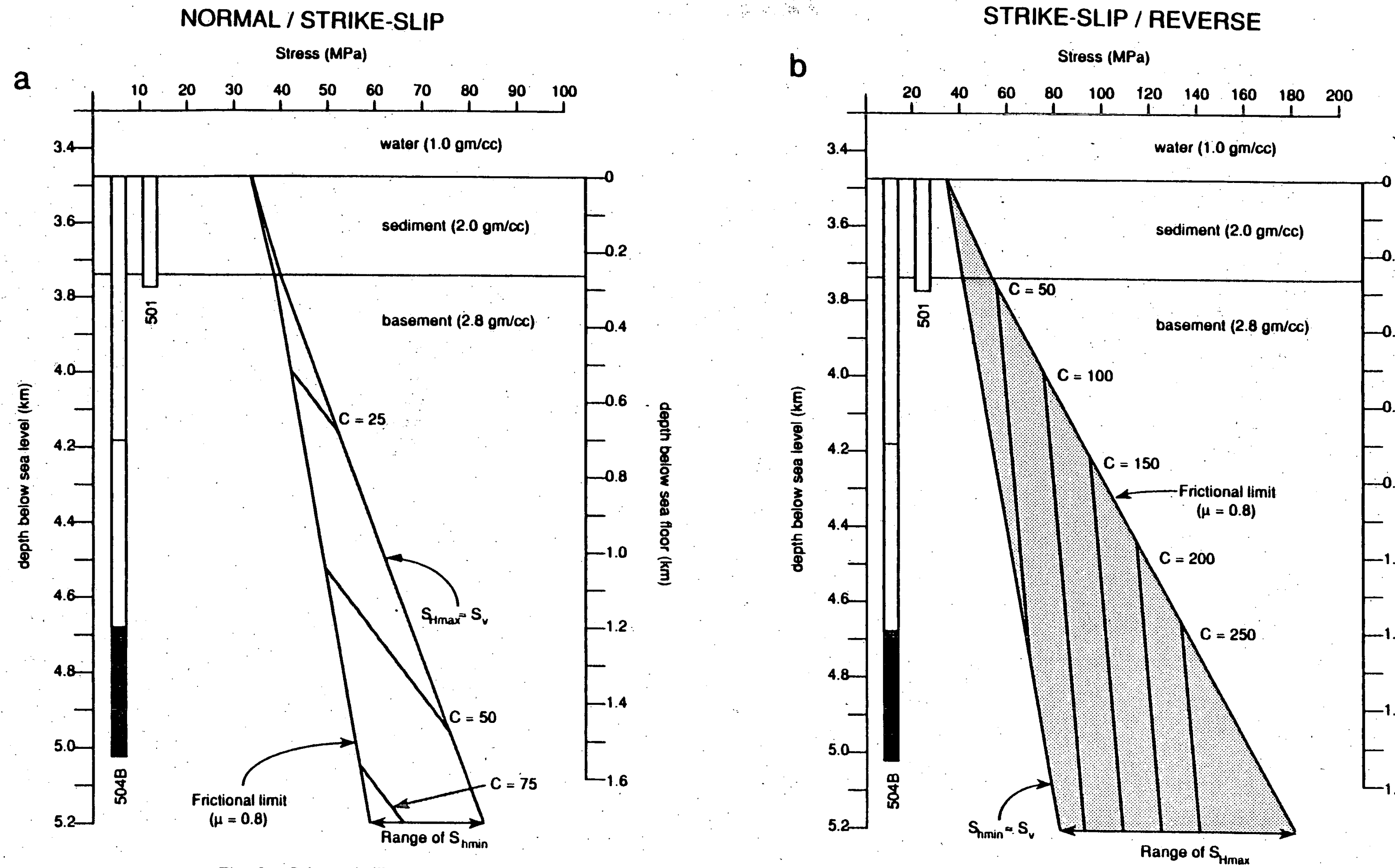


Fig. 9. Schematic illustration of possible stress conditions at DSDP sites 504 and 501. Also shown is the incidence of breakouts in holes 504B [*Morin et al.*, this issue] and 501. No breakouts were observed in 501, and breakouts were intermittent in 504B below about 700 mbsf, common below about 1.2 km below seafloor, and nearly continuous below about 1.5 km below seafloor. (*a*) A normal/strike-slip environment, with $S_{Hmax} = S_v = S_1$, $S_{hmin} = S_3$, is shown. S_{hmin} can range from equal to S_{Hmax} to a minimum value controlled by friction (equation (1)). The lines are $S_{Hmax} = \frac{1}{3}(S_{hmin} + P_0 + C)$, for the values of C shown. (*b*) A strike-slip/reverse environment, with $S_{hmin} = S_v = S_3$, $S_{Hmax} = S_1$, is also illustrated. S_{Hmax} can range from equal to S_{hmin} to a maximum value controlled by friction (equation (1)). The lines are $S_{hmin} = 3S_{Hmax} - C - 2P_0$ for the values of C shown. In each case, breakouts will form only if the rock strength C is below the contoured values. For strengths of 200–270 MPa, typical of samples from hole 504B [*Bauer and Handin*, 1985], breakouts would not be expected in a normal/strike-slip environment at any depth penetrated by hole 504B. The observations of breakouts are, however, consistent with a reverse-faulting regime with S_{Hmax} close to the limit imposed by a coefficient of friction $\mu = 0.8$.

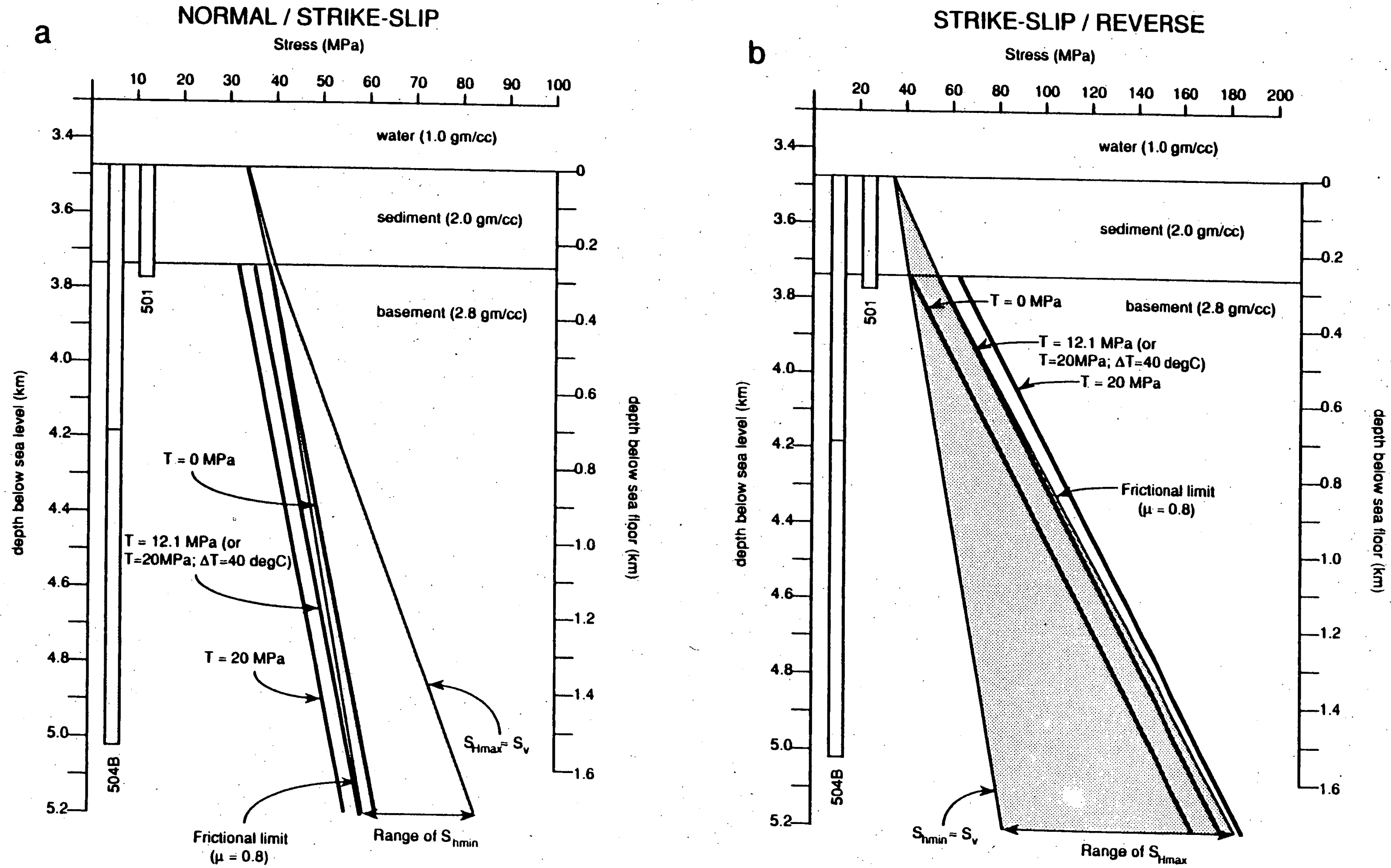


Fig. 10. Schematic illustration of possible stress conditions at DSDP sites 504 and 501. The stress states are as described in the caption Figure 9. Also shown is the depth range over which tensile failure was observed in hole 504B [*Morin et al.*, this issue]. (*a*) The maximum values of S_{hmin} for which tensile failure would occur at a given depth if the tensile strength of the rock is below the indicated values and the stress regime is transitional between normal and strike-slip faulting. (*b*) The minimum values of S_{Hmax} for which tensile failure would occur at a given depth if the tensile strength of the rock is below the indicated values and the stress regime is transitional between reverse and strike-slip faulting. In both cases it is assumed that the fluid pressure in the well bore is equal to the pore pressure in the rock and that the fluid temperature is equal to the ambient temperature. The intermediate value of tensile strength is the effective tensile strength computed assuming a 40°C decrease in well bore temperature during fluid circulation and a tensile strength of 28.5 MPa. Note that the presence of tensile cracks is only somewhat more likely for a reverse-faulting regime, but that in either a reverse- or normal-faulting regime the maximum horizontal stress difference (strike-slip equilibrium) is required.

DSDP HOLE 395A

DSDP site 395 is situated on the edge of a small sediment pond near the center of magnetic anomaly 4, at 22°45'N latitude, in 7.4 Ma crust between the Kane and the Vema fracture zones (Figure 8). Hole 395A was drilled to a total depth of 664 m below seafloor in 4493 m of water, through 93 m of sediments and 571 m of pillow basalts. A borehole televiewer log was obtained during DSDP leg 78B in the interval from 112 mbsf to 609 mbsf [*Hickman et al.*, 1984*b*]. Well bore enlargements satisfying the criteria for breakouts (that is, that enlargements were observed on both sides of the hole over a series of successive scans) were observed only near the bottom of the hole. No indications of well bore failure in tension were observed within hole 395A.

Plate 1*c* shows an example of the breakout data within DSDP hole 395A. Although the breakouts are impossible to resolve in the panel on the left, the well bore cross sections on the right clearly reveal shallow, poorly developed well bore enlargements oriented at approximately N20°W and S20°E. These indicate a maximum compressive stress N70°E, about 60° to the trend of the mid-Atlantic Ridge. The fact that the breakouts are very small and occur only intermittently suggests that the stresses are barely large enough to cause failure, and then only for anomalously weak rock.

Figure 11 shows possible stress regimes at site 395, along with lines for breakout formation as a function of maximum stress for various values of rock strength. As in the case of hole 504B, no breakouts would be expected in an extensional regime (Figure 11*a*) unless the rock is extraordinarily weak. Furthermore, Figure 11*b* illustrates that for a rock strength of 200 MPa, breakouts would not be expected even near the bottom of the hole, regardless of the state of stress. The well bore enlargements seen near the bottom of the hole could only occur by compressive shear failure if the rock strength in that short interval is about 150 MPa and if S_{Hmax} was at the limiting stress for reverse faulting and $S_{\mathrm{hmin}} = S_v$. These results are quite similar to those obtained at site 504, and together they suggest that in relatively young crust in both the Atlantic and the Pacific Oceans, very large compressive stresses are at a large angle to the ridge axes.

An attempted hydraulic fracturing experiment in this hole [*Hickman et al.*, 1984*a*] was unsuccessful after attaining an excess well bore fluid pressure of 15.2 MPa. The experiment was conducted with the packer set at a depth of 582 mbsf, in competent rock near the bottom of the hole. Using the values for tensile strength from Table 2 (23–34 MPa), the fact that breakdown did not occur is not surprising. Even if the state of stress implied by the breakouts near the bottom of the hole is correct, the expected breakdown pressure would be over 50 MPa. Temperature profiles recorded during leg 78B [*Becker et al.*, 1984] and during ODP leg 109 [*Shipboard Scientific Party*, 1988*b*] indicate that temperatures were essentially isothermal to 250 mbsf. Extrapolating a conductive gradient to total depth indicates a maximum thermal "shock" of less than 5°C, and thus the maximum applied circumferential tensile stress at the borehole wall due to this flow is about 7 MPa, much too small to substantially aid development of tensile cracks.

DSDP HOLE 597C

Site 597 is located at latitude 18°14'S, longitude 129°46'W, and is the westernmost site of an east-west transect of the southeast Pacific conducted during DSDP leg 92. DSDP hole 597C, drilled into 28.5-Ma crust (water depth 4160 m) generated at the Mendoza Rise, penetrated 52.5 m of sediments and 91 m of oceanic basalts; the hole has a reentry cone and therefore can be reoccupied and deepened in the future. Recovery was almost 54% and consisted largely of massive basalts [*Shipboard Scientific Party*, 1985]. Two complete BHTV logs were made in the hole within the basement interval. *Newmark et al.* [1984] reported the presence of intermittent breakouts throughout the total depth of the hole, from which a maximum horizontal compressive stress direction of N110°E ± 25° was determined. The presence of breakouts at such shallow depths is quite unusual, on the basis of both our experience and the theories presented above, and therefore we reanalyzed the data to confirm their presence.

No evidence of breakouts was found. Although the water depth and sediment thickness are slightly different at site 597 than those at sites 395 or 504, a figure similar to Figures 9 or 11 would reveal that breakouts could not develop at the depths penetrated by hole 597C (to 140 mbsf) even in a highly compressive stress regime, unless rock strength is extremely low. For a compressive strength of 200–270 MPa this borehole would have to be drilled an additional 600 m before breakouts might be expected. On the basis of these considerations, measurements of stress orientation from well bore enlargements in hole 597C should be treated with caution.

DISCUSSION OF SITES 504B AND 395A

Summarizing the results of previous work and of the above analyses, breakouts were observed in DSDP hole 504B and in the bottom of DSDP hole 395A, and no breakouts were observed at shallow depths in DSDP hole 501 or in DSDP hole 597C. Tensile failure within hole 504B could have occurred only with the addition of large tensile stresses generated by well bore cooling. The orientation of maximum compression inferred from the breakouts in holes 504B and 395A is roughly perpendicular to nearby ridge axes and in the case of hole 504B is parallel to that inferred from nearby earthquake focal mechanisms, as pointed out by *Morin et al.* [this issue]. In order for breakouts to occur at the depths penetrated by these wells, the stress state must be $S_{\mathrm{hmin}} \approx S_v \ll S_{\mathrm{Hmax}}$; S_{Hmax} must be large enough to cause reverse faulting on planes with a coefficient of friction μ = 0.8.

The presence of thermally induced tensile fractures in hole 504B, and their absence in hole 395A, can be related to differences in the temperature profiles within the two holes. Heat flow at site 504 is about 200 mW/m^2 [e.g., *Langseth et al.*, 1988; *Becker et al.*, 1989], and the temperature gradient in hole 504B is also quite high. In contrast, heat flow in the sediments at site 395 is of the order of 37 mW/m^2, less than one fifth that at site 504 [*Hussong et al.*, 1979]. The undisturbed temperature gradient within basement at site 395 is similarly quite low, a consequence of strong lateral convection within shallow basement [e.g., *Becker et al.*, 1984; *Kopietz et al.*, 1990]. Thus temperatures increase much more slowly with depth within hole 395A, and the likelihood of large thermal stresses generated by fluid circulation at equivalent depths in 395A is therefore much smaller than in 504B.

Figure 12*a*, which gives an overview of earthquake focal

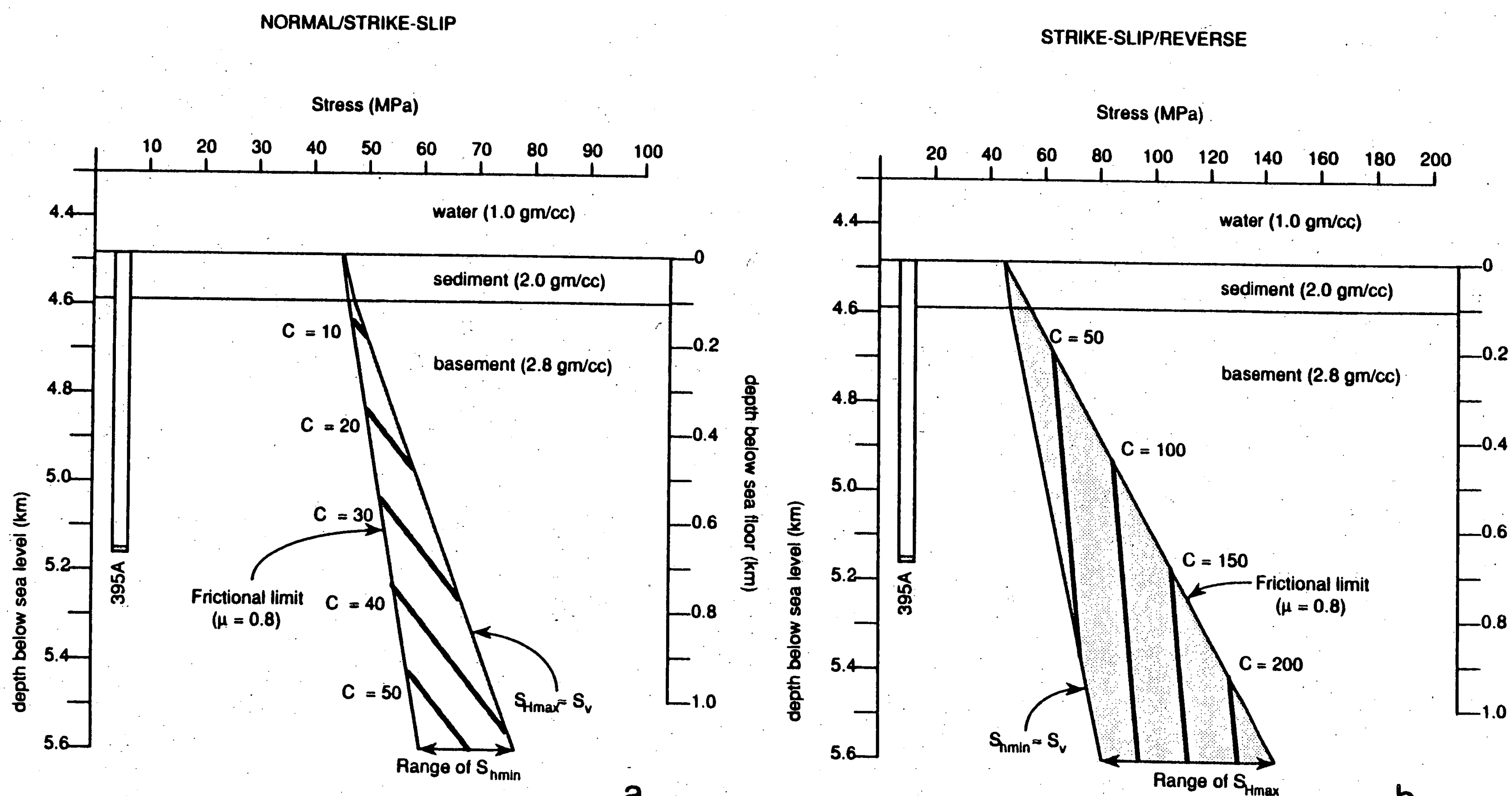


Fig. 11. Schematic illustration of possible stress states at DSDP site 395, if stresses are controlled by the frictional strength of well-oriented fault planes. The figure is similar to Figure 9 but for the conditions in hole 395A. Note that for breakouts to occur at 0.6 km below seafloor within DSDP hole 395A the compressive strength of the rock must be less than 150 MPa, and the stress regime must be as illustrated in Figure 11*b*.

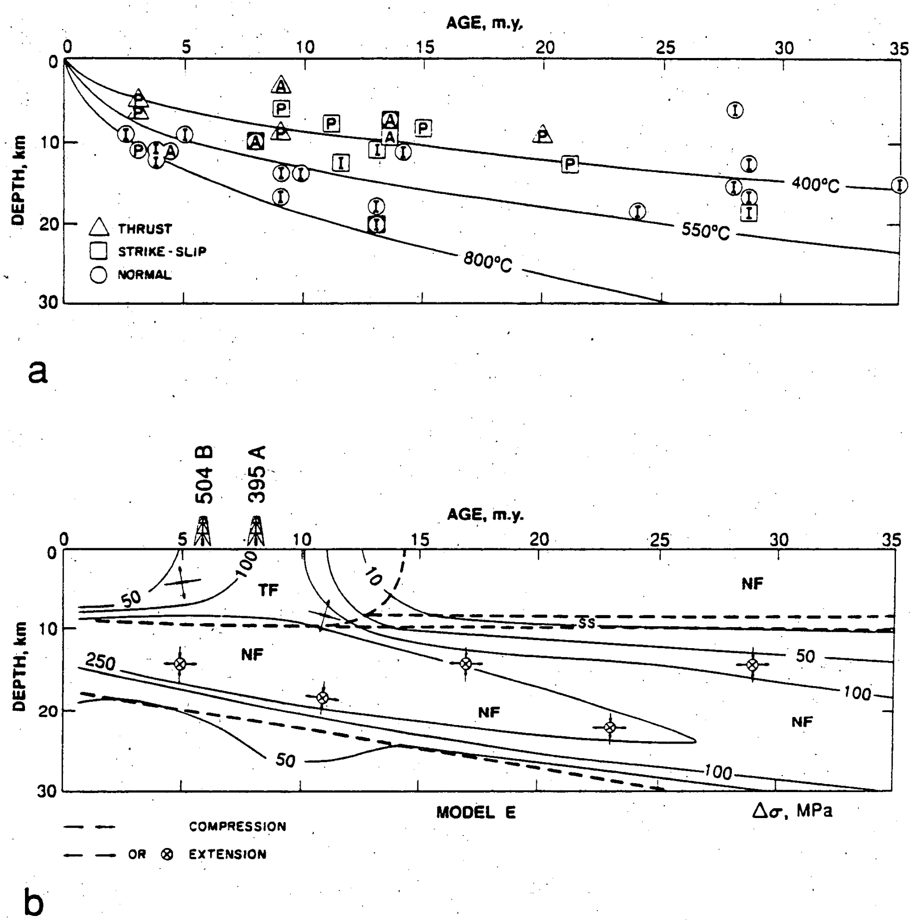


Fig. 12. (*a*) Focal mechanism and centroid depth relative to the seafloor as a function of lithospheric age for 32 near-ridge earthquakes from *Bratt et al.* [1985], after *Bergman and Solomon* [1984]. Mixed-faulting earthquakes are indicated by superimposed symbols, and the ocean in which each earthquake occurs is indicated by A (Atlantic), P (Pacific), and I (Indian Ocean). (*b*) Model E of *Bratt et al.* [1985] illustrates the effect of a 10-km-thick cooled layer with an elastic blocking temperature of 550°C, overlying a conductively cooling half-space, and a time constant for stress relaxation of 10 Ma. The age of the crust at sites 395 and 504 is shown.

mechanisms within oceanic lighosphere as a function of crustal age as tabulated by *Bergman and Solomon* [1984], reveals that reverse faulting predominates at shallow depths in young crust and that at greater depths and as the crust ages, strike-slip and normal faulting become more common. *Bratt et al.* [1985] have proposed that this state of stress is generated by thermoelastic effects in a plate consisting of a convectively cooled lid over a conductively cooling half-space, as illustrated in Figure 12*b*. The differential stresses generated by thermoelastic effects can exceed 100 Mpa at shallow depth, for crustal ages similar to those of sites 395 and 504. Ridge push forces cannot explain this stress distribution, as the horizontal stress generated by ridge push is zero at the ridge crest and increases with crustal age [e.g., *Bott and Kuznir*, 1984]. Although various models for stress relief and the depth of hydrothermal cooling lead to differences in the age to which shallow compressional stresses persist, thrust faulting predominates to ages older than 5 Ma in every case examined by *Bratt et al.* [1985], and the maximum deviatoric compression is horizontal and perpendicular to the ridge axis. In *Bratt et al.*'s [1985] model, stress relief is a function of time. This is quite different than the model used here, where the frictional strength of suitably oriented faults controls the maximum stress difference. However, if we combine the thermoelastic stress model of *Bratt et al.* [1985] with the frictional constraint on stress magnitudes, then in young oceanic lithosphere a thrust-faulting regime should predominate at shallow depths with S_{Hmax} maintained at a value constrained by strength and the (fixed) magnitude of the vertical stress, as in (1), and S_{hmin} approximately equal to S_v (there is no thermoelastic contribution to the horizontal stress parallel to the ridge axis), as required by the presence of breakouts within holes 504B and 395A.

As the crust ages, however, the model of *Bratt et al.* [1985] predicts that the importance of thermoelastic stress on the total lithospheric stress decreases. At an age of approximately 10–15 Ma, thermoelastic stresses are less important than the accumulated ridge push, and although the superposition of the two effects causes compressional stress normal to the ridge axis at all ages, the magnitude of the deviatoric compression is less than 50 MPa to ages of more than 35 Ma. Two implications arise from this observation. First, earthquakes and stress measurements within oceanic lithosphere younger than 15 Ma probably do not record plate-driving stress, and second, it is unlikely that in situ stresses in older oceanic lithosphere are large enough to allow their orientation to be established by observing well bore failure at depths less than 1 km below the seafloor. This second conclusion may be invalidated by the presence of additional stress sources such as midplate swells, seamounts, or bending stresses related to subduction. Unfortunately, these stresses would also obscure those related to plate-driving forces.

CONCLUSIONS

We have presented here a simple model describing the conditions necessary for compressive and tensile failure of well bores in response to far-field stresses and well bore temperature variations generated by circulation of drilling fluids to depth. Using a simple elastic model for the stress concentration around a borehole, we find that the presence or absence of breakouts allows reasonable constraints to be placed on the magnitude of the horizontal principal stresses. Comparisons of the model predictions and the measured stresses in boreholes drilled on land show that in most cases the relatively simple failure criterion enables us to predict the depths at which breakouts are actually observed. The single largest uncertainty lies in the large variation of strength in these rocks and the lack of precise values to use in this analysis.

The presence of breakouts in DSDP holes 504B and 395A requires very high horizontal compression in young (5.9 and 7.3 Ma, respectively) crust, with $S_{\mathrm{Hmax}} \gg S_{\mathrm{hmin}} = S_v$. S_{Hmax} is within 30° of the spreading direction in both cases and reaches a value of more than 100 MPa at depths less than 0.5 km subbasement. Our conclusion that the stress magnitudes must be large enough to cause reverse faulting on planes with a coefficient of friction $\mu = 0.8$ is consistent with the observation of reverse and strike-slip earthquake focal mechanisms within young oceanic crust.

Thermally induced stresses due to well bore cooling by drill fluid circulation can play a large role in the generation of tensile failure at the azimuth of S_{Hmax}, as seen in DSDP hole 504B. This is especially true where heat flow and the geothermal gradient are both quite high, either in young oceanic crust or in geothermal regimes on the continents, but is less important in the case of DSDP hole 395A, where the temperature increase with depth is more modest. The occurrence of thermally induced tensile cracks in hole 504B is consistent with the strike-slip/reverse-faulting regime indicated by the breakout analysis. These thermally generated tensile cracks do not propagate away from the well bore unless the well bore fluid pressure exceeds the minimum far-field principal stress, which is unlikely unless the formation is severely underpressured.

The compressive crustal stresses required by observations of breakouts in DSDP holes 504B and 395A are due to thermoelastic effects of plate cooling and are not associated with plate-driving forces. Measurements of stresses from observations of well bore failure in crust older than 25 Ma, where stresses are dominated by the forces which drive the plates, require boreholes with significant penetration below the seafloor. This is a consequence of the high strength of oceanic basalts and the fact that the horizontal stresses are limited by the vertical stress and the strength of the crust.

Acknowledgments. The authors benefited in the preparation of this paper from discussions with a number of people, including Stephen Hickman, Lev Vernik, Oona Scotti, and Gadi Shamir. Larry Mastin and Karl Fuchs informally reviewed the paper, and we appreciate their comments. We also thank Roger Morin and Robin Newmark for permission to use their data in this work and Colleen Barton, who designed and programmed the borehole televiewer digitization and analysis system. The paper benefited substantially from thoughtful and insightful reviews by Bezalel Haimson and Randall Richardson. The research was supported by the National Science Foundation under contract OCE-8907922.

REFERENCES

Allison, M. L., and D. L. Nielson, Stress in active geothermal systems, Advances in Geothermal Reservoir Technology, *Tech. Rep. ESL-88027-JP*, Lawrence Berkeley Lab., Berkeley, Calif., 1988.

Anderson, E. M., *The Dynamics of Faulting and Dike Formation With Applications in Britain*, 2nd ed., Oliver and Boyd, Edinburgh, 1951.

Anderson, R. N., and M. D. Zoback, Permeability, underpressures and convection in the oceanic crust near the Costa Rica Rift, eastern equatorial Pacific, *J. Geophys. Res., 87*, 2860–2868, 1982.

Angelier, J., Determination of the mean principal directions of stresses for a given fault population, *Tectonophysics, 56*, T17–T26, 1979.

Barton, C. A., Development of in-situ stress measurement techniques for deep drillholes, Ph.D. thesis, 192 pp., Stanford Univ., Stanford, Calif., 1988.

Barton, C. A., M. D. Zoback, and K. L. Burns, In-situ stress orientation and magnitude at the Fenton Hill geothermal site, New Mexico, determined from wellbore breakouts, *Geophys. Res. Lett., 15*, 467–470, 1988.

Bauer, S. J., and J. Handin, Mechanical properties of basalt cores from Deep Sea Drilling Project hole 504B, *Initial Rep. Deep Sea Drill. Proj., 83*, 371–378, 1985.

Becker, K., M. G. Langseth, and R. D. Hyndman, Temperature measurements in hole 395A, leg 78B, *Initial Rep. Deep Sea Drill. Proj., 78B*, 689–698, 1984.

Becker, K., et al., Drilling deep into the oceanic crust at hole 504B, Costa Rica Rift, *Rev. Geophys., 27*, 79–102, 1989.

Bell, J. S., and D. I. Gough, Northeast-southwest compressive stress in Alberta: Evidence from oil wells, *Earth Planet. Sci. Lett., 45*, 475–482, 1979.

Bell, J. S., and D. I. Gough, The use of borehole breakouts in the study of crustal stress, in *Hydraulic Fracturing Stress Measurements*, edited by M. D. Zoback and B. C. Haimson, pp. 201–209, National Academy Press, Washington, D. C., 1983.

Bergman, E. A., Intraplate earthquakes and the state of stress in oceanic lithosphere, *Tectonophysics, 132*, 1–35, 1986.

Bergman, E. A., and S. C. Solomon, Source mechanisms of earthquakes near mid-ocean ridges from body wave inversion: Implications for the early evolution of oceanic lithosphere, *J. Geophys. Res., 89*, 11,415–11,441, 1984.

Bott, M. H. P., and N. J. Kuzsnir, The origin of tectonic stress in the lithosphere, *Tectonophysics, 105*, 1–13, 1984.

Brace, W. F., and D. L. Kohlstedt, Limits on lithospheric stress imposed by laboratory experiments, *J. Geophys. Res., 85*, 6248–6252, 1980.

Bratt, S. R., E. A. Bergman, and S. C. Solomon, Thermoelastic stress: How important as a cause of earthquakes in young oceanic lithosphere? *J. Geophys. Res., 90*, 10,249–10,260, 1985.

Byerlee, J. D., Friction of rock, *Pure Appl. Geophys., 116*, 615–626, 1978.

Carmichael, R. S., *Handbook of Physical Properties of Rocks*, vol. II, 345 pp., CRC Press, Boca Raton, Fla., 1982.

Clark, S. P., Handbook of Physical Constants, *Mem. Geol. Soc. Am., 97*, 587 pp., 1966.

Coussy, O., Thermoporoelastic response of a borehole, *Int. J. Rock Mech. Min. Sci.*, in press, 1990.

Cox, J. W., Long axis orientation in elongated boreholes and its correlation with rock stress data, *Trans. SPWLA Annu. Logging Symp., 24th*, 1983.

Coyle, B. J., and M. D. Zoback, In situ permeability and fluid pressure measurements at ~2 km depth in the Cajon Pass research well., *Geophys. Res. Lett., 15*, 1029–1032, 1988.

Fairhurst, C., Methods of determining in situ rock stresses at great depths, *Tech. Rep. TRI-68*, Mo. River Div. Corps of Eng., Omaha, Nebr., 1968.

Gough, D. I., and J. S. Bell, Stress orientations from oil well fractures in Alberta and Texas, *Can. J. Earth Sci.*, *18*, 1358–1370, 1981.

Haimson, B. C., and C. G. Herrick, Borehole breakouts—A new tool for estimating in situ stress?, paper presented at the International Symposium on Rock Stress and Rock Stress Measurements, Luleå Univ. of Technol., Stockholm, Sweden, 1986.

Haimson, B. C., and C. G. Herrick, Borehole breakouts and in situ stress, in *Proceedings of the 12th Annual Energy-Sources Technology Conference and Exhibition*, pp. 17–22, American Society of Mechanical Engineers, New York, 1989.

Hickman, S. H., M. G. Langseth, and J. F. Svitek, In situ permeability and pore-pressure measurements near the mid-Atlantic Ridge, Deep Sea Drilling Project hole 395A, *Initial Rep. Deep Sea Drill. Proj.*, *78B*, 699–708, 1984*a*.

Hickman, S. H., J. F. Svitek, and M. G. Langseth, Borehole televiewer log of hole 395A, *Initial Rep. Deep Sea Drill. Proj.*, *78B*, 709–715, 1984*b*.

Hubbert, M. K., and D. G. Willis, Mechanics of hydraulic fracturing, *J. Pet. Technol.*, *9*, 153–168, 1957.

Hussong, D. M., P. B. Fryer, J. D. Tuthill, and L. K. Wipperman, The geological and geophysical setting near site 395, North Atlantic, *Initial Rep. Deep Sea Drill. Proj.*, *45*, 23–38, 1979.

Hyndman, R. D., and M. H. Salisbury, The physical nature of young upper oceanic crust on the mid-Atlantic Ridge, Deep Sea Drilling Project hole 395A, *Initial Rep. Deep Sea Drill. Proj.*, *78B*, 839–848, 1984.

Jaeger, J. C., and N. G. W. Cook, *Fundamentals of Rock Mechanics*, 3rd ed., 593 pp., Chapman and Hall, New York, 1979.

Kirsch, G., Die Theorie der Elastizitat und die Bedurfnisse der Festigkeitslehre, *VDI Z.*, *42*, 797–807, 1898.

Kopietz, J., K. Becker, and Y. Hamano, Temperature measurements at site 395, ODP leg 109, in *Proceedings of ODP, Scientific Results*, vol. 106/109, edited by R. Detrick, pp. 197–203, Ocean Drilling Program, College Station, Tex., 1990.

Kozlovski, Y. A., *The Superdeep Well of the Kola Peninsula*, 558 pp., Springer-Verlag, New York, 1984.

Langseth, M. G., M. J. Mottl, M. Hobart, and A. Fisher, The distribution of geothermal and geochemical gradients near site 501/504: Implications for hydrothermal circulation in the oceanic crust, in *Proceedings of ODP, Initial Reports, Part A*, vol. 111, pp. 23–32, Ocean Drilling Program, College Station, Tex., 1988.

Mastin, L. G., The development of borehole breakouts in sandstone, M.S. thesis, Stanford Univ., Stanford, Calif., 1984.

Mastin, L. G., Effect of borehole deviation on breakout orientations, *J. Geophys. Res.*, *93*, 9187–9195, 1988.

McGarr, A., Some constraints on levels of shear stress in the crust from observations and theory, *J. Geophys. Res.*, *85*, 6231–6238, 1980.

McGarr, A., On the state of lithospheric stress in the absence of applied tectonic forces, *J. Geophys. Res.*, *93*, 13,609–13,617, 1988.

McKenzie, D. P., The relation between fault plane solutions for earthquakes and the directions of the principal stresses, *Bull. Seismol. Soc. Am.*, *59*, 591–601, 1969.

Morin, R. H., R. L. Newmark, C. A. Barton, and R. N. Anderson, State of lithospheric stress and borehole stability at Deep Sea Drilling Project site 504B, eastern equatorial Pacific, *J. Geophys. Res.*, this issue.

Mount, V. S., and J. Suppe, State of stress near the San Andreas Fault: Implications for wrench tectonics, *Geology*, *15*, 1143–1146, 1987.

Newmark, R. L., M. D. Zoback, and R. N. Anderson, Orientation of in situ stresses in the oceanic crust, *Nature*, *311*, 424–428, 1984.

Okal, E. A., Intraplate seismicity of the southern part of the Pacific Plate, *J. Geophys. Res.*, *89*, 10,053–10,071, 1984.

Okal, E. A., J. Talandier, K. A. Sverdrup, and T. H. Jordan, Seismicity and tectonic stress in the south-central Pacific, *J. Geophys. Res.*, *85*, 6479–6495, 1980.

Plumb, R. A., and J. W. Cox, Stress directions in eastern North America determined to 4.5 km from borehole elongation measurements, *J. Geophys. Res.*, *92*, 4805–4816, 1987.

Price, R. H., and S. J. Bauer, Analysis of the elastic and strength properties of Yucca Mountain tuff, Nevada, *Proc. U.S. Symp. Rock. Mech.*, *26th*, 89–96, 1985.

Raleigh, C. B., J. H. Healy, and J. D. Bredehoeft, Faulting and crustal stress at Rangeley, Colorado, in *Flow and Fracture of Rocks*, *Geophys. Monogr. Ser.*, vol. 16, edited by H. C. Heard et al., pp. 275–284, AGU, Washington D. C., 1972.

Ritchie, R. H., and A. Y. Sakakura, Asymptotic expansions of solutions of the heat conduction equation in internally bounded cylindrical geometry, *J. Appl. Phys.*, *27*, 1453–1459, 1956.

Rummel, F., Stresses and tectonics of the upper continental crust—A review, in *Proceedings of the International Symposium on Rock Stress and Rock Stress Measurements, Stockholm, 1986 September 1–3*, Centek Publishers, Luleå, Sweden, 1986.

Shamir, G., M. D. Zoback, and C. A. Barton, In situ stress orientation near the San Andreas fault: Preliminary results to 2.1 km depth from the Cajon Pass scientific drillhole, *Geophys. Res. Lett.*, *15*, 989–992, 1988.

Shipboard Scientific Party, Site 597, *Initial Rep. Deep Sea Drill. Proj.*, *92*, 25–97, 1985.

Shipboard Scientific Party, Site 504, in *Proceedings of ODP, Initial Reports, Part A*, vol. 111, edited K. Becker et al., pp. 35–252, Ocean Drilling Program, College Station, Tex., 1988*a*.

Shipboard Scientific Party, Site 395, in *Proceedings of ODP, Initial Reports, Part A*, vol. 106/109, edited by R. B. Detrick et al., pp. 175–202, Ocean Drilling Program, College Station, Tex., 1988*b*.

Sibson, R. H., Frictional constraints on thrust, wrench and normal faults, *Nature*, *249*, 542–544, 1974.

Stephens, G., and B. Voight, Hydraulic fracturing theory for conditions of thermal stress, *Int. J. Rock Mech. Min. Sci.*, *19*, 279–284, 1982.

Stock, J. M., J. H. Healy, S. H. Hickman, and M. D. Zoback, Hydraulic fracturing stress measurements at Yucca Mountain, Nevada, and the relationship to the regional stress field, *J. Geophys. Res.*, *90*, 8691–8706, 1985.

Vardoulakis, I., J. Sulem, and A. Guenot, Borehole instabilities as bifurcation phenomena, *Int. J. Rock. Mech. Min. Geomech. Abstr.*, *25*, 159–170, 1988.

Wiebols, G. A., and N. G. W. Cook, An energy criterion for the strength of rock in polyaxial compression, *Int. J. Rock Mech. Min. Sci.*, *5*, 529–549, 1968.

Wiens, D. A., and S. Stein, Intraplate seismicity and stress in young oceanic lithosphere, *J. Geophys. Res.*, *89*, 11,442–11,464, 1984.

Zemanek, J., E. E. Glenn, Jr., J. J. Norton, and R. L. Caldwell, Formation evaluation by inspection with the borehole televiewer, *Geophysics*, *35*, 254–269, 1970.

Zheng, Z., J. Kemeny, and N. G. W. Cook, Analysis of borehole breakouts, *J. Geophys. Res.*, *94*, 7171–7182, 1989.

Zoback, M. D., and R. N. Anderson, Ultrasonic borehole televiewer investigation of oceanic crustal layer 2A, Costa Rica Rift, *Nature*, *295*, 375–379, 1982.

Zoback, M. D., and J. H. Healy, Friction, faulting and in situ stress, *Ann. Geophys.*, *2*, 689–698, 1984.

Zoback, M. L., and M. D. Zoback, State of stress in the conterminous United States, *J. Geophys. Res.*, *85*, 6113–6156, 1980.

Zoback, M. D., D. Moos, L. Mastin, and R. N. Anderson, Well bore breakouts and in situ stress, *J. Geophys. Res.*, *90*, 5523–5530, 1985.

Zoback, M. D., et al., New evidence on the state of stress of the San Andreas fault system, *Science*, *238*, 1105–1111, 1987.

Zoback, M. L., et al., Global patterns of intraplate stress: A status report on the world stress map project of the International Lithosphere Program, *Nature*, *341*, 291–298, 1989.

D. Moos and M. D. Zoback, Department of Geophysics, Stanford University, Stanford, CA 94305.

(Received July 28, 1989;
revised February 20, 1990;
accepted January 29, 1990.)

OCEAN DRILLING PROGRAM

Wireline Logging Manual

Volume 5

Perspectives on Scientific Logging
from the Ocean Drilling Program

Borehole Research Group
Lamont-Doherty Geological Observatory
Columbia University
Palisades, New York 10964

OCTOBER, 1988

TABLE OF CONTENTS - Volume 5

Chapter 1: Introduction to Perspectives on Scientific Logging

Chapter 2: Scientific Uses of Wireline Logs

Chapter 3: Ocean Crust, Fluids, and Volcanic Processes

Chapter 4: Global Environmental Changes

Chapter 5: Formation and Deformation Processes at Rifted and Compressional Continental Margins

Chapter 1: Introduction to Perspectives on Scientific Logging

As of this writing, twenty-two legs of the Ocean Drilling Program (ODP) have been completed. Below, we present new methodologies for doing marine geoscience in the conceptual framework of the Second Conference on Scientific Ocean Drilling (COSOD II, 1987), using additional examples from ODP Legs 111-122. These examples are presented solely for educational purposes, as are those of the other volumes of this manual. Where appropriate, we have indicated in the section headers the articles upon which the examples and discussion are based. Logging data are proprietary to the shipboard scientific staff of each leg for one year after the end of each cruise. Those interested in the logging results from legs within the one year proprietary period should contact the JOIDES Logging Scientist or co-chief scientists of that particular leg.

We will begin with a synopsis of future uses of scientific logging from the most recent review of the ODP logging program prepared for the COSOD II report by Worthington et al. (1988). This "white paper" clearly spells out the current status and direction of the logging program.

We then place the logging effort into perspective within the newly emerging international scientific drilling and logging programs which are loosely coordinated through the International Lithosphere Program of the International Union of Geodesy and Geophysics (IUGG). Here we find deep scientific wells being drilled through the continental crust, the results of which complement the COSOD II goals of the ODP. In the USSR for example, eleven ultradeep holes are being drilled, each of which is aimed at a total penetration depth of at least 10 km. A worldwide survey of scientific drilling shows a clear view of how ODP and various continental drilling programs (Federal Republic of Germany, Japan, Sweden, United States, and USSR) contribute to a truly global movement toward *in situ* investigation of the earth's crust (Figures 1-1 to 1-3).

We end this introductory chapter with an example of the synergy between continental and oceanic drilling by describing the various inter-calibration studies being done on land between standard core analyses and the new geochemical logging techniques. Studies in a variety of geological environments, from granites to basalts to metamorphic and sedimentary rocks, provides the ODP with the "ground truth" required to calibrate geochemical logging measurements in ocean-floor rocks and sediments.

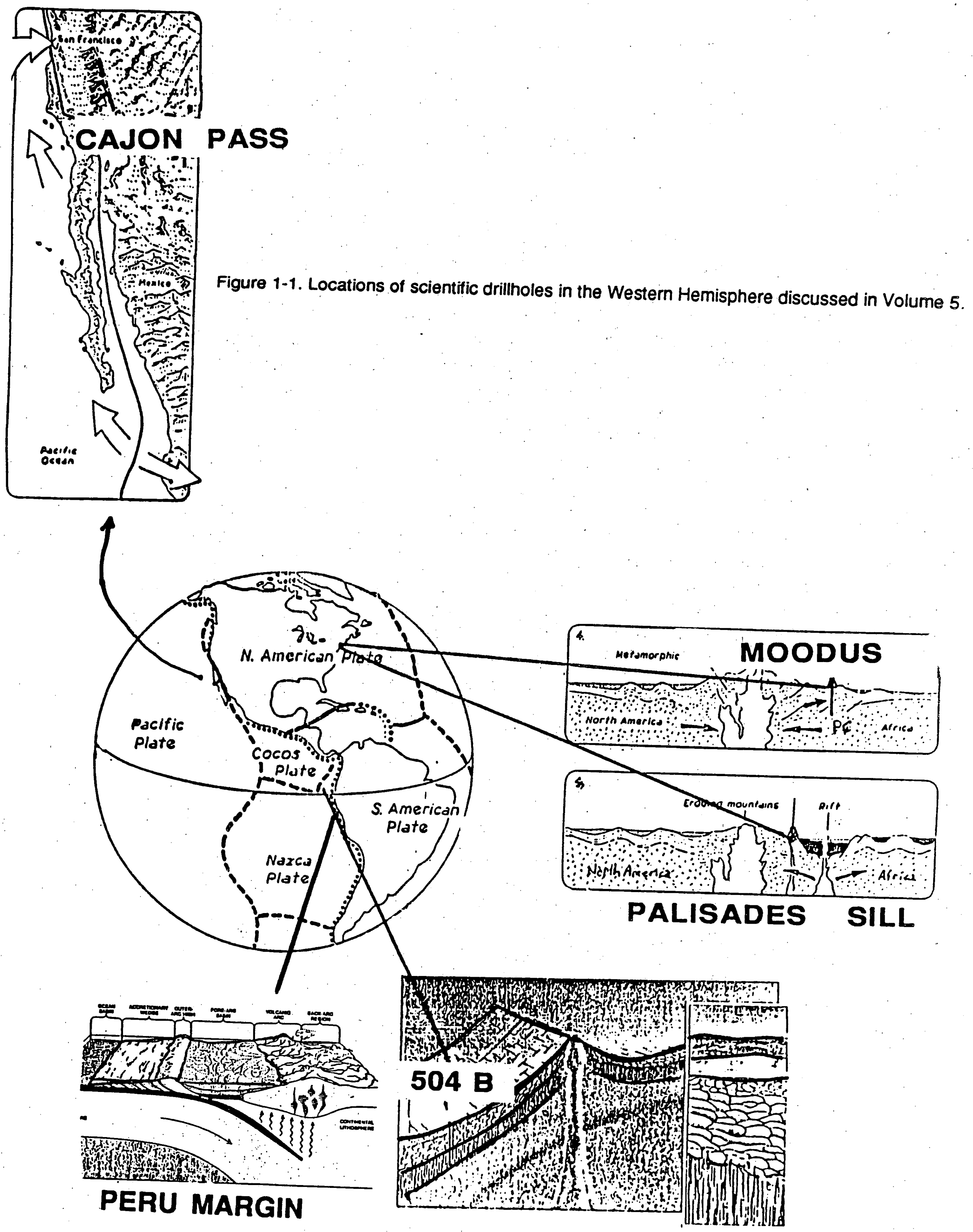


Figure 1-1. Locations of scientific drillholes in the Western Hemisphere discussed in Volume 5.

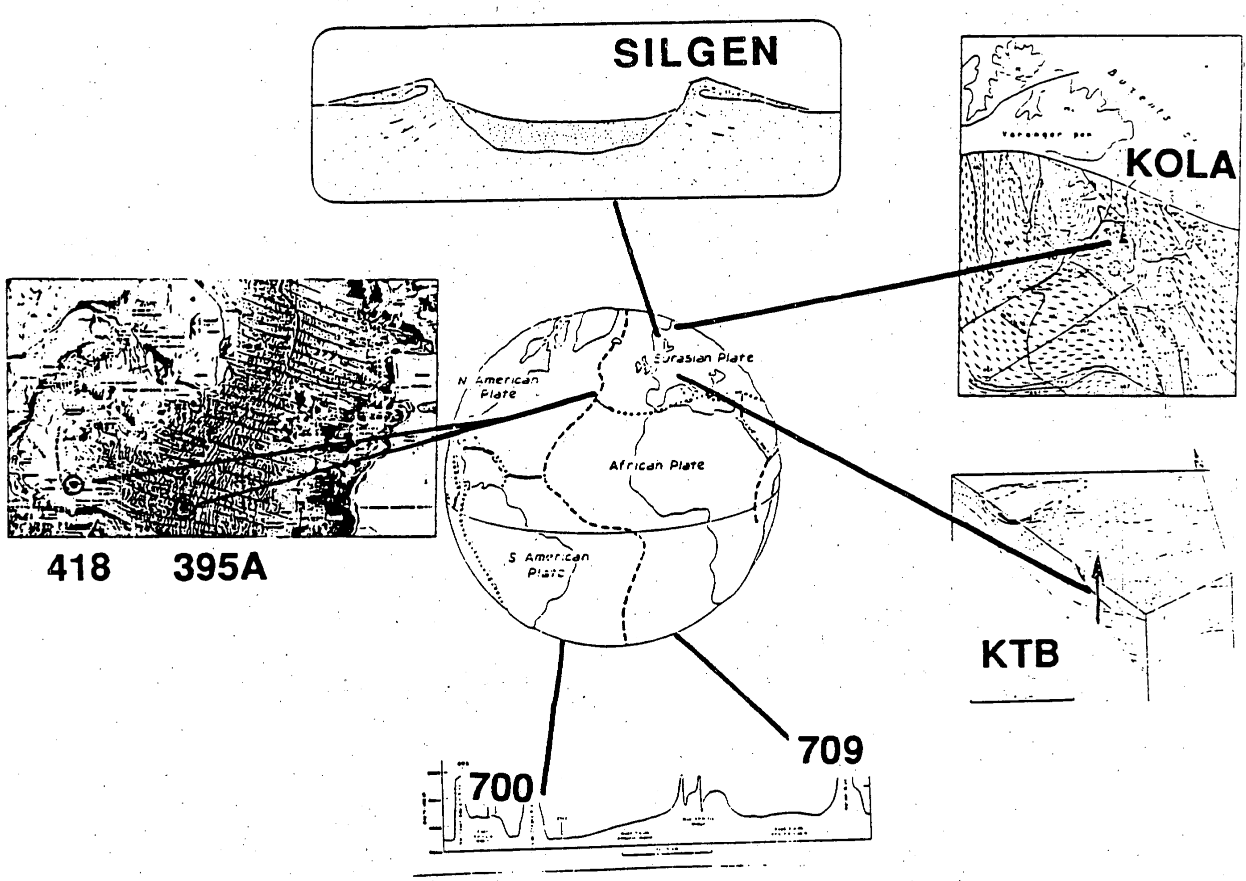


Figure 1-2. Locations of scientific drillholes in the Atlantic Ocean area discussed in Volume 5.

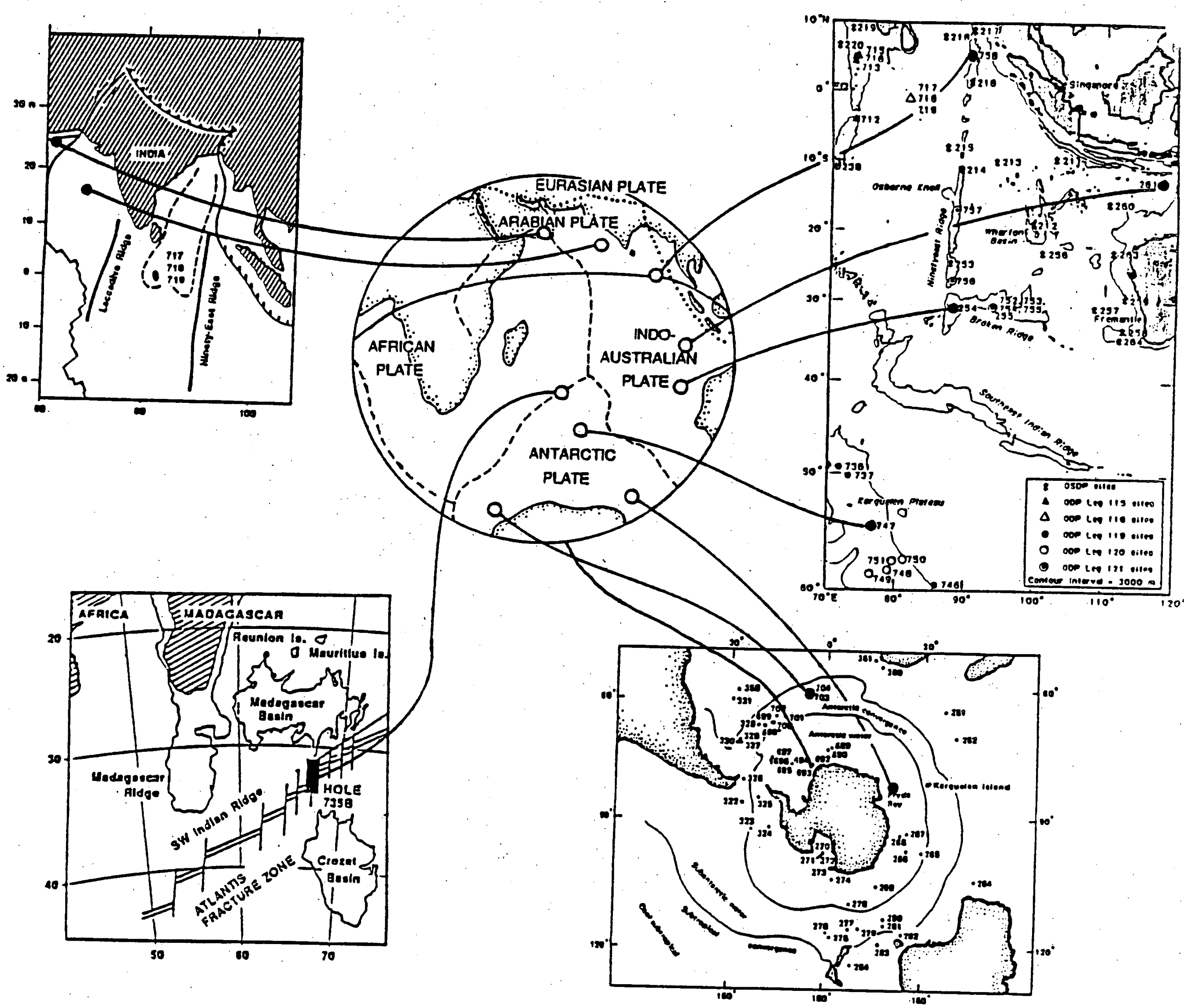


Figure 1-3. Locations of scientific drillholes in the Indian Ocean discussed in Volume 5.

JOIDES Downhole Measurement Panel White Paper for COSOD II: Conclusions and Recommendations

"An ODP borehole is a scientific legacy; it is not a mere relic of a core acquisition procedure. Scientific measurements in boreholes and on recovered core should be planned on the basis of their incorporation into a regional or global model, their future reinterpretation and, in some cases, the reoccupation of the drill site for further investigations. Core recovery is discontinuous and represents a small volume of sampled material. Core data are often used to calibrate the interpretation of wireline logs. Wireline well logs provide a continuous record of the succession and sample a volume about 100 times greater than that of recovered core. The cost of well-logging is small compared to the expense of drilling a hole in the first place. In terms of cost-effectiveness and the volume sampled, well-logging programs produce substantial returns.
Well-logging is neither a replacement for core analysis nor is it a subordinate discipline. It provides complementary information which is often of a different type from that which can be determined by core analysis. Logging is not therefore a luxurious add-on to a drilling program. It is an integral part of data acquisition within any deep drilling program and has a specific and important role of its own. This premise has been proved time and time again outside ODP, at sea or on land, in pure geophysics or in the mining and oil industries."

Scientific Applications of ODP Logs (from Worthington et al., 1988)

Many marine geological discoveries of the past followed new technical developments in observational capability. For example, the revolutionary advances made by the Deep Sea Drilling Project (DSDP) were derived from analyses of samples from deep beneath the sea floor. The discoveries made during those early years of research drilling in the oceans were based substantially on qualitative descriptions of core material supplemented by laboratory measurements of chemical and physical properties of spot samples. The volumes sampled were therefore small and the vertical data records were discontinuous.

Earth science is now in the throes of another revolutionary phase, stimulated by important developments in downhole-measurement technology. These developments have made possible accurate *in situ* measurements of a broader range of chemical and physical properties. Unlike core material, which is often disturbed during acquisition, *in situ* measurements characterize the environment around the borehole and lead to the determination of chemical and physical properties in that environment. Furthermore, the resulting data in the form of continuous well logs relate to much larger sampling volumes than do core data, thereby providing an intermediate scale between core measurement and surface geophysics. By using these logs, the interpretation of drilling results from the ODP can be placed on a much sounder quantitative footing than has been hitherto achievable.

Important Points about Logging Tool Response to Keep in Mind

First, logging tools provide a complete and representative response to changes in formation characteristics by sampling every 15 cm over the entire logged interval, regardless of lithology. In contrast, the effectiveness of core recovery is often controlled by those same formation characteristics, so that the degree of core recovery can be partially a function of rock type. Furthermore, in alternating lithologies, preferential core recovery of one lithology may give a non-representative sample. Core recovery averages 99% for hydraulic piston cores (usually the top 100-150m) but only 46% for rotary cores; of this latter amount, a significant proportion is disturbed and mixed by the drilling process.

Second, the usefulness of individual logs in evaluating mineralogy and porosity in different downhole environments also depends very much on the vertical resolution of the logging tools. This varies from a few millimeters to over a meter according to the physical principles and configurations of the different measurement systems. Most logging tools have a vertical resolution of about 0.5 m. i.e., a bed of thickness less than 0.5 m would not manifest itself sufficiently in logging tool response to be characterized.

Finally, nearly all logging tools respond *primarily* to changes in the mineralogy and porosity of the rock. The determination of porosity from logs inevitably requires a knowledge of the mineralogy. With the logging tools currently available, one can invert log responses and solve for the percentages of all minerals present in amounts greater than about 5%. The principal complication to such an inversion is that some clay minerals vary in composition (and therefore log response) as a function of both depth and locale; these variations degrade the accuracy of mineralogy determinations from logs.

Application of Downhole Measurements to Specific Scientific Topics of COSOD II

In the succeeding chapters of Volume 3, we will deal in detail with the mechanics of how to use logs to solve the specific thematic questions outlined in the Second Conference on Scientific Ocean Drilling (COSOD II) held in Strasbourg, France in 1987. These scientific themes to be addressed in future ODP logging are outlined below, again from Worthington, et al. (1988).

Theme: Global Environmental Changes

Rhythmic, cyclic and long-term environmental changes recorded in the mineralogy or grain size of marine sediments can be recognized in modern well logs provided that the sedimentation rate is high enough to produce resolvable events. Logs are especially well suited for addressing problems of environmental change since the solutions frequently require a continuous stratigraphic record in order that the effects of variations in climate and ocean circulation upon sediment composition and texture can be recognized. Improvements in stratigraphic resolution should be most achievable through the combined use of seismic information, well logs, and bio- and lithostratigraphic data from core studies. The use of core data *alone* is not defensible for these studies since they are rarely sufficiently continuous.

Mineralogy or porosity changes can be caused by climatic variables such as aridity/humidity, wind patterns, eustatic sea level, water temperature, and oceanic upwelling:

a. Aridity/humidity changes affect clay type and/or clay abundance. Changes in clay type are apparent in natural gamma spectral, spectral density, and aluminum activation logs. Changes in clay abundance are apparent in gamma ray, natural gamma spectral, and the combination of neutron and spectral density logs.

b. Wind patterns affect the grain size and the abundance and type of minerals in pelagic sediments. Porosity is closely related to grain size for uncemented pelagic sediments and is very well determined from logs. Porosity is often the dominant variable controlling the responses of the sonic, resistivity and spectral density logs. Hydrogen content, a porosity indicator, is determined by the neutron and induced gamma spectral logs. The elements Ca, Si, Al, Mg, Ti, K, Fe, Mn, S, Th, H, Cl, U, and Gd are determined from the geochemical logs (the natural gamma spectral, aluminum activation and induced gamma spectral tools). Mineral abundance can be determined from inversion of either the geophysical logs (sonic, resistivity, spectral density and gamma ray) or the geochemical logs. ODP generally uses both.

c. Eustatic sea level changes, like wind pattern changes, affect the grain size and mineralogy of sediments. Log responses to these sedimentary changes have been described above. The logs alone cannot distinguish whether changes are caused by wind pattern or sea level variations, but sedimentological studies of cores often remove this ambiguity.

d. Changes in either water temperature or upwelling affect the type or abundance of biogenous sediment components. Biogenous components are determined in the same way as other minerals. Determination of calcite abundance is relatively straightforward; however, the logs do not distinguish whether the calcite is in nannofossils, foraminifera, or detrital grains. Determination of radiolarian and diatomaceous opal is more difficult, as most other minerals also contain silica. Changes in radiolarian and diatom contents are more often indicated indirectly by logs, through their effects on porosity.

A major issue to be addressed by ODP is the enhancement of stratigraphic resolution through the recognition of the Milankovitch climatic cycles in ocean sediments. These climatic cycles are believed to be driven by the earth's orbital variations. These orbital changes will often cause some type of cyclic variation in the local pelagic sequence, though the most important climatic fluctuations will vary regionally. Milankovitch (1941) recognized eccentricity changes at 95,000 year periods, obliquity changes at 41,000 years, and precession changes at 19,000 and 23,000 years. Verification of these cycles is a principal ODP objective to which logging can make substantial contributions.

For the study of Milankovitch cycles in ODP holes, logs have two powerful advantages over cores: (1) continuous, uniform sampling throughout the drilling interval, independent of core recovery, and (2) measurement of a wide variety of variables that may be climatically influenced. Accurate sedimentation rates from cores are needed in order to determine the temporal frequency of log cycles. Virtually all studies of Milankovitch cycles in DSDP and ODP cores have been limited to the Plio- Pleistocene, because only hydraulic piston cores have sufficient core recovery and they seldom can be used deeper than 150m. In contrast, continuous sampling by logs is not depth-limited.

Changes in depositional environment are often recognized on regional seismic lines rather than in cores. It is essential to have an accurate tie between core (or log) depth and seismic travel time, so that one can either recognize the location in cores of regional seismic reflectors or extrapolate regionally from the depositional changes recognized in cores. Most seismic reflectors are interference patterns caused by impedance variations over a 20-30 m interval; thus it is hazardous to try to tie core-depth to seismic-time based on either discrete physical property measurements or observed sedimentological changes. Instead, sonic and density logs are routinely used to calculate synthetic seismograms. Matching the synthetic to the seismic section yields a detailed and correct link between core-depth and seismic travel-time.

Theme: Mantle-Crust Interactions

Downhole measurements including wireline logging and special borehole geophysical experiments have already played a major role in furthering our knowledge of oceanic crustal structure. Logging is an essential element of crustal drilling programs because it provides a complete record of physical properties in the borehole, in contrast to the usually sparse recovery of core material in hard rock. Borehole geophysical experiments expand the scale of the information acquired from the borehole from a few meters to a few hundreds of meters or kilometers, which is the scale of typical marine geophysical surveys. In sedimentary sequences it is common to assume that the structure intersected by the borehole and sampled at a lateral resolution of less than a meter extends horizontally for at least hundreds of meters. This assumption is not valid in oceanic crust, where strong lateral heterogeneities can occur over length scales from centimeters to kilometers.

Because of the scale of sampling associated with ODP, almost any conceivable ocean crustal objective will require that drilling results be placed in a regional setting. Wireline logging and special downhole experiments meet this need.

For example, virtually all models of crust/mantle interaction are constrained by seismic structure which is, in turn, affected considerably by porosity and fractures. It became evident in the early 1970s that laboratory-measured velocities of cores could not be directly correlated with refraction velocities because of the presence of secondary voids. Since integrated sonic logs and oblique seismic experiments did take account of these voids, they agreed much better with seismic refraction data. Well logs and borehole seismic methods, therefore, have an important role to play in establishing the seismic stratigraphy of the oceanic crust, which is an essential indicator of crust/mantle interactions.

Theme: Fluid Circulation and Global Geochemical Budget

Drill holes provide unique opportunities to obtain invaluable data on the patterns of fluid flow and the physical properties that control such in oceanic sediments and crust. By carefully applying currently available logging and experimental technology in ODP holes, reasonable estimates can be made of vertical flow rates and the two critical, controlling properties, porosity and permeability.

As drilling penetrates deep into sediments and crust, it allows detailed measurements of temperature and thermal conductivity with depth. Concurrently, analyses of pore waters sampled *in situ* or from recovered cores yield complementary profiles of concentrations of important chemical species. Fitting the thermal and chemical data to one-dimensional advection/diffusion models yields independent estimates of vertical advection rates. A different kind of flow, in the form of vertical movement of fluids through the borehole column, provides important information relating to permeability and pore pressure within the drilled section. In stable holes, this kind of flow can be monitored by detailed temperature logs.

The properties that control fluid storage and flow in oceanic sediments and crust are porosity and permeability. Porosity involves pore spaces that range over several orders of magnitude in size. Permeability is a measure of the ability of fluids to flow through a rock and is related to that proportion of porosity which is interconnected.

Since the oceanic crust is a porous medium, nearly all of its bulk physical properties depend on porosity. Thus, most of the properties that are logged are sensitive to porosity, e.g. sonic velocities, electrical resisitivity, density, neutron activation. However, nearly all the logs respond in different ways to porosity over different scales, and it is unclear which log(s) can be interpreted to yield the most accurate estimates of porosity. This is partly a consequence of calibration uncertainties in hard rock.

Present directions in log interpretation for porosity include: (1) multi-log evaluation to yield the "best" estimates of total porosity; (2) comparative analyses to try to separate the different components of porosity, particularly fracture porosity; (3) direct detection of fractures; and (4) analyses of neutron activation logs sensitive to geochemistry for the presence of alteration products that seal original porosity.

With present technology, permeability can only be measured *in situ* using a packer to isolate hydraulically the formation penetrated by the borehole. With such a hydraulic seal, the hydrological properties of the formation, including permeability and pore pressure can be tested by applying fluid pressure or flow to the formation.

Two drillstring packers have been developed during the first two years of ODP (see Appendix 1):

(1) A nonrotatable, single or straddle-packer that has worked reliably in stable re-entry holes in basaltic crust.

(2) A rotatable packer intended for use in a coring bottom-hole-assembly or in unstable sedimentary formations. The initial tests of this packer in 1986 showed that additional development work was needed.

In addition, ODP is purchasing an electrically-powered wireline packer to be run as a special logging tool starting in 1989. This packer will be intended primarily for measurements of pore pressure and water sampling over short (one meter) straddled intervals.

Hydrothermal circulation in young oceanic crust is accompanied by chemical exchange between crust and seawater. The most dramatic examples of this exchange are black smokers which are the surface manifestation of the chemical scouring of iron, manganese, etc. from oceanic crust by seawater. Assessment of the volumetric extent of basalt/seawater exchanges requires continuous geochemical analyses as a function of depth in the oceanic crust. Core recovery in basalts, however, is usually only about 20% and may be biased in favor of the least altered rocks. Furthermore, core geochemical analyses are of very small volumes (about 1-5 cm) that may be unrepresentative. In contrast, geochemical logs provide a continuous record of major element changes throughout the drilled crustal section, with each data point representing an averaging over a rock volume of close to one cubic meter. Thus, geochemical logs might constitute the only viable approach to the estimation of the overall geochemical exchange between basalt and seawater.

Theme: Brittle and Ductile Deformation of the Lithosphere

The ODP's well logging and downhole measurement program provides continuous records of information which, in turn, permits hole-to-hole correlation of physical and chemical parameters pertinent to an improved understanding of the lithosphere. For investigations which involve documenting and accounting for brittle and ductile deformation of the lithosphere, three categories of information are available:

(1) Data for establishing the tectonic history of the drillsites and their surrounding areas
(2) Data bearing on the physical and chemical properties of the drilled section, and
(3) Indications of ongoing tectonic activity.

The subsidence/uplift record of a drill site is deciphered largely from core-derived palaeontological, sedimentological and geochemical data. These insights can, however, be augmented and focussed by downhole logs. For example, the evaluation of decompaction and subsidence requires continuous and representative vertical records of density and porosity, parameters measured by logging tools on a routine basis. Logs can also provide lithological continuity where cores are lacking, pinpoint faults and unconformities, and often identify subtle stratigraphic cycles of tectonic significance, which are not immediately apparent from the samples. For example, past lithospheric flexure could have caused tectonic rotation or changed the bathymetry of an oceanic area through time. The former can be detected using a gyrostabilized borehole magnetometer. The latter may be reflected in the chemical composition of the sediments which were deposited, and this composition, in turn, may be detectable from well logs. Gamma ray spectral logs can directly identify some chemical variations such as Thorium or Uranium; others may become apparent when the responses of several logging tools are cross-correlated. In addition, thickness of the missing section at unconformities can sometimes be inferred from logs of porosity, density or acoustic velocity.

Perhaps the major contribution well logs make to unravelling tectonic history is in calibrating reflection seismic records, i.e., tying the travel-time of reflections to depth and thereby to actual rock in the drill hole. The only way to do this with precision is to measure the acoustic properties of the section either with sonic logging tools or by means of a borehole seismic velocity survey. This type of information is essential for definitive interpretations of structural history form seismic records. Log-derived acoustic and density data can also be used for seismic modeling of problematic reflection configurations.

Physical properties which can be measured by ODP logging tools and downhole measurement devices, or which can be derived from their records, include: specific gravity, density, acoustic velocity, electrical resistivity, temperature, presence of fractures, elastic properties, shear strength, pore pressure, porosity, permeability, fluid content, rock composition, radioactivity, and magnetic intensity and susceptibility. In one application or another, all these variables have figured in investigations of lithospheric deformation. For example, provided the rock units are mechanically isotropic, their elastic constants can be derived from 'P' and 'S' wave velocities (from long-spacing sonic waveform logs) and density (given by gamma ray density logs). Borehole televiewer records can provide excellent documentation of fractures, borehole geometry and bed form. Modified drill-stem-test tools with packers can sample formation fluids and measure pore pressure.

Ocean bottom seismometers operating remotely in abandoned boreholes can provide virtually noise-free records of earthquakes for epicenter location and first motion studies. The greatest contribution to ongoing studies of lithospheric deformation is likely to come form ocean-bottom-seismometer arrays set up to monitor all scales of earthquake activity around areas such as plate boundaries. Proposals are in hand for ODP ocean-bottom-seismometer deployment near plate margins offshore of Japan.

At this time, there is particular interest in the geodynamics of accretionary prisms; the deployment of instruments to measure downhole temperatures, permeability, pore pressures, *in situ* stresses and a range of mechanical properties is currently at the planning stage. Without downhole measurements, we would have much more difficulty advancing our understanding of these active thrust wedges.

An interesting tectonic application of well logs is the determination of *in situ* stress orientations using the borehole televiewer, with an ultimate goal of producing a global horizontal stress azimuth map. Where regional tectonic stresses exceed the strength of the wall-rock around a borehole, and the horizontal principal stresses are anisotropic, failure will occur. The cavities so created are called "breakouts". Breakouts are detectable using the borehole televiewer. The orientation of breakout failure in a semi-vertical borehole is perpendicular to the direction of the larger horizontal compressional stress.

Theme: Evolution and Extinction of Oceanic Biota

Downhole geophysical logs have yet to contribute substantially to the study of evolution and extinction of oceanic biota in ODP. Logs have contributed only indirectly through their detection of environmental change in the sedimentary column. This approach to the history of biotic events is achievable through well logging provided that three important conditions are met. First, the emergence of a marine organic community changes in its diversity, and its ultimate disappearance must be attributable to physical and chemical processes or other environmental factors that are manifested in the oceanic sedimentary record. Second, these diagnostic physical-chemical characteristics of sediments must be sufficiently distinctive in terms of electrical, nuclear or sonic properties that environmentally-governed sedimentary zones can be recognized definitively. Third, the time interval must be such that the characteristic sediments are sufficiently thick to be resolved by contemporary logging tools.

There are two ways in which future logging could make a powerful contribution to the study of evolution and extinction: (1) removal of the core-depth ambiguity, and (2) using Milankovitch cycles to greatly refine the age-dating of sediments.

Core-depth ambiguity results from incomplete core recovery. If a zone boundary is found in a 10-m core with only 10% recovery, then that boundary may actually occur anywhere within a 9 m interval. If the character of some property of the core can be correlated with a similar character in downhole logs, then the depth ambiguity is removed. The necessary prerequisites are similar high vertical resolutions (1-5 cm) in both core and log measurements, and a type of core measurement that is continuous, fast, and nondestructive. Two routine physical property measurements (density and velocity) are now run continuously on cores. Both properties depend primarily on porosity, and porosity-sensitive logging tools with similar 1-5 cm vertical resolution could eventually be introduced into ODP. However, the correlation problem would remain non-trivial because core disturbance can dominate the core porosity structure and make log vs. core comparisons difficult even with data of similar vertical resolutions. Furthermore, the ship's heave can introduce additional uncertainties in correlation of logging and coring depths.

For many years the age-precision of each palaeontological datum was limited by the 5% uncertainty of potassium-argon ages. In fact, the length of a palaeontological zone could be uncertain by a factor of two. A major increase in the accuracy of the time scale occurred when palaeontological zones were linked to magnetic reversal stratigraphy. The next great increase in accuracy has already begun through the counting of Milankovitch cycles between magnetic reversals or between palaeontological zone boundaries. One must, of course, know the Milankovitch frequency being detected (19-23,000 years for precession, 41,000 years for obliquity and 95,000 years for eccentricity). Milankovitch cycles in logs, coupled with biostratigraphy and reversal stratigraphy of cores, offers the potential for substantially improving the yardstick against which evolution and extinction of oceanic biota are measured.

In the much longer term, two potentially useful logging tools for the study of sediment age and evolution/extinctions are at early stages of development: (1) a downhole magnetometer capable of determining reliably the reversal stratigraphy of weakly magnetized sediments; and (2) a cryogenic geochemical logging tool with high elemental resolution that might measure iridium concentration and other extinction boundary "tracers" directly. A finer spatial resolution for this tool is also essential.

International Scientific Drilling: The Fit of Oceans to Continents (from Anderson, et al.,1988)

The above COSOD II goals attainable with scientific logging are being complemented by thematic objectives studied by scientific logging in continental drillholes. The important point is that the same logging technologies are being used in both drilling programs.

Ironically, the success of DSDP and ODP is causing a shift in earth-science research back toward land. Although many mysteries remain for the marine researcher, the dynamics under the ocean seem simple compared with far more complex goings-on within the continents. We know that the continents have accumulated through repeated collisions with ocean plates or other continents, but beyond that simple details are hard to pin down. For example: how do sedimentary basins develop and subside? How is it possible that thin horizontal sheets of ocean crust (ophiolites) can overthrust deep into an existing continent? What are the controlling factors behind earthquakes or volcanoes?

To answer these and other difficult questions, several nations have developed on-land deep-drilling projects. The Soviet Union planned deep holes from the early 1960's and began drilling its first on the Kola Peninsula through solid granite and metamorphic rock in 1970 (Figure 1-2). The hole has reached 12,200 meters (40,000 feet), a world record, and is targeted for 14,000 meters (46,000 feet). The Kola hole, which is almost completely cored and logged, has provided several surprises (Figure 1-4). The formation at 12,000 meters (39,400 feet) appears much more hydrologically active than expected, with fluid movement and ore deposition in fractures where open permeability had been previously considered impossible. Also note the acoustic velocity inversion below 4500 meters (15,000 feet). Contrary to expectations, acoustic velocities decrease the deeper the depth in the Kola crust (Figure 1-4). Another well targeted deep into a sedimentary basin in the Soviet Republic of Georgia is currently at 7,600 meters (25,000 feet). The Soviets have begun drilling nine other super-deep wells.

Besides adding knowledge to earth science, the Kola well also spurred dramatic improvements in drilling and logging technology. The Soviets' logging arsenal at Kola includes: resistivity, acoustic (compressional and shear), natural gamma-ray spectrometry, neutron porosity, lithodensity, pulsed-neutron, multi-arm caliper, magnetic susceptibility, inclination, temperature, and vertical seismic profiling. Most of these logging tools are rated to 200 ^{o}C (400 ^{o}F), some to 250 ^{o}C (480 ^{o}F). The logging cable comprises several connected sections with repeaters to boost the electronic signal to the surface. Cable sections that reach near the bottom of the hole are relatively small in diameter and therefore light, but are resistant to high temperatures and pressures. Cable sections near the surface are larger diameter and strong enough to carry everything below. The Soviets use several devices to ensure successful fishing in the event of a cable break. To prevent cable wear against the hole, logging tools are lowered through drill pipe to just above the section being logged (the method also used by ODP).

Continental deep drilling is not without practical or even commercial applications, i.e., hazardous waste disposal and the harnessing of geothermal energy. In Sweden, a consortium including the Swedish State Power Board and the US Gas Research Institute is drilling a 7,500 meter (24,600 feet) hole to test a controversial and commercially interesting

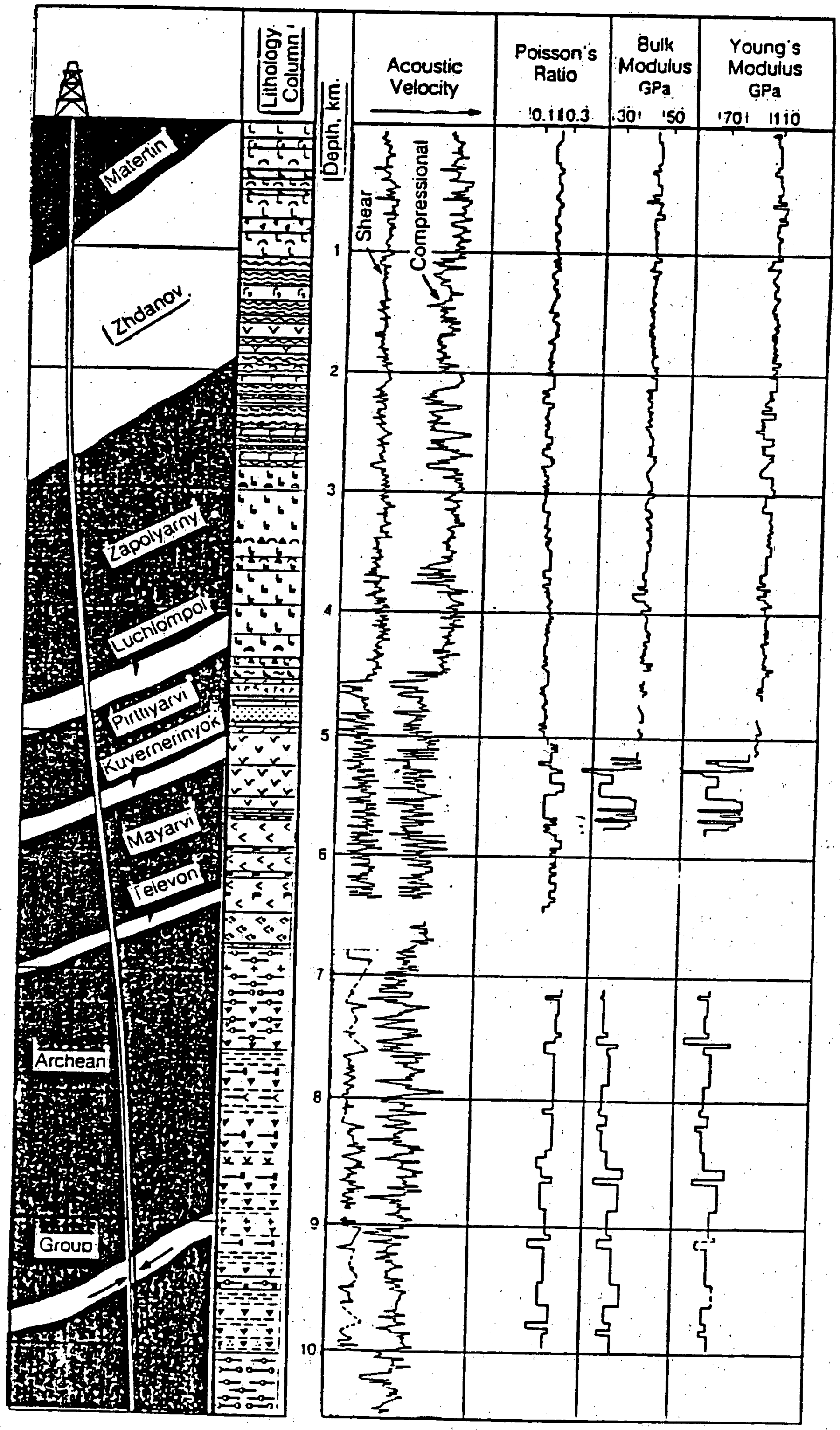


Figure 1-4. Compressional and shear velocity logs run in the Soviet Union's Kola Peninsula drillhole. These are the deepest logs ever run into the Earth. Poisson's Ratio, Bulk and Young's Moduli are elastic properties of the rock determined from these velocity logs. Note the drop in velocities at 4.5 km depth. Lithologies are various forms of metamorphic rocks. Arrows at 9 km indicate mineralized, fluid flow zone encountered. This is deepest mineralization ever found.

idea of the astronomer, Thomas Gold (Figure 1-2). Gold claims that the earth contains vast untapped reservoirs of "abiogenic" gas, which is not formed from decayed organisms, but generated deep in the mantle.

The drilling site is on the rim of the large Siljan Ring meteorite crater (Figure 1-2). Gold contends that on impact the meteorite might have fractured the surrounding rock and allowed abiogenic gas to seep upward. Currently, the well is at 6,600 meters (21,700 feet). The hole produced some gas-- methane, ethane, and pentane, but the biogenic composition of these gases has so far disproved Gold's idea. For a moment, when circulation was suddenly lost at about 6,000 meters, drillers thought they had hit a porous zone. A more likely explanation is that the heavy mud (1.6 g/cc or 13.5 lb/gal.) had induced a hydraulic fracture of the borehole wall.

The West German continental deep-drilling program, KTB, is federally financed and managed by the Geological Survey of Lower Saxony. Plans call for two wells in the Oberpfalz area of Northeast Bavaria (Figure 1-2). A pilot well, currently being drilled, will go to a depth of 3,000 to 5,000 meters (9,800 to 16,400 feet). A second well, to be located one hundred meters away from the first, is planned to go to 14,000 meters (46,000 feet). The West German scientists aim to study how continental crust was formed when the European and African plates collided long ago.

Deep continental drilling in the United States is supported by the National Science Foundation and planned by an organization called Deep Observation and Sampling of the Earth's Continental Crust (DOSECC). DOSECC teams up with the US Department of Energy for geothermal projects and the US Geological Survey (USGS) for earthquake studies. The major project of DOSECC is a well being drilled at Cajon Pass on the southern edge of the Mojave desert just 4 kilometers (2 1/2 miles) from the San Andreas fault where the Pacific and North American plates are sliding apart. Discovering the fundamental forces causing catastrophic earthquakes is the main objective.

One focus of logging research at Cajon Pass is the "heat flow-stress paradox". The problem is that there is no heat flow anomaly along the San Andreas fault, even though it is thought that heat flow must be elevated near highly stressed faults because of friction generated as the blocks grind across each other. The lack of a heat flow anomaly implies that the San Andreas is a low stress fault generating no extra heat; a fact that contradicts laboratory measurements of rock strength. Possible reasons for the lack of a heat flow anomaly are that frictional heat is being dissipated either by ground-water flow or through rock having higher than usual thermal conductivity. Scientists usually measure rock thermal conductivity directly from cores, but in the Cajon Pass project, they are also using geochemical logs to provide the rock's mineralogy. Established thermal conductivity values of minerals then permit an estimation of the rock's thermal conductivity. Radiogenic heat production from the rock can be measured from potassium, uranium and thorium concentrations measured by the natural gamma-ray spectrometry tool. These data, and also extremely precise temperature logs, are then used to calculate heat flow at every measurement interval in the well (Figure 1-5). The log-derived heat flow-versus-depth curve shows constant heat flow throughout the logged interval indicating that heat is mostly being dissipated conductively through the rock and not via the ground water, at least in the upper 1800 m (6000 feet) of the well. The Cajon Pass drillhole is targeted for 4900 m (16,000 feet). The heat flow-versus-depth log would have to remain constant to total depth

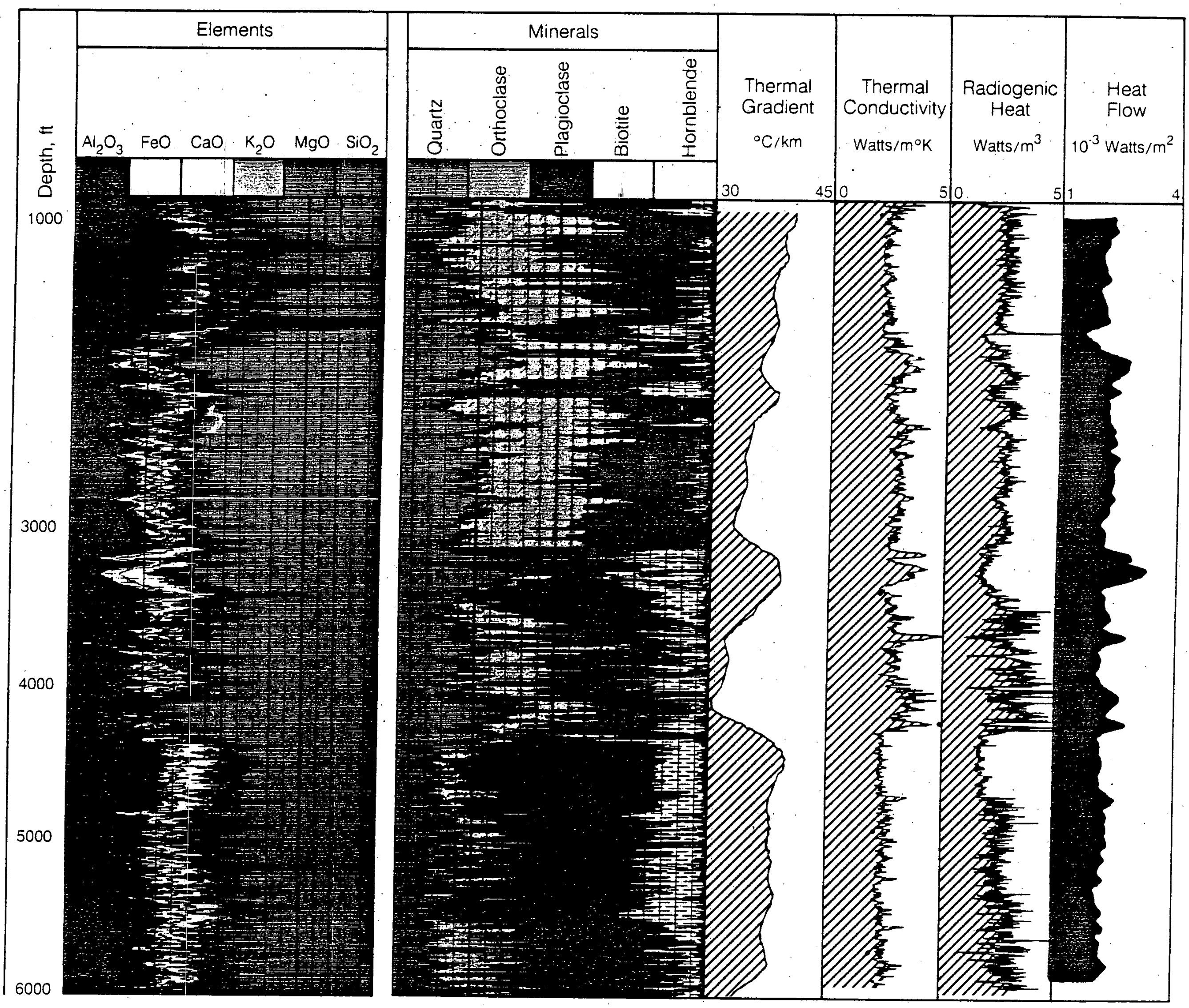


Figure 1-5. Heat Flow log from Cajon Pass (right) determined from thermal gradient from temperature log, thermal conductivity from geochemical logs, and radiogenic heat generation from natural gamma-ray spectroscopy log. Geochemical log (left) measures abundances of elements in the borehole wall. These, in turn, are inverted to estimate mineralogy (left, center). Major changes in thermal gradient at 3000 ft are caused not by fluid flow, but by thermal conductivity and radiogenic heat generation anomalies. The heat flow is generally constant with depth as would be expected in a conductive thermal regime.

to conclusively prove that the San Andreas is a low stress fault with little frictional heat being generated.

Another controversial explanation for the lack of a temperature anomaly is that, near the Cajon Pass hole at least, the rock is being compressed perpendicular to the San Andreas fault rather than parallel to it. Thus, the blocks are colliding rather than ripping apart, eliminating frictional shear heating. The hypothesis is supported by breakouts observed on the dipmeter-caliper and borehole televiewer logs-- both show the direction of maximum stress always perpendicular to the fault. It remains to be determined whether other parts of the San Andreas fault are similarly stressed.

A Worldwide Scientific Logging Database

Scientists from different logging programs have cooperated directly with ODP scientists. The KTB project, for instance, is operated from the same geological survey in Hanover that coordinates the involvement of the Federal Republic of Germany (FRG) in ODP. With so many of the scientific logging activities on the continents operating in parallel with the ODP wireline logging program, it is only natural that strong synergism is rapidly developing. As an example, consider the effort being expended to calibrate the Geochemical Logging Tool (GLT) measurements of oxide weight percentages. If accurate, this logging tool will revolutionize the scientific return from the logging of any hole. The GLT tool operates by doing 256 channel spectral analysis of gamma rays stimulated by neutron bursts from a downhole accelerator. It provides a continuous elemental analysis of the rock and fluid composition of a drillhole at 15 cm intervals (Figure 1-6). More measurements of elemental abundances have been made on the ODP Legs 109-122 than have previously been done at all Joint Oceanographic Institution universities. The main problem with this tool is accuracy. The nature of the constraints on hardware and the harsh natural environment make these measurements an order-of-magnitude less accurate than laboratory measurements of core samples. Are these reconnaissance measurements accurate enough to yield geological information?

KTB

The best attempt to calibrate the geochemical logging tool measurements to date comes from the KTB project of the Federal Republic of Germany (Figure 1-2). As part of their ultradeep drilling effort, they took extensive cutting and core samples of the metamorphic rocks encountered in their pilot hole drilled in 1988. The geochemical logging tool (GLT) was then run into the hole and the results of chemical analyses compared (Figure 1-7). A very interesting result is the better agreement between the geochemical logging results and cutting analyses (Figure 1-8) than versus core analyses (Figure 1-9).

The GLT irradiates approximately one cubic meter of rock, a volume which more closely approximates that mixed during cutting-retrieval than that sampled by discrete core-plugs. These plugs are 3-cm in diameter, and even though they were cut every 1 meter along continuously recovered core, they indicate bias toward sampling away from Fe- and Ti-rich rock.

Measurement Precision Elements

Geochemical Logging Tool Nuclear Measurements					
Element	Tool	Source	Bombarding Particle, Energy	Interaction	Detected Particle, Energy
C,O	Gamma Spectrometry (GST*) tool	Accelerator	n 14 MeV	Inelastic scattering	γ 1.5 to 7.5 MeV
Ca,Cl,Fe,H,S,Si Ti,Gd				Thermal-neutron absorption	
Al	Aluminum Activation Clay (AACT) tool	Cf^{252}	n 2.35 MeV†	Thermal-neutron absorption activation	γ 180 keV to 2 MeV
Th,U,K	Natural Gamma Spectrometry (NGS*) tool	—	—	Natural radiation	γ 180 keV to 3 MeV

*Mark of Schlumberger †Approximate mean energy

	Al	Ca	Fe	K	Si	S	Th (ppm)	Ti	U (ppm)	Gd (ppm)
Expected range of measurement	0-15	0-40	0-10	0-5	0-50	0-5	0-30	0-1	0-20	0-10
Standard deviation	0.1-0.8	0.7-3.1	0.2-0.6	0.26	1.6-6.5	0.1-1.8	2	0.1-0.6	5	0.3-2.4

Figure 1-6. The Schlumberger Geochemical Logging Tool measures oxides using the nuclear sources and physical reactions show in the top part of the figure. The accuracy in determinations for sedimentary rocks is given in the bottom part of the figure.

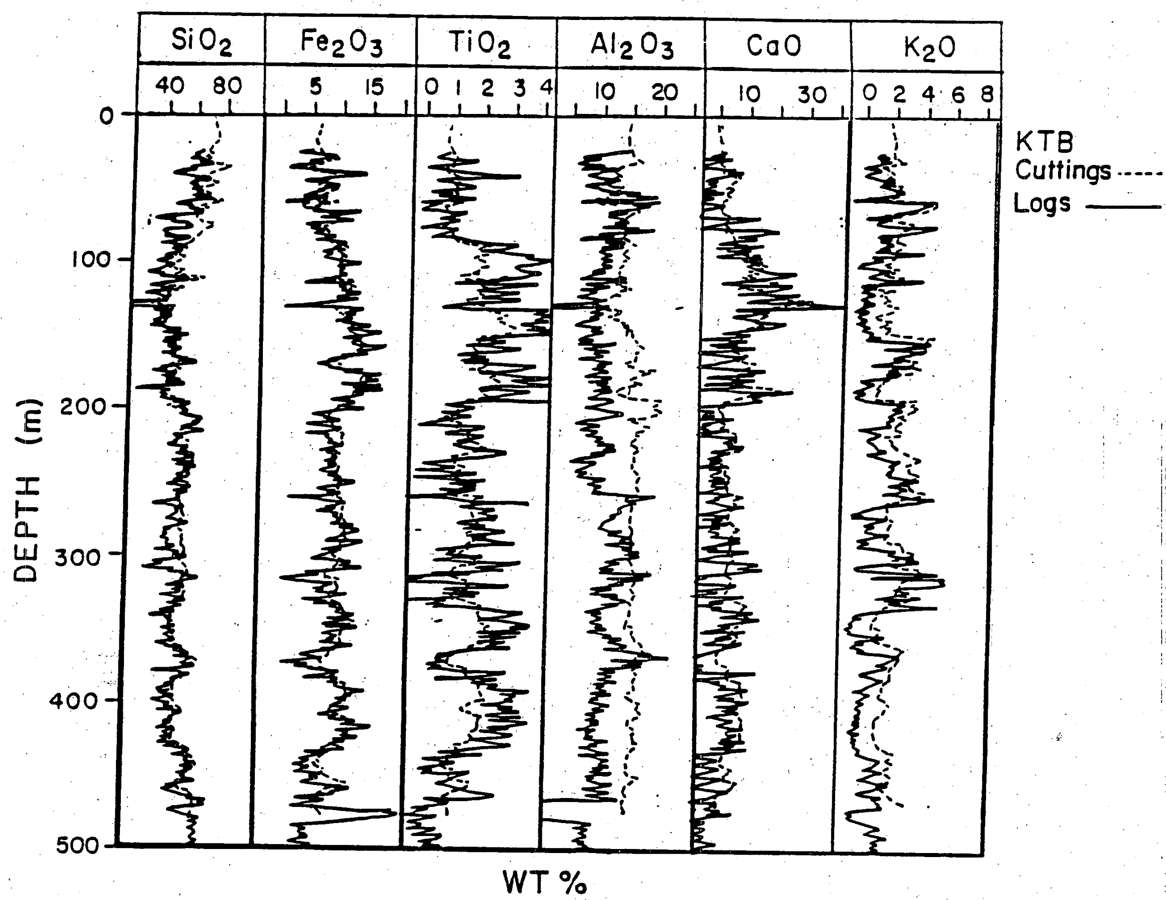


Figure 1-7. The most complete calibration experiment conducted to date is in the metamorphic rocks of the KTB drillhole, Federal Republic of Germany. Here, the dry weight percent oxide elemental abundances from X-ray fluorescence analyses of cutting samples are compared to the geochemical logging results.

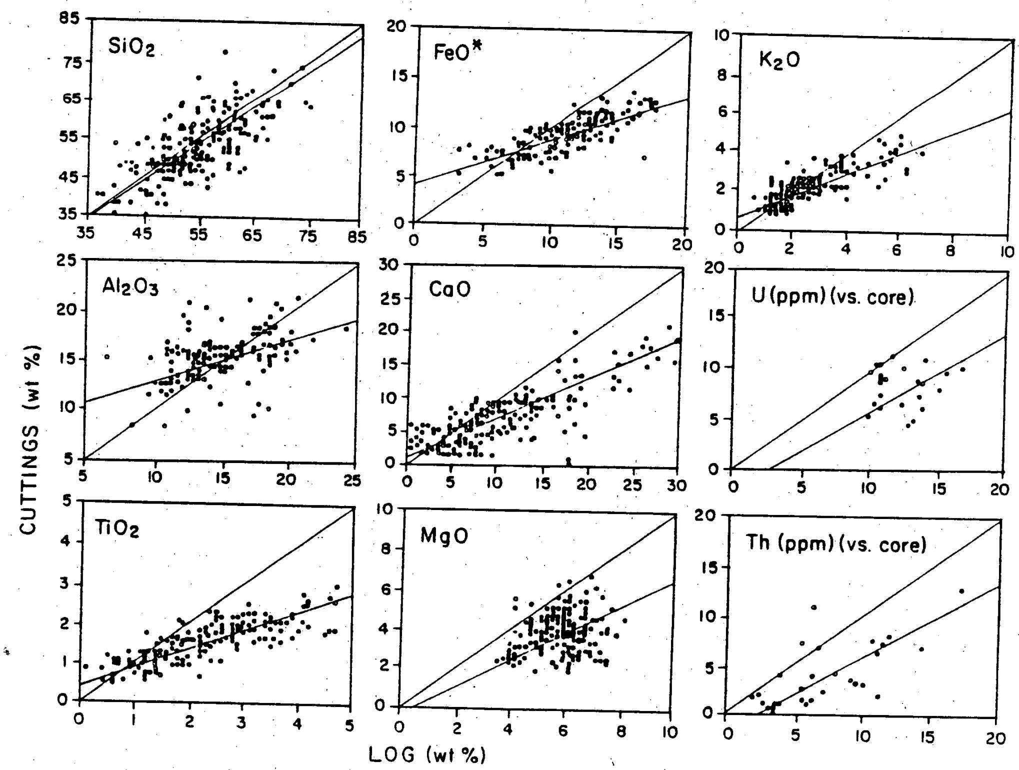


Figure 1-8. Cross-plots of cutting analyses (vertical axes) versus logging analyses (horizontal axes) for the data from the KTB drillhole shown in figure 1-7. Open circles are comparisons to centrifuged fines from cutting for comparison of any possible biasing due to grain size selection. U and Th are analyses from core plugs. 1:1 slope is expected fit, other lines are least-squares regression lines to data. The geochemical logging results should be calibrated to correct for these differences in this well. Universal hard-rock calibration-corrections are being sought.

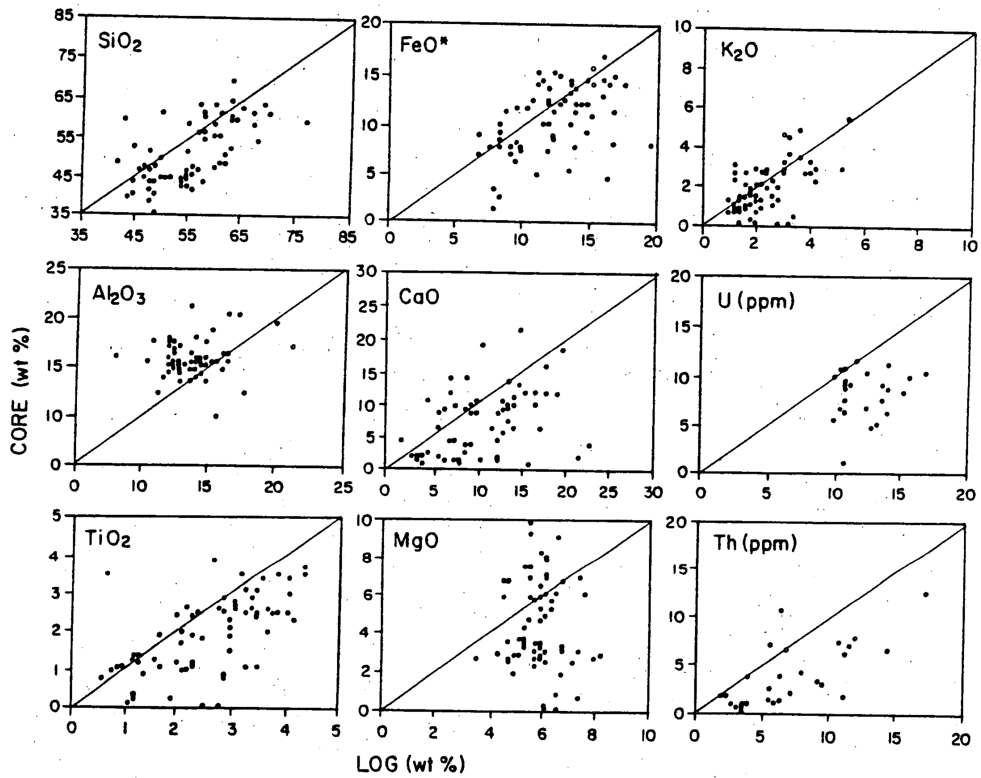


Figure 1-9. Geochemical log-derived chemical analyses from KTB drillhole do not compare as well to laboratory analyses from discrete core plugs. Some sampling bias is indicated by skewing of results away from mafic compositions. Clearly, care must be taken when calibrating geochemical logs, with a one cubic meter irradiation volume, to analyses from small volume core samples.

Another interesting result of the GLT-cutting comparison is that the GLT results are quite good, but small calibration shifts are necessary to move the fitted line relating cutting and log values to the proper 1:1 slope (Figure 1-8).

The misfit of aluminum is thought to be caused by abundant Mn in the rock. Although Schlumberger has been struggling to correct for Mn for some time, they have not yet been successful (Figures 1-7, 1-8 , and 1-9).

Once the validity of the GLT elemental chemical analyses has been established, a matrix inversion can be performed to determine the most likely mineral abundances present in the well. Ideal mineral compositions must be assumed. These in turn can be compared with determinations of mineral abundances derived from x-ray defraction analyses of thin sections. These were done every 1 m in the KTB well (Figure 1-10), with generally positive results. It is clear that the GLT provides excellent chemical reconnaissance of the KTB drillhole in metamorphic rocks.

Cajon Pass

A somewhat more elaborate calibration experiment was performed in granites as part of the DOSECC Cajon Pass Scientific Drillhole into the San Andreas Fault, California, (Figure 1-1). Here, cores of up to 1.7-m length were sliced vertically to remove a wedge-shaped sample of the entire length of the core. The entire wedge was then powdered and mixed. Several samples were then measured using x-ray fluorescence and the average composition compared to the GLT average over the same interval (Figure 1- 11). The results are comparable to the KTB cuttings rather than to core analyses and point to the extreme care that must be taken when conducting log calibration tests with core. Special problems arise when, as in the ODP example, continuous coring only results in partial core recovery.

At Cajon Pass, mineralogy was determined as at the KTB site (Figure 1-5) and compared to modal analysis of thin sections, again with good agreement (Figure 1-12). The model results were then inverted to predict the beginning elemental composition. A comparison of these "reconstructed" curves with the original data provides a "goodness-of-fit" determination for the model-based mineralogy (Figure 1-13). When the model is good, as at Cajon Pass, the reconstructed curves overlay the original data.

Cajon Pass provides an excellent example of the usefulness of the calibrated GLT results for discriminating lithologies. Major lithologic units of granodiorite and granite are easily determined from simple cross-plots of elemental compositions such as TiO and Gd vs. SiO_2 (Figure 1-14).

Palisades Sill

Basalts similar in composition to those of the oceanic crust have been cored and logged in the Palisades Sill of southern New York (Figure 1-1). GLT results easily identify trends in basalt fractionation identified on the samples (Figure 1-15). For example, the olivine layer near the bottom of the sill formed by the settling of these heavy crystals is easily seen on the Si, Al, Ca, Fe, Mg and Ti curves. The increase upward in light, plagioclase

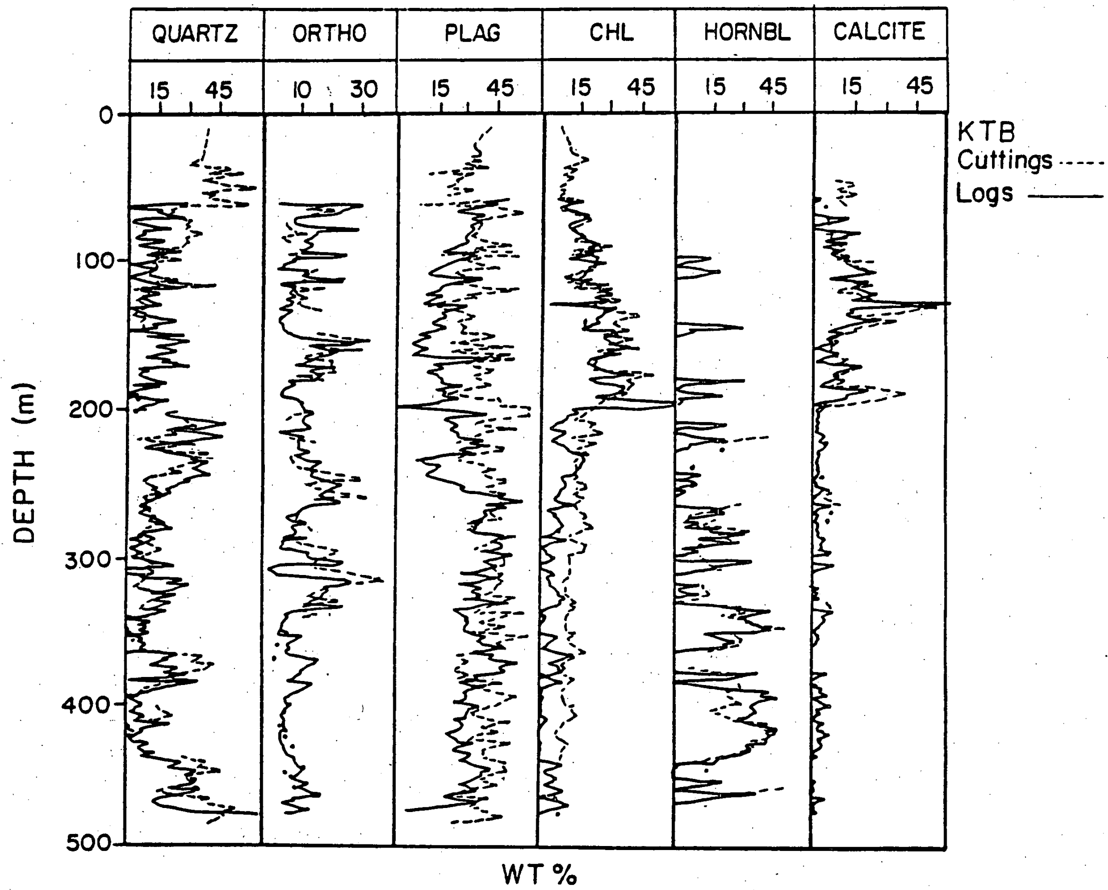


Figure 1-10. Comparison between abundances of minerals determined from quantitative X-ray diffraction on cutting samples and mineral inversion results from geochemical logs at the KTB drillhole.

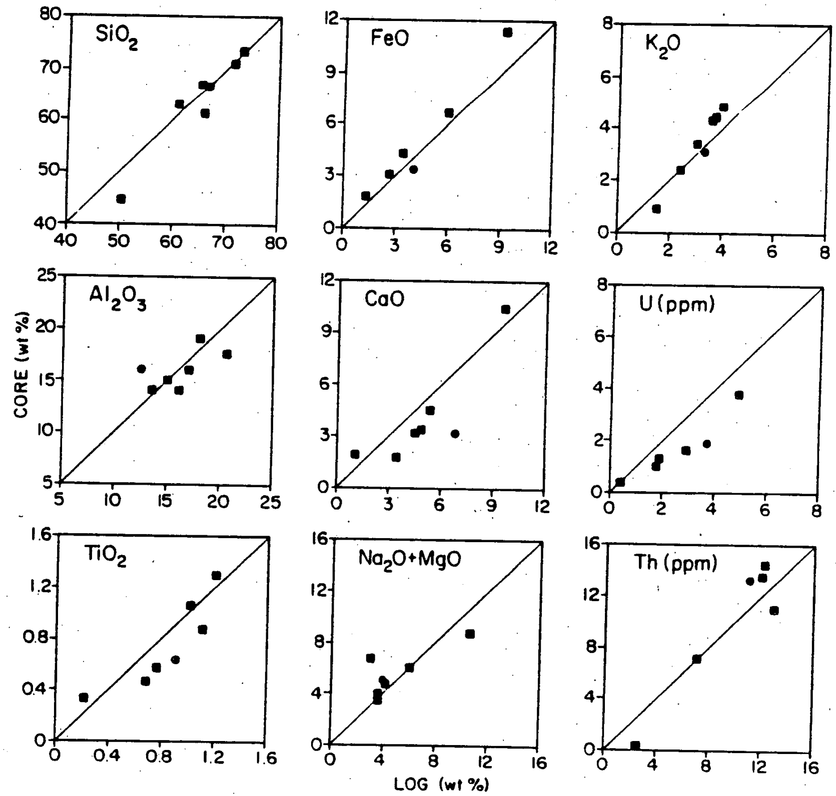


Figure 1-11. Calibration experiment in granites from the Cajon Pass drillhole. Here, continuous wedges were cut from long cores to more closely approximate the measurement volume of the geochemical logging tool.

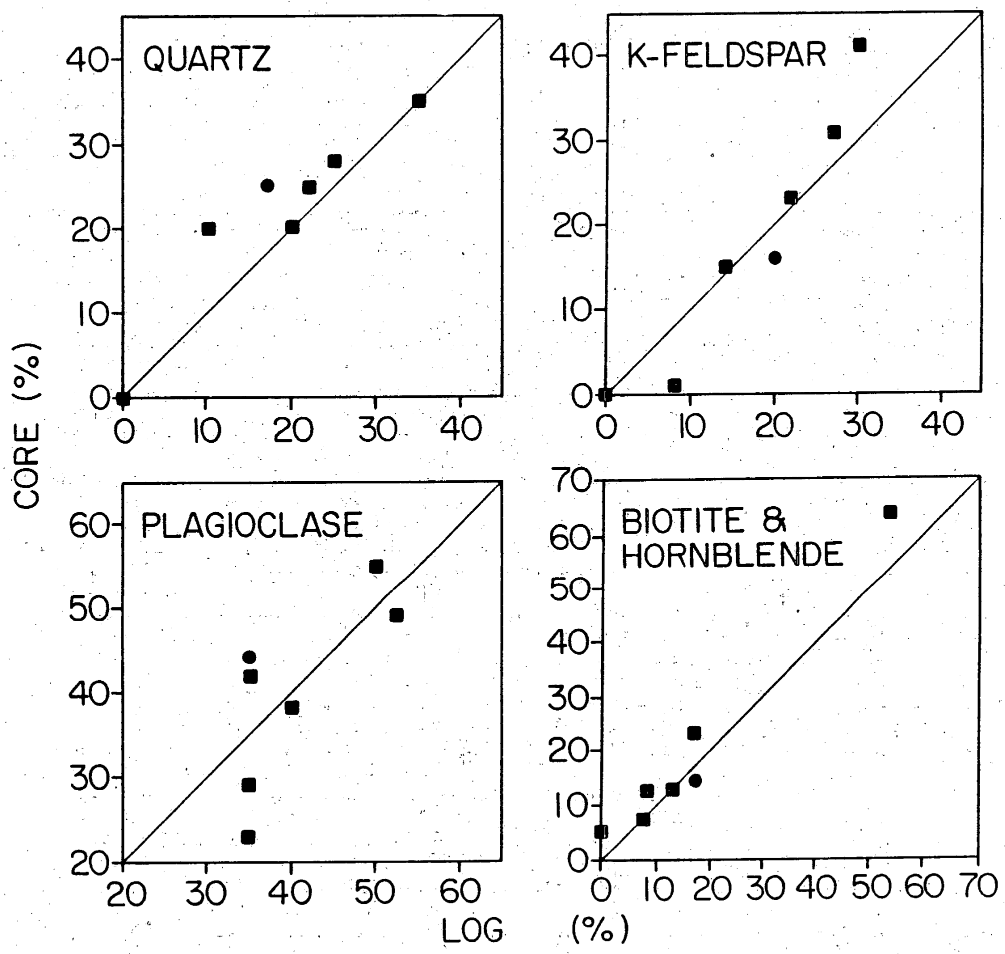


Figure 1-12. Comparison between mineral inversion from geochemical logging analyses and point-counts from thin-sections of cutting samples in granites of Cajon Pass drillhole. The accuracy is affected by bad hole conditions (solid dot).

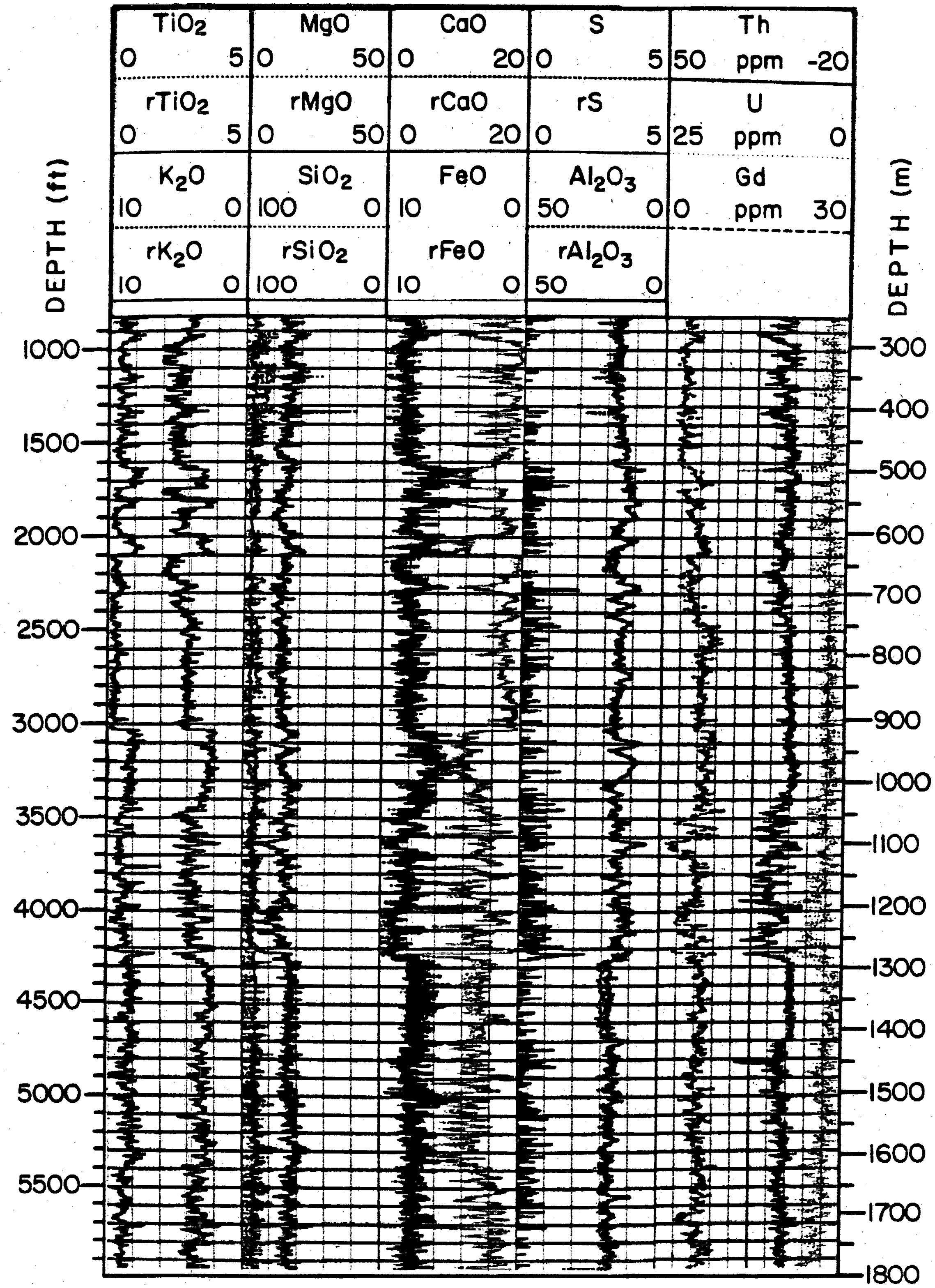
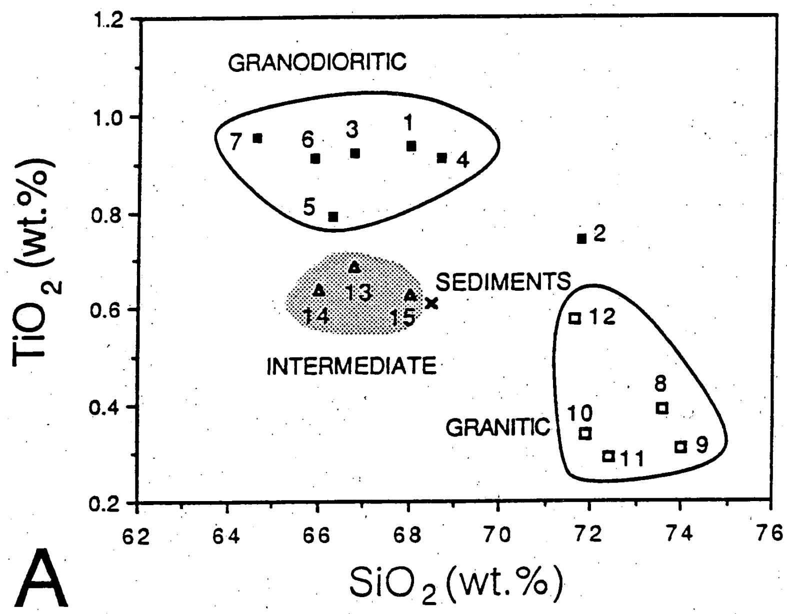


Figure 1-13. The mineralogy inversion of geochemical logging results from the Cajon Pass drillhole can itself be inverted to calculate, or "reconstruct", the ideal elemental compositions that would give the exact mineral abundances determined by the model. Since ideal mineral compositions were used by the model, the comparison of reconstructed abundances with log-derived abundances points out discrepancies with the real rock, and gives a qualitiative feel for goodness-of-fit.



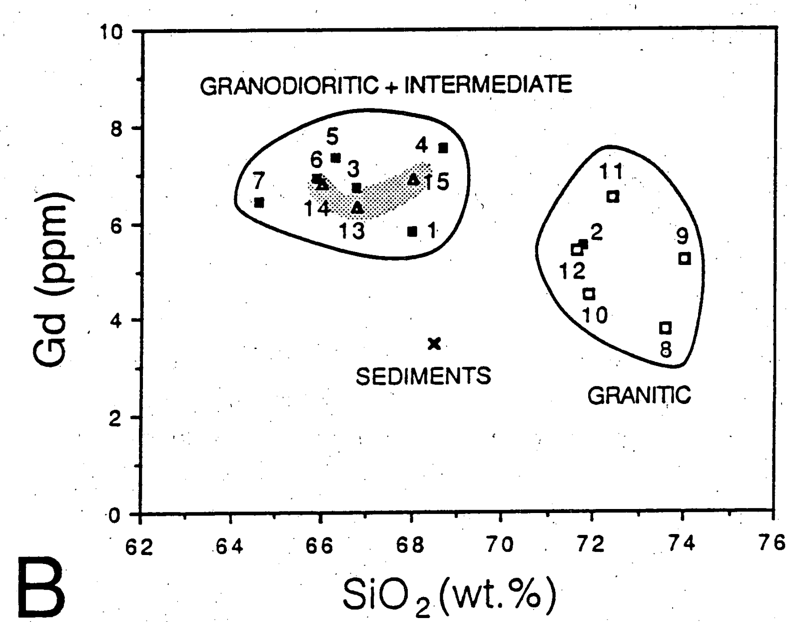


Figure 1-14. The elemental abundances determined from geochemical logging can be used to differentiate between different lithologies as demonstrated in the granitic rocks of the Cajon Pass drillhole. Here, granodiorites have higher Ti (above) and Gd (below) and lower Si contents than do granites.

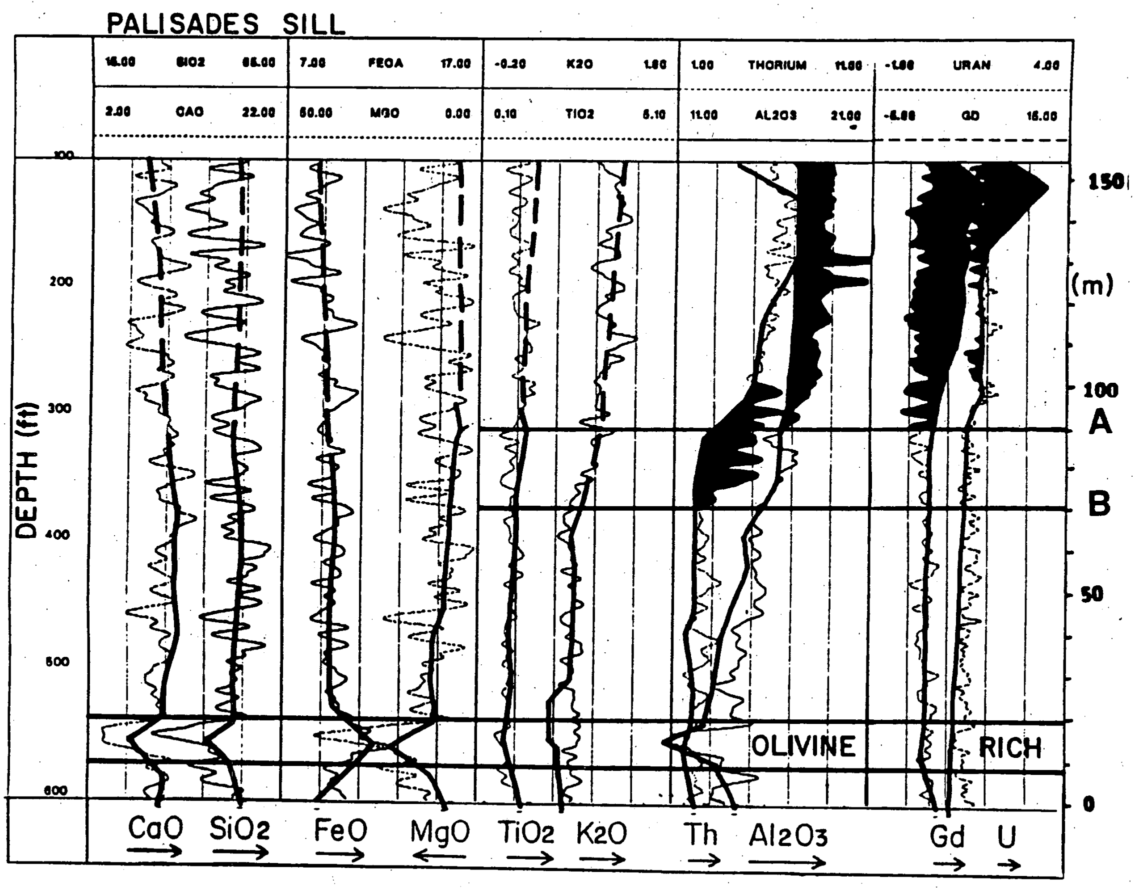


Figure 1-15. Geochemical logging analyses from basalts of the Palisades Sill are compared to analyses from rock outcrops of the same formation taken from the Palisades Cliffs a few miles away. Shading indicates disagreement. The logs locate an increase in Th content from a later stage intrusion more precisely than do the outcrop samples. Disagreement in Gd, Al, and U at top of the well may be due to subtle stratification within the Sill itself. The enrichment zone at the bottom of the well is clearly delineated by the geochemical logs.

phenocryst content is seen in the increase upward in Al abundance. The discrepancies in Th, U, and Gd probably reflect bias in sampling rather than errors in the GLT. In fact, the location of a second intrusion event is more precisely located by the Th log than by sample analyses (A vs B depth in Figure 1-15).

The Palisades Sill Scientific Drillhole also provides the first basaltic test for the geochemical logging technology of the future: cryogenic-germanium-crystal spectroscopy recorded with a 4096-channel spectral analyzer. The USGS is developing such a tool, and they ran it in the Palisades Sill hole to compare with the Schlumberger GLT results. While the data analysis is not finished yet, several important results are available which point to the importance of high-resolution logging in the future using the Ge crystals.

As a synthetic spectrum of an ideal composition "Palisades Sill Basalt" shows in Figure 1-16, large major element peaks are evident in the 6-8 MeV energy windows. The actual geochemical log midway into the Palisades Sill (Figure 1-16) shows these peaks (heights give the abundances) and peaks of Ni and Sc, Cr, V, and Xr are seen in other energy windows as well. For the first time, the Ni/Al ratio in basalt has been determined with a logging tool (Figure 1-17). The Ni/Al ratio increases with depth toward the bottom of the hole because fractionation has caused the more mafic components of the basalt to sink as the light plagioclase floated as the sill cooled.

Anadarko Basin

Schlumberger designed the Geochemical Logging Tool for use in sedimentary basins and they have completed important calibration tests in sediments using side-wall cores for comparison. The Conoco test well in the Anadarko Basin in Oklahoma provides perhaps the best example of the usefulness of the GLT in sediments (Figure 1-18). Carbonates at 2750 ft are easily identified by the high Ca and U contents and low Fe, Si, Al, K and Th. Sandstones at 2450-2500 ft are easily distinguished from clays at 2500-2700 feet because of their higher Si and lower Fe, Al, and K contents. The core measurements agree with a precision of 1 to 2% in this test case (Figure 1-18).

A Gulf Coast sand-shale sequence was also used as a calibration test between side-wall cores and the GLT (Figure 1-19). The shale at 450-600 feet is easily distinguished from the sands above and below by the Si, Al, Fe and K curves. Schlumberger tested mineral determinations with abundances measured on cores and found excellent agreement (as seen earlier for granitic and metamorphic rocks; Figure 1-20).

Summary

In succeeding chapters, further scientific application of geophysical, as well as the new geochemical logging techniques will be demonstrated using ODP examples. The continental efforts will continue in parallel, of course, producing measurements from the same tool suite in complementary tectonic environments. We must always remember the importance of understanding how the whole earth works beneath both oceans and continents. As with seismology, logging provides a powerful data set to span the whole earth.

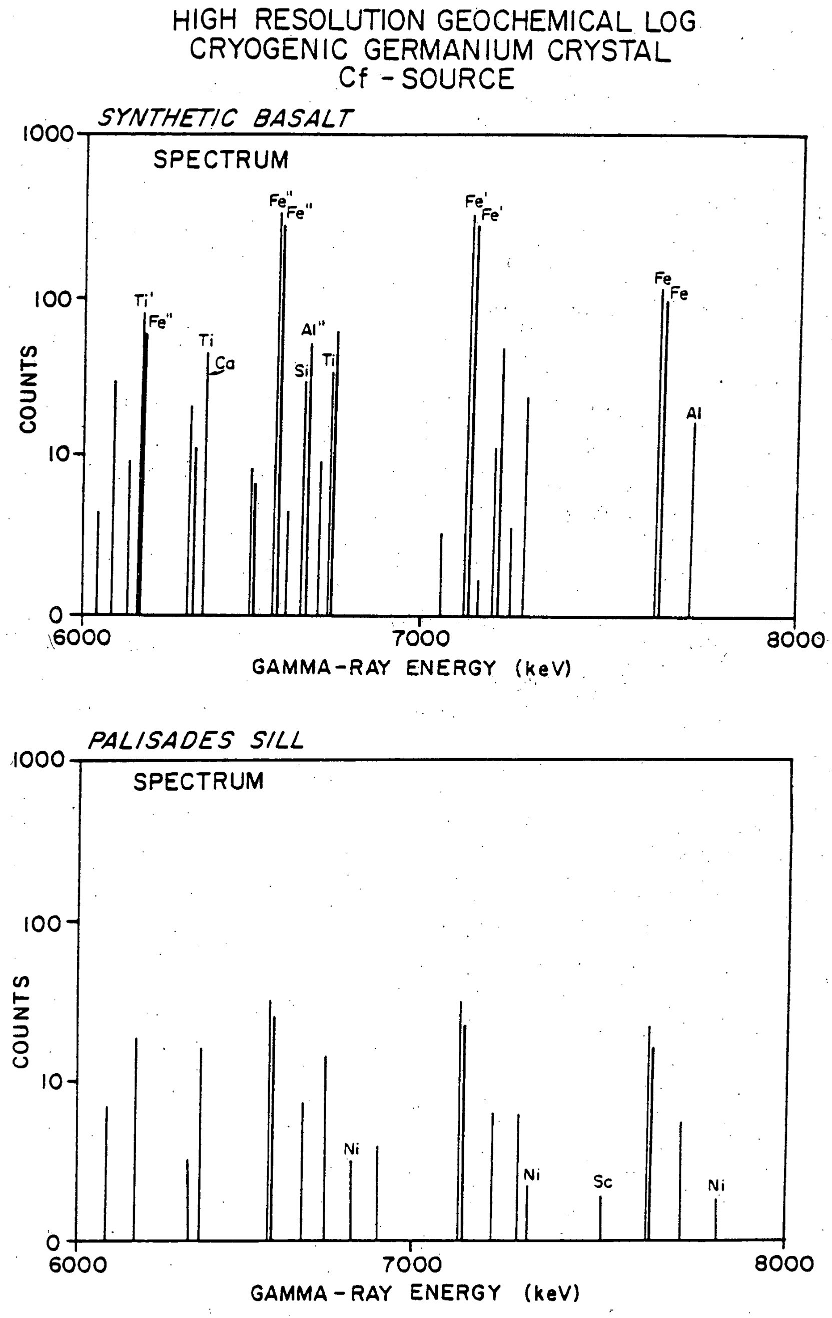


Figure 1-16. A cryogenic Germanium detector, geochemical log was also run in the Palisades Sill well. This tool provides enhanced sensitivity to the NaI crystal detector of the geochemical logging tool, but the logging speed must be 100 feet per hour or slower. Ni peaks (below) are identified in the Sill rock that were not present in the synthetic spectra (above). The Sc peak is likely measuring the composition of the steel in the tool itself.

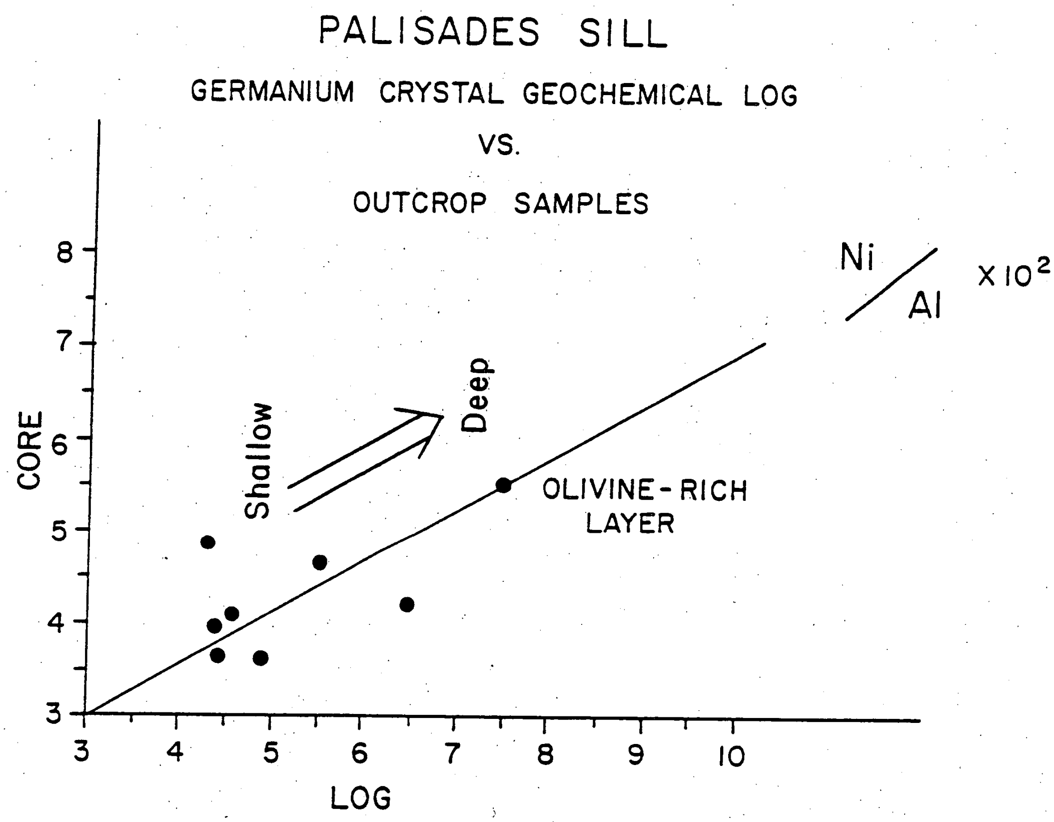


Figure 1-17. The Ni/Al ratios determined from geochemical logs using the Ge-crystal tool in the Palisades Sill compare favorably with analyses from outcrop samples. The increase in Ni/Al with depth in the well indicated crystal fractionation has occurred in the Sill, with mafic crystal sinking and plagioclase crystals floating.

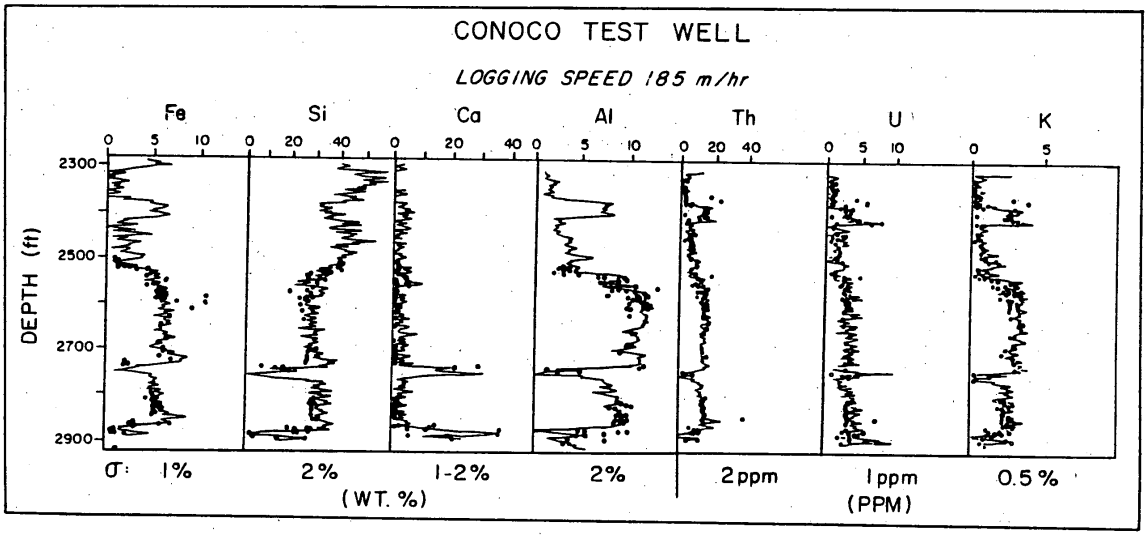


Figure 1-18. Geochemical logging results compared with analyses on side-wall core samples from the Conoco Test Well in the Anadarko Basin. Standard deviations between core and log results are shown at bottom.

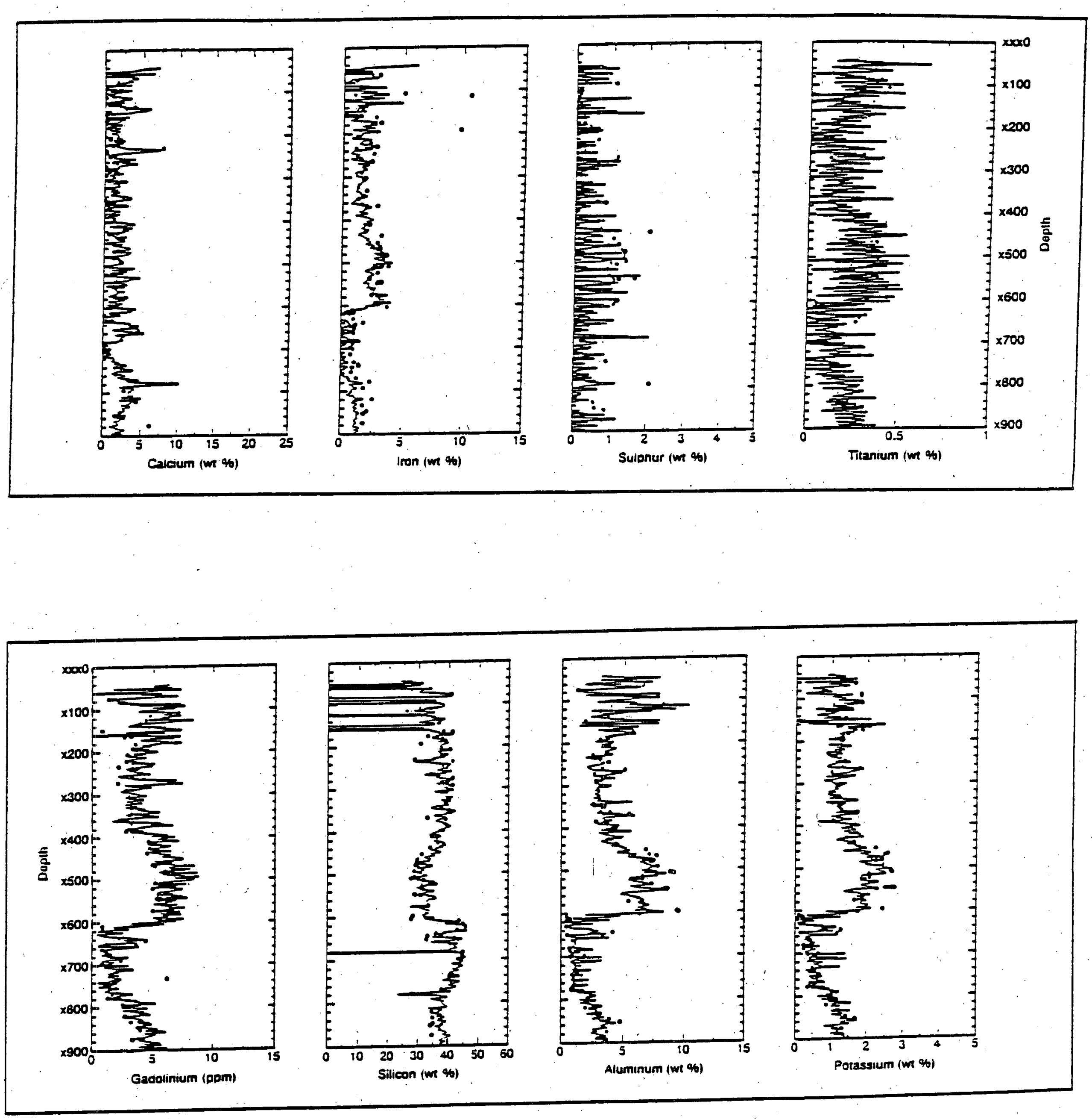


Figure 1-19. Geochemical log-derived analyses from the U.S. Gulf Coast compared to analyses on side-wall cores. The increased "noise" in the geochemical logs are likely from thin-interbedding.

Log Minerals vs. Core

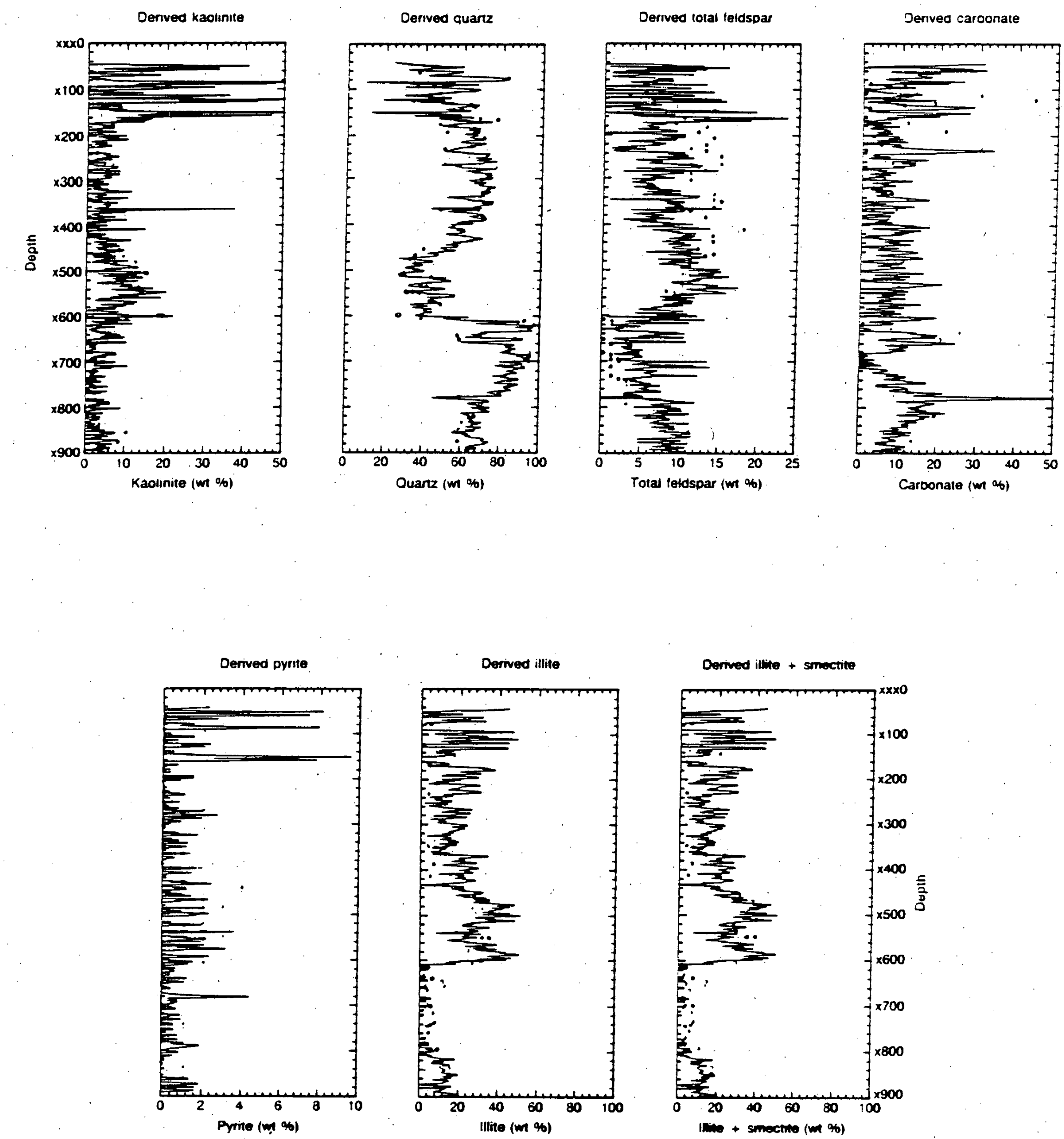


Figure 1-20. Mineral inversions from geochemical log results of figure 1-19 compared to quantitative X-ray diffraction results.

Chapter 2: Scientific Uses of Wireline Logs

A drillhole beneath the seafloor is a treasured natural laboratory for the recovery, measurement and monitoring of geophysical and geochemical properties of the geological past and present. It is expensive; but, if done properly, definitive. For example, the dating of sediments recovered during the DSDP is often cited as the irrefutable measurements that established the validity of plate tectonics. Who could question the recovery of core that repeatedly demonstrated that the oldest sediment above basement was the age predicted by magnetic anomalies?

The Ocean Drilling Program carries an additional arsenal of geophysical and geochemical weapons for determining the geology of the drillhole. It is important to recognize the differences between coring and logging of a hole. They are complementary, and together provide the most complete picture possible of the geology encountered by the drill bit. Below, we review the added information determined by ODP Logging.

Missing Section

The most obvious addition to the ODP program is the determination of *in situ* properties of the section of the borehole that was not recovered through coring. Continuous coring does not result in continuous core recovery. In fact, average recovery by techniques other than hydraulic piston coring is 50 % in sediments and 40 % in basement. The core that is recovered cannot be properly located stratigraphically because of the missing rock intervals. Logging measures a wide variety of geochemical and geophysical parameters at 15 cm intervals throughout the logged interval.

Site 719 (ODP Leg 116) in the mid-plate deformation zone of the central Indian Ocean provides an excellent example of the value of logging to fill a missing section (Figure 2-1). Here, core recovery was > 75 % in clays, but < 10 % in silts. Lithology determined from logs located the silts by higher gamma ray, high velocity, density, and resistivity, and lower porosity (black in the lithology column of Figure 2-1). The clays were easily distinguished by opposite features (white in Figure 2-1). The logs clearly show that the core recovery was highly successful in the clays but very poor in the silts. The fact that the distribution of these two lithologies is about equal in the hole would have gone unrecognized without the logs.

Geophysical and Geochemical Logs

It is important to recognize that not only are there differences between the information delivered by core versus logs, but there are major differences between the formation responses of the various logs run in a hole. The chemistry of sediments and basement rocks, and the physical changes caused by different geological processes can be quite different. Both data sets are much more informative than either alone.

Core recovery can be lithology-dependent: logs give continuous data

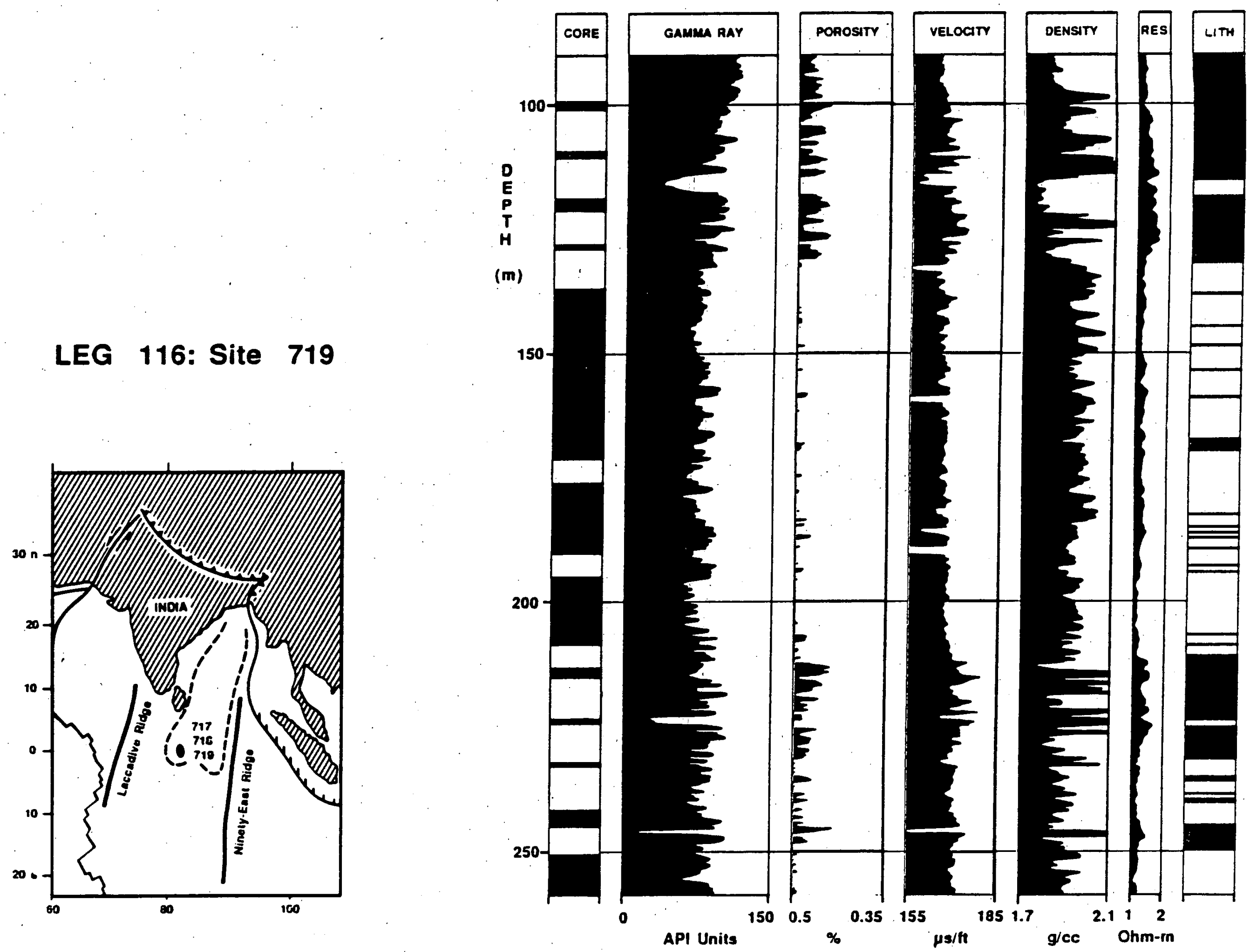


Figure 2-1. The geophysical logs from ODP Leg 116, Hole 719 can be used to classify two lithologies-- a clay with lower gamma ray, velocity, resistivity, and high porosity, and a silt with opposite features. The lithology log at right indicates lithologies picked from the logs (white-clay, black-silt). The coring program recovered the clay preferentially over the silt (left-hand column, black indicates core recovery). The logs are of obvious importance for filling in the gaps left by selective core recovery.

Consider logs from Site 731 (ODP Leg 117), a turbidite sequence on the Owen Ridge of the northwestern Indian Ocean (Figure 2-2). The turbidites are not very different one from the other in chemical composition, so the GLT elemental compositions are rather uniform throughout the sequence. Fe, Si, Ca, and K hardly change from top to bottom within each sequence (Figure 2-2). The geophysical logs, however, show dramatic changes related to the grain size changes that accompany turbidite deposition. The velocity log, for example, clearly deliniates the different turbidite events (Figure 2-2).

In the interval just above the turbidites in the same well, the reverse phenomenon occurs (Figure 2-3). Here, an alternating sequence of chalks and oozes contains fine interlayers of carbonate and silica that produce large variations in the GLT measurements of Si and Ca. The geophysical logs show only slightly varying velocity and electrical resistivity that indicate that the major chemical changes produce rocks with rather uniform physical properties (Figure 2-3). It is important that ODP wells are logged with both geophysical and geochemical logging tools.

Core versus Log Comparisons and Synthetic Seismograms

A major use of core in the oil industry, particularly side-wall cores, is for the spot calibration of logs. The ODP methodology calls for the reverse - logs used to calibrate cores, particularly physical property measurements. Site 752 (ODP Leg 121), provides an excellent example of the similarities and differences between physical property measurements from core and logs (Figure 2-4). Density and velocity measurements are of similar character between core and log results, but the logs show much finer character, and locate precisely the boundaries within the well. This enhanced resolution is important for precise definition of the impedance of the sediment (velocity times bulk density), from which a synthetic seismogram can be calculated to tie the core to the seismic section (Figure 2-5). The onset of the dipping reflector sequence in this well would have been missed without the log-derived velocity contact identified at 170m depth. Also, the velocity and density are more precisely determined *in situ* than from measurements on cores because of disturbance during the recovery operation. The laboratory-derived velocities were somewhat lower than the logs, as shown in Figure 2-4.

Amplitude and Attenuation

Multichannel sonic logs determine *in situ* elastic properties of the rock that simply cannot be reliably measured on core. The propagation of acoustic energy from source to an array of receivers is similar in geometry to a refraction seismic experiment. The source energy level naturally falls as a function of distance from the near receivers to the far receivers (Figure 2-6, from Site 637, ODP Leg 103). As the tool moves across lithologic boundaries, fractures and alteration zones, additional decreases in amplitude can be identified. The sporadic core recovery in the serpentinite basement at the toe of the Goban Spur off Portugal did not allow for a characterization of either alteration state or degree of brecciation and fracturing. The latter cause low-amplitude compressional waves to be recorded that indicate the location of highly attenuating zones (Figure 2-7). Semblance,

Alternating silt and clay layers have large velocity changes but small chemical differences

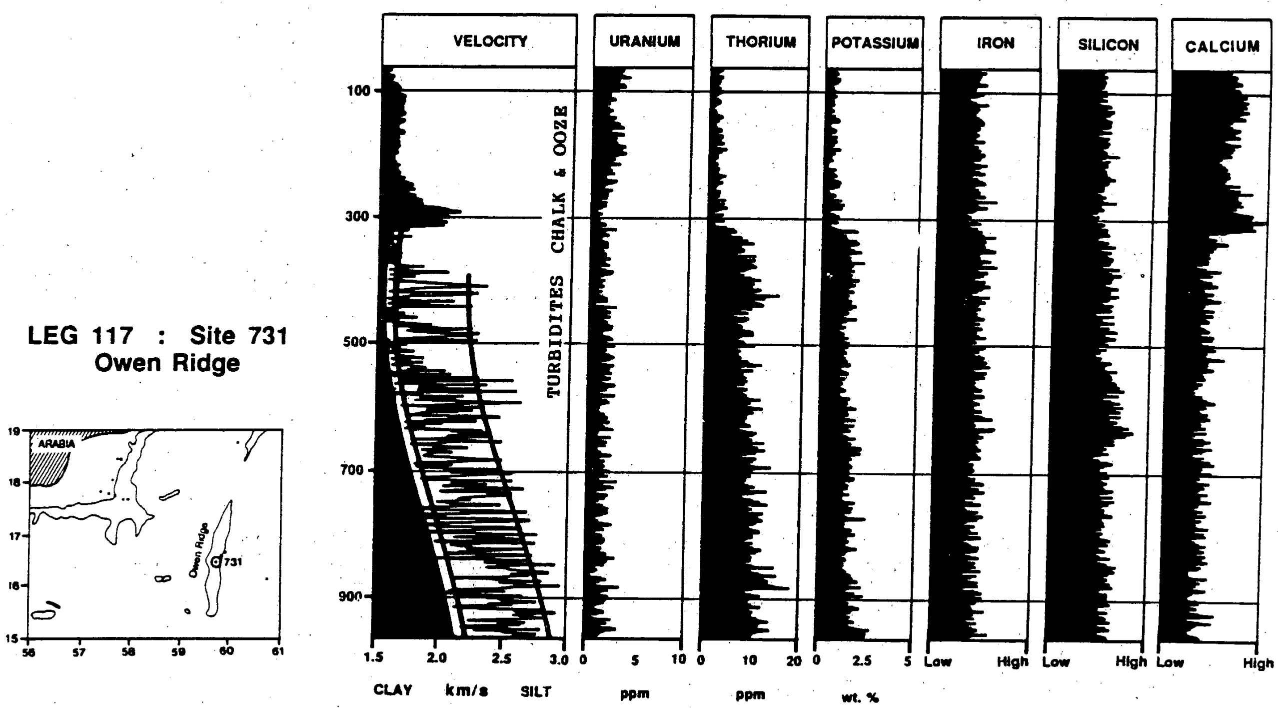


Figure 2-2. Geochemical logs (center and right) from ODP Leg 117, Hole 731 show only small changes in composition within turbidites on the Owen Ridge that decrease in grain-size upward. The change in grain size produces a very large change in sonic velocity within each turbidite layer (left).

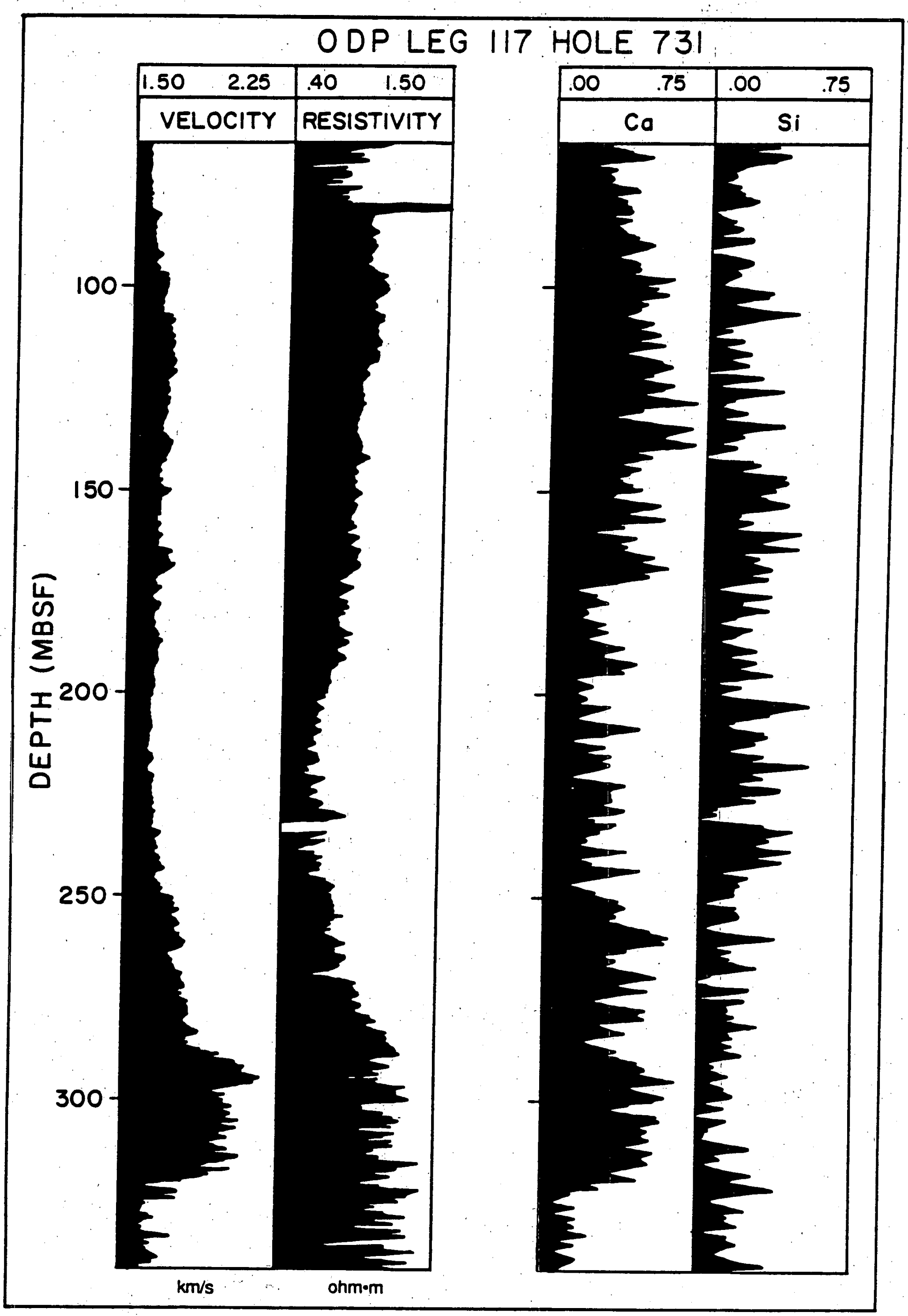
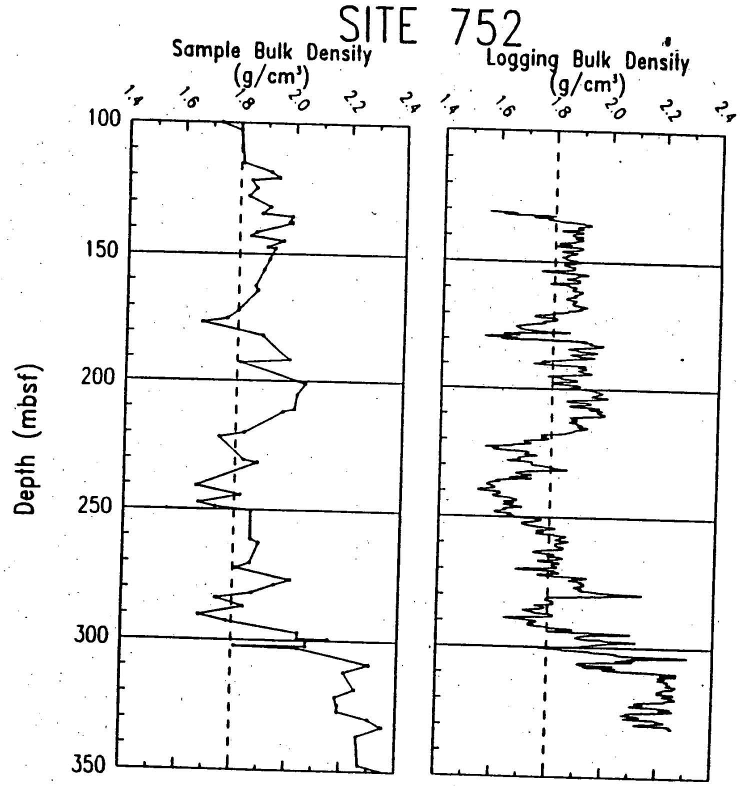


Figure 2-3. In the section just above the turbidite sediments in Hole 731 (figure 2-2), the alternation of carbonate-rich and silica-rich sediments produces large changes in the geochemical logs, but geophysical properties such as velocity and resistivity are very similar between the two lithologies. Geophysical and geochemical logs together provide a much more powerful geological interpretation than either alone.



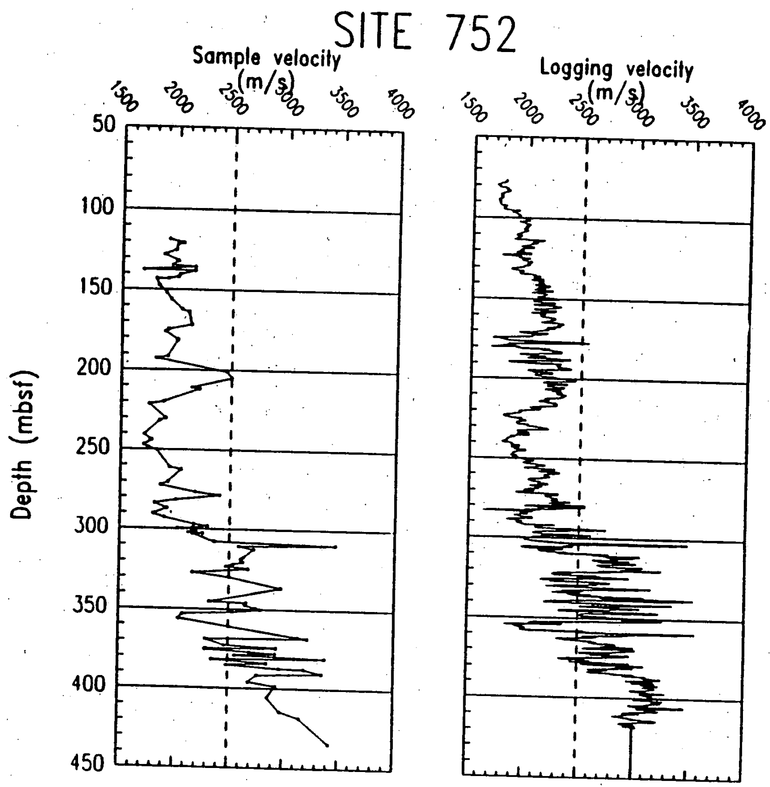


Figure 2-4. Log-derived velocity (right) and density (left) fill in the detail, and calibrate the results from laboratory measurements on recovered core, as in this example from ODP Leg 121, Hole 752 on Broken Ridge.

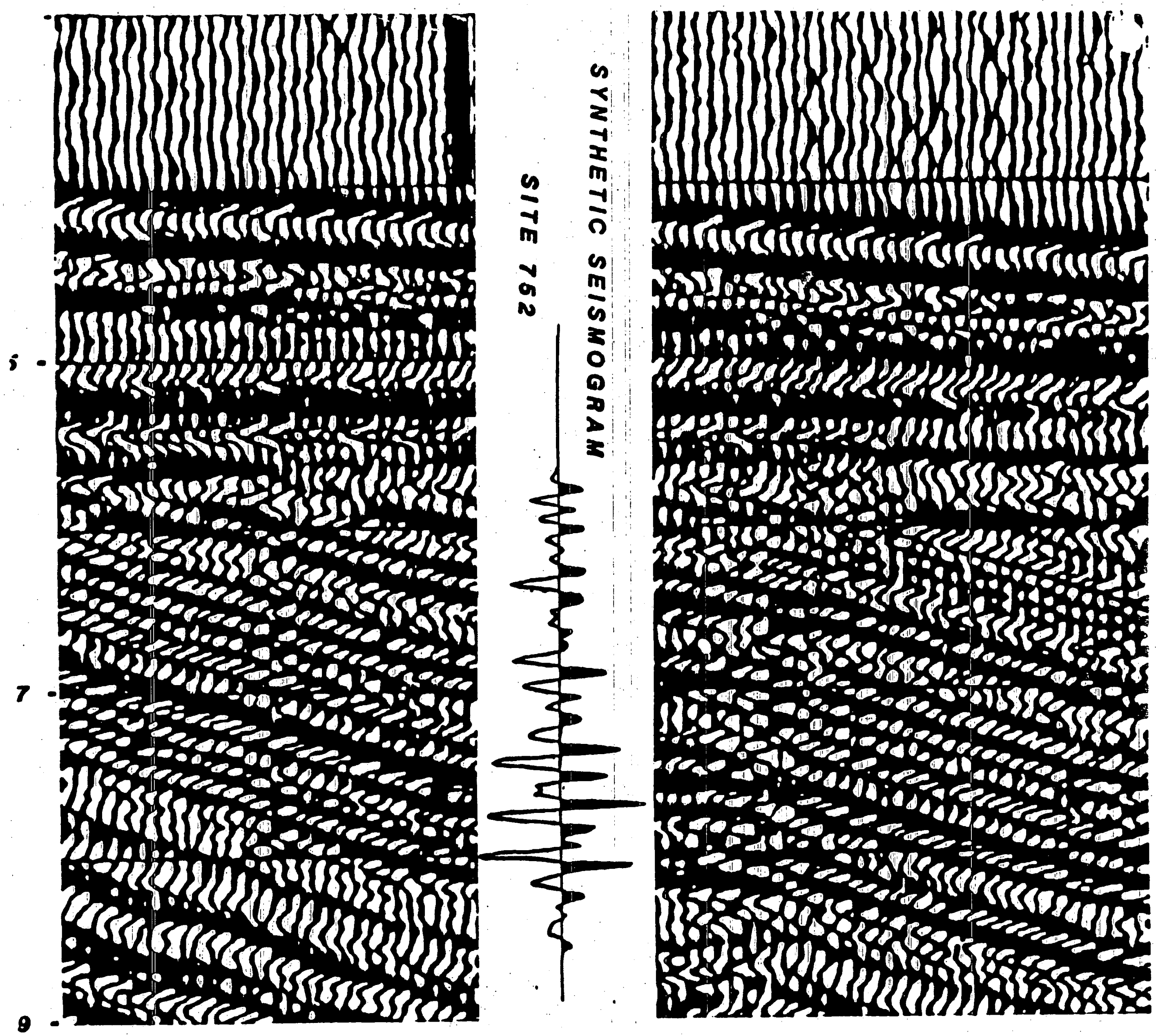


Figure 2-5. Detail in velocity and density determinations from logs provides an excellent impedance log for the calculation of synthetic seismograms to compare with surface seismic profiles. The dipping reflectors of Hole 752 are precisely located in depth from such logs.

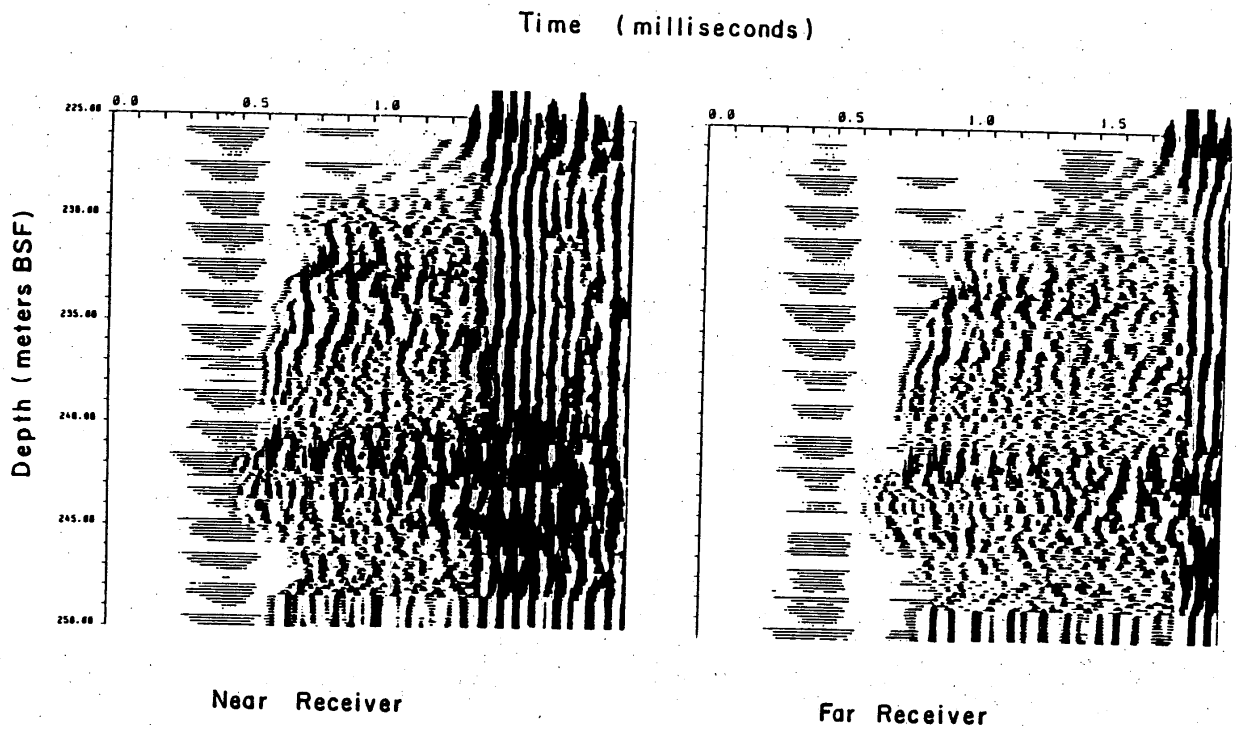


Figure 2-6. Multichannel sonic logs record the dissipation of sonic energy across several meters of borehole, as in this example from ODP Leg 103, Hole 637, drilled into the serpentinites at the toe of the Gobnan Spur off Portugal. The hard streak within the serpentinites at 240-245 m depth is evident from the increased energy recorded by the array at that depth.

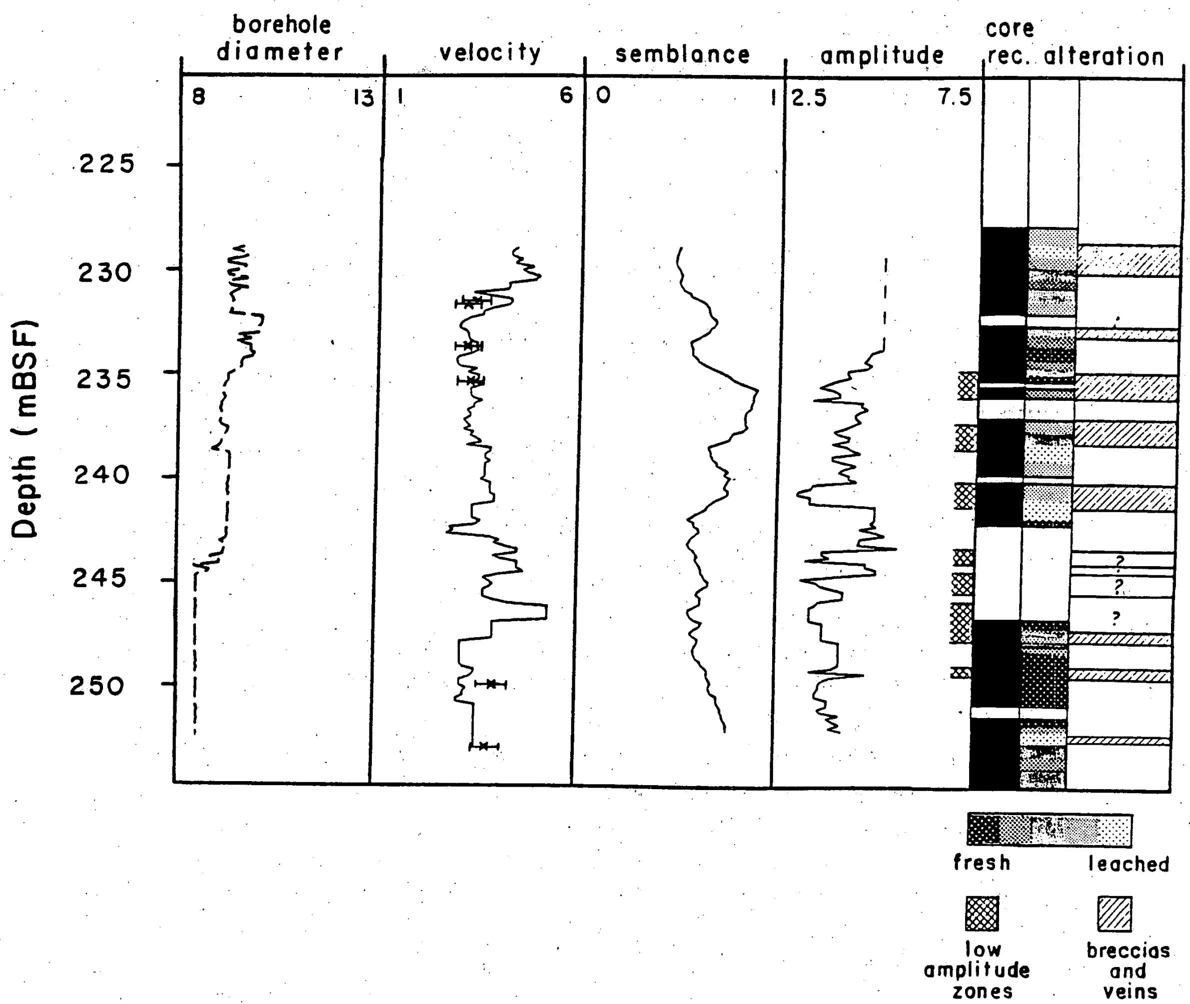


Figure 2-7. A semblance analysis of slowness across the multichannel sonic array of figure 2-6 shows more coherence (greater semblance value) in the fresher rock such as that at 235-245 m depth. Higher amplitudes also delineate the fresher rock. Notice that the core preferentially recovered the breccia zones (black at right).

which measures the coherence of energy between receivers as another way of quantifying relative amplitudes, and velocity, are not as sensitive indicators of alteration as compressional amplitude changes (Figure 2-7). It is important to utilize the multichannel sonic log amplitudes of shear and Stoneley and compressional waves in addition to velocities for complete elastic characterization of a formation.

A Worldwide Database of Basement Lithostratigraphy

The use of the same geophysical and geochemical logging measurements in all ODP boreholes has resulted in the gradual development of a logging database in all oceans. In the oceanic crust, for example, velocity, resistivity, and density logs can be compared from crust of different ages and from ocean to ocean. Consider the crust sampled on ODP Leg 111, Hole 504B (5.9 million years old, medium spreading rate), ODP Leg 109, Hole 395A (7 Ma, slow spreading rate), and ODP Leg 102, Hole 418A (110 Ma, slow spreading rate, Figure 2-8). The thicknesses and transition zones between the seismic layers 2A, 2B, and 2C can be compared at these three sites. For example, seismologists have noticed that layer 2A thins with age and distance from the ridge axis. The logs from the various oceanic crustal holes indeed show that the high-porosity layer 2A is eventually altered into layer 2B as hydrothermal circulation on the flanks of ridges gradually clogs the plumbing of the fractured pillows by the deposition of alteration products (Figure 2-8).

The transition zones found between these layers are not well imaged by seismic profiling because of the long wavelengths of the seismic energy (20-30 m). Logs provide the detail missed by seismic techniques. The borehole televiewer, for example, is an ultrasonic imaging tool that delivers to the surface an acoustic image of the borehole wall. The transition zone between pillow basalts and dikes in Hole 504B was imaged with the BHTV (Figure 2-9), and pillows were seen well into the dike section of the hole, well below the depth of the last recognized pillow in the core. Observations in ophiolites show similar phenomena. The transitions from one layer to the next are zones in which a gradual change occurs from a stratigraphic predominance of one structure to another.

Imaging of Structure and Stratigraphy

The electrical resistivity of a wellbore wall can be imaged using the Formation Microscanner dipmeter (FMS; Figure 2-10). This tool provides 1-mm resolution and produces an image of the electrical conductivity anomalies found along the borehole wall. Faults, breccias, and fractures can be imaged to determine if they are open (filled with low resistivity water) or cemented (filled with high resistivity calcite, quartz or other alteration products; Figure 2-10). Sediment structures such as slumps, laminations and bedding can also be imaged with unprecedented resolution.

The tool essentially delivers to the surface an electronic core image. Fractures, for example, may not only be counted, but their "electrical permeability" quantified by measurement of the electrical current flowing into them (Figure 2-11). In the example from Cajon Pass, sealed fault zones can easily be distinguished from open, permeable ones.

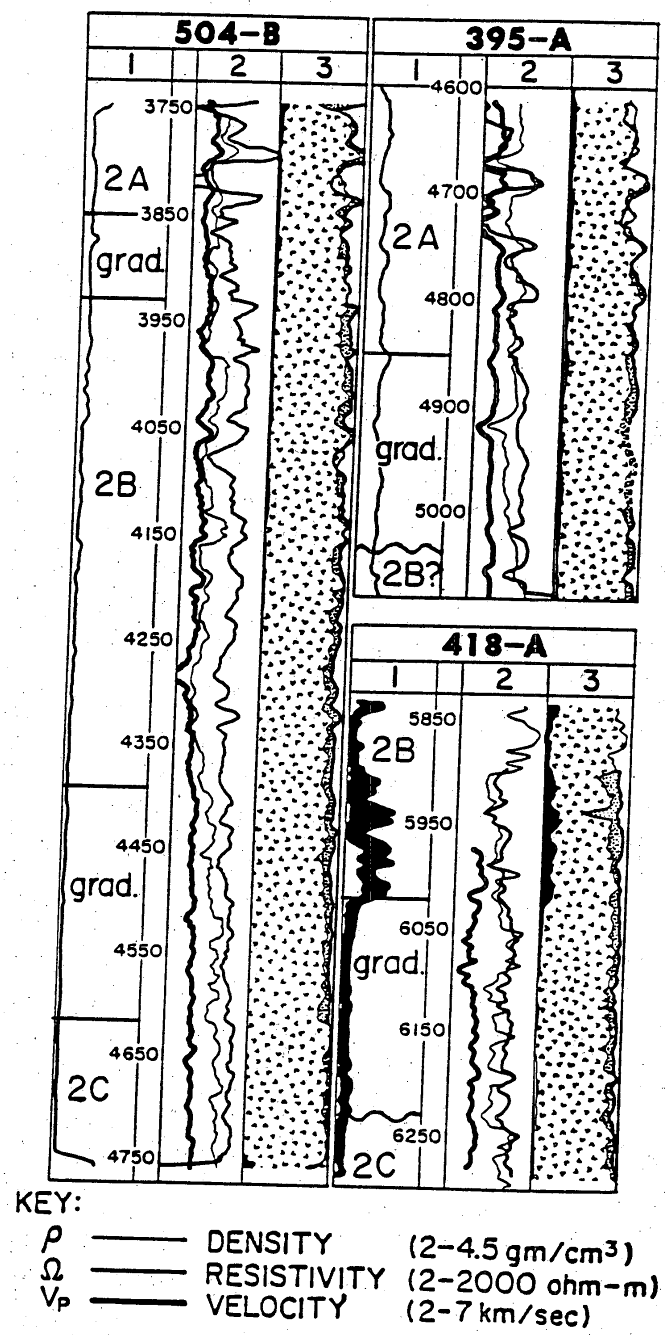


Figure 2-8. Density, resistivity and velocity at three drillholes (Holes 504B from Leg 111, 395A from Leg 109, and 418A from Leg 102) show similar transitions and layering in the upper oceanic crust, although the thicknesses of each vary. Eventually, ODP will produce an archive of the physical and chemical properties of oceanic crust from around the world.

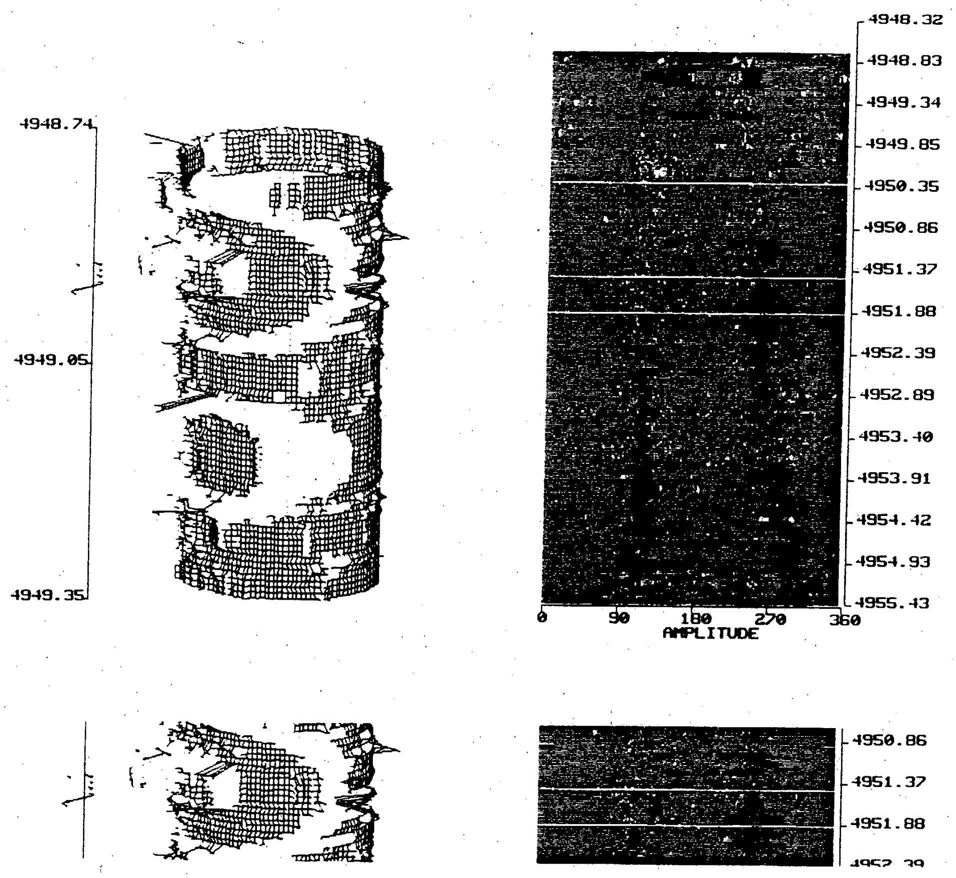


Figure 2-9. The Borehole Televiewer is an ultrasonic imaging device that is capable of discriminating pillow basalts from dikes, as in this example from Hole 504B. The image of an elliptical feature in the side of the wellbore is similar to shapes seen in shallow excavations of pillow flows in Hawaii.

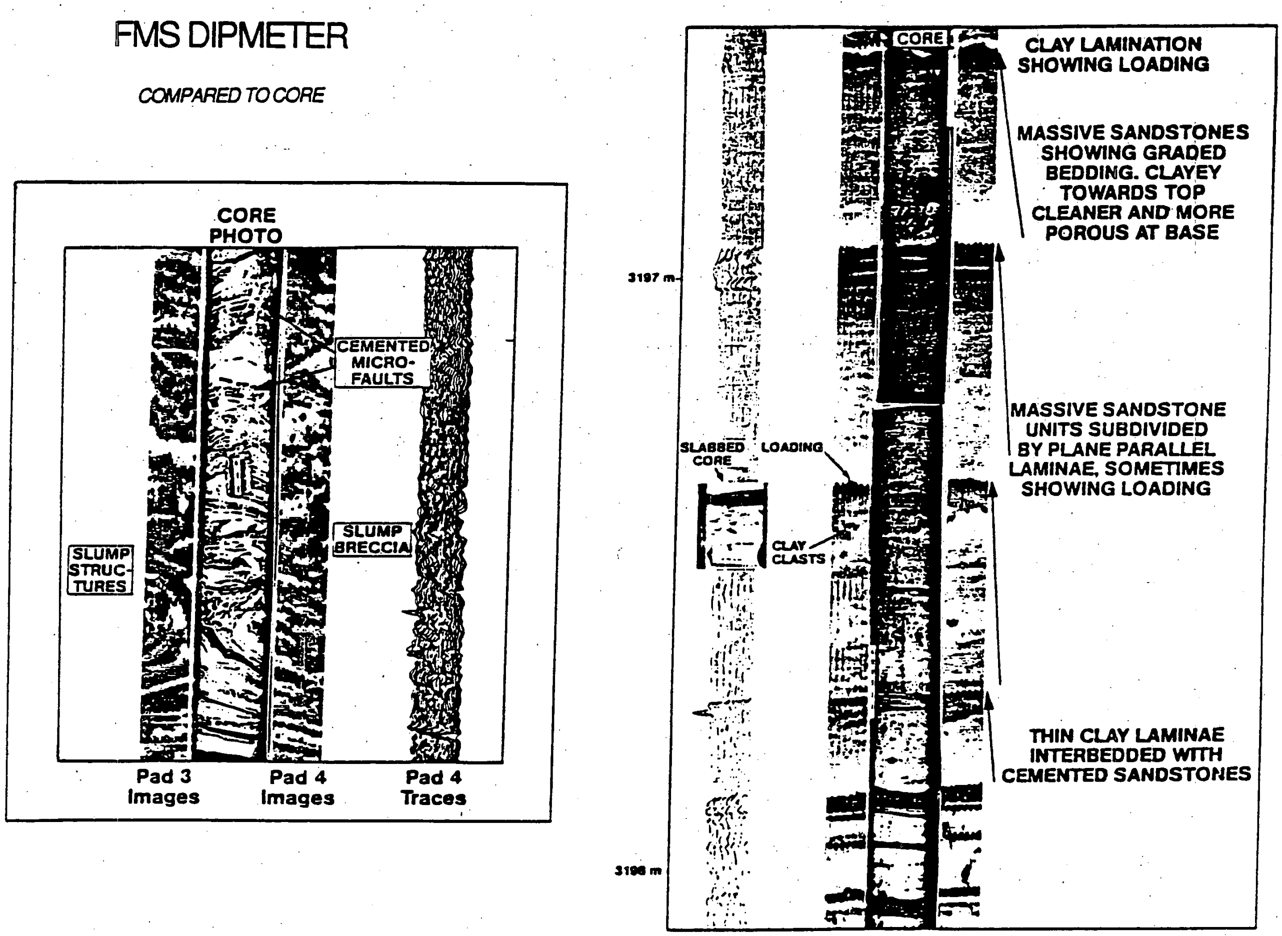


Figure 2-10. The Formation Microscanner is a dipmeter with four orthogonal pads that are dragged up the wall of a borehole. Electrical current is pushed out from 16 finely spaced "buttons" on each pad to provide an image of the electrical conductivity of the formation. The tool is capable of imaging laminations, bedding, cementation in fractures, slumps and other fine-scale stratigraphic information that was previously only available from analyses of core.

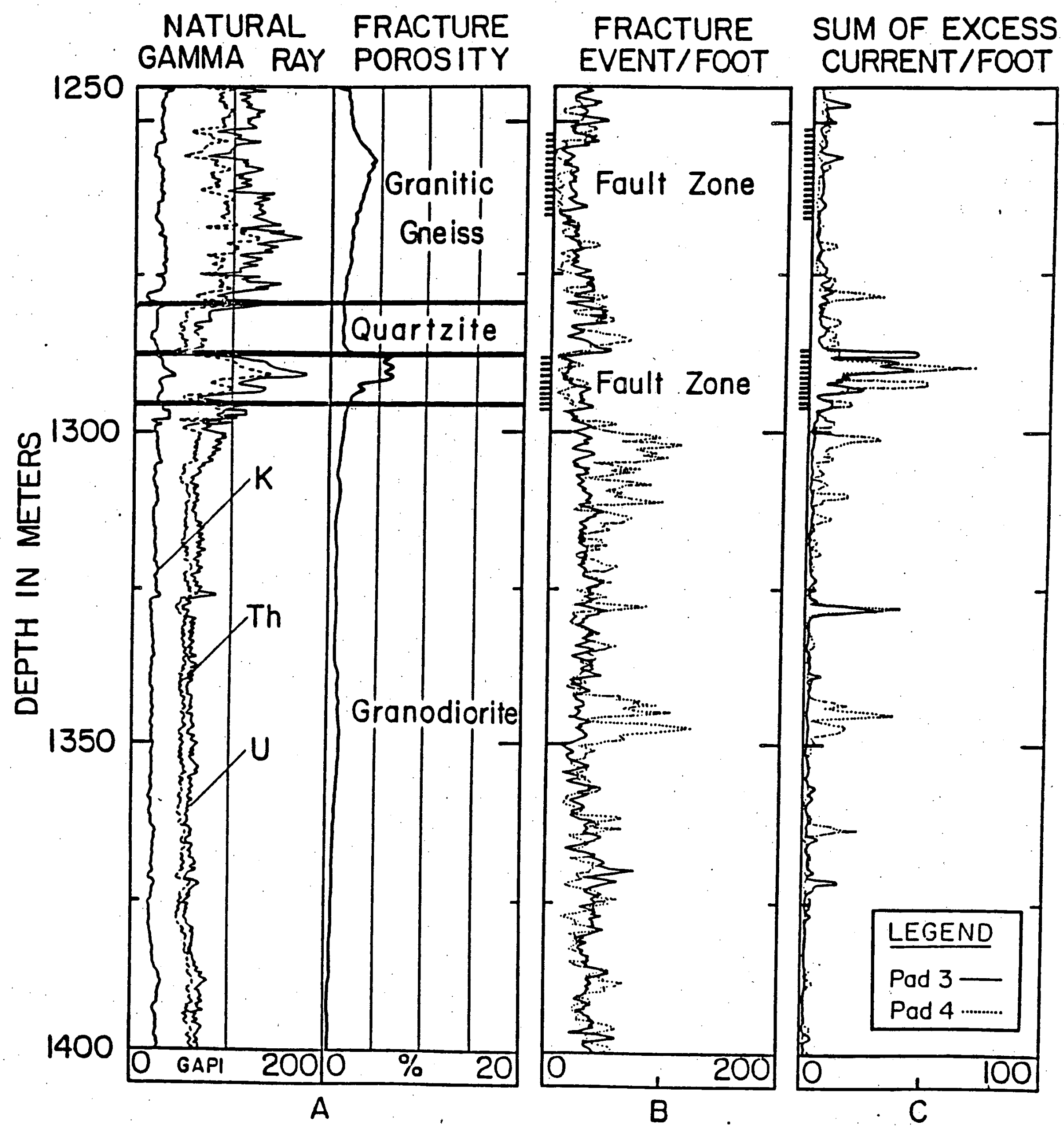


Figure 2-11. (A) The natural gamma ray and the fracture porosity logs are displayed at the left. The latter is derived from the difference between deep and shallow penetrating electrical resistivity curves of the dual laterolog. (B) Fracture intensity determined by counting fractures imaged by the FMS. (C) Electrical conductivity due to fracturing is identified from the analysis of FMS images as zones of excess current that the tool must pump into the rock to produce an image. For (B) and (C), each curve represents the data recorded by one pad of the FMS, and both scales are in normalized, dimensionless units.

Dipmeter Determination of Structure and Stratigraphy

The Formation Microscanner also provides the traditional dipmeter information of orientation of bedding and fractures. In the Cajon Pass drillholes, dips were significantly different in two wells only 100 m apart (Figure 2-12). In addition, basement rocks were encountered 170 m deeper in one hole than in the other. These structural and stratigraphic features constrained the geometry such that a previously unknown thrust fault, dipping almost vertically, must be located between the two wells (Figure 2-13). The advantages of stratigraphic interpretation using the dipmeter are so important that it continues to be the most heavily used oil field logging tool in the world. Beginning on Leg 126, the FMS dipmeter will be part of the routine ODP logging suite.

Summary

In conclusion, the ODP logging program allows the measurement of geophysical parameters such as velocity, density, porosity, radioactivity and acoustic attenuation, and geochemical parameters such as elemental mass abundances of Si, Al, Fe, Mg, Ca, K, Ti, S, Gd, U, and Th continuously throughout a logged interval. These data complement core analyses for an enhanced geological interpretation. The Ocean Drilling Program makes logging measurements in holes that are exactly like those made in scores of continental scientific drillholes. The result is a truly global database of *in situ* measurements in the earth's crust.

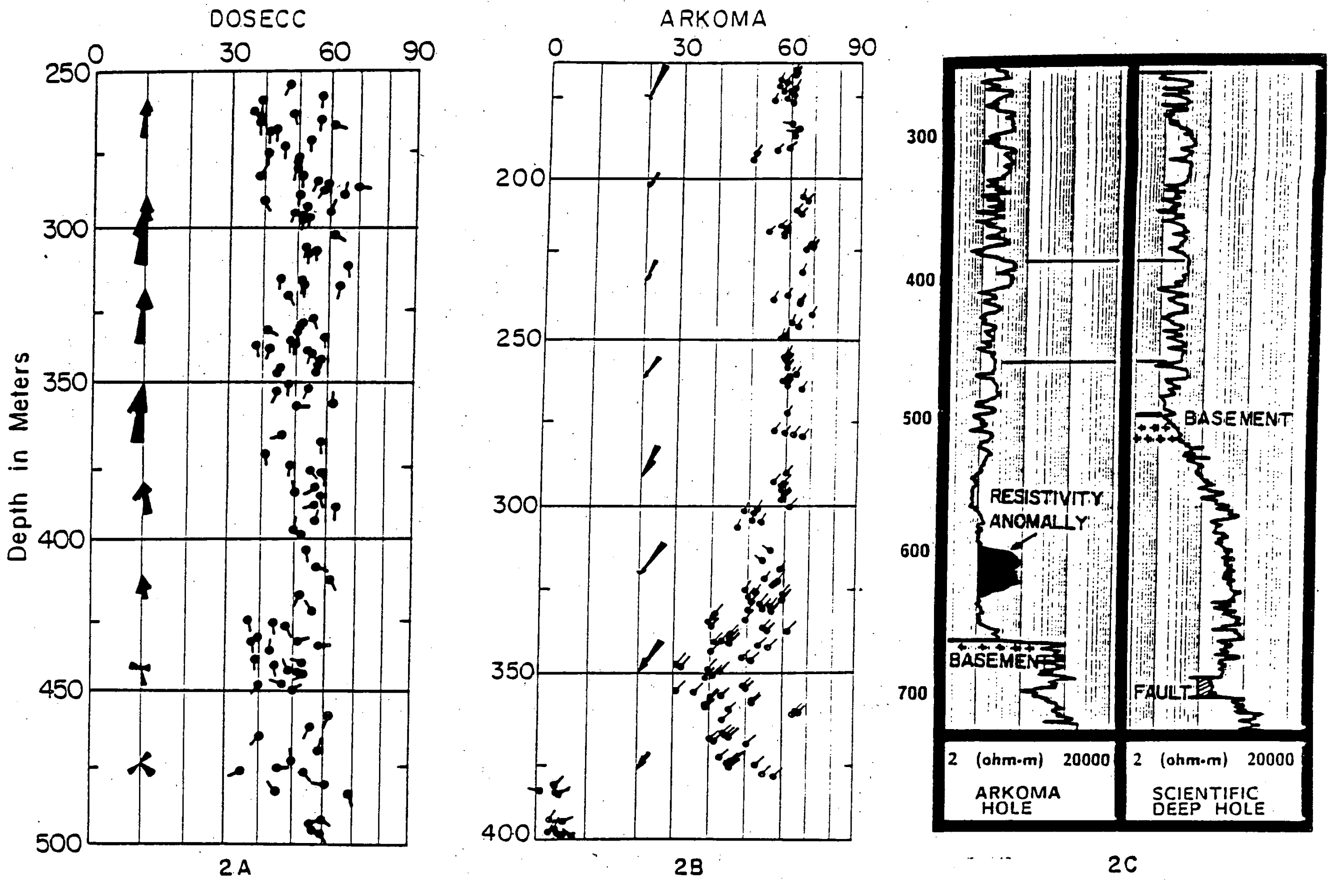
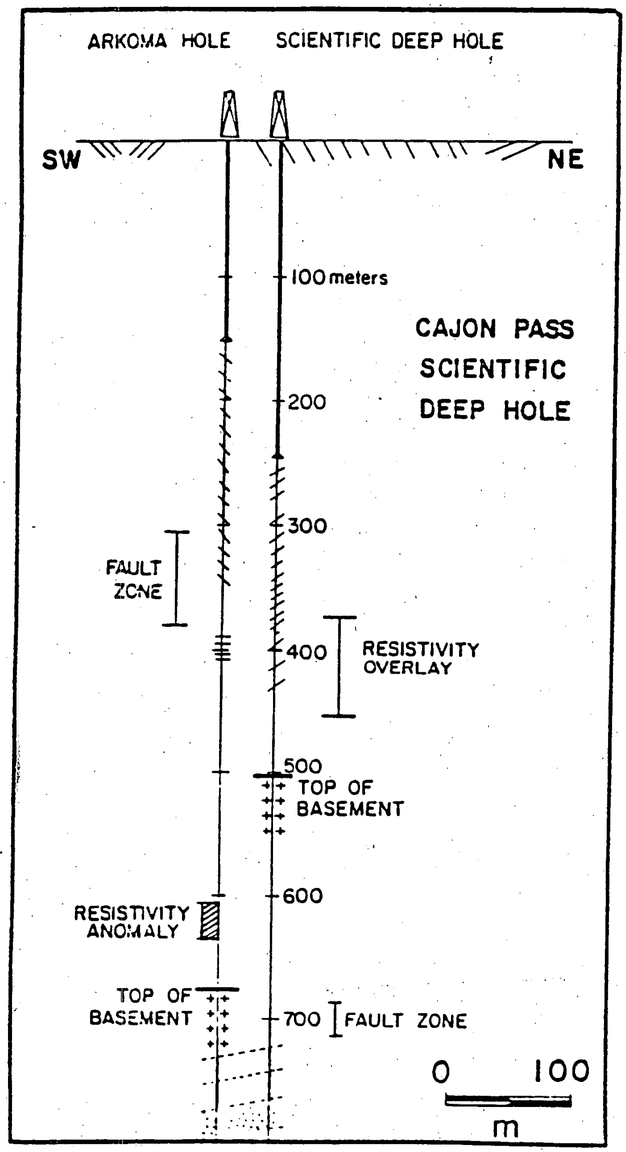
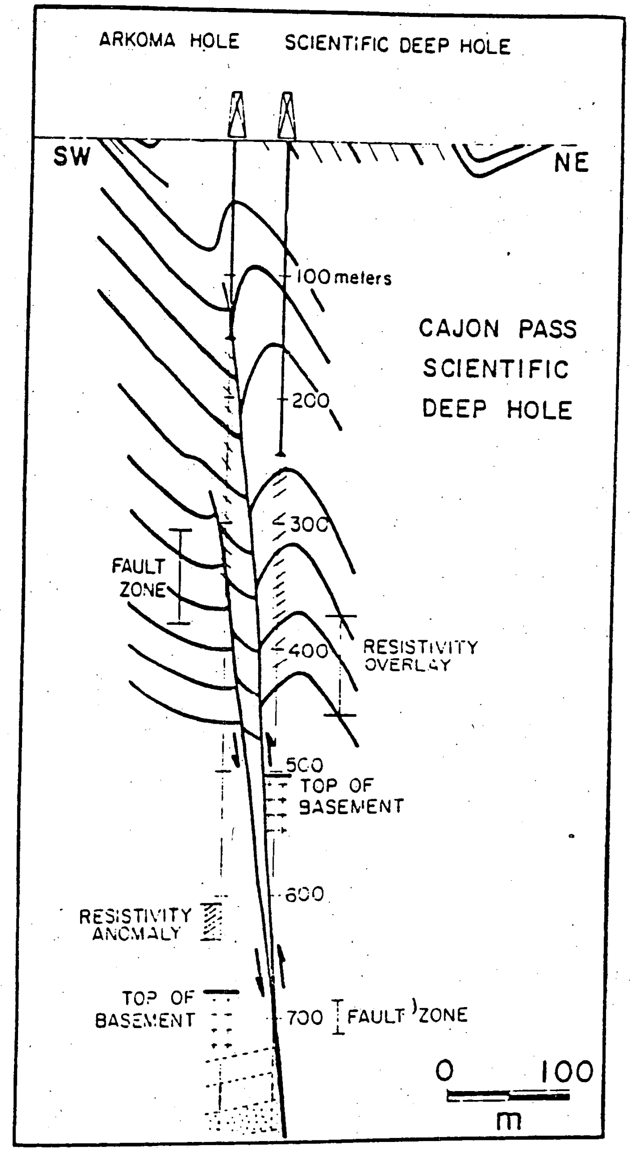


Figure 2-12. (A) Dip angle and azimuth from dipmeter data in the Cajon Pass drillhole. The dots represent the dip angle, and the tails point in the down-dip direction. A rose-diagram summarizes the results for dip orientation every 25 m. (B) Dip angle and azimuth from dipmeter log in the adjacent Arkoma oil well. Note dip change even though wells are only 150 m apart. (C) Resistivity data recorded with electrical resistivity logging tools in the Cajon Pass and Arkoma drillholes.



3A



3B

Figure 2-13. Southwest-northeast cross-sections running through the Arkoma and Cajon Pass drillholes. (a) Data from dipmeter logs, and (b) interpretation of the thrust fault running between the two wells. There is no vertical exaggeration in these drawings.

Chapter 3: Ocean Crust, Fluids, and Volcanic Processes

Hole 504B is perhaps the most famous scientific borehole in the world, rivaling the Kola superdeep drillhole of the Soviet Union and the Bertha Rogers drillhole of oil industry lore.Hole 504B has penetrated to the deepest depths in the oceanic crust (1.5 km), as have Kola into the continental crust (14 km), and the Bertha Rogers into a sedimentary basin (10 km). It is important to realize the expenditure of funds already invested into science in Hole 504B - $ 16 M in rig-time alone- makes it perhaps our best hope for a permanent scientific observatory in the deep oceanic crust. A summary of logging and downhole experiments conducted in the hole during the five legs in which ODP and DSDP have occupied the site is presented below because Hole 504B exemplifies the power of integrated, multi-disciplinary, downhole experimentation towards investigation of the ocean crust.

Geophysical and Geochemical Logging in Hole 504B (from Becker et al., 1988)

One of the most elusive objectives of JOIDES and ODP is to core as deeply as possible beneath the ocean floor at carefully-selected sites, simply to provide "ground-truth" for our models of the structure and evolution of the oceanic crust. With one notable exception, deep sea drilling to date has penetrated no farther than 0.6 km into the basaltic, upper layer of the ocean crust, which has often proven quite difficult to drill. Since pillow lavas extruded at the mid-ocean ridges and the overlying sediments generally constitute only 1-2 km of a typical 6 to 8 km thick crustal section, the greater part of the oceanic crust has never been directly sampled *in situ* and in section. Thus, much of our incomplete understanding of the deeper crust must be inferred from remote geophysical and geochemical investigations and from studies of ophiolites (subaerial sections of crust formed in island arc, back-arc, or mid-ocean ridge settings, that have been tectonically emplaced and incompletely represent *in situ* oceanic crust).

The only borehole that clearly penetrates through the pillow lavas into the underlying sheeted dikes is Hole 504B, which is located under 3460m of water in Nazca Plate crust that formed 5.9 million years ago at the Costa Rica Rift (Figure 1-1). Here, five legs of DSDP and ODP have cored to a total depth of 1562.3 m beneath the seafloor (mbsf), more than 1200 m of which is into oceanic crust (over twice as deep into oceanic basement as any other hole), and scientists have conducted the most extensive program of logging and downhole measurements of any deep ocean hole. As core recovery has been relatively poor in the hole (< 20%) the remarkably comprehensive logging and downhole measurements have been especially important in resolving the state of the crust at Site 504.

Hole 504B has been logged with a wide range of logs and special experiments designed to continuously assess the downhole variation of several key geophysical and geochemical properties *in situ*, including temperature, sonic and seismic velocities, electrical resistivity, density, porosity, permeability, the magnetic field, lithology, and the state of stress. These logs and experiments were in many cases calibrated by laboratory measurements of physical and chemical properties of recovered basalts, including sonic velocity, density, porosity, electrical and thermal conductivities, and magnetic properties. The logs and experiments conducted in Hole 504B provide a remarkably comprehensive and consistent description of the physical state of the crust at the site.

Many of the logs and experiments in Hole 504B suggest the presence of a 100 to 200m thick geophysical Layer 2A in the porous upper pillow lavas, which is the only permeable interval in the entire cored section. Layer 2B apparently corresponds to the lower section of pillow lavas, which is partially sealed as a result of hydrothermal alteration. Nearly all of the logs show significant changes *in situ* at the transition zone between 900-1000 mbsf, some 100-200m deeper than a relict fault hypothesized from the results of the magnetic log. This indicates that the transition between pillow lavas and sheeted dikes in Hole 504B corresponds quite closely to that between Layers 2B and 2C.

1. Borehole temperatures and geothermal observations.

During the five legs that worked at Site 504, downhole temperatures were measured thirteen times, including one profile of sediment temperatures in Hole 504C and twelve logs of borehole temperatures in Hole 504B. Of the twelve profiles in Hole 504B, four were measured under equilibrium conditions, when Legs 70, 83, 92, and 111 initially reentered Hole 504B at long time intervals after the drilling on previous legs. These equilibrium temperatures are shown in Figure 3-1, along with the temperatures measured in the sediments at Hole 504C. Hole 504B is easily the hottest hole yet drilled by DSDP or ODP, with an equilibrium bottom-hole temperature of about 165 °C at the present total depth of 1562.3 mbsf.

Temperatures measured in the upper 400m of Hole 504B show the effect of a transient phenomenon that has been active only since the hole was drilled: ever since Hole 504B penetrated through the relatively impermeable sediment layer and into the upper 100m of basement, cold ocean bottom water has flowed down the 276.5m-long casing through the sediments and into the upper section of permeable, porous pillow lavas. This was inferred from depressed temperatures measured in the upper 400m (Figure 3-1) and was confirmed by actually sampling ocean bottom water as deep as 355 mbsf and by measuring pressures in the formation that were lower than hydrostatic (underpressured). The equilibrium gradient in the sediments in Hole 504C provided the essential initial and boundary condition that allowed the rate of downhole flow to be determined from the depressed temperatures in Hole 504B. The results indicate that the rate of downhole flow commenced at about 100m/hr (7000 l/hr) when the hole was first drilled, and decayed to less than 1% of this rate in the seven years between Legs 69 and 111.

The approach of temperatures at about 400m to the undisturbed conductive profile indicates that the downhole flow of bottom water extends no deeper, but instead must be exiting the borehole into the upper 100-125m of pillow lavas. Flow tests using a drillstring packer showed that this section of basement was underpressured by about 1 MPa, so that the ocean bottom water was literally being sucked down the hole and was not circulating hydrothermally. A total of about 10^8 kg of ocean bottom water has been drawn into this underpressured reservoir; the decay of the downhole flow suggests that the reservoir is of limited lateral extent and/or that the underpressures have been quenched by the total flux of seawater.

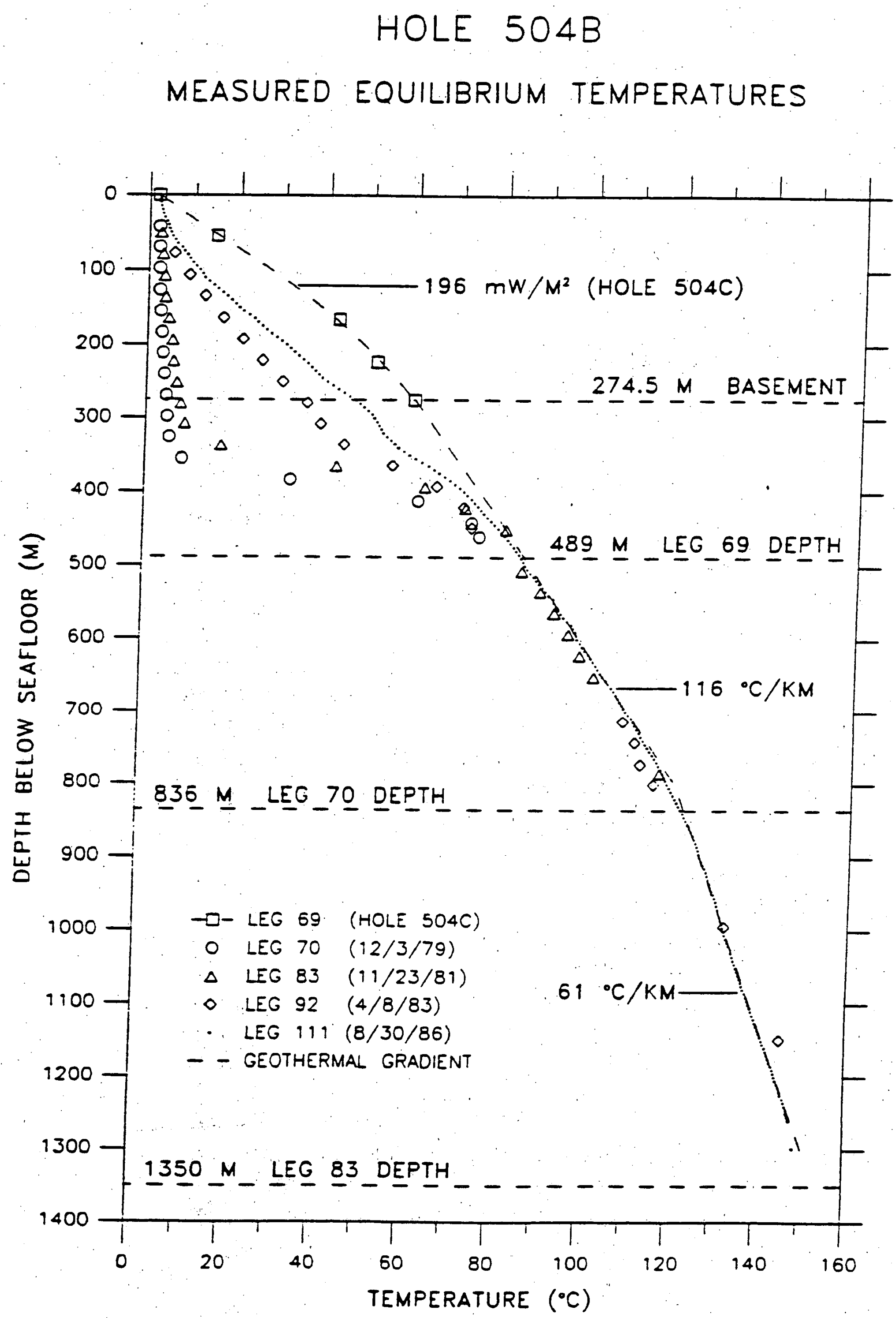


Figure 3-1. High-precision temperature logs (above) from several legs over the last ten years are shown for Hole 504B. The drop in temperatures in the upper 400 m of Hole 504B temperatures versus Hole 504C is due to drawdown of ocean bottom water into an underpressured reservoir that is the upper oceanic crustal Layer 2A. The steady increase in temperatures with time in this interval is evidence that the reservoir is being slowly filled to equilibrium. A reservoir model assuming lateral continuity of measured permeabilities produces a prediction of the drop in inflow into the crust that closely matches observed rates, and that predicts future temperatures to be found in the zone. The next test will be in 1991-92.

Similar observations of downhole flow have been made in several other DSDP holes, notably holes penetrating sediment ponds in young Atlantic crust, e.g., Holes 335 and 395A. The results in these holes and in Hole 504B suggest that the upper pillow lavas in sedimented young oceanic crust may commonly be underpressured. The underpressures in Hole 504B result from hydrothermal circulation in the oceanic crust, which the detailed surface heat flow measurements also require. Models of such circulation beneath an impermeable sedimentary cap rock have been quite successful at simulating the observations of underpressures and downhole flow in Hole 504B.

2. *In situ* permeability and porosity

Hole 504B is one of only four DSDP/ODP holes (395A, 504B, 735B, and 765B) in which the key property that controls circulation - permeability - has been directly measured *in situ*. These measurements were made utilizing drillstring packers to isolate various sections of basement and to determine bulk permeabilities of these zones by applying differential fluid pressures. In the upper 100-200 m of the pillows lavas, bulk permeabilities are on the order of 200 millidarcys. In the remaining section, which comprises over one kilometer of sealed pillow lavas and sheeted dikes, bulk permeabilities are orders-of-magnitude lower, on the order of 10 microdarcys (Figure 3-2). The uniformity of the low permeability of the entire lower kilometer penetrated by Hole 504B was unexpected, given that this section spans the transition between pillow lavas and sheeted dikes, but it confirms that the lower 400 m of pillow lavas are truly sealed. The only section penetrated by the hole that is presently permeable to hydrothermal circulation is the upper 100-200 m, which is the zone into which ocean bottom water has flowed since the hole was drilled, and which corresponds closely to seismic Layer 2A.

While permeability is very difficult to measure directly, it is much easier to estimate a related property, the porosity of the formation, from continuous geophysical logs. As the upper oceanic crust is a porous medium, many of the geophysical properties that are logged depend to varying degrees on porosity, e.g. sonic and seismic velocities, electrical conductivity, density. The porosity of the oceanic crust, however, occurs on several scales, ranging from grain-boundary and vesicular porosity seen in cores to large-scale fracture porosity that probably dominates the contribution to permeability but cannot be easily sampled with the drill. Thus, the log-derived porosity values cannot be calibrated against the core, and it is unclear which of the logs yields the most realistic estimates of *in situ* porosity.

As the electrical conductivity of the crustal pore fluids (which are very nearly seawater) is orders of magnitude greater than that of basalts, logs of electrical resistivity are quite sensitive to the porosity of the crust. Figure 3-2 shows electrical resistivities measured in Hole 504B, and apparent bulk porosities estimated by applying Archie's empirical relationship between resistivity and porosity. Among all the logs run in Hole 504B, the resistivity logs probably show the sharpest change across the transition from pillow lavas to sheeted dikes, with measured resistivities increasing by over an order of magnitude at about 900 mbsf, where greenschist-facies alteration minerals abruptly appear in the core. This is accompanied by a sharp reduction in estimated porosities, which approach 1% in the deepest dikes.

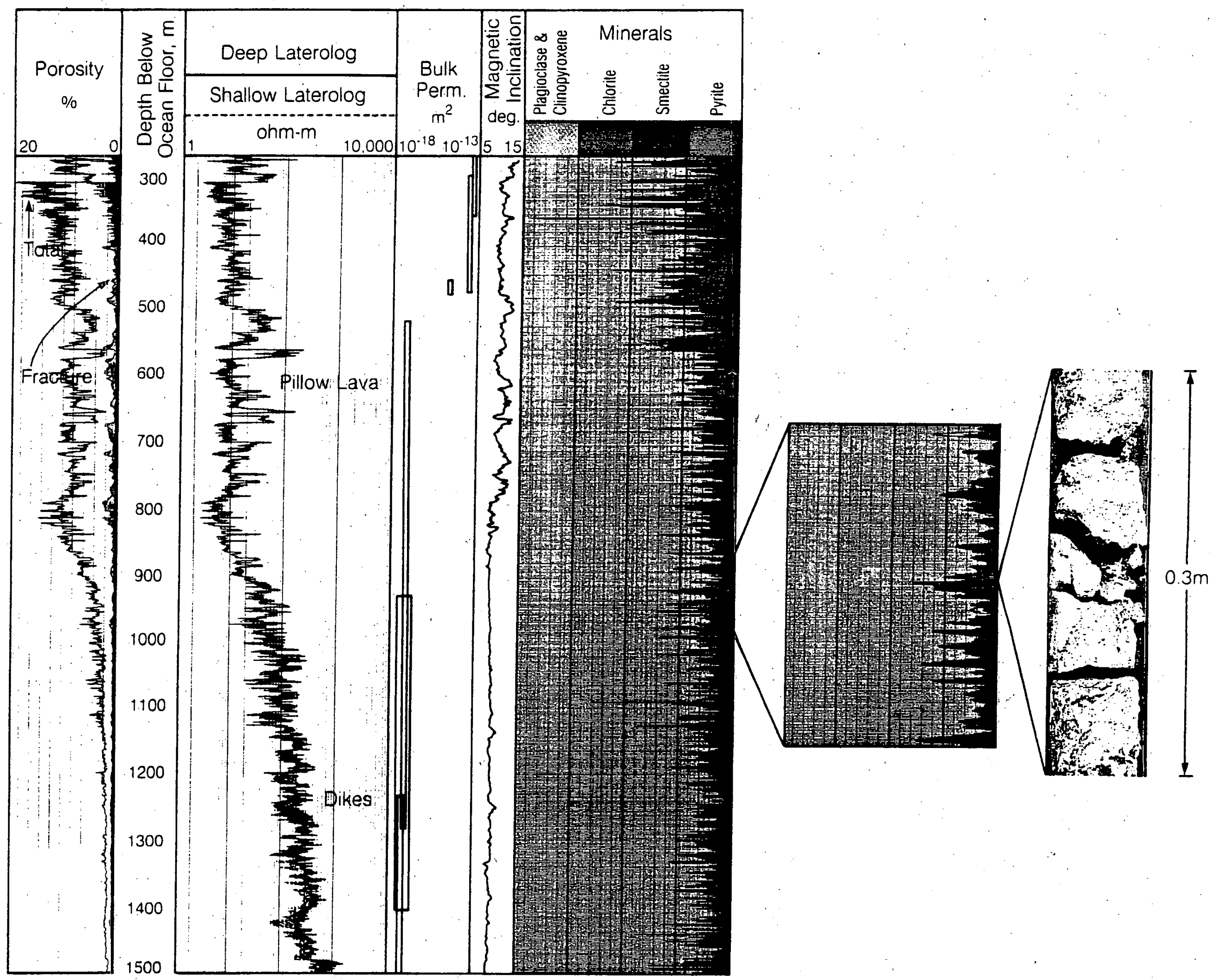


Figure 3-2. Geophysical and geochemical logs from ODP Leg 111, Hole 504B. The logs show porous and permeable pillow lavas (at top), grading into nonporous and impermeable sheeted dikes (at bottom). Total and fracture porosity were measured with a Dual-Laterolog electrical resistivity tool; permeability, with flow tests across packed-off intervals; magnetic inclination, from a 3-component, flux-gate magnetometer tool; and mineralogy, from elemental abundances measured by the geochemical logging tool. There is excellent agreement between core and geochemical logging results as can be seen from the blow-up at the right, where smectites (grey), laumontite (white), pyrite (yellow crystals)), and calcopyrite (yellow) minerals can be seen within a mineralized breccia zone indicated on the geochemical log as spikes of chlorite, smectite and pyrite in a matrix of fresh basalt (plagioclase and clinopyroxene).

The contribution of fracture porosity to the total porosity was estimated by applying the same algorithm to resistivities measured with the Dual Laterolog, a medium-spaced log with shallow and deep scales of investigation that are respectively insensitive and sensitive to large fractures. As Figure 3-2 shows, the measured permeabilities correlate much better with the estimated fracture porosities, which are low throughout the lower pillow lavas and sheeted dikes, than with estimated total porosities, which are fairly high in the sealed pillow lavas of Layer 2B. The results of the permeability measurements and the geochemical logs suggest an alternate interpretation of the resistivity-derived apparent bulk porosity in Layer 2B (see below).

3. Magnetic structure of the crust at Hole 504B

Given its depth of penetration, Hole 504B provides key data on the properties of the magnetized layer that produces marine magnetic anomalies, which is often assumed to be on the order of 0.5-1 km thick. Several investigators have studied the magnetic properties of many relatively homogeneous, generally less-altered samples from Hole 504B. A synthesis of the results through Leg 83, emphasizes that the magnetic properties of the basalts are strongly controlled by post-emplacement alteration of the magnetic minerals. Therefore, the magnetic structure of the crust at Hole 504B should not be assumed to apply generally to oceanic crust, which is probably altered to different extents at other sites.

Hole 504B is located within a positive magnetic anomaly caused by reversely-magnetized crust formed about 5.9 Ma ago. As the site is located near the magnetic equator and the cores could not be oriented azimuthally, reversals were impossible to detect in the measurements on recovered samples, but were suggested by analyses of the horizontal components of the magnetic field logged downhole.

In pillow lavas, titanomagnetite formed at low temperature is the main magnetic mineral, and the average natural remanent magnetization is about 5 A/m. This is comparable to values from pillow lavas at other sites and slightly higher than the average values in most models of the marine magnetized layer. In the transition zone, primary titanomagnetite is strongly altered because of high-temperature hydrothermal circulation, and the mean natural remanent magnetization is less than 1 A/m; therefore, the transition zone probably does not contribute to the magnetic source layer. In the sheeted dikes, alteration is generally less extensive, magnetite is the main magnetic mineral, and the natural remanent magnetization is 1-2 A/m. Thus, the sheeted dikes are sufficiently magnetized to significantly contribute to the crustal magnetic field.

The average inclinations of the samples ranged from about -30° in the pillow lavas to about 8° in the dikes, leading to a proposal that the section penetrated by Hole 504B had been rotated about an axis parallel to the ridge axis, with the amount of rotation varying from about 20° in the pillow lavas to near 0° in the dikes (Becker, Sakai, et al., 1988). Such rotations due to extensional processes have been proposed to explain anomalous inclinations at other DSDP sites. However, if the crust at the site is indeed reversely magnetized, then it would have to have been rotated toward the ridge crest in order to produce the observed negative inclinations, contrary to most models for ridge crest processes (Becker, Sakai, et al., 1988).

The suggestion of a rotation of the upper section was strongly confirmed by a three-component magnetometer log conducted during Leg 111, which showed a change in the logged inclinations at about 800 mbsf within the deeper pillow lava section, from about 15° in the pillow lavas to about 8° in the transition basalts and sheeted dikes below (Figure 3-2). This observation suggests that Hole 504B may intersect a tectonic feature - the relict trace of early lystric faulting within the rift valley - about 100-200 m shallower than the lithologic transition between pillow lavas and sheeted dikes. Such a fault trace may have been the permeable conduit for circulating hydrothermal fluids that strongly altered the magnetic minerals in the transition zone, and produced the heavily mineralized stockwork observed at the base of the pillow lavas.

4. Geochemical logging

During Leg 111, Hole 504B was logged with the geochemical logging tool. The variation in the log-determined geochemistry and mineralogy (Figure 3-2) is a response both to the original chemistry of the phyric and aphyric basalts and to the presence of alteration products such as clays, sulfides in the stockwork zone, and chlorite and actinolite in the dikes. The log results are consistent with the studies of recovered cores (Figure 3-2), but the logs clearly show that the secondary alteration products are tightly confined to fractures (the "spikes" of Figure 3-2) along contacts between relatively unaltered units of fairly homogeneous geochemistry. These contacts were poorly sampled in the recovered core, suggesting that the effects of alteration on the physical and chemical properties of the crust at Hole 504 are greater than was revealed in the core.

The confinement of alteration products to the discrete "breccia zones"confirms that the contacts between units were originally porous and permeable, but have been sealed by deposition of hydrothermal alteration products. The logged abundances of "breccia zones"or alteration products correlate with the apparent bulk or total porosities calculated from measured resistivities, in contrast to the lack of correlation between measured permeabilities and the resistivity-derived porosities (Figures 3-2). This suggests that some of the calculated apparent porosity may represent original porosity that has been filled with electrically conductive alteration products, particularly in the lower pillow alteration zone (Figure 3-3) within Layer 2B. Laboratory and log-derived measurements of Cation Exchange Capacity (CEC) of the clays in Hole 504B verify that the apparent porosity calculated from resistivities in the sealed pillow lavas of Layer 2B is too high. Better correlation exists between measured permeabilities and the true, clay-corrected *in situ* porosity than was originally thought.

5. Sonic and seismic structure of the crust

The short-wavelength sonic logs showed that the basement penetrated by Hole 504B can be divided into Layers 2A, 2B, and 2C on the basis of gradients in sonic velocity (Figure 3-4); the average sonic velocities in these layers are consistent with typical seismic layer velocities of the crust. The sonic velocity structure in Hole 504B is largely controlled by porosity; Layer 2B has apparently grown upward with time as pore spaces in Layer 2A have been filled with alteration products. Also, the sonic velocities of relatively unporous, homogeneous basalt samples from the dikes of Layer 2C are about 10% higher than similar fresh samples of pillow basalts from Layer 2B.

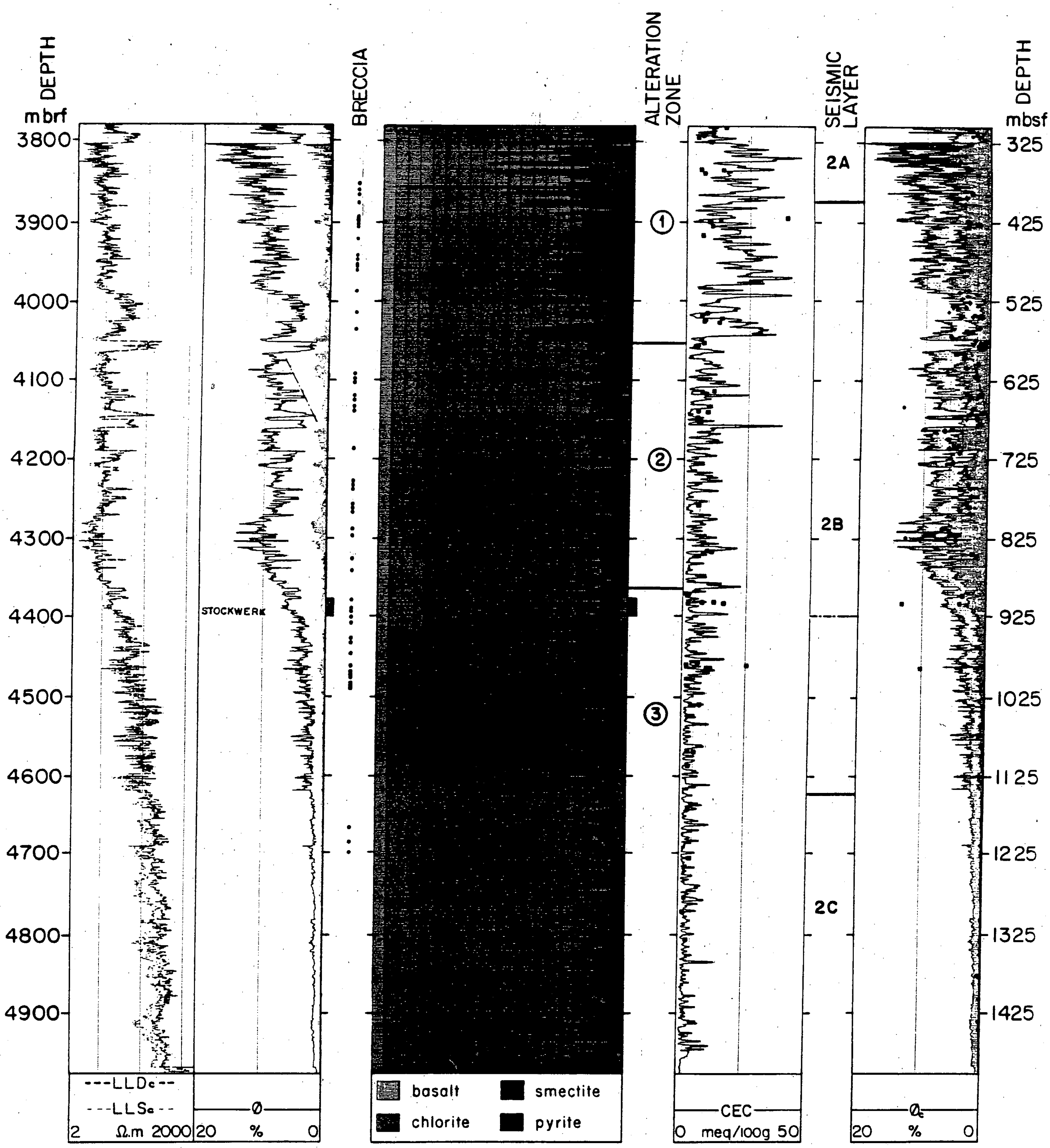


Figure 3-3. Detailed description of porosity structure off the upper oceanic crust at Hole 504B. Left, resistivity from shallow (LLS) and deep (LLD) penetrating Laterolog electrical resistivity log. The total porosity and fracture porosity are then derived from these curves. However, the total porosity also contains a signal that is from clays, not porosity. The breccia zones indicated by the geochemical log's mineralogy inversion (center) must be corrected for Cation Exchange Capacity (CEC) before reliable total porosity can be determined (right). The porosities measured on core samples agree much better to this curve.

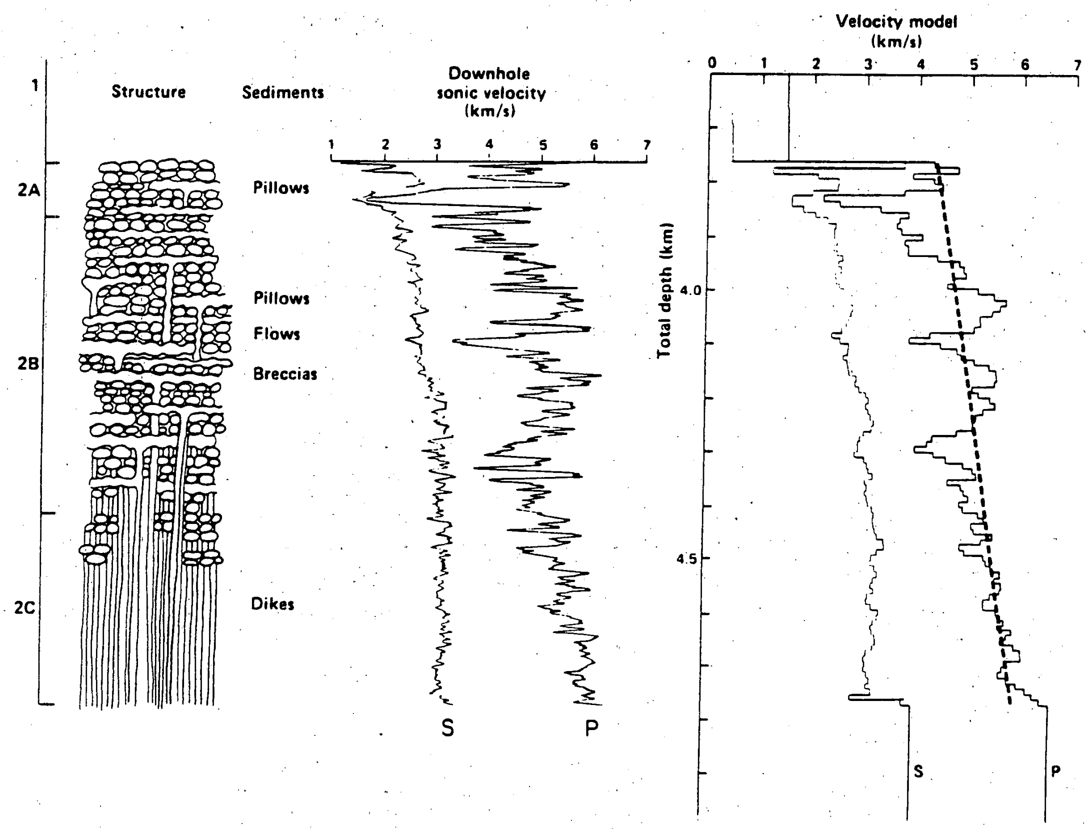


Figure 3-4. Sonic velocities measured by a multichannel sonic log (center), determine the fine-scale features of the crust at Hole 504B. The model at right produces a structural interpretation (left) that agrees with the geophysical and geochemical logs, core results, vertical seismic profile (VSP) of figure 3-5, and the surface seismic profile of figure 3-6.

The velocity-depth function at Site 504 at wavelengths relevant to those used in seismic reflection profiling was measured with a vertical seismic profile (VSP) conducted during Leg 111. VSP interval velocities are generally consistent with the division of the section into Layers 2A, 2B, and 2C based on the sonic logs. More important, the VSP shows several prominent reflectors, some of which can be correlated with lithologic boundaries seen in the recovered core (Figure 3-5), allowing the hole to be fixed in the seismic section (Figure 3-6), and providing essential ground-truth for the interpretation of the regional seismic survey.

Even more exciting for future drilling prospects, there are two prominent reflectors below the present total depth of the hole (E and X on Figure 3-5), which may correspond respectively to the top of Layer 3 and to strong dipping reflectors within Layer 3. The depths to these reflectors are about 150 and 900 m below the present depth of the hole. Thus, it appears that the transition between Layers 2C and 3, presumably the transition between sheeted dikes and gabbros, which has never before been sampled *in situ*, is in reach of the next drilling leg to Hole 504B.

The longer-wavelength oblique seismic experiments detected a strong, ubiquitous refractor between Layer 2B and 2C about 1 km into basement, but did not detect the thin Layer 2A seen in the sonic logs and VSP. Significant anisotropy was detected in the upper crust immediately surrounding the hole, with velocities lower in the direction of spreading, consistent with a preferential orientation of fractures (sealed and/or unsealed) parallel to the axis of spreading. Strong lateral gradients in velocities, and presumably porosities, are found at scales of 1 km or more, and this variability may be related to the subdued hydrothermal circulation that was mapped by the surface heat flow survey.

Geochemical Fluxes in the Oceanic Crust (from Anderson et al., 1989)

The fluxes of elements into and out of the oceanic crust affect geological processes in a wide variety of locales. The entire volume of the oceans is thought to circulate through the ridge axes in approximately 7 Ma. Chemical exchange with basalt not only significantly alters the crust, but buffers the composition of the oceans. One-half of all the elemental species making up the stable composition of the oceans comes from this hydrothermal exchange, making this source as important to the chemistry of the ocean as river-input. Helium-3 and methane gasses which escape with the hydrothermal fluids provide geochemical tracers which can be used to map the deep circulation patterns of the oceans. 350 °C, superheated hydrothermal fluids exit the ridge axis at "black smokers", providing a view of active metallogenesis, as metal-laden sulfides are deposited directly onto the sea-floor. Far off onto the flanks of mid-ocean ridges, cold-water circulation continues to exchange a chemical mass flux between the oceans and the crust. The chemical exchange with sea water produces clays and greenschist metamorphic alteration of the oceanic crust which, when subducted, releases a mass flux into the deep mantle producing volcanism above subducting plates, such as at island arcs.

Yet, we have little quantitative information about the geochemical mass balance between the oceanic crust and the oceans. The black smokers were not discovered until 1977. Mass fluxes out of the black smokers of the East Pacific Rise, Juan de Fuca Ridge, one locale on the Mid-Atlantic Ridge, one place in the Mariana back-arc basin, and the sediment-filled

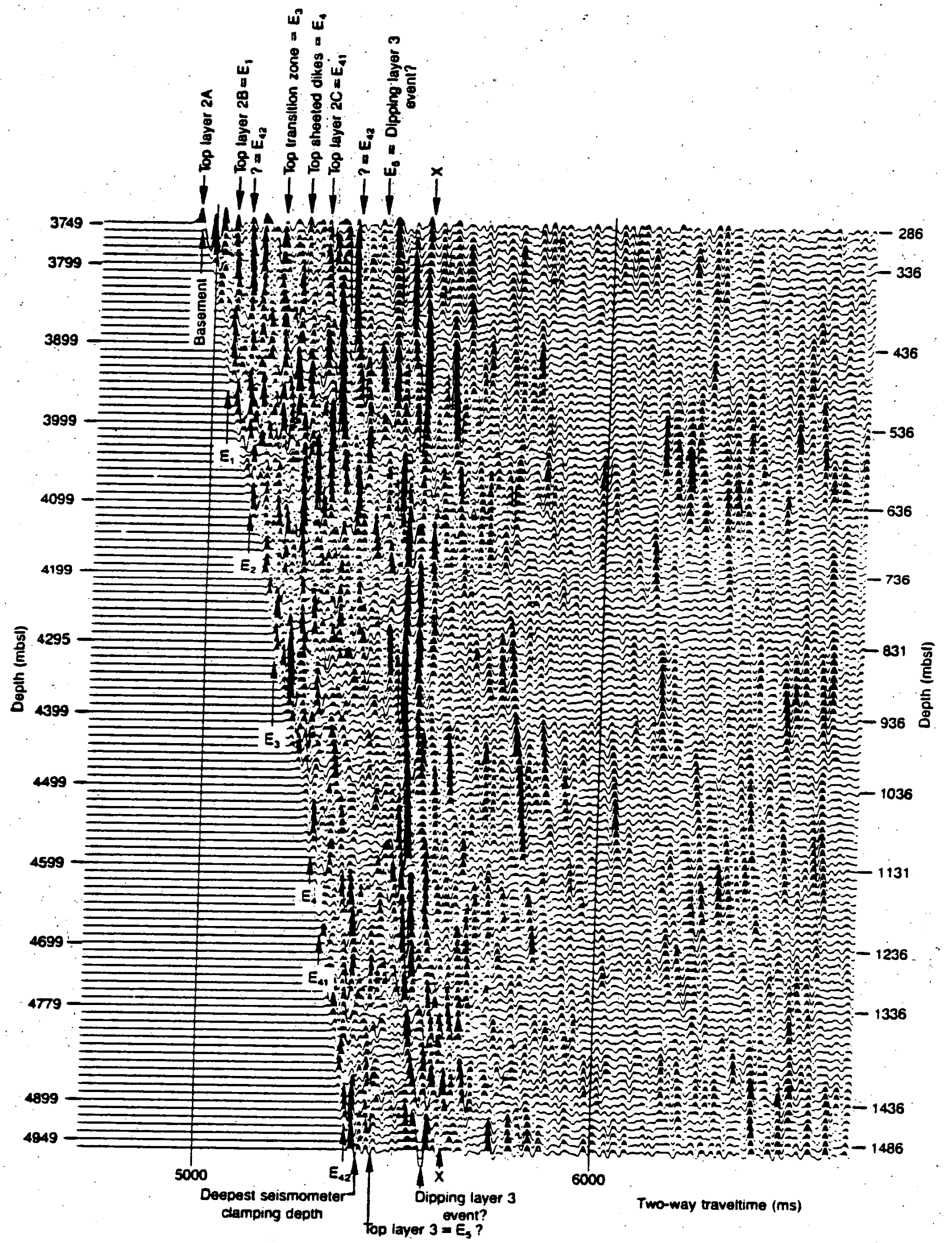


Figure 3-5. Vertical Seismic Profile at Hole 504B. The many internal reflectors can be directly correlated with the structure from logs and core (right). Layered reflectors are also detected below total depth of the well (left).

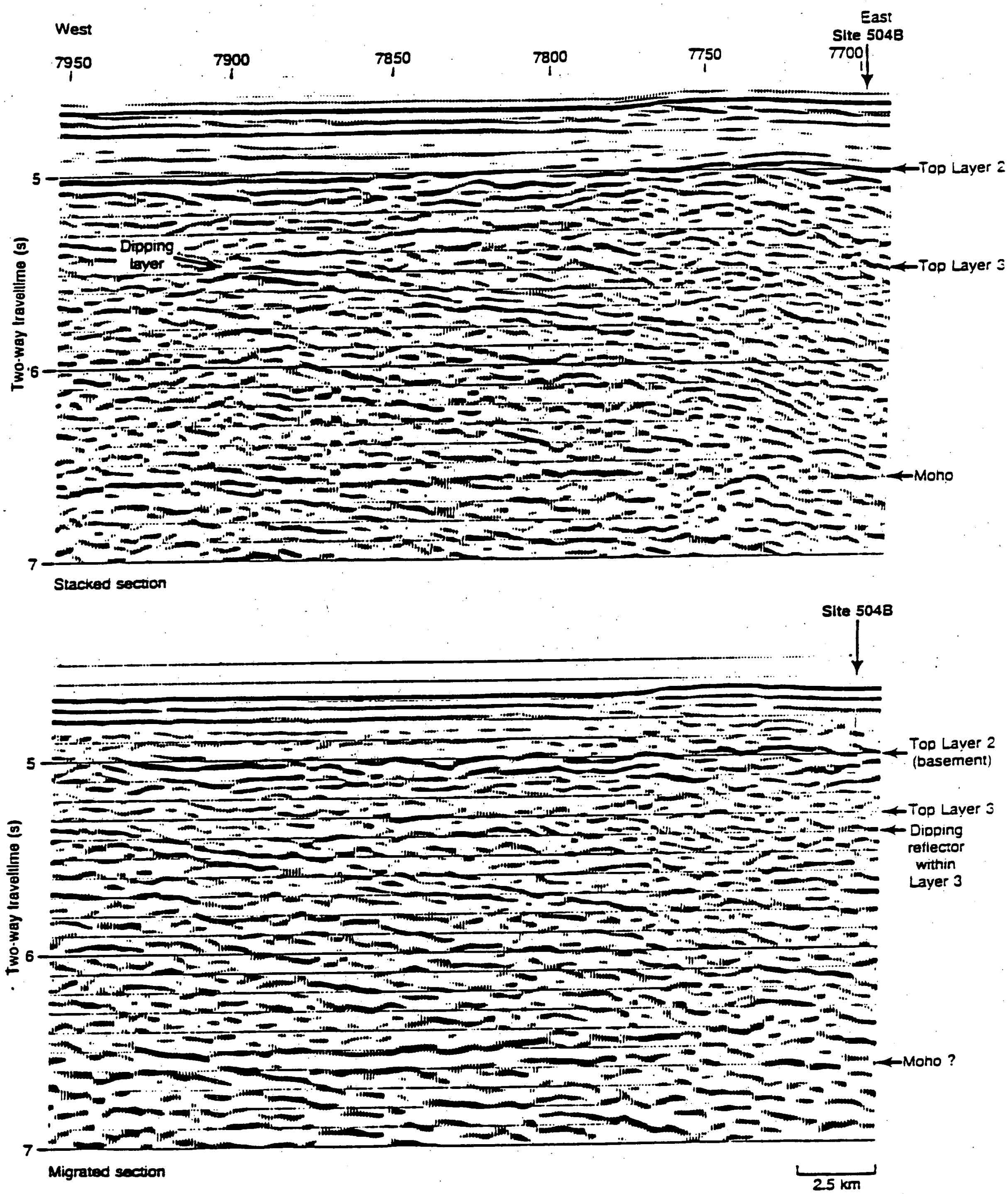


Figure 3-6. Surface seismic reflection profiles from the area around Hole 504B. Stacked (above) and migrated (below) sections both show the layered nature of the oceanic crust.

Gulf of California have been reasonably well-documented. But not 1 % of the ridge axis has been explored to date, let alone sampled. Only a primitive idea of the mass flux on the ridge flanks is available from two exhalation sites, the Galapagos and Mariana mounds. Chemical anomalies in sediment pore fluid show Mg, Ca, and Cl anomalies that indicate their source to be fluids altered by basalt-sea water exchange, but little time-dependent information is available from these data. Ophiolites offer an integrated view of the sum of all hydrothermal processes that have previously affected that sea floor, unfortunately including an overprinting of alteration accompanying emplacement onto land.

Additional information about the variability and evolution of the geochemical mass flux between the oceanic crust and sea-water can be gained from measurements made inside the oceanic crust. Hole 504B is the deepest penetration yet into the oceanic crust, and as such, it is the first reference section of oceanic lithosphere for comparison to geochemical mass balance models based upon laboratory experiments, surface sampling, and ophiolite models. However, the core recovery in Hole 504B was less than 20% of the drilled section. Geochemical logs of Hole 504B allow us to quantitatively determine the integrated, geochemical mass exchange that has occurred between the oceanic crust and sea-water over the 5.9 Ma history of the rock column (including that missed by the core).

There is widespread evidence at Hole 504B for extensive hydrothermal alteration of basalts from at least three different fluids. At the ridge axis, a high temperature, "black smoker-type" fluid interaction with cold, downward flowing sea-water resulted in the deposition of the "stockwork " mineralization zone found in the transition between pillow basalts and dikes. A subsequent low temperature ridge flank event deposited zeolites and clays throughout the pillow basalts, and particularly in Layer 2A. Metamorphism to a greenschist facies mineral suite has subsequently occurred in the transition zone and dikes.

Of importance is the total cation exchange between basalt and sea-water that occurred during these three alteration events. The geochemical logs allow us to characterize the changes in elemental abundances between the freshest and deepest dike basalts and the shallower, more heavily altered rocks.

The geochemical log-derived, dry weight percent oxide variations of major elements over the depth interval of Hole 504B can be estimated by smoothing the geochemical, log-derived elemental abundances, then normalizing each to the composition of the freshest basalt present in the dikes at the very bottom of the hole (Figure 3-7). Significant horizontal fluxes may enter or exit the column, and as such would be seen as abrupt changes in the gradients of elemental fluxes. The assumption of a beginning composition for fresh basalt becomes critical, therefore, because a change in compositional abundances of fresh basalt with depth would introduce large errors into the vertical flux calculation. Fortunately, the composition of fresh basalt within Hole 504B remains remarkably constant (with the exception of a few thin flows of Fe-Ti enriched basalts).

To quantify the geochemical mass flux in Hole 504B, we must calculate the total mass of each element that has been moved by estimating the integrated change in composition of each element from the fresh basalt composition (Figure 3-8). There is little Al change throughout the well, but Si, Ca, Mg and Fe all show significant mass fluxes. Ti concentration appears to accompany that of Fe, as might be expected from laboratory experiments of basalt-sea water interaction. Si increases from the bottom of the hole to 4300 m, then decreases to the surface. Quartz precipitation upon cooling of an upward

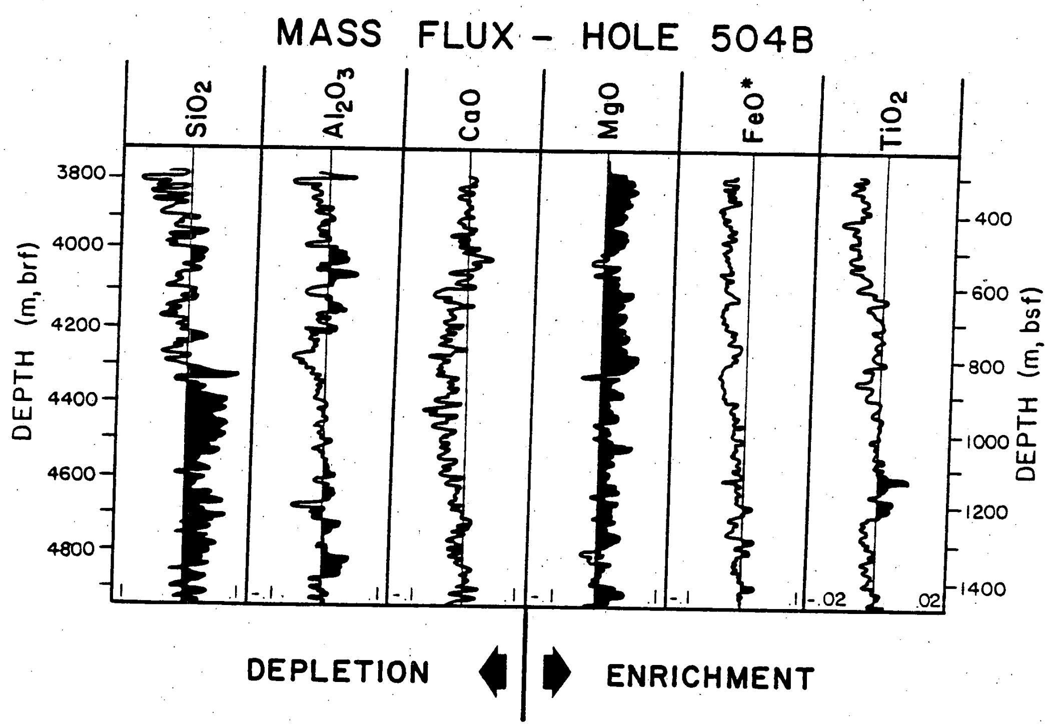


Figure 3-7. Smoothed major element oxide concentrations from geochemical logs at Hole 504B, normalized to the mean composition of the freshest basalt found in the dikes at the bottom of the hole. Shading is enrichment, white is depletion relative to the freshest basalt standard (vertical lines).

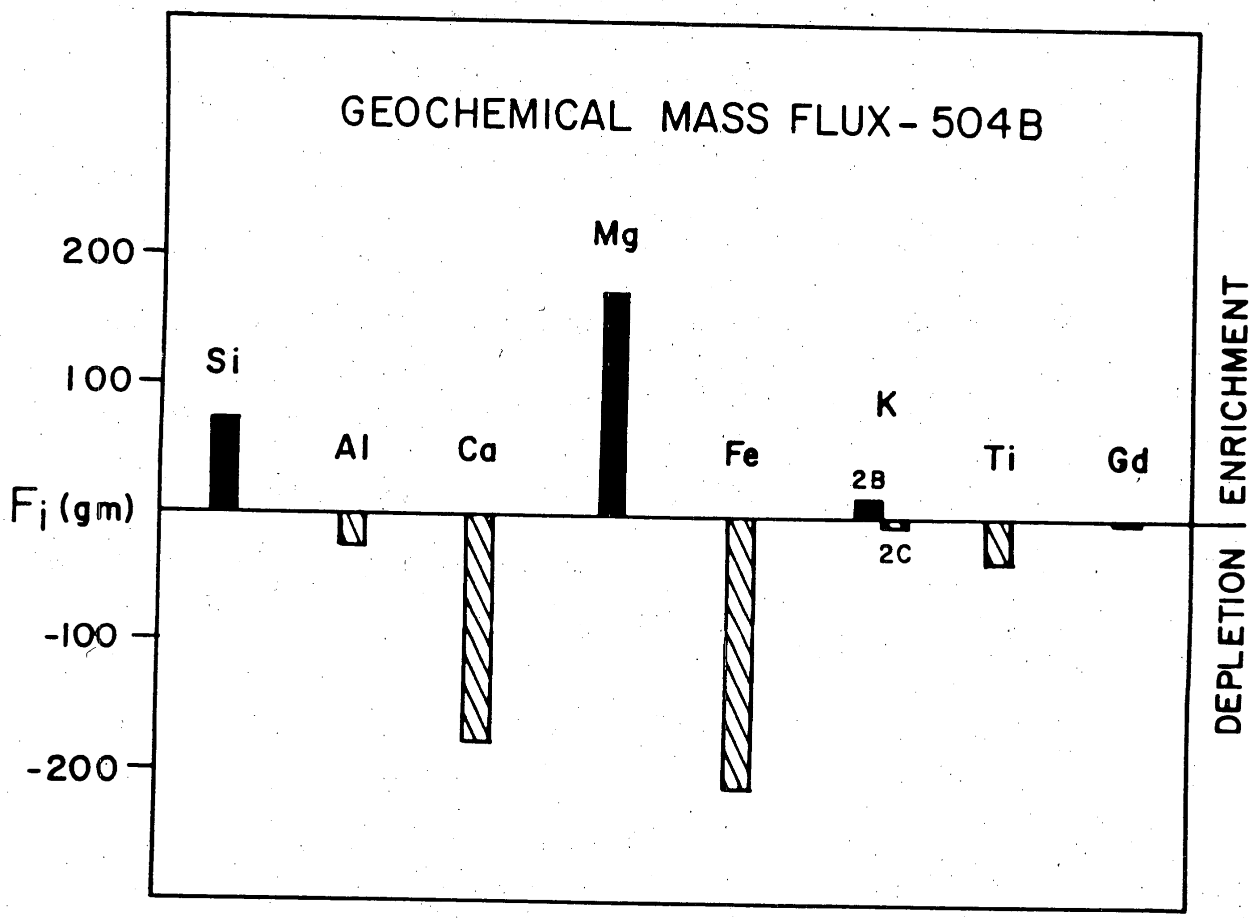


Figure 3-8. Total geochemical mass flux in Hole 504B calculated by integrating geochemical logging curves of figure 3-7 from bottom to top of the well. These fluxes are the predicted total elemental exchanges that have occurred to date over the 5.9 Ma "lifetime" of this ocean crust.

moving hydrothermal fluid would account for such an increase in Si content. Abundant quartz was found filling fractures in this section of the hole.

Mg increase and Ca decrease is caused by exchange of cations during reaction of hot sea water and basalt. The recovered clays, chlorite, other alteration products, and pore fluids from the borehole prove that such reactions have occurred in Hole 504B. The integrated geochemical mass flux (F_i) quantifies the elemental fluxes involved in these reactions throughout the hole to the present day. In quantitative terms, 76.5 gm of Si, and 164.3 gm of Mg per square cm have been added to the oceanic crust of Hole 504B over a column the height of Hole 504B. Correspondingly, 178.6 gm of Ca and 211.6 gm of Fe have been lost to the oceans from the same volume.

The mass fluxes, F_i, as percentages of the total mass of each element available in the freshest dike basalt, F_t, are shown in Figure 3-9. The geochemical mass flux analysis suggests that Al has not moved substantially Si appears large in relative terms, but not in absolute terms because of the large number of Si cations available in basaltic rocks. K, as well as Ti, fluxes become important when viewed in percentage terms. It appears that almost 10 percent of the K is missing from Layer 2C, whereas almost 20% more K than that in fresh basalt resides in Layer 2A. Addition of K from both Layers 2B and 2C and cold sea water is therefore required in Layer 2A. Ti appears to have been lost during low temperature alteration - a surprise.

Thus, the chemical exchange between the oceans and the crust could be quantified if enough geochemical logs are obtained through a diverse suite of crustal drillholes. This is a long-term, thematic goal of the ODP Lithosphere Panel.

Gabbros of the Oceanic Crust (from Goldberg, 1988; Robinson et al., 1989)

Our knowledge of the composition and structure of the oceanic crust was increased significantly by logs from Hole 735, drilled on ODP Leg 118 into the Atlantis Fracture Zone on the Southwest Indian Ridge (Figure 3-10). While most of the hole penetrated relatively fresh gabbro for the first time in ODP, the geophysical logs clearly indicate a very high density zone filled with high neutron capture-cross-section elements (explained presently) located about 250m into the section (Figure 3-10). Photoelectric effect (P_e) and capture cross section (Σ) respond to the matrix mineralogy and to the presence of high neutron absorbers respectively. The geochemical logs show that elements responsible for the P_e and Σ anomalies are Fe and Ti (Figure 3-11). The cores from this interval also show enriched Fe and Ti, but the geochemical logs detail the variation, or layered structure of the Fe and Ti-rich zone much more completely (Figure 3-11). Depletion of Si, Al, and Ca accompanies the enrichment of Ti and Fe in this mafic intrusion zone.

The geochemical logs give an even more dramatic view of the processes that accompanied intrusion of this Fe-Ti-rich zone within the axial magma chamber that eventually froze to form this segment of crustal layer 3 (Figure 3-12). Below the Fe-Ti rich zone is a high gadolinium, high Thorium interval that likely represents a pathway for very high temperature fluids. Borehole packer tests and temperature log anomalies support this conclusion. Th is mobile only at 400 °C and higher. The heavy rare earth element Gd is not

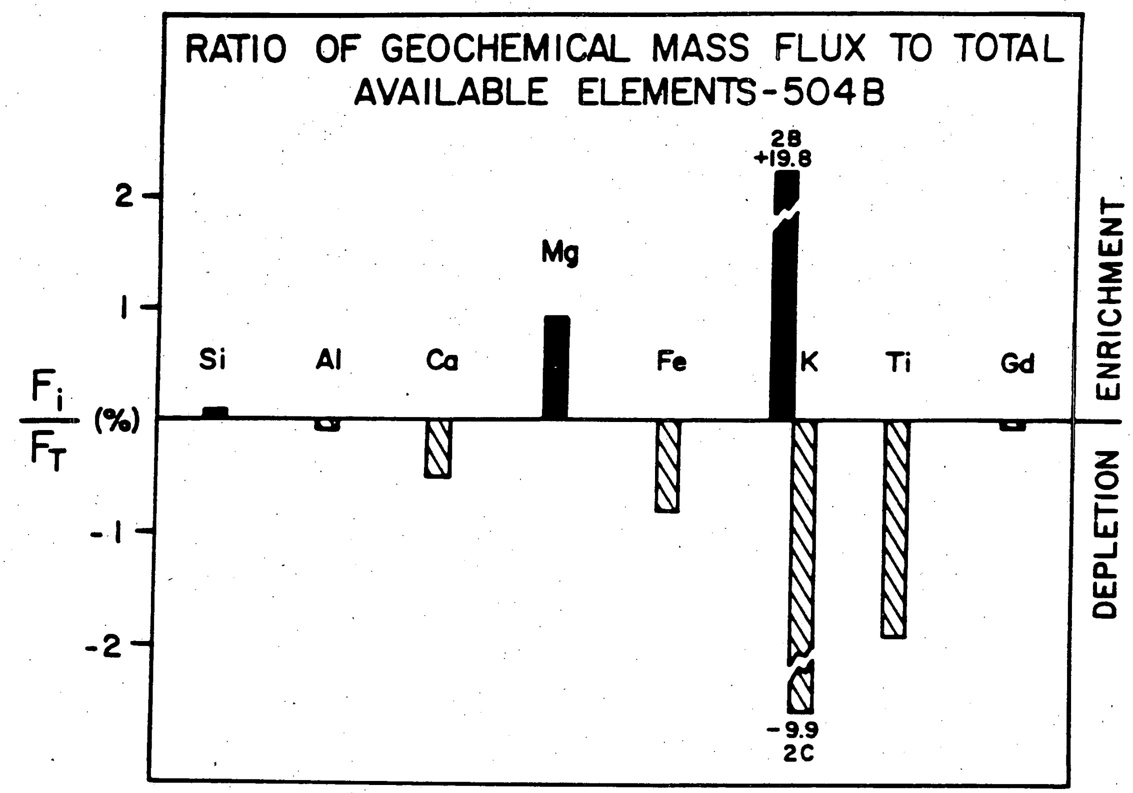


Figure 3-9. The ratio of the total mass flux (figure 3-8) to the total mass of each cation available in the fresh basalt at Hole 504B gives a clear idea of the relative exchange that has occurred between basalt and sea water over the "lifetime" of the crust. Note the major exchange of potassium that has occurred both between the dikes (depletion) and the pillows (more enrichment from sea water than that delivered from below by hydrothermal fluids). The loss of Ti was unexpected. The exchanges of the other cations are predicted by laboratory experiments.

Geophysical logs in gabbro show Titanium-rich layer

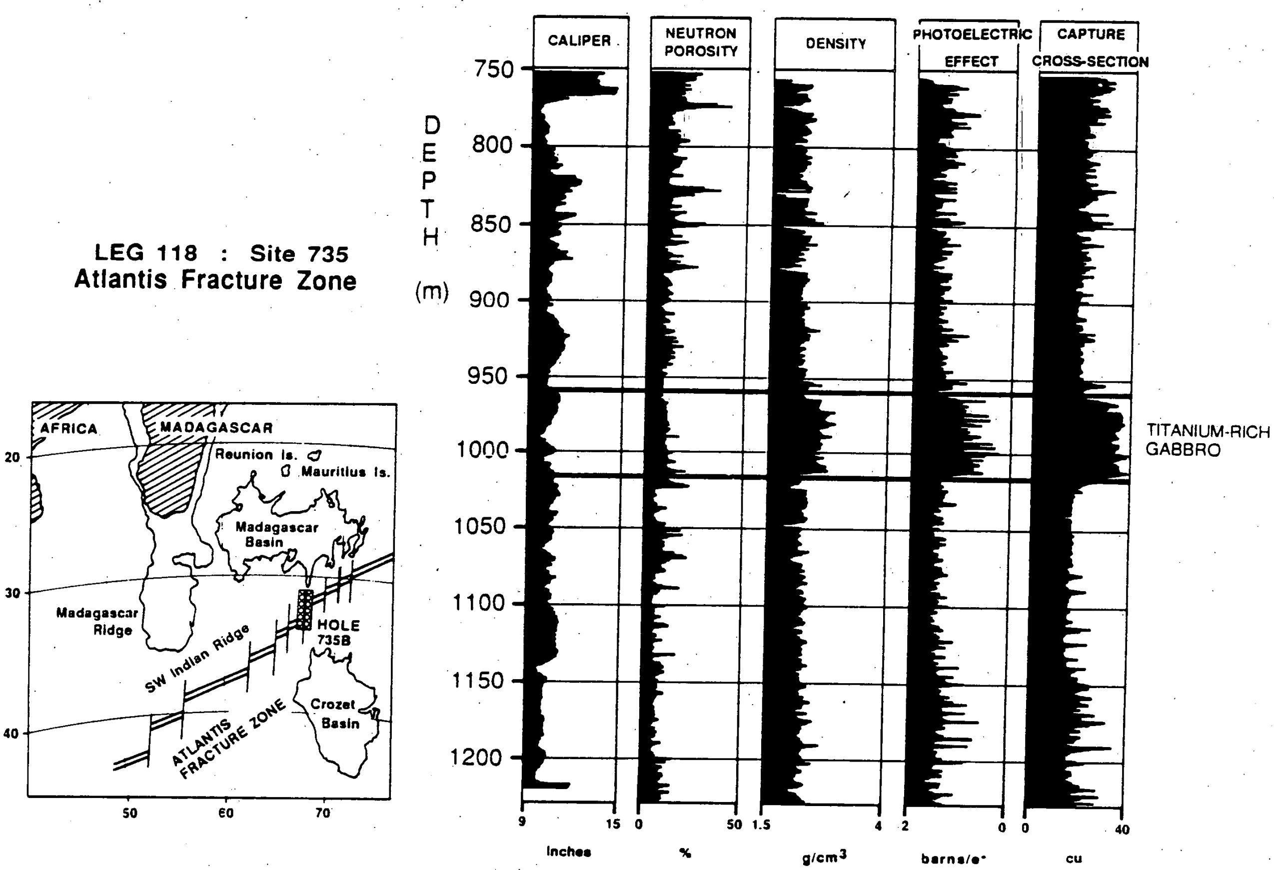


Figure 3-10. Geophysical logs from ODP Leg 118, Hole 735 drilled into gabbros of the Atlantis Fracture Zone. The density, photoelectric capture spectrum, and total capture cross-section (sigma) logs show clear indications of a titanium-rich fault zone or intrusion midway into the well.

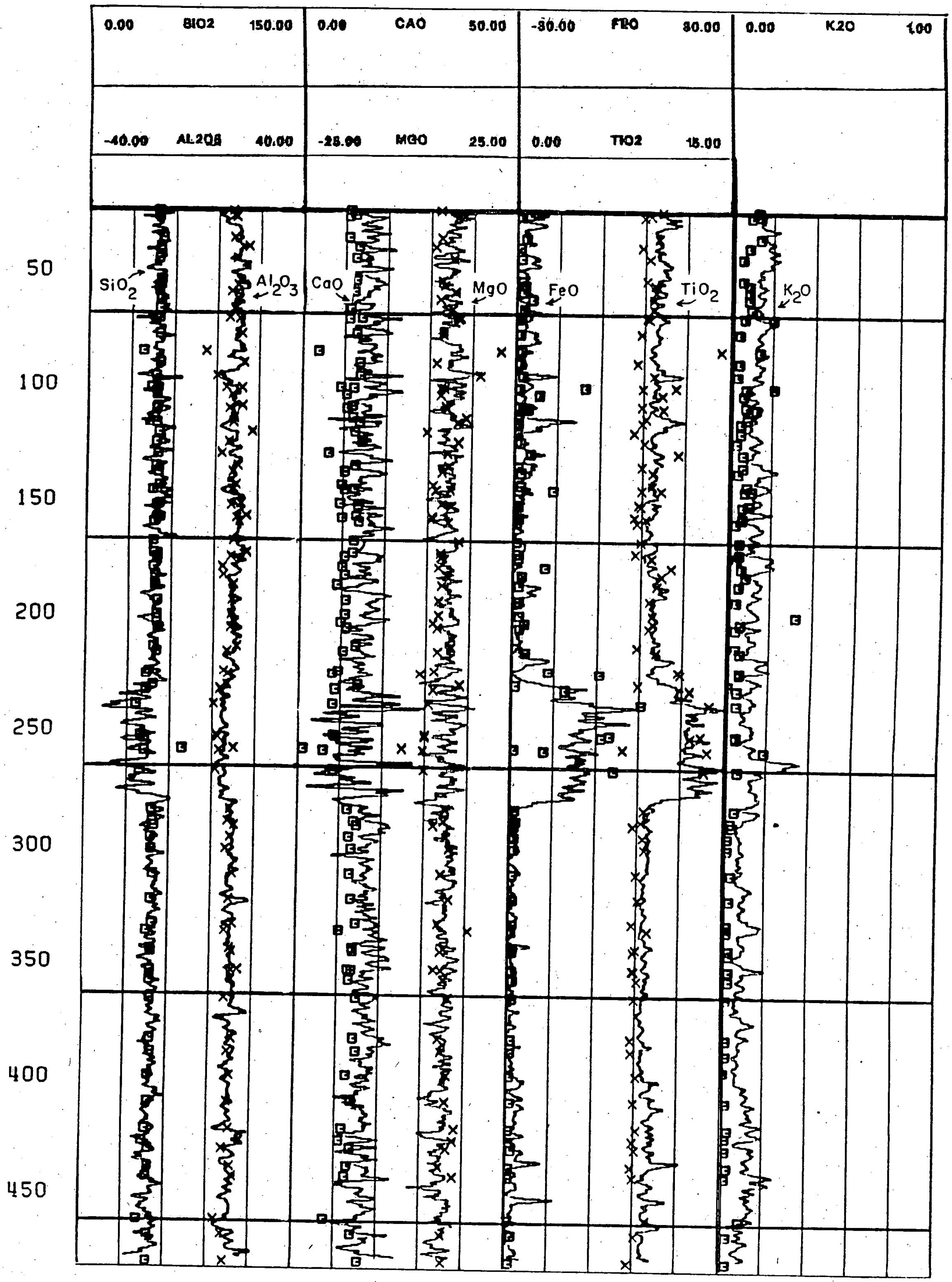


Figure 3-11. Geochemical log-derived elemental concentrations calibrate well with laboratory analyses of core sample chemistry. The Ti-rich zone is defined more clearly by the logs than by the core analyses. Interlayering has produced the variability seen in the core results.

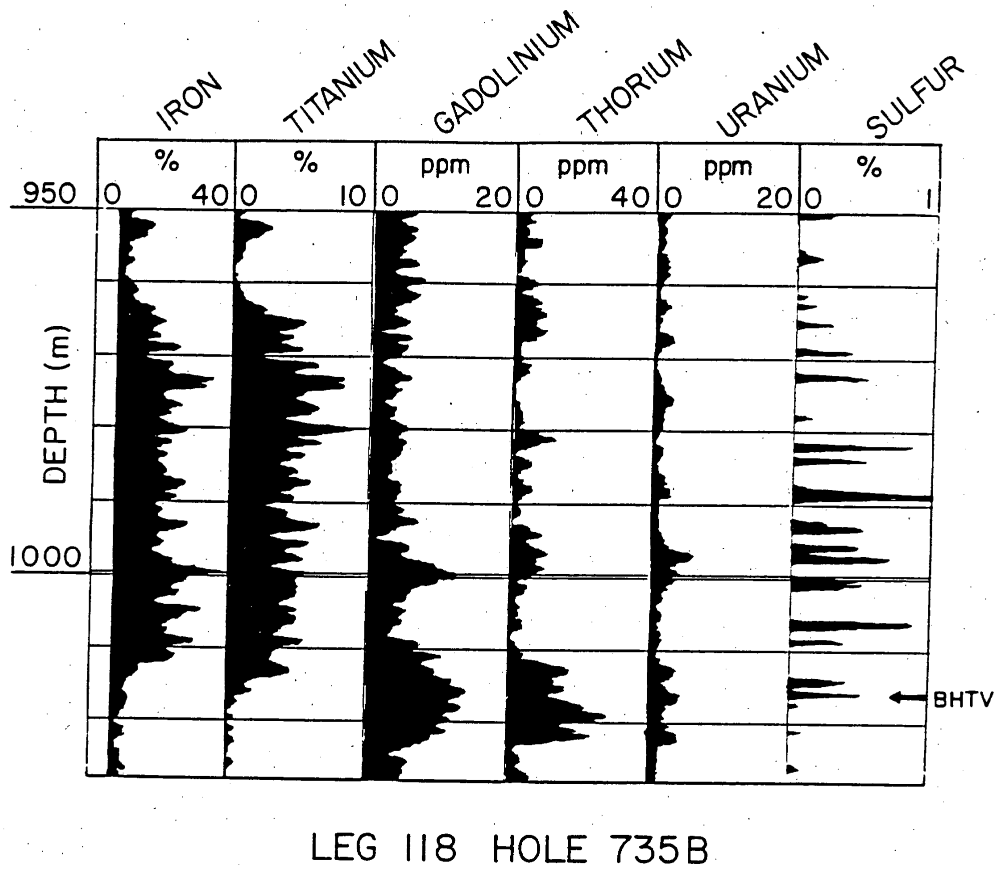


Figure 3-12. Details of the geochemical logs in the Ti-rich zone show that a thorium and gadolinium enriched interval forms the lower boundary of the Ti and Fe enriched interval. Pyrite mineralization within fractures are identified by sulfur spikes. The Borehole Televiewer ultrasonic image of one of these fractures is shown in Figure 3-13.

supposed to be mobile at all, indicating that this interval may contain a trondhjemite, or very late stage fractionate. Abundant Si supports this conclusion.

The sulfur curve locates pyrite rich veins that appear as distinct fractures on the ultrasonic borehole televiewer image of the wellbore (compare Figures 3-12 and 3-13). The geophysical and geochemical logs can not only locate fractures, but determine the chemistry of any fracture-filling alteration products.

Hot Spot Volcanic Cycles (from Pierce, Weissel et al., 1989)

Geochemical logs allow us to characterize variations in hot spot volcanics, as well as estimate their compositions. Consider the Hole 715 drilled during ODP Leg 115 on the Chagos-Laccadive Ridge, an island trail from the Mauritius hot spot that connects northward to the Deccan Traps of India (Figure 1-3). The basaltic basement of the Chagos-Laccadive Ridge is layered between what appears to be normal Mid-Ocean Ridge Basalt (MORB) and a Fe-Ti rich basalt that is not as heavily fractionated as the Leg 118 Fe-rich gabbros (Figure 3-14). The Gd curve clearly distinguishes the Rare Earth enriched hot spot Fe-Ti basalts from the depleted MORBs.

The sequence of eruptive activity for a hot spot is unknown because few drillholes such as Hole 715 exist. Do hot spots deliver a constant magma flux to the surface, or are we seeing magma blobs that periodically produce hot spot volcanism? An alternative way to determine the eruptive history of a hot spot is to record the variations in the abundance of volcanic ash on the sea floor surrounding a hot spot. ODP Legs 119 and 120 drilled several holes near the Kerguelen hot spot in the southeastern Indian Ocean (Figure 1-3). The volcanic platforms of Kerguelen, Broken Ridge and the Ninety-East Ridge were built up from Cretaceous time by volcanic activity of the hot spot.

The cyclicity of that eruptive history is shown by examining the volcanic ash layers from Sites 747, south of the hot spot, and 754 to the east (Figure 3-15). Core recovery in Hole 754 was too sparse to delineate any periodicity at all (Figure 3-16), except that there was a steady decrease in the total amount of ash as the site moved north away from the hot spot during the Tertiary. In contrast, the geochemical logs determine at least five major zones of abundant ash content, separated by quiescent zones (Figure 3-17).

A more precise tag between the volcanic ash cycles and Kerguelen comes from the Th/U ratio of the ashes. Basaltic sources typically have Th/U ratios of 4 to 6 whereas pelagic sediments have ratios of 1 or lower (Figure 3-18). The variation of the Th/U ratio logged at Sites 747 and 752 measured by the geochemical log shows a cyclical eruption history that can be dated using sedimentation rates determined from the cores (Figure 3-19). The cyclicity south of Kerguelen found in sediments deposited 70-90 ma has a periodicity of about every 2 Ma, whereas the period of volcanic ash occurrences in Hole 752B is shorter, at about every 640 Ka. The explanation for the discrepancy in period between the two wells may come from the position of each hole relative to the direction of prevailing winds then (Figure 3-15). Because Hole 752B was directly down wind from the hot spot, it received ashes from most eruptions. However, Hole 747A which is to the south of the hot spot, may have received only ashes from the largest eruptions.

The logging program thus provides evidence of temporal variations in hot spot volcanism that are only possible from continuous data. For example, magnetic

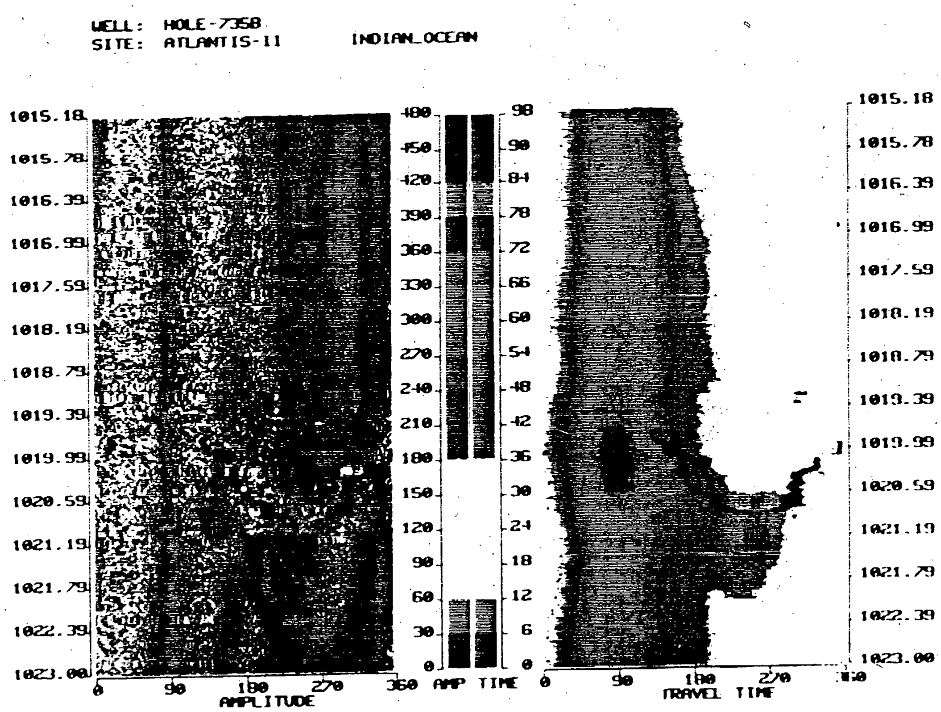


Figure 3-13. Amplitude and travel time images from the ultrasonic Borehole Televiewer display the fracture filled with pyrite that caused the spike of Sulfur in the geochemical log (figure 3-12). The images are of the cylindrical hole "unwrapped", with North at the left and right edges and the degrees displayed along the horizontal axes.

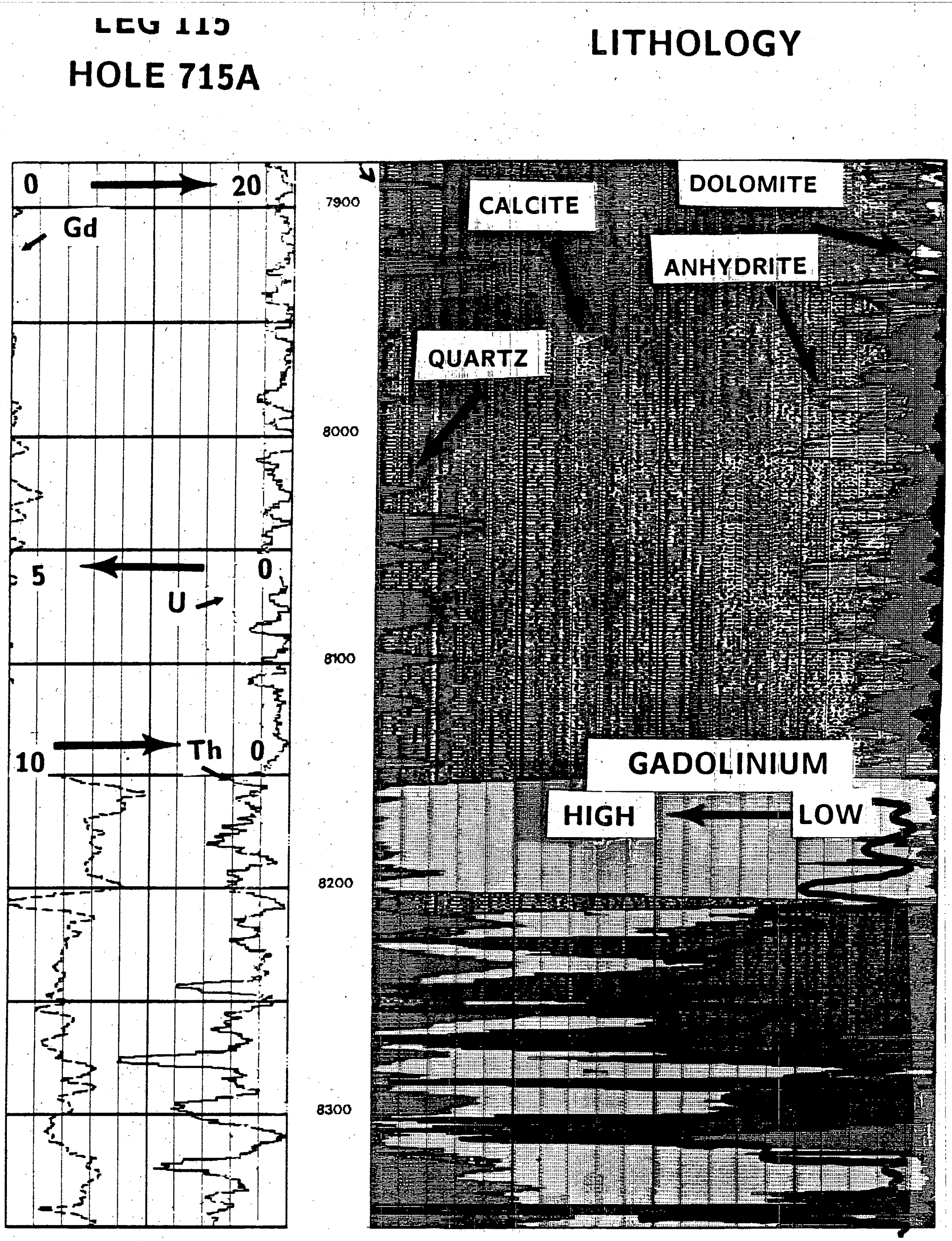


Figure 3-14. Mineralogy model of Hole 715 derived from elemental abundances measured by the geochemical logging tool. U, Th and Gd abundances in ppm are displayed at left. The reef from 7890 to 8150 feet depth is predominantly carbonate. The Sulfur content is associated with seladinite. The basalts of the Chagos-Laccadive Ridge basement are an alternating sequence of depleted MORBs and HREE enriched, Fe-Ti rich hot spot plume basalts.

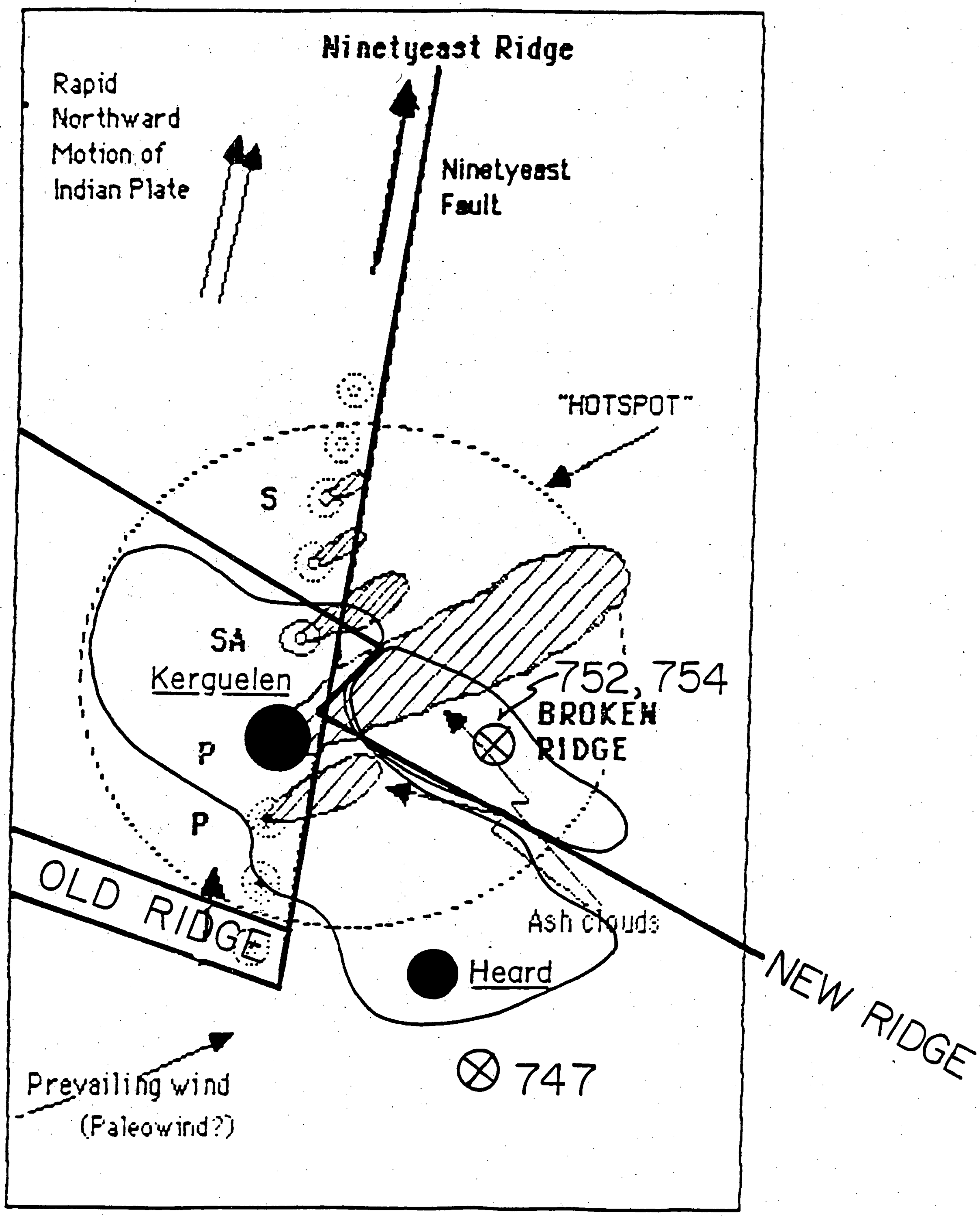


Figure 3-15. A reconstruction of Broken Ridge back into place in the Kerguelen Plateau in Cretaceous time places the site of Hole 752 downwind from the likely prevailing paleowind direction then. Hole 747 was orthogonal to the wind direction, so presumably, a great eruption of the hot spot would be required to deliver volcanic ashes to this site. The spreading directions of old and new Southeast Indian Ridge spreading centers are also shown. The Ninetyeast Ridge is a hot spot trail away from Kerguelen.

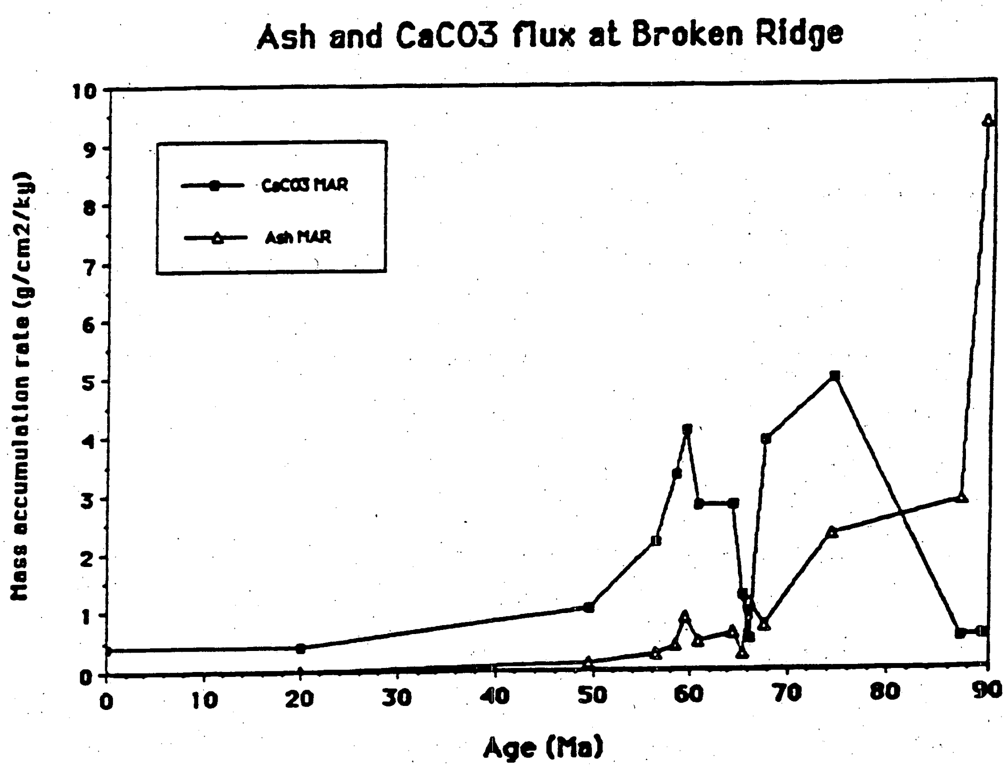


Figure 3-16. The change over time of the amount of volcanic ash in Hole 754 estimated from recovered core. The general decrease in younger sediments is from the northward drift of Broken Ridge away from the Kerguelen hot spot after rifting by the Southeast Indian Ridge.

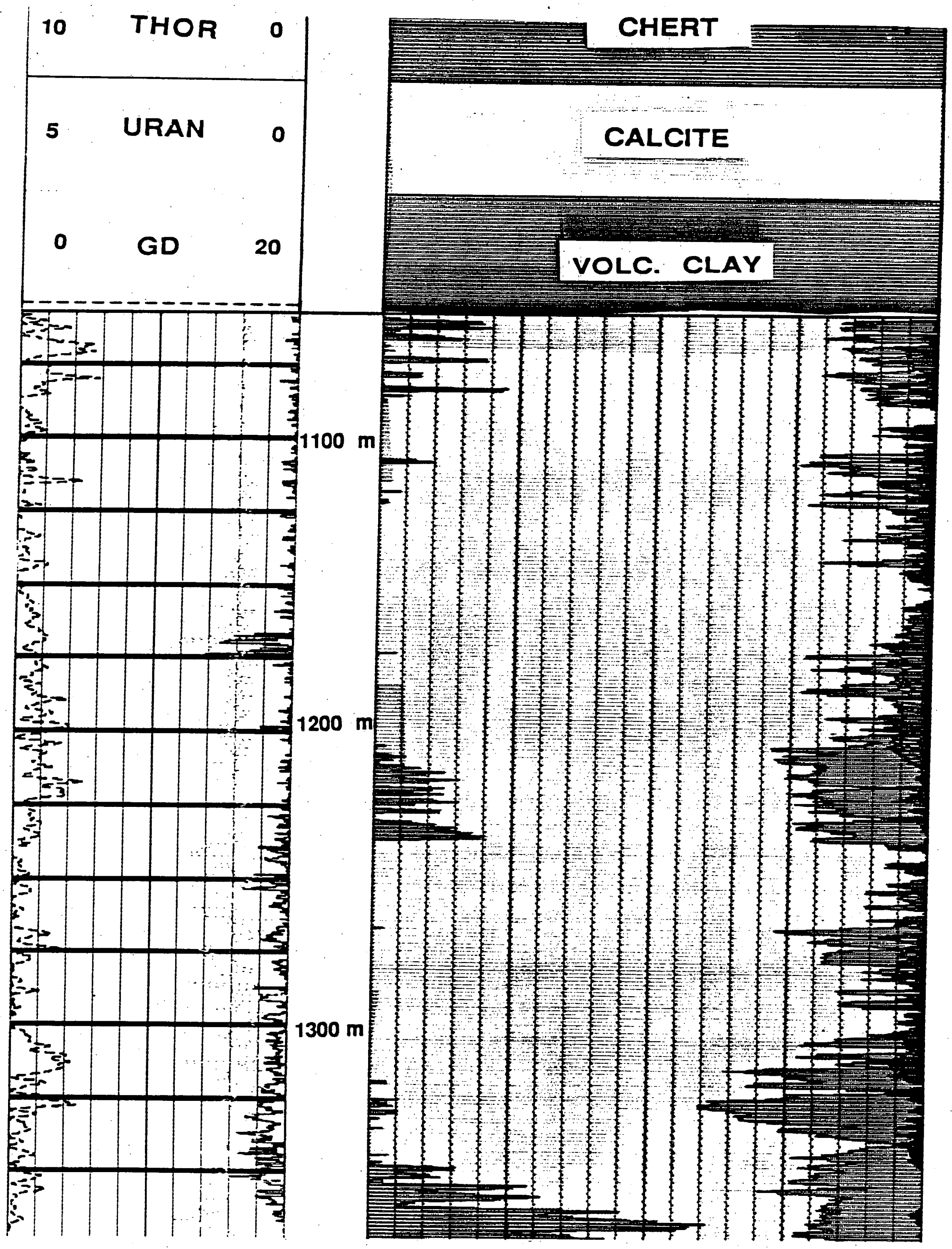


Figure 3-17. Mineralogy model of Hole 754 derived from elemental abundances measured by the geochemical logs. Note the cyclic nature of the variation in abundance of volcanic clays, compared to that observed in core (figure 3-16).

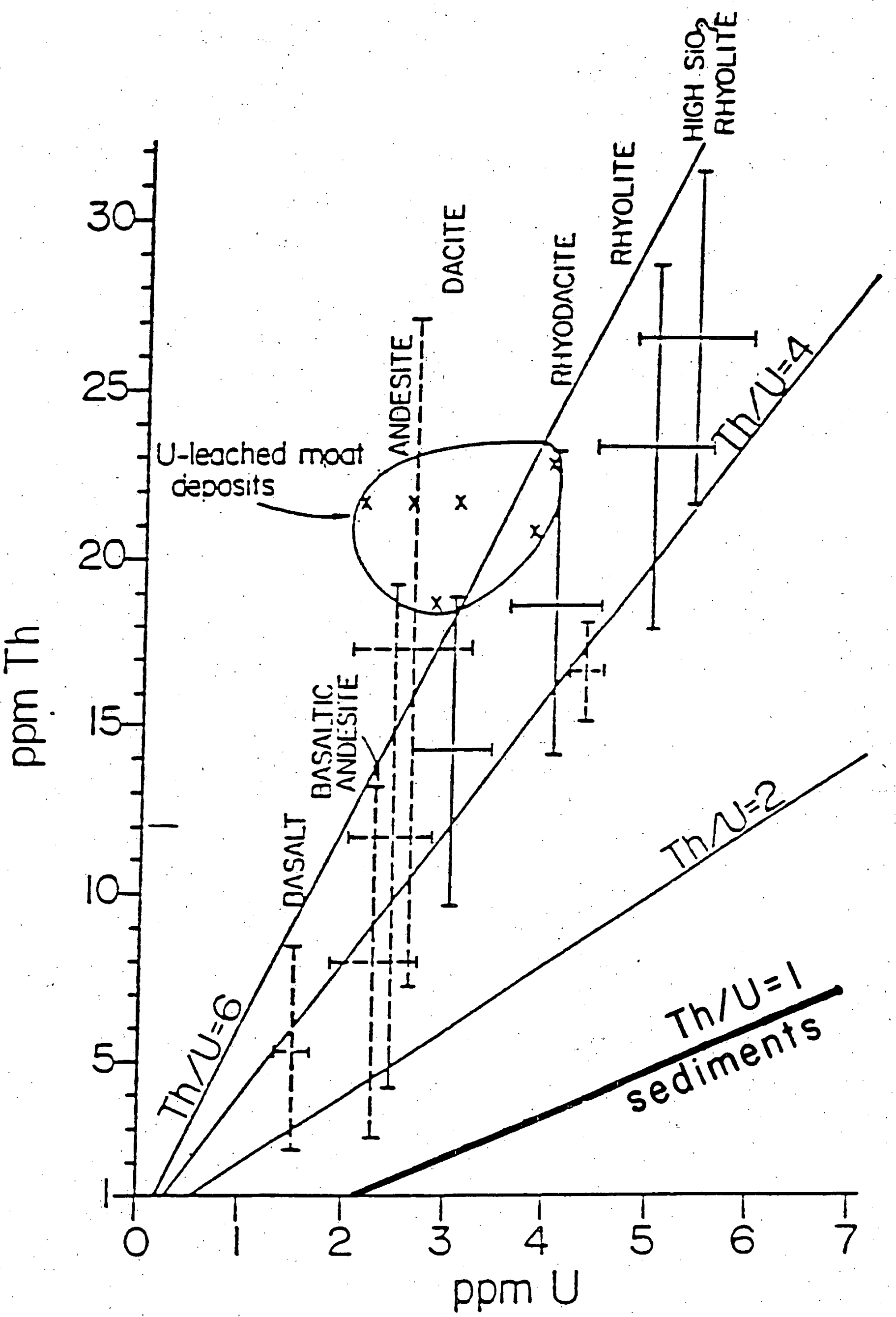


Figure 3-18. The Th/U ratio of basalts, andesites, and even high silica rhyolites averages 4:1, whereas that of pelagic sediments is < 1:1. The x's show that even leached volcanic ashes from the moats of volcanic islands like Hawaii maintain this high Th/U ratio.

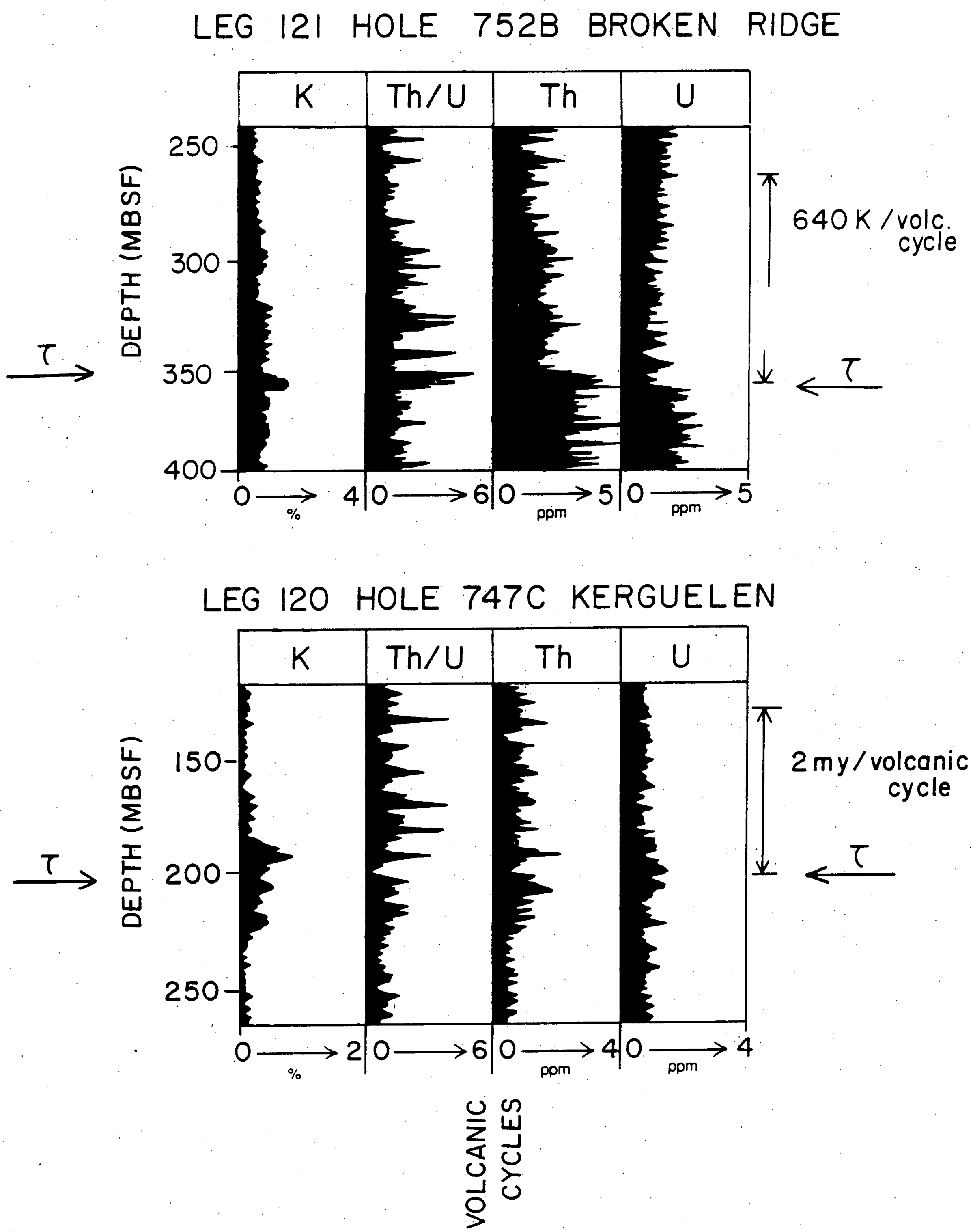


Figure 3-19. K, Th, U and Th/U variations with depth recorded in Holes 752 and 747 by the geochemical logs. The volcanic ash units are distinguished by their high Th/U ratio as expected (figure 3-18). Note that whereas the K is enriched near the K-T boundary, the Th/U is not unusually high compared to other eruptive cycles. The high K is from the deposition of deep-sea clays when carbonate sedimentation was interrupted by the extinction event. The cyclical eruptive history of the Kerguelen hot spot appears to be independent of the extinction event. The shorter period of eruptions at Hole 752 versus that at Hole 747 is thought to be because of the more favorable placement of the former downwind from the hot spot. Only the largest eruptions deposited extensive ashes to the south.

susceptibility measured on cores also distinguishes ash flows because of their higher susceptibility, but the core record is not complete enough to define the pattern of cyclicity with anything like the accuracy of the log data (Figure 3-20).

State-of-Stress in the Lithosphere (from Pierce, Weissel et al., 1988)

Basement logs record another unique piece of geophysical data that is one of the main focal points of the COSOD II report: the state of tectonic stress in the oceanic lithosphere. Worldwide, the forces that drive plate tectonics work in a very systematic way (Figure 3-21). Where they have been mapped well, such as on the North American continent, the maximum compressive stresses are regionally consistent; in this case, generally northeast-southwest oriented. Before we can determine the forces responsible for such uniform stresses, we must map stress directions throughout several plates. However, plates are under the ocean, so the ODP must have some mechanism for mapping the distribution of tectonic stresses within and across plates, or we will never fully understand the driving mechanism for plate tectonics; or its corollary, how these forces interact across plate boundaries.

The determination of stress orientation in a borehole depends upon our ability to image the borehole wall, because basement rock fails under differential stresses that are relieved when the hole is drilled (Figure 3-22). Such borehole "breakouts" determine the direction of least compressive stress, which is perpendicular to the compressive stress direction.

Site 758 (ODP Leg 121), on the northern Ninety-East Ridge in the Indian Ocean (Figure 1-3) provides an excellent example of the usefulness of the measurement of borehole breakouts for the testing of tectonic models that predict the magnitudes and directions of the forces that push and pull plates across the earth's surface. The prediction of stress orientation in the vicinity of Site 758 from one such model is for compression in the NNW-SSE direction (Figure 3-23). Breakouts imaged in the basalt of Site 758 by the borehole televiewer show minimum compression in the east-west direction, an observation that verifies the prediction of the model that maximum horizontal compressive stress should be oriented N - S (Figure 3-24).

Summary

The study of the chemical and physical variations associated with construction and alteration of the oceanic lithosphere is not possible without logs and other *in situ* downhole experiments carried out in the ocean crust. In the future, long-term observatories will be established to continuously monitor active processes in the crust. We will probably look back at the expensive drillship trips back to such Holes as 504B, 395A and 418A as only the crude beginnings of our exploration effort to establish laboratories of the ocean floor. The technological advances necessary to construct such permanent observatories are in place. Only the will to proceed remains to be found. COSOD II clearly demonstrates that the future is fast approaching for direct, long-term observation of the oceanic crust.

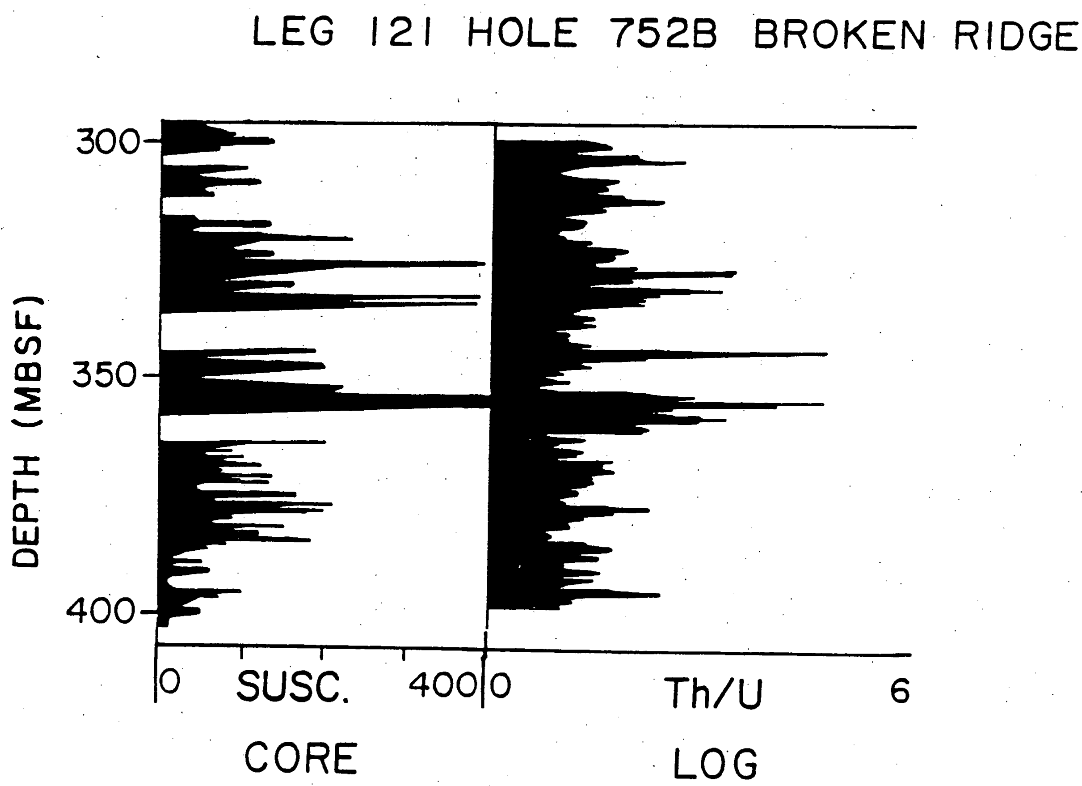


Figure 3-20. The cyclical nature of volcanic ash deposition in Hole 752 is also indicated by the magnetic susceptibility measurements made on core, but gaps in the recovery cause several ash layers to be missed completely. Compare the continuous record from the Th/U log to the discontinuous susceptibility measurements. A borehole magnetic susceptibility log would make an excellent tool for the recording of volcanic ash sequences.

WORLD STRESS MAP - S_{Hmax} ORIENTATIONS

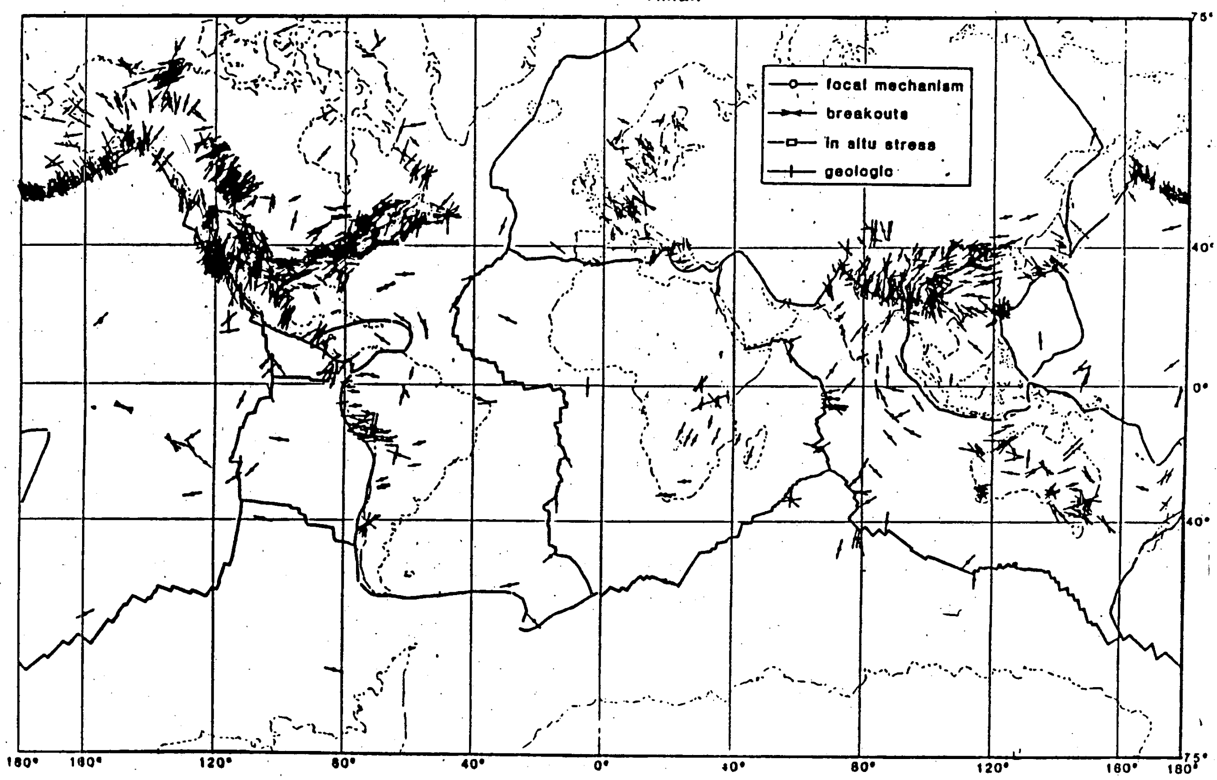


Figure 3-21. The world stress map contains estimates of the direction of maximum compressional stress within the plates derived from earthquake focal mechanisms, borehole breakouts, hydraulic fracture measurements, and contemporary surface folding. Huge gaps exist in Asia and on all oceanic plates.

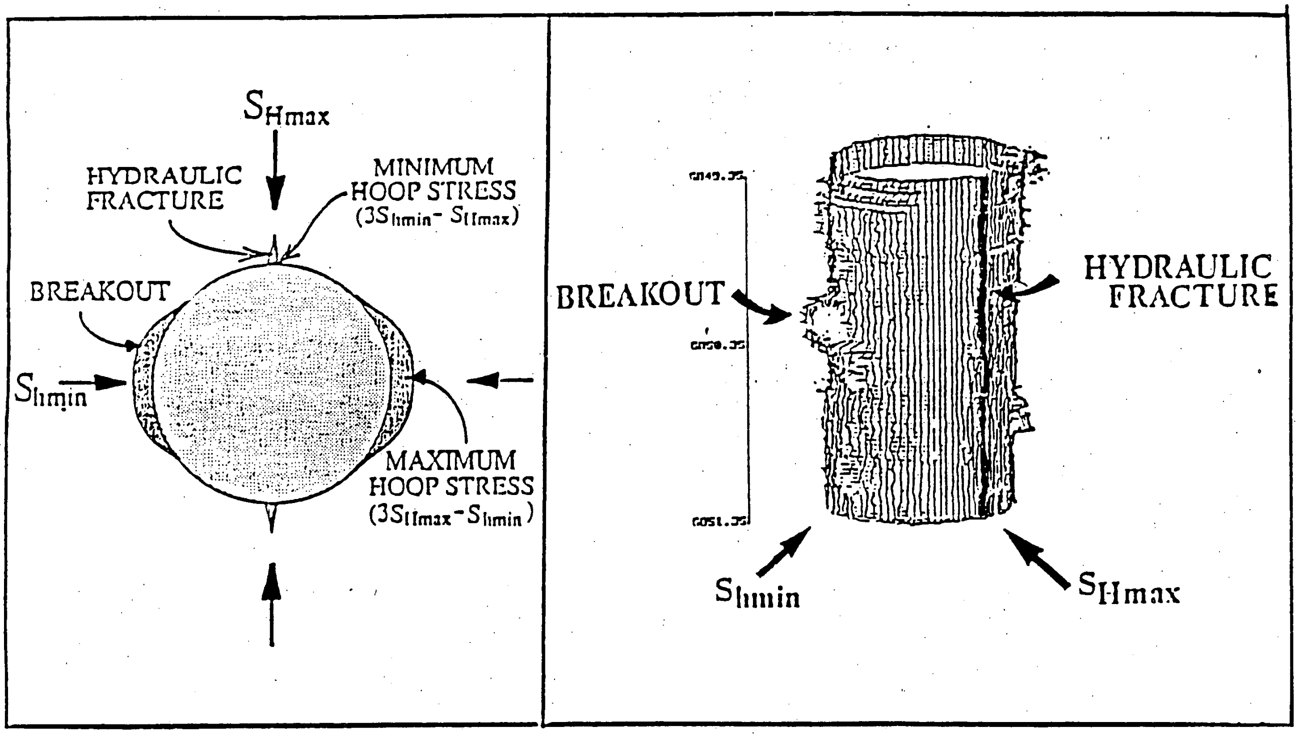


Figure 3-22. Borehole breakouts are failures of the wall rock from wellbore caused by the local concentration of hoop stresses driven by tectonic stresses. Breakouts are found perpendicular to induced hydraulic fractures, as seen in this image of both in the Cajon Pass well, because the breakouts are oriented in the direction of minimum horizontal compressive stress, and hydraulic fractures propagate in the direction of maximum compressive stress.

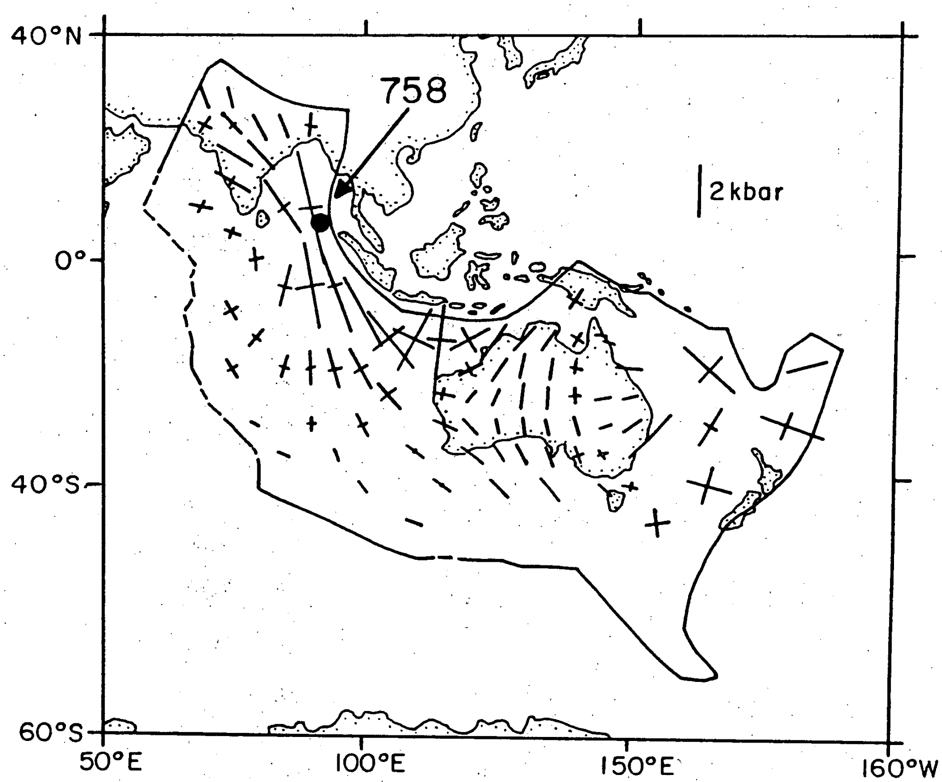


Figure 3-23. A model for the driving forces responsible for the northward migration of the Indian Plate predicts maximum horizontal compressive stresses west of Indonesia to be oriented NNW-SSE. Hole 758 is located in sea floor predicted to have the largest differential horizontal stresses in the Indian Plate, and so should be an excellent place to look for breakouts to test the predictions of the driving-force model.

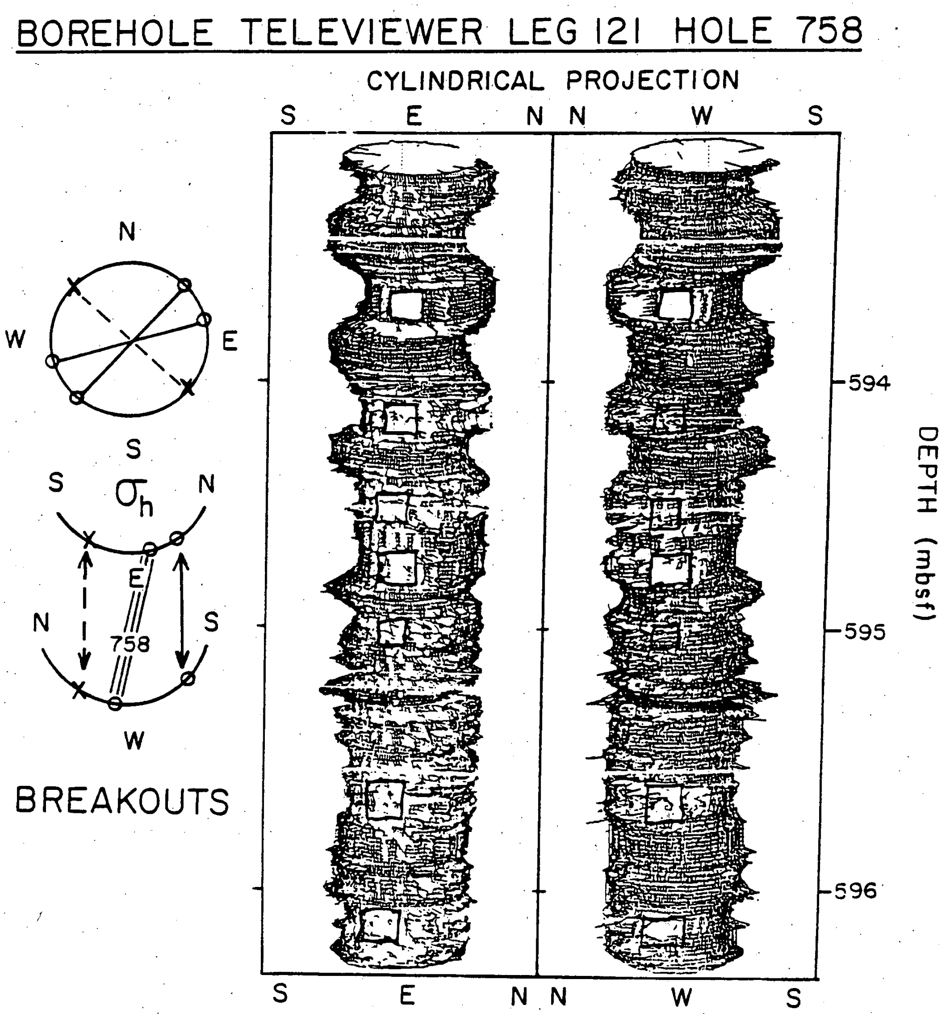


Figure 3-24. Borehole televiewer records from basement in Hole 758 locate breakouts on the east and west walls of the wellbore, indicating the maximum horizontal compressive stress direction to be N-S. The non-cylindrical image of the borehole is from eccentralization of the tool, which can be easily corrected for by forcing the image to become a cylinder. This correction will not affect the orientation of the breakouts in the general direction predicted by the driving-force model.

Chapter 4: Global Environmental Changes

A major new understanding of global climatic oscillations responding to the earth's own orbital perturbations provides the theoretical foundation that allows us to project present day phenomena into the geological past. Below, we begin with an understanding of how Milankovitch climate cycles produce geological change. Wireline logs that continuously record the sea floor's reaction to orbital cycles provide the pathway to discovery of past climates. From Milankovitch, we progress to glaciation, sea level change, and the extinction of the dinosaurs. Not only will we find climatic information in logs, but we will discover that an understanding of the geological mechanism responsible for cycles allows us to derive information about the age of rock from logs. Once we have understood the cause-and-effect between orbital perturbations and sediments, we can count cycles to refine sedimentation rates, place cores in their proper stratigraphic place, and ultimately, derive a climatic cycle-stratigraphy. The "Vail" coastal onlap curves are likely to be looked on in the future as our first attempt at such an understanding of the effect of climate on the stratigraphic record.

Milankovitch Climate Cycles and Wireline Logs (from Jarrard and Arthur, 1989)

Changes in the earth's orbital parameters are now recognized as an important cause of cyclical variations in global and regional climate. The periods of eccentricity (95,000-123,000 and 413,000 years), obliquity (41,000 years), and precession (19,000-23,000 years) have been observed in a variety of sedimentary sequences. These "Milankovitch periods" most often have been detected in Pleistocene deep sea sediments because of the available combination of both very strong glacial/interglacial climatic fluctuations and high-resolution dating of cores. The climatic effect of these cycles is not limited to the Pleistocene; they have been detected in Cretaceous chalk/shale sequences and Triassic lacustrine sediments as well (Arthur et al., 1984; Fischer, 1986; Fischer and Schwarzacher, 1984; and Olsen, 1986).

Chemical "tracers" such as variations in calcium carbonate concentration and oxygen isotopes, which are indicators of paleoproductivity, paleotemperature, and ice volume, are the parameters most frequently used for the study of Milankovitch cycles in pelagic deep sea sediments. More generally, the sedimentary response to the Milankovitch forcing function should vary regionally, depending on the type of paleoclimatic signal impressed on the sediments. Aridity/humidity cycles, for example, may cause detectable fluctuations in clay mineralogy or abundance in one region, while cycles of upwelling or surface temperature change may cause fluctuations in the biogenous component to be the dominant sedimentary response in another region. Thus, a comprehensive analysis of Milankovitch cycles in any sedimentary column requires determination throughout the sequence of the mineralogical abundances, and either porosity or grain size (Table 4-1).

ORBITAL PARAMETERS ➔ PERIODIC CHANGES ➔ GLOBAL/LOCAL CLIMATE ➔ MINERALOGY/POROSITY ➔ LOG RESPONSES

ORBITAL PARAMETERS	PERIODIC CHANGES
Eccentricity	95000yrs
Obliquity	41000yrs
Precession	23000yrs 19000yrs

GLOBAL/LOCAL CLIMATE	MINERALOGY/POROSITY	Sonic	Resistivity	Gamma Ray	Spectral Density	Neutron	Natural Gamma Spectral	Aluminium Activation	Induced Gamma Spectral
aridity/humidity	clay type						●	●	●
	clay abundance			●	●	●	●		
wind patterns	grain size	●	●		●	●		●	●
	mineral type and abundance	●	●	●	●		●	●	●
temperature/upwelling	biogenous type and abundance	●	●	●	●	●	●	●	●

Table 4-1. The sequence of cause-and-effect between Milankovitch orbital parameter changes and log responses. Changes in eccentricity, obliquity, and precession cause changes in the amount of the Sun's energy to hit the planet. This, in turn, causes cycles in aridity/humidity, wind and ocean current patterns, and sea-surface temperatures. These changes cause cycles of clay type and abundance, grain size, mineralogy, and composition and abundance of organisms that die to form deep sea sediments. The logs respond differently to several of these changes producing a complex interaction of geophysical and geochemical responses to climate change.

Wireline logs as well as core data can be used to detect periodic changes in mineralogy or porosity associated with orbital changes. Both physical properties (e.g., velocity, porosity, resistivity) and major element geochemistry can be used to detect such changes. Furthermore, continuous measurements are made every 15 cm down the borehole and most logging tools have a vertical resolution of about 50 cm so that no gaps exist in the recorded interval.

For detection of Milankovitch frequencies, wireline logs have three principal advantages over core analyses. First, the wide variety of geochemical and physical properties measured at each depth interval makes it likely that almost any significant periodic change in mineralogy or porosity will be detectable. Second, logging is much faster than laboratory analyses of a comparable number of discrete core samples. Third, the continuous logging measurements are independent of core recovery. The change from using a hydraulic piston corer to using either an extended core barrel or rotary corer results in a decrease in average ODP core recovery from 99% in the upper 150 m of the sediment column to 50-60% below 200 m. Also, this uneven core recovery includes both disturbed and undisturbed sediments with substantial uncertainty existing in the original depths of the undisturbed material.

For detection of Milankovitch frequencies, wireline logs share some of the same limitations as cores and have two unique, potential disadvantages. Both cores and logs require very good age control for accurate conversion from frequencies-in-depth to frequencies-in-time. They also both suffer from a limit due to spatial resolution. This is much more pronounced for logs, however, and temporal cycles which , for a given sedimentation rate, produce spatial cycles below the resolution limit of the tool will not be detected. Cycles in either cores or logs can sometimes be caused by local sedimentary processes rather than by regional climatic change. An example is turbidites, with a spatial-frequency that depends on source supply and source distance, and with a temporal-frequency that bears only a very indirect relation to climate. Additionally, logs obtained on ODP conceivably could contain a frequency that is an artifact of ship heave, in spite of the use of a wireline heave compensator. (In practice, logs obtained at different times show a close character match, indicating that residual ship heave is minor). Finally, the conversion from log response to mineralogy is not unique and requires some knowledge from cores of what minerals are present.

1. An example of Milankovitch climate cycles: ODP Site 645

ODP Site 645 was drilled in the west-central Baffin Bay, between Greenland and Canada during Leg 105. A 1147 m thick sequence of silty clays and clayey silts that were deposited during the last 24 m.y. make up the sedimentary section in this well. The sedimentary intervals corresponding to 1.3-1.7 and 2.1-3.3 Ma were logged with sonic, resistivity, and gamma ray tools. The strong similarity in character between sonic and resistivity logs (Figure 4-1) indicates that velocity variations are controlled by porosity variations. A strong cyclicity in the velocity log is present throughout the logged interval. The cycles lack the saw-tooth pattern characteristic of turbidites (gradually upward decreasing velocity and resistivity followed by abrupt, sharp rises). This observation confirms the core analysis that few turbidites are present. Possibly because porosity variations in cores are difficult to recognize visually, the cycles recognized from the logs

Logs can be used to determine variations in geological response to climate cycles over time

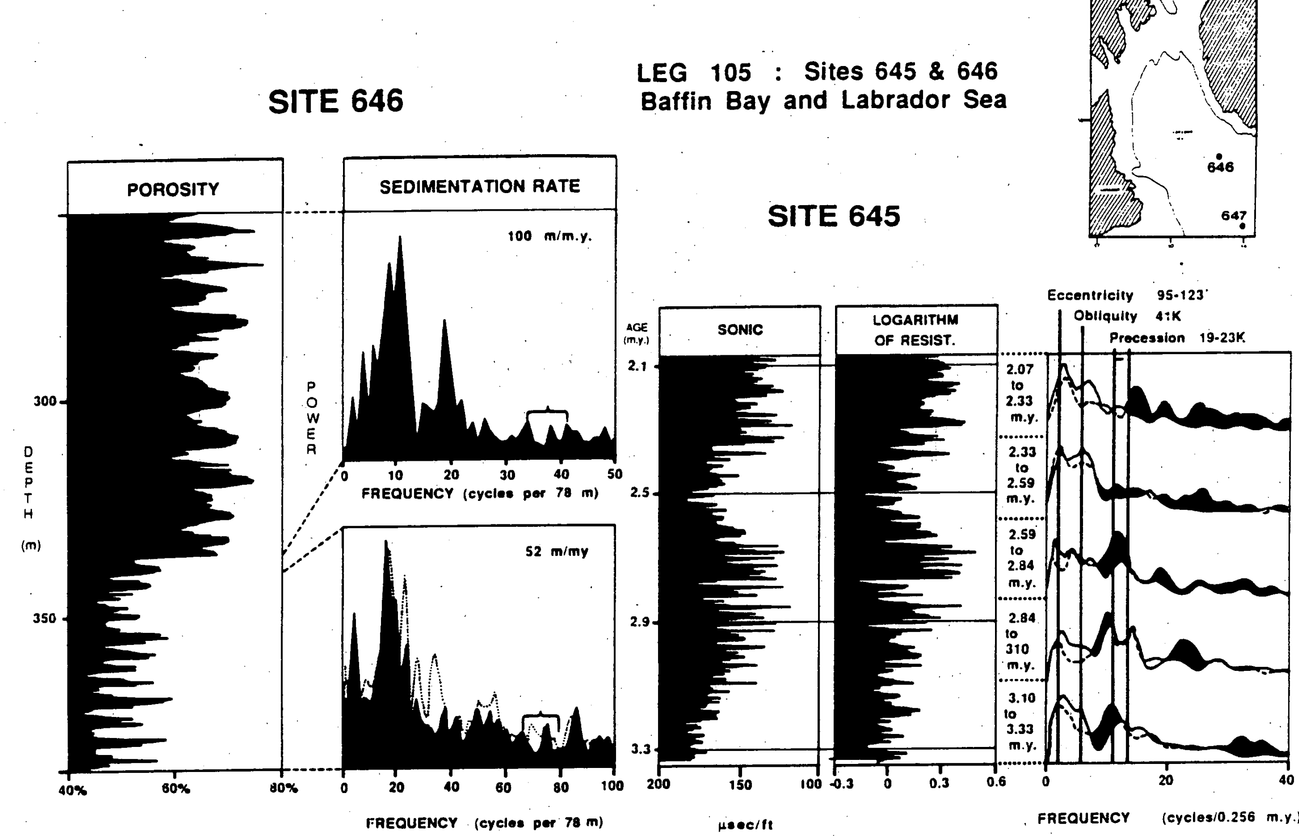


Figure 4-1. The Fourier transformation from logs versus depth or calibrated to time produce amplitude spectra that have power peaks at periods of Milankovitch orbital variations. In these cases from Holes 646 and 645, porosity changes from bottom current changes correlate with the long wavelength periods of the Milankovitch climate cycles. The logs do not resolve the finer scale variations at these sedimentation rates. Each log has a distinctive resolution, with the Formation Microscanner dipmeter able to decipher mm changes, and the dual laterolog electrical resistivity tool only m changes, as the two extremes.

were not detected by shipboard core descriptions. However, an approximately 1-2 meter cyclicity in color banding was noted.

The logged interval is almost barren of microfossils, but the combination of sparse micropaleontological control and detailed magnetic reversal stratigraphy allows for rather good age control for this interval. Using the derived age/depth curve, the logs were converted from depth to age (Figure 4-1).

Fourier transformation to amplitude spectra permit a detailed examination of the frequency content of the logs. The spectra for five age windows of the sonic and resistivity logs from Site 645 are shown in Figure 4-1. Note that the natural logarithm of resistivity is used rather than raw resistivity because resistivity is logarithmically related to porosity. It is apparent that the same general frequencies are present in all age windows, although the relative magnitudes change through time. For example, from 2.1 to 2.5 Ma the dominant period of resistivity variations appears to be about 100,000 years (eccentricity), whereas from 2.65 to 3.3 Ma a much higher frequency of about 20,000 years (precession) is apparent. Peaks are evident at the 41,000 year obliquity period and 19,000-23,000 year precession period with gradual trends of increasing precession energy and decreasing obliquity energy with increasing age. Slight errors in the assumption of constant sedimentation rate are suggested by small systematic shifts of all observed peaks with respect to predicted peaks within a spectrum. For the 2.8-3.1 Ma. interval, observed peaks are centered about 10% left of predicted peaks, suggesting that the sedimentation rate is about 150 m/m.y. rather than 135 m/m.y. A similar shift to the right in the interval 2.1-2.3 Ma suggests a sedimentation rate of about 120 m/m.y. In the interval 2.8-3.1 Ma, the portion of the amplitude spectrum tentatively correlated with precession may permit the resolution of both the 19,000 and 23,000 year precession periods. Thus, the logs can be used to refine the age-dating available from the core. But what is it the climate change that produces the cyclical porosity variation?

Fluctuations in bottom current activity are probably responsible for the cyclical variations in sonic and resistivity log responses at Site 645. These two porosity-sensitive logs are correlated with gamma-ray fluctuations in that increasing clay content is associated with higher sonic traveltime (lower velocity) and lower resistivity. During periods of decreased contour current intensity, more fine-grained clay minerals were deposited at this site. The geological reasons for the changes with time in predominant orbital control of sedimentation among eccentricity, obliquity, and precession are not so apparent! Yet we must understand cause and effect in the past if we are to predict such in the future.

2. A further example: ODP Site 646

ODP Site 646 from Leg 105 is located in the Labrador Sea on the Eirik Ridge about 300 km southwest of the southern tip of Greenland. A 767 m interval of visually monotonous silty clays and clayey silts was penetrated. The sediments represent approximately the last 8.5 Ma.with an average sedimentation rate of about 90 m/m.y. On seismic sections, the Eirik Ridge is interpreted to be formed of drift deposits, with local sediment accumulation rates affected by bottom current activity. The onset of ice rafting at Site 646 occurs at 236 m, or about 2.5 Ma, based on the first occurrence of significant quantities of dropstones in the cores.

The entire drilled interval (0-750 m) was logged with the neutron, spectral gamma ray, and gamma spectroscopy tools. The openhole interval below pipe (206-737 m) was also logged with the sonic, gamma ray, and resistivity tools. A porosity log was calculated from resistivity using Archie's equation (Figure 4-1). This rescaling of the log does not affect visible cyclicity or amplitude spectra. As at Site 645, the sonic and transformed resistivity logs show very similar small-scale character because both logs are primarily controlled by porosity. The sudden porosity increase at 340 mbsf is caused by the first occurrence of siliceous microfossils and is accompanied by a change in mineralogy from 65% clay minerals and 20% quartz, to 45% clay and 45% quartz.

In the upper interval of Site 646, a strong amplitude peak occurs at a frequency of 9-11 cycles/78m, with a much smaller peak at 19-20 cycles/78m. Assuming a sedimentation rate of 95 m/m.y., the major peak has a temporal period of 85-100,000 years (eccentricity) and the secondary peak has a period of 38,000-45,000 years (obliquity). The amplitude spectrum in the lower interval is similar in character but shifted by approximately a factor of two in frequency, as expected for a constant temporal frequency but 50% reduction of the calculated sedimentation rate from core data. Again, the dominant period is about 100,000 years, but here the 41,000-year period is evident only on the sonic spectrum.

The simplest explanation of the velocity and porosity amplitude spectra of Figure 4-1 is that the patterns result from orbital variations with Milankovitch periods modulated by the vertical resolutions of the various logging tools. The sampling interval for all logs is 15 cm, but the vertical resolution is very different, 0.6 m for the sonic tool and about 1 m for the resistivity tool. These resolutions correspond to minimum temporal resolutions of 12,000 and 20,000 years at the 95 m/m.y. sedimentation rate in the upper interval, and 30,000 and 50,000 years for the lower sedimentation rate in the lower interval of Site 646. The 100,000 year eccentricity cycle should be readily resolvable in both intervals if present in the sediments; this temporal period is the strongest period in each interval. The 41,000 year obliquity period should be readily detectable in the upper interval, but in the lower interval it should be barely detectable on the sonic and probably undetectable on the resistivity-porosity logs. This is exactly the pattern seen in the amplitude spectra. The 19,000-23,000 year precession period, if present, should be detectable only by the sonic in the upper interval. It is not seen by either log from either interval. Peaks on amplitude spectra are increasingly smeared at higher frequencies by slight sedimentation rate variations.

The logging data suggest that fluctuations in clay content cause the cyclical porosity variations in the logged interval of both sites 645 and 646. The simplest explanation for this condition is that porosity fluctuations are caused by changes in strength of bottom currents. During times of weaker currents fine-grained clay minerals and nannoplankton can accumulate, and relatively small amounts of coarser-grained quartz and feldspar are carried to the site; consequently porosity is high. During times of stronger currents, the current intensity retards deposition of clay and nannoplankton; relatively more quartz and feldspar are deposited. However, the log data cannot determine whether the stronger currents cause an absolute increase in the accumulation rate of the coarser-grained minerals. The ultimate causes of the sedimentological cycles are that bottom currents change as climatic warming and cooling occurs at the surface of the oceans. Upwelling zones move in latitude and bottom currents change correspondingly.

Milankovitch Climate Cycles in Geochemical Logs from the South Atlantic (from Mwenifumbo et al., 1988)

Geochemical logs provide a direct measurement of the changes in mineralogy accompanying the earth's response to Milankovitch climate cycles. On ODP Leg 114, Hole 704 was drilled into the Meteor Rise in the southern Atlantic Ocean (Figure 4-2). Calcium and silica measurements from the geochemical logging tool reflect changes in carbonate versus siliceous sedimentation as diatom content in the sediments varied with upwelling. Hotter climates pushed the upwelling zone to the south, while colder climates moved the diatom source to the north. The cyclical variation in calcium content is clearly out-of-phase with both silica and hydrogen, which are in phase (Figure 4-2), indicating that diatom-rich sediments are characterized by higher porosity than diatom-poor sediments.

Amplitude spectra for a moving depth window of 100 m, stepped every 50 m, show predominant energies at 3 and 5 m wavelengths (Figure 4-3). At the appropriate sedimentation rates determined from core, these cycles are at 44,000 years (obliquity) and 77,000 years (eccentricity). The suspected eccentricity period is less than the observed 95,000-110,000 year range for eccentricity , possibly indicating that the sedimentation rate determined from sporadic core recovery is too high by about 10%.

Climatic Cycles Back into the Past -A 31 Ma Example from the Weddell Sea (from Golovchenko et al., 1990)

The great promise of data from wireline logs for the determination of past climate change comes from their ability to produce continuous data regardless of the age of the sediment drilled through. In ODP holes core recovery drops dramatically with both age and depth .

On ODP Leg 113, Hole 693 was drilled into 31 Ma sediments on the Antarctic continental margin (Figure 4-4). Amplitude spectra of gamma ray, resistivity and sonic logs suggest a change in orbital drives when compared with predominant peaks in recent sediments (previous examples). The 41,000 year obliquity peak is much more prominent than the eccentricity peak at 95,000 years; this is a reversal from that in more recent sediments. Although a much more complete study of such differences is obviously required, the logging data clearly contain a vast wealth of information related to possible temporal and regional changes in the relative importance of orbital variations through geologic time.

Glaciation and its Effects on Wireline Logs (from Ollier et al., 1988)

Perhaps the most dramatic effect of global climate change in the recent geological past has been the rapid expansion and retreat of the great ice sheets. The timing and earliest onset of glaciation in the southern hemisphere was a major thematic goal of ODP Legs 113, Climate changes produce cyclic alternation of Calcium and Silica-rich layers

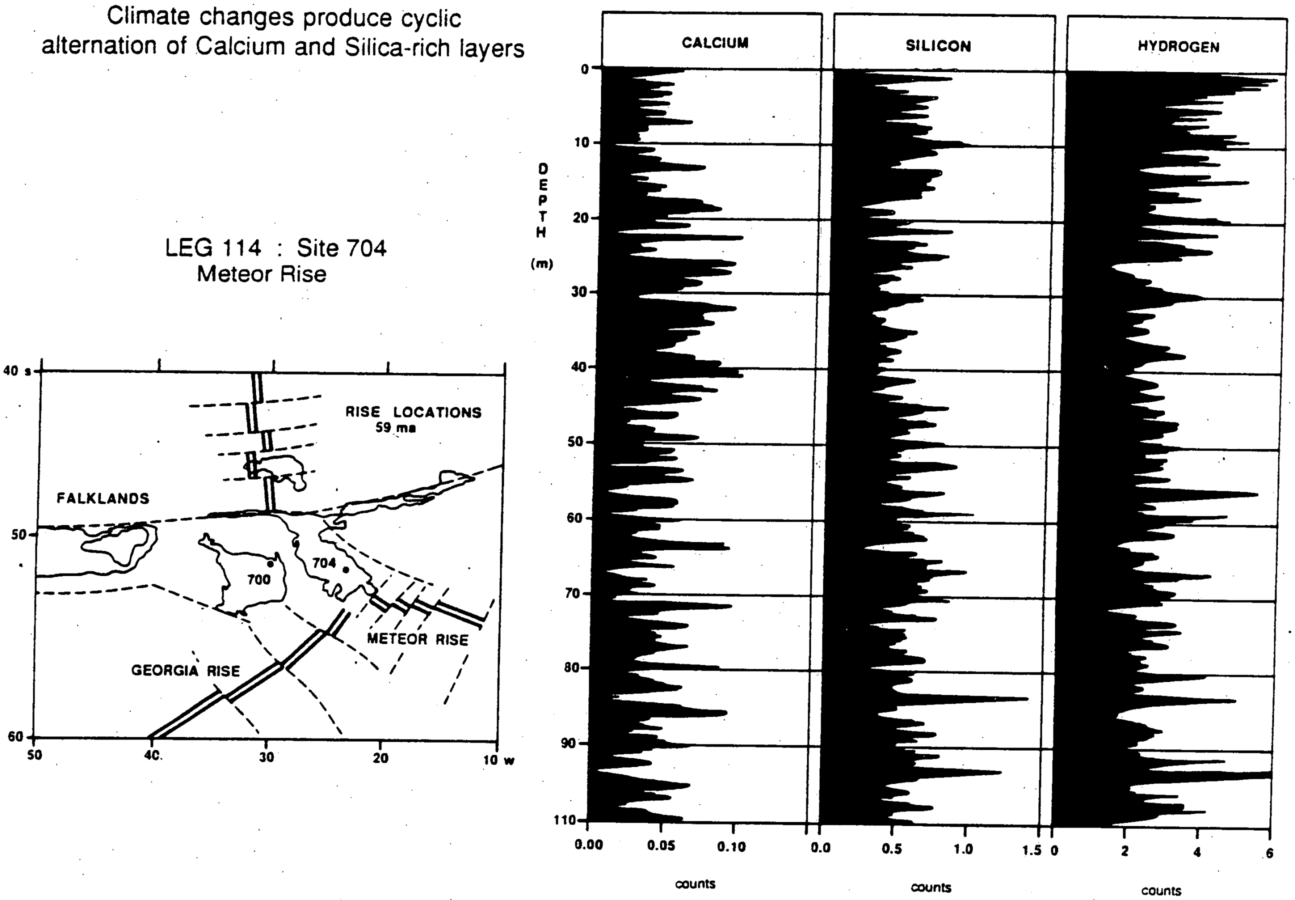
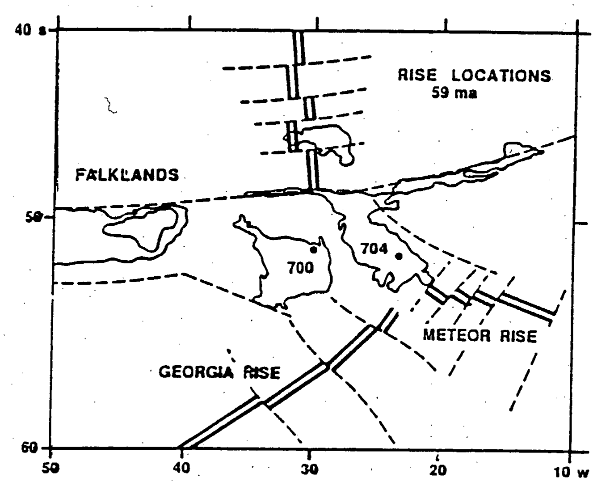


Figure 4-2. Geochemical logs measure variations in Ca and Si that are out of phase because the Milankovitch climatic cycles have produced a latitudinal movement of the upwelling current that resided above this site in the recent past. Diatoms rich in Si were deposited when the upwelling current was above the site, and Ca shelled foraminifera were abundant when the upwelling zone moved away from the site. The porosity of the sediment, (seen from the abundance of H), is high when the diatomaceous Si-rich sediments were deposited, and low when the carbonate predominated.

Climate changes produce cyclic alteration of Calcium and Silica-rich layers

LEG 114 : Site 704
Meteor Rise



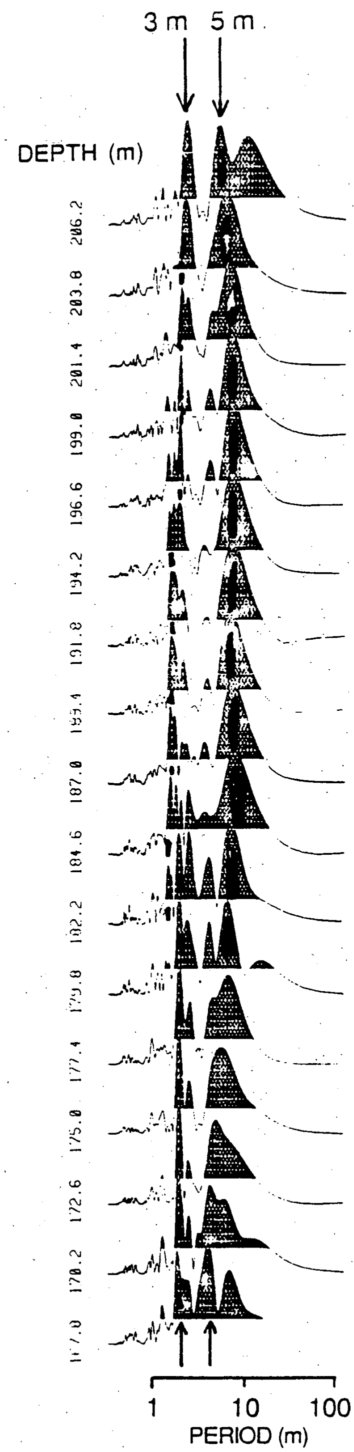


Figure 4-3. A 100 m wide moving amplitude spectrum was calculated at 2.4 m intervals of the Ca curve from figure 4-2. The predominant wavelengths of high Ca-content are at 3 and 5 m. Dating of recovered core place these periods at 44,000 and 77,000 years. The likelihood that these cycles are caused by Milankovitch climate cycles allows us to determine that the core-derived sedimentation rates are somewhat low, by about 10 %. The fine scale variation in sedimentation rate can be seen from the variation in period of the predominant power peaks over this 50 m interval. The geochemical logs are being used to AGE-DATE the sediments for the first time.

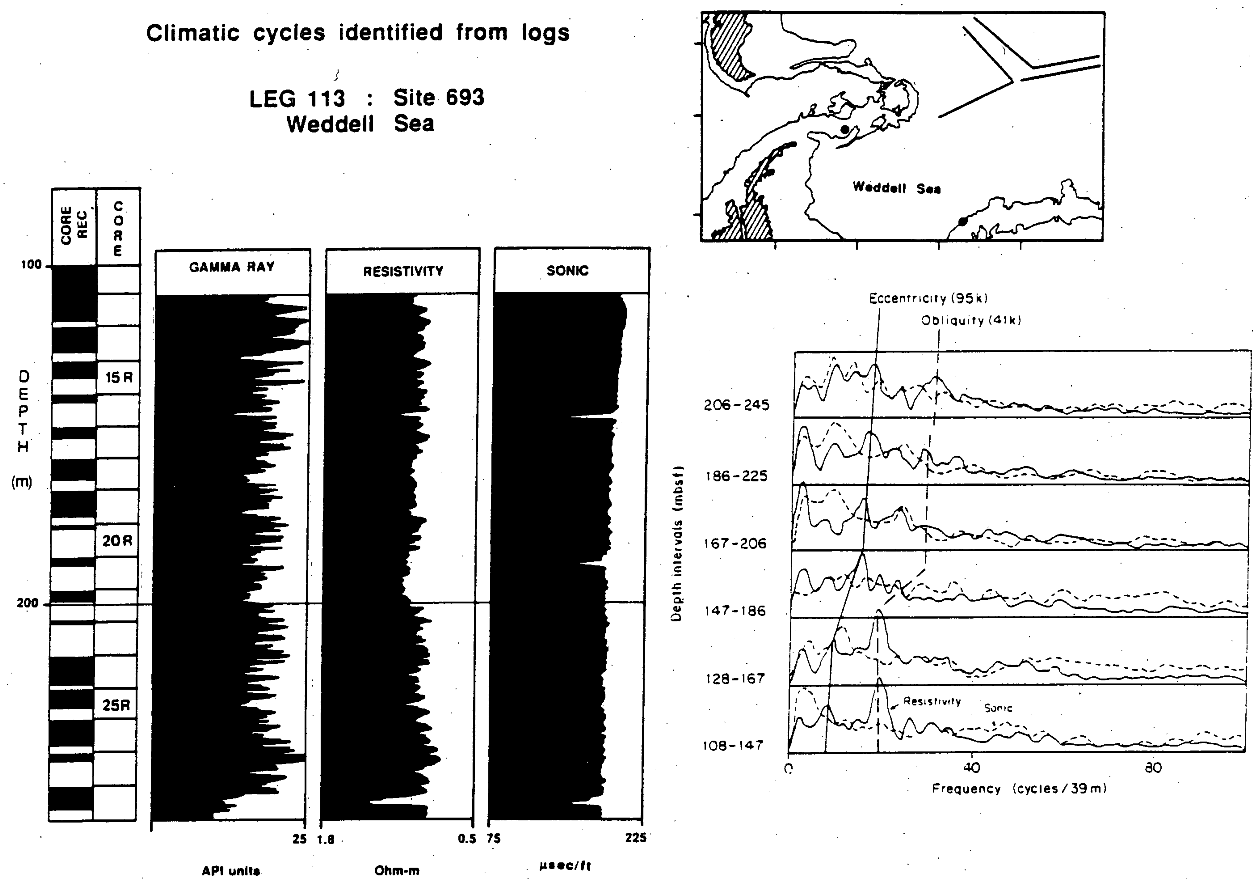


Figure 4-4. Logs provide a continuous record of sediment variations in a well. As long as unconformities are not crossed, it should be possible to map the relative interactions of the three Milankovitch orbital drives with the climate of the Earth long into its geological past. In amplitude spectra from 100 to 250 m into Hole 693 in the Weddell Sea, we can see that the sedimentary response to obliquity produces a steadily decreasing change in clay-content (gamma-ray log), and porosity (resistivity log), whereas the eccentricity change produced a steady increase in response of clay-content and porosity. We must understand why such changes occur in the response of the climate to external drives before we can have complete confidence in our predictive abilities to deal with man-made perturbations.

119 and 120. The effects of glacial advance and retreat can be readily seen from logs in Holes 739 and 742, drilled in Prydz Bay, Antarctica, during Leg 119. Here, a steeply dipping set of seismic reflectors has been truncated by advancing ice, forming an angular unconformity .

Geophysical logs show a sequence of high porosity, low porosity, high porosity layers, within the dipping reflectors which are present beneath about 175 mbsf in both wells (Figure 4-5). The occurrence of low porosities (<10 %) within 100 m of the sea floor is an indicator of overcompacted sediments. For example, the North Sea is floored by such low porosity sediments as a result of erosion by ice. The sequence of tilting, ice erosion and retreat, deposition of unit 2, ice advance, and finally, ice retreat is indicated by the logs.

The hydraulics of this loading event are interesting, because though unit 2 is severely overcompacted in both wells, the dipping reflector unit 3 is not. The compaction of one layer sitting on top of an uncompacted layer requires that part of the weight of the overburden be supportable by fluid pressures in the uncompacted interval. Very low permeability is therefore required to prevent the squeezing out of the pore fluids in the dipping reflectors. In turn, high permeabilities must have allowed the pore fluids from unit 2 to be squeezed horizontally away from the ice load (Figure 4-5).

Sea Level Changes

Variations in sea level in the geological past have been inferred from transgressions and regressions recorded in sediments deposited on continental margins (Figure 4-6). These sea level changes are attributable to a variety of mechanisms including climatic changes or volume changes of the ocean basins caused by worldwide acceleration or deceleration of mid-ocean ridge spreading rates. The variation in sea level produces noticeable logging responses regardless of the driving force involved.

Consider for example the sea level record from an Eocene carbonate reef drilled at Hole 715 on the Chagos-Lacadive Ridge of the Indian Ocean (Figure 1-3) during ODP Leg 115. Geochemical logs show the reef to be composed of over 80% carbonate, but variations in sulfur composition also reflect changes in depositional environment as the reef grew (Figure 4-7). These changes affected the abundances of evaporites in the reef although none of the 5% of the section that was successfully cored were sulfates. The changes *may* be related to changes in eustatic sea level. These appear on the geochemical logs as sulfur-rich zones (Figure 4-7).

Amplitude spectra of the sulfur curve shows strong energy peaks at 25- and 50-foot wavelengths (Figure 4-8), whereas the Vail eustatic curve (Figure 4-6) shows low stands in the Eocene at 36, 40, 42, 49, and 54 Ma. A reef does not have a traditional "sedimentation rate" to convert from depth to age, but if the rock corresponding to the peaks in the sulfur curve could not be dated, the sulfur log might be used to identify low-stand ages for the reef (once again assuming that the evaporite abundances were being controlled by sea level related factors).

A more straightforward sea level-geochemical log correlation was found at Site 761, drilled into the Exmouth Plateau off western Australia on Leg 122 (Figure 1-3). Two clear low stands below the Cretaceous-Tertiary boundary were identified from lithological

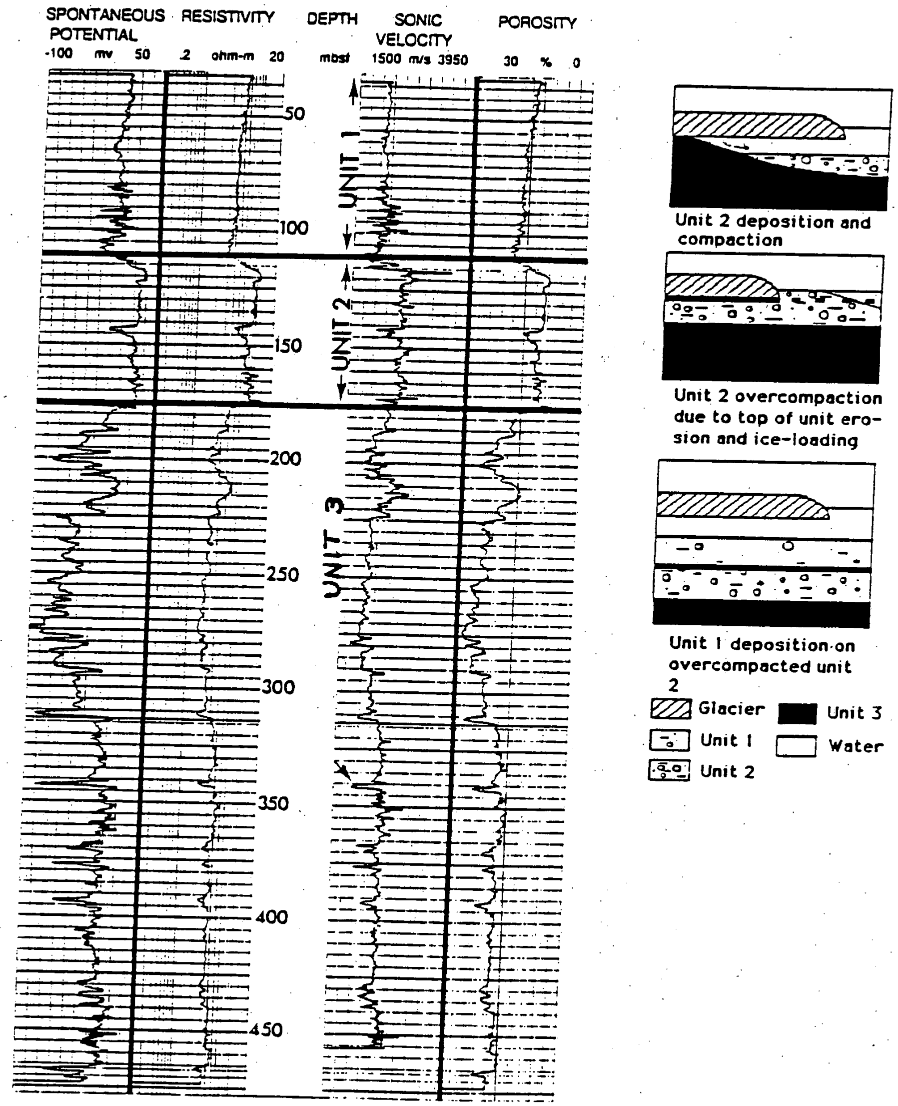


Figure 4-5. Ice encroachment, loading and melt-back produce major changes in sediment properties of the sea floor. In Hole 739, drilled during Leg 119 in Prydz Bay of Antarctica, high porosity sediments (low resistivity) are found both above and below a unit of very low porosity (high resistivity). The stratigraphic progression is believed to be tilting of Unit 3, truncation by an advancing ice sheet, deposition of Unit 2 during melt-back, then loading of Unit 2 by new ice. Unit 2 compacted as pore waters were squeezed out horizontally in from of the advancing ice. Unit 3, however, did not compact because the pore waters could not escape down dip along the dipping reflectors. Unit 1 was finally deposited passively as the ice melted-back again. A similar compaction history is found in nearby Hole 742.

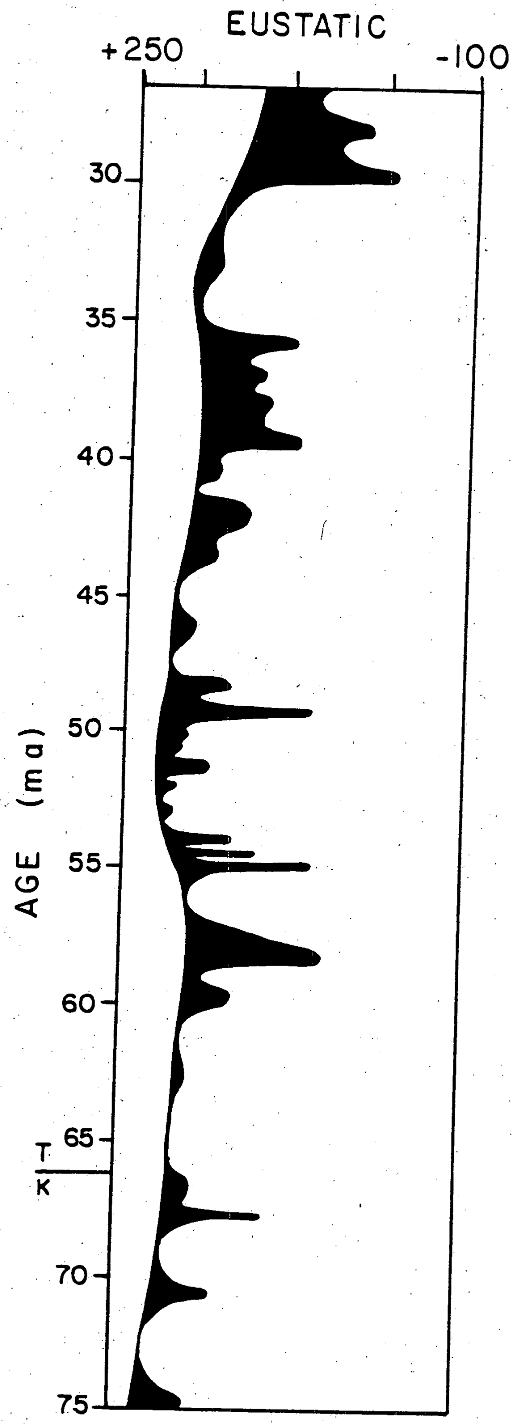


Figure 4-6. Eustatic sea level changes derived from sequence stratigraphic interpretations of seismic reflection profiles produce high - and low-stand deposits, that if identified in logging data, can locate the well in time.

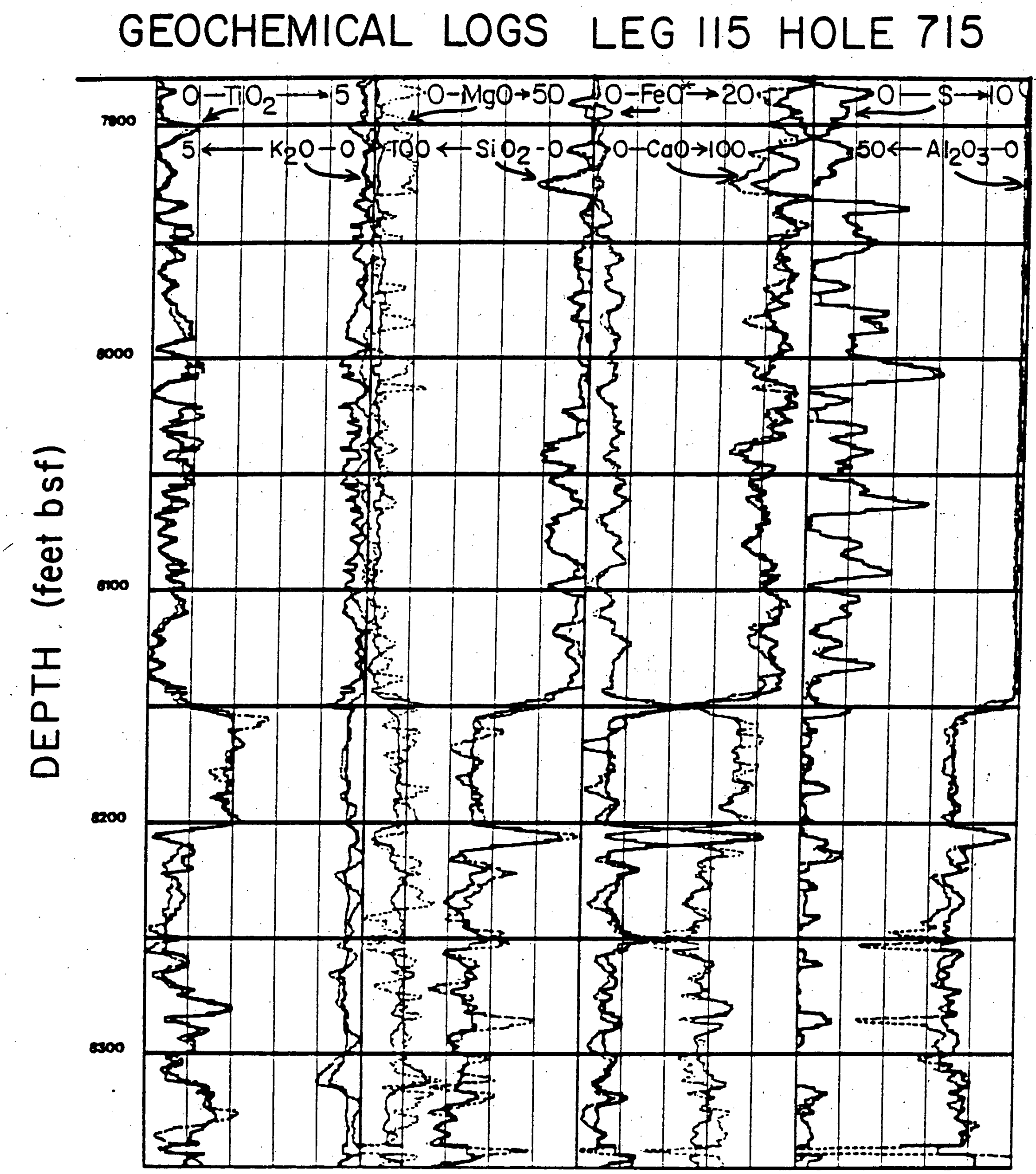


Figure 4-7. Changes in sulfur content in Hole 715 are attributed to environmental variations changing the abundance of evaporites. These *may* be due to changes is eustatic sea level.

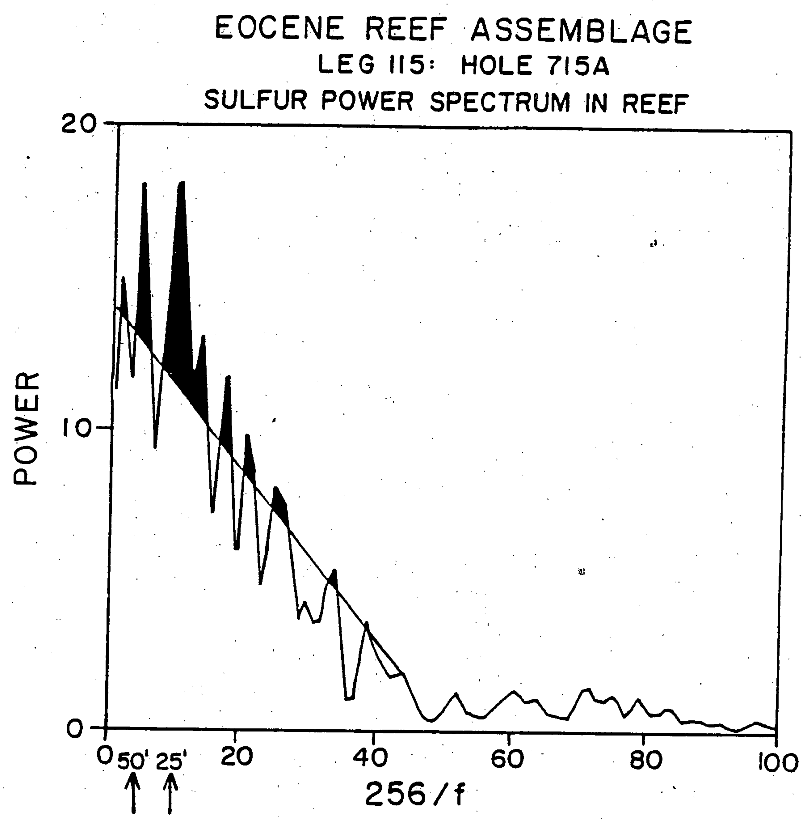


Figure 4-8. The amplitude spectrum of the sulfur concentration from the geochemical log in Hole 715 (figure 4-7) shows periods of the sulfur peaks to be 25 and 50 ft. If this periodicity is due to sea level changes, then it can be used to tie into the eustatic sea level sequence curve (Figure 4-6).

changes observed in the geochemical logs (Figure 4-9). The Si-content of the sediment increases whereas the Ca-content falls as sea level drops. Al increases somewhat with Si indicating that clay-content is also increasing. The low-stands are marked by interbedded chalks and mudstones whereas the high-stands are represented by limestones. The depositional environment changes from shallow marine to deep-water carbonate platform then, as the margin continues to subside in the Tertiary, to deep marine. Not only can sea level changes be determined, but stratigraphic sequences from log patterns can be identified. Determination of such a sequence stratigraphy from logs is a far cry from a simple determination of impedance contrasts used to generate synthetic seismograms for correlation with surface seismic surveys. We are now able to see real cause and effect in the interaction of sea level change with marine sediments.

The Cretaceous-Tertiary Boundary

So far during the Ocean Drilling Program, logging data have been obtained across the extinction boundary between the Cretaceous and Tertiary (K-T) at 6 wells in the south Atlantic and eastern Indian Oceans. Beginning with the well we have just discussed, Site 761, we find the K-T boundary to be marked by abrupt changes in gamma ray, resistivity and velocity (Figure 4-10) as well as high clay content (Figure 4-9).

Hole 762, also drilled on the Exmouth Plateau (Leg 122, Figure 1-3), also records an increase in clay content across the K-T boundary as well as an even stronger velocity contrast (Figure 4-11). Here, the clays continue to a substantial depth above the boundary, where low velocities are no longer correlated with low resistivities.

The high gamma ray counts recorded above the K-T boundary may be from volcanic ashes from the Kerguelen hot spot, which was just to the south at this time (see below). However, low resistivity and velocity indicate high porosity for this interval. It is concluded that the increased clay content is from non-deposition of carbonates rather than from a dramatic increase in deposition from either a worldwide volcanic eruption event or from increased dust from a meteorite impact, the two most popular theories for the extinction of the dinosaurs.

Volcanic ashes can be identified on the logs by studying the Th/U ratios. As discussed in chapter 3, hot spot volcanics have Th/U ratios ranging from 4 to 6, whereas pelagic sediments have Th/U ratios < 1. The Th/U ratios of K-T boundary ashes from Sites 747 (Leg 120), and 752 (Leg 121), show not only that similar ashes are found both above and below the K-T boundary, but also that the occurrence of the ash deposits is related to hot spot activity rather than to an extinction event (Figure 4-12). Furthermore, the volcanic ash layers from the two sites have a trace element signature very similar to that of the volcanic rocks of the Kerguelen hot spot.

The K-T boundary is more than an extinction event, as was observed at Site 750, drilled into the central Kerguelen Plateau during Leg 120 (Figure 1-3). The boundary is a hydraulic discontinuity at this well, separating high permeability nannofossil chalks from only slightly less porous, but clearly less permeable chalks above. This conclusion is derived from an "invasion" profile of the well (Figure 4-13) showing that high resistivity, fresh water muds have significantly invaded the formation below the K-T boundary, but not above. The higher resistivity drilling mud raises the reading on the shallow resistivity

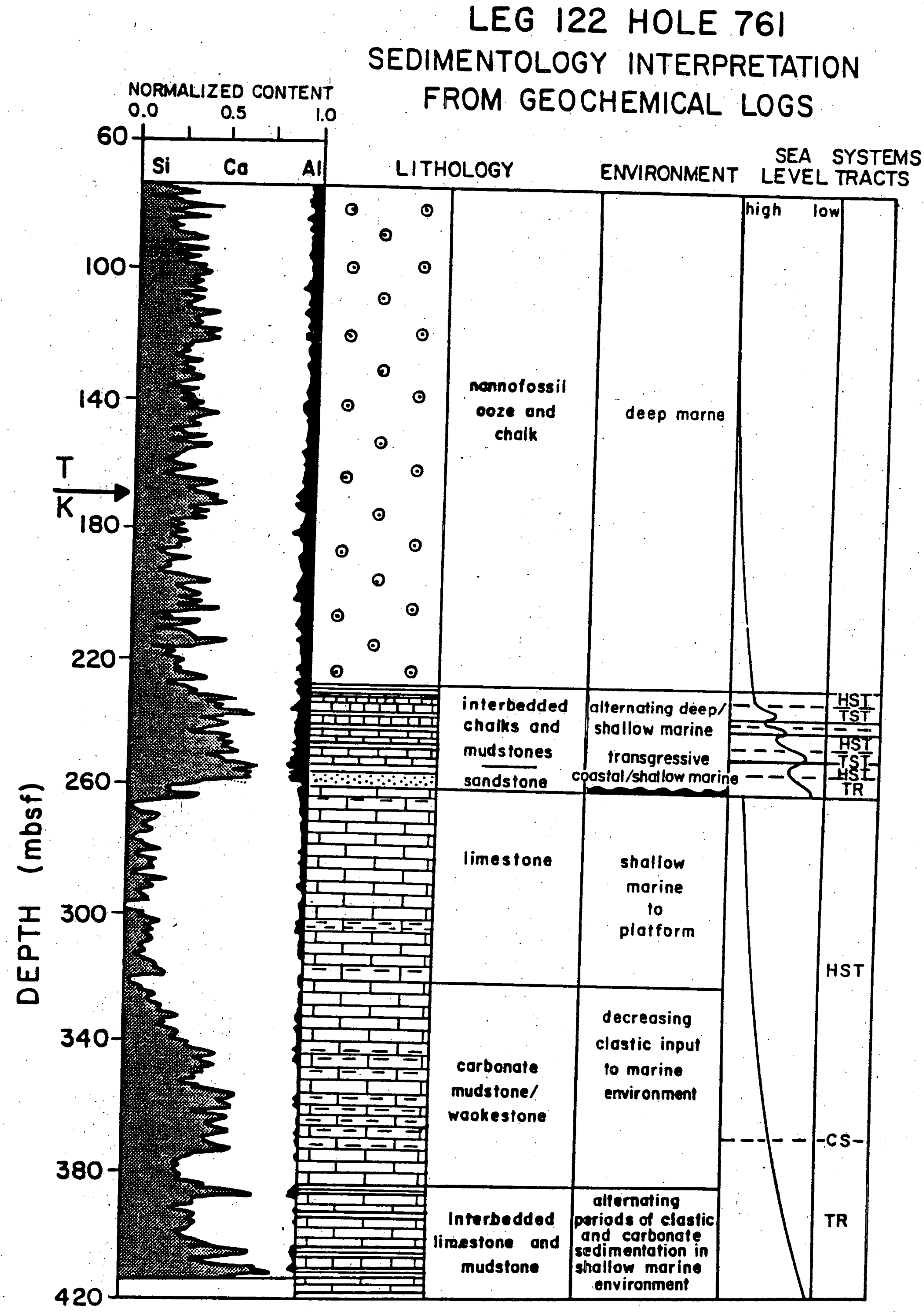


Figure 4-9. Geochemical logs from Hole 761 on the Exmouth Plateau off western Australia show an increase in Si-content as sea level low stands deliver more sandy sediments. The clay content of the sediments increases also, as can be seen from the increased Al -content. The Vail systems tracts, lithologies, and depositional environments can be identified solely from the elemental variations in the logs. The K-T boundary is recorded at 165 m depth as a decrease in carbonate-content.

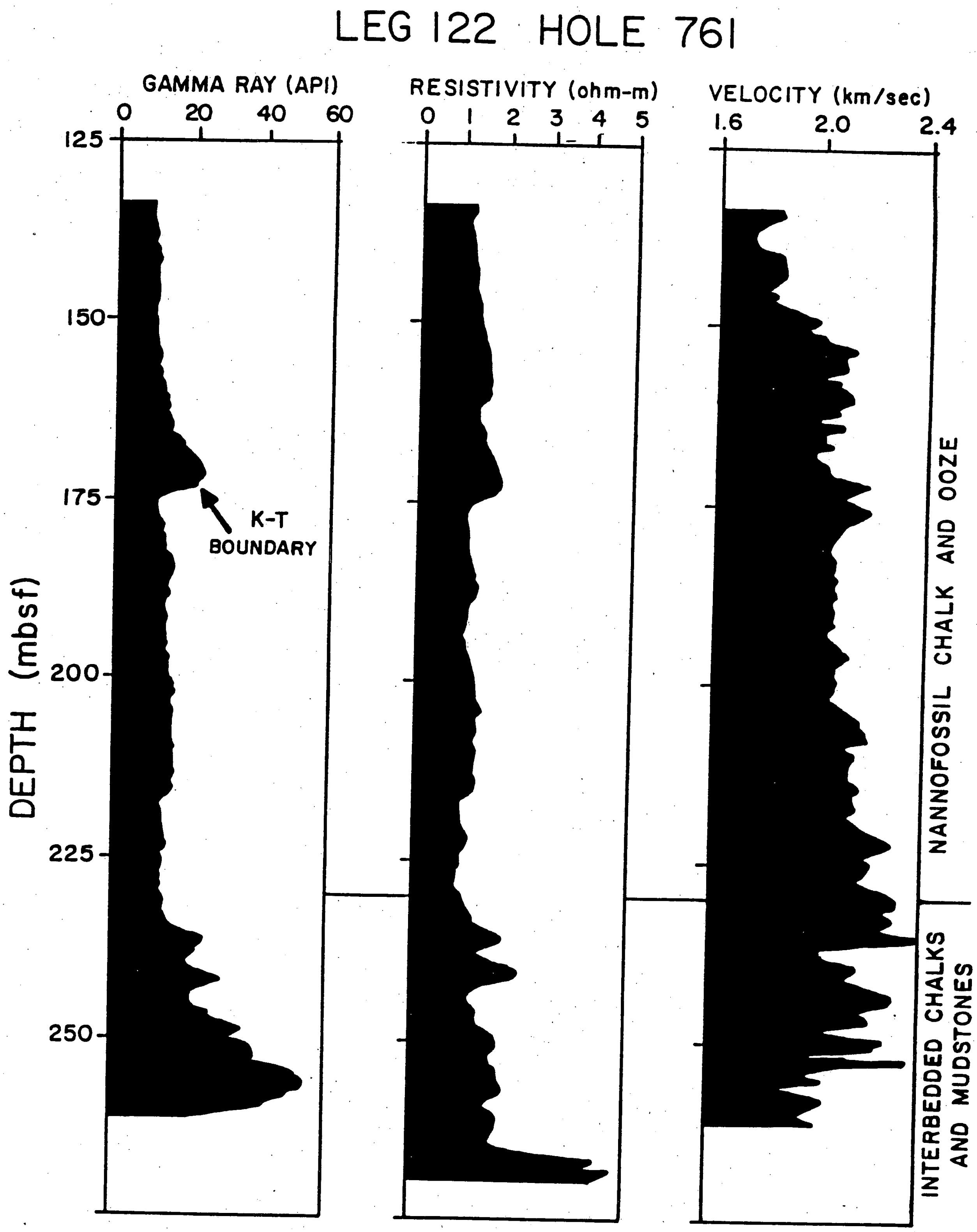


Figure 4-10. The K-T boundary (figure 4-9) is seen at 170 m in Hole 761 geophysical logs as a high resistivity, high velocity, highly radioactive zone of low porosity.

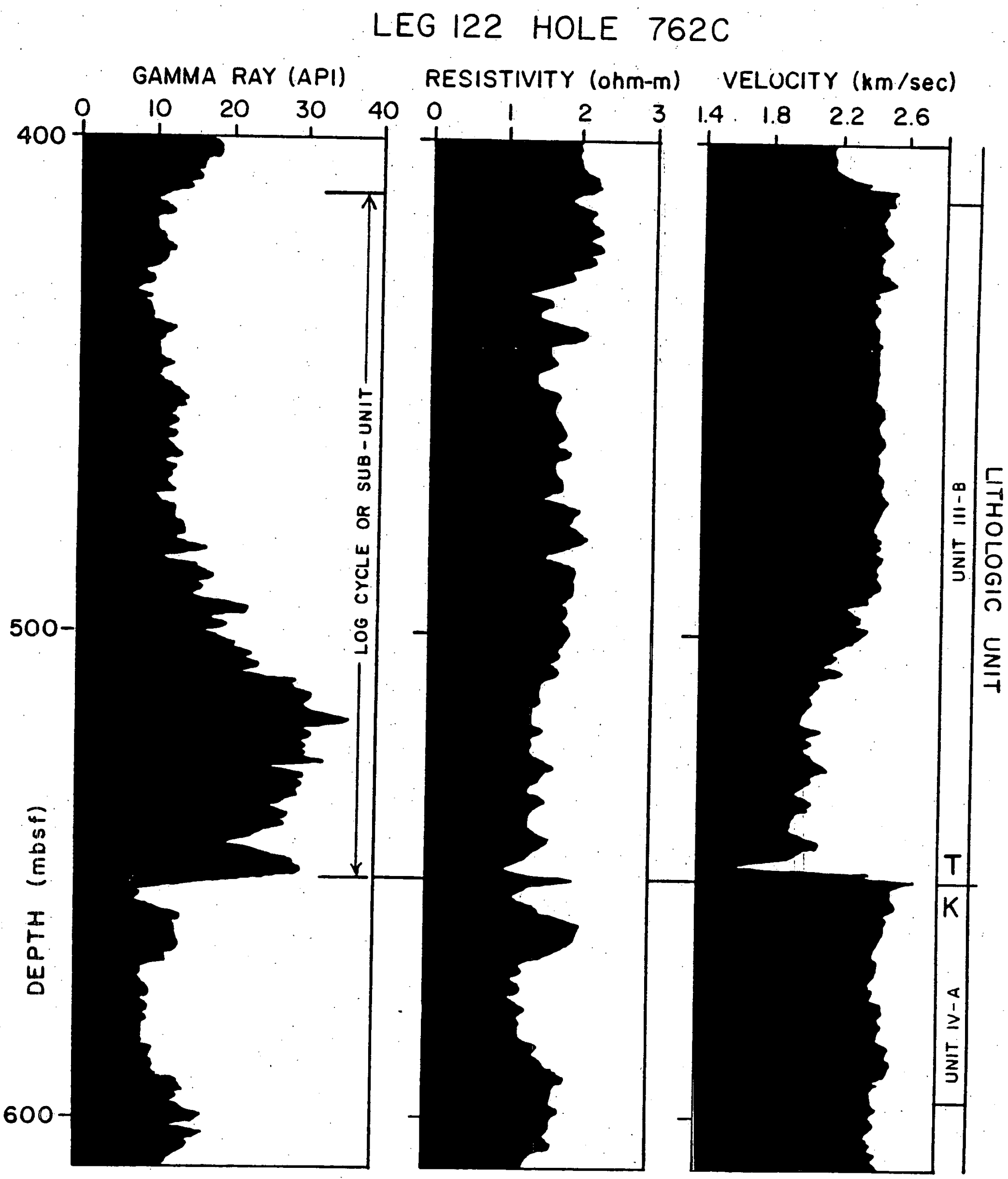


Figure 4-11. The K-T boundary in Hole 762 on the Exmouth Plateau is a much sharper contrast of Gamma-ray energy, resistivity and velocity than in Hole 761.

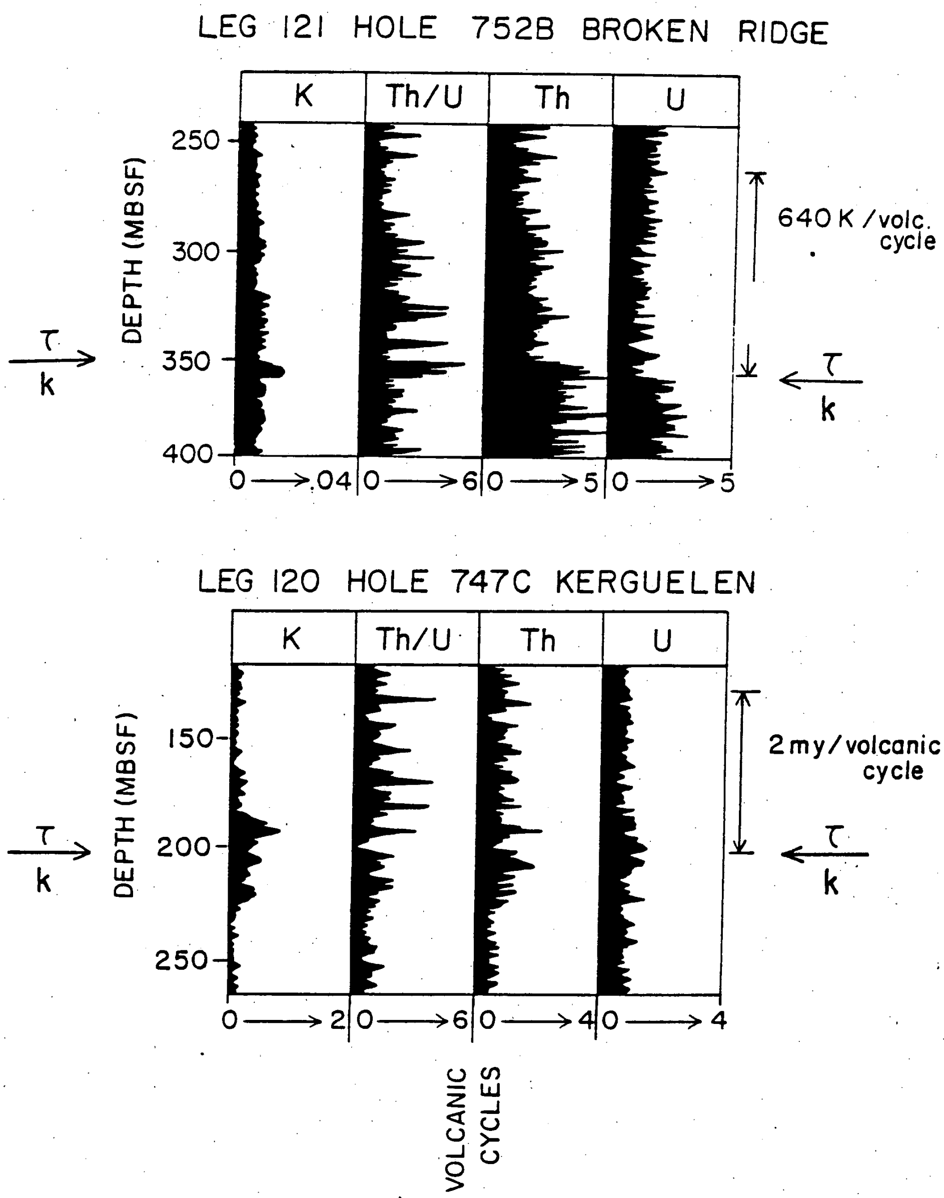


Figure 4-12. The K-T boundary was logged in both Holes 747 and 752 from the Kerguelen Plateau and Broken Ridge. Note the different character of the Th and K curves between the two wells. Hole 752 has a sharp K anomaly from clay deposition right at the boundary, whereas Hole 747 shows a built-up in clay deposition somewhat before the extinction event. Th-content in Hole 752 drops above the boundary, but increases in Hole 747. Therefore, local depositional variations seem as important as the extinction event.

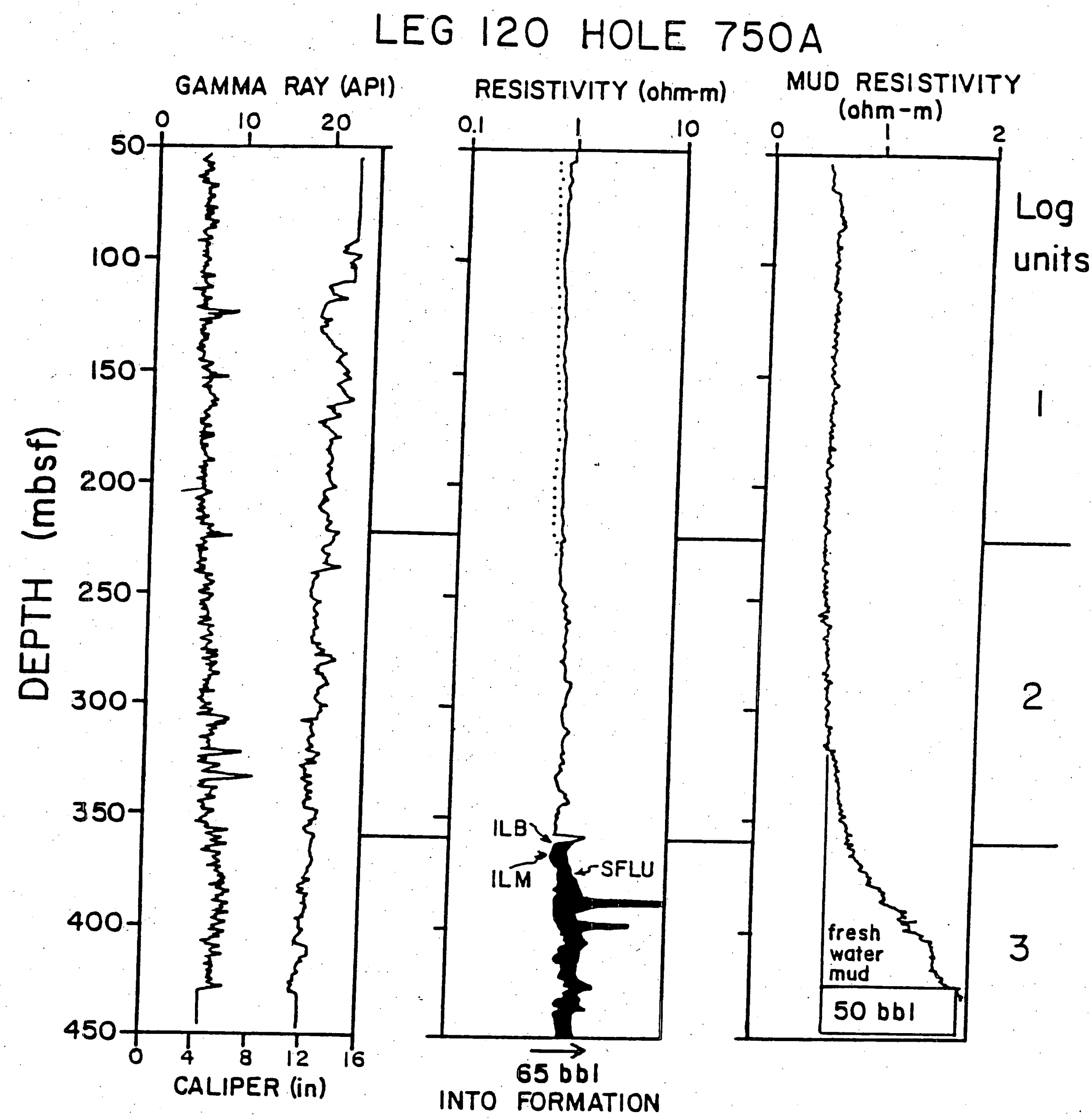


Figure 4-13. The K-T boundary in Hole 750 south of Kerguelen is a major hydrological transition from permeable sediments below to impermeable sediments above, a can be seen from the invasion of the formation below the K-T boundary by fresh drilling fluids. The higher resistivity of the shallow sensing SFLU electrical resistivity curve is a further corroboration that fresh, higher resistivity drilling fluids have invaded the formation close to the borehole, but not far away (because the ILD and ILM deep penetrating resistivity curves still report the low resistivities of the saline formation fluids.

Geochemical logs record the Cretaceous-Tertiary boundary

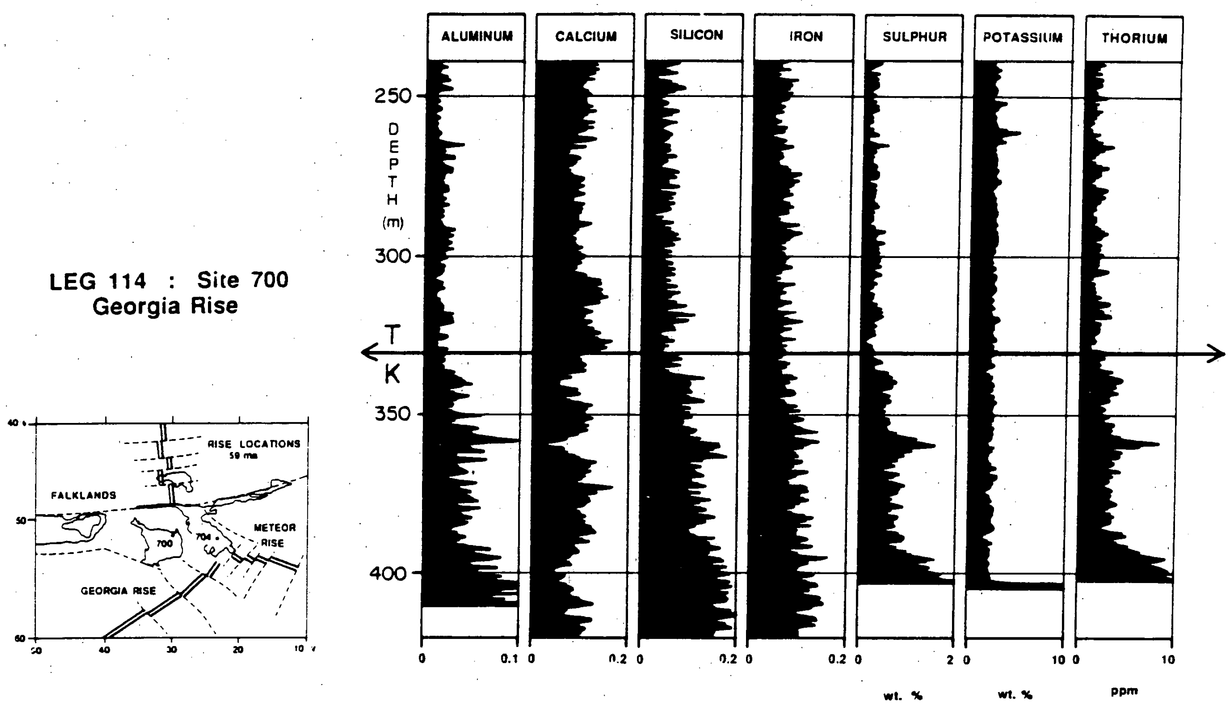


Figure 4-14. Geochemical logs from Hole 700 on the Georgia Rise of the south Atlantic record the K-T boundary at 330 m depth. Here, there is no clay deposition at the event boundary, as can be seen from the lack of an anomaly in U, Th, K or Al curves. There is generally more clay present in the Cretaceous section than in the Tertiary sediments, however. The rapid increase in Ca above the K-T boundary shows how rapidly this nutrient-rich are returned to carbonate productivity after the extinction event.

curve but does not affect the deep resistivity log. The correspondence between the onset of invasion and the depth of the K-T boundary is striking.

Another K-T boundary was sampled at Site 700, drilled during Leg 114 in the southern Atlantic Ocean (Figure 1-2). The logs show no "ash flow event" at the K-T boundary similar to those observed near the Kerguelen hot spot. Clay content does steadily increase below the Cretaceous boundary, however, as can be seen from increased Al, Si, S, Th and Fe contents and decreased Ca-content in the geochemical logs (Figure 4-14). These clays are also from a potassium-rich source, the same as at the K-T boundary in the eastern Indian Ocean, but there is no "event" at the boundary. In contrast, the Ca content reaches its highest value 5 m above the extinction boundary, demonstrating the speed with which the prolific circum-Antarctic surface waters re-established productivity levels after the extinction event.

Summary

It is conceivable that someday we will be able to directly measure such chemical variations attributable to major climatic changes as iridium, oxygen isotopes, and carbon 14 with logging tools. Cryogenic germanium crystal detecters, focused neutron accelerators, and 4096-channel spectral analyzers are already under development. Many of the geochemical analysis techniques being developed by NASA for space may eventually find their way into the borehole. In any event, the future appears bright for the detection of climate changes with logs.

Chapter 5: Formation and Deformation Processes at Rifted and Compressional Continental Margins

Continental margins are of fundamental scientific importance because they provide a window into past earth history. They contain the vast thicknesses of sediments that record paleoenvironment, continental erosion, flexure of the lithosphere, and thermal evolution of the basins. These sediments are encapsulated in a time-ordered sequence that provides the basic evidence for basin evolution. Evidence of rifting is preserved in margin sediments that describe how vast landmasses are torn apart as plate tectonic processes carry the continents chaotically about the earth's surface. The collision of plates produces accretion along the margins of continents that preserve ancient ocean basins and slices of old oceanic crust. Sedimentary basins formed at continental margins are of immense economic importance because they provide most of the world's hydrocarbons. It is in these basins that organic debris is collected, buried and cooked to produce oil and gas. Almost all of the evaporite deposits, potash, phosphate, lithium, and cadmium in the world are deposited here. Hot fluids moving through continental margins produce large and economically important "hydrothermal" concentrations of manganese, cobalt, zinc, iron, lead, copper, sulfur, lithium, uranium, silver, and gold.

Drillholes into rifted and compressional margin sediments provide a direct view into the processes that have shaped the geological history of our planet. Wireline logging measurements are often the only continuous data recorded in these wells, and as such, they provide the framework for the interpretation of observations made on core.

The Oman Rifted Margin and Wireline Logs (from Prell, Niitsuma et al., 1989)

The rifting of the Oman Margin was accomplished by a combination of mega-shearing associated with strike-slip motion between the Arabian and Indian Plates, and more classically rifted, pull-apart, listrically faulted, and tilted basement blocks (Figure 5-1). A set of holes was drilled during ODP Leg 117 across the rifted margin to study the interaction of a widespread oxygen minimum zone in the ocean waters associated with summer monsoonal upwelling and the subsidence and depositional processes of basin formation.

The anoxic bottom waters along the margin cause the organic content of the sediments to be extremely high, and the processes of burial of carbon-rich sediments are obviously relevant to the eventual maturation of these sediments into hydrocarbon-bearing source rocks in a future basin. The geophysical logs at Hole 723 (Figure 5-1) show strong correlation with the uranium variation determined from the geochemical logs (Figure 5-2). Velocity, resistivity, density and porosity reflect the character of the uranium variation downhole. These correlations indicate that a component high in uranium causes high porosity, with associated effects on other physical properties of the sediment. Clay minerals contain some uranium and cause high porosity. First, high porosities are found in

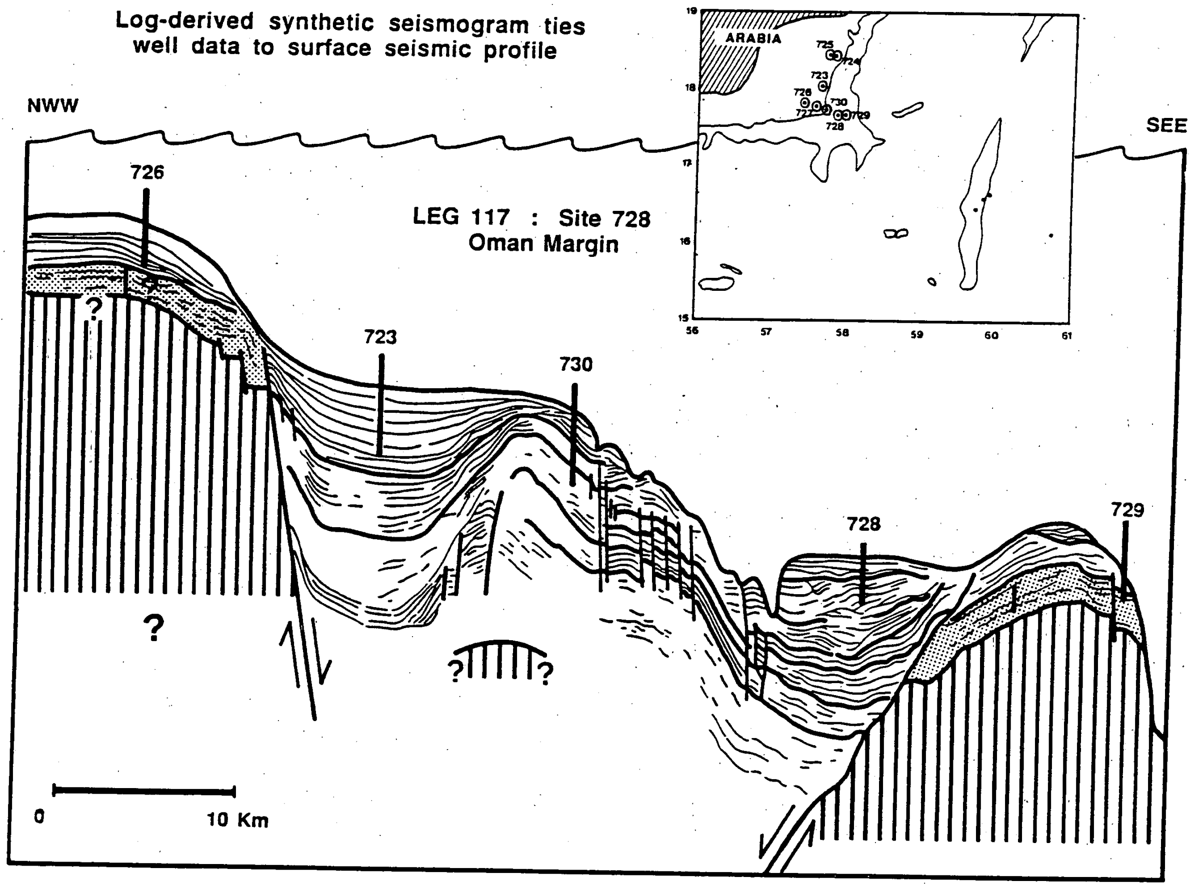
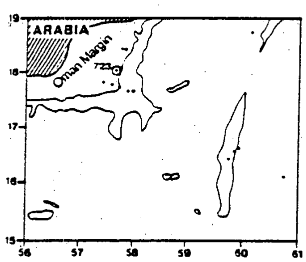


Figure 5-1. Structure of the Oman rifted margin with locations of Holes 723 and 728.

Physical properties are controlled by a component rich in Uranium

LEG 117 : Site 723
Oman Margin



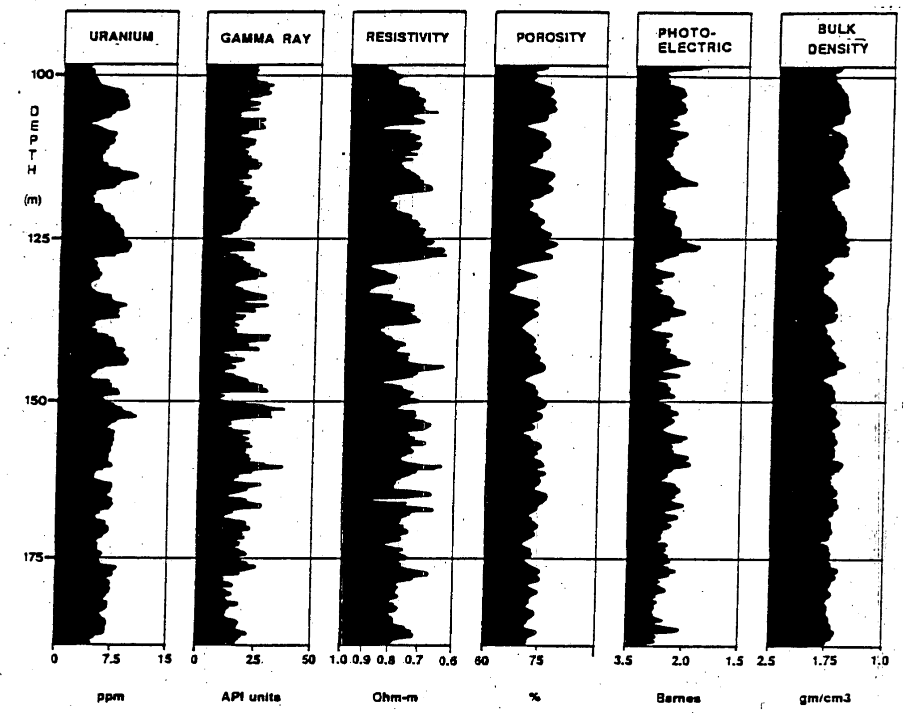


Figure 5-2. Uranium-content from geochemical logs in Hole 723 correlates with major changes in resistivity, photoelectric cross section, and density from geophysical logs, especially in 100-150 m depth interval.

the enriched zones, and clays are usually associated with low porosities. Uranium, however, does not correlate with either thorium or potassium content in the well, as would be the case if uranium-rich component were clays.

Both the total uranium and organic matter contents in the hole are an order-of-magnitude higher than in most deep-sea sediments. Organic matter is known to be often enriched in uranium, because uranium is precipitated from seawater at organic-controlled redox fronts.There is a general correspondence between uranium content and organic carbon abundance observed in the cores of both Holes 723 and 728 (Figure 5-3). Further, organic matter increases porosity, accounting for the strong correlation between uranium and porosity-sensitive logs. Therefore, the organic content of the wells can be determined from the uranium logs.

The anoxic bottom waters are not the only chemical anomaly found in the area. The surprising discovery of dolomite stringers within 200 m of the sea floor indicates active diagenesis is occurring in Hole 723 (Figure 5-4). The geochemical logs identify a freshening of the pore fluids in the diagenetic interval of the well, a point that was verified by chemical analyses on recovered pore waters. The geochemical logs (Figure 5-5) show excellent correlation between Mg and Ca, indicating that diagenesis is proceeding throughout the low chlorinity interval, not just in the dolomitized stringers themselves. Is the influx of fresher waters from land causing the dolomitization and the lowered chlorinity content? A regional "groundwater survey" using geochemical logs in shallow boreholes would answer this question.

The Exmouth Plateau and Wireline Logs (from Haq, Von Rad et al., 1990)

ODP Leg 122 drilled several holes on the Exmouth Plateau off western Australia (Figure 1-3), a rifted margin of similar structure to that shown in Figure 5-1. Holes 759 and 760 are in a position seaward of that occupied by Hole 728 on the Oman Margin (Figure 5-6). Both wells show excellent examples of shoaling upward sequences caused by small-scale sea level variations superimposed upon a general subsidence of the basement block. The sediments of Hole 759 change from deltaic deposits of siltstones at 300 m depth to a deepening carbonate platform in which the characteristic sawtooth ramping of the gamma ray curve is caused by coarsening of grain sizes within each sea level cycle (Figure 5-7). In Hole 760, the sawtooth pattern deposits are found in non-marine claystones, silts and sandstones (Figure 5-8). The finer grained claystones contain abundant thorium whereas the coarser sandstones have low thorium content. Notice that the compaction of these intervals did not proceed uniformly, with two undercompacted sequences resisting porosity loss.

Subsidence can also be observed in Hole 762, drilled on the southern Exmouth Plateau. The geophysical logs show the general subsidence as a dramatic decrease in gamma ray counts and an increase in sonic velocity. The resistivity shows that compaction is again not uniform, with an overcompacted interval just above the transition from Barrow Delta sediments to nannofossil chalks (Figure 5-9).

The geochemical logs add another piece to the subsidence story. The transition from deltaic clays and silts to pelagic chalk is marked by an increase in Si content and a minimum

Uranium log tracks organic Carbon from core

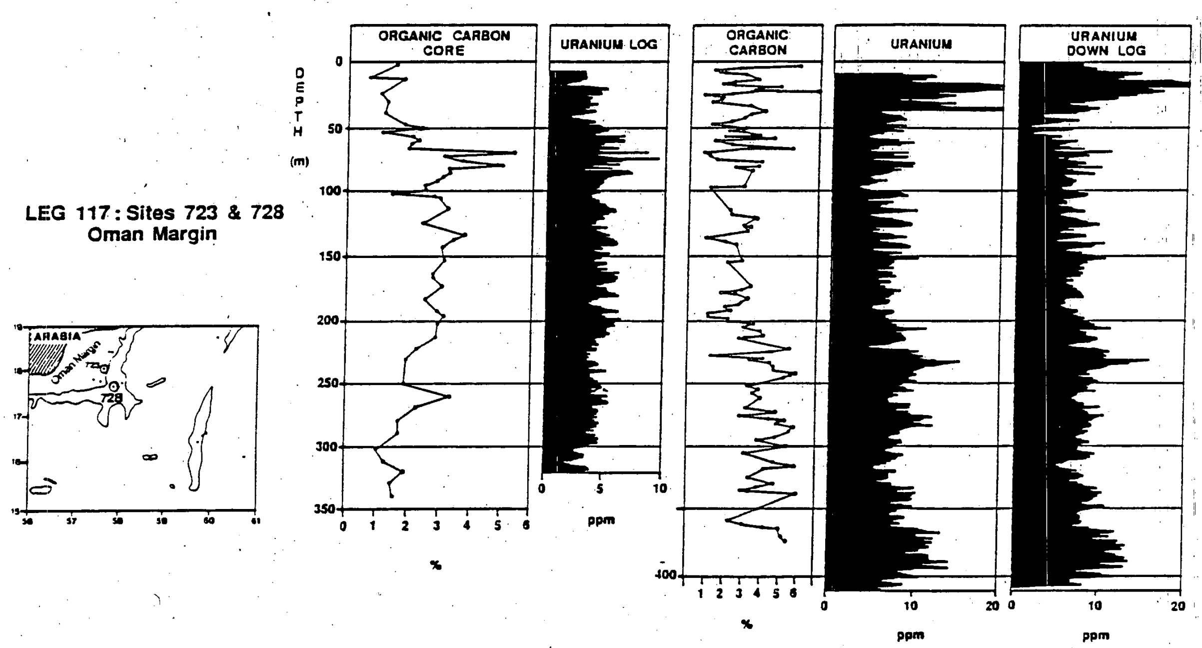


Figure 5-3. The Uranium-content also correlates with organic carbon variations measured on core from Holes 723 (left) and 728 (right). U_2O_3 is complexing with organic molecules.

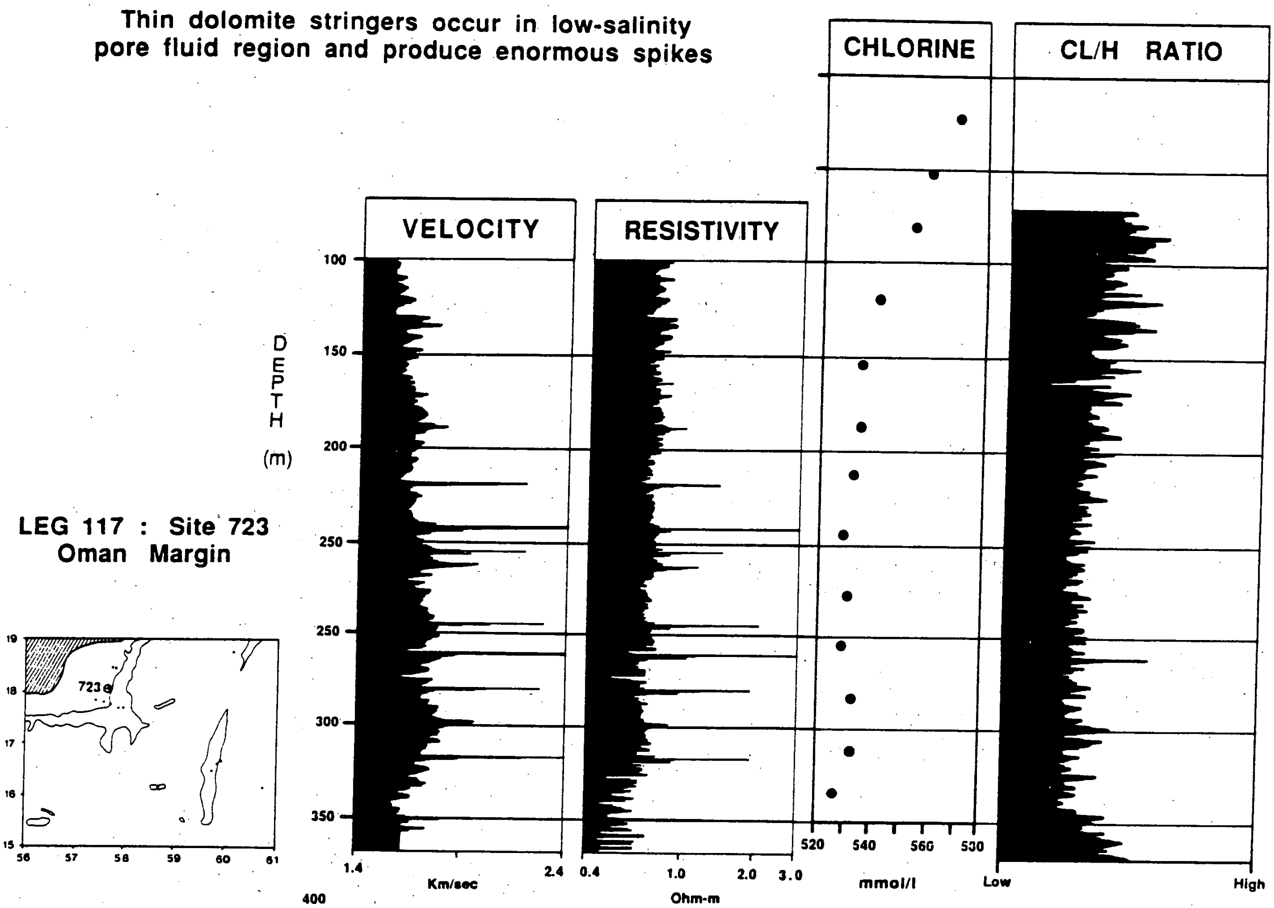


Figure 5-4. At Hole 723, dolomite stringers are seen as very high velocity and resistivity spikes formed by diagenesis in the interval of the well with relatively fresh pore fluids, as recorded by not only the Cl/H ratio from the geochemical logs but also from laboratory measurements of pore fluids recovered by a downhole sampler.

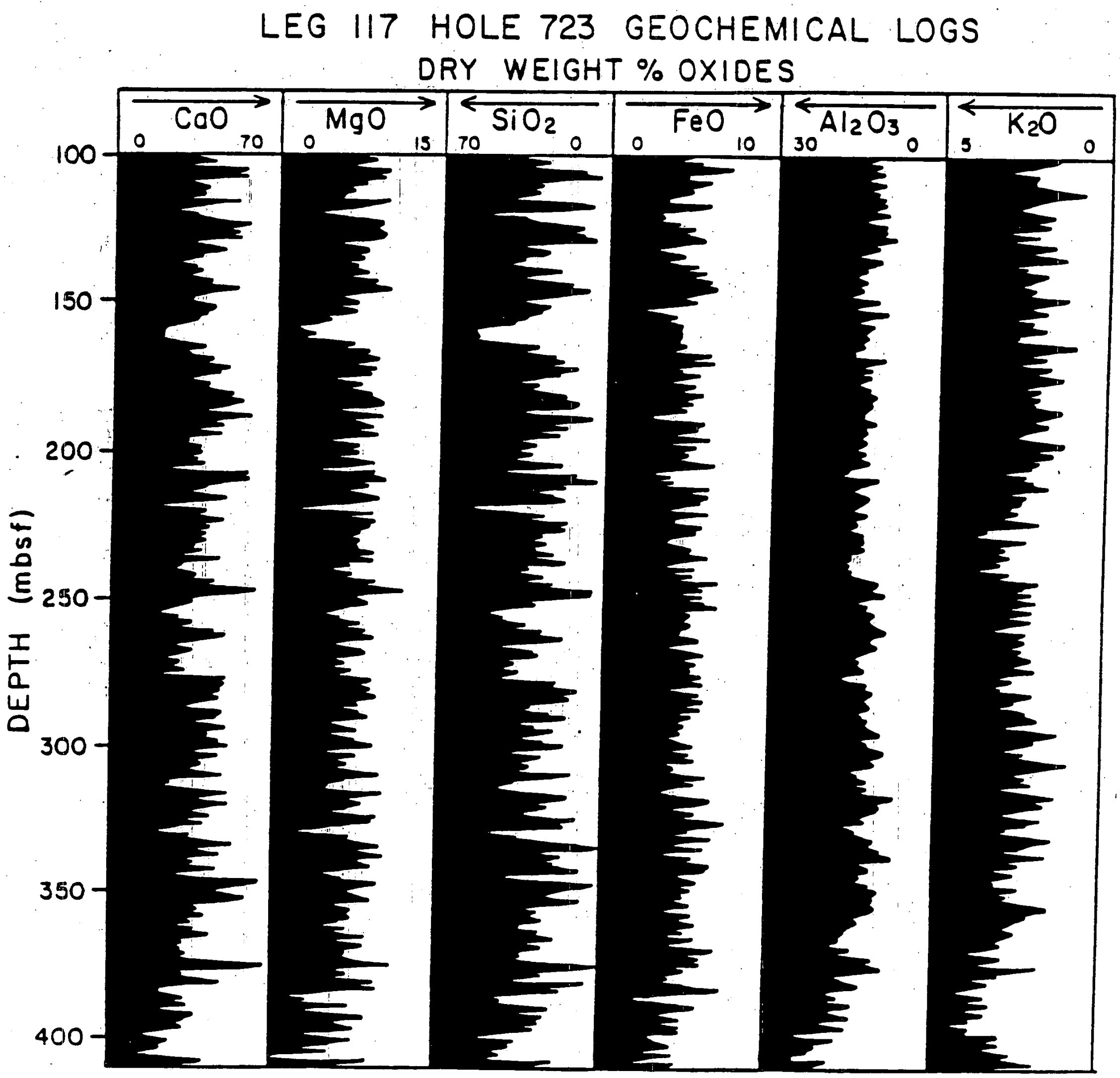


Figure 5-5. The geochemical logs show that throughout the fresh pore water interval of Hole 723, there is a positive correlation between Ca and Mg. An inverse correlation between these cations and Si indicates that interlayers are forming between dolomitic carbonate and silica-rich sediments. Diagenetic reactions from Ca-carbonates to Mg-carbonates are beginning throughout the interval, not just in the well-developed dolomitic stringers of figure 5-4.

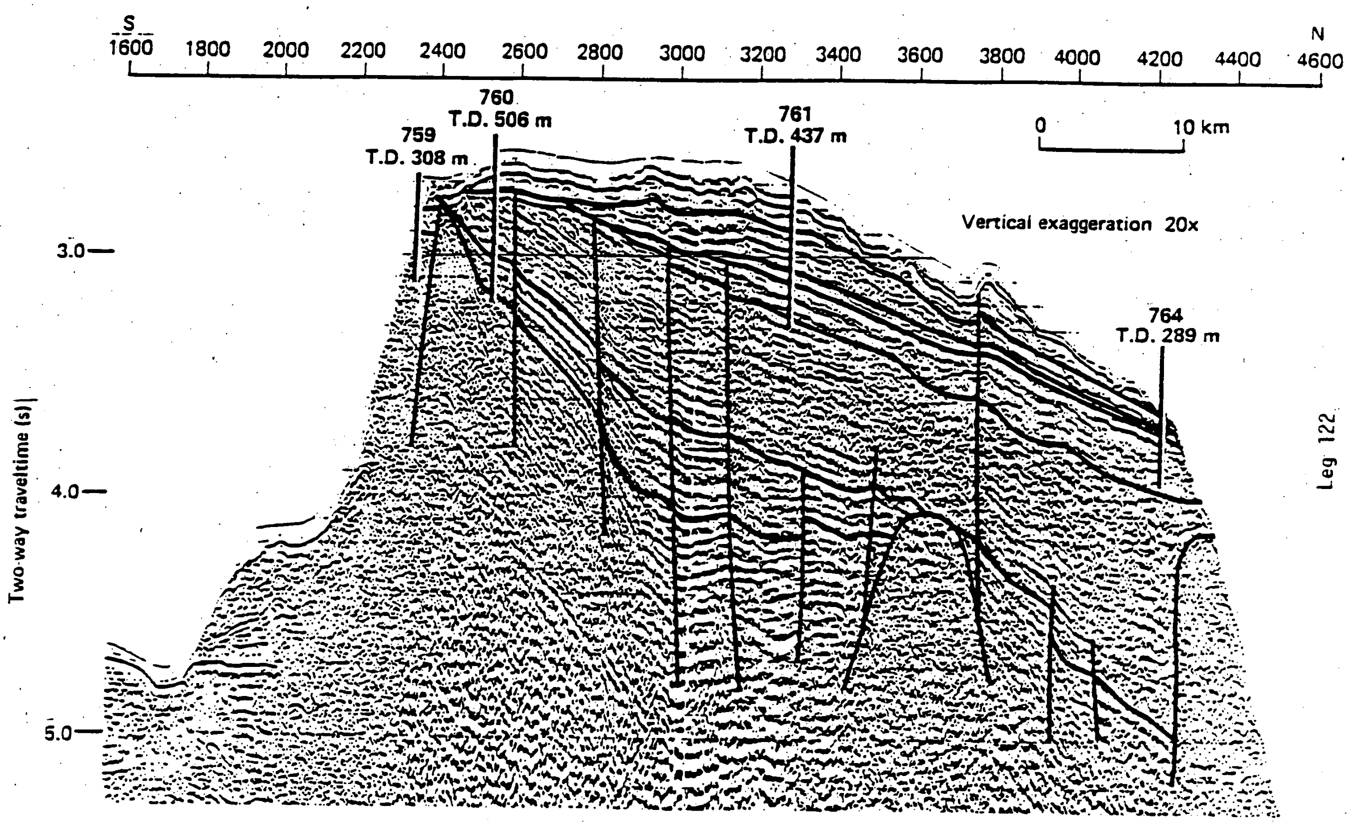


Figure 5-6. Seismic profile across tilted block at the base of the Exmouth Plateau off western Australia, with locations of ODP Leg 122 wells shown. This block is in a similar structural position to that below Hole 729 of the Oman margin (figure 5-2).

Leg 122

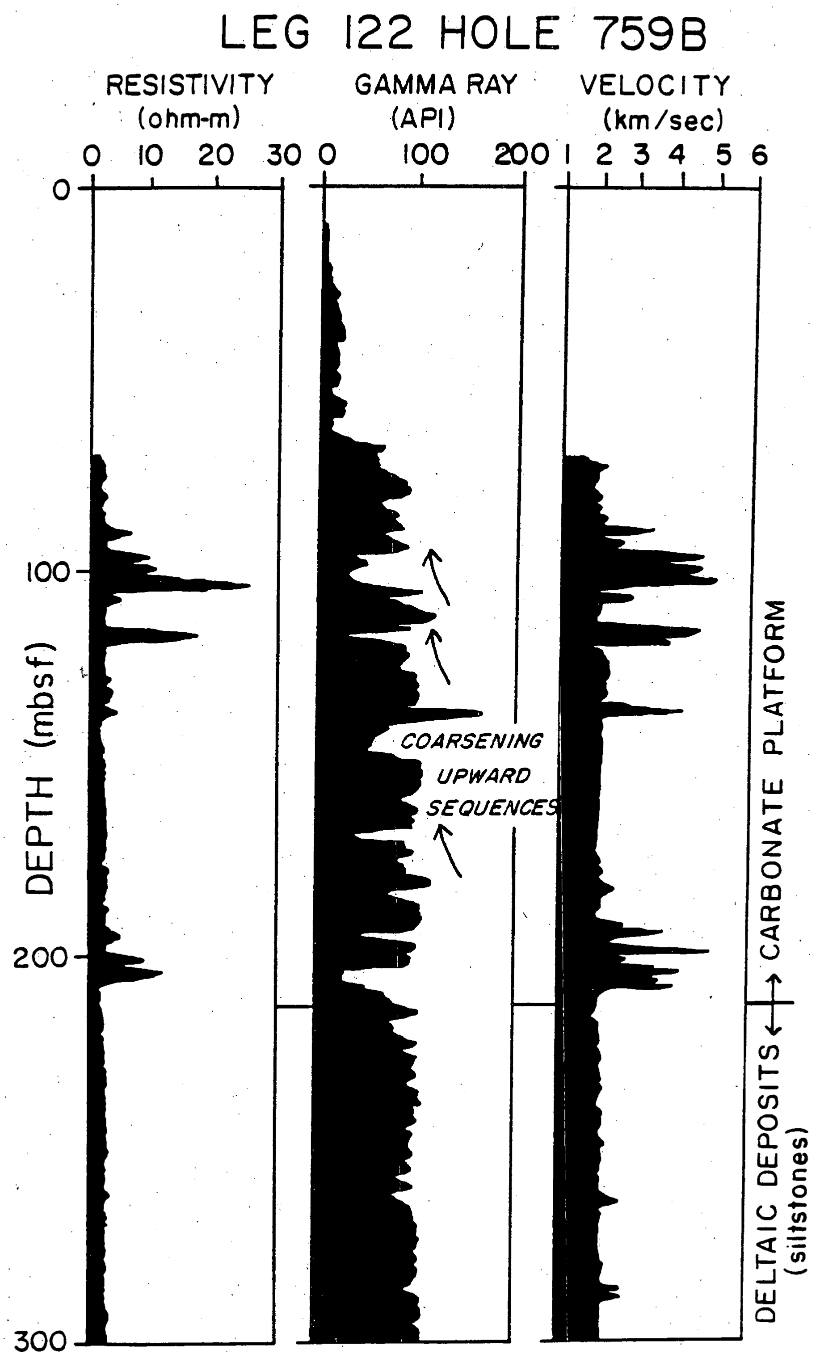


Figure 5-7. Subsidence produced a transition from deltaic deposition on the tilted block to coarsening upward sequences within the newly forming carbonate platform of figure 5-6. The gamma-ray log shows these sequences particularly well because of the increased radioactivity if the finer grained component of each sequence. Resistivity and velocity show little change because to porosities within each sequence change little.

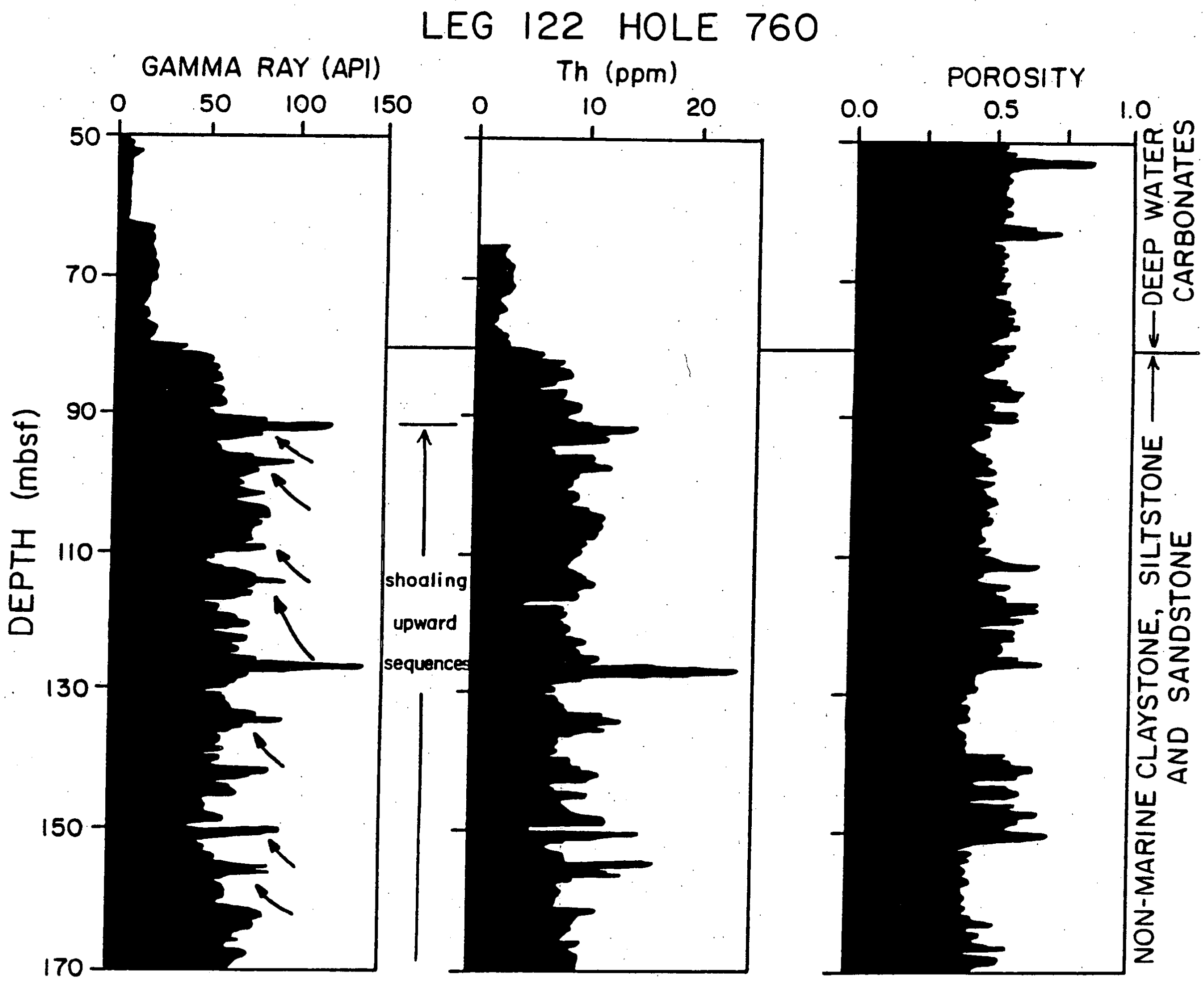


Figure 5-8. On top of the tilted block (figure 5-6), the geophysical logs show an even more abrupt transition from shallow water deposition of non-marine clays, silts, and sandstones to deep water carbonates of the platform. In this well, the coarsening-upward sequences are found in the shallow water deposits rather than in the platform carbonates.

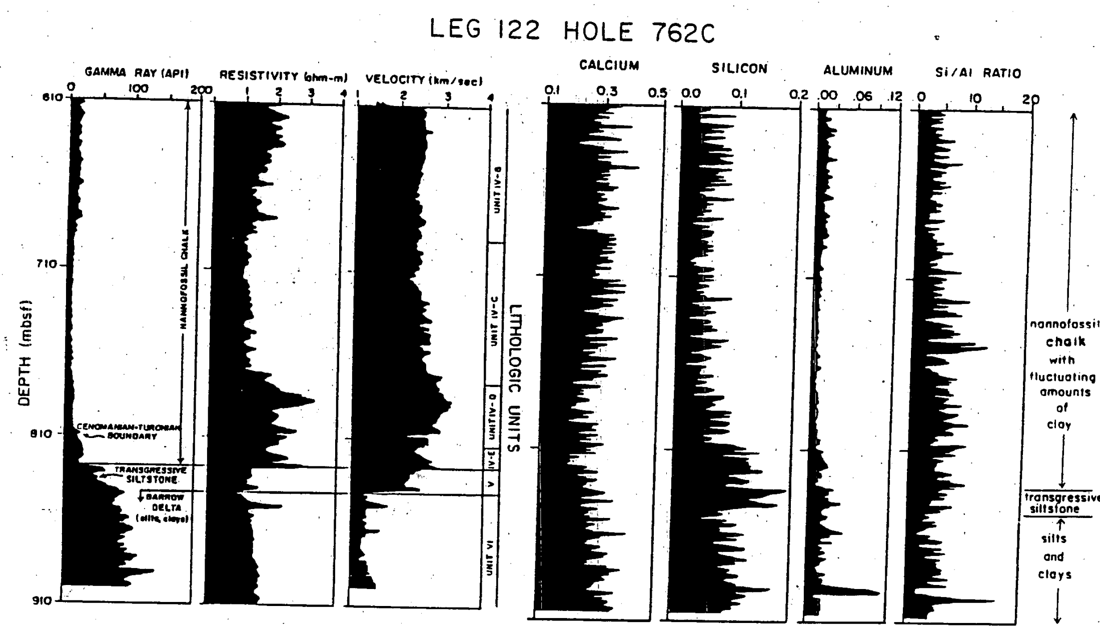


Figure 5-9. The contrast in information delivered by the geophysical versus the geochemical logs is shown in Hole 762 on the Exmouth Plateau. The radioactivity, resistivity, and velocity logs show dramatic changes in depositional environment from silts and clays of the Barrow delta, through a transgressive siltstone sequence, to pelagic nannofossil chalks. The large decrease in velocity at the bottom of the hole is an artifact due to sonic tool problems. The geochemical logs do not show much chemical change as the plateau subsides, except that the sands of the transgressive sequence stand out as a high Si zone. The clays stay about the same composition throughout because the Si/Al ratio remains constant. However, the geochemical logs show in great detail how the nannofossil oozes contain finely interlayered clay units (the high frequency signal in the Si, Ca and Al curves). These climatically driven variations are not recorded by the geophysical logs because they do not produce large changes in physical properties of the sediments.

in carbonate deposition (Figure 5-9). The high frequency signal in both Si and Ca logs is from interlayering of clays throughout the well, as can be seen from the Si/Al ratio (a low Si/Al ratio is found in clays). However, the overall deposition of clays does not change much throughout the well because the average ratio remains relatively constant. Thus, the clay deposition rate remains constant as the Si content drops by half. The coarse sands are no longer being deposited as the sea floor is subsiding.

The South Orkney Rifted Margin

The sedimentary wedges built onto tilted basement blocks during rifting become excellent traps for hydrocarbons in the later history of a basin. Hole 696, drilled on ODP Leg 113, penetrated the top of such a wedge near the South Orkney Islands (Figure 1-2). Buildups of natural gas in the subsurface often are associated with "bright spots" in surface seismic profiles. High amplitudes from such a bright spot, followed by strong energy attenuation below,were interpreted from a seismic profile near Hole 696. This was a strong indication that gas might be encountered in the well (Figure 5-10). The hole was drilled only to the top of the bright spot for safety reasons, but the geophysical logs demonstrate that gases were indeed encountered. Consider the anomalous behavior of the logs from 580 to 600 mbsf. The caliper shows tight hole, but the velocity and resistivity indicate very high porosities. The deep penetrating resistivity measurement is actually much lower than the shallow resistivity curve, indicating further that the porosities increase away from the hole. There is no question but that this is an overpressured zone, indicating that an abundant gas reservoir probably exists below the well.

Compressional Continental Margins: the Peru-Chile and Barbados Trenches

The ODP logging experience in compressional continental margins is not as extensive as that on rifted margins, partly because of the more difficult drilling and logging conditions associated with accretion. However, several important results come from holes logged during Leg 112 on the Peru margin (Figure 1-1).

Hole 679 penetrated 300 m into the fore-arc basin 150 km west of the Peruvian coast (Figure 5-11). Resistivity and density logs show a normal decrease in porosity associated with compaction, but the salinity curve derived from the Cl/H ratio measured by the geochemical logs indicates freshening of the pore fluids below a diagenetic permeable layer which causes a prominent seismic reflector that can be traced to shore. The logs show no correlation between dolomitization and salinity, as was observed in the Oman Margin holes (compare Figures 5-3, 5-4, and 5-11). Instead, the fresher pore waters appear to be from an aquifer being fed by ground waters from land. Conclusive proof of such a hypothesis would again require an extensive set of geochemical logs in shallow boreholes in the region. Such mapping of regional ground water chemistry is routinely done on land, although pore fluid samples are usually used instead of log data.

Evidence of the accretion process itself is seen in logs run in the toe of the subduction zone during the same leg (Figure 5-12). Hole 685 penetrated a seismic reflector from one of the decollement surfaces caused by the underthrusting of young sediments scraped off

Velocity inversion and tight hole show overpressure zone

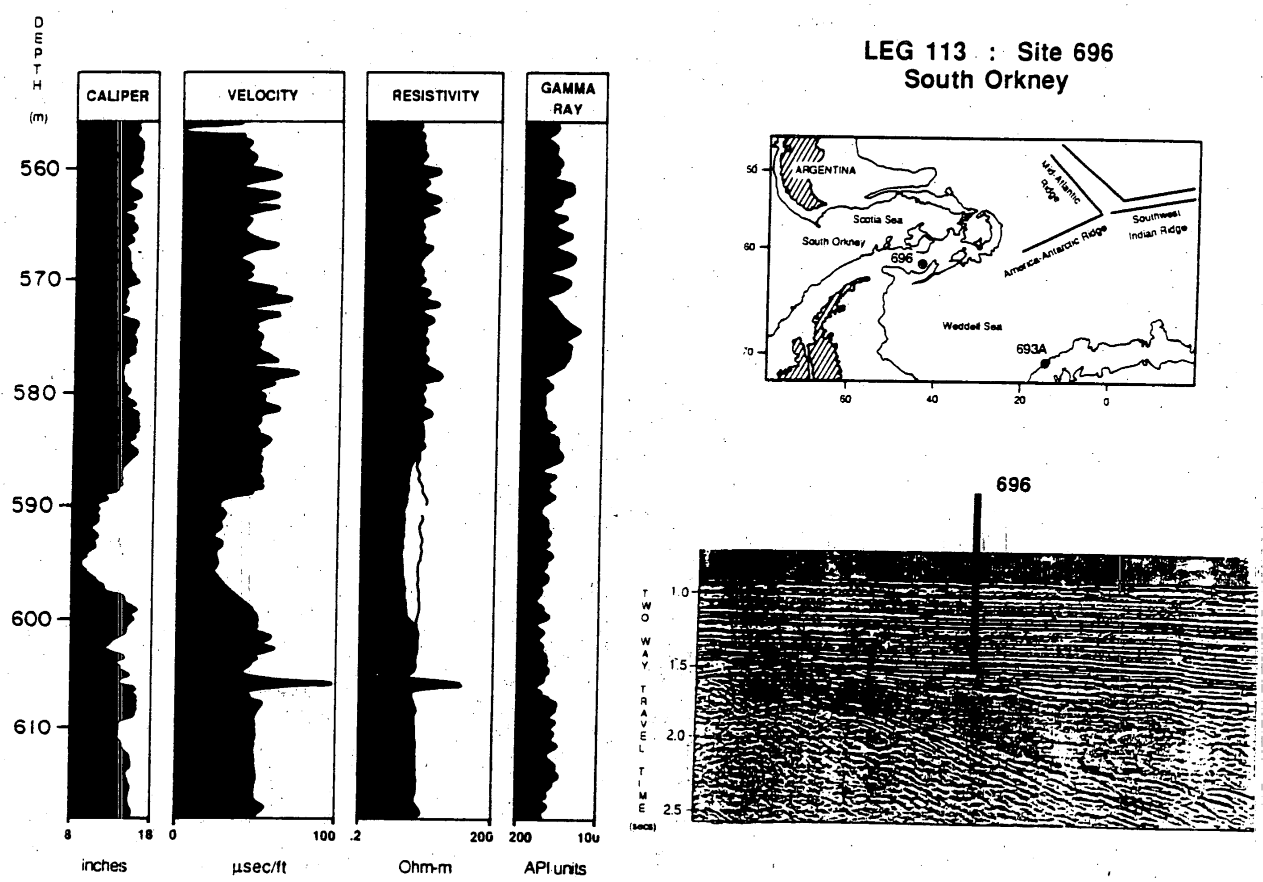


Figure 5-10. Anomalous behavior of log-responses frequently yield valuable information, such as in Hole 696 off the South Orkney Islands. The bright spot above diffuse reflectors indicates the possible existence of a natural gas reservoir in this tilted block. The first reflector was penetrated, then drilling was suspended because of safety considerations. The geophysical logs indicate that was a good decision. The caliper indicates closure of the well at 590 m depth, yet the velocity and shallow penetrating resistivity are extremely low indicating very high porosities. The further fact that the deep resistivity shows lower porosity supports a conclusion that this zone is gas-prone. The high porosities but tight hole indicate that gas is flowing toward the well.

Salinity inversion in the continental shelf off Peru

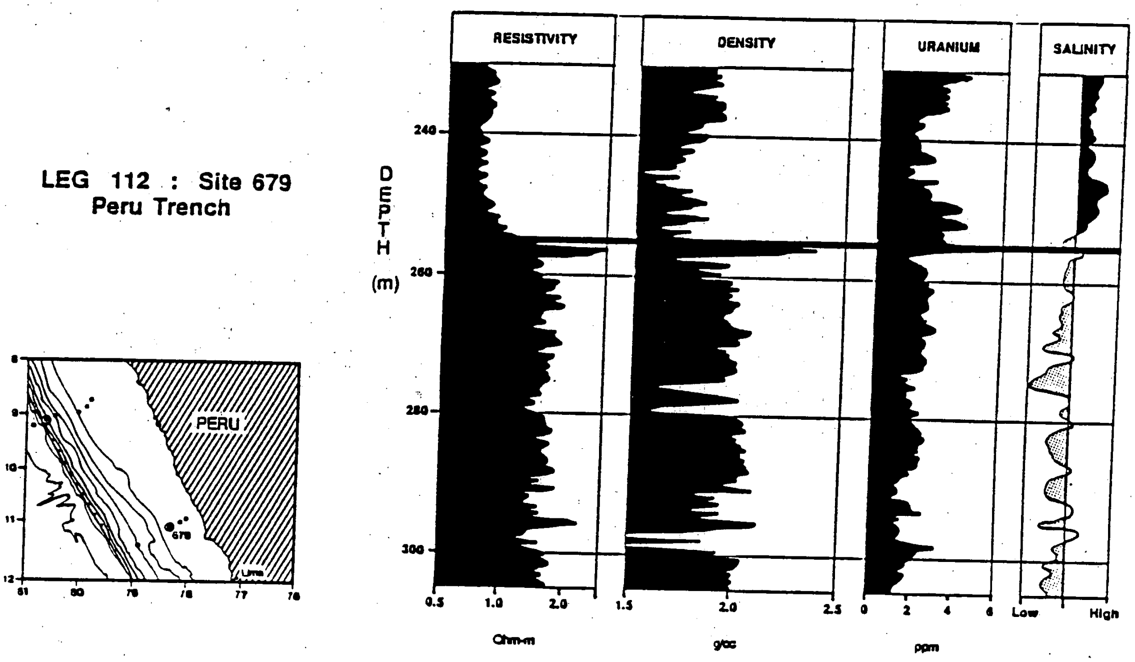


Figure 5-11. In the fore-arc of the Peru Trench, geophysical logs in Hole 679 identified a major seismic impedance boundary that forms a prominent reflector throughout the area. The geochemical logs show that the pore waters below the reflector are fresher than those above. The Cl/H ratio is used to determine chlorinity and infer salinity. The likely source of the fresh waters is an acquifer being fed from land 100 km to the east.

Logs show porosity inversion as a result of accretion across decollement

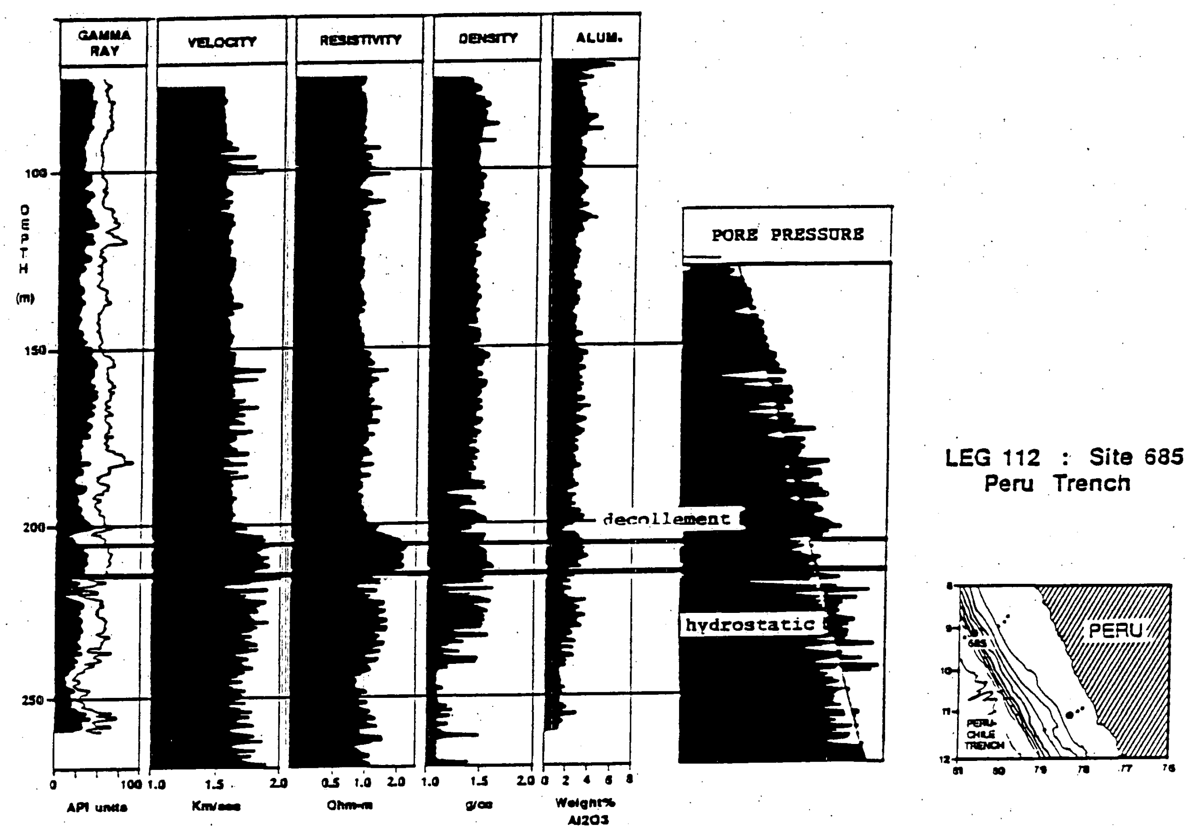


Figure 5-12. At the toe of the accretionary prism of the Peru Trench, logs from Hole 685 define the impedance contrast that is responsible for the seismic reflector identified as a decollement surface between accreting sedimentary wedges. The impedance contrast is from a low porosity, high density, clay rich zone (high Al) bounded top and bottom by low clay (low Al) sediments.

the oceanic Nazca Plate onto the South American Plate's accretionary prism. Velocity, resistivity and density logs identify the reflector as a overcompacted sediment that appears to form a hydrological cap over overpressured sediments that are below the reflector (Figure 5-12). However, the aluminum-content log shows that there is less clay associated with the overpressured sediments, which suggests that they may be higher in porosity rather than severely undercompacted. Thus, the combination of geophysical and geochemical logging gives a much more complete picture of the geology of this wellbore than does either alone.

On ODP Leg 110, a decollement reflector was also penetrated at Site 672, in the deformation front of the Barbados Trench. Here, the density also increases at the reflector depth. Slowness (1/velocity) determined from the multichannel sonic tool also delineates this impedance boundary that becomes the predominant reflector interpreted as the decollement surface (Figure 5-13). Fluids seem to be traveling along this surface, judging from pore fluid chemistry of samples recovered from this zone, whereas the reflector in the Peru accretionary prism seems to be the seal of an overpressured zone that extends for 30 m below the reflector (contrast Figures 5-12 and 5-13).

Depositional Processes in Sedimentary Fans

The major sedimentary basins of the world were constructed where large rivers build deltas and deep sea fans across continental margins. Logs provide detail necessary to decipher the stratigraphy of such fan deposits. The Indus and Bengal Fans, two of the largest active fans on the planet, were drilled during ODP Legs 116 and 117. ODP Leg 117 penetrated the distal end of the Indus Fan at Hole 720 (Figure 1-3). The depositional history of the sediments in Hole 720 was found to be dominated by alternating cycles of pelagic sedimentation, and of turbidites and coarse-grained channel flows from the Indus River to the north. The geochemical logs clearly show the pelagic cycles as low thorium-content sediments, and the Indus River deposits as thorium-rich rocks originating from the erosion of the Himalayas (Figure 5-14). Using impedance logs from the geophysical logging results to tie the thorium log to the surface seismic profile, the depositional signature of the seismic sequences in the vicinity of the hole were determined (Figure 5-14). Such detail could not be reconstructed from the cores, unless core recovery was 100% and considerable amount of time was spent analyzing core plugs. Comparison of logs data to cores indicates that core recovery was 80% in the pelagic sediments but only 10% in the turbidites.

At the distal end of the gigantic Bengal Fan, two tectonic processes are intermixed. Mid-plate compression has produced buckling and thrust faulting in the center of the Indian Plate, probably driven by forces from the collision of the Indian and Asian Plates forming the Himalayas. At the same time, the Bengal Fan has built out to the mid-plate deformation zone. Heat flow measurements across the deformation zone show heat being redistributed through fluid convection in the sediments and/or basement. Is the fluid flow driven by compression or by de-watering from the load of the Bengal Fan sediments?

Partly to answer this question, Hole 719 was drilled on the northern flank of one of these mid-plate thrust faults during ODP Leg 116 (Figure 5-15). Geophysical and geochemical logs in Hole 719 show porosity variations related to differential compaction.

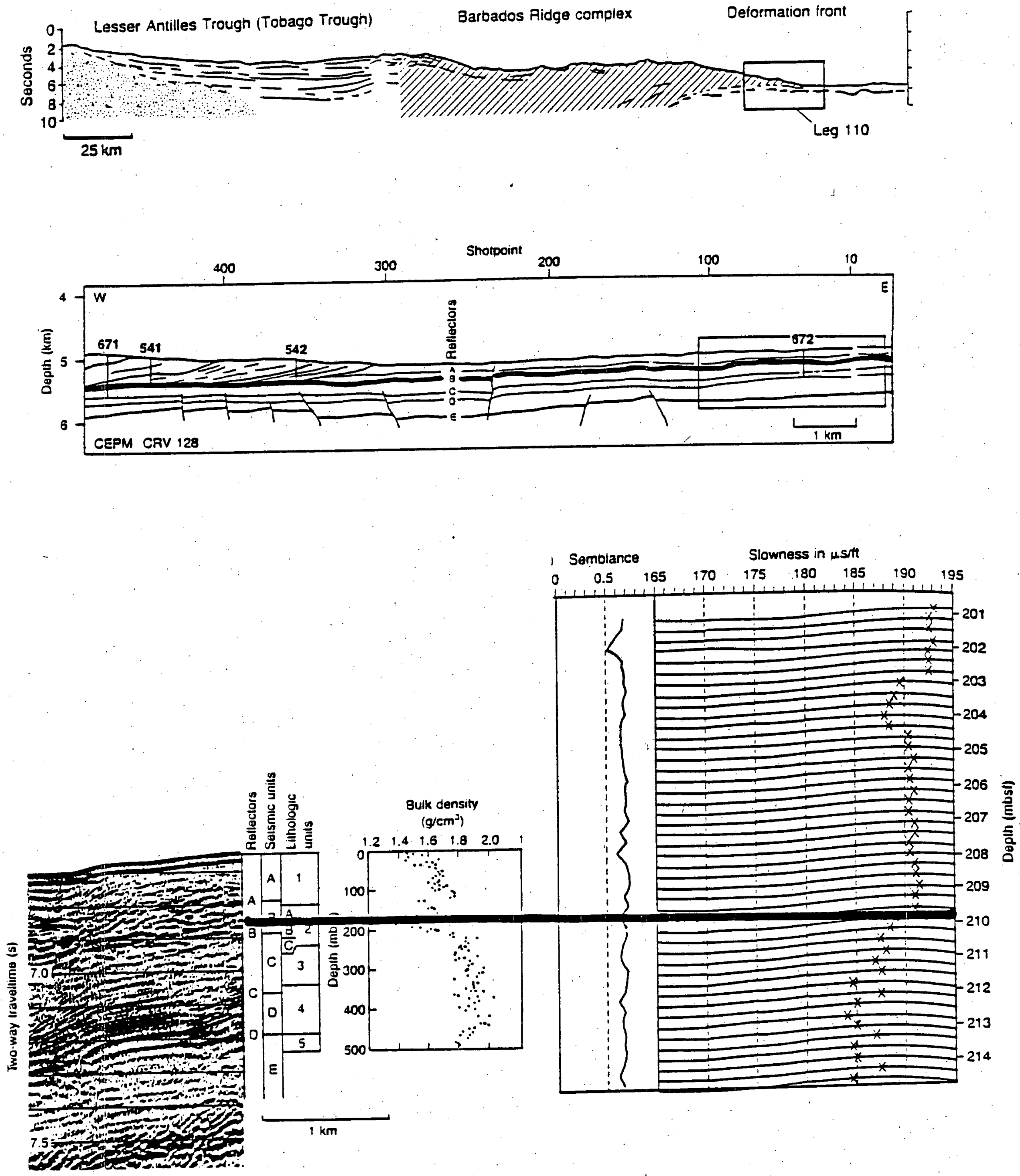


Figure 5-13. The decollement surface was drilled and logged in the toe of the Barbados Trench at Hole 672. Here, multichannel sonic logs show a velocity boundary (decreased slowness) that was also found to be a density contrast from core measurements. Pore fluid chemistry indicated that fluids were flowing along this impedance boundary.

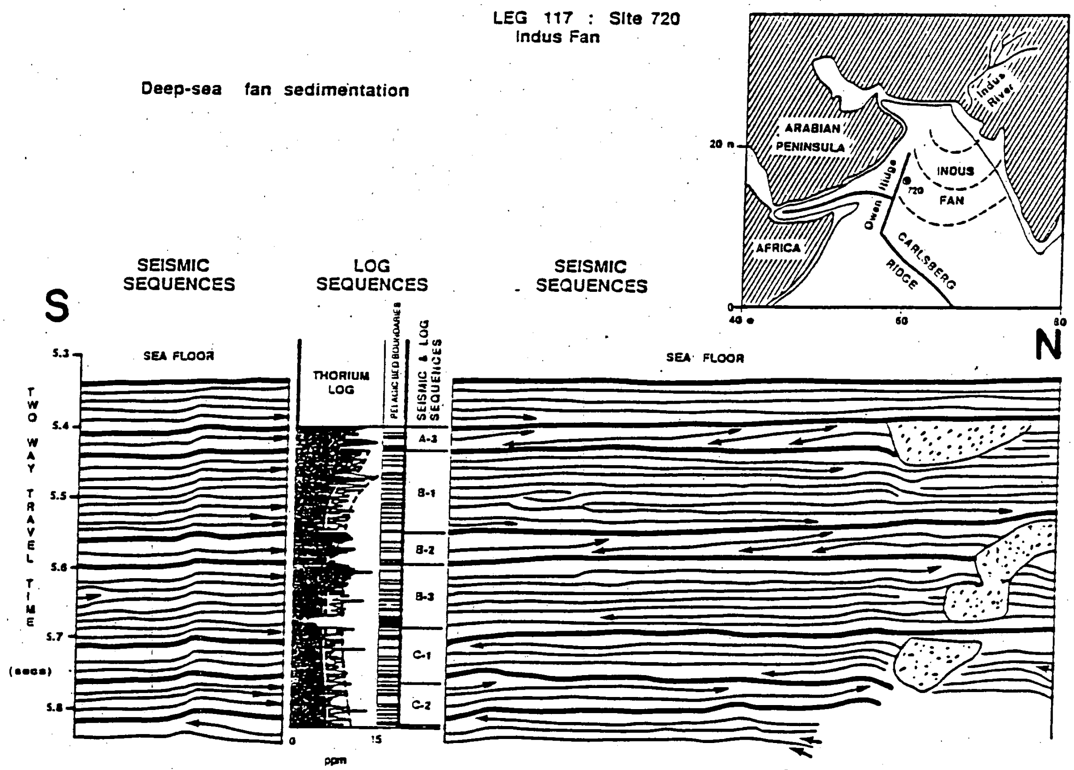


Figure 5-14. The origins of seismic sequences can be described by geochemical logs such as the Th curve recorded in the Indus Fan Hole 720 southwest of India. Here, low Th zones are pelagic deposits from the south, whereas high Th intervals are turbidites and abandoned fan channels from the Indus Cone. The direction of deposition can be inferred from the combination of geochemical logging and seismic reflection profiling (arrows).

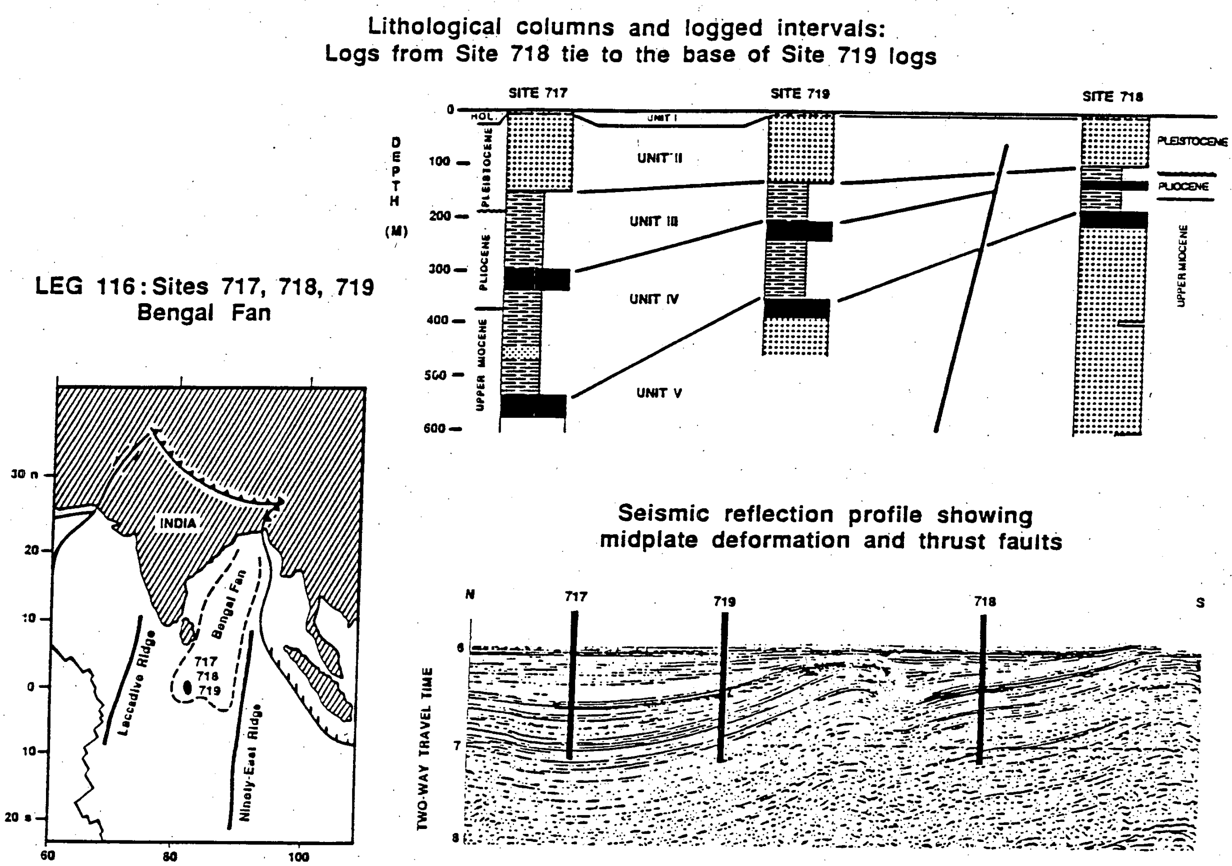


Figure 5-15. During Leg 116, the extremities of the Bengal Fan were drilled in the mid-plate deformation zone south of India. The collision of the Indian and Asian Plates to form the Himalayas is thought to have caused compressive buckling of the plate in this area, as can be seen from the thrust faulting in the seismic profile. The heat flow in the area indicates fluids are flowing toward the thrust faults along several seismic horizons. Is the fluid flow from compaction in the Bengal Fan, or from hydrothermal circulation in the basement?

The Ca, Si and Al contents of the more compacted silts (Figure 5-16) show them to be lower in carbonate content than the more pelagic, high porosity, carbonate rich units. The silts are composed of a largely continental assemblage of feldspars, quartz and exotic "Himalayan" minerals rather than pelagic clays, as can be seen from the lack of correlation between Si, Al, K and Th in the well. De-watering of these Bengal Fan sediments provides a hydrological source for at least part, if not all, of the hydrothermal fluids observed to be convecting in the mid-plate deformation zone.

Summary

While we are admittedly just beginning to understand fluid flow processes in rifted and accreted continental margins, it is obvious that geophysical and geochemical logging delivers the essential data required to fully understand these phenomena. Neither cores nor surface seismic profiles preserve the *in situ* information and continuous records required to determine dynamic processes.

Geochemical logs show unit boundaries Site 719

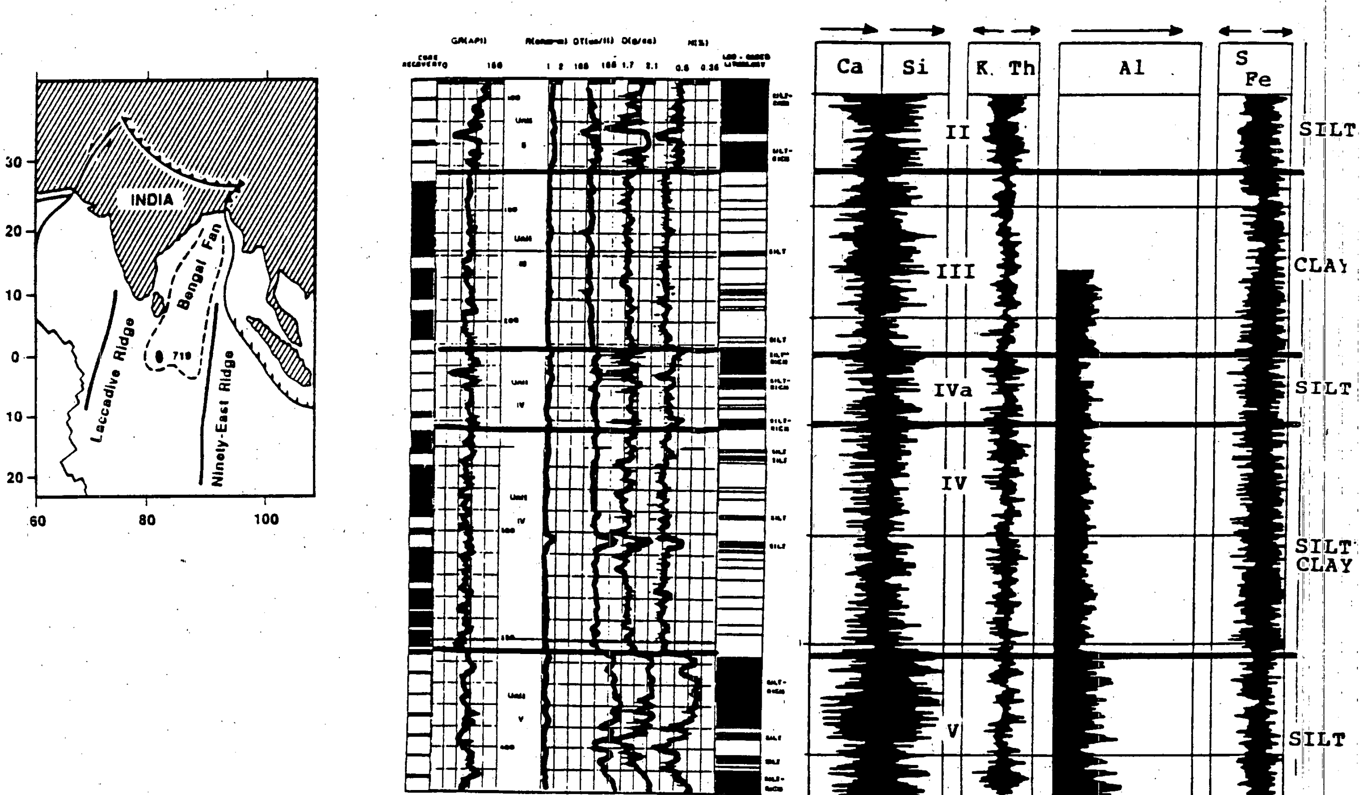


Figure 5-16. The logs from Hole 719 indicate that differential compaction is occurring between silts and clays of the Bengal Fan. High porosity units are sandwiched between lower porosity units (e.g., unit 3 between units 2 and 4). The geochemical logs show that the Si-rich sediments are not pelagic clays (with association of Si and Al, but not with K and Th), but Bengal Fan sediments composed of feldspars, quartz and other erosional products from the Himalayas. These silicates are more compacted than the carbonates (the Ca-rich units).

References

Anderson, R. N., Alt, J. C., and Malpas, J., 1989. Geochemical well logsand the determination of ntegrated chemical fluxes in Hole 504B, Eastern Equatorial Pacific, in, Becker, K., Sakai, H., et al., Proc. ODP Sci. Results, 111, 119-132.

Anderson, R. N., Jarrard, R. D., Pezard, P. A., Williams, C., and Dove, R., 1988. Logging for science: The Technical Review, Houston, Tx: Schlumberger Educational Services, 36(4), 4-11.

Arthur, M. A., Dean, W. E., Bottjer, D., and Scholle, P. A., 1984. Rhythmic bedding in Mesozoic-Cenozoic pelagic carbonate sequences: the primary and diagenetic origin of Milankovitch-like cycles. in Berger, A., Imbrie, J., et al. (eds.), Milankovitch and Climate, I, Boston: D. Reidel, 191-222.

Becker, K., Sakai, H. et al., 1988. Proc. ODP, Init. Reports, 111, College Station, TX (Ocean Drilling Program).

_________, 1989. Ground truth from the young oceanic crust at Hole 504B: Summary of results from DSDP/ODP Legs 69, 70, 83, 92 and 111, Reviews of Geophysics, in press.

Fischer, A. G., 1986. Climatic rhythms recorded in the strata, Ann. Rev. Earth Planet. Sci., 14, 351-376.

Fischer, A. G., and Schwarzacher, W., 1984. Cretaceous bedding rhythms under control? in Berger, A., Imbrie, J., et al. (eds.), Milankovitch and Climate, I, Boston: D. Reidel, 163-175.

Goldberg, D., 1988. Report of wireline services, JOIDES Journal, 14(1), 38-39

Golovchenko, X., O'Connell, S., and Jarrard, R., 1990. Sedimentary response to paleoclimate from downhole logs at Site 693, , Antarctic Continental Margin. In Barker, P., and Kennett, J., et al., Proc. ODP, Sci. Results, 113, 239-251

Haq, B.U., von Rad, U., et al., 1990. Proc. ODP, Init. Reports, 122.

Jarrard, R. D., and Arthur, M. A., 1989. Milankovitch paleoceanographic cycles in geophysical logs from ODP Leg 105: Labrador Sea and Baffin Bay. In Srivastava, S. ,Arthur, M. A., et al., Proc. ODP, Sci. Results, 105, 757-772.

Milankovitch, M., 1941. K. Serb. Okad. Beogr. Spec. Publ. 132, Jerusalem: Israel Program for Scientific Translations, English translation, 1969.

Mwenifumbo, C. J. et al., 1989. Geochemical log cycles in the southern Atlantic. In Ciesielski, P. F., Kristoffersen, Y., et al., Proc. ODP, Sci. Results, 114, in press.

Ollier, G., et al., 1988. Leg 119: Logs help interpret geologic and glacial history, Joides Journal, 14(2), 31-32.

Olsen, P. E., 1986. A 40-million-year lake record of early Mesozoic climatic forcing, Science, 234, 842-848.

Pierce, J., and Weissel, J., et al., 1989. Ocean drilling in Broken Ridge and Ninety East Ridge, in, Proc. ODP, Init. Reports, 121.

Prell, W.L., Niitsuma, N., et al., 1989. Proc. ODP, Init. Reports, 117.

Robinson, P., Von Herzen, R., et al., 1989. Proc. ODP, Init. Reports, 118.

Worthington, P., Anderson, R. N., Bell, S., Becker, K., Jarrard, R. D., Salisbury, M., and Stephen, R., 1988. Downhole measurements for the Ocean Drilling Program, Report of the Second Conference on Scientific Ocean Drilling (COSOD II), Strasbourg, France: European Science Foundation, 131-136.

OCEAN DRILLING PROGRAM

Wireline Logging Manual

Volume 6

Scientific Applications of Wireline Logs (1985-1986)

Borehole Research Group
Lamont-Doherty Geological Observatory
Columbia University
Palisades, New York 10964

DECEMBER, 1986

TABLE OF CONTENTS - Volume 6

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 5

Chapter 6

Chapter 7

Chapter 8

Chapter 1

Introduction to Scientific Well Logging

The JOIDES Resolution sails the world's oceans, drilling and logging holes in the sea floor, often in waters deeper than 5 km. Geophysical and geochemical measurements made by lowering into each borehole highly sophisticated sensors attached to an electrically-conducting wireline are important to understanding the geology at each Ocean Drilling Program (ODP) site. Because logging tools and interpretation techniques were developed largely for use by the oil industry, they are designed to detect the composition and quantity of pore fluid (oil, gas, and water) present in a formation. ODP uses these high-technology tools for a different mission: to determine the character of a formation as well as the composition of the pore fluid. The main goal of the ODP Wireline Logging Program, operated by the Borehole Research Group at Lamont-Doherty Geological Observatory, is to develop new log interpretation techniques and so to demonstrate to the scientific community the versatility and power of logs as scientific tools. Below we reconsider logs by moving away from the traditional porosity-velocity-resistivity approach of the oil industry to one defined in marine geological terms. Consequently, we will discuss the different applications of logging not, for example, in terms of lithology, synthetic seismogram generation techniques, or porosities, but rather in terms of a plate-tectonic framework.

ODP has pursued the investigatory course set up by the International Phase of Ocean Drilling (IPOD), which divided the study of the oceans according to the theory of plate tectonics. The study of the ocean crust focuses on the physical and chemical processes which form and then age the oceanic lithosphere. The study of passive and active margins explores the tectonic processes of subduction, rifting, sedimentary basin formation, and continent/ocean boundary interactions. Research in the field of paleoclimate and sedimentary process postulates how the Earth itself has evolved through geological time.

These themes, as they have been expanded and modified by ODP, determine the major drilling and logging targets of the JOIDES Resolution. Below we present examples of how wireline logs are used to investigate geological processes beneath the sea floor. The examples are meant only to be illustrative, not exhaustive. In order to provide the most relevant demonstrations of the uses of ODP's wireline logging, we have tried to use ODP and DSDP case studies whenever possible. The data are derived from ODP and DSDP cruises up until Leg 111, which was completed in September, 1986, and are used here for educational purposes only.

Scientific Well Logging Techniques

Volume 3 of this Manual describes in detail the logging tools operated by the Ocean Drilling Program as well as their primary applications. As of September, 1986, three basic measurements were made in boreholes by wireline logs: acoustic, electrical, and nuclear.

The resistivity tool, which measures the electrical resistivity of the formation, allows us to estimate the porosity of rock by recording variations in current intensity that depend on the type of fluid present in the pores and on the degree of interconnection of the pore space itself. The sonic tool excites small "micro-earthquakes" at kilohertz frequencies and, after the sound energy has passed through the rock, it records the "seismograms" at multiply-spaced receivers. Each sonic "firing" is like a small-scale refraction experiment conducted vertically over a few meters of the borehole. Analyses using many of the same techniques that are used in surface multichannel seismic reflection processing yield the elastic property information of the rock. Not only compressional and shear waves, but also Stoneley surface waves and normal mode coda are analyzed for velocity, spectral amplitude, and frequency changes, and coherency. The parameters change with lithology, degree of fracturing, alteration, diagenesis, permeability, and porosity. Ultrasonic imaging delivers a reflected image of the borehole wall as well as a precise, 360 degree caliper of borehole size changes. The logs, therefore, can detect and map borehole breakouts, which are caused by stress-induced, wellbore spalling. These logs are the only available so far that deliver information about the state of stress in the lithosphere.

Nuclear tools produce the most sophisticated downhole measurements. Not only do they measure the naturally radioactive components of rock, and so determine quantitative uranium, thorium and potassium contents, but also they bombard the formation with neutrons and gamma rays shot from chemical sources. The returned gamma rays can be read to infer porosity, density, and lithology. The newly-designed Geochemical tool string activates aluminum and manganese directly with a californium source, pulses neutrons into the formation with a "minitron", and counts the returned "neutron activation" spectrum with a 256-channel, downhole analyzer. Each 0.15 meters of the logged interval can yield contents of iron, aluminum, calcium, silicon, hydrogen, chlorine, titanium, gadolinium, potassium, and sulfur. Thus major- and selected minor-element chemistry is measured downhole. Though not as accurate in absolute terms as laboratory measurements made on core, the chemical logs detect relative changes occurring down the wellbore with accuracy and repeatability. With the measurements taken from the nuclear logging suite, lithologies can be inverted to their normative mineralogy so that alteration zones and formation boundaries become clearly defined.

Below we will see how to use the combination of these physical and chemical logging measurements to determine paleoclimate changes, volcanic cycles of island arcs, subsidence changes related to the rifting of continents, basalt stratigraphies and alteration histories, stratigraphic ties to multichannel seismic profiles, excess pore pressures within accretionary wedges, compaction and thermal histories of sedimentary basins, and the stress fields which drive plate tectonics.

The logging techniques are presented within the geological context of oceanic lithosphere, axial spreading and alteration, ocean/crust chemical interchange, stratigraphy, sedimentation, subduction, continental rifting, formation of sedimentary basins, plate-driving forces, and - because understanding ocean processes ultimately will lead to understanding continents - continental formation and deformation.

Chapter 2

Uses of the ODP Logging Suite

The three types of logging tools used on the JOIDES Resolution - acoustic, electrical and nuclear - can be combined to form a logging string customized to deliver the maximum information about any particular geological problem. The question targeted by the drilling expedition will determine the configuration of the string. It is in the combination of different types of measurements of geological parameters that logging finds its greatest interpretive power.

Before we see how to construct and interpret a logging suite, however, we should address a fundamental question. Why log? Doesn't ODP's continuous-coring program provide enough information to answer all geological questions about a particular site? The question and the logic behind it are not universal. For the oil industry, of course, they are turned around. Why core, when logging delivers all of the necessary geological information about a well? The industry sees continuous coring as wasteful and logging, which was designed expressly for finding hydrocarbons, as cost-effective. Marine geologists, on the other hand, can use cores to answer their most pressing questions about the lithology and the structure of a formation, but see pore fluid composition as of secondary interest. For the geologist the importance of logging lies in the inefficiency of coring.

Even if continuous coring resulted in continuous core recovery, which is not the case at the present time, logs measure physical and chemical properties for a considerable distance away from the wellbore itself, and at *in situ* temperature and pressure. When considering that the average core recovery rate is 50% in sediments and even less in hard rocks, the importance of logging as a continuous measurement becomes obvious. The recovered core must be placed in its proper lithostratigraphic position within the well. Important boundaries, time series variations, and entire units can be missed completely if logs are not available to provide context and to fill in the gaps. Both cores and logs are strengthened as interpretative tools by the use of the other when analyzing a well.

Log Applications

The geological uses of logging tools focus around determining 5 major characteristics of a well:

1. Stratigraphy, both seismic and structural
2. Lithology
3. Porosity and permeability
4. Rheological properties, such as elastic constants

5. Geochemistry and mineralogy.

Each logging string gathers information about one or more of the characteristics listed above (see Volume 3). The Dual Laterolog, for example, is an electrical tool which focuses a strong current horizontally into the rock surrounding a hole. It delivers very good porosity information, is an excellent bed-boundary detector, but is inadequate as a detector of impedance contrasts used to recognize seismic reflection horizons. The acoustic tool, on the other hand, detects impedance boundaries well, but yields only fair information about mineralogy changes in a well. Gamma ray spectroscopy, a nuclear tool, detects mineralogy changes very effectively. Again, it is the combination of these various tools which gives logging its strength as an interpreter of geology.

Relationships Between Logs

Consider a standard example of an excellent logging suite obtained during ODP Leg 103, which took place off the west coast of Spain.

The Galicia Margin is an old, passive, continental margin. Nonetheless, buried beneath the surface is geological evidence of the rifting between North America and Europe 160 million years ago. By drilling a transect of holes across the deepest part of this margin, ODP obtained the syn-rift and post-rift sedimentary records of the event (Figure 2-1). The standard Schlumberger logging suite from Site 639 (Figure 2-2) consisted of gamma ray, caliper, bulk density, photoelectric effect, sonic velocity, induction electrical resistivity, and natural spectral gamma ray.

The most obvious features seen in these logs are the one- to five-meter-thick levels characterized by high density (2.7 g/cm^3), high sonic velocity (>6 km/sec), and high electrical resistivity (2000 Ωm). Despite the presence of these indicators, this rock was not determined to be igneous when the low photoelectric-effect value and the low potassium, uranium, and thorium contents were considered as well.

How did we determine the composition not only of these hard rock stringers, but also of the slow-velocity, high-porosity rock in between?

The lithological response to variations in bulk density and porosity was known for sedimentary basin rocks drilled by the oil industry (Figure 2-3). Yet the porosities of our hard rock stringers fell at the far left and bottom of the cross-plot of Figure 2-3, while those of the soft, slow sediments fell at the top right. Consider the sonic velocity-porosity relationship (Figure 2-4). Data from soft, marine sediments fell considerably off the standard "Wyllie relation," which is a linear interdependence between velocity and porosity. Our porosities for the sediment were often so large (>50%) that the matrix interconnectedness was poor. Thus we had the nonlinear behavior, which made determination of lithology by the conventional methods developed by the oil industry impossible.

Other lithologies, however, could be identified simply by looking at variations in velocity, density, and porosity logs. On board the ship it was possible to produce the lithology plot of Figure 2-5 by classifying the log responses of the formation into eight clusters. These clusters could then be identified by their best-fit positions within an M-N plot (Figure 2-6), where travel time divided by density was plotted against neutron

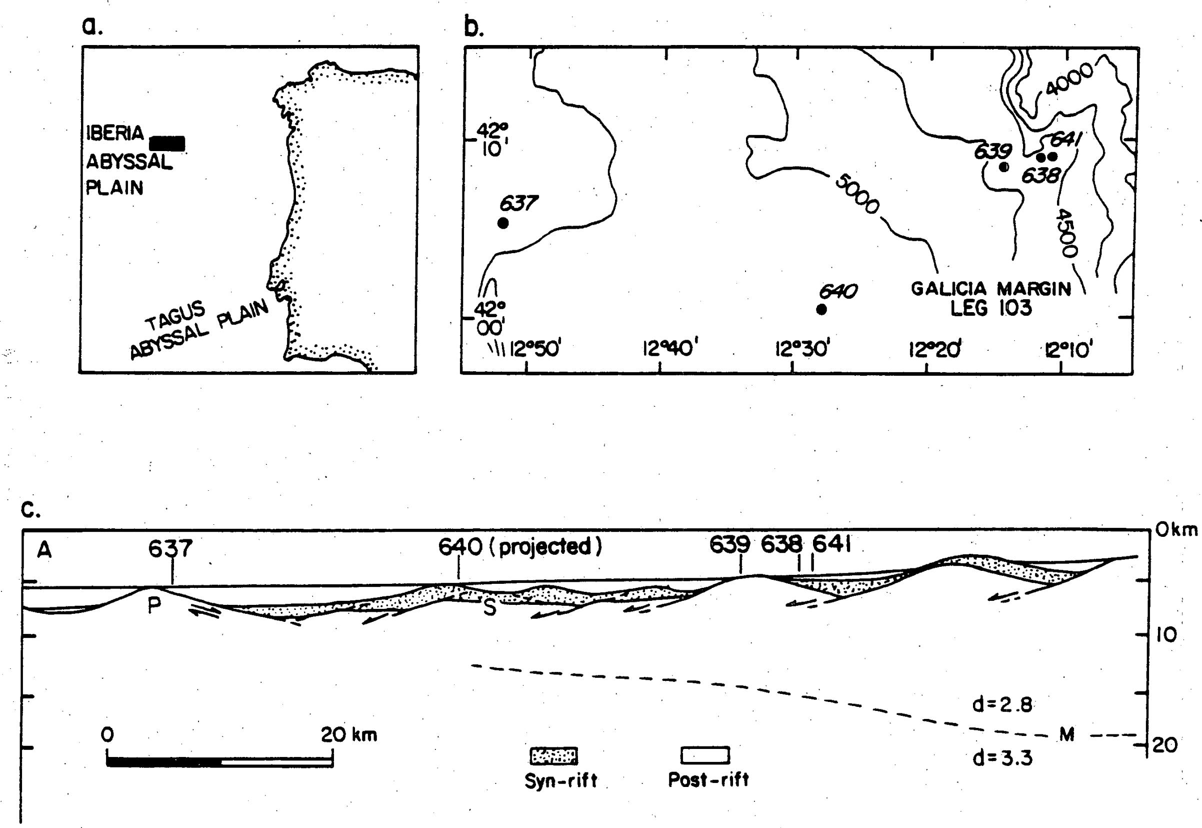


Figure 2-1. Ocean Drilling Program Leg 103 drillholes into the Galicia margin, offshore Spain (location above). Sedimentary structure (below) includes syn-rift and post-rift sediments deposited after the Galicia margin spread away from the east coast of North America.

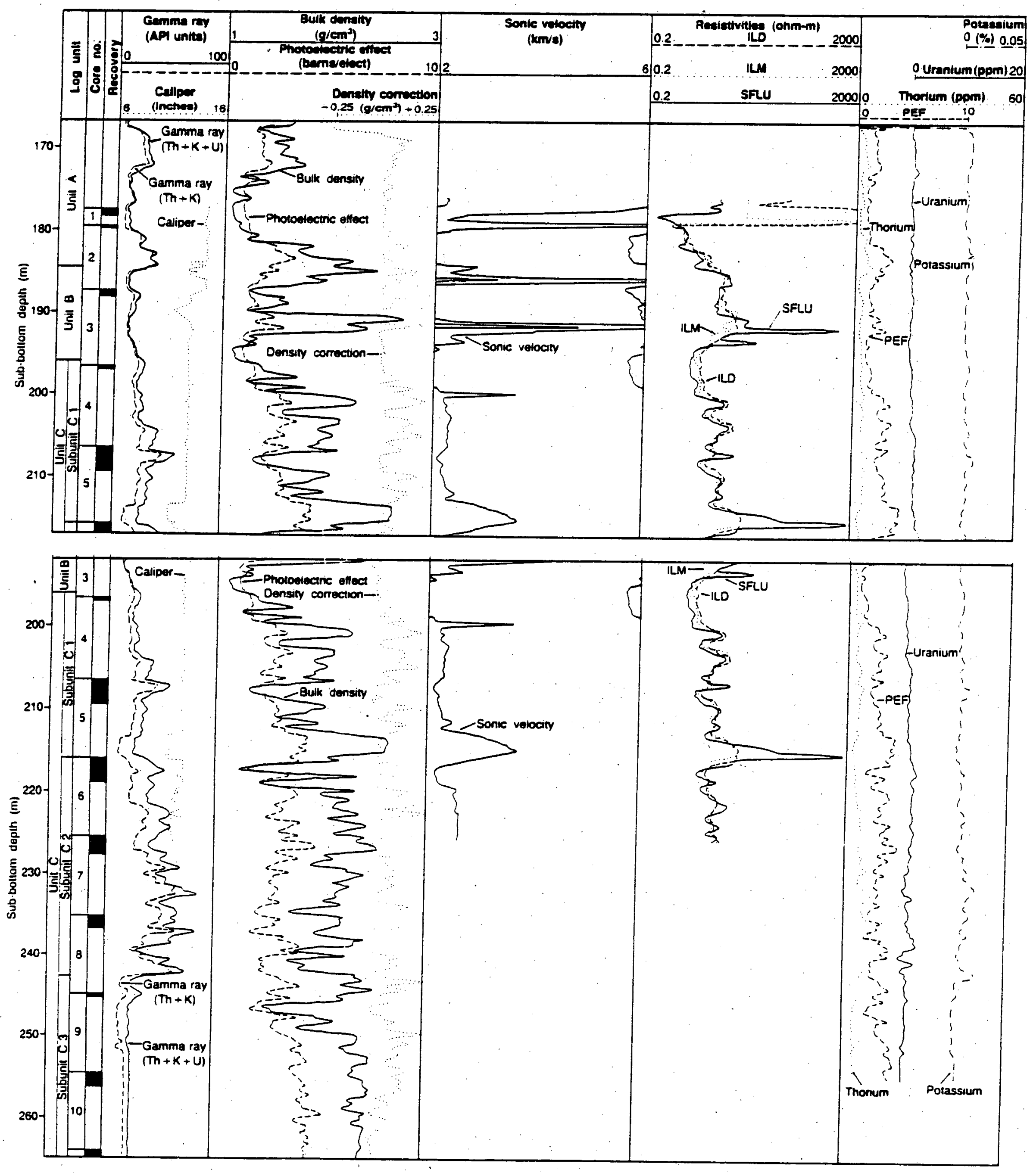


Figure 2-2. Schlumberger logs from ODP Site 639, Leg 103 (Figure 2-1). Shaded areas are dolomite occurrences. On left is core recovery.

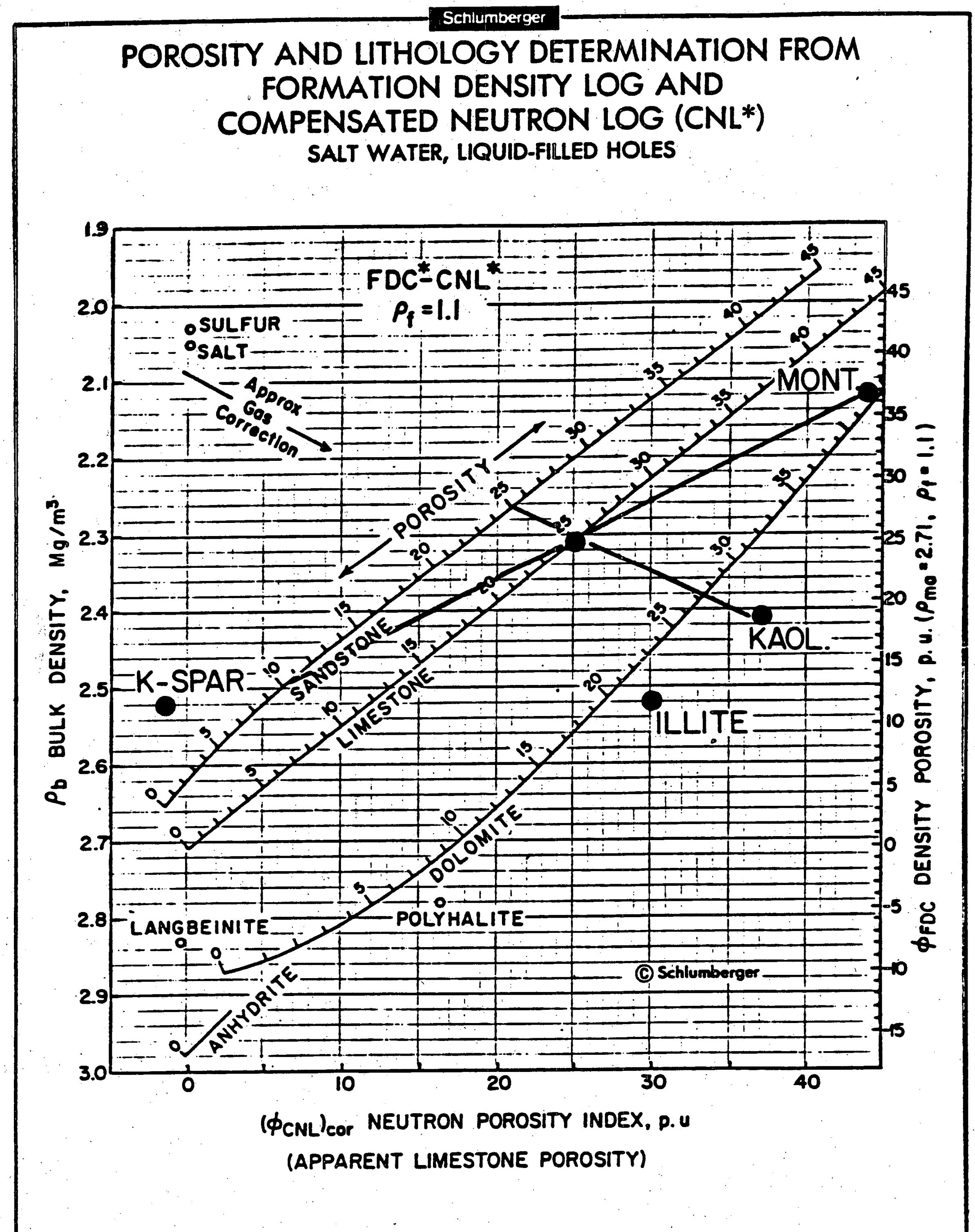


Figure 2-3. Porosity and lithology determination from formation density log and compensated neutron log (courtesy of Schlumberger). Mineral locations also indicated.

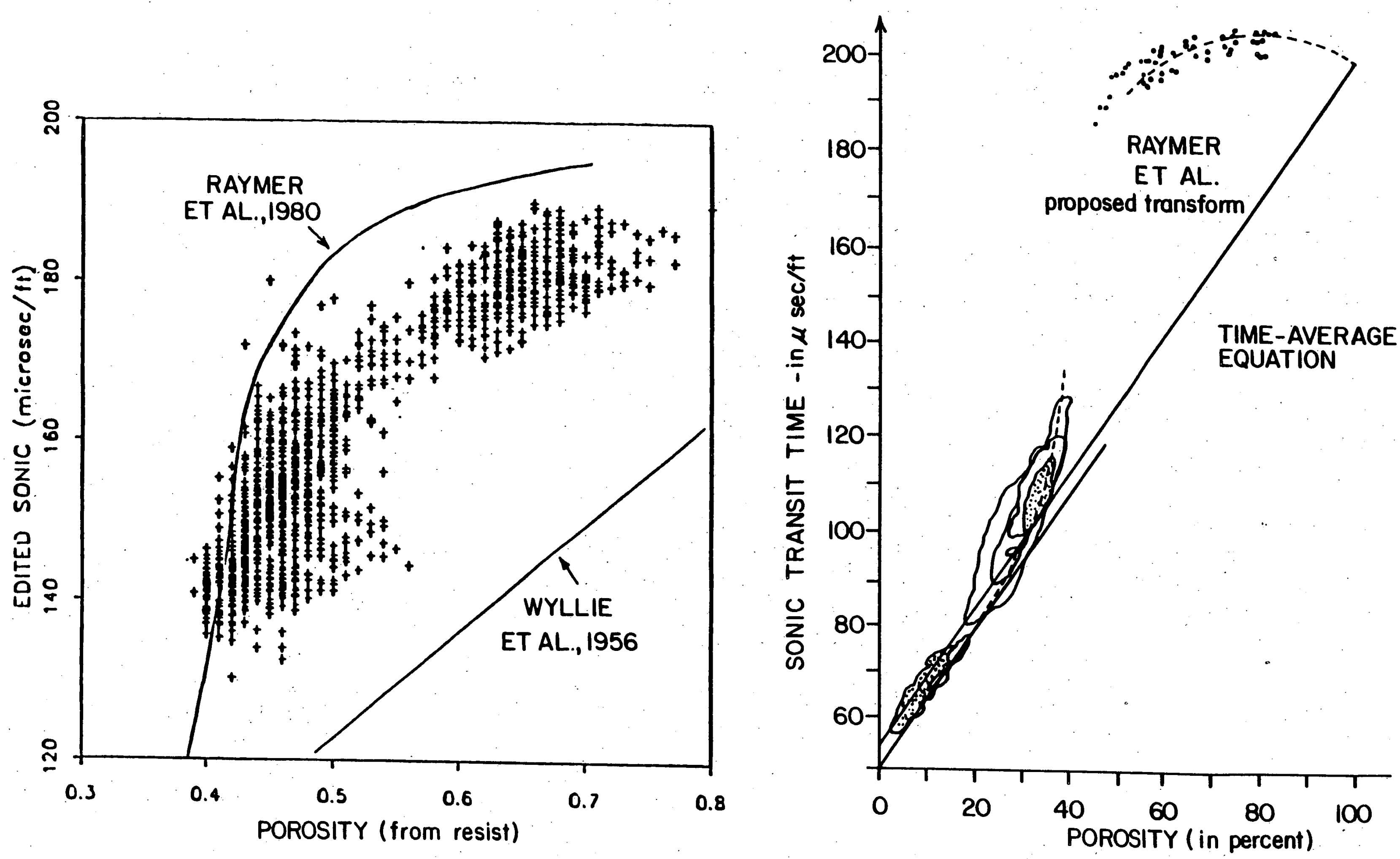


Figure 2-4. Porosity versus sonic travel time crossplot showing the change between very high porosity sediments (Raymer Transform blown-up to right) and sedimentary rocks.

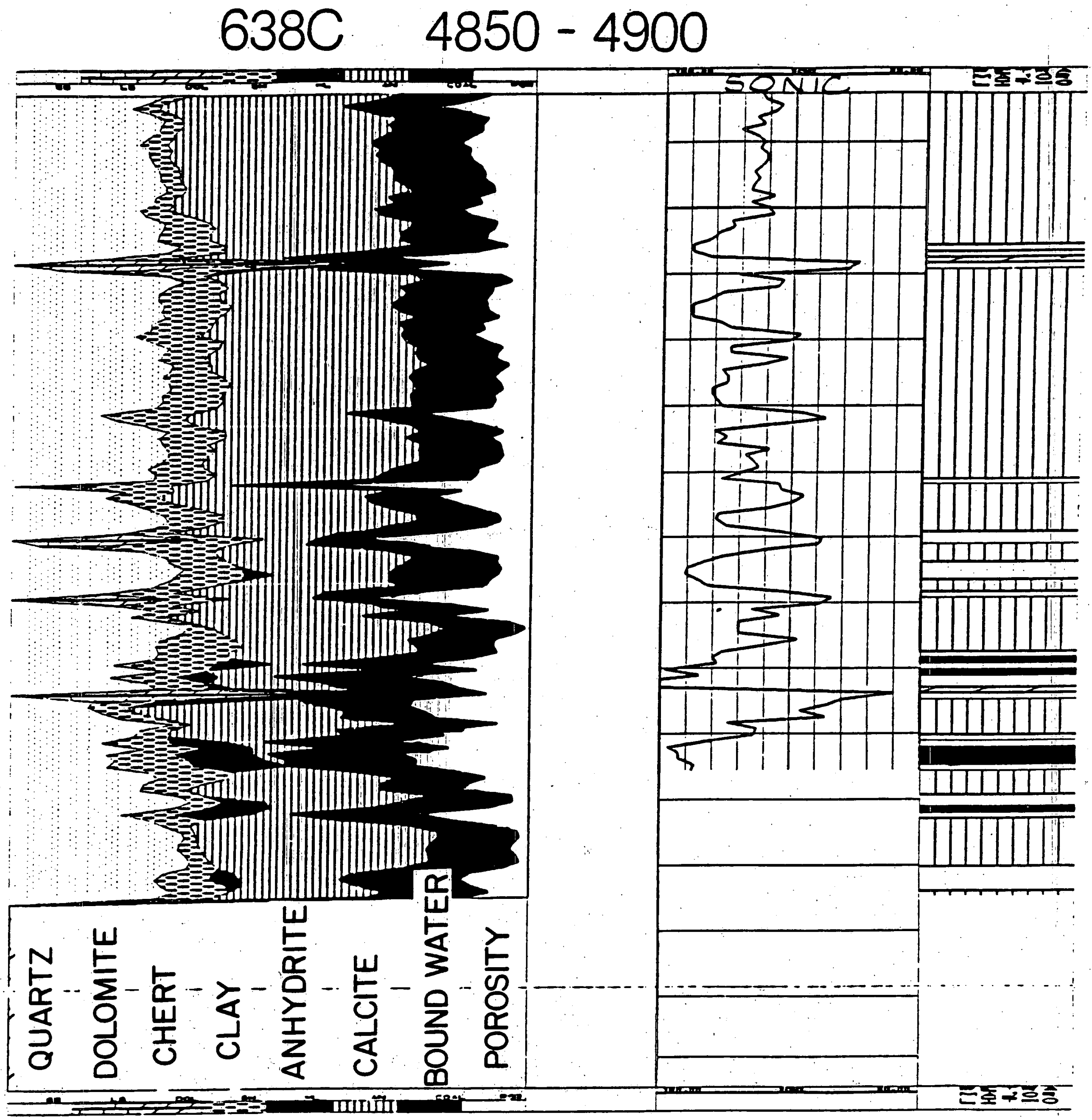
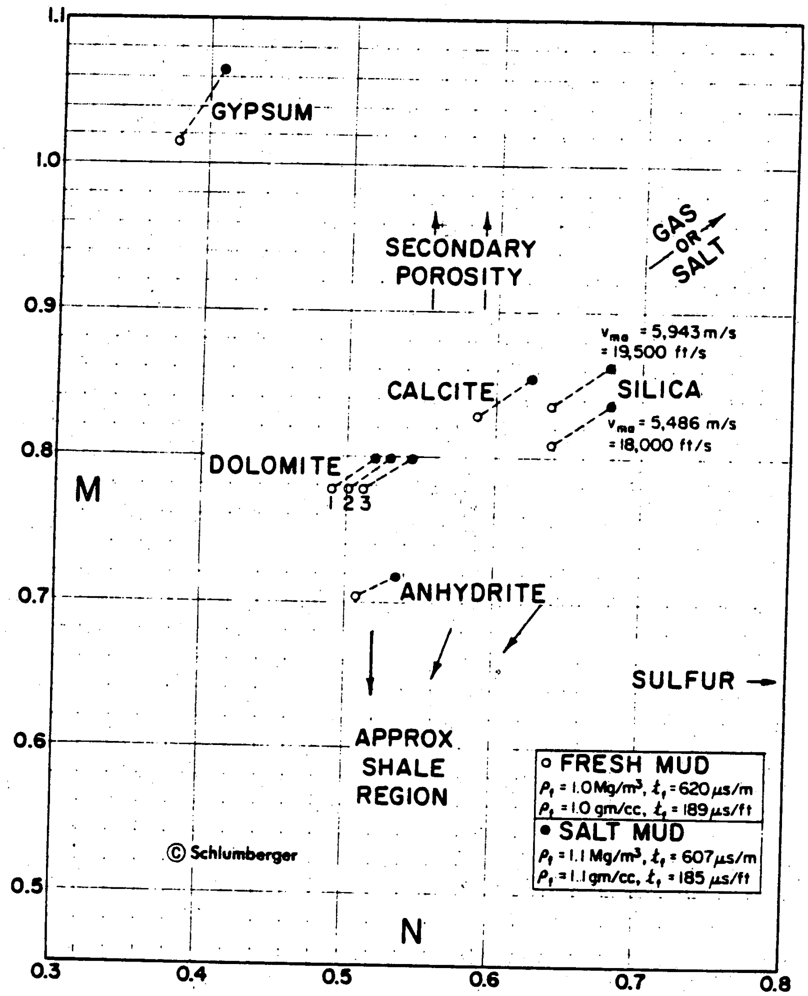


Figure 2-5. Terralog cluster analysis of sonic (center), resistivity, neutron porosity and density logs from Hole 638C, Leg 103 (Figure 2-1). Lithologic column to right; percentages to left.



This crossplot may be used to help identify mineral mixtures from Sonic, Density, and Neutron logs. (The Neutron log used in the above chart is the CNL*.) Except in gas-bearing formations, M and N are practically independent of porosity. They are defined as:

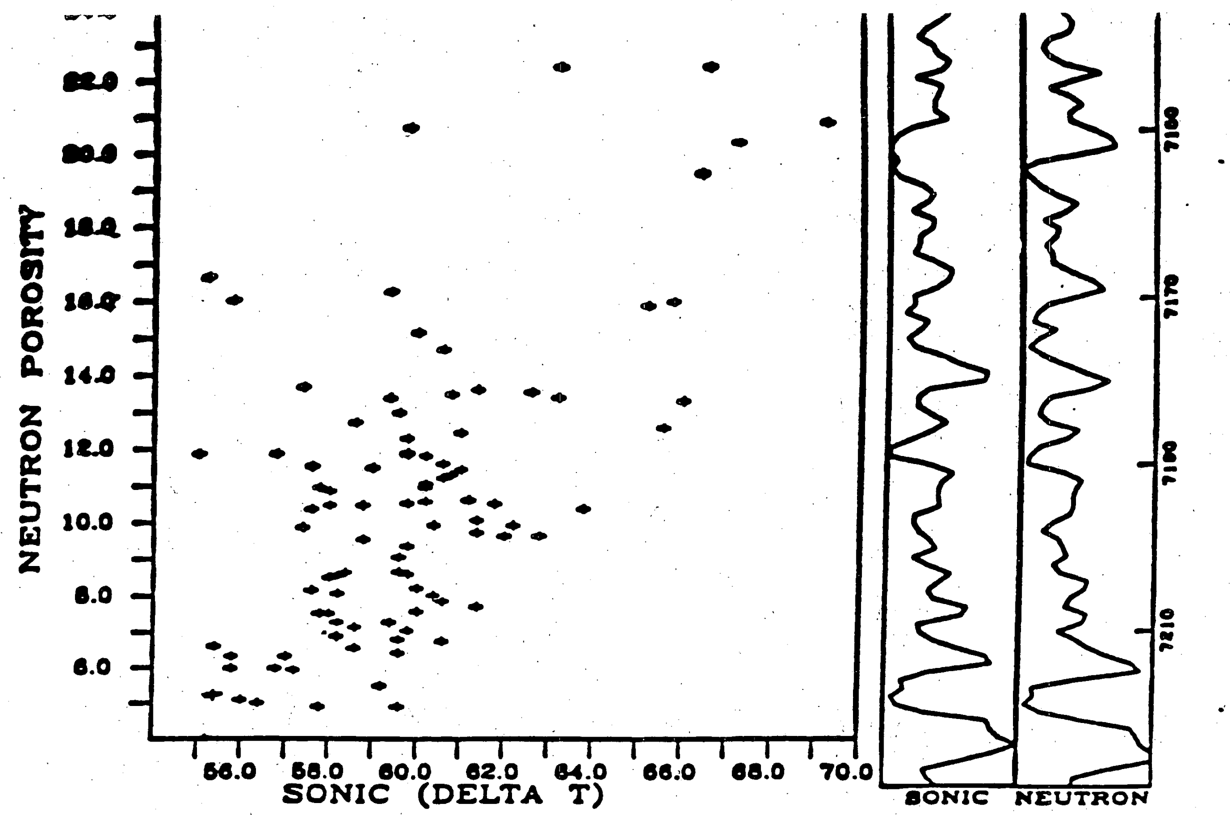
$$M = \frac{t_f - t}{\rho_b - \rho_f} \times 0.01 \text{ (English)}; \qquad M = \frac{t_f - t}{\rho_b - \rho_f} \times 0.003 \text{ (Metric)}; \qquad N = \frac{(\phi_N)_f - \phi_N}{\rho_b - \rho_f} \text{ (Either)}$$

Points for binary mixtures plot along a line connecting the two mineral points. Ternary mixtures plot within the triangle defined by the three constituent minerals. The effect of gas, shaliness, secondary porosity, etc. is to shift data points in the directions shown by the arrows.

The dolomite lines are divided as to porosity as follows:

1) $\phi = 5.5$ to 30 p.u. 2) $\phi = 1.5$ to 5.5 p.u. and $\phi > 30$ p.u. 3) $\phi = 0$ to 1.5 p.u.

Figure 2-6. M-N crossplot (see legend) of sonic, neutron and density log results with mineral locations shown (courtesy of Schlumberger).



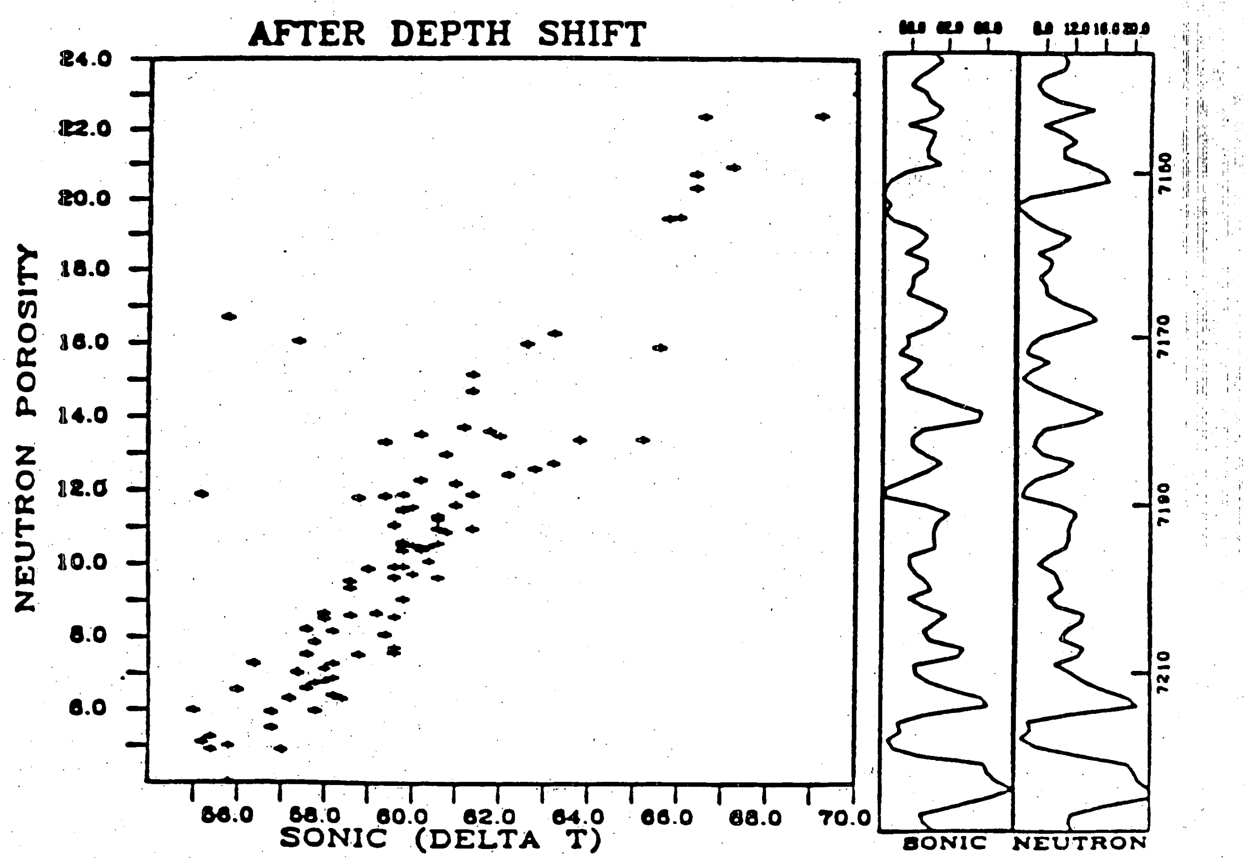


Figure 2-7. Effect of misidentified depths results in apparent scatter (top), which disappears when the true depths are established (bottom).

TABLE 2-1. TYPES OF EDITING REQUIRED

- MECHANICAL ERRORS IN LOGS
  - DEPTH SHIFTING
  - LOG CALIBRATION
  - INSTRUMENT/ELECTRONIC NOISE (E.G. CYCLE SKIPS)
  - HOLE WASHOUT
  - HYDROCARBON EFFECTS (INVADED ZONE)
- INTERPRETIVE
  - CHECK SHOT OR VSP CALIBRATION
  - DEPTH TREND RELATIONSHIPS
  - INTERLOG RELATIONSHIPS (CROSSPLOTS)

porosity divided by density. Quartz, calcite, and clays were correctly identified, and the high-density spikes were identified as dolomite. There was, however, no anhydrite in the cores from 639.

We turned to the core to verify the composition predicted by the logs. Even though recovery was poor in the more cemented intervals, a few pieces of dolomite were brought to the surface during coring. To assist in the log interpretation, physical properties derived from core analyses located dolomite on the M-N diagram. The logs in turn provided information about thickness and frequency of dolomite layers in the hole.

Log Corrections

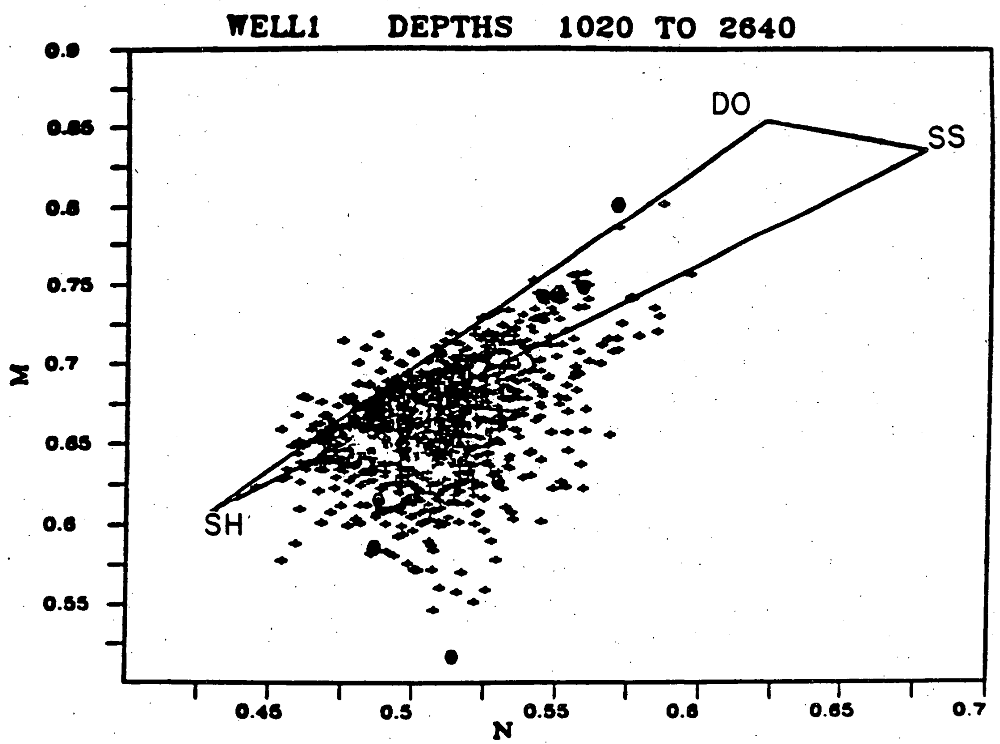
Comparisons between logs must depend upon careful editing of common, misleading, data acquisition errors. These are usually of two types: mechanical errors occurring during recording, and interpretive errors, which are correc Table by calibration and deskewing (Table 2-1). Depth-shifting is usually required because the wireline cable stretches between different lowerings of the tool string into the hole. Depth is often considered the most important datum recorded in logging; even so, it is not recorded downhole, but instead at the surface with mechanical wheel-counters.

Depth-shifting to calibration points, such as total depth or a casing shoe, can clear up considerable noise in a log (Figure 2-7). This can improve interpretation, as shown in the sandstone-limestone-shale lithology model of Figure 2-8. Here clusters of log responses are assigned either a sandstone, dolomite, or shale designation for a plot, such as that in Figure 2-5. After depth-shifting and editing, however, limestone, not dolomite, is seen to be the third lithologic component in the well.

Another technique useful for log comparison is the generation of "pseudo-logs". Consider the relationship between velocity and resistivity. Wyllie's and Archie's laws can be used to construct a pseudo-sonic log from the resistivity log alone (Table 2-2). If we are in a lithology foreign to these two logs, the pseudo-sonic and sonic logs will have little resemblance. But if we are in familiar sedimentary environments, they will correlate nicely (Figure 2-9). In some cases, in fact, the pseudo-log agrees better with the high-resolution, full-waveform sonic log than does the standard sonic log (Figure 2-10). Such techniques are useful for identifying not only bad or noisy data, but unusual log responses as well, as is typical in formations drilled by ODP.

Seismic-Core Ties Via Log-Generated Synthetic Seismograms

A seismic reflection survey is the main geophysical information used to decide not only where but also why to drill a particular hole. An important objective of logging is then to identify which rocks are responsible for seismic reflections coming from the sub-seafloor. The logs contribute to the interpretation of seismic reflection profiles through lithology and porosity determinations at exact depths in the well, as opposed to the time-depth relationship of the reflection profile. The generation of impedance logs from velocity and density logs allows for the calculation of synthetic seismograms which tie specific reflectors to exact depth intervals in the well (Table 2-3).



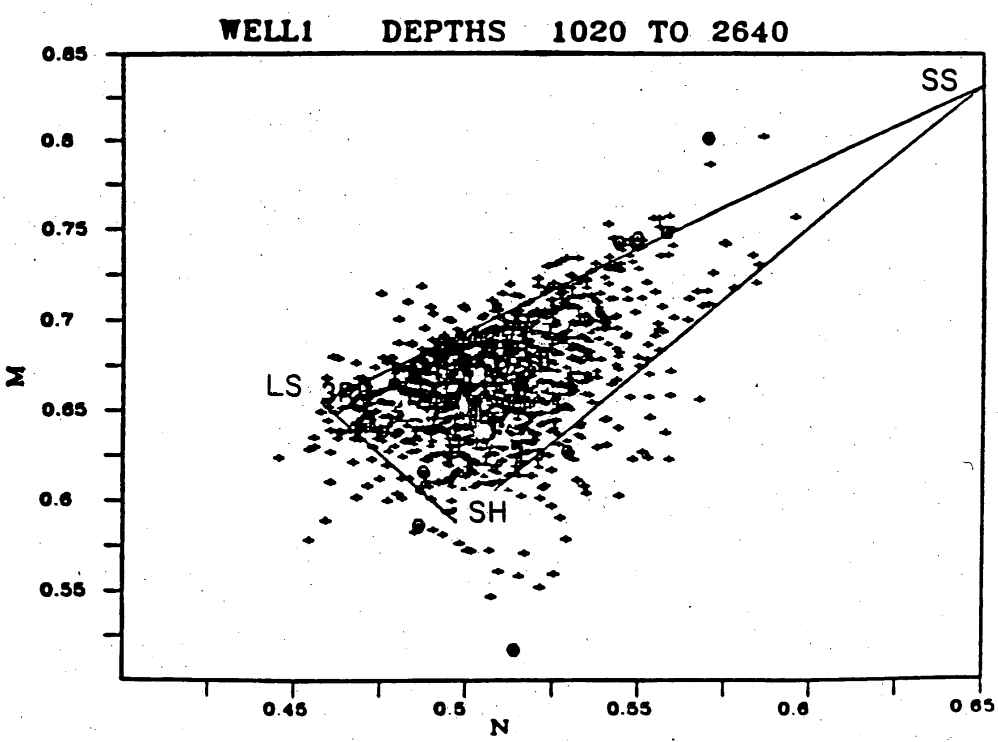


Figure 2-8. Use of M-N plot to determine lithologies. Logging data are assumed to be composed of combination of only these three lithologies at each depth point.

TABLE 2-2. PSEUDOSONIC LOGS

WYLLIE

$$\phi = \frac{\Delta T - \Delta T_{MA}}{\Delta T_F - \Delta T_{MA}}$$

ARCHIE

FLUSHED ZONE: $$S_W^{\,N} = \frac{A}{\phi^M}\left(\frac{R_{MF}}{R_{XO}}\right)$$

DEEP FORMATION: $$S_W^{\,N} = \frac{A}{\phi^M}\left(\frac{R_W}{R_T}\right)$$

LET: $S_W = 1$, $M = 2$

MATRIX METHOD

FLUSHED ZONE: $$\Delta T = \Delta T_{MA} + (\Delta T_F - \Delta T_{MA}) \times \sqrt{\frac{A \times R_{MF}}{R_{XO}}}$$

DEEP FORMATION: $$\Delta T = \Delta T_{MA} + (\Delta T_F - \Delta T_{MA}) \times \sqrt{\frac{A \times R_W}{R_T}}$$

OR:

REGRESSION METHOD

$$\Delta T = A + B \times \sqrt{\frac{R_{MF}}{R_{XO}}}$$

$$\Delta T = A + B \times \sqrt{\frac{1}{R_T}}$$

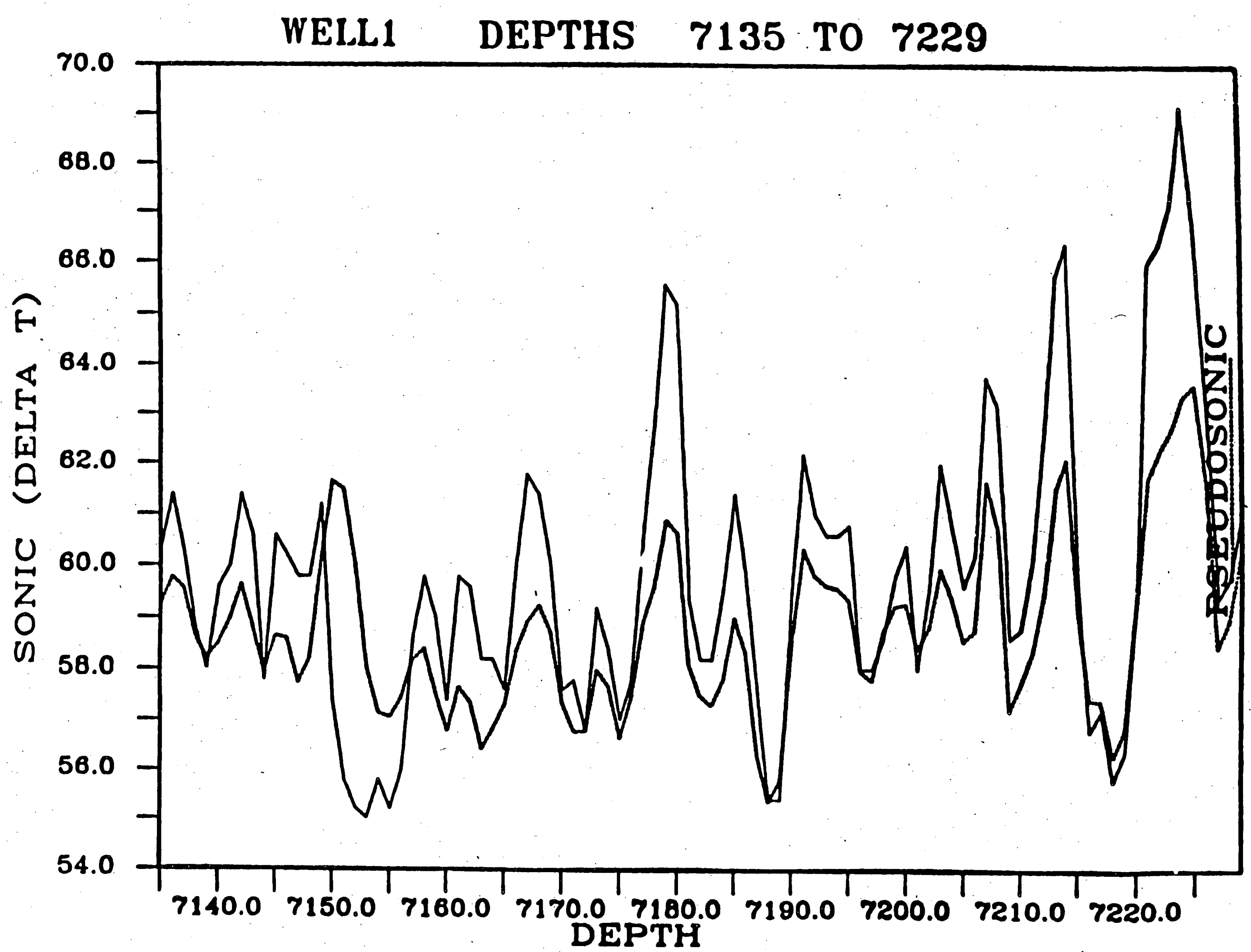


Figure 2-9. Pseudosonic log from resistivity log as in Table 2-2 compared to measured sonic travel times. Discrepancies are often locations of anom ıs pore fluids (oil or gas) and/or pore pressures.

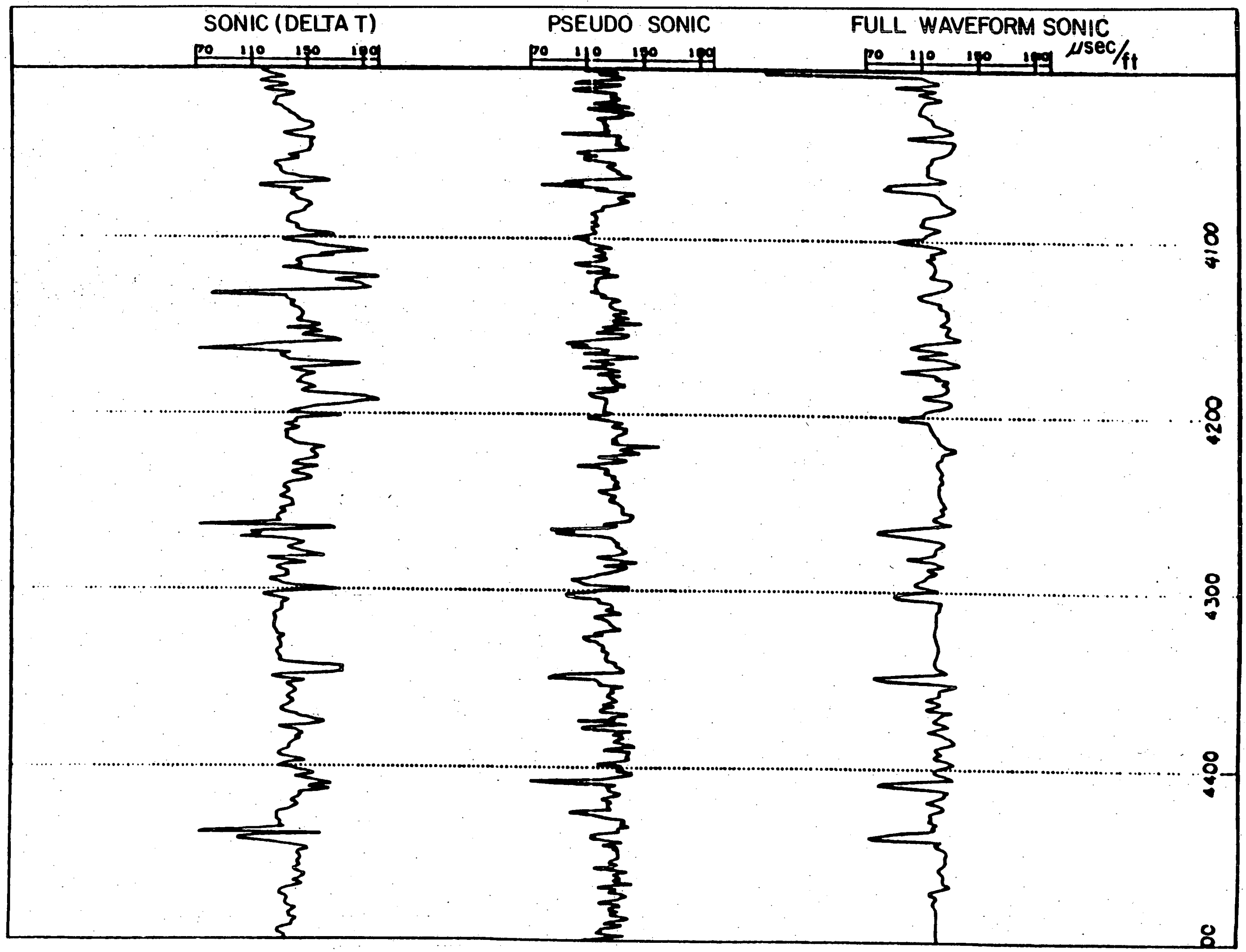
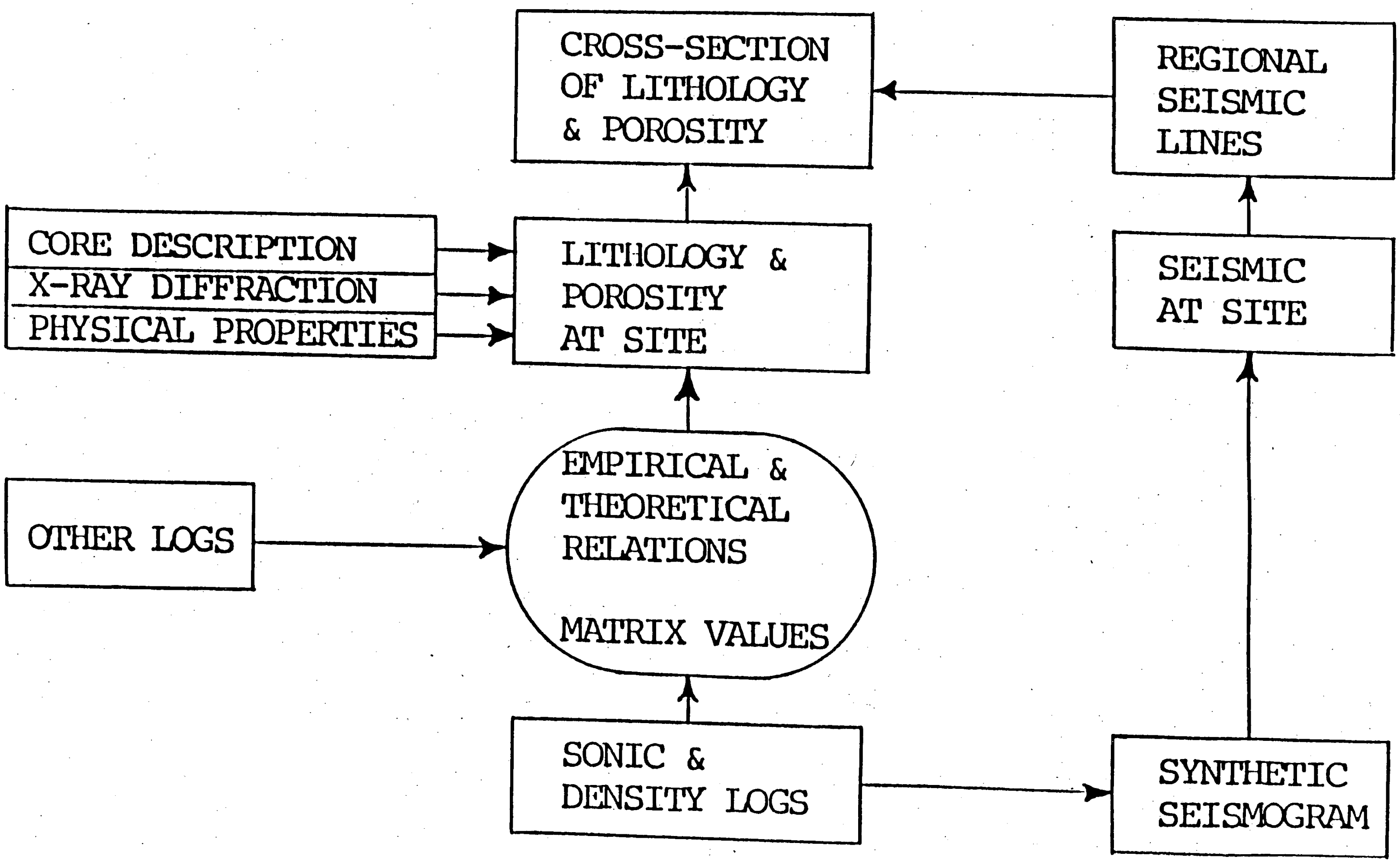


Figure 2-10. Pseudosonic log from resistivities as in Table 2-2 (center) is often closer to that measured by multichannel sonic log (right) than is simple sonic travel time log (left).

Table 2-3 :SEISMIC LITHOLOGY



Laboratory density and velocity measurements can be used to generate an impedance log, but even if recovery is high, the core values are often biased to too high values in igneous rocks and too low values in soft sediments. The igneous core samples selected for shipboard measurements are often the least affected by alteration, and therefore show the fastest velocity and highest density encountered in the well; the soft sediments, on the other hand, have been disturbed and mixed by the coring process, which causes unrealistically low velocities and densities. Logs circumvent these problems by measuring the impedance parameters at *in situ* pressure and temperature conditions (Figure 2-11).

The dolomite stringers encountered at Sites 638 and 639 of Leg 103 produce excellent impedance contrasts. They are clearly density and velocity boundaries; the question is whether they are too thin to produce reflections of seismic energy of 10 to 100 m wavelengths. The synthetic seismogram generated from the logs at Site 638 shows that the accumulation of dolomite interbeds is indeed thick enough to produce the reflectors mapped across the toe of the Goban Spur (Figure 2-12).

The geological question of the relation between these dolomites and syn-rift sediments is not answered either by the seismic section or by the logs. That interpretation is left to the scientists of Leg 103. Nonetheless, it is eveident that the reflectors resulted from a secondary process which occurred after rifting was complete.

Multichannel Sonic Logging

We referred above to the enhanced resolution which can be attained from recording multiple sonic waveforms at progressively greater distances from the source. The Borehole Research Group Multichannel Sonic Tool brings the powerful seismic processing techniques developed for surface reflection surveying to logging data analysis.

Each 'chirp' of the sonic source becomes a mini-refraction experiment, because the sound energy moves radially outward from the tool, which is centralized in the well. At the rock interface, the sonic energy enters and travels down the wall of rock, appears again in the drilling fluid, and is received by the 12-transducer array located 1 to 3 m below the source (Figure 2-13).

The waveforms recorded with the Multichannel Sonic Tool resemble small micro-earthquake seismograms and can be analyzed as such. The compressional, shear, and surface wave coda separate into individual energy packets as the energy moves across the receiver array (Figure 2-13). The velocities of the coda packets are precisely measured by a seismic technique called "semblance". With semblance analysis, a series of increasing velocity increments are used to find the maximum statistical coherence of the multiple receivers, which gives a precise determination of velocity (Figure 2-14). The semblance coherence statistics are a good measure of the degree of energy loss across the array as well (Figure 2-15), and they correlate with the occurrence of open fractures encountered in the wellbore (Figure 2-15). The traditional full waveform display of a single receiver also allows for the qualitative identification of such energy loss (right in Figure 2-16), but the semblance statistic quantifies this energy loss for each separate coda (center of Figure 2-16, compared to the Borehole Televiewer ultrasonic image of the fracture at the left). This semblance statistic correlates well with fracture maps of the wellbore from Borehole Televiewer imaging (compare also the right with the center of Figure 2-13).

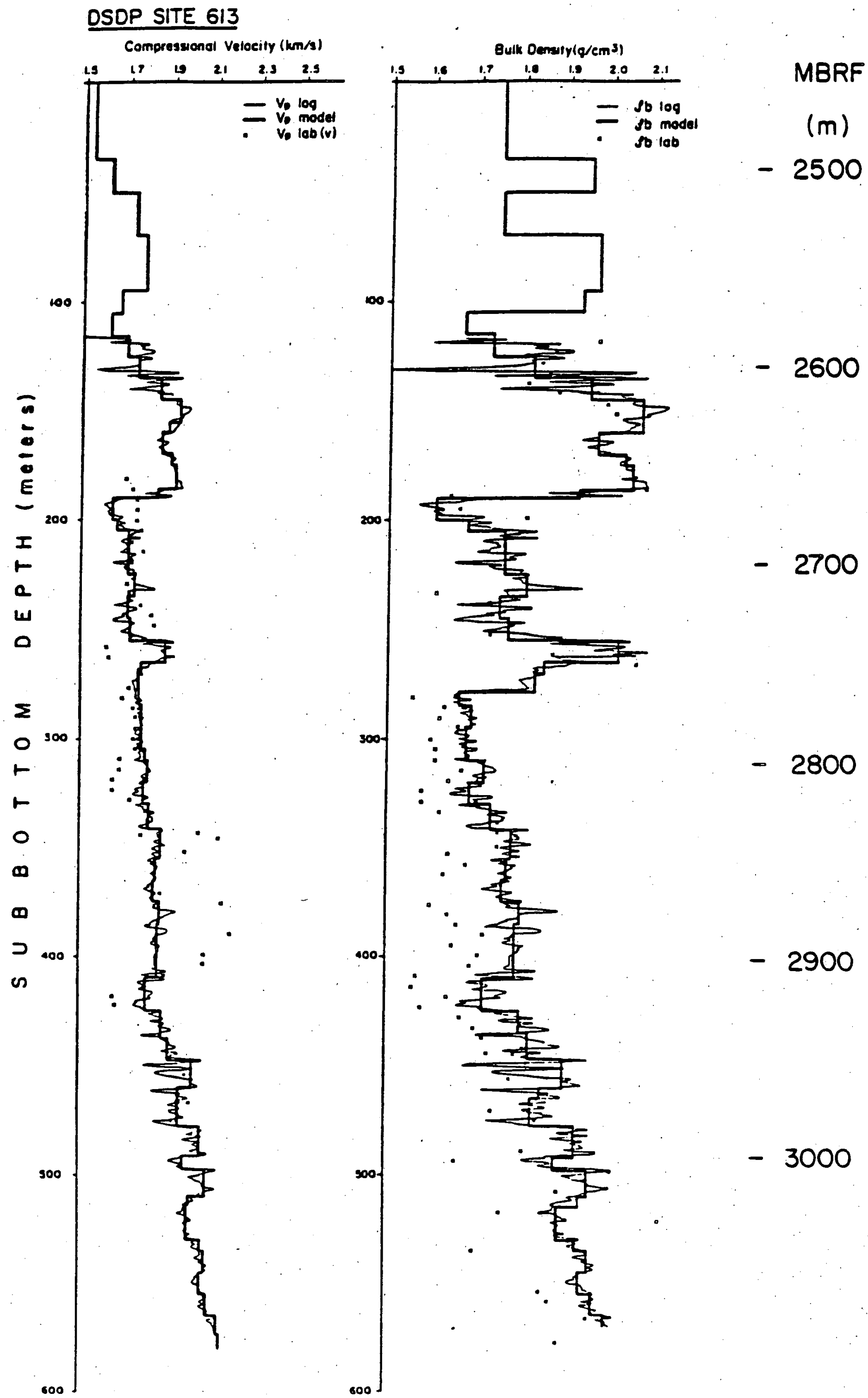


Figure 2-11. Compressional velocities and densities from logs compared to laboratory measurements on core (dots) from DSDP Site 613, Leg 95. Five meter average of log results is also displayed.

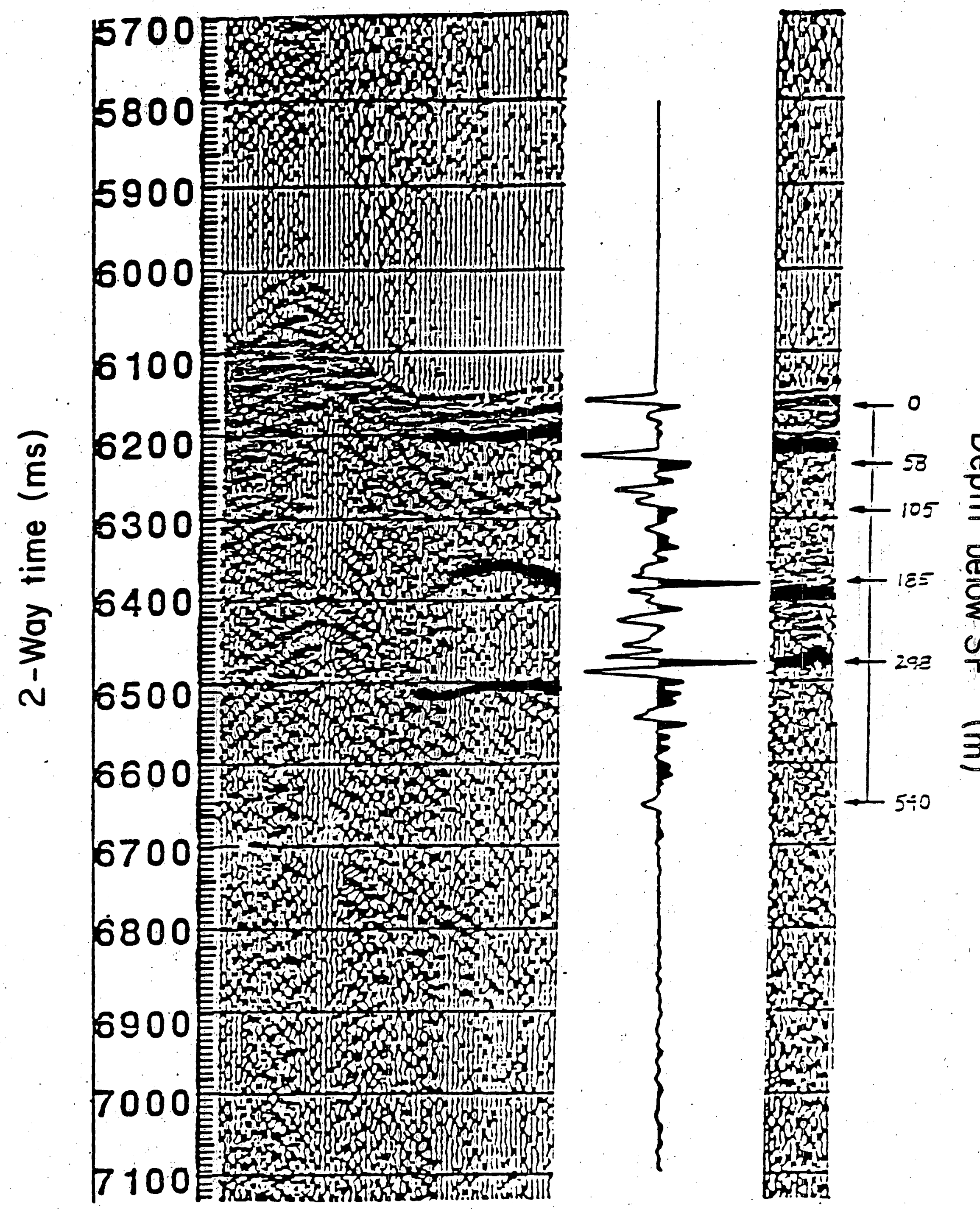


Figure 2-12. Synthetic seismogram generated from sonic velocity and density logs (ODP Leg 103) provides absolute depth tie to surface multichannel seismic reflection record. The reflectors at 6350 and 6500 msec travel time below the surface are encountered in the well at 185 and 298 m bsf. This identification allows for the correlation of reflector depths for considerable distances away from the wellsite.

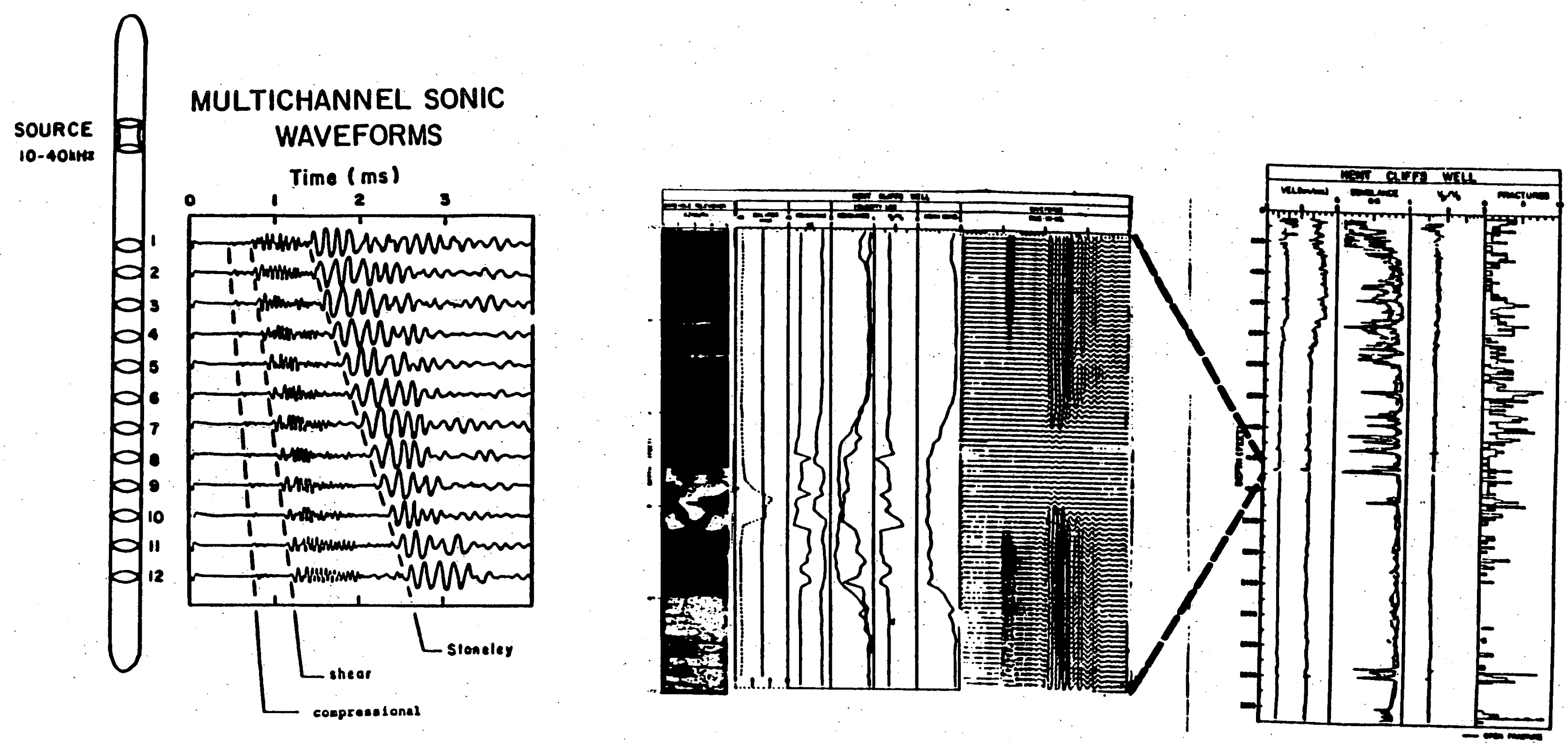


Figure 2-13. Multichannel sonic logging tool contains 12 receivers spaced at 25 cm beginning 1 m below a 10-40 kHz source (left). The waveforms recorded from each 'chirp' of the source provide moveout velocities of compressional, shear and Stoneley energy (left). In addition, coherence statistics can be used to identify open fractures from energy loss within each waveform coda (center, compared to Borehole Televiewer image). The well can then be described in terms of 'semblance coherence', which correlates well with fracture locations determined from the BHTV (right).

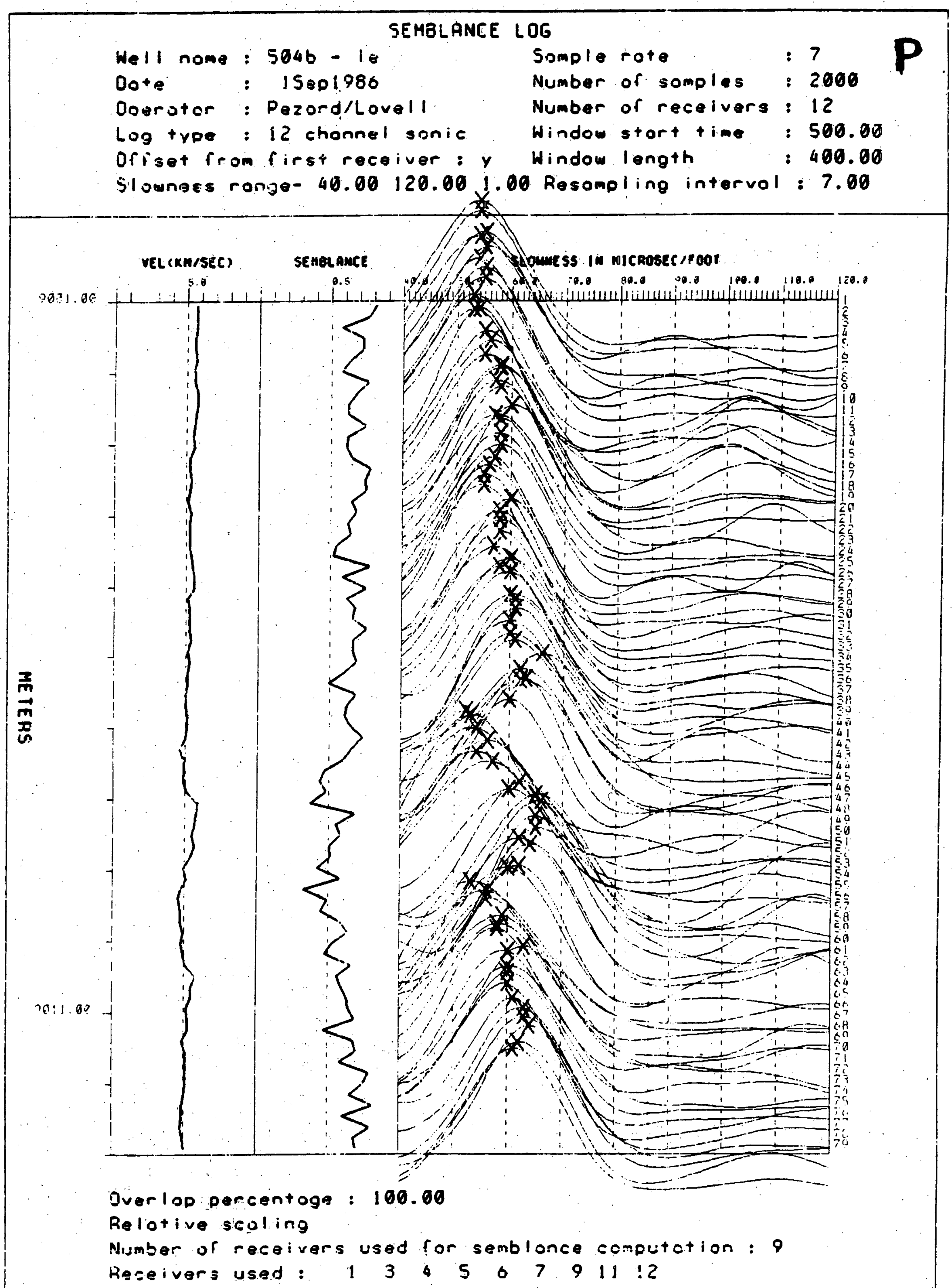


Figure 2-14. Semblance analysis provides accurate velocity determinations by identifying the velocity of maximum coherence energy (right) within the twelve receiver waveforms for each source firing. The semblance coherence statistic is as useful as velocity itself (left) for geological interpretation.

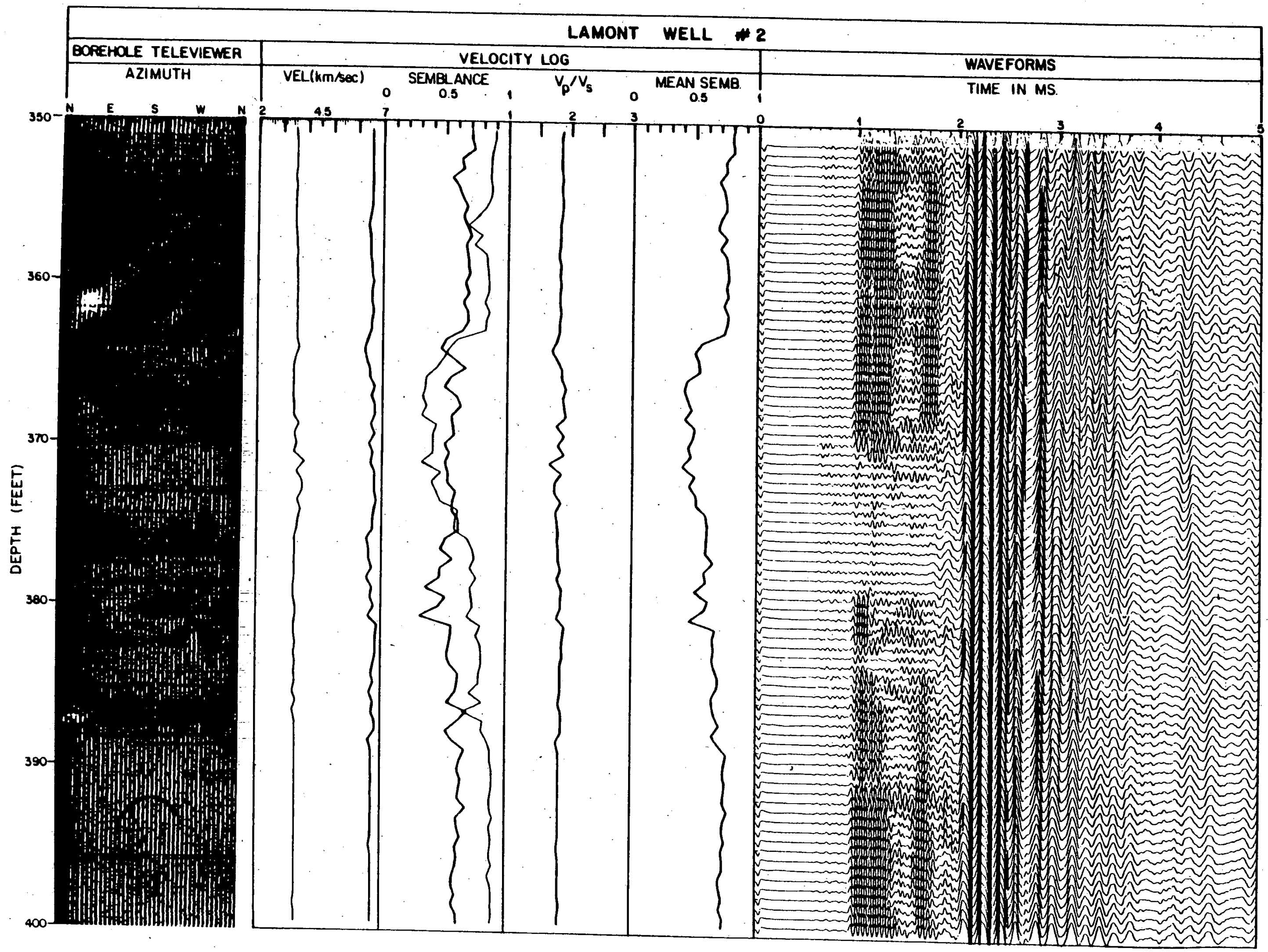
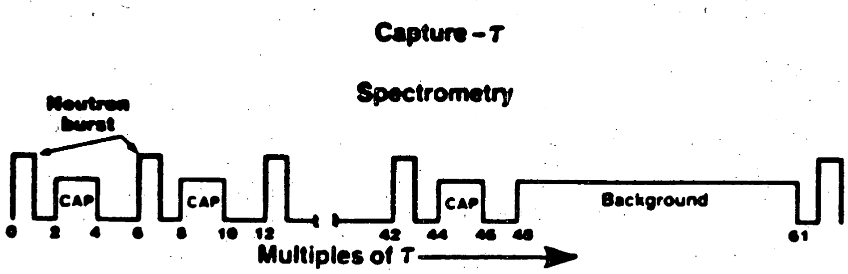


Figure 2-15. Borehole Televiewer images (left) and multichannel sonic waveforms (right) make a powerful combination for the location and identification of open fracture systems within a well, such as at 70 m into the Palisades Sill, New York. The apparent lag of the sonic waveforms to deeper depth is cau--d by the zero reference depth of the tool being taken at the sourc m above the receiver 12 waveform position (right).

GST Timing Programs



Capture Spectra

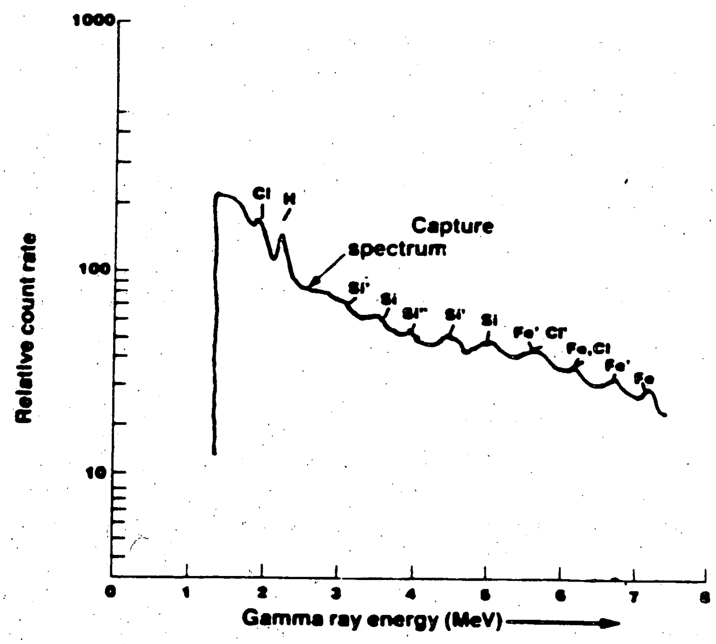


Figure 2-16. Timing of minitron neutron bursts from the Schlumberger neutron activation logging tool (GST). 10^8 neutrons are burst into the formation each 100 microseconds by a 60,000 volt charge released into a Tritium tube(top). The resulting gamma ray emission spectrum of the formation is recorded by a 256 channel photomultiplier. Elemental abundances can then be determined (courtesy of Schlumberger).

Nuclear Logging

In recent years, the traditional sonic, electrical, and nuclear logging tools have been enhanced in their geological interpretative capabilities by the introduction of multiple detectors and sonic/ultrasonic combinations. In the newly designed Induced Gamma Ray Spectrometry Tool a 'minitron' tube of tritium is pulsed once every 100 microseconds by 65,000 to 100,000 volts. The resulting burst of 10 neutrons from the tool produces gamma rays which impact a NaI crystal. The crystal then emits photoelectric energy. A downhole, 256-channel spectral analyzer transmits the gamma ray count rate from each separate energy window back to the surface (Figure 2-16). Hydrogen, chlorine, silicon, calcium, iron, titanium, gadolinium, and sulfur yields are extracted from their respective peak energy channels.

The Lithodensity Tool carries a cesium source in a pad pressed against the wellbore. Gamma rays emitted by the source are either Compton-scattered or photoelectrically absorbed by the electrons in the formation. The amount of gamma ray energy returning to a NaI-counting crystal is therefore inversely proportional to the electronic density of the formation, which is a function of its bulk density.

The Photoelectric Factor (PEF), on the other hand, is a measure of the capture cross-section of an element. By grouping into windows low energy (PEF) and higher energy (density) gamma ray regions of the total gamma ray spectrum, the PEF can be separated from the density measurement. The photoelectric absorption index of elements and minerals can be measured in the laboratory; the total PEF of a formation is the sum of the components. If we determine the major elemental concentrations of the rock-fluid system by neutron activation for all of the major elements, the PEF can then be used to calculate the abundance of the missing residual element. Si, Al, Fe, Ca, Ti, K, Gd, Cl, and H are measured by the geochemical tool. Of the major elements in basalt, only Mg and Na are not measured. Most Na encountered in the borehole is associated with Cl in the fluid (both borehole and formation fluid). The difference between the recorded PEF and that derived from the sum of the abundances of the other major elements (Table 2-4), results in an estimate of the weight percent of Mg and Na in the rock.

The addition of Mg and Na provides a virtually complete and continuous chemical determination of the major oxides composing the vertical section of the wellbore. In turn, this allows for the characterization not only of the structural and lithological units encountered in the hole, but also of the normative mineralogical constituents of the formation.

Both oxides and mineral estimates can be compared with x-ray defraction and fluorescence results from core analyses (Figure 2-17).

In the future there will be available an even more sophisticated geochemical tool that utilizes a cryogenic germanium crystal to obtain better spectral resolution than the existing NaI crystal (Figure 2-18). Such elements as Ni, Co, V, Sc, and Cr will eventually be measured by nuclear logs.

One practical use of this combination of neutron porosity and geochemical tools is that they can be recorded through the steel drill pipe when hole conditions are too degraded to allow open-hole logging. On Leg 101 in the Providence Channel of the Bahamas platform,

TABLE 2-4

NAME	FORMULA	MOLECULAR WEIGHT	P_e	Z_{eq}	ρ	ρ_e	ρ_b	c
A. Elements								
	H	1.000	-00025	1				1.984
	C	12.011	-15898	6				-9991
	O	16.000	-44784	8				1.0000
	Na	22.991	1.4093	11				.9566
	Mg	24.32	1.9277	12				.9868
	Al	26.98	2.5715	13	2.700	2.602	2.596	.9637
	Si	28.09	3.3579	14				.9968
	S	32.066	5.4304	16	2.070	2.066	2.022	.9979
	Cl	35.457	6.7549	17				.9589
	K	39.100	10.081	19				.9719
	Ca	40.08	12.126	20				.9980
	Ti	47.90	17.089	22				.9186
	Fe	55.85	31.181	26				.9311
	Cu	63.5	43.5	29				
	Sr	87.63	122.24	38				.8673
	Zr	91.22	147.03	40				.8770
	Ba	137.36	493.72	56				.8154
B. Minerals								
Anhydrite	CaSO4	136.146	5.055	15.69	2.960	2.957	2.977	.9989
Barite	BaSO4	233.366	266.8	47.2	4.500	4.011		.8913
Calcite	CaCO3	100.09	5.084	15.71	2.710	2.708	2.710	.9991
Carnallite	$KC1\text{-}MgC1_2\text{-}6H_20$	277.88	4.089	14.79	1.61	1.645	1.573	1.0220
Celestite	SrSO4	183.696	55.13	30.4	3.960	3.708		.9363
Corundum	$A1_20_3$	101.96	1.552	11.30	3.970	3.894		.9808
Dolomite	$CaCO_3\text{-}MgCO_3$	184.42	3.142	13.74	2.870	2.864	2.877	.9977
Gypsum	$CaSO_4\text{-}2H_20$	172.18	3.420	14.07	2.320	2.372	2.350	1.0222
Halite	NaC1	58.45	4.169	15.30	2.165	2.074	2.031	.9580
Hematite	Fe_20_3	159.70	21.48	23.45	5.240	4.987		.9518
Illmenite	$FeO.TiO_2$	151.75	16.63	21.87	4.70	4.46		.9489
Magnesite	$MGCO_3$	84.33	0.829	9.49	3.037	3.025	3.049	.9961
Magnetite	Fe_3O_4	231.55	22.08	23.65	5.180	4.922		.9501
Marcasite	FeS_2	119.98	16.97	21.96	4.870	4.708		.9668
Pyrite	FeS_2	119.98	16.97	21.96	5.000	4.834		.9668
Quartz	SiO_2	60.09	1.806	11.78	2.654	2.650	2.648	.9985
Rutile	TiO_2	79.90	10.08	19.02	4.260	4.052		.9512
Siderite	$FeCO_3$	115.86	14.69	21.09	3.94		3.89	
Sylvite	KC1	74.557	8.510	18.13	1.984	1.916	1.862	.9657
Zircon	$ZrSiO_4$	183.31	69.10	32.45	4.560	4.279		.9383
C. Liquids								
Water	H_20	18.016	.358	7.52	1.000	1.110	1.000	1.1101
Salt Water	(120,000 ppm)		.807	9.42	1.086	1.185	1.080	1.0918
Oil	$CH_1\text{-}6$		.119	5.53	.850	.948	.826	1.1157
	CH_2		.125	5.61	.850	.970	.849	1.1407
D. Miscellaneous								
Berea Sandstone			1.745	11.67	2.308	2.330	2.305	.9993
Pecos Sandstone			2.70	13.18	2.394	2.414	2.395	1.0000
Average Shale			3.42	14.07	2.650	2.645	2.642	.998
Anthracite Coal	C:H:O= 93:3:4		.161	6.02	1.700	1.749	1.683	1.0287
Bituminous Coal	C:H:O= 82:5:13		.180	6.21	1.400	1.468	1.383	1.0485

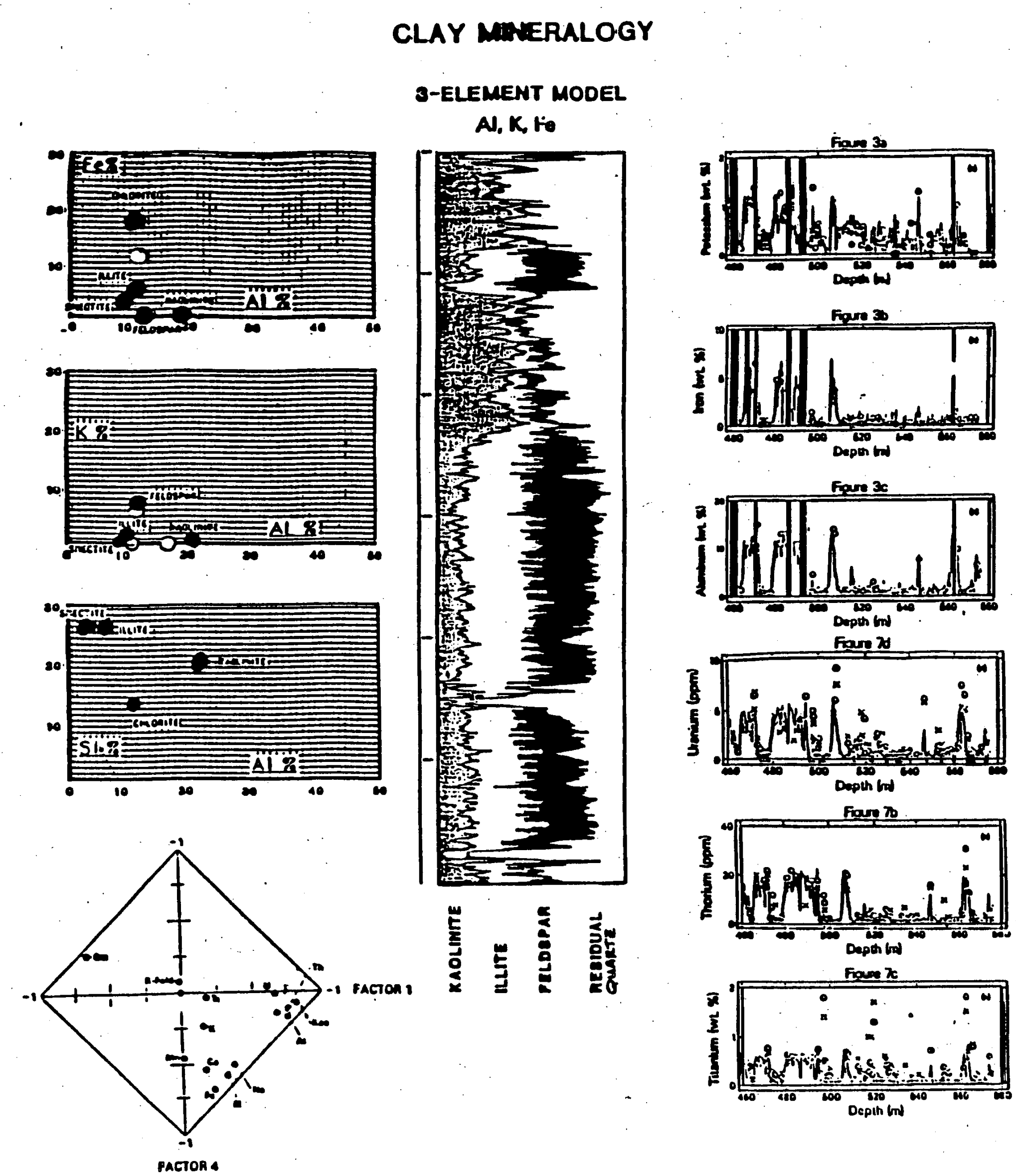


Figure 2-17. From the abundances of elements (right), and mineral normative compositions (left), a factor analysis plot determines the relative abundances of minerals within the elemental yields (left, bottom). The result is a normative mineralogy log showing kaolinite, illite, feldspar, and quartz variations from Al, K and Fe elemental logs (cent). (courtesy of Schlumberger)

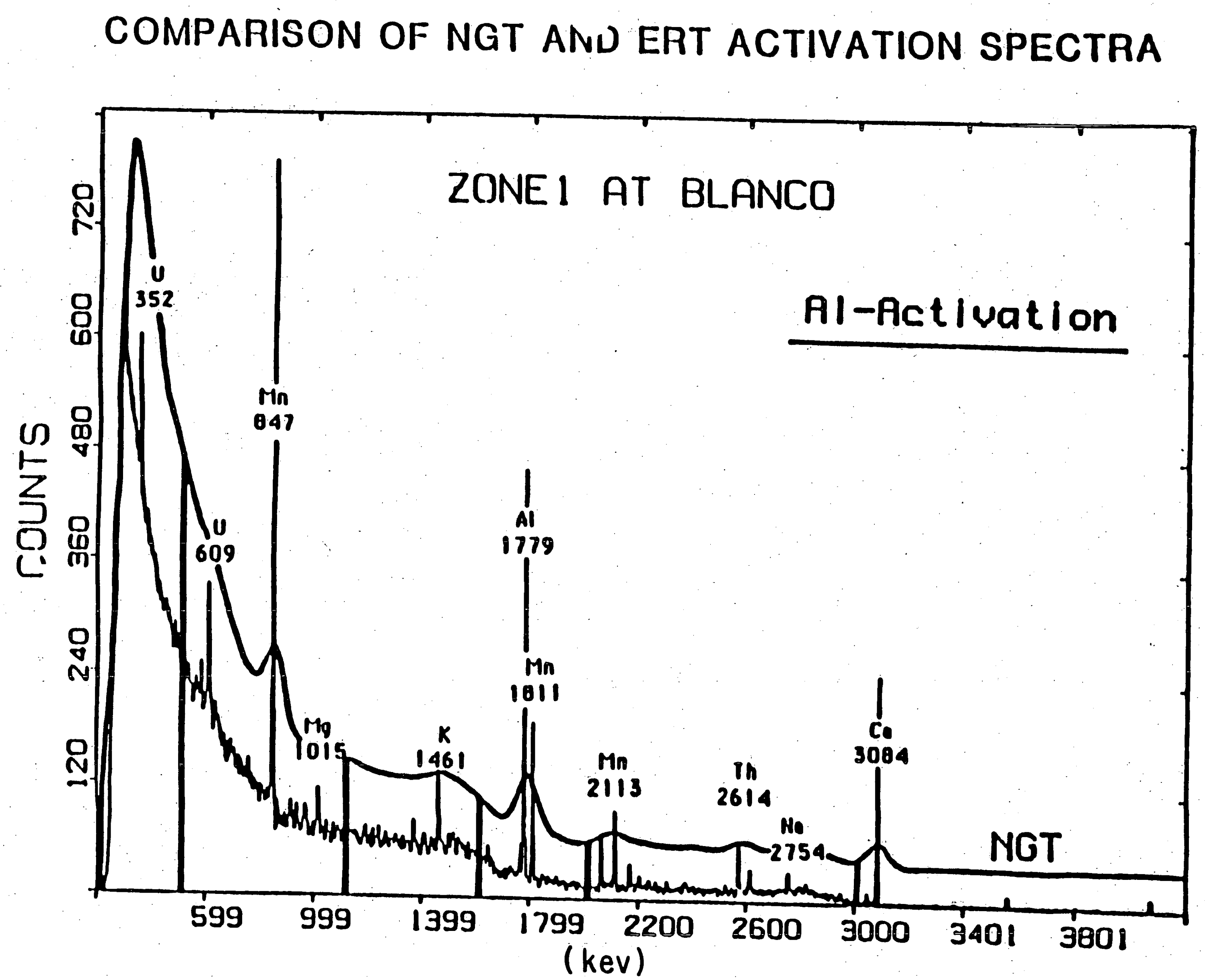


Figure 2-18. The spectrum measured by the NaI crystal currently in use is smooth and relatively insensitive compared to the new cryogenic Ge crystal tool now under development by Schlumberger (the ERT, enhanced resolution tool).

the drill string became stuck while the geochemical tool was being run. The main objective of the drilling was to determine the nature of the seismic reflectors, but this could not be accomplished solely by drilling, as the core recovery was only 7%. Instead, pseudo-density and pseudo-sonic velocities were estimated from the elemental variations measured by geochemical logging through the pipe. A pseudo-impedance log then produced a synthetic seismogram from the geochemical data. Prominent reflectors were indeed identified (Figure 2-19), but the geochemical log showed that the most prominent reflector ("A" in the Figure) at the bottom of the hole was caused by a "peg-leg" multiple (energy bouncing back and forth between the sea floor and a reflector higher up in the section). The real lithological reflector ("B") was smaller than this peg-leg multiple and was caused by porosity and chert content changes within the massive limestone of the platform top.

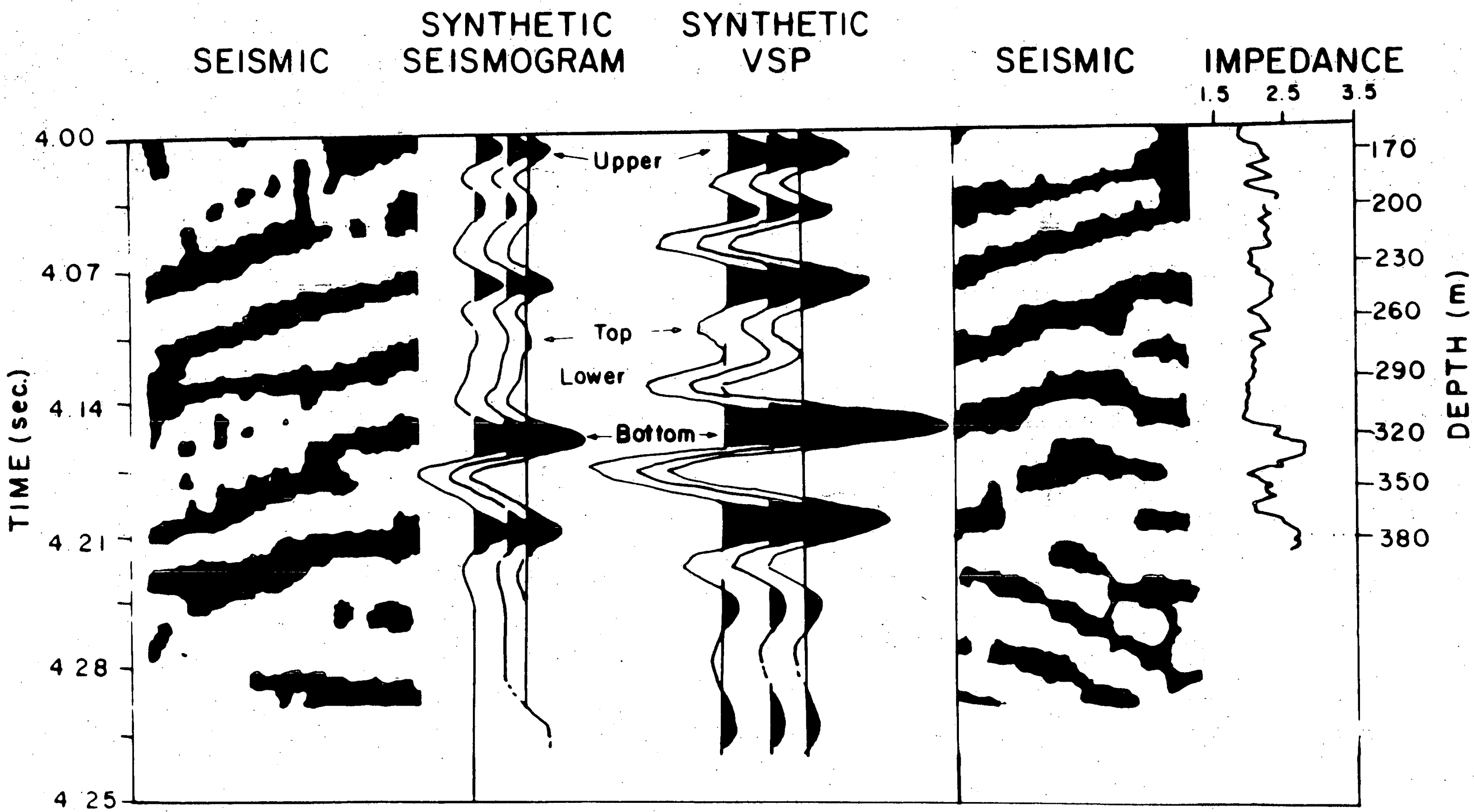


Figure 2-19. The neutron activation log was used on ODP Leg 101 to measure the elemental yields behind a stuck drillpipe at Site 626. The resulting pseudodensity and velocity logs made from these elemental yields produced an impedance log (right), and a synthetic seismogram (left, center) which identifies the rock layers responsible for the major seismic reflector in the well (left, and right center).

Chapter 3

Origin and Evolution of the Oceanic Crust

The current Ocean Drilling Program (ODP), as the successor to the Deep Sea Drilling Project (DSDP), focuses on geological objectives outlined by COSOD (Conference on Scientific Ocean Drilling). The main mission of ODP is to bring new technologies to bear on the following, broadly-defined geological problems:

1. Origin and evolution of the oceanic crust
2. Tectonic evolution of continental margins
3. Origin and evolution of marine sedimentary sequences
4. Causes of long-term changes in the atmosphere, oceans, cryosphere, biosphere and magnetic field.

In the next Chapters, we will consider how logging data can contribute to scientific insights into each of these problems. First, we begin with the most exotic logging application: determination of ocean crustal properties. Even though logging tools and techniques were designed for use in sedimentary basins and not in basalts, the utility of logging measurements in this igneous environment is perhaps the easiest to illustrate. Though porosities are generally lower than any encountered in basins, the rock itself has such a strong lithological signal compared to the pore fluid that log response is easy to quantify.

Consider the basic stratigraphy of the ocean crust. It has long been assumed that seismic layering detects the presence of pillow basalts lying over dikes, which are over the gabbros of frozen magma chambers, which is over Moho and the mantle. Yet the geophysical measurements of the exact causes of those acoustic contrasts had not been fully understood until logs were run in layers 2A, 2B, and 2C of the oceanic crust. This is as far as the drill bit has penetrated the oceanic crust to this time.

Logs in Igneous Basement of Continents

On land the drill bit has penetrated geophysical basement reflectors, and logs have recorded their impedance contrasts. In fact, some of the most famous dry holes in the oil industry history have recorded long logging sections through igneous basement. The geological causes of the supposedly sedimentary seismic reflectors proved to be as variable as the general geological contrasts encountered on continents. Two of these wells serve to illustrate the importance of logging in the determination of igneous lithostratigraphy.

The Anschutz, Arizona State #1 was a 16,000-foot well which entered granites of the Arizona "overthrust" (Figure 3-1) at 700 feet beneath the surface and never exited into the

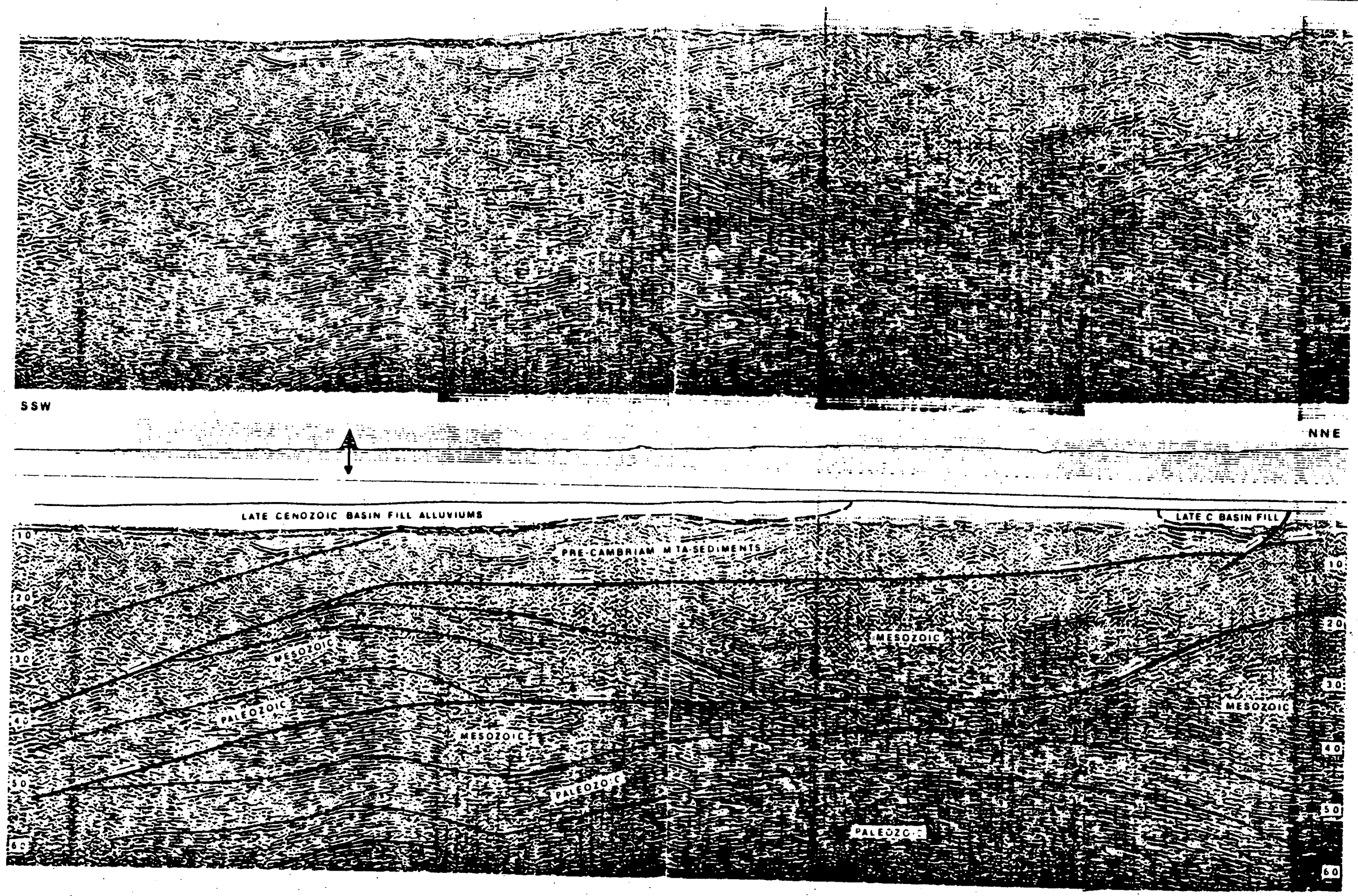


Figure 3-1. Arizona seismic cross section. Upper panel is uninterpreted "raw data". Lower panel is Anschutz interpretation. Numbers at margins of sections represent time in seconds. Anschutz-Texoma drillsite has been projected on to the section. Seismic data courtesy of Pacific West Exploration Company, Denver, Colorado.

underlying sediments thought to be responsible for layered seismic reflectors evident beneath the overthrust (Figure 3-1). Sonic velocity, density, and gamma ray logs identified faults, mafic intrusives within the granite, and lithologic units discriminated by potassium content changes within the granite (Figure 3-2). Impedance contrasts from these changes explained two prominent deep reflectors crossed by the drill bit ("A" and "B" of Figure 3-2). These large overthrusts of granite over granite, however, could not explain the fine layering thought to represent sedimentary bedding in the seismic section. A dipmeter log, in which four orthogonal micro-resistivity electrode pads are pressed against the borehole wall, helped to explain this finer scale layering. The dipmeter precisely determines down to centimeter scales strike and dip of electrically contrasting units. A spectral analysis of the Anschutz well dip changes versus depth shows coherent cycles spaced every 200-300 feet varying between high- and low-dipping units (Figure 3-3). A synthetic seismogram, made with the assumption that dip changes produce reflection coefficient changes, predicts that much of the fine layering is caused by this coherent cyclicity of dip in the well (Figure 3-2). The geological cause of the dip changes must be related to mica or to other mineral elongation which is tilted by multiple, small thrust faults throughout the granitic section.

The Nellie #1 well in Pecos County, Texas, is another deep well that was drilled through igneous rock. The gabbros of an ancient magma chamber underlie the failed rift of the West Texas Permian Basin. Logs of compressional and shear sonic velocity and density and of photoelectric effect in the gabbros delineate impedance contrasts, which can account for the major reflections (A through F) seen by seismic reflection profiles near the well site (Figure 3-4). A geochemical log can be constructed from the mineralogical clustering of these log response parameters (Figure 3-4). Thus, in order to account for the reflection boundaries seen from the surface, gabbro, high Fe chlorite, and plagioclase variations down the hole are predicted.

The Seismic Stratigraphy of the Oceanic Crust

Logs are particularly useful for the identification of seismic boundaries because, unlike cores, they provide a continuous record. Impedance boundaries are made from vertically-stratified variations in the elastic properties of the rock.

The ocean crust is seismically layered. Take, for example, Hole 504B, which was drilled into 6-million-year-old crust on the south flank of the Costa Rica Rift in the eastern equatorial Pacific (Figure 3-5). This hole is both the deepest hole ever drilled in oceanic crust and that with the most complete suite of logging data. Sonic velocities through the pillows, breccias, and dikes of layers 2A, 2B, and 2C show a rather gentle change in slope from top to bottom of Hole 504B (Figure 3-5). The surface multichannel seismic section, in contrast, not only shows strong reflectors at the Moho and at layer 2-3 boundaries, but also shows dipping reflectors within layer 2 (Figure 3- 6).

The Borehole Televiewer shows abrupt slope changes in most of the physical parameters at the layer 2B-2C, pillow-basalt-to-dike boundary. An impedance log from sonic and density logs shows several gentle increases in impedance within the dikes, with lower impedance "layers" found within layer 2B. These unit boundaries produce larger reflectors within layer 2B than do either the 2B-2C boundary (which is a broad slope

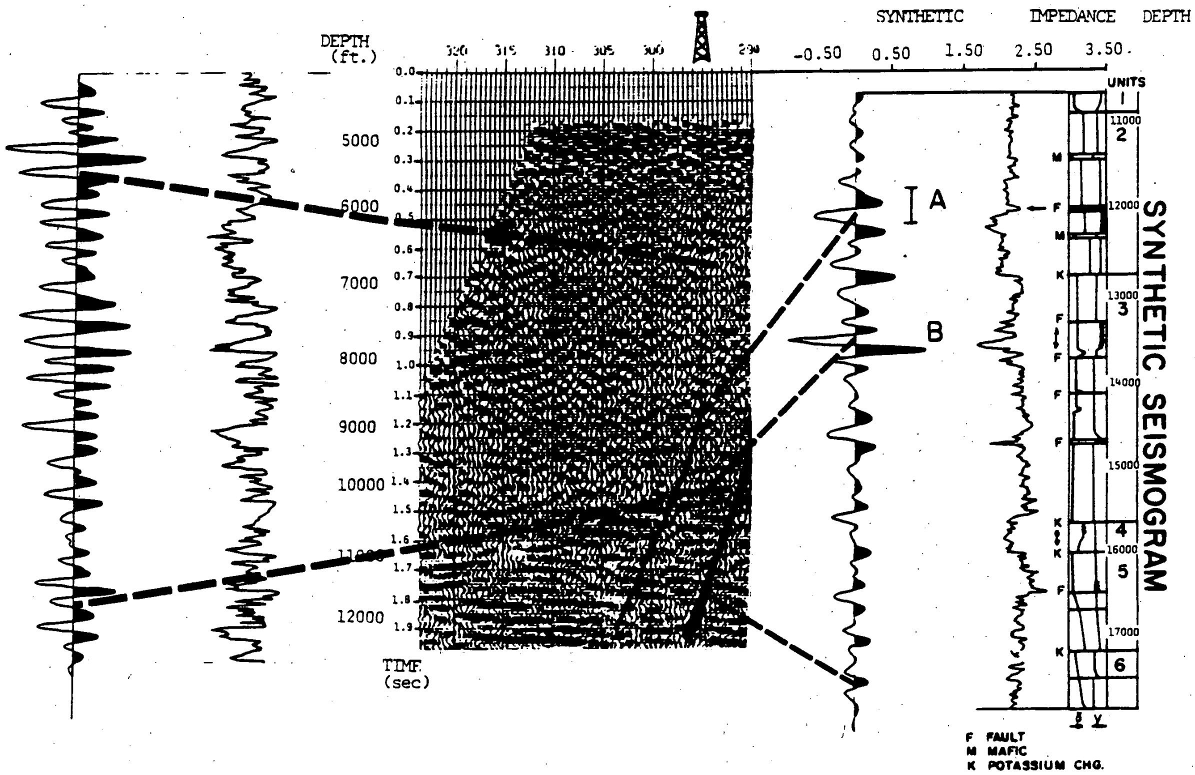


Figure 3-2. Synthetic seismograms generated from impedance contrasts measured by the traditional velocity and density logging data (right), and that predicted from dip changes measured by the dipmeter (left), compared to the surface seismic reflection profile across the Anschutz wellsite (center). The dipmeter impedance contrast produces more high frequency reflectors than the traditional display, as observed in the seismic profile.

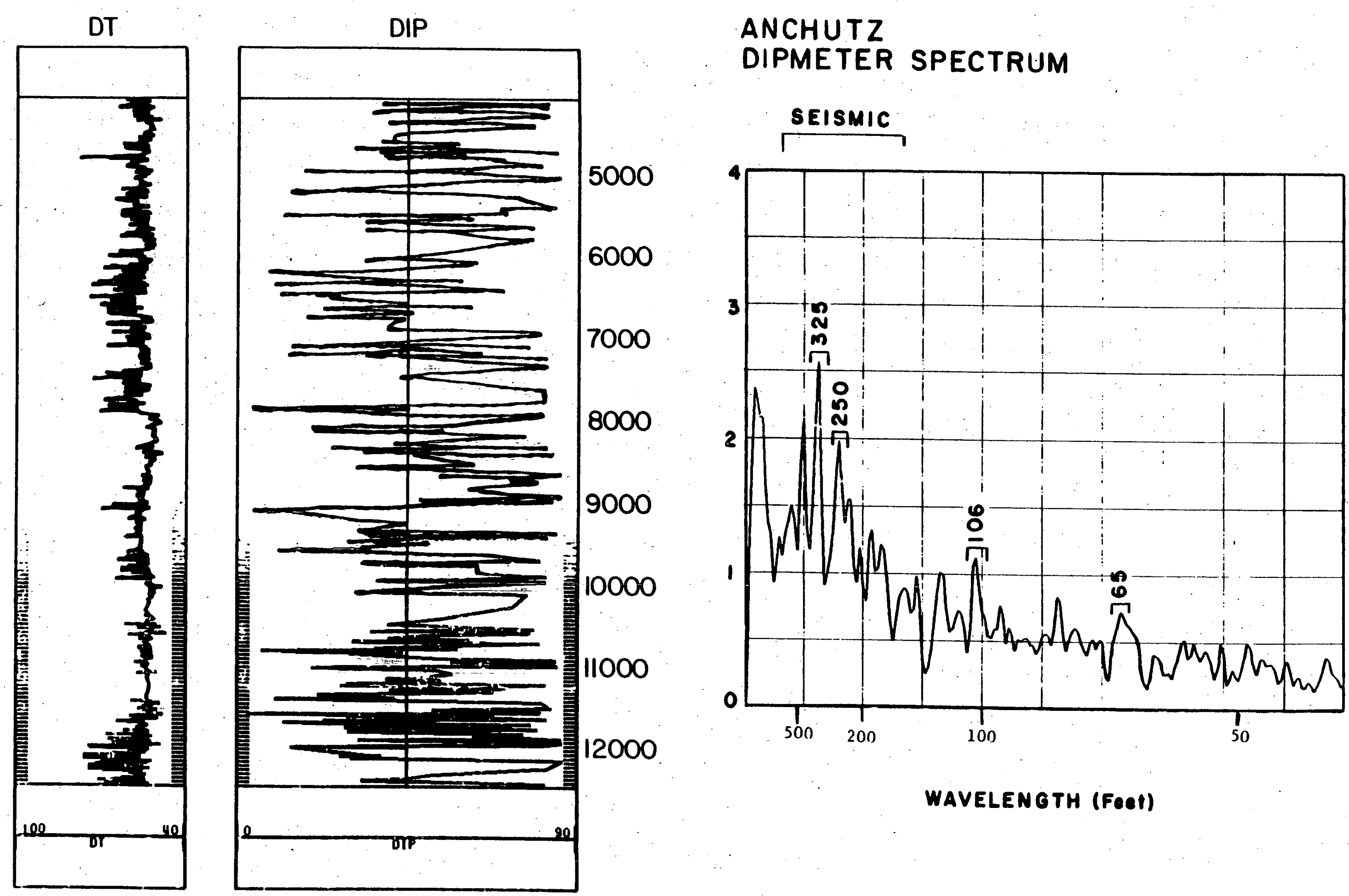


Figure 3-3. Dipmeter and velocity logs (left) which were used to calculate pseudo impedance log and synthetic seismogram of Figure 3-2 at Anschutz well. Power spectrum from Fourier transform of dipmeter log shows predominant energy at 250 to 325 feet wavelengths, which produce excellent reflectors from seismic sources.

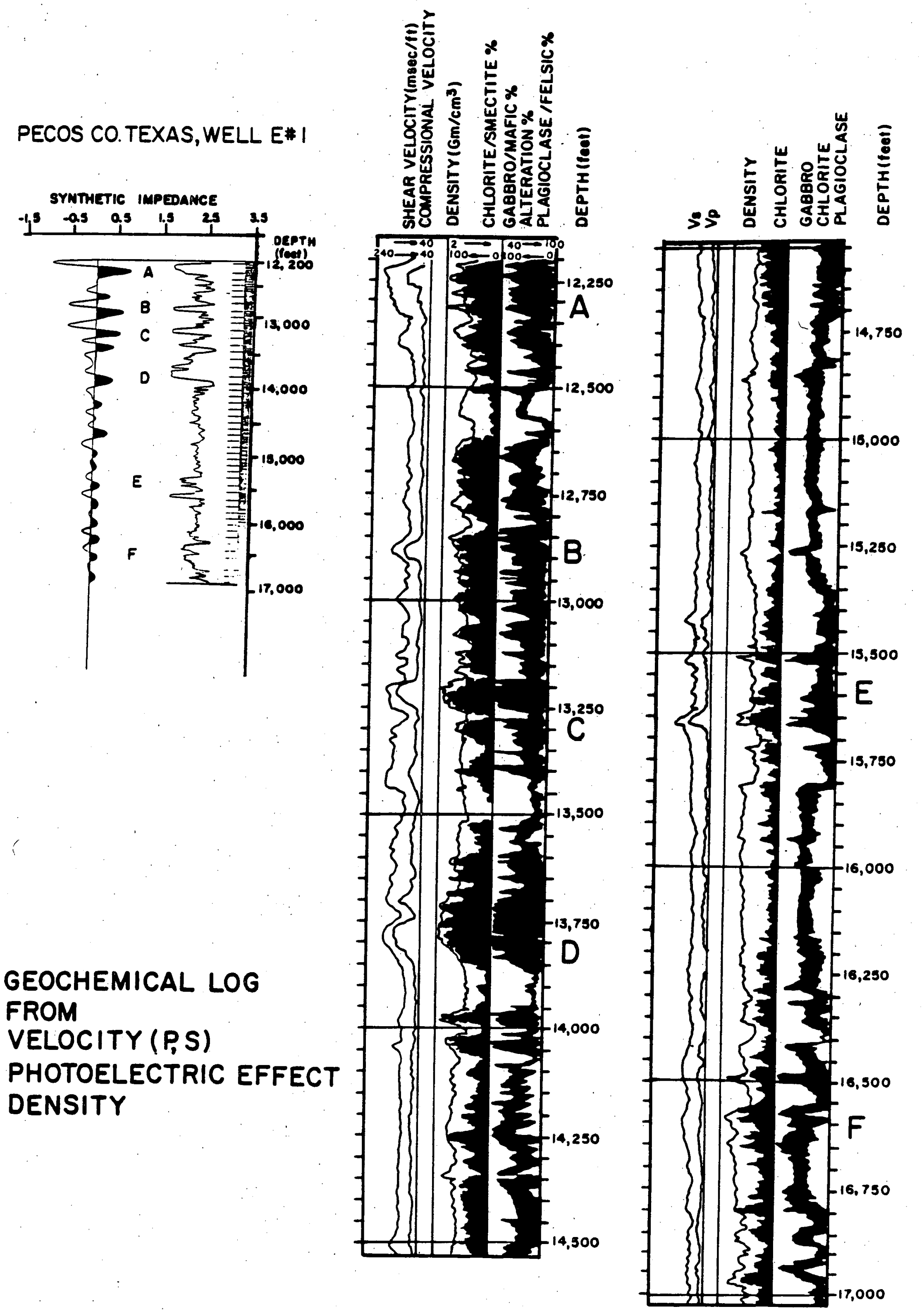


Figure 3-4. Mineralogy logs can be generated from the 'clustering' of velocity, photoelectric factor and density log data about three endmember compositions: gabbro, chlorite, and plagioclase. A matrix inversion can be used to solve for the abundance of each lithology if the average velocity, PEF and density of each can be specified. Here, basement well Nellie #1 in Pecos County, Texas yields logs that can be converted to a pseudo-impedance log (left) and a synthetic seismogram that predicts the reflectors A-F are caused by lithology changes indicated.

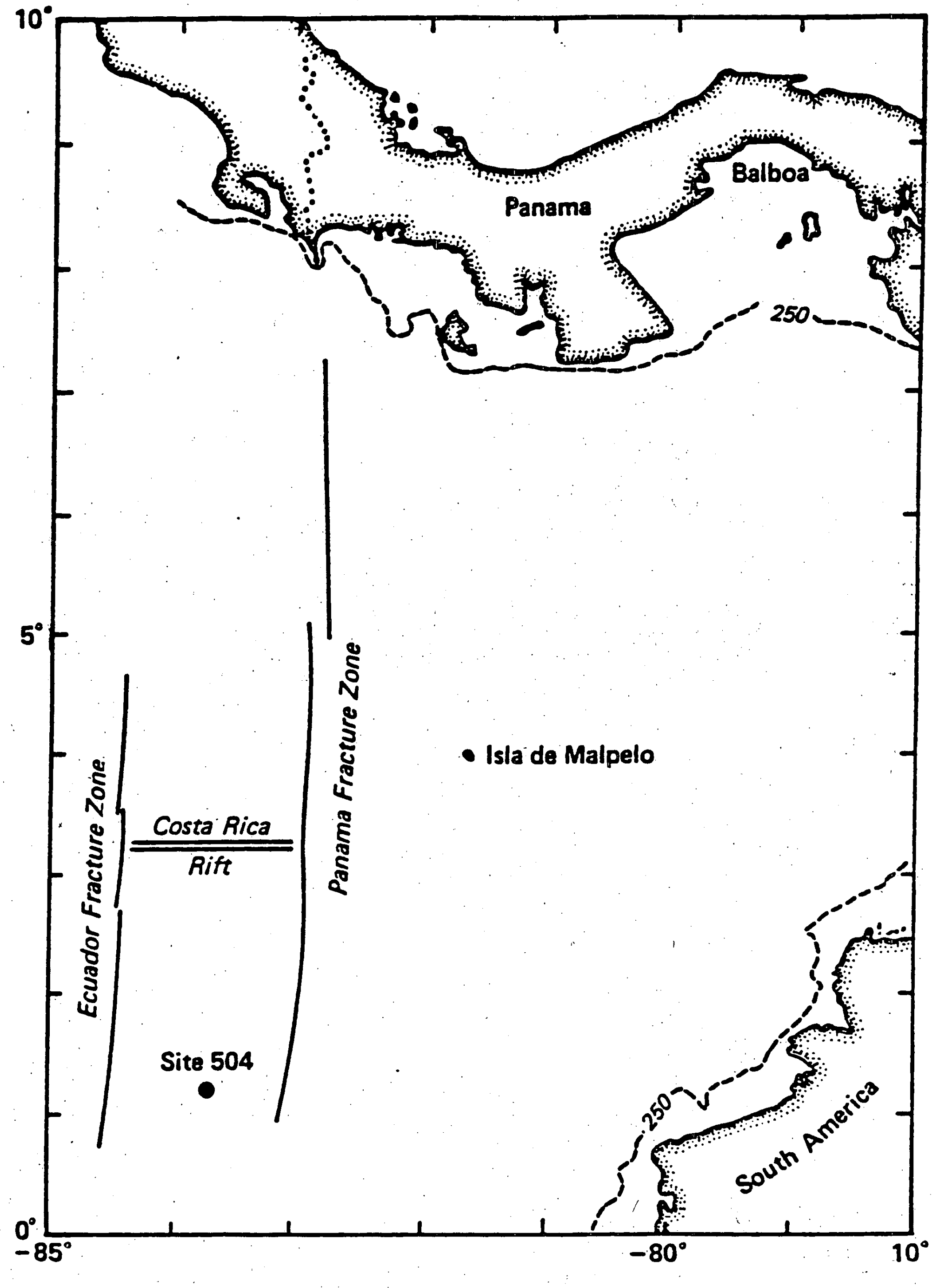
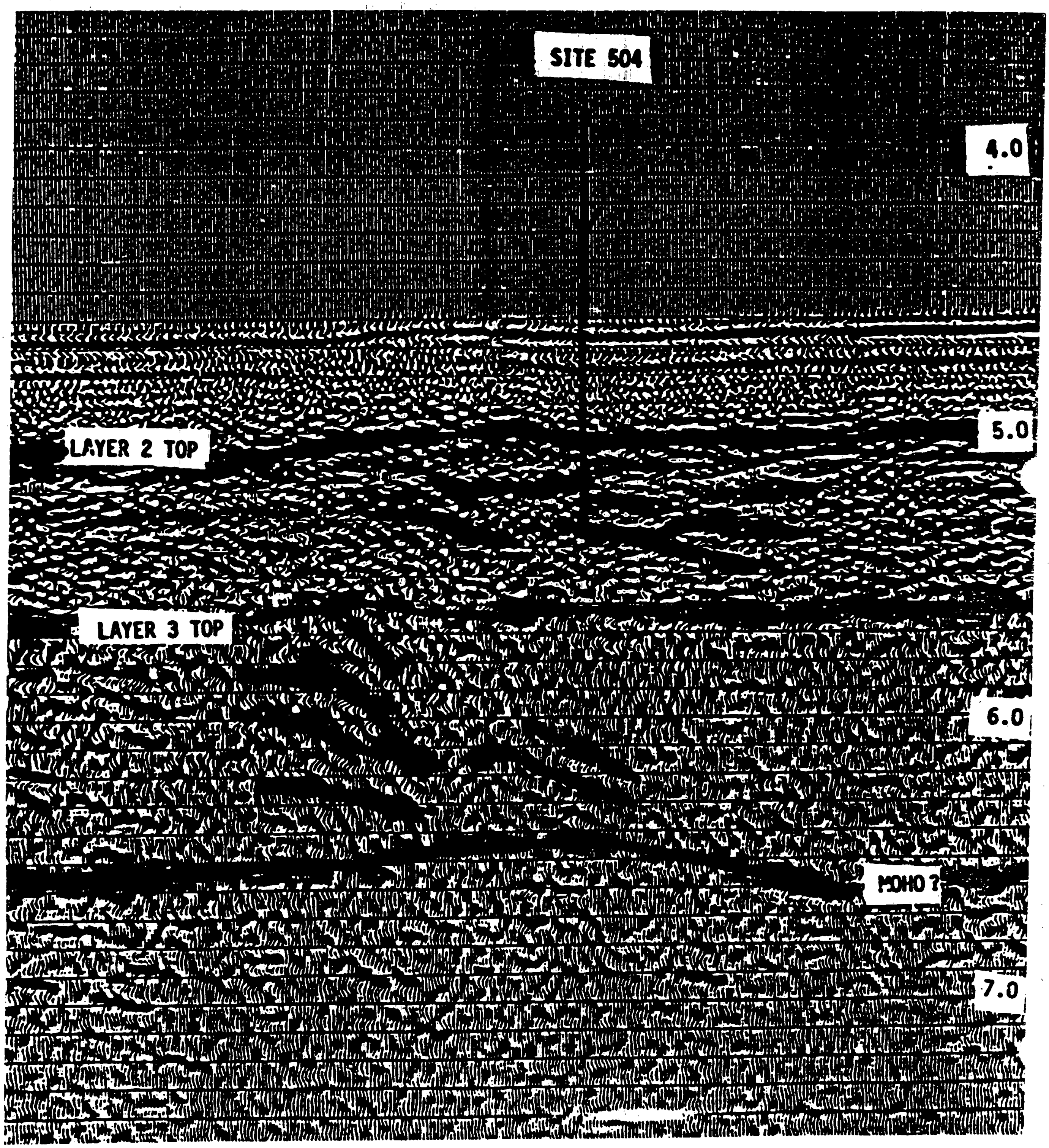


Figure 3-5. Downhole sonic velocities in the upper 1 km of basement in DSDP Hole 504B. On left is a schematic section indicating dominant lithologic units with depth. In the center are 10-m running averages of the downhole P and S velocities. On the right is a simplified velocity model where the sediment column is divided into three layers and the basement is divided into 100 10-m thick layers.

Figure 3-6. Seismic reflection profile across Hole 504B (figure 3-5).



change occurring over 100 m) or the interior of layer 2C itself (the upper section of which is predicted to be acoustically transparent; Figure 3-7).

Another form of oceanic crustal layering occurs at rifted margins where the first ocean crust is formed against stretched continental crust. The Voring Plateau was drilled on Leg 104 in an attempt to determine the cause of the prominent, seaward-dipping reflectors indicated by seismic reflection profiles across this rifted margin (Figure 3-8).

The wireline logs run in the hole showed strong physical property contrasts, with solid basaltic units of variable thicknesses separated by volcaniclastic sedimentary rock (Figure 3-9). The core alternated between basalts and volcaniclastic erosional debris from a shallow and quickly infilling ocean basin similar to that forming currently in the Red Sea. A detailed look at the logs shows that the contrasting responses to the hard basalt and to the soft volcaniclastic debris produce a cyclical impedance pattern (Figure 3-9).

A synthetic seismogram made from the impedance log (velocity times density) shows that prominent reflectors are predicted from the thickest flow basalt units (Figure 3-8). If the basaltic flows are too thin, the wavelength of seismic energy is too large to be reflected off these surfaces. The impedance match of seismic wavelength to basaltic flow thickness determines which reflectors appear on seismic across the region.

Logging in Old Oceanic Crust

Moving seaward from the earliest oceanic crust generated during rifting, Leg 102 conducted a full suite of logs at DSDP Hole 418A, drilled to a depth of 868 mbsf (324 m of sediments and 544 m of basalts) into 110-million-year-old Atlantic crust south of Bermuda. Differences in gamma ray activity allow one to separate the basement interval into three zones (Figure 3-10): an upper 64 m-thick unit (massive + slightly altered pillow basalts) showing low gamma ray values and high velocities, an intermediate 126 m-thick unit (highly altered pillow basalts and breccia) characterized by high gamma ray counts and lower velocities, and a lower unit, 274 m-thick (slighlty altered pillows and massive basalts) which displays low gamma ray values and high velocities. Although velocities within the intermediate altered zone are lower than in the remainder of the hole (4.5 km/s versus 5.3 km/s), nowhere in Hole 418A are they as low as those that characterize the seismic Layer 2A. Here, alteration products such as smectite, calcite, and k-feldspar have almost completely filled the pore space, thus raising the *in-situ* velocities and eliminating Layer 2A as part of the crustal aging process. This hypothesis hsa been tested using the gamma ray curve as an indicator of alteration. In fact, because a good correlation is observed between the alteration profile obtained from cores and the gamma ray curve (Figure 3-11), this has been used to estimate the amount of smectite within the rocks and to correct the porosity measurements (Figure 3-12). The volume of smectite estimated should reflect the amount of smectite added to the crust by interaction with seawater since the basalts were emplaced at the Mid-Atlantic Ridge. Removal of smectite would leave the baslts in thir original state. An upper and lower bound on the original porosity and velocity of the basement (Figure 3-13) are obtained assuming that (a) smectite replaced only part of the original porosity and (b) the original basalt matrix was also partly replaced by smectite (Figure 3-14). In the upper and lower units the reconstructed velocity is almost

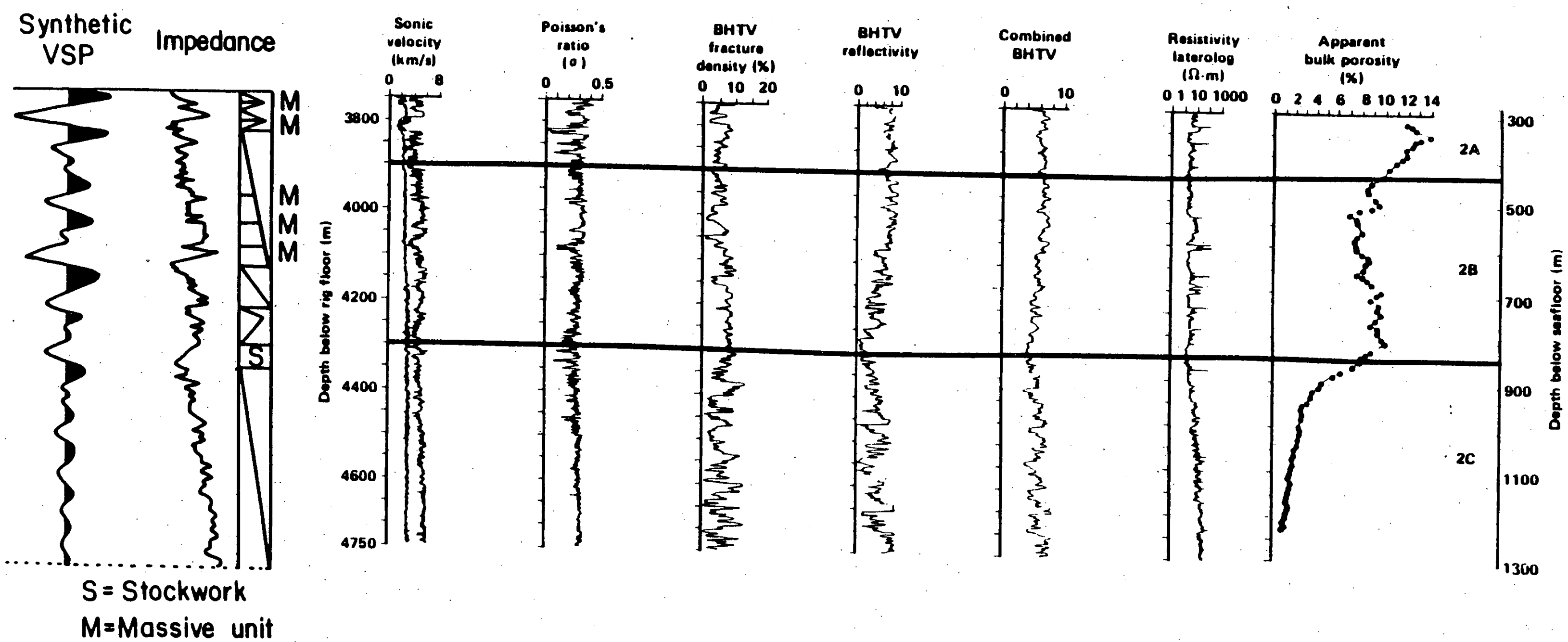


Figure 3-7. Geophysical logs from Hole 504B, including fracture density and reflectivity from Borehole Televiewer imagery, clay content from nuclear, and porosity from long-spaced electrical resistivity, show gradient changes from Layer 2A downward into Layers 2B and 2C. Impedance from velocity and density produce synthetic seismogram (left) which shows strong reflector within Layer 2B, and relatively few reflectors of low amplitude within the top of the dikes of Layer 2C.

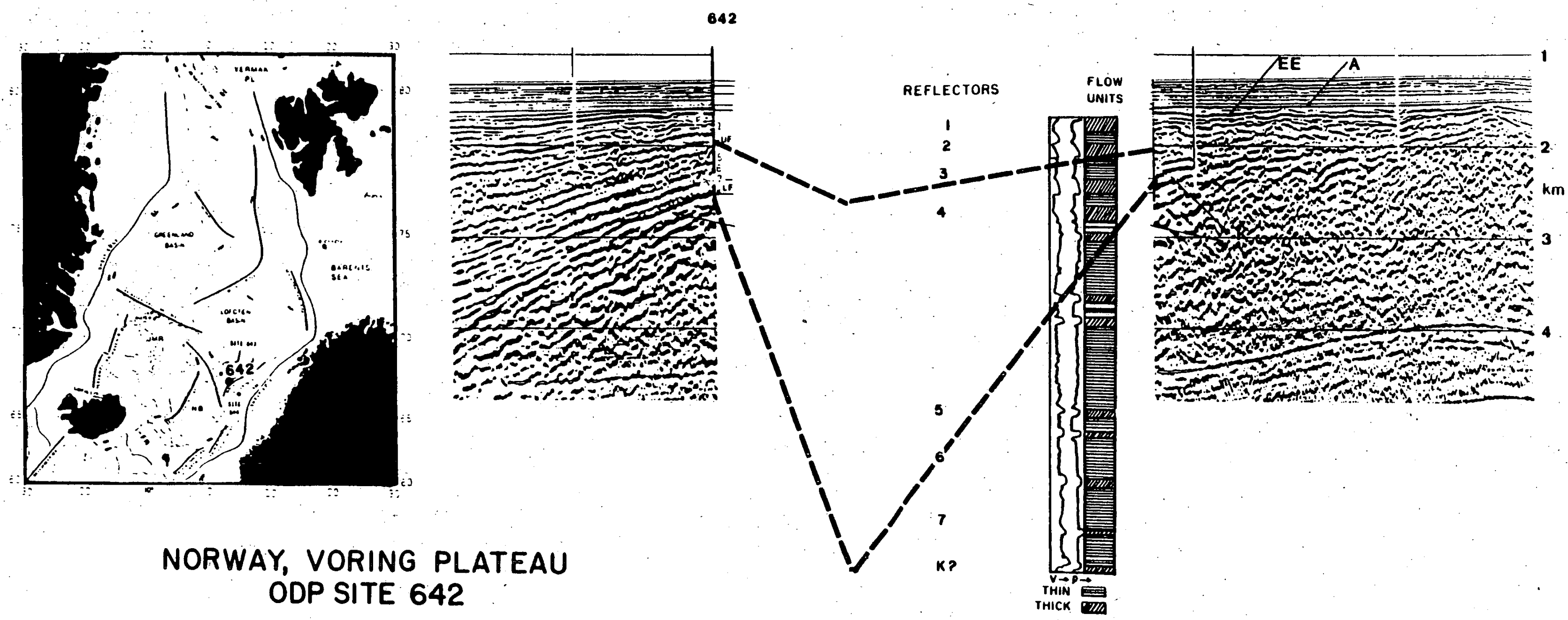


Figure 3-8. Composite of location, seismic reflection profile, synthetic seismogram, impedance log, lithological column, and velocity-density logs of ODP Leg 104 Site 642. Major reflectors are caused by thick flow units within thinner, more interlayered units.

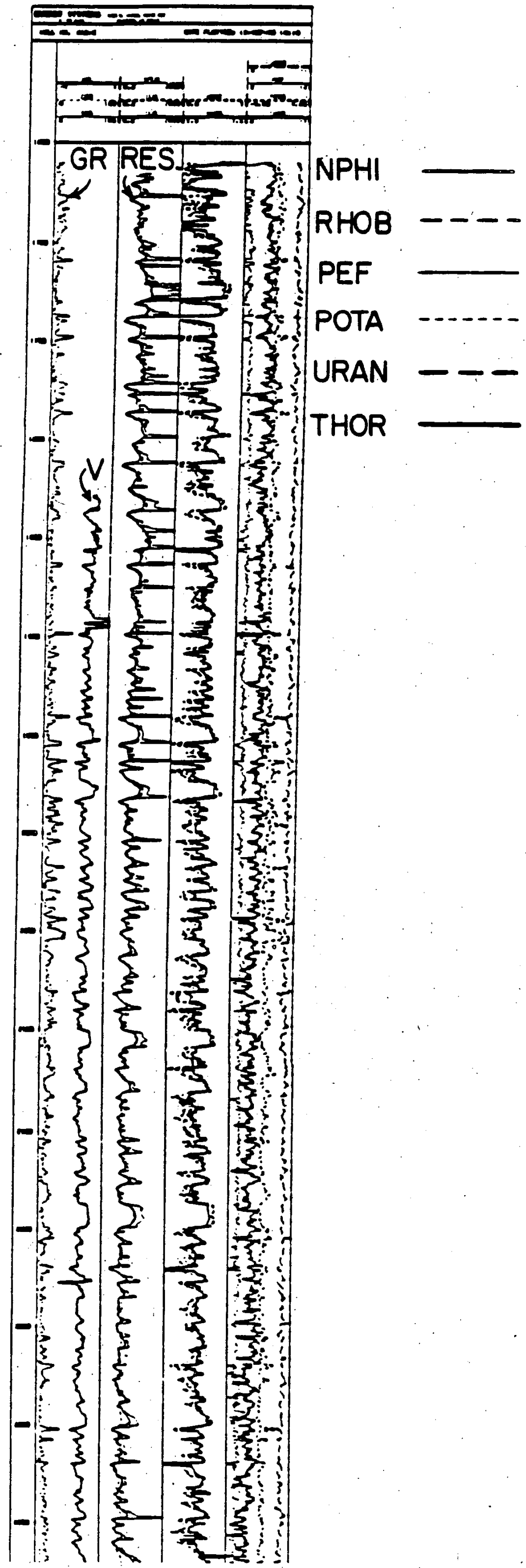


Figure 3-9. Geophysical logs from Site 642 (Figure 3-8). Flow basalts are characterized by high velocity, density, and resistivity values interbedded with highly radiogenic volcaniclastic levels.

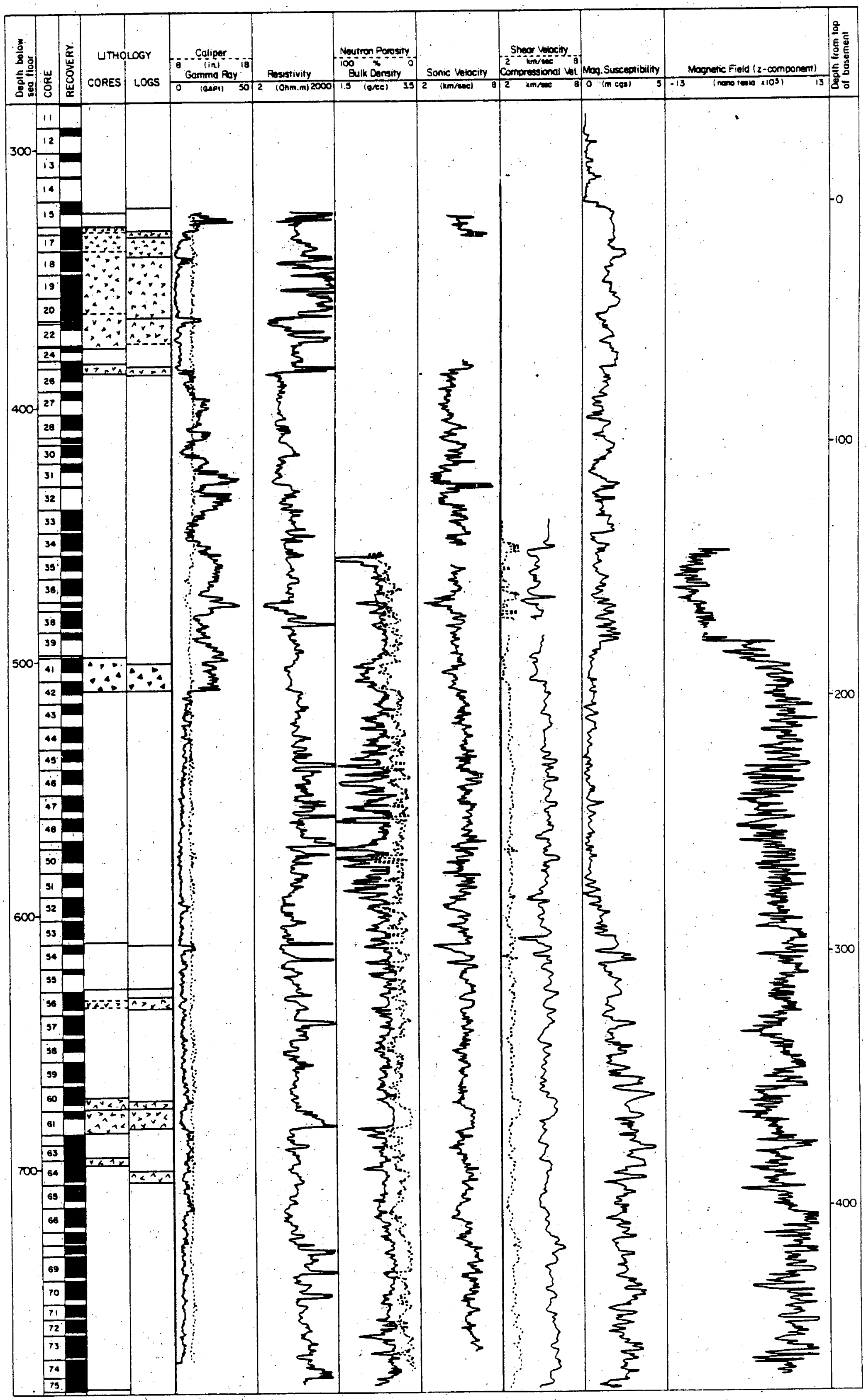


Figure 3-10. Logs from ODP Leg 102, a re-entry of DSDP Hole 418A in 110 My old oceanic crust at the southern end of the Bermuda Rise. Lithologic column from cores (left) and logs (right). Note the magnetic reversal recorded with the 3-axis magnetometer.

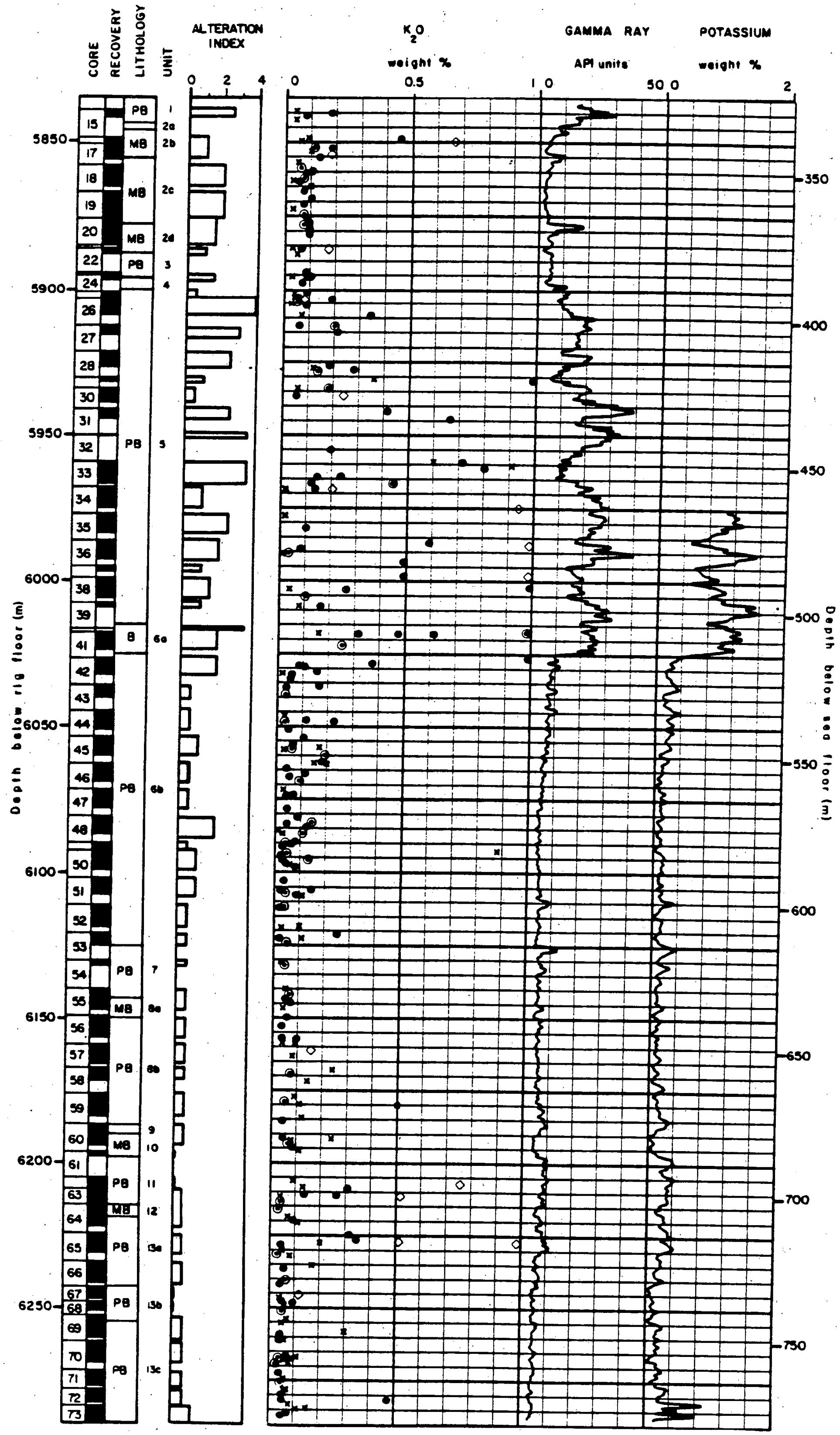


Figure 3-11. Hole 418A, Leg 102 potassium content and total gamma ray counts plotted next to K_2O weight percent from analysis of cores. Also shown is a qualitative alteration index based on visual inspection of cores and core recovery percentages.

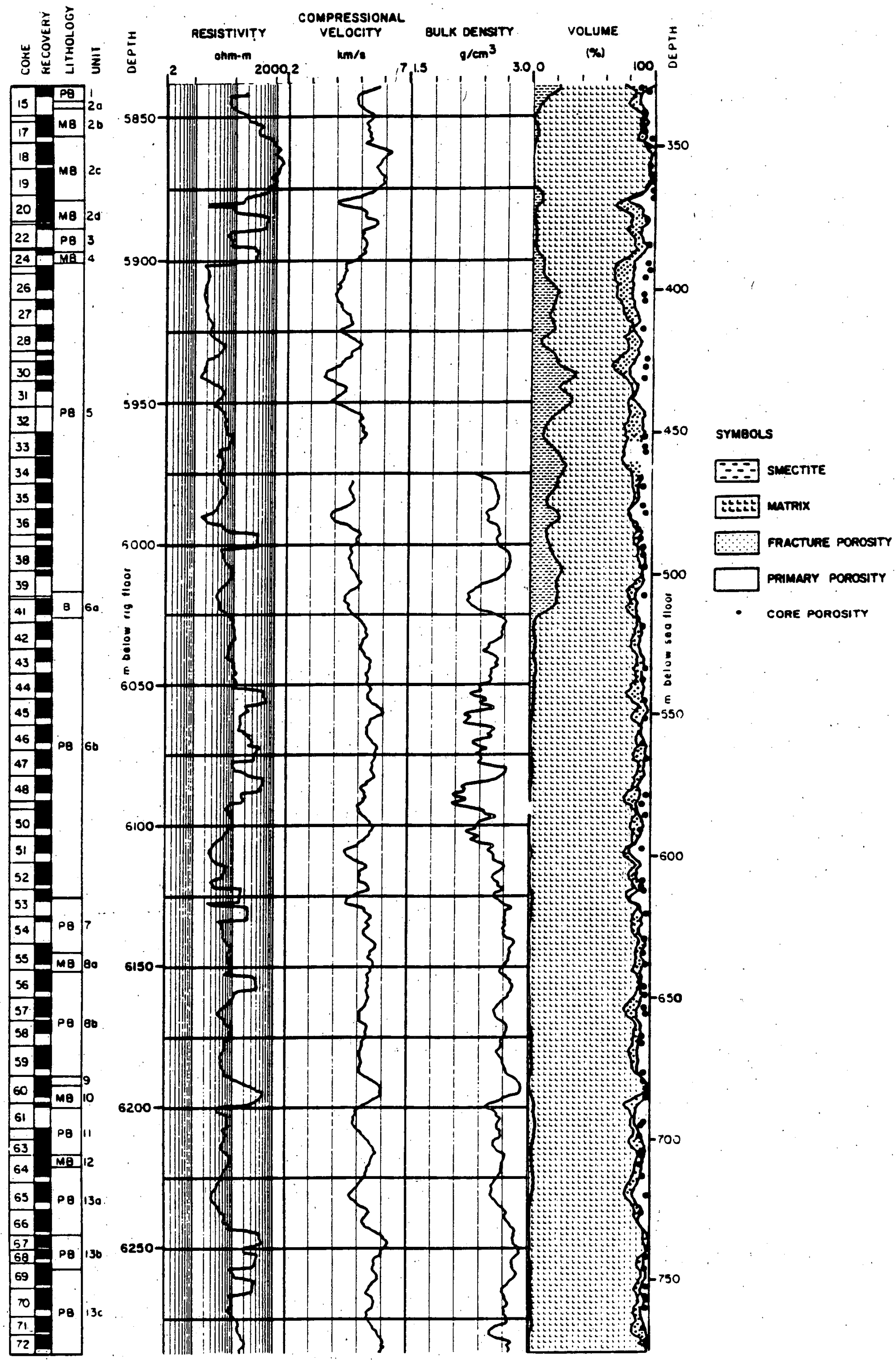


Figure 3-12. Summary of physical properties of basaltic rocks computed from logs at Hole 418A. Smectite volume calculation from gamma ray; total porosity from density-neutron combination after calibration and correction for smectite content; primary porosity computed from sonic log. Curves are smoothed by using a 31-point running average (5 m depth interval). PB = pillow basalt; MB = massive basalt; B = breccia.

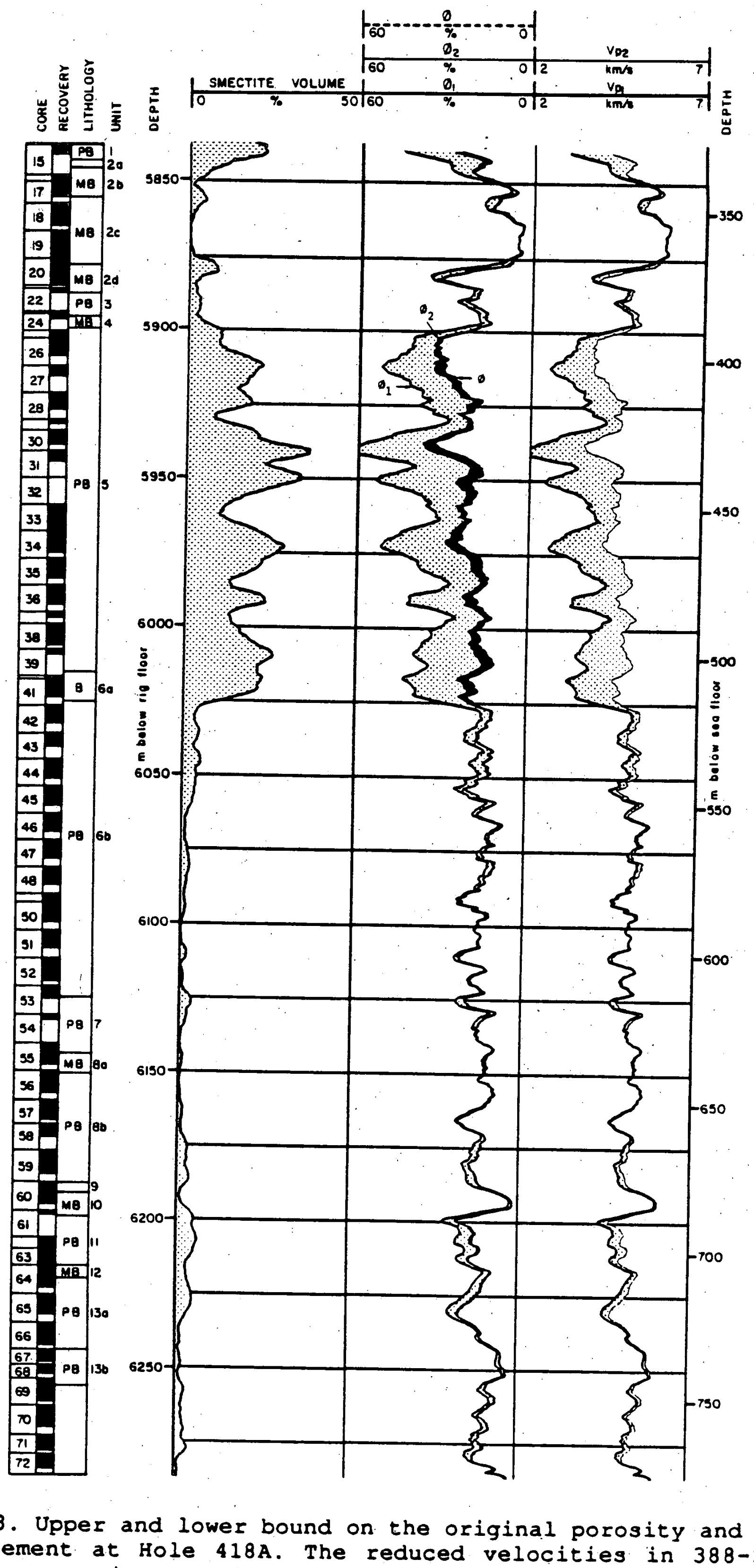


Figure 3-13. Upper and lower bound on the original porosity and velocity of the basement at Hole 418A. The reduced velocities in 388-514 mbsf interval are consistent with seismic Layer 2A velocities previously calculated.

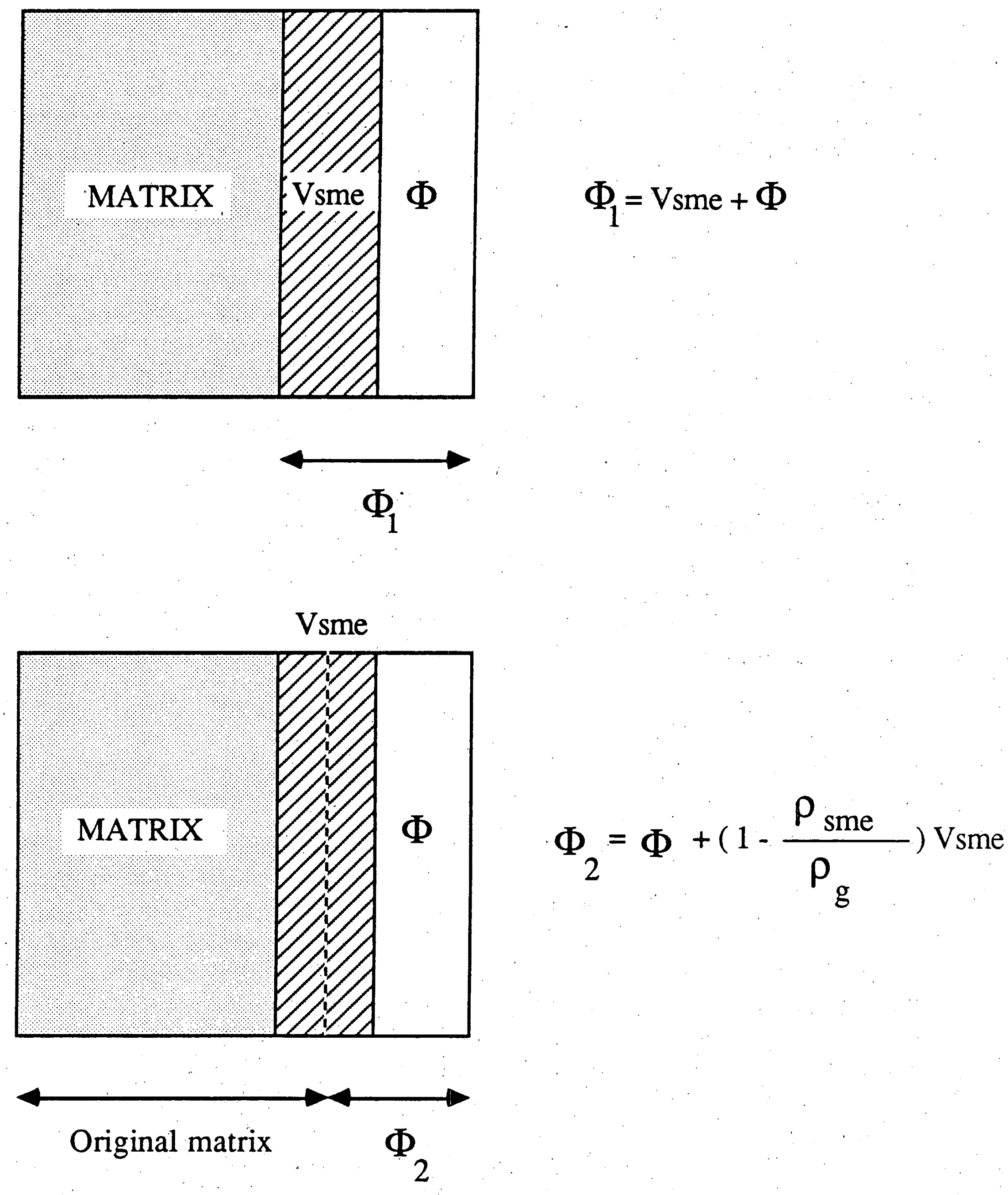


Figure 3-14. Model proposed to reconstruct the original porosity of the basement at Hole 418A. Replacement of the pore space by smectite (above) and replacement of the pore space plus basaltic matrix by smectite (below). ϕ = present porosity; ρg = grain density of basalt; ρsme = grain density of smectite.

unchanged;.in the altered zone, however, the reduced velocities are in accordance with those of seismic Layer 2A.

The lower zone corresponds to the upper part of seismic Layer 2B. It does not show such extreme alteration infilling because it is composed of more tightly structured pillows and by massive units; also, there might have been a much lower initial permeability within this interval.

Permeability is measured by seating a packer across an interval of hole and pumping a small "slug" of pressure into the rock. The packer prevents the flow from returning to the sea floor around the outside of the drillpipe and forces fluid into the formation instead. The formation response to this pulse of pressure then determines its permeability. (See Appendix 1 for a description of the permeability measurement technique by Keir Becker, U. Miami).

Two other logs provided unique information at Hole 418A. The United States Geological Survey ran a magnetic susceptibility tool and the Federal Republic of Germany measured the 3 components of the earth's magnetic field with a magnetometer logging tool. Just above the layer 2A/2B boundary, a magnetic reversal was crossed, with basalts above being negatively magnetized and those below positively magnetized. Magnetic susceptibilities also change at this boundary, but they increase again 100 meters deeper in the section (Figure 3-10). This magnetic boundary is 10 to 20 m shallower than the gamma ray count change marking the layer 2A/2B boundary.

Another useful comparison between logs comes from the velocity structure of the crust measured by the two-source/two-receiver Schlumberger sonic tool (sonic velocity column in Figure 3-10) against compressional and shear velocities determined by the 12-channel sonic tool (Figure 3-10, next column to the right). Even though the general structure is similar, the multichannel sonic tool is less noisy, and bed boundaries are more precisely determined.

Intermediate-Age Oceanic Crust

Site 556 drilled in 37-million-year-old basalt to the west of the Mid-Atlantic Ridge, a DSDP hole in intermediate-age crust, yielded significant logging results (Figure 3-15). Compressional and shear velocities were measured by the Schlumberger two-channel tool, and Poisson's Ratio, combined with density, neutron porosity, and resistivity measurements, were used to identify five major lithological units (Figure 3-16): pillow basalts, massive flow units, basaltic breccia, gabbro breccia, serpentinized gabbro.

Since the latter two are thought to constitute the rock of the lower crustal layer 3, an examination of the log response within these lithologies was made. An M-N crossplot (see Chapter 2) clearly identifies clusters around which the log responses of the different units concentrate (Figure 3-17). The percentage of hydrous minerals in each lithology can then be determined from the apparent porosity differences between the sonic, nuclear, and electrical logs. As shown in Figure 3-18, the serpentinites are easily identifiable from the volume of hydrous alteration minerals. The gabbro, however, appears fresh and relatively unaltered. The serpentinites may have come close to the surface as the top and bottom of either a gabbroic intrusive sill or as a slice caught up in movement along a fault. In any event, the compressional and shear sonic energy spectra show a clear correlation with the

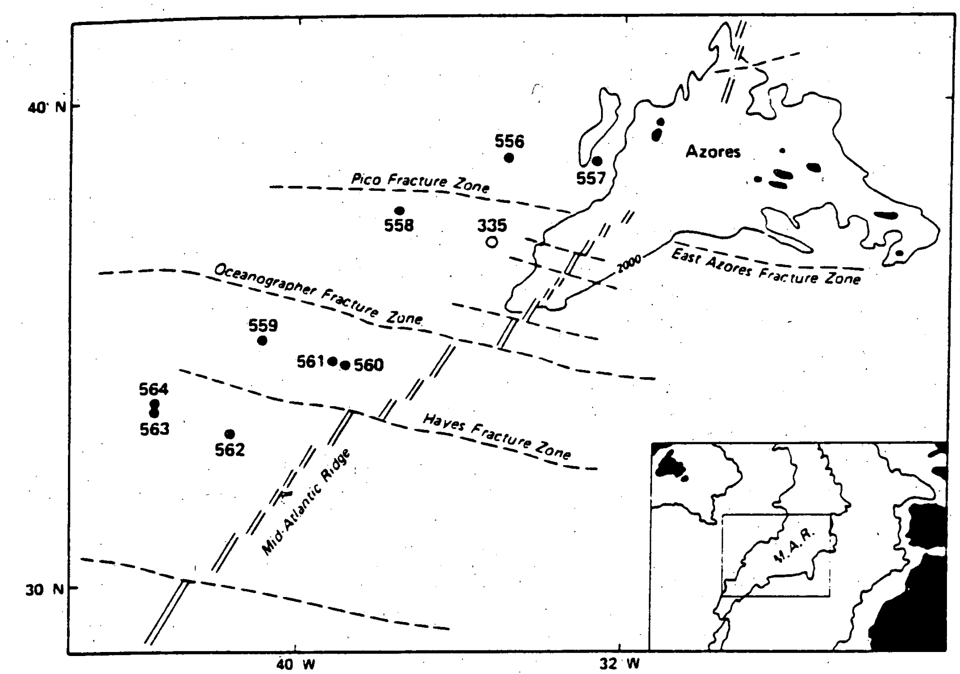
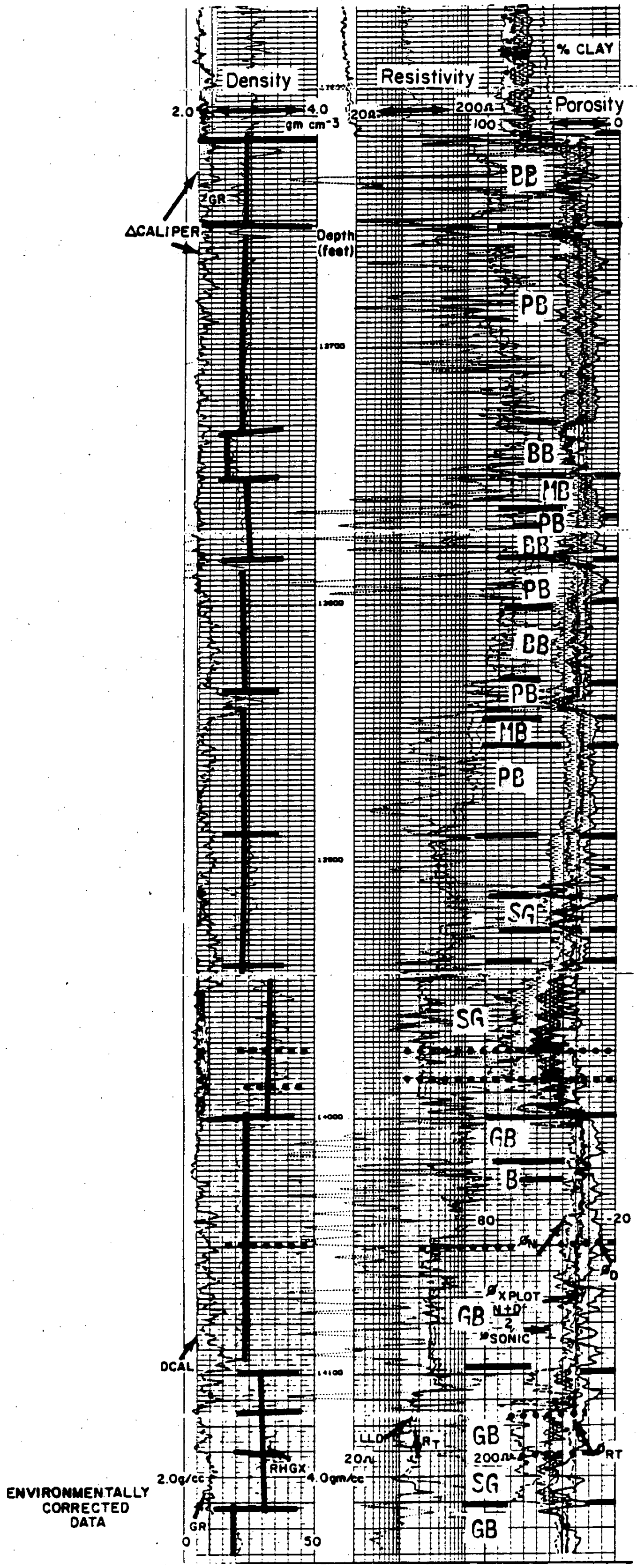


Figure 3-15. Location map for DSDP Hole 556 drilled at 38° 56.38' north latitude and 34° 41.12' west longitude in 3672 m water depth. Total depth drilled was 639 m, 461.5 m into calcareous sediments and 177.5 m into basalt and gabbro.



SITE 556
17ma in Mid-Atlantic Ridge flank (west)

Figure 3-16. Composite logs run at Hole 556 by Schlumberger Well Services. Center: DCAL (caliper hole size minus bit size), gamma-ray density, and laterolog electrical resistivity. Right: several porosity determinations. Lithology boundaries were generally placed by the core recovery that decreased from about 50% in the basalts to less than 20% in the gabbros. Specific lithology boundaries were then determined from the changes in the porosity-sensitive logs. Several stringers are inferred where no core was recovered. Environmental corrections were for hole size, temperature, and pressure. Porosities are not corrected for bound water. Left: compressional and shear-wave velocity with Poisson's ratio as bold line on far left.

LITHOLOGY

PB - Pillow Basalt
MB - Massive Basalt
BB - Basalt Breccia
GB - Gabbro Breccia
SG - Serpentine Gabbro

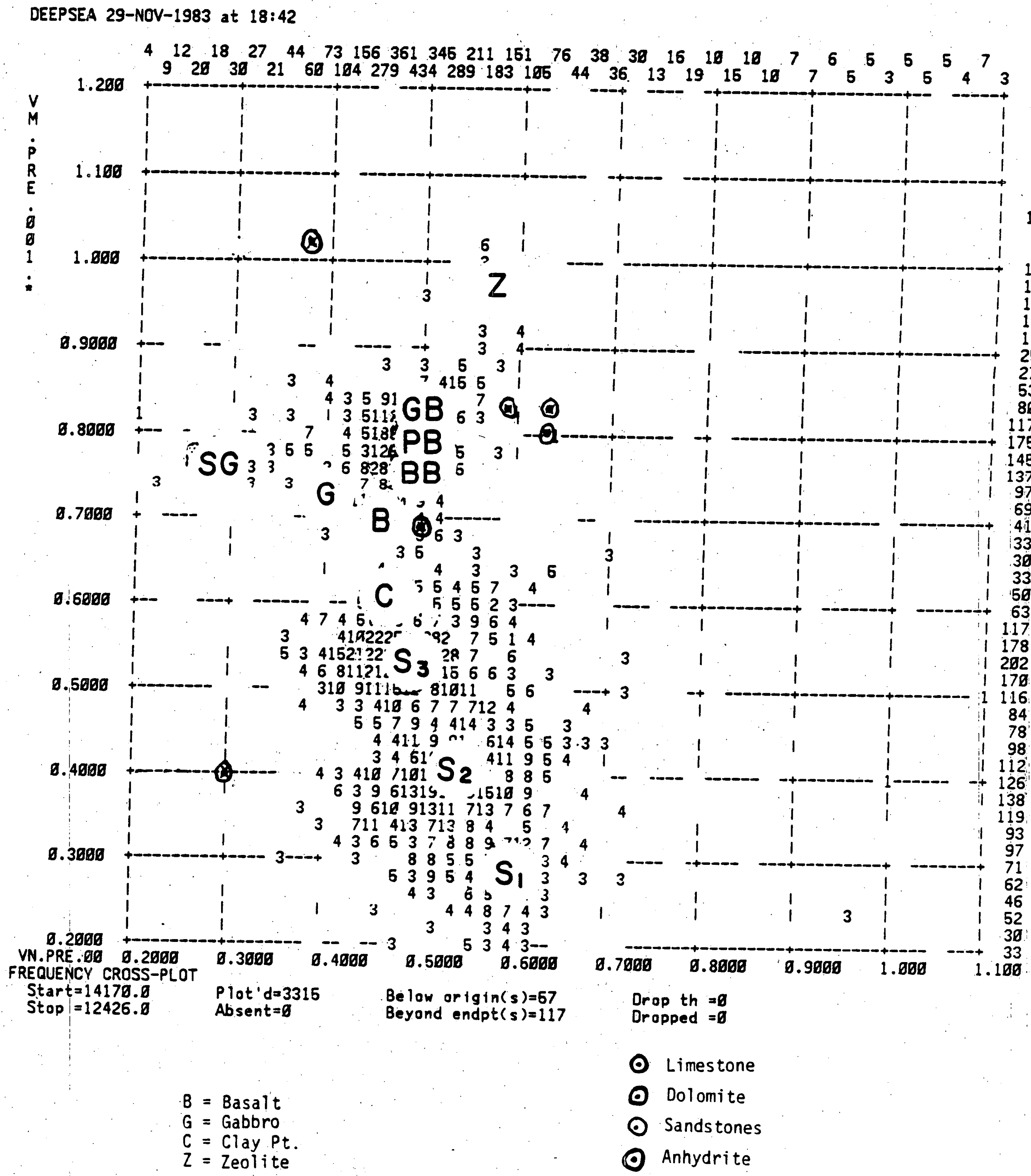


Figure 3-17. Lithologies are identifiable on an M-N crossplot in Hole 556. S1, S2, and S3 are different sedimentary units. The igneous lithology locations other than those from Hole 556 are from oil-bearing formations in Argentina.

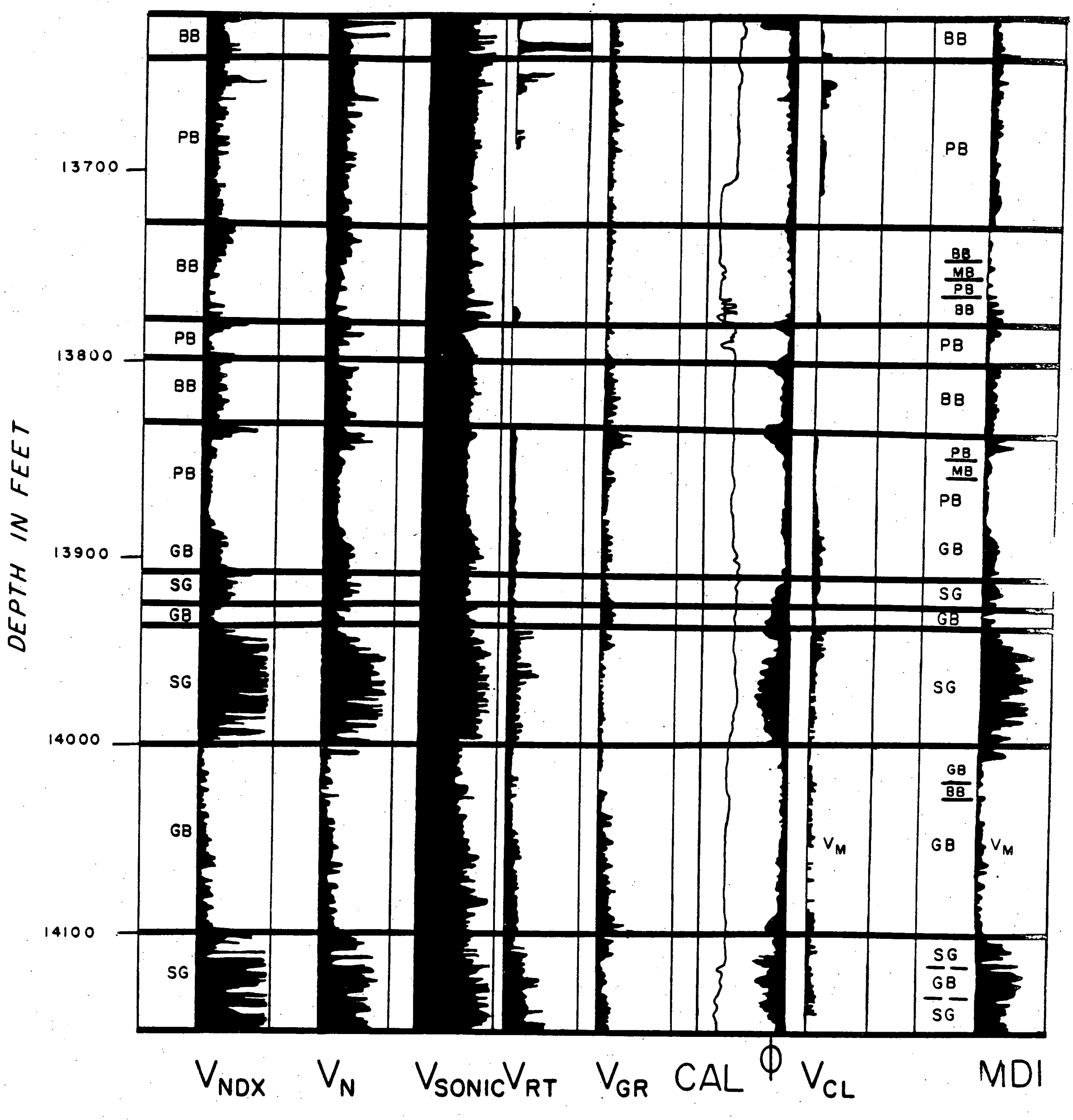


Figure 3-18. Clay-content log for Hole 556. Free water porosities for this hole are probably low, but the ratio is correct. Alteration has bound more water in hydroxyl minerals than is free in pore spaces in this hole. Fully 60% of the minerals in the serpentinite zones are hydrated. Clay-content log shown at right against volumes of clay on left.

degree of alteration in the deeper section of the hole (Figure 3-19). As the energy was preferentially lost in the serpentinite alteration zones, it suggested that the origin of gabbro in the shallow oceanic crust may have been faulting. In fact, fractures are a very efficient conduit for energy transmittal away from the borehole (attenuation).

Young Oceanic Crust

Hole 504B penetrates over 1.5 km of 6-million-year-old oceanic crust in the eastern Pacific (Figure 3-5). Here the logging suite reveals three distinct layers: an upper, 150-m section of very low seismic velocity and resistivity, a middle layer of increased velocity and slightly higher resistivity, and a deep zone of high velocity and resistivity (Figure 3-7). The upper unit, even in this young crust, is highly altered, as can be seen from the neutron-density log porosity contrast. The density log sees a bulk rock density which is only lowered slightly by alteration products (the density of hydrous minerals is about 15% less dense than fresh basalts), whereas the neutron porosity reads quite high because of the abundant hydrogen present in both the pore space and the crack-filling hydrous minerals (Figure 3-18).

The most interesting section of this hole, however, is at the pillow basalt/dike transition boundary (layer 2B/2C). A massive sulfide mineralization stockwork was discovered here (Figure 3-20). This zone appears as the largest hydrous mineral content zone in the hole. Hot, upwelling, mineralized, hydrothermal fluids mixed with cold sea water at this depth in the crust to cause the deposition of this stockwork zone.

The degree of alteration in the hole also affects the sonic waveforms (Figure 3-21). Alteration content and attenuation of the sonic waveforms correlate qualitatively. Quantitative estimates of the amount of energy loss due to alteration zones of either open or filled fractures can be determined from spectral analyses of the sonic waveforms. There is over a 0.75 correlation coefficient between zones of low P and S sonic energy (measured in dB from the power spectra of the different waveform coda) and open fracture zones imaged by the ultrasonic Borehole Televiewer (Figure 3-22). Stoneley surface wave energy, and very high frequency normal modal energy and frequency changes also correlate with zones of fracturing seen by the BHTV. Energy loss and frequency shifts are likely from acoustic attenuation, or energy loss away from the borehole wall through open interconnected fractures. An as yet unsolved problem is the quantitative interrelation between acoustic attenuation and hydraulic permeability.

One of the interesting results from logging in Hole 504B was the detection of cyclicity down the wellbore. These cycles affect all the logs, including velocity, resistivity and the degree of fracturing, as recorded by the BHTV (Figure 3-23). Core recovery was <15% in the basaltic section of this hole, so the cores were not of much help in determining the cause of the cyclicity. The core did show high potassium contents in the layer 2A and upper 2B pillows, and high Fe, low Al, and low Ca in the stockwork and just below. But no cyclicity with a wavelength of 50 meters or so was detected in the chemistry from the cores.

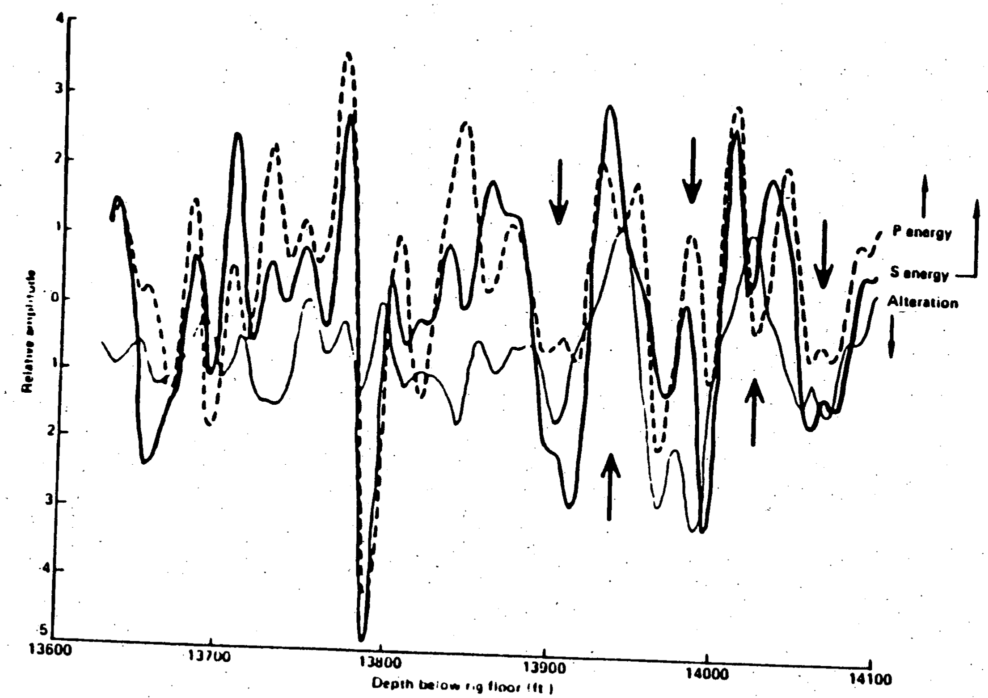


Figure 3-19. The P energy, S energy, and alteration logs from Hole 556 were detrended, normalized, and bandpass filtered to pass only wavelengths of 20-100 ft. Note particularly strong correlation between P and S energy (arrows).

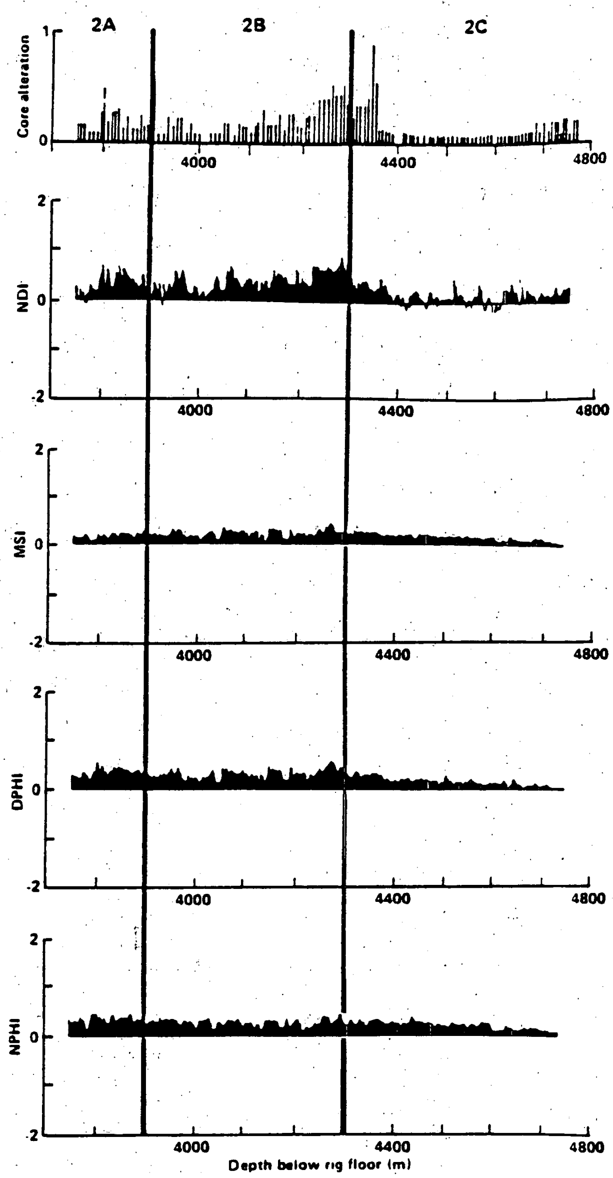


Figure 3-20. Average values in Hole 504B for NPHI (porosity calculated from the neutron log), DPHI (density calculated from the gamma-ray density log), MSI (minimum shale index from a dual-water CYBERLOOK program), NDI (hydroxl-mineral content calculation from the differencing scheme), and core alteration. The last histogram was determined from least altered (0) to most altered (1), using visual descriptions from barrel sheets.

SONIC WAVEFORM-HYDROXYL ANALYSIS CORRELATION

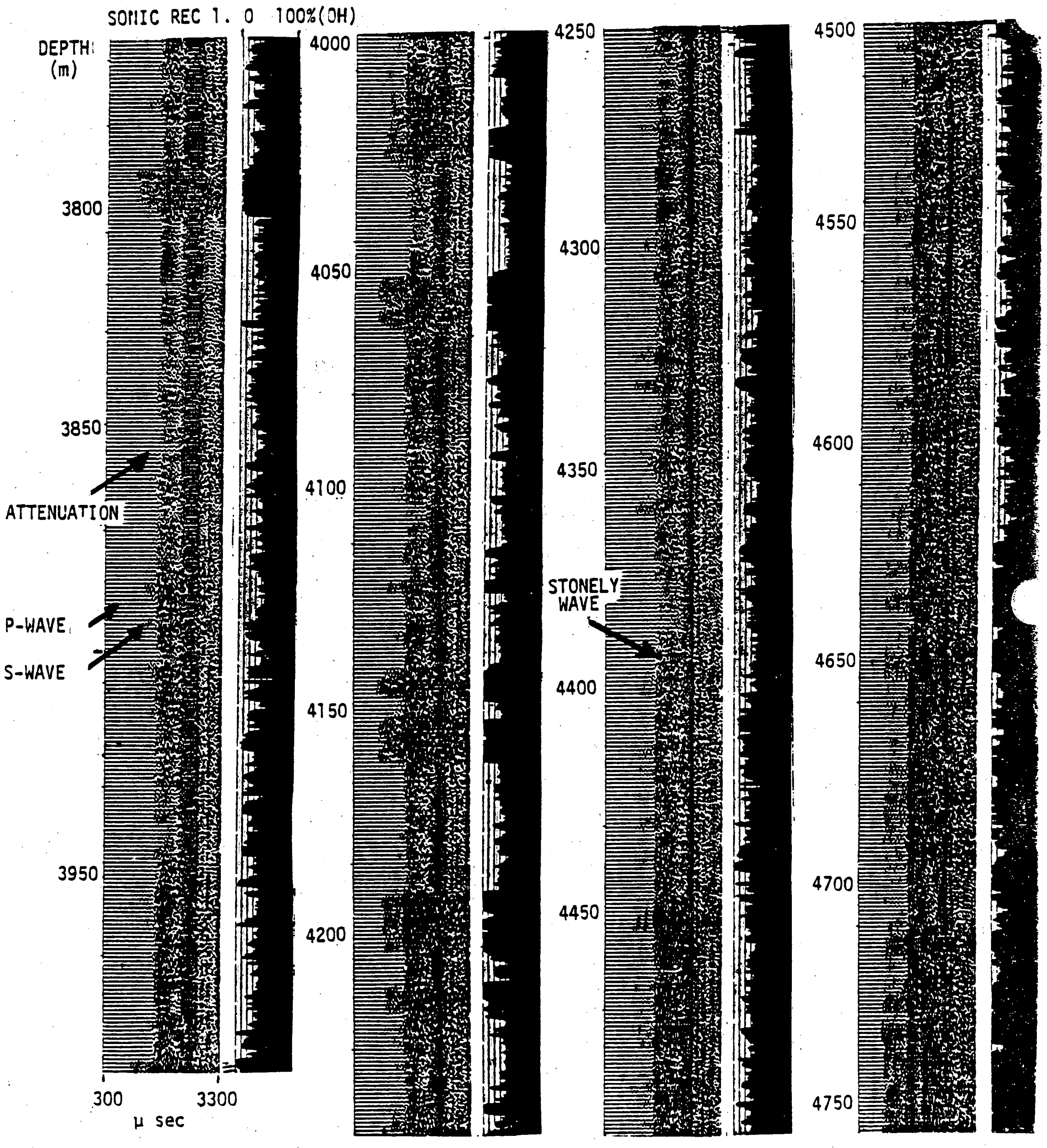


Figure 3-21 . The raw sonic waveforms from the first receiver located 8 ft. above the source are correlated with the hydroxyl content log NDI. Blackness in the last curve is the percentage of matrix material, horizontal bars are every 10% of alteration products present (e.g., at 4100 m depth, 30% altered clays and zeolites, and 70% unaltered basalt are present in the rock).

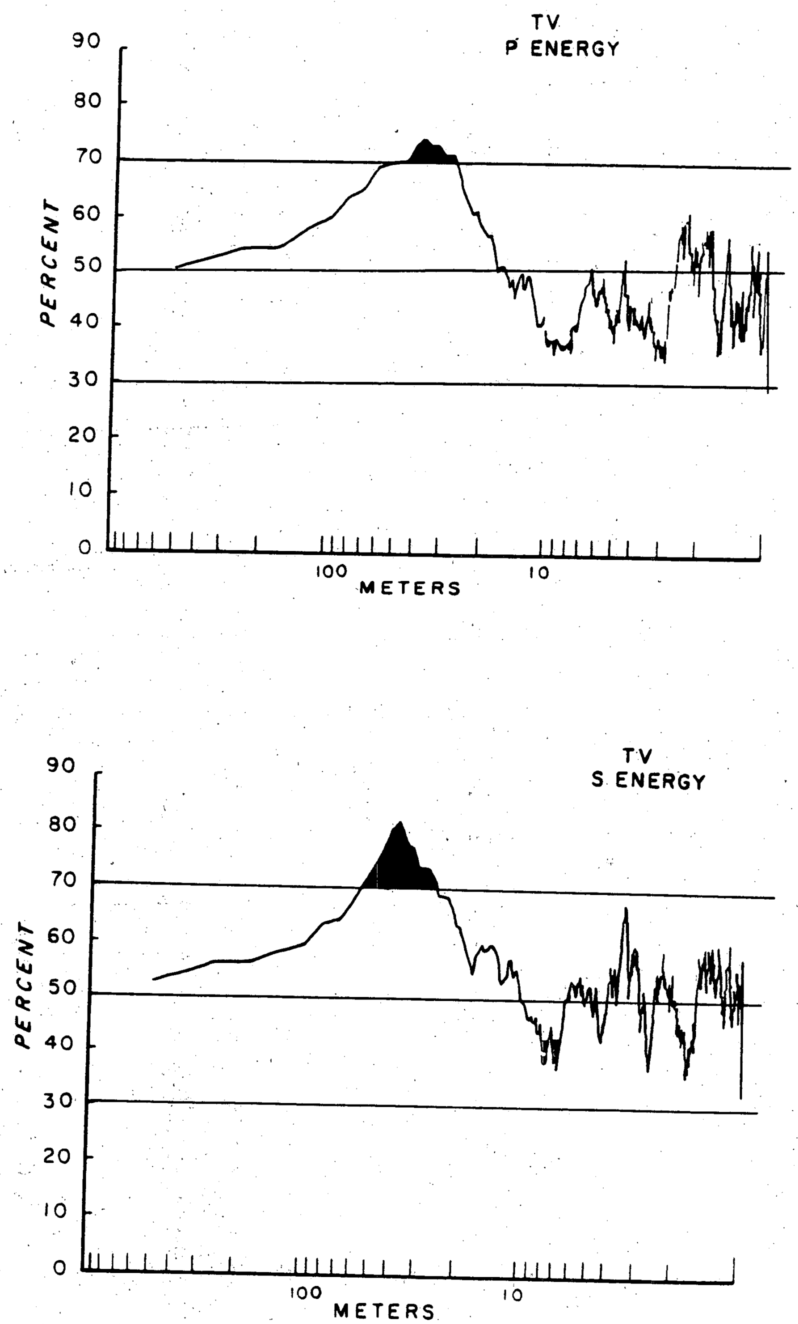


Figure 3-22. Phase difference of TV (BHTV fractures plus voids) and P and S energy in Hole 504B. Positive correlation is between high energy and zones of low fracture level.

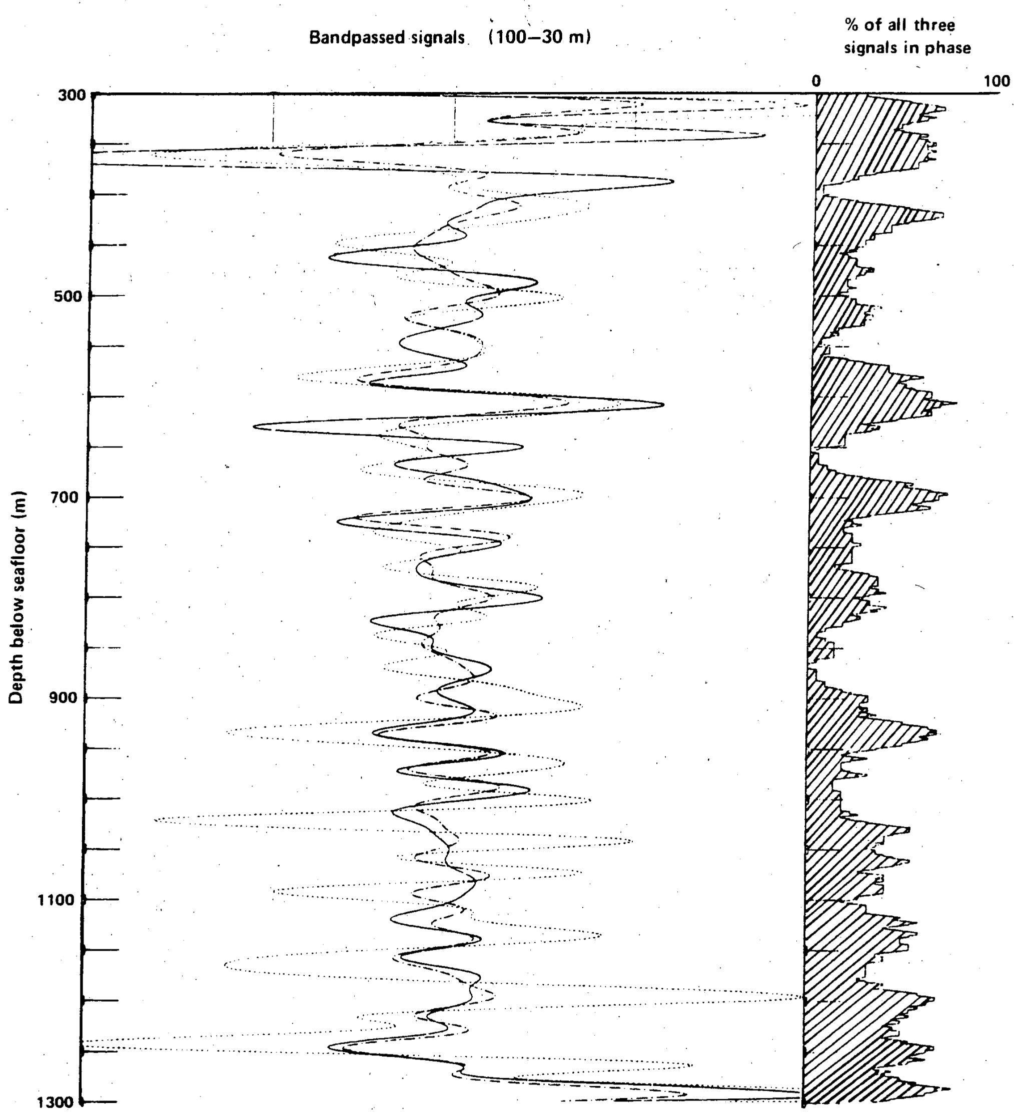


Figure 3-23. Band-passed velocity (solid), resistivity (dashed), and borehole televiewer fractures (dotted) logs from Hole 504B.

Nuclear Logging

Resistivity-acoustic-nuclear logs were recorded during Leg 83 through the pillow lavas of layers 2A and 2B and in the uppermost section of layer 2C dikes. In addition, during Leg 111, a geochemical logging string measured elemental abundances in the hole, allowing for the detection of cyclicity in aluminum content (Figure 3-24). The Al abundance changes appear gradual within units of a few meters thickness, whereas abrupt shifts occur between units (e.g., between 4500 m and 4700 m). The variation in Al content can be directly attributed to the plagioclase variations in the different basalt units encountered in the hole. High Al plagioclase-olivine and plagioclase-olivine-clinopyroxene phyric basalt units alternate with low Al olivine phyric basalts to cause the cyclicity (Figure 3-22). Mg/Ca versus Al/Fe has been shown to be an excellent differentiator of mid-ocean ridge basaltic magma evolution, with olivine fractionation distinctly higher in Mg/Ca than the high Al/Fe plagioclase trend (Figure 3-25). The Hole 504B bulk chemical composition shows that, although there are both phyric and aphyric units intermixed within each layer, there is a distinct trend toward the intersection of phyric and aphyric compositions toward the bottom of the hole. The dikes are the lowest Mg/Ca and Al/Fe rocks in the hole.

The Mg abundance calculated from the photoelectric effect in Hole 504B further shows characteristic "spikes" of high Mg systematically recorded throughout the section (Figure 3-24). These spikes generally correspond to the boundaries of Al units, and likely indicate the presence of Mg-clay bearing breccia zones. In addition, there is a general decrease in Mg content with depth in the well (Figure 3-24). This result contrasts with core analyses, which indicate a slight increase in Mg with depth. Cores probably represent the least-altered basalt present in the formation, while logs respond to the bulk composition of the rock.

Normative Mineralogy Log

The variation in Si, Al, Fe, Mg, and Ca recorded by the nuclear logs can be used to calculate normative mineralogy changes within Hole 504B. The distribution of minerals falls within a five-cornered solid with a major element at each point called a tri-dipyramid (a tridip diagram) (Figure 3-26). With five elements, six minerals can be calculated using matrix inversion techniques. The elemental composition of each mineral is specified from microprobe analyses of core (Table 3-1). These minerals fall within specific clusters of four-corner plots made from projected compositions for each face of the solid (Figure 3-26).

The log of mineral abundances shows two major mineralogical suites within the hole (Figure 3-27). Plagioclase + clinopyroxene + olivine forms the bulk of the formation (this is the basalt itself). A second component divides the basalt into specific units, and appears as large spikes of Mg, Ca, and Si-rich Amphibole (Actinolite in the dike section); Al, Fe, and Mg-rich Chlorite (in the dikes); Fe, Mg, and Si-rich Smectite clays (Figure 3-28).

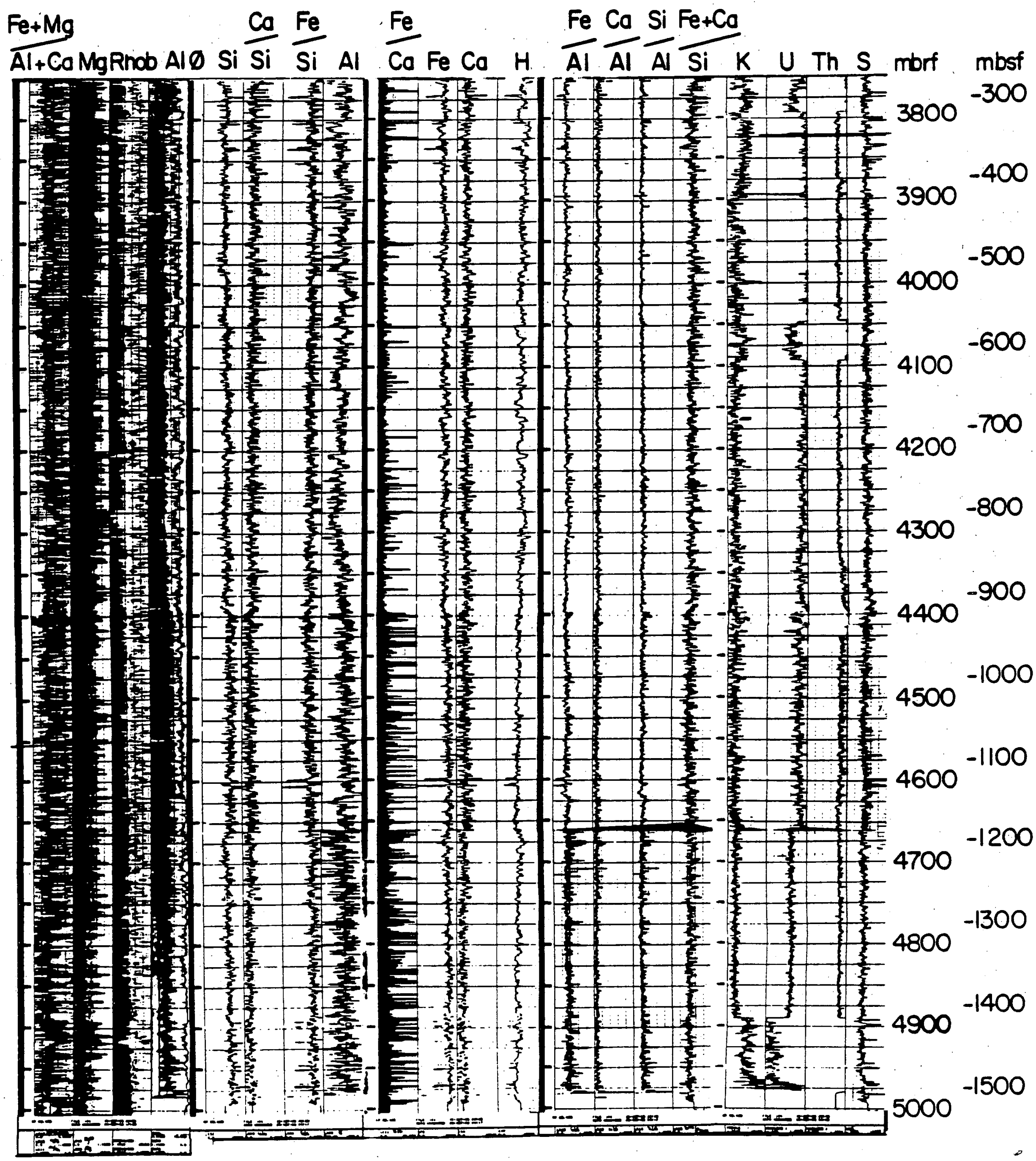


Figure 3-24. Elemental abundances and ratios from Nuclear logs over Hole 504B basement section.

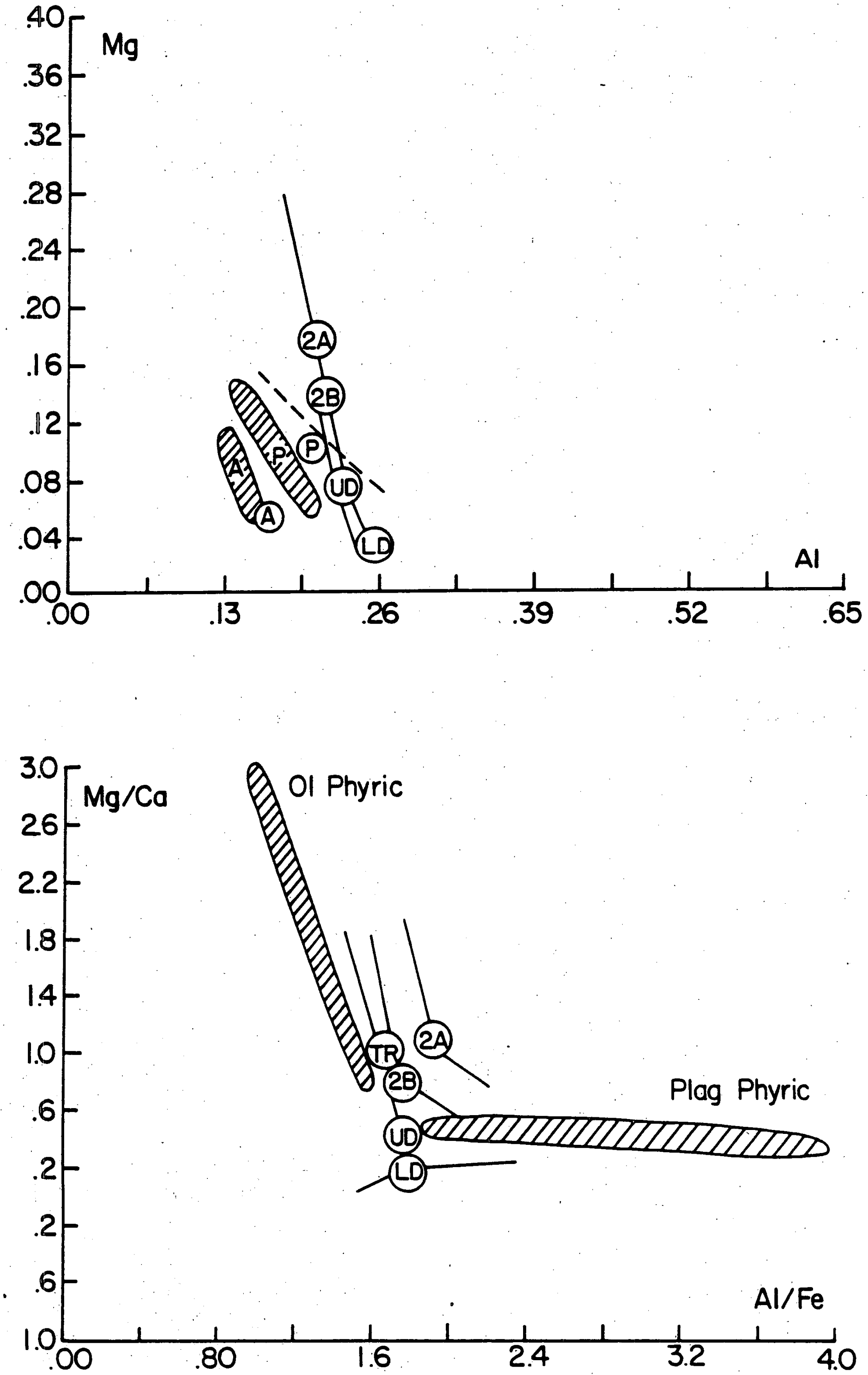


Figure 3-25. Mg versus Al and Mg/Ca versus Al/Fe cross plot for Hole 504B. Data from lower dikes. Trends and medians shown for other layers to show how composition changes up the hole. Olivine phyric and plagioclase phyric MORB basalt trends shown.

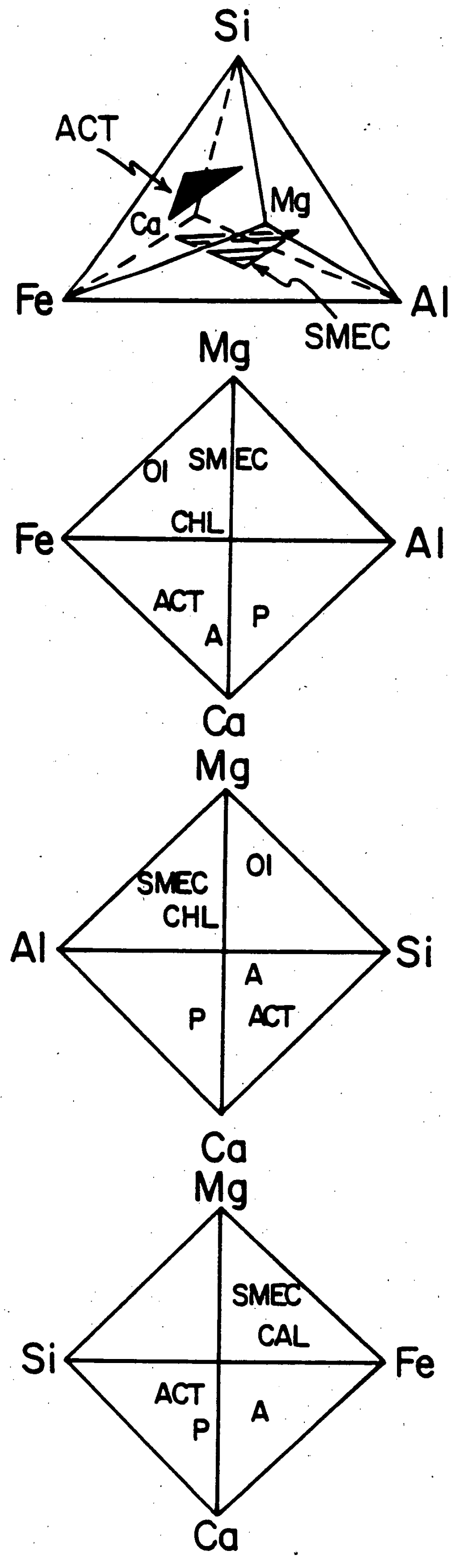


Figure 3-26. Three faces (below) of five-pointed tri-dipyramid solid (top) with mineral "cluster" locations indicated within elemental yields.

Table 3-1

	ACT	CHL	SMEC	PLAG	CPX	OL
Si	.53	.28	.49	.49	.55	.36
Al	.02	.17	.06	.38	.002	.002
Fe	.15	.21	.12	.02	.22	.08
Mg	.13	.18	.23	.02	.10	.53
Ca	.13	.002	.016	.13	.10	.002
Mg/Ca	1	53	20.5	.15	1	26.5
Fe/Ca	1.1	113	10.2			
Al/Fe				19	.01	.025

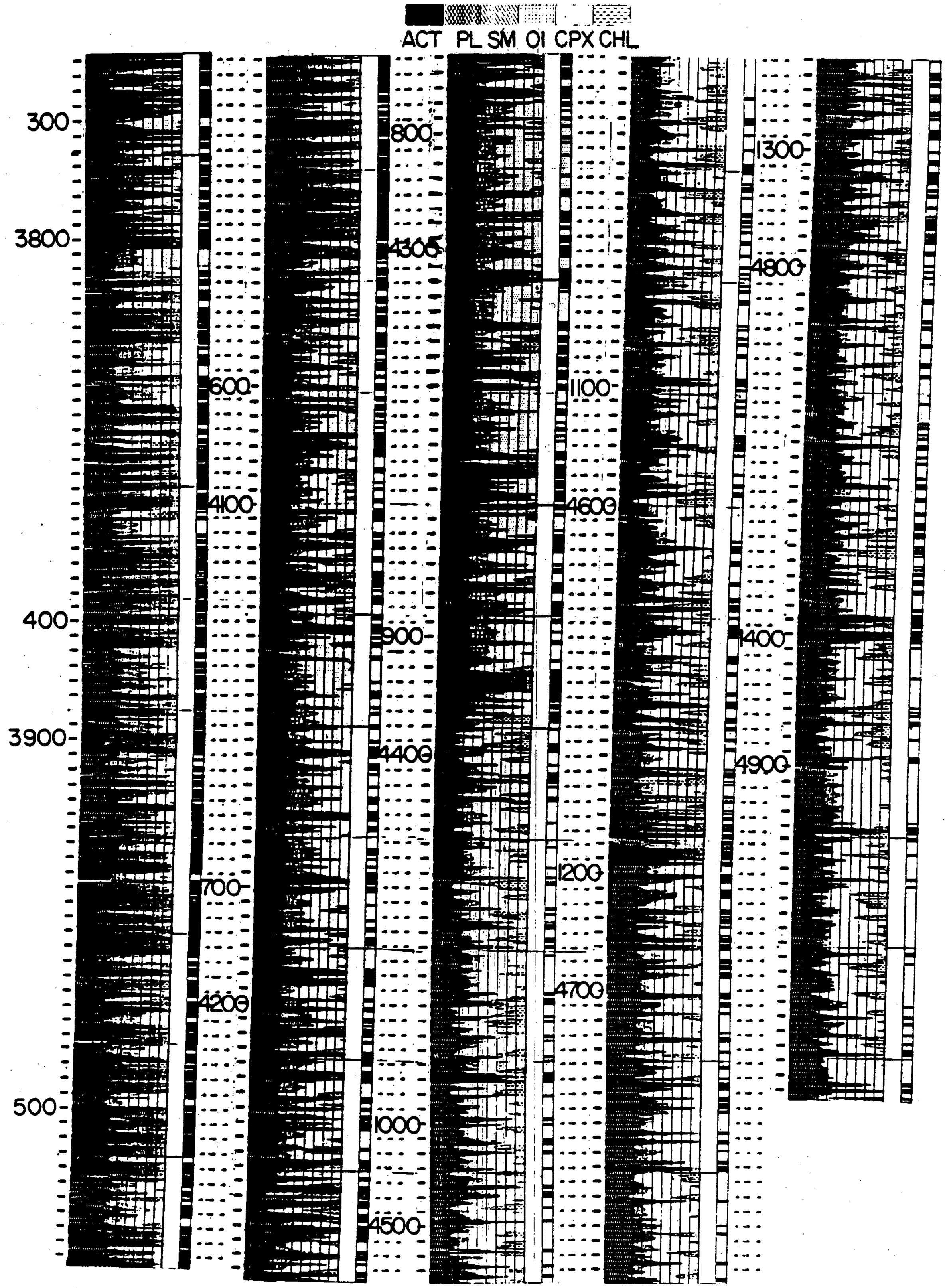


Figure 3-27. Normative mineral log from Hole 504B nuclear log elemental abundances and matrix inversion of normative mineral compositions shown in Table 3-1. Dark shading is abundance of actinolite and its low-temperature clay equivalent.

Summary of Logging Results at Hole 504B

The mineralogical variations in Hole 504B allow us fully to describe the geochemistry of the section through which we drilled, in spite of less than 20% core recovery. We find it remarkably homogeneous, with largely unaltered basalts separated into distinct units by breccia zones, both within the pillows and within the dikes (Figure 3-28). Basaltic chemical changes are predominantly plagioclase-olivine primary magma variations which show up as alternating zones of high plagioclase, low clinopyroxene phyric basalts and high olivine, low plagioclase aphyric basalts (Figure 3-28).

In addition, the extensive volume of alteration minerals in the pillow layers 2A and 2B results in higher Mg and Fe and lower Ca content than in the dikes (Figure 3-28). This suggests that the degree of alteration is decreasing into the dikes, just as might be expected from the permeability and porosity variations which showed the dikes to be much tighter, lower porosity rock than the pillows (Figure 3-29). Fe and Ca are differently affected by alteration, with much more Ca leaving the basalt into hydrothermal fluids than Fe, which is more readily redeposited from the fluid into clays, chlorite, and other alteration products. Since the neutron activation log sees bulk chemistry, the chlorite or clay-rich breccia zones, including those at unit boundaries, are recorded as high Fe/Ca and Mg/Ca ratio areas (Figure 3-28). The increase in Fe/Ca spikes below the stockwork suggests that the alteration in the dike section is predominantly chlorite, just as was indicated by the laboratory x-ray defraction analyses of mineralogical changes in the hole.

It is clear that the nuclear logs are sensitive to the chemical evolution of this young oceanic crust. A reasonable scenario for the evolutionary history of that crust might be as follows: Variable Al content eruption events alternated during original deposition of the 504B crust at the Costa Rica Rift ridge axis. The logs and core suggested that plagioclase changes caused these primary Al content variations. Subsequently, interaction with hot sea water began as the crust spread and aged away from the ridge crest. High temperature alteration appears to have been present throughout the dikes, but low temperature alteration trends are present within the log responses in the pillow section (the smectite to chlorite-rich clay transition. The cause of the cyclicity in geophysical and geochemical logs is the basaltic unit variation in plagioclase content of eruptive flows, pillows, and dikes, each of which is separated by distinct breccia zones.

Basalt-Sea Water Interaction

The information contained in the nuclear logs relates to bulk chemical changes occurring at the time of emplacement of the basalt from the magma chamber (plagioclase concentration changes) and to subsequent hydrothermal pore fluid-rock interactions. Expected changes are K and Mg into the rock in exchange for Ca, Fe, and Si out of the rock at low temperatures. Ca mostly exits the system in the pore fluid; whereas Fe, Mg, and Si are redeposited in vein-filling minerals. This is particularly evident in the distinct Fe/Ca and Mg/Ca spikes seen at Al unit boundary fracture zones in both wells (Figure 3-28).

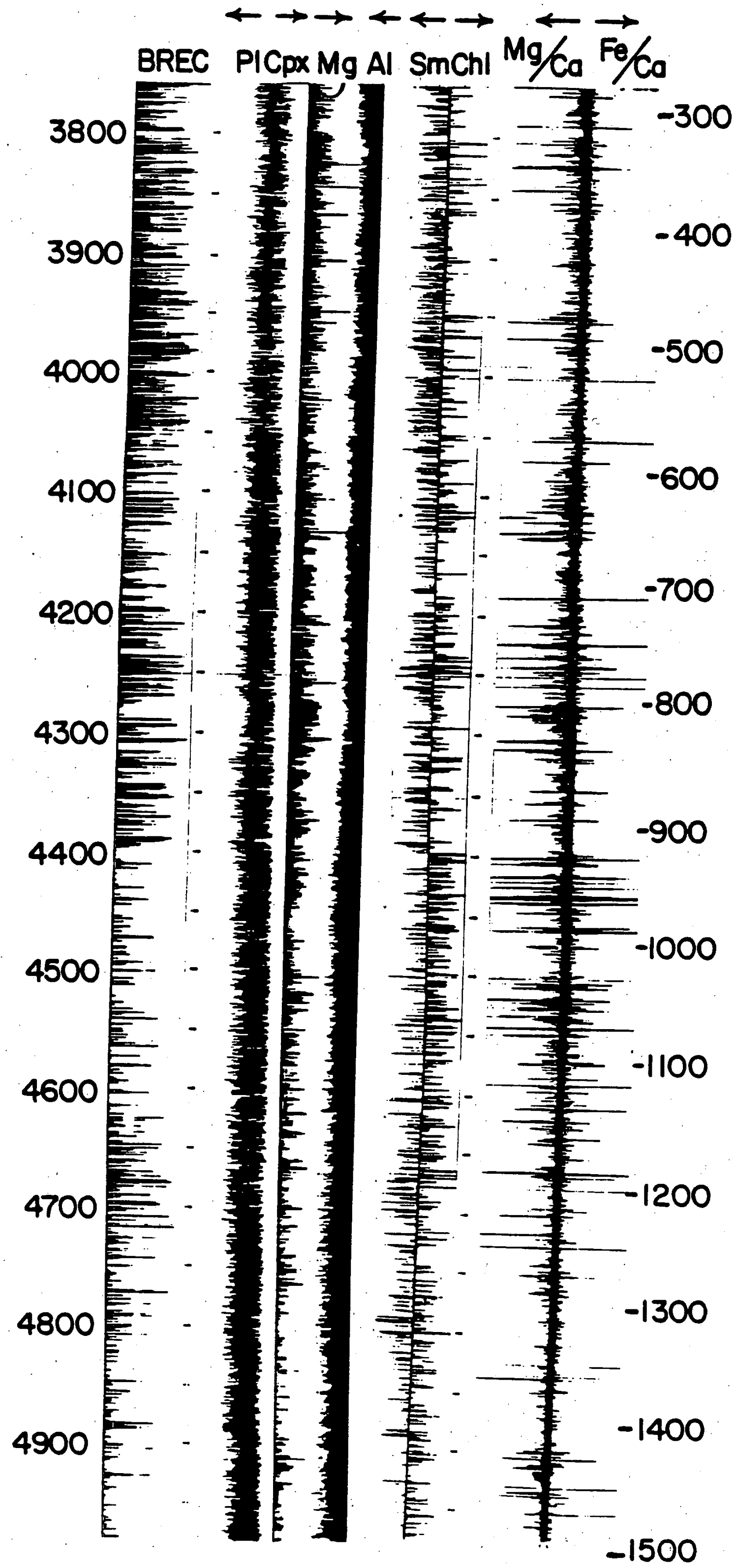


Figure 3-28. Alteration state in Hole 504B shown from breccia curve (Act+Smec), plagioclase, clinopyroxene, Mg, Al, smectite, chlorite, Mg/Ca, and Fe/Ca abundances derived from Nuclear Logs.

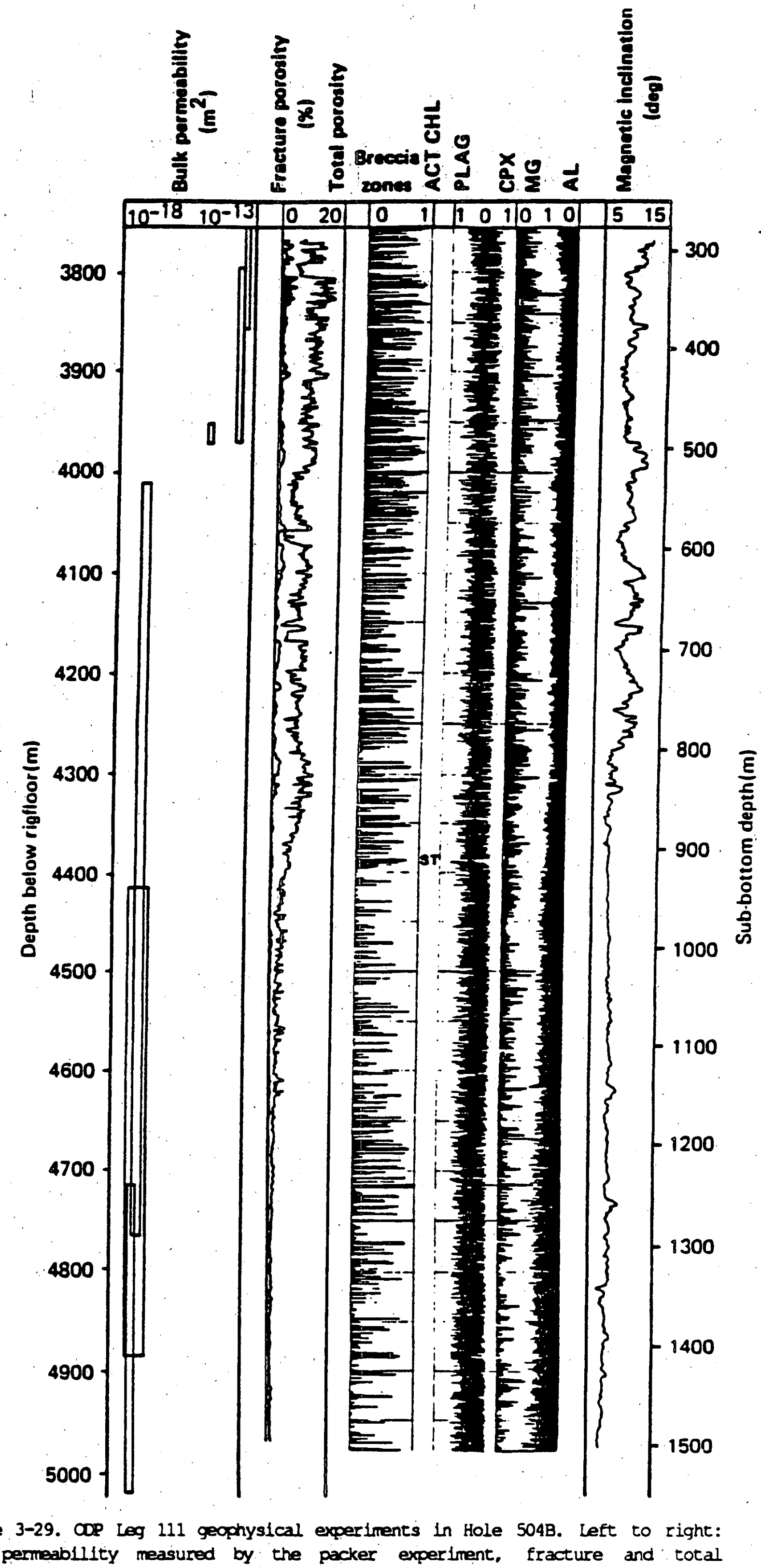


Figure 3-29. ODP Leg 111 geophysical experiments in Hole 504B. Left to right: bulk permeability measured by the packer experiment, fracture and total porosities determined from electrical resistivities, normative mineralogies and relative MgO and Al_2O_3 contents determined from spectral analysis of neutron activation logs, and magnetic inclination. Normative mineralogies were determined by recalculating elemental contents of Si, Al, Fe, Mg, and Ca into the normative components actinolite (ACT), chlorite (CHL), plagioclase (PLAG), clinopyroxene (CPX), olivine and smectite, assuming typical local compositions for the normative minerals.Normative plot units indicate the fraction (1 signifies 100 normative weight percent) of the rock formed by each normative component. Relative contents of MgO (MG) and Al_2O_3 (AL) were shown as counts, where 1 signifies the maximum observed. Average amount of MgO is 7 weight percent, and of Al_2O_3 is 22 weight percent. ST denotes the 18 m thick stockwork-like unit.

The relative chemical exchange budget can be calculated from the bulk rock elemental abundance changes. The estimated weight percent exchanges between sea water and basalt in Hole 504B are less than 0.01% K, but more Mg (1.8%), entering the rock, and 2.2% Ca, 4% Fe, and 1.9% Si exiting the system. These fluxes compare favorably with the ridge axis exchange fluxes measured from hydrothermal waters currently being exhumed by the newly forming oceanic crust (Table 3-2). Ca, Fe, and Si are all greater in the hot spring fluids than bottom sea water, with most of the Fe forming pyrite and other sulfide mineralization on and below the sea floor (the stockwork).

In conclusion, the Nuclear Logs are a powerful geochemical tool, which, combined with the full suite of geophysical logging tools, will add to the scientific insights possible from future drilling into oceanic crust.

Table 3-2. The fluxes of dissolved chemical species into and out of the ridge axes.

Species	Ridge flux mol/a	River flux mol/a	Ridge/River
K	1.25×10^{12}	1.9×10^{12}	0.66
Mg	-7.7×10^{12}	5.3×10^{12}	-1.4
Ca	$2\text{-}4 \times 10^{12}$	12×10^{12}	0.4-0.2
Mn	$.6\text{-}1.8 \times 10^{11}$	4×10^{9}	15-45
Si	3.1×10^{12}	6.4×10^{12}	0.48

Chapter 4

Stratigraphy and Sedimentation

The two major physical determinations made from logging data are lithology and porosity. These, in turn, carry information about the stratigraphic sequence penetrated by the drill bit and the sedimentology surrounding the drillhole. In order to make general geological conclusions from logs, they must be tied to core results and to seismic information.

Sonic waveform analyses, electrical resistivities, natural gamma ray counts, neutron porosity and bulk density logs combine to provide sedimentological, as well as physical property information about the rock. Consider DSDP Site 613 in the Baltimore Canyon area offshore New Jersey. Here, the density and the compressional velocity logs show an interesting inversion between 2600 m to 2775 m below rig floor (100 to 325 m below sea floor) (Figure 4-1). Below 2775 m there is the typical increase in both velocity and density with depth. Laboratory measurements on recovered core (small dots of Figure 4-1) are consistently lower than the log values, as can be expected in soft, surface sediments with 50-70% porosities. In fact, this velocity and density inversion might not be believed without corroboration from the logs.

The very low velocities and densities are accompanied, surprisingly, by very high sonic amplitudes (Figure 4-2). A Hilbert transform breaks the incoming sonic waveform into complex and real components, which permits displays of changes in instantaneous amplitude and frequency as different waveform energy packets arrive at the receiver. This seismic technique is particularly useful for differentiating coda within the waveform. The Hilbert-transformed amplitude envelope clearly shows the unusual characteristic of the faster velocity section below 2775 m being also of lower amplitude than the slower formation above (Figure 4-3). Such an amplitude-velocity anomaly is caused by diagenesis at this well site. The slower, lighter sediments above the diagenesis boundary must be rigid enough to pass energy efficiently, though slowly. Below, the energy must pass quickly, but be attenuated severely by the sediments. Electron microscopy analyses of the core show the diagenetic origin of this particular anomaly. Above the boundary, forams and radiolaria form a "hollow sand" matrix with high porosity, low density, and a rigid, "slow but loud" latticework. The spaces within the forams and radiolaria are all filled with pore water. At 325 m below the sea floor (2775 mbrf), the pressure and temperature increases enough so that the silica dissolves from the rad shells and reforms within the foram shells. Suddenly, there is a high density, high velocity matrix, but the new latticework is not nearly so well interconnected. Energy loss increases even though the sonic velocity also increases.

We can observe this decrease in rigidity directly from further analysis of the Hilbert-transformed sonic waveforms. Ordinarily, the shear wave is not recognizable in soft sediments because if it is excited at all, it travels at slower velocities than the direct water wave moving down the wellbore from source to receiver. Since the water wave is of large

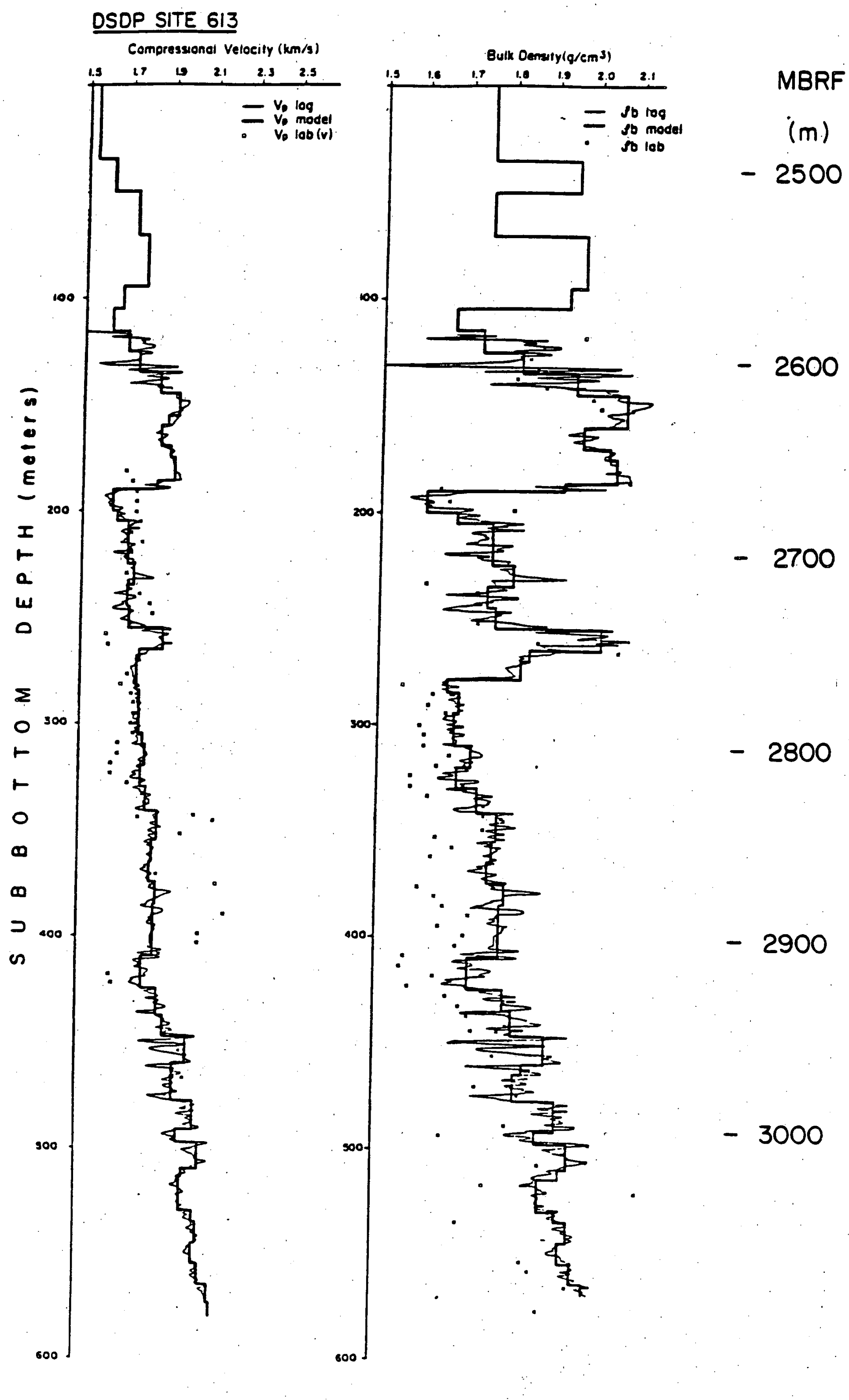


Figure 4-1. Velocity and bulk density from logs, DSDP Leg 95, Site 613. Dots are measurements made on recovered core. Bars are five meter averages of log data.

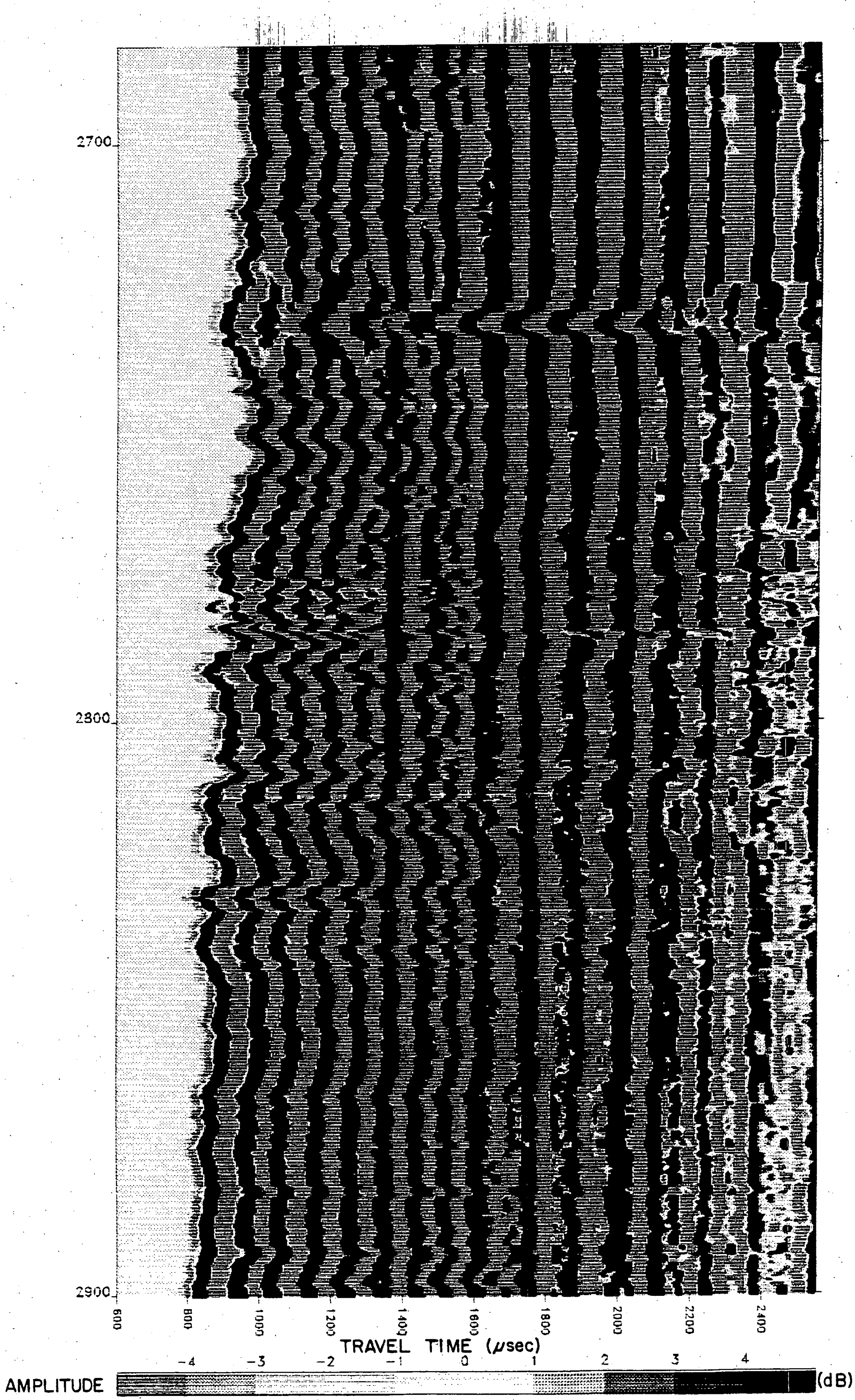


Figure 4-2. Sonic waveform log of DSDP, Leg 95 Site 612. There is no recognizable S-wave between the first-arriving compressional wave and the highest amplitude Stoneley wave from the near 8' receiver.

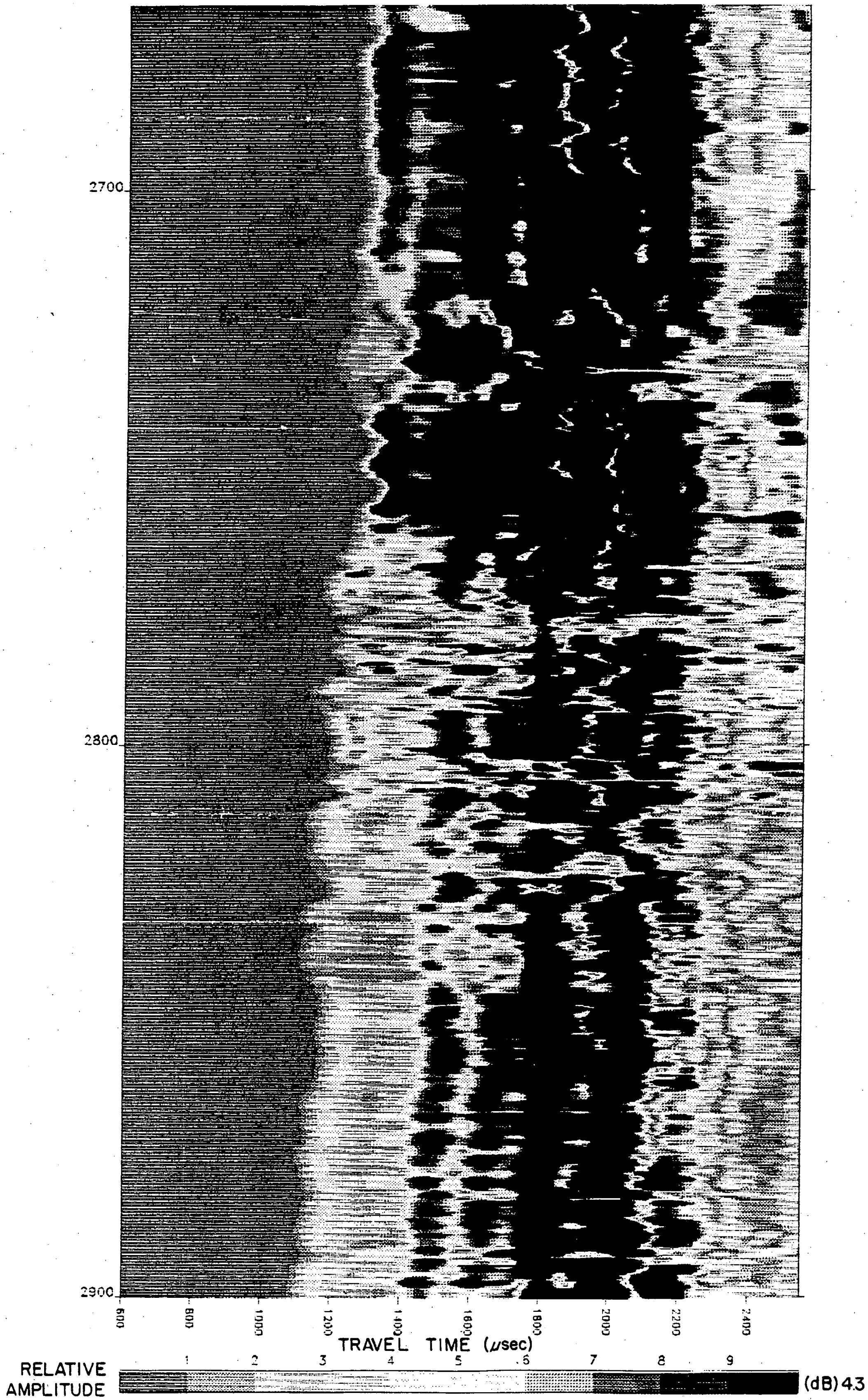


Figure 4-3. Hilbert transform of sonic log waveform, DSDP Leg 95 Site 612 yields envelope of instantaneous amplitude spectrum. Note that though velocity increases at 2750 m depth (arrival time decreases) and amplitude decreases for the receiver 12' from the source.

amplitude, the shear wave arrival is masked. There are surface normal modes, called pseudo-Rayleigh waves, which are induced in boreholes through soft sediment and travel at about 95% of the velocity of the shear wave. Their frequency, and that of the shear wave itself, are higher than that of the water wave. A Hilbert-transformed instantaneous frequency analysis of the sonic waveforms across this diagenesis boundary shows a clear shear or pseudo-Rayleigh wave arriving at 1800 to 2000 microseconds travel time, from which Poisson's Ratio can be estimated (Figure 4-4). The high Poisson's Ratio above versus below the diagenesis boundary (slower P wave but same S wave velocity above) verifies the conclusion that the latticework is less rigid after dissolution than before.

An inverted depth-porosity sequence is also found at Site 647 in the Labrador Sea, drilled on ODP Leg 105. Here porosities detected by the resistivity log increase to >80% 125 m below the sea floor (Figure 4-5). Porosities appear to be 60% both above and below this 125-m-thick interval. The core results showing the same porosities might not be believed without independent corroboration from the logs. A lowered natural gamma ray output of the sediments suggests lower clay content. The high porosities are from a diatomaceous ooze layer, which supports extremely high porosities within its shell structure.

At Leg 105 Site 646, again in the Labrador Sea, we see a clear lower boundary to the high porosity diatom layer at 335 mbsf (Figure 4-6). Notice, however, that the Th/K ratio is higher in the diatom layer than below. We suspect, therefore, a change in clay type across the transition from high Th to low Th clay. Rather than crossing a diagenesis boundary at 335 m, which would not affect the Th/K ratio, we conclude that the zone of upwelling nutrients responsible for the abundance of diatoms moved away from the well site at the age of the transition sediments. Such a change in oceanographic currents carries climate information, as we will see when we return to this site in the stratigraphy section of this chapter.

Diagenetic information of another kind is found in the sedimentary column at Hole 504B in the eastern Pacific. In order to drill a deep basalt hole, casing was set before logging the sediment section. At Hole 501, a few hundred meters to the west, the youngest occurrence of chert in the oceans was found during DSDP Leg 68. The extent of the chert layering was hinted at by the Borehole Televiewer imagery, which suggested that the apparently thick chert layer was instead composed of numerous thin chert stringers. The thickest chert layer imaged was only 3 m thick (Figure 4-7). The hydrology of the basement at Hole 504B depends on the extent to which the ocean crust's hydrothermal convection system is sealed off from the ocean by an impermeable sedimentary cap. Obviously, a continuous chert layer is an excellent hydraulic seal. The geophysical measurements in Hole 504B suggest that drilling penetrated just such a cap, with the basement convection system isolated from the ocean so that large underpressures below the hydrostatic built up beneath the chert. Consequently, ocean bottom water began flowing into the basalt once the chert lid was penetrated.

On ODP Leg 111 geochemical logs were recorded through the cased-off sediments at Hole 504B. While there was a clear signal of high sulfur content from the gypsum in the casing cement, numerous thin chert layers high in Si were recorded within 100 m of basement (Figure 4-8). The thickest was 2 m, and the most numerous zone was 50-75 m above basement. The similarity between chert layering at holes 501 and 504B suggests at

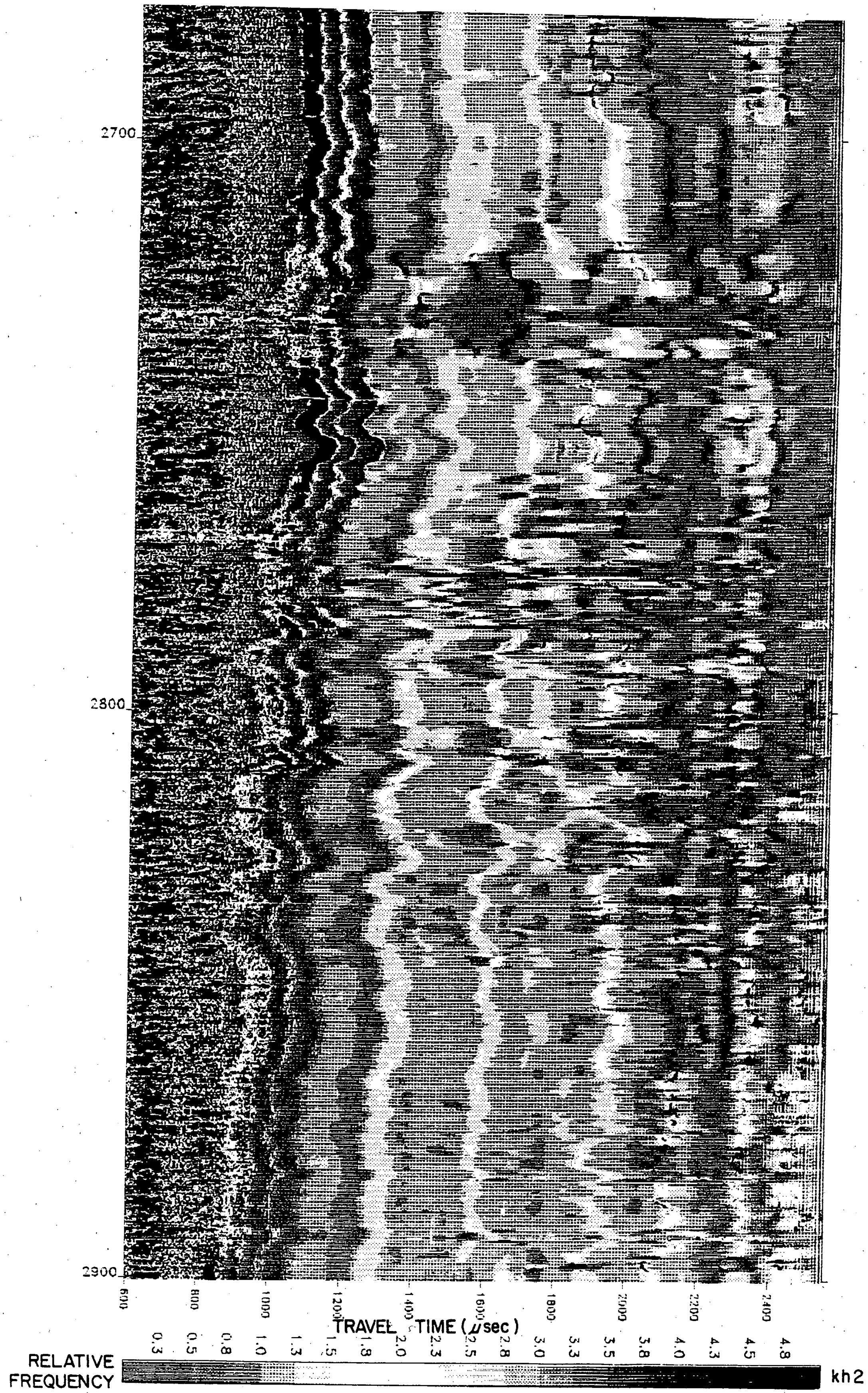


Figure 4-4. Instantaneous frequency from Hilbert transform of sonic waveforms (near receiver), DSDP Leg 95 Site 612. Note S-wave identifiable from departure of frequency packet at 1900 microseconds arrival time (2725 m) from the trend of the P-wave energy.

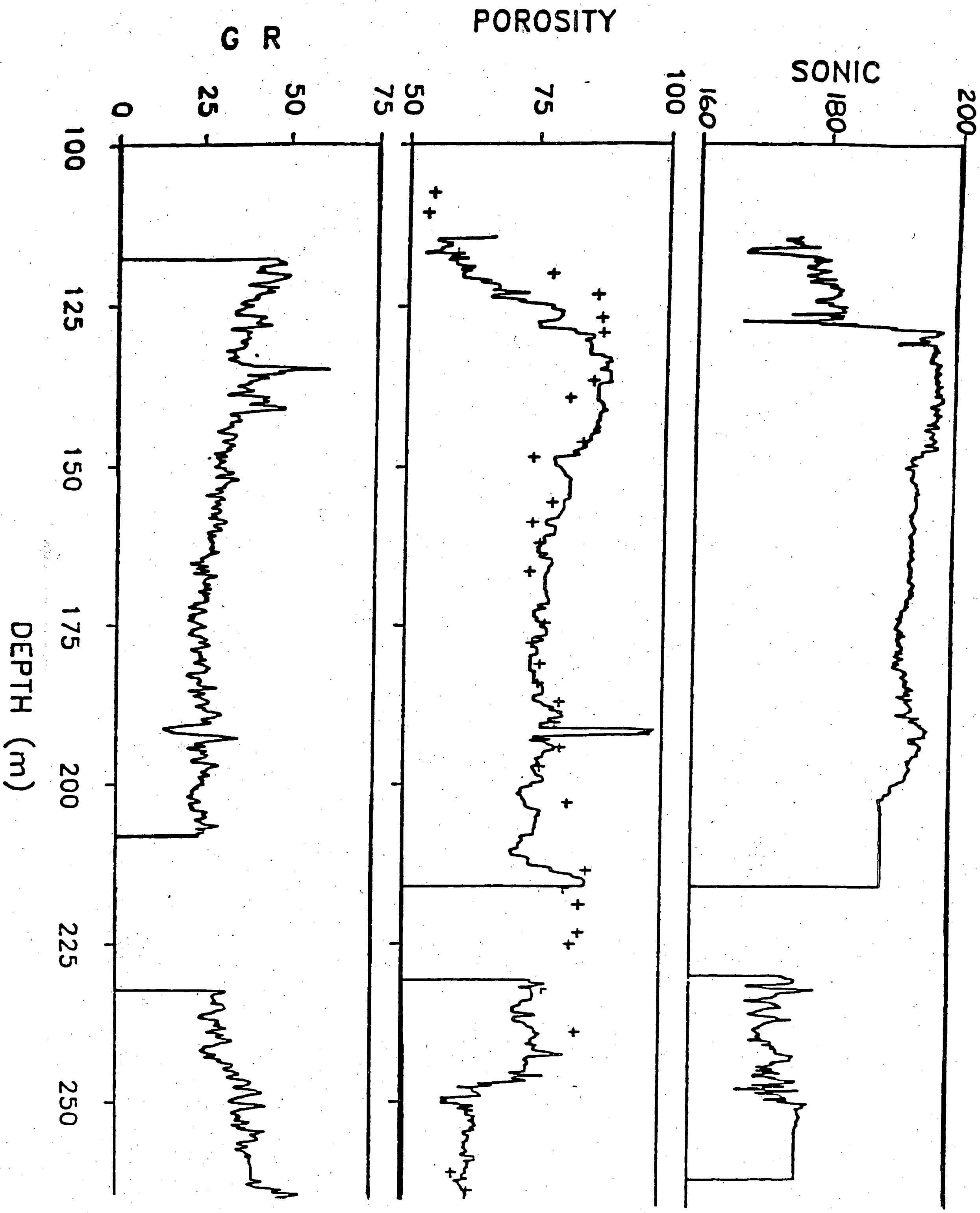


Figure 4-5. Gamma ray, porosity from electrical resistivity and sonic travel time from logs, ODP Leg 105 Site 647, Labrador Sea. Pluses are porosity measurements from core. Note porosity and travel time inversion at 125 mbsf.

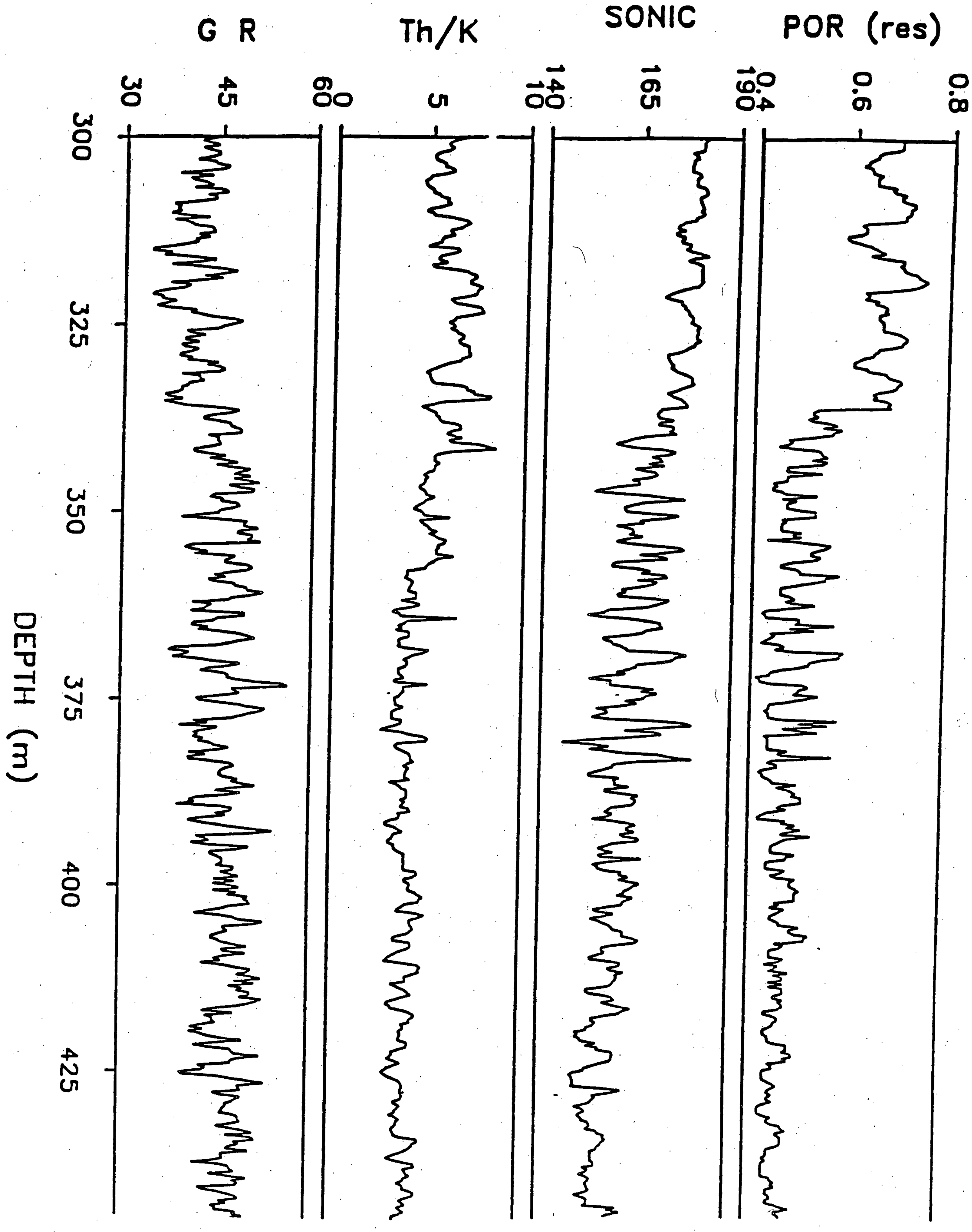


Figure 4-6. Gamma ray, Thorium, Potassium (K), sonic travel time and porosity from resistivity log, ODP Leg 105, Site 646.

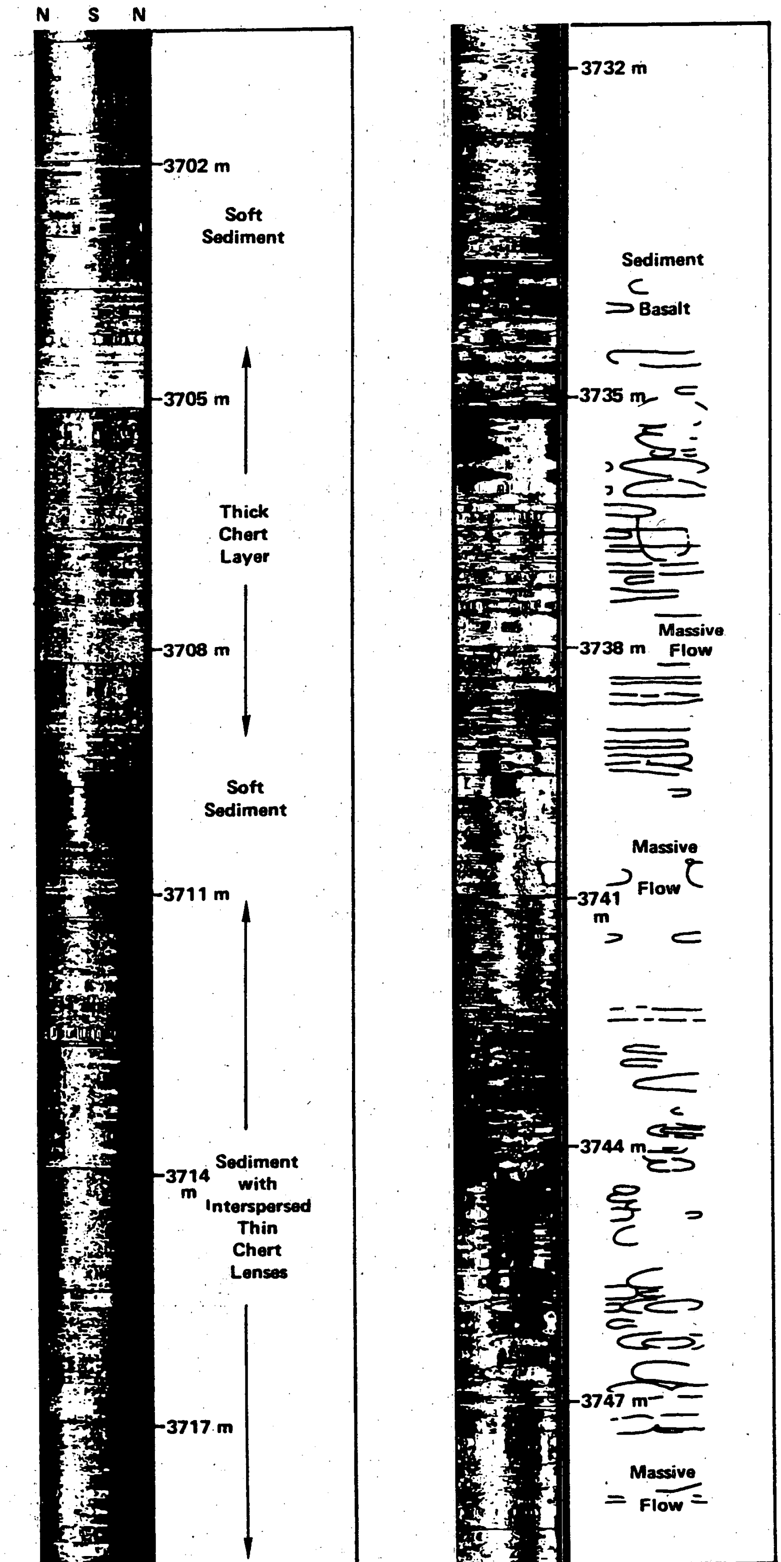


Figure 4-7. Borehole televiewer imagery at DSDP Site 501. The horizontal axis represents the televiewer sweep azimuth around the borehole; horizontal exaggeration is 3:1. Strongly reflectivity of the borehole is shown in white; weak reflectivity is shown in black.

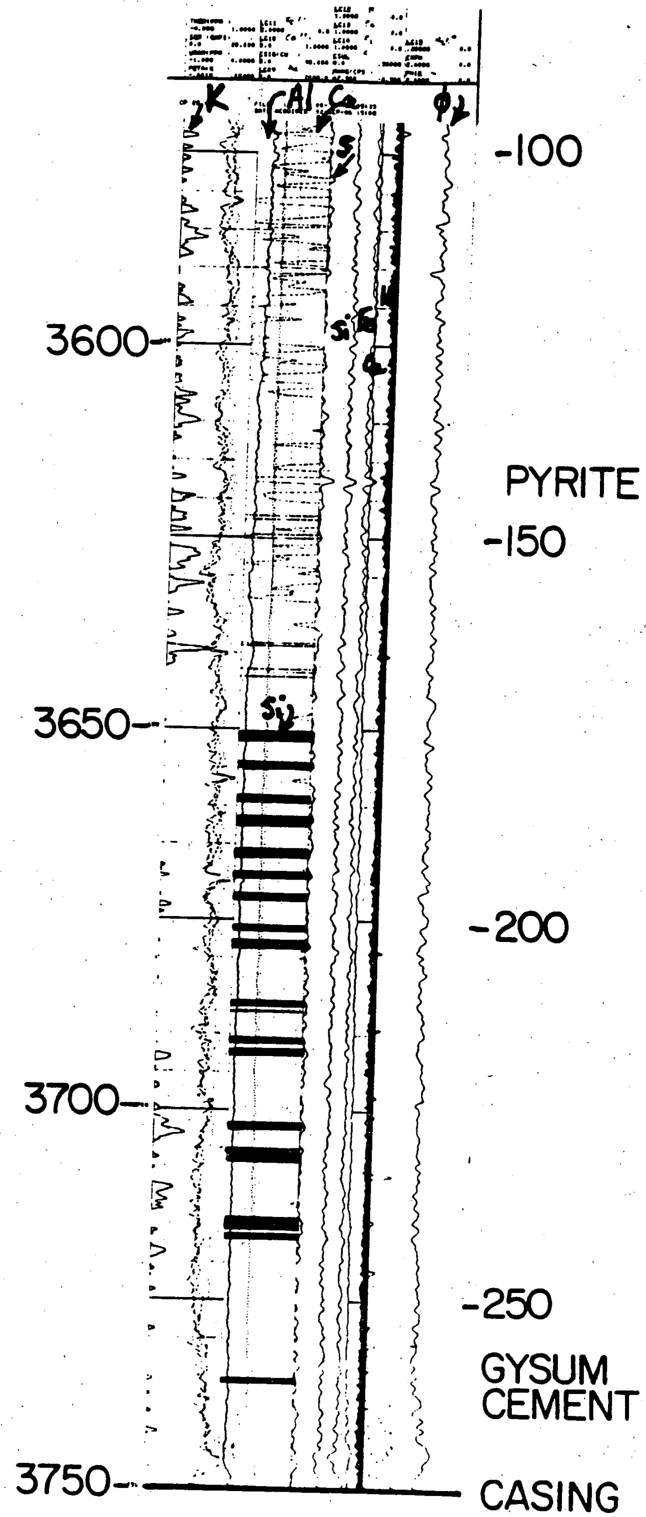


Figure 4-8. Neutron activation log of sedimentary section of Hole 504B, ODP Leg 111, done through casing. Chert stringers are indicated by abundant silicon zones (black bars). The clay-rich zone is shown by the high level of potassium at 3570 to 3642 m.

least local continuity of the chert beds and large underpressures within the crust which were probably supported by this relatively impermeable cap.

Logs and Stratigraphy

The stratigraphic sequence penetrated by the drill bit is both the most frequent drilling target (usually based upon seismic reflection interpretations), and the hardest to decipher purely from cores. Consider, for example, the Baffin Bay Site 645 of Leg 105. Somewhere between 3.1 and 3.3 seconds of two-way travel time on the seismic reflection profile across the drill site is the onset of ice rafting, which marks the last retreat of an ice cover on the Northern Baffin Bay (A-B of Figure 4-9). This major reflector is a marker horizon for the whole area. The drilling mission was to determine the exact stratigraphic sequence accompanying the proposed onset event.

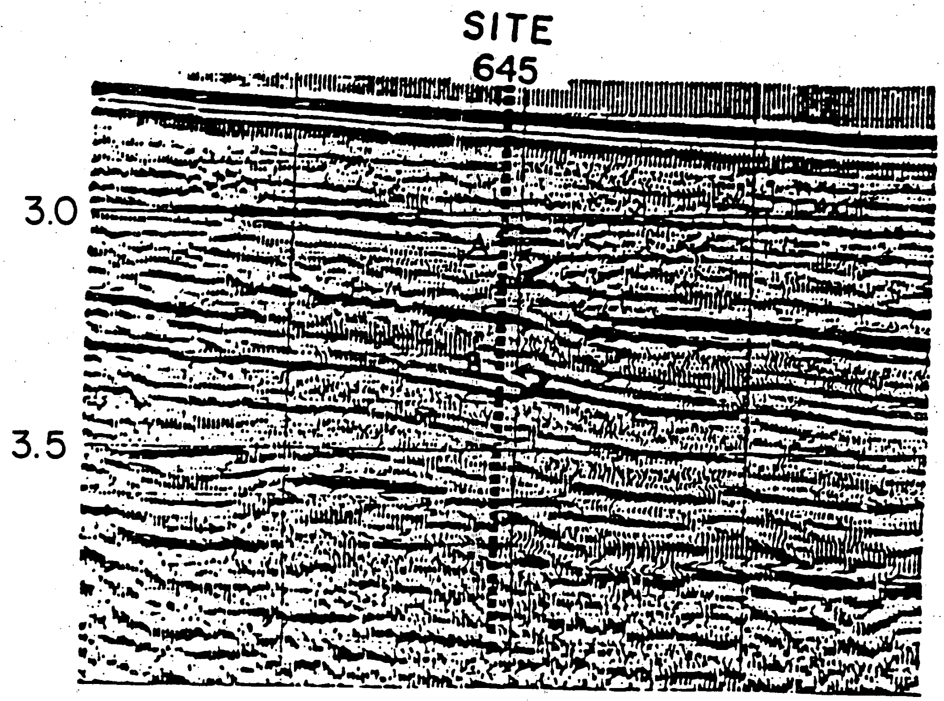
Two attempts were made to core through the suspected reflector event with little to no core recovery. Where is the onset, and why was the recovery so poor? The suspicion onboard the JOIDES Resolution was that the interval was sand-rich and that the sand was washing out.

The gamma ray log indicated that the interval was generally clay-rich, with perhaps two thin sand units, which were indicated by low gamma ray values at 360 mbsf and 390 mbsf (Figure 4-9). The resistivity and velocity logs suggest, however, that a major impedance boundary is located at the deeper sand-rich interval. This is the onset reflector for ice rafting. X-ray diffraction data on recovered core, representing a substantial effort to obtain clay mineral contents (right in Figure 4-9), does not recognize this boundary, but erroneously puts it at either 350 m or 430 m depth. Contrast these spot readings with the continuous log results. The core and log results are each mutually supporting. It is the combination of core and log data which gives the true stratigraphic sequence at Site 645.

The sonic and density logs produce an impedance contrast which can be used to generate a synthetic seismogram explaining remarkably well the observed reflection profile (Figure 4-9).

One has to be extremely careful about inferring seismic reflectors from core changes, because nearly all seismic reflectors are interference patterns. The thickness of a given impedance contrast versus the particular wavelength of seismic energy can have as much to do with the strength of a reflector as with he stratigraphic contrast. An high-frequency water gun can see a different set of reflectors from those produced by a low frequency air gun.

There are two additional logs which are useful when deciphering the correlation between the velocity-density impedance log and the seismic reflection record. The Multichannel Sonic Tool (MCS) gives highly accurate interval velocities, and the Well Seismic Tool (WST), a downhole hydrophone, receives low frequency seismic energy from the surface and transmits the signal up a logging cable. The latter can also record reflections from below total depth in the well, and so is extremely useful for identifying how much more drilling is required to reach a particular reflection horizon beneath the bit.



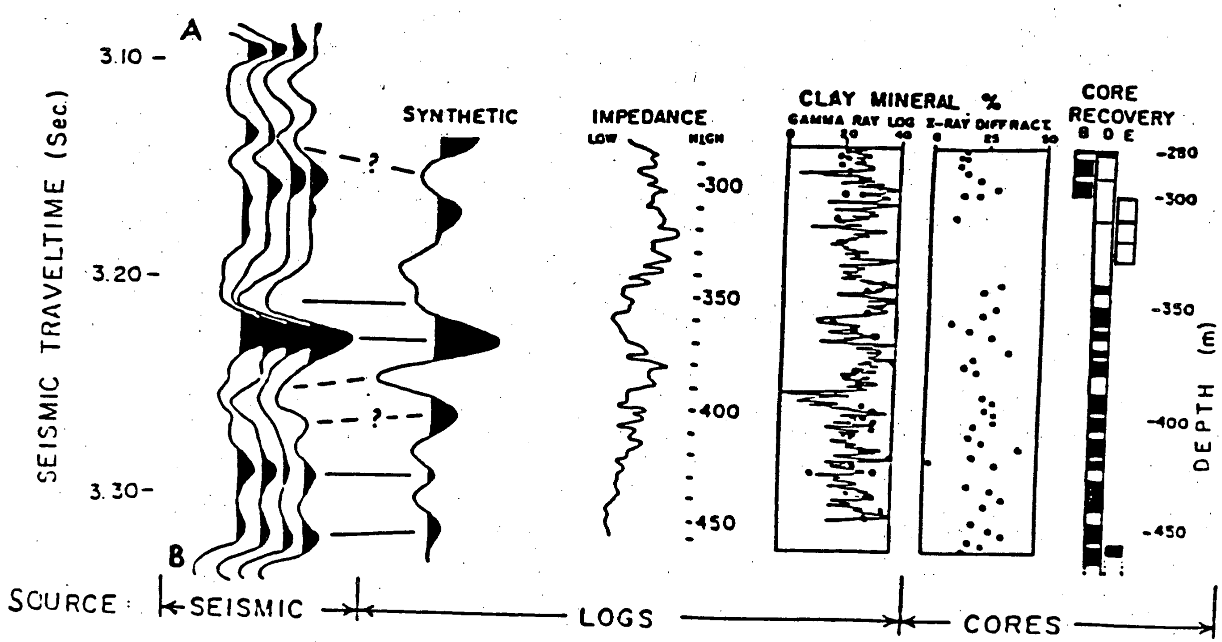


Figure 4-9. Top, seismic reflection profile across ODP Leg 105 Site 645. Bottom, seismic reflection section A-B (see above), compared to impedance log and synthetic seismogram (center) from velocity and density logs. Clay mineral content from natural gamma ray log compared to core measurements (dots) and core recovery (right). The major reflector seen on the seismic section can be clearly identified in the logs as a high gamma ray, clay-rich zone at 370-380 mbsf. Core from that reflector horizon can then be identified.

Stratigraphic Cycles and Milankovitch Climate Changes

Causes of long-term changes in ocean circulation and how they relate to climate and earth orbital parameter changes are first-order problems to be addressed by ODP. How the circulation pattern of the oceans changes with time in response to orbital changes will allow us to carry back in time the climatic history of the planet. Deep-sea sediments record these changes within their stratigraphic record, and logs form an important methodology for detecting these changes. The problem requires a continuous stratigraphic record of the well in order to track movements of upwelling zones, boundary currents and cold versus warm water cells. Cores have time gaps caused by imperfect recovery. Even hydraulic piston coring, which returns >95% of the cored interval, requires costly and time consuming double, and sometimes triple, overlap because the critical boundary is invariably in the missing section. Logging, however, returns a continuous set of measurements every 15 cm with standard logs, and every 2.5 mm with ultra-high resolution electrical resistivity imaging.

The response of glaciers to climate change has led to identification of cold and warm water cycles in oxygen 18 isotopic variability in deep-sea sediments, which have major correlation peaks every 19, 24, 43, and 106 thousand years (Figure 4-10). Earth orbital parameter variations are thought to drive these climatic cycles (collectively known as Milankovitch cycles; Figure 4-10). Eccentricity changes at 95 thousand years, obliquity at 41 thousand, and precession changes at 19 and 23 thousand year intervals were recognized by Milankovitch in the 1940's. These changes are thought to drive the climatic history of the earth. Verification of these cycles back in time is a major mission of stratigraphic work carried out on the JOIDES Resolution.

A mission of drilling in the Laborador Sea on Leg 105 was to track the movement of an upwelling zone across the drill site from the Paleocene to the lower Pliocene. Logs run in the hole recorded cycles which are clearly correlatable with the main Milankovitch climatic cycles (Figure 4-11). At Site 646, the diatoms above the major sedimentation boundary at 335 m record a change in porosity caused by fluctuations in the latitude of the center of the upwelling zone across the well site prior to 2.8 million years ago. This change produces variability of over 15 % in porosity, an easily detectable change in resistivity and sonic logs run in the hole. The extremely high sedimentation rate of 100 m/my makes the wavelength of each cycle easily detectable within the resolution powers of the logging tools to periods of 41,000 years. The log cycles versus depth must be converted to cycles versus time by age-dating the core and, subsequently, determining the sedimentation rate.

The sensitivity of the standard logs to porosity cycles can be seen by examining the porosity changes encountered below the diatom rich layer, where the sedimentation rate falls to 52 m/my. The cycles versus depth are condensed (Figure 4-11), and the sonic log detects the 41,000 year period, but the resistivity tool does not. The vertical resolution of the sonic tool is about half a meter, whereas the resistivity tool averages values over about one meter surrounding the logging tool.

Ordinarily, the usefulness of logging tools to detect Milankovitch climate cycles is reduced in low sedimentation regions because of the lack of vertical resolution that we mentioned above, but the recent move toward high resolution logging tools has quickly

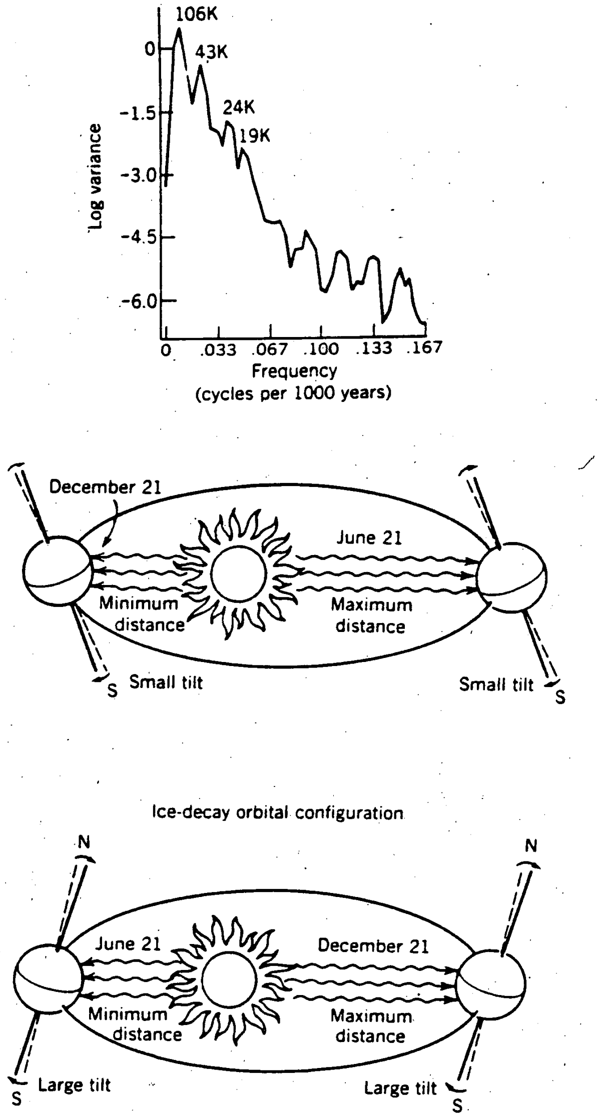


Figure 4-10. Top: Power spectrum of the climatic changes from O^{18} changes plotted against the frequency of occurrence. Peaks in power at 106,000, 43,000 and 24,000 years mean that glacial events are likely to occur with this cyclicity. Milankovitch calculated cyclicity of the Earth's orbital changes that match the periodicity of glaciers over the last few hundred thousand years. There is a delay between changes in the orbit and the onset of glaciation that would be expected.

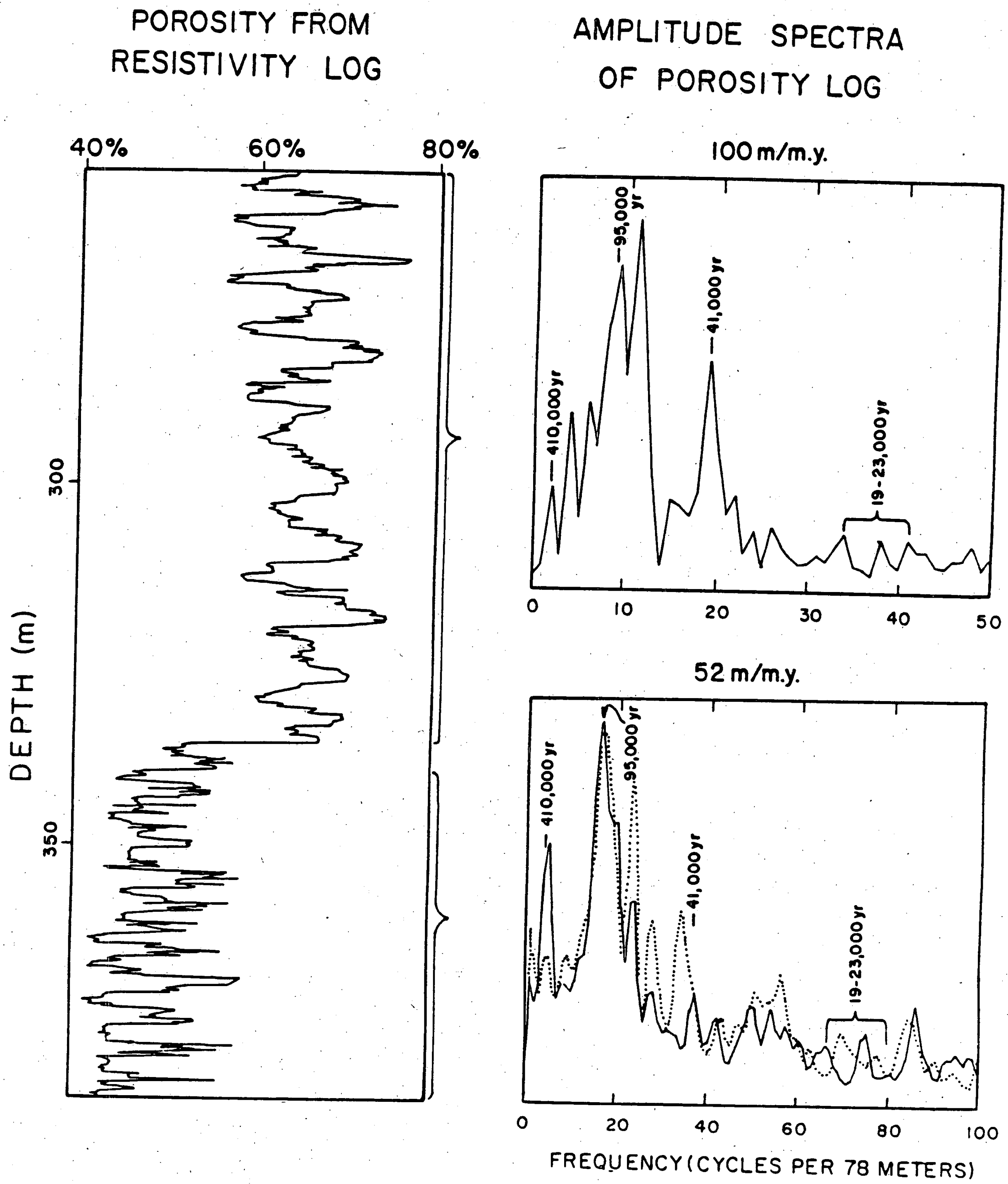


Figure 4-11. Porosity from electrical resistivity log, ODP Leg 105 Site 646 (left). Power spectrum from Fourier transform of porosity log above 340 m shows major energy peaks at 95,000 and 41,000 year periods (right, top). Sedimentation rates are from core paleontology. Spectra of porosity and velocity logs below 340 m show peak energy at 410,000 and 95,000 year periods (porosity log) and 95,000 and 41,000 years (sonic spectrum dotted).Sedimentation rate changes from 100 m/my (top) to 52 m/my below 340 m. The periods of dominant log energy are similar to cycle periods from Milankovitch climate changes.

improved the situation. For example, Site 646 was the first for which the geochemical tool was available for routine ODP use. The calcium/silicon compositional variation curve from this nuclear log has a resolution of 1.5 cm, so both the 19,000- and 23,000-year cycles were recognizable within the spectra of the calcium and silicon abundance logs (Figure 4-12).

The utility of such time series logging extends beyond climate-cycle identification. If a clear Milankovitch cyclicity can be established, then the cycles can be counted with depth to give the logs an ability which they never had: age dating. We can assume, for example, that each major peak encountered down the well at Site 646 is an added 95,000 years of stratigraphic time-progression.

The New Formation Microscanner

One new tool, for which ODP has a great need, is the Formation Microscanner (FMS) from Schlumberger. Because its diameter, however, is too large to be lowered through the drill pipe, efforts are underway to modify it. *(Note: the redesigned Formation Microscanner has been routinely used in ODP boreholes starting with Leg 126).*

The FMS is a four-arm dipmeter, with 16 high-resolution electrodes on each pad (Figure 4-13). These buttons measure the changes in formation electrical resistivity to such fine resolution that an electrical image of the rock encountered by the pad can be produced (Figure 4- 14). Fractures, dipping beds and major porosity changes are detectable with the ample resolution of this tool, which makes it a powerful dipmeter as well as a potential age-dating log for the future. For example, consider drilling into a delta to find patterns of deposition. Two other cycles are superimposed upon those induced by the river: climate and the closely related fluctuations in sea level. Ultra-high resolution logs might allow one to identify and filter out the climate and sea level peaks from the spectrum of the log, leaving a clearly attributable signal of the past movements of the delta.

Additionally, the combination of FMS and neutron-activation logging will allow for the identification of chemical changes seen in the layering. Figure 4-15 shows a set of beds dipping 45 degrees to the north-northeast (tadpole plot at left) cut by a vertical, healed fracture (image at center). The beds are identified as being composed of alternating layers of Ca rich calcilutite and Si rich calcisiltite from the neutron activation log.

Major stratigraphic and sedimentological missions of ODP not only benefit from logging, but probably could not be accomplished without logging. Logs provide the essential addition to core of a continuous time series measurement of the geology of the borehole wall. Together, continuous core and continuous logs give the best possible methodology for solving the remaining geological problems to be addressed by ODP.

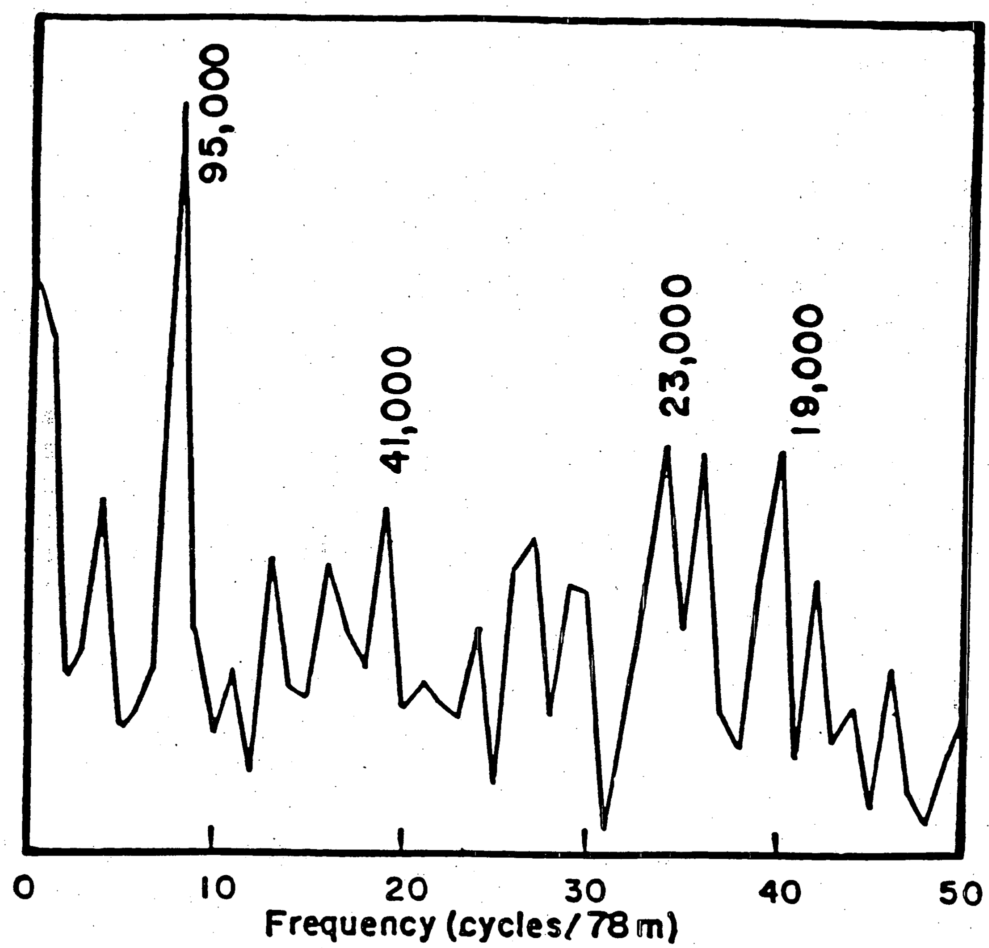


Figure 4-12. Neutron activation log measures sedimentary parameters with greater resolution than resistivity or sonic logs. Power spectrum of calcium/silicon elemental abundance ratio, ODP Site 646, shows prominent energy peaks at 19,000 and 23,000 years as well as 41,000 and 95,000 years. Again these are periods of Milankovitch climate cycles.

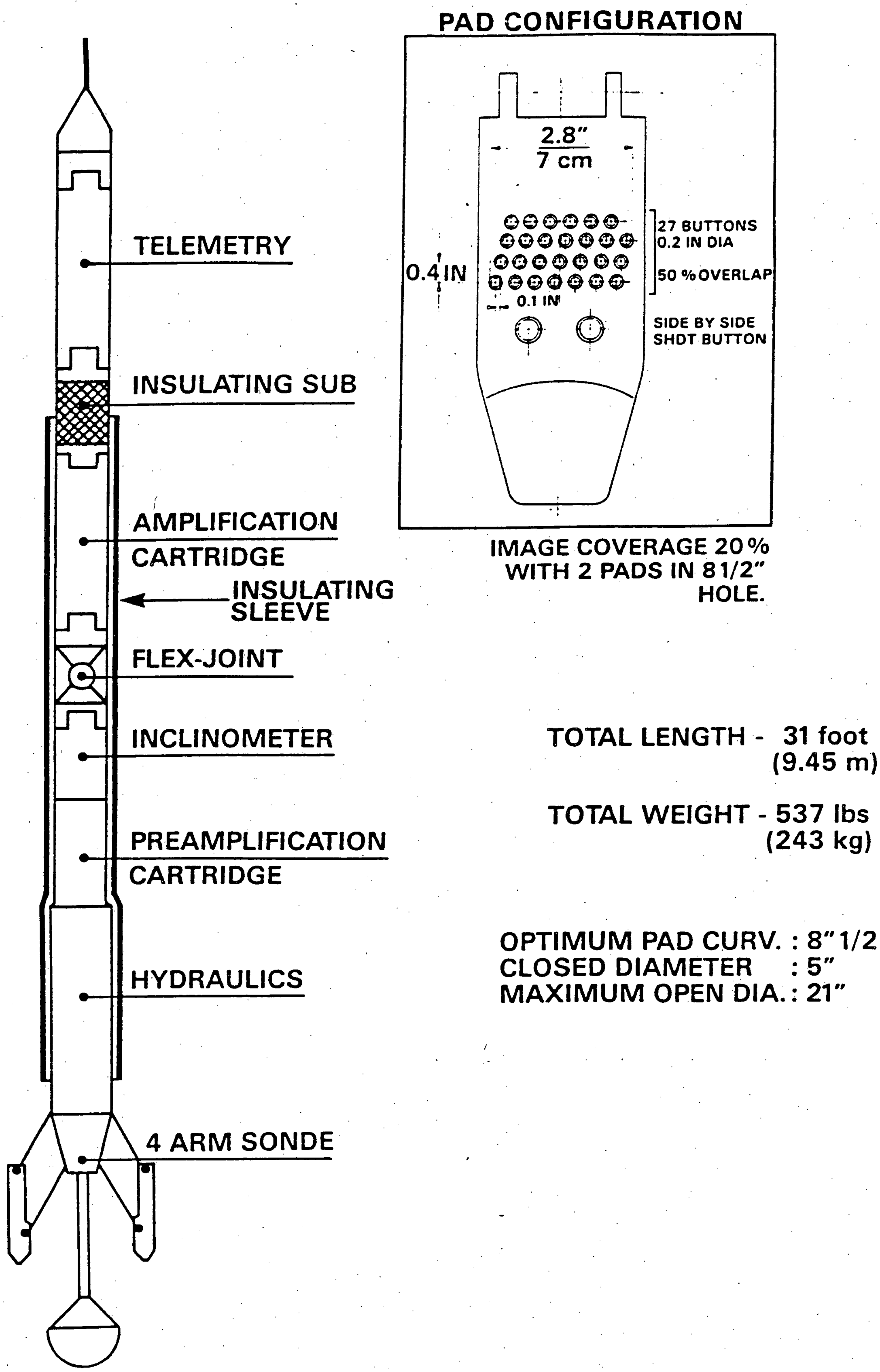


Figure 4-13. Tool configuration of formation microscanner, Schlumberger's advanced dipmeter (courtesy of Schlumberger).

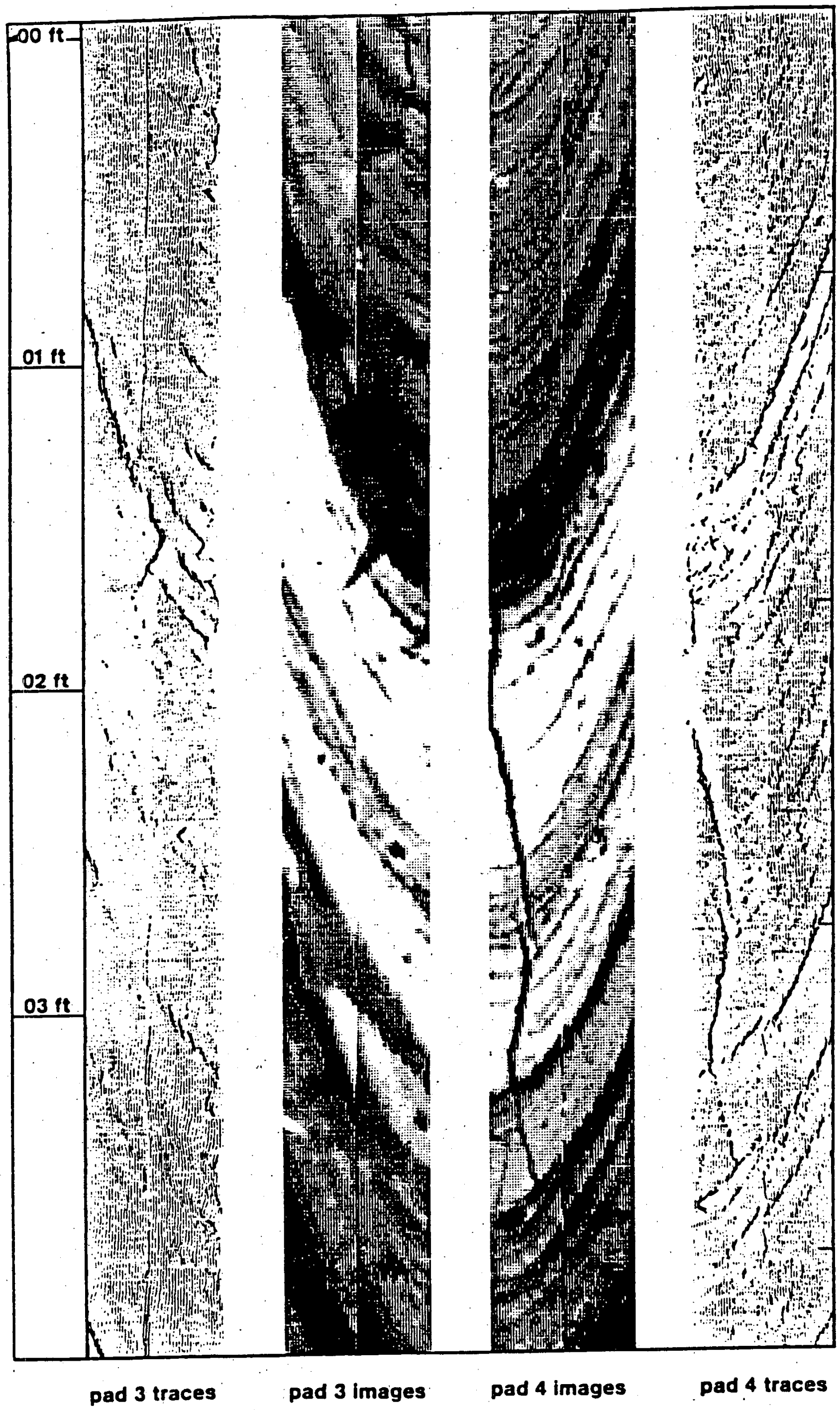


Figure 4-14. Resistivity changes are measured over such short spacing (0.15 cm) that images can be reconstructed of the electrical resistivity of the wellbore wall.

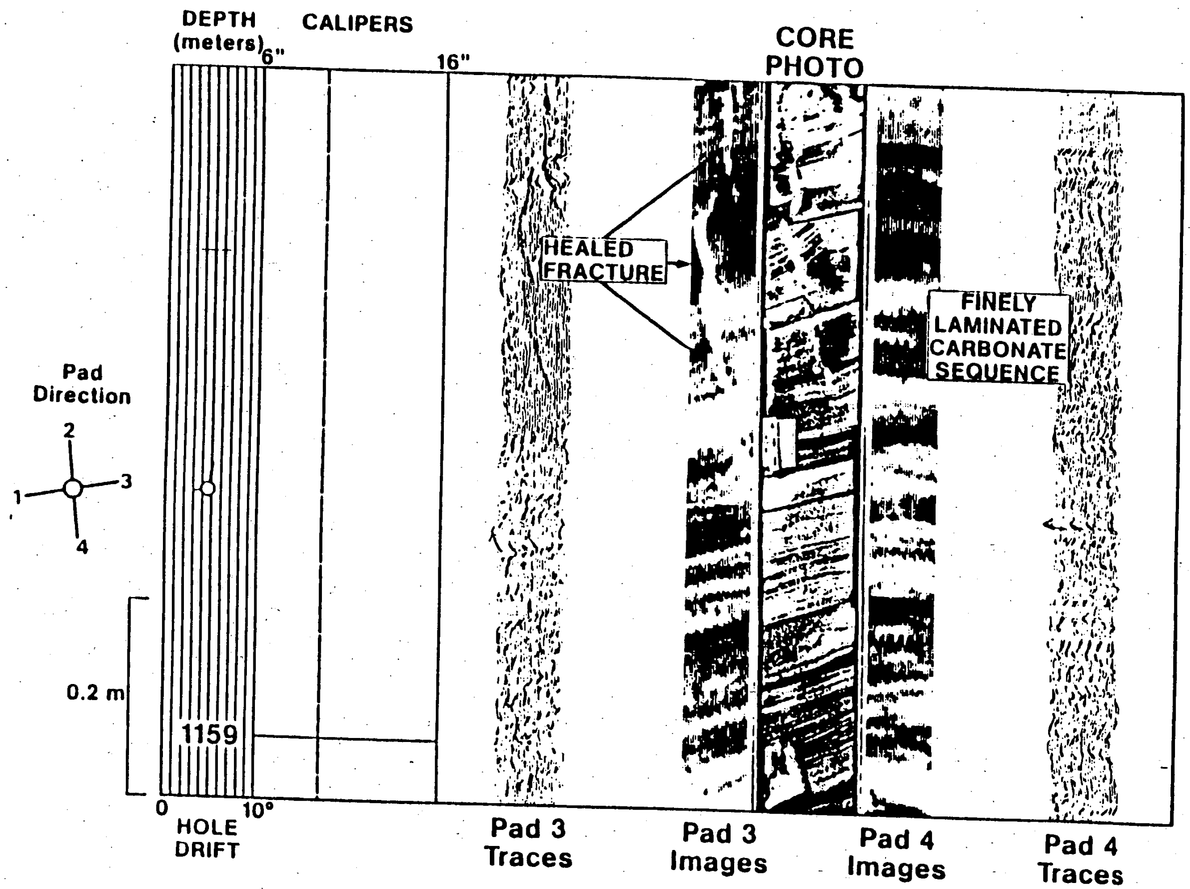


Figure 4-15. Dip, resistivity traces, formation microscanner images and core for comparison of imaging ability of Formation Microscanner (courtesy of Schlumberger).

Chapter 5

Logging in Subduction Zones

The continental margins of the Earth are formed by three tectonic processes related to the present and past movements of the plates: 1) shear motion such as that occurring along the west coast of California associated with slip along the San Andreas Fault, 2) passive subsidence since initial rifting of a continent such as that occurring along the east coast of the United States, and 3) accretion from subduction of one plate beneath another such as the volcanicity and associated tectonics of the northwestern United States. Logs add important information about the geological processes prevalent in each of these environments. Because much of the destructive earthquake activity and volcanicity is associated with subduction tectonics, we will examine the usefulness of logging in such areas first.

One major objective of ODP is to study the accretionary processes that add sea floor sediments and crustal rocks to the edges of continents at subduction zones ((Figure 5-1). Previous DSDP results from offshore Japan and Guatemala show that both erosion of continent and accretion to continent can occur at subduction zones. The pressure, flow and composition of pore fluids provides one important control for these processes, and logs are extremely useful for the quantitative study of such fluid-rock interactions (such as overpressure).

Consider the Guatemala Trench drilled on DSDP Leg 84. One of the few complete suites of Schlumberger geophysical logs recorded during DSDP was run in Site 570 in the forearc region of the subduction zone (Figure 5-2). Evidence of overpressure was found in both cores and logs. Clathrates, or frozen methane hydrates were cored from a 10 m thick interval about 250 m below the sea floor, and the logs recorded low gamma ray, very high electrical resistivity, fast velocities and very low densities in this interval (Figure 5-3). These hydrates are in an otherwise uniform lithology of grayish green to olive mudstones. The frozen hydrates are at the appropriate thermodynamic conditions for their formation: cold temperature, but high pressure, and are a common and unremarkable occurrence in accretionary prisms.

Of particular interest is the zone from below the hydrates to basement. The standard log response in a well is decreasing porosity with increasing depth from the sonic, resistivity and density logs. This normal compaction process is evident in the logs above the clathrate zone (Figure 5-4). Below the clathrate, however, the relationship between porosities determined from the three different logs is reversed. Low density-determined porosities correlate with high resistivity-derived and sonic-derived porosities. Such log responses characterize unconsolidated zones in sedimentary basins and indicate the presence of overpressure. The clathrates appear to be an impermeable cap trapping excess pore pressures which in turn appear to extend downward even into the serpentinite basement rocks at Site 570 (Figure 5-5).

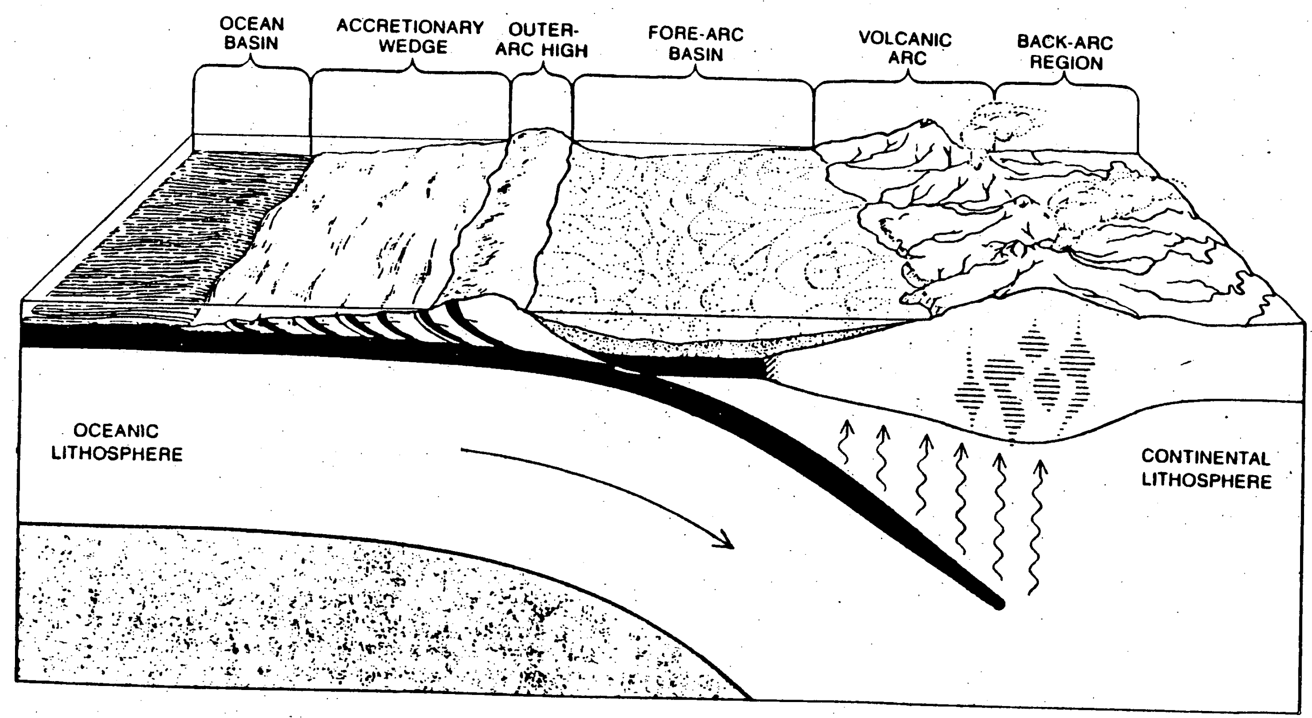


Figure 5-1. The structure of all subduction zones is generally the same, with an accretionary wedge of sediment from the ocean basin being offscraped onto the landward plate. A forearc basin forms when sediments from the volcanic island arc are ponded between the accretionary wedge and the arc. Decollement faults are found within the accretionary wedge (heavy black lines).

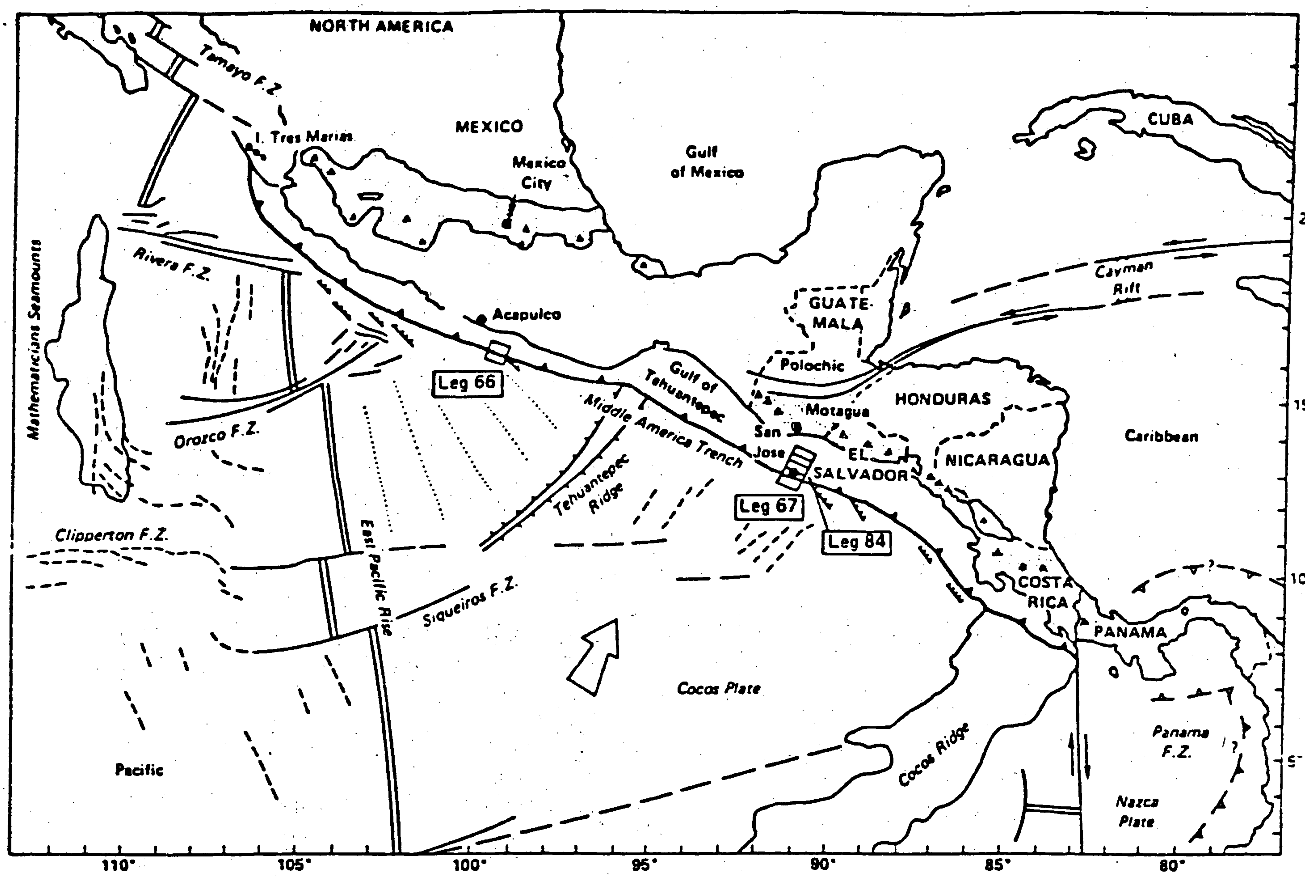


Figure 5-2. Sketch map of the Middle America Trench. DSDP Leg 84 rectangle shows the location of the Guatemala transect drillholes, and the smaller square represents Site 565 off Costa Rica.

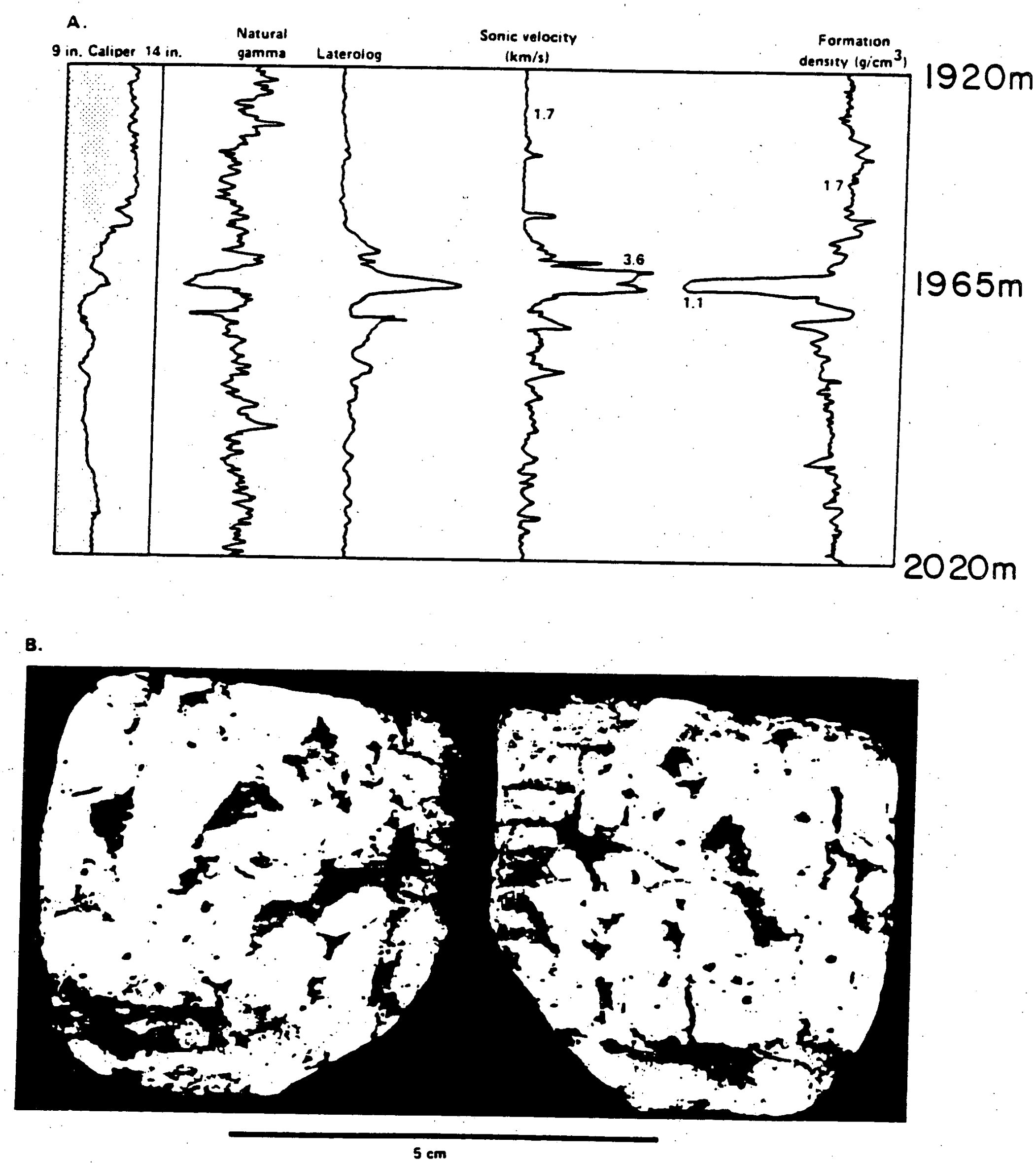
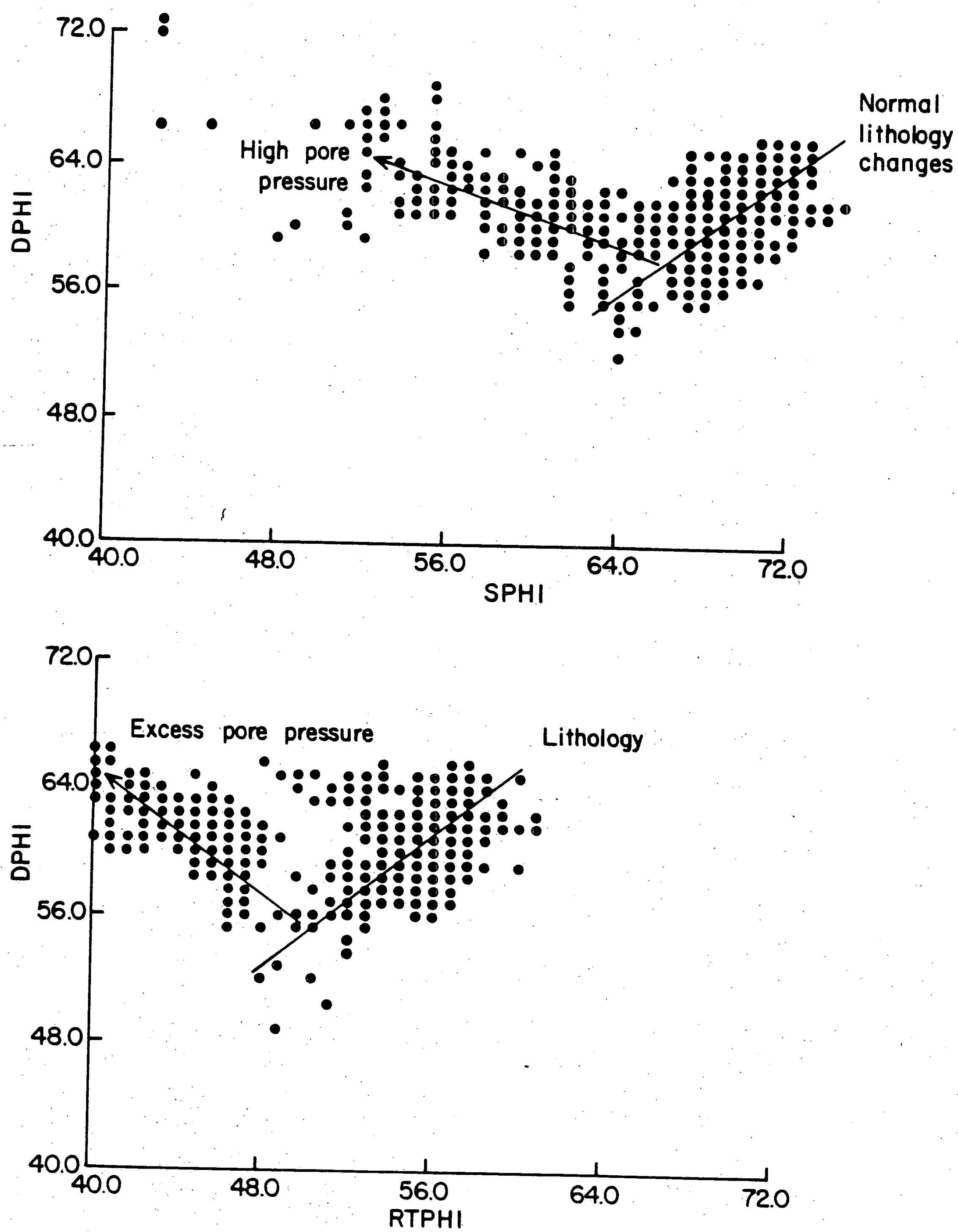


Figure 5-3. Caliper, gamma ray, laterolog electrical resistivity, sonic velocity and density from logs of DSDP Site 570, Leg 84, offshore Guatemala. Clathrate zone of frozen gas hydrates at 1965 m on logs (above) is seen in core (below).

Figure 5-4. Cross-plots of porosities calculated from density and resistivity logs (top), DSDP Site 570. Excess pore pressures trapped beneath the gas hydrate cap produce high density-derived porosities and low resistivity-derived porosities. Crossplot of porosities derived from density and sonic logs, DSDP Leg 84, Site 570 (below). Excess pore pressures beneath clathrate cap cause high apparent density-derived porosities and low sonic-derived porosities.



DSDP WELL 570, GUATAMALA TRENCH

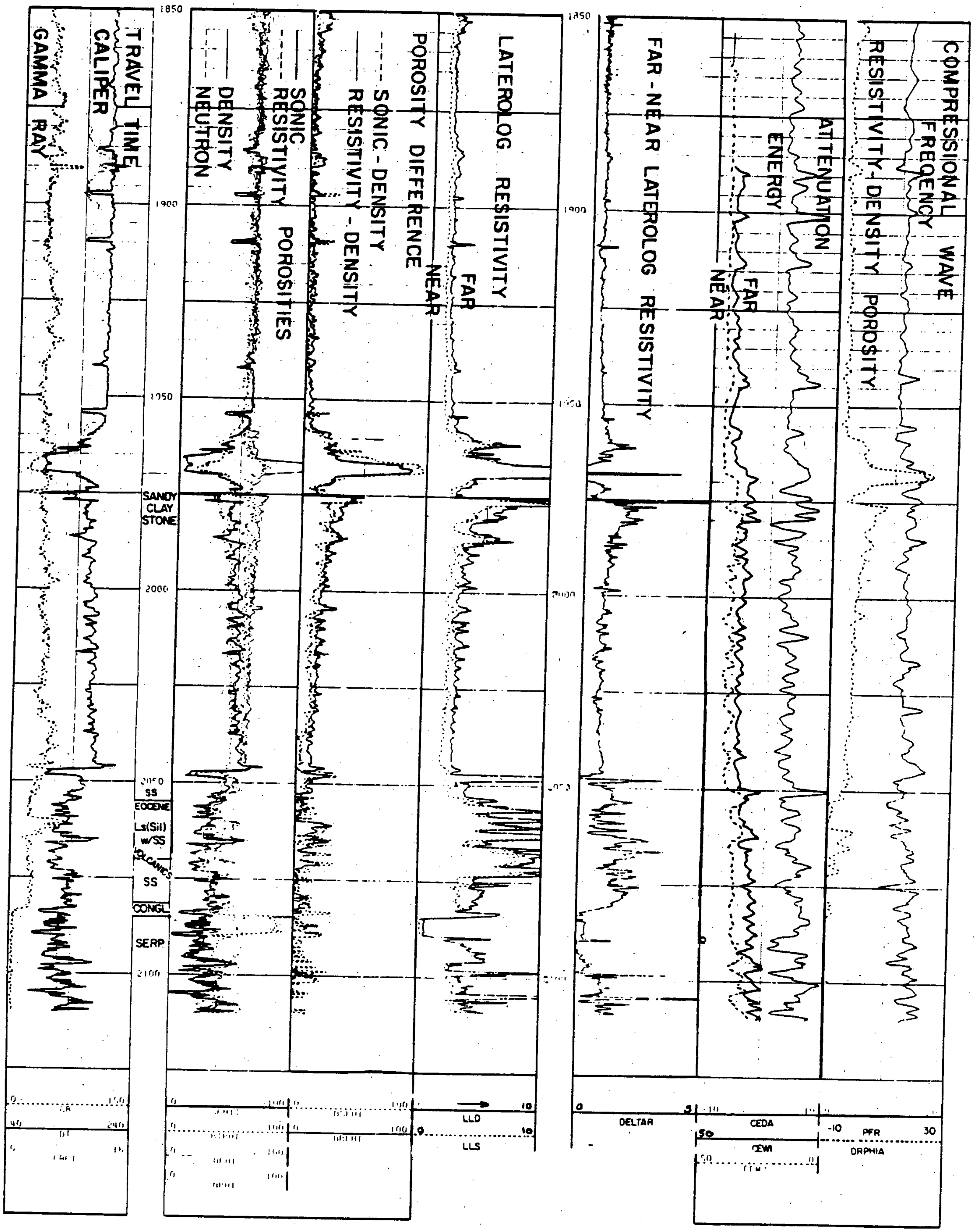


Figure 5-5. Left, sonic, resistivity, density and neutron porosities from Site 570. DSPHI and RPHI are density-sonic porosity and density-resistivity porosity differences. LLD and LLS are deep and shallow Laterolog resistivities, and the difference is shown as DELTAR. CEDA is compressional energy difference between waveforms 1 (CEW1) and 2 (CEW2). PFRA is averaged compressional spectrum center frequency.

Density-derived porosity is calculated from bulk rock densities, and excess pore pressures lower the whole rock density. That is, overpressures lower the bulk density and therefore raise the porosities calculated from the density log. In contrast, resistivities and velocities are significantly raised by excess methane hydrate present in an overpressure zone, and porosities so calculated are very low. The differences between sonic-derived versus density-derived porosities and resistivity-derived versus density-derived porosities are excellent indicators of overpressures from methane hydrates (Figures 5-5 and 5-6).

The degree of overpressure appears to drop exponentially beneath the clathrate cap (Figure 5-5). This is an indication that overpressures are trapped beneath the clathrate cap. Also, there is a marked difference between shallow and deep Laterolog resistivities, which indicates that the pore pressure near the borehole is less than that far from the borehole. That is, there is pressure release into the borehole. The overpressure itself cannot be very large, however, because the lithostatic pressure from 250 m of sediments with 55% porosities is only 7 bars above hydrostatic pressure. If *in situ* excess pore pressure were to exceed this value, hydraulic fracturing of the overlying cap rock would be likely.

Another indicator of overpressure is the attenuation effect of excess pore pressures on the transmissivity of sonic energy. The spectral analysis of compressional sonic waveforms shows an energy drop and center frequency increase in the higher pore pressure section of the well (Figure 5-5). The increased attenuation is likely caused by the decrease in contact-point rigidity of the matrix caused by the increased pore pressures. A crossplot of center frequency versus density shows an increase in frequency abruptly at the clathrate boundary, then a gradual decrease in center frequency with continued depth as the excess pore pressures decrease back to normal (Figure 5-6). This phenomenon is caused by the 'filter-characteristics' of the overpressured zone. Higher frequency energy is preferentially passed as low frequency energy is lost in the larger volume of pore spaces separating the rock matrix.

The processes which deform sediments from the subducting plate during subduction-related accretion are driven by excess pore pressures. That is, mobility of thrust sheets depends upon reduced shear strength from increased pore pressures. The source of the water is the compaction process itself, and that force is from plate convergence (Figure 5-7). The example above, though for a specialized segment of the overpressure problem, demonstrates the utility of logs for quantitative descriptions of pore pressures encountered during drilling.

Volcanic Processes at Subduction Zones

At subduction zones, cold lithosphere is underthrust back into the hot mantle, cooling it somewhat. Yet this mechanism produces most of the volcanoes active on the Earth's surface. Further, most of the violent eruptions in human history have come from volcanoes positioned above subducting lithosphere. Both the violence, and more fundamentally, generation of the magmas are thought to be related to volatiles released during dehydration of the oceanic crust at considerable depths beneath volcanic arcs during subduction (Figure 5-8).

This volcanic process is still poorly understood, however. For example, we know little about the mechanism or the timing of the magma ascent above slabs. Logging delivers

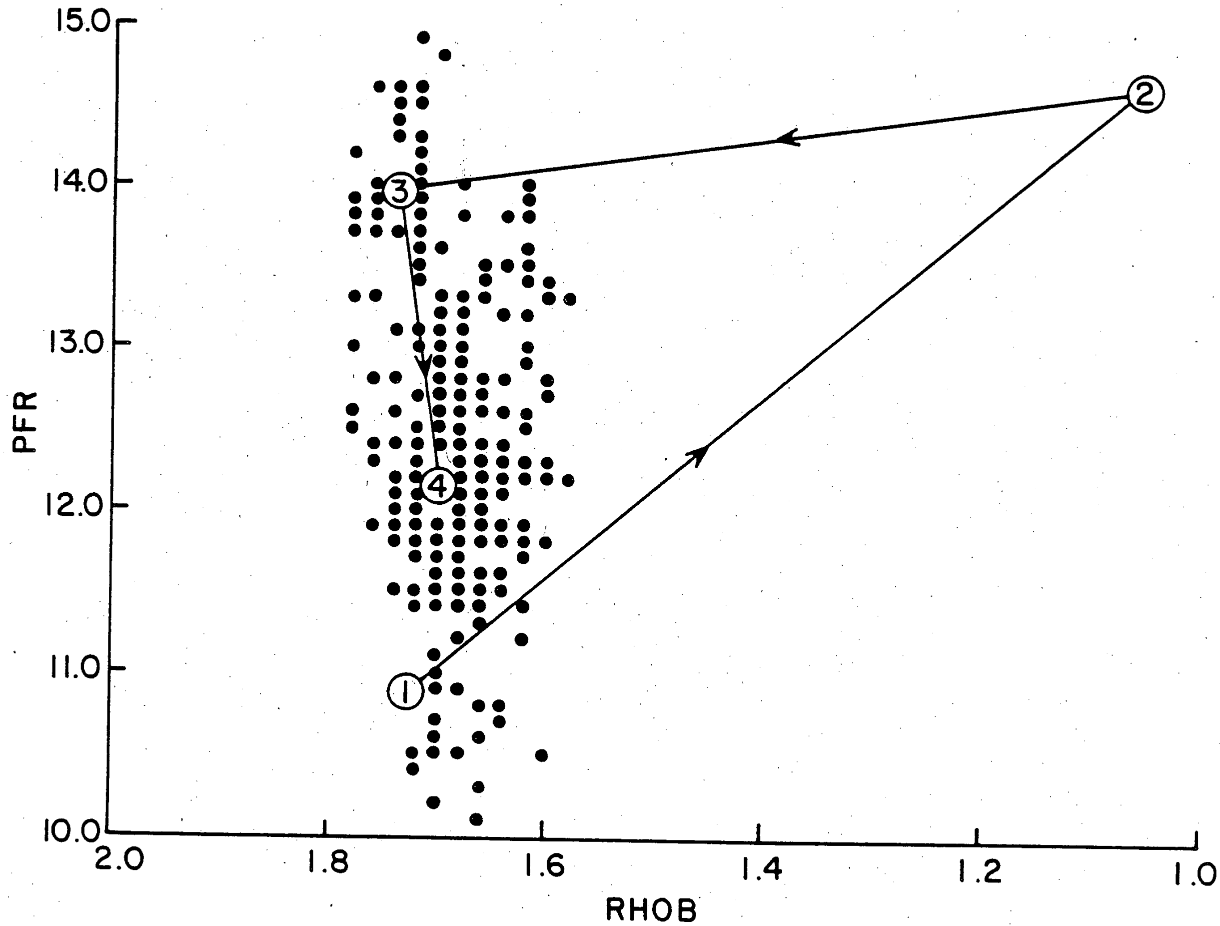


Figure 5-6. Compressional wave center-frequency crossplotted versus density from logs of Site 570. 1 is above the clathrate, 2 is the clathrate zone, 3 is from overpressured zone just beneath gas hydrate, and 4 is in basement.

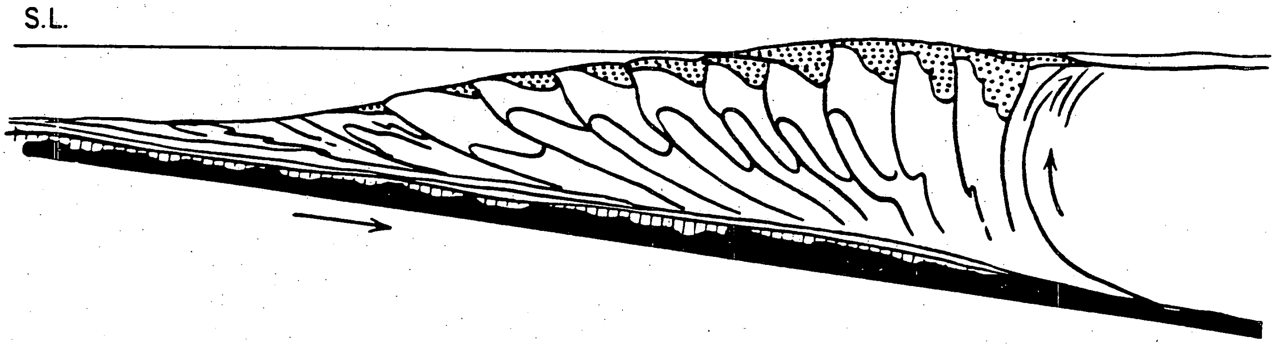


Figure 5-7. Subduction scrapes off soft sediments into an accretionary wedge of inverted stratigraphy. The sediments nearest the surface are often the oldest, with new sediments from the plate being added to the bottom of the pile. The wedge must grow greater than 30 km thick before its height overcomes its increased weight and the prism breaks the surface and becomes land.

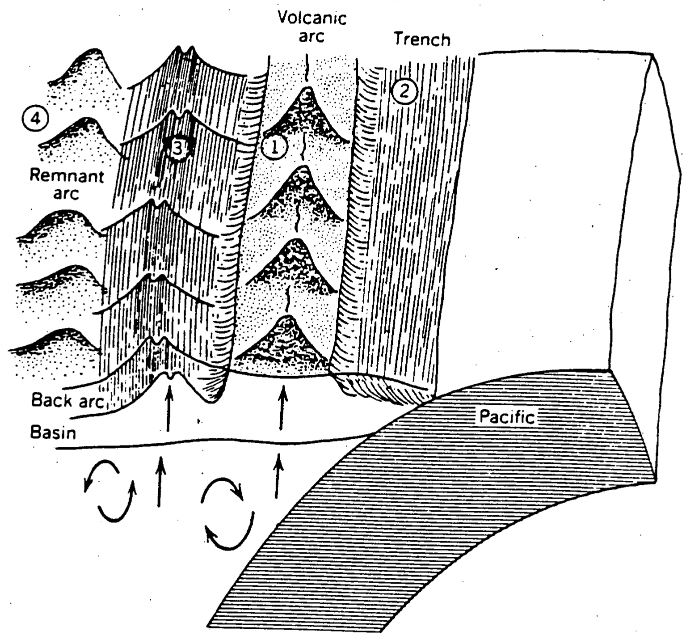


Figure 5-8. The detailed structure of a subduction complex.

useful information about the timing and composition of volcanic eruptions from long ago in geological history. Interestingly, this information is often recorded not in lava flows, but in ash layers and volcaniclastic sediments deposited long distances from the volcanic source.

ODP Leg 107 Site 651 drilled in the Tyrrhenian Sea between Italy and Sardinia in the Mediterranean Sea (Figure 5-9). The Tyrrhenian Sea is a back-arc basin formed very recently by sea floor spreading behind the northwest dipping subduction zone beneath the boot of Italy. As such, its geometry is similar to other back arc basins such as the eastern Caribbean, Scotia Sea, and Banda Sea (Figure 5-10). Active volcanoes surround the basin on three sides.

One mission of the drilling was to determine the relative importance of volcanic sediment versus pelagic carbonate deposition in the newly opened basin. Core recovery averaged about 40%, and most was a carbonate rich, fine grained mudstone. Few volcanic sediments were recovered.

The logs run in the hole indicate instead that the predominant sediment at the site is not carbonate, but volcaniclastics rich in potassium, uranium and thorium (Figure 5-10). Velocity, density, neutron porosity and electrical resistivity log responses were used to perform an analysis of the lithology of the well. The results suggest four major layers of extensive volcaniclastics were deposited within the upper 300 m of sediments at Site 651 (Figure 5-11). Carbonate variations in the core results do not clearly define these layers, but in retrospect, support the log interpretation.

There appear to be four separate eruption-frequency peaks: near 140 m, 180 m, 250 m, and 290 mbsf (Figure 5-11). Sediment ages from paleontological analysis of recovered core from near these ash-rich intervals date them crudely at 180,000, 330,000, 500,000, and about 700,000 years before present. The logs are recording evidence of massive eruption events on the continents surrounding the Tyrrhenian Sea. The thick layers of ash concentrated at these four depths require multiple eruptions from multiple volcanoes to produce the thicknesses observed.

We have little other geological evidence of such long-term periodicity of volcanic eruptions in arc volcanoes above subduction zones. How the cycles relate to the subduction process and its accompanying supply of volatiles into the mantle remains unknown. The logs do, however, carry further evidence about the place of origin of the ash. Uranium/thorium levels in volcanic provinces surrounding the Tyrrhenian Sea show two provinces (Figure 5-12). The high U to Th ratio of the volcaniclastics indicate that they originated from the northern Roman Province to the north of the drill site, rather than from the Province to the southeast. The logs even contain data pertaining to the prevalent wind and ocean circulation patterns over southern Italy over the past one million years: from the north rather than the south.

Logs have only recently begun to be applied to subduction zone problems, but their ability to deliver a continuous measure of physical and chemical parameter variations with depth promises to add considerably to our understanding of forearc, arc and back-arc processes. We have a particular need for data on the timing and variability of subduction zone events such as, for example, the beginning and subsequent cessation in back-arc spreading.

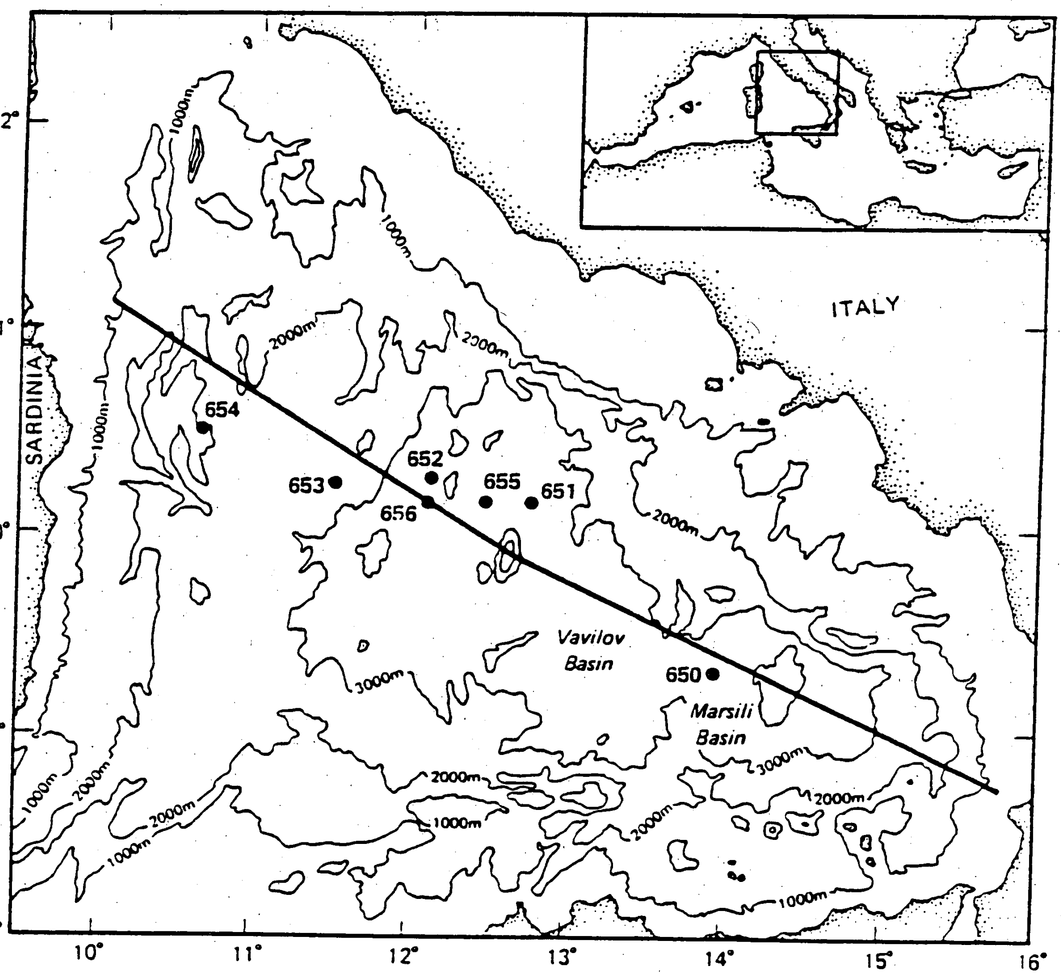


Figure 5-9. Location map of holes drilled in the Tyrrhenian Sea during ODP Leg 107.

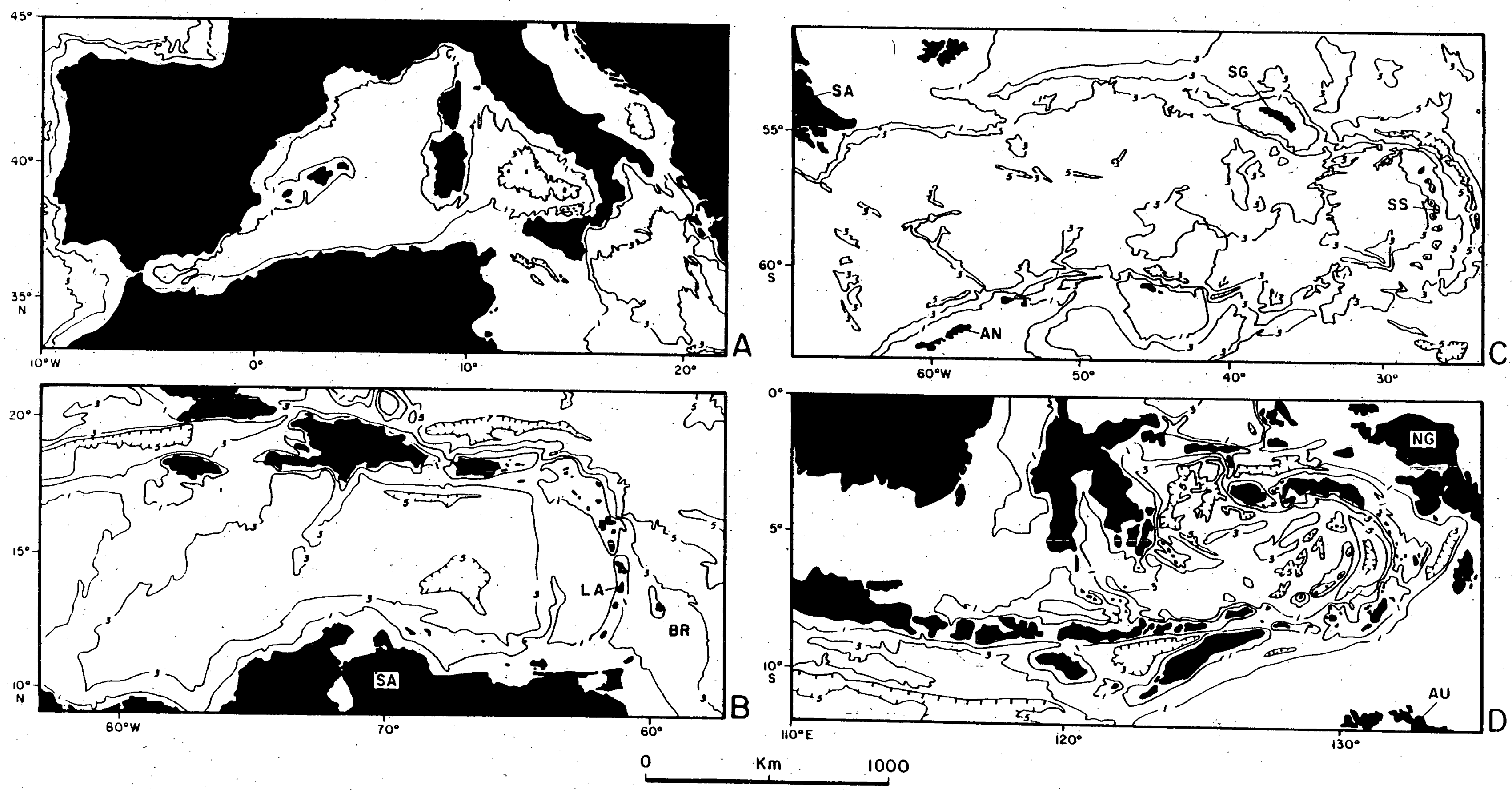


Figure 5-10. Structure of the Tyrrhenian Sea (top left) is similar to other back-arc basins such as the Carribean (bottom left), Scotia Sea (top right), and Banda Sea (bottom right).

Hole 651-A, Leg 107 (Tyrrhenian Sea)

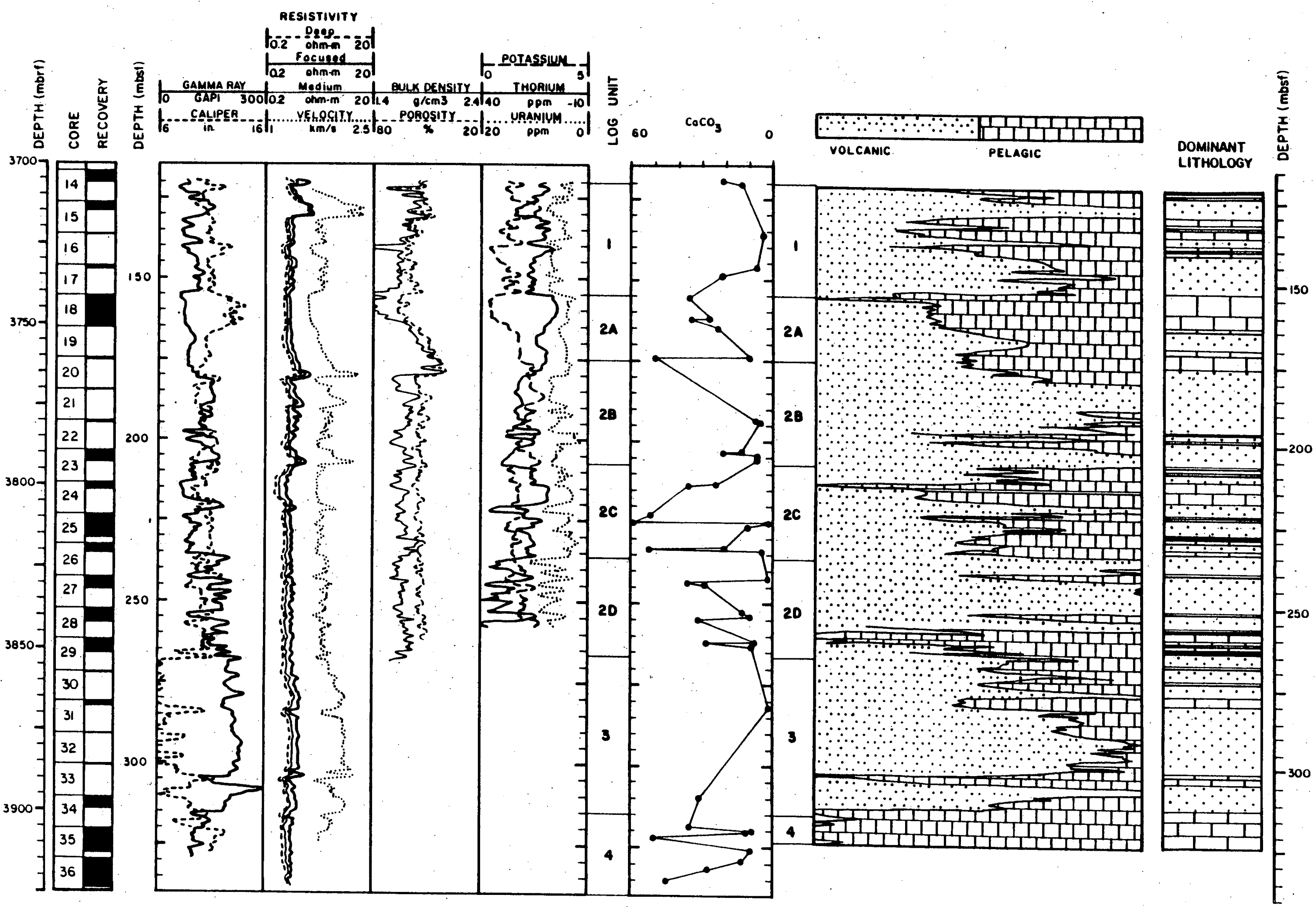


Figure 5-11. Logs from Leg 107, Site 651. Carbonate content from limited core recovery (center) cannot discriminate volcaniclastic cycles determined from logs (right).

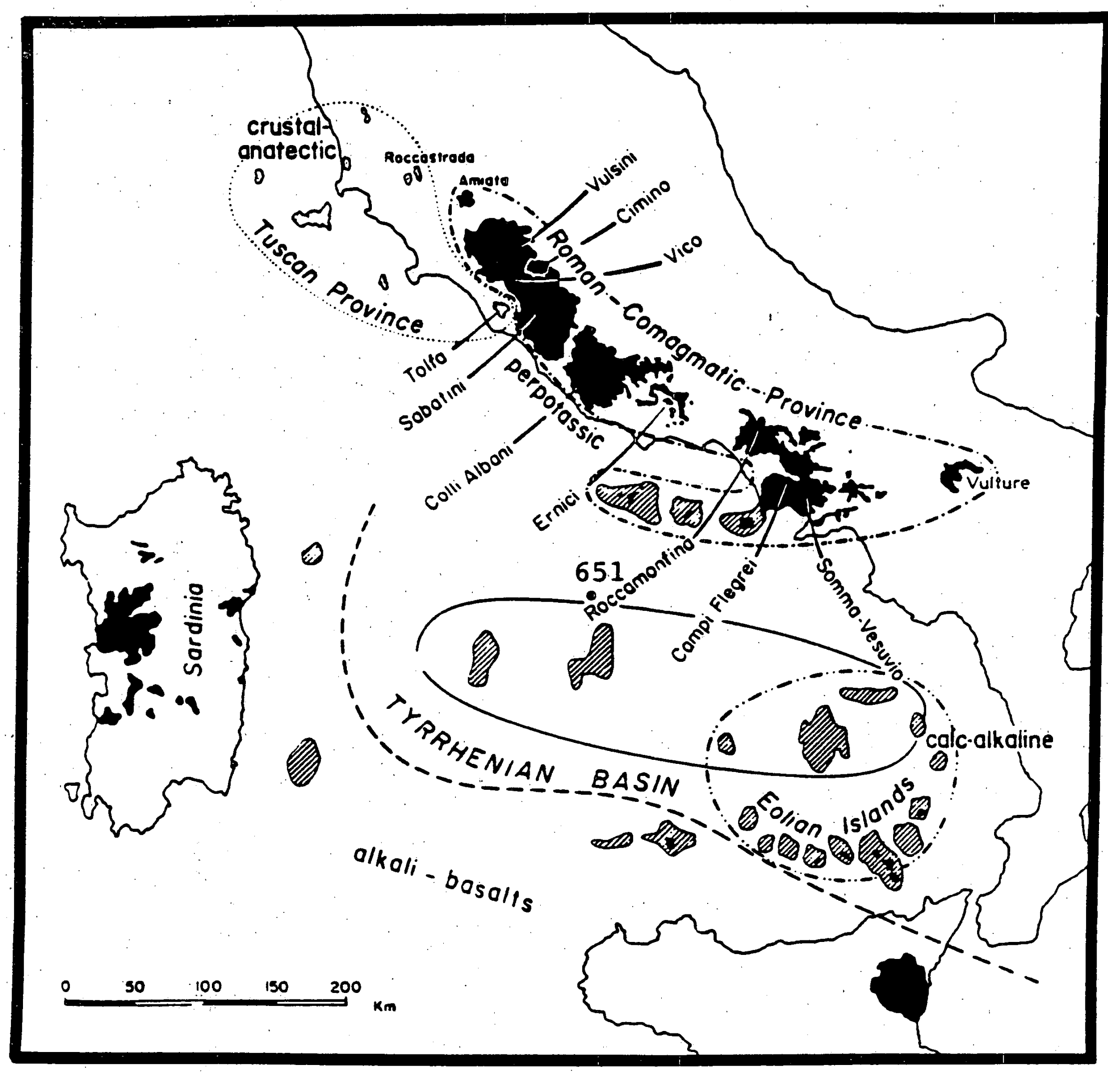


Figure 5-12. Possible volcanic sources for volcaniclastic ash layers deposited in Tyrrhenian Sea.

Chapter 6

Rifting and Subsidence of Continental Margins

The early rifting history of continental margins remains one of the outstanding problems of the Earth Sciences. Such events are important not only because they are the mechanism by which new oceans are formed and continents are torn apart, but because the heat and desiccation which accompany rifting produce the hydrocarbon maturation and eventual structural traps (salt domes) for many of the world's oil and gas deposits.

Ocean drilling is the only way to study this process in detail because the predominant forces involved come from great depth and a continuous depth section of the well is recorded. Below, we discuss the methodology to use geophysical and geochemical logs both in newly rifted and old, well developed sedimentary basins. In the latter case, the determination of the relative importance of the major forces driving subsidence of a basin are emphasized.

The Rifting Event

The predominant forces involved in the rifting of continents are extensional. Continents are pulled apart by deeper seated processes acting on entire plates. The evidence for this is the prevalence of normal faulting, and the thinning of the continental crust which comes from stretching. This stretching event brings the asthenosphere closer to the surface, until eventually, no continental crust remains. A new ocean basin then begins to form with sea floor spreading producing normal oceanic crust and mantle.

The stretching process is recorded in the sediments deposited in the graben formed by brittle failure caused by stretching (Figure 6-1). The rift zone topography very much approximates that of a mid-ocean ridge rift valley.

It is these syn-rift sediments, rather than the post-rift sediment which yield most geological information about the stretching process. ODP Leg 107 drilled Site 652 into the pre-, syn-, and post-rift sediments of a tilted block of the lower continental margin of eastern Sardinia (Tyrrhenian Sea; Figure 5-9). The sequence logged through the upper Miocene (Messinian) consists of thin alternations of gypsum- and carbonate-bearing sandy silts or sands, and less calcareous clays and muds. These are separated from a similar sequence. richer in gypsum and anhydrite, by a poligenic pebble horizon, about 15 m-thick. The entire sedimentary sequence is barren, and likely deposited in a shallow lacustrine environment during the early stages of rifting.

Neutron activation logging through the Messinian section of the well from 200 to 350 mbsf recorded Fe, Ca, Si, H, and Cl variations through the hole. Ratios of these curves (Figure 6-2) were calculated for a better identification of the lithologic changes. High Fe and Si layers (corresponding to high IIR and LIR) can be observed within the dominant

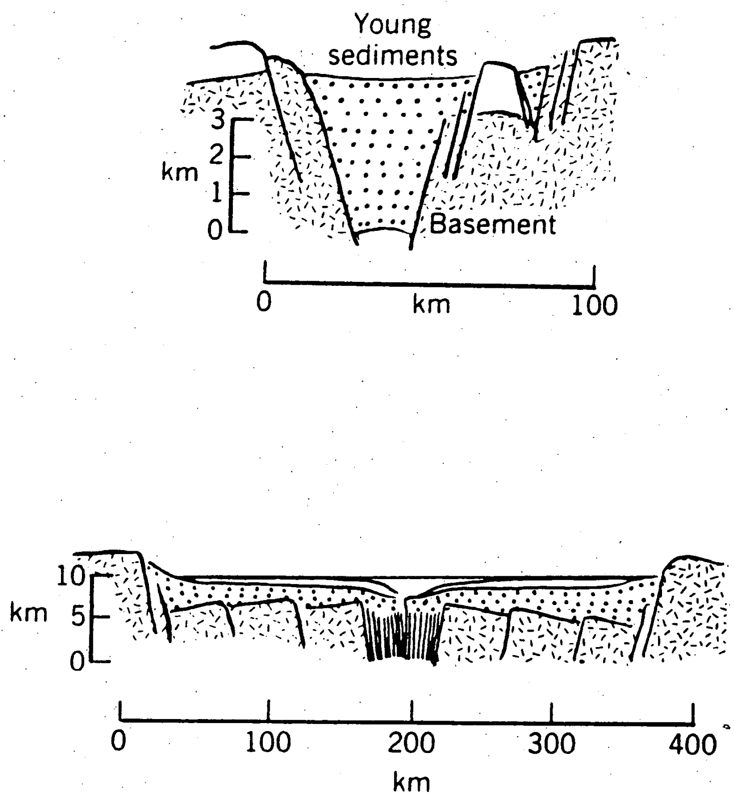


Figure 6-1. Left: Syn-rift sediments are deposited into a new forming basin, which is caused by the stretching of continental crust. Right: Post-rift sediments are deposited into the new ocean basin, as extension by sea-floor spreading takes over after continental stretching is complete.

Hole 652-A, Leg 107 (Tyrrhenian Sea)

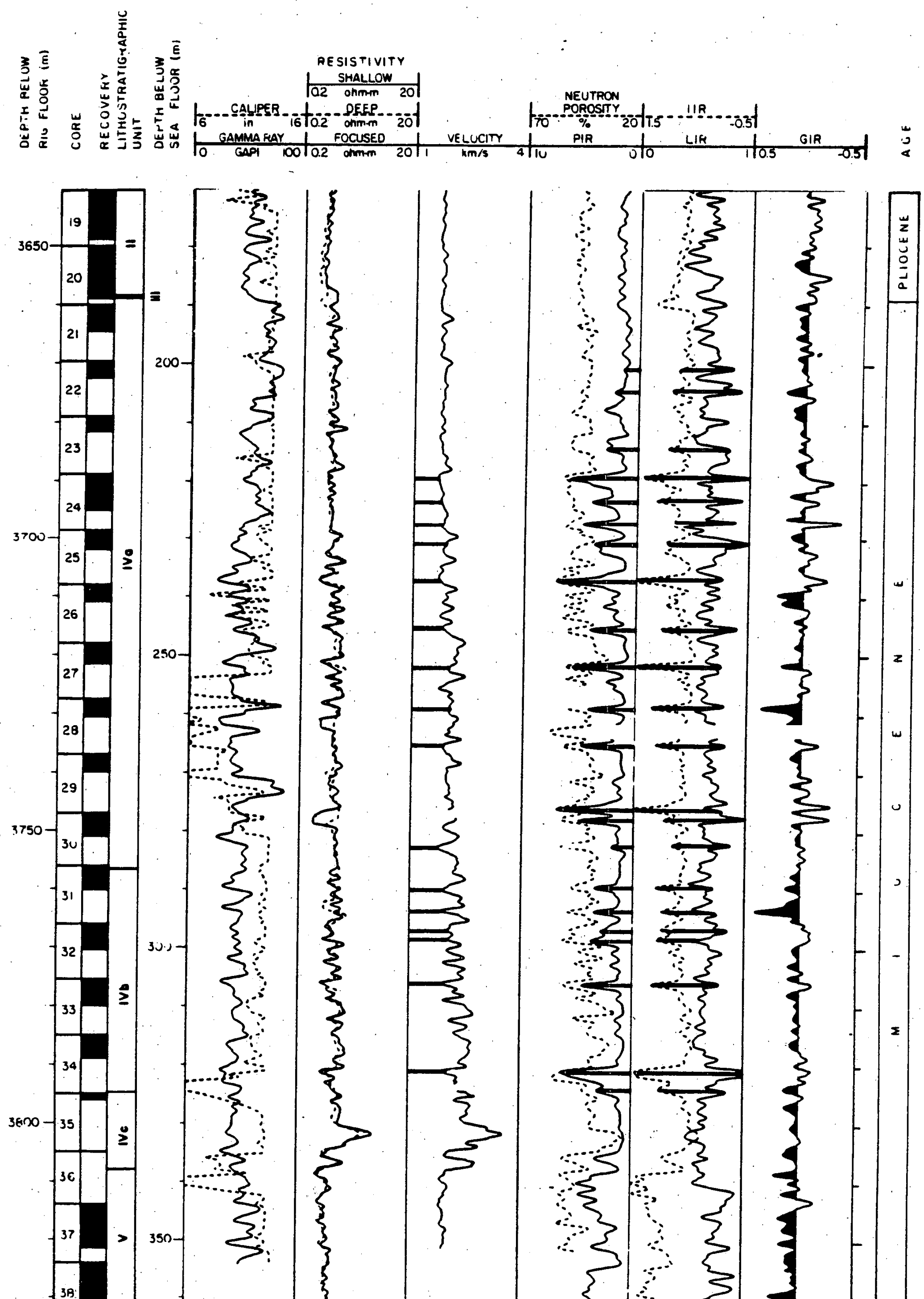


Figure 6-2. Neutron activation log from Site 652, Leg 107. IIR (iron indicator) = Fe/Si+Ca; PIR (porosity indicator) = H/Cl; LIR (lithology indicator) = Si/Si+Ca; GIR (gypsum indicator) = S/Ca+Si. Clay-rich levels, interpreted as cycles, are marked by black bars.

high Ca (low IIR and LIR) carbonate section. These layers have been interpreted as clay-rich levels. Since during the Messinian the Mediterranean desiccated and evidence of fluctuations of the sea level due to evaporation or influx of water from the Gibraltar Strait are frequently recorded in the sedimentary sequences, the deposition of these clay-rich layers might have been climatically controlled. As alternative, they might represent occasional deeper water erosional infilling from the surrounding continent which rapidly fills the newly forming basin whenever it suddenly deepens from rift related subsidence. On the other hand, the coarser grained carbonatic sediments deposited when the basin remained passive for long periods of time.

This observation can be directly tied to stretching models of continental rifting, since these models predict exponential subsidence accompanying the rifting and stretching process. The logs add to the models in that the clay layers are possibly infilling events caused by rapid subsidence, or "jerks downward". The carbonatic deposition occurs when subsidence is passive, and slow enough to allow uniform carbonate sedimentation. This active downthrow is likely accomplished along basin boundary faults. The fact that the depth interval between turbidite events is decreasing uphole suggests that stretching is slowly progressing from long-spaced jerks to shorter, more frequent jerks culminating in steady-state spreading or that the sedimentation rate has decreased upward in the section. The observed periodicity in subsidence and sedimentation is consistent with stretching models, but adds detail to the models not seen in either seismic reflection profiles from the area, or in the core from the well.

Backstripping and the Subsidence History of Rifted Margins

The vertical movements detected in the rifting stage by the logs from the Tyrrhenian Sea continue to a lesser extent throughout the evolution of a continental margin. It is this subsidence which drives the formation of sedimentary basins, since the accumulation of sediment itself requires only proximity to an erosional source (continents) and a depression in which to accumulate (the newly deepening basin). Although the load of a massive sedimentary pile drives the basin to sink further, it is the tectonic subsidence which provides the continued downward force responsible for the primary accumulation of the sedimentary section.

The force driving tectonic subsidence is thermal contraction from cooling of the lithosphere after the heating event which results in rifting. The development of models to describe the history of this heating and subsequent cooling event is an area of intense research at the moment. Complexities such as multiple heating pulses and complicated subsidence histories must be delineated before the origin and causes of continental rifting can be understood. The North Sea, for example, is a basin which underwent multiple heating events. The hydrocarbon accumulations associated with North Sea traps, and other tectonically subsiding basins of the world, owe their thermal maturation to these heating events.

The prediction of where new accumulations of hydrocarbons might be found depends upon an understanding of the thermal history of a rifted continental margin. Consider the east coast of the United States. There are large hydrocarbon traps to be found within the more than 10 km of sediments in this basin which resulted from the cooling and subsidence of continental margin crust rifted from Africa in the Jurassic. Was there enough heating from initial rifting to mature hydrocarbons to fill these traps?

In fact, there are three inter-related forces which result in subsidence of an old margin such as that offshore New Jersey: thermal cooling, thinning of the crust itself so that the cooled crust returns to a lower base level than it started, and loading from the sediments which fill any depression in the surface of the Earth (Figure 6-3). Maturation depends only on the first of these forces, thermal heating and cooling.

The eastern U.S. coast consists of many structures which would ordinarily provide traps for hydrocarbons. A prominent reef accompanied by diapirs exists on the edge of the margin (Figure 6-4). These are two of the most prolific trapping mechanisms known. The question is whether the margin was stretched sufficiently to heat the sediments to maturation. In order to answer this question, the amount of stretching and thermal subsidence must be measured in logs from wells.

Logs provide the crucial information to "backstrip" a margin. Backstripping removes sedimentary load-induced subsidence in order to reveal the true heat signature from tectonic stretching, thinning, and cooling.

The COST B-2 and B-3 wells were drilled offshore New Jersey not to find oil, but by the U.S.G.S. as a 'stratigraphic test'. The logs from those wells contribute compaction and porosity information necessary to calculate the subsidence caused by the weight of sediments. The difference between this subsidence and the total thickness of the well is the tectonic subsidence, after minor fluctuations in sea level are accounted for (Figure 6-5). The tectonic subsidence can then be compared to rifting models to predict the degree of stretching responsible for the additional subsidence observed beyond that accounted for by backstripping. The steeper this change in depth with time, the more severe the stretching. The degree of stretching and thinning is represented by the 'Beta' value of a margin. Beta values of 3 to 4 for offshore New Jersey indicate two to three hundred percent stretching of the crust during rifting (Figure 6-6). That is, the resultant thinned continental crust beneath the margin sediments is one half to one third its original thickness. This amount of heating would produce hydrocarbons, but in 80 to 120 million year old sediments now buried 5 to 10 km beneath the surface. Whether these hydrocarbons have migrated upsection to suitable, and economically developable, traps is still in question.

Subsidence of the Straits of Florida

To further illustrate the insights gained from logs in such environments, consider the tectonic problem of the subsidence history of the Bahama platform studied during ODP Leg 101. There are two conflicting hypotheses about the origin of the Bahamas platform: either grabens, rifting and differential subsidence related to the initial rifting away from Africa has produced the present topographic relief of the platform, or passive carbonate bank progradation and differential growth of the reef has produced that relief. Obviously, the hot tectonic source of the former would mature hydrocarbons more efficiently than the cold biological source of the latter.

Site 626 was drilled 450 m into the deep water sediments of the Straits of Florida, an area never drilled before, but where more subsidence should have occurred if rifting produced the topography of the Bahamas Bank. An 18,000 foot oil company well exists in

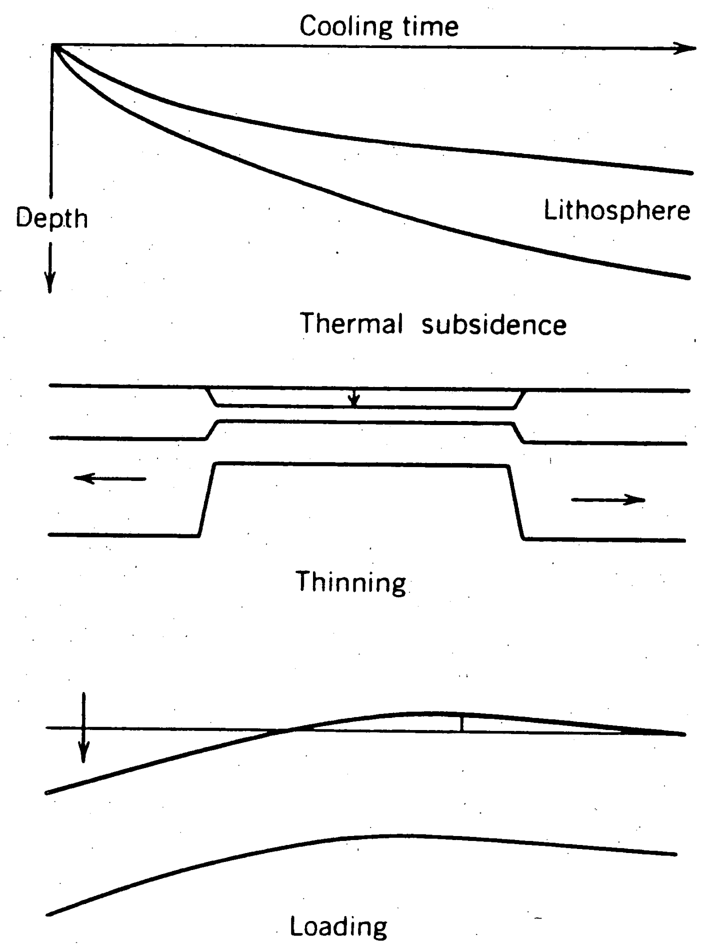


Figure 6-3. Three principle modes of lithospheric subsidence are thermal cooling, thinning, and emplacement of a load.

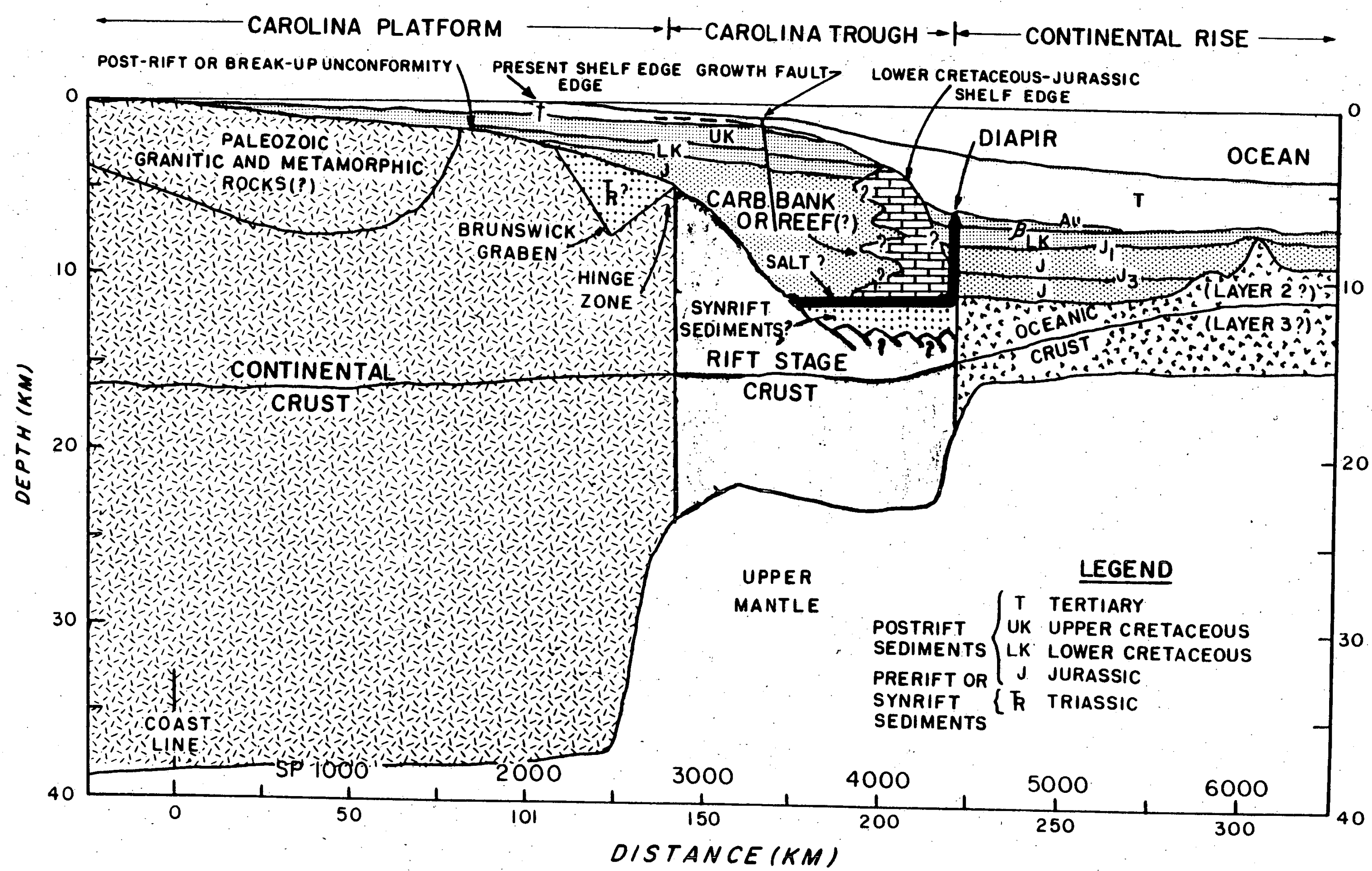


Figure 6-4. The corresponding rifted margin of North America has over 10 km of sediment under the continental margin. The outward growing reef at the continent-ocean boundary also tells a tale of the changes in the edge of the continent with time.

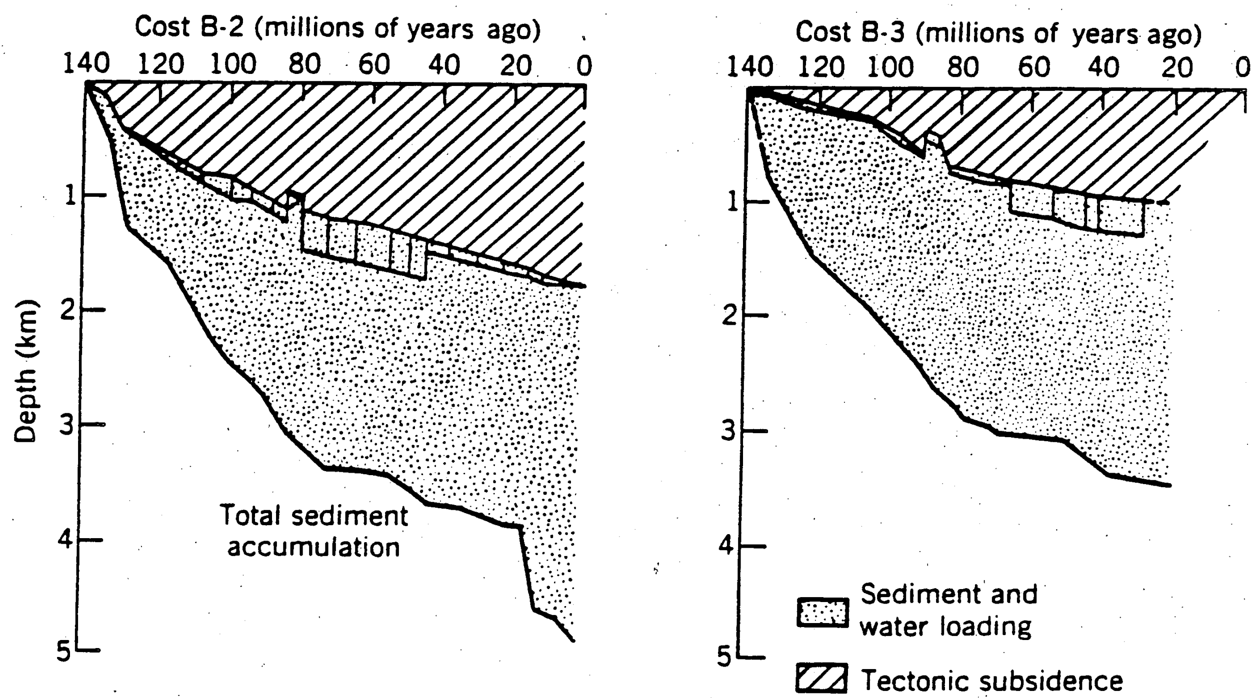


Figure 6-5. Total subsidence at two deep wells drilled off the east coast of the United States. The total subsidence is made up of three principal components, sedimentary load-induced (stippled), thermal or tectonic cooled (hatched), and minor sea-level changes (vertical hatching). Tectonic subsidence, which is called "backstripping", is obtained by removing the sedimentary load-induced component and sea-level changes from the total subsidence.

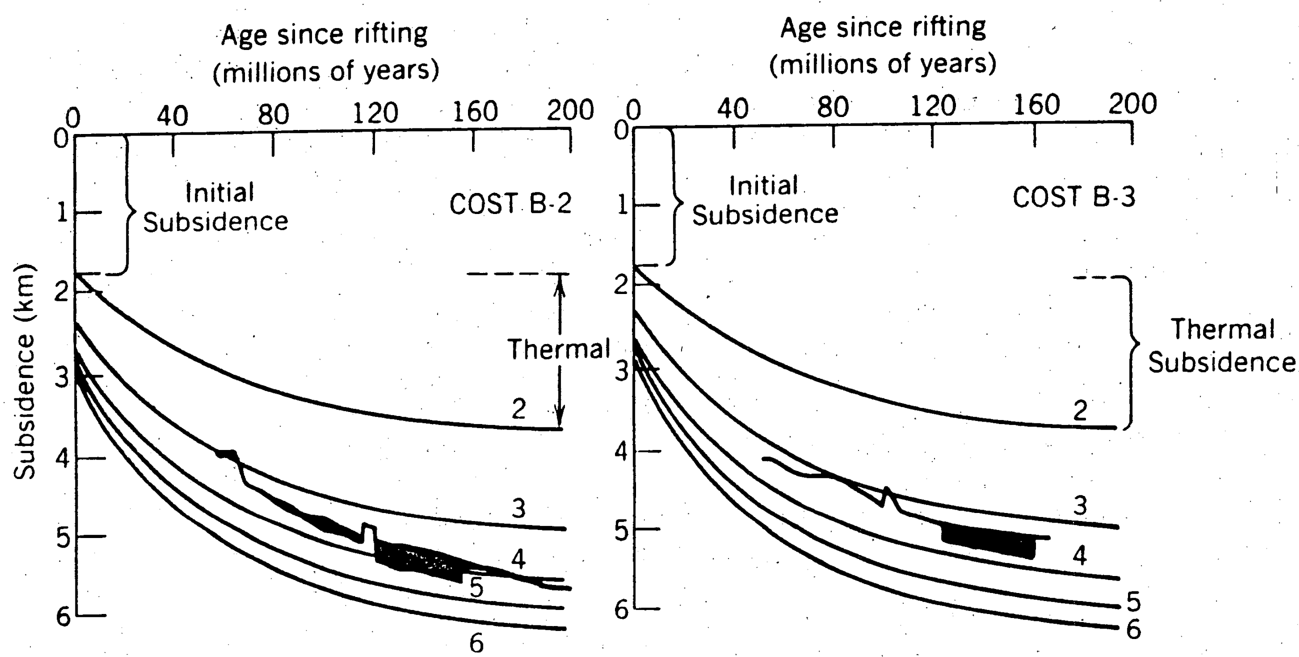


Figure 6-6. The amount of stretching during initial continental rifting controls the amount of heat in a basin during its cooling process. Here, backstripping was used to identify 200 to 300 percent (beta = 3 to 4) stretching offshore New Jersey.

shallow water on the western edge of the Bahamas bank (the Great Isaac well), and there are several wells available on the east coast of Florida with which to compare subsidence histories with those from the Straits of Florida (Figure 6-7). Either the Bank and Straits wells subsided at the same tectonic rate and biological progradation was the dominant force which generated the topography of the western Bahamas Platform, or the Straits shows evidence of much greater thermal subsidence because they are above the old stretched crust of a rifted graben.

Neutron porosity logs from the two different wells show the same general compaction relation (Figure 6-8) of decreasing porosity with increasing depth. This porosity versus depth relation must be combined with accurate biostratigraphic ages in order to establish accurate sedimentation rates. Cores are of course the best way to determine this, although the Great Isaac well has no core (cuttings were used). Third, sea level changes must be known. Since the wells are so close to each other, sea level changes should affect each in the same way, and so sea level changes were neglected.

The sedimentation rate and compaction histories of Site 626, the Great Isaac well and two on the east coast of Florida, the Palm Beach and Key Largo wells, show that Great Isaac is subsiding at a much greater rate than the others (Figure 6-9). Sedimentation rates have not yet been backstripped from these wells, so the differential subsidence could be from a much greater sediment load at Great Isaac instead of from thermal subsidence.

These backstripping calculations still leave Great Isaac subsiding at twice the rate of the other wells (Figure 6-10). This is suspicious because the other side of the bank (Florida) is subsiding the least, as if a thermal rifting event were off to the east of Great Isaac instead of in the Straits (the only deep water, graben-like structure in the immediate area).

An additional complexity can account for further 'subsidence' of Great Isaac sediments. The Bahamas Bank has prograded across the location of this well but not the others (Figure 6-11). Thus the sedimentation rate has greatly increased as the water became shallower at Great Isaac. The added subsidence observed in the Great Isaac well is not from thermal subsidence but from growth of the reef complex from east toward the west.

The tectonic subsidence corrected for both backstripping and progradation shows that Site 626 has indeed subsided more than the Bahamas and Florida wells, but the amount of additional subsidence is only 200 m or so (Figure 6-12). The origin of this differential subsidence rate could simply be from the fact that the crust beneath the Straits is older, and therefore has subsided by an added 200 m, to that beneath the Bahamas Bank and Florida. No dramatic evidence for stretching beneath Site 626 versus Great Isaac and the Florida wells is evident. Therefore, thermal rifting is not suspected as the mechanism driving subsidence in this area.

Although the well logs enter only one segment of the backstripping equation, they are an essential determinant of the compaction history of the sediment column. As such, they contribute equally to a better understanding of the subsidence history of sedimentary basins.

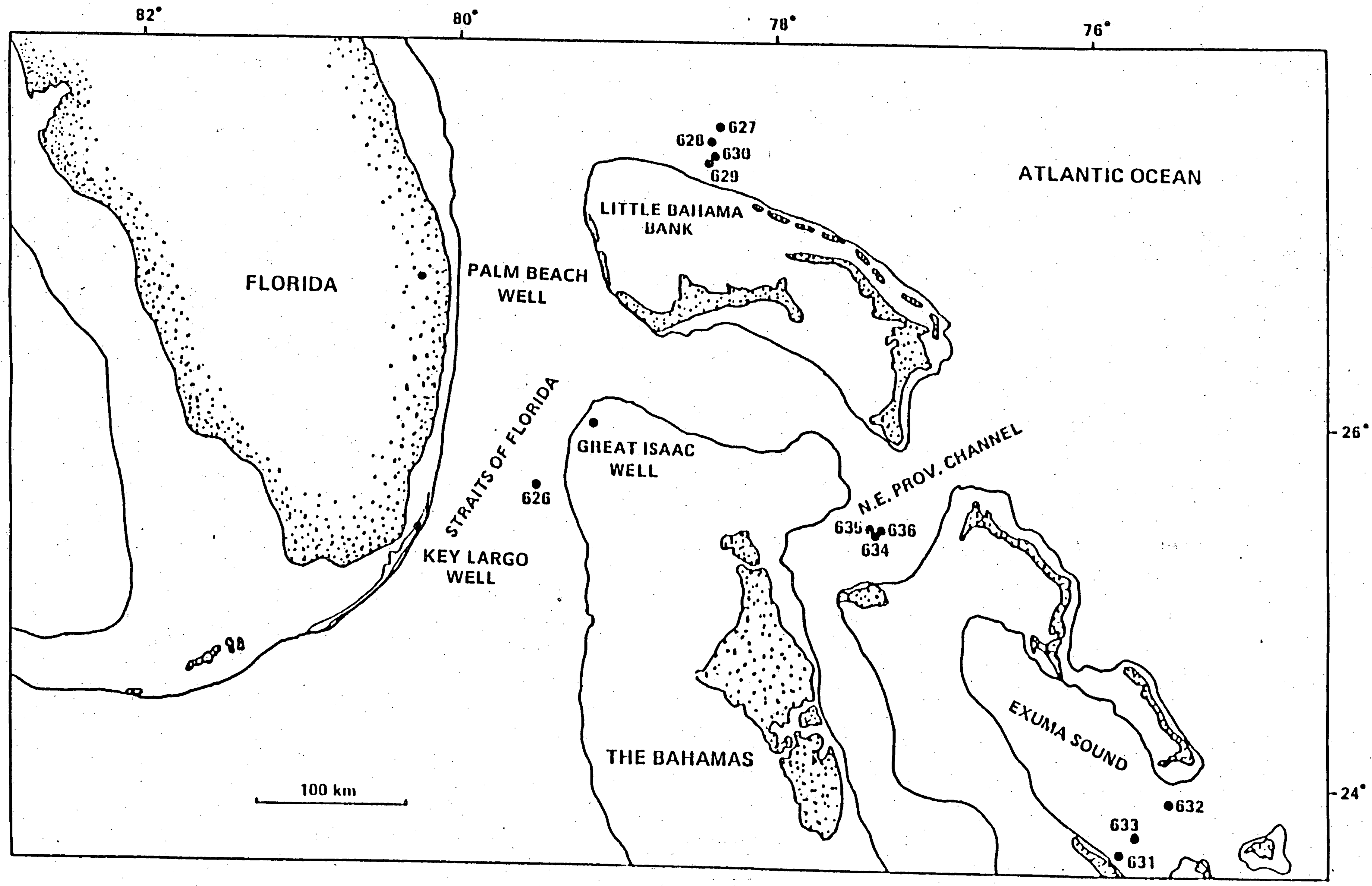


Figure 6-7. Location of sites occupied on Leg 101.

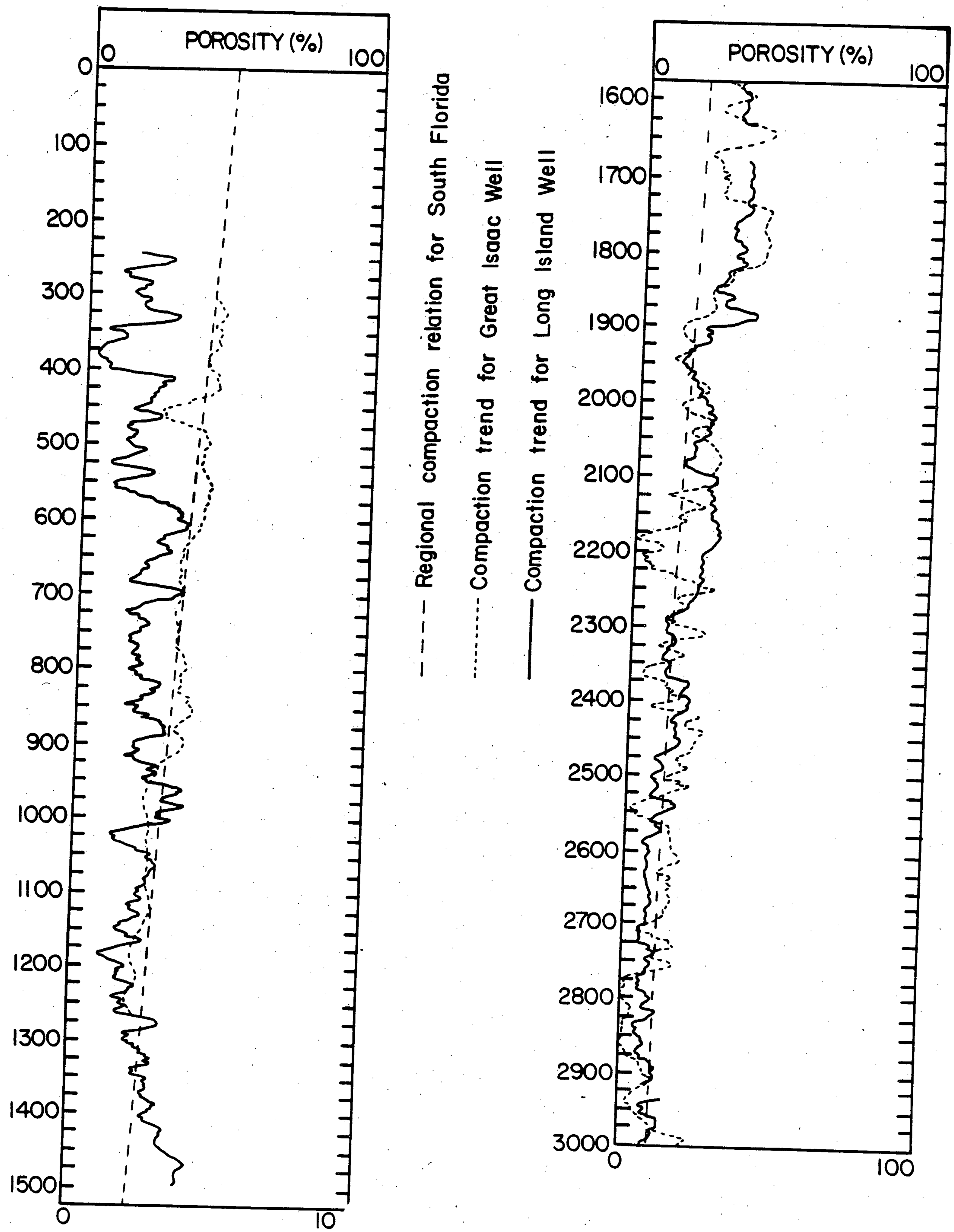


Figure 6-8. Porosities from neutron logs, ODP Leg 101 Site 626 (dotted) and the Great Isaac oil well (solid).

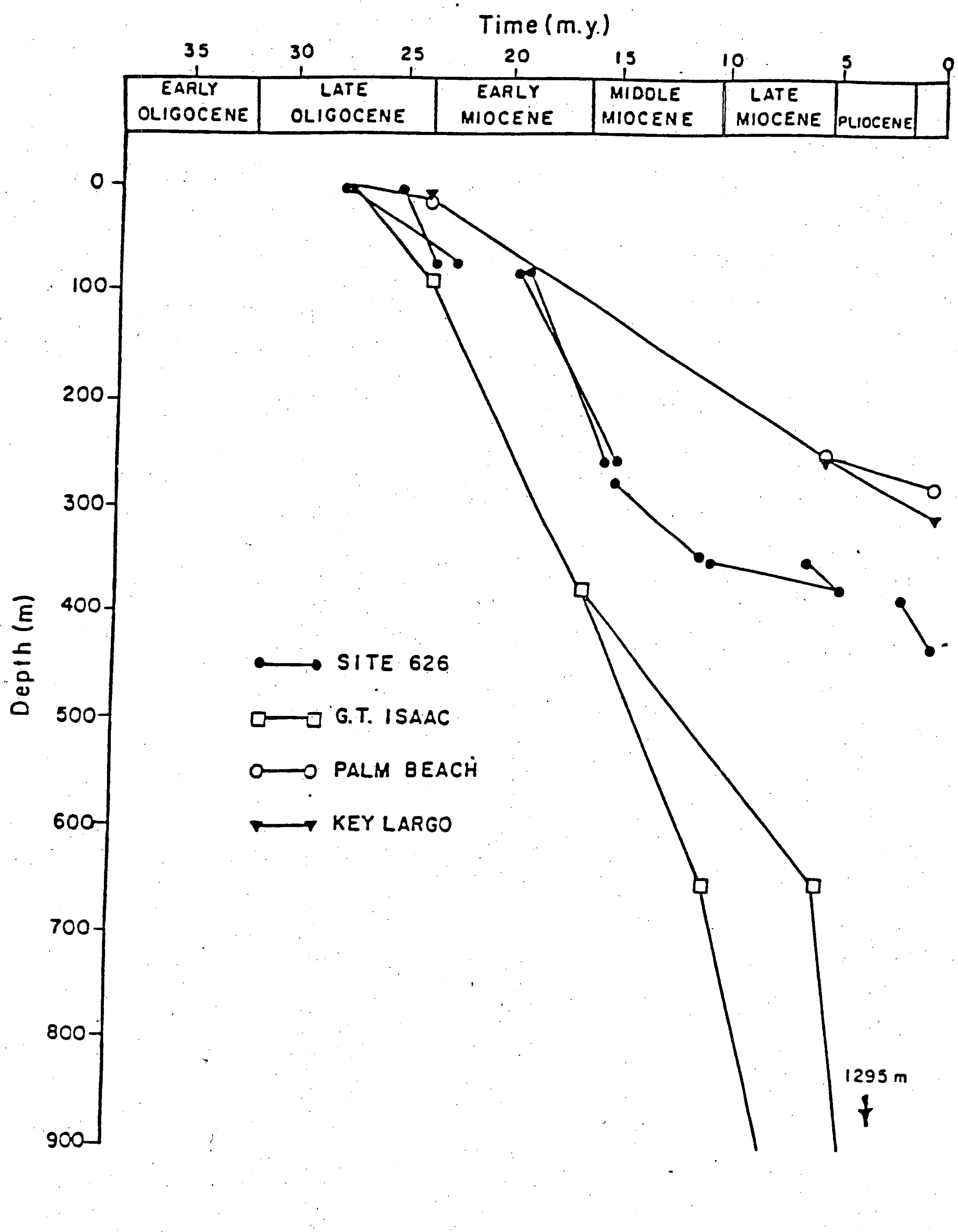


Figure 6-9. Subsidence curves for Site 626 and the Great Isaac, Palm Beach, and Key Largo wells. The indication of two ages in the Great Isaac well at the same depth represents uncertainty in the Miocene section of the well.

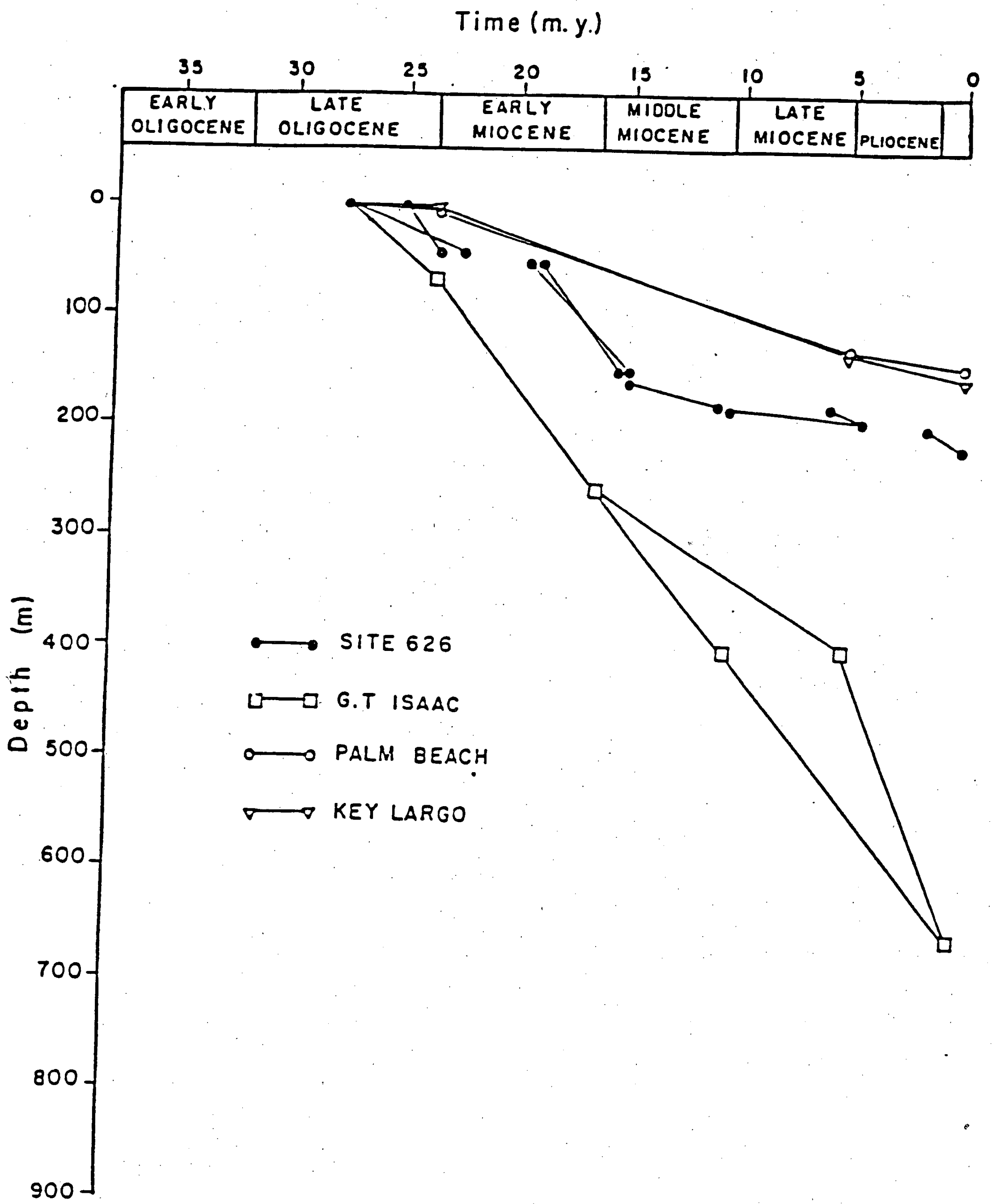


Figure 6-10. Backstripped wells from the Straits of Florida, corrected for compaction, and non-tectonic subsidence.

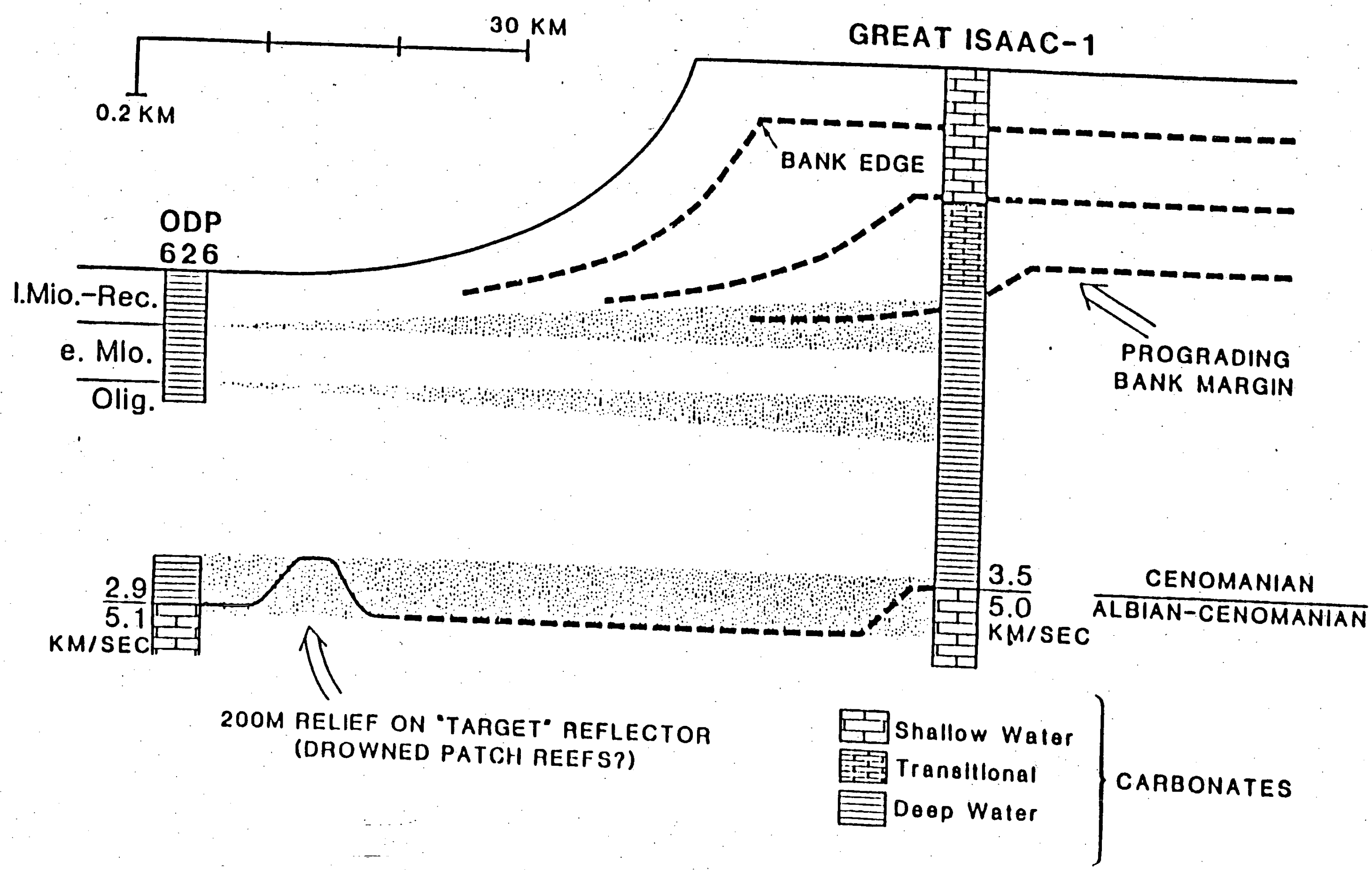


Figure 6-11. Progradation history of the Bahamas bank between the Great Isaac well and the Site 626 wells.

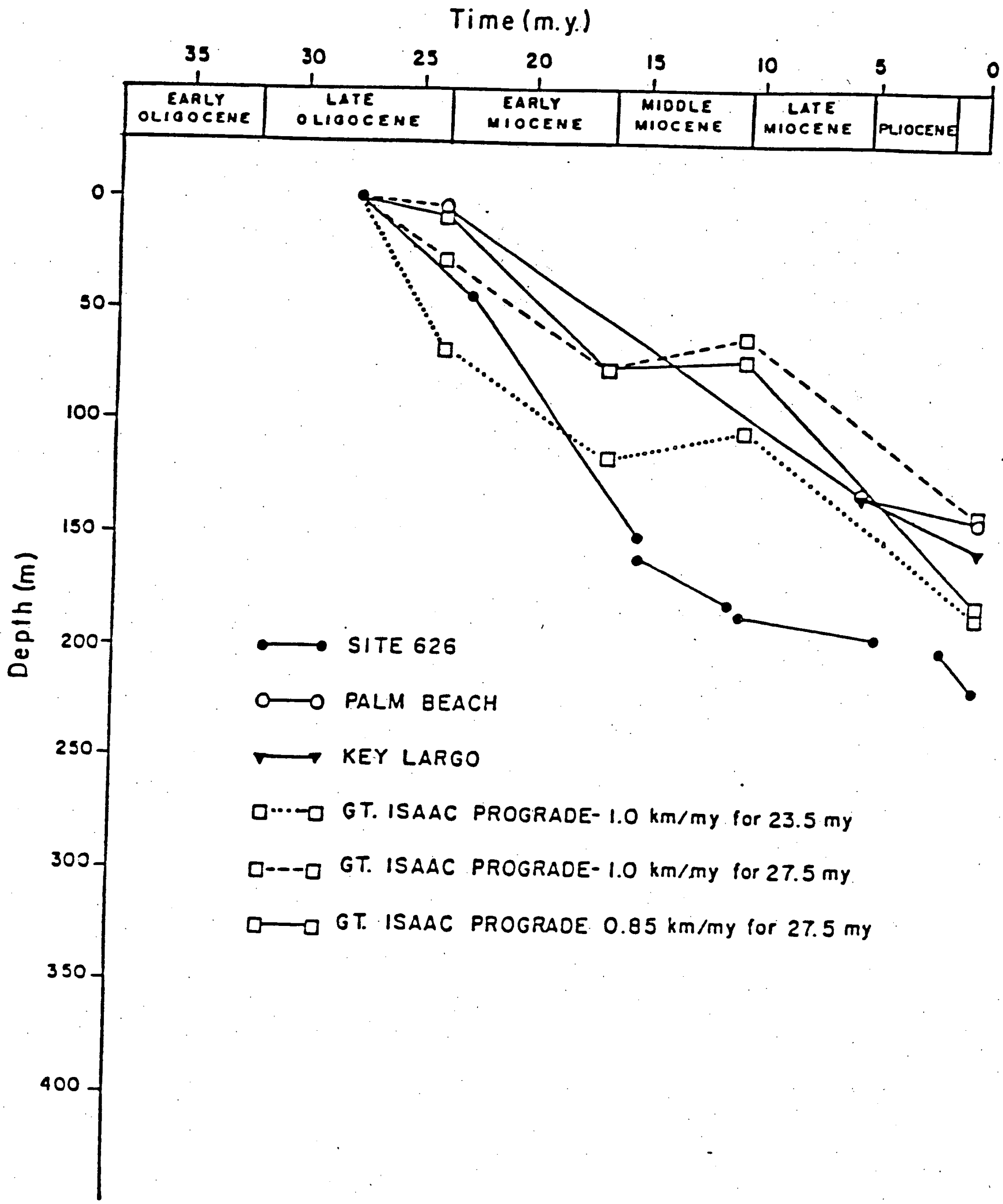


Figure 6-12. Subsidence history of the Straits of Florida wells backstripped, then corrected for progradation. The resultant subsidence curves are from tectonic processes such as thermal cooling.

Chapter 7

Logs From Transform Fault Plate Boundaries

Other tectonic environments to be drilled in ODP include shear zones such as transform fault plate boundaries, fracture zones, and backarc basins. The problems to be addressed by logging in such regimes are somewhat different from those within stable plate interiors and at ridges and subduction zones. Structural relationships are both more complex and more crucial to the deciphering of the tectonic processes active in shear zones. The major logging tool from the oil industry used to determine structural information *in situ*, the dipmeter, is presently unavailable to ODP because the drill pipe is too small for the tool. A modified version is in the planning stages, so a discussion of how to do science with the dipmeter is relevant to ODP scientists. *(NOTE: Dipmeter and Formation Microscanner have been routinely run in ODP boreholes since Leg 126).* Also, the Borehole Televiewer (BHTV) provides formation dip whenever the layers produce strong acoustic reflectivity contrasts (about 50% of the time).

The determination of strike and dip of layers is the most fundamental measurement made by a structural geologist. Such data are particularly useful in zones of complex tectonic deformation such as at shear boundaries. Here, plate tectonics does not work completely and precisely. Overthrusting, onlap and offscraping all occur as the broad forces pushing and pulling plates are complicated by the detailed three dimensional topography of plate edges. Strike and dip variations measured within wells add a third dimension to surface mapping.

The primary tool for measurement of strike and dip is the electrical resistivity difference recorded by four orthogonal pads squeezed against the wellbore wall (Figure 7-1). The orientation relative to magnetic north is recorded at the same time so that electrical conductivity contrasts around the well can be oriented. The exact geological cause of the conductivity contrasts is not of so much interest as the depth in the well at which high or low resistivity layers are detected by each of the four pads. Strikes and dips of these layers are then determined.

The Borehole Televiewer images the borehole, so if hardness or lithology contrasts result in differing reflection coefficients for different layers, it too can image dip and determine strike (Figure 7- 2). Because the BHTV is a 360 degree rotating transducer oriented to north by a fluxgate magnetometer, it is much more accurate at determining dip. Its vertical resolution is about 1.27 cm, whereas the dipmeter resolution is about 1 cm.

The Dipmeter and Faulting Along The San Andreas Fault

As an example of the utility of dipmeter logging along transform fault boundaries and with the hope that this service will soon be available to ODP, consider the results from the

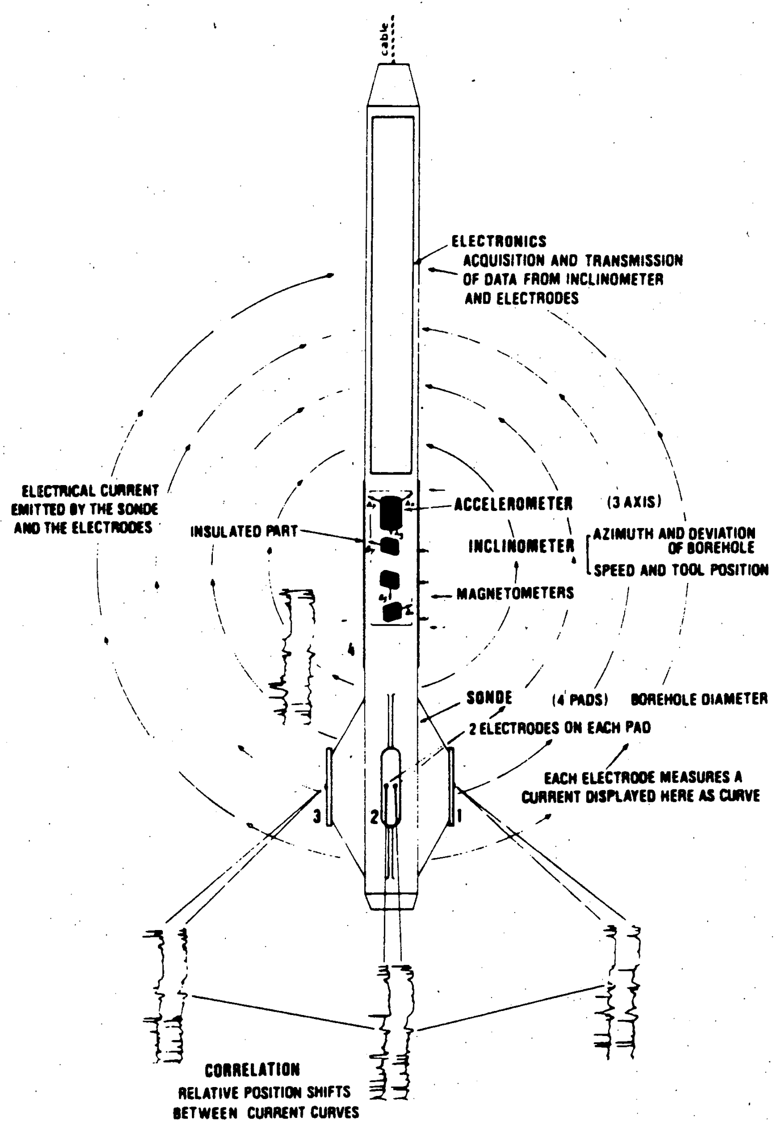
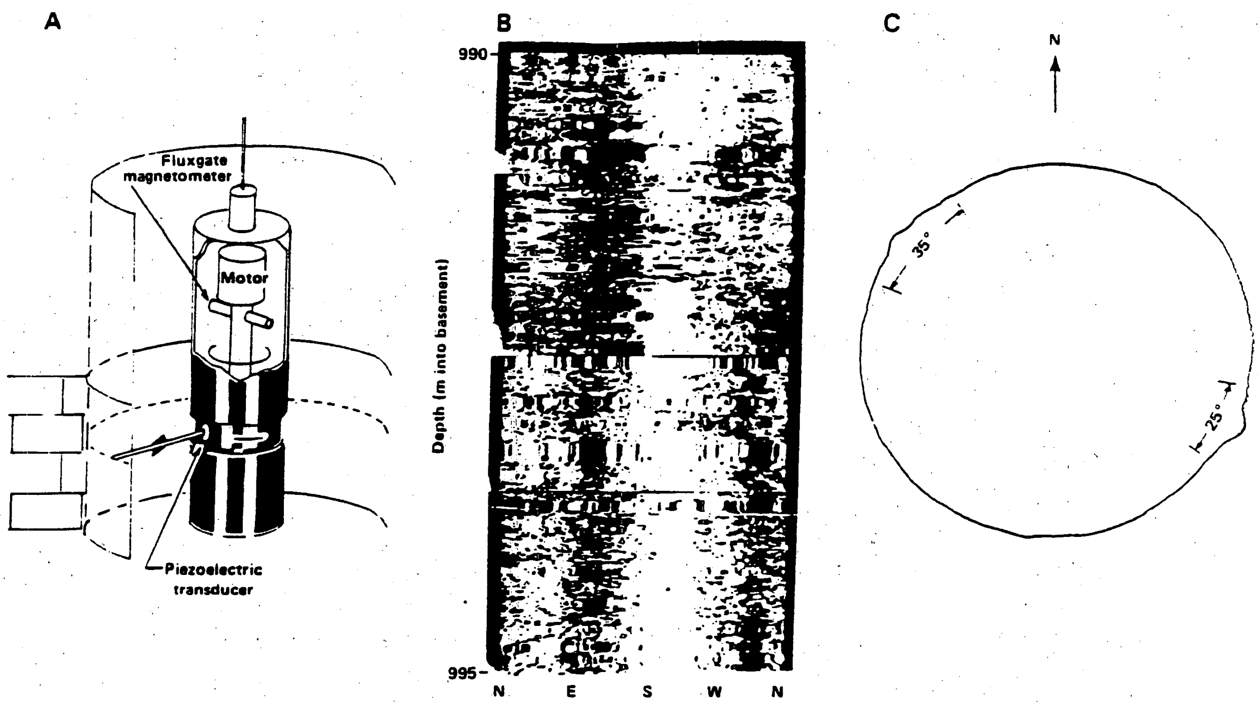


Figure 7-1. The different measurements of the 4-arm dipmeter (courtesy of Schlumberger).



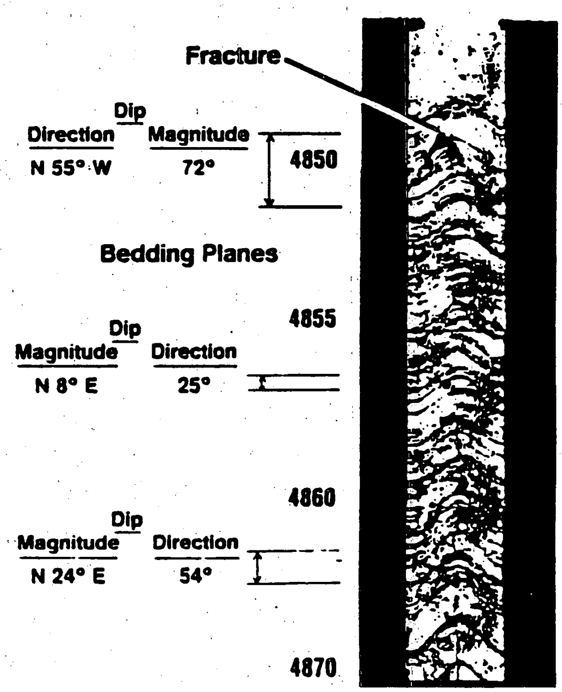


Figure 7-2. Televiewer for ultrasonic borehole imaging, used to measure the state of stress deep in the crust. By imaging the borehole wall with ultrasound signal, it is possible to "see" where the rock has broken away because of the same stress that drives the plates across the surface of the Earth. The orientations of these "breakouts" indicate the direction the maximum push is coming from, and helps to establish which forces are driving the plates.

site of the United States' continental scientific drill hole at Cajon Pass, California. Here, the Transverse Range mountains and the San Andreas Fault meet (Figure 7-3). The result is a dogleg in the fault, and severe tectonic disruption of the strike-slip forces active along the fault. Major secondary faults branch off the San Andreas to the south (the San Jacinto Fault) and to the east (the Squaw Peak Fault; Figure 7-4). Arkoma Oil and Gas Co. drilled a 2 km well within 4 km of the San Andreas fault hoping to find oil trapped in sediments squeezed by the conflicting tectonic forces. Instead, they encountered granite at 750 m depth, and did not come out of basement to total depth.

A dipmeter log was run in the hole to attempt to determine why the sedimentary section is so thin. The dipmeter shows uniform, steeply dipping beds over the upper 375 m which are Punchbowl terrigenous sandstones dipping 50-70 degrees to the northeast (Figure 7-5). At 375 m, a drastic unconformity is crossed, with beds beneath dipping less than 10 degrees. The interval between 300 and 375 m consists of a series of shallow to steep shear zones characteristic of drag along the topside of a major thrust fault. One other major fault is seen in the dipmeter log at 300 m, with shallow to steep dips all facing to the northwest rather than to the northeast. There are also three minor faults at 190, 215, and 270 m, each with horizontal dips.

Steep structural dips can be removed from a dipmeter log to reveal the depositional dips masked by the deformation. Gentle 10 to 20 degree folding to the south is also recorded in the log data, but is partially obscured by the steep structural dip. The usefulness of the dipmeter log becomes apparent when these structural constraints are applied to a geological model of deformation along the San Andreas fault in the vicinity of Cajon Pass.

There are two sedimentological formations evident from the well cuttings and the regional geology surrounding the well: the Punchbowl above and the contemporaneous Crowder terrestrial sands below the unconformity. Prior to 10 million years ago, deposition of these two units occurred from stream beds feeding into two adjacent basins. The San Andreas fault did not yet exist in Southern California because the Farallon Plate had not been fully subducted beneath the Sierra Nevada subduction complex (Figure 7-6).

The subduction of the Farallon spreading center 10 million years ago placed North American Plate in contact with Pacific Plate (Figure 7-6). The resultant motion was strike-slip, with the Pacific Plate moving to the northwest along the newly formed San Andreas Fault. The wellsite at Cajon Pass however was thrust from the southwest to the northeast by the dogleg in the San Andreas. The steep dips encountered in the well above 375 m resulted when the Punchbowl was forced on end as it was thrust across the top of the Crowder (Figure 7-7).

The dipmeter then records 20 degree folding to the southwest in this entire sedimentary section. The northwest striking fault is likely a normal fault which was the last structural overprint of the existing wellsite geology. Present day extension was preceded by initial thrusting and considerable strike-slip movement since other pieces of the Punchbowl-Crowder system are found 150 km to the northwest on the Pacific side of the San Andreas fault.

This example from Cajon Pass demonstrates how important oriented structural information is from a well. Logs are the only sure way to obtain such data in a continuous fashion.

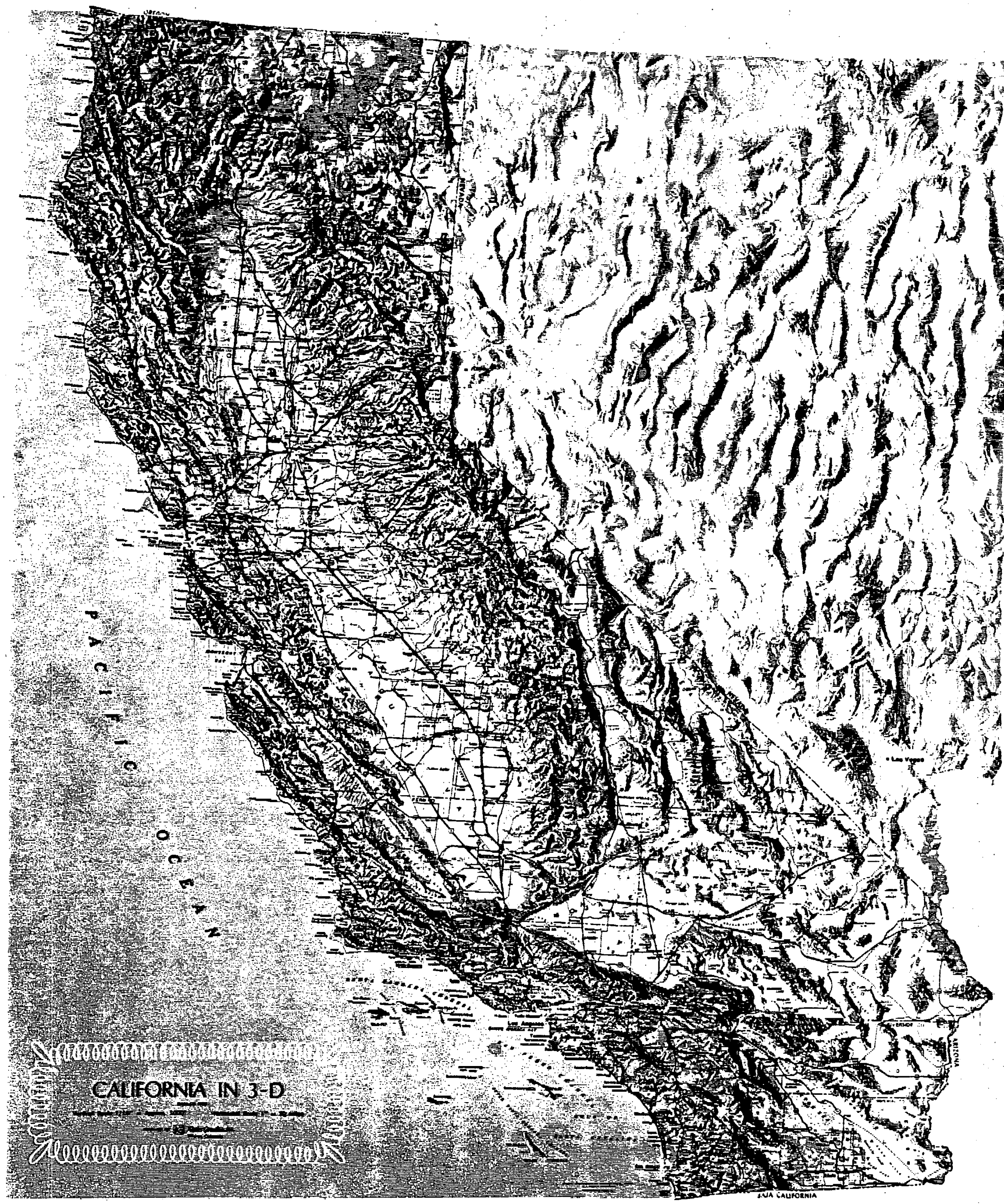


Figure 7-3. Physiographic map of California and Nevada. The San Andreas Fault is the linear, northwest-southeast striking feature separating the great valley of central California from the coast. The Sierra Nevada mountains separate the rest of California from the stark Basin and Range of eastern California and all of Nevada. The Cajon Pass scientific well is at the intersection of the San Andreas Fault and the east-west trending Transverse Range in southern California.

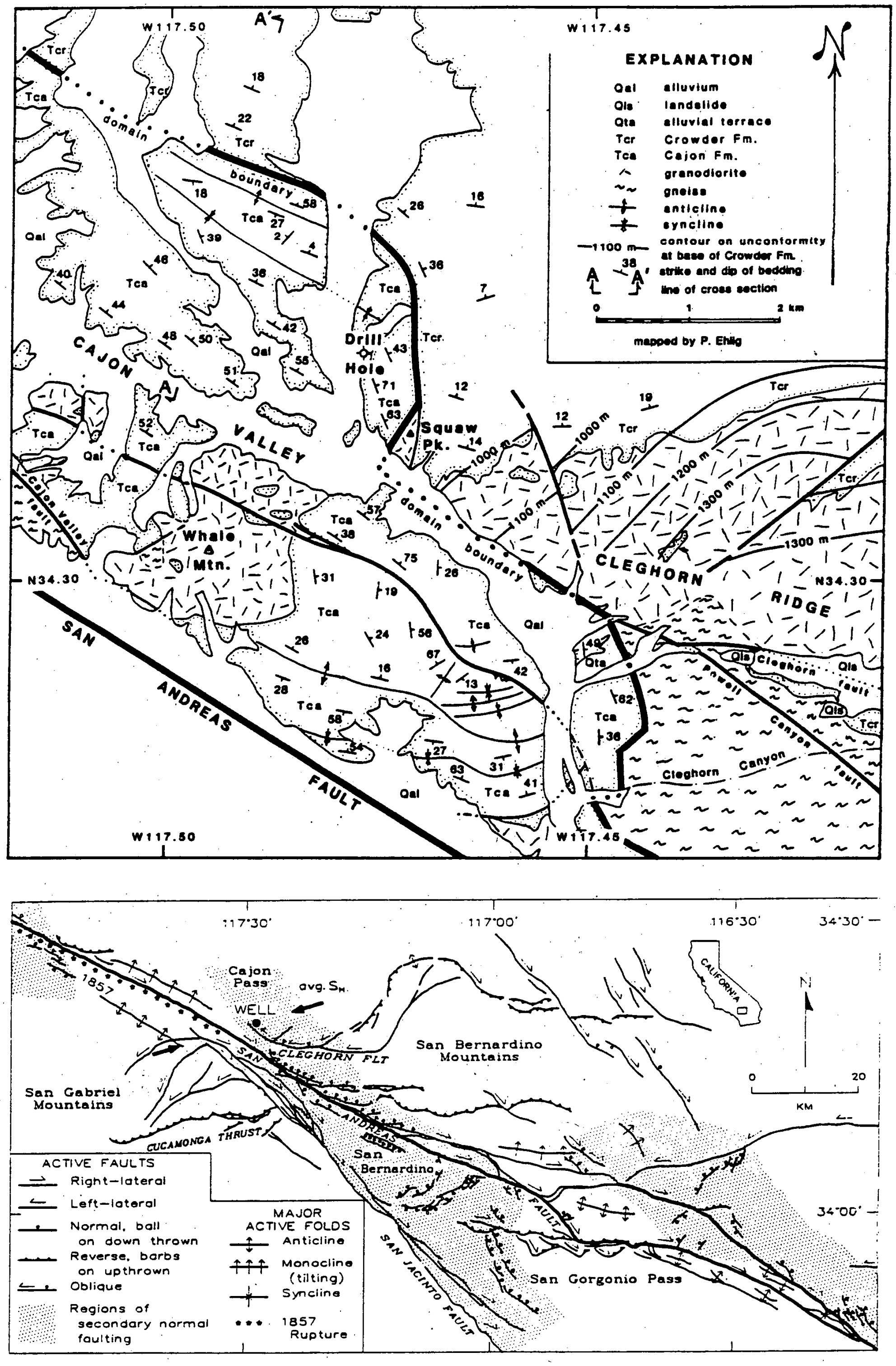


Figure 7-4. Detailed geological maps of the area surrounding the Cajon Pass continental scientific drillhole.

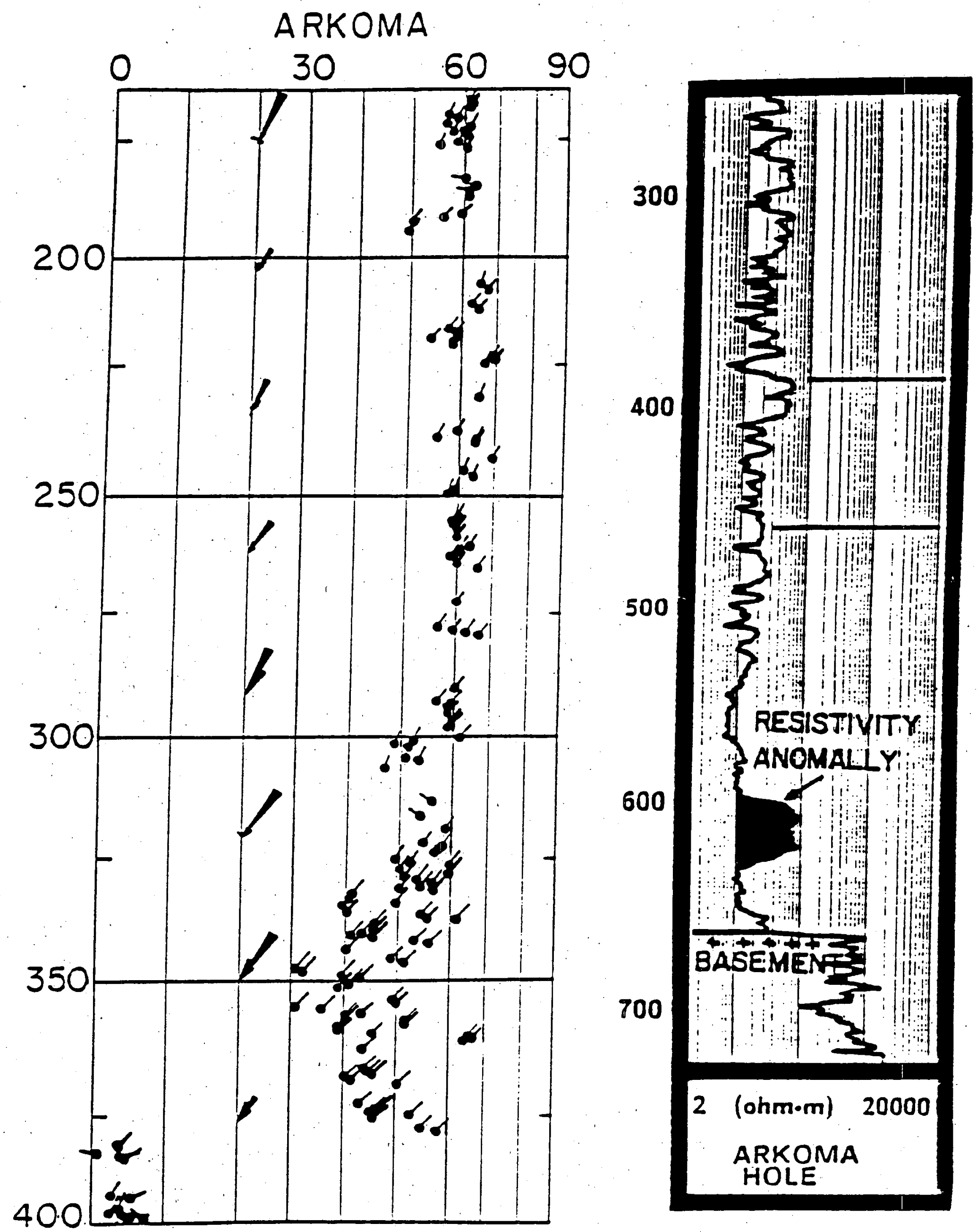


Figure 7-5. Left: Dip angle and azimuth from dipmeter data in the Arkoma Federal 1-26 well (correlation length 1.2m, step distance 0.6m, and search angle 30°). Right: Resistivity data recorded with a spherically focused sensor in the Arkoma hole.

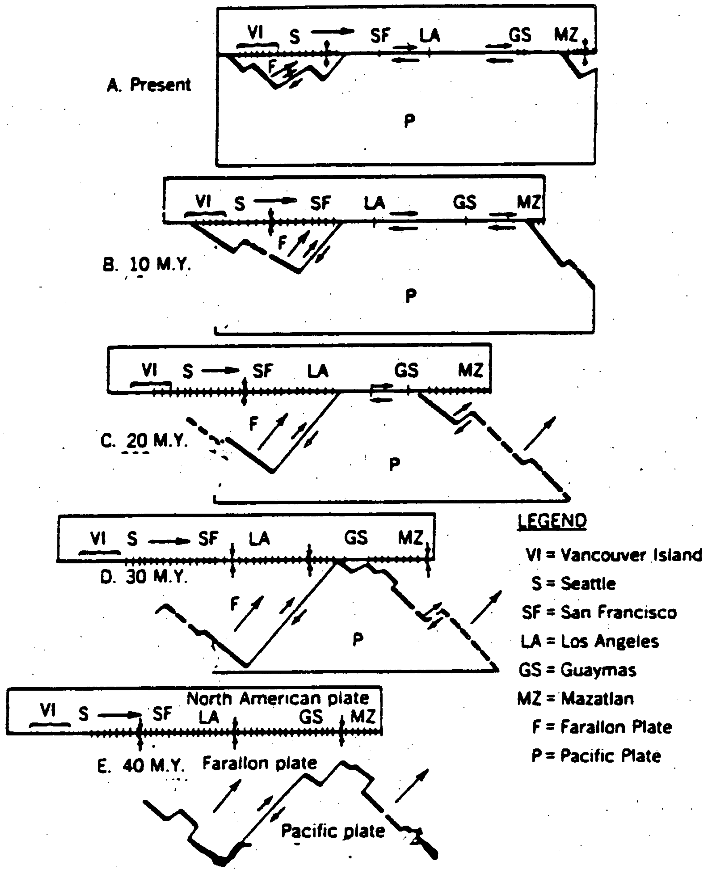


Figure 7-6. From bottom to top, the Farallon plate is being progressively shortened by subduction (railroad track symbols) under California. The Sierra Nevada mountains were formed at the start of this subduction. Gradually, the East Pacific Rise was subducted as entire pieces of the Farallon plate disappeared. When the ridge axis was subducted, the plate boundary motions along the California coast switched from the North America-Farallon pole to the North America-Pacific pole of rotation and the San Andreas Fault (horizontal arrows) was born.

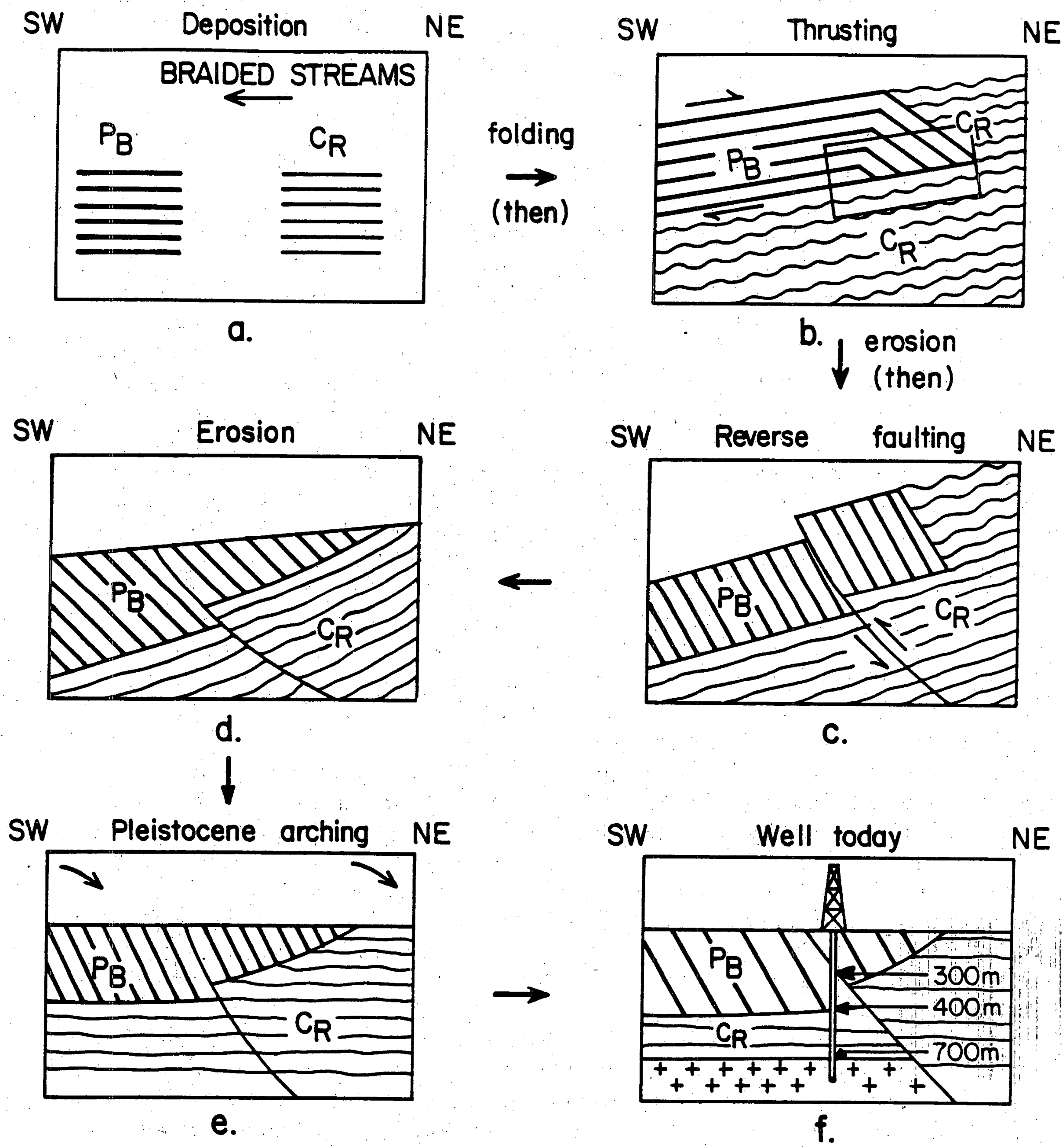


Figure 7-7. Schematic of tectonic model which can explain the dipmeter structural information at Cajon Pass. Upper left, Punchbowl and Crowder terrestrial sandstones deposited in adjoining basins 10 million years ago. Upper right, Punchbowl was overthrust from the SW over Crowder. Middle right, a steeply dipping thrust fault cut through the thrust plane. Middle left, erosion exposed the thrust plane and thrust fault. Lower left, entire section was folded 20 degrees to the NE. Lower right, normal fault cut the section, and then further erosion truncated the folded section, exposing the thrust plane and thrust fault.

Chapter 8

Borehole Shape and The Stresses That Drive Plate Motions

Perhaps the most important unanswered question concerning plate tectonics is: "What forces drive the plates and determine their relative and absolute motions?"

As a result of these unknown driving forces, the stress regime internal to each plate and at its boundaries is only partially understood. At ocean ridge crests, hot molten material rises topographically above the existing cold lithosphere, and a "downhill" gravitational force pushes laterally from the ridge crest. In addition, the gravitational force of a cold lithospheric slab subducting in oceanic trenches pulls the plate laterally. The former creates compressional stresses and the latter tensional stresses in each plate (Figure 8-1). The resultant force in each plate then contributes to the forces at its boundaries, and the relative motion of the two plates determines the type of interaction at their boundary. For example, cold lithospheric plates moving laterally against one another create transverse boundary forces and ultimately transverse faults, such as the San Andreas or mid-ocean transforms. Alternatively, when two plates are pulling or being pulled apart, a spreading center forms where molten material wells up into the expanding fissure and creates new lithosphere. If instead, two plates are converging, one usually subducts beneath the other into the mantle. The the interaction at plate boundaries is thereby the result of intraplate stresses, and vice-versa. As such, the driving force for plate tectonics remains an enigma because the initiation of the process is still unknown.

The absolute motions of lithospheric plates relative to a fixed mantle can yield insight into the relative orientation and magnitude of these intraplate and boundary stresses. In Figure 8-2, the Pacific plate, for example, is moving in a northerly direction relative to North America, but in a northwesterly direction relative to the mantle. Fixed mantle plumes, such as that forming the Hawaiian-Emperor seamount chain, can be used to determine the relative motion of the lithospheric plates as they leave a traceable geologic record. At the 40 million-year-old Coco seamount, a rapid change in plate motion occured leaving a bend in the seamount chain, and the tectonic stresses that gave rise to this relic remain a puzzle to geoscientists.

To determine the tectonic driving forces, a knowledge of intraplate stresses and the resultant plate motions is clearly required. Fortunately, the determination of the orientation and magnitude of intraplate forces is now retrievable from direct geophysical measurments. Earthquake focal mechanisms, hydraulic fracturing and well logging in boreholes can all provide information relevant to this question. However, earthquakes do not occur in geographically widespread areas and the resultant intraplate stresses cannot be fully resolved. Hydraulic fracturing is an alternative method commonly used for stress determination which creates a rupture inside a borehole parallel to the maximum horizontal stress direction. With this technique, the hydraulic pressure in a packed-off interval of the borehole is increased until the rock breaks at a level related to the magnitude of the

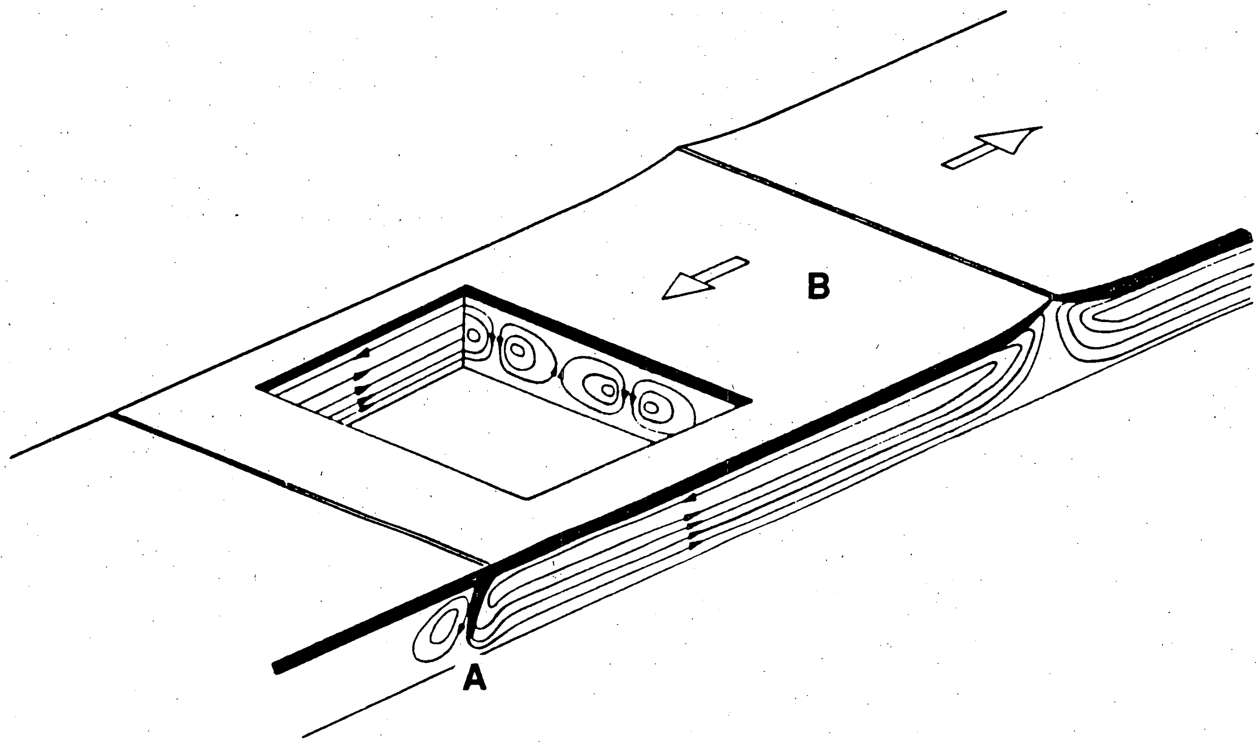


Figure 8-1. Longitudinal rolls in the mantle are caused by plate drag. Other plate forces are thought to arise from gravitation pull from the slab (A) and push from the elevated ridge axis (B).

EURA — Eurasian plate;
INDI — Indian plate;
ARAB — Arabian plate;
ANTA — Antarctic plate;
AFRC — African plate;
NOAM — North American plate;
SOAM — South American plate;
COCO — Cocos plate;
NAZC — Nazca plate;
PCFC — Pacific plate

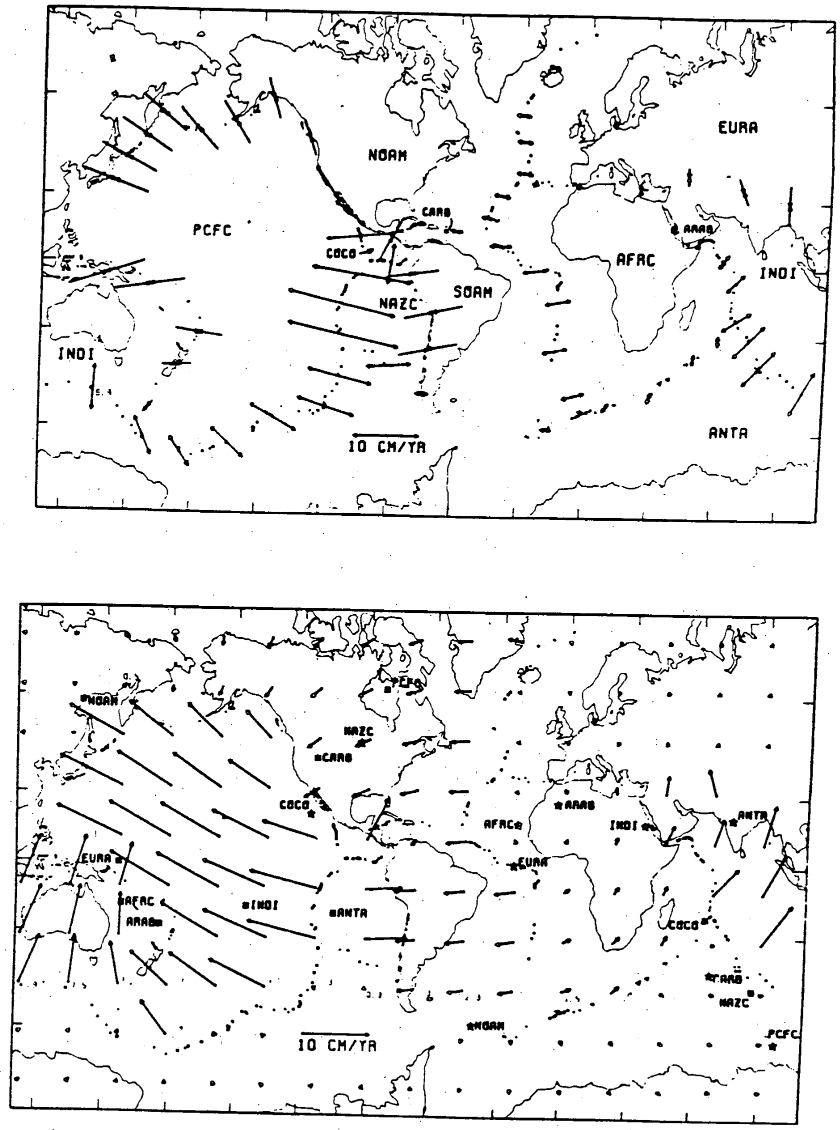


Figure 8-2. Relative (top) and absolute (bottom) plate motions. Arrows are vectors with velocity represented by the length of each arrow.

maximum horizontal stress. Measurements can also be obtained as a function of depth using borehole techniques.

The intraplate stresses in the continental United States have been routinely updated on maps produced by M.D. Zoback and M.L. Zoback using [primarily] earthquake and hydrofracture data (Figure 8-3). They observed that the United States central craton is generally under northeast-southwest compressional stress, whereas the western basin and range province is under northwest-southeast tensional stress.

The Borehole Televiewer as a Stress Determinant

The orientation and magnitude of intraplate forces is also directly measurable by determination of breakouts of the borehole wall. Breakouts form as drilling of the borehole places the wallrock into local tension and the regional stresses concentrate around the new opening. Borehole wall failure, or breakout, occurs when these stresses exceed the shear strength of the wallrock.

Well logging, in particular using the acoustic borehole televiewer, can provide a high-resolution geometric scan of the shape of the borehole to indentify breakouts (see Ch. 1, BHTV). The orientation of a drilling-induced breakout is perpendicular to the direction of maximum compressional stress, whereas a hydraulic fracture is parallel to this direction.

Consider the state of stress in southeastern New York state in the Kent Cliffs #1 borehole. This mid-craton site is remote from active North American plate margins and ideal for an intraplate stress study. Both hydraulic fracture stress measurements and a borehole televiewer survey were made at the same time. As shown in Figure 8-4a, a wellbore breakout and a hydraulic fracturing occur between 2835 and 2845 ft. The hydraulic fracture is obeserved as a thin, dark sinusoid intersecting the borehole at 2839 ft and exiting at 2843 ft with a northeast-southwest strike and southeast dip. Note that the hole is inclined 15 degrees from vertical, explaining why the vertical fracture appears as a steeply dipping feature. The breakouts observed in the televiewer image are shown as wide, stripped zones in the Figureoriented in the northwest and southeast quadrants. A televiewer-derived cross-section of the wellbore at line 2841' shows the depth of the breakouts into the borehole wall. Hence, in the Kent Cliffs borehole the direction of maximum horizontal compression is parallel to the northeast-southwest strike of the hydraulic fracture; the minimum horizontal compression is parallel to the northwest-southeast orientation the breakouts. These stresses may have been produced by compression from the mid-Atlantic Ridge far off to the Northeast.

State of Stress at Hole 504B

As 70% of the Earth's surface is covered by oceans, the use of ODP boreholes for the determination of intraplate stresses will greatly increase the map coverage of stress measurements. A borehole at Site 504B on the southern flank of the Costa Rica Rift is an ideal place to begin such intraplate stress investigations, because a "ridge-push" force from the north and a "trench-pull" force from the southeast may both affect the local stress

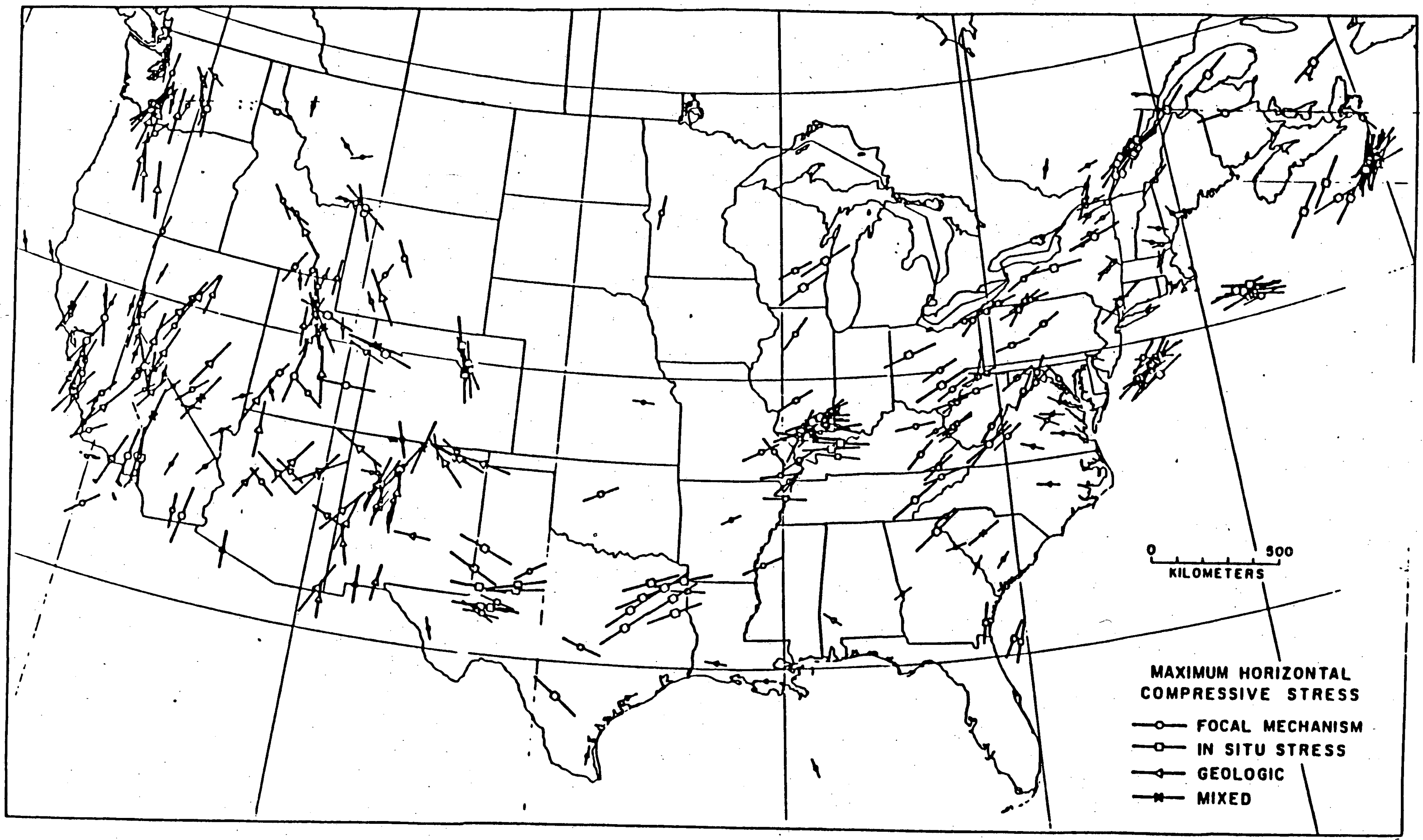


Figure 8-3. Map of maximum horizontal compressive stress orientations. Quality of data indicated by weight; relative magnitude indicated by length of line.

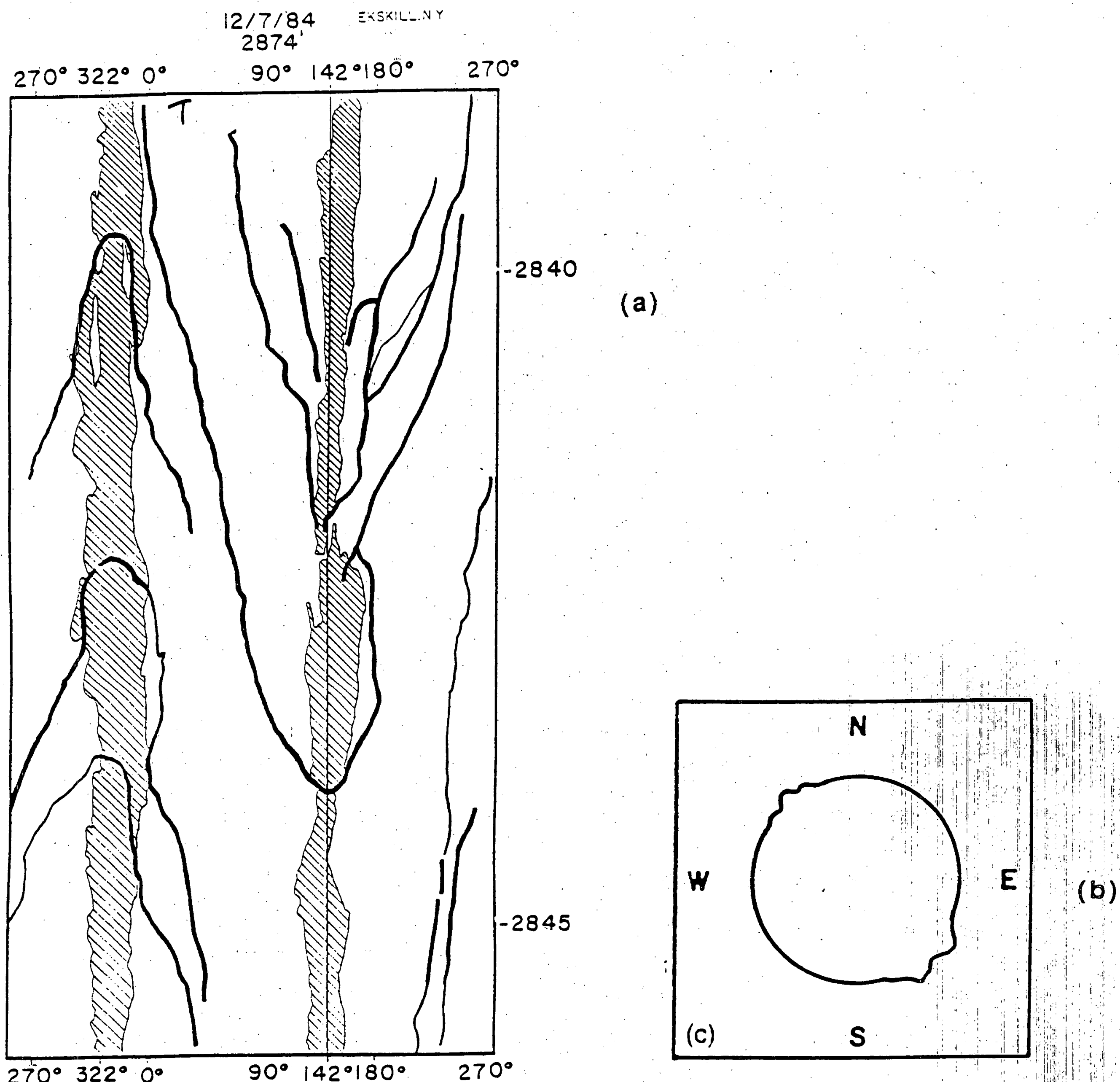


Figure 8-4. (a) Hydraulic fracture image returned to the surface from soft rubber impression packer (solid line), and borehole breakouts from BHTV images. The hydraulic fracture strikes in the maximum horizontal stress direction, and breakouts form along the minimum horizontal compression direction.
(b) Cross-section of the borehole at 2841 ft showing breakout azimuth (from televiewer data).

regime (Figure 8-5). The site is located in 6 million year old crust only 220 km distant from and one km deeper than the ridge crest. The Costa Rica Rift is also the easternmost spreading center segment before the Nazca-Cocos-American plate triple junction.

In Figure 8-6, the BHTV images in basaltic ocean crust at the site show that breakouts are oriented WNW-ESE. This orientation is maintained throughout the uppermost km of the ocean crust (Figure 8-7) and suggests that both compression (ridge-push) from the NNE ridge boundary and extension (trench-pull) from the ESE trench boundary affect the intraplate stress at this site.

Another Pacific drillhole shows breakouts in a 35 million-year-old mid-plate setting 1500 km west of the East Pacific Rise (Figure 8-8). In Figure 8-9, wellbore breakouts can be observed in BHTV images in Hole 597C in a NNE-SSW orientation. This orientation is not perpendicular to the East Pacific Rise, implying that ridge-push is not a dominant force far from spreading centers. Near this site, however, convective rolls in the mantle beneath the Pacific Plate have been imaged by satellite altimetry and are aligned in a west northwesterly direction, exactly perpendicular to these mantle rolls (Figure 8-10). The mid-plate stress regime may be controlled by these mantle rolls, or alternatively by an underplate frictional force (mantle drag).

Magnitude of Stress From Breakouts

The borehole televiewer data also provides information about the magnitude of local stresses. The predicted shape of a breakout as a funciton of differential horizontal stress is shown in Figure 8-11. Variability in real cross-sectional shapes can be averaged to compare with these theoretical predictions. As this theory suggests, increasing the differential horizontal stress widens and deepens the breakout while increasing the differential pressure between the formation and the borehole annulus decreases the stress required for breakout formation. Threrefore, additional information on the in-situ pore pressure or the differential horizontal stresses is needed to estimate stress magnitudes from breakout shape.

In the Kent Cliffs #1 borehole, the breakout shape (Figure 8-4) can be interpreted to result from three different stress regimes based on the theory discussed above:

a) 100 bars differential horizontal stress with no differential pore pressure between the formation and the annulus
b) 75 bars differential horizontal stress with formation pore pressure less than the annulus pressure by about 25 bars
c) 125 bars differential horizontal stress with formation pore pressure greater than the annulus pressure by about 25 bars

The hydraulic fracture at this depth was created by a maximum horizontal stress of 200 bars and minimum horizontal stress of 86 bars. The differential stress (114 bars) implies a formation overpressure of 20 bars. As determined by the pumping history at this depth, large overpressures were maintained in the packed-off interval for 45 minutes and pressure diffusion into the formation could likely have produced the excess formation pressures. Since no breakouts existed before the hydraulic fracture was induced, the breakouts probably formed after the pressure in the annulus was bleed off, leaving a stress regime

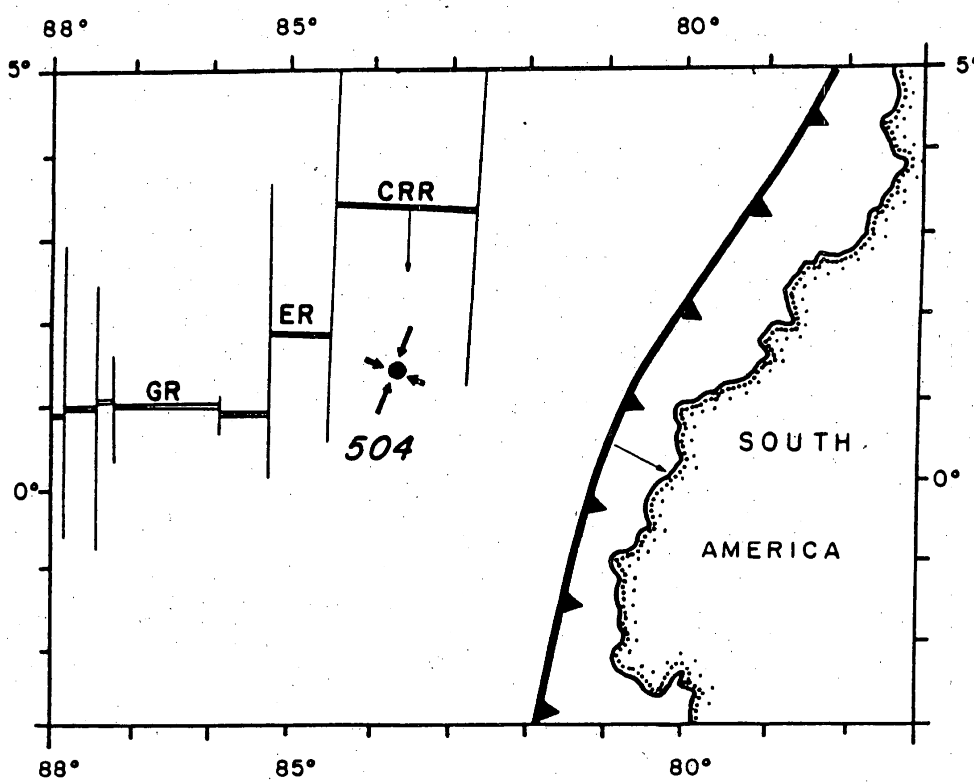


Figure 8-5. Location map of Hole 504B, with ridge push force from the north and trench pull force from the east, southeast. Borehole breakout stress directions determined from BHTV imagery also shown.

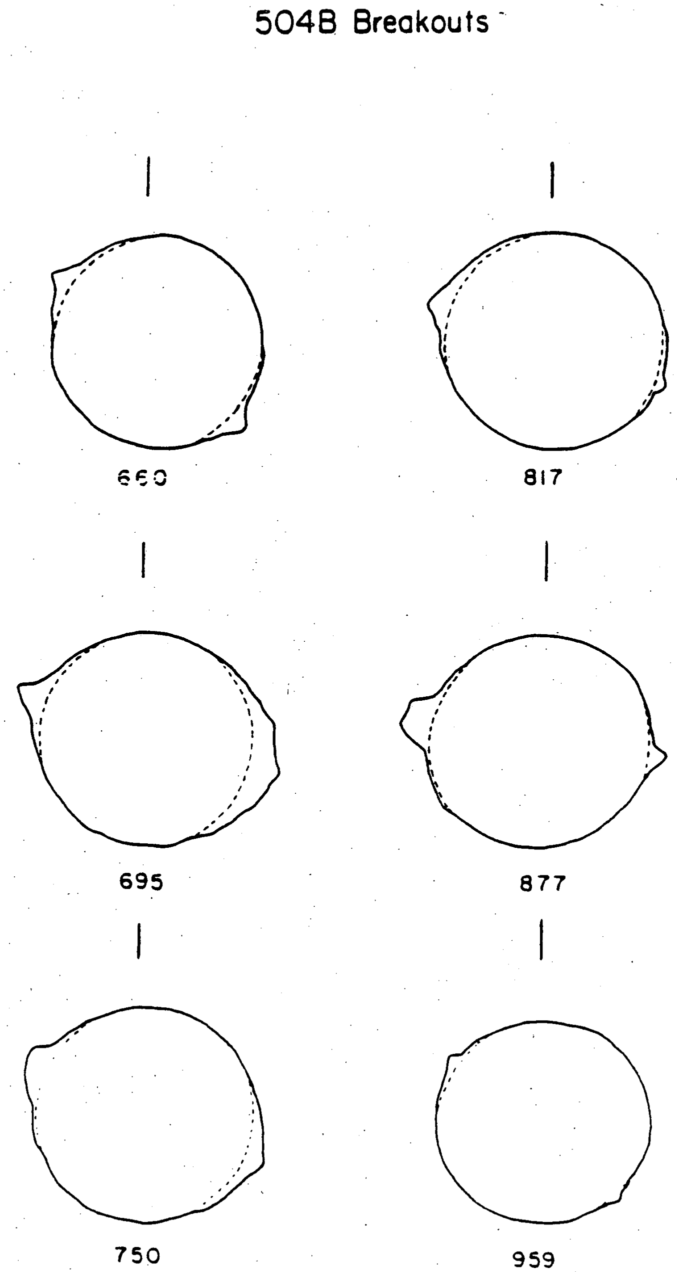


Figure 8-6. Borehole breakouts imaged with a BHTV in Hole 504B at depths indicated.

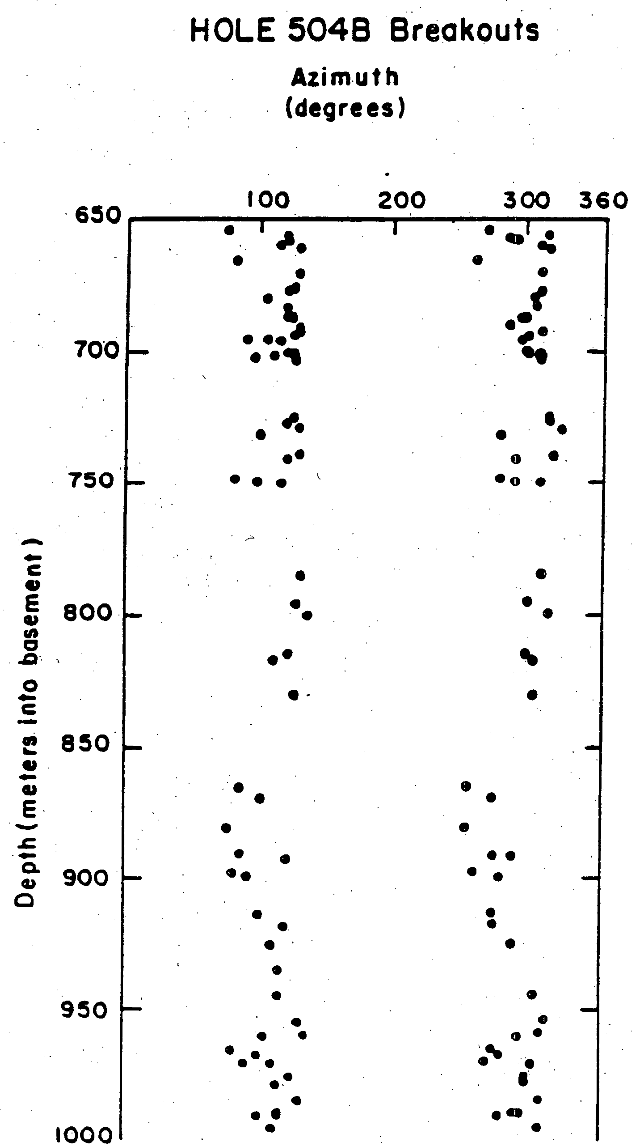


Figure 8-7. Cumulative orientations of BHTV imagery, Hole 504B. Least compressive stress is horizontal and oriented 120 and 300 degrees.

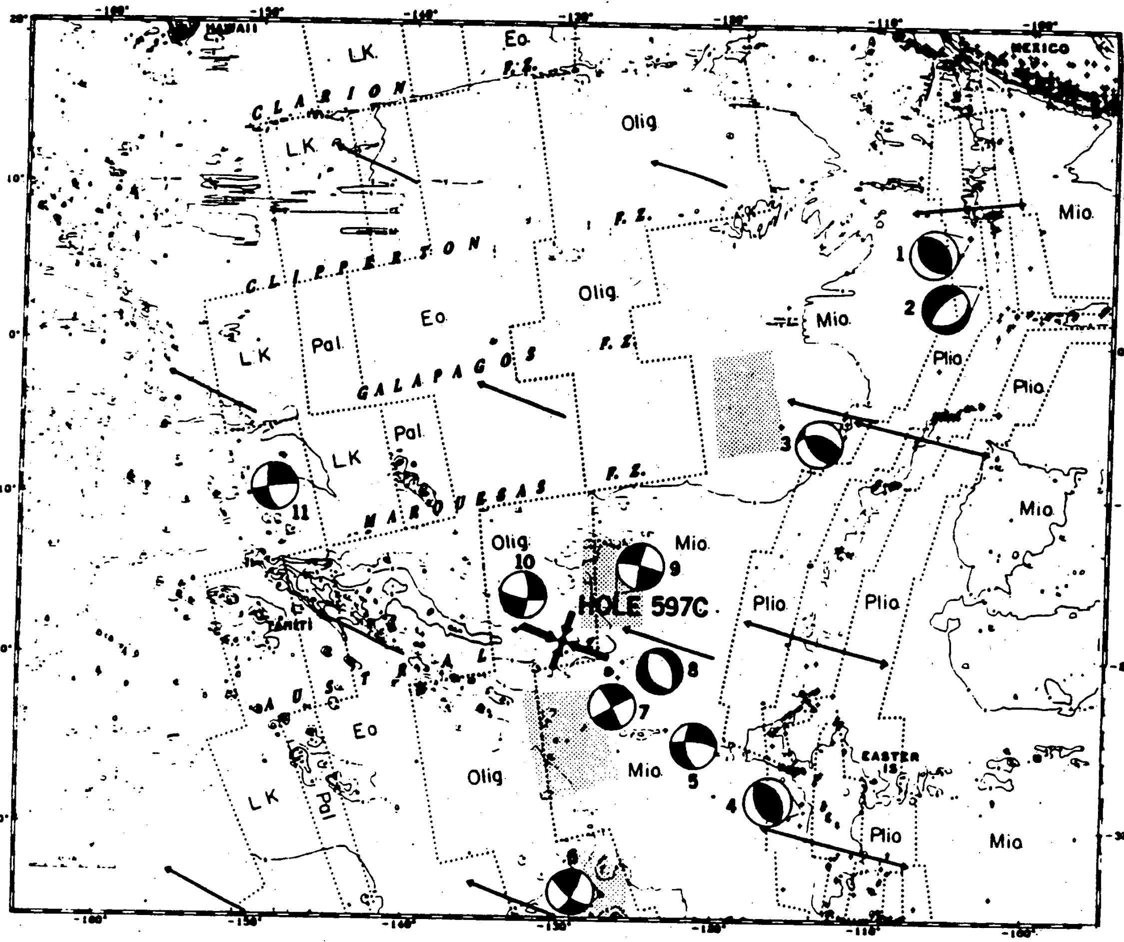


Figure 8-8. Location map, and earthquake focal mechanism solutions around DSDP Hole 597C. Age isochrons shown along with absolute plate motion of the Pacific Plate (bold arrows). Maximum and minimum horizontal stress directions determined from BHTV imagery of breakouts also shown.

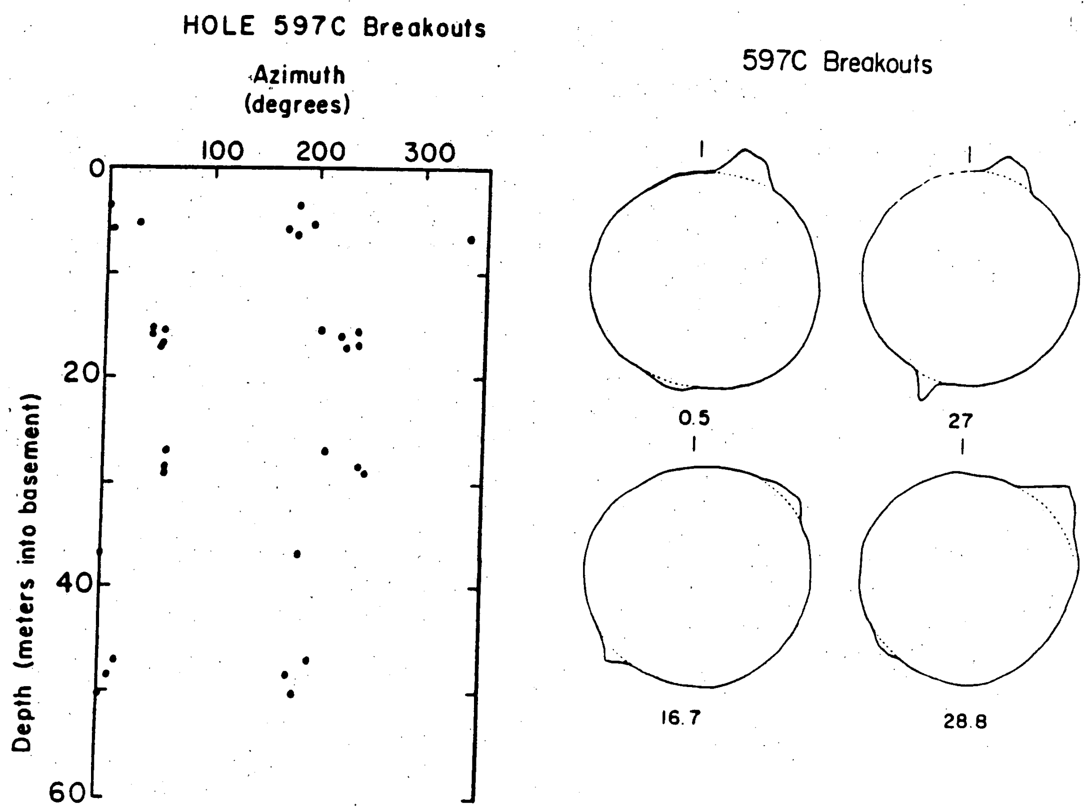


Figure 8-9. Cumulative orientations (left) from borehole breakouts imaged with BHTV (right).

Figure 8-10. The horizontal rolls under the Pacific plate can be observed from the small difference in the Earth's gravity pull between upwelling (highs) and downwelling (lows) limbs of the rolls. This image comes from satellite measurements of gravity. The Pacific Plate is moving to the Northwest. The fracture zones are east-southeast scars in the plate.

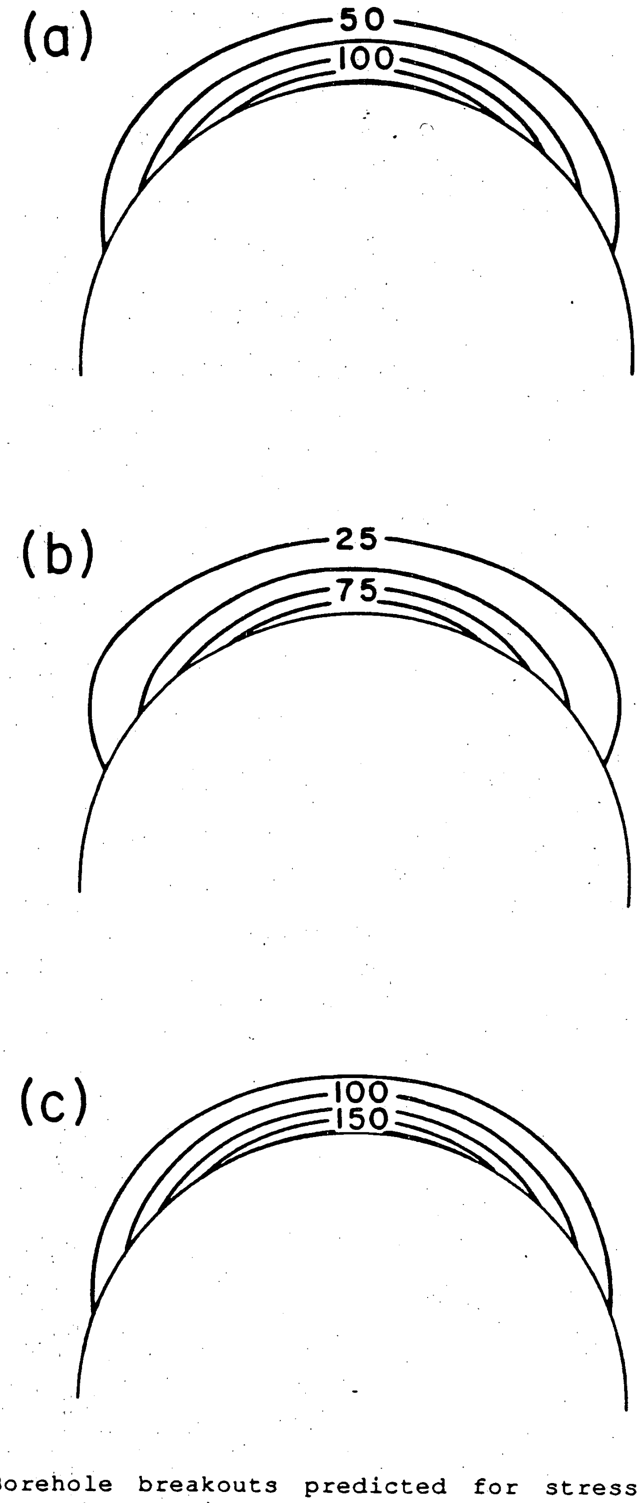


Figure 8-11. Borehole breakouts predicted for stress differences indicated (in bars). (a) no differential pressure between borehole and formation. (b) formation pore pressure greater than borehole pressure (mud weight). (c) borehole pressure greater than formation pore pressure. For case (c) the heavy mud weights prevent breakouts and stabilize the hole during drilling.

similar to (c) predicted above. Despite the complexity of this example, it is clear that the BHTV delivers a unique set of information to determine in-situ stress regimes in the crust.

Conclusions

In this volume, we have given examples of geophysical and geochemical log analysis to help understand puzzles in the geological sciences. There is extensive work published on the use of logs in sedimentary basins which is partially reproduced by a U.S.G.S bibliography in Appendix II. The topics covered include facies analysis, depositional environments, abnormal pressure detection, and geothermal well logging. The exciting new developments in scientific well logging in the ODP will consistently deliver new scientific answers leg after leg.

APPENDIX I

A GUIDE TO ODP TOOLS

FOR DOWNHOLE MEASUREMENTS

Keir Becker
Rosenstiel School of Marine and Atmospheric Science
University of Miami
4600 Rickenbacker Causeway
Miami, Florida 33149

OCEAN DRILLING PROGRAM

TEXAS A&M UNIVERSITY

TECHNICAL NOTE

NUMBER 10

1988

Technical Note No. 10
First Printing 1988

Distribution

Copies of this publication may be obtained from the Director, Ocean Drilling Program, Texas A&M University Research Park, 1000 Discovery Drive, College Station, Texas 77840. In some cases, orders for copies may require a payment for postage and handling.

DISCLAIMER

This publication was prepared by the Ocean Drilling Program, Texas A&M University, as an account of work performed under the international Ocean Drilling Program, which is managed by Joint Oceanographic Institutions, Inc., under contract with the National Science Foundation. Funding for the program is provided by the following agencies:

Department of Energy, Mines and Resources (Canada)
Deutsche Forschungsgemeinschaft (Federal Republic of Germany)
Institut Francais de Recherche pour l'Exploitation de la Mer (France)
Ocean Research Institute of the University of Tokyo (Japan)
National Science Foundation (United States)
Natural Environment Research Council (United Kingdom)
European Science Foundation Consortium for the Ocean Drilling Program (Belgium, Denmark, Finland, Iceland, Italy, Greece, the Netherlands, Norway, Spain, Sweden, Switzerland, and Turkey)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

A. Purposes of this manual

Logging and downhole measurements have been emphasized in the Ocean Drilling Program (ODP) as important scientific tools that provide key data to significantly augment and complement the results of coring. Because of the strong commitment to downhole measurements for ODP, a very advanced suite of logs and downhole experiments is presently available or under development for routine ODP use. However, it is sometimes difficult for the uninitiated shipboard scientist to understand the limitations and operational requirements of the many available tools, and to plan and then successfully implement a specific downhole experiment on a given leg or series of legs.

The primary purpose of this manual is, therefore, to provide some guidance for scientists interested in those downhole tools that ODP *routinely* provides, by describing several key aspects regarding these tools: requirements for advance planning, procedures for shipboard operations, and basic methods for data interpretation. For many of the ODP downhole tools, fully-detailed operating instructions written by the tool designers or manufacturers are available at ODP and on board *JOIDES Resolution*, and will only be briefly summarized here, emphasizing those factors that are important in planning and then conducting the measurements.

The purpose of this manual is quite similar to that of the *ODP Logging Manual*, which describes the logging tools and scientific logging services provided by the Borehole Research Group (BRG) at Lamont-Doherty Geological Observatory (LDGO). (Copies of the *ODP Logging Manual* are available from BRG, and Worthington et al. (1987) have written a brief, useful summary of the ODP logging facilities.) In this manual, 'ODP' will be used to refer to the ODP Science Operator at TAMU, and 'LDGO' will refer to the ODP Logging Contractor. ODP and LDGO divide responsibilities for downhole tools as follows: LDGO is responsible for providing logs measured with tools run on the seven-conductor logging cable (or 'wireline'), whereas ODP is responsible for those tools used with the drill string and/or the non-conducting coring line (or 'sand line').

Most of this manual consists of chapters describing the following types of measurements that can be routinely made with tools provided by ODP: (1) borehole- or pore-fluid sampling, possibly with *in situ* pressure measurements, (2) temperature measurements in sediment or in open borehole, (3) permeability measurements using drillstring packers, and (4) orientation of advanced hydraulic piston corer (APC) cores. Many other types of measurements are possible, and several new tools are being developed by investigators cooperating with ODP. The final chapter of this manual describes some of the new tools now under development, and specifies the conditions that must be satisfied before ODP will assume responsibility for routinely providing these measurements.

The remainder of this introductory chapter summarizes the information that is essential to assure that the routine measurements provided by ODP can actually be made in a manner that satisfies scientific goals:

(1) requirements for advance planning for measurements using ODP tools, (2) an overview of the tools routinely available from ODP, and (3) the compatibility of these tools with the various ODP coring and engineering systems.

B. Advance planning requirements for routine ODP tools

To ensure successful use of specific ODP downhole tools on a particular leg, it is advisable to start planning at least one year pre-cruise, and it is essential to keep two organizations fully informed: ODP itself, and the JOIDES panel structure via the Downhole Measurements Panel (DMP).

ODP is charged with implementing the scientific planning approved by the JOIDES Planning Committee (PCOM), which acts with the advice of the JOIDES panels, including DMP. About one year pre-cruise, DMP considers the proposed programs for logging and downhole measurements for each site of each leg, and passes its advice to PCOM, to ODP, and to LDGO. In its deliberations, DMP reviews measurements included within normal drilling proposals and separate proposals for special experiments. During the first two operating years of ODP, DMP has generally endorsed full programs of logging and downhole measurements at most sites, and PCOM has often accepted this advice unless ship time is very limited.

Thus, 'normal' programs for use of ODP tools are usually approved for all sites by DMP and PCOM. However, details of implementing these programs are often not considered by these committees, but instead are left to the co-chief scientists to specify at the planning meeting that normally occurs about 4 months pre-cruise at ODP. To ensure that ODP is fully equipped and staffed to support a program of routine downhole measurements on a given leg, it is essential that the co-chief scientists develop a comprehensive plan for these measurements well before this pre-cruise meeting.

For extraordinary programs of downhole measurements with ODP tools -- e.g., special 'holes' devoted to pore-water sampling and temperature measurements, or extensive programs of packer measurements -- JOIDES approval is required well before the pre-cruise meeting to guarantee the necessary ship time and extra effort by ODP. Such approval can be obtained by including the plans for special downhole measurements in the original drilling proposals considered by the JOIDES panels, or by submitting special proposals to JOIDES for consideration by DMP and PCOM.

C. Overview of downhole measurements provided by ODP

ODP provides the tools and technical support to allow downhole sampling of fluids (in addition to pore fluids recovered in cores) and the measurement of several basic physical parameters: temperature, pore pressure, permeability, and APC-core orientation. With the exception of APC-core orientation, several different tools are available to measure these parameters in different situations, such as while coring sediments, between cores at the bottom of the hole, or in open hole. The ODP tools are not used with the logging cable, but instead are deployed using the drillstring and/or coring line in several possible modes, for example: (a) lowered on the coring line to either seat in the bit or run beyond the bit in open hole, (b) lowered to the bit as part of the APC coring assembly, or

(c) built into the drill string. There are many options for using these tools, and the focus of this section and the next is to outline these options, leaving other details for subsequent chapters.

ODP will generally staff each leg with at least one marine technician trained in the use of these tools, with the exception of the drill-string packers, which may require a special tools engineer in addition to a packer scientist. The marine technician is responsible for preparing and deploying the tools, and for the initial transfer of raw data to the shipboard computer and standard processing for archival at ODP. The shipboard scientists are then responsible for further processing and data interpretation. Some of the computer programs available aboard ship for this processing are discussed in later chapters.

Fluid sampling and _in situ_ pressure measurements

Two probe-type tools are routinely available for sampling fluids ahead of the bit in sediments soft enough for the probes to penetrate. These tools are officially termed ODP WSTP samplers because they are capable of measuring _t_emperature or _p_ressure in addition to taking a _w_ater _s_ample. However, they are sometimes referred to as the old Barnes/Uyeda probe (inherited from DSDP) and the new Barnes sampler, after the original proponents, Drs. R. Barnes and S. Uyeda.

The WSTP samplers are run on the coring line between cores and require 2-3 hours in addition to coring time to collect samples. The probe lands in the bit so that it extends up to 1 m into the sediment ahead of the bit; thus, the sediment to be cored next is disturbed. The WSTP samplers collect small fluid samples (30-70 ml primary samples) through an orifice in a probe that may also be instrumented with a thermistor or one or two pressure transducer(s). If the pressure data on penetration are of sufficiently good quality, they can sometimes be interpreted to estimate _in situ_ pore pressure and possibly permeability.

In sediments that are too lithified for the WSTP probes to penetrate, a probeless pore-water sampler can be used in conjuction with the rotatable drill-string packer. This 'probeless PWS' consists of a WSTP sampler without the probe (i.e., without temperature or pressure sensors), so nothing extends beyond the bit, and several sealed core barrels used as a 'vacuum' source to draw a large volume of fluid through a small sample chamber. This tool is meant to be used with the rotatable drill-string packer to seal the annulus so that pore fluids are sampled, not drilling fluids. Use of the packer requires considerable time and effort, as outlined below.

In open hole, the WSTP samplers can also be used to sample borehole fluids up to 1 m below the bit. Also, larger volume samples (0.5 liter) can be taken with tools made by Kuster Co. that are run on the coring line to a distance below the bit deemed safe by the Operations Superintendent. (In addition, Schlumberger tools for sampling open hole fluids may be available through LDGO.)

Temperature measurements

Two types of tools are routinely available for measuring temperatures in sediment and in open hole: the WSTP tools mentioned above, and miniature recorders used within special APC cutting shoes. These tools are normally used separately to obtain single measurements of temperature at discrete depths during a sequence of coring a hole through sediments. Or, they can be configured together for simultaneous use without coring. Either tool or the combination can be washed and pushed through soft sediments or run into open hole to measure temperatures at multiple depths during a single lowering.

The APC temperature recorders were originally developed by Dr. R. Von Herzen during DSDP; ODP is purchasing a newly designed version from Bowmar-White Co. This device monitors the temperature of a single sensor within the APC cutting shoe; on penetration, the corer must be held in the sediment for 5-10 minutes to obtain enough data to allow extrapolation to in situ temperature. It is typically run every 2-4 cores in an APC hole, but can be used only to depths where the force required for pullout is within safe limits, usually about 100-200 meters below seafloor (mbsf).

The WSTP tools can generally be used to greater depths, but require 2-3 hours for runs on the coring line between cores. These tools continuously sample the resistances of single thermistors mounted in cylindrical probes that are lowered into the bit and then pushed into the sediments. Thus, these tools can be used only in sediments soft enough to be safely penetrated, typically to a few hundred mbsf. The probe must be held in place for 5-10 minutes to obtain enough data to allow extrapolation to in situ temperature.

Permeability measurements using packers

A packer produces a hydraulic seal in a borehole, allowing the hydrologic properties of the formation to be tested by applying differential fluid pressures to the isolated section. Three packers are available in ODP: (1) a drill-string straddle packer presently supported by an NSF grant to the University of Miami, (2) a rotatable drill-string packer operated by ODP, and (3) a wireline packer operated as a logging tool by LDGO. All of these packers are manufactured by TAM International, and use inflatable rubber/steel elements to seal the borehole.

Of these packers, only the drill-string straddle packer has been used successfully and proven for routine use. With sufficient advance notice, this packer is generally available for ODP, but it can be used only as part of a non-coring bottom-hole assembly (BHA) in reentry holes that penetrate reasonably stable formations. Permeability measurements in holes that penetrate unstable formations or in single-bit holes require the ODP rotatable drill-string packer, which is designed to allow rotation, circulation, and, ideally, very limited coring without inflating the packers.

Any use of these packers will require considerable preparation and significant amounts of ship time. To date, skillful SEDCO core technicians have undertaken the responsibility of preparing drill-string packers for deployment. The procedures for formation testing with drill-string packers are quite complicated, and require participation of a shipboard packer scientist, possibly with the help of an ODP special tools engineer.

The prime data in formation testing are fluid pressures measured with recorders that are run into the isolated zone when the packer is inflated. Both drill-string packers utilize mechanical Kuster pressure recorders attached to 'go-devils' that are dropped down the drill-string into the packers and enable the mechanisms for inflating the packers. The Kuster pressure records are scratched (quite accurately) onto special charts, which should be read with a Kuster microscope. In the future, electronic pressure recorders may also be available, instead of or in addition to the reliable Kuster recorders.

Formation testing procedures at each setting depth typically run 4-8 hours, including the time required to drop and retrieve the go-devils. For permeability measurements using the straddle packer after coring a reentry hole, up to one day's time will be required for a pipe trip to build the packer into a logging BHA. In some cases this will not actually cost extra time, as the packer is compatible with logging and it may be possible to accomplish a full program of logging and packer measurements during the single pipe trip required to deploy a logging BHA in a reentry hole.

The LDGO wireline packer is designed primarily for measuring in situ pore pressure and sampling formation fluids from a narrow straddled zone, but it may allow permeability measurements at low test pressures. The probeless PWS mentioned above was designed (but has not yet been used) for sampling fluids from formations isolated by the rotatable packer, and other sampling go-devils for the drill-string packers may be developed soon (Chapter VI).

Orientation of APC cores

The azimuth and deviation from vertical of (non-rotary) cores taken with the advanced hydraulic piston corer (APC) can be measured routinely using an Eastman-Christensen magnetic 'multishot' camera. This device records photographs of a magnetic compass and pendulum taken at pre-selected intervals. It is installed in a non-magnetic sinker-bar/pressure-case that connects the coring line to the APC barrel, and must be used with a special non-magnetic drill collar in the BHA.

Thus, the decision to obtain oriented piston cores at a given site must be made before the BHA is made up and pipe run into the hole. An extra 5-10 minutes per oriented core is required for handling the multishot assembly. Oriented cores can be obtained only to depths that are safe to core with the APC, typically on the order of 100-200 mbsf, depending on the force required for pullout.

D. Compatibility of ODP tools with ODP operations and engineering systems

ODP is a very advanced and specialized drilling program, and has developed a wide range of engineering and coring systems for use in various operational situations. The ODP tools for downhole measurements are not always compatible with certain engineering and coring systems, and care must be taken to verify that measurements can actually be made as planned.

Table I-1 summarizes the situations in which ODP downhole tools are normally used; these normal methods are discussed in the following chapters. There are many other operational configurations that are not listed in Table I-1 in which it may still be possible to make these kinds of measurements. The full range of possibilities is considered in Table I-2, which summarizes the compatibility of the ODP downhole tools with the various ODP engineering and coring systems.

The ODP downhole tools, coring systems, and engineering systems will be modified as necessary for enhanced performance, and the information presented in Tables I-1 and I-2 and in this manual may be subject to change. The information presented in this version is current as of the end of Leg 118 in December 1987. For further information, clarification, or updates regarding the compatibility of possible configurations, please contact Mr. Dan Reudelhuber, Senior Drilling Engineer at ODP, or the ODP Supervisor of Drilling Operations, or the ODP Supervisor of Development Engineering.

Table I-1. 'Normal' configurations for routine deployment of ODP tools for downhole measurements. 'Time required' is time needed in addition to planned coring operations.

Type of Measurement	Tool Used	Method of Deployment	Time Required
Pore water sampling:			
Unlithified sediments	WSTP	Lowered on coring line into bit between cores	2-3 hours
Semi-lithified sediments	Probeless PWS	Lowered on coring line into bit, with rotatable packer inflated	4-6 hours
Borehole water sampling (in open reentry hole)	WSTP	Lowered on coring line into clean-out bit in open hole	2-3 hours
	Kuster sampler	Lowered on coring line through bit into open hole	2-3 hours
Pore pressure:			
Sediments	WSTP	Lowered on coring line into bit between cores	2-3 hours
Hard formation	Kuster pressure gauge	In go-devil freefallen to inflate drill-string packer	3-4 hours
Temperature:			
Sediments	APC T tool	(1) In APC while coring	10-15 minutes
		(2) Lowered on coring line into bit without coring	2-3 hours
	WSTP	Lowered on coring line into bit without coring	2-3 hours
Borehole (in open reentry hole)	APC T tool	Lowered on coring line into bit	2-3 hours
	WSTP	Lowered on coring line into bit	2-3 hours
Orientation of APC core	Multishot camera	In sinker bar while APC coring	5-10 minutes
Permeability:			
(Soft sediments)	*maybe* WSTP	Lowered on coring line into bit between cores	2-3 hours
Semi-lithified sediment	Rotatable packer	In BHA; activated by freefallen go-devil	4-8 hours*
Hard rock	Straddle packer	In BHA; activated by freefallen go-devil	4-8 hours*

* - use of either drill-string packer may also require up to a day for a pipe trip to install the packer in the BHA.

Table I-2. Compatibility of ODP downhole tools among themselves and with principal ODP operations and coring systems.

	WSTP (a) in sediment	(b) open reentry hole	Probeless PWS	Kuster Water Sampler	APC T (a) while coring sediment	(b) in sediment w/o coring	(c) open reentry hole	APC Orientation	Straddle Packer	Rotatable Packer	Kuster Pressure Gauge
<u>Downhole Tools</u>											
WSTP (a) in sediment		-	?	?	*	!	-	*	X	?	?
(b) open reentry hole	-		*	*	-	-	!	-	*	*	*
Probeless PWS	?	*		*	X	X	X	X	!	!	?
Kuster Water Sampler	?	*	*		?	*	*	?	*	*	*
APC T (a) coring sediment	*	-	X	?		*	-	!	X	X	X
(b) in sed. w/o coring	!	-	X	*	*		*	*	X	X	*
(c) open reentry hole	-	!	X	*	-	*		-	*	X	*
APC Orientation	*	-	X	?	!	*	-		X	X	?
Straddle Packer	X	*	!	*	X	X	*	X		X	!
Rotatable Packer	?	*	!	*	X	X	X	X	X		!
Kuster Pressure Gauge	?	*	?	*	X	*	*	?	!	!	
<u>Rig Floor Systems</u>											
Coring Line	R	R	R	R	R	R	R	R	R	R	R
Drill-string Heave Comp.	!	!	R	!	!	!	!	!	R	R	!
Wireline Logging	*	*	*	*	*	*	*	*	*	*	*
Side-Entry Sub	*	*	*	*	*	*	*	*	*	*	*
<u>Hole Types and Casing Systems</u>											
Single-Bit Hole	*	-	*	*	*	*	-	*	X	!	*
Cased Reentry Hole	*	R	*	*	-	*	R	-	R	*	*
Freefall Reentry Cone	*	*	*	*	*	*	*	*	*	*	*
Drill-in Casing	*	*	?	*	X	X	X	X	X	X	*
Hard-Rock Guide Base	-	*	*	*	-	-	*	-	*	*	*
Unsupported Hard-Rock Spud-in	-	-	X	*	-	-	*	-	X	X	*
<u>Coring Systems</u>											
RCB (Rotary Core Barrel)	*	*	*	*	X	X	X	X	X	*	*
APC (Advanced Piston Corer)	*	-	X	*	R	-	-	R	X	X	*
XCB (Extended Core Barrel)	*	*	X	*	*	*	*	*	X	X	*
NCB (Navidrill Core Barrel)	*	*	X	*	*	*	*	*	X	X	*
PDM (Positive Displacement Motor)	X	X	X	*	X	X	X	X	X	X	*
<u>Bit Releases and Float Valves</u>											
Mechanical Bit Release	*	X	*	?	*	*	*	*	-	*	*
Hydraulic Bit Release	*	X	*	?	X	X	X	X	-	*	*
Passive (Baker) Float Valve	!	!	R	!	!	!	!	!	-	!	!
Lockable Float Valve	!	!	X	!	!	!	!	!	-	X	!

Key:
R Required for operation of tool listed at top of column.
! Can be activated simultaneously, during a single trip of the coring line.
* Can be run separately during the same pipe trip, in the proper sequence.
? Not incompatible, but operationally undesirable or questionable.
X Incompatible during a single pipe trip - can be run in the same hole only during separate pipe trips into a reentry hole.
- Not applicable - by definition the possibility should not arise.

II. IN SITU FLUID SAMPLING AND PORE PRESSURE MEASUREMENTS

A. Introduction

Tools to sample fluids in situ were built early during DSDP and have continued to evolve during ODP. Barnes (1979) pioneered this effort and has developed two generations of tools designed to sample sedimentary pore fluids through a probe that extends about 1 m ahead of the bit. The first generation tool was modified during DSDP to allow measurements of temperature (Yokota et al., 1980: Uyeda and Horai, 1982) or pore pressure (von Huene, 1985). These capabilities have been integrated into the redesigned second-generation tool (Barnes, 1988), and these tools are now officially termed the ODP WSTP tools (water sampler, temperature, pressure tools). The use of the WSTP tools to measure temperature is discussed in Chapter III.

Barnes' (1979) goals were to sample sedimentary pore fluids in situ, in order to (1) complement and calibrate the chemical analyses of pore fluids squeezed from cores, and (2) provide undisturbed samples for determination of in situ concentrations of dissolved gases. The tools developed for these purposes have also proven useful in sampling borehole fluids that have partially re-equilibrated with pore fluids in reentered basement holes, such as Holes 395A, 418A, and 504B. However, the borehole fluids that the WSTP tools sample in the vicinity of the bit are often displaced and/or contaminated by the massive drill string. When it is essential to avoid the effect of the drill string on borehole fluids in a reentry hole, ODP now operates Kuster water samplers that can be run on the coring line through the bit to sample fluids from open, undisturbed hole.

The WSTP and Kuster tools can all be described as 'passive' samplers (Mottl et al., 1983, 1985), in that the fluids sampled are those that are in the immediate vicinity of the sampler, whether in sediments penetrated by a probe or in open hole. In some situations it may be more desirable to actively draw a sample from the formation, such as in semi-lithified or lithified sediments that cannot be penetrated by the WSTP probe, or in open basement holes where the borehole fluids have not equilibrated with pore fluids. In such cases, it may be possible to use either the LDGO wireline packer, or a 'probeless PWS' (a WSTP with the TP-probe removed) in conjunction with a drill-string packer to seal the annulus and prevent sampling of borehole fluids. Such 'active' methods involving wireline or drill-string packers would require several hours per sample and have not been attempted as of Leg 118, but they are feasible.

B. Pore fluid sampling with the WSTP tools

Barnes (1979) described the first generation WSTP sampler, which was modified several times during DSDP, and was often called the 'Barnes sampler' or the Barnes-Uyeda probe.' Barnes (in press) describes the redesigned WSTP tool for ODP (Figure II-1), and the excellent results obtained with the prototype during Leg 110. The WSTP tools are self-contained, battery-powered tools adapted to an inner core barrel assembly that is deployed in the BHA. The sample chamber and electronics (timer and temperature pressure data recorder) are contained within the inner core barrel: only a strong probe that contains the sampler filter and temperature or pressure sensors protrudes below the bit.

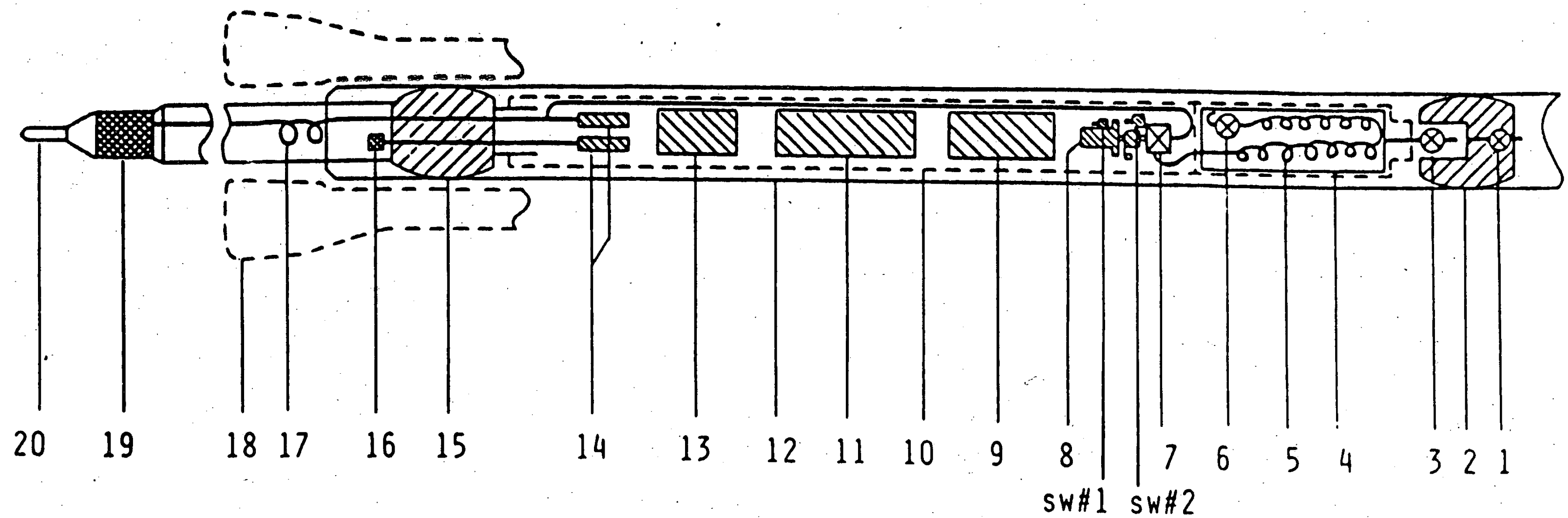


Figure II-1. Block diagram (not to scale) of the WSTP tool. (1) pressure case relief valve, (2) upper pressure case bulkhead, (3) sample chamber pressure relief valve, (4) sample overflow chamber, (5) sample coil, (6) sample coil pressure relief check valve, (7) sampling control valve, (8) D.C. gear motor, (9) timer-controller, (10) inner case assembly, (11) data recorder or other electronics package, (12) pressure case, (13) nickel-cadmium battery pack, (14) pressure transducers, (15) lower pressure case bulkhead, (16) pressure transducer inlet filter, (17) 0.8 mm bore fluid inlet tubing, (18) drill bit, (19) filter element, (20) thermistor probe. SW#1 = motor shut-off and reversing switch, SW#2 = manual motor switch. Solid heavy lines are fluid pathways.

Barnes has written a very detailed shipboard operating manual for the new generation of WSTP tools, copies of which are available from ODP. Table II-1 shows Barnes' table of contents, indicating the range of subjects and instructions covered in detail in the manual. Table II-2 repeats the specifications for the WSTP tools, as given by Barnes. Appendix A includes a copy of the form that is completed by the scientist or downhole tools technician who oversees deployment of the WSTP tools. The following overview of the methods to deploy the WSTP tool for sampling pore fluids from sediments is excerpted from section III-B of Barnes' manual ('The Downhole Run'):

> Downhole conditions vary and the procedures used to ensure a useful sample will have to vary accordingly. However, fill at the bottom of a hole is a normal occurrence, so the procedure should be designed to remove as much fill as possible and permit the probe to penetrate undisturbed sediment at the hole bottom. Several deployment methods have been devised for the WSTP tool: (1) latched-in operation, (2) free fall, (3) collet system, and (4) rotatable packer. Other deployment methods are under consideration, but the necessary special hardware has not been developed at this time.
>
> (1) Latched-in operation can be used during any drilling mode, but it is the only normal deployment method available during rotary coring.... The sampler is lowered on the coring line and latched into the BHA like a regular core barrel. Only the filter probe extends below the drill bit. The usual procedure would be to keep the fill washed out of the hole by pumping as the tool descends. The bit should be raised several feet above hole bottom long enough to latch the sampler into place, and then lowered while still pumping until the bit reaches the hole bottom or the desired weight on bit is attained [to allow heave compensation and maintain probe positioning], whichever comes first. Then the circulation pumps should be shut down.
>
> The probe should be lowered into the bottom about 3 minutes before the delay time ends and raised about 3-1/2 minutes after the sample time ends.... The sampler must be left in the mud long enough for the valve to close, in addition to a timer safety margin.
>
> (2) Free fall deployment was first tried on Leg 112. It can be used during APC/XCB [extended core barrel] mode. The sampler ... is connected to two inner core barrels, one standard 15' and one short 12'.... With this assembly the whole WSTP tool can drop below the drill bit.
>
> The hole is washed to the bottom and the drill bit is then raised several feet off the hole bottom. The sampler-core barrel assembly is pumped down the drill pipe and the filter probe penetrates the formation below the drill bit using the kinetic energy of the fast free fall. The drill bit can move up and down without disturbing the filter because the inner and outer barrels are not latched together.... In addition, the drill bit is raised

Table II-1. Table of Contents of R. Barnes' manual for the operation of the WSTP tool.

TABLE OF CONTENTS

Table II-2. General specifications: ODP wireline water sampler, temperature, pressure tool.

OPERATING PRESSURE:	Design = 10,000 psi minimum ($6.9x10^7$ Pa), collapse/burst = 20,000 psi minimum ($13.8x10^7$ Pa).
OPERATING TEMPERATURE:	Currently to 75°C, with new electronics to 125°C, high temperature version (planned) to 250°C minimum.
pH, SALINITY:	Compatible with 15-5PH, 304 and 316 stainless steel, and 4130 alloy.
NUMBER OF SAMPLES PER RUN:	One.
OPERATING DEPTH:	10,000 m (max) at 0-30°C using backup rings, 6500 m (max) to upper temperature limits.
SAMPLE VOLUME:	A) High quality sample suitable for chemistry and gas concentration, up to approximately 70 mL. B) Overflow sample mixed with approximately 75 mL distilled water and 1 mL drill water, up to 1200 mL. C) With extra Lynes Sample Barrels (Packer Configuration), approximately 60 L. All of these sample volumes available simultaneously.
TEMPERATURE:	±0.05°C precision.
FLUID PRESSURE:	0-10,000 psi, 2 channels; 1 channel--Formation Fluid Pressure, 1 channel--Drill Hole Pressure. Temperature and pressure data recorded digitally in 64K byte RAM memory.
OPERATING TIME:	A) Delay to sample: 0-13.2 hr (normal range 0-6.6 hr). B) Sample time: 0-13.2 hr (normal range 0-49.5 min). C) Accuracy: ±0.4% (0-30°C).
TYPE OF SAMPLING:	High quality suitable for quantitative gas concentration analysis, and chemistry compatible with stainless steel container. Low contamination by borehole fluid during soft sediment sampling.
LIMITATION:	Formation fluid cannot be filtered from low water content, low permeability sediments. However, temperature and formation fluid pressures can be measured to strength limits of probe.

off the hole bottom, which may be important for accurate formation fluid pressure measurements.... This deployment method should not be used if lithified layers might be encountered, because the penetration of the probe is not controlled. In soft sediments, the probe may penetrate several meters into the next core section.

(3) As an alternative to the free fall method, ODP is developing ... the collet delivery system. This system has been tested, but it is still under engineering development as of Leg 117. The idea is to provide a controlled penetration as in the latched-in method, a limited range of decoupling between the BHA and the sampler as in the free fall method, and in addition a mechanism to allow the probe to retract inside the drill bit if hard sediment is encountered that could otherwise bend the filter probe. [As this method is developed, more details will become available from the ODP engineers.]

(4) A special sealed probe system [probeless PWS] has been developed to use the WSTP tool with the rotatable packer.... This system has not yet been used and has been taken back to shore.... Anticipated usage of this system is low [until the rotatable packer is successfully field-tested -- see section E of this chapter, and Chapter IV].

Note that these methods as described by Barnes are the best methods to use when the primary purpose of the tool lowering is to obtain a water sample However, when it is equally important to measure in situ temperature, it may be necessary to modify these methods as described in Chapter III. For example, while only one water sample can be taken during a single deployment, it is possible also to make several measurements of temperature at different depths during the same deployment, but it is critical to carefully plan the sequence so that the probe is at the desired depth at the proper time for sampling fluids.

Note also that the success of the WSTP tool in capturing pore fluids as opposed to drilling fluids depends both on penetrating the sediment and on holding the probe stable during the sampling period. With the standard, 'latched-in' method of deployment, maintaining probe position is best accomplished using the drill-string heave compensator, which requires placing about 5000 lb weight on the bit. Thus it is difficult to sample pore fluids from very shallow sediments, which are generally not competent enough to support this weight. In deeper, more lithified sediments, greater amounts of weight may be required for penetration, and the act of penetration may open fractures in the formation, allowing drilling fluids to contaminate the sample. In practice, the WSTP samplers have been effective at depths of about 50 to a few hundred mbsf, depending on the properties of the sediment.

C. Pore pressure measurements with the WSTP tools

Pore pressure is a crucial parameter that reflects and influences hydrogeologic and tectonic processes, but it is difficult to measure in situ because the emplacement of a measuring tool often disturbs the formation and fluid pressures in the vicinity of the tool. The WSTP probes have been instrumented with pressure transducers to determine pore pressures, but the results have been difficult to interpret in any quantitative sense. Ideally, pore pressure and possibly even permeability could be determined either from the decay of a pressure pulse on instantaneous insertion of a probe or from the rebound of pressures after a period of fluid sampling through the probe (Figure II-2).

The DSDP WSTP tool was first instrumented with a pressure transducer in an attempt to measure excess pore pressures in sediments cored during Leg 84 (von Huene, 1985) The redesigned WSTP tool can be equipped with two pressure transducers, one for reference hydrostatic pressure, the other to measure sediment pore pressure around the probe (Barnes, 1988). While these transducers have worked well, the data have justified only qualitative interpretation because of possible physical disturbances during emplacement in the sediment. In fact, Barnes (1988) found the pressure data more useful as diagnostic of downhole events during the sampling process (Figure II-3).

Note that the WSTP was configured to allow concurrent measurements of temprature and pressure, as illustrated in Figure II-3, only during Legs 110-112. However, in its present configuration, the WSTP will support the measurement of temperature or pressure, but not both at the same time, in addition to water sampling. In the future it is possible that the WSTP probe could be redesigned to once again allow concurrent temperature and pressure measurements.

The disturbances that may affect pore pressure measurements include (1) movement of the probe during the measurement, disrupting the seal between the probe and surrounding sediments and allowing contamination by borehole fluids at hydrostatic pressure, and (2) compression of the formation and pore fluids from above by the weight put on the bit in attempting to hold the probe stationary. Any concurrent temperature measurements and water samples will of course also be sensitive to probe movements, but will not be affected as much as pressure measurements by weight placed on the bit and transmitted to the formation.

If the WSTP is deployed using the normal 'latched-in' method described above, the only way to keep the probe stable in the formation is to use the heave compensator, which requires that a minimum amount of weight (at least 5000 lb) be put on the bit. Thus it may be impossible to avoid the effect of this weight on measured pressures, unless a different method of deployment is used. For example, the collet delivery system that is presently being developed would allow some decoupling between the bit and the probe, and might lessen the effect of any bit weight on the pressure measurements.

Note that, when the new WSTP is used for sampling and temperature or pressure measurements during a single run, it may use much of its battery power before the run is over. While the recorder is presently being modified to reduce the battery drain, it is prudent to check at the pre-cruise meeting that an adequate supply of the rechargable batteries will be on board JOIDES Resolution for legs with heavy planned usage of the WSTP tools.

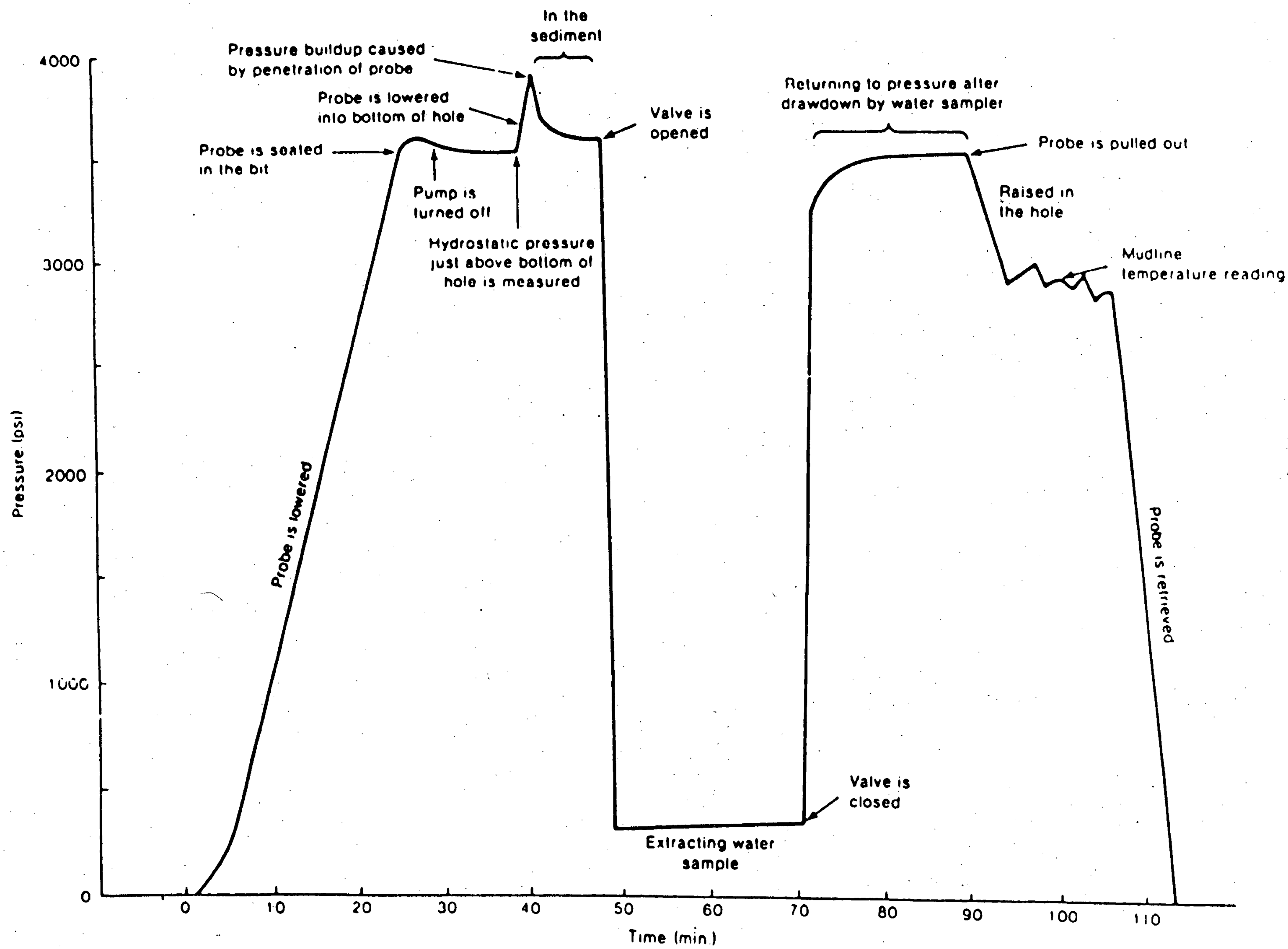
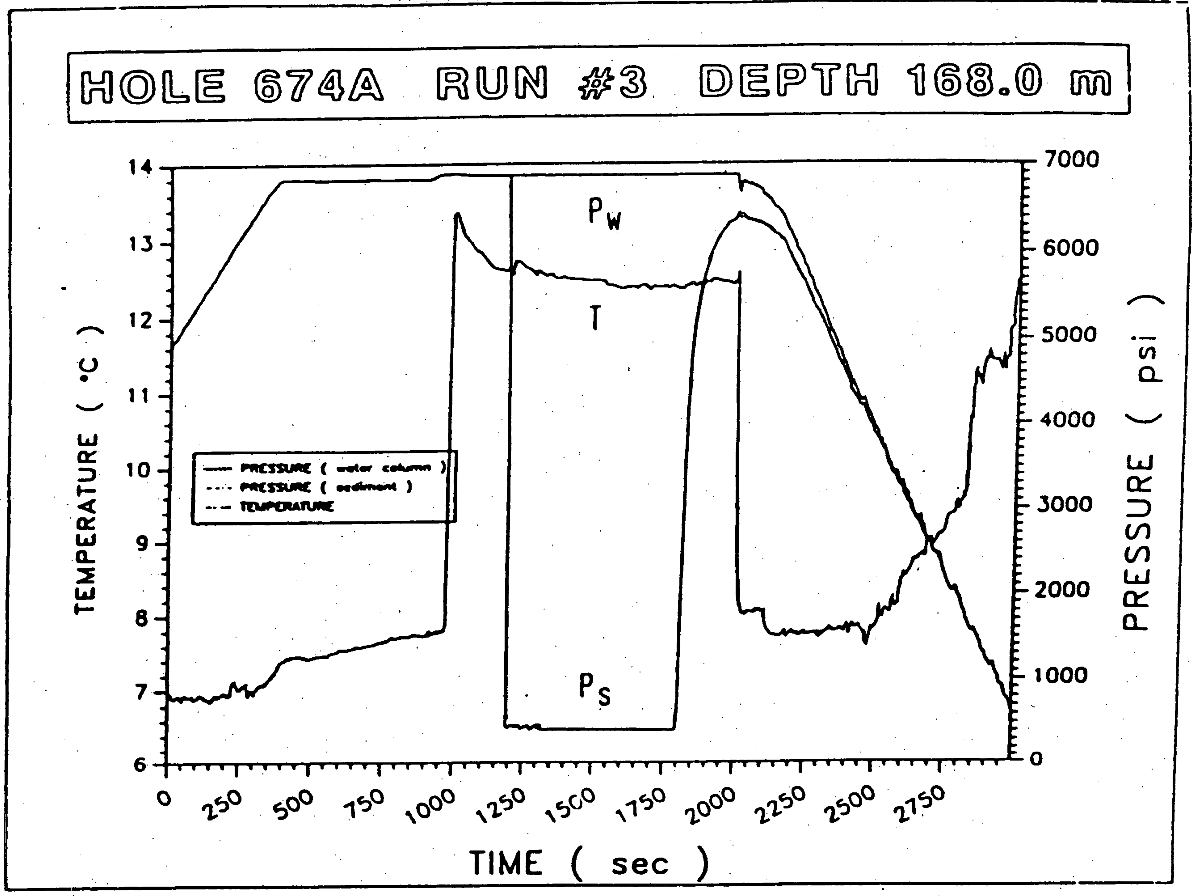


Figure II-2. Generalized record of pressures measured with the WSTP tool. Annotated to show functioning of probe during a set of measurements. From von Huene (1985).



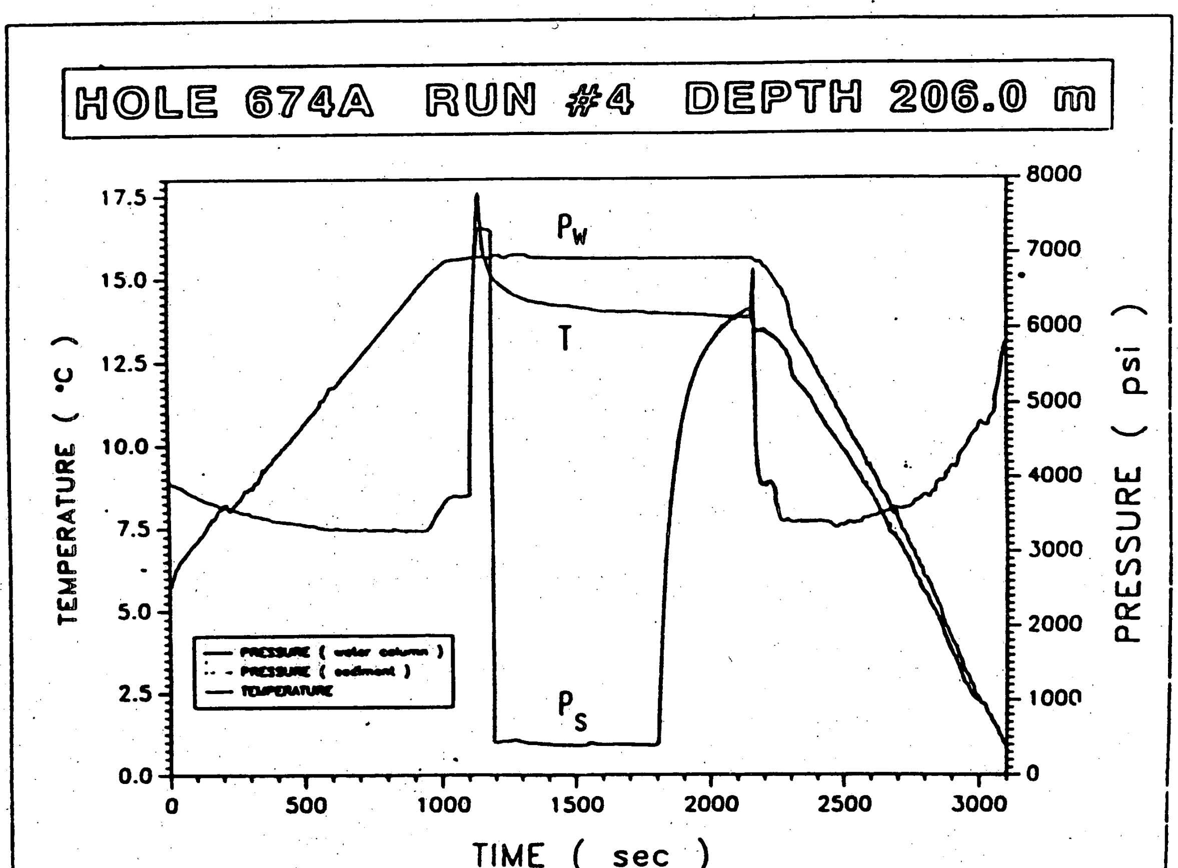


Figure II-3. Actual records of pressures and temperatures measured with the WSTP tool during ODP Leg 110. Note that as presently condigured,

D. Borehole fluid sampling with WSTP and Kuster tools

In addition to sampling pore fluids from penetrated sediments, the WSTP tools can also be used to sample borehole fluids, as can larger volume fluid samplers made by Kuster Company of Long Beach, California. The WSTP tools are described in the previous section; Figure II-4 shows the Kuster sampler, and Table II-3 gives its operating specifications. ODP purchased three of the 500-ml Kuster samplers for Leg 111, and now maintains them for use as needed. Kuster provided relatively brief operating instructions, which are available from ODP and are summarized in the following paragraph.

The Kuster sampler is a relatively simple tool consisting of a sample bottle with an inlet valve, two non-return valves, a locking device, and a mechanical clock. In operation, the clock is wound and the tool is lowered into open hole on the coring line. When the clock reaches the programmed sampling time (60 or 150 minutes after being wound), it releases the locking mechanism, thereby allowing the inlet valve to open and the sample chamber to fill. When the fluid pressure inside the chamber plus the spring pressure of the non-return valve reaches in situ fluid pressure, the non-return valves close and seal the sample chamber. Once the sample has been taken, the sampler should not be lowered any deeper into the hole, as increasing the external pressure will re-open the valves and allow the sample to be contaminated.

When the tool is retrieved to the surface, the pressurized sample must be released using a special extractor body, to which a system of high-pressure valves and hoses is attached. There is no 'standard' valve/hose system available, and a custom system may need to be constructed for each leg, depending on such factors as anticipated sample pressures, requirements to preserve dissolved gases, etc. It is the responsibility of the co-chief scientists, in consultation with participating fluid chemists, to specify any special requirements for such a sample extraction system at the pre-cruise meeting.

Operational considerations for sampling borehole fluids

Immediately after drilling a hole, the borehole fluids are composed primarily of the surface seawater used to flush cuttings during drilling. Thus it is normally of interest to sample borehole fluids only if considerable time has elapsed since the hole was drilled, so that the fluids have partially re-equilibrated with in situ pore fluids -- a situation that occurs only when a reentry hole is revisited. If borehole fluids are to be sampled (and temperatures measured) when a re-equilibrated borehole is reentered, it is essential that this be done before any significant disturbance to the borehole fluids occurs, as might be produced in reaming the hole, circulating to condition for logging, or even running a sinker bar on the coring line to verify that the hole is open.

The WSTP and Kuster tools are deployed on the coring line in different ways, which will affect the choice of a sampler in a given situation. To sample borehole fluids, the WSTP is lowered (but not latched) into the bit, so that the probe collects fluids from within 1 m of the bit, which may have been somewhat disturbed, displaced, or contaminated by the massive steel drill-string. On the other hand, the Kuster samplers are lowered

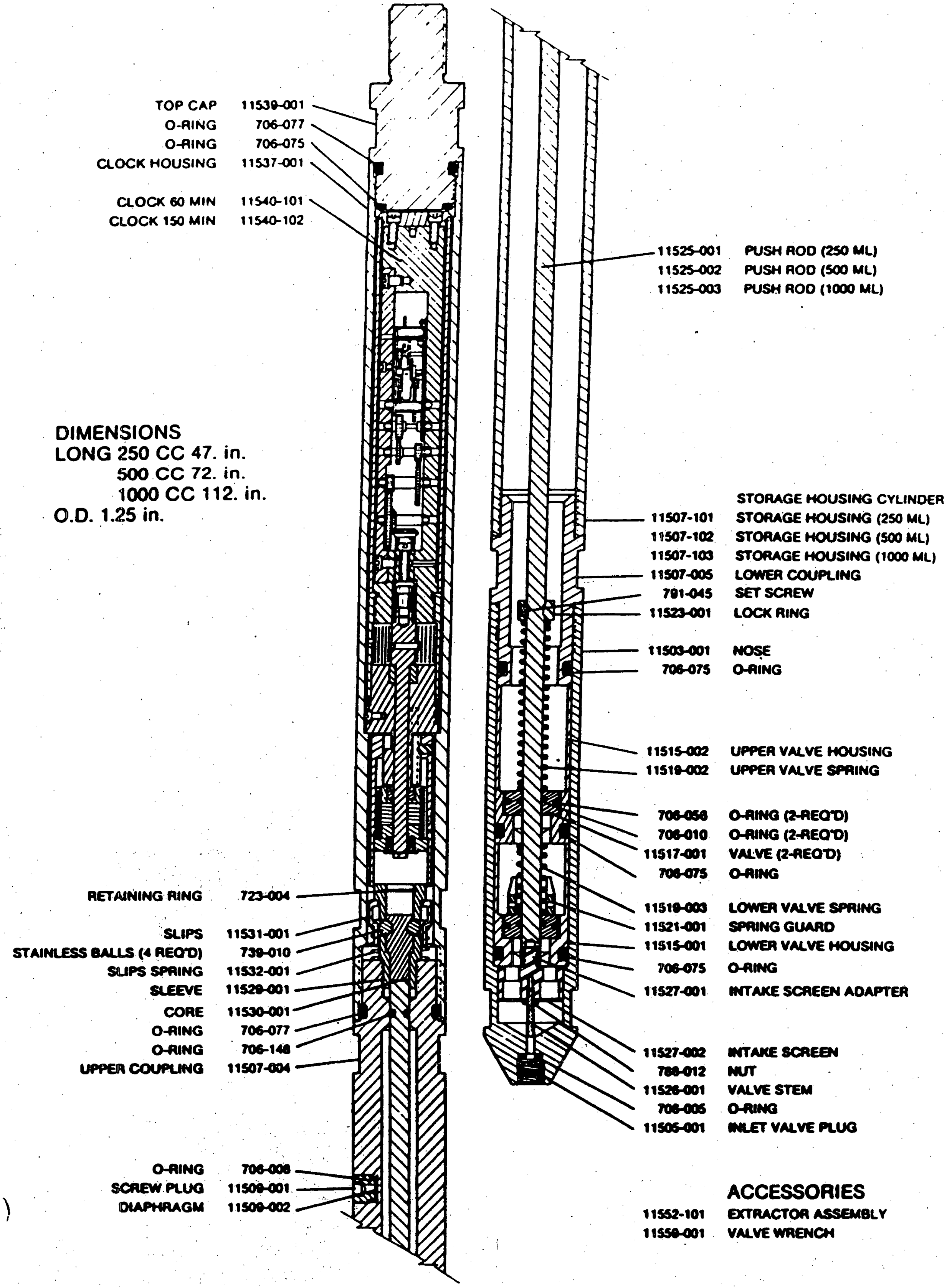


Figure II-4. Schematic of the Kuster water sampler.

Table II-3. Specifications, Kuster water sampler.

SAMPLER PART NO. 11500

SPECIFICATIONS

Temperature	300°C max
Pressure	1400 kg/cm^2
pH	2.5-9.0
Salinity	0-300,000 ppm
Operating depth, water	50 m min 5000 m max

Capacity, mL	250	500	1000
Dimensions			
Length, cm	118	178	292
in.	46.375	70.25	115
Outside diameter		31.8 mm	
Weight, kg	4.25	6.2	19.2

Material Stainless steel, copper-nickel alloy, copper, nitrile neoprene

Clocks 60 or 150 minutes, programmable

Sampler	250 cm^3		P/N 11500
	250 cm^3	Operation above 200°C	P/N 11500-1
	500 cm^3		P/N 11501
	500 cm^3	Operation above 200°C	P/N 11501-3
	1000 cm^3		P/N 11501-1
	1000 cm^3	Operation above 200°C	P/N 11501-2

NOTE:

1. For operation above 200°C use hi-temp O-rings.
2. For continued operation above 260°C use perfluoroelastomer O-rings.

---

through the bit into open hole, ideally far enough away from the drill string to sample undisturbed fluids.

The Kuster sampler might therefore seem to be a better choice to obtain undisturbed fluids, but the WSTP tool may be required if there are any doubts about whether the hole is free and clear of any bridges or obstructions. If there is any chance of obstructions, it is safer to reenter the hole with a clean-out bit and run the drill string to the bottom of the hole, rotating and circulating where necessary to clean the hole. As the bit is worked down the hole during such a clean-out process, it is possible to pause at nearly any depth in the hole, to lower the WSTP tool into the bit and sample borehole fluids just ahead of the bit, which may be affected to some degree by any required rotation and/or circulation.

There will probably be concerns about hole conditions in reentering holes into sedimentary formations, holes into rubbly basement, and basement holes in which the sediments are not completely cased off. Such concerns should be carefully considered by the co-chief scientists and ODP engineers at the pre-cruise meeting, where the decision should be made as to what apparatus is to be run first into a reentered hole. These concerns will be relatively minor in reentering a properly cased basement hole with a good drilling history and no indications of hole stability problems.

Two examples may be helpful:

(1) Leg 102 reentered Hole 418A in 1985, about 8 years after it was drilled with little difficulty during Legs 51 and 52. However, as the lower 200 m of sediment had never been cased, and a logging tool was feared to have been lost in the hole during Leg 52, the initial reentry was made with a clean-out bit, which was run to hole bottom, encountering bridges but no logging tool. During two pauses in this clean-out pipe trip, the WSTP tool was lowered into the bit to sample borehole fluids and measure borehole temperatures, with fair results (Salisbury, Scott, et al., 1986).

(2) When Legs 70, 83, and 92 revisited Hole 504B, the initial reentries were made with a clean-out bit, and the WSTP tool was deployed several times during the clean-out pipe trips. As no obstructions were encountered, no rotation or circulation was required, and the fluid samples and temperature measurements were generally good (Mottl et al., 1983, 1985; Gieskes et al., 1986; Becker et al., 1983a, 1983b, 1985). When Leg 111 reentered Hole 504B, no hole problems were expected, and the initial reentry was made with a light-weight French temperature logging tool, which was run to within 55 m of hole bottom, followed by several runs of Kuster water samplers and a Schlumberger water sampler. The temperature data were excellent but the water samplers were plagued by tool failures unrelated to hole conditions (Becker, Sakai, et al., 1988).

E. Active fluid sampling utilizing packers

When a packer is used to seal a borehole, the fluids in the sealed section are isolated from further contamination and mixing with seawater. If a sufficient volume of fluids can be pumped from a zone sealed by a packer, pore fluids will be drawn into the borehole, and a borehole fluid sample may then contain a significant component of pore fluids. Several devices have been proposed to sample pore fluids in such an 'active' manner in conjunction with packers, but none of these has been tested or proven as of the end of Leg 118. In the future, the following tools may be available for active sampling using packers: the LDGO wireline packer, the ODP 'probeless PWS,' and a sampling go-devil for the drill-string straddle packer that is presently being developed and is briefly described in Chapter VI.

The wireline packer is configured like a logging tool, and is intended to be run on the logging line into open hole, to sample fluids from isolated zones of the formation. It consists of a short straddle packer, 1-4 sample bottle(s), downhole pumps and valves to inflate the packers or pump fluids from the formation to the sample bottles, and electronic sensors to monitor key properties of the fluids to be sampled, such as pressure, temperature, pH, Eh, and concentrations of certain ions. With real-time surface readout of these fluid properties, the operator will be able to assess whether the fluids being pumped past the sensors contain true formation fluids, and to fill the sample bottle(s) when the fluids are worth sampling for detailed analyses. The wireline packer is presently being constructed by TAM International, the manufacturer of the ODP drill-string packers, and is scheduled for testing during Leg 124E. Further information is available from the LDGO Borehole Research Group.

The 'probeless PWS' (pore water sampler) comprises a WSTP tool modified to be used in conjuction with the inflated ODP rotatable drill-string packer, which is described in Chapter IV. The WSTP tool is modified by replacing the probe containing its temperature and pressure sensors with a short filter assembly, so that no part of the probeless PWS extends beyond the bit (Figure II-5). In addition, a large (up to 60 l), divided, evacuated core barrel is attached, with the intent of drawing a large volume of fluids from the isolated section of the borehole. The last 0.1-1.2 l of fluid drawn into the sampler is captured separately, in the normal WSTP sample coils and chambers. If a sufficiently small section of permeable formation is isolated by the packer, then the fluids sampled later should contain a greater component of pore fluids. It should then be possible to estimate the composition of *in situ* pore fluids by extrapolating along a mixing line determined by the successive sample aliquots.

As noted above, the rotatable packer has not been used successfully yet, and the probeless PWS has therefore never been tested. Development of this mode of sampling has been suspended until the rotatable packer is proven, but it may also be feasible with the reliable drill-string straddle packer. Note that any procedures and equipment developed to sample fluids in conjunction with drill-string packers must be consistent with procedures for using the packers, which are described in more detail in Chapter IV.

In particular, it may not be possible to lower a sampler into a drill-string packer after it has been inflated, for the following reason: Once the packer is inflated, the drill-string heave compensator must be engaged to avoid dislodging the packer; as the packer will hold the bottom of the drill string in place, the heave compensation will result in relative movement between the top of the pipe and the rig floor. It would

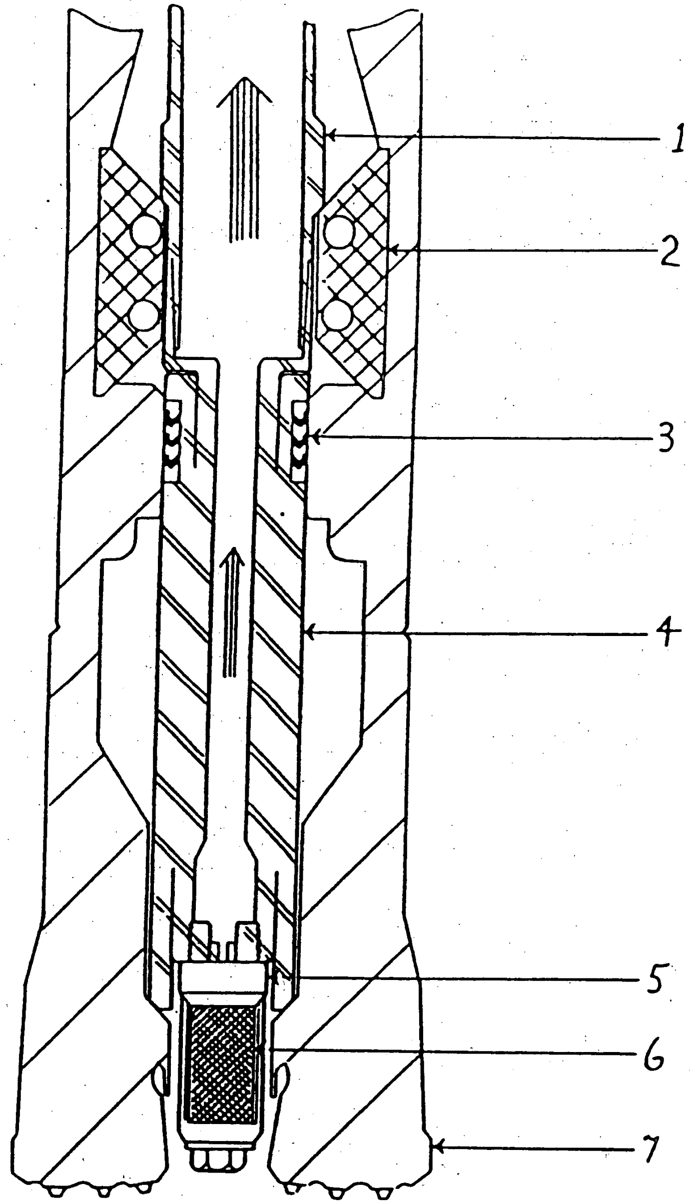


Figure II-5. Schematic of sealing probe assembly for use with the ODP drill-in packer. Packer element is located on the outer core barrel above the section shown in the figure. The lower bulkhead of the WSTP tool is attached to the probe about 25cm above the landing sub. The arrows show flow of water through the probe from the filter to the water sampler inlet port. (1) standard ODP landing sub, (2) support bearing, (3) probe to outer core barrel seal, (4) special sealing sub-assembly, (5) probe tip assembly, (6) filter element, (7) drill bit.

then be very difficult, dangerous, and probably contrary to SEDCO safety policies to attempt to 'stab' a sampling tool into the moving top of the pipe. (It might be possible to hold the top of the pipe stationary at the rig floor if bumper subs have been included in the BHA, but bumper subs may seriously compromise the packer operations.) Therefore, any sampler must be lowered into the packer before the packer is inflated, and the sampler must then also functionally substitute for the go-devil that would normally be used to enable packer inflation. (See Chapter IV.)

III. TEMPERATURE MEASUREMENTS

A. Introduction

The geothermal gradient is a fundamental property of the crust that influences and reflects the effects of tectonic, hydrologic, and geochemical processes, and accordingly temperature was among the first downhole properties to be measured during DSDP. In fact, Von Herzen and Maxwell (1964) actually measured sediment temperatures during drilling at the preliminary Mohole site, and a strong effort was made to measure downhole temperatures from the beginning of DSDP. Erickson et al. (1975) and Hyndman et al. (1987) reviewed the downhole temperature measurements made during DSDP and the techniques for determining in situ temperatures from the measured values.

Several methods are presently available in ODP to measure downhole temperatures, including two tools operated by ODP to measure sediment temperatures -- the WSTP and the APC temperature (T) recorders -- and logging tools operated by LDGO and some independent investigators to measure temperatures in open boreholes. The use of the ODP WSTP and APC T tools in their primary mode, measuring sediment temperatures during the process of coring a hole, will be described in detail in this chapter. In addition, the use of these tools to obtain profiles of borehole temperatures in open hole or of sediment temperatures in an uncored 'hole' will be discussed.

While the WSTP and APC T recorders can both be used to measure sediment temperatures, they differ in their application in three key ways: (1) The WSTP is used to measure temperatures between coring periods, and thus requires 1-3 hours for each measurement, whereas the APC T tool is used during the process of cutting a hydraulic piston core, and only requires 10-15 minutes of additional time. (2) During a measurement, the WSTP tool is pushed into uncored sediments and will disturb the section to be cored next, whereas the APC T tool should not affect the quality of the next core. (3) The WSTP can be used to depths at which the sediments can be safely penetrated with the probe, typically several hundred mbsf. In contrast, the APC T tool can be used only to depths at which the force required on pullout is within safe limits, typically to about 100 mbsf. Neither the WSTP nor the APC T tool is effective at very shallow depths, where the sediments are not competent enough to hold the probe stable.

Temperatures measured in the probes downhole do not often reach full equilibrium with in situ values, and must usually be corrected for two major effects, the thermal disturbance to the borehole and surrounding formation by drilling and circulation (e.g., Bullard, 1947; Jaeger, 1961), and the transient approach of probe temperature to sediment temperature (Bullard, 1954), typically due to the decay of frictional heating of the probe on penetration into the sediments. The former will be mentioned only briefly, as it usually affects open-hole temperature logs measured shortly after drilling, which are not normally attempted using the ODP tools. The gradual approach of probe temperatures to in situ values is clearly seen in data measured in sediments with the WSTP or APC T tool, and the methods and shipboard computer programs required to extrapolate the measured temperatures to in situ values will be briefly summarized.

B. Temperature measurements with the WSTP tools

Most of the tools used to measure temperatures during the early stages of DSDP (Figure III-1; see Erickson et al., 1975) were similar in concept to the present WSTP tool, which also incorporates the capability to sample pore fluids and to measure pressure instead of temperature (Chapter II; Barnes, 1988). Yokota et al. (1980) and Uyeda and Horai (1982) described the temperature recorder for the first WSTP tool, which they developed before Leg 60. This tool was known during DSDP as the Barnes-Uyeda probe or Tokyo T-probe and is still used extensively on JOIDES Resolution. There are two versions of the temperature recorder for the present WSTP tool, redesigned by R. Current, C. Current, and D. Cash at ODP.

Tool specifications

The temperature-measuring systems of the two generations of WSTP tools are similar in concept, but differ primarily in their electronic capabilities. The WSTP tools employ battery-powered recorders with electronic memories to monitor the resistance of a single thermistor in a probe that protrudes about 1 m ahead of the bit (Figure III-1). The first-generation WSTP tool is limited to storing only 128 values of thermistor resistance, and can be programmed to read these values at 1- or 2-minute intervals during stations that last about two or four hours, respectively. The first version of the second-generation WSTP recorder can sample 16,000 values from three channels (temperature plus two pressure transducers) at an interval of up to about 5 seconds. This recorder has occasionally failed under tough deployment conditions, and a simpler, more reliable recorder is also available. This new version can record only one data channel (i.e., temperature but not pressure), and can store up to 2048 values sampled at a programmable interval.

The single thermistor is encased in a steel probe with an outer diameter of 1.25 cm, with a slight taper on the new version (Figure III-2). Therefore the probe has a time constant in sediments on the order of 2-3 minutes, and it must be held in position for about 10 minutes to obtain enough data to reliably extrapolate to in situ sediment temperature.

Preparation and deployment

The WSTP tool will be programmed and prepared for deployment by the ODP downhole tools technician(s), who will need to know the parameters to be measured (temperature or pressure and/or fluid sample) and the depth of measurement several hours in advance. It is advisable to check the thermistor calibration and electronic circuits by verifying the ice-point reading occasionally and by substituting a decade box for the thermistor before and after sites. A fully charged battery should be used, particularly if extensive instrument testing is conducted immediately before deployment and/or a long station is planned with all three measurement capabilities.

As described in Barnes' operating manual and excerpted in Chapter II, the WSTP can be used in several deployment modes. Barnes' instructions are directed toward obtaining the best water sample, and will generally apply to measuring temperature. However, if the primary objective of lowering

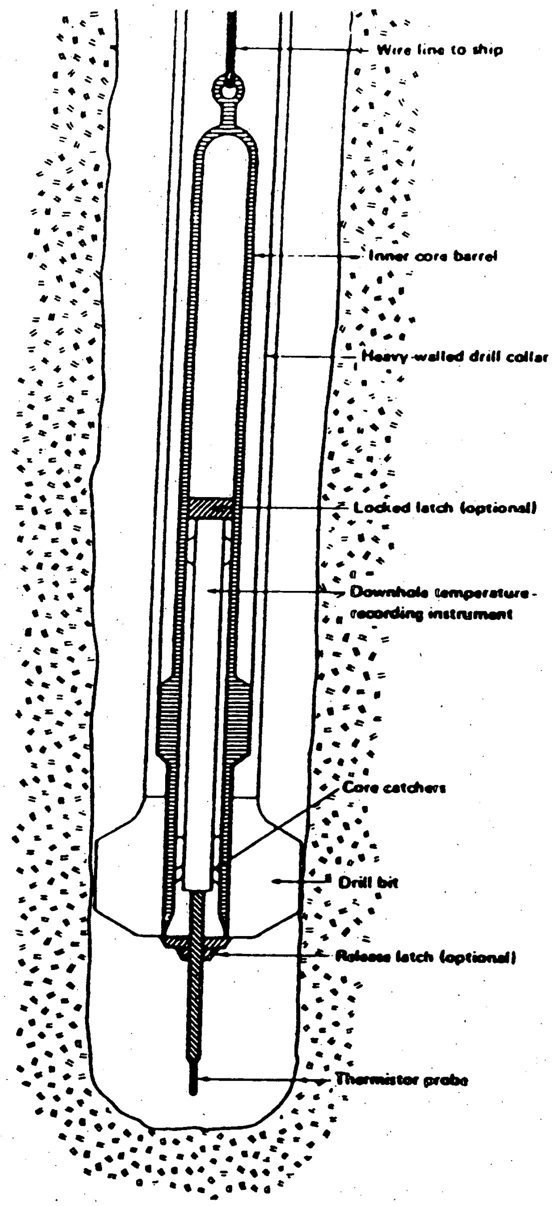


Figure III-1. Diagram of the type of sediment temperature probe used for the majority of the Deep Sea Drilling Project heat flow measurements (after Erickson et al., 1975). From Hyndman et al. (1987).

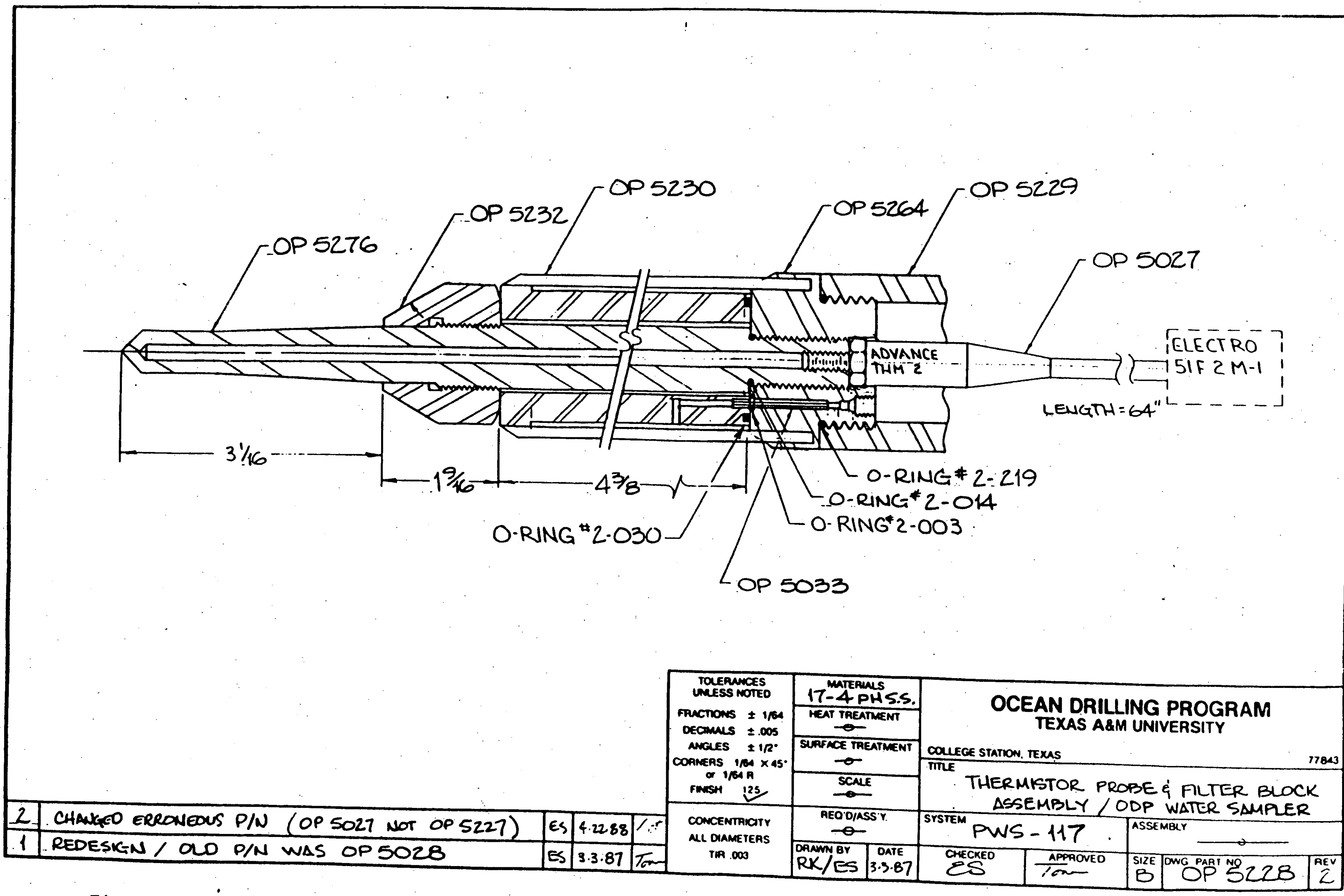


Figure III-2. Detail of the thermistor probe and pore fluid filter assembly for the ODP WSTP tool.

the WSTP is to obtain the best temperature data, slightly different procedures might be followed, as will be discussed here.

The standard method is described by Barnes as 'latched-in operation' (see Chapter II) and requires about 1-3 hours between cores (depending primarily on water depth) to measure temperatures at a chosen depth. Normally, the tool is lowered on the coring line and latched into the bit held just above the measurement depth. As the tool is lowered to the bit, a 5- to 10-minute pause to check recorder performance should be made at the mud line, where the temperatures inside the pipe should be close to (but possibly slightly higher than) the stable bottom water temperature. Once the tool is latched into the bit, the pipe is then lowered, pushing the probe to the measurement depth in sediments ahead of the hole that ideally are undisturbed by previous drilling. If pore fluid sampling is the primary goal, Barnes recommends pumping as the tool is lowered to wash fill from the bottom of the hole; if a good temperature measurement is the primary goal, it may be better to minimize pumping and avoid disturbing temperatures at the measurement depth.

At the measurement depth, the probe is held stationary using the heave compensator, as follows: As the probe is pushed into the sediments, a small amount of weight can be transferred from the derrick to the bit, by adjusting the amount of weight that is compensated. The heave compensator will be effective at maintaining the position of the bit and probe only when the amount of weight that will be held by the bit is greater than the sensitivity of the heave compensator, about 5000 lb. Thus, the measurement should be taken at the depth where sufficient weight can be maintained to hold the probe stationary, which will not necessarily correspond precisely to a pre-selected depth. In particular, it is very difficult to measure temperatures in very shallow sediments, which are not competent enough to support the minimum weight required for heave compensation.

Maintaining the probe stationary for about 10 minutes is the primary consideration in obtaining good temperature data with the WSTP. The weight required to penetrate the sediments and to hold the probe in place will depend on the strength of the sediments, and will generally increase deeper in the section. If too little weight is applied, the probe may be allowed to move, degrading the data through two possible factors, additional frictional heating on probe movement and leakage of borehole fluids around the probe. On the other hand, if too much weight is placed on the bit, the probe may be slowly pushed ever deeper, resulting in continuous frictional heating, and the formation may even be fractured, allowing borehole fluids to leak around the probe and affect the measurement. For temperature measurements, it may be better to apply slightly too much weight, unless it is also critical to obtain good pore pressure data that would be degraded by compression of the sediments.

Data retrieval and processing

The ODP downhole tools technician is responsible for dumping the raw thermistor resistance data to the shipboard VAX, for converting these data to temperatures, and for producing a standard plot of measured temperatures versus time using the 'PicSure' graphics program on the VAX (e.g., Figure II-3). This is accomplished in the technicians' 'DOWNHOLE' account on the

VAX, from which the scientist may obtain copies of the data files and standard data reduction programs. The data files are archived as prime data at ODP, but require further processing to determine in situ temperature, which is the responsibility of the scientist.

The scientist should be concerned with at least two stages of processing: first, possibly correcting the raw data according to the results of calibrations before or after the station or at mud line during the station; and second, extrapolating the corrected temperatures to the in situ value. A rigorous theory describes the approach of a cylindrical probe to in situ temperature after penetration (Bullard, 1954; Jaeger, 1956), and the in situ temperature should be determined by fitting the measured values to Bullard's (1954) F-function (tabulated by Lister, 1979; see also Hyndman et al., 1979). At present no official ODP programs are installed on the shipboard VAX to accomplish this, but various programs have been left by shipboard scientists, and Lister's (1979) table is available in the shipboard collection of reprints (see Appendix B).

C. APC temperature tools

With the advent of the hydraulic piston corer during the late stages of DSDP, Dr. R. Von Herzen developed a miniature recorder designed to fit in the cutting shoe and measure sediment temperatures as a core was taken (Figure III-3; Horai and Von Herzen, 1985; Koehler and Von Herzen, 1986). The last of these tools is still in use on JOIDES Resolution, but has a limited useful life remaining. ODP has had a redesigned version on order from Bowmar-White Co., to be delivered in 1988. The Von Herzen and Bowmar-White tools are similar in function and are collectively termed APC T tools (advanced hydraulic piston corer temperature tools).

As noted above, the major advantage of the APC tool over the WSTP is that the APC tool is used to measure temperatures as a piston core is taken, with very little time required in addition to that needed to take the core. On the other hand, use of the APC tool is limited to depths at which the force required on pullout is within safe limits, roughly the upper 100 m. This depth limit is somewhat less than the limit for simple APC coring, because the sediments will 'grip' the corer more tightly during a 10-minute station to measure temperatures than during a 1-minute penetration to cut a core.

Tool specifications

The APC T tool consists of a programmable miniature recorder about 12 cm long and a small battery pack, both of which fit into cavities in the APC cutting shoe (Figure III-3). Originally, separate cavities were cut for the recorder and battery pack, but the newest design features a semi-annular cavity with a removable carrier for the recorder and battery pack. The Von Herzen version can be programmed to record up to 1300 values of the resistance of a calibrated thermistor, sampled at a selectable interval of 0.1 second to as much as 100 minutes. The Bowmar-White version uses a calibrated platinum resistance device, and can be programmed to record up to 3000 values of the raw temperature values, sampled at an interval of 0.1 second to 24 hours. The tools and programming instructions are more fully described in two users' manuals, one by Koehler and Von Herzen (1986) and one in preparation for the Bowmar-White tool.

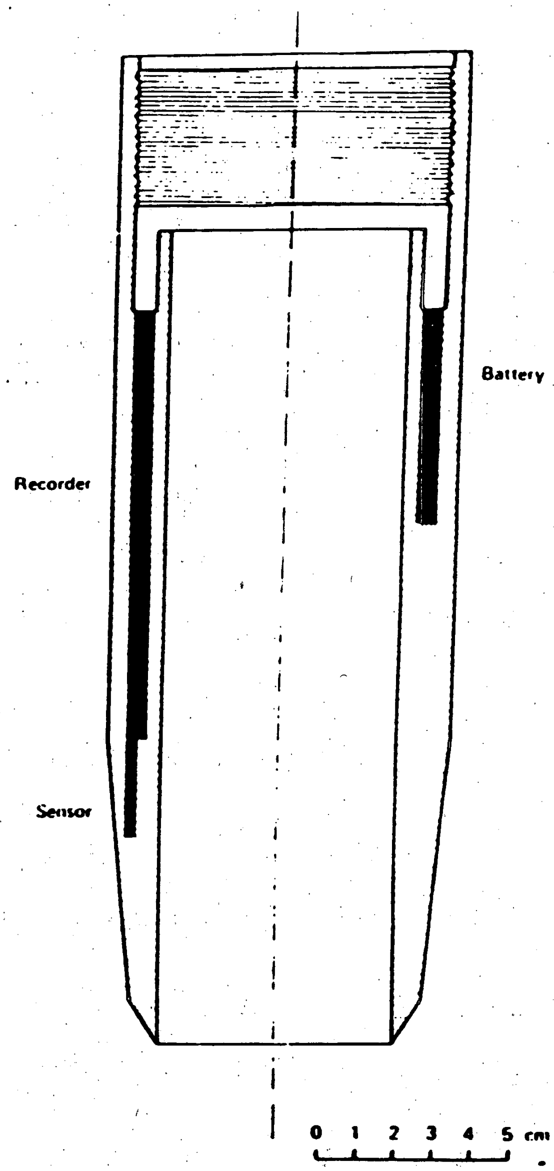


Figure III-3. Diagram of the hydraulic piston corer temperature measurements system embedded in the core shoe (after Horai and Von Herzen, 1985). From Hyndman et al. (1987).

The single sensor of the APC tool is positioned close to the tip and edge of the cutting shoe (Figure III-3), which is represented as a perfectly conducting annular cylinder in processing the measured temperatures (Horai and Von Herzen, 1985; Horai, unpublished ms.). The wall thickness of this annular cylinder is about 1.5 cm, giving it an effective time constant of roughly 2-3 minutes in sediments. Thus the APC must be held in place for about 10 minutes to record enough data to reliably extrapolate to in situ sediment temperature.

Preparation and deployment

The APC T tool is normally used on selected cores in a sequence of APC cores in the upper 100-200 m of sediments, and the allowable depths of measurement are determined by the lengths of the cored intervals, usually 9.5 m. The selection of temperature stations and preparation of the recorder must be carefully coordinated to avoid disrupting the coring routine, which can be surprisingly rapid-fire at a typical APC hole. The scientist must consult in advance with the ODP lab officer and downhole tools technician, to specify the cores on which temperature is to be measured and the recorder programs to be used. In recent usage, the Von Herzen recorder has typically been programmed to record thermistor resistance every 10 or 15 seconds during a station 2 or 3 hours long.

The downhole tools technician will prepare the recorder and cutting shoe, and deliver the assembly to the rig floor at the appropriate time. Until the Bowmar-White tool is produced in quantity, it will probably not be possible to measure temperatures more frequently than every third core, because of the time required to dump previous data, replace batteries, reprogram the recorder, replace it in the cutting shoe, and redress the shoe.

If the APC T tool and cutting shoe are ready at the appropriate time, the station will proceed like a normal piston core, with one obvious exception: After the corer is hydraulically fired into the sediment, it must be held in position for about 10 minutes to record enough data to allow in situ temperature to be determined. The corer is then retrieved in normal fashion; when it is brought on deck, the cutting shoe is broken off and given to the downhole tools technician before the core is removed from the core barrel.

Data retrieval and processing

As with the WSTP tool, the downhole tools technician is responsible for dumping the raw data to the shipboard VAX, for converting these data to temperatures (if necessary), and for producing a standard plot of temperatures versus time. This will be accomplished in the technicians' 'DOWNHOLE' account on the VAX, from which the scientist may copy the data files and data reduction programs. As presently written, the programs and command files pertain to temperatures obtained by converting resistances of the thermistor in the Von Herzen tool, and they will require some revision to accommodate the Bowmar-White tool. The data files and standard plots are archived as prime data at ODP, but require further processing to determine in situ temperature, which is the responsibility of the scientist.

To determine the best estimate of true sediment temperature, the measured temperatures must be fit to the function that describes the approach of the APC cutting shoe to in situ temperature after penetration. This function was formulated by Horai (unpublished ms.) and the data reduction procedure is summarized by Horai and Von Herzen (1985). Copies of these papers are available in the shipboard reprint collection (see Appendix B). The procedure for data reduction is somewhat interactive and subjective, and must be conducted carefully, because (1) Horai's formula probably does not apply at very short times after penetration, and (2) the thermal properties of the cutting shoe introduce an ambiguity in assigning an effective time origin in treating the data.

Horai's programs were rewritten and throroughly documented for ODP in 1987 by K. Becker, and are available on the shipboard VAX in the scientists' 'HEATFLOW' directory. Copies of the programs and documentation are available from ODP. Figure III-4 shows an example of excellent data recorded with the Von Herzen tool during Leg 111, and the fit of the data to the theoretical cooling curve, calculated with the revised programs presently available. When the Bowmar-White tool is put into service, these programs will require further revision, although the basic algorithms will remain effective.

D. Use of ODP tools for discrete temperature 'logs'

The sections above have concerned the deployment of the ODP temperature recorders in their normal mode of obtaining single values of sediment temperature per tool lowering at discrete depths during the process of coring a sediment hole. It is also possible to use these tools to obtain readings of temperatures at multiple depths during a single lowering, either in open borehole or in sections of sediment that are not cored. For such stations, the procedures for tool preparation and data processing are basically the same as discussed above, although somewhat longer recording programs may be appropriate. Only the methods of deployment are different, as will be discussed here.

To obtain such discrete temperature 'logs,' either the APC T recorder or the WSTP can be used, although the APC tool is often preferable for reasons discussed below. During these stations, the tool is lowered to the bit, and the pipe is moved in stages so that the temperature sensor is held for about 10 minutes at each of the measurement depths. The tool can be lowered to the bit either on the coring line or by freefall, but if it is run on the coring line, the range of measurement depths is limited to about 20 m because it will not be possible to add or remove pipe over the coring line. Twenty meters corresponds to the approximate length of drill pipe that can be drawn up in the derrick before the station and then lowered into the hole with the coring line once the tool is run to the bit at the beginning of the station. Thus, deployment by freefall is necessary if it is desired to measure temperatures over a depth range that is greater than about 20 m. The APC T tool is more appropriate for freefall, because it will generally withstand the deceleration on landing much better than the WSTP tool.

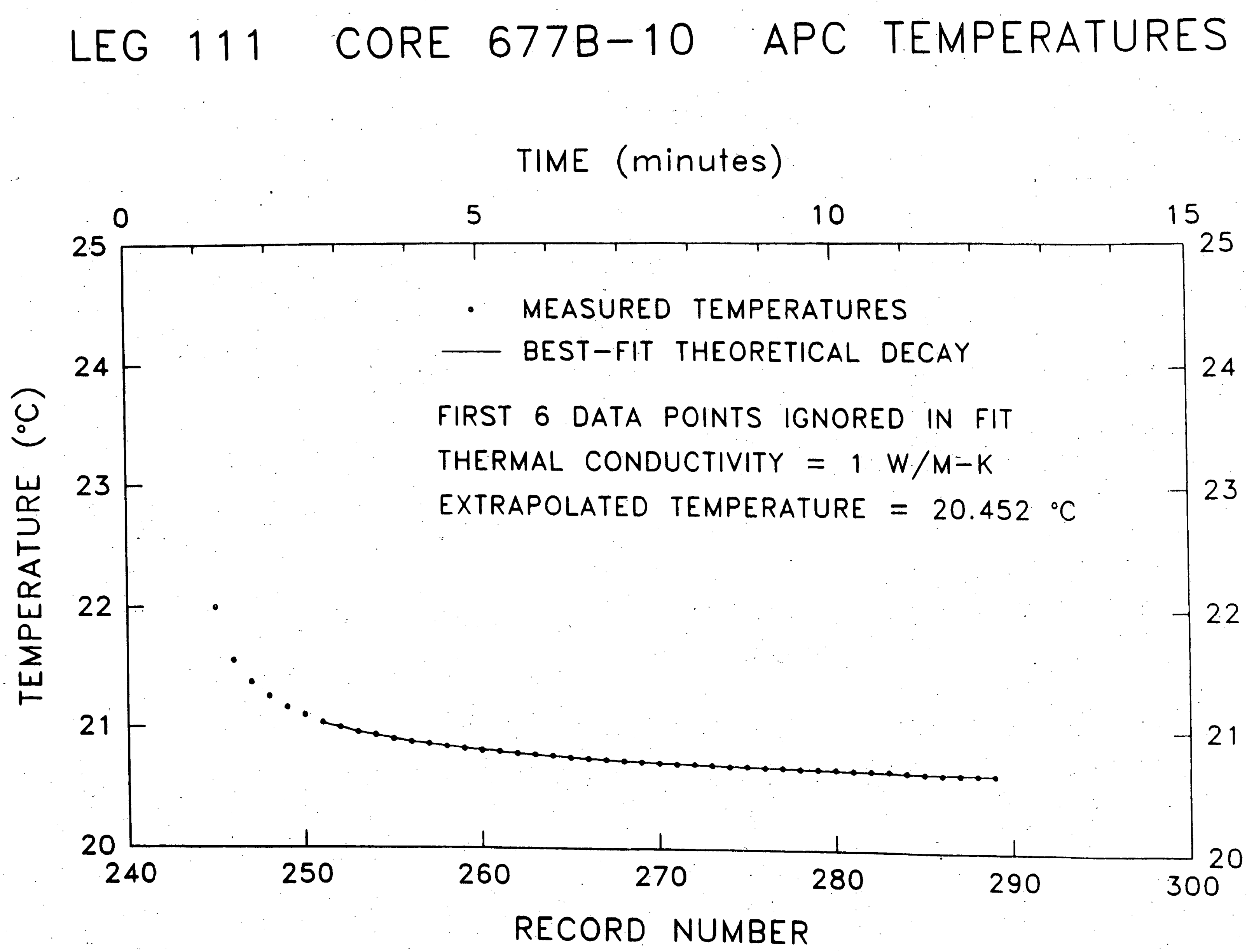


Figure III-4. Actual temperature data collected with the APC T recorder during Leg 111, with the best-fit model for the approach of the cutting shoe to in situ temperature.

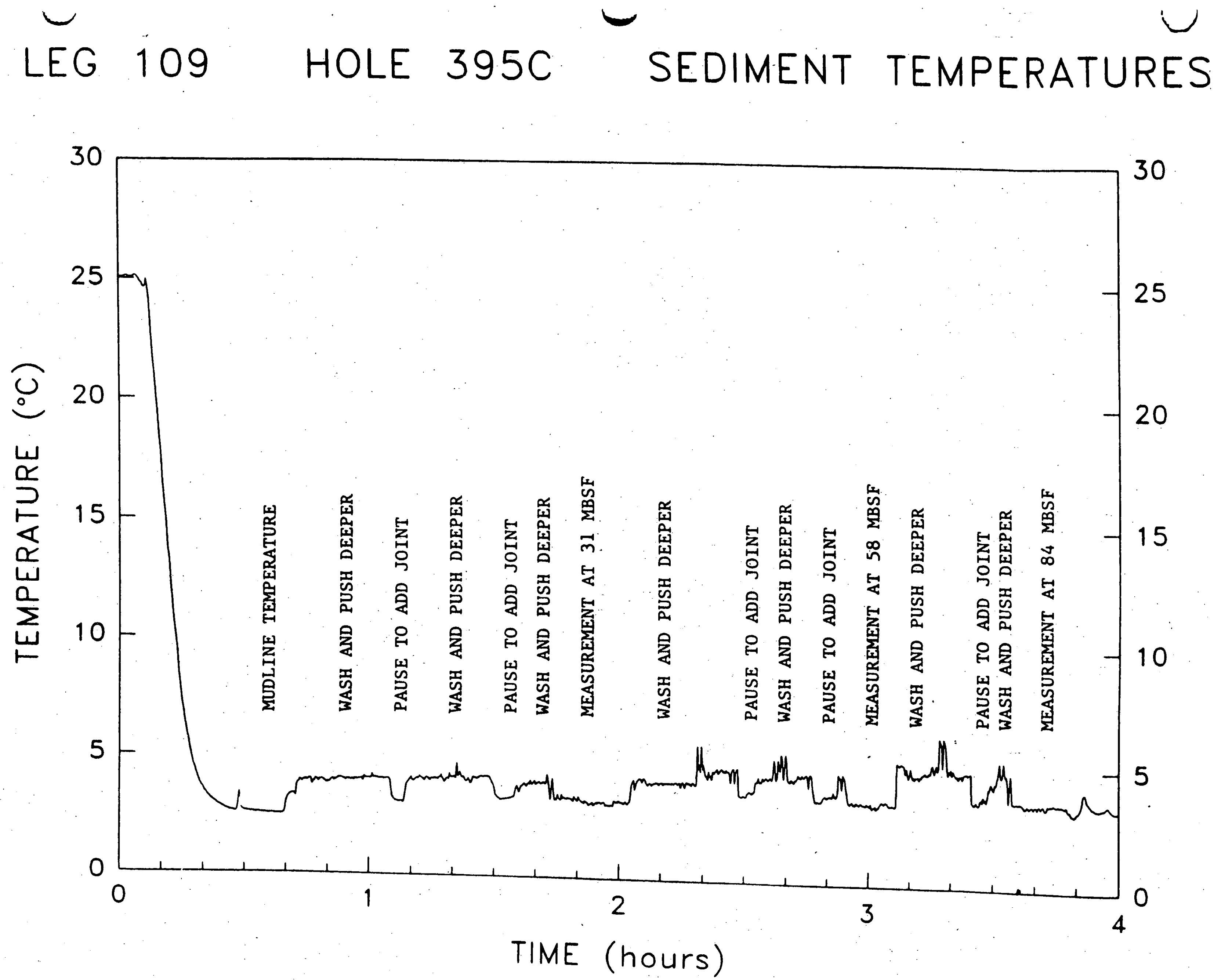
Logging sediment temperatures without coring

If the temperature profile is to be measured in sediments, the recorder must be latched into the bit. The pipe is then pushed and washed through the sediments to just above each of the measurement depths; the pumps are then shut off and the tool is pushed into place and held stationary for about 10 minutes using the drill-string heave compensator as described in section B. It is preferable to use the APC T tool for this kind of station because less sediment must be displaced in penetrating with the annular APC cutting shoe than with the larger profile WSTP. In addition, the WSTP probe may bend if an obstruction is encountered, possibly preventing it from being withdrawn through the bit by normal means. As illustrated by the example in Figure III-5 (from Detrick, Honnorez, Bryan, Juteau, et al., 1988, at a low heat flow site), the resulting temperature record will clearly show the effects of fluid circulation and frictional heating as the probe is moved between measurement points, but good data can still be collected at the measurement depths if the probe can be held stationary.

Logging open-hole temperatures

Upon returning to a reentry hole in which the borehole fluids have reequilibrated with the geothermal gradient, it is usually critical to log borehole temperatures and sample fluids before any other operations disturb the borehole. Ideally, a continuous temperature log should be obtained using a lightweight tool on the logging cable, as was done when Leg 111 revisited Hole 504B (Becker, Sakai, et al., 1988). However, this will not be allowed if the hole is not expected to be completely free of bridges or obstructions. In that case, true logging will not be permitted until the hole has been cleaned out by running the pipe and bit to hole bottom, but this cleanout pipe trip will disturb the thermal equilibrium of the borehole fluids.

Nevertheless, a temperature log and fluid samples can still be obtained, by deploying an ODP temperature tool to the bit as this cleanout trip is made. During such an operation, the recorder probably should not be latched into the bit, so that it will be pushed back up inside the pipe if an obstruction should be encountered. To minimize disturbances to the borehole fluids, the pipe should be run very slowly and carefully into the hole, avoiding circulation and rotation unless absolutely necessary to clear an obstruction. Pauses can be made during this cleanout pipe trip at nearly any depth, to measure temperatures, sample fluids, or retrieve and re-deploy the tool. It is even possible to configure the WSTP and APC T tools together, and run them simultaneously to assure recovery of equilibrium temperature data in the event of a tool failure. Figure III-6 shows the data obtained with the APC T recorder during this kind of station when Leg 92 reentered Hole 504B (Leinen, Rea, et al., 1986); the WSTP tool was run simultaneously to sample fluids and record backup temperature data which are not shown.



'gure III-5. Temperatures measured with the APC ecorder during Leg 109 in the uncored sediment of 'Hole' 395C.

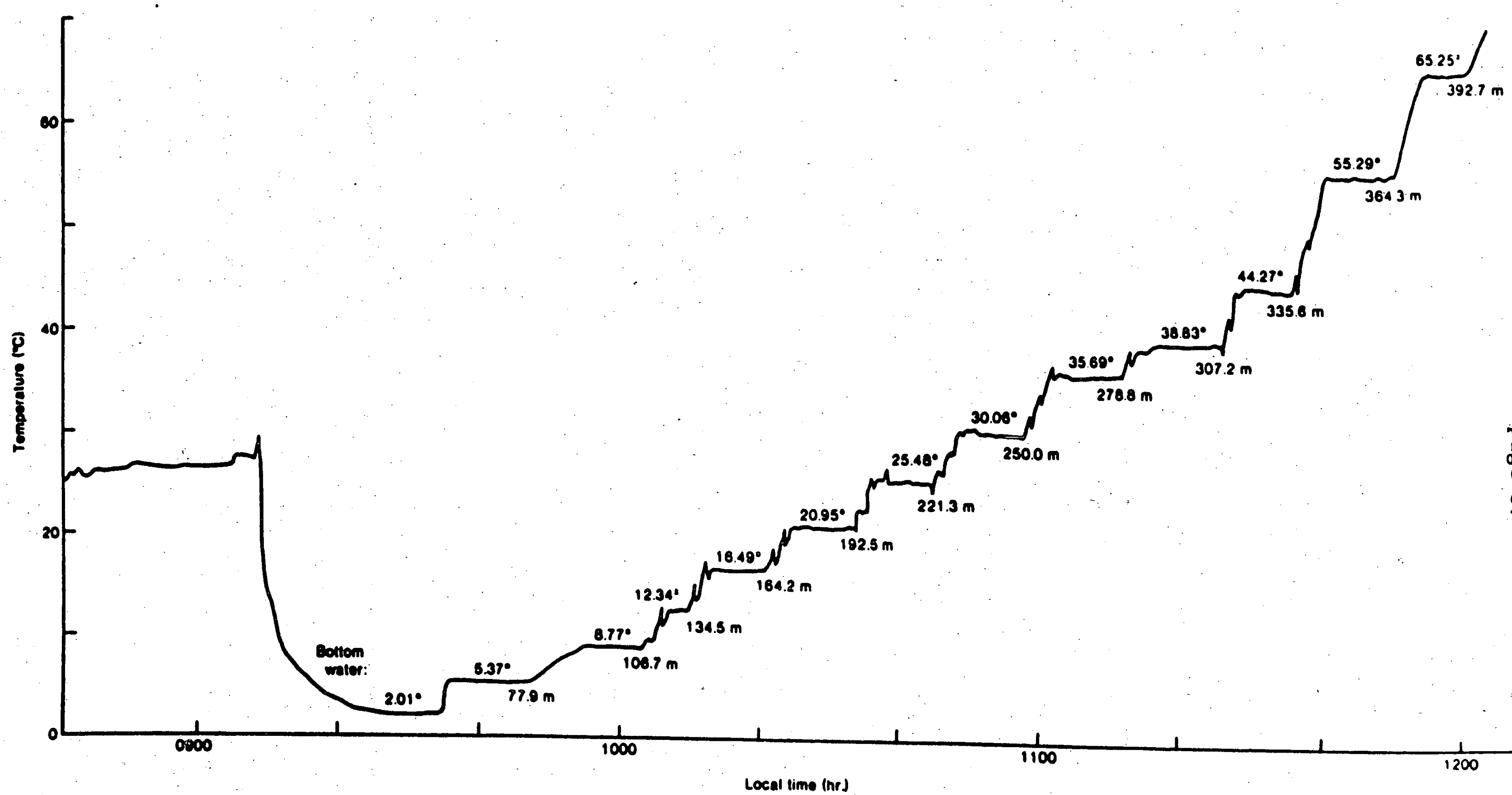


Figure III-6. Temperatures measured with the Von Herzen APC T recorder during Leg 92 reentry of Hole 504B.

IV. DRILL-STRING PACKERS

A. Introduction: Packers

A packer can be defined simply as a device that produces a hydraulic seal in a borehole (Figure IV-1). If the integrity of this hydraulic seal is properly maintained, the hydrologic properties of the formation can be tested, by applying differential fluid pressures to the isolated section. Formation properties that can be measured using a packer include pore pressure, transmissivity, from which permeability can be derived, and (less accurately) storage coefficient, which is directly related to formation porosity. In addition, it may be possible to sample fluids from the section of borehole isolated by a packer; if the formation is permeable enough, the sample may contain a component of formation fluids.

A drill-string packer is designed to be part of the BHA; a wireline packer is a separate tool lowered on a conducting cable into open hole, like a logging tool. A drill-string packer or a wireline packer can be configured as a straddle packer, which incorporates two hydraulic seals and allows the zone between the seals to be tested or sampled. In contrast, a single-element packer isolates the zone between the packer seal and the bottom of the hole.

Three packers are presently available in ODP, all manufactured by TAM International of Houston, Texas:

(1) A non-rotatable drill-string packer that can be configured as a single packer or a straddle packer, presently supported by an NSF grant to the University of Miami. This packer was used successfully during Legs 109, 111, and 118, and is available for use in reentry holes that penetrate stable formations.

(2) A rotatable drill-string packer operated by ODP, intended for use in less stable formations, where a rotational capability may be required for safety reasons. This packer was tested during Leg 110, and the design was subsequently modified, but the redesigned version has not yet been used. It is sometimes called the 'TDP,' or TAM Drilling Packer.

(3) A wireline packer operated by the Borehole Research Group at LDGO, intended primarily for fluid sampling, but also capable of limited formation testing. The wireline packer has not been used yet, but is scheduled for land tests in 1988 and full ODP testing during Leg 124E.

The use of the two drill-string packers will be fully discussed in this chapter. The use of the wireline packer will not be detailed here, as it is an LDGO logging tool and has not yet been proven for routine use.

B. ODP drill-string packers

Unless it is specially engineered, a drill-string packer should be kept in tension, like the drill pipe above the BHA, and should not be included as part of a coring, rotating BHA. Thus, formation testing with the non-rotatable drill-string packer will require separate pipe trips into

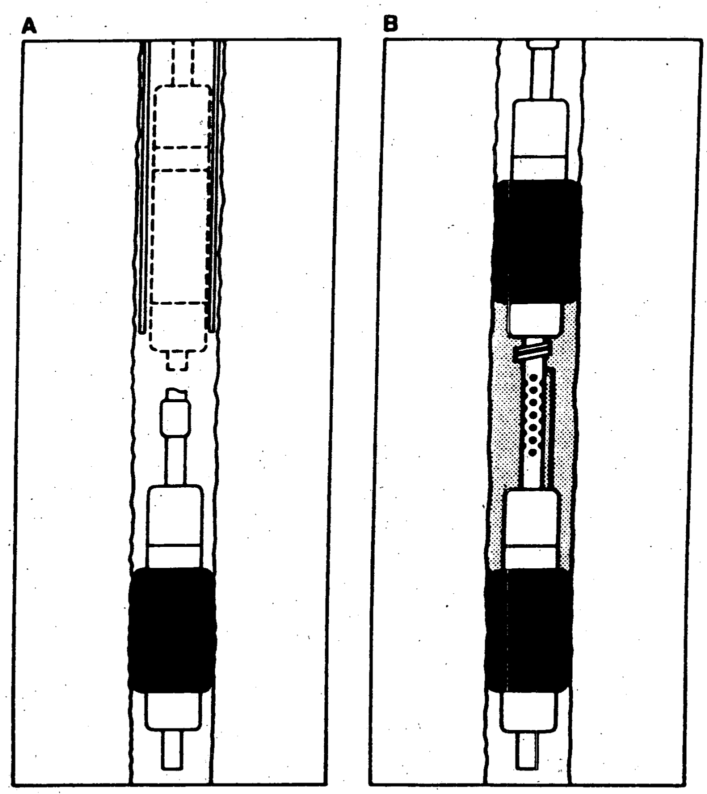


Figure IV-1. Sketches of TAM inflatable drill-string packers.
A. A single-element packer, which isolates the formation between the element and the bottom of the hole.
B. A straddle packer, which separately isolates the zone between the elements and the zone between the lower element and the bottom of the hole.

reentry holes that have already been cored. As described below, the packers are compatible with logging, and it may be possible to accomplish logging and packer measurements during a single pipe trip.

The special engineering required of the rotatable drill-string packer includes a strengthened internal mandrel to withstand both the torque and compressive loads of drilling, and a plumbing system that will permit cuttings to be circulated away without inadvertently inflating the packer elements. While the ODP rotatable packer was designed to be compatible with coring, during initial testing rotation has destroyed the packer elements. Thus this packer has not yet been proven for use in a ideal mode of coring ahead, pausing for measurements, coring ahead, etc. Instead, it should probably be used in a reentry/logging mode, in holes where there is any chance that the formation may collapse around the packer, necessitating a rotating capability to free the BHA (e.g., in sediments).

Packer elements

The packers used in ODP are <u>inflatable packers</u>, which seal the borehole using hybrid rubber/steel <u>elements</u> that are inflated with seawater pumped down the drill string from the rig floor. Each of these elements consists of an internal rubber bladder, which is bonded to an expandable steel strength member, which in turn is bonded to an outer rubber cover. The outer rubber and the steel serve to 'grip' and seal against the borehole wall, and to protect the inner bladder, which must remain unpunctured for the packer to remain inflated.

The proprietary TAM design uses a tight, 'Chinese-finger weave of stainless steel wire rope as the element's internal strength member (Figure IV-2). This has the advantage that good bonds can be maintained between the woven cable and both the inner and outer rubber during expansion and contraction of the element. However, this type of element may be weak at very high degrees of inflation, if the cables separate to the extent that the rubber in the gaps must bear too much of the inflation pressure.

The elements for the two TAM drill-string packers have the same external dimensions, threads, and seal surfaces, but different internal diameters. The internal mandrel of the rotatable packer is larger to withstand torque during rotation. Thus the element for the rotatable packer has a larger internal diameter, and it can be used on the non-rotatable (straddle) packer. However, the elements for the non-rotatable packer have too small an internal diameter to be used on the rotatable packer.

Inflation of packer elements using go-devils

The TAM packer elements can safely be inflated to as much as twice their uninflated diameters. However, a greater degree of inflation requires more time for full deflation, and produces a weaker hydraulic seal that can withstand a lesser range of test pressures (Figure IV-3). Thus, effective formation testing requires that the packer(s) be positioned in zones where the borehole is in good condition and in gauge, where the degree of packer inflation can be kept reasonable. Such zones are usually apparent in logs that should be run before packer tests are begun, such as caliper, borehole televiewer, resistivity, density, and sonic logs.

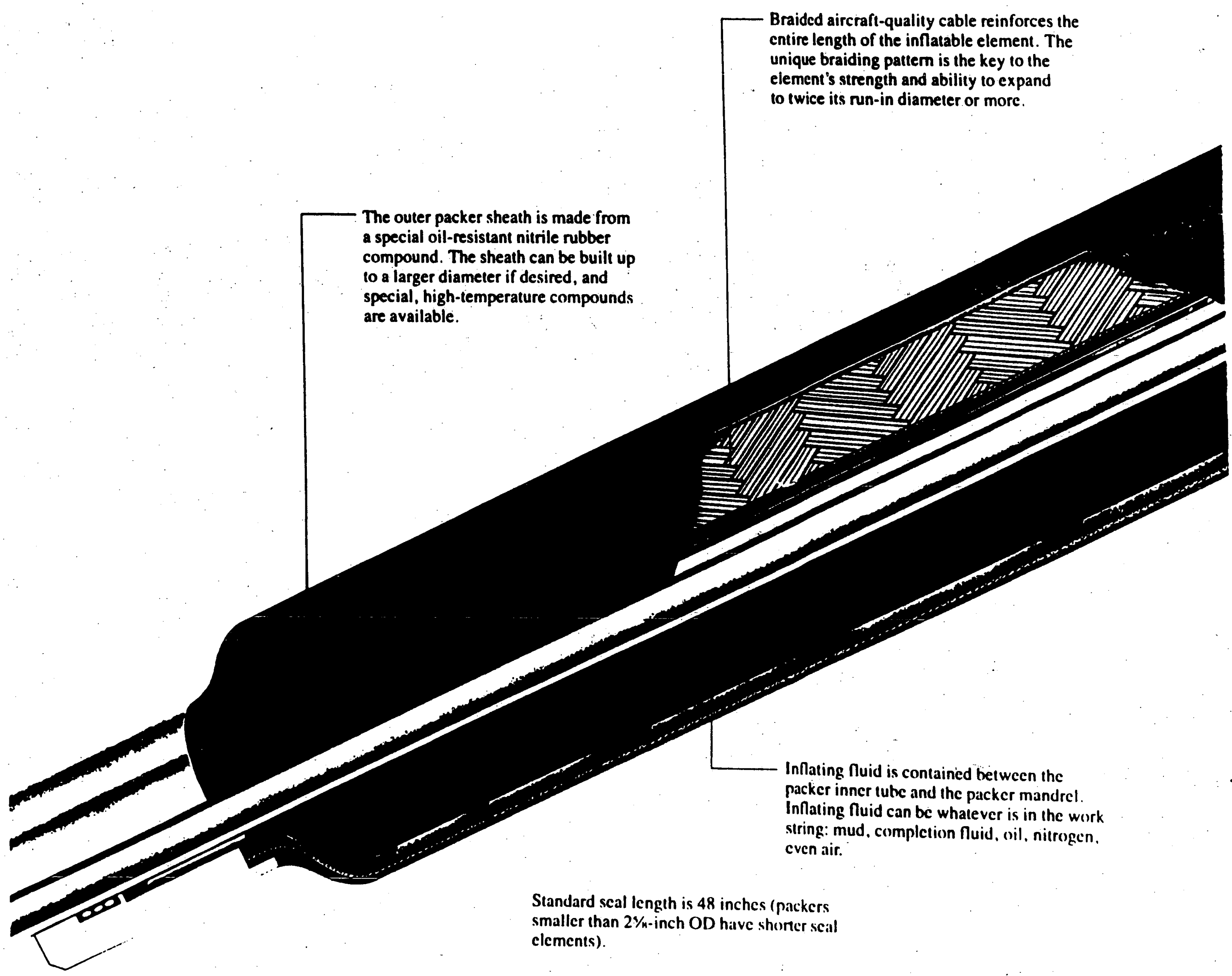


Figure IV-2. Anatomy of the rubber elements used on the ODP drill-string packers manufactured by TAM International.

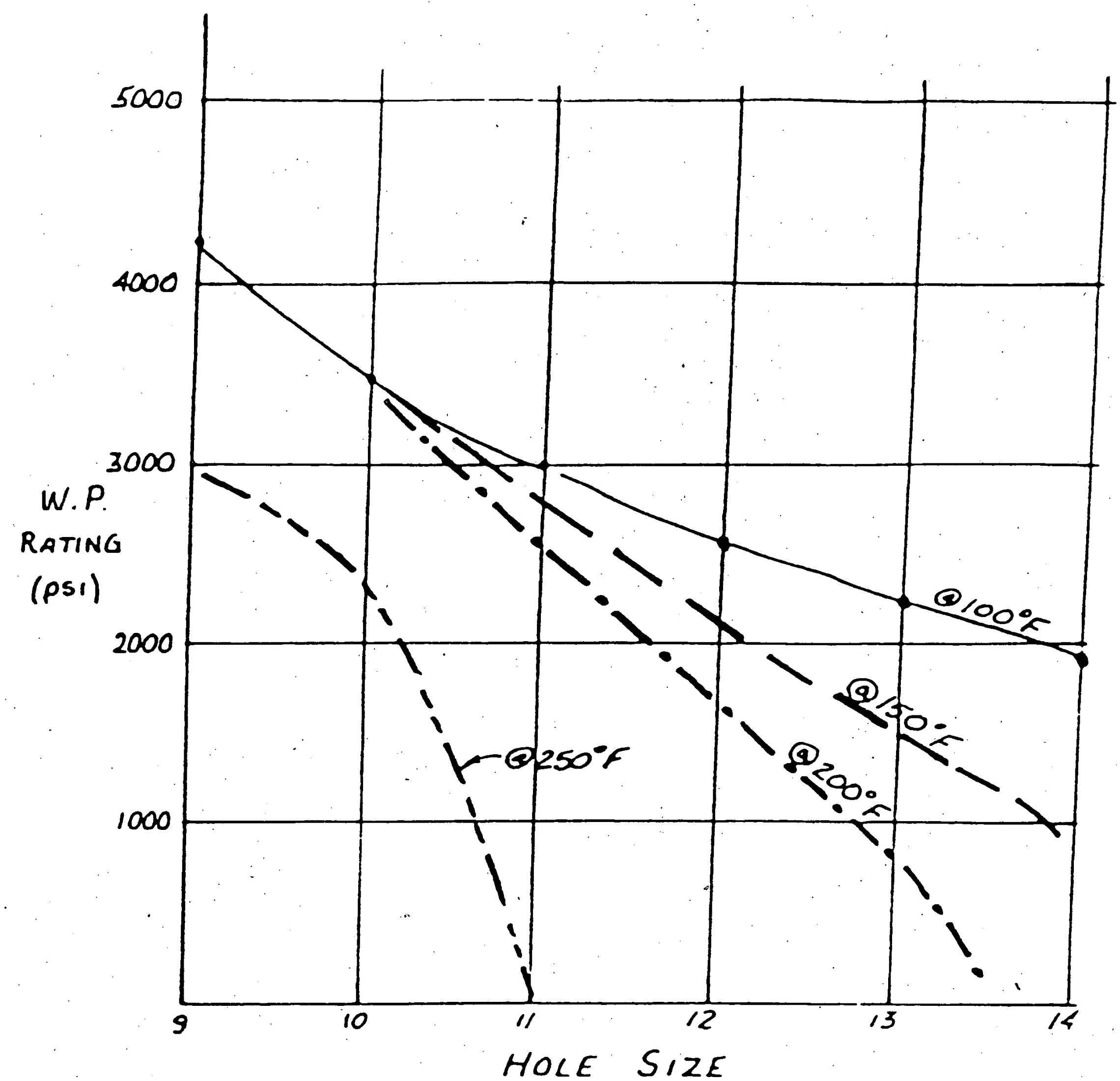


Figure IV-3. Capabilities of the standard TAM elements to withstand differential test pressures versus hole size.

After the drill-string packer is positioned in the desired zone, inflation of the element(s) is accomplished by pumping seawater from the ship down the pipe. Before pumping, the inflation mechanism is enabled by free-falling a retrievable go-devil, which keys into the packer plumbing system. (Note that inflation of the LDGO wireline packer is accomplished by an electrically powered downhole pump.) A properly seated go-devil may perform several functions, including (1) forming a hydraulic seal within the packer to direct the fluids pumped from the rig either into the elements for inflation or into the formation for testing, (2) carrying the pressure recorders that monitor the data needed to determine pore pressure and permeability, and (3) possibly carrying a sample chamber. Using go-devils that are retrievable with the coring line, multiple sets of the ODP drill-string packers can be made, as long as the elements hold pressure and seal the borehole.

Temperature limitations of the ODP drill-string packers

The temperatures to which the drill-string packers can be used are limited by the temperature ratings of the rubber compounds that compose the packer elements and inner seals. Standard nitrile o-rings and elements are rated to about 100°C. Commercially available o-rings made of special elastomers are effective to temperatures as high as 300°C. However, the combination of elasticity, strength, and resetability required of the rubber in the inflation elements is difficult to achieve at high temperatures. Packer elements made with high-temperature rubber compounds will probably be effective to 200-250°C, but only at limited test pressures and limited degrees of expansion (<10-20%), and such elements may last only for single settings. During Leg 111, two special elements rated to 120°C were successfully used at temperatures of 120-145°C in Hole 504B, but lasted for only one setting each.

Compatibility of ODP drill-string packers with logging

All of the standard logging tools will pass through either drillstring packer, unless a packer go-devil is in place. Either packer can be built into a logging BHA, and packer measurements may not require a special pipe trip in addition to the trip necessary for logging. Packer measurements are usually run after the completion of wireline logging, because of the chances of a go-devil getting stuck in the pipe or of rubber from the packer elements stripping off in the hole. Also, the logs are usually important in locating formations in which to set the packer.

In some situations, it may be better for operational reasons to run a separate pipe trip for packer measurements. For example, the packer BHA may require more drill collars than an optimal logging BHA to balance the upward force on pressurizing the zone isolated below the packer. It may be necessary that most or all of the BHA be in the hole below seafloor during logging, and a heavier, longer packer BHA would limit the shallowest depth to which logs could be run. Thus, if it is essential to log the upper 50 m of a reentry hole, separate pipe trips might be required for logging and packer measurements.

Logging or experiments will generally not be permitted through an inflated packer, as this would involve unsafe procedures on the rig floor.

as follows: When the packer is inflated and gripping the borehole wall, the BHA is immobilized, and the drill string must be heave-compensated to avoid tearing the packer loose. With the drill string compensated, the upper end of the pipe will move relative to the heaving rig floor, and it would be very difficult and unsafe to attempt to 'stab' a long logging tool into the end of the pipe. In addition, the compensation of the wireline is not coordinated with the compensation of the drill string, and the risk of coiling or stretching the cable within the pipe might be unacceptable.

C. TAM straddle packer

The design of the TAM straddle packer is quite simple, as it has no rotational capability and is intended primarily for measurements in reentry holes that penetrate stable formations. By assembling it in the BHA with or without a few essential parts, this packer can be used in four resettable modes:

(1) as a single-element packer,
(2) as a double-element (double-seal) single packer,
(3) as a straddle packer,
(4) as a straddle packer allowing the option to separately test the straddled interval or the interval below the packer.

All of these configurations are fully compatible with logging, so that packer measurements will not necessarily require an exclusive pipe trip. (The minimum I.D. of this packer is 3.94" for a single packer configuration or 3.81" for a straddle packer configuration.)

When a straddle configuration is used, the straddle interval can be as small as 1 m, and can be changed by spacing 9-m sections of drill pipe between the elements. Hydraulic continuity is maintained between the elements by connecting them with 3/8"-diameter stainless steel tubing external to the spacing drill pipe. Thus, if either element or the tubing fails to hold pressure, neither element can be inflated. This is a good safety feature, in that once the packers are inflated, a hydraulic failure anywhere in the system will result in the deflation of both elements, not permitting an element to remain locked in an undeflatable position.

Depending respectively on whether a single or a straddle configuration is deployed, the first or both of two go-devils assembled from common parts will be used:

(1) a go devil with 3.99"-diameter seals and stop rings, that seals above the single packer (or the upper straddle element) and keys into the sub-assembly that controls inflation and deflation of the single (or entire straddle) packer;

(2) a go-devil with 3.89"-diameter seals and stop rings that passes through the control sub and seals the drill pipe at the lower straddle packer, allowing the straddled interval to be tested.

Self-contained Kuster pressure recorders are attached to the upper go-devil to record pressures in the isolated section, whether it be between a single packer and the bottom of the hole or between the two inflated elements of the straddle configuration. During operations with the straddle packer, a single pressure recorder can also be hung below the lower go-devil to test for leakage from the straddled interval. In the near future, self-contained electronic pressure recorders that function like the Kuster recorders may be available.

At present neither go-devil can sample formation fluids, but it would be feasible to develop this capability. In fact, J. Cann is presently developing an electronic sampler that functions like a go-devil in controlling packer inflation; this sampler is described briefly in Chapter VI. In addition, it might someday be feasible to configure modules of the LDGO wireline packer in a similar fashion as a sampling go-devil for the straddle packer.

Each go-devil must be retrieved with a standard overshot on the coring line. The use of the single packer configuration is straightforward, requiring just one freefall/retrieval round-trip of a single go-devil. Use of the straddle configuration requires a more complex and time-consuming sequence of go-devil operations: First, the upper go-devil must be dropped to allow inflation of both packers and possibly testing of the zone below the lower packer; second, to test the straddled interval the upper go-devil must be retrieved, the lower go-devil dropped into place, and the upper go-devil dropped a second time; and third, at the end of the experiment, two trips of the coring line are required to retrieve both go-devils.

Inflation of the TAM straddle packer utilizes the drill-string heave compensator, as follows: To enable inflation, the upper go-devil must seal properly in the packer control sub. This assembly incorporates one principal moving part that can shift vertically by about 20 cm, controlling whether or not the inflate/deflate port to the elements is open. This control tube is directly connected to the drill string, and its position is controlled from the rig floor using the sensitive drill-string heave compensator. When the drill string is freely suspended, both the flow paths into the elements and down the pipe/up the annulus are open, so that pressure in the elements must remain the same as in the borehole. Thus, the elements will remain uninflated until the upper go-devil is in place and the rig pumps are used to pressurize the elements. When the elements are fully inflated against the borehole wall, the heave compensator is adjusted to put some weight on the packer, shifting the control tube so that the inflate/deflate ports are closed and the packer elements are locked in the inflated position. Then, after the completion of formation testing, the packers can be deflated simply by pulling up on the drill string at the rig floor, opening the inflate/deflate port whether or not the go-devil is in place.

A shipboard manual contains full schematics and gives detailed instructions for:

(1) assembling the non-rotatable drill-string packer as a single packer or as a straddle packer,
(2) testing the assembled packer before deployment, and
(3) deploying and operating the packer and go-devil(s).

been produced by the ODP engineers responsible for its development. The redesigned TAM rotatable packer has not yet been used, but is scheduled for testing during Leg 124E in early 1989. The ODP manual and this section may be revised after completion of these tests. In particular, after these tests it will be more apparent to what extent the rotatable packer will actually work in a rotating mode, and how well formation fluids can be sampled using the 'probeless PWS' with the packer, as is discussed briefly in Chapter II.

E. Formation testing using ODP drill-string packers

Using a packer, several hydrologic parameters of the formation can be determined in various types of tests that involve controlled pumping of seawater from the rig floor into the isolated interval. In all of these tests, the critical parameter that is actually measured and from which the formation properties are derived is fluid pressure in the isolated section of the borehole. During testing it is also important to measure fluid pressure at the rig floor pumps, as well as the volume and rate at which fluid is pumped into the isolated zone.

On JOIDES Resolution, two powerful pumps are available for inflating the packer and testing the formation: the 'cement' pump and the 'mud' pump. The mud pump is directly controlled at the rig floor by the driller and is more convenient, particularly for setting the packers. The cement pump is controlled below the rig floor and is thus much less convenient, but it may be more appropriate when accurately measured, smaller volumes of higher pressure fluid are required.

Downhole pressure recorders

Downhole pressures can be measured using several kinds of recorders. At present, ODP maintains three self-contained mechanical model K-3 recorders made by Kuster Co. (Figure IV-5, Table IV-1). These are calibrated for three different pressure ranges (0-9950, 0-11,900, and 0-15,275 psi), and can be set to record for 3, 6, or 12 hours. The pressure records are scratched quite accurately onto small coated brass charts. As only one size of chart is produced, some resolution is lost if a longer recording time is chosen; in recent practice, the recorders have been set for 3 or 6 hours. The charts must be read using a calipered, microscopic chart reader, one of which is kept at the University of Miami.

The Kuster K-3 recorders are housed in special carriers that attach to the go-devil that enables inflation of the packer. Normally, two K-3 recorders are attached to the go-devil to provide redundant data in case one recorder malfunctions. In the near future, self-contained electronic pressure recorders will be purchased through the University of Miami. Like the Kuster recorders, these electronic recorders will be housed in special carriers attached to the go-devil. Thus, the electronic recorders will be effectively interchangeable with the Kuster recorders, except that the electronic data will be accessible immediately after the go-devil is retrieved.

K-3(1¼") PRESSURE RECORDER, Part No. 301-

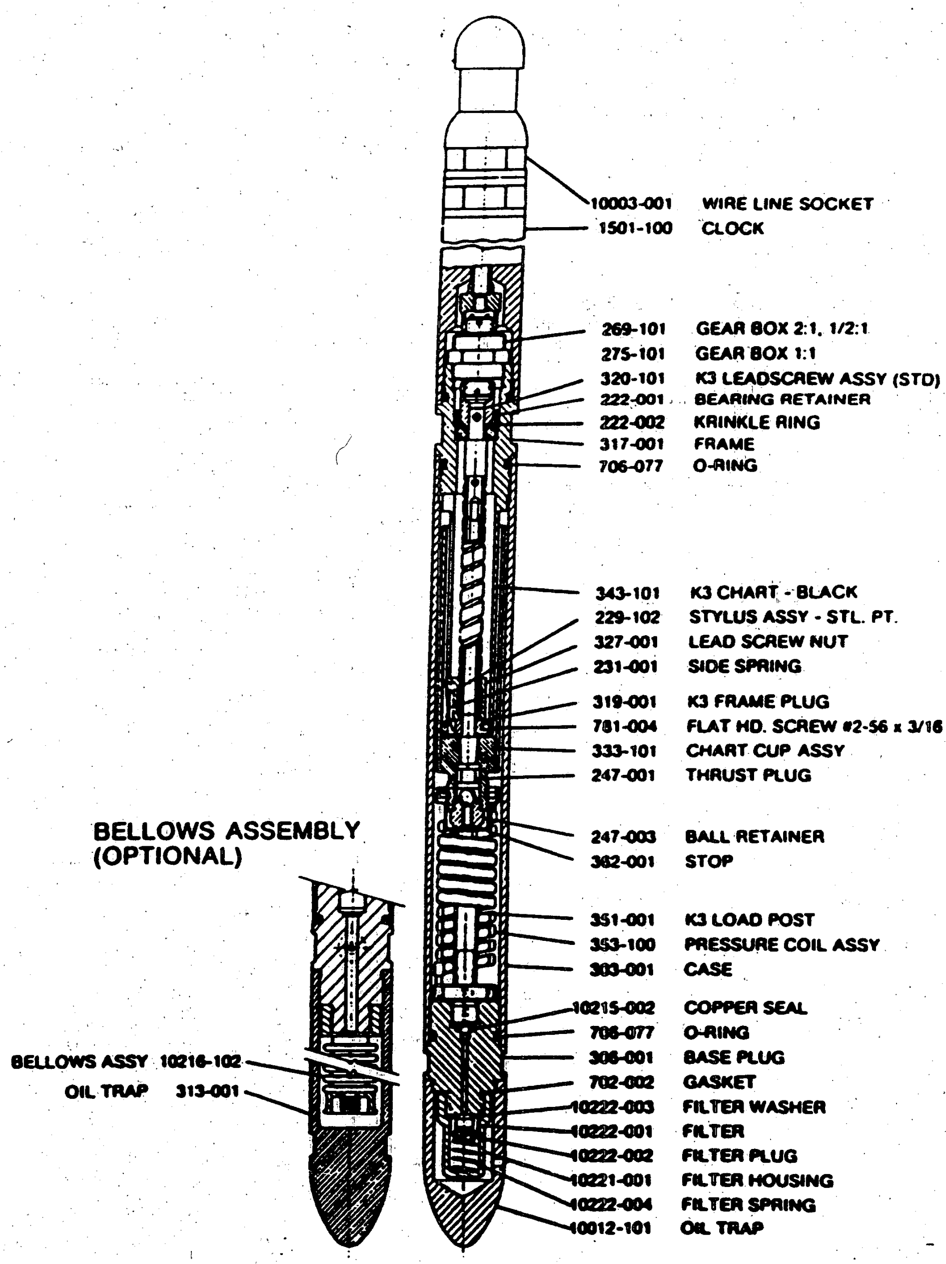


Figure IV-5. Schematic of the Kuster K-3 pressure recorder used to measure pressures in the intervals isolated with the ODP drill-string packers.

Table IV-1. Specifications, Kuster K-3 pressure gauge.

SPECIFICATIONS

	K-2	K-3
Ranges		
Pressure Element	1,000-16,000	1,000-20,000
Temperature Element	32°-700°F. (0°-370°C.) (Limit span to 200°F.)	
Dimensions		
Diameter	1"	1¼"
Length, with filter	39.1"	41.3"
Length, with bellows	44.6"	47.4"
Length, with Temp. Element	51"	53½"
Weight		
Pressure Gauge, pounds	6	9
Temperature Gauge, pounds	6½	9½
Accuracy		
Pressure Recorder	¼ of 1% of range	
Temperature Recorder	± 2°	
Sensitivity	.05%	.04%
Stylus Travel, inches	3	4
Clock Ranges	3, 6, or 12 hours 12, 24 or 48 hours 30, 60 or 120 hours	
Lead Screw Turns	10	12
Chart Size	2¼"x3⅝" 57.2 mm x 92 mm	2⅝"x4⅞" 66.7 mm x 124 mm

Pressures measured during formation testing

In testing the formation using a packer, it is important to carefully control the packer inflation pressure. This is defined as the pressure (relative to hydrostatic) at which fluid is pumped into the packer element(s) when it is inflated and is measured at the rig floor pumps during inflation. The inflation pressure must be carefully chosen, based on anticipated hole conditions and formation properties, and on the planned test pressures. Given good hole conditions, the elements should be inflated to about 500-1000 psi, or to roughly half the planned test pressures if higher pressures are planned. If the inflation pressure is improperly chosen (either too high or too low), a 'leaky' packer seal may result, which will certainly affect any measurements but will not necessarily be recognizable in the pressure data. In addition, care must be taken not to inflate the element(s) to a pressure high enough to actually fracture the formation and thereby invalidate any testing. This upper limit on inflation pressure will depend on the lithostatic pressure and strength of the formation.

It is critical to measure and distinguish three different pressure values in the isolated section of the borehole: hydrostatic pressure, <u>in situ</u> pore pressure, and test pressures. This necessity dictates the overall sequence in the testing procedure at each isolated zone:

(1) Hydrostatic pressure must be measured first, before the packer is inflated, both to check the recorder calibrations and to provide a reference baseline to compare the measurements of <u>in situ</u> pore pressure and test pressures. The hydrostatic pressure baseline is usually obtained by waiting 10-20 minutes after the go-devil lands in the packer, before pressuring up to inflate the packer.

(2) When the packer is inflated, fluid pressure in the isolated section of the borehole will slowly approach <u>in situ</u> pore pressure of the formation, which may differ from hydrostatic pressure. If it is critical to determine pore pressure, as much as 2-3 hours of passive recording may be required before active testing to provide sufficient pressure data to accurately extrapolate to <u>in situ</u> pressure.

(3) In active testing, permeability can be estimated from the transient behavior of pressure in the borehole in response to controlled pumping from the rig floor through the go-devil and into the formation. Two principal kinds of tests have been used in previous DSDP/ODP permeability measurements, pulse or 'slug' tests and constant-rate injection tests, which are described in detail below.

Active formation testing

The permeability of a formation that is isolated by a packer can be determined by any number of methods. The simplest and most direct of these are pulse tests and constant-rate injection tests, both of which involve applying controlled fluid pressure to the isolated zone using the rig floor pumps. Figure IV-6 reproduces a Kuster pressure record from Leg 118 that illustrates both kinds of tests.

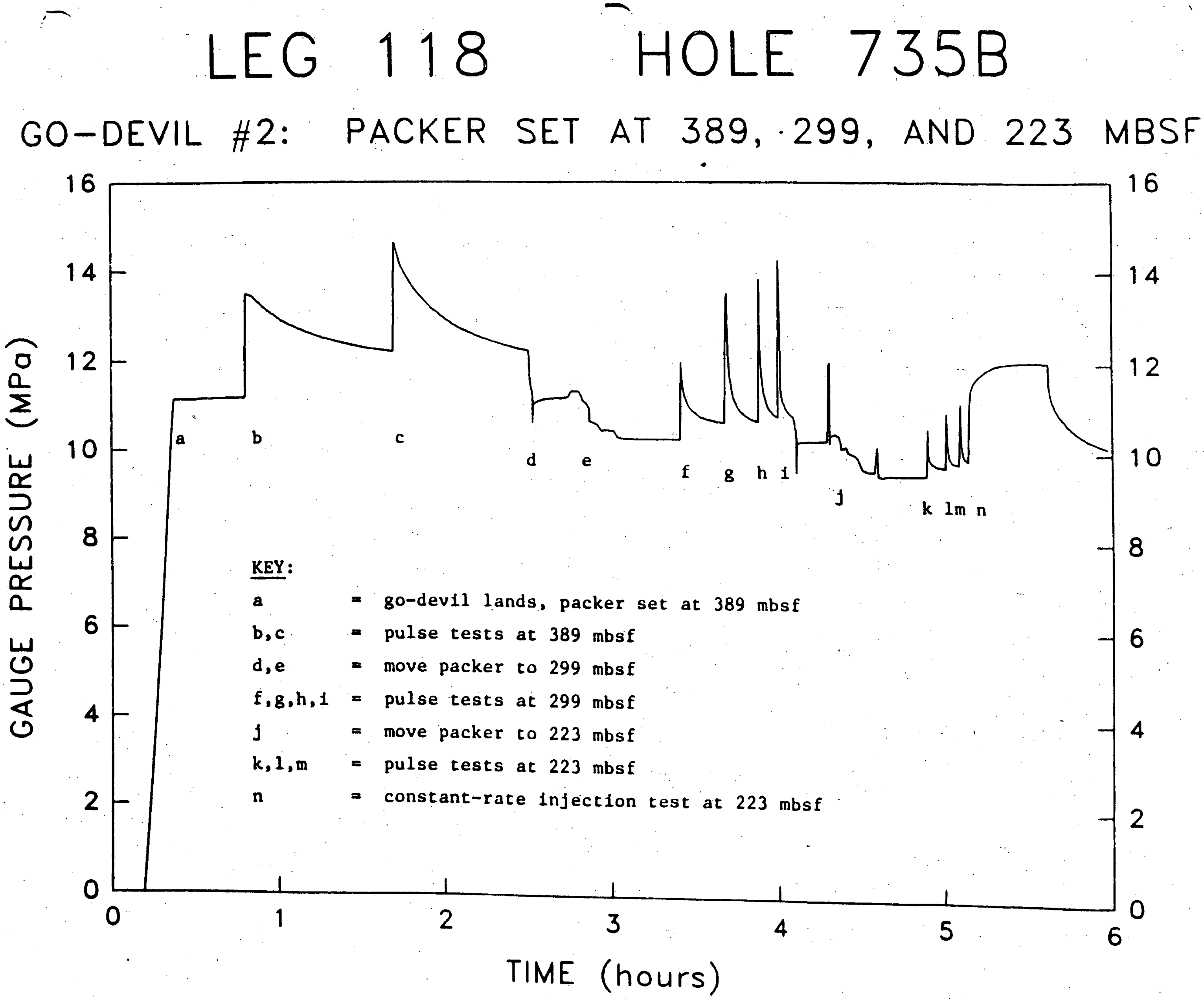


Figure IV-6. Actual pressure data collected with the Kuster K-3 recorder during Leg 118 operations using the non-rotatable drill-string packer as a single packer, showing good examples of both pulse tests and constant-- injection tests.

In a pulse test, the downhole recorders monitor the decay of a short, effectively instantaneous pressure pulse applied by the rig floor pumps. In a relatively impermeable formation, the decay of such a pulse will be long compared to the duration of the pulse, and the pressure data can be treated with the theory for an instantaneous pulse (Cooper et al., 1967; Papadopulos et al., 1973; Bredehoeft and Papadopulos, 1980). The decay of an instantaneous pulse is described by a complicated integral involving two dimensionless parameters, which depend respectively on 'transmissivity' (a function of permeability) and 'storage coefficient' (a function of porosity). Fitting pulse test pressure data to this function generally resolves transmissivity much better than storage coefficient, yielding estimates of permeability but not necessarily of porosity.

In a relatively permeable formation, a pressure pulse will decay too rapidly to allow resolution of transmissivity, and constant-rate injection tests are appropriate. These involve pumping into the formation from the rig floor at a known constant rate, and monitoring the approach of the downhole pressure to a nearly steady-state value. The transmissivity and permeability can be estimated using the theory for a constant line-sink with a Darcy's Law boundary condition (e.g., Matthews and Russell, 1967; Snow, 1968). In practice, it may take upwards of an hour of constant-rate injection for quasi-steady-state to be reached, and permeability is usually estimated from the results of several injection tests at different rates.

Formation tests, particularly pulse tests, may be more effective if the isolated formation is 'shut-in' downhole, i.e., if the fluids in the tested interval are kept isolated from the fluids in the borehole above the test interval. Downhole shut-in can be achieved using a one-way valve in the go-devil that will allow pumping into the isolated formation but will not allow pressure to transmit up the drill string once pumping is stopped. If the isolated zone is shut in, the downhole pressure data may provide more accurate estimates of formation properties, but the pressures measured at the rig floor will reveal nothing about the downhole testing. If the test interval is not shut in, downhole conditions can be monitored by measuring pressure and flow rate at the rig floor, but the downhole pressure data must be corrected for the properties of the entire pressurized column of fluid in the borehole, and larger errors are likely in calculating permeabilities. Downhole shut-in has not been attempted in ODP packer work to date, partly because of go-devil complications, but mostly because it has been deemed important to monitor downhole conditions and events in real time with the rig floor gauges and recorders.

In oceanic sediments and crust, the ranges of permeability over which pulse tests and constant-rate injection tests yield reasonable permeability estimates overlap, and it is often not possible to determine before testing which type of test will be more appropriate. As injection tests disturb the pressure field in the isolated formation to a greater degree than pulse tests, it is advisable to attempt pulse tests before injection tests. If several pulse and/or injection tests are to be attempted in a single formation, the pressurized system should not be allowed to 'flow back' between tests, and the pressure should be allowed to decay naturally as much as possible between tests. If the hole is kept 'shut in' (at the wellhead or downhole), the effects of the individual tests will be superimposed in a straightforward manner, and it will be possible to correct for the effects of previous tests.

The programs of testing will vary from hole to hole, depending on the formation permeability. Further guidance can be gleaned from several good examples: the work done during DSDP in Hole 395A by Hickman et al. (1984) and in Hole 504B by Anderson and Zoback (1982) and Anderson et al. (1985), and the measurements made during ODP Legs 109, 111, and 118 in Holes 395A, 504B, and 735B by Becker et al. (in preparation). (For the ODP work, see also relevant sections in Detrick, Honnorez, Bryan, Juteau, et al., 1988; Becker, Sakai, et al., 1988; and Robinson, Von Herzen, et al., in press.)

V. "MULTISHOT" CORE ORIENTATION TOOL

ODP operates an Eastman-Christensen magnetic multishot camera to measure orientation of non-rotary cores taken with the advanced hydraulic piston corer (APC). This tool provides a photographic record of a magnetic reference azimuth, the deviation of the core from vertical determined with a pendulum, and the magnetically determined azimuth of that deviation. The multishot continuously records images of its compass/pendulum 'angle unit' on 10-mm movie film at pre-selected intervals. As with other tools used with the APC, the use of the multishot tool is limited to depths at which the force required on pullout is within safe limits, typically 100-200 mbsf.

To fully utilize the magnetic orientation capabilities of the multishot tool, a special 30' non-magnetic drill collar must be included in the BHA just above the lowermost drill collar (also known as the outer core barrel). Therefore the decision to obtain oriented piston cores at a given site must be made before the BHA is made up and the pipe is run into the hole. The multishot camera is housed in a non-magnetic pressure case that is installed between two non-magnetic sinker bars in the assembly used to connect the coring line to the APC core barrel. When coring commences, handling the multishot will add 10-15 minutes per core to normal coring times.

The ODP downhole tools technician is responsible for all phases of operating the multishot tool, including tool preparation for each core, removing and developing the film after the run, interpreting the film record, and recording the relative azimuth angle, deviation from vertical, and direction of deviation on special envelopes in which the developed film is stored. The azimuth orientation angle is recorded as the clockwise angle (when looking down) between magnetic north and the double lines drawn on the core liner. The physical alignment between the double line on the core liner and the reference 'lubber' line that is superimposed over the compass image on the multishot pictures is accomplished using a series of mechanical devices built into the equipment. The total error in the azimuth orientation reading introduced by these mechanical devices should not exceed 3^{o}.

Even if the non-magnetic drill collar is not installed in the BHA, the multishot can be used to measure the deviation from vertical without any determination of orientation, also known as 'drift' of the hole. The multishot angle unit determines the verticality using a pendulum suspended over a bulls-eye. The amount of drift can be read from the developed film, although the azimuth of deviation from vertical is meaningless when the multishot tool is used in the presence of a magnetic drill collar.

VI. TOOLS DEVELOPED AND/OR OPERATED BY THIRD PARTIES

Many of the ODP tools described in this manual were first developed by independent scientists and then turned over to DSDP/ODP for routine use. Similarly, several advanced tools are presently under development by 'third-party' investigators, independently of but with the cooperation of ODP and/or LDGO, and may someday be available for routine ODP use. The scientists developing these tools are fully responsible for all aspects of their operation, until such time as the tools are proven for routine use and ODP or LDGO assumes responsibility for maintaining and deploying them.

The ODP policies for assisting in tool development and for assumption of responsibility for a proven tool are described in this chapter. In late 1987, PCOM became concerned that certain future legs depend heavily on the development of particular tools and/or experiments, and instructed DMP to actively monitor the development of these tools. ODP had adopted procedures for dealing with 'third-party tools' in mid-1987, and DMP suggested a policy that was consistent with these guidelines, but that applied to both new downhole tools for ODP and new logging tools for LDGO. The essence of this policy is as follows (subject to revision by DMP and PCOM):

DMP categorized two types of tools--instruments under development and established tools—and suggested procedures to be followed during development and during transfer of established tools to ODP (or LDGO). Even before DMP begins to monitor a tool under development, an investigator should contact ODP regarding preliminary ideas for a new tool. The primary initial contact is ODP's Manager of Development Engineering and Drilling Operations, who will advise the investigator on design feasibility and compatibility with existing ODP systems, and will refer the investigator to other key ODP personnel with relevant input.

A. Policies for tools under development

It is the responsibility of the investigator to obtain funding for the development of a new tool, and to obtain DMP endorsement and PCOM approval of the ship time required to develop and deploy the tool. For DMP to monitor a tool under development or to consider endorsing deployment on JOIDES Resolution, the principal investigator should prepare a development plan, in consultation with ODP and DMP. This development plan should:

- justify the acceptance, desirability, and usefulness of the measurement,
- identify development milestones,
- make provison for land testing,
- satisfy safety considerations,
- specify shipboard requirements such as data processing, technical support, and special facilities, and
- confirm that the tool will be available for ODP use after development, with endorsement by the funding agency if title and responsibility for the tool are to be transferred to ODP.

If DMP endorses the proposed plan, DMP will review progress at regular intervals and will evaluate tool performance after each deployment. ODP will work closely with the principal investigator on the development of an approved tool. The ODP effort will be coordinated by an engineer in the

Engineering Department, and will also involve periodic review and input from key personnel in the Science Operations and Science Services departments.

B. Policies for transfer of established tools to ODP

Once a third-party tool has been developed, tested, and successfully deployed from JOIDES Resolution, the investigator may either retain control of maintenance and future deployments of the tool, or transfer responsibility for routine maintenance and operations to ODP (or LDGO, if appropriate). If the investigator elects to retain control of the tool, he/she then assumes full responsibility for obtaining funding, DMP and PCOM endorsement of all scheduled deployments, and invitations from ODP for the participation of necessary shipboard personnel. If the investigator wants ODP to assume responsibility for the tool, formal approval is required from ODP, DMP, and PCOM. This approval will be based on the following criteria:

- The tool is in demand for use on future ODP cruises.
- The nature and quality of the data produced are a valuable addition to the ODP database.
- Deployment of the tool is safe and truly routine, i.e., the rig floor crew and marine technicians are fully trained in running the tool and recovering the data.
- ODP can afford to operate the tool, in terms of both funds required for supplies and maintenance, and time required of the technical staff.
- The independent investigator has provided ODP with (a) a full manual for operations and maintenance, including design drawings, (b) complete information regarding sources, costs, and time required to obtain replacement parts and supplies, and (c) full documentation of the processing that must be applied to the data and/or samples collected.
- Approval of the pertinent funding agencies.

If a third-party tool has been developed and tested, but has not yet met the above criteria for transfer of responsibility to ODP, then shipboard scientists or site proponents who wish to use the tool on a given leg must make arrangements with the third-party investigator. Such arrangements will require endorsement by DMP and PCOM, and ODP must be kept fully informed because shipboard operations, time estimates, shipping requirements, etc., will be affected. In such a case, it should not be assumed that ODP will automatically provide the technical support and supplies for the third-party tool, and these responsibilities should be clarified at the pre-cruise meeting.

C. Third-party tools presently under development

Several new tools are presently under development by independent investigators, with varying degrees of documentation. When PCOM formalizes (in mid-1988) the DMP criteria for tools under development, more uniform documentation will become available. If more information is desired than is provided in the following brief descriptions, the independent investigators should be contacted directly.

Geoprops probe (D. Karig and E. Taylor)

The Geoprops probe is essentially a miniature, instrumented straddle packer, to be deployed on the coring line into a 4"-diameter hole cored up to 4 m ahead of the bit with the Navi-Drill. The tool is to be equipped with sensors to measure temperature, pore pressure, and permeability, to sample pore fluids, and to map borehole breakouts. Efforts to develop this tool have been prompted by the difficulties experienced in attempting to measure important hydrogeologic parameters in unstable formations in subduction zone complexes, but the tool will be applicable in many other situations. A feasibility study was completed in early 1988, and a proposal was submitted to NSF for development of a tool in time for Leg 129 drilling in the Nankai Trough.

APC lateral stress tool (K. Moran, Canada)

The lateral stress tool (LAST-I) will include sensors to measure anisotropic horizontal stress, pore fluid pressure, and temperature in situ, in conjuction with the APC. The instrumentation will be incorporated into the present APC shoe, with a special, reverse cutting edge to minimize sediment disturbance on the outside of the shoe. The LAST-I is the first phase of a two-phase program to develop ODP instrumentation to measure in situ stress and deformational properties in sediments; in the second phase a self-boring pressuremeter will be developed. The LAST-I is scheduled for non-ODP sea trials in 1988, and is intended for ODP use during Leg 129 drilling in the Nankai Trough.

APC pore water sampler (R. Barnes)

In 1987, Dr. R. Barnes was developing a small-volume fluid sampler intended to be inserted in the cutting shoe of the APC and to sample pore fluids as an APC core is taken, similar in operation to the APC T tool. A prototype of this tool was not quite ready for testing scheduled for Leg 117, and further development has proceeded slowly since then.

Pressure core sampler (ODP)

ODP expects to complete development of a new pressure core sampler (PCS) in 1988 and test the unit during Leg 124 or 124E. This tool will be freefallen into position and hydraulically actuated to recover a pressurized sample. Figure VI-1 illustrates the conceptual design for the detachable pressurized sample chamber, which is rated for a 10,000-psi working pressure. The first version of the PCS will recover a pressurized sample 1-9/16" in diameter and 32" long, and will allow for subsampling of the gases and interstitial water before decompressing the sample. ODP will supply subsampling manifolds, designed to fulfill the requirements of the scientific community. Any input or inquiries for further information should be directed to T. Pettigrew, the ODP Development Engineer responsible for design and testing of the PCS.

Sampler go-devil for drill-string straddle packer (J. Cann, U.K.)

J. Cann is presently developing an electronic sampler that functions like a go-devil in controlling packer inflation, and incorporates

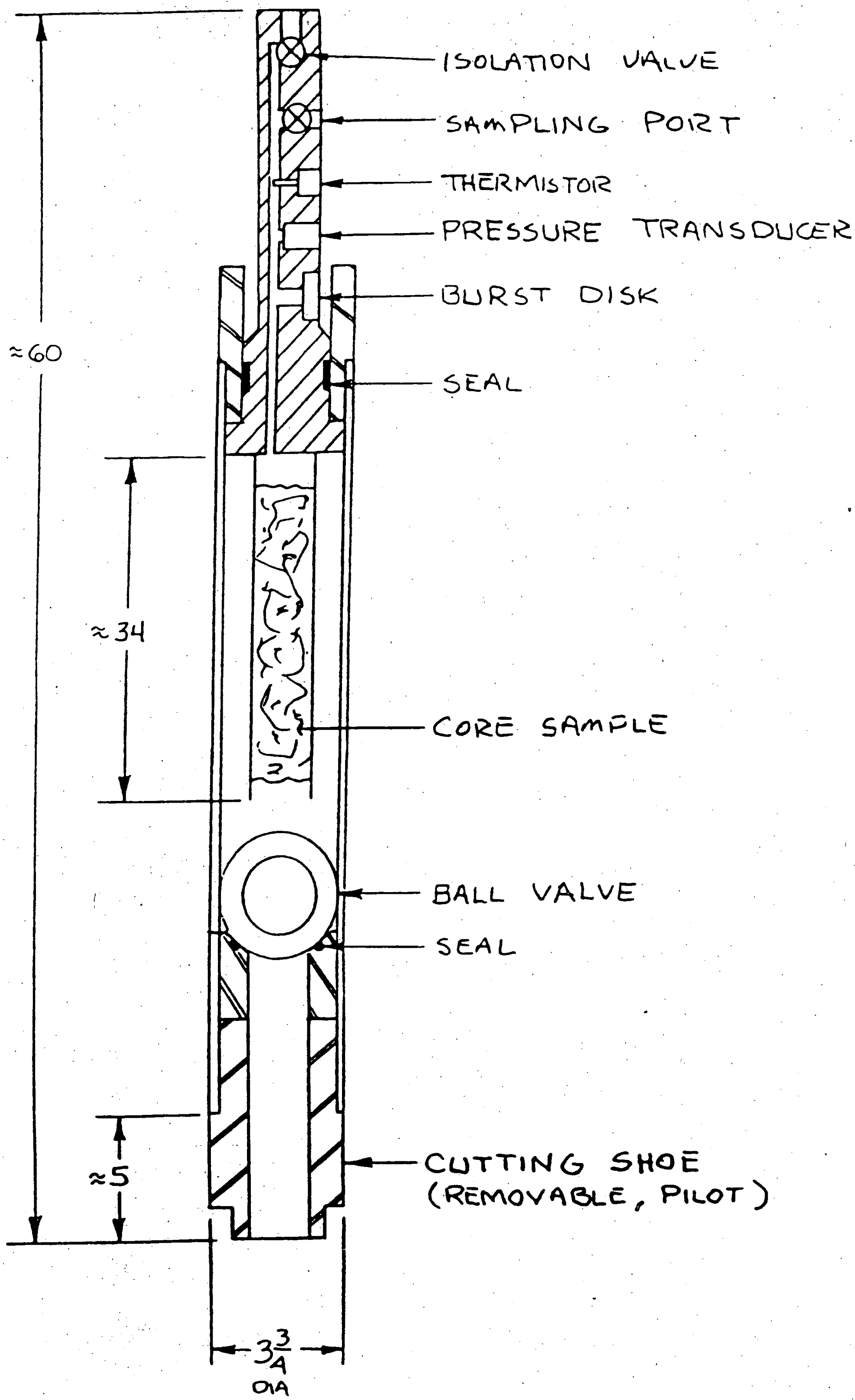


Figure VI-1. Conceptual schematic for the new ODP pressure core sampler.

electrodes for feedback regarding the in situ composition of pore fluids to be sampled. The sampler will probably include sensors to measure temperature, pressure, pH, eH, and concentrations of various ions. The problems discussed in Chapter IV regarding use of tools on the logging cable in an inflated packer will probably require that this tool be developed as a battery-powered, downhole-recording unit that does not allow real-time feedback to the rig floor as to sample composition. This tool is intended to be tested in 1989.

REFERENCES

Anderson, R.N. and Zoback, M.D., 1982. Permeability, underpressures, and convection in the oceanic crust near the Costa Rica Rift, eastern equatorial Pacific. J. Geophys. Res., 87:2860-2868.

Anderson, R.N., Zoback, M.D., Hickman, S.H., and Newmark, R.L., 1985. Permeability versus depth in the upper oceanic crust: in situ measurements in DSDP Hole 504B, eastern equatorial Pacific. J. Geophys. Res., 90:3659-3669.

Barnes, R., 1979. Operation of the IPOD in situ water sampler. In Sibuet, J.-C., Ryan, W.B.F., et al., Init. Repts. DSDP, 47B: Washington (U.S. Govt. Printing Office), 19-22.

Barnes, R., 1988. ODP in situ fluid sampling and measurement: a new wireline tool. In Mascle, A., Moore, J.C., et al., Proc. ODP, Init. Repts., 110: College Station, TX (Ocean Driling Program), 55-63.

Becker, K., 1986. Special report: development and use of Packer in ODP. JOIDES Journal, 12(2):51-57.

Becker, K., Langseth, M.G., and Von Herzen, R.P., 1983a. Deep crustal geothermal measurements, Hole 504B, Deep Sea Drilling Project Legs 69 and 70. In Cann, J.R., Langseth, M.G., Honnorez, J., Von Herzen, R.P., White, S.M., et al., Init. Repts. DSDP, 69: Washington (U.S. Govt. Printing Office), 223-235.

Becker, K., Langseth, M.G., Von Herzen, R.P., and Anderson, R.N., 1983b. Deep crustal geothermal measurements, Hole 504B, Costa Rica Rift. J. Geophys. Res., 88:3447-3457.

Becker, K., Langseth, M.G., Von Herzen, R.P., Anderson, R.N., and Hobart, M.A., 1985. Deep crustal geothermal measurements, Hole 504B, Deep Sea Drilling Project Legs 69, 70, 83, and 92. In Anderson, R.N., Honnorez, J., Becker, K., et al., Init. Repts. DSDP, 83: Washington (U.S. Govt. Printing Office), 405-418.

Becker, K., Sakai, H., et al., 1988. Proc. ODP, Init. Repts., 111: College Station, TX (Ocean Drilling Program).

Bredehoeft, J.D., and Papadopulos, S., 1980. A method for determining the hydraulic properties of tight formations. Water Resources Res., 16:233-238.

Bullard, E.C., 1947. The time necessary for a bore hole to attain temperature equilibrium. Monthly Notices Roy. Astron. Soc., Geophys. Suppl., 5:127-130.

Bullard, E.C., 1954. The flow of heat through the floor of the Atlantic Ocean. Proc. R. Soc. London, A 222:408-429.

Cooper, H.H., Bredehoeft, J.D., and Papadopulos, I.S., 1967. Response of a finite-diameter well to an instantaneous charge of water. Water Resources Res., 3:263-269.

Detrick, R., Honnorez, J., Bryan, W.B., Juteau, T., et al., 1988. Site 395. In Bryan, W.B., Detrick, R., Juteau, T., Honnorez, J., Adamson, A.C., et al., Proc. ODP, Init. Repts., 106/109: College Station, TX (Ocean Drilling Program), 175-202.

Erickson, A.J., Von Herzen, R.P., Sclater, J.G., Girdler, R.W., Marshall, B.V., and Hyndman, R., 1975. Geothermal measurements in deep-sea drill holes. J. Geophys. Res., 80:2515-2528.

Gieskes, J.M., Kastner, M., Erzinger, J., Boulegue, J., and Hart, S.R., 1986. Geochemical studies in Hole 504B, Leg 92. In Leinen, M., Rea, D.K., et al., Init. Repts. DSDP, 92: Washington (U.S. Govt. Printing Office), 547-562.

Hickman, S.H., Langseth, M.G., and Svitek, J.F., 1984. In situ permeability and pore-pressure measurements near the Mid-Atlantic Ridge, Deep Sea Drilling Project Hole 395A. In Hyndman, R.D., Salisbury, M.H., et al., Init. Repts. DSDP, 78B: Washington (U.S. Govt. Printing Office), 699-708.

Horai, K., and Von Herzen, R.P., 1985. Measurement of heat flow on Leg 86 of the Deep Sea Drilling Project. In Heath, G.R., Burckle, L.H., et al., Init. Repts. DSDP, 86: Washington (U.S. Govt. Printing Office), 759-777.

Hyndman, R.D., Davis, E.E., and Wright, J.A., 1979. The measurement of marine geothermal heat flow by a multipenetration probe with digital acoustic telemetry and in situ thermal conductivity. Mar. Geophys. Res., 4:181-215.

Hyndman, R.D., Langseth, M.G., and Von Herzen, R.P., 1987. Deep Sea Drilling Project geothermal measurements: a review. Rev. Geophys., 25:1563-1582.

Jaeger, J.C., 1956. Conduction of heat in an infinite region bounded internally by a circular cylinder of a perfect conductor. Austr. J. Phys., 9:167-179.

Jaeger, J.C., 1961. The effect of the drilling fluid on temperatures measured in bore holes. J. Geophys. Res., 66:563-569.

Koehler, R. and Von Herzen, R.P., 1986. A Miniature Deep Sea Temperature Data Recorder: Design, Construction, and Use: Tech. Rept. WHOI-86-3, Woods Hole Oceanogr. Inst.

Leinen, M., Rea, D.K., et al., 1986. Site 504. In Leinen, M., Rea, D.K., et al., Init. Repts. DSDP, 92: Washington (U.S. Govt. Printing Office), 187-214.

Lister, C.R.B., 1979. The pulse-probe method of conductivity measurement. Geophys. J. R. Astron. Soc., 57:451-461.

Matthews, C.S. and Russell, D.G., 1967. Pressure Buildup and Flow Tests in Wells. Soc. Pet. Eng. AIME Monogr., 1.

Mottl, M.J., Anderson, R.N., Jenkins, W.J., and Lawrence, J.R., 1983. Chemistry of waters sampled from basaltic basement in Deep Sea Drilling Project Holes 501, 504B, and 505B. In Cann, J.R., Langseth, M.G., Honnorez, J., Von Herzen, R.P., White, S.M., et al., Init. Repts. DSDP, 69: Washington (U.S. Govt. Printing Office), 475-483.

Mottl, M.J., Druffel, E.R.M., Hart, S.R., Lawrence, J.R., and Saltzman, E.S., 1985. Chemistry of hot waters sampled from basaltic basement in Hole 504B, Deep Sea Drilling Project Leg 83, Costa Rica Rift. In Anderson, R.N., Honnorez, J., Becker, K., et al., Init. Repts. DSDP, 83: Washington (U.S. Govt. Printing Office), 315-328.

Papadopulos, S.S., Bredehoeft, J.D., and Cooper, H.H., 1973. On the analysis of "slug test" data. Water Resources Res., 9:1087-1089.

Robinson, P., Von Herzen, R.P., et al., in press. Proc. ODP, Init. Repts., 118.

Salisbury, M. H., Scott, J. H., et al., 1986. Proc. ODP, Init. Repts., 102: College Station, TX (Ocean Drilling Program).

Snow, D.T., 1968. Rock fracture spacing, openings and porosities. J. Soil Mech. Found. Div., ASCE Proc., 94.

Uyeda, S., and Horai, K., 1982. Heat flow measurements on Deep Sea Drilling Project Leg 60. In Hussong, D., Uyeda, S., et al., Init. Repts. DSDP, 60: Washington (U.S. Govt. Printing Office), 789-800.

Von Herzen, R.P., and Maxwell, A.E., 1964. Measurements of heat flow at the preliminary Mohole site off Mexico. J. Geophys. Res., 69:741-748.

von Huene, R., 1985. Direct measurement of pore fluid pressure, Leg 84, Guatemala and Costa Rica. In von Huene, R., Aubouin, J., et al., Init. Repts. DSDP, 84: Washington (U.S. Govt. Printing Office), 767-772.

Worthington, P., Anderson, R.N., Bell, J.S., Becker, K., Jarrard, R.D., Salisbury, M.H., and Stephen, R.A., 1987. Downhole measurements for the Ocean Drilling Programme. In Report of the Second Conference on Scientific Ocean Drilling (COSOD II): Strasbourg (Eur. Sci. Found., 131-136.

Yokota, T., Kinoshita, H., and Uyeda, S., 1980. New DSDP (Deep Sea Drilling Project) downhole temperature probe utilizing IC RAM (memory) elements. Earthquake Res. Inst. Tokyo Bull., 55:75-88.

ODP DOWNHOLE TOOL
DATA SHEET

Channel	Measuring	Filename
0	______	______________________
1	______	______________________
2	______	______________________
3	______	______________________
4	______	______________________
5	______	______________________

LEG	SUB	SITE	HOLE

DATE	OBSERVER

HF ____ PW ____ P ____

Recording interval______________
HF & Pressure Delay Time____min
PW Delay Time____min
PW Sample Time______min
Water Depth_____meters
Subbottom Depth_____meters
Probe Depth______meters

Probe Length_____cm
Thermistor #______________
Recorder Package #__________
Sea State______________
Last Core #______________
Overpull Pressure_____x 10^3 lbs

DELAY		OPERATIONS	REMARKS
00 Min	00 Sec	On Deck Turn-on Time	Local Time ____________
____	____	Start Down Pipe	
____	____	Start Pumping	Strokes/minute ________
____	____	Stop Pumping	
____	____	At Mudline	Stay_____min
____	____	Start Down	
____	____	Check for Latch-in	
____	____	Lowering to Bottom	
____	____	On Bottom	Stay_____min
____	____	Heave Comp On	
____	____	Heave Comp Off	
____	____	Bit off Bottom	
____	____	At Mudline	Stay_____min
____	____	Start Up	
____	____	On Deck	
____	____	Instrument Off	

Distance of Bit Off Bottom____m. Weight on Bit____x 10^3 lbs
Wt. on Bit: Steady?____Variable?____Increasing?____Decreasing?____
Total water filtered______ml Cu coil colume_____ml
Stainless coil volume____ml

Comments:

FM5000 These data are to be processed into a computerized data base along with existing standardized data from other legs and will be accessible to the scientific community at large. RECORD ALL MEASUREMENTS CAREFULLY, COMPLETELY, AND LEGIBLY.

REV. 9/86

LEG	SUB	SITE	HOLE

DATE	OBSERVER

ODP
DOWNHOLE TOOL DATA SHEET

HF ☐ PW ☐ P ☐ HPC/HF ☐

RECORDING INTERVAL 1 OR 2 MIN

PROBE ____________

PW DELAY TIME ____________ MIN

THERMISTOR ____________

PW SAMPLE LENGTH ____________ MIN

HPC/HF RECORDER # ____________

SUBBOTTOM DEPTH ____________ M

WATER DEPTH ____________

SEA STATE ____________

LOWERING TYPE, WIRELINE ____________ OR FREE FALL ____________

DELAY		OPERATIONS	REMARKS
___ MIN	___ SEC	ON DECK TURN ON TIME	LOCAL TIME ____________
___	___	START DOWN PIPE	
___	___	START PUMPING	STROKES/MIN ____________
___	___	STOP PUMPING	
___	___	AT MUDLINE	STAY ____________ MIN
___	___	START DOWN	
___	___	CHECK FOR LATCH-IN	
___	___	LOWERING TO BOTTOM	
___	___	ON BOTTOM	STAY ____________ MIN
___	___	HEAVE COMP ON	
___	___	HEAVE COMP OFF	
___	___	BIT OFF BOTTOM	
___	___	AT MUDLINE	STAY ____________ MIN
___	___	START UP	
___	___	ON DECK	HPC/HF SHOT TIME ____________ MIN
___	___	INSTRUMENT OFF	

WT ON BIT ____________ x 10^3 lbs

STEADY ____________

VARIABLE ____________ INCREASING ____________ DECREASING ____________

APPENDIX B. CONTENTS OF "SELECTED REPRINTS FOR ODP DOWNHOLE MEASUREMENTS"
(shelved in Logging section, shipboard library)

A. Theory of heat conduction

(See Carslaw, H.S. and Jaeger, J.C., 1959. Conduction of Heat in Solids. (2nd ed.): London (Oxford Univ. Press), available in shipboard library)

(1) Jaeger, J.C., 1965. Application of the theory of heat conduction to geothermal measurements. In Lee, W.H.K. (Ed.), Terrestrial Heat Flow. Am. Geophys. Union Monogr., 8:7-23.

B. Approach of a cylindrical probe to in situ temperature

(2) Bullard, E. C., 1954. The flow of heat through the floor of the Atlantic Ocean. Proc. R. Soc. London, A222:408-429.

(3) Table of Bullard's F(2,tau), calculated by Lister, C.R.B., 1979. The pulse-probe method of conductivity measurement. Geophys. J. R. Astr. Soc., 57:451-461.

(4) Hyndman, R.D., Davis, E.E., and Wright, J.A., 1979. The measurement of marine geothermal heat flow by a multipenetration probe with digital acoustic telemetry and insitu thermal conductivity. Mar. Geophys. Res., 4:181-215.

C. Approach of the APC shoe to in situ temperature

(5) Horai, K., unpublished manuscript. A theory of processing down-hole temperature data taken by the hydraulic piston corer (HPC) of the DSDP.

(6) Horai, K., and Von Herzen, R.P., 1985. Measurement of heat flow on Leg 86 of the Deep Sea Drilling Project. In Heath, G.R., Burckle, L.H., et al., Init. Repts. DSDP, 86: Washington (U.S. Govt. Printing Office), 759-777.

D. Thermal conductivity measurements

(7) Jaeger, J.C., 1958. The measurement of thermal conductivity and diffusivity with cylindrical probes. Trans. Am. Geophys. Union, 39:708-710.

(8) Von Herzen, R.P. and Maxwell, A.E., 1959. The measurement of thermal conductivity of deep-sea sediments by a needle-probe method. J. Geophys. Res., 64:1557-1563.

E. Borehole temperatures -- theory

(9) Bullard, E.C., 1947. The time necessary for a bore hole to attain temperature equilibrium. Monthly Notices R. Astron. Soc., Geophys. Suppl., 5:127-130.

(10) Jaeger, J.C., 1961. The effect of the drilling fluid on temperatures measured in bore holes. J. Geophys. Res., 66:563-569.

(11) Lesem, L.B., Greytok, F., Marotta, F., and McKetta, J.J., 1957. A method of calculating the distribution of temperature in flowing gas wells. Pet. Trans. AIME, 210:169-176.

F. Borehole temperatures -- DSDP review and examples

(12) Erickson, A.J., Von Herzen, R.P., Sclater, J.G., Girdler, R.W., Marshall, B.V., and Hyndman, R., 1975. Geothermal measurements in deep-sea drill holes. J. Geophys. Res., 80:2515-2528.

(13) Hyndman, R.D., Langseth, M.G., and Von Herzen, R.P., 1987. Deep Sea Drilling Project geothermal measurements: a review. Rev. Geophys., 25:1563-1582.

(14) Becker, K., Langseth, M.G., and Von Herzen, R.P., 1983. Deep crustal geothermal measurements, Hole 504B, Deep Sea Drilling Project Legs 69 and 70. In Cann, J.R., Langseth, M.G., Honnorez, J., Von Herzen, R.P., White, S.M., et al., Init. Repts. DSDP, 69: Washington (U.S. Govt. Printing Office), 223-235.

(15) Becker, K., Langseth, M.G., Von Herzen, R.P., and Anderson, R.N., 1983. Deep crustal geothermal measurements, Hole 504B, Costa Rica Rift. J. Geophys. Res., 88:3447-3457.

(16) Becker, K., Langseth, M.G., Von Herzen, R.P., Anderson, R.N., and Hobart, M.A., 1985. Deep crustal geothermal measurements, Hole 504B, Deep Sea Drilling Project Legs 69, 70, 83, and 92. In Anderson, R.N., Honnorez, J., Becker, K., et al., Init. Repts. DSDP, 83: Washington (U.S. Govt. Printing Office), 405-418.

(17) Becker, K., Langseth, M.G., and Hyndman, R.D., 1984. Temperature measurements in Hole 395A, Leg 78B. In Hyndman, R.D., Salisbury, M.H., et al., Init. Repts. DSDP, 78B: Washington (U.S. Govt. Printing Office), 689-698.

G. Permeability measurements and hydrofracture -- theory

(18) Cooper, H.H., Bredehoeft, J.D., and Papadopulos, I.S., 1967. Response of a finite-diameter well to an instantaneous charge of water. Water Resources Res., 3:263-269.

(19) Papadopulos, S.S., Bredehoeft, J.D., and Cooper, H.H., 1973. On the analysis of "slug test" data. Water Resources Res., 9:1087-1089.

(20) Bredehoeft, J.D., and Papadopulos, S.S., 1980. A method for determining the hydraulic properties of tight formations. Water Resources Res., 16:233-238.

(21) Neuzil, C.E., 1982. On conducting the modified 'slug' test in tight formations. Water Resources Res., 18:439-441.

(22) Barker, J.A. and Black, J.H., 1982. Slug tests in fissured aquifers. Water Resources Res., 19:1558-1564.

(23) Hayashi, K., Ito, T., and Abe, H., 1987. A new method for the determination of in situ hydraulic properties by pressure pulse tests and application to the Higashi Hachimantai geothermal field. J. Geophys. Res., 92:9168-9174.

(24) Hickman, S.H. and Zoback, M.D., 1983. The interpretation of hydraulic fracturing pressure-time data for in-situ stress determination. In U.S. National Committee for Rock Mechanics, Hydraulic Fracturing Stress Measurements: Proceedings of a Workshop December 2-5, 1981: Washington (Natl. Acad. Press), 44-54.

H. Permeability measurements and hydrofracture -- DSDP examples

(25) Anderson, R.N., and Zoback, M.D., 1982. Permeability, underpressures, and convection in the oceanic crust near the Costa Rica Rift, eastern equatorial Pacific. J. Geophys. Res., 87:2860-2868.

(26) Anderson, R.N., Zoback, M.D., Hickman, S.H., and Newmark, R.L., 1985. Permeability versus depth in the upper oceanic crust: in situ measurements in DSDP Hole 504B, eastern equatorial Pacific. J. Geophys. Res., 90:3659-3669.

(27) Hickman, S.H., Langseth, M.G., and Svitek, J.F., 1984. In situ permeability and pore-pressure measurements near the mid-Atlantic Ridge, Deep Sea Drilling Project Hole 395A. In Hyndman, R.D., Salisbury, M.H., et al., Init. Repts. DSDP, 78B: Washington (U.S. Govt. Printing Office), 699-708.

I. Large-scale resistivity experiment

(28) Archie, G.E., 1942. The electrical resistivity log as an aid in determining some reservoir characteristics. Trans. AIME, 146:54-62.

(29) Von Herzen, R.P., Francis, T.J.G., and Becker, K., 1983. In situ large-scale electrical resistivity of ocean crust, Hole 504B. In Cann, J.R., Langseth, M.G., Honnorez, J., Von Herzen, R.P., White, S.M., et al., Init. Repts. DSDP, 69: Washington (U.S. Govt. Printing Office), 237-244.

(30) Becker, K., et al., 1982. In situ electrical resistivity and bulk porosity of the oceanic crust, Costa Rica Rift. Nature, 300:594-598.

(31) Becker, K., 1985. Large-scale electrical resistivity and bulk porosity of the oceanic crust, Deep Sea Drilling Project Hole 504B, Costa Rica Rift. In Anderson, R.N., Honnorez, J., Becker, K., et al., Init. Repts. DSDP, 83: Washington (U.S. Govt. Printing Office), 419-427.

OCEAN DRILLING PROGRAM

Wireline Logging Manual

Appendix II

Bibliography of Well Log Applications
(Cumulative Edition)

Stephen Prensky
U.S Geological Survey
Denver, Colorado 80225

SEPTEMBER, 1990

Introduction

This edition of the the *Bibliography of Well-Log Applications* is a new cumulative version which combines the original bibliography by Prensky (1987) with the published annual updates (Prensky, 1987, 1988, 1989). The, as yet unpublished, update for 1989-90 is included as well. In addition, many papers have been re-grouped and several new topical areas added. The bibliography now has over 2,700 individual citations.

No attempt has been made either to cull older citations, which by now may have been superceded by newer papers, or to select the "best" papers on a particular topic. All papers that come to my attention which meet the criteria stated below, and which can be obtained by the USGS library, are included.

The purpose of this bibliography is to emphasize *applications* and various uses of well-log data. The following general criteria are applied to papers to determine whether they will be included: 1) the paper must be written in English, 2) It must be obtainable by a research library, 3) the majority of the paper should discuss a particular application of well-log data or have immediate impact on the use of such data. Consequently papers concerning theoretical or mathematical subjects (i.e., modelling), instrumentation design and development, and laboratory research, are generally excluded. For lack of space, abstracts are excluded (except for extended abstracts) and cross-indexing has been kept to a minimum. This edition is now available on diskette upon request to the author.

TABLE OF CONTENTS: Appendix II

Part A: BASIC WELL LOGGING

1. FUNDAMENTALS OF WELL LOGGING AND WELL-LOG INTERPRETATION

I. Books and Review Papers

Alger, R.P., 1980, Geological use of wireline logs, in G.D. Hobson, editor, Developments in petroleum geology no. 2: Applied Science Publishers Ltd., London, p. 207-272.

Anderson, N.W., 1987, Introduction to modern mechanical well-logging technology, chapter 23, in L.W. LeRoy, D.O. LeRoy, S.D. Schwochow, and J.W. Raese, editors, Subsurface geology, 5th edition: Colorado School of Mines, Golden, p. 412-438.

Asquith, G.B., 1985, Handbook of log evaluation techniques for carbonate reservoirs: American Association of Petroleum Geologists, Methods in Exploration No. 5, 47 p.

Asquith, G.B., 1990, Log evaluation of shaly sandstones--a practical guide: AAPG Continuing Education Course Note Series No. 31, ?p.

Asquith, G.B., and Gibson, C.R., 1982, Basic well log analysis for geologists: American Association of Petroleum Geologists, Methods in Exploration Series No. , 216 p.

Bateman, R.M., 1984, Log quality control: IHRDC Press, Boston, 398 p.

Bateman, R.M., 1984, Cased-hole log analysis and reservoir performance monitoring: IHRDC Press, Boston, 380 p.

Bateman, R.M., 1985, Openhole log analysis and formation evaluation: IHRDC Press, Boston, 647 p.

Bateman, R.M., 1987, Other well logs [MWD, dipmeter, caliper, casing inspection], chapter 53, in H.B., Bradley, editor-in-chief, Petroleum Engineering Handbook: Society of Petroleum Engineers, p. 53-1 - 53-26.

Bigelow, E., 1987, Fundamentals of Diplog analysis: Atlas Oilfield Services, Houston, 210 p.

Bigelow, E.L., 1990, Cement evaluation: Atlas Wireline Services, Houston, TX, 142 p.

Bradley, H.B., editor-in-chief, 1987, Petroleum Engineering Handbook: Society of Petroleum Engineers, variously paginated.

Brock, J., 1984, Analyzing your logs, volume 1 (fundamentals of open hole log interpretation): Petro-Media, Inc., Tyler, Texas, 270 p.

Brock, J., 1984, Analyzing your logs, volume 2 (advanced open hole log interpretation): Petro-Media, Inc., Tyler, Texas, 186 p.

Brock, J., 1985, Analyzing your logs, volume 3--Cased hole log interpretation: Petro-Media, Inc., Tyler, Texas, ? p. [was this ever actually published?]

Brock, J., 1986, Applied open-hole log analysis: Gulf Publishing Company, Houston, Contributions in Petroleum Geology and Engineering, volume 2, 292 p.

Canadian Well Logging Society (CWLS), annual (1968-present), Journal : Canadian Well Logging Society, Calgary.

Canadian Well Logging Society (CWLS), biannual (1968-present), Formation evaluation symposium transactions: Canadian Well Logging Society, Calgary.

Canadian Well Logging Society, 1985, Log analysis handbook: Canadian Well Logging Society, variously paginated. [Type logs and analysis for major Canadian oil and gas fields.]

Chapman, R.E., 1983, Chapter 6, in Petroleum geology: Elsevier, New York, p. 107-137.

Crain, E.R., 1986, The log analysis handbook, volume 1--Quantitative log analysis methods: PennWell Books, Tulsa, 684 p.

Desbrandes, R., 1985, Encyclopedia of well logging: Gulf Publishing Company, Houston, 585 p.

Dewan, J.T., 1983, Essentials of modern open-hole log interpretation: PennWell Books, Tulsa, 361 p.

Dickey, P.A., 1986, Electrical and other wireline logs, chapter 5, in Petroleum development geology, 3rd edition: Petroleum Publishing Co., Tulsa, p. 62-98.

Dresser Atlas, 1982, Interpretive methods for production well logs, 2nd edition: Dresser Industries, Houston, Document No. 9441, 159 p.

Dresser Atlas, 1983, Neutron Lifetime Log: Dresser Industries, Houston, Publication No. 3319, 100 p. [Interpretation and application manual.]

Dresser Atlas, 1984, Well logging and interpretation techniques, the home study course: Dresser Industries, Houston, Publication No. 9333, variously paginated. [Includes a discussion on the use of SP for evaluating depositional environments.]

Dresser Atlas, 1984, Wireline services catalog: Dresser Industries, Houston, Publication No. 9102, 43 p. [Brief discussions, with illustrations, of the various logging devices and processing services currently available.]

Durrance, E.M., 1986, Radioactivity and petroleum, chapter 11, in Radioactivity in geology, principles and applications: John Wiley & Sons, New York, p. 342-363.

Ellis, D., and Boucau, J., 1983, The future development of logging techniques: Oil and Enterprise, no. 2, September, p. 60-66.

Ellis, D.V., 1987, Well logging for earth scientists: Elsevier Science Publishing Company, New York, 532 p.

Ellis, D.V., Schweitzer, J.S., and Ullo, J.J., 1987, Nuclear techniques for subsurface geology: Annual Review Nuclear Particle Science, v. 37, p. 213-241.

Etnyre, L.M., 1989, Finding oil and gas from well logs: Van Nostrand Reinhold, New York, 306 p.

Fetter, C.W., 1988, Geophysical logs, chapter 12, Field methods, in Applied hydrology, 2nd edition: Merrill Publishing Company, Columbus, Ohio, 506-518.

Fertl, W.H., 1983, Advances in well logging and well interpretation, in 11th world petroleum congress, proceedings, volume 3: John Wiley, New York, p. 341-354. Later published in condensed form in 1984, Oil and Gas Journal, v. 82(16), April 16, p. 85-91.

Fertl, W.H., and Overton, H., 1982, Formation evaluation, chapter 8, in L.M. Edwards, G.V. Chilingar, H.H. Rieke, III, W.H. Fertl, editors, Handbook of geothermal energy: Gulf Publishing Company, Houston, p. 326-425.

Frank, R.W., 1986, Prospecting with old E-logs: Schlumberger Educational Services, Houston, 161 p.

Gilreath, J.A., Cox, J.W., Fett, T.H., and Grace, L.M., 1985, Practical dipmeter interpretation: Schlumberger Educational Services, Houston, variously paginated.

Hallenburg, J.K., 1984, Geophysical logging for mineral and engineering applications: PennWell Books, Tulsa, 254 p.

Hearst, J.R., and Nelson, P.H., 1985, Well logging for physical properties: McGraw-Hill, New York, 576 p.

Helander, D.P., 1983, Fundamentals of formation evaluation: Oil and Gas Consultants International, Tulsa, 332 p.

Hilchie, D.W., 1977, Nuclear well logging for petroleum, in J.G. Morse, editor, Nuclear methods in mineral exploration and production: Elsevier, New York, Developments in Economic Geology No. 7, p. 201-213.

Hilchie, D.W., 1978, Applied openhole log interpretation: D.W. Hilchie, Inc., Golden, CO., variously paginated.

Hilchie, D.W., 1979, Old (pre-1958) electical log interpretation: D.W. Hilchie Inc., Golden, CO., 161 p.

Hilchie, D.W., 1979, Cumulative index, 1960-1978--The Log Analyst, SPWLA symposium papers, SPWLA European symposium papers, CWLS symposium papers, and CWLS Journal: The Log Analyst, v. 20(1), January-February, p. 6-39.

Hilchie, D.W., 1982, Advanced well log interpretation: D.W. Hilchie, Inc., Golden, CO., variously paginated.

Hill, A.D., 1990, Production logging--theoretical and interpretative elements: Society of Petroleum Engineers Memoir No. 14, 154 p.

Hobson, G.D., and Tiratsoo, E.N., 1975, Formation evaluation, chapter 7, in Introduction to petroleum geology: Scientific Press, Ltd., Beaconsfield, England, p. 176-204.

Hollo, R., and Fifadara, H., 1981, TI-59 reservoir engineering manual, 2nd edition: PennWell Books, Tulsa, 249 p.

Hurst, A., Lovell, M.A., and Morton, A.C., editors, 1990, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, 357 p.

Jain, K.C., 1982, Well logs in exploration, chapter 7, in K.C. Jain and R.J.P. deFigueiredo, editors, Concepts and techniques in oil and gas exploration: Society of Exploration Geophysicists, p. 199-226.

Johnson, D.E., and Pile, K.E., 1988, Well logging for the nontechnical person: PennWell Publishing Co., Tulsa, 198 p.

Jorden, J.R., and Campbell, F.L., 1984, Well logging I--Rock properties, borehole environment, mud and temperature logging: Society of Petroleum Engineers, Monograph Series No. 9, 167 p.

Jorden, J.R., and Campbell, F.L., 1986, Well logging II--Electric and acoustic logging: Society of Petroleum Engineers, Monograph Series No. 10, 192 p.

Kaufman, A.A., and Keller, G.V., 1989, Induction Logging: Elsevier, Amsterdam, Methods in Geochemistry and Geophysics No. 27, 600 p.

Kelley, D.R., 1969, A summary of major geophysical logging methods: Pennsylvania Geological Surey Bulletin M61, 82 p.

Keys, W.S., 1988, Borehole geophysics applied to ground-water hydrology: U.S. Geological Survey Open-File Report 87-539, 305 p. Later published in 1989: National Water Well Association, Dublin, Ohio, 313 p.

Kunetsov, O.L., Akselrod, S.M., Denisov, S.B., and Pyatakhin, V.I., 1987, New logging methods are an efficient tool to solve complex geological problems, in 12th world petroleum congress proceedings, v. 3, production: John Wiley & Sons, New York, p. 295-306.

Labo, J., 1987, A practical introduction to borehole geophysics--An overview of wireline well logging principles for geophysicists: Society of Exploration Geophysicists, 330 p.

Mares, S., 1984, Geophysical logging, chapter 7, in Introduction to applied geophysics: D. Reidel Publishing Co., Boston, p. 474-568.

Mathur, S.P., 1977, Borehole geophysical methods, in V.L.S. Bhimasankaram and V.K. Gaur, editors, Lectures on exploration geophysics for geologists and engineers: The Association of Exploration Geophysicists, Hyderabad, India, p. 265-286.

Merkel, R.H., 1979, Well log formation evaluation: American Association of Petroleum Geologists, Continuing Education Course Note Series No. 14, 82 p.

Nelson, R.A., 1985, Geologic analysis of naturally fractured reservoirs: Gulf Publishing Company, Houston, Contributions in Petroleum Geology and Engineering Series, volume 1, 320 p.

Pickett, G.R., 1977, Resistivity, radioactivity and acoustic logs, chapter 13, in L.W. LeRoy, D.O. LeRoy and J.W. Raese, editors, Subsurface geology, 4th edition: Colorado School of Mines, Golden, CO., p. 304-336.

Pirson, S.J., 1963, Handbook of well log analysis for oil and gas formation evaluation: Prentice-Hall, Englewood Cliffs, New Jersey, 325 p.

Pirson, S.J., 1983, Geologic well log analysis, 3rd edition: Gulf Publishing Company, Houston, 475 p.

Ransom, R.C., editor, 1984, Glossary of terms and expressions used in well logging, 2nd edition: Society of Professional Well Log Analysts, 116 p.

Repsold, H., 1989, Well logging in groundwater development: International Association of Hydrogeologists, International Contributions to Hydrogeology, v. 9, 136 p.

Rider, M.H., 1986, The geological interpretation of well logs: John Wiley & Sons, Inc., New York, 175 p.

Roscoe Moss Company, 1989, Geophysical borehole logging, chapter 4, in Handbook of ground water development: John Wiley & Sons, New York, p. 52-84.

Ryley, D.J., 1980, Well logging, in R. DiPippo, H.E. Khalifa, D.J. Ryley, editors, Sourcebook on the production of electricity from geothermal energy: U.S. Department of Energy Report DOE/RA/4051-1, p. 155-172.

Schlumberger, 1972, The essentials of log interpretation practice: Schlumberger Ltd., Houston, Document No. M-081002, 57 p.

Schlumberger, 1973, Production log interpretation: Schlumberger Well Services, Houston, Document No. C-11811, 91 p.

Schlumberger, 1976, The essential of thermal decay time logging: Schlumberger Ltd., New York, Document No. M-081003, 31 p.

Schlumberger, 1981, RFT--Essentials of pressure test interpretation: Schlumberger Technical Services, Paris, Document No. M-081022, 77 p.

Schlumberger, 1982, Essentials of natural gamma ray spectrometry interpretation: Schlumberger Technical Services, Paris, Document No. M-081025, 69 p.

Schlumberger, 1983-1986, Service modules: Schlumberger Technical Services, Paris. [Concise descriptions of the newest generation of open- and cased-hole logging tools and their interpretation. In 14 individual full color pamphlets.]

Schlumberger, 1984, Production services catalog: Schlumberger Well Services, Document No. SMP-7005, 60 p. [A brief discussion with illustrations of the various logging devices and processing services currently available.]

Schlumberger, 1985, Openhole services catalog: Schlumberger Well Services, Houston, Document No. SMP-7004, 72 p. [A brief discussion with illustrations of the various logging devices and processing services currently available.]

Schlumberger, 1986, Dipmeter interpretation--Fundamentals: Schlumberger Well Services, Houston, Document No. SMP-7002, 76 p.

Schlumberger, 1986-Present, Middle East Well Evaluation Review: Schlumberger Technical Services, semi-annual journal.

Schlumberger, 1989, Log interpretation charts: Schlumberger Educational Services, Houston, 151 p.

Schlumberger, 1989, Cyber Service Unit, CP32, wellsite products, calibrations guide, and mneumonics: Schlumberger Educational Services, Houston, Document No. SMP-7003, 122 p.

Schlumberger, 1989, Log interpretation principles/applications: Schlumberger Educational Services, Houston, Document No. SMP-7017, variously paginated.

Schlumberger, 1990, Cased hole log interpretation principles/applications: Schlumberger Educational Services, Houston, Document No. SMP-7025, variously paginated.

Schlumberger, 1990, Historical charts: Schlumberger Educational Services, Houston, Document No. SMP-7030, 88 p.

Segesman, F.F., 1980, Well-logging method: Geophysics, v. 45(11), p. 1667-1684. [A concise history of well logging, see references.]

Sengel, E.W., 1984, Well logging handbook: Institute for Energy Development (IED), Oklahoma City, 168 p.

Serra, O., 1984, Fundamentals of well-log interpretation volume 1--The acquisition of data: Elsevier, New York, Developments in Petroleum Science No. 15A, 423 p.

Serra, O., 1985, Sedimentary environments from wireline logs: Schlumberger Technical Services, Paris, Document No. M-081030/SMP-7008, 211 p. [extracted from Serra, O., 1986, Fundamentals of well-log interpretation volume 2--The interpretation of logging data, chapters 4-6: Elsevier Science Publishers, Amsterdam, Developments in Petroleum Science No. 15B, 684 p.]

Serra, O., 1986, Fundamentals of well-log interpretation volume 2--The interpretation of logging data: Elsevier Science Publishers, Amsterdam, Developments in Petroleum Science No. 15B, 684 p.

Serra, O., 1986, Advanced interpretation of wireline logs: Schlumberger Well Services, Houston, Document No. M-090028, 295 p. [extracted from Serra, O., 1986, Fundamentals of well-log interpretation volume 2--The interpretation of logging data, chapters 2-3, 7-12: Elsevier Science Publishers, Amsterdam, Developments in Petroleum Science No. 15B, p. 61-135, 341-555.]

Serra, O., 1986, Stratigraphy, tectonics and multiwell studies using wireline logs: Schlumberger Well Services, Houston, Document No. M-090029, 127 p. [extracted from Serra, O., 1986, Fundamentals of well-log interpretation volume 2--The interpretation of logging data, chapters 13-15: Elsevier Science Publishers, Amsterdam, Developments in Petroleum Science No. 15B, p. 557-652]

Serra, O., 1986, Wellsite interpetation of wireline logs: Schlumberger Well Services, Houston, Document No. M-090027, 60 p. [extracted from Serra, O., 1986, Fundamentals of well-log interpretation volume 2--The interpretation of logging data, chapter 1: Elsevier Science Publishers, Amsterdam, Developments in Petroleum Science No. 15B, 11-60.]

Smolen, J.J., 1986, Production logging: J.J. Smolen, Missouri City, Texas, variously paginated.

Snyder, D.D., and Fleming, D.B., 1985, Well logging--A 25-year perspective: Geophysics, v. 50(12), p. 2504-2529. See references.

Society of Professional Well Log Analysts, 1978, Acoustic logging reprint volume: Society of Professional Well Log Analysts, various pagination. [Contains 26 significant papers on tool development, operation and application.]

Society of Professional Well Log Analysts (SPWLA), Annual (1960-present), Logging symposium transactions: Society of Professional Well Log Analysts.

Society of Professional Well Log Analysts (SPWLA), biannual (1972-1985); annual 1986-present), European formation evaluation symposium transactions: Society of Professional Well Log Analysts.

Society of Professional Well Log Analysts (SPWLA), bimonthly (1960-present), The Log Analyst: Society of Professional Well Log Analysts.

Society of Professional Well Log Analysts (SPWLA), irregular, Reprint volumes: Society of Professional Well Log Analysts.

Society of Professional Well Log Analysts, Houston Chapter, 1979, The art of ancient log analysis: Society of Professional Well Log Analysts, 131 p. + reprints of 22 classic papers on interpretation of old electric (normal and lateral) logs.

Sperry-Sun Drilling Services, 1989, MWD technical information manual: Sperry-Sun Drilling Serices, Houston, variously paginated.

Threadgold, P., 1985, Advances in formation evaluation, chapter 3 in R.A. Dawe and D.C. Wilson, editors, Developments in petroleum engineering, volume 1: Elsevier Applied Science Publishers, New York, p. 43-87.

Timur, A., 1982, Open hole well logging, SPE-10037, in International petroleum conference [Beijing] proceedings: Society of Petroleum Engineers, p. 639-674. Later published in condensed form 1982, Advances in well logging: Journal of Petroleum Technology, v. 34(6), p. 1181-1185.

Tittman, J., 1986, Geophysical well logging: New York, Academic Press, Inc., 175 p.

University of Tulsa, 1985, Index to well logging literature: Petrolem Abstracts, University of Tulsa, 399 p.

Verdier, M., editor, 1986, Wireline logging tool catalog, 2nd edition: Gulf Publishing Co., Houston, 409 p.

Wyman, R.E., 1981, Well logging, in S.P. Parker, editor, Encyclopedia of energy, 2nd edition: McGraw-Hill, New York, p. 778-785.

II. Electric Logging and General Formation Evaluation (Including Petrophysics and Case Histories)

(See also VII. Shaly sand; 18. Mineral evaluation)

Aaboe, E., 1984, Influence of shaliness upon conductivity in shaly sandstones in the northern North Sea area, paper LL, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 17 p.

Adams, J., Blott, N., Boyeldieu, C. Cheruvier, E., Cull, R. Mobed, R., Haines, P. Jr., Spurlin, J., 1989, Advances in log interpretation in oil-base mud: Oilfield Review, v. 1(2), p. 22-40.

Aguilera, R., 1977, A new approach for log analysis of the pulsed neutron and resistivity log combination, SPE-6995: Society of Petroleum Engineers. Later published 1979, Journal of Petroleum Technology, v. 31(4), p. 415-418.

Aguilera, R., 1988, New methods for evaluation of shaly formations by wells logs, SPE-17517, in SPE Rocky Mountain regional meeting proceedings: Society of Petroleum Engineers, p. 365-376.

Aguilera, R., 1988, A new approach for analysis of the nuclear magnetic log-resistivity combination, paper 88-39-109, in 39th annual technical meeting, preprints, volume 3: Petroleum Society of CIM [Canadian Institute of Mining], Calgary, p. 12 p. Later published in 1990, Journal of Canadian Petroleum Technology, v. 29(1), January-February, p. 67-71.

Aguilera, R., and Van Poolen, H.K., 1979, Porosity and water saturation can be estimated from logs: Oil and Gas Journal, v. 77, January 8, p. 101-108.

Ajam, S.O., Henzell, L.A., Wang, J., Syarif, A.M., and Soedirdja, H., 1982, Wellsite log evaluation of the Miocene carbonates in Salawati Basin, in 11th annual convention proceedings, volume 1: Indonesian Petroleum Association, Jakarta, p. 357-377.

Alexander, S.C., Tieh, T.T., and Berg, R.R., 1985, The effects of diagenesis on reservoir properties in the Lobo Sandstones, Webb County, Texas: Transactions Gulf Coast Association of Geological Societies, v. 35 p. 301-307.

Algan, U., and Toksoz, M.N., 1986, Depth of fluid penetration into a porous permeable formation due to sinusoidal pressure source in a borehole: The Log Analyst, v. 27(6), November-December, p. 30-37.

Alger, R.P., 1966, Interpretation of electric logs in fresh water wells in unconsolidated formations, paper CC, in 7th annual logging sumposium transactions: Society of Professional Well Log Analysts, p.

Alger, R., and Harrison, C.W., 1988, Improved fresh water assessment in sand aquifers utilizing geophysical well logs, paper I, in 2nd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applications [Golden, Colorado, October 6-8, 1987], proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society Chapter-at-Large, p. 99-118. Also published in 1988, in FOCUS conference on southwestern ground water issues [Albuquerque, New Mexico, March 23-35], proceedings: National Well Water Association, Dublin, Ohio, p. 281-309. Also published in 1988, in 2nd national outdoor action conference on aquifer restoration, ground water monitoring, and geophysical methods [Las Vegas, May 23-26] proceedings, volume 2: Association of Ground Water Scientists and Engineers (AAAS), p. 939-968. Later published in 1989, The Log Analyst, v. 30(1), January-February, p. 31-44.

Alger, R.P., Luffel, D.L., and Truman, R.B., 1987, New unified method of integrating core capillary pressure data with well logs, SPE-16793, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 461-473. Later published in 1989, SPE Formation Evaluation, v. 4(2), p. 145-152.

Allan, G.W., and McDougall, J.G., 1989, Advances in evaluating thin-bed response, paper V, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 14 p.

Allen, D.F., 1982, The effect of mud salinity on EPT attenuation: The Technical Review, v. 30(3), December, p. 4-9.

Allen, D., Coates, G., and others, 1988, Probing for permeability--An introduction of measurements: The Technical Review, v. 36(1), p. 6-20.

Almon, W.R., 1979, A geologic appreciation of shaly sands, paper WW, in 20th annual logging symposium transactions: Society of Professional Well Logging Analysts, 14 p. Reprinted in 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. I5-I18.

Almon, W.R., and Schultz, A.L., 1979, Electric log detection of diagenetically altered reservoirs and diagenetic traps: Gulf Coast Association of Geological Societies Transactions, v. 29, p. 1-10.

Amin, A.T., Wafta, M., and Awad, M.A., 1987, Accurate estimation of water saturations in complex carbonate reservoirs, SPE-15714, in 5th SPE Middle East oil show [Manama, Bahrain], proceedings: Society of Petroleum Engineers, p. 199-214.

Anderson, B., 1986, The analysis of some unsolved induction interpretation problems using computer modeling, paper II, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 18 p. Later published in 1986, The Log Analyst, v. 27(5), September-October, p. 60-73.

Anderson, B., and Barber, T.D., 1987, Strange induction logs--A catalog of environmental effects, paper G, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p. Later published in 1988, The Log Analyst, v. 29(4), July-August, p. 229-243.

Anderson, B., and Barber, T.D., 1988, Using computer modeling to provide missing information for interpreting resistivity logs, paper H, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 22 p.

Anderson, B., Barber, T.D., Singer, J., and Broussard, T., 1989, ELMOD--Putting electromagnetic modeling to work to improve resistivity log interpretation, paper M, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p.

Anderson, B., Safinya, K.A., and Habashy, T., 1986, Effects of dipping beds on the response of induction tools, SPE-15488: Society of Petroleum Engineers, 61st annual meeting preprint, 11 p. Later published in 1988, SPE Formation Evaluation, v. 3(1), p. 29-36.

Anderson, B.I., Safinya, K.A., Habeshy, T.M., Davidson, A., and Gilmore, R., 1987, The response of the Electromagnetic Propagation Tool to bed boundaries, SPE-16768, in SPE annual technical meeting and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 267-282

Anderson, B., and Tabanou, J., 1987, The quest for true formation resistivity: The Technical Review, v. 35(2), p. 36-43.

Anderson, W.G., 1986, Wettability literature survey, part 3--The effects of wettability on the electrical properties of porous media: Journal of Petroleum Technology, v. 38(13), p. 1371-1378.

Andreani, M., 1989, Quantitative evaluation of highly laminated, complex lithology formations, SPE-17944, in SPE Middle East oil technical conference and exhibition [Manama, Bahrain], proceedings: Society of Petroleum Engineers, p. 155-166.

Anonymous, 1987, Statistical methods for assessing log quality: The Technical Review, v. 35(4), p. 12-13.

Anonymous, 1988, Archie's law; electrical conduction in clean, water-bearing rock: The Technical Review, v. 36(3), p. 4-13.

Anonymous, 1988, Archie II--Electrical conduction in hydrocarbon-bearing rocks: The Technical Review, v. 36(4), October, p. 12-21.

Anonymous, 1989, Archie III; electrical conduction in shaly sands: Schlumberger Oilfield Research, v. 1(3), October, p. 43-53.

Anonymous, 1990, Formation anistropy; reckoning with its effects: Schlumberger Oilfield Review, v. 2(1), January, p. 16-23.

Argaud, M., Giouse, H., Straley, C., Tomanic, J., and Winkler, K., 1989, Salinity and saturation effects on shaly sadnstone conductivity, SPE-19577, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 49-60.

Asquith, G.B., 1979, Chapter 4, in Subsurface carbonate depositional models--A concise review: Petroleum Publishing Co., Tulsa, p. 103-116.

Asquith, G.B., 1985, Handbook of log evaluation techniques for carbonate reservoirs: American Association of Petroleum Geologists, Methods in Exploration No. 5, 47 p.

Asquith, G.B., 1986, Microporosity in the O'Hara oolite zone of the Mississippian Ste. Genevieve Limestone, Hopkins County, Kentucky, and its implications for formation evaluation: Carbonates and Evaporites, v. 1(1), p. 7-12.

Asquith, G.B., 1990, Log evaluation of shaly sandstones--a practical guide: AAPG Continuing Education Course Note Series No. 31, ?p.

Asquith, G.B., and Gibson, C.R., 1982, Basic well log analysis for geologists: American Association of Petroleum Geologists, Methods in Exploration Series No. , 216 p.

Augier, C., 1980, Log Interpretation in Complex Lithologies [in French]: Bulletin des Centres Recherches Exploration-Production Elf-Aquitaine, v. 4(1), p. 143-177.

Azer, S.R., and A.M. Borai, 1987, An overview of the formation evaluation of recent discoveries in the Thamama, Arab and Araej reservoirs, offshore Abu Dhabi, SPE-15744, in 5th SPE Middle East oil show [Manama, Bahrain] proceedings, : Society of Petroleum Engineers, p. 455-464.

Badrinadh, V., Cherukapalli, P.K., Suryanarayana, K., Rai, K., and Gupta, D.K., 1989, Dual porosity and dual saturation model in the evaluation of vuggular carbonate reservoirs of Bombay offshore, India, paper H, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 11 p.

Baldwin, B.A., and Yamanashi, W.S., 1989, Determining fluid saturation distribution in cores using NMR imaging, SCA-8714, part I, paper N, in Annual technical conference reprints, v. 1 (1987-1989): Society of Professional Well Log Analysts, Society of Core Analysts, Chapter-at-Large, 24 p.

Barba, R.E., 1987, Improving production in the Spraberry trend with wireline inputs, in 34th annual short course proceedings: Southwestern Petroleum Short Course Association, Lubbock, Texas, p. 128-140.

Barber, T.D., 1986, Invasion profiling with the Phasor Induction Tool, paper EE, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 14 p.

Barber, T.D., and Howard, A.Q., 1989, Correcting the induction log for dip effect, SPE-19607, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 371-380.

Basan, P., Hook J.R., and Hughes, K., 1988, Measuring porosity, saturation and permeability from cores--An appreciation of the difficulties: The Technical Review, v. 36(4), October, p. 22-36.

Bass, D.M., Jr., 1987, Properties of reservoir rocks, chapter 26, in H.B., Bradley, editor-in-chief, Petroleum Engineering Handbook: Society of Petroleum Engineers, p. 26-1 - 26-33.

Bateman, R.M., 1984, Log quality control: IHRDC Press, Boston, 398 p.

Bateman, R.M., 1985, Openhole log analysis and formation evaluation: IHRDC Press, Boston, 647 p.

Bateman, R.M., and Perez, J., 1989, Advances in log analysis lead to improved productivity from feldspathic shaly sandstone, paper C, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 15 p.

Beaudoin, B., Pinoteau, B., and Delhomme, J.P., 1983, Geological analysis of logs and dipmeter data for well-to-well correlation, paper BBB, in 24th annual logging symposium transactions: Society of Professional Well Log Analysts, 18 p. Deep-sea fan example.

Beck, J., Schultz, A., and Fitzgerald, D., 1977, Reservoir evaluation of fractured Cretaceous carbonates in south Texas, paper M, in 18th annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Becker, K., Langseth, M.G., Von Herzen, R.P., Anderson, R.N., and Hobart, M.A., 1985, Deep crustal geothermal measurements, hole 504b, Deep Sea Drilling Project legs 69, 70, 83, and 92, in Initial reports of the Deep Sea Drilling Project, v. 83: U.S. Government Printing Office, p. 405-418.

Berilgen, B.A., Sinha, A.K., and Fertl, W.H., 1985, Estimation of productivity of Lobo 6 sand, Lower Wilcox, Texas, by identifying diagenetic clays with well log data, SPE-14278: Society of Petroleum Engineers, 60th annual meeting preprint, 15 p. Later published in 1988, SPE Formation Evaluation, v. 3(2), p. 393-406.

Biehle, A.A., and Crocker. C.M., 1987, Comparison of petrographic characteristics of selected carbonate rocks to their petrophysical log response--Smackover Formation (Upper Jurassic): Gulf Coast Association of Geological Societies Transactions, v. 37, p. 25-34.

Biella, G., Lozej, A., and Tabacco, I., 1983, Experimental study of some hydrogeophysical properties of unconsolidated porous media: Ground Water, v. 21(6), November-December, p. 741-751. A discussion of the limitations of Archie's equation.

Bilsland, M., Mobed, R., Cheruvier, E., and White, J., 1989, Predicting hydrocarbon saturations in thin sandstones drilled with oil-based mud, paper J, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 16 p.

Blakeman, E.R., 1989, Application of bimodal porosity concepts to the development of log interpretation models, SPE-19575, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 25-38.

Blenkinsop, M., Baker, P., Clavier, C., Kenyon, W., and des Ligneris, S., 1986, Deep Electromagnetic Propagation Tool interpretation, paper XX, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 26 p.

Boardman, C.R., Hammack, G.W., Fertl, W.H., and Atkinson, C.H., 1972, Evaluation of low-permeability gas-bearing formations in Rio Blanco County, Colorado, SPE-4097: Society of Petroleum Engineers, 47th annual meeting [San Antonio] preprint. Later published in 1973, Journal of Petroleum Technology, v. 25(10), p. 1125-1129.

Boone, D.E., 1987, New logging concept defines clay invasion while drilling, SPE-16987, in 1987 SPE annual meeting proceedings, volume delta: Society of Petroleum Engineers, p. 471-476.

Borai, A.M., 1985, A new correlation for the cementation factor in low-porosity carbonates, SPE-14401: Society of Petroleum Engineers, 60th annual meeting preprint, 8 p. Later published in 1987, SPE Formation Evaluation, v. 2(4), p. 495-499.

Bosworth, A.F., 1972, Log calibrations surface and downhole: Canadian Well Logging Society Journal, v. 5(1), p. 39-68.

Boutemy, Y., Calvier, C., and Simond, R.F., 1979, Field studies--A progress report on the contribution of logging, SPE-8178: Society of Petroleum Engineers, 13 p.

Boyce, R.E., 1980, Determination of the relationships of electrical resistivity, sound velocity, and density/porosity of sediment and rock by laboratory techniques and well logs from Deep Sea Drilling Project sites 415 and 416 off the coast of Morocco, in Initial reports of the Deep Sea Drilling Project, v. 50: U.S. Government Printing Office, p. 305-318.

Boyce, R.E., 1984, Deep Sea Drilling Project drill sites 530 and 532 in the Angola Basin and on the Walvis Ridge--Interpretation of induction log data, and laboratory sound velocity, density, porosity-derived reflection coefficients, and vane shear strength, in Initial reports of the Deep Sea Drilling Project, v. 75, part 2: U.S. Government Printing Office, p. 1137-1187.

Boyeldieu, C., 1982, Evaluating fracture porosity in hard carbonate formations: The Technical Review, v. 30(2), September, p. 15-22.

Boyeldieu, C., Coblentz, A., and Pelissier-Combescure, J., 1984, Formation evaluation in oil base mud wells, paper BB, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 18 p.

Boyeldieu, C., and Draxler, J., 1987, Deep-well formation logging; the problems, the logging tools, in H.J. Beher, editor, Observation of the continental crust through drilling [International symposium Seeheim, West Germany (October 3-6, 1983), proceedings]: Springer-Verlag, New York, p. 207-223.

Bradburn, F.R., and Cheatham, C.A., 1988, Improved core recovery in laminated sand and shale sequences, SPE-18570: Journal of Petroleum Technology, v. 40(12), p. 1544-1546.

Brevetti, J.C., Greer, G., and Weis, B.R., 1985, Evaluation of fractured carbonates in the Mid-Continent region, paper III, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 19 p.

Brock, J., 1984, Analyzing your logs, volume 2 (advanced open hole log interpretation): Petro-Media, Inc., Tyler, Texas, 186 p.

Brock, J., 1984, Analyzing your logs, volume 1 (fundamentals of open hole log interpretation): Petro-Media, Inc., Tyler, Texas, 270 p.

Brock, J., 1986, Applied open-hole log analysis: Gulf Publishing Company, Houston, Contributions in Petroleum Geology and Engineering, volume 2, 292 p.

Broussard, S., 1989, The annulus effect: The Technical Review, v. 37(1), January, p. 41-47.

Brown, G.A., 1986, A mathematical comparison of common saturation equations, paper T, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 24 p.

Brown, G.A., 1988, The formation porosity exponent; the key to improved estimates of water saturation in shaly sands, paper AA, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 24 p.

Brown, L.D., 1989, NMR imaging; principles and recent progress, SCA-8812, part II, paper L, in Annual technical conference reprints, v. 1 (1987-1989): Society of Professional Well Log Analysts, Society of Core Analysts, Chapter-at-Large, 27 p.

Brugler, M., and Hynson, M.F., 1989, Offhshore Gulf Coast formation evaluation; comparison and use of unconsolidated core data, SCA-8906, in 1987-1989 annual technical conference preprints: Society of Professional Well Log Analysts, Society of Core Analysts, Chapter-at-Large, 21 p.

Brylkin, Y.S., Blokh, A.S., and Mikhailov, Y.Y., 1988, Various methods of interpreting dielectric logging diagrams and their effectiveness: Soviet Geology and Geophysics, v. 29(11), p. 127-132.

Buller, D., Kenyon, B., Rasmus, J., and Miller, S., 1987, Evaluating porosity and producibility in oomoldic carbonates: The Technical Review, v. 35(3), July, p. 14-18.

Bussian, A.E., 1983, A comparison of shaly sand models, paper E, in 24th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p.

Canadian Well Logging Society, 1985, Log analysis handbook: Canadian Well Logging Society, variously paginated. [Type logs and analysis for major Canadian oil and gas fields.]

Cannon, D.E., and Coates, G.R., 1990, Applying mineral knowledge to standard log interpretation, paper V, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 24 p.

Castanier, L.M., 1989, An introduction to computerized X-ray tomography for petroleum research: U.S. Department of Energy Report No. DOE/BC/14126-7, 24 p.

Casu, P.A., Cigni, M., and Magrassi, M., 1988, Improved evaluation methods for thin and very thin gas bearing beds, paper B, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 19 p.

Chemali, R., Gianzero, S., and Su, S.M., 1988, The dual laterolog in common complex situations, paper U, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 25 p.

Chemali, R., Su., S.M., and Goetz, J.F., 1989, Measuring Rxo and dip in oil-based mud with the six-arm dipmeter, paper O, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Cheruvier, E., and Suau, J., 1986, Applications of micro-wave dielectric measurements in various logging environments, paper MMM, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 23 p.

Chilingarian, G.V., and Fertl, W.H., 1988, Formation evaluation of carbonate rocks: Journal of Petroleum Science and Engineering, v. 1(3), p. 181-194.

Chilingarian, G.V., and Vorabutr, P., 1981, Drilling and drilling fluids: Elsevier, Amsterdam, Developments in Petroleum Science No. 11, 767 p.

Chilingarian, G.V., and Yen, T.F., 1986, Notes on carbonate reservoir rocks, no. 3--Fractures: Energy Sources, v. 8(2/3), p. 261-275.

Chilingarian, G.V., and Yen, T.F., 1987, Note on carbonate reservoir rocks, part 5--Interrelationships among various properties of carbonates: Energy Sources, v. 9(1), p. 51-65.

Chmelik, F.B., Bouma, A.H., and Rezak, R., 1969, Comparison of electrical logs and physical parameters of marine sediment cores: Transactions of the Gulf Coast Association of Geological Societies, v. 19, p. 63-70.

Clavier, C., Coates, G., and Dumanoir, J., 1977, Theoretical and experimental bases for the dual-water model for interpretation of shaly sands, SPE-6859: Society of Petroleum Engineers, 52nd annual meeting [Denver] preprint 16 p. Reprinted in 1982, Shaly sand reprint volume: Society of Professional Well Log Analysts, p. V5-V20. Later published in 1984, Society of Petroleum Engineers Journal, v. 24(2), p. 153-169. Reprinted in 1986, in Openhole well logging: Society of Petroleum Engineers, SPE Reprint Series No. 21, p. 357-372.

Clavier, C., Heim, A., and Scala, C., 1976, Influence of pyrite on resistivity and other logging measurements, paper HH, in 17th annual logging symposium transactions: Society of Professional Well Log Analysts, 33 p.

Clavier, C., and Rust, D.H., 1976, MID plot--A new lithology technique: The Log Analyst, v. 17(6), November-December, p. 16-24. Reprinted in 1986, in Openhole well logging: Society of Petroleum Engineers, SPE Reprint Series No. 21, p. 515-523.

Clenchy, D.R., 1985, Effect of borehole diameter on log data quality and interpretation--Grand Banks area, east coast Canada, paper V, in 10th formation evaluation symposium transactions: Canadian Well Logging Society, 26 p.

Coates, G.R., and Crary, S.F., 1989, The SP--the forgotten saturation measurement, paper U, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 18 p.

Cockcraft, P.J., Imanudin, Owens, J.A., and Basuki, W., 1986, The effect of KOH [potassium hyroxide] lignosulfonate drilling muds on spontaneous potential log interpretation, in 15th annual convention proceedings, v. 2: Indonesian Petroleum Association, Jakarta, p. 27-42. Later published in 1987 as unsolicited SPE-16467: Society of Petroleum Engineers, 19 p.

Cohen, A., 1985, Enhanced lithological discrimination through application of graphical log cross-reference (crossplotting)--A case study of Shiqma 5 (Saqiye Group, Neogene, Israel): Geological Survey of Israel, Mineral Energy Infrastructure Report GSI/44/85, 22 p.

Collier, H.A., 1988, The effect of isolated biomoldic porosity on the log analysis of a Pennsylvanian carbonate reservoir in north Texas, paper X, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 16 p.

Collier, H.A., 1989, Assessment of the dielectric tool as a porosity device, in 3rd national outdoor action conference on aquifer restoration, ground water monitoring and geophysical methods [Orlando, Florida], proceedings: National Well Water Association, Dublin, Ohio, p. 151-165. Also published in 1989 as paper L, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 183-197.

Collier, H.A., 1989, Recognizing high porosity-low permeability sandstone reservoirs with routine logs; a case history, paper W, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Collins, H.N., 1984, Regression analysis - some loose ends: Canadian Well Logging Society Journal, v. 13, p. 61-65.

Collins, J.L., 1989, Log response as a model for production--deep Wilcox sandstones, Provident City field, Lavaca County, Texas: Transactions Gulf Coast Association of Geological Societies, v. 29, p. 27-36.

Connolly, E.T., and Reed, P.A., 1983, Full spectrum formation evaluation: Canadian Well Logging Society Journal, v. 12(1), p. 23-69.

Conway, A.M., 1986, Geology and petrophysics of the Victor field, in J. Brooks, J.C. Goff, and B. van Hoorn, editors, Habitat of Paleozoic gas in NW Europe: Geological Society of London, Special Publication No. 23, p. 237-249.

Cooke-Yarborough, P., 1984, Reservoir analysis by wireline formation tester; pressures, permeabilities, gradients, and net pay: The Log Analyst, v. 26(6), November-December, p. 36-46.

Cooke-Yarborough, P., 1987, A method for reconciliation of log-derived and core-derived porosity, paper DD, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 24 p.

Cooley, B.B., 1974, The delta tension curve for better log quality, paper F, in 15th annual logging symposium transactions: Society of Professional Well Log Analysts, 9 p. Later reprinted in 1974, The Log Analyst, v. 15(4), July-August, p. 8-13.

Coppinger, W.W., and Schlutz, A.L., 1983, Using the self-potential curve to define depositional trends in Lower Wilcox sands, McMullen County, Texas: Bulletin of the South Texas Geological Society, v. 23(6), p. 16-28.

Cox, J.W., and Raymer, L.L., 1976, The effect of potassium-salt muds on gamma ray, and spontaneous potential measurements, paper I, in 17th annual logging symposium transactions: Society of Professional Well Log Analysts, , 20 p.

Cox, P.T., 1983, Evaluation of the Texaco dielectric log in central Sumatra, in 12th annual convention proceedings, v. 2: Indonesian Petroleum Association, Jakarta, p. 255-264.

Craft, M., and Keelan, D., 1985, Coring, part 7--Analytical aspects of sidewall coring: World Oil, v. 201(4), September, p. 77-90.

Crain, E.R., 1981, Log evaluation results in the Deep Basin area of Alberta, paper A, in 8th formation evaluation symposium transactions: Canadian Well Logging Society, 14 p.

Crain, E.R., 1986, The log analysis handbook, volume 1--Quantitative log analysis methods: PennWell Books, Tulsa, 684 p.

Crane, S.D., 1990, Impacts of microporosity, rough pore surfaces and conductive minerals on saturation calculations from electric measurements--an extended Archie's "law", paper AA, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 21 p.

Crues, J.V., Jr., 1982, Recognizing large SP anomalies in the Cretaceous carbonates along the Balcones systems and how to interpret them: Bulletin of the South Texas Geological Society, v. 23(5), December, p. 16-27. Reprinted in 1986, in W.L. Stapp, editor, Contributions to the geology of south Texas, 1986: South Texas Geological Society, San Antonio, p. 398-406.

Czubek, J.A., 1976, Comparison of nuclear well logging data with the results of core analysis, in Nuclear techniques in geochemistry and geophysics: International Atomic Energy Agency, Vienna, Austria, p. 93-106.

Dahlberg, K.E., 1989, A practical model for analysis of compensated neutron logs in complex formations, paper PP, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p.

Davis, B.K., 1981, Log analysis in the search for brackish water in the Kurnub and Arad Groups in the northeastern Negev: Israel Journal of Earth Sciences, v. 30, p. 93-101.

de Pazzis, L.L., Delahaye, T.R., Besson, L.J., and Lombez, J.P., 1989, New gas logging system improves gas shows analysis and interpretation, SPE-19605, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 345-353.

de Waal, J.A., 1987, Influence of clay distribution on shaly sand conductivity, SPE-16786, in 1987 annual technical conference and exhibition proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 421-429. Later published in 1989, SPE Formation Evaluation, v. 4(3), September, p. 377-383.

de Witte, L., 1972, Formation evaluation, chapter 4, in G.V. Chilingar, R.W. Mannon, H.R. Rieke, III, editors, Oil and gas production from carbonate rocks: Elsevier, New York, 143-215.

Deakin, M.J.W., 1987, Wettability, formation resistivity factor and excess conductivity, SPE-16518: Society of Petroleum Engineers, unsolicited paper, 13 p.

Dennis, C.B., and Lawrence, T.D., 1984, Log evaluation of clastic shaly formations using corrected R_{wa}-ratio techniques, paper R, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p.

Desbrandes, R., 1985, Encyclopedia of well logging: Gulf Publishing Company, Houston, 585 p.

Desbrandes, R., and Gualdron, J., 1987, In situ rock wettability determination with formation pressure, paper Z, in 28th annual logging symposium transactions: Society of Professional Wel Log Analysts, 20 p. Later published in 1988, The Log Analyst, v. 29(4), July-August, p. 244-252.

Dewan, J.T., 1983, Essentials of modern open-hole log interpretation: PennWell Books, Tulsa, 361 p.

Dickey, P.A., 1986, Electrical and other wireline logs, chapter 5, in Petroleum development geology, 3rd edition: Petroleum Publishing Co., Tulsa, p. 62-98.

Djevanshir, R.D., 1987, Relationships between clay minerals, low temperatures, high pore pressures, and oil and gas reservoirs at great depths in the Baku archipelago, U.S.S.R.: Journal of Petroleum Science and Engineering, v. 1(2), December, p. 155-162.

Donaldson, E.C., and Bizerra, M.J., 1985, Relationship of wettability to the Archie saturation component, in 3rd international UNITAR/UNDP heavy crude and tar sands conference preprints [Long Beach, California, July 22-31, 1985], v. 2: United Nations Institute for Training and Research, Information Center for Heavy Crude and Tars, New York, p. 664-684. Later published in 1989, as Donaldson, E.C., and Siddiqui, T.K., SPE Formation Evaluation, v. 4(3), September, p. 359-370.

Donaldson, E.C., and Siddiqui, T.K., 1987, Relationship between the Archie saturation exponent and wettability, SPE-16790, in volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, 1987 annual meeting [Dallas], proceedings, p. 439-446.

Donovan, H.L., 1982, Determining water saturation in anisotropic shaly formations: Canadian Well Logging Society Journal, v. 11(1), p. 19-28.

Draxler, J.K., and Edwards, D.P., 1986, Evaluation procedures in the Carboniferous of northern Europe, in J. Brooks, J.C. Goff, and B. van Hoorn, editors, Habitat of Paleozoic gas in NW Europe: Geological Society of London, Edinburgh, Special Publication No. 23, p. 151-167.

Dresser Atlas, 1984, Well logging and interpretation techniques, the home study course: Dresser Industries, Houston, Publication No. 9333, variously paginated. [Includes a discussion on the use of SP for evaluating depositional environments.]

Dunlap, H.F., and Dorfman, M.H., 1981, Problems and partial solutions of using the SP log to predict water salinity in deep hot wells, in D.G. Bebout and A.L. Bachman, editors, 5th conference on geopressured-geothermal energy, proceedings: Louisiana State University, Baton Rouge, p. 189-192. Also published in 1981, Geothermal Resource Council Transactions, v. 5, October, p. 283-286.

Dunlap, H.F., Dupree, J.H., Jr., and Lower, T.A., 1985, Effect of makeup water and mud additives on drilling fluid resistivity, in M.H. Dorfman and R.A. Morton, editors, 6th U.S. Gulf Coast geopressured-geothermal energy conference [Austin, Texas, February 4-6], proceedings: Pergamon Press, New York, p. 149-155.

Dusenbery, R.A., and Osoba, J.S., 1986, Determination of formation water resistivity using shale properties, SPE-14137, in 1986 SPE Permian Basin oil and gas recovery conference, proceedings: Society of Petroleum Engineers, p. 387-397.

Dyos, C.J., Petler, J.S., Jones, M.R.O., Cuddy, S., and Wilkinson, D., 1988, Reconciliation of S_w from logs and core in the North Sea Magnus Jurassic sandstone reservoir, paper D, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 10 p.

Dziuba, T.T., 1986, Mud filtrate effects on the laterolog in Alberta foothills carbonates, paper 86-37-16, in 36th annual technical meeting of the Petroleum Society of CIM preprints, v. 1: Petroleum Institute of the Canadian Institute of Mining, Calgary, p. 211-234. Later published in 1987, Journal of Canadian Petroleum Technology, v. 26(5), September-October, p. 41-50.

Edelstein, W.A., Roemer, P.B., Mueller, O.M., Vinegar, H.J., and Tutunjian, P.N., 1988, NMR imaging for core analysis, SPE-18272, in 1988 SPE annual technical conference and exhibition proceedings, volume sigma, Reservoir engineering: Society of Petroleum Engineers, p. 101-112.

Edwards, D.P., Lacour-Gayet, P.J., and Suau, J., 1981, Log evaluation in wells drilled with inverted oil emulsion mud, SPE-10206: Society of Petroleum Engineers, 56th annual meeting [San Antonio] preprint, 19 p.

Ehrlich, R., and Davies, D.K., 1989, Image analysis of pore geometry; relationship to reservoir engineering and modeling, SPE-19054, in SPE gas technology symposium [Dallas], proceedings: Society of Petroleum Engineers, p. 15-30.

El Shafai, I., Zaki, M., and Andreani, M., 1989, Estimating formation permeability and producibility in oil-based mud using the EPT, SPE-17946, in SPE Middle East oil technical conference and exhibition [Manama, Bahrain], proceedings: Society of Petroleum Engineers, p. 181-186.

Elek, I., 1990, Fast porosity estimation by principal component analysis: Geobyte, v. 5(3), p. 25-34.

Elkington, P.A.S., and Patel, H.K., 1987, R_t determination from digital induction conductivity measurements, paper D, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p. Also published in 1987, in 11th formation evaluation symposium transactions, paper G: Canadian Well Logging Society, 20 p.

Elliott, P.J., and Thomas, L.T., 1986, Interpetation of lithology from the formation resistivity methods for a homogeneous half-space: Exploration Geophysics, v. 17(2), June, p. 75-79.

Ellis, D.V., 1987, Well logging for earth scientists: Elsevier Science Publishing Company, New York, 532 p.

Ellis, D., and Boucau, J., 1983, The future development of logging techniques: Oil and Enterprise, no. 2, September, p. 60-66.

Ellis, D., Howard, J., and others, 1988, Mineral logging parameters--Nuclear and acoustic: The Technical Review, v. 36(1), p. 38-52.

Enderlin, M.B., Hansen, D.K.T., and Hoyt, B.R., 1989, The role of rock volumes in log-to-core integration, paper B, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 14 p.

Eriksen, S.H., 1988, Use of the EPT and capillary pressure to estimate saturation and permeability; a case study, paper L, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 23 p.

Eslinger, E., and Pevear, D., 1988, Clay minerals and log analysis, chapter 9, in Clay minerals for petroleum geologists and engineers: Society of Economic Mineralogists and Paleontologists, Short Course Notes No. 22, 38 p.

Etnyre, L.M., 1989, Finding oil and gas from well logs: Van Nostrand Reinhold, New York, 306 p.

Evans, C.B., 1980, The changing role of well logging in reservoir evaluation--A challenge of the 1980s, in Tenth world petroleum congress, proceedings, v. 3: London, Heyden, p. 181-189.

Everett, R.V., Schweitzer, J.S., and Baker, P.L., 1987, Grain size effects on electromagnetic and spectrometry logs, paper R, in 11th formation evaluation symposium transactions: Canadian Well Logging Society, 32 p.

Farina, J., 1984, Geological applications of reservoir engineering tools: AAPG Continuing Education Course Note Series No. 28, 99 p.

Fertl, W.H., 1972, Status of shaly sand evaluation, paper I, in 4th formation evaluation conference transactions: Canadian Well Logging Society, 26 p.

Fertl, W.H., 1977, Shale density studies and their application, in G.D. Hobson, editor, Developments in petroleum geology no. 1: Applied Science Publishers, London, p. 293-327.

Fertl, W.H., 1978, How subsurface temperature affects formation evaluation: Oil and Gas Journal, v. 76(30), July 24, p. 54-62.

Fertl, W.H., 1979, Interpretive well logging concepts assist south Texas formation evaluation problems: Transactions of the Gulf Coast Association of Geological Societies, v. 29, p. 64-73.

Fertl, W.H., 1980, Well log analysis concepts in clastic and argillaceous U.S. Gulf Coast sediments: Transactions of the Gulf Coast Association of Geological Societies v. 30, p. 81-89.

Fertl, W.H., 1983, Advances in well logging and well interpretation, in 11th world petroleum congress, proceedings, volume 3: John Wiley, New York, p. 341-354. Later published in condensed form in 1984, Oil and Gas Journal, v. 82(16), April 16, p. 85-91.

Fertl, W.H., 1986, Log-derived evaluation of shaly clastic reservoirs, SPE-14061, in 1986 SPE international meeting on petroleum engineering [Beijing, March 17-20], proceedings: Society of Petroleum Engineers. Later published in 1987, Journal of Petroleum Technology, v. 39(2), p. 175-194.

Fertl, W.H., 1986, Clay typing based on well logs, paper 86-37-18, in 37th annual technical meeting of the Petroleum Society of CIM [Calgary, June 8-11], preprints, v. 1, : Petroleum Institute of the Canadian Institute of Mining, Calgary, p. 257-272.

Fertl, W.H., and Chilingar, G.V., 1988, Determination of volume, type, and distribution modes of clay minerals from well logging data, SPE-17145, in 8th SPE symposium on formation damage control, proceedings: Society of Petroleum Engineers, p. 13-28.

Fertl, W.H., and Chilingarian, G.V., 1990, Type and distribution modes of clay minerals from well logging data: Journal of Petroleum Science and Engineering, v. 3(4), January, p. 321-332.

Fertl, W.H., and Frost E., Jr., 1979, Evaluation of shaly clastic reservoir rocks, SPE-8450: Society of Petroleum Engineers, 54th annual meeting [Las Vegas] preprint. Later published in 1980, Journal of Petroleum Technology, v. 31(9), p. 1641-1646. Reprinted in 1981, in Spectralog: Dresser Industries, Houston, Publication No. 3334.

Fertl, W.H., and Hammack, G.W., 1971, A comparative look a water saturation computations in shaly pay sands, paper R, in 12th annual logging symposium transactions: Society of Professional Well Log Analysts, 18 p. Reprinted in 1972, The Log Analyst, v. 13(2), March-April, p. 12-20.

Fertl, W.H., and Hammack, G.W., 1976, Solid particle penetration into porous reservoir rocks and its effect on well log analysis, paper F, in 17th annual logging symposium transactions: Society of Professional Well Log Analysts, 10 p.

Fertl, W.H., King, E.E., Vercellino, W.C., Kumar, R., Denoo, S., Schoonover, L.G., and Aguilera, R., 1978, Practical log analysis--A twenty-two part series: Oil and Gas Journal, v. 76-77, May 15, 1978 through September 19, 1979.

Fertl, W.H., and Martin, J.R., 1987, Well logging technology for highly deviated and horizontal boreholes: Journal of Petroleum Science and Engineering, v. 1, p. 83-90.

Fertl, W.H., and Nice, S.B., 1988, Well logging in extended-reach and horizontal boreholes, OTC-5828, in 20th annual offshore technology conference proceedings, v. 4: Society of Petroleum Engineers, p. 193-206.

Finklea, E.E., 1981, Advanced logging techniques, paper 3-11, in World oil and natural gas supplies, workshop proceedings [June 1979]: Electric Power Research Institute Report No. WS-79-182, 23 p.

Flaum, C., moderator, 1989, Strategies for thin-bed formation evaluation, a round-table discussion: Schlumberger Oilfield Research, v. 1(3), October, p. 28-42.

Focke, J.W., and Munn, D., 1985, Cementation exponents in Middle Eastern carbonate reservoirs, SPE-13735, in SPE Middle East oil technical conference and exhibition [Bahrain, March 11-14], proceedings: Society of Petroleum Engineers. Later published in 1987, SPE Formation Evaluation, v. 2(2), p. 155-167.

Focke, J.W., and van Popta, J., 1989, Reservoir evaluation of the Permian Gharif Formation, sultanate of Oman, SPE-17978, in SPE Middle East oil technical conference and exhibition [Manama, Bahrain], proceedings: Society of Petroleum Engineers, p. 517-528.

Frank, R.W., 1978, Formation evaluation with logs in the Ark-La-Tex Cotton Valley: Transactions of the Gulf Coast Association of Geological Societies, v. 28, part 1, p. 131-141.

Frank, R.W., 1986, Prospecting with old E-logs: Schlumberger Educational Services, Houston, 161 p.

Freedman, R., and Grove, G.P., 1988, Interpretation of EPT-G logs in the presence of mudcakes, SPE-18116, in 1988 SPE annual technical conference proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 87-102.

Funk, J.J., Choinski, M.C., Saxman, B.B., and Callender, 1989, Characterization of carbonate porosity using petrophysical properties and image analysis, SPE-17943, in SPE Middle East oil technical conference and exhibition [Manama, Bahrain], proceedings: Society of Petroleum Engineers, p. 143-153.

Ganer, B.L., 1985, Case history of Cotton Valley sand log interpretation for a north Louisiana field: Journal of Petroleum Technology, v. 37(11), SPE-12182, p. 1995-2205.

Gardner, G.H.F., Gardner, L.W., and Gregory, A.R., 1974, Formation velocity and density--The diagnostic basics for stratigraphic traps: Geophysics, v. 39(6), December, p. 770-780.

Garg, R.C., Saxena, G.C., and Gupta, R., 1988, Dielectric log in fresh water Tipam sands in Upper Assam, India, SPE-18586: Society of Petroleum Engineers, unsolicited manuscript, 16 p.

Garga, P., Sharma, S.K., and Gupta, D.K., 1982, A new model for the interpretation of logs of TS-1 and TS-2 sands of Lakwa and Lakhmani: Bulletin of the Oil and Natural Gas Commission [India], v. 19(2), p. 221-228.

Gautier, D.L, Starkey, H.C., and Takahashi, K.I., 1983, Clays, cations and geophysical log response of gas-producing and non-producing zones in the Gammon Shale (Cretaceous), southwestern North Dakota: Clays and Clay Minerals, v. 31(2), p. 122-128.

Gianzero, S.C., Konene, C.E., Chemali, R.E., and Strickland, R.W., 1986, Sondes for big hole logging, SPE-15542: Society of Petroleum Engineers, 61st annual meeting [New Orleans] preprint, 9 p.

Gillard, P., and Boigelot, J., 1989, Cementation factor analysis--a case study from an Albo-Cenomanian dolomitic reservoir of the Lower Congo basin in Angola, paper E, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 12 p.

Gilliland, R.E., and Coles, M.E., 1989, Use of CT scanning in the investigation of damage to unconsolidated cores due to coring operations and handling procedures, SCA-8902, part III, paper B, in Annual technical conference reprints, v. 1 (1987-1989): Society of Professional Well Log Analysts, Society of Core Analysts SPWLA Chapter-at-Large, 13 p.

Gilmore, W.H., and Sanclemente, J.B., 1989, A case history review of the effects of drilling fluids on shale stability in the central Gulf of Mexico, SPE/IADC-18640, in 1989 SPE/IADC drilling conference, proceedings: Society of Petroleum Engineers, p. 867-874.

Gilreath, J.A., 1968, Electric log characteristics of diapiric shale, in J. Braunstein and G.D. O'Brien, editors, Diapirism and diapirs: American Association of Petroleum Geologists, Memoir No. 8, p. 137-144.

Givens, W.W., 1986, Formation factor, resistivity index, and related equations based upon a conductive rock matrix model (CRMM), paper P, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 18 p. Later published in 1987, The Log Analyst, v. 28(2), March-April, p. 138-151.

Givens, W.W., and Schmidt, E.J., 1988, A generic electrical conduction model for low-contrast resistivity sandstones, paper E, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 25 p.

Gladwin, M.T., Rowlands, D., and Leven, J., 1987, A multifunction sonde for horizontal borehole logging: Geoexploration, v. 24(4-5), p. 329-345.

Glanville, C.R., 1970, Log interpretation of thinly-bedded oil-productive sands with unusually low resistivities, paper M, in 11th annual logging symposium transactions: Society of Professional Well Log Analysts.

Glanville, C.R., 1984, A method for direct log calculation of excess conductivity applied to shaly sand log interpretation, paper, in 25th annual logging symposium transactions X: Society of Professional Well Log Analysts, 17 p.

Goetz, J.F., Chemali, R., and Seifert, D.J., 1989, Thin bed resolution and the determination of flushed zone resistivity in oil-based mud, paper I, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 14 p.

Goetz, J.F., Prins, W.J., and Logar, J.F., 1977, Reservoir delineation by wireline techniques: The Log Analyst, v. 18(5), September-October, p. 12-40.

Gomez-Rivero, O., 1982, Physical basis of well logging, chapter 6, in K.C. Jain and R.J.P. deFigueiredo, editors, Concepts and techniques in oil and gas exploration: Society of Exploration Geophysicists, p. 161-198.

Goodchild, M.W., and Bryant, P., 1986, The geology of the Rough gas field, in J. Brooks, J.C. Goff, and B. van Hoorn, editors, Habitat of Paleozoic gas in NW Europe: Geological Society of London, Edinburgh, Special Publication No. 23, p. 223-235.

Gray, T., and Rasmus, J.C., 1988, A laboratory study of oomoldic rock substantiating a conductivity-dielectric interpretation technique and the non-interdependence of the Archie petrophysical parameters, paper J, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 25 p.

Grief, M.A., and Koopersmith, C.A., 1985, Petrophysical evaluation of thinly bedded reservoirs in high angle/displacement development wells with the NL Baroid recorded lithology logging system, paper S, in 10th formation evaluation symposium transactions: Canadian Well Logging Society, 12 p.

Griffin, T.J., Jr., 1983, The CoRes log, a core-resistivity log evaluation for enhanced formation evaluation: Canadian Well Logging Society Journal, v. 12(1), p. 73-86. Later reprinted in 1984, in J.A. Lorsong, and M.A. Wilson, editors, Oil and gas in Saskatchewan: Saskatchewan Geological Society Special Publication No. 7, p. 271-281.

Gundestrup, N.S., and Hansen, B.L., 1984, Bore-hole survey at Dye 3, south Greenland: Journal of Glaciology, v. 30(106), p. 282-288.

Guo, Y.A., 1986, Estimation of TDS in sand aquifer water through resistivity log: Ground Water, v. 24(5), p. 598-600.

Hagiwara, T., 1986, Archie's "m" for permeability: The Log Analyst, v. 27(1), January-February, p. 39-42.

Hallenburg, J.K., 1978, Use of the spontaneous potential curve in a mineral mapping technique, paper U, in 19th annual logging symposium transactions: Society of Professional Well Log Analysts, 12 p.

Hallenburg, J.K., 1984, Geophysical logging for mineral and engineering applications: PennWell Books, Tulsa, 254 p.

Halyburton, R.V., and Locke, A.L., 1988, Log response in a pyrite-cemented sandstone reservoir--A case study from offshore north Western Australia, OSEA-88160, in 7th offshore South East Asia conference proceedings: Southeast Asia Petroleum Society, p. 526-530.

Hammond, H., and Forbes, D., 1989, An updated approach to shallow gas evaluation, paper Q, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 25 p.

Hardwick, A., 1989, X_{ls}; a new shale parameter for resistivity log evaluation, SPE-19576, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 39-48.

Hartmann, D.J., 1975, Effect of bed thickness and pore geometry on log response, paper Y, in 16th annual logging symposium transactions: Society of Professional Well Log Analysts.

Hartmann, D.J., 1985, Formation evaluation, pay recognition, subtle trap definition: Society of Economic Paleontologists and Mineralogists, Continuing Education Seminar Notes, 45 p.

Hassan, M., 1973, Radio elements and diagenesis in shale and carbonate sediments, paper 7, in 2nd annual logging symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 12 p.

Hastings, A., 1982, Identifying gas in low porosity fractures; Gulf of Sabinas, Mexico: The Technical Review, v. 30(3), December, p. 26-42.

Hawkins, J., 1989, Comparison of three methods of relative permeability measurement, SCA-8804, part II, paper D, in Annual technical conference reprints, v. 1 (1987-1989): Society of Professional Well Log Analysts, Society of Core Analysts, Chapter-at-Large, 16 p. Later published in 1989, The Log Analyst, v. 30(5), September-October, p. 363-371.

Hearst, J.R., and Nelson, P.H., 1985, Well logging for physical properties: McGraw-Hill, New York, 576 p.

Heflin, J.D., Neill, B.E., and DeVries, M.R., 1976, Log evaluation in the California Miocene, SPE-6160: Society of Petroleum Engineers, 51st annual meeting [New Orleans] preprint, 17 p. Reprinted in 1981, Spectralog: Dresser Industries, Houston, Publication No. 3334.

Helal, A.N., and Schon, J.H., 1989, Determination of the Archie's exponent "m" and matrix parameters from logs by an iterative method, paper F, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 8 p.

Helander, D.P., 1983, Fundamentals of formation evaluation: Oil and Gas Consultants International, Tulsa, 332 p.

Helgoy, R., 1984, Prediction techniques from logging tools--Are the results confirmed by testing?, paper G4, in Offshore North Seas conference [August 21-24, Stavanger] : Norwegian Petroleum Scoiety, Stavanger, 25 p.

Hemphill, A.T., and Mayes, T.M., 1988, Obtaining native-state cores with a specially designed water-free coring fluid, IADC/SPE-17243, in 1988 IADC/SPE drilling conference proceedings: Society of Petroleum Engineers, p. 529-535.

Henry, K.C., 1979, Gas detection in the extremely shaly Bowdoin Formation of northern Montana, paper T, in 20th annual logging symposium transactions: Society of Professional Well Log Analysts, 45 p.

Hensel, W.M., Jr., 1987, A perspective look at fracture porosity, SPE-16806, in 1987 SPE annual technical conference proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 571-578. Reprinted in 1988, in Permian basin oil and gas recovery symposium, proceedings: Society of Petroleum Engineers, p. 65-72. Later published in 1989, SPE Formation Evalution, v. 3(4), December, p. 531-534.

Herrick, D.C., 1988, Conductivity models, pore geometry, and conduction mechanisms, paper D, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 24 p.

Heslop, A., 1972, Gamma-ray log response of shaly sandstone: Canadian Well Logging Society Journal, v. 5(1), p. 29-38. Reprinted in 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. II59-II69.

Hiatt, C.R., and Nordeng, S., 1985, A petrographic and well log analysis of five wells in the Trenton-Utica transition in the northern Michigan Basin, in Ordovician and Silurian rocks of the Michigan Basin and its margins: Michigan Basin Geological Society Special Paper No. 4, p. 33-43.

Hietala, R.W., and Connolly, E.T., 1984, Integrated rock-log calibration in the Elmworth Field, Alberta Canada--Part II, Well log analysis methods and techniques, in J.A. Masters, editors, Elmworth--case study of a Deep Basin gas field: AAPG Memoir No. 38, p. 215-242.

Hietala, R.W., Connolly, E.T., King, H.R., and Sneider, R.M., 1984, Integrated rock-log calibration in the Elmworth Field, Alberta Canada--Part III, Selected samples illustrating integration of rock-log data to determine reservoir petrophysical characteristics, in J.A. Masters, editors, Elmworth--case study of a Deep Basin gas field: AAPG Memoir No. 38, p. 243-282.

Higgins, L., Ghauri, A., and Sinha, A., 1989, Recent advancements in reservoir description techniques: Transactions Gulf Coast Association of Geological Societies, v. 29, p. 97-103.

Hilchie, D.W., 1978, Applied openhole log interpretation: D.W. Hilchie, Inc., Golden, CO., variously paginated.

Hilchie, D.W., 1979, Old (pre-1958) electical log interpretation: D.W. Hilchie Inc., Golden, CO., 161 p.

Hilchie, D.W., 1982, Advanced well log interpretation: D.W. Hilchie, Inc., Golden, CO., variously paginated.

Hilchie, D.W., 1985, SP (spontaneous potential) hydrocarbon suppression (a conceptual approach): Canadian Well Logging Society Journal, v. 14, p. 43.

Hilchie, D.W., 1988, NML-The hope for production prediction: Journal of Petroleum Technology, v. 40(3), P. 273-275.

Hill, D.G., 1986, Geophysical well log calibration and quality control, in P.G. Killeen, editor, Borehole geophysics for mining and geotechnical applications [international symposium and workshop, (Toronto, Ontario, August 29-31, 1983), proceedings]: Geological Survey of Canada Paper 85-27, p. 379-392.

Hirakawa, S., and Miyake, Y., 1983, A method for well log interpretation of a carbonate oil reservoir: Butsuri-Tanko, v. 36(4), p. 22-31.

Hobson, G.D., 1989, Carbonate deposits and oil accumulations, chapter 12, in Mason, J.F., and Dickey, P.A., editors, Oil field development techniques: AAPG Studies in Geology No. 28, p. 159-174.

Hobson, G.D., and Tiratsoo, E.N., 1975, Formation evaluation, chapter 7, in Introduction to petroleum geology: Scientific Press, Ltd., Beaconsfield, England, p. 176-204.

Holbrook, P.W., 1985, A new method for estimating hydrocarbon saturation in shaley sands for exploration applications, paper GGG, in 26th annual logging symposium transactions : Society of Professional Well Log Analysts, 27 p.

Holgate, M.M., 1960, The microlog as a porosity datum for the neutron log in the Swan Hills field, Alberta: Canadian Institute of Mining and Metallurgy [CIM] Bulletin, v. 53, p. 324-328.

Holloway, J.W., and Michael Holmes, M., 1990, Oil, gas, and water saturations calculated as separate entities from density, neutron, and resistivity logs, paper MM, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 15 p.

Holmes, M., 1980, A new method for calculating water resistivity from logs within hydrocarbon-bearing intervals, paper C, in 21st annual logging symposium transactions: Society of Professional Well Log Analysts, 15 p.

Honarpour, M., DeGroat, C., and Manjnath, A., 1986, How temperature affects relative permeability measurement: World Oil, v. 202(5), May, p. 116-126.

Honarpour, M., Szpakiewicz, M., Sharma, B., Chang, M-M., Schatzinger, R., Jackson, S., Tomutsa, L., and Maerefat, N., 1989, Integrated reservoir assessment and characterization, final report: U.S. Department of Energy Report No. NIPER-390, 336 p.

Honarpour, M.M., Szpakiewicz, M.J., Schatzinger, R.A., Tomutsa, L., Carroll, H.B., Jr., and Tillman, R.W., 1988, Integrated geological/engineering model for barrier island deposits in Bell Creek field, Montana, SPE-17366, in 6th SPE/DOE Enhanced oil recovery symposium proceedings: Society of Petroleum Engineers, p. 491-512.

Hsieh, F.S., 1990, Introducing a new resistivity log equation, SPE-20299: Society of Petroleum Engineers, unsolicited paper, 9 p.

Hurst, A., 1987, Problems of reservoir characterization in some North Sea sandstone reservoirs solved by application of microscale geological data, chapter 11, in J. Kleppe, E.W. Berg, A.T. Buller, O. Hjelmeland, and O. Torsaeter, editors, North Sea oil and gas reservoirs: Graham & Totman Ltd., London, p. 153-167.

Hurst, A., and Archer, J.S., 1986, Some applications of clay mineralogy to reservoir description: Clay Minerals, v. 21, p. 811-826.

Hurst, A., and Archer, J.S., 1986, Sandstone reservoir description--An overview of the role of geology and mineralogy: Clay Minerals, v. 21, p. 791-809.

Hutcheon, I., and Lefebvre, R., 1988, Sedimentology, diagenesis and thermal effects on petrophysical properties in the Aberfeldy field, Saskatchewan: Bulletin of Canadian Petroleum Geology, v. 36(1), March, p. 70-85.

Huurdeman, A.J.M., Breunese, J.N., Al-Asbahi, A., Lutgert, J.E., and Floris, F.J.T., 1989, Assessment of halite-cemented reservoir zones with a combined geological/engineering approach; a case study, SPE-19603, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 335-343.

Hynson, M.F., Chiasson, C.G., and Brugler, M.L., 1989, Offshore Gulf Coast formation evaluation; comparison and use of unconsolidated core data, wireline logs, and sidewall core data, SCA-8906, part III, paper F, in Annual technical conference reprints, v. 1 (1987-1989): Society of Professional Well Log Analysts, Society of Core Analysts SPWLA Chapter-at-Large, 21 p.

Itoh, T., Kato, S., and Miyairi, M., 1982, A quick method of log interpretation for very low resistivity volcanic tuff by the use of CEC data, paper NN, in 23rd annual logging symposium transactions: Society of Professional Well Log Analysts, 26 p.

Jain, K.C., 1982, Well logs in exploration, chapter 7, in K.C. Jain and R.J.P. deFigueiredo, editors, Concepts and techniques in oil and gas exploration: Society of Exploration Geophysicists, p. 199-226.

Janssen, J.C., and Nunn, J.A., 1985, Bulk density, velocity, and porosity relationships in Tertiary sandstones of southwest Louisiana, in B.F. Perkins and G.B. Martin, editors, Habitat of oil and gas in the Gulf Coast [Gulf Coast Section SEPM 4th annual research conference (Houston, November 27-30, 1983), proceedings]: Gulf Coast Section Society of Economic Paleontologists and Mineralogists, p. 129-138.

Javandel, I., 1989, On the field determination of effective porosity, in Conference on new field techniques for quantifying the physical and chemical properties of heterogeneous aquifers [March 20-23, Dallas, TX], proceedings: National Water Well Association, Dublin, OH, p. 155-172.

Jennings, H.Y., and Timur, A., 1973, Significant contributions in formation evaluation and well testing: Journal of Petroleum Technology, v. 25(12), p. 1432-1446, SPE-4704.

Johnson, D.E., and Pile, K.E., 1988, Well logging for the nontechnical person: PennWell Publishing Co., Tulsa, 198 p.

Johnson, H.D., and Stewart, D.J., 1985, Role of clastic sedimentology in the exploration and production of oil and gas in the North Sea, in P.J. Brenchley and B.P.J. Williams, editors, Sedimentology--Recent developments and applied aspects: Blackwell Scientific Publications, Boston, p. 249-310.

Johnson, W., 1978, Effect of shale on log response: Canadian Well Logging Society Journal, v. 10(1), p. 29-57.

Johnson, W.L., and Linke, W.A., 1977, Some practical applications to improve formation evaluation of sandstones in the Mackenzie Delta, paper R, in 6th formation evaluation symposium transactions: Canadian Well Logging Society, 19 p. Reprinted in 1978, in 19th logging symposium transactions, paper C: Society of Professional Well Log Analysts, 19 p. Reprinted 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. V47-79.

Johnston, D.H., 1987, Physical properties of shale at temperature and pressure: Geophysics, v. 52(10), October, p. 1391-1401. An abbreviated version published in 1986, Oil and Gas Journal, v. 84(44), November 3, p. 60-65.

Jorden, J.R., and Campbell, F.L., 1984, Well logging I--Rock properties, borehole environment, mud and temperature logging: Society of Petroleum Engineers, Monograph Series No. 9, 167 p.

Jorden, J.R., and Campbell, F.L., 1986, Well logging II--Electric and acoustic logging: Society of Petroleum Engineers, Monograph Series No. 10, 192 p.

Jorgensen, D.G., 1989, Using geophysical logs to estimate porosity, water resistivity, and intrinsic permeability: U.S. Geological Survey Water-Supply Paper 2321, 24 p.

Joyce, D.G., and Pitts, H., 1987, Results of quicklook overlays of electromagnetic propagation logs with high resolution porosity logs in western Canada, paper Z, in 11th formation evaluation symposium transactions: Canadian Well Logging Society, 10 p.

Juhasz, I., 1986, Assessment of the distribution of shale, porosity and hydrocarbon saturation in shaly sands, paper AA, in 10th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Aberdeen Chapter, 15 p.

Kamon, K., and Dorfman, M.H., 1986, Identification of carbonate depositional texture from well-log response; West Seminole field, Gaines County, Texas, in D.G. Bebout and P.M. Harris editors, Hydrocarbon reservoir studies, San Andres/Grayburg Formations, Permian basin [Proceedings of research conference, Midland, Texas, October 7-9, 1986]: Society of Economic Mineralogists and Paleontologists, Permian Basin Chapter Publication 86-26, p. 75-77.

Kane, A., 1968, Some solutions to logging problems on the west side of the California's San Joaquin Valley, in S.E. Karp, editor, Geology and oilfields, west side southern San Joaquin Valley: Pacific Sections AAPG/SEPM/SEG, Bakersfield, 43rd annual meeting guidebook, p. 43-48.

Kartawidjaja, F., and Luciani, J.P., 1985, The streaming SP--A flow indicator, in 14th annual convention proceedings: Indonesian Petroleum Association, Jakarta, p. 611-633.

Kashik, A.S., Gogonenkov, G.N., and Sokhranov, N.N., 1980, Use of well logging for defining oil and gas pool limits, in Tenth world petroleum congress, proceedings volume 3: Heyden, London, p. 157-163.

Kaufman, A.A., and Keller, G.V., 1989, Induction Logging: Elsevier, Amsterdam, Methods in Geochemistry and Geophysics No. 27, 600 p.

Keech, D.A., 1988, Hydrocarbon thickness on groundwater by dielectric well logging, in Conference on petroleum hydrocarbons and organic chemicals in ground water; prevention detection, and restoration [November 9-11, Houston]: National Water Well Association, Dublin, Ohio, p.275-289.

Keelan, D., 1985, Coring, part 8--Plug and full diameter analysis: World Oil, v. 201(6), November, p. 103-111.

Keelan, D.K., and McGinley, D.C., 1979, Application of cation exchange capacity in a study of the Shannon Sand of Wyoming, paper W, in 20th annual logging symposium transactions: Society of Professional Well Log Analysts.

Keith, B.D., and Pittman, E.D., 1983, Bimodal porosity in oolitic reservoir--Effect on productivity and log response, Rodessa Limestone (Lower Cretaceous), East Texas Basin: AAPG Bulletin, v. 67(9), p. 1391-1399.

Keller, G.V., 1967, Induced polarization well logging, paper W, in 8th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p.

Kennaird, T., 1988, Some appliations of the combined use of core analysis and electric log data: Bulletin Geological Society of Malaysia [Buletin Persatuan Geologi Malaysia], no. 22, p. 85-99.

Kenyon, W.E., and Baker, P.L., 1984, EPT interpretation in carbonates drilled with salt muds, SPE-13192: Society of Petroleum Engineers, 59th annual meeting [Houston] preprint. Later published in 1986, SPE Formation Evaluation, v. 1(5), p. 521-531.

Kenyon, W.E., Day, P.I., Straley, C., and Willemsen, J.F., 1986, Compact and consistent representation of rock NMR data from permeability estimation, SPE-15643: Society of Petroleum Engineers, 61st annual meeting preprint, 22 p. Later published in 1988 as, A three-part study of NMR longitudinal relaxation properties of water-saturated sandstones: SPE Formation Evaluation, v. 3(3), p. 622-636.

Kerford, S.J., and Georgi, D.T., 1987, Application of time-series analysis to wireline logs, paper M, in 11th formation evaluation symposium transactions: Canadian Well Logging Society, 19 p. Later published in 1990: The Log Analyst, v. 31(3), May-June, p. 150-157.

Kern, J.W., Hoyer, W.A., and Spann, M.M., 1976, Low porosity gas sand analysis using cation exchange and dielectric constant data, paper PP, in 17th annual logging symposium transactions: Society of Professional Well Log Analysts, 17 p. Reprinted 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. I69-I85.

Kersey, D.G., 1986, Coring, part 9-Geological aspects: World Oil, v. 202(1), January, p. 103-108.

Keys, W.S., and MacCary, L.M., 1973, Location and characteristics of the interface between brine and fresh water from geophysical logs of boreholes in the upper Brazos River basin, Texas: U.S. Geological Survey Professional Paper 809-B, 23 p.

Khatchikian, A., 1982, Log analysis of oil-bearing igneous rocks, paper AA, in 23rd annual logging symposium transactions: Society of Professional Well Log Analysts, 34 p. Later published in condensed form 1983, World Oil v. 197(7), December, p. 79-98.

Khatchikian, A., and Lesta, P, 1973, Log evaluation of tuffites and tuffaceous sandstones in southern Argentina, paper K, in 14th annual logging symposium transactions: Society of Professional Well Log Analysts, 23 p.

Khokhar, R.W., and Johnson, W.M., Jr., 1989, A deep laterolog for ultrathin formation evaluation, paper SS, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 10 p.

King, D.E., 1990, Incorporationg geological data in well log interpretation, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 45-55.

King, D.E., and Quirein, J., 1987, Systematic incorporation of geologic data in the log interpretation process with applications to lithlogy analysis, paper N, in 11th formation evaluation symposium transactions: Canadian Well Logging Society, 14 p.

Koepnick, R.B., 1985, Distribution and permeability of styolite-bearing horizons within a Lower Cretaceous carbonate reserovir in the Middle East, SPE-14173: Society of Petroleum Engineers, 60th annual meeting [Las Vegas], preprint, 7 p.

Koerperich, E.A., 1974, Applications of Waxman-Smits and Archie equations for determination of oil saturation in shaly sand reservoirs, SPE-5038: Society of Petroleum Engineers, 49th annual meeting [Houston] preprint. Later published 1975, Journal of Petroleum Technology, v. 27

Kowalski, J.J., and Asekun, S.O., 1979, It may not be shale, paper P, in 20th annual logging symposium transactions: Society of Professional Well Log Analysts, 15 p. Also published 1979, as paper G, in 7th formation evaluation symposium transactions: Canadian Well Logging Society.

Kramers, J.W., Bachy, S., Cuthiell, D., and others, 1988, The Provost Upper Mannville B pool; an integrated analysis for reservoir characterization, paper 88-39-112, in 39th annual technical meeting, preprints, volume 3: Petroleum Society of CIM [Canadian Institute of Mining], Calgary, 27 p.

Kreigh, K.R., Williams, R.E., and Waldrop, B.S., 1988, The salt solution; an integrated interpretation around a salt dome structure in the Gulf of Mexico, OTC-5679, in 20th annual offshore technology conference proceedings, volume 2: Society of Petroleum Engineers, p. 17-19.

Kutasov, I.M., 1988, Empirical correlation determines downhole mud density: Oil and Gas Journal, v. 86(50), p. 61-63.

Kwader, T., 1982, Interpretation of geophysical logs in shallow carbonate environments and their applications to ground water resource investigations: T. Kwader Inc., 201 p.

Labo, J., 1987, A practical introduction to borehole geophysics--An overview of wireline well logging principles for geophysicists: Society of Exploration Geophysicists, 330 p.

Lacour-Gayet, P., 1981, The Groningen effect: The Technical Review, v. 29(1), p. 37-47.

Land, L.S., and MacPherson, 1989, Geochemistry of formation water, Plio-Pleistocene reservoirs, offshore, Louisiana: Transactions Gulf Coast Association of Geological Societies, v. 29, p. 421-430.

Lang, W.H., Jr., 1986, Correlation with multiple logs: The Log Analyst, v. 27(1), January-February, p. 43-52.

Lau, M.N., and Bassiouni, Z., 1989, Oil detection in fractured carbonates of Chapayal basin, Guatemala: The Log Analyst, v. 30(4), July-August, p. 261-269.

Lawrence, T.D., Ball, S., and Harris, M., 1984, Continuous carbon/oxygen and neutron lifetime log proposed interpretation for organic and/or shaly depositional environments, paper QQ, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 19 p.

Lawrence, T.D., and Fernandez, J., 1987, Simplified dielectric log interpretation in variable salinities using resistivity versus phase angle crossplots, paper L, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 23 p.

Lee, H.J., and Chough, S.K., 1987, Bulk density, void ratio, and porosity determined from average grain and water content--An evaluation of errors: Marine Geotechnology, v. 7(1), p. 53-62.

Leeth, R., and Holmes, M., 1978, Log interpretation of shaly formations using the velocity ratio plot, paper CC, in 19th annual logging symposium transactions: Society of Professional Well Log Analysts, 9 p.

Leitham, R., 1987, Improved saturation determination with the EPT in western Canada's vugular dolomitic carbonates, paper X, in 11th formation evaluation symposium transactions: Canadian Well Logging Society, 15 p.

Levell, B.K., Braakman, J., and Rutten, K.W., 1988, Oil-bearing sediments of Gondwana glaciation in Oman: AAPG Bulletin, v. 72(7), p. 776-796.

Lewis, M.G., Sharma, M.M., and Dunlap, H.F., 1988, Wettability and stress effects on saturation and cementation exponents, paper K, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 24 p.

Lin, W., and Daily, W., 1988, Laboratory-determined transport properties of core from the Salton Sea Scientific Drilling Project: Journal of Geophysical Research, v. 93(B11), November, 10, p. 13,047-13,056.

Lindsey, G.P., 1985, Dry hole resistivity logging, in 1985 NWWA conference on surface and borehole geophysical methods in ground water investigations [Fort Worth, Texas, February 12-14], proceedings: National Water Well Association, Worthington, Ohio, p. 371-376.

Littleton, R.T., and Burnett, E.E., 1976, The salinity profile of the East Mesa Field as determined from dual induction resistivity and SP logs, in 1st EPA workshop on sampling geothermal effluents, proceedings: U.S. Environmental Protection Agency Report No. EPA-600/9-76-011, p. 114-125.

Lock, B.E., 1982, Towards a better understanding of Gulf Coast Miocene deep water sediments: Transactions of the Gulf Coast Association of Geological Societies, v. 32, p. 283-288.

Logan, D., Kovacs, J., and Morriss, C., 1989, Identification of mobile water in bitumen reservoirs using the nuclear magnetic log, paper 89-40-71, in Building on 40 years of achievement [annual meeting preprints, volume II]: Petroleum Society of CIM, Calgary, 16 p.

Longeron, D.G., 1986, Effect of overburden pressure, nature and microscopic distribution of the fluids on electrical properties of rock samples, SPE-15383: Society of Petroleum Engineers, 61st annual meeting preprint, 12 p. Later published in 1989, SPE Formation Evaluation, v. 4(2), p. 194-202.

Longeron, D.G., Argaud, M.J., and Bovier, L., 1989, Resistivity index and capillary pressure measurements under reservoir conditions using crude oil, SPE-19589, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 187-200.

Longton, M.J., and Amiard, J.P., 1988, Improved interpretation in oil base mud systems using the 200 Mhz dielectric tool, paper Z, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 23 p.

Lorenz, J.C., Sattler, A.R., and Stein, C.L., 1989, The effects of depositional environment on petrophysical properties of Mesaverde reservoirs, northwestern Colorado, SPE-19583, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 119-132.

Loutfi, G., and Hamd, M.A., 1989, Permian Khuff in Abu Dhabi; geological re-evaluation using well logs, cores, testing, and sesimic data, SPE-17979, in SPE Middle East oil technical conference and exhibition [Manama, Bahrain], proceedings: Society of Petroleum Engineers, p. 529-543.

Loveless, D.K., McCall, D.C., and Grayson, S., 1988, Logging techniques; new solutions, improved reserves: Petroleum Management, v. 10(7), p. 35-39.

Lovell, J.R., and Chew, W.C., 1990, Effect of tool eccentricity on some electrical well-logging tools: IEEE Transactions on Geoscience and Remote Sensing, v. 28(1), January, p. 127-136.

Lowe, T.A., and Dunlap, H.F., 1986, Estimation of mud filtrate resistivity in fresh water drilling muds: The Log Analyst, v. 27(2), March-April, p. 77-84.

Lucia, F.J., and Conti, R.D., 1987, Rock fabric, permeability, and log relationships in an upward-shoaling, vuggy carbonate sequence: Texas Bureau of Economic Geology Geological Circular 87-5, 22 p.

Luffel, D.L., and Guidry, F.K., 1989, Reservoir rock properties of Devonian shale from core and log analysis, SCA-8910, part III, paper J, in Annual technical conference reprints, v. 1 (1987-1989): Society of Professional Well Log Analysts, Society of Core Analysts SPWLA Chapter-at-Large, 15 p.

MacCary, L.M., 1978, Interpretation of well logs in a carbonate aquifer: U.S. Geological Survey Water-Resources Investigations No. 78-88, 30 p. Later published in 1983 as, Geophysical logging in carbonate aquifers: Ground Water, v. 21(3), p. 324-342.

MacCary, L.M., 1980, Use of geophysical logs to estimate water-quality trends in carbonate aquifers: U.S. Geological Survey Water-Resources Investigations no. 80-57, 23 p.

MacCary, L.M., 1984, Relation of formation factor to depth of burial in aquifers along the Texas Gulf Coast, in D.M. Nielsen and M. Curl, editors, 1984 NWWA/EPA conference on surface and borehole geophysics methods in ground water investigations, proceedings: National Water Well Association, Worthington, Ohio, p. 722-742.

Maciula, E.A., and Cochrane, J.E., 1967, Quantitative use of calibration data to correct miscalibrated well logs, SPE-1940: Society of Petroleum Engineers, 42nd annual meeting [Houston] preprint. Later published in 1968, Journal of Petroleum Technology, v. 20(7), p. 663-670.

Magara, K., 1979, Formation water salinity and its exploration application, paper S, in 7th formation evaluation symposium transactions: Canadian Well Logging Society, 8 p.

Magara, K., 1981, Direct estimate of hydrocarbon volume from a conductivity log: Journal of the Japanese Association of Petroleum Technologists [Sekiyu Gijutsu Kyokaishi] v. 46(3), p. 183-188.

Magara, K., 1986, Lithostatistical study of Frio Formation in Texas Gulf Coast, chapter 12, in Geological models of petroleum entrapment: Elsevier Applied Science Publishers, London, p. 235-263.

Magnusson, K.A., and Duran, O., 1984, Comparison between core, log, hydraulic, and geophysical measurements in boreholes: Geoexploration, v. 22, p. 169-186.

Mahmood, S.M., Maerefat, N.L., and Chang, M.M., 1988, Laboratory measurements of electrical resistivity at reservoir conditions: U.S. Department of Energy Report NIPER-298, 40 p.

Manning, M.J., and Athavale, K.A., 1986, Dielectric properties of pyrite samples at 1100 MHz: Geophysics, v. 51(1), p. 172-182.

Martinovic, S., and Vojnovic, V., 1989, Evaluation of water saturation in oil-bearing shaly sands, paper G, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 12 p. Later published in 1990: Geobyte, v. 5(3), p. 17-24.

Marzano, M.S., 1988, Controls on permeability for unconsolidated sands from conventional core data, offshore Gulf of Mexico: Transactions Gulf Coast Association of Geological Societies, v. 38, p.113-120.

Mathew, P.J., and Anderson, M.R., 1986, A gamma-gamma method for measuring the diameters of air-filled holes, in P.G. Killeen, editor, Borehole geophysics for mining and geotechnical applications [international symposium and workshop, (Toronto, Ontario, August 29-31, 1983), proceedings]: Geological Survey of Canada Paper 85-27, p. 260-276.

Mathews, M., and LaDelfe, C., 1981, Log comparison and quantification, paper I, in 8th formation evaluation syposium transactions: Canadian Well Logging Society.

Matiisen, A., and Shehata, M., 1987, The Midale beds log-core correlations in Tatagwa oil field, southern Saskatchewan, Canada: Bulletin of Canadian Petroleum Geology, v. 35(4), December, p. 443-453.

Maute, R.E., Lyle, W.D., and Sprunt, E.S., 1989, Improved data analysis method of determining Archie parameters "m" and "n" from core data, SPE-19399: Society of Petroleum Engineers, unsolicited paper, 14 p.

May, J.A., and Eyles, D.R., 1985, Well log and seismic character of Tertiary Terumbu carbonate, South China Sea, Indonesia: AAPG Bulletin, v. 69(9), p. 1339-1358.

McCall, C., Van Gonten, W.D., and Osoba, J.S., 1971, The effect of hydrocarbons on the SP opposite sands, paper C, in 12th annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p.

McCall, D.C., Allen, D.F., and Culbertson, J.S., 1987, High-resolution logging--The key to accurate formation evaluation, SPE-16769, in 1987 annual technical meeting and exhibition proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 283-298.

McCluskey, L.D., 1986, Moveable hydrocarbon determination--fact, fancy, or differential pressure, paper A, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 13 p.

McConnell, C.L., 1983, Spontaneous potential corrections for ground-water salinity calculations; Carter County, Oklahoma, U.S.A.: Journal of Hydrology, v. 65, p. 363-372.

McConnell, C.L., 1985, Salinity and temperature anomalies over structural oil fields, Carter County, Oklahoma: AAPG Bulletin, v. 69(5), p. 781-787.

McConnell, C.L., 1985, Time dependence of the quivalent water resistivity in fresh water wells: The Log Analyst, v. 26(3), May-June, p. 12-17.

McConnell, C.L., 1986, Equivalent mud filtrate resistivities in fresh water wells: The Log Analyst, v. 27(2), March-April, p. 85-90.

McConnell, C.L., 1987, A natural inverted groundwater salinity profile in southern Oklahoma: Shale Shaker, v. 38(1), July-August, p. 2-6.

McConnell, C.L., 1988, A general correction for spontaneous potential well logs in fresh water: Journal of Hydrology, v. 101(1-4), p. 1-13.

McCoy, R.L., and Smith R.F., 1979, The use of interlog relationships for geological and geophysical evaluations, paper G, in 20th annual logging symposium transactions: Society of Professional Well Log Analysts.

McGann, G.J., Riches, H.A., and Renoult, D.C., 1988, Formation evaluation in a thinly bedded reservoir; a case history, Scapa field, North Sea, paper V, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 20 p.

McGinley, T.R., and McKnight, T.N., Jr., 1984, Log-derived stratigraphic reservoir description, SPE-12597, in 1984 Permian Basin oil and gas recovery conference [Midland, March 8-9], proceedings: Society of Petroleum Engineers, p. 179-188.

McGlothlin, R.E., and Krause, H., 1980, Water base drilling fluids, in Research on environmental fate and effects of drilling fluids and cuttings symposium, proceedings, volume I: U.S. Department of Energy Report DOE/CONF-800172, p. 30-37. [A concise description of the composition and uses of commonly used water-based drilling muds.]

McKee, A., Geehan, T., and Mowat, G., 1986, Drilling mud properties and formation evaluation, in 15th annual convention proceedings, v. 2: Indonesian Petroleum Association, Jakarta, p. 181-196.

McKenna, P., McDonald, J., Kubica, P., 1989, Geochemical logging for connate water saturation, Keg River Sandstone, paper E, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 22 p.

McMordie, W.C. Jr., 1980, Oil base drilling fluids, in Research on environmental fate and effects of drilling fluids and cuttings symposium, proeceedings, volume I: U.S. Department of Energy Report DOE/CONF-800172, p. 38-42. [A concise description of the composition and uses of oil-based drilling muds.]

Menger, S., and Schepers, R., 1988, Method to derive high-resolution caliper logs from borehole televiewer traveltime data, in 1988 annual meeting expanded abstracts with biographies, volume 1: Society of Exploration Geophysicists, p. 554-556.

Merkel, R.H., 1979, Well log formation evaluation: American Association of Petroleum Geologists, Continuing Education Course Note Series No. 14, 82 p.

Michette, A.G., Darling, A.M., Fiddy, M.A., Ward, W.A., and Franklin, E., 1984, Resolution enhancement of well log and seismic data: Geophysical Prospecting, v. 32(4), p. 564-580.

Middleton, M.F., 1979, Correlation between well log and surface resistivity measurements; a case study in the Eromanga Basin, Queensland: Bulletin of Australian Society of Exploration Geophysicists, v. 10(2), p. 176-178.

Misk, A., Mowat, G.R., Goetz, J.F., Vivet, B., 1977, Effects of hole conditions on log measurement and formation evaluation, paper 22, in 5th European logging symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 16 p. Reprinted in 1978, in Measuring accuracy of parameters used in formation evaluation in the North Sea [Norwegian Petroleum Society conference, 10/30-11/2/77]: Norwegian Information Publishers, Oslo, p. 21-37.

Mitchell-Tapping, H.J., 1983, Petrophysical evaluation of the Smackover oomoldic porosity of East Texas and Southern Arkansas: The Log Analyst, v. 24(4), July-August, p. 3-13.

Mitchell-Tapping, H.J., 1988, Application of petrophysics of oolitic limestone in petroleum exploration, in Wagner, H.C., Wagner, L.C., Wang, F.F.H., and Wong, F.L., editors, Petroleum resources of China and related subjects: Circum-Pacific Council for Energy and Mineral Resources [Houston, TX], Earth Science Series, v. 10, p. 849-861.

Moran, J.H., and Chemali, R., 1985, Focused resistivity logs in A.A. Fitch, editor, Developments in geophysical exploration methods--6: Elsevier Applied Science Publishers, London, p. 225-260.

Morin, R.H., 1985, Physical properties of calcareous sediments from the southwest Pacfic, chapter 31, in J.P. Kennett and C.C. von der Borch, editors, Initial reports of the Deeep Sea Drilling project, volume 90: U.S. Government Printing Office, p. 1239-1246.

Moss, B.P., 1990, Stochastic reservoir description; a methodology, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 57-75.

Moss, B., and Harrison, R., 1985, Statistically valid log analysis method improves reservoir description, SPE-13981: Society of Petroleum Engineers, Offshore Europe conference [Aberdeen, 9/10-13/85], preprint, 32 p.

Murphy, R.P., and Owens, W.W., 1971, A new approach for low resistivity sand log analysis, SPE-3569: Society of Petroleum Engineers, 46th annual meeting [New Orleans] preprint. Later published in 1972, Journal of Petroleum Technology, v. 24(11), p. 1302-1306.

Murthy, V.R., and Gupta, A.K., 1982, Evaluation of formation porosities in Bombay High field using cased hole compensated neutron log: Bulletin of the Oil and Natural Gas Commission [India], v. 19(2), p. 243-256.

Neasham, J.W., 1977, The morphology of dispersed clay in sandstone reservoir and its effect on sandstone shaliness, pore space and fluid flow properties, SPE-6858: Society of Petroleum Engineers, 52nd annual meeting [Denver] preprint, 8 p. Reprinted 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. I87-I94.

Nelson, R.A., Lenox, L.C., and Ward, B.J., Jr., 1987, Oriented core--Its use, error, and uncertainty: AAPG Bulletin, v. 71(4), p. 357-367.

Nelson, R.J., and Mitchell, W.K., 1990, Improved vertical resolution of well logs by resolution matching, paper JJ, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Nelson, S.O., Lindroth, D.P., and Blake, R.L., 1989, Dielectric properties of selected minerals at 1 to 22 GHz: Geophysics, v. 54(10), p. 1,344-1,349.

Neuman, C.H., and Brown, R.J.S., 1981, Applications of nuclear magnetism logging to formation evaluation, SPE-10108: Society of Petroleum Engineers, 56th annual meeting [San Antonio] preprint, 10 p. Later published in 1982, Journal of Petroleum Technology, v. 34(12), p. 2853-2862.

Noblett, B.R., and Howard, L.P., 1989, New resistivity fracture detection concepts for the evaluation of shale formations, paper X, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 12 p.

Nurmi, R., 1984, Pore structure in carbonate rocks: The Technical Review, v. 32(1), September, p. 14-23.

Nurmi, R., 1984, Permeability in sandstones: The Technical Review, v. 32(1), September, p. 4-9.

Nyberg, O., Lindberg, P.A., Lien, K., and Smistad, J.K., 1978, Mineral composition, an aid in classical log analysis used in Jurassic sandstones of the northern North Sea, paper M, in 19th annual logging symposium transactions: Society of Professional Well Log Analysts, 35 p.

Olson, D.M., 1986, Calibration of log and core saturation data--case history from the San Ardo field, paper Z, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 11 p.

Osoba, J., Gist, R., and Carroll, H., 1980, Porosity determination from density logs in western gas sands, paper JJ, in 21st annual logging symposium transactions: Society of Professional Well Log Analysts, 10 p. Later published in abridged form in 1981, as, Log evaluation techniques in Uinta basin found faulty: World Oil, v. 192(6), June, p. 235-244.

Oteri, A., 1988, Electric log interpretation for the evaluation of salt water intrusion in the eastern Niger Delta: Hydrological Sciences Journal, v. 33(1), p. 19-30.

Owen, J.D., 1975, Log analysis of Ekofisk field, in J.E. Kastrop, editor, Oil and gas production handbook: Petroleum Engineer Publishing Co., Dallas, p. 14-21.

Oyeneyin, M.B., 1987, Formation sand size prediction from well-log correlations, SPE-16345: Society of Petroleum Engineers, unsolicited paper, 18 p.

Pachett, P.G., Berry W.R., II, Burlingame, R.W., Moore, C.V., Spalding, J.S., Wichmann, P.A., and Woodhouse, R., 1986, Problematic overview--A series of six studies on difficult log analysis, paper NNN, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 23 p.

Paillet, F., and Morin, R., 1986?, Quantitative analysis of geophysical well-log data: U.S. Geological Survey Short Course Notes, 105 p.

Palomino Cardenas, J.R., and Carozzi, A.V., 1979, Sedimentology and electric log interpretation of the Cabo Blanco Sandstone (Lower Eocene), Talara Basin, northeast Peru: Archives des Sciences [Societe de Physique et d'Histoire Naturelle de Geneve], v. 32(2), p. 127-149.

Patchett, J.G., 1975, An investigation of shale conductivity, paper U, in 16th annual symposium transactions: Society of Professional Well Log Analysts, 41 p. Reprinted 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. I95-I135.

Patchett, J.G., 1986, The determination of the properties of clays in shales from logs with an example of one interpretation technique, paper P, in 10th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Aberdeen Chapter, 23 p.

Patchett, J.G., and Coalson, E.B., 1982, The determination of porosity in sandstone and shaly sandstone, part 2--Effects of complex mineralogy and hydrocarbons, paper T, in 23rd annual logging symposium transactions: Society of Professional Well Log Analysts, 50 p.

Peeters, M., and Fung, L.L., 1983, Triple-fluid evaluations using density, neutron, and electromagnetic propagation logs, paper Q, in 8th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, London Chapter, 23 p. Later published in 1986, SPE Formation Evaluation, v. 1(2), April, p. 193-204.

Peveraro, R.C.A., and Russell, K.J., 1984, Interpretation of wireline log and core data from a Mid-Jurassic sand/shale sequence: Clay Minerals, v. 19, p. 483-505.

Phillips, I.C., and Roberts, W.R., 1986, Use of fine resolution logging tools to evaluate thinly laminated North Sea reservoirs, paper BB, in 10th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Aberdeen Chapter, 10 p.

Pickett, G.R., 1977, Resistivity, radioactivity and acoustic logs, chapter 13, in L.W. LeRoy, D.O. LeRoy and J.W. Raese, editors, Subsurface geology, 4th edition: Colorado School of Mines, Golden, CO., p. 304-336.

Pirson, S.J., 1963, Handbook of well log analysis for oil and gas formation evaluation: Prentice-Hall, Englewood Cliffs, New Jersey, 325 p.

Pirson, S.J., 1983, Geologic well log analysis, 3rd edition: Gulf Publishing Company, Houston, 475 p.

Pochitaloff, A., and Verdier, M., editors, 1982, Geological and mud logging in drilling control - catalog of typical cases: Gulf Publishing Company, Houston, 81 p.

Policky, B.R., and Iverson, W.P., 1988, Water resistivity from spontaneous potential logs in the Minnelusa Formation, Powder River basin, Wyoming, SPE-17516, in SPE Rocky Mountain regional meeting proceedings: Society of Petroleum Engineers, p. 353-364.

Porter, K.E., 1989, An overview of formation damage, SPE-19894: Journal of Petroleum Technology, v. 41(8), p. 780-796.

Prard, Y.M., Prins, W.J., and Cramez, C., 1976, Recent developments in logging techniques and interpretation in Indonesia, in 5th annual convention proceedings, volume 1: Indonesian Petroleum Association, Jakarta, p. 171-199.

Puffer, J., d'Ablaing, G., IV, Toth, T., and Darling, H., 1987, Use of thermal and epithermal neutron measurements in shaly sand evaluation: Transactions Gulf Coast Association of Geological Societies, v. 37, p. 185-194.

Rafie, M.Y., and Yongblood, W.E., 1987, Advances in quantitative reservoir description and monitoring in Saudi Arabia, in 12th world petroleum congress proceedings, v. 3, production: John Wiley & Sons, New York, p. 317-329.

Rahman, A.U., and Jacka, A.D., 1986, Petrographic images and log response of the Lower San Andres Formation, northwestern shelf of the Permian Basin, New Mexico: The Log Analyst, v. 27(3), May-June, p. 72-80.

Raiga-Clemenceau, J., 1988, Taking into account the conductivity contribution of shale laminations when evaluating closely interlaminated sand-shale hydrocarbon bearing reservoirs, paper DD, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 14 p.

Raiga-Clemenceau, J., Fraisse, C., and Grosjean, Y., 1984, The dual-porosity model, a newly developed interpretation method for shaly sands, paper F, in 25th annual loggging symposium transactions: Society of Professional Well Log Analysts, 16 p.

Raiga-Clemenceau, J., Martin, J.P., and Nicoletis, S., 1986, The concept of acoustic formation factor for more accurate porosity determination from sonic transit time data, paper G, in 27th annual logging symposium transactions:

Society of Professional Well Log Analysts, 14 p. Later published in 1988, The Log Analyst, v. 29(1), January-February, p. 54-60.

Ramberger, R., 1989, Enhancing log interpretation by core mineral analysis in a micacaeous shaly sand, paper D, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 10 p.

Rasmus, J.C., 1981, Determining the type of fluid contained in the fractures of the Twin Creek limestone by using the Dual Laterolog tool, paper C, in 1981 SPE/DOE low-permeability symposium [Denver], proceedings: Society of Petroleum Engineers, p. Later published in 1982, Journal of Petroleum Technology, v. 34(11), p. 2673-2682.

Rasmus, J.C., 1986, A summary of the effects of various pore geometries and their wettabilities on measured and in-situ values of cementation and saturation exponents, paper PP, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p. Later published in 1987, The Log Analyst, v. 28(2), March-April, p. 152-164.

Rasmus, J.C., and Kenyon, W.E., 1985, An improved petrophysical evaluation of oomoldic Lansing-Kansas City Formations utilizing conductivity and dielectric log measurements, paper V, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 18 p. Reprinted 1985, as, paper G, in 10th formation evaluation symposium transactions: Canadian Well Logging Society, 18 p.

Raymer, L.L., and Burgess, K.A., 1980, The role of well logs in reservoir modeling, SPE-9342: Society of Petroleum Engineers, 55th annual meeting [Dallas] preprint.

Raymer, L.L., and Freeman, P.M., 1984, In-situ determination of capillary pressure, pore throat size and distribution, and permeability from wireline data, paper CCC, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 12 p.

Ringer, J.K., and Hove, A., 1987, The use of x-ray tomography in core analysis, chapter 15, in J. Kleppe, E.W. Berg, A.T. Buller, O. Hjelmeland, and O. Torsaeter, editors, North Sea oil and gas reservoirs: Graham & Totman Ltd., London, p. 209-216.

Rixon, M.D., Kasperski, B.W., and Morriss, C.E., 1989, Vertical resolution enhancement of the Phasor Induction; applications in western Canada, paper 89-40-77, in Building on 40 years of achievement [annual meeting preprints, volume III]: Petroleum Society of CIM, Calgary, 16 p.

Robertson, H.A., Stapp, D., Harville, D., and Philipson, C., 1989, Determining lithology from continuously collected drill cuttings, using Fourier transform infrared spectroscopy, paper T, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 16 p.

Robertson, J.D., 1987, Carbonate porosity from S/P traveltime ratios: Geophysics, v. 52(10), October, p. 1346-1354.

Roehl, P.O., and Choquette, editors, 1985, Carbonate petroleum reservoirs: Springer-Verlag, New York, 622 p. [Contains 35 papers on facies and petrophysics of selected carbonate petroleum reservoirs of different geologic ages.]

Rolle, F., 1985, Late Cretaceous-Tertiary sediments offshore central west Greenland--Lithostratigraphy, sedimentary evolution, and petroleum potential: Canadian Journal of Earth Science, v. 22, p. 1001-1019.

Roy, K.K., and Saha, A., 1975, Discussion on SP log interpretation: Canadian Well Logging Society Journal, v. 8(1), p. 41-46.

Ruhovets, N., 1989, A log analysis technique for evaluating laminated reservoirs in the Gulf Coast area, paper C, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 23 p.

Ruhovets, N., and Fertl, W.H., 1981, Digital shaly sand analysis based on Waxman-Smits model and log-derived clay typing, paper 25, in 7th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 26 p. Reprinted in 1982, The Log Analyst, v. 23(3), May-June, p. 7-23. Reprinted 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. V107-V134.

Ruhovets, N., and Fertl, W.H., 1982, Volumes, types and distribution of clay minerals in reservoir rocks based on well logs, SPE/DOE-10796, in SPE/DOE unconventional gas recovery symposium, proceedings: Society of Petroleum Engineers, p. 67-82.

Ruhovets, N., and Oliver, D.W., 1985, Log analysis problems and solutions in complex lithology reservoirs, SPE-14187: Society of Petroleum Engineers, 60th annual meeting [Las Vegas], preprint, 12 p.

Ryskal, O.E., Malinin, V.F., and Akhmetov, R.T., 1989, Porosity types in complex carbonate reservoirs based on petrophysical studies: Journal of Petroleum Science and Engineering, v. 2(1), March, p. 27-30.

Safinya, K. Habashy, T., Randall, C., Clark, B., Perez-Falcon, A., 1985, Experimental and theoretical study of the Electromagnetic Propagation Tool in layered and homogeneous media, SPE-14188: Society of Petroleum Engineers, 60th annual meeting [Las Vegas], preprint, 17 p.

Sahay, B., 1986, Geologging in oil and gas exploration: Energy Sources, v. 8(4), p. 331-354.

Salich, H.A., 1980, Methods of identifying those oil and gas reservoirs which can be developed commercially in rocks with poor reservoir properties, in Tenth world petroleum congress, proceedings v. 3: Heyden, London, p. 191-199.

Sallee, J.E., and Wood, B.R., 1982, Use of microresistivity from the dipmeter to improve formation evaluation in thin sands, northeast Kalimantan, Indonesia, SPE-10462, in Offshore South East Asia conference, proceedings: Society of Petroleum Engineers, 24 p. Later published in 1984, Journal of Petroleum Technology, v. 36(9), p. 1535-1544.

Schlein, N., and Spivak, D., 1986, A log interpreted mineralogical composition for solution mining of underground caverns in Mount Sedom, in Y. Arkin, editor, Engineering geology in Israel: Israel Journal of Earth-Sciences, v. 35(2), p. 136-148.

Schlumberger, 1972, The essentials of log interpretation practice: Schlumberger Ltd., Houston, Document No. M-081002, 57 p.

Schlumberger, 1981, RFT--Essentials of pressure test interpretation: Schlumberger Technical Services, Paris, Document No. M-081022, 77 p.

Schlumberger, 1989, Log interpretation principles/applications: Schlumberger Educational Services, Houston, Document No. SMP-7017, variously paginated.

Schlumberger, 1989, Log interpretation charts: Schlumberger Educational Services, Houston, 151 p.

Schlumberger, 1990, Historical charts: Schlumberger Educational Services, Houston, Document No. SMP-7030, 88 p.

Schmidt, G.W., 1973, Interstitial water composition and geochemistry of deep Gulf Coast shales and sandstones: AAPG Bulletin, v. 57(2), p. 321-337.

Schmoker, J.W., 1988, A method for determining average values of wireline-log traces: U.S. Geological Survey Open-File Report 88-0511, 5 p.

Schultz, A.L., 1979, Electric log evidence for hydrocarbon production and trapping in sandstones possessing diagenetic clay minerals: Houston Geological Society Bulletin, v. 21(2), p. 4-8. Also published in 1979, Bulletin of the South Texas Geological Society, v. 19(8). Reprinted 1986, in W.L. Stapp, editor, Contributions to the geology of south Texas, 1986: South Texas Geological Society, San Antonio, p. 479-482.

Schultz, A.L., 1986, A guide to qualitative interpretation of south Texas electric logs, in W.L. Stapp, editor, Contributions to the geology of south Texas, 1986: South Texas Geological Society, San Antonio, p. 467-478.

Schulze, R.P., Ives, G.L., and Smalley, E.A., 1985, Evaluation of low-resistivity Simpson series of formations, SPE-14282: Society of Petroleum Engineers, 60th annual meeting [Las Vegas], preprint, 8 p.

Scott, T.D., Jr., and Purdy, C.C., 1988, Log derived permeability and flushed zone saturation utilizing high frequency electromagnetic wave attenuation and propagation time, paper I, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 23 p.

Semmelbeck, M.E., and Holditch, S.A., 1985, The effects of mud-filtrate invasion on the interpretation of induction logs, SPE-14491, in SPE eastern regional meeting proceedings: Society of Petroleum Engineers, p. 27-38. Later published in 1988, SPE Formation Evaluation, v. 3(2), p. 386-392.

Senecal, J.E., and Mulhern, M.E., 1985, Monterey Formation analysis--State-of-the-art interpretation of lithology, fractures and fluid identification in fine-grained mineralogically variable rocks, paper KKK, in 26th annual logging symposium transactions,: Society of Professional Well Log Analysts, 16 p.

Sengel, E.W., 1984, Well logging handbook: Institute for Energy Development (IED), Oklahoma City, 168 p.

Serra, O., 1984, Fundamentals of well-log interpretation volume 1--The acquisition of data: Elsevier, New York, Developments in Petroleum Science No. 15A, 423 p.

Serra, O., 1986, Stratigraphy, tectonics and multiwell studies using wireline logs: Schlumberger Well Services, Houston, Document No. M-090029, 127 p. [extracted from Serra, O., 1986, Fundamentals of well-log interpretation volume 2--The interpretation of logging data, chapters 13-15: Elsevier Science Publishers, Amsterdam, Developments in Petroleum Science No. 15B, p. 557-652]

Serra, O., 1986, Fundamentals of well-log interpretation volume 2--The interpretation of logging data: Elsevier Science Publishers, Amsterdam, Developments in Petroleum Science No. 15B, 684 p.

Serra, O., 1986, Advanced interpretation of wireline logs: Schlumberger Well Services, Houston, Document No. M-090028, 295 p. [extracted from Serra, O., 1986, Fundamentals of well-log interpretation volume 2--The interpretation of logging data, chapters 2-3, 7-12: Elsevier Science Publishers, Amsterdam, Developments in Petroleum Science No. 15B, p. 61-135, 341-555.]

Serra, O., 1986, Wellsite interpetation of wireline logs: Schlumberger Well Services, Houston, Document No. M-090027, 60 p. [extracted from Serra, O., 1986, Fundamentals of well-log interpretation volume 2--The interpretation of logging data, chapter 1: Elsevier Science Publishers, Amsterdam, Developments in Petroleum Science No. 15B, 11-60.]

Serra, O., 1989, Formation MicroScanner image interpretation: Schlumberger Educational Service, Houston, SMP-7028, 117 p.

Serra, O., Delfiner, P., Levert, J.C., 1985, Lithology determination from well-logs--Case studies, paper WW, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 19 p.

Sharma, M.M., and Wunderlich, R.W., 1985, The alteration of rock properties due to interactions with drilling fluid components, SPE-14302: Society of Petroleum Engineers, 60th annual meeting [Las Vegas], preprint 12 p. Later published in 1987, Journal of Petroleum Science and Engineering, v. 1(2), December, p. 127-143.

Sharma, S.K., Nohwar, U.V.S., Raj, H., Koithara, J., and Chilingar, G.V., 1980, Interrelationships among various petrophysical parameters of carbonate reservoir rocks in the Bombay High oil field, India: Energy Sources, v. 5(1), p. 53-69.

Shen, L.C., 1985, Problems in dielectric-constant logging and possible routes to their solution: The Log Analyst, v. 26(6), November-December, p. 14-25.

Shen, L.C., and Hardman, R.H., 1986, Effect of formation dip or hole deviation on induction logs, paper I, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 13 p.

Shen, L.C., Manning, M.J., and Price, J.M., 1984, Application of Electromagnetic Propagation Tool to formation evaluation, paper J, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 14 p.

Shen, L.C., Savre, W.C., Price, J.M., and Athavale, K., 1985, Dielectric properties of reservoir rocks at ultra-high frequencies: Geophysics, v. 50(4), p. 692-704.

Sherman, M.M., 1985, The calculation of porosity from dielectric constant measurements--A study using laboratory data, paper HH, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts. 15 p. Reprinted in 1986, The Log Analyst, v. 27(1), January-February, p. 15-24.

Sherman, M.M., 1987, A model for determination of water saturation from dielectric permittivity measurements: The Log Analyst, v. 28(3), May-June, p. 282-288.

Sherman, M.M., 1988, A technique for the interpretation of dielectric permittivity measurements in the 20 to 50 MHz frequency range, SPE-17605, in SPE international meeting on petroleum engineering [Tianjin, China], proceedings: Society of Petroleum Engineers, p. 559-566. Later published in 1990, SPE Formation Evaluation, v. 5(1), March, p. 76-80.

Sibbit, A., and Faivre, O., 1985, The Dual Laterolog response in fractured rocks, paper T, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 34 p.

Silva, P., and Bassiouni, Z, 1981, Accurate determination of geopressured aquifer salinity from the SP log, in D.G. Bebout and A.L. Bachman, editors, 5th conference on geopressured-geothermal energy, proceedings: Louisiana State University, p. 193-196. Also published in 1981, Geothermal Resources Council Transactions, v. 5, p. 737-740.

Silva, P., and Bassiouni, Z., 1981, A new approach to the determination of formation water resistivity from the SP log, paper G, in 22nd annual logging symposium transactions: Society of Professional Well Log Analysts, 15 p.

Silva, P., and Bassiouni, Z., 1985, One step chart for SP log interpretation, paper Q, in 10th formation evaluation symposium transactions: Canadian Well Logging Society, 22 p.

Silva, P.L., and Bassiouni, Z., 1985, A shaly sand conductivity model based on variable equivalent counter-ion conductivity and dual water concepts, paper RR, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 21 p.

Silva, P.L., and Bassiouni, Z., 1986, Statistical evaluation of the S-B conductivity model for water-bearing shaly formations: The Log Analyst, v. 27(3), May-June, p. 9-19.

Silva, P.L., and Bassiouni, Z., 1986, Hydrocarbon saturation equation in shaly sands according to the S-B conductivity model, SPE-16039: Society of Petroleum Engineers, unsolicited paper, 23 p. Later published in 1988, SPE Formation Evaluation, v. 3(3), p. 503-509.

Silva, P.L., and Bassiouni, Z., 1987, Prediction of membrane potentials in shale and shaly sands using the S-B conductivity model: The Log Analyst, v. 28(2), March-April, p. 129-136.

Simpson, J.P., 1985, The drilling mud dilemma, recent examples: Journal of Petroleum Technology, v. 37(2), p. 201-206. Discussion and reply v. 37(7), p. 1230.

Sims, J.C., Cox, P.T., and Simpson, R.S., 1986, Complex dielectric interpretation of 20-MHz electromagnetic logs, SPE-15486: Society of Petroleum Engineers, 61st annual meeting preprint, 6 p. Later published in 1988, SPE Formation Evaluation, v. 3(1), p. 24-28.

Skandsen, J., Backe, K.R., Lile, O.B., and Griffiths, C.M., 1989, A knowledge-based system for interpretation of wireline logs, in Artificial intelligence in petroleum exploration and production, proceedings: Texas A&M University, College Station, p. 51-58.

Smith, B.W., and Wenzel, A.W., 1989, Electrical exploration for oil and gas; a new empirical approach, paper POS 2.3, in Expanded abstracts with biographies 59th annual meeting, v. 1: Society of Exploration Geophysicists, p. 420-423.

Smith, D., 1990, Predicting a down-dip water level using capillary pressure relationsips, paper Z, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 11 p.

Smith, S.W., and Keen, D., 1979, A simplified true vertical thickness (TVT) calculation using a programmable pocket calculator: The Log Analyst, v. 20(2), March-April, p. 28-32.

Smolen, J.J., and Litsey, L.R., 1977, Formation evaluation using wireline formation tester pressure data, SPE-6822: Society of Petroleum Engineers,52nd annual meeting [Denver] preprint. Later published in 1979, Journal of Petroleum Technology, v. 31(1), p. 25-32.

Sneider, R.M., and King. H.R., 1984, Integrated rock-log calibration in the Elmworth Field, Alberta Canada--Part I, reservoir rock detection and characterization, in J.A. Masters, editors, Elmworth--case study of a Deep Basin gas field: AAPG Memoir No. 38, p. 205-214.

Snyder, D.D., and Merkel, R.H., 1977, Induced polarization measurements in and around boreholes, in Induced polarization for exploration geologists and geophysicists [short course, March 14-16, 1977]: University of Arizona Department of Geosciences, p. 161-220.

Snyder, D.D., Merkel, R.H., and Williams, T.T., 1977, Complex formation resistivity--The forgotten half of the resistivity log, paper Z, in 18th annual logging symposium transactions: Society of Professional Well Log Analysts, 39 p.

Society of Petroleum Engineers, 1986, Openhole well logging: Society of Petroleum Engineers, Reprint Series No. 21, 575 p. [Contains 39 significant papers on tool development, application and interpretation.]

Society of Professional Well Log Analysts, 1982, Shaly sand reprint volume: Society of Professional Well Log Analysts, variously paginated. [Contains 38 significant papers + extensive bibliography. Excellent source for studying the shaly sand problem.]

Society of Professional Well Log Analysts, Houston Chapter, 1979, The art of ancient log analysis: Society of Professional Well Log Analysts, 131 p. + reprints of 22 classic papers on interpretation of old electric (normal and lateral) logs.

Soendenaa, E., Bratteli, G., Kolltveit, K., and Normann, H.P., 1989, A comparison between capillary pressure data and saturation exponent obtained at ambient conditions and at reservoir conditions, SPE-19592, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 213-225.

Solomon, S.T., and Amiard, J.P., 1990, Evaluation of the 200 MHz dielectric tool-response in a Rotliegendes gas reservoir drilled with oil-based mud, paper LL, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Spreux, A.M., Louis, A., and Rocca, M., 1987, Logging horizontal wells; field practice for various techniques, SPE-16565, in 1987 SPE offshore Europe conference proceedings: Society of Petroleum Engineers. Later published in 1988, SPE Formation Evaluation, v. 3(3), p. 1352-1354.

Sprunt, E.S., 1989, Arun core analysis; special procedures for vuggy carbonates, SCA-8805, part II, paper E (abstract only), in Annual technical conference reprints, v. 1 (1987-1989): Society of Professional Well Log Analysts, Society of Core Analysts, Chapter-at-Large. Later published in 1989, The Log Analyst, v. 30(5), September-October, p. 353-362.

Standen, E., 1982, Correlating the dipmeter to EPT moved-oil plots: The Technical Review, v. 30(3), December, p. 43-49.

Stevenson, J.A., 1981, Log evaluation of wells in the Tuscaloosa trend of south Louisiana, in Tuscaloosa Trend of South Louisiana: New Orleans Geological Society, p. 27-46.

Stiles, J.H., Jr., and Hutfilz, J.M., 1988, The use of routine and special core analysis in characterizing Brent group reservoirs, U.K. North Sea, SPE-18386, in SPE European petroleum conference [London] proceedings: Society of Petroleum Engineers, p. 475-491.

Stoker, R.C., Goldman, D., and Kunze, J.F., 1977, Deducing production zones from well logs: Geothermal Resources Council Transactions, v. 1, p. 279-280.

Stosur, J.J., and David, A., 1975, Petrophysical evaluation of the diatomite formation of the Lost Hills field, California, SPE-5501: Society of Petroleum Engineers, 50th annual meeting [Dallas] preprint. Later published in 1976, Journal of Petroleum Technology, v. 28(10), p. 1138-1144.

Stowe, I., and Hock, M., 1988, Facies analysis and diagenesis from well logs in the Zechstein carbonates of northern Germany, paper HH, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 24 p.

Struyk, C., and Poon, A., 1989, Log interpretation in horizontal wells, paper K, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 11 p.

Suau, J. Boyeldieu, C. Roccabianca, R., Cigni, M., and Spila, M., 1978, Evaluation of very low-porosity carbonates (Malossa, Italy), paper W, in 19th annual logging symposium transactions: Society of Professional Well Log Analysts.

Suau, J., and Spurlin, J., 1982, Interpretation of micaceous sandstones in the North Sea, paper G, in 23rd annual logging symposium transactions: Society of Professional Well Log Analysts, 32 p.

Sujono, A.D., and Sumaryana, 1985, Resistivity measurements and their interpretation using dual laterolog and dual induction log in Gunung Kemala and Benuang fields, south Palembang district, Pertamina UEP-II, in 14th annual convention proceedings: Indonesian Petroleum Association, Jakarta, p. 587-609.

Sukandar, S., Siregar, S.A., and Leverbvre, L., 1982, A reservoir description, based on wireline logs, geologicial and production data, aids selection of new well locations for optimum oil production, in 11th annual convention proceedings, volume 1: Indonesian Petroleum Association, Jakarta, p. 415-427.

Sumner, J.S., 1976, Principles of induced polarization for geophysical exploration: Elsevier Scientific Publishing Company, New York, Developments in Economic Geology No. 5, 277 p.

Sumner, J.S., 1979, The induced-polarization exploration method, in P.J. Hood, editor, Geophysics and geochemistry in the search for metallic ores [Exploration 77, (Ottawa, Canada, October 1977), proceedings]: Geological Survey of Canada Economic Geology Report No. 31, p. 123-133.

Swanson, B.F., 1985, Microporosity in reservoir rocks--Its measurement and influence on electrical resistivity, paper F, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 17 p. Later published in 1985, The Log Analyst, v.26(6), November-December, p. 42-52.

Tan, T., 1986, A new method of gas-bearing zone identification by well logging, SPE-15544: Society of Petroleum Engineers, 61st annual meeting [New Orleans] preprint, 8 p.

Tan, T.D., Li, S.Y., and Shang, H.C., 1988, Effective well-log evaluation of light-oil zones, Dagang oil field, China, in Wagner, H.C., Wagner, L.C., Wang, F.F.H., and Wong, F.L., editors, Petroleum resources of China and related subjects: Circum-Pacific Council for Energy and Mineral Resources [Houston, TX], Earth Science Series, v. 10, p. 491-504.

Tan, T., Liao, M., and Liu, Z., 1987, Log interpretation for various reservoirs, in 12th world petroleum congress proceedings, v. 3, production: John Wiley & Sons, New York, p. 277-285.

ten Have, A., and Hillier, A., 1986, Reservoir geology of the Sean North and South gas fields, UK southern North Sea, in J. Brooks, J.C. Goff, and B. van Hoorn, editors, Habitat of Paleozoic gas in NW Europe: Geological Society of London, Special Publication No. 23, p. 267-273.

Teti, M.J., 1987, Log analyst's role in Williston reappraisal: Oil and Gas Journal, v. 85(23), June 8, p. 73-5.

Teti, M.J., and Krug, J.A., 1986, Log analysis methods and empirical derivation of net pay parameters for carbonate reservoirs in the eastern Montana part of the Williston basin: Canadian Well Logging Society Journal, v. 15(1), p. 7-18. Later published in 1987, as Log analysis methods and empirical derivation of net pay parameters in the eastern Montana part of the Williston Basin: The Log Analyst, v. 28(3), May-June, p. 259-281.

Thomas, D.C., and Pugh, V.J., 1989, A statistical analysis of the accuracy and reproducibility of standard core analysis, SCA-8701, part I, paper A, in Annual technical conference reprints, v. 1 (1987-1989): Society of Professional Well Log Analysts, Society of Core Analysts, Chapter-at-Large, 7 p. Later published in 1989, The Log Analyst, v. 30(2), March-April, p. 71-77.

Thomas, E.C., and Steiber, S.J., 1975, The distribution of shale in sandstones and its effect upon porosity, paper T, in 16th annual logging symposium transaction: Society of Professional Well Log Analysts, 15 p.

Thompson, K.D., 1978, Well log interpretation of shaly sands with the programmable calculator, paper X, in 19th annual logging symposium transactions: Society of Professional Well Log Analysts, 26 p.

Threadgold, P., 1971, Some problems and uncertainties in log interpretation, paper W, in 13th annual logging symposium transactions: Society of Professional Well Log Analysts, 19 p. Later reprinted in 1972, The Log Analyst, v. 12(2), March-April, p. 3-11.

Threadgold, P., 1985, Advances in formation evaluation, chapter 3 in R.A. Dawe and D.C. Wilson, editors, Developments in petroleum engineering, volume 1: Elsevier Applied Science Publishers, New York, p. 43-87.

Tilley, C.W., 1988, Computerized spreadsheet calculates cuttings lag quickly: World Oil, v. 207(5), November, p. 114-116.

Tilly H.P., Gallagher, B.J., and Taylor, T.D., 1981, Methods for correcting porosity data in a gypsum-bearing carbonate reservoir, SPE-9716, in 1981 SPE Permian Basin oil and gas recovery symposium, proceedings: Society of Petroleum Engineers. Later published in 1982, Journal of Petroleum Technology, v. 34(10), p. 2449-2454.

Timur, A., 1982, Open hole well logging, SPE-10037, in International petroleum conference [Beijing] proceedings: Society of Petroleum Engineers, p. 639-674. Later published in condensed form 1982, Advances in well logging: Journal of Petroleum Technology, v. 34(6), p. 1181-1185.

Timur, A., and Toksoz, M.N., 1985, Downhole geophysical logging: Annual Reviews of Earth and Planetary Science, v. 14, p. 315-344.

Ting-Dong, T., 1985, Log interpretation characteristics of China's offshore hydrocarbon reservoirs, in Offshore China '85 symposium [Canton, November 26-30] proceedings, v. 1: Third Offshore China Oil Exhibition and Conference, Ltd., Canton, p. 371-393.

Tittman, J., 1986, Geophysical well logging: New York, Academic Press, Inc., 175 p.

Tixier, M.P., 1987, Electrical logging, chapter 49, in H.B., Bradley, editor-in-chief, Petroleum Engineering Handbook: Society of Petroleum Engineers, p. 49-1--49-42.

Tixier, M.P., Morris, R.L., and Connell, J.G., 1968, Log evaluation of low resistivity pay sands in the Gulf Coast, paper E (abstract only), in 9th annual logging symposium transactions: Society of Professional Well Log Analysts. Later published in 1968, The Log Analyst, v. 9(6), p. 3-21. Reprinted 1971, in Well logging: Society of Petroleum Engineer, Reprint Series No. 1, p. 342-367. Reprinted 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. IV125-IV142. Reprinted 1986, in Openhole well logging: Society of Petroleum Engineers, SPE Reprint Series No. 21, p. 331-356.

Tobola, D.P., and Holditch, S.A., 1989, Determination of reservoir permeability from repeated induction logging, SPE-19606, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 355-370.

Tomutsa, L., Brinkmeyer, A., and Raible, C., 1989, Determining petrophysical properties of reservoir rocks by image analysis: U.S. Department of Energy (NIPER) Report NIPER-378, 27 p.

Tootle, J.R., 1979, The prediction of well productivity from wireline logs, McAllen Ranch field, paper H, in 20th annual logging symposium transactions: Society of Professional Well Log Analysts. Reprinted 1979, paper AA, in 7th formation evaluation syposium transactions: Canadian Well Logging Society.

Trojan, M., 1985, Effects of diagenesis on reservoir properties and log response, Upper Jurassic Taylor Sandstone, Cotton Valley Group, Lincoln Parish, Lousisiana: Transactions Gulf Coast Association of Geological Societies, v. 35 p. 515-523.

Truman, R.B., Howard, W.A., Davies, D.K., and Vessell, R.K., 1986, Utilization of rock characterization data to improve well log interpretation, paper V, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 19 p.

Truman, R.B., Howard, W.E., and Luffel, D.L., 1989, Shale porosity; its impact on well-log modeling and interpretation, paper Q, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 17 p.

Tsay, F.S., and Fang, J.H., 1986, A core-log study of the Hastselle Sandstone in north Alabama with emphasis in log interpretation problems in tight gas sands, SPE-15211, in 1986 unconventional gas technology symposium, proceedings: Society of Petroleum Engineers, p. 47-62.

Tselentis, G., 1986, On-site assessment of rock discontinuities from resistivity logs; T-L log--A new logging technique: Journal of Hydrology, v. 83, p. 269-283.

Turner, J.R., 1984, Problematic petrophysical characteristics of the Smackover at Bayou Middle Fork field, Claiborne Parish, Louisiana, in M.W. Presley, editor, The Jurassic of east Texas [East Texas Jurassic exploration conference, Tyler, Texas, March 27-28]: East Texas Geological Society, p. 95-106.

Turner, J.R., 1984, Problematic petrophysical characteristics of the Smackover at Bayou Middle Fork field, Claiborne Parish, Louisiana, in M.W. Presley, editor, The Jurassic of east Texas: East Tecas Geological Society, Tyler, Texas, p. 95-106.

Turner, R.F., Lynch, M.B., and others, 1987, Well log interpretation, chapter 6, in Turner, R.F., editor, Geological and operational summary, Kodiak Shelf stratigraphic test wells, western Gulf of Alaska: U.S. Minerals Management Service OCS Report MMS 87-0109, p. 103-138.

Tyne, E.D., Thorburn, M.J., Daggar, D.H., 1985, A major advance in borehole IP logging technology: Exploration Geophysics [Bulletin of the Australian Society of Exploration Geophysicists], v. 16(2/3), p. 303-309.

Ucok, H., 1981, A laboratory study of the effect of temperature gradient on the development of spontaneous-potential in geothermal wellbore, paper K, in 22nd annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p.

Ucok, H., 1988, Reservoir modeling to verify geologic and petrophysical data; a case study, SPE-17436, in 1988 California regional meeting proceedings: Society of Petroleum Engineers, p. 337-349.

Udegbunam, E.O., and Ndukwe, L.C., 1988, Rock property correlations for hydrocarbon producing reservoir sands of the Niger Delta: Oil and Gas Journal v, 86(6), February 8, p. 55-58.

Vajner, E.A., Kidwell, C.M., and Haley, R.A., 1977, Surprising productivity from low-resistivity sands, paper EE, in 18th annual logging syumposium transactions: Society of Professional Well Log Analysts, 11 p. Reprinted 1978, as, Low resistivity masks high potential of Gulf Coast sands, World Oil, v. 186(2), February 1, p. 49-54.

Veneziani, I.I., Pirson, S.J., Colombo, U., and Broome, M.B., 1972, The Redox log, paper D, in 13th annual logging symposium transactions: Society of Professional Well Log Analysts, 18 p.

Vinegar, H.J., Tutunjian, P.N., Crabtreee, P.T., Raffaldi, F.J., DiFoggio, R., and Edelstein, W.A., 1989, NMR spectroscopy of tight, gypsum-bearing carbonates, paper HH, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 15 p.

Vinegar, H.J., Tutunjian, P.N., Edelstein, W.A., and Roemer, P.B., 1989, ^{13}C NMR of whole cores, SPE-19590, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 201-212.

Vinegar, H.J., Tutunjian, P.N., Edelstein, W.A., and Roemer, P.B., 1989, Determining carbonate content of cores by ^{13}C NMR, SCA-8901, part III, paper A, in Annual technical conference reprints, v. 1 (1987-1989): Society of Professional Well Log Analysts, Society of Core Analysts SPWLA Chapter-at-Large, 18 p.

Vinegar, H.J., and Waxman, M.H., 1984, Induced polarization of shaly sands: Geophysics, v. 49(8), p. 1267-1287.

Vinegar, H.J., Waxman, M.H., Best, M.H., and Reddy, K., 1985, Induced polarization logging--Tool development, borehole departure curves and field test results, paper AAA, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 62 p.

Vinegar, H.J., Waxman, M.H., Best, M.H., and Reddy, I.K., 1986, Induced polarization logging--Borehole modelling, tool response and field tests: The Log Analyst, v. 27(2), March-April, p. 25-61.

Visser, R., Bourts, K.A.T., and van Baaren, J.P., 1988, Effective porosity estimation in the presence of dispersed clay, paper BB, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 13 p.

Visser, R., and van Baaren, J.P., 1985, Optimisation [sic] of the shale correction using well logs, paper C, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 14 p.

Vittachi, A.R., 1985, A high resolution, three mineral lithology analysis utilizing sonic and litho-density measurements, paper F, in 10th formation evaluation symposium transactions: Canadian Well Logging Society, 9 p.

Vonhof, J.A., 1966, Water quality determination from spontaneous-potential electric log curves: Journal of Hydrology, v. 4, p. 341-347.

Vuataz, F-D., Brach, M., Criaud, A., Fouillac, C., 1990, Geochemical monitoring of drilling fluids; a powerful tool to forecast and detect formation waters: SPE Formation Evaluation, v. 5(2), June, p. 177-184.

Vutz, F.D., Brach, M., Criaud, A., and Zouillac, C., 1988, Geochemical monitoring of drilling fluids; a powerful tool to forecast and detect formation water, SPE-18734: Society of Petroleum Engineers, unsolicited paper, 45 p.

Watfa, M., and Nurmi, R., 1987, Calculation of saturation, secondary porosity and producibility in complex Middle East carbonate reservoirs, paper CC, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 24 p.

Watkins, E.A., and Anderson, J.B., 1987, Vertical grain size progressions as an aid in interpreting depositional environments, Queen City Formation (Eocene) east Texas: Transactions Gulf Coast Association of Geological Societies, v. 37, p. 499-512.

Waxman, M.H., and Smits, L.J.M., 1967, Electrical conductivities in oil-bearing shaly sands, SPE-1863-A: Society of Petroleum Engineers, 42nd annual meeting [Houston] preprint, 16 p. Later published in 1968, Society of Petroleum Engineers Journal, v. 8(2), p. 107-122. Reprinted 1971, in Well Logging: Society of Petroleum Engineers, Reprint Series No. 1, p. 101-116. Reprinted 1982, in Shaly sand: Society of Professional Well Log Analysts, Reprint Volume, p. V145-V160. Reprinted 1986, in Openhole well logging: Society of Petroleum Engineers, SPE Reprint Series No. 21, p. 315-330.

Waxman, M.H., and Thomas, E.C., 1972, Electrical conductivities in shaly sands, part I--The relation between hydrocarbon saturation and resistivity index; part II--The temperature coefficient of electrical conductivity, SPE-4094: Society of Petroleum Engineers, 47th annual meeting [San Antonio] preprint. Later published in 1974, Journal of Petroleum Technology, v.26(2), p. 213-225. Reprinted 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. V161-V173.

Wellington, S.L., and Vinegar, H.J., 1987, X-ray computerized tomography [its use in core characterization]: Journal of Petroleum Technology, v. 39(8), p. 885-898.

Wescott, W.A., 1983, Diagenesis of Cotton Valley Sandstone (Upper Jurassic), east Texas--Implications for tight gas formation pay recognition: AAPG Bulletin, v. 67(6), p. 1002-1013. A discussion and reply published in 1985, AAPG Bulletin v. 69(5), p. 813-816.

Whitman, W.W., Towle, G. H., and Kim, J-H., 1989, Inversion of normal and lateral well logs with borehole compensation: The Log Analyst, v. 30(1), January-February, p. 1-11.

Whittaker, A., editor, 1985, Mud logging, principles and interpretations: International Human Resources Development Corporation, Boston, 92 p.

Whittaker, A.H., 1987, Mud logging, chapter 52, in H.B., Bradley, editor-in-chief, Petroleum Engineering Handbook: Society of Petroleum Engineers, p. 52-1-52-31.

Whittaker, A., and Sellens, M., 1987, Advances in mud logging (3 parts): Oil and Gas Journal, v. 85(13, 16, 20), March 30, April 20, May 18, 14 p.

Wilkens, R.H., Schreiber, B.C., Caruso, L., and Simmons, G., 1987, The effects of diagenesis on the microstructure of Eocene sediments bordering the Baltimore Canyon trough, in K.L. Turner, editor, Initial reports of the Deep Sea Drilling Project, volume 95: U.S. Government Printing Office, p. 527-547.

Wilkinson, J., 1978, Effect of shale distribution on porosity and water saturation: Canadian Well Logging Society Journal, v. 10(1), p. 61-77.

Williams, H., and Dunlap, H.E., 1984, Short-term variations in drilling fluid parameters; their measurement and implications: The Log Analyst, v. 25(5), September-October, p. 3.

Willink, R.J., 1989, A methodical approach to critical well re-evaluation: APEA [Australian Petoleum Exploration Association] Journal, v. 29, part 1, p. 269-286.

Wilson, M.D., and Pittman, E.D., 1977, Authigenic clays in sandstones--recognition and influence on reservoir properties and paleoenvironmental analysis: Journal of Sedimentary Petrology, v. 47(1), p. 3-31. Reprinted 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. I137-I165.

Withjack, E.M., 1987, Computed tomography for rock-property determination and fluid-flow visualization, SPE-16951, in 1987 SPE annual technical conference and exhibition proceedings, volume sigma, Reservoir engineering: Society of Petroleum Engineers, p. 183-196. Later published in 1988, SPE Formation Evaluation, v. 3(4), December, p. 696-704.

Woloschyk, M.A., Olson, W.P., and Hamel, A.L., 1985, Gas detection in Upper Cretaceous formations, paper 85-36-40, in 36th annual technical meeting, preprints, volume 2, : Petroleum Society of CIM, p. 607-623. Later published in 1986, Journal of Canadian Petroleum Technology, v. 25(6), p. 48-54.

Wood, B.R., and Westaway, P., 1982, Applications of the electromagnetic propagation tool in Indonesia, in 11th annual convention proceedings, v. 1: Indonesian Petroleum Association, Jakarta, p. 379-400.

Woodhouse, R., 1978, The laterolog Groningen phantom can cost you money, paper R, in 19th annual logging symposium transactions: Society of Professional Well Log Analysts, 17 p.

Worthington, P.F, 1985, The evolution of shaly-sand concepts in reservoir evaluation: The Log Analyst, v. 26(1), p. 23-40.

Worthington, P.F., and Collar, F.A., 1982, The relevance of induced polarization to quantitative formation evaluation, paper U, in 23rd annual logging symposium transactions: Society of Professional Well Log Analysts, 42 p.

Worthington, P.F., Pallatt, N., and Toussaint-Jackson, J.E., 1985, Influence of microporosity upon the evaluation of hydrocarbon saturation, SPE-14296: Society of Petroleum Engineers, 60th annual meeting preprint 12 p. Later published in 1989, SPE Formation Evaluation, v. 4(2), p. 203-209.

Worthington, P.F., Toussaint-Jackson, J.E., and Pallatt, N., 1986, Effect of sample preparation upon saturation exponent in the Magnus field, U.K., North Sea, paper W, in 10th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Aberdeen Chapter, 11 p. Later published in 1988, The Log Analyst, v. 29(1), January-February, p. 48-53.

Xu, X., Colpitts, R., and Bretz, R.E., 1988, A fractured/matrix model for estimating water saturations in reservoir rocks, SPE-17562, in SPE international meeting on petroleum engineering [Tianjin, China], proceedings: Society of Petroleum Engineers, p. 99-111

Yale, D.P., 1985, Recent advances in rock physics: Geophysics, v. 50(12), p. 2480-2491. See references.

Yamaguchi, S., and Hirakawa, S., 1983, A method for well log interpretation of a fractured oil reservoir: Butsuri-Tanko [Geophysical Exploration], v. 36(1), p. 16-22 p.

Yuan, H.H., and Diederix, K.M., 1989, The role of membrane potential measurements in shaly sand evaluation: The Log Analyst, v. 30(6), November-December, p. 415-423.

Zemanek, J., 1987, Low-resistivity hydrocarbon-bearing sand reservoirs, SPE-15713, in 5th SPE Middle East oil show [Manama, Bahrain], proceedings, : Society of Petroleum Engineers, p. 185-196. Later published in 1989, SPE Formation Evalution, v. 3(4), December, p. 515-521.

III. MWD (Measurement While Drilling)

Aldred, W., Bergt, D., Rasmus, J., Voisin, B., 1989, Real-time overpressure detection: Schlumberger Oilfield Review, v. 1(3), October, p. 17-27.

Alixant, J.L., Desbrandes, R., and Delahaye, T., 1989, A new approach to real-time pore pressure evaluation, SPE-19336, in SPE eastern regional conference, proceedings: Society of Petroleum Engineers, p. 281-290.

Allen, D., Bergst, D., Best, D., Clark, B., Falconser, I., Hache, J-M., Kienitz, C., Lesage, M., Rasmus, J., and Wraight, P., 1989, Logging while drilling: Schlumberger Oilfield Review, v. 1(1), April, 4-17.

Allen, D.F., and Luling, 1989, Integration of wireline resistivity data with dual depth of investigation 2-MHz MWD resistivity data, paper C, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Anderson, B., Bonner, S., Luling, M.G., and Rosthal, R., 1990, Response of 2-MHz LWD resistivity and wireline induction tools in dipping beds and laminated formations, paper A, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts,25 p.

Baker, C., Fristad, P., and Seim, P., 1987, Reservoir evaluation with MWD logs--Present potential and future requirements, paper B, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 19 p.

Best, D., Wraight, P., and Holenka, J., 1990, An innovative approach to correct density measurements-while-drilling for hole size effect, paper G, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 21 p.

Boone, D.E., 1987, New logging concept defines clay invasion while drilling, SPE-16987, in 1987 SPE annual meeting proceedings, volume delta: Society of Petroleum Engineers, p. 471-476.

Brindley, C.P., 1988, Continuous orientation measurement systems minimize drilling risk during coring operations, IADC/SPE-17217, in 1988 IADC/SPE drilling conference proceedings: Society of Petroleum Engineers, p. 341-346.

Clark, B., Allen, D.F., Best, D., Bonner, S.D., Jundt, J., Luling, M.G., and Ross, M.O., 1988, Electromagnetic propagation logging while drilling; theory and experiment, SPE-18117, in 1988 SPE annual technical conference proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 103-117.

Coope, D.F., 1986, Formation evaluation using measurements recorded while drilling, in Measurements while drilling conference [London, June 6] papers: IBC Technical Services Ltd., London, 28 p.

Coope, D.F., and Hendricks, W.E., 1984, Formation evaluation using measurements recorded while drilling, paper FF, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 21 p. Later published in 1985 as, MWD logs provide fast, accurate formation data, World Oil, v. 20(2), August 1, p. 46-52.

Coope, D.F., and Yearsley, E.N., 1986, Formation evaluation using EWR logs, SPE-14062, in 1986 SPE international meeting on petroleum engineering [Beijing, China, March 17-20], proceedings : Society of Petroleum Engineers, p. 415-425.

Cunningham, A.B., Jay, K.L., and Opstad, E., 1990, Applications of MWD technology in nonconventional wells, Pruhoe Bay, North Slope Alaska, paper D, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 24 p.

Delafon, H., 1989, Evaluating the accuracy of directional surveys: Offshore, v. 49(2), February, p. 23-27.

Dempsey, P., 1987, MWD technology comes of age: World Oil, v. 205(1), July, p. 29-31.

Desbrandes, R., 1988, Status report--MWD technology, part I--Data acquisition and downhole recording and processing; part II--Data transmission; part III--Processing display, and application: Petroleum Engineer International, v. 60(9), p. 27-33; v. 60(10), p. 48-54; v. 60(11), p. 42-51.

Elliott, L.R., Barolak, J.G., Coope, D.F., and Hendricks, W.E., 1983, Recording downhole formation data while drilling, SPE-12360 in SPE production technology symposium [November 14-15, Lubbock], : Society of Petroleum Engineers. Later published in 1985, Journal of Petroleum Technology, v. 37(7), p. 1231-1238.

Evans, M., Wraight, P., Marienbach, E., Rhein-Knudsen, E., and Best, D., 1988, Formation porosity measurement while drilling, paper C, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 18 p.

Fredericks, P.D., Hearn, F.P., and Wisler, M.M., 1989, Formation evaluation while drilling with a dual propagation resistivity tool, SPE-19622, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 521-536. Also published in 1989 as paper L, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 12 p.

Gabris, P.M., Hansen, R.R., and Bartrina, J., 1988, A field comparison of the directional accuracy of MWD in comparison with six other survey tools, IADC/SPE-17214, in 1988 IADC/SPE drilling conference proceedings: Society of Petroleum Engineers, p. 669-676.

Gearhart, L.M., Moselely, L.M., and Foster, M., 1986, Current state of the art of MWD and its application in exploration and development drilling, SPE-14071, in 1986 SPE international meeting on petroleum engineering [Beijing, China], proceedings: Society of Petroleum Engineers, p. 515-523.

Grupping, T.I.F., Harrell, J.W., and Dickinson, R.T., 1988, Performance update of a dual-resistivity MWD tool with some promising results in oil-based mud applications, SPE-18115, in 1988 SPE annual technical conference proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 73-85. Also published in 1988 as Recent performance of the dual resistivity MWD tool, SPE-18380, in SPE European petroleum conference [London] proceedings: Society of Petroleum Engineers, p. 411-422. Later published in 1990, SPE Formation Evaluation, v. 5(2), June, p. 171-176.

Harrell, J.W., Dickinson, R.T., and Wiley, W.W., III, 1988, The application of a modular measurement-while-drilling system for directional control and formation evaluation in horizontal wells, SPE-17612, in SPE international meeting on petroleum engineering [Tianjin, China], proceedings: Society of Petroleum Engineers, p. 641-652.

Harrison, W.H., Mazza, R.L., Rubin, L.A., and Yost, A.B., II, 1990, Air-drilling, electromagnetic, MWD system development, IADC/SPE-19970, in IADC/SPE drilling conference, proceedings: Society of Petroleum Engineers, p. 485-495.

Holbrook, P.W., 1989, A new method for predicting fracture propagation pressure from MWD or wireline log data, SPE-19566, in SPE annual technical conference and exhibition, proceedings, volume delta, Drilling: Society of Petroleum Engineers, p. 475-487.

Hutchinson, M.W., 1990, Measurements while and after drilling by multiple service companies through Upper Carboniferous formations at a borehole test facility, Kay County, Oklahoma, IADC/SPE-19969, in IADC/SPE drilling conference, proceedings: Society of Petroleum Engineers, p. 477-484.

Jantzen, R.E., Foreman, R.D., Keltner, L., and McCoy, R.S., 1987, Format, content, and information transfer standards for digital rigsite data, SPE-16141, in SPE/IADC drilling conference, proceedings: Society of Petroleum Engineers, p. 793-806. Later published in 1989, as Wellsite information transfer specification (WITS) for digital rig-site data, SPE Drilling Engineering, v. 4(4), December, p. 291-300.

Jensen, J.L., and Triptee, D.S., 1989, A comparison of wireline and MWD gamma ray spectral responses, paper M, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 10 p.

Koopersmith, C.A., and Barnett, W.C., 1987, Environmental parameters affecting neutron porosity, gamma ray, and resistivity measurements made while drilling, SPE-16758, in 1987 annual meeting proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 155-162.

Lesso, W.G., Jr., and Burgess, T.M., 1986, Pore pressure and porosity from MWD measurements, IADC/SPE-14801, in 1986 IADC/SPE drilling conference, proceedings: Society of Petroleum Engineers, p. 643-656.

Montgomery, S.L., 1990, Logging horizontal wells; options and opinions, chapter 6, in Techniques of horizontal drilling; concepts and consequences: Petroleum Frontiers, v, 7(1), [Petroleum Information, Denver], p. 33-36.

Norve, K.H., and Saether, H., 1989, Field experience using the full suite MWD-combination for reservoir logging and evaluation, paper A, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 26 p.

Paske, W.C., Mack, S.G., Rao, R.L., Spross, and J.R. Twist, 1990, Measurement of hole size while drilling, paper F, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 24 p.

Rao, M.V., 1987, Recent advances in measurement-while-drilling, in 34th annual short course proceedings: Southwestern Petroleum Short Course Association, Lubbock, Texas, p. 275-281.

Rao, M.V., and Fontenot, J.E., 1988, MWD poised for the future, 5 part series: Oil and Gas Journal, v. 86(4, 6, 7,11, 13), January 25, p. 65-69, February 8, p. 44-48, February 15, p. 40-47, March 14, p. 60-65, and March 28, p. 52-56.

Roesler, R.F., Barnett, W.C., and Paske, W.C., 1987, Theory and application of a measurement-while-drilling (MWD) neutron porosity sensor, SPE/IDC-16057, in 1987 SPE/IADC drilling conference [New Orleans, March 15-18], proceedings: Society of Petroleum Engineers, p. 81-86.

Rose, R.J., Taylor, M.J., and Jantzen, R.E., 1989, Information standards for well-site data, paper F, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 4 p.

Simms, G.J., and Koopersmith, C.A., 1989, Hydrocarbon type identification using MWD neutron porosity logging; a case study, SPE-19620, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 495-504.

Sorensen, K., 1989, A method for measurement of the electrical formation resistivity while auger drilling: First Break, v. 7(10), p. 403-407.

Sperry-Sun Drilling Services, 1989, MWD technical information manual: Sperry-Sun Drilling Serices, Houston, variously paginated.

Struyk, C., and Poon, A., 1989, Log interpretation in horizontal wells, paper K, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 11 p.

Wraight, P., Evans, M., Marienbach, E., Rhein-knudsen, E., and Best, D., 1989, Combination formation density and neutron porosity measurements while drilling, paper B, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 23 p.

IV. Cased Hole and Production Logging; Determination of ROS
(See also V. Nuclear logging)

Aguilera, R., 1977, A new approach for log analysis of the pulsed neutron and resistivity log combination, SPE-6995: Society of Petroleum Engineers. Later published 1979, Journal of Petroleum Technology, v. 31(4), p. 415-418.

Ahmed, A.E., 1977, A neutron logging method for locating the top of cement behind borehole casing: Journal of Petroleum Technology, v. 29(9), p. 1089-1090, SPE-6498.

Ahmed, U., 1987, Fracture-height predictions and post-treatment measurements, chapter 10, in M.J. Economides and K.G. Nolte, editors, Reservoir stimulation: Schlumberger Educational Services, Houston, Document No. SMP-7018, 13 p.

Ahmed, U., Markley, M.E., Crary, S.F., and Liu, O.Y., 1989, Enhanced in-situ stress profiling using microfrac, core and sonic logging data, SPE-19004, in SPE joint Rocky Mountain regional/low permeability reservoirs symposium [Denver], proceedings: Society of Petroleum Engineers, p. 707-719.

Albert, L.E., Standley, T.E., Tello, L.N., and Alford, G.T., 1987, A comparison of CBL, RBT, and PET logs in a test well with induced channels, SPE-16817, in 1987 annual technical conference and exhibition, proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 681-689. Later published in 1988, Journal of Petroleum Technology, v. 40(8), p. 1211-1216.

Albright, J.C., 1985, Use of well logs to characterize fluid flow in the Maljamar CO_2 pilot, SPE-13142: Society of Petroleum Engineers, 59th annual meeting [Houston] preprint. Later published in 1986, Journal of Petroleum Technology, v. 38(9), p. 883-890.

Anderson, R.A., 1972, Fracture pressure gradient determination from well logs, SPE-4135: Society of Petroleum Engineers, 47th annual meeting [San Antonio] preprint, 15 p.

Armstead, H.C.H., and Tester, J.W., 1987, Rock fracturing practice--reservoir diagnostics, chapter 9, in Heat mining: E. & F.N. Spon, London, p.172-189.

Arnold, D.M., and Paap, H.J., 1978, Quantitative monitoring of water flow behind and in wellbore casing, SPE-7107: Society of Petroleum Engineers. Later published in 1979, Journal of Petroleum Technology, v. 31(1), p. 121-130.

Ataya, A.A., and Youssef, F.Z., 1987, Cement Evaluation Tool and its applications to communication testing, SPE-15757, in 5th SPE Middle East oil show [Manama, Bahrain], proceedings, : Society of Petroleum Engineers, p. 559-573.

Baldwin, J.L., Morris, C.L., Pegors, Latz, C.W., Wahsa, R.J., Harris, E.B., and Wishart, R.A., 1986, Pulsed neutron log application in California--Improved capability via borehole decay correction, in 1986 offshore technolgy conference, proceedings, OTC-5278: Society of Petroleum Engineers, p. 463-480.

Bateman, R.M., 1984, Cased-hole log analysis and reservoir performance monitoring: IHRDC Press, Boston, 380 p.

Bazzari, J.A., 1989, Well casing leaks, history and corrosion monitoring study, Wafra field, SPE-17930, in SPE Middle East oil technical conference and exhibition [Manama, Bahrain], proceedings: Society of Petroleum Engineers, p. 45-54.

Beirute, R.M., Wilson, M.A., and Sabins, F.L., 1988, Attenuation of casing cemented with conventional and expanding cements across heavy oil and sandstone formations, SPE-18027, in 1988 SPE technical conference and exhibition proceedings, volume delta, Drilling: Society of Petroleum Engineers, p. 97-111.

Bergren, F.E., and Bradley, D.A., 1988, Design and evaluation of pump-in temperature surveys for detecting cement channels above perforations, SPE-18145, in 1988 SPE annual technical conference proceedings, volume omega, Formation evaluation and reservoir geology and in volume delta, Drilling: Society of Petroleum Engineers, P. 389-396 (omega) and p. 385-392 (delta).

Berner, J.G., 1987, Planning successful temperature surveys, in Symposium on subsurface injection of oilfield brines [New Orleans, May 4-6], proceedings: Underground Injection Practices Council, Oklahoma City, p. 512-534.

Bettis, F., Schnorr, D., Borden, C., Rowe, W., and Schwanitz, 1987, Sonic logging in cased wells--Opportunities for enhancing old fields: The Technical Review, v. 35(4), p. 14-18.

Bigelow, E.L., 1990, Cement evaluation: Atlas Wireline Services, Houston, TX, 142 p.

Bingle, C.F., 1987, Combining transient rate and pressure data with production logging for enhanced well test analysis, SPE-16224, in SPE Production operations symposium proceedings, : Society of Petroleum Engineers, p. 391-401. Also published in 1988, in 34th annual short course proceedings: Southwestern Petroleum Short Course Association, Lubbock, Texas, p. 1414-156.

Blount, C.G., Copoulos, A.E., Myers, G.D., 1990, A channel detection technique using the pulsed neutron log, SPE-20042, in SPE California regional meeting, proceedings: Society of Petroleum Engineers, p. 255-263.

Boyd, D., 1989, Thermal decay logging of western Canadian carbonate reefs, paper 89-40-78, in Building on 40 years of achievement [annual meeting preprints, volume II]: Petroleum Society of CIM, Calgary, 18 p.

Brie, A., Hsu, K., Eckersley, C., 1988, Using the Stoneley normalized differential energies for fractured reservoir evaluation, paper XX, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 25 p. Also published in 1988, paper F, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 25 p.

Brock, J., 1985, Analyzing your logs, volume 3--Cased hole log interpretation: Petro-Media, Inc., Tyler, Texas, ? p. [was this ever actually published?]

Brown, C.A., 1989, Water flooding, coring, testing, and logging, chapter 7, in Mason, J.F., and Dickey, P.A., editors, Oil field development techniques: AAPG Studies in Geology No. 28, p. 87-95.

Brown, R.J.S., and Neuman, C.H., 1980, Processing and display of nuclear magnetism logging signals--Application to residual oil determination, paper K, in 21st annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Buchanan, J.C., Clearman, D.K., Heidbrink, L.J., and Smith, H.D., Jr., 1984, Applications of TMD pulsed neutron logs in unusual downhole environments, paper KKK, in 25th annual loggining symposium transactions: Society of Professional Well Log Analysts, 17 p.

Cannon, D.E., and LaVigne, J.A., 1983, Through-casing reservoir evaluation, in SPE production technology symposium [Lubbock, November 14-15], proceedings, SPE-12359: Society of Petroleum Engineers. Later published in 1987, SPE Formation Evaluation, v. 2(2), 201-208.

Carlson, N.R., and Barnette, J.C., 1990, Judging the quality of continuous spinner flowmeter logs, paper R, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 14 p.

Carlson, N.R., Barnette, J.C., and Davarzani, M.J., 1988, Using downhole calibrations for improved production profiles in three-phase flows, paper WW, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 12 p.

Carlson, N.R., and Davarzani, M.J., 1989, New method for accurate determination of water cuts in oil-water flows, paper BB, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 12 p.

Carpenter, W.W., 1990, Measuring silicon quantity; a gravel pack analysis alternative: World Oil, v. 210, January, p. 54-58.

Causin, E., Rochon, J., and Marzorati, D., 1990, Field measurements of remaining oil saturation, SPE/DOE-20260, in SPE/DOE symposium on enhanced oil recovery, proceedings: Society of Petroleum Engineers, p. 847-855.

Chandler, R.N., Kenyon, W.E., Morriss, C.E., 1987, Reliable nuclear magnetism logging--with examples in effective porosity and residual oil saturation, paper C, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 24 p.

Chang, M.M., and Maerefat, N.L., 1986, State-of-the-art report summarizing techniques to determine residual oil saturation and recommendations on the requirements for residual oil saturation research and development: National Institute for Petroleum and Energy Research, Bartlesville, OK, Report NIPER-64, 42 p.

Chang, M.M., Maerefat, N.L., Tomutsa, L., and Honarpour, M.M., 1986, Evaluation and comparison of residual oil saturation determination techniques, SPE/DOE-14887, in SPE/DOE 5th symposium on enhanced oil recovery, proceedings: Society of Petroleum Engineers, p. 77-96.

Charlson, G.S., Bilhartz, H.L., Jr., and Stalkup, F.I., 1978, Use of time-lapse logging techniques in evaluating the Willard Unit CO_2 flood mini-test, in 5th symposium on improved methods for oil recovery [Tulsa, April 16-19, 1978], proceedings: Society of Petroleum Engineers, 10 p. Reprinted in 1985, in Miscible processes II: Society of Petroleum Engineers, Reprint Series, No. 18, p. 691-700.

Charyulu, K.S., and Bakshi, S.S., 1985, Role of production logging in effective reservoir management: Journal of Association of Exploration Geophysicists, v. 6(1), p. 33-38.

Chen, S.T., and Eriksen, E.A., 1988, Direct logging of formation P and S-waves in cased hole using a multipole tool, in 1988 annual meeting expanded abstracts with biographies, volume 1: Society of Exploration Geophysicists, p. 129-131.

Cigni, M., and Magrassi, M., 1987, Gas detection from formation density and compensated neutron log in cased hole, paper W, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Connolly, E.T., 1965, Resume and current status of the use of logs in production, paper L, in 6th annual logging symposium transactions: Society of Professional Well Log Analysts. Reprinted in 1985, Production logging: Society of Petroleum Engineers Reprint Series No. 19, p. 268-352.

Connolly, E.T., 1970, Interpretation and recognition of calibration and recording abnormalities on production logs: Canadian Well Logging Society Journal, v. 3(1), December, p. 89-122.

Constant, W.D., and Bourgoyne, A.T., Jr., 1986, Fracture gradient prediction for offshore wells, in 56th SPE California regional meeting, proceedings, SPE-15105: Society of Petroleum Engineers, p. 125-128. Also published in 1986 as, Method predicts frac gradient for abnormally pressured formations: Petroleum Engineer International, v. 58(1), January, p. 38-46.

Cooke, C.E., Jr., and Meyer, A.J., 1979, Application of radial differential temperature (RDT) logging to detect and treat flow behind casing, paper UU, in 20th annual logging symposium transactions: Society of Professional Well Log Analysts, 10 p.

Cooke-Yarborough, P., 1989, United Kingdom North Sea--unusual applications of the wireline formation tester, paper U, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 12 p.

Cooper, R.E., 1988, Coiled tubing in horizontal wells, SPE-17581, in SPE international meeting on petroleum engineering [Tianjin, China], proceedings: Society of Petroleum Engineers, p. p. 323-334.

Corwith, J.R., and Mengel, F., 1988, Applications of pulsed neutron capture logs in the Ekofisk area fields, SPE-18147, in 1988 SPE annual technical conference proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 413-421. Later published in 1990, SPE Formation Evaluation, v. 5(1), March, p. 16-22.

Cryer, J., Dennis, B., Lewis, R., Palmer, K., Watfa, M., 1987, Logging techniques for casing corrosion: The Technical Review, v. 35(4), p. 32-39.

Davarzani, J., and Roesner, R.E., 1985, Surveying steam injection wells using production logging instruments: Geothermal Resources Council Transactions, v. 9, part 2, p. 451-456.

Davarzani, J., and Sloan, M., 1988, Simultaneous TPS logging system: Geothermal Resources Council Transactions, v. 12, p. 441-448.

Davis, R.J., 1987, Use of log-derived parameters for completion design enhancement in the Medina Formation, SPE-17035, in 1987 SPE eastern regional meeting proceedings: Society of Petroleum Engineers, p. 87-99.

Davis, R.J., 1988, Better Medina completions achieved with log data: Petroleum Engineer International, v. 60(11), p. 20-28.

Dennis, B., 1989, Cathodic protection evaluation of well casings using wireline techniques, paper D, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 23 p.

Draxler, J.K., Jacob, K., and Stark, D.M., 1986, Cased hole evaluation with oil, gas and varying water salinities in the formation by pulsed neutron techniques, paper E, in 10th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Aberdeen Chapter, 12 p.

Dresser Atlas, 1982, Interpretive methods for production well logs, 2nd edition: Dresser Industries, Houston, Document No. 9441, 159 p.

Dunlap, H.F., and Coates, G.R., 1988, Boron--Tracking a trace element: The Log Analyst, v. 29(6), November-December, p. 410-417.

Dupree, J.H.,, 1988, Cased-hole nuclear logging interpretation, Prudhoe Bay, Alaska, paper TT, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 22 p. Later published in 1989, The Log Analyst, v. 30(3), May-June, p. 162-177.

Edgson, J.J., and MacFarlane, C.J., 1987, Cased hole logging technique to evaluate reservoirs in new and old wells, paper 87-38-35, in 38th annual meeting preprints, v. 2: Petroleum Society of CIM [Canadian Institute of Mining], Calgary, p. 583-607. Later published in 1988, Journal of Canadian Petroleum Technology, v. 27(4), July-August, p. 30-43.

Edwards, D.P., 1983, Zones of sand production identified by log-derived mechanical properties--A case study, paper S, in 8th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, London Chapter, 23 p.

Edwards, D., Joranson, H., and Spurlin, J., 1988, Field normalization of formation mechanical properties for use in sand control management, paper Y, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 24 p.

Elkington, P.A.S., Samworth, J.R., and Enstone, M.C., 1990, Vertical enhancement by combination and transformation of associated responses, paper HH, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p.

Elkins, L.F., 1978, Evaluation, chapter 8, in Determination of residual oil saturation: Interstate Oil Compact Commission, Oklahoma City, p. 177-261.

Felder, R.D., 1988, Cased-hole logging for evaluating bypassed reserves, SPE-18507: Journal of Petroleum Technology, v. 40(8), p. 969-973.

Felder, R.D., and Hoyer, W.A., 1982, The use of well logs to monitor a surfactant flood pilot test, SPE-11147: Society of Petroleum Engineers, 57th annual meeting [New Orleans] preprint, 24 p. Later published in 1984, Journal of Petroleum Technology, v. 36(8), p. 1379-1392.

Fertl, W.H., 1979, Determination of residual oil saturation from geophysical well logs in tertiary recovery projects: Energy Sources, v. 4(3), p. 259-277.

Fertl, W.H., 1982, Well logging and its applications in cased holes, SPE-10034, in International petroleum conference [Beijing], proceedings: Society of Petroleum Engineers, p. 541-561. Later published in 1984, Journal of Petroleum Technology, v. 36(2), p. 249-266.

Fertl, W.H., and Chilingarian, G.V., 1988, Determination of residual oil saturation from well logs: Energy Sources, v. 10(2), p. 95-101.

Fertl, W.H., and Chilingarian, G.V., 1989, Determination of residual oil saturation based on geophysical well logging techniques, chapter 3, in E.C. Donaldson, G.V. Chilingarian, and T.F. Yen, editors, Enhanced oil recovery, II; Processes and operations: Elsevier Scientific Publishers, Amsterdam, Developments in Petroleum Science No. 17B, p. 451-494.

Fertl, W.H., and Chilingarian, G.V., 1989, Evaluation and monitoring of enhanced oil recovery projects based on geophysical well logging techniques, chapter 15, in E.C. Donaldson, G.V. Chilingarian, and T.F. Yen, editors, Enhanced oil recovery, II; Processes and operations: Elsevier Scientific Publishers, Amsterdam, Developments in Petroleum Science No. 17B, p. 451-494.

Fertl, W.H., Conley, S., Frost, E., and Thompson, J.B., 1983, Evaluation and monitoring of enhanced recovery projects in California and cased-hole exploration and recompletions in west Texas based on the continuous carbon/oxygen log [combined SPE-9714 and SPE-10739]: Journal of Petroleum Technology, v. 35(1), p. 143-157.

Fertl, W.H., and Wichmann, P.A., 1977, Exploration for and evaluation of hydrocarbon resources in cased boreholes, paper 25, in Fifth European logging symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 17 p.

Forne, O., and Haugland, T., 1988, The determination of residual oil saturation in the Brent reservoir, paper FF, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 21 p.

Freedman, R., and Rouault, G.F., 1987, Nuclear magnetism logging; signal processing for residual oil saturation, SPE-16771, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 309-321. Later published in 1989 as, Remaining-oil determination using nuclear magnetism logging, SPE Formation Evaluation, v. 4(2), p. 21-130.

Freeman, D.W., and Fenn, C.J., 1989, An evaluation of various logging methods for the determination of remaining oil saturation in a mixed salinity environment, SPE-17976, in SPE Middle East oil technical conference and exhibition [Manama, Bahrain], proceedings: Society of Petroleum Engineers, p. 495-506.

Fulton, D.D., 1985, A primer to DST chart interpretation, in 32nd annual southwestern petroleum short course, proceedings: Southwestern Petroleum Short Course Association, Lubbock, Texas, p. 15-33.

Gadeken, L.L., Gartner, M.L., and Sharbak, D.E., 1989, Improved evaluation techniques for multiple radioactive tracer applications, paper KK, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 13 p.

Gadeken, L.L., and Smith, H.D. Jr., 1989, A relative distance indictor from gamma ray spectroscopy measurements with radioactive tracers, SPE-17962, in SPE Middle East oil technical conference and exhibition [Manama, Bahrain], proceedings: Society of Petroleum Engineers, p. 357-364.

Gadeken, L.L., Smith, H.D., Jr., and Seifert, D.J., 1987, Calibration and analysis of borehole and formation sensitivites for gamma ray spectroscopy measurements with multiple radioactive tracers, paper V, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 23 p. Later published in 1988, The Log Analyst, v. 29(3), May-June, p. 159-177.

Georgi, D.T., 1989, Application of time-series analysis to induced gamma ray spectroscopy logs from two Cold Lake heavy-oil observation wells, SPE-19602, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 323-334.

Georgi, D.T., Heavysege, R.G., Chen, S.T., and Eriksen, E.A., 1989, Application of shear and compressional transit-time data to cased hole carbonate reservoir evaluation, paper L, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 24 p.

Goldberg, D., Speed, D., Wilkinson, C., and Scholz, E., 1990, A correlation of hydraulic conductivity from pulse tests with sonic log amplitudes, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 297-302.

Goodwin, K.J., 1989, Guidelines for cement sheath evaluation, SPE-19538, in SPE annual technical conference and exhibition, proceedings, volume delta, Drilling: Society of Petroleum Engineers, p. 207-214.

Grooms, G.E., and Schulte, R.K., 1985, Contributions of observation well logging to the evaluation of polymer-augmented waterflood pilots, SPE-14396: Society of Petroleum Engineers, 60th annual meeting [Las Vegas], preprint, 12 p.

Gunter, J.M., and Moore, C.V., 1986, Improved use of wireline testers for reservoir evaluation, SPE-14063, in 1986 SPE international meeting on petroleum engineering [Beijing, China, March 17-20], proceedings: Society of Petroleum Engineers, p. 401-413. Later published in 1987, Journal of Petroleum Technology, v. 39(6), SPE-16481, p. 634-644.

Har, P.E., and Pohler, M.A., 1989, Pulsed neutron log analysis techniques and results for Gulf Coast and east Texas sandstones, paper Y, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p.

Harness, P.E., Hansen, M.D., Terzian, G.A., Fowler, S.H., Jr., and Golino, F.J., 1990, An overview of reeled-tubing-conveyed production logging capabilities in California, SPE-20028, in SPE California regional meeting proceedings: Society of Petroleum Engineers, p. 155-163

Hashem, M.N., 1990, Saturation evaluation of secondary recovered reservoirs, SPE_20095, in SPE California regional meeting, proceedings: Society of Petroleum Engineers, p.581-590.

Head, E., and Flaum, C., 1989, A new technique for time-based interpretation, paper B, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 9 p.

Heffernan, P.D., 1985, Well logging requirements for miscible flood projects in the Permian Basin, in 32nd annual southwestern petroleum short course, proceedings: Southwestern Petroleum Short Course Association, Lubbock, Texas, p. 196-214.

Hilchie, D.W., 1988, NML-The hope for production prediction: Journal of Petroleum Technology, v. 40(3), P. 273-275.

Hill, A.D., 1990, Production logging--theoretical and interpretative elements: Society of Petroleum Engineers Memoir No. 14, 154 p.

Hill, A.D., Boehm, K.E., and Akers, T.J., 1988, Tracer placement techniques for improved radioactive tracer logging, SPE-17317, in Permian basin oil and gas recovery symposium proceedings: Society of Petroleum Engineers, p. 379-390. Also published, in 1988 California regional meeting proceedings: Society of Petroleum Engineers, p. 75-86. Later published in 1988, Journal of Petroleum Technology, v. 40(11), p. 1484-1492.

Hill, F.L., III, Barnette, J.C., Koenn, L.D., and Chace, D.M., 1989, New instrumentation and interpretive methods for identifying shielded waterflow using pulsed neutron technology, paper S, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 14 p.

Hobson, G.D., 1989, Production from carbonate reservoirs, chapter 14, in Mason, J.F., and Dickey, P.A., editors, Oil field development techniques: AAPG Studies in Geology No. 28, p. 193-207.

Holditch, S.A., 1989, Pretreatment formation evaluation, chapter 2, in Gidley, J.L., Holditch, S.A., Nierode, D.E., and Veatch, R.W., Jr., editors, Recent advances in hydraulic fracturing: Society of Petroleum Engineers, p. 39-56.

Hopkinson, E.C., Fertl, W.H., and Oliver, D.W., 1981, The continuous carbon/oxygen log--basic concepts and recent field experiences, SPE-9613, in 1981 SPE Middle East oil technical conference [Manama, Bahrain, March 9-12], proceedings: Society of Petroleum Engineers. Later published in 1982, Journal of Petroleum Technology, v. 34(10), p. 2441-2448. Reprinted in 1981, in Carbon/oxygen log: Dresser Industries, Houston, Publication No. 9417, paper 6.

Horner, S.C., and Sanyal, S.K., 1984, The prediction of saturation using the carbon/oxygen log: U.S. Department of Energy Report DOE/SF/11564--9, 36 p.

Hull, R.L., and Johnson, D.E., 1985, The Muldoon field--an evaluation of behind-casing pay zones in a freshwater environment, SPE-14464: Society of Petroleum Engineers, 60th annual meeting preprint, 5 p. Later published in 1988, SPE Formation Evaluation, v. 3(1), p. 92-96.

Hunt, E., and Ebinger, C.D., 1989, Keys to good fracturing, part 1--Use of new tools, techniques enhance fracturing results: Oil and Gas Journal, v. 87(13, March 27, p. 33-41.

Hunt, E.R., 1987, FRACLOG - an integrated log analysis approach to completion and hydraulic fracture design: In Focus--tight Gas Sands, v. 4(1), March, p. 9-22.

Hunt, E.R., Raymond, D.H., Haskett, C.E., and Pirie, R.G., 1981, Application of new well logs and geology to fracturing and producibility in tight gas sands, Cotton Valley Group, SPE/DOE-9832, in 1981 SPE/DOE symposium on low permeability gas reservoirs, proceedings: Society of Petroleum Engineers, p. 35.

Hutomo, P., and Jordan, W.V., 1985, Wireline pressures detect fluid contacts, Ikan Pari field, Natuna Sea, in 14th annual convention proceedings: Indonesian Petroleum Association, Jakarta, p. 543-563.

Interstate Oil Compact Commission, 1978, Determination of residual oil saturation: Interstate Oil Compact Commission, Oklahoma City, 302 p.

Jackson, C.E., and Gartner, M.L., 1988, A technique for evaluation of hydraulic fractures using quantitative concentrations of derived from the natural gamma ray spectrum, SPE-18152, in 1988 SPE annual technical conference proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 439-448.

Jackson, J.A., 1984, Nuclear magnetic resonance logging: The Log Analyst, v. 25(5), September-October, p. 16.

Jarrell, M., and Lyle, R., 1987, Application of the temperature survey in demonstrating the mechanical integrity of injection wells, in NWWA FOCUS conference on Midwestern ground water issues [Indianapolis, April 21-23], proceedings: National Water Well Association, Dublin, Ohio, p. 569-590.

Jeckovich, G.T., and Olesen, J-R., 1989, Enhancing through-tubing formation evaluation capabilities with the Dual-Burst Thermal Decay tool, SPE_19580, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 83-98.

Joly, E.L., Dormigny, A.M., Pincon, F.P., Louis, A.J.P., and Catala, G.N., 1988, New production logging technique for horizontal wells, SPE-14463: SPE Production Engineering, v. 3(3), p. 328-332.

Jones, R.L., 1982, Bootstrapping your way into TDT analysis: The Log Analyst, v. 23(4), July-August, p. 3-13.

Jutten, J.J., 1988, Studies with narrow cement thicknesses lead to improved CBL [cement bond logs] in concentric casings, SPE-18028, in 1988 SPE technical conference and exhibition proceedings, volume delta, Drilling: Society of Petroleum Engineers, p. 113-124.

Jutten, J.J., and Corrigall, E., 1989, Studies with narrow cement thickness lead to improved CBL in concentric casings: Journal of Petroleum Technology, v. 41(11), p. 1,158-1,192.

Jutten, J.J., and Parcevaux, P., 1987, Relationship between Cement Bond Log output and borehole geometrical parameters, SPE/IDC-16139, in 1987 SPE/IADC drilling conference [New Orleans, March 15-18], proceedings: Society of Petroleum Engineers, p. 763-772.

Katahara, K.W., Kyle, D.G., Siegfried, R.W., Gard, M.F., Goodwill, W.P., Schasteen, T., and Petermann, S.G., 1988, Detection of external pipe defects with a modified borehole televiewer, paper UU, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 20 p.

Kessler, C., and Sanders, L., 1989, Cased-hole hydrocarbon detection in the Permain basin using the full-wave sonic tool, SPE-19610, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 403-410. Later published in 1990, in SPE California regional meeting, proceedings: Society of Petroleum Engineers, p. 65-72.

Knight, B.L., and Davarzani, M.J., 1984, Injection well logging using viscous EOR fluids, SPE-13143: Society of Petroleum Engineers, 59th annual meeting [Houston] preprint. Later published in 1986, SPE Formation Evaluation, v. 1(3), p. 300-308.

Komorowski, P., McDonald, J., and Scribbins, B., 1989, Evaluation of a formation flooded by fresh water, using geochemical, dielectric, and nuclear magnetic measurements, paper M, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 26 p.

Kular, G.S., Chhina [sic], H.S., Best, D.A., and Mackenzie, W.T., 1988, Multiple hydraulic fracture propagation in oil sands, SPE-17534, in SPE Rocky Mountain regional meeting proceedings: Society of Petroleum Engineers, p. 477-491.

Lachance, D.P., and Winston, R.T., 1985, Recognition of waterflood sweep and formation lithology in a giant Egyptian oil field by applied petrophysics, SPE-14277: Society of Petroleum Engineers, 60th annual meeting [Las Vegas], preprint, 8 p. Later published in 1987, SPE Formation Evaluation, v. 2(2), p. 150-154.

Lacy, L.L., and Smith M.B., 1989, Fracture azimuth and geometry determination, chapter 16, in Gidley, J.L., Holditch, S.A., Nierode, D.E., and Veatch, R.W., Jr., editors, Recent advances in hydraulic fracturing: Society of Petroleum Engineers, p. 341-356.

Leslie, H.D., Selliers, J. de, and Pittman, D.J., 1987, Coupling and attenuation--A new measurement pair in cement bond logging, SPE-16207, in Production operations symposium [Oklahoma City, March 8-10], proceedings, : Society of Petroleum Engineers, p. 243-250.

Lester, R.A., 1989, The segmented bond tool; a pad-type cement bond device, paper A, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 13 p.

Loveless, D.K., McCall, D.C., and Grayson, S., 1988, Logging techniques; new solutions, improved reserves: Petroleum Management, v. 10(7), p. 35-39.

Lucia, F.J., Bebout, D.G., Hocott, C.R., Fogg, G.E., and Vander Stoep, G.W., 1988, Calculation of remaining mobile oil, Dune field, University Lands, Crane County, Texas, in 35th annual southwestern petroleum short course, proceedings: Southwestern Petroleum Short Course Association, 143-154.

MacEwen, H., 1988, Coiled-tubing-conveyed logging systems, SPE-18350, in SPE European petroleum conference [London] proceedings: Society of Petroleum Engineers, p. 167-171.

Mahdavi, M., Olesen, J-R., Preeg, B., Bhasin, M., and Watfa, M., 1989, Pulsed-neutron news: Schlumberger Oilfield Review, v. 1(1), April, p. 43-53.

Major, R.P., and Holtz, M.H., 1989, Effects of geologic heterogeneity on waterflood efficiency at Jordan field, University Lands, Ector and Crane Counties, Texas, SPE-19874, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 633-640.

Maki, V.E., Jr., and Hamilton, L., 1988, Cement bond logs of fiberglass casing, SPE-18143, in 1988 SPE annual technical conference proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 367-374. Also in volume delta, Drilling, p. 377-384.

Martin, K.I., 1982, The application of log-derived transmissibililty in well completion design and well performance evaluation, in 11th annual convention proceedings, volume 1: Indonesian Petroleum Association, Jakarta, p. 401-414.

Masse, P.J., Gosney, T.C., and Long, D.L., 1990, The use of pulsed neutron capture logs to identify steam breakthrough--case study; South Belridge middle expansion steamflood project, SPE/DOE-20252, in SPE/DOE symposium on enhanced oil recovery, proceedings: Society of Petroleum Engineers, p. 773-784.

McCann, C., 1987, Simultaneous mechanical caliper-electromagnetic caliper log, in 34th annual short course proceedings: Southwestern Petroleum Short Course Association, Lubbock, Texas, p. 178-188.

McKinley, R.M., 1982, Production logging, SPE-10035, in International petroleum exhibition and technical symposium [Bejing] proceedings: Society of Petroleum Engineers, p. 563-594. Reprinted in 1985, in Production logging: Society of Petroleum Engineers, Reprint Series No. 19, p. 176-207.

McKinley, R.M., and Bower, F.M., 1977, Specialized applications of noise logging, SPE-6784: Society of Petroleum Engineers, 52 annual meeting [Denver] preprint. Later published in 1979, Journal of Petroleum Technology, v. 31(11), November, p. 1387-1395.

Merkel, R.H., and Head, W.J., 1977, The use of computerized log analysis to determine in situ lithologic characteristics pertinent to secondary recovery: Bulletin of Canadian Petroleum Geologists, v. 25(2), May, p. 291-304.

Minette, D.C., 1990, Thin-bed resolution enhancement--potential and pitfalls, paper GG, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Mohamad, A.Y., and Snijder, G.L., 1986, Using Gamma-ray spectrometry tool in old wells, in 6th SPE offshore South East Asia conference [Singapore, January 28-31], proceedings: South East Asia Petroleum Exploration Society, p. 426-436.

Morgan, W.D., and Hertzog, R.C., 1983, The application of induced gamma-ray spectroscopy in cased hole formation evaluation in Sumatra, Indonesia, in 12th annual convention proceedings, v. 2: Indonesian Petroleum Association, Jakarta, p. 275-300.

Murphy, R.P., and Owens, W.W., 1972, The use of special coring and logging procedures for defining reservoir residual oil saturations, SPE-3793: Society of Petroleum Engineers, Symposium on improved oil recovery preprint. Later published in 1973, Journal of Petroleum Technology, v. 25(7), p. 841-850.

Murphy, R.P., Foster, G.T., and Owens, W.W., 1976, Evaluation of waterflood residual oil saturations using log-inject-log procedures, in 4th SPE-AIME symposium on improved oil recovery [Tulsa], proceedings: Society of Petroleum Engineers. Later published in 1977, Journal of Petroleum Technology, v. 29(2), p. 178-186.

Newman, J., and McDuff, J., 1988, Electric wireline methods for in situ capture of wellbore samples and determining their flow rates and direction, in 2nd national outdoor action conference on aquifer restoration, ground water monitoring, and geophysical methods [Las Vegas, May 23-26] proceedings, volume 1: Association of Ground Water Scientists and Engineers (AAAS), p. 97-122.

Norel, G., Dubois, C., and Georges, G., 1988, Test-bench checks cement in horizontal holes: Petroleum Engineer International, v. 60(11), p. 54-59.

North, R.J., 1987, Through-casing reservoir evaluation using gamma ray spectroscopy, SPE-16356, in SPE California regional meeting, proceedings: Society of Petroleum Engineers, p. 329-342.

Nutt, R.L., and Watfa, M., 1989, Time-lapse saturation monitoring and its application to time-lapse mapping, SPE-17975, in SPE Middle East oil technical conference and exhibition [Manama, Bahrain], proceedings: Society of Petroleum Engineers, p. 483-494.

Oliver, D.W., Wyatt, D.F., Jr., and Smith, H.D., Jr., 1986, Reservoir monitoring with the thermal multgate decay log, SPE-14137, in 1986 SPE Permian Basin oil and gas recovery conference, proceedings: Society of Petroleum Engineers, p. 7-26. Also published in 1986, in 1986 SPE international meeting on petroleum engineering [Beijing, China, March 17-20], proceedings: Society of Petroleum Engineers, p. 217-236.

Paillet, F.L., Waltz, J., and Boyle, R.E., 1989, Geophysical log investigation of formation changes produced by hydraulic fracture stimulation in a crystalline bedrock aquifer, paper EE, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 571-594.

Parikh, H.N., Ayachit, V.V., Chakravarthy, N.C.V.N., and Carg, R.K., 1989, Borehole geophysical logging techniques for delineating fractured zones and cavities in hard rock areas for hydrofracturing; a case study, in Gupta, C.P., editor, Appropriate methodologies for development and management of groundwater resources in developing countries [Hyperabad, India, February 28-March 4], proceedings, volume 1: Oxford & IBH Publishing Company, New Delhi, p. 249-262.

Pecine, R.J., Welbridge, E.W., Vandegrift, Herzenberg, C.L., Seitz, M.G., and Heemstra, R., 1984, Assessment of gamma-inject logging techniques for the determination of residual oil saturation: U.S. Department of Energy Report DOE/BC/10383-30, 74 p.

Peeters, M., and Hartley, R., 1984, Induced fracture height detection from wireline logs, paper GGG, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p.

Pelletier, R., 1987, NML applications in the Belly River formation of southern Alberta, paper W, in 11th formation evaluation symposium transactions: Canadian Well Logging Society, 14 p.

Pemper, R.R., Flecker, M.J., McWhirter, V.C., and Oliver, D.W., 1988, Hydraulic fracture evaluation with multiple radioactive tracers: Geophysics, v. 53(10), p. 1323-1333.

Petovello, B.G., 1975, Evaluation of well performance through production logging: Canadian Well Logging Society Journal, v. 8(1), p. 47-56. Reprinted in 1975, in 16th annual logging symposium transactions, paper E: Society of Professional Well Log Analysts. Reprinted in 1985, in Production Logging: Society of Petroleum Engineers, Reprint Series No. 19, p. 112-117.

Piers, G.E., 1989, Inflatable diverter flowmeter, paper CC, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 21 p.

Pilkington, P.E., 1987, Perennial CBL centering problem can be minimized: Oil and Gas Journal, v. 85(48), 45-49.

Prasada, S.V.V., Rao, G., Varadarajan, P., Prasad, P.P., Subrahmanyam, K., and Seshunarayana, T., 1989, Borehole resistivity logging in PVC screened well, in Gupta, C.P., editor, Appropriate methodologies for development and management of groundwater resources in developing countries [Hyperabad, India, February 28-March 4], proceedings, volume 1: Oxford & IBH Publishing Company, New Delhi, p. 457-460.

Rackley, S.A., and Tannemaat, R.J., 1988, Analysis of uncertainties in applying the Waxman-Smits equation to the determination of remaining oil saturation in the Baram delta, OSEA-88183, in 7th offshore South East Asia conference proceedings: Southeast Asia Petroleum Society, p. 710-722. Later published in 1989, SPE Formation Evaluation, v. 4(3), September, p. 363-370.

Rafie, M.Y., and Yongblood, W.E., 1987, Advances in quantitative reservoir description and monitoring in Saudi Arabia, in 12th world petroleum congress proceedings, v. 3, production: John Wiley & Sons, New York, p. 317-329.

Rambow, F.H.K., 1988, Cement evaluation in fiberglass casing; a case for pulse-echo tools, paper VV, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 21 p.

Rambow, F.H.K., 1990, Active listening--an alternative method for detecting flow and measuring flow velocity behind casing, paper P, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 18 p.

Rang, C.L., 1987, Evaluation of gas flows in cement, SPE-16385, in SPE California regional meeting, proceedings: Society of Petroleum Engineers, p. 587-592.

Richardson, J.E., 1977, Monitoring flood profiles with induction logs, SPE-6785: Society of Petroleum Engineers, 52nd annual meeting [Denver] preprint. Later published in 1979, Journal of Petroleum Technology, v. 31(1), p. 19-24.

Roberts, D.L., and Richards, J.W., 1987, Casing corrosion evaluation using ultrasonic techniques; a unique approach for west Texas wells, in 34th annual short course proceedings: Southwestern Petroleum Short Course Association, Lubbock, Texas, p. 20-33.

Roberts, D.L., and Walter, J.L., 1985, Cement and casing evaluation using sonic and ultrasonic techniques, in 32nd annual southwestern petroleum short course, proceedings: Southwestern Petroleum Short Course Association, Lubbock, Texas, p. 67-95.

Robinson, J.D., Loren, J.D., Vajnar, E.A., and Hartman, D.E., 1972, Determining residual oil with the nuclear magnetism log, SPE-3797, in Symposium on improved oil recovery, proceedings: Society of Petroleum Engineers. Later published in 1974, Journal of Petroleum Technology, v. 26(2), p. 226-236.

Robinson, W.S., 1974, Field results from the noise-logging technique, SPE-5088: Society of Petroleum Engineers, 49th annual meeting [Houston] preprint. Later published in 1976, Journal of Petroleum Technology, v. 28(11), p. 1370-1376. Reprinted 1985, in Production logging: Society of Petroleum Engineers, Reprint Series No. 19, p. 233-239.

Roesner, R.E., LeBlanc, A.J., and Davarzani, J., 1988, Effects of flow regimes on production logging instrument tools, in 1988 SPE annual technical conference and exhibition proceedings, volume pi, Production operations and engineering: Society of Petroleum Engineers, p. 253-265.

Roest, J.A., Runia, D.J., and Trebolle, R., 1989, Reconciliation of contradictory ROS data from a Venezuelan light-oil sandstone reservoir: Journal of Petroleum Science and Engineering, v. 2(2), April, p. 207-216.

Roscoe, B.A., and Grau, J.A., 1985, Response of the carbon/oxygen measurement for an inelastic gamma ray spectroscopy tool, SPE-14460: Society of Petroleum Engineers, 60th annual meeting preprint, 7 p. Later published in 1988, SPE Formation Evaluation, v. 3(1), p. 76-80.

Saeedi, J., 1986, Interpretation and use of vertically distributed pressures from Repeat Formation Tester measurements, paper 86-37-36, in 37th annual technical meeting of the Petroleum Society of CIM [Calgary, June 8-11], preprints, v. 1: Petroleum Institute of the Canadian Institute of Mining, Calgary, p. 499-527.

Schlumberger, 1973, Production log interpretation: Schlumberger Well Services, Houston, Document No. C-11811, 91 p.

Schlumberger, 1976, The essential of thermal decay time logging: Schlumberger Ltd., New York, Document No. M-081003, 31 p.

Schlumberger, 1980, Dual water model cased reservoir analysis: Schlumberger Educational Services, Houston, variously paginated.

Schlumberger, 1990, Cased hole log interpretation principles/applications: Schlumberger Educational Services, Houston, Document No. SMP-7025, variously paginated.

Schwanitz, B.J., 1988, A combination of logging measurements for quantitative monitoring of CO_2 floods, SPE-17276, in Permian basin oil and gas recovery symposium proceedings: Society of Petroleum Engineers, p. 121-127.

Schwanke, B.E., Hopkinson, E.C., and Taylor, J.C., III, 1990, Gamma ray tracers help evaluate acid diversion: Petroleum Engineering International, v. 62(2), February, p. 40-41.

Setser, G., and Williams, M.R., 1985, Measurement of remaining oil saturation in northern Michigan using nuclear magnetism log data and pressure core, SPE-14276: Society of Petroleum Engineers, 60th annual meeting [Las Vegas], preprint, 10 p.

Sheives, T.C., Tello, L.N., Maki, V.E., Jr., Standley, T.E., and Blankinship, T.J., 1986, A comparison of new ultrasonic cement and casing evaluation logs with standard cement bond logs, SPE-15436: Society of Petroleum Engineers, 61st annual meeting [New Orleans] preprint, 8 p.

Shultz, A.L., Bell, W.T., and Urbanosky, H.J., 1974, Advancements in uncased-hole, wireline formation-tester techniques, SPE-5035: Society of Petroleum Engineers, 49th annual meeting [Houston] preprint. Later published in 1975, Journal of Petroleum Technology, v. 27(11), p. 1331-1336.

Smith, M.B., Reeves, T.L., and Miller, W.K. II, 1989, Multiple fracture height measurements; a case history, SPE-19092, in SPE gas technology symposium, proceedings: Society of Petroleum Engineers, p. 351-362.

Smith, M.P., and Wyatt, D.F., Jr., 1987, Quantitative flood monitoring utilizing a new pulsed neutron tool modeling concept, in Formation evaluation and reservoir geology, SPE-16815, volume omega, Formation evaluation: Society of Petroleum Engineers, 1987 annual meeting proceedings, p. 655-669. Also published in 1988 as OSEA-88166, in 7th offshore South East Asia conference proceedings: Southeast Asia Petroleum Society, p. 230-241.

Smolen, J.J., 1986, Cased-hole logging--A perspective, paper K, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 22 p. Later published in 1987, The Log Analyst, v. 28(2), p. 165-174.

Smolen, J.J., 1986, Production logging: J.J. Smolen, Missouri City, Texas, variously paginated.

Smolen, J.J., and Litsey, L.R., 1977, Formation evaluation using wireline formation tester pressure data, SPE-6822: Society of Petroleum Engineers,52nd annual meeting [Denver] preprint. Later published in 1979, Journal of Petroleum Technology, v. 31(1), p. 25-32.

Society of Petroleum Engineers, 1985, Production logging: Society of Petroleum Engineers, Reprint Series No. 19, 375 p. [Contains 26 significant papers on tool design and application.]

Society of Professional Well Log Analysts, 1979, Pulsed neutron logging reprint volume: Society of Professional Well Log Analysts, 448 p. [Contains 32 significant papers on tool operation and application.]

Steinman, D.K., Adolph, R.A., Mahdavi, M., Marienbach, E., Preeg, W.E., and Wraight, P.D., 1986, Dual-burst thermal decay time logging principles, SPE-15437: Society of Petroleum Engineers, 61st annual meeting preprint, 15 p. Later published in 1988, SPE Formation Evaluation, v. 3(2), p. 377-385.

Stoker, R.C., Goldman, D., and Kunze, J.F., 1977, Deducing production zones from well logs: Geothermal Resources Council Transactions, v. 1, p. 279-280.

Streeter, R.W., and Hunt, E.R., 1989, Prefracture analysis of Red Mountain sands--An integrated analysis of openhole and cased hole logs, SPE-19003, in SPE joint Rocky Mountain regional/low permeability reservoirs symposium [Denver], proceedings: Society of Petroleum Engineers, p. 695-706.

Swulius, T.M., 1984, Porosity calibration of neutron logs, SACROC unit, SPE-13289: Society of Petroleum Engineers, 59th annual meeting [Houston] preprint. Later published in 1986, Journal of Petroleum Technology, v. 38(4), p. 468-476.

Tanner, H.L., 1985, Evaluation of low-resistivity cased-off reserves using the shale-compensated chlorine log, SPE-14459: Society of Petroleum Engineers, 60th annual meeting [Las Vegas], preprint, 8 p. Later published in 1987, SPE Formation Evaluation, v. 2(3), p. 284-288.

Tesarek, P.B., and Heysse, D.R., 1987, Water injection profiles in Eola field determined by changes in thermal neutron capture cross section, SPE-16816, in 1987 annual technical meeting and exhibition proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 671-679.

Thomas, E.C., and Ausburn, B.E., 1976, Determining swept-zone residual oil saturation in a slightly consolidated Gulf Coast sandstone reservoir, SPE-5803, in SPE-AIME improved oil recovery symposium, proceedings, : Society of Petroleum Engineers. Later published in 1979, Journal of Petroleum Technology, v. 31(4), p. 513-524.

Thomas, E.C., Richardson, J.E., Shannon, M.T., and Williams, M.R., 1986, ROS measurement and flood monitoring techniques, SPE-14060, in 1986 SPE international meeting on petroleum engineering [Beijing, China, March 17-20], proceedings, : Society of Petroleum Engineers, p. 193-208.

Thuaudet, G., Beardsell, M., and Corrigan, M., 1989, Production logging in non-eruptive wells, paper OO, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 13 p.

Timur, A., 1967, Pulsed nuclear magnetic resonance studies of porosity, movable fluid and permeability of sandstones, SPE-2045: Society of Petroleum Engineers, 42nd annual meeting preprint. Later published in 1969, Journal of Petroleum Technology, v. 21(6), p. 775-786.

Timur, A., 1968, An investigation of permeability, porosity, and residual water saturation relationships for sandstone reservoirs, paper J, in 9th annual well logging symposium transactions: Society of Professional Well Log Analysts, 18 p. Later published in 1968, The Log Analyst, v. 9(4), July-August, p. 8-17.

Toney, J.B., and Johnston, J.M., 1989, A unique mechnical and logging combination for detecting and repairing gravel-pack deficiencies, paper AA, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 15 p.

Tubman, K.M., Cheng, S.T., Willen, D.E., Toksoz, M.N., 1984, Determination of formation properties in cased boreholes using full waveform acoustic logs, paper CC, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 19 p.

Umiastowski, K., and Buniak, M., 1977, Influence of the rock heterogeneity on the results of gamma-gamma logging, in Nuclear techniques and mineral resources 1977: International Atomic Energy Agency, Vienna, p. 273-280.

Uswak, G.M., Virginillo, C.B., and Ackert, D.L., 1989, Assisted lift production logging of pumped wells using coiled-tubing and gas lift techniques, paper X, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 11 p.

van den Berg, F.G., 1989, The capability of pulsed neutron capture logging to determine oil and gas saturations, SPE-19614, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 437-446.

Von Lunen, E., 1988, Through casing sonic transit time measurement using the array-sonic tool, in 35th annual southwestern petroleum short course, proceedings: Southwestern Petroleum Short Course Association, 143-154.

Walker, M., Dupree, J., and Hellman, H., 1989, Formation tester applications in the Endicott field of Alaska, paper K, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 24 p.

Ward, R.W., and Asakura, S., 1985, The evaluation of casing wear in deviated holes using high performance acoustic calipers, in 1st oil and gas Australia petroleum conference [Perth, November 26-28], proceedings: ?, 8 p. Also published in 1986 in, 6th SPE offshore South East Asia conference [Singapore, January 28-31], proceedings: South East Asia Petroleum Exploration Society, p. 467-473.

Watfa, M., 1989, Downhole casing corrosion and interpretation techniques to evaluate corrosion in multiple casing strings, SPE-17931, in SPE Middle East oil technical conference and exhibition [Manama, Bahrain], proceedings: Society of Petroleum Engineers, p. 55-66.

Westaway, P., Whittman, M., and Rochette, P., 1979, Applications of nuclear techniques to reservoir monitoring, SPE-7776, in 1979 Middle East oil technical conference [Manama, Bahrain, March 25-29], proceedings: Society of Petroleum Engineers. Later published in 1981, Journal of Petroleum Technology, v. 33(1), p. 46-54.

Williams, G.B., 1970, Sonic principles applied to formation fracture location and cement bond logging: Canadian Well Logging Society Journal, v. 3, p. 7.

Williams, R.L., and McCarthy, J.T., 1987, Using multiple radioactive tracers to optimize stimulation designs, SPE-16383, in SPE California regional meeting, proceedings: Society of Petroleum Engineers, p. 555-566.

Woodhouse, R., and Kerr, S.A., 1988, The evaluation of oil saturation through casing using carbon/oxygen logs, SPE-17610, in SPE international meeting on petroleum engineering [Tianjin, China], proceedings: Society of Petroleum Engineers, p. 621-632.

Wooley, G.R., and Hatcher, M., 1987, Improved interpretation of casing logs for casing failure, SPE-16108, in 1987 IADC/SPE drilling conference proceedings: Society of Petroleum Engineers, p. 509-515. Later published in 1989, SPE Drilling Engineering, v. 4(1), p. 66-70.

Wyatt, D.F., Smith, H.D., Jr., and Oliver, D.W., 1986, Reservoir monitoring with the thermal multigate decay log, SPE-14137, in 1986 SPE international meeting on petroleum engineering, proceedings: Society of Petroleum Engineers. Later published in 1987, SPE Formation Evaluation, v. 2(4), p. 401-411.

Wyman, R.E., 1977, How should we measure residual-oil saturation?: Bulletin of Canadian Petroleum Geology, v. 25(2), May, p. 233-270.

Wyman, R.E., 1978, Logging methods, chapter 5, in Determination of residual oil saturation: Interstate Oil Compact Commission, Oklahoma City, p. 89-116.

Yang, Y., Xiancai, Q., and Guocai, Y., 1986, Determination of residual oil saturation in place by carbon/oxygen (C/O) logging in Daqing oilfield, SPE-14838, in 1986 SPE international meeting on petroleum engineering [Beijing, China, March 17-20], proceedings: Society of Petroleum Engineers, p. 209-215.

Youngblood, W.E., 1979, The application of pulsed-neutron-decay time logs to monitor waterfloods with changing salinity, SPE-7777, in 1979 Middle East oil technical conference [Bahrain], proceedings: Society of Petroleum Engineers, p.

Zhixing, H., and Liandi, S., 1986, Mechanism of transit time increase and its interpretation after water injection into reservoir M in Lao Jun Miao oil field, SPE-14846, in 1986 SPE international meeting o petroleum engineering [Beijing, March 17-20], proceedings: Society of Petroleum Engineers, p.427-447.

Zhu, D., and Hill, A.D., 1988, The effect of flow from perforations on two-phase flow; implications for production logging, SPE-18207, in 1988 SPE technical conference and exhibition proceedings, volume pi, Production operations and engineering: Society of Petroleum Engineers, p. 267-275.

V. Acoustic Logging
(Including P and S, Full Waveform, Borehole Seismic, and VSP)

(See also 15. Fracture detection)

Ahmed, H., 1984, Reservoir delineation and porosity evaluation from VSP, in Expanded Abstracts with Biographies, 1984 Technical Program, : Society of Exploration Geophysicists, p. 847-850. Later published in 1987 as SPE-16462: Society of Petroleum Engineers, 42 p.

Angeleri, G.P., and Joli, F., 1986, Analysis of the applications of the VSP, paper X, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 19 p.

Arditty, P.C., Arens, G., and Staron, P., 1984, Improvement of formation properties evaluation through the processing and interpretation results of the EVA tool recordings, in Expanded Abstracts with Biographies, 1984 Technical Program, : Society of Exploration Geophysicists, p. 31-35. Later published as Arditty, P.C., Mathieu, F., and Staron, P., 1986, Evaluation of formation properties from processing and interpretation of the EVA tool logs: APEA [Australian Petroleum Exploration Association] Journal, v. 26, part 1, p. 187-191.

Aron, J. Murray, J., and Seeman, B., 1978, Formation compressional and shear interval transit-time logging by means of long spacings and digital techniques, SPE-7446: Society of Petroleum Engineers, 53rd annual meeting [Houston] preprint, 11 p.

Astbury, S., and Worthington, M.H., 1986, The analysis and interpretation of full waveform sonic data, part 1--Dominant phases and shear wave velocity: First Break, v. 4(4), p. 7-16.

Astbury, S., and Worthington, M.H., 1986, The analysis and interpretation of full waveform sonic data, part 2--Multiples, mode conversions and reflections: First Break, v. 4(6), June, p. 15-24.

Ausburn, B.E., 1977, Well log editing in support of detailed seismic studies, paper F, in 18th annual logging symposium transactions: Society of Professional Well Log Analysts, 38 p. Later reprinted in 1989, in Geophysics II; tools for seismic interpretation: AAPG Treatise of Petroleum Geology Reprint Series No. 13, p. 45-80.

Babec, J.R., and Struss, S.E., 1985, Vertical seismic profiling (VSP)--Bridging the gap: Canadian Well Logging Society Journal, v. 14, p. 85.

Baker, L.J., 1981, The effect of the invaded zone on full wavetrain acoustic logging: Society of Exploration Geophysicists, 51st annual meeting [Los Angeles] preprint S11.2, v. 5, p. 2609-2625. Later published in 1984, Geophysics, v. 49(6), p. 796-809.

Balch, A.H., and Lee, M.W., editors, 1984, Vertical seismic profiling--technique, applications, and case histories: International Human Resource Development Corporation (IHRDC), Boston, 488 p.

Belaud, D., Christie, P., de Montmollin, V., Dodds, K., James, A., Kamata, M., and Schaffner, J., 1988, Detecting seismic waves in the borehole: The Technical Review, v. 36(3), p. 18-29.

Bettis, F., Schnorr, D., Borden, C., Rowe, W., and Schwanitz, 1987, Sonic logging in cased wells--Opportunities for enhancing old fields: The Technical Review, v. 35(4), p. 14-18.

Blakeman, E.R., 1982, A case study of the effect of shale alteration on sonic transit times, paper II, in 23rd annual logging symposium transactions: Society of Professional Well Log Analysts, 14 p.

Botter, B.J., 1982, Circumferential acoustic waves in boreholes for the delineation of vertical fractures, paper S, in 23rd annual logging symposium: Society of Professional Well Log Analysts, 21 p.

Brito dos Santos, W.L., Ulrych, J.J., and de Lima, O.A.L., 1988, A new approach for deriving pseudovelocity logs from resistivity logs: Geophysical Prospecting, v. 36, p. 83-91.

Brown, R.L., Cook, R.N., Lynn, D., 1989, How useful is Poisson's ratio for finding oil/gas?: World Oil, v. 209(4), October, p. 99-106.

Burns, D.R., and Cheng, C.H., 1986, Determination of in-situ permeability from tube wave velocity and attenuation, paper KK, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 15 p.

Cassell, B., 1984, Vertical seimic profiles--An introduction: First Break, v. 2(11), November, p. 9-19.

Castagna, J., 1985, Accuracy and limitation of sonic log and VSP measurements for seismic exploration, in 1985 technical program abstracts and biographies: Society of Exploration Geophysicists, p. 281-283.

Castagna, J.P., Batzle, M.L., and Eastwood, R.L., 1985, Relationships between compressional-wave and shear-wave velocities in clastic silicate rocks: Geophysics, v. 50(4), p. 571-581. Later reprinted in 1989, in Geophysics II; tools for seismic interpretation: AAPG Treatise of Petroleum Geology Reprint Series No. 13, p. 325-335.

Castagna, J.P., and Gaiser, J.E., 1984, Digital processing improves sonic log reliability: World Oil, v. 198(5), April, p. 71-74.

Castagna, J.P., Zucker, S.M., and Shoberg, T.G., 1987, Permeability indication with conventional sonic waveforms, paper MM, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 22 p.

Chang, S.K., Everhart, A.H., and Hornby, B., 1984, Full waveform sonic logging in a shale formation--Field data and theoretical waveforms, in Expanded abstracts with biographies, 1984 technical program, : Society of Exploration Geophysicists, p. 3-5.

Chemali, R., Gianzero, S., and Su, S.M., 1984, The depth of investigation of compressional wave logging for the standard and the long spacing sonde, paper 13, in 9th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 10 p.

Chen, S.T., and Eriksen, E.A., 1988, Direct logging of formation P and S-waves in cased hole using a multipole tool, in 1988 annual meeting expanded abstracts with biographies, volume 1: Society of Exploration Geophysicists, p. 129-131.

Cheng, C.H., Wilkens, R.H., and Meredith, J.A., 1986, Modelling of full waveform acoustic logs in soft marine sediments, paper LL, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 14 p.

Chilingarian, G., and Fertl, W.H., 1987, Fracture detection using circumferential acoustic logs: Energy Sources, v. 9(3), p. 149-160.

Cline, W.M., 1989, Measured logs vs. calculated logs for seismic interpretation: Oil and Gas Journal, v. 87(44), p. 52-56.

Corley, B.H., 1984, Predicting interval transit time for synthetic seismograms from nuclear well logs, in Expanded abstracts with biographies, 1984 technical program: Society of Exploration Geophysicists, p. 360-363.

Crain, E.R., and Boyd, J.D., 1979, Determination of seismic response using edited well log data, paper V, in 7th formation evaluation syposium transactions: Canadian Well Logging Society.

Cramer, P.W., 1986, Reservoir development using offset VSP techniques in the Denver-Julesburg Basin, SPE-15506: Society of Petroleum Engineers, 1986 annual meeting preprint. Later published in 1988, Journal of Petroleum Technology, v. 40(2), p. 2197-205.

Crampin, S., Lynn, H.B., and Booth, D.C., 1987, Shear-wave VSP's; a powerful new tool for fracture and reservoir description, SPE-16866, in 1987 SPE annual technical conference and exhibition proceeding, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers. Later published in 1989, Journal of Petroleum Technology, v. 41(3), p. 283-288.

Dennis, B., 1985, Digital Sonic (SDT) - full waveform logging applications in western Canada: Canadian Well Logging Society Journal, v. 14, p. 63.

Dos Santos, W.L.B., Ulrych, T.J., and De Lima, O.A.L., 1988, A new approach for deriving pseudovelocity logs from resistivity logs: Geophysical Prospecting, v. 36(1), p. 83-91.

Durrance, E.M., 1986, Radioactivity and petroleum, chapter 11, in Radioactivity in geology, principles and applications: John Wiley & Sons, New York, p. 342-363.

Eastwood, R.L., and Castagna, J.P., 1983, Basis for interpretation of V_p/V_s ratios in complex lithologies, paper G, in 24th annual logging symposium transactions: Society of Professional Well Log Analysts, 17 p. Later reprinted, in Later reprinted in 1989, in Geophysics II; tools for seismic interpretation: AAPG Treatise of Petroleum Geology Reprint Series No. 13, p. 295-311.

Eberhart-Phillips, D., Han, D-H., and Zoback, M.D., 1989, Empirical relationships among seismic velocity, effective pressure, porosity, and clay content: Geophysics, v. 54(1), p. 82-89.

Edmundson, H.N., 1985, Perspectives on sonic logging [historical review]: The Technical Review, v. 33(1), p. 5-18.

Ellis, D., Howard, J., and others, 1988, Mineral logging parameters--Nuclear and acoustic: The Technical Review, v. 36(1), p. 38-52.

Engelhard, L., 1985, Shear wave well logging from wavetrain analysis, chapter 5, in G.P. Dohr, editor, Seismic shear waves, seismic exploration volume 15A, part A--Theory: Geophysical Press, London, p. 283-351.

Ensley, R.A., 1986, Classified bibliography of shear-wave seismology, in S.H. Danbom, and S.N. Domenico, editors,Shear-wave exploration: Society of Exploration Geophysicists Geophysical Development Series, v. 1, p. 255-270.

Faraguna, J.K., Chace, and Schmidt, M.G., 1989, An improved borehole televiewer system--image acquisition, analysis, and integration, paper Q, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 11 p.

Fertl, W.H., 1990, Circumferential acoustics logs detect natural fractures and determine their orientation, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 255-262.

Fitch, A.A., 1984, Interpretation of vertical seimic profiles: First Break, v. 2(6), June, p. 19-23.

Fontaine, J.M., Cussey, R., Lacaze, J., Lanaud, R., and Yapaudjian, L., 1987, Seismic interpetation of carbonate depositional environments: AAPG Bulletin, v. 71(3), p. 281-297.

Frost, E., Jr., and Fertl, W.H., 1982, Shear wave travel time determination using an unconventional approach, SPE-11032: Society of Petroleum Engineers, 57th annual meeting [New Orleans] preprint, 11 p.

Gallagher, J.G., Jr., 1988, V_p/V_s ratio measurements of multicomponent lithological systems; a borehole and surface seismic data case study, in 1988 annual meeting expanded abstracts with biographies, volume 1: Society of Exploration Geophysicists, p. 172-176.

Garotta, R., 1985, Observation of shear waves and correlation with P events, chapter 1, in G.P. Dohr, editor, Seismic shear waves, seismic exploration volume 15B, part B--Applications: Geophysical Press, London, p. 1-86. [A discussion of P and S waves, their potential, and application in formation evaluation.]

Georgi, D.T., Heavysege, R.G., Chen, S.T., and Eriksen, E.A., 1989, Application of shear and compressional transit-time data to cased hole carbonate reservoir evaluation, paper L, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 24 p.

Gevers, E.C.A., and Watson, S.W., 1978, Quantitative interpretation of seismic data using well logs, SPE-7439: Society of Petroleum Engineers, 53rd annual meeting [Houston] preprint, 4 p.

Goetz, J.F., Dupal, L., and Bowler, J., 1979, An investigation in to discrepancies between sonic log and seismic check shot velocities: Australian Petroleum Exploration Association Journal, V. 19(1), P. 131-141.

Goldberg, D., and Grant, W.T., 1987, Shear-wave processing of sonic log waveforms in a limestone reservoir: Geophysics, v. 53(5), p. 668-676.

Goldberg, D.S., Grant, W.T., Siegfied, R.W., and Castagna, J.P., 1984, Processing and interpretation of sonic log waveforms--A case study, in Expanded Abstracts with Biographies, 1984 Technical Program: Society of Exploration Geophysicists, p. 28-31.

Goldberg, D., Moos, D., and Anderson, R.N., 1985, Attenuation changes due to diagenesis in marine sediments paper KK, in 26th annual well logging symposium transactions: Society of Professional Well Log Analysts, 18 p.

Guy, J.O., Fertl, W.H., and Oliver, D.W., 1986, The use of circumferentially propagated acoustic waves in well logging, SPE-15484: Society of Petroleum Engineers, 61st annual meeting [New Orleans] preprint, 15 p.

Han, D-H., Nur, A., and Morgan, D., 1986, Effects of porosity and clay content on wave velocities in sandstones: Geophysics, v. 51(11), November, p. 2093-2107. Discussion and reply published in 1987, Geophysics, v. 52(10), October, p. 1439-1441.

Han, D., Nur, A., and Morgan, F.D., 1986, Velocity measurement and empirical modeling in sandstones, paper OO, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 23 p.

Hardage, B.A., 1985, The uses and abuses of vertical seismic profiling: World Oil, v. 201(7), December, p. 53-56.

Hardage, B.A., 1985, Vertical seismic profiling--a measurement that transfers geology to Geophysics, in O.R. Berg and D.G. Woolverton, editors, Seismic stratigraphy II--an integrated approach to hydrocarbon exploration: American Association of Petroleum Geologists, Memoir No. 39, P. 13-34.

Hardage, B.A., 1987, Blending log data, borehole geophysics, and surface seismic measurements into unified geological messages, paper INV-AC, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 21 p.

Hardage, B.A., editor, 1987, Seismic stratigraphy: Geophysical Press, London, Handbook of Geophysical Exploration, Section I-Seismic Exploration, v. 9, 432 p. [Especially chapters 2,3 and 8.]

Hartley, K.B., 1981, Factors affecting sandstone acoustic compressional velocities and an examination of empirical correlations between velocities and porosities, paper PP, in 22nd annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p.

Hoard, R.E., 1983, Sonic waveform logging--A new way to obtain subsurface geologic information, paper XX, in 24th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p. Later published in 1985, Oil and Gas Journal, v. ;83(26), July 1, p. 70-74.

Holt, R.M., and Fjaer, E., 1987, Acoustic behavior of sedimentary rocks during failure, chapter 23, in J. Kleppe, E.W. Berg, A.T. Buller, O. Hjelmeland, and O. Torsaeter, editors, North Sea oil and gas reservoirs: Graham & Totman Ltd., London, p. 311-316.

Hornby, B.E., 1989, Imaging of near-borehole structure using full-waveform sonic data: Geophysics, v. 54(6), p. 747-757. Also published in 1989 as SPE-19872, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 615-622.

Hornby, B.E., and Chang, S.K., 1985, A case study of shale and sandstone alteration using a digital sonic tool paper H, in 26th annual well logging symposium transactions: Society of Professional Well Log Analysts, 10 p.

Hornby, B.E., and Murphy, W.F., III, 1986, Shear from Stonley in unconsolidated oil sands, in Expanded abstracts with biographies, 1986 technical program [Houston]: Society of Economic Geophysicists, p. 30-33. Later published in 1987 as Vp/Vs in unconsolidated oil sands--Shear from Stonley: Geophysics, v. 52(4), p. 502-513.

Howard, M., 1989, Advances in borehole imaging with second generation CBIL borehole televiewer instrumentation, paper CC, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 13 p.

Hsu, K., and Burridge, R., 1989, Effects of averaging and sampling on statistics of reflection coefficients, paper BG 2.6, in Expanded abstracts with biographies 59th annual meeting, v. 1: Society of Exploration Geophysicists, p. 47-50.

Husten, P., 1979, Analysis of sonic wave trains, paper D, in 6th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, London Chapter, 15 p.

Ikwuakor, K.C., 1988, V_p/V^s revisited; pitfalls and new interpretation techniques: World Oil, v. 207(3), September, p. 41-46.

Iverson, W.P., and Fuller, B.N., 1989, Formation evaluation with shear and compressional logs, paper BG 2.4, in Expanded abstracts with biographies 59th annual meeting, v. 1: Society of Exploration Geophysicists, p. 40-42.

Iverson, W.P., and Walker, J.N., 1988, Shear and compressional logs derived from nuclear logs, in 1988 annual meeting expanded abstracts with biographies, volume 1: Society of Exploration Geophysicists, p. 111-116.

Jackson, C.E., and Gartner, M.L., 1988, A technique for evaluation of hydraulic fractures using quantitative concentrations of derived from the natural gamma ray spectrum, SPE-18152, in 1988 SPE annual technical conference proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 439-448.

Jorden, J.R., and Campbell, F.L., 1986, Well logging II--Electric and acoustic logging: Society of Petroleum Engineers, Monograph Series No. 10, 192 p.

Jutten, J.J., 1988, Studies with narrow cement thicknesses lead to improved CBL [cement bond logs] in concentric casings, SPE-18028, in 1988 SPE technical conference and exhibition proceedings, volume delta, Drilling: Society of Petroleum Engineers, p. 113-124.

Jutten, J.J., and Parcevaux, P., 1987, Relationship between Cement Bond Log output and borehole geometrical parameters, SPE/IDC-16139, in 1987 SPE/IADC drilling conference [New Orleans, March 15-18], proceedings: Society of Petroleum Engineers, p. 763-772.

King, K.C., and Costain, J.K., 1982, Correlation of offshore velocity spectra with onshore sonic logs in North Carolina: Geological Society of America Bulletin, v. 93, p. 37-45.

Knize, S., 1989, Evaluation of full wave sonic data by analysis of instantaneous characteristics and colorgrams, paper II, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 14 p.

Knize, S., and Patton, B., 1989, Application of complex waveform analysis and color displays, paper H, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 20 p.

Koerperich, E.A., 1979, Shear wave velocities determined from long- and short-spaced borehole acoustic devices, SPE-8237: Society of Petroleum Engineers, 54th annual meeting [Las Vegas] preprint. Later published in 1980, Society of Petroleum Engineers Journal, v. 20(5), p. 317-326.

Krief, M., Garat, J., Stellingwerff, J., and Ventre, J., 1989, A new petrophysical interpretation using the velocities of P and S waves (full waveform sonic), paper HH, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 9 p.

Lang, W.H., Jr., 1978, Determination of prior depth of burial using interval transit time, paper B, in 19th annual logging symposium transactions: Society of Professional Well Log Analysts. Later published in 1980, Oil and Gas Journal, v. 78(4), January 28, p. 222-232.

Larkin, T.J., and Taylor, P.W., 1979, Comparison of downhole and laboratory shear-wave velocities: Canadian Geotechnical Journal, v. 16(1), p. 152-162.

Lavergne, M., and Willm, C., 1977, Inversion of seismograms and pseudo velocity logs: Geophysical Prospecting, v. 25(2), p. 231-250. Later reprinted in 1989, in Geophysics II; tools for seismic interpretation: AAPG Treatise of Petroleum Geology Reprint Series No. 13, p. 25-43.

Leeth, R., and Cossette, B., 1979, The velocity ratio plot in tight Canadian carbonate formations, paper X, in 7th formation evaluation symposium transactions: Canadian Well Logging Society, 17 p.

Leslie, H.D., and Mons, F., 1982, Sonic waveform analysis--Applications, paper GG, in 23rd annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Leslie, H.D., Selliers, J. de, and Pittman, D.J., 1987, Coupling and attenuation--A new measurement pair in cement bond logging, SPE-16207, in Production operations symposium [Oklahoma City, March 8-10], proceedings, : Society of Petroleum Engineers, p. 243-250.

Lew, M., and Campbell, K.W., 1985, Relations between shear wave velocity and depth of overburden, in R.D. Woods, editor, Measurement of use of shear wave velocity for evaluating dynamic soil properties [Proceedings of a ASCE convention session (Denver, May 1, 1985)]: American Society of Civil Engineers, New York, p. 63-76.

Lewkowicz, J.F., Resichman, R., and Walsh, J.J., 1983, Results from open hole and cased hole vertical seismic profiles, paper MM, in 24th annual logging symposium transactions: Society of Professional Well Log Analysts, 13 p.

Lindseth R.O., 1979, Synthethic sonic logs--A process for stratigraphic interpretation: Geophysics, v. 44(1), p. 3-26. Later reprinted in 1989, in Geophysics I, seismic methods: AAPG, Treatise of Petroleum Geology Reprint Series No. 12, p. 379-402.

Lindseth, R.O., and Ward, J.A., 1983, Delineation of hydrocarbon reservoirs with synthethic sonic logs, in AAPG stratigraphic interpretation of seismic data [course notes, Colorado Springs, Colorado, November 29-December 3]: American Association of Petroleum Geologists, 80 p.

Liu, H.L., 1986, Estimating shear velocity from the Stonely wave--Its resolution and depth of investigation, in Expanded abstracts with biographies, 1986 technical program [Houston]: Society of Economic Geophysicists, p. 28-30.

Liu, O.Y., 1987, The sources of errors in [acoustic] slowness measurements and an evaluation of full waveform compensation techniques, SPE-16772, in 1987 annual technical meetinng and exhibition proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 323-338.

Magara, K., 1976, Thickness of removed sedimentary rocks, paleopore pressure, and paleotemperature, southwestern part of western Canada basin: AAPG Bulletin, v. 60(4), p. 554-565. Valuable uses of sonic log data.

Mares, S., 1984, Geophysical logging, chapter 7, in Introduction to applied geophysics: D. Reidel Publishing Co., Boston, p. 474-568.

Mathieu, F., and Toksoz, M.N., 1984, Application of full waveform acoustic logging data to the estimation of reservoir permeability, in Expanded abstracts with biographies, 1984 technical program: Society of Exploration Geophysicists, p. 9-12.

Mathieu, G., Yver, J-P., Cheung, P., Brie, A., Hornby, B., and Hsu, K., 1985, Applying sonic data; fracture detection: The Technical Review, v. 33(1), p. 69-79.

McDougall, J., and Fertl, W.H., 1987, Circumferential acoustic logging in Canada, paper 87-38-67, in 38th annual meeting preprints: Petroleum Society of CIM [Canadian Institute of Mining], Calgary, v. 3, p. 1,101-1,112. Later published in 1988, Energy Sources, v. 10(1), p. 43-53.

Mendelson, J., 1989, Inversion of geophysical logs to determine lithology, in Cheng, C.H., editor, Full waveform acoustic logging consortium, annual report: Massachusetts Institute of Technology, Earth Resources Laboratory, p. 172-188.

Menger, S., and Schepers, R., 1988, Method to derive high-resolution caliper logs from borehole televiewer traveltime data, in 1988 annual meeting expanded abstracts with biographies, volume 1: Society of Exploration Geophysicists, p. 554-556.

Michette, A.G., Darling, A.M., Fiddy, M.A., Ward, W.A., and Franklin, E., 1984, Resolution enhancement of well log and seismic data: Geophysical Prospecting, v. 32(4), p. 564-580.

Michon, D., 1987, Use of vertical seismic profiles (VSP) for reservoir delineation, in 12th world petroleum congress proceedings, v. 3, production: John Wiley & Sons, New York, p. 241-247.

Miller, C.H., and Odum, J.K., 1986, A review of concepts and techniques for obtaining shear-wave velocities from measured Rayleigh- and compressional-wave velocities at engineering sites: Bulletin of the Association of Engineering Geologists, v. 23(3), p. 317-324.

Minear, J.W., 1982, Clay models and acoustic velocities, SPE-11031: Society of Petroleum Engineers, 57th annual meeting [New Orleans] preprint, 11 p.

Minear, J.W., 1986, Full wave logging--A brief perspective, paper AAA, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p.

Minear, J.W., and Ajam, S.O., 1984, Full wave acoustic logging--some examples, SPE-12399, in 5th offshore South East Asia conference [February 21-24, Singapore], proceedings: Society of Petroleum Engineers, 13 p.

Moore, T.K., 1988, Initial borehole acoustic televiewer data processing algorithms: Los Alamos National Laboratory Report No. LA-011327-MS, 178 pp.

Moos, D., 1984, A case study of vertical seismic profiling in fractured crystalline rock, in M. Simaan, editor, Advances in geophysical data processing, volume 1: JAI Press, Greenwich, Connecticut, p. 9-37.

Moos, D., and Zoback, M.D., 1983, In situ studies of velocity in fractured crystalline rocks: Journal of Geophysical Research, v. 88(B3), March 10, p. 2345-2358.

Morris, R.L., Grine, D.R., and Arkfeld, T.E., 1964, Using compressional and shear acoustic amplitudes for the location of fractures: Journal of Petroleum Technology, v. 16(6), p. 623-632.

Nations, J.F., 1974, Lithology and porosity from acoustic shear and compressional wave transit time relationships, paper Q, in 15th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p. Later published in 1975, The Log Analyst, v. 16(6), November-December, p. 3-8. Reprinted in 1978, paper Y, in Acoustic logging: Society of Professional Well Log Analysts, Reprint Volume, 16 p.

Neitzel, E.B., and Kan, T.K.,, 1984, Reconciliation of measurement differences observed from seismic, well logs, and VSP, in Expanded abstracts with biographies, 1984 technical program: Society of Exploration Geophysicists, p. 25-28.

Norris, A.N., 1986, Tube wave attentuation and dispersion in permeable formations, in Expanded abstracts with biographies, 1986 technical program [Houston]: Society of Economic Geophysicists, p. 25-28.

Nur, A., 1987, Seismic reservoir description and monitoring, in 12th world petroleum congress proceedings, v. 2, exploration: John Wiley & Sons, New York, p. 133-141.

Omnes, G., 1978, The vertical seismic profile--A bridge between velocity logs and surface seismograms, SPE-7436: Society of Petroleum Engineers, 53rd annual meeting [Houston] preprint, 12 p.

Omnes, G., 1979, Logs from P and S vertical seismic profiles, SPE-8364: Society of Petroleum Engineers, 54th annual meeting [Las Vegas] preprint. Later published in 1980, Journal Petroleum Technology, v. 32(10), p. 1843-1849.

Oristaglio, M.L., 1985, A guide to current use of vertical seismic profiles: Geophysics, v. 50(12), p. 2473-2479.

Overton, A., 1975, Borehole seismic methods, in A.V. Dyck, editor, Borehole geophysics applied to metallic mineral prospecting--A review: Geological Survey of Canada Paper No. 75-31, p. 3-12.

Paillet, F.L., 1985, Applications of borehole-acoustic methods in rock mechanics, in E. Ashworth, editor, Research and engineering applications in rock masses [26th U.S. symposium on rock mechanics, South Dakota School of Mines and Technology, Rapid City, 26-28 June, proceedings]: A.A. Balkema, Boston, p. 207-220.

Paillet, F.L., and Turpening, R., 1984, Borehole and surface-to-borehole seismic applications in fracture characterization, in Expanded abstracts with biographies, 1984 technical program: Society of Exploration Geophysicists, p. 333-334.

Paillet, F.L., Cheng, C.H., Hess, A.E., and Hardin, E.L., 1986, Comparison of fracture permeability estimates based on tube-wave generation in vertical seimic profiles, acoustic waveform-log attenuation, and pumping-test analysis, in Surface and borehole geophysical methods and ground water instrumentation conference and exposition [Denver, October 15-17], proceedings: National Water Well Association, Dublin, Ohio, p. 398-416.

Pennebaker, E.S., 1968, An engineering interpretation of seismic data, SPE-2165: Society of Petroleum Engineers, 43rd annual meeting [Houston] preprint, 12 p. Also published, in part, 1968, World Oil, v. 166(7), June, p. 73-77. [Important uses and interpretations of sonic log data.]

Peterson, R.A., Fillipone, W.R., and Coker, F.B., 1955, The synthesis of seismograms from well log data: Geophysics, v. 20(3), p. 516-538. Later reprinted in 1989, in Geophysics II; tools for seismic interpretation: AAPG Treatise of Petroleum Geology Reprint Series No. 13, p. 1-24.

Pilkington, P.E., 1987, Perennial CBL centering problem can be minimized: Oil and Gas Journal, v. 85(48), 45-49.

Poster, C.K., 1989, Acoustic characterization of permeable zones from full waveform array sonic data, SPE-17964, in SPE Middle East oil technical conference and exhibition [Manama, Bahrain], proceedings: Society of Petroleum Engineers, p. 373-376.

Poulton, H.N., and Strozeski, B.B., 1989, Ultrasonic Diplog; a system for measuring dips in wells drilled with oil-base mud, paper GG, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 15 p.

Rafavich, R., Kendall, C.H., St., C., and Todd, T.P., 1984, The relationship between acoustic properties and the petrographic character of carbonate rocks: Geophysics, v. 49(10), p. 1622-1636.

Rafison, B.J., 1988, Application of petrophysical measurements to the prediction of sesimic responses of differing lithology or pore fluids: Geophysical Prospecting, v. 36(8), p. 847-856.

Raiga-Clemenceau, J., Martin, J.P., and Nicoletis, S., 1986, The concept of acoustic formation factor for more accurate porosity determination from sonic transit time data, paper G, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 14 p. Later published in 1988, The Log Analyst, v. 29(1), January-February, p. 54-60.

Rambow, F.H.K., 1984, The borehole televiewer--Some field examples, paper C, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 21 p.

Rambow, F.H.K., 1988, Cement evaluation in fiberglass casing; a case for pulse-echo tools, paper VV, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 21 p.

Raymer, L.L., Hunt, E.R., and Gardner, J.S., 1980, An improved sonic transit time-to-porosity transform, paper P, in 21st annual logging symposium transactions: Society of Professional Well Log Analysts, 12 p.

Reynolds, E.B., Timko, D.J., Zanier, A.M., 1972, Potential hazards of acoustic-log shale pressure plots, SPE-4020: Society of Petroleum Engineers, 47th annual meeting [San Antonio] preprint. Later published in 1973, Journal of Petroleum Technology, v. 25(9), p. 1039-1044.

Roberts, D.L., and Richards, J.W., 1987, Casing corrosion evaluation using ultrasonic techniques; a unique approach for west Texas wells, in 34th annual short course proceedings: Southwestern Petroleum Short Course Association, Lubbock, Texas, p. 20-33.

Roberts, D.L., and Walter, J.L., 1985, Cement and casing evaluation using sonic and ultrasonic techniques, in 32nd annual southwestern petroleum short course, proceedings: Southwestern Petroleum Short Course Association, Lubbock, Texas, p. 67-95.

Robertson, J.D., 1987, Carbonate porosity from S/P traveltime ratios: Geophysics, v. 52(10), October, p. 1346-1354.

Rudman, A.J., 1982, Interrelationship of resistivity and velocity logs, in A.A. Fitch, editor, Developments in geophysical exploration methods--3: Applied Science Publishers, London, p. 33-60.

Rudman, A.J. Whaley, J.F., Blakely, R.G., and Biggs, M.E., 1975, Transformation of resistivity to pseudovelocity logs: AAPG Bulletin, v. 59(7), p. 1151-1165. Also published in 1976, The Log Analyst, v. 16(2), March-April, p. 11.

Scott, J.H., and Sena, J., 1974, Acoustic logging for mining applications, paper P, in 15th annual logging symposium transactions: Society of Professional Well Log Analysts, 10 p.

Seiler, D., Edmiston, C., Torres, D., and Goetz, J., 1990, Field performance of a new borehole televiewer tool and associated image processing techniques, paper H, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p.

Setser, G.G., 1981, Fracture detection by circumferential propagation of acoustic energy, SPE-10204: Society of Petroleum Engineers, 56nd annual meeting [San Antonio] preprint, 8 p.

Sheives, T.C., Tello, L.N., Maki, V.E., Jr., Standley, T.E., and Blankinship, T.J., 1986, A comparison of new ultrasonic cement and casing evaluation logs with standard cement bond logs, SPE-15436: Society of Petroleum Engineers, 61st annual meeting [New Orleans] preprint, 8 p.

Sheriff, R.E., 1989, Borehole measurements, chapter 26, in Geophysical methods: Prentice Hall, Englewood Cliffs, New Jersey, p. 530-543.

Smith, R.F., McCoy, R.L., Ausburn, B.E., and Pottorf, B.R., 1978, Determining acoustic velocity of subsurface formations from well log data, SPE-7435: Society of Petroleum Engineers, 53rd annual meeting [Houston] preprint. Later published in 1979, Journal of Petroleum Technology, v. 31(11), p. 1453-1461.

Snodgrass, J.J., 1989, Sonic full-waveform applications to stress evaluation in coal mines, paper MM, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 731-745.

Society of Professional Well Log Analysts, 1978, Acoustic logging reprint volume: Society of Professional Well Log Analysts, various pagination. [Contains 26 significant papers on tool development, operation and application.]

Stein, N., 1989, Porosity of friable sand using acoustic wave velocity, paper LL, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 715-729.

Stephen, R.A., Cardo-Casa, F., and Cheng, C.H., 1985, Finite-difference synthetic acoustic logs: Geophysics, v. 50(10), p. 1588-1609.

Stewart, R.P., and Disiena, J.P., 1989, The values of VSP in interpretation: Geophysics; the leading edge of exploration, v. ?, December, p. 16-23.

Stewart, R.R., Huddleston, P.D., and Kan T.K., 1984, Seismic versus sonic velocities; a vertical seismic profiling study: Geophysics, v. 49(8), p. 1153-1168. Also published in 1984, in A.H. Balch and M.W. Lee, editors, Vertical seismic profiling; technique, applications, and case histories: International Human Resource Development Corporation (IHRDC), Boston, p. 385-423.

Stone, D.G., and Evans, H.B., 1980, Extrapolating logs run in exploration or development wells using seismic data, paper KK, in 21st annual logging symposium transactions: Society of Professional Well Log Analysts, 35 p.

Strozeski, B.B., Hilliker, D.J., and Oliver, D.W., 1989, Theoretical and experimental development of the ultrasonic DIPLOG System, paper DD, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 21 p.

Szulyovsky, I., 1985, Detection of thin beds with the pseudo-acoustic impedance section: Geophysical Prospecting, v. 35(3), p. 221-335.

Tatham, R.H., 1982, V_p/V_s and lithology: Geophysics, v. 47(3), p. 336-344. Later reprinted in 1989, in Geophysics II; tools for seismic interpretation: AAPG Treatise of Petroleum Geology Reprint Series No. 13, p. 348-356.

Tatham, R.H., 1985, Shear waves and lithology, chapter 2, in G.P. Dohr, editor, Seismic shear waves, seismic exploration volume 15B, part B--Applications: Geophysical Press, London, p. 87-133.

Thomas, D.H., 1977, Seismic applications of sonic logs, paper 7, in 5th European logging symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 23 p. Later published in 1978, The Log Analyst, v. 19(1), January-February, p. 23-32.

Timur, A., 1987, Acoustic logging, chapter 51, in H.B., Bradley, editor-in-chief, Petroleum Engineering Handbook: Society of Petroleum Engineers, p. 51-1 - 51-52.

Tixier, M.P., Loveless, G.W., and Anderson, R.A., 1973, Estimation of formation strength from the Mechanical Properties Log, SPE-4532: Society of Petroleum Engineers, 48th annual meeting [Las Vegas] preprint, 14 p. Later published in 1975, Journal of Petroleum Technology, v. 27(12), p. 283-293. Reprinted 1978, paper X, in Acoustic logging: Society of Professional Well Log Analysts, Reprint Volume, 11p.

Toksoz, M.N., Wilkens, R.H., and Cheng, C.H., 1985, Shear wave velocity and attenuation in ocean bottom sediments from acoustic log waveforms: Geophysical Research Letters, v. 12(1), p. 37-40.

Tosaya, C., and Nur, A., 1982, Effects of diagenesis and clays on compressional velocities in rocks: Geophysical Research Letters, v. 9(1), p.

Tsay, F.S., and Dindoruk, B., 1990, A numerical solution for CNL environmental corrections: Geobyte, v. 5(2), April, p. 69-75.

Tubman, K.M., Cheng, S.T., Willen, D.E., Toksoz, M.N., 1984, Determination of formation properties in cased boreholes using full waveform acoustic logs, paper CC, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 19 p.

Turk, N., and Dearman, W.R., 1986, A suggested approach to rock characterization in terms of seismic velocities, in H.L. Hartman, editor, Rock mechanics--Key to energy production [27th U.S. symposium on rock mechanics (Tuscaloosa, Alabama, June 23-25, 1986), proceedings]: Society of Mining Engineers, Littleton, Colorado, p. 168-174.

Vail, P.R., 1987, Seismic stratigraphy interpretation using sequence stratigraphy, Part 1, Seismic stratigraphy interpretation procedure, in A.W. Bally, editor, Atlas of seismic stratigraphy, v. 1: AAPG Studies in Geology No. 27, p. 1-10.

Von Lunen, E., 1988, Through casing sonic transit time measurement using the array-sonic tool, in 35th annual southwestern petroleum short course, proceedings: Southwestern Petroleum Short Course Association, 143-154.

Wang, Z., and Nur, A., 1986, Effect of temperature on wave velocities in sands and sandstones with hydrocarbons, SPE-15645: Society of Petroleum Engineers, 61st annual meeting [New Orleans] preprint, 8 p. Also published in 1986, in Expanded abstracts with biographies, 1986 technical program [Houston]: Society of Economic Geophysicists, p. 3-5.

Wang, Z., Nur, A.M., and Batzle, M.L., 1988, Acoustic velocities in petroleum oils, SPE-18163, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 571-585. Later published in 1990, Journal of Petroleum Technology, v. 42(2), p. 192-200.

Ward, J.A., 1986, Seismic sonic logs yield critical E&D paramters: World Oil, v. 203(5), November, p. 38-45.

West, G., 1981, An ultrasonic velocity borehole logger for use in rock: Ultrasonics, v. 19(2), p. 67-71.

Westermark, R.V., and Scholes, P., 1987, Fracture identification in openhole from a Cement Evaluation Tool, SPE-16387, in SPE California regional meeting, proceedings: Society of Petroleum Engineers, p. 601-607.

White, J.E., 1983, Waves along cyclindrical boreholes, chapter 5, in Underground sound, application of seismic waves: Elsevier, Amsterdam, Methods in Geochemistry and Geophysics No. 18, p. 139-245.

White, J.E., and Sengbush, R.L., 1987, Borehole waves and instrumentation, chapter 5, in Production seismology; Handbook of Geophysical Exploration, part I--Seismic Exploration, v. 10, : Geophysical Press, London, p. 147-202.

Williams, D.M., 1990, The acoustic log hydrocarbon indicator, paper W, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 22 p.

Williams, D.M., Leavitt, E.M., and Theriot, D.G., 1988, Estimation of in-situ stress variations for fracture height calculations using Mobil's shear wave acoustic log, paper CC, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 23 p.

Willis, M.E., and Toksoz, M.N., 1983, Automatic P and S velocity determination from full waveform digital acoustic logs: Geophysics, v. 48(12), p. 1631-1644.

Winterstein, D.F., and Paulsson, B.N.P., 1990, Velocity anistropy is shale determined from crosshole seismic and vertical seismic profile data: Geophysics, v. 55(4), p. 470-479.

Woods, R.D., editor, 1985, Measurement of use of shear wave velocity for evaluating dynamic soil properties [Proceedings of a ASCE convention session (Denver, May 1, 1985)]: American Society of Civil Engineers, New York, 78 p.

Woods, T.F., von Lunen, E., Iverson, W.P., Cozzens, J.R., and Smithson, S.B., 1986, Applications of compressional and shear seismic methods in the Permian Basin, in Expanded abstracts with biographies, 1986 technical program [Houston]: Society of Economic Geophysicists, p. 35-38.

Zemanek, J., Caldwell, R.L., Glenn, E.E., Jr., Holcomb, S.W., Norton, L.J., and Straus, A.J.D., 1968, The Borehole Televiewer--A new logging concept for fracture location and other types of borehole inspection, SPE-2402: Society of Petroleum Engineers, 43rd Annual meeting [Houston] preprint. Later published in 1969, Journal of Petroleum Technology, v. 21(6), p. 762-774.

Zemanek, J., Williams, D.M., Caldwell, R.L., Dennis, C.L., and Angona, F.A., 1985, New developments in acoustic logging, in 14th annual convention proceedings: Indonesian Petroleum Association, Jakarta, p. 565-586.

Zhixing, H., and Liandi, S., 1986, Mechanism of transit time increase and its interpretation after water injection into reservoir M in Lao Jun Miao oil field, SPE-14846, in 1986 SPE international meeting o petroleum engineering [Beijing, March 17-20], proceedings: Society of Petroleum Engineers, p.427-447.

VI. Nuclear Logging; Geochemical Logging (Elemental Analysis)

(See also IV. Cased hole logging; 18. Mineral evaluation)

Ajam, S.O., and Rahal, V.E., 1985, Applications of thermal multigate decay pulsed neutron logs in unusual downhole logging environments: Australian Petroleum Exploration Association [APEA] Journal, v. 25, part 1, p. 265-274. Later published in 1986, in 6th SPE offshore South East Asia conference [Singapore, January 28-31], proceedings: South East Asia Petroleum Exploration Society, p. 437-446.

Anderson, R.N., Alt, J.C., and Malpas, J., 1989, Geochemical well logs and the determination of integrated chemical fluxes in hole 504B, eastern equatorial Pacific, section 11, in Mazzullo, E.K., editor, Proceedings of the Ocean Drilling Program, v. 111, Scientific results: Texas A & M University, Ocean Drilling Program, p. 119-132.

Anderson, R.N., Broglia, C., Pezard, A., Williams, C.F., 1988, Lithostratigraphy determined from discriminant analysis of geochemical well logs from the Cajon Pass scientific drillhole, California: Geophysical Research Letters, v. 15(9, supplement), p. 957-960.

Anderson, R.N., Dove, R.E., Broglia, C., Silver, L.T., James, E.W., and Chappell, B.W., 1988, Elemental and mineralogical analyses using geochemical logs from Cajon Pass scientific drillhole, California, and their preliminary comparison with core analyses: Geophysical Research Letters, v. 15(9, supplement), p. 969-972.

Anderson, R.N., Dove, R.E., and Pratson, E., 1990, Geochemical well logs; calibration and lithostratigraphy in basaltic, granitic, and metamorphic rocks, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 177-194.

Anderson, R.N., Jarrard, R., Pezard, P., Williams, C., and Dove, R., 1988, Logging for science: The Technical Review, v. 36(4), October, p. 4-11.

Berger, P., and Roestenburg, J., 1989, High resolution in-situ geochemical and image analysis applied to a well in the South China Sea, paper N, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 16 p.

Blackburn, J.S., and Brimage, R.C., 1978, Estimation of formation pressures in clean gas sands from the dual-spacing TDT log, paper V, in 19th annual logging symposium transactions: Society of Professional Well Log Analysts, 14 p.

Borai, A.M., and Muhsin, M.A., 1985, LDT tool gives improved formation evaluation: Oil and Gas Journal, v. 83(27), July 8, p. 60-63.

Borsaru, M., Eisler, P.L., and Charbucinski, J., 1988, Quantitative nuclear borehole logging based on neutron excited gamma reactions, in Current trends in nuclear borehole logging techniques for elemental analysis [consultants meeting (Ottawa, Canada, November 2-6, 1987), proceedings]: International Atomic Energy Agency, Vienna, Report IAEA-TECDOC-464, p. 31-53.

Branisa, F., 1974, Filtering of well-log curves: Geophysics, v. 39(4), August, p. 545-549.

Brewer, T.S., Lovell, M.A., Harvey, P.K., Pelling R., Atkin, B.P., and Adamson, A., 1990, Preliminary geochemical results from DSDP/ODP hole 504B; a comparison of core and log data, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 195-202.

Bristow, Q. [?], 1988, Nuclear techniques for elemental analyses and applications, chapters 2-3, in Current trends in nuclear borehole logging techniques for elemental analysis [consultants meeting (Ottawa, Canada, November 2-6, 1987), proceedings]: International Atomic Energy Agency, Vienna, Report IAEA-TECDOC-464, p. 8-18.

Bristow, Q., Killeen, P.G., and Mwenifumbo, J.C., 1982, Comparison of standardized gamma-ray log calibration measurements--Ottawa, Adelaide and Grand Junction, in Symposium on uranium exploration methods [Paris, June 1-4, 1982], proceedings: Nuclear Energy Agency, Organization for Economic Cooperation and Development, Paris, p. 715-727.

Brown, R.J.S., and Neuman, C.H., 1982, The nuclear magnetism log--A guide for field use: The Log Analyst, v. 23(5), September-October, p. 4-9.

Caldwell, R.L., Desai, K.P., and Mills, W.R., Jr., 1976, Geophysical well-logging using nuclear techniques, in Nuclear techniques in geochemistry and geophysics: International Atomic Energy Agency, Vienna, Austria, p. 3-19.

Caldwell, R.L., Mills, W.R., Jr., Orr, W.L., and Allen, L.S., 1977, Nuclear techniques in oil and gas exploration and production, in Symposium on nuclear technology in exploration, extraction and processing mineral resources, 1977, proceedings: International Atomic Energy Agency, Vienna, Austria, p. 3-41.

Chace, D.M., Schmidt, M.G., Frost, E., and Fertl, W.H., 1985, Advance in cased hole logging - the multiparameter spectroscopy instrument continuous carbon/oxygen log, in 3rd international UNITAR/UNDP heavy crude and tar sands conference preprints [Long Beach, California, July 22-31, 1985]: United Nations Institute for Training and Research, Information Center for Heavy Crude and Tars, v. 3, p. 1404-1419.

Chandler, R.N., Kenyon, W.E., Morriss, C.E., 1987, Reliable nuclear magnetism logging--with examples in effective porosity and residual oil saturation, paper C, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 24 p.

Chapman, S., Colson, J.L., Flaum, C., et al., 1987, The emergence of geochemical well logging: The Technical Review, v. 35(2), p. 27-35.

Chapman, S., Colson, J.L., Flaum, C., Hertzog, R.C., Pirie, G., Scott, H., La Vigne, J., Quierein, J., Everett, B., Herron, M.M., Schweitzer, J.S., and Wendlandt, R., 1989, Geochemical well logging in early evolutionary stage: Offshore, v.49(5), p. 82-89.

Charbuciniski, J., Aylmer, J.A., Eisler, P.L., and Borsaru, M., 1989, Quantitative and qualitative applications of the neutron-gamma borehole logging: Nuclear Geophysics, v. 3(4), p. 475-485.

Charbucinski, J., Eisler, P.L., and Borsaru, M., 1988, Quantitative nuclear borehole logging based on neutron excited gamma-reactions: Nuclear Geophysics, v. 3(2), p. 137-150.

Charbucinski, J., and Umiastowski, K., 1977, Some factors affecting accuracy in determinations of heavy element concentrations in the selective gamma-gamma method, in Nuclear techniques and mineral resources 1977: International Atomic Energy Agency, Vienna, Austria, p. 281-300.

Charyulu, K.S., and Raju, P.B., 1983, Uses of radio active [sic] isotopes in exploration for oil and minerals, in Symposium on exploration geophysics in India [Calcutta, November 21-24, 1978], proceedings: Geological Survey of India, Special Publication Series No. 2, v. 2, p. 529-542.

Clavier, C., Hoyle, W., Meunier, D., 1969, Quantitative interpretation of thermal neutron decay time logs--part I, fundamentals and techniques, SPE-2658-II: Society of Petroleum Engineers, 44th annual meeting [Denver] preprint. Later published in 1971, Journal of Petroleum Technology, v. 23(6), p. 743-763.

Colson, J.L., Grau, J.A., Herron, M.M., Herron, S.L., Schweitzer, J.S., Hertzog, R.C., Preeg, W.E., Nurmi, R.D., and Johnston, J., 1989, Applications using geochemical logs, SPE-17963, in SPE Middle East oil technical conference and exhibition [Manama, Bahrain], proceedings: Society of Petroleum Engineers, p. 365-372.

Conaway, J.G., 1979, Problems in gamma-ray logging--The effect of dipping beds on the accuracy of ore grade determinations: Geological Survey of Canada Paper 79-1A, p. 41-44.

Conaway, J.G., 1982, Principles of inverse filtering applied to gamma ray logs, in Symposium on uranium exploration methods [Paris, June 1-4, 1982], proceedings: Nuclear Energy Agency, Organization for Economic Cooperation and Development, Paris, p. 753-766.

Conaway, J.G., 1983, Digital filtering of geophysical logs in A.A. Fitch, editor, Developments in geophyscial methods--5: Applied Science Publishers, London, p. 65-105.

Conaway, J.G., Allen, K.V., Blanchard, Y.B. Bristow, Q., Hyatt, W.G., and Killeen, P.G., 1979, The effects of borehole diameter, borehole fluid, and casing thickness on gamma ray logs in large diameter boreholes: Geological Survey of Canada Paper 79-1C, p. 37-40.

Conaway, J.G., Killeen, P.G., and Bristow, Q., 1981, Variable formation parameters and nonlinear errors in quantitative gamma ray log interpretation, paper M-11, in 50th annual meeting technical papers, : Society of Exploration Geophysicists, v. 5, p. 2523-2534.

Corwith, J.R., and Mengel, F., 1988, Applications of pulsed neutron capture logs in the Ekofisk area fields, SPE-18147, in 1988 SPE annual technical conference proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 413-421. Later published in 1990, SPE Formation Evaluation, v. 5(1), March, p. 16-22.

Czubek, J.A., 1976, Comparison of nuclear well logging data with the results of core analysis, in Nuclear techniques in geochemistry and geophysics: International Atomic Energy Agency, Vienna, Austria, p. 93-106.

Czubek, J.A., 1983, Advances in gamma-gamma logging, in C.G. Clayton, editor, Nuclear geophysics--Selected papers on applications of nuclear techniques in mineral exploration, mining and process control: Pergamon Press, Oxford, England, p. 153-172.

Czubek, J.A., 1985, Slowing down of fast neutrons in magmatic rocks: Acta Geophysica Polonica, v. 33(1), p. 45-54.

Czubek, J.A., Loskiewicz, J., Gyurcsak, J., Lenda, A., Umiastowski, K., and Zorski, T., 1977, Geostatistical method of interpretation of nuclear well logs, in Nuclear techniques and mineral resources 1977: International Atomic Energy Agency, Vienna, Austria, p. 313-332.

Dahlberg, K.E., 1989, A practical model for analysis of compensated neutron logs in complex formations, paper PP, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p.

Das, H.A., Faanhof, A., and van der Sloot, H.A., 1989, The user of radioactivity detectors and radioactive sources for in situ analysis, chapter 9, in Radioanalysis in geochemistry: Elsevier, Amsterdam, Developments in Geochemistry No. 5, p. 433-459.

Dewan, J.T., 1986, Open-hole nuclear logging--State of the art, paper MM, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p.

Dove, R.E., and Williams, C.F., 1989, Thermal conductivity estimated from elemental concentration logs: Nuclear Geophysics, v. 3(2), p. 107-112.

Dresser Atlas, 1981, Carbon/Oxygen log: Dresser Industries, Houston, Publication No. 9417, variously paginated. [Reprints of papers on tool operation, interpretation and application.]

Dresser Atlas, 1983, Neutron Lifetime Log: Dresser Industries, Houston, Publication No. 3319, 100 p. [Interpretation and application manual.]

Dupree, J.H., and Cunningham, A.B., 1989, The application of carbon/oxygen logging technology to the Ivishak Sandstone, Prudhoe Bay, Alaska, SPE-19615, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 447-458.

Eisler, P.L., Charbucinski, J., Borsaru, M. and Indrans, A.P., 1988, Spectrometric gamma-gamma borehole methods for iron-ore mining, paper P, in 2nd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applications [Golden, Colorado, October 6-8, 1987], proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society Chapter-at-Large, p. 189-201.

Ellis, D.V., 1985, Neutron porosity devices--What do they measure?, in 1985 technical program abstracts and biographies: Society of Exploration Geophysicists, p. 285-286. Later published in 1986, First Break, v. 4(3), p. 11-17.

Ellis, D.V., 1987, Nuclear logging techniques, chapter 50, in H.B., Bradley, editor-in-chief, Petroleum Engineering Handbook: Society of Petroleum Engineers, p. 50-1--50-38.

Ellis, D.V., Flaum, C., Galford, J.E., and Scott, H.D., 1987, The effect of formation absorption on the thermal neutron porosity measurement, SPE-16814, in volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, 1987 annual meeting proceedings, p. 639-654.

Ellis, D., Grau, J., Schwietzer, J., and Hertzog, R., 1987, Basics of nuclear logging: The Technical Review, v. 35(3), July, p. 4-10.

Ellis, D., Howard, J., and others, 1988, Mineral logging parameters--Nuclear and acoustic: The Technical Review, v. 36(1), p. 38-52.

Ellis, D.V., Schweitzer, J.S., and Ullo, J.J., 1987, Nuclear techniques for subsurface geology: Annual Review Nuclear Particle Science, v. 37, p. 213-241.

Everett, R.V., McDonald, J.E., and Herron, M.M., 1988, Wireline geochemical log analysis of thin-bed reservoirs, Gulf of Mexico, in J.R.J. Studlick, J.G. Bryant, J.G., J.A. Hartman, and R.D. Shew, editors, Offshore Louisiana oil and gas fields, volume II: New Orleans Geological Society, p. 37-79.

Everett, R.V., Schweitzer, J.S., and Baker, P.L., 1987, Grain size effects on electromagnetic and spectrometry logs, paper R, in 11th formation evaluation symposium transactions: Canadian Well Logging Society, 32 p.

Flaum, C., Galford, J.E., and Hastings, A., 1989, Enhanced vertical resolution processing of dual detector gamma-gamma density logs: The Log Analyst, v. 30(3), May-June, 139-149.

Flaum, C., Holenka, J.M., and Case, C.R., 1989, Eliminating the effect of rugosity from compensated density logs by geometrical response modeling, SPE-19612, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 419-427.

Flolo, L.H., 1988, Improved reservoir description by use of induced gamma spectroscopy, paper EE, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 18 p.

Flolo, L.H., 1990, Calculating injected-gas saturation from cased-hole compensated neutron logs, paper VV, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p.

Gadeken, L.L., and Smith, H.D. Jr., 1989, A relative distance indictor from gamma ray spectroscopy measurements with radioactive tracers, SPE-17962, in SPE Middle East oil technical conference and exhibition [Manama, Bahrain], proceedings: Society of Petroleum Engineers, p. 357-364.

Galford, J.E., Flaum, C., Gilchrist, W.A., Jr., and Duckett, S.W., 1986, Enhanced resolution processing of Compensated Neutron Logs, SPE-15541: Society of Petroleum Engineers, 61st annual meeting preprint, 13 p. Later published in 1989, SPE Formation Evaluation, v. 4(2), p. 131-137.

Galford, J.E., Flaum, C., Gilchrist, W.A., Jr., Soran, P.D., and Gardner, J.S., 1986, Improved environmental corrections for compensated neutron logs (CNL), SPE-15540: Society of Petroleum Engineers, 61st annual meeting preprint, 14 p. Later published in 1988, SPE Formation Evaluation, v. 3(2), p. 371-376.

Galford, J.E., Hertzog, R.C., Flaum, C., and Galindo, G., 1988, Improving pulsed neutron gamma ray spectroscopy elemental weight percent estimates through automatic dimensioning of the spectral fitting process, SPE-18151, in

SPE annual technical conference and exhibition proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 423-438.

Gearhart, D.A., 1987, The effect of borehole size, mudcake, and standoff on the P_e measurement, SPE-16770, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 299-308. Later published in 1989, SPE Formation Evaluation, v. 4(2), p. 138-144.

Georgi, D.T., 1989, Application of time-series analysis to induced gamma ray spectroscopy logs from two Cold Lake heavy-oil observation wells, SPE-19602, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 323-334.

Gilchrist, W.A., Jr., Quirein, J.A., Boutemy, Y.L., and Tabanou, J.R., 1982, Application of gamma ray spectroscopy to formation evaluation, paper B, in 23rd annual logging symposium transactions: Society of Professional Well Log Analysts, 28 p.

Givens, W.W., and Stromswold, D.C., 1989, Prompt fission neutron logging for uranium: Nuclear Geophysics, v. 3(4), p. 299-307.

Goldman, L.H., and Marr, H.E., 1979, Applications of high resolution gamma ray spectroscopy to well logging, paper GG, in 20th annual logging symposium transactions: Society of Professional Well Log Analysts, 8 p.

Grau, J.A., Ellis, D.V., Herron, M.M., Schweitzer, J.S., and Rissler-Akesson, G., 1988, Geochemical logging in the Siljan ring, in A. Boden, and K.G. Eriksson, editors, Deep drilling in bedrock, volume 1, The deep gas drilling in the Siljan impact structure, Sweden and astroblemes: Springer-Verlag, New York, 230-252.

Grau, J.A., Roscoe, B.A., and Tabanou, J.R., 1985, A borehole correction model for capture gamma-ray spectroscopy logging tools, SPE-14462: Society of Petroleum Engineers, 60th annual meeting preprint, 8 p. Later published in 1988, SPE Formation Evaluation, v. 3(1), p. 62-68.

Grau, J.A., and Schweitzer, J.S., 1989, Elemental concentrations from thermal neutron capture gamma-ray spectra in geological formations: Nuclear Geophysics, v. 3(1), p. 1-9.

Grau, J.A., Schweitzer, J.S., Ellis, D.V., and Hertzog, R.C., 1989, A geological model for gamma-ray spectroscopy logging measurements: Nuclear Geophysics, v. 3(4), p. 351-359.

Hallenburg, J.K., 1973, Interpretation of gamma-ray logs, paper G, in 14th annual logging symposium transactions: Society of Professional Well Log Analysts, 28 p. Reprinted in the 1973, The Log Analyst, v. 14(6), November-December, p. 3. [Quantitative use of the gamma ray curve for uranium assay.]

Hammond, H., and Forbes, D., 1989, An updated approach to shallow gas evaluation, paper Q, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 25 p.

Hartley, K.B., 1979, Evaluation of wireline down-log information and effects of increased log speeds on data quality, SPE-8363: Society of Petroleum Engineers, 54th annual meeting [Las Vegas] preprint. Later published in 1980, Journal of Petroleum Technology, v. 32(7), p. 1151-1160. Also published in 1981, Oil and Gas Journal, v. 79(8 and 9), February 23, p. 66-76, and March 2, p. 99-100.

Herrick, R.C., Couturie, S.H., and Best, D.L., 1979, An improved nuclear magnetism logging system and its application to formation evaluation, SPE-8361: Society of Petroleum Engineers, 54th annual meeting [Las Vegas] preprint, 7 p.

Herron, M.M., 1986, Mineralogy from geochemical well logging: Clays and Clay Minerals, v. 34(2), p. 204-213.

Herron, M.M., 1987, Estimating the intrinsic permeability of clastic sediments from geochemical data, paper HH, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 22 p.

Herron, M.M., 1987, Future applications of elemental concentrations from geophysical logging: Nuclear Physics, v. 1(3), p. 197-211.

Herron, M.M., 1988, Geochemical classification of terrigenous sands and shales from core or log data: Journal of Sedimentary Petrology, v. 58(5), September, p. 820-829.

Herron, M.M., and Herron, S.L., 1990, Geological applications of geochemical well logging, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 165-175.

Herron, M.M., Herron, S.L., Everett, R.V., and McDonald, J.E., 1990, Enhanced resistivity interpretation in three wells using geochemical log data, paper U, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Hertzog, R., Colson, L., Seeman, B., O'Brien, M., Scott, H., McKeon, D., Grau, J., Ellis, D., Schweitzer, J., and Herron, M., 1987, Geochemical logging with spectrometry tools, SPE-16792, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 447-460. Later published in 1989, SPE Formation Evaluation, v. 4(2), p. 153-162.

Hilchie, D.W., 1977, Nuclear well logging for petroleum, in J.G. Morse, editor, Nuclear methods in mineral exploration and production: Elsevier, New York, Developments in Economic Geology No. 7, p. 201-213.

Hopkinson, E.C., Fertl, W.H., and Oliver, D.W., 1981, The continuous carbon/oxygen log--basic concepts and recent field experiences, SPE-9613, in 1981 SPE Middle East oil technical conference [Manama, Bahrain, March 9-12], proceedings: Society of Petroleum Engineers. Later published in 1982, Journal of Petroleum Technology, v. 34(10), p. 2441-2448. Reprinted in 1981, in Carbon/oxygen log: Dresser Industries, Houston, Publication No. 9417, paper 6.

Horner, S.C., and Sanyal, S.K., 1984, The prediction of saturation using the carbon/oxygen log: U.S. Department of Energy Report DOE/SF/11564--9, 36 p.

Humphreys, B., and Lott, K., 1990, An investigation into nuclear log responses of North Sea Jurassic sandstones using mineralogical analysis, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 223-240.

Huppert, P., Borsaru, M., Charbucinski, J., Ceravolo, C., and Eisler, P.L., 1989, Combined natural-gamma/gamma-gamma borehole lithology logging: Nuclear Geophysics, v. 3(4), p. 381-386.

Iverson, W.P., and Walker, J.N., 1988, Shear and compressional logs derived from nuclear logs, in 1988 annual meeting expanded abstracts with biographies, volume 1: Society of Exploration Geophysicists, p. 111-116.

Jackson, J.A., 1984, Nuclear magnetic resonance logging: The Log Analyst, v. 25(5), September-October, p. 16.

Jameson, J.B., McGhee, B.F., Blackburn, J.S., and Leach, B.C., 1976, Dual-spacing TDT applications in marginal conditions, SPE-5904: Society of Petroleum Engineers, Rocky Mountain meeting [Casper] preprint. Later published in 1977, Journal of Petroleum Technology, v. 29(9), p. 1067-1077.

Jones, M.F., Gesell, T.F., Nanus, J., and Racster, C.E., 1981, Radioactive well logging; a review and an analysis of Texas incidents: Health Physics, v. 40(3), p. 31-368.

Jones, R., 1988, North Sea field applications of the dual-burst pulsed neutron logging tool, paper GG, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 20 p.

Jones, R.L., 1982, Bootstrapping your way into TDT analysis: The Log Analyst, v. 23(4), July-August, p. 3-13.

Jorro, R.V.J., 1989, A new calibration and quality control system for neutron logging instruments: The Log Analyst, v. 30(3), May-June, p. 129-138.

Karus, E.V., and Shimelevich, Y.S., 1983, Nuclear geophysics in prospecting, exploration and development of oil and gas fields, in C.G. Clayton, editor, Nuclear geophysics--Selected papers on applications of nuclear techniques in mineral exploration, mining and process control: Pergamon Press, Oxford, England, p. 95-117.

Kerford, S.J., and Georgi, D.T., 1987, Application of time-series analysis to wireline logs, paper M, in 11th formation evaluation symposium transactions: Canadian Well Logging Society, 19 p. Later published in 1990: The Log Analyst, v. 31(3), May-June, p. 150-157.

Kessler, C., and Sanders, L., 1989, Cased-hole hydrocarbon detection in the Permain basin using the full-wave sonic tool, SPE-19610, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 403-410. Later published in 1990, in SPE California regional meeting, proceedings: Society of Petroleum Engineers, p. 65-72.

Killeen, P.G., 1975, Nuclear techniques for borehole logging in mineral exploration, in A.V. Dyck, editor, Borehole geophysics applied to metallic mineral prospecting--A review: Geological Survey of Canada Paper 75-31, p. 39-52.

Killeen, P.G., 1982, Gamma-ray logging and interpretation, in A.A. Fitch, editor, Developments in geophysical exploration methods--3: Applied Science Publishers, London, p. 95-150.

Killeen, P.G., and Mwenifumbo, C.J., 1988, Downhole assaying in Canadian mineral deposits with the spectral gamma-gamma method, in Current trends in nuclear borehole logging techniques for elemental analysis [consultants meeting (Ottawa, Canada, November 2-6, 1987), proceedings]: International Atomic Energy Agency, Vienna, Report IAEA-TECDOC-464, p. 23-29.

Kozhevnikov, D.A., and Shagin, V.L., 1989, A method of treating the spectral response of a tool in open and cased boreholes to determine the natural radioactivity of rocks: Nuclear Geophysics, v. 3(1), p. 17-29.

Lau, M.N., Luquette, M.B., and Bassiouni, Z., 1989, Correction for oil-based mud effects on neutron and density tools, SPE-19611, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 411-418.

Lysne, P., 1988, Neutronic properties of Mesaverde sands, part II, Results: Nuclear Geophysics, v. 2(2), p. 113-122.

Mahdavi, M., Olesen, J-R., Preeg, B., Bhasin, M., and Watfa, M., 1989, Pulsed-neutron news: Schlumberger Oilfield Review, v. 1(1), April, p. 43-53.

Mathis, G.L., 1989, The effect of thermal neutron temperature upon ^{3}He detector response: Nuclear Geophysics, v. 3(1), p. 11-15.

Mathis, G.L., 1990, The effect of detector temperature on the formation density log, paper RR, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts,9 p.

Mathis, G.L., and Gearhart, D., 1989, The vertical resolution of Pe and density logs: The Log Analyst, v. 30(3), May-June, p. 150-161.

McKenna, P., McDonald, J., Kubica, P., 1989, Geochemical logging for connate water saturation, Keg River Sandstone, paper E, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 22 p.

McKeon, D.C., and Scott, H.D., 1988, SNUPAR--A nuclear parameter code for nuclear geophysics applications: Nuclear Geophysics, v. 2(4), p. 215-230.

Mikesell, J.L., Senftle, F.E., Anderson, R.N., and Greenberg, M., 1989, Elemental concentrations in diabase determined by high-resolution borehole gamma-ray spectrometry: Nuclear Geophysics, v. 3(4), p. 501-519.

Mills, D.R., Allen, L.S., and Stromswold, D.C., 1988, Pulsed neutron porosity logging based on epithermal neutron die-away: Nuclear Geophysics, v. 2(2), p. 81-93.

Mills, W.R., Stromswold, D.C., and Allen, L.S., 1988, Pulsed neutron porosity logging, paper KK, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 21 p. Later published in 1989, as Pulsed neutron porosity logging using epithermal neutron lifetime: The Log Analyst, v. 30(3), May-June, p. 119-128.

Moake, G.L., and Schultz, W.E., 1987, Improved density log lithology identification using a borehole-compensated photoelectric factor, paper FF, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 22 p. Also published in 1987, in 11th formation evaluation symposium transactions, paper Q: Canadian Well Logging Society, 20 p. Later published in 1989 as SPE-17961, in SPE Middle East oil technical conference and exhibition [Manama, Bahrain], proceedings: Society of Petroleum Engineers, p. 337-355.

Moore, D.C., 1980, Interpretation of total gamma logs in thin and dipping beds: Geophysics, v. 45(1)2, p. 1847-1856.

Murthy, V.R., and Gupta, A.K., 1982, Evaluation of formation porosities in Bombay High field using cased hole compensated neutron log: Bulletin of the Oil and Natural Gas Commission [India], v. 19(2), p. 243-256.

Nelson, P.H., and Glenn, W.E., 1975, Influence of bound water on the neutron log in mineralized igneous rock, paper M, in 16th annual logging symposium transactions: Society of Professional Well Log Analysts, 9 p.

Neuman, C.H., and Brown, R.J.S., 1981, Applications of nuclear magnetism logging to formation evaluation, SPE-10108: Society of Petroleum Engineers, 56th annual meeting [San Antonio] preprint, 10 p. Later published in 1982, Journal of Petroleum Technology, v. 34(12), p. 2853-2862.

O'Brian, W.J., Brown, S.L., and Sanyal, S.K., 1982, Crossplot technique for the analysis of the carbon/oxygen log, SPE-10740, in California regional meeting, proceedings: Society of Petroleum Engineers, p. 243-266.

O'Brian, W.J., Sanyal, S.K., and Brown, S.L., 1983, Comprehensive analysis of the carbon/oxygen log: U.S. Department of Energy Report DOE/ET/12056-28, January 1983, 69 p.

Oliver, D.W., Wyatt, D.F., Jr., and Smith, H.D., Jr., 1986, Reservoir monitoring with the thermal multgate decay log, SPE-14137, in 1986 SPE Permian Basin oil and gas recovery conference, proceedings: Society of Petroleum Engineers, p. 7-26. Also published in 1986, in 1986 SPE international meeting on petroleum engineering [Beijing, China, March 17-20], proceedings: Society of Petroleum Engineers, p. 217-236.

Pelletier, R., 1987, NML applications in the Belly River formation of southern Alberta, paper W, in 11th formation evaluation symposium transactions: Canadian Well Logging Society, 14 p.

Pelling, R., Harvey, P.K., and Lovell, M.A., 1989, Statistical analysis of geochemical logging data from ODP boreholes, paper V, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 349-383.

Peterson, F.L., 1974, Neutron well logging in Hawaii: University of Hawaii, Water Resources Research Technical Report 75, 42 p.

Pinault, J.-L., 1988, Nuclear quantitative analysis of P, Si, Ca, Mg, Fe, and Al in boreholes on a phosphate mine, in Current trends in nuclear borehole logging techniques for elemental analysis [consultants meeting (Ottawa, Canada, November 2-6, 1987), proceedings]: International Atomic Energy Agency, Vienna, Report IAEA-TECDOC-464, p. 93-104. Also published in 1988: Nuclear Geophysics, v. 3(2), p. 191-199.

Primmer, T.J., Kerr, S.A., and Myers, K.J., 1990, Feasiblity of in situ elemental analysis in mudrock evaluation, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 203-210.

Puffer, J., d'Ablaing, G., IV, Toth, T., and Darling, H., 1987, Use of thermal and epithermal neutron measurements in shaly sand evaluation: Transactions Gulf Coast Association of Geological Societies, v. 37, p. 185-194.

Quirein, J., La Vigne,, J., and Chapman, S., 1987, Enhancements to the pulsed neutron gamma ray spectroscopy interpretation process, paper Y, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 22 p.

Quirein, J.A., and Purdy, C.C., 1989, Improved resolution of nuclear well logs, paper A, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 12 p.

Roscoe, B.A., and Grau, J.A., 1985, Response of the carbon/oxygen measurement for an inelastic gamma ray spectroscopy tool, SPE-14460: Society of Petroleum Engineers, 60th annual meeting preprint, 7 p. Later published in 1988, SPE Formation Evaluation, v. 3(1), p. 76-80.

Rupp, J., Hertzog, R., and Schweitzer, J., 1989, Using log-derived elemental concentrations in stratigraphic correlation of argillaceous sediments, paper W, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 385-396.

Russell, M.J., and Ogehenejobo, M.J.O., 1984, Experience with a new petrophysical evaluation tool--the gamma ray spectroscopy tool (GST), SPE-LS-126, in 8th annual international SPE Nigeria sectional conference: Society of Petroleum Engineers, preprint, 14 p.

Schweitzer, J.S., Ellis, D.V., Grau, J.A., and Hertzog, R.C., 1988, Elemental concentrations from gamma-ray spectroscopy logs, in Current trends in nuclear borehole logging techniques for elemental analysis [consultants meeting (Ottawa, Canada, November 2-6, 1987), proceedings]: International Atomic Energy Agency, Vienna, Report IAEA-TECDOC-464, p. 55-66. Also published in 1988: Nuclear Geophysics, v. 2(3), p. 175-181.

Schweitzer, J.S., Hertzog, R.C., and Soran, P.D., 1987, Nuclear data for geophysical spectroscopic logging: Nuclear Physics, v. 1(3), p. 213-225.

Senftle, F.E., and Mikesell, J.L., 1988, Borehole capture gamma-ray spectrometry in very dry rocks: Nuclear Geophysics, v. 2(3), p. 151-162.

Serpas, C.J., Wichmann, P.A., Fertl, W.H., DeVries, M.R., and Randall, R.R., 1977, The dual detector Neutron Lifetime Log--theory and practical applications, paper CC, in 18th annual logging symposium transactions: Society of Professional Well Log Analysts, 37 p.

Smith, H.D., Jr., and Wyatt, D.F., Jr., 1989, A technique for obtaining high vertical resolution formation capture cross sections from the Thermal Multigate Decay log, paper TT, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 12 p.

Smith, M.P., 1989, Temperature effects on dual-spaced thermal neutron logging tool, paper QQ, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p.

Society of Professional Well Log Analysts, 1978, Gamma ray, neutron and density logging reprint volume: Society of Professional Well Log Analysts, variously paginated. [Contains 32 significant papers in these areas.]

Society of Professional Well Log Analysts, 1979, Pulsed neutron logging reprint volume: Society of Professional Well Log Analysts, 448 p. [Contains 32 significant papers on tool operation and application.]

Steinman, D.K., Adolph, R.A., Mahdavi, M., Marienbach, E., Preeg, W.E., and Wraight, P.D., 1986, Dual-burst thermal decay time logging principles, SPE-15437: Society of Petroleum Engineers, 61st annual meeting preprint, 15 p. Later published in 1988, SPE Formation Evaluation, v. 3(2), p. 377-385.

Swulius, T.M., 1984, Porosity calibration of neutron logs, SACROC unit, SPE-13289: Society of Petroleum Engineers, 59th annual meeting [Houston] preprint. Later published in 1986, Journal of Petroleum Technology, v. 38(4), p. 468-476.

Tittle, C.W., 1987, The effect of neutron absorption on the apparent porosity of the compensated neutron log: Nuclear Geophysics, v. 1(4), p. 301-307.

Tittle, C.W., 1989, Model wells for nuclear well logging: Nuclear Geophysics, v. 3(3), p. 193-202.

Tittle, C.W., 1989, A history of nuclear well logging in the oil industry: Nuclear Geophysics, v. 3(2), p. 75-86.

Tittle, C.W.,, 1990, Interpreting the compensated neutron log for gas, paper UU, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 9 p.

Umiastowski, K., and Buniak, M., 1977, Influence of the rock heterogeneity on the results of gamma-gamma logging, in Nuclear techniques and mineral resources 1977: International Atomic Energy Agency, Vienna, p. 273-280.

van den Oord, R.J., 1990, Experience with geochemical logging, paper T, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Veach, C.L., and Wheatley, J.C., 1977, A look at the development of neutron logging, in 24th annual southwestern petroleum shortcourse [Lubbock, Texas, April 21-22], proceedings: Southwestern Petroleum Short Course Association, Lubbock, Texas, p. 105-112.

Wendlandt, R.F., and Bhuyan, K., 1990, Estimation of mineralogy and lithology from geochemical log measurements: AAPG Bulletin, v. 74(6), p. 837-856.

Westaway, P., Whittman, M., and Rochette, P., 1979, Applications of nuclear techniques to reservoir monitoring, SPE-7776, in 1979 Middle East oil technical conference [Manama, Bahrain, March 25-29], proceedings: Society of Petroleum Engineers. Later published in 1981, Journal of Petroleum Technology, v. 33(1), p. 46-54.

Woodhouse, R., and Kerr, S.A., 1988, The evaluation of oil saturation through casing using carbon/oxygen logs, SPE-17610, in SPE international meeting on petroleum engineering [Tianjin, China], proceedings: Society of Petroleum Engineers, p. 621-632.

Working Group on Nuclear Techniques in Hydrology, 1971, Nuclear well logging in hydrology: Vienna, Austria, International Atomic Energy Agency, Technical Reports Series, No. 126, 90 p.

Wyatt, D.F., Smith, H.D., Jr., and Oliver, D.W., 1986, Reservoir monitoring with the thermal multigate decay log, SPE-14137, in 1986 SPE international meeting on petroleum engineering, proceedings: Society of Petroleum Engineers. Later published in 1987, SPE Formation Evaluation, v. 2(4), p. 401-411.

Youngblood, W.E., 1979, The application of pulsed-neutron-decay time logs to monitor waterfloods with changing salinity, SPE-7777, in 1979 Middle East oil technical conference [Bahrain], proceedings: Society of Petroleum Engineers, p.

VII. Shaly Sands
(See also II. Electric logging)

Aaboe, E., 1984, Influence of shaliness upon conductivity in shaly sandstones in the northern North Sea area, paper LL, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 17 p.

Aguilera, R., 1988, New methods for evaluation of shaly formations by wells logs, SPE-17517, in SPE Rocky Mountain regional meeting proceedings: Society of Petroleum Engineers, p. 365-376.

Alexander, S.C., Tieh, T.T., and Berg, R.R., 1985, The effects of diagenesis on reservoir properties in the Lobo Sandstones, Webb County, Texas: Transactions Gulf Coast Association of Geological Societies, v. 35 p. 301-307.

Allan, G.W., and McDougall, J.G., 1989, Advances in evaluating thin-bed response, paper V, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 14 p.

Almon, W.R., 1979, A geologic appreciation of shaly sands, paper WW, in 20th annual logging symposium transactions: Society of Professional Well Logging Analysts, 14 p. Reprinted in 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. I5-I18.

Almon, W.R., and Schultz, A.L., 1979, Electric log detection of diagenetically altered reservoirs and diagenetic traps: Gulf Coast Association of Geological Societies Transactions, v. 29, p. 1-10.

Andreani, M., 1989, Quantitative evaluation of highly laminated, complex lithology formations, SPE-17944, in SPE Middle East oil technical conference and exhibition [Manama, Bahrain], proceedings: Society of Petroleum Engineers, p. 155-166.

Anonymous, 1989, Archie III; electrical conduction in shaly sands: Schlumberger Oilfield Research, v. 1(3), October, p. 43-53.

Argaud, M., Giouse, H., Straley, C., Tomanic, J., and Winkler, K., 1989, Salinity and saturation effects on shaly sadnstone conductivity, SPE-19577, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 49-60.

Atwater, J.E., 1986, Correlation of cation exchange capacity with core spectral gamma ray logs, paper QQ, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p.

Bateman, R.M., 1990, Thin-bed analysis with conventional log suites, paper II, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 24 p.

Bateman, R.M., and Perez, J., 1989, Advances in log analysis lead to improved productivity from feldspathic shaly sandstone, paper C, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 15 p.

Bilsland, M., Mobed, R., Cheruvier, E., and White, J., 1989, Predicting hydrocarbon saturations in thin sandstones drilled with oil-based mud, paper J, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 16 p.

Bradburn, F.R., and Cheatham, C.A., 1988, Improved core recovery in laminated sand and shale sequences, SPE-18570: Journal of Petroleum Technology, v. 40(12), p. 1544-1546.

Brown, G.A., 1988, The formation porosity exponent; the key to improved estimates of water saturation in shaly sands, paper AA, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 24 p.

Bussian, A.E., 1983, A comparison of shaly sand models, paper E, in 24th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p.

Cannon, D., and LaVigne, J., 1988, Shaly sands field data compared to theory, paper CC, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 25 p.

Casu, P.A., Cigni, M., and Magrassi, M., 1988, Improved evaluation methods for thin and very thin gas bearing beds, paper B, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 19 p.

Chisholm, J.L., Schenewerk, P.A., and Donaldson, E.C., 1985, A comparison of shaly-sand inteperpretation techniques in the Mesaverde Group of the Uinta Basin, Utah, SPE-14281: Society of Petroleum Engineers, 60th annual meeting preprint. Later published in 1987, SPE Formation Evaluation, v. 2(4), p. 478-486.

Clavier, C., Coates, G., and Dumanoir, J., 1977, Theoretical and experimental bases for the dual-water model for interpretation of shaly sands, SPE-6859: Society of Petroleum Engineers, 52nd annual meeting [Denver] preprint 16 p. Reprinted in 1982, Shaly sand reprint volume: Society of Professional Well Log Analysts, p. V5-V20. Later published in 1984, Society of Petroleum Engineers Journal, v. 24(2), p. 153-169. Reprinted in 1986, in Openhole well logging: Society of Petroleum Engineers, SPE Reprint Series No. 21, p. 357-372.

de Waal, J.A., 1987, Influence of clay distribution on shaly sand conductivity, SPE-16786, in 1987 annual technical conference and exhibition proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 421-429. Later published in 1989, SPE Formation Evaluation, v. 4(3), September, p. 377-383.

Deakin, M.J.W., 1987, Wettability, formation resistivity factor and excess conductivity, SPE-16518: Society of Petroleum Engineers, unsolicited paper, 13 p.

Dennis, C.B., and Lawrence, T.D., 1984, Log evaluation of clastic shaly formations using corrected R_{wa}-ratio techniques, paper R, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p.

Elkington, P.A.S., Samworth, J.R., and Enstone, M.C., 1990, Vertical enhancement by combination and transformation of associated responses, paper HH, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p.

Eslinger, E., and Pevear, D., 1988, Clay minerals and log analysis, chapter 9, in Clay minerals for petroleum geologists and engineers: Society of Economic Mineralogists and Paleontologists, Short Course Notes No. 22, 38 p.

Everett, R.V., McDonald, J.E., and Herron, M.M., 1988, Wireline geochemical log analysis of thin-bed reservoirs, Gulf of Mexico, in J.R.J. Studlick, J.G. Bryant, J.G., J.A. Hartman, and R.D. Shew, editors, Offshore Louisiana oil and gas fields, volume II: New Orleans Geological Society, p. 37-79.

Fertl, W.H., 1972, Status of shaly sand evaluation, paper I, in 4th formation evaluation conference transactions: Canadian Well Logging Society, 26 p.

Fertl, W.H., 1986, Clay typing based on well logs, paper 86-37-18, in 37th annual technical meeting of the Petroleum Society of CIM [Calgary, June 8-11], preprints, v. 1, : Petroleum Institute of the Canadian Institute of Mining, Calgary, p. 257-272.

Fertl, W.H., 1986, Log-derived evaluation of shaly clastic reservoirs, SPE-14061, in 1986 SPE international meeting on petroleum engineering [Beijing, March 17-20], proceedings: Society of Petroleum Engineers. Later published in 1987, Journal of Petroleum Technology, v. 39(2), p. 175-194.

Fertl, W.H., and Chilingar, G.V., 1988, Determination of volume, type, and distribution modes of clay minerals from well logging data, SPE-17145, in 8th SPE symposium on formation damage control, proceedings: Society of Petroleum Engineers, p. 13-28.

Fertl, W.H., and Chilingarian, G.V., 1990, Type and distribution modes of clay minerals from well logging data: Journal of Petroleum Science and Engineering, v. 3(4), January, p. 321-332.

Fertl, W.H., and Frost E., Jr., 1979, Evaluation of shaly clastic reservoir rocks, SPE-8450: Society of Petroleum Engineers, 54th annual meeting [Las Vegas] preprint. Later published in 1980, Journal of Petroleum Technology, v. 31(9), p. 1641-1646. Reprinted in 1981, in Spectralog: Dresser Industries, Houston, Publication No. 3334.

Fertl, W.H., and Hammack, G.W., 1971, A comparative look a water saturation computations in shaly pay sands, paper R, in 12th annual logging symposium transactions: Society of Professional Well Log Analysts, 18 p. Reprinted in 1972, The Log Analyst, v. 13(2), March-April, p. 12-20.

Flaum, C., moderator, 1989, Strategies for thin-bed formation evaluation, a round-table discussion: Schlumberger Oilfield Research, v. 1(3), October, p. 28-42.

Galford, J.E., Flaum, C., Gilchrist, W.A., Jr., and Duckett, S.W., 1986, Enhanced resolution processing of Compensated Neutron Logs, SPE-15541: Society of Petroleum Engineers, 61st annual meeting preprint, 13 p. Later published in 1989, SPE Formation Evaluation, v. 4(2), p. 131-137.

Gautier, D.L, Starkey, H.C., and Takahashi, K.I., 1983, Clays, cations and geophysical log response of gas-producing and non-producing zones in the Gammon Shale (Cretaceous), southwestern North Dakota: Clays and Clay Minerals, v. 31(2), p. 122-128.

Givens, W.W., and Schmidt, E.J., 1988, A generic electrical conduction model for low-contrast resistivity sandstones, paper E, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 25 p.

Glanville, C.R., 1970, Log interpretation of thinly-bedded oil-productive sands with unusually low resistivities, paper M, in 11th annual logging symposium transactions: Society of Professional Well Log Analysts.

Glanville, C.R., 1984, A method for direct log calculation of excess conductivity applied to shaly sand log interpretation, paper, in 25th annual logging symposium transactions X: Society of Professional Well Log Analysts, 17 p.

Goode, P., and Sen, P.N., 1988, Charge density and permeability in clay-bearing sandstones: Geophysics, v. 53(12), p. 1610-16132.

Grief, M.A., and Koopersmith, C.A., 1985, Petrophysical evaluation of thinly bedded reservoirs in high angle/displacement development wells with the NL Baroid recorded lithology logging system, paper S, in 10th formation evaluation symposium transactions: Canadian Well Logging Society, 12 p.

Grimnes, J.P., 1988, Brage--The "invisible" reservoir, paper C, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 17 p.

Hardwick, A., 1989, X_{ls}; a new shale parameter for resistivity log evaluation, SPE-19576, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 39-48.

Harville, D.G., and Freeman, D.L., 1988, The benefits and application of rapid mineral analysis provided by Fourier transform infrared spectoscopy, SPE-18120, in 1988 SPE annual technical conference proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 141-150.

Heckel, B.H., 1985, Enhanced hydrocarbon recognition--A new approach to well evaluation for sand-shale sequences, paper 85-36-45, in 36th annual technical meeting, Petroleum Society of CIM [Edmonton], preprints, volume 2, : Petroleum Society of CIM, Calgary, p. 645-661. Also published in 1986, in 10th formation evaluation symposium transactions, paper L: Calgary, Canadian Well Logging Society, 17 p.

Heinze, D.M., 1985, Clay identification and amount measured by laboratory techniques compared to well log responses--Application to tight gas sands and shales: Sandia National Laboratory Report SAND/85-0312, March, 36 p.

Henry, K.C., 1979, Gas detection in the extremely shaly Bowdoin Formation of northern Montana, paper T, in 20th annual logging symposium transactions: Society of Professional Well Log Analysts, 45 p.

Herrick, D.C., 1988, Conductivity models, pore geometry, and conduction mechanisms, paper D, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 24 p.

Herron, M.M., Herron, S.L., Everett, R.V., and McDonald, J.E., 1990, Enhanced resistivity interpretation in three wells using geochemical log data, paper U, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Heslop, A., 1972, Gamma-ray log response of shaly sandstone: Canadian Well Logging Society Journal, v. 5(1), p. 29-38. Reprinted in 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. II59-II69.

Hilchie, D.W., 1985, SP (spontaneous potential) hydrocarbon suppression (a conceptual approach): Canadian Well Logging Society Journal, v. 14, p. 43.

Holbrook, P.W., 1985, A new method for estimating hydrocarbon saturation in shaley sands for exploration applications, paper GGG, in 26th annual logging symposium transactions : Society of Professional Well Log Analysts, 27 p.

Holloway, J.W., and Michael Holmes, M., 1990, Oil, gas, and water saturations calculated as separate entities from density, neutron, and resistivity logs, paper MM, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 15 p.

Hornby, B.E., and Chang, S.K., 1985, A case study of shale and sandstone alteration using a digital sonic tool paper H, in 26th annual well logging symposium transactions: Society of Professional Well Log Analysts, 10 p.

Hurst, A., 1987, Mineralogical analysis and the evaluation of the petrophysical parameter V_{shale} for reservoir description: Marine and Petroleum Geology, v. 4(1), February, p. 82-91.

Hynson, M.F., Chiasson, C.G., and Brugler, M.L., 1989, Offshore Gulf Coast formation evaluation; comparison and use of unconsolidated core data, wireline logs, and sidewall core data, SCA-8906, part III, paper F, in Annual technical conference reprints, v. 1 (1987-1989): Society of Professional Well Log Analysts, Society of Core Analysts SPWLA Chapter-at-Large, 21 p.

Johnson, W., 1978, Effect of shale on log response: Canadian Well Logging Society Journal, v. 10(1), p. 29-57.

Johnson, W.L., and Linke, W.A., 1977, Some practical applications to improve formation evaluation of sandstones in the Mackenzie Delta, paper R, in 6th formation evaluation symposium transactions: Canadian Well Logging Society, 19 p. Reprinted in 1978, in 19th logging symposium transactions, paper C: Society of Professional Well Log Analysts, 19 p. Reprinted 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. V47-79.

Johnston, D.H., 1987, Physical properties of shale at temperature and pressure: Geophysics, v. 52(10), October, p. 1391-1401. An abbreviated version published in 1986, Oil and Gas Journal, v. 84(44), November 3, p. 60-65.

Juhasz, I., 1986, Assessment of the distribution of shale, porosity and hydrocarbon saturation in shaly sands, paper AA, in 10th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Aberdeen Chapter, 15 p.

Keelan, D.K., and McGinley, D.C., 1979, Application of cation exchange capacity in a study of the Shannon Sand of Wyoming, paper W, in 20th annual logging symposium transactions: Society of Professional Well Log Analysts.

Kern, J.W., Hoyer, W.A., and Spann, M.M., 1976, Low porosity gas sand analysis using cation exchange and dielectric constant data, paper PP, in 17th annual logging symposium transactions: Society of Professional Well Log Analysts, 17 p. Reprinted 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. I69-I85.

Koerperich, E.A., 1974, Applications of Waxman-Smits and Archie equations for determination of oil saturation in shaly sand reservoirs, SPE-5038: Society of Petroleum Engineers, 49th annual meeting [Houston] preprint. Later published 1975, Journal of Petroleum Technology, v. 27

Kukal, G.C., and Hill, R.E., 1986, Log analysis of clay volume--An evaluation of techniques and assumptions used in an Upper Cretaceous sand-shale sequence, paper RR, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 21 p.

Marett, G., Chevalier, P., Souhaite, P., and Suau, J., 1976, Shaly sand evaluation using gamma ray spectrometry applied to the North Sea Jurassic, paper DD, in 17th annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p. Reprinted 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. IV43-IV63.

Martinovic, S., and Vojnovic, V., 1989, Evaluation of water saturation in oil-bearing shaly sands, paper G, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 12 p. Later published in 1990: Geobyte, v. 5(3), p. 17-24.

Marzano, M.S., 1988, Controls on permeability for unconsolidated sands from conventional core data, offshore Gulf of Mexico: Transactions Gulf Coast Association of Geological Societies, v. 38, p.113-120.

McCall, C., Van Gonten, W.D., and Osoba, J.S., 1971, The effect of hydrocarbons on the SP opposite sands, paper C, in 12th annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p.

McCall, D.C., Allen, D.F., and Culbertson, J.S., 1987, High-resolution logging--The key to accurate formation evaluation, SPE-16769, in 1987 annual technical meeting and exhibition proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 283-298.

McGann, G.J., Riches, H.A., and Renoult, D.C., 1988, Formation evaluation in a thinly bedded reservoir; a case history, Scapa field, North Sea, paper V, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 20 p.

Minette, D.C., 1990, Thin-bed resolution enhancement--potential and pitfalls, paper GG, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Morriss, C.E., and Laverdiere, L., 1988, Nuclear magnetism log interpretation in shaly sand formations, paper EE, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 22 p.

Murphy, R.P., and Owens, W.W., 1971, A new approach for low resistivity sand log analysis, SPE-3569: Society of Petroleum Engineers, 46th annual meeting [New Orleans] preprint. Later published in 1972, Journal of Petroleum Technology, v. 24(11), p. 1302-1306.

Neasham, J.W., 1977, The morphology of dispersed clay in sandstone reservoir and its effect on sandstone shaliness, pore space and fluid flow properties, SPE-6858: Society of Petroleum Engineers, 52nd annual meeting [Denver] preprint, 8 p. Reprinted 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. I87-I94.

Nelson, R.J., and Mitchell, W.K., 1990, Improved vertical resolution of well logs by resolution matching, paper JJ, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Nery, G.G., 1990, The dual water "R_{wb}" parameter as determined through the osmotic filtration process, paper FF, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 23 p.

Pande, K.N., 1987, Use of physical properties of shale for evaluating reliable correlation between electrofacies and chronostratigraphic correlation, paper S, in 11th formation evaluation symposium transactions: Canadian Well Logging Society, 18 p.

Patchett, J.G., 1975, An investigation of shale conductivity, paper U, in 16th annual symposium transactions: Society of Professional Well Log Analysts, 41 p. Reprinted 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. I95-I135.

Patchett, J.G., 1986, The determination of the properties of clays in shales from logs with an example of one interpretation technique, paper P, in 10th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Aberdeen Chapter, 23 p.

Patchett, J.G., and Coalson, E.B., 1982, The determination of porosity in sandstone and shaly sandstone, part 2--Effects of complex mineralogy and hydrocarbons, paper T, in 23rd annual logging symposium transactions: Society of Professional Well Log Analysts, 50 p.

Pittman, E.D., 1989, Problems related to clay minerals in reservoir sandstones, chapter 17, in Mason, J.F., and Dickey, P.A., editors, Oil field development techniques: AAPG Studies in Geology No. 28, p. 237-244.

Primmer, T.J., Kerr, S.A., and Myers, K.J., 1990, Feasiblity of in situ elemental analysis in mudrock evaluation, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 203-210.

Rackley, S.A., and Tannemaat, R.J., 1988, Analysis of uncertainties in applying the Waxman-Smits equation to the determination of remaining oil saturation in the Baram delta, OSEA-88183, in 7th offshore South East Asia conference proceedings: Southeast Asia Petroleum Society, p. 710-722. Later published in 1989, SPE Formation Evaluation, v. 4(3), September, p. 363-370.

Raiga-Clemenceau, J., 1988, Taking into account the conductivity contribution of shale laminations when evaluating closely interlaminated sand-shale hydrocarbon bearing reservoirs, paper DD, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 14 p.

Raiga-Clemenceau, J., Fraisse, C., and Grosjean, Y., 1984, The dual-porosity model, a newly developed interpretation method for shaly sands, paper F, in 25th annual loggging symposium transactions: Society of Professional Well Log Analysts, 16 p.

Ramberger, R., 1989, Enhancing log interpretation by core mineral analysis in a micacaeous shaly sand, paper D, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 10 p.

Ransom, R.C., 1977, Methods based on density and neutron well-logging responses to distinguish characteristics of shaly sandstone reservoir rock: The Log Analyst, v. 18(3), p. 47-62. Reprinted in 1982, Shaly sand reprint volume: Houston, Society of Professional Well Log Analysts, p. II105-II120.

Ruhovets, N., 1989, A log analysis technique for evaluating laminated reservoirs in the Gulf Coast area, paper C, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 23 p.

Ruhovets, N., and Fertl, W.H., 1981, Digital shaly sand analysis based on Waxman-Smits model and log-derived clay typing, paper 25, in 7th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 26 p. Reprinted in 1982, The Log Analyst, v. 23(3), May-June, p. 7-23. Reprinted 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. V107-V134.

Ruhovets, N., and Fertl, W.H., 1982, Volumes, types and distribution of clay minerals in reservoir rocks based on well logs, SPE/DOE-10796, in SPE/DOE unconventional gas recovery symposium, proceedings: Society of Petroleum Engineers, p. 67-82.

Schmidt, G.W., 1973, Interstitial water composition and geochemistry of deep Gulf Coast shales and sandstones: AAPG Bulletin, v. 57(2), p. 321-337.

Schultz, A.L., 1979, Electric log evidence for hydrocarbon production and trapping in sandstones possessing diagenetic clay minerals: Houston Geological Society Bulletin, v. 21(2), p. 4-8. Also published in 1979, Bulletin of the South Texas Geological Society, v. 19(8). Reprinted 1986, in W.L. Stapp, editor, Contributions to the geology of south Texas, 1986: South Texas Geological Society, San Antonio, p. 479-482.

Schulze, R.P., Ives, G.L., and Smalley, E.A., 1985, Evaluation of low-resistivity Simpson series of formations, SPE-14282: Society of Petroleum Engineers, 60th annual meeting [Las Vegas], preprint, 8 p.

Schwartz, L.M., and Sen, P.N., 1988, Electrolytic conduction in partially saturated shaly formations, SPE-18131, in 1988 SPE annual technical conference proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 263-272.

Sen, P.N., 1987, Electrochemical origin of conduction in shaly formations, SPE-16787, in 1987 annual technical meeting and exhibition proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 431-437.

Sen, P.N., and Goode, P.A., 1988, Shaly sand conductivity at low and high salinities, paper F, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 22 p.

Sen, P.N., Straley, C., Kenyon, W.E., and Whittingham, M.S., 1990, Surface-to-volume ration, charge density, nuclear magnetic relaxation, and permeability in clay-bearing sandstones: Geophysics, v. 55(1), p. 61-69.

Silva, P.L., and Bassiouni, Z., 1985, A shaly sand conductivity model based on variable equivalent counter-ion conductivity and dual water concepts, paper RR, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 21 p.

Silva, P.L., and Bassiouni, Z., 1986, Hydrocarbon saturation equation in shaly sands according to the S-B conductivity model, SPE-16039: Society of Petroleum Engineers, unsolicited paper, 23 p. Later published in 1988, SPE Formation Evaluation, v. 3(3), p. 503-509.

Silva, P.L., and Bassiouni, Z., 1986, Statistical evaluation of the S-B conductivity model for water-bearing shaly formations: The Log Analyst, v. 27(3), May-June, p. 9-19.

Silva, P.L., and Bassiouni, Z., 1987, Prediction of membrane potentials in shale and shaly sands using the S-B conductivity model: The Log Analyst, v. 28(2), March-April, p. 129-136.

Sinha, A., Lawrence, T., Simmons, B., 1989, An advanced interpretation technique integrates well log and core data fro thin-bed reservoir evaluation: Transactions Gulf Coast Association of Geological Societies, v. 29, p. 267-274.

Slack, H.A., and Otte, C., 1960, Electric log interpretation in exploration for stratigraphic traps in shaly sands: AAPG Bulletin, v. 44(12), p. 1874-1894.

Society of Professional Well Log Analysts, 1982, Shaly sand reprint volume: Society of Professional Well Log Analysts, variously paginated. [Contains 38 significant papers + extensive bibliography. Excellent source for studying the shaly sand problem.]

Stenson, J.D., and Sharma, M.M., 1989, A petrophysical model for shaly sands, SPE-19574, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 9-24.

Tanner, H.L., 1985, Evaluation of low-resistivity cased-off reserves using the shale-compensated chlorine log, SPE-14459: Society of Petroleum Engineers, 60th annual meeting [Las Vegas], preprint, 8 p. Later published in 1987, SPE Formation Evaluation, v. 2(3), p. 284-288.

Tepper, R., 1989, A clay-corrected neutron-density crossover method as a useful gas/oil interpretation technique for Gulf of Mexico shaly sandstone reservoirs, paper R, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 22 p.

Thomas, E.C., and Steiber, S.J., 1975, The distribution of shale in sandstones and its effect upon porosity, paper T, in 16th annual logging symposium transaction: Society of Professional Well Log Analysts, 15 p.

Tixier, M.P., Morris, R.L., and Connell, J.G., 1968, Log evaluation of low resistivity pay sands in the Gulf Coast, paper E (abstract only), in 9th annual logging symposium transactions: Society of Professional Well Log Analysts. Later published in 1968, The Log Analyst, v. 9(6), p. 3-21. Reprinted 1971, in Well logging: Society of Petroleum Engineer, Reprint Series No. 1, p. 342-367. Reprinted 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. IV125-IV142. Reprinted 1986, in Openhole well logging: Society of Petroleum Engineers, SPE Reprint Series No. 21, p. 331-356.

Troullier, J-C., Delhomme, J-P., Carlin, S., and Anxionnaz, H., 1989, Thin-bed reservoir analysis from borehole electrical images, SPE-19578, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 61-72.

Truman, R.B., Howard, W.E., and Luffel, D.L., 1989, Shale porosity; its impact on well-log modeling and interpretation, paper Q, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 17 p.

Vajner, E.A., Kidwell, C.M., and Haley, R.A., 1977, Surprising productivity from low-resistivity sands, paper EE, in 18th annual logging syumposium transactions: Society of Professional Well Log Analysts, 11 p. Reprinted 1978, as, Low resistivity masks high potential of Gulf Coast sands, World Oil, v. 186(2), February 1, p. 49-54.

Vinegar, H.J., and Waxman, M.H., 1984, Induced polarization of shaly sands: Geophysics, v. 49(8), p. 1267-1287.

Vinegar, H.J., Waxman, M.H., Best, M.H., and Reddy, I.K., 1986, Induced polarization logging--Borehole modelling, tool response and field tests: The Log Analyst, v. 27(2), March-April, p. 25-61.

Vinegar, H.J., Waxman, M.H., Best, M.H., and Reddy, K., 1985, Induced polarization logging--Tool development, borehole departure curves and field test results, paper AAA, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 62 p.

Visser, R., and van Baaren, J.P., 1985, Optimisation [sic] of the shale correction using well logs, paper C, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 14 p.

Visser, R., Bourts, K.A.T., and van Baaren, J.P., 1988, Effective porosity estimation in the presence of dispersed clay, paper BB, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 13 p.

Volk, L.J., Carroll, H.B., and Raible, C.J., 1979, Influence of shale conductivities on the electrical conductivity of low-permeability rocks, SPE-7918, in 1979 symposium on low-permeability gas reservoirs [Denver], proceedings: Society of Petroleum Engineers, p. Later published in 1980, Journal of Petroleum Technology, v. 32(5), p. 865-867.

Waxman, M.H., and Smits, L.J.M., 1967, Electrical conductivities in oil-bearing shaly sands, SPE-1863-A: Society of Petroleum Engineers, 42nd annual meeting [Houston] preprint, 16 p. Later published in 1968, Society of Petroleum Engineers Journal, v. 8(2), p. 107-122. Reprinted 1971, in Well Logging: Society of Petroleum Engineers, Reprint Series No. 1, p. 101-116. Reprinted 1982, in Shaly sand: Society of Professional Well Log Analysts, Reprint Volume, p. V145-V160. Reprinted 1986, in Openhole well logging: Society of Petroleum Engineers, SPE Reprint Series No. 21, p. 315-330.

Waxman, M.H., and Thomas, E.C., 1972, Electrical conductivities in shaly sands, part I--The relation between hydrocarbon saturation and resistivity index; part II--The temperature coefficient of electrical conductivity, SPE-4094: Society of Petroleum Engineers, 47th annual meeting [San Antonio] preprint. Later published in 1974, Journal of Petroleum Technology, v.26(2), p. 213-225. Reprinted 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. V161-V173.

Waxman, M.H., and Vinegar, H.J., 1987, Complex conductivity model for shaly sands, in 12th world petroleum congress proceedings, v. 3, production: John Wiley & Sons, New York, p. 287-294.

Wilkinson, J., 1978, Effect of shale distribution on porosity and water saturation: Canadian Well Logging Society Journal, v. 10(1), p. 61-77.

Wilson, M.D., and Pittman, E.D., 1977, Authigenic clays in sandstones--recognition and influence on reservoir properties and paleoenvironmental analysis: Journal of Sedimentary Petrology, v. 47(1), p. 3-31. Reprinted 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. I137-I165.

Worthington, P.F, 1985, The evolution of shaly-sand concepts in reservoir evaluation: The Log Analyst, v. 26(1), p. 23-40.

Worthington, P.F., and Collar, F.A., 1982, The relevance of induced polarization to quantitative formation evaluation, paper U, in 23rd annual logging symposium transactions: Society of Professional Well Log Analysts, 42 p.

Yuan, H.H., and Diederix, K.M., 1989, The role of membrane potential measurements in shaly sand evaluation: The Log Analyst, v. 30(6), November-December, p. 415-423.

Zemanek, J., 1987, Low-resistivity hydrocarbon-bearing sand reservoirs, SPE-15713, in 5th SPE Middle East oil show [Manama, Bahrain], proceedings, : Society of Petroleum Engineers, p. 185-196. Later published in 1989, SPE Formation Evalution, v. 3(4), December, p. 515-521.

VIII. Borehole Gravimetry

Beyer, L.A., 1983, Borehole gravity surveys--Theory, mechanics and nature of measurements: U.S. Geological Survey, Open-File Report 83-0079, 91 p.

Beyer, L.A., 1987, Porosity of unconsolidated sand, diatomite, and fractured shale reservoirs, South Belridge and West Cat Canyon oil fields, California, in R.F. Myer, editor, Exploration for heavy crude oil and natural bitumen [AAPG/UNITAR research conference (Santa Maria, California, October 29-November 2, 1984), proceedings]: AAPG, Studies in Geology No. 25, p. 395-413.

Beyer, L.A., 1987, Borehole gravimetry, OAK crater, in T.W. Henry and B.R. Wardlaw, editors, Pacific Enewetak Atoll crater exploration (PEACE) program, part 4, analysis of borehole gravity surveys and other geological and bathymetric studies in vicinity of OAK and KOA craters: U.S. Geological Survey Open-File Report 87-665, p. 2-1 - 2-56.

Beyer, L.A., and Clutsom, F.G., 1989, Basic data and preliminary density and porosity profiles from three borehole gravity surveys made in the Kuparuk River and Prudhoe Bay oil fields, Alaska: U.S. Geological Survey Open-File Report No. 80-369, 26 p.

Beyer, L.A., Clutsom, F.G., and Grubb, F.V., 1989, Basic data and preliminary density profile from a borehole gravity survey made in the Cajon Pass scientific drillhole, California: U.S. Geological Survey Open-File Report No. 89-458, 18 p.

Beyer, L.A., Robbins, S.L., and Clutsom, F.G., 1985, Basic data and preliminary density and porosity profiles for twelve borehole gravity surveys made in the Los Angeles, San Joaquin, Santa Maria, and Ventura Basin, California: U.S. Geological Survey, Open-File Report 85-42, 66p.

Black, A.J., 1986, Borehole gravity surveying, current instrumentation, capabilities and applications, in P.G. Killeen, editor, Borehole geophysics for mining and geotechnical applications [International symposium and workshop, (Toronto, Ontario, August 29-31, 1983), proceedings]: Geological Survey of Canada Paper 85-27, p. 181-188.

Black, A.J., and Herring, A.T., 1983, Offset of borehole gravity densities due to geologic structures: Calgary, Canadian Society of Exploration Geophysicists, annual meeting preprint, 33 p. Available from Edcon, Inc., Denver, Colorado.

Bradley, J.W., 1975, Application of the borehole gravimeter to the evaluation and exploration of oil and gas reserves: Society of Exploration Geophysicists, 45th annual meeting [Denver] preprint, 15 p.

Brown, A.R., and Lautzenhiser, T.V., 1982, The effect of dipping beds on a borehole gravimeter survey: Geophysics, v. 47(1), p. 25-30.

Caton, P.W., 1981, Improved methods for reducing borehole-gravity data--Applications and analyses of reduced gravity plots, paper RR, in 22nd annual logging symposium transactions: Society of Professional Well Log Analysts, 41 p.

Edcon, Inc., no date, Borehole gravity density logging: Edcon, Inc., Denver, 30 p.

Gournay, L.S., and Lyle, W.D., 1984, Determination of hydrocarbon saturation and porosity using a combination borehole gravimeter and deep investigating electric log, paper WW, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 14 p.

Gournay, L.S., and Maute, R.E., 1982, Detection of bypassed gas using borehole gravimeter and pulsed neutron capture logs: The Log Analyst, v. 23(3), May-June, p. 27-32.

Hearst, J.R., 1977, On the range of investigation of a borehole gravimeter, paper E, in 18th annual logging symposium transactions: Society of Professional Well Log Analysts, 11 p.

Hearst, J.R., 1977, Estimation of dip and lateral extent of beds with borehole gravimetry: Geophysics, v. 42, p. 990-994.

Hearst, J.R., 1987, Investigation of subsurface structure with borehole gravimetry: Transactions of the Society of Mining Engineers of AIME, v. 282, p. 1,817-1,824.

Hearst, J.R., and Carlson, R.C., 1982, Measurement and analysis of gravity in boreholes, in A.A. Fitch, editor, Developments in geophysical exploration methods 3: Applied Science Publishers, London, p. 269-303.

Hearst, J.R., and McKague, H.L., 1976, Structure elucidation with borehole gravimetry: Geophysics, v. 41(3), p. 491-505.

Hsui, A.T., and Zychinski, T., 1989, Study of subsurface structure based on borehole gravimetry, paper BG 3.2, in Expanded abstracts with biographies 59th annual meeting, v. 1: Society of Exploration Geophysicists, p. 59-61.

Jageler, A.H., 1975, Improved hyrocarbon reservoir evaluation through use of borehole gravimeter data, SPE-5511: Society of Petroleum Engineers, 50th annual meeting [Dallas] preprint, 20 p. Later published in 1976, Journal of Petroleum Technology, v. 28(6), p. 709-718.

Jones, B.R., 1972, The use of downhole gravity data in formation evaluation, paper M, in 13th annual logging symposium transactions: Society of Professional Well Log Analysts, 13 p. Later published in abridged form in 1972, as Downhole gravity tool spots distant porosity: World Oil, v. 175(2), August 1, p. 56-59.

Kasameyer, P.W., and Hearst, J.R., 1988, Borehole gravity measurements in the Salton Sea Scientific Drilling Project well State 2-14: Journal of Geophysical Research, v. 93(B11), November, 10, p. 13037-13045.

LaFehr, T.R., 1983, Rock density from borehole gravity surveys: Geophysics, v. 48(3), p. 341-356.

MacQueen, J.D., 1989, Inversion of borehole gravimeter data, paper BG 3.1, in Expanded abstracts with biographies 59th annual meeting, v. 1: Society of Exploration Geophysicists, p. 57-58.

Maute, R.E., and Gournay, L.S., 1985, Determination of residual oil saturation with the borehole gavity meter, SPE-13703, in 4th Middle East oil technology conference, proceedings: Society of Petroleum Engineers, p. 185-190.

McCalpin, G.A., 1985, Operational and technical results of a multiwell borehole gravity survey, in M.J. Davidson, editor, 4th symposium on unconventional methods in exploration for petroleum and natural gas, proceedings: Southern Methodist University, Institute for the Study of Earth and Man, 313-320.

McCulloh, T.H., Kandle, J.R., and Schoellhamer, 1968, Application of gravity measurements in wells to problems of reservoir evaluation, paper O, in 9th annual logging symposium transactions: Society of Professional Well Log Analysts, 28 p.

Nekut, A.G., 1989, Borehole gravity gradiometry: Geophysics, v. 54(2), p. 225-234.

Overton, A., 1975, Borehole gravimetry, in A.V. Dyck, editor, Borehole geophysics applied to metallic mineral prospecting--A review: Geological Survey of Canada Paper 75-31, p. 31-34.

Rasmussen, N.F., 1975, The successful use of the borehole gravity meter in northern Michigan: The Log Analyst, v. 16(5), September-October, p. 3-10.

Rasmussen, N.F., 1975, Borehole gravimeter finds bypassed oil, gas: Oil and Gas Journal, v. 73(39), September 29, p. 100-104.

Robbins, S.L., 1980, Bibliography with abridged abstracts of subsurface gravimetry (especially borehole) and corresponding in-situ rock density determinations: U.S. Geological Survey Open-File Report, 80-710, 47 p.

Robbins, S.L., 1986, The use of borehole gravimetry in water well and waste disposal site evaluation, in Surface and borehole geophysical methods and ground water instrumentation, conference proceedings: National Well Water Association, Dublin, Ohio, p. 474-486.

Robbins, S.L., 1989, Borehole gravimetry reviews; part 1, What is borehole gravimetry; part 2, Borehole gravity measurements, data reduction and precision; part 3, Bibliography with abridged abstracts of borehole gravimetry and corresponding in-place rock density measurements: U.S. Geological Survey Circular 890, 64 p.

Schmoker, J.W., 1977, Density variations in a quartz diorite determined from borehole gravity measurements, San Benito County, California: The Log Analyst, v. 18(2), March-April, p. 32-38.

Schmoker, J.W., 1978, Accuracy of borehole gravity data: Geophysics, v. 43(3), p. 538-542.

Schultz, A.K., 1989, Monitoring fluid movement with the borehole gravity meter: Geophysics, v. 54(5), p. 1,267-1,273.

Snyder, D.D., 1976, The borehole Bouguer gravity anomaly--Application to interpreting borehole gravity surveys, paper AA, in 17th annual logging symposium transactions: Society of Professional Well Log Analysts.

IX. Permeability Determination From Logs

(See also V. Acoustic logging; VII. Shaly sands; 15. Fracture detection)

Aguilera, R., 1988, A new approach for analysis of the nuclear magnetic log-resistivity combination, paper 88-39-109, in 39th annual technical meeting, preprints, volume 3: Petroleum Society of CIM [Canadian Institute of Mining], Calgary, p. 12 p. Later published in 1990, Journal of Canadian Petroleum Technology, v. 29(1), January-February, p. 67-71.

Ahmed, U., Crary, S.F., and Coates, G.R., 1989, Permeability estimation; the various sources and their interrelationship, SPE-19604, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 649-662.

Allan, D.R., 1979, Prediction of permeability from logs by multiple regression, paper M, in 6th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, London Chapter, 13 p.

Allen, D., Coates, G., and others, 1988, Probing for permeability--An introduction of measurements: The Technical Review, v. 36(1), p. 6-20.

Barlai, Z., 1976, Determination of permeability and specific surface area of the pore channels from well logs in fine grained sandstones, paper C, in 17th annual logging symposium transactions: Society of Professional Well Log Analysts.

Best, D.L., 1982, NML; using the nuclear magnetism log to predict permeability: The Technical Review, v. 30(2), September, p. 4-13.

Bolviken, E., Helgeland, J., Storvik, G., Siring, E., and van der Wel, D., 1988, Statistical permeability prediction from wireline logs by switching and Markov regime models, paper Q, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 17 p.

Brown, A.A., 1977, Permeability from well logs Shaybah Field, Saudi Arabia, paper Q, in 18th annual logging symposium transactions: Society of Professional Well Log Analysts, 22 p.

Brown, R.J.S., and Neuman, C.H., 1982, The nuclear magnetism log--A guide for field use: The Log Analyst, v. 23(5), September-October, p. 4-9.

Burck, L.J.S., and Forsyth, D., 1984, Permeability prediction in shaly sands, paper 19, in 9th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 18 p.

Burns, D.R., and Cheng, C.H., 1986, Determination of in-situ permeability from tube wave velocity and attentuation, paper KK, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 15 p.

Burns, D.R., Cheng, C.H., Schmitt, D.P., and Toksoz, M.N., 1988, Permeability estimation from full waveform acoustic logging data: The Log Analyst, v. 29(2), March-April, p. 112-122.

Castagna, J.P., Zucker, S.M., and Shoberg, T.G., 1987, Permeability indication with conventional sonic waveforms, paper MM, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 22 p.

Coates, G.R., and Dumanoir, J.L., 1973, A new approach to improved log-derived permeability, paper R, in 14th annual logging symposium transactions: Society of Professional Well Log Analysts. Later published in 1974, The Log Analyst, v. 15(1), January-February, p. 17-31. Reprinted in 1986, in Openhole well logging: Society of Petroleum Engineers, SPE Reprint Series No. 21, p. 539-551.

Cooke-Yarborough, P., 1984, Reservoir analysis by wireline formation tester; pressures, permeabilities, gradients, and net pay: The Log Analyst, v. 26(6), November-December, p. 36-46.

Day, P., 1984, Permeability from the NML: The Technical Review, v. 32(1), September, p. 57-60.

Dorfman, M.H., Newey, J.J., and Coates, G.R., 1990, New techniques in lithofacies determination and permeability prediction in carbonates using well logs, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 113-120.

El Shafai, I., Zaki, M., and Andreani, M., 1989, Estimating formation permeability and producibility in oil-based mud using the EPT, SPE-17946, in SPE Middle East oil technical conference and exhibition [Manama, Bahrain], proceedings: Society of Petroleum Engineers, p. 181-186.

Eriksen, S.H., 1988, Use of the EPT and capillary pressure to estimate saturation and permeability; a case study, paper L, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 23 p.

Ershaghi, I., Dougherty, E.L., Herzberg, D., and Ucok, H., 1981, Permeability determination in liquid dominated geothermal reservoirs using the Dual Induction Laterolog, in I. Ershaghi, E.E. Dougherty, L.L. Handy, editors, Formation evaluation in liquid dominated geothermal reservoirs: U.S. Department of Energy Report No. DOE/ET/28384-T1, p. 41-59.

Goode, P., and Sen, P.N., 1988, Charge density and permeability in clay-bearing sandstones: Geophysics, v. 53(12), p. 1610-16132.

Hawkins, J., 1989, Comparison of three methods of relative permeability measurement, SCA-8804, part II, paper D, in Annual technical conference reprints, v. 1 (1987-1989): Society of Professional Well Log Analysts, Society of Core Analysts, Chapter-at-Large, 16 p. Later published in 1989, The Log Analyst, v. 30(5), September-October, p. 363-371.

Herron, M.M., 1987, Estimating the intrinsic permeability of clastic sediments from geochemical data, paper HH, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 22 p.

Hess, A.E., and Paillet, F.L., 1989, Characterizing flow paths and permeability distribution in fractured-rock aquifers using a sensitive, thermal, borehole flowmeter, in Conference on new field techniques for quantifying the physical and chemical properties of heterogeneous aquifers [March 20-23, Dallas, TX], proceedings: National Water Well Association, Dublin, OH, p. 155-172.

Huntley, D., 1986, Relations between permeability and electrical resistivity in granular aquifers: Ground Water, v. 24(4), p. 466-474.

Jackson, J.A., 1984, Nuclear magnetic resonance logging: The Log Analyst, v. 25(5), September-October, p. 16.

Jensen, J.L., and Lake, L.W., 1985, Optimization of regression-based porosity-permeability predictions, paper R, in 10th formation evaluation symposium transactions: Canadian Well Logging Society, 22 p.

Johnson, A., 1987, Permeability averaged capillary data--A supplement to log analysis in field studies, paper EE, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 19 p.

Jorgensen, D.G., 1988, Estimating permeability in water-saturated formations: The Log Analyst, v. 29(6), November-December, p. 401-409.

Jorgensen, D.G., 1989, Using geophysical logs to estimate porosity, water resistivity, and intrinsic permeability: U.S. Geological Survey Water-Supply Paper 2321, 24 p.

Kapadia, S.P., and Menzie, D.E., 1985, Determination fo permeability variation factor V from log analysis, SPE-14402: Society of Petroleum Engineers, 60th annual meeting [Las Vegas], preprint, 10 p.

Katsube, T.J., and Hume, J.P., 1987, Permeability determination in crystalline rocks by standard geophysical logs: Geophysics, v. 52(3), p. 342-352.

Katz, A.J., and Thompson, A.H., 1986, Quantitative prediction of permability and electrical conductivity in porous rock, in Expanded abstracts with biographies, 1986 technical program [Houston]: Tulsa, Society of Economic Geophysicists, p. 6-7.

Kenyon, W.E., Day, P.I., Straley, C., and Willemsen, J.F., 1986, Compact and consistent representation of rock NMR data from permeability estimation, SPE-15643: Society of Petroleum Engineers, 61st annual meeting preprint, 22 p. Later published in 1988 as, A three-part study of NMR longitudinal relaxation properties of water-saturated sandstones: SPE Formation Evaluation, v. 3(3), p. 622-636.

Komorowski, P., McDonald, J., and Scribbins, B., 1989, Evaluation of a formation flooded by fresh water, using geochemical, dielectric, and nuclear magnetic measurements, paper M, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 26 p.

Kukal, G.C., and Simons, K.E., 1985, Log analysis techniques for quantifying the permeability of sub-millidarcy sandstone reservoirs, SPE/DOE-13880, in 1985 SPE/DOE symposium on low permeability reservoirs, proceedings: Society of Petroleum Engineers, p. 303-310. Later published in SPE Formation Evaluation, v. 1(6), December, p. 609-622.

Kwader, T., 1984, Estimating acquifer permeability from formation resistivity factors, in D.M. Nielsen and M. Curl, editors, 1984 NWWA/EPA conference on surface and borehole geophysics methods in ground water investigations, proceedings: National Water Well Association, Worthington, Ohio, p. p.713-721.

Lancaster, J.R., and Atkinson, A., 1987, Computer processing of selected drilling, lithologic, and geophysical log data produces accurate permeability values and comprehensive aquifer analysis, including specific yield: COGS [Computer Oriented Geological Society] Computer Contributions, v. 3(1), February, p. 13-36.

Lebreton, F., and Vaubourg, P., 1983, Contribution of well logs to determining permeability and porosity in crystalline rocks, in J.B.W. Day, editor, Recent advances in hydrogeological research in France: Natural Environment Research Council, Institute of Geological Sciences, Report 82-6, p. 21-30.

Logan, W.D., 1989, Bridging the gap between core permeability and log-derived permeability, paper V, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 23 p.

Loren, J.D., 1972, Permeability estimates from NML measurements, SPE-3334: Society of Petroleum Engineers, 47th annual meeting reprint. Later published in 1972, Journal of Petroleum Technology, v. 24(8), p. 923-928.

Marzano, M.S., 1988, Controls on permeability for unconsolidated sands from conventional core data, offshore Gulf of Mexico: Transactions Gulf Coast Association of Geological Societies, v. 38, p.113-120.

Mathieu, F., and Toksoz, M.N., 1984, Determination of fracture permeability using acoustic logs, paper 47, in 9th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 39 p.

Mathieu, F., and Toksoz, M.N., 1984, Application of full waveform acoustic logging data to the estimation of reservoir permeability, in Expanded abstracts with biographies, 1984 technical program: Society of Exploration Geophysicists, p. 9-12.

Norris, A.N., 1986, Tube wave attentuation and dispersion in permeable formations, in Expanded abstracts with biographies, 1986 technical program [Houston]: Society of Economic Geophysicists, p. 25-28.

Nurmi, R., 1984, Permeability in sandstones: The Technical Review, v. 32(1), September, p. 4-9.

Ogbe, D., and Bassiouni, Z., 1978, Estimation of aquifer permeabilities from electric well logs: The Log Analyst, v. 19(5), September-October, p. 21-27.

Paillet, F.L., 1988, Fracture characterization and fracture-permeability estimation at the underground research laboratory in southeastern Manitoba, Canada: U.S. Geological Survey Water Resources Investigations Report 88-4009, 42 p.

Paillet, F.L., Cheng, C.H., Hess, A.E., and Hardin, E.L., 1986, Comparison of fracture permeability estimates based on tube-wave generation in vertical seimic profiles, acoustic waveform-log attenuation, and pumping-test analysis, in Surface and borehole geophysical methods and ground water instrumentation conference and exposition [Denver, October 15-17], proceedings: National Water Well Association, Dublin, Ohio, p. 398-416.

Pape, H., Riepe, L and Schopper, J.R., 1984, Calculating permeability from electrical logging data, paper 22, in 9th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 11 p.

Poncetta, J.H., Torres, A.G., and MacPherson, J.D., 1989, Basin prospecting using porosity and permeability from surface outcrop samples, paper T, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 10 p.

Poster, C.K., 1989, Acoustic characterization of permeable zones from full waveform array sonic data, SPE-17964, in SPE Middle East oil technical conference and exhibition [Manama, Bahrain], proceedings: Society of Petroleum Engineers, p. 373-376.

Raymer, L.L., and Freeman, P.M., 1984, In-situ determination of capillary pressure, pore throat size and distribution, and permeability from wireline data, paper CCC, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 12 p.

Riepe, L., Schopper, J.R., and Wehr, R., 1986, Permeability estimations from nuclear measurements (NMR-, spectral gr-data), paper X, in 10th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Aberdeen Chapter, 15 p.

Rollins, J.B., Holditch, S.A., and Lee, W.J., 1989, Characterizing average permeability in oil and gas formations, SPE-19793, in SPE annual technical conference and exhibition, proceedings, volume sigma, Reservoir engineering: Society of Petroleum Engineers, p. 239-252.

Sakurai, S., and Melvin, J., 1988, Facies discrimination and permeability estimation from well logs for the Endicott field, paper FF, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 18 p.

Scott, T.D., Jr., and Purdy, C.C., 1988, Log derived permeability and flushed zone saturation utilizing high frequency electromagnetic wave attenuation and propagation time, paper I, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 23 p.

Stalkup, F.I., and Ebanks, W.J., Jr., 1986, Permeability variation in a sandstone barrier island-tidal channel-tidal delta complex, Ferron Sandstone (Lower Cretaceous), central Utah, SPE-15532: Society of Petroleum Engineers, 61st annual meeting [New Orleans] preprint, 13 p.

Timur, A., 1967, Pulsed nuclear magnetic resonance studies of porosity, movable fluid and permeability of sandstones, SPE-2045: Society of Petroleum Engineers, 42nd annual meeting preprint. Later published in 1969, Journal of Petroleum Technology, v. 21(6), p. 775-786.

Timur, A., 1968, Effective porosity and permeability of sandstones investigated through nuclear magnetic principles, paper K, in 9th annual logging symposium transactions: Society of Professional Well Log Analysts, 18 p. Later published in 1969, The Log Analyst, v. 10(1), January-February, p. 3-11.

Timur, A., 1968, An investigation of permeability, porosity, and residual water saturation relationships for sandstone reservoirs, paper J, in 9th annual well logging symposium transactions: Society of Professional Well Log Analysts, 18 p. Later published in 1968, The Log Analyst, v. 9(4), July-August, p. 8-17.

Tobola, D.P., and Holditch, S.A., 1989, Determination of reservoir permeability from repeated induction logging, SPE-19606, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 355-370.

Watfa, M., and Youssef, F.Z., 1987, An improved technique for estimating permeability in carbonates, SPE-15732, in 5th SPE Middle East oil show [Manama, Bahrain (March 7-10)], proceedings: Society of Petroleum Engineers, p. 351-360.

Wendt, W.A., Sakurai, S., and Nelson, P.H., 1986, Permeability prediction from well logs using multiple regression, in L.W. Lake and H.B. Carroll, Jr., editors, Reservoir characterization: Academic Press, New York, p. 181-221.

Yildiz, T., and Desbrandes, R., 1989, A new model to determine permeability from wireline formation testing, paper T, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

X. Borehole Imaging and Applications (Including BHTV, FMS, and radar)

(See also II. Electric logging; V. Acoustic logging; 6. Dipmeter applications; 15. Fracture detection)

Adams, J., Bourke, L, Buck, S., 1990, Integrating Formation MicroScanner images with core: Schlumberger Oilfield Review, v. 2(1), January, p. 52-65.

Andersson, K.P., Andersson, P.M., Gustafsson, E., and Olsson, O., 1989, Mapping groundwater flow paths in crystalline bedrock using differential radar crosshole tomography measurements utilizing saline tracers, paper H, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 117-125.

Badr, A.R., and Ayoub, M.R., 1989, Study of a complex carbonate reservoir using the Formation Microscanner (FMS) tool, SPE-17977, in SPE Middle East oil technical conference and exhibition [Manama, Bahrain], proceedings: Society of Petroleum Engineers, p. 507-516.

Bateman, R.M., 1986, Determination of high angle fracture plane orientations from SHDT dipmeter recordings using a microcomputer: Canadian Well Logging Society Journal, v. 15(1), p. 85-100.

Barton, C.A., and Zoback, M.D., 1989, Utilization of interactive analysis of digital borehole televiewer data for studies of macroscopic fracturing, paper GG, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 623-653.

Berger, P., and Roestenburg, J., 1989, High resolution in-situ geochemical and image analysis applied to a well in the South China Sea, paper N, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 16 p.

Bourke, L.T., 1989, Recognizing artifact images of the Formation MicroScanner, paper WW, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Bourke, L, Delfiner, P., Trouiller, J-C, Fett, T., Grace, M., Luthi, S., Serra, O., and Standen, E., 1989, Using Formation Microscanner images: The Technical Review, v. 37(1), January, p. 16-40.

Burns, K.L., 1985, Information extraction from noisy televiewer logs of inclined wellbores in hard rock: Geothermal Resources Council Transactions, v. (, part 2, p. 441-445.

Burns, K.L., 1987, Geological structures from televiewer logs of GT-2 Fenton Hill, New Mexico, part I--Feature extraction: Los Alamos National Laboratory Report LA-10619-HDR, part I, 40 p.

Burns, K.L., 1988, Televiewer measurement of the orientation of in situ stress at the Fenton Hill hot dry rock site, New Mexico: Los Alamos National Laboratory Report LA-UR-88-1775, 6 p. Also published in 1988, Geothermal Resources Council Transactions, v. 12, p. 229-235.

Buscher, M., 1989, Formation MicroScanner--a direct comparison of 2-pad versus 4-pad tool, paper O, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 10 p.

Carson, C.C., and Bauman, T., 1987, Use of an acoustic borehole televiewer to investigate casing corrosion in geothermal wells: Materials Performance, v. 26(6), p. 53-59.

Casarta, L.J., McNaughton, D.A., Bornemann, E., and Bettis, F.E., 1989, Fracture identification and matrix characterization using a new borehole imaging device in the Lisburne carbonate, Prudhoe Bay, Alaska, paper XX, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 10 p.

Chang, H-T., 1989, Borehole directional radar system for subsurface scanning, SPE-19609, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 395-402.

Clerke, E.A., and Van Akkeren, T.J., 1986, Borehole televiewer improves completion results in a Permian basin San Andres reservoir, SPE-15503, in 1986 SPE Permian Basin oil and gas recovery conference proceedings: Society of Petroleum Engineers. Later published in 1988, SPE Production Engineering, v. 3(1), p. 89-95.

Cruden, D.M., Lau, J.S.O., Auger, L.F., and Bisson, J.G., 1987, Subsurface fracture surveys using a borehole television camera and acoustic televiewer: Canadian Geotechnical Journal, v. 24, p. 499-508.

Cull, R., 1988, Formation Microscanner tool imaging and laterolog resistivity measurements in interpretation of crystalline terrains, in A. Boden and K.G. Eriksson, editors, Deep drilling in crystalline bedrock, volume 2: Springer-Verlag, Berlin, p. 315-327.

Ekstrom, M.P., Dahan, C.A., Chen, M., Lloyd, P.M., and Rossi, D.J., 1986, Formation imaging with microelectrical scanning arrays, paper BB, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 21 p. Later published in 1987, The Log Analyst, v. 28(3), May-June, p. 294-306.

Faraguna, J.K., Chace, and Schmidt, M.G., 1989, An improved borehole televiewer system--image acquisition, analysis, and integration, paper Q, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 11 p.

Georgi, D.T., 1985, Geometrical aspects of borehole televiewer images, paper O, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p.

Gonfalini, M., and Anxionnaz, H., 1990, A complete use of structural information from borehole imaging techniques [FMS]; a case history for a deep carbonate reservoir, paper J, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Grace, L.M., Luthi, S.M., and Pirie, R.G., 1986, Stratigraphic interpretation using formation imaging and dipmeter analyses, SPE-15611: Society of Petroleum Engineers, 61st annual meeting [New Orleans] preprint, 4 p.

Graham, R.L., Walbe, K., and McBane, R.A., 1986, Application of the borehole TV camera: Eastern Devonian Gas Shales Technology Review, v. 3(3), December, p. 19-23.

Hackbarth, C.J., and Tepper, B.J., 1988, Examination of BHTV, FMS, and SHDT images in very thinly bedded sands and shales, SPE-18118, in 1988 SPE annual technical conference proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 119-127.

Hansen, S.M., 1988, Application of the Formation MicroScanner imaging tool in the Permian basin, in 35th annual southwestern petroleum short course, proceedings: Southwestern Petroleum Short Course Association, 143-154.

Healy, J.H., Hickman, S.H., Zoback, M.D., and Ellis, W.L., 1984, Report on televiewer log and stress measurements in core hole USW-G1, Nevada test site, December 13-22, 1981: U.S. Geological Survey Open-File Report 84-15, 47 p.

Holloway, A.L., 1989, Rock mass characterization studies in granite using borehole radar at Canada's underground research laboratory, paper DD, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 4 p.

Hornby, B.E., 1989, Imaging of near-borehole structure using full-waveform sonic data: Geophysics, v. 54(6), p. 747-757. Also published in 1989 as SPE-19872, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 615-622.

Hornby, B.E., Luthi, S.M., and Plumb, R.A., 1990, Comparison of fracture apertures computed from electrical borehole scans and reflected Stoneley waves--an automated interpretation, paper L, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Howard, M., 1989, Advances in borehole imaging with second generation CBIL borehole televiewer instrumentation, paper CC, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 13 p.

Iizuka, Y., Ishii, T., Nagata, K., Matsumoto, Y., Murakami, O., and Noguchi, K., 1987, New system for borehole TV logging and evaluation of weathered granites according to their colour indices, in Herget, G., and Vongpaisal, S., editors, 6th international congress on rock mechanics, proceedings, v. 1: International Society for Rock Mechanics, p. 393-396.

Jorgensen, S.D., and James, S.W., 1988, Integration of Stratigraphic High Resolution Dipmeter data into the development of the Minnelusa "B" sand reservoir in Hawk Point field, Campbell County, Wyoming, in R.P. Diedrich, M.A.K. Dyka, and W.R. Miller, editors, Eastern Powder River Basin-Black Hills: Wyoming Geological Association, 39th Field Conference Guidebook, p. 105-116.

Kantzas, A., Marentette, D.F., and Skalinski, M.T., 1989, Computer-assisted tomography as a complementary to well logging, paper P, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 23 p.

Katahara, K.W., Kyle, D.G., Siegfried, R.W., Gard, M.F., Goodwill, W.P., Schasteen, T., and Petermann, S.G., 1988, Detection of external pipe defects with a modified borehole televiewer, paper UU, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 20 p.

Kerzner, M.G., 1986, Image processing in well log analysis: IHRDC Press, Boston, 140 p.

Keys, W.S., 1980, The application of the acoustic televiewer to the characterization of hydraulic fractures in geothermal wells, in Raft River well stimulation experiments, geothermal reservoir well stimulation program: U.S. Department of Energy Report DOE/AL/10563-T7, p. A1-A11.

Koepsell, R.J., Jensen, F.E., and Langley, R.L., 1989, Gulf Coast fault orientation determined by formation imaging techniques, paper VV, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Koespsell, R.J., Jensen, F.E., and Langely, R.L., 1989, Formation imaging, part 1, Formation imaging yields precise fault orientation, minimizes dry offsets: Oil and Gas Journal, v. , p. 55-58.

Koespsell, R.J., Jensen, F.E., and Langely, R.L., 1989, Formation imaging, part 2, Imaging aids visualization of faults: Oil and Gas Journal, v. , p. 85-86.

Lanyon, G.W., 1986, Interactive computer analysis of borehole televiewer data, paper S, in 10th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Aberdeen Chapter, 14 p.

Lloyd, P.M., Dahan, C., and Hutin, R., 1986, Formation imaging with micro-electrical scanning arrays--a new generation of stratigraphic high resolution dipmeter tool, in 10th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Aberdeen Chapter, 19 p.

Luthi, S.M., and Banavar, J.R., 1988, Application of borehole images to three-dimensional geometric modeling of eolian sandstone reservoir: AAPG Bulletin, v. 72(9), p. 1074-1089.

Moore, T.K., 1988, Initial borehole acoustic televiewer data processing algorithms: Los Alamos National Laboratory Report No. LA-011327-MS, 178 pp.

Morin, R.H., Anderson, R.N., and Barton, C., 1989, Analysis and interpretation of the borehole televiewer log; information on the state of stress and the lithostratigraphy at hole 504B, chapter 10, in Mazzullo, E.K., editor, Proceedings of the Ocean Drilling Program, v. 111, Scientific results: Texas A & M University, Ocean Drilling Program, p. 109-118.

Nurmi, R.D., 1984, Geological evaluation of high resolution dipmeter data, paper YY, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 23 p.

Olsson, O., Falk, L., Sandberg, S., Carsten, S., and Magnusson, K-A, 1985, Results from borehole radar reflection measurements, in Radioactive waste disposal in situ experiments in granite [Proceedings of 2nd NEA/Stripa Project symposium, June 1985]: Nuclear Energy Agency, Paris, p. 190-202.

Olsson, O., Falk, L., Sandberg, E., Forslund, O., and Lundmark, L., 1989, Radar measurements with a directional borehole antenna, paper E/G 1.4, in Expanded abstracts with biographies 59th annual meeting, v. 1: Society of Exploration Geophysicists, p. 222-225.

Olsson, O., Forslund, O, Lundmark, L, Sandberg, E., and Falk, L., 1985, The design of a borehole radar system for detection of fracture zones, in Radioactive waste disposal in situ experiments in granite [Proceedings of 2nd NEA/Stripa Project symposium, June 1985]: Nuclear Energy Agency, Paris, p. 172-189.

Olsson, O., and Nilsson, B., 1986, Some examples from borehole radar measurements, in P.G. Killeen, editor, Borehole geophysics for mining and geotechnical applications [international symposium and workshop, (Toronto, Ontario, August 29-31, 1983), proceedings]: Geological Survey of Canada Paper 85-27, p. 197-206.

Overby, W.K., Jr., Yost, L.E., and Yost, A.B., II, 1988, Analysis of natural fractures observed by borehole video camera in a horizontal well, SPE-17760, in SPE gas technology symposium [Dallas], proceedings: Society of Petroleum Engineers, p. 9-16.

Paillet, F.L., 1985, Acoustic-televiewer and acoustic-waveform logs used to characterize deeply buried basalt flows, Hanford site, Benton County, Washington: U.S. Geological Survey Open-File Report 85-419, 90 p.

Paillet, F.L., Barton, C., Luthi, S., Rambow, F., and Zemanek, J., editors, 1990, Borehole imaging: Society of Professional Well Log Analysts Reprint Volume, 472 p. Contains an overview + 32 papers.

Paillet, F.L., Barton, C., Luthi, S., Rambow, F., and Zemanek, J., 1990, Borehole imaging and its application in well logging--an overview, chapter 1, in Borehole imaging: Society of Professional Well Log Analysts Reprint Volume, p. 1-23.

Paillet, F.L. Keys, W.S., and Hess, A.E., 1985, Effects of lithology on televiewer log quality and fracture interpretation, paper JJJ, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 31 p.

Pasternack, E.S., and Goodwill, W.P., 1983, Applications of digital borehole televiewer logging, paper X, in 24th annual logging symposium transactions: Society of Professional Well Log Analysts, 12 p.

Pezard, P.A., and Anderson, R.N., 1990, In situ measurements of electrical resistivity, formation anisotropy, and tectonic context, paper M, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 24 p.

Pezard, P.A., and Luthi, S.M., 1988, Borehole electrical images in the basement of the Cajon Pass scientific drillhole, California; fracture identification and tectonic implications: Geophysical Research Letters, v. 15(9, supplement), p. 1,017-1,020.

Plumb, R.A., and Luthi, S.M., 1986, Application of borehole images to geologic modelling of an eolian reservoir, SPE-15487: Society of Petroleum Engineers, 61st annual meeting [New Orleans] preprint, 11 p. Later published in 1989, SPE Formation Evaluation, v. 3(4), p. 505-514.

Rambow, F.H.K., 1984, The borehole televiewer--Some field examples, paper C, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 21 p.

Ramirez, A.L., Lytle, R.J., and Harben, P., 1984, Crosshole geophysical methods used to investigate the near vicinity of high level waste repositories: Lawrence Livermore National Laboratory Report NUREG/CR-3758 [UCID-20060], 65 p.

Sandberg, E., Olsson, O., and Falk, L., 1989, Combined interpretation of fracture zones in crystalline rock using single hole, crosshole, tomography, and directional borehole radar data, paper G, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 97-116.

Seiler, D., Edmiston, C., Torres, D., and Goetz, J., 1990, Field performance of a new borehole televiewer tool and associated image processing techniques, paper H, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p.

Serra, O., 1989, Formation MicroScanner image interpretation: Schlumberger Educational Service, Houston, SMP-7028, 117 p.

Standen, E., 1989, The analysis of fracture anomalies on electrical wellbore images, paper G, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 20 p.

Startzman, R.A., and Kuo, T.B., 1989, A knowledge-based approach to the interpretation of well-bore images, in Artificial intelligence in petroleum exploration and production, proceedings: Texas A&M University, College Station, p. 35-42.

Staub, A., Lebert, F., and Valla, P., 1989, ELIAS: a slimhole electrical imaging probe, pape K, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 161-181.

Taylor, T.J., 1983, Interpretation and application of borehole televiewer surveys, paper QQ, in 24th annual logging symposium transactions: Society of Professional Well Log Analysts, 19 p.

Torres, D., Strickland, R., and Gianzero, M., 1990, A new approach to determining dip and strike using borehole images, paper K, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts,20 p.

Troullier, J-C., Delhomme, J-P., Carlin, S., and Anxionnaz, H., 1989, Thin-bed reservoir analysis from borehole electrical images, SPE-19578, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 61-72.

Wolfsburger, R.T., Welychka, E.P., and Standen, E.J.W., 1988, Formation MicroScanner applications in southwestern Ontario, in 27th annual conference transactions: Ontario Petroleum Institute, London, Ontario, Canada, p. 22 p.

Wong, S.A., Startzman, R.A., and Kuo, T-B., 1989, Enhancing borehole image data on a high-resolution PC, SPE 19124, in SPE Petroleum computer conference [San Antonio], proceedings: Society of Petroleum Engineers, p. 37-48.

Wong, S.A., Startzman, R.A., and Kuo, T-B., 1989, A new approach to the interpretation fo wellbore images, SPE-19579, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 73-82.

Zemanek, J., Caldwell, R.L., Glenn, E.E., Jr., Holcomb, S.W., Norton, L.J., and Straus, A.J.D., 1968, The Borehole Televiewer--A new logging concept for fracture location and other types of borehole inspection, SPE-2402: Society of Petroleum Engineers, 43rd Annual meeting [Houston] preprint. Later published in 1969, Journal of Petroleum Technology, v. 21(6), p. 762-774.

Zemanek, J., Glenn, E., Norton, L.J., and Caldwell, R.L., 1970, Formation evaluation by inspection with the borehole televiewer: Geophysics, v. 35(2), April, p. 254-269.

Zoback, M.D., and Anderson, R.N., 1982, Ultrasonic borehole televiewer investigation of oceanic crustal layer 2a, Costa Rica rift: Nature, v. 295, February 4, p. 375-379.

XI. Temperature Logging, Determination of Static BHT; Applications of BHT Data; Heat-flow and Geothermics

(See also 21. Geothermal logging)

Abd Allatif, T.A., 1982, Determination of the discharge of various individual aquifers from temperature logging: Desert Institute Bulletin [Egypt], v. 32(1-2), p. 13-17.

Alam, A.H.M.S., and Pilger, R.H., Jr., 1986, Subsurface temperature investigations using seismic and bore hole temperature data, Vermilion and Lafourche Parishes, Louisiana: Gulf Coast Association of Geological Societies Transactions, v. 36, p. 1-7.

Anderson, B.C., 1987, Use of temperature logs to determine intra-wellbore flows, Yucca Mountain, Nevada: Colorado School of Mines, Golden, unpublished MS thesis, 112 p.

Bachu, S., 1985, Influence of lithology and fluid flow on the temperature distribution in a sedimentary basin--A case study from the Cold Lake area, Alberta, Canada: Tectonophysics, v. 120, p. 257-284.

Bachu, S., Sauveplane, C.M., Lytviak, A.T., and Hitchon, B., 1987, Analysis of fluid and heat regimes in sedimentary basins--Techniques for use with large data bases: AAPG Bulletin, v. 71(7), p. 822-843.

Barelli, A., and Palama, A., 1981, A new method for evaluating formation equilibrium temperature in hole during drilling: Geothermics, v. 10(2), p. 95-102.

Beck, A.E., 1976, The use of thermal resistivity logs in stratigraphic correlation: Geophysics v. 41(2), p. 300-309. Reprinted in 1977, The Log Analyst, v. 17(1), January-February, p. 17-22.

Beck, A.E., 1982, Precision logging of temperature gradients and the extraction of past climate: Tectonophysics, v. 83, p. 1-11.

Beck, A.E., and Balling, N., 1988, Determination of virgin rock temperatures, in R. Haenel, L. Rybach, and L. Stegna, editors, Handbook of terrestrial heat-flow density determination: Kluwer Academic Publishers, Dordrecht, Netherlands, p. 59-85.

Beck, A.E., and Shen, P.Y., 1989, On a more rigorous approach to geothermic problems: Tectonophysics, v. 164, p. 83-92.

Becker, K., Large-scale electrical resistivity and bulk porosity of the upper oceanic crust at hole 395A, chapter 16, in Stewart, N.J., editor, Proceedings of the Ocean Drilling Program, volume 106/109, scientific results, : Texas A&M University, Ocean Drilling Program, p. 205-212.

Ben Dhia, H., 1988, Tunisian geothermal data from oil wells: Geophysics, v. 53(11), p. 1479-1487.

Bergren, F.E., and Bradley, D.A., 1988, Design and evaluation of pump-in temperature surveys for detecting cement channels above perforations, SPE-18145, in 1988 SPE annual technical conference proceedings, volume omega, Formation evaluation and reservoir geology and in volume delta, Drilling: Society of Petroleum Engineers, P. 389-396 (omega) and p. 385-392 (delta).

Berner, J.G., 1987, Planning successful temperature surveys, in Symposium on subsurface injection of oilfield brines [New Orleans, May 4-6], proceedings: Underground Injection Practices Council, Oklahoma City, p. 512-534.

Bodner, D.P., and Sharp, J.M., Jr., 1988, Temperature variations in south Texas subsurface: AAPG Bulletin, v. 72(1), p. 21-32.

Cao, S., Hermanrud, C., and Lerche, I., 1988, Estimation of formation temperature from bottom-hole temperature measurements--COST No. 1 well, Norton Sound, Alaska: Geophysics, v. 53(12), p. 1619-1621.

Cao, S., and Lerche, I., 1989, Geohistory, thermal history, and hydrocarbon generation history of Navarin basin COST No. 1 well, Bering Sea, Alaska: Journal of Petroleum Geology, v. 12(3), July, p. 325-352.

Cao, S., Lerche, I., and Hermanrud, C., 1988, Formation temperature estimation by inversion of borehole measurements, part 2--Effects of fluid penetration on bottom-hole temperature recovery: Geophysics, v. 53(10), p. 1347-1354.

Carlson, N.R., and Barnette, J.C., 1988, Determining a reliable estimate of the geothermal gradient from shut-in temperature recordings, SPE-18144, in 1988 SPE annual technical conference proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 375-387.

Carstens, H., and Finstad, K.G., 1981, Geothermal gradients of the northern North Sea basin, 59-62°N, in L.V. Illing and G.D. Hobson, editors, Petroleum geology of the continental shelf of north-west Europe: Heyden & Sons, Ltd., London, p. 152-161.

Chapman, D.S., Keho, T.H., Bauer, M.S., and Picard, M.D., 1984, Heat flow in the Unita Basin determined from bottom hole temperature (BHT) data: Geophysics, v. 49(4), p. 453-466.

Chaturvedi, L., and Ory, J.K., 1981, A preliminary evaluation of geothermal potential of San Juan Basin, New Mexico, using bottom hole temperatures from oil and gas wells: Geothermal Resources Council, Transactions, v. 4, p. 21-24.

Cheung, P.K., 1979, Geothermal gradient mapping--Oklahoma, paper T, in 7th formation evaluation syposium transactions: Canadian Well Logging Society.

Conaway, J., 1988, Temperature logging as an aid to understanding groundwater flow in boreholes, paper F, in 2nd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applications [Golden, Colorado, October 6-8, 1987], proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society Chapter-at-Large, p. 51-59.

Conaway, J.G., and Beck, A.E., 1977, Fine-scale correlation between temperature gradient logs and lithology: Geophysics, v. 42, p. 1,401-1,410.

Cooke, C.E., Jr., and Meyer, A.J., 1979, Application of radial differential temperature (RDT) logging to detect and treat flow behind casing, paper UU, in 20th annual logging symposium transactions: Society of Professional Well Log Analysts, 10 p.

de Rito, R.F., Lachenbruch, A.H., Moses, T.H., Jr., and Munroe, R.J., 1989, Heat flow and thermotectonic problems of the central Ventura Basin, southern California: Journal of Geophysical Research, v. B94(1), p. 681-699.

Decker, E.R., Heasler, H.P., Buelow, K.L., Baker, K.H., and Hallin, J.S., 1988, Significance of past and recent heat-flow and radioactivity studies in the Southern Rocky Mountains region: Geological Society of America Bulletin, v. 100(12), p. 1851-1885.

Deming, D., 1989, Application of bottom-hole temperature corrections in geothermal studies: Geothermics, v. 18(5-6), p. 775-786.

Deming, D., and Chapman, D.S., 1987, Inversion of bottom-hole temperature data--The Pineview field, Utah-Wyoming thrust belt: Geophysics, v. 53(5), p. 707-720.

Deming, D., and Chapman, D.S., 1988, Heat flow in the Utah-Wyoming thrust belt from analysis of bottom-hole temperature data measured in oil and gas wells: Journal of Geophysical Research, v. 93(B11), p. 13,657-13,672.

Dhia, H.B., 1987, The geothermal gradient map of central Tunesia--Comparison with structural, gravimetric, and petroleum data: Tectonophysics, v. 142, p. 99-109.

Dornst%dter, J., and Sattel, G., 1985, Thermal measurments in the research borehole Konzen, Hohes Venn (West Germany): Neues Jahrbuch f,r Geologie und Pal%ontologie, v. 1711-3), p. 117-130.

Dove, R.E., and Williams, C.F., 1989, Thermal conductivity estimated from elemental concentration logs: Nuclear Geophysics, v. 3(2), p. 107-112.

Dowdle, W.L., and Cobb, W.M., 1974, Static formation temperature from well logs--an empirical method, SPE-5036: Society of Petroleum Engineers, 49th annual meeting [Houston] preprint. Later published in 1975, Journal of Petroleum Technology, v. 27(11), p. 1326-1330. Reprinted in 1982, Geothermal log interpretation handbook: Society of Professional Well Log Analysts, p. V-61-V-65.

Drury, M.J., 1984, On a possible source of error in extracting equilibrium formation temperatures from borehole BHT data: Geothermics, v. 13(3), p. 175-180.

Drury, M.J., 1989, Fluid flow in crystalline crust; detecting fractures by temperature logs, in Beck, A.E., Garven, G., and Stegena, editors, Hydrological regimes and their subsurface thermal effects: American Geophysical Union Geophysical Monograph 47, p. 129-135.

Edwardson, M.J., Girner,, H.M., Parkinson, H.R., Williams, C.D., and Mathews, C.S., 1962, Calculation of formation temperature disturbances caused by mud circulation: Journal of Petroleum Technology, v. 14(4), p. 416-426.

Fernandez, M., and Banda, E., 1989, An approach to the thermal field in northeastern Spain: Tectonophysics, v. 164, p. 259-266.

Fertl, W.H., 1985, Determination of true static formation temperature: Canadian Well Logging Society Journal, v. 14, p. 77.

Fertl, W.H., 1985, Logs help approximate reservoir temperature: Oil and Gas Journal, v. 83(17), April 29, p. 89-95.

Fertl, W.H., and Wichmann, P.A., 1977, How to determine static BHT from well data: World Oil, v. 184(1), January, p. 105-106.

Fertl, W.H., Chilingarian, G.V., and Yen, T.F., 1986, Determination of true static formation temperature from well logs: Energy Sources, v. 8(2/3), p. 277-290.

Fialka, B.N., Pyszka, M.H., and Chhina, H.S., 1990, The evaluation of temperature logging in thermal application, SPE-20084, in SPE California regional meeting, proceedings: Society of Petroleum Engineers, p. 571-580.

Fujii, N., 1986, Downhole flow of bottom water--Implications from temperature logging at hole 462A, Nauru Basin, Deep Sea Drilling Project Leg 89, in S. Orlofsky, editor, Initial reports of the Deep Sea Drilling Project, volume 89: U.S. Government Printing Office, p. 597-601.

Fylling, A., and Spurlin, J., 1988, Induction simulation, the logs analysts' perspective, paper T, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 16 p.

Gable, R., 1984, Temperature disturbances observed in sedimentary basins and their interpretation, in B. Durand, editor, Thermal phenomena in sedimentary basins [international colloquium, (Bordeaux, France, June 7-10, 1983), proceedings]: Editions Technip, Paris, Colloquium and Seminar Series No. 41, p. 55-63.

Gable, R., Morin, R.H., and Becker, K., 1989, Geothermal state of hole 504B; ODP Leg 111 overview, chapter 8, in Mazzullo, E.K., editor, Proceedings of the Ocean Drilling Program, volume 111, scientific results: Texas A&M University Ocean Drilling Program, p. 87-96.

Goss, R., and Combs, J., 1976, Thermal conductivity measurement and prediction from geophysical well log parameters with borehole application, in 2nd United Nations symposium on the development and use of geothermal resources [San Francisco, May 20-29, 1975]: U.S., Government Printing Office, p. 1019-1027.

Gretener, P.E., 1981, Geothermics--Using temperature in hydrocarbon exploration: AAPG Education Course Note Series No. 17, 156 p.

Grisafi, T.W., Rieke, H.H., III, and Skidmore, D.R., 1974, Approximation of geothermal graidents in northern West Virginia using bottom-hole temperature from electric logs: AAPG Bulletin, v. 58(2), p. 321-323.

Hagedorn, D.N., 1985, The calculation of synthetic thermal conductivity logs from conventional geophysical well logs: Southern Methodist University, unpublished MS thesis, 110 p.

Harrison, W.E., and Luza, K.V., 1986, Temperature-gradient information from several boreholes drilled in Oklahoma: Oklahoma Geological Survey, Special Publication No. 86-2, 42 p. Valuable study of the length of time rquired for borehole-fluid temperature stabilization.

Hearst, J.R., and Nelson, P.H., 1985, Temperature, chapter 4, in Well logging for physical parameters: McGraw-Hill Book Company, New York, p. 63-84.

Hermanrud, C., 1988, Determination of formation temperature from downhole measurements: University of South Carolina, Department of Geological Sciences unpublished PhD. dissertation, 203 p.

Hermanrud, C., Meisingset, K.K., and Lerche, I., 1989, Formation temperatures from drillstem tests, SPE-19464: Society of Petroleum Engineers, unsolicited paper, 59 p.

Hermanrud, C., and Shen, P.Y., 1989, Virgin rock temperatures from well logs; accuracy analysis for some advanced inversion models: Journal of Petroleum Science and Engineering, v. 3(4), January, p. 321-332.

Hilchie, D.W., 1977, Caliper and temperature logging, chapter 15, in L.W. LeRoy, D.O. LeRoy and J.W. Raese, editors, Subsurface geology, 4th edition: Colorado School of Mines, Golden, p. 342-346.

Houseman, G.A., Cull, J.P., Muir, P.M., and Paterson, H.L., 1989, Geothermal signatures and uranium ore deposits on the Stuart shelf of South Australia: Geophysics, v. 54(2), p. 158-170.

Issler, D.R., and Beaumont, C., 1987, Thermal and subsidence history of the Labrador and West Greenland continental margins, in C. Beaumont, and A.J., Tankard, editors, Sedimentary basins and basin-forming mechanisms: Canadian Society of Petroleum Geologists Memoir No. 12, p. 45-69.

Jarrell, M., and Lyle, R., 1987, Application of the temperature survey in demonstrating the mechanical integrity of injection wells, in NWWA FOCUS conference on Midwestern ground water issues [Indianapolis, April 21-23], proceedings: National Water Well Association, Dublin, Ohio, p. 569-590.

Jessop, A.M., 1990, Analysis and correction of heat flow on land, chapter 2, in Thermal geophysics: Elsevier, Amsterdam, Developments in Solid Earth Geophysics No. 17, p. 57-85.

Jessop, A.M., and Judge, A.S., 1975, Temperature measurement in boreholes for the mining industry, in A.V. Dyck, editor, Borehole geophysics applied to metallic mineral prospecting--A review: Geological Survey of Canada Paper 75-31, p. 55-66.

Jolivet, J., Bienfait, G., Vigneresse, J.L., and Cuney, M., 1989, Heat flow and heat production in Brittany, western France: Tectonophysics, v. 159(1-2), p. 61-72.

Jones, F.W., Lam, H.L., and Majorowicz, J.A., 1985, Temperature distributions at the Paleozoic and Precambrian surfaces and their implications for geothermal energy recovery in Alberta: Canadian Journal of Earth Science, v. 22, p. 1774-1780.

Jones, F.W., and Majorowicz, J.A., 1987, Some aspects of the thermal regime and hydrodynamics of western Canadian sedimentary basins, in J.C. Goff, and B.P.J. Williams, editors, Fluid flow in sedimentary basins and aquifers: Geological Society of London Special Publication No. 34, p. 79-85.

Jones, F.W., Majorowicz, J.A., and Embry, A.F., 1989, A heat flow profile across the Sverdrup Basin, Canadian Arctic Islands: Geophysics, v. 54(2), p. 171-180.

Jones, F.W., Majorowicz, J.A., Linville, A., and Osadetz, K.G., 1986, the relationship of hydrocarbon occurrences to geothermal gradients and time-temperature indices in Mesozoic formations of southern Alberta: Bulletin of Canadian Petroleum Geology, v. 34(2), June, p. 226-239.

Jorden, J.R., and Campbell, F.L., 1984, Temperature logging, chapter 5, in Well logging I--Rock properties, borehole environment, mud and temperature logging: Society of Petroleum Engineers, Monograph Series No. 9, p. 127-146.

Joyner, H.D., 1975, A correlation of electric-log-indicated reservoir temperature with actual reservoir temperature - southwest Louisiana: Journal of Petroleum Technology, v. 27(2), p. 181-182.

Keet, B., 1982, Temperature log analysis with a pocket calculator--Interpretation program for discrete temperature logs in small-diameter well: Geologie en Mijnbouw, v. 61(3), p. 293-295.

Kehle, R.O., Schoeppel, R.J., and Deford, R.K., 1970, The AAPG geothermal survey of North America [U.N. symposium on the development and utilitization of geothermal resources (Pisa, Italy)]: Geothermics, special issue no. 2, part 1, p. 358-367.

Kopietz, J., Becker, K., and Hamano, Y., 1990, Temperature measurements at site 395, ODP Leg 109, chapter 15, in Stewart, N.J., editor, Proceedings of the Ocean Drilling Program, volume 106/109, scientific results: Texas A&M University, Ocean Drilling Program, p. 197-203.

Kukkonen, I.T., 1988, Terrestrial heat flow and groundwater circulation in the bedrock in the central Baltic Shield: Tectonophysics, v. 156(1-2), p. 59-74.

Kumar, M.B., 1989, Geothermal patterns of Louisiana salt domes: Transactions Gulf Coast Association of Geological Societies, v. 29, p. 159-170.

Kutasov, I.M., Caruthers, R.M., Targhi, A.K., and Chaaban, H.M., 1988, Prediction of downhole circulating and shut-in pressures: Geothermics, v. 17(4), p. 607-618. Also published in 1989, in abridged form, Oil and Gas Journal, v. 87(28), July 10, p. 94-95.

Lachenbruch, A.H., and Marshall, B.V., 1986, Changing climate--Geothermal evidence from permafrost in the Alaskan Arctic: Science, v. 234, November 7, p. 689-696.

Lam, H.L., and Jones, F.W., 1982, A statistical analysis of bottom-hole temperature data in the Hinton area of west-central Alberta: Tectonophysics, v. 103, p. 273-281.

Lam, H.L., and Jones, F.W., 1986, An investigation of the potential for geothermal energy recovery in the Calgary area in southern Alberta, Canada, using petroleum exploration data: Geophysics, v. 51(8), p. 1661-1670.

Lam, H.L., Jones, F.W., and Majorowicz, J.A., 1985, A statistical analysis of bottom-hole temperature data in southern Alberta: Geophysics, v. 50(4), p. 677-684.

LeBlanc, Y., Lam, H.L., Pascoe, L.J., and Jones, F.W., 1982, A comparison of two methods of estimating static formation temperature from well logs: Geophysical Prospecting, v. 30, p. 348-357.

Lucazeau, F., and Ben Dhia, H., 1989, Preliminary heat-flow density data from Tunesia and the Pelagian Sea: Canadian Journal of Earth Science, v. 26(5), p. 993-1,000.

Lucazeau, F., and Vasseur, G., 1989, Heat flow density data from France and surrounding margins: Tectonophysics, v. 164, p. 251-258.

Majorowicz, J.A., Jones, F.W., and Jessop, A.M., 1988, Preliminary geothermics of the sedimentary basins in the Yukon and Northwest Territories (60∞N-70∞N)--Estimates from petroleum bottom-hole temperature data: Bulletin of Canadian Petroleum Geology, v. 36(1), March, p. 39-51.

Majorowicz, J.A., Jones, F.W., and Judge, A.S., 1990, Deep subpermafrost thermal regime in the Mackenzie delta basin, northern Canada--analysis from petroleum bottom-hole temperature data: Geophysics, v. 55(3), p. 362-371.

Majorowicz, J.A., Jones, F.W., Lam, H.L., and Jessop, A.M., 1985, Terrestrial heat flow and geothermal gradients in relation to hydrodynamics in the Alberta basin, Canada: Journal of Geodynamics, v. 4(1-4), p. 265-283.

McConnell, C.L., 1985, Salinity and temperature anomalies over structural oil fields, Carter County, Oklahoma: AAPG Bulletin, v. 69(5), p. 781-787.

Michalski, A., 1989, Application of temperature and electrical conductivity logging in ground water monitoring: Ground Water Monitoring Review, v. 9(3), p. 112-118.

Middleton, M.F., 1979, A model for bottom-hole temperature stabilization: Geophysics, v. 44(8), p. 1458-1462.

Middleton, M.F., 1982, Bottom-hole temperature stabilization with continued circulation of drilling mud: Geophysics, v. 47(12), p. 1716-1723.

Mongelli, F., 1981, evaluation of geotemperatures from oil wells in Italy: Geothermics, v. 10(1), p. 29-38.

Muramoto, F.S., and Elders, W.A., 1984, Identification of zones of progressive hydrothermal metamorphism from wireline logs and their correlation to reservoir temperatures in the Salton Sea and Westmorland geothermal systems, Imperial Valley, California, in C.A. Rigsby, editor, The Imperial basin tectonics, sedimentation, and thermal aspects: Pacific Section Society of Economic Paleontologists and Mineralogists, p. 87-95.

Nagao, T., and Uyeda, S., 1989, Heat flow measurements in the northern part of Honshu, northeast Japan, using shallow holes: Tectonophysics, v. 164(2-4), p. 301-314.

Oxburgh, E.R., and Andrews-Speed, C.P., 1981, Temperature, thermal gradients and heat flow in the southwestern North Sea, in L.V. Illing and G.D. Hobson, editors, Petroleum geology of the continental shelf of north-west Europe: Heyden & Sons, Ltd., London, p. 141-151.

Perrier, J., and Raiga-Clemenceau, J., 1984, Temperature measurements in boreholes, in B. Durand, editor, Thermal phenomena in sedimentary basins [international colloquium, (Bordeaux, France, June 7-10, 1983), proceedings]: Editions Technip, Paris, Colloquium and Seminar Series No. 41, p. 47-54.

Pfieffer, D.S., and Sharp, J.M. Jr., 1989, Subsurface temperature distributions in south Texas: Transactions Gulf Coast Association of Geological Societies, v. 29, p. 231-245.

Plisga, G.J., 1987, Temperature in wells, chapter 31, in H.B., Bradley, editor-in-chief, Petroleum Engineering Handbook: Society of Petroleum Engineers, p. 31-1 - 31-7.

Rainis, A.E., Skidmore, D.R., and Rieke, H.H., III, 1974, A computational method for determining segmental and overall geothermal gradients and geothermal heat flow values: Geothermics, v. 3(3), p. 113-117.

Reiter, M., Eggleston, R.E., Broadwell, B.R., and Minier, J., 1986, Estimates of terrestrial heat flow from deep petroleum tests along the Rio Grand rift in central and southern New Mexico: Journal of Geophysical Research, v. 91(B6), May 10, p. 6225-6245.

Reiter, M., Mansure, A.J., and Peterson, B.K., 1980, Precision continuous temperature logging and comparison with other types of logs: Geophysics, v. 45(12), p. 1857-1868. Also published in 1981, as, Deep subsurface temperature studies in the basins of New Mexico and neighboring geologic areas--Precision continuous temperature logging and comparison with other types of logs: New Mexico Energy Research and Development Program Report EMD-2-67-2321, 30 p.

Reiter, M., and Tovar, J.C., 1982, Estimates of terrestrial heat flow in northern Chihuahua, Mexico, based upon petroleum bottom-hole temperatures: Geological Society of America Bulletin, v. 93, p. 613-624.

Ross, E.W., Vagelatos, N., Dickerson, J.M., and Nguyen, V., 1982, Nuclear logging and geothermal log interpretation--Formation temperature sonde evaluation: Los Alamos National Laboratory Report No. LA-9159-MS, 56 p. Reprinted 1982, in Geothermal log interpretation handbook: Society of Professional Well Log Analysts, p. V-3-V-60.

Roux, B., Sanyal, S.K., and Brown, S.L., 1980, An improved approach to estimating true reservoir temperature from transient temperature data, SPE-8888, in 50th California regional meeting proceedings: Society of Petroleum Engineers, 8 p. Reprinted 1982, in Geothermal log interpretation handbook: Society of Professional Well Log Analysts, p. V-53-V-60.

Rybach, L., 1989, Heat flow techniques in geothermal exploration: First Break, v. 7(1), January, p. 9-16.

Saskai, A., 1984, An empirical method and a few problems for estimating formation temperature from bottom-hole temperature recorded during logging [in Japanese, except for English abstract]: Journal of the Japanese Association for Petroleum Technology, v. 49(5), September, p. 7.

Saskai, A., 1987, A reliability [sic] of Horner-plot method for estimating static formation temperatures from well log data: Journal of the Japanese Association of Petroleum Technology, v. 52(3), p. 243-252. [In Japanese, English abstract].

Schoeppel, R.J., and Gilarranz, S., 1965, Use of well log temperatures to evaluate regional geothermal gradients, SPE-1297: Society of Petroleum Engineers, 40th annual meeting [Denver] preprint. Later published in 1966, Journal of Petroleum Technology, v. 18(6), p. 667-673.

Shen, P.Y., and Beck, A.E., 1983, Determination of surface temperature history from borehole temperature gradients: Journal of Geophysical Research, v. 88(B9), September 10, p. 7385-7493.

Shen, P.Y., and Beck, A.E., 1986, Stabilization of bottom hole temperature with finite circulation time and fluid flow: Geophysical Journal of the Royal Astronomical Society, v. 86, p. 63-90.

Speece, M.A., Bowen, T.D., Folcik, J.L., and Pollack, H.N., 1985, Analysis of temperatures in sedimentary basins--The Michigan Basin: Geophysics, v. 50(8), p. 1318-1334.

Staub, W.P., and Treat, N.L., 1981, Analysis of bottom-hole temperature data from oil and gas wells of the Tennessee Valley region: Geothermal Resources Council Transactions, v. 5, p. 129-132.

Sweeney, J.J., Burnham, A.K., and Braun, R.L., 1986, A model of hydrocarbon maturation in the Uinta basin, Utah, USA, in J. Burrus, editor, Thermal modeling in sedimentary basins [1st IPF exploration research conference (Carcans, France, June 3-7, 1985) proceedings]: Editions Technip, Paris, Collection Colloques et Seminaires No. 44, p. 547-561.

Taylor, A., Judge, A., and Allen, V., 1989, The automatic well temperature measuring system installed at Cape Allison C-47, offshore well, Arctic Islands of Canada; part 2, Data retrieval and analysis of the thermal regime: Journal of Canadian Petroleum Technology, v. 28(2), March-April, p. 95-101.

Tittman, J., 1989, The earth's heat: Schlumberger Oilfield Review, v. 1(1), April, p. 54-61.

Treguer, J.P., 1981, Temperature measurement in oil wells, in Heat flow; combined proceedings of the joint ASCOPE/CCOP workshops I [Jakarta, 1981] and II [Bangkok, 1984]: United Nations, New York, CCOP Project Office Report CCOP/TP 15, p. 61-69.

Tulipano, L., 1988, Temperature log intepretation for the identification of preferential flow pathways in the coastal carbonatic and karstic aquifer of the Salento peninsula (southern Italy), in 21st congress [Guilin, China, (October 10-15)], proceedings, volume 2, Karst hydrogeology and karst environment protection: International Association of Hydrogeologists, Publication No. 176

Urban, T.C., and Diment, W.H., 1982, An interpretation of precision temperature logs in a deep geothermal well near Desert Peak, Churchill County, Nevada: Geothermal Resources Council Transactions v. 6, p. 317-321.

Urban, T.C., and Diment, W.H., 1985, Convection in boreholes--Limits on interpretation of temperature logs and methods for determining anomalous fluid-flow, in 1985 NWWA conference on surface and borehole geophysical methods in ground water investigations [Fort Worth, Texas, February 12-14], proceedings: National Water Well Association, Worthington, Ohio, p. 399-414.

Vacquier, V., 1985, Calculation of terrestrial heat flow solely from oil well logging records, in Joint ASCOPE/UN CCOP heat flow workshop [Jakarta, Indonesia, 10/19-23/81], proceedings: United Nations, New York, CCOP Technical Publication No. 15, p. 45-48.

Vacquier, V., Mathieu, Y., Legendre, E., and Blondin, E., 1988, Experiment on estimating thermal conductivity of sedimentary rocks from oil well logging: AAPG Bulletin, v. 72(6), p. 758-764.

Verma, R.K., 1977, Temperature logging and its application to geophysical problems, in V.L.S. Bhimasankaram and V.K. Gaur, editors, Lectures on exploration geophysics for geologists and engineers: The Association of Exploration Geophysicists, Hyderabad, India, p. 287-300.

Vugrinovich, R., 1989, Subsurface temperatures and surface heat flow in the Michigan basin and their relationships to regional subsurface fluid movement: Marine and Petroleum Geology, v. 6(1), February, p. 60-70.

Willett S.D., and Chapman, D.S., 1987, Temperatures, fluid flow, and the thermal history of the Uinta Basin, in B. Doligez, editor, Migration of hydrocarbons in sedimentary basins [2nd IFP exploration research conference, Carcans, France, June 15-19, proceedings]: Editions Technip, Paris, Colloqiums and Seminars No. 45, p. 533-551.

Willett, S.D., and Chapman, D.S., 1987, Analysis of temperatures and thermal processes in the Uinta basin, in C. Beaumont, and A.J., Tankard, editors, Sedimentary basins and basin-forming mechanisms: Canadian Society of Petroleum Geologists Memoir No. 12, p. 447-461.

Williams, C.F., Anderson, R.N., and Broglia, C., 1988, In situ investigations of thermal conductivity, heat production, and past hydrothermal circulation in the Cajon Pass scientific drillhole, California: Geophysical Research Letters, v. 15(9, supplement), p. 985-988.

Williams, J.H., Carswell, L.D., Lloyd, O.B., Jr., and Roth, W.C., 1984, Characterization of ground water circulation in selected fractured rock aquifers using borehole temperature and flow logs, in D.M. Nielsen and M. Curl, editors, 1984 NWWA/EPA conference on surface and borehole geophysics methods in ground water investigations, proceedings: National Water Well Association, Worthington, Ohio, p. 842-852.

Xu, H., and Desbrandes, R., 1990, Formation evaluation using in-situ measurements of formation thermal properties, paper KK, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Zembruscki, S.G., and Kiang, C.H., 1989, Geothermal gradient map of Brazilian sedimentary basins [in Portugese, with expanded English abstract]: Boletim de Geosciencias da Petrobras, v. 3(3), p. 215-227.

XII. Conditions and Special Situations Affecting Tool Response

Ajam, S.O., and Rahal, V.E., 1985, Applications of thermal multigate decay pulsed neutron logs in unusual downhole logging environments: Australian Petroleum Exploration Association [APEA] Journal, v. 25, part 1, p. 265-274. Later published in 1986, in 6th SPE offshore South East Asia conference [Singapore, January 28-31], proceedings: South East Asia Petroleum Exploration Society, p. 437-446.

Allen, D.F., 1982, The effect of mud salinity on EPT attenuation: The Technical Review, v. 30(3), December, p. 4-9.

Anderson, B., and Barber, T.D., 1987, Strange induction logs--A catalog of environmental effects, paper G, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p. Later published in 1988, The Log Analyst, v. 29(4), July-August, p. 229-243.

Anderson, B., Safinya, K.A., and Habashy, T., 1986, Effects of dipping beds on the response of induction tools, SPE-15488: Society of Petroleum Engineers, 61st annual meeting preprint, 11 p. Later published in 1988, SPE Formation Evaluation, v. 3(1), p. 29-36.

Anonymous, 1971, Logging oddities--radioactive clean dolomite: Canadian Well Logging Society Journal v. 4(1), p. 95-98.

Barber, T.D., and Howard, A.Q., 1989, Correcting the induction log for dip effect, SPE-19607, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 371-380.

Blakeman, E.R., 1982, A case study of the effect of shale alteration on sonic transit times, paper II, in 23rd annual logging symposium transactions: Society of Professional Well Log Analysts, 14 p.

Buchanan, J.C., Clearman, D.K., Heidbrink, L.J., and Smith, H.D., Jr., 1984, Applications of TMD pulsed neutron logs in unusual downhole environments, paper KKK, in 25th annual loggining symposium transactions: Society of Professional Well Log Analysts, 17 p.

Burnett, T.M., Koopersmith, C.A., and Spross, R.L., 1990, Drill collar effects on MWD epithermal-, thermal-, and capture-gamma-ray-neutron porosity meaurements, paper E, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 22 p.

Chemali, R., Gianzero, S., and Su, S.M., 1988, The dual laterolog in common complex situations, paper U, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 25 p.

Clavier, C., Heim, A., and Scala, C., 1976, Influence of pyrite on resistivity and other logging measurements, paper HH, in 17th annual logging symposium transactions: Society of Professional Well Log Analysts, 33 p.

Clenchy, D.R., 1985, Effect of borehole diameter on log data quality and interpretation--Grand Banks area, east coast Canada, paper V, in 10th formation evaluation symposium transactions: Canadian Well Logging Society, 26 p.

Cockcraft, P.J., Imanudin, Owens, J.A., and Basuki, W., 1986, The effect of KOH [potassium hyroxide] lignosulfonate drilling muds on spontaneous potential log interpretation, in 15th annual convention proceedings, v. 2: Indonesian Petroleum Association, Jakarta, p. 27-42. Later published in 1987 as unsolicited SPE-16467: Society of Petroleum Engineers, 19 p.

Conaway, J.G., Allen, K.V., Blanchard, Y.B. Bristow, Q., Hyatt, W.G., and Killeen, P.G., 1979, The effects of borehole diameter, borehole fluid, and casing thickness on gamma ray logs in large diameter boreholes: Geological Survey of Canada Paper 79-1C, p. 37-40.

Connolly, E.T., 1970, Interpretation and recognition of calibration and recording abnormalities on production logs: Canadian Well Logging Society Journal, v. 3(1), December, p. 89-122.

Cooke-Yarborough, P., 1986, Son of crossplot fights back, in 6th SPE offshore South East Asia conference [Singapore, January 28-31], proceedings: South East Asia Petroleum Exploration Society, p. 447-454.

Cox, J.W., and Raymer, L.L., 1976, The effect of potassium-salt muds on gamma ray, and spontaneous potential measurements, paper I, in 17th annual logging symposium transactions: Society of Professional Well Log Analysts, , 20 p.

Crues, J.V., Jr., 1982, Recognizing large SP anomalies in the Cretaceous carbonates along the Balcones systems and how to interpret them: Bulletin of the South Texas Geological Society, v. 23(5), December, p. 16-27. Reprinted in 1986, in W.L. Stapp, editor, Contributions to the geology of south Texas, 1986: South Texas Geological Society, San Antonio, p. 398-406.

Dickson, B.L., and Ramsden, A.R., 1986, Significance of the Toolebuc gamma ray anomaly in the search for and evaluation of oil shale in the Eromanga Basin: Australian Journal of Earth Sciences, v. 33(4), p. 429-441.

Dunlap, H.F., and Coates, G.R., 1988, Boron--Tracking a trace element: The Log Analyst, v. 29(6), November-December, p. 410-417.

Dunlap, H.F., Dupree, J.H., Jr., and Lower, T.A., 1985, Effect of makeup water and mud additives on drilling fluid resistivity, in M.H. Dorfman and R.A. Morton, editors, 6th U.S. Gulf Coast geopressured-geothermal energy conference [Austin, Texas, February 4-6], proceedings: Pergamon Press, New York, p. 149-155.

Dziuba, T.T., 1986, Mud filtrate effects on the laterolog in Alberta foothills carbonates, paper 86-37-16, in 36th annual technical meeting of the Petroleum Society of CIM preprints, v. 1: Petroleum Institute of the Canadian Institute of Mining, Calgary, p. 211-234. Later published in 1987, Journal of Canadian Petroleum Technology, v. 26(5), September-October, p. 41-50.

Fertl, W.H., 1978, How subsurface temperature affects formation evaluation: Oil and Gas Journal, v. 76(30), July 24, p. 54-62.

Fertl, W.H., and Hammack, G.W., 1976, Solid particle penetration into porous reservoir rocks and its effect on well log analysis, paper F, in 17th annual logging symposium transactions: Society of Professional Well Log Analysts, 10 p.

Fertl, W.H., King, E.E., and Kumar., R., 1978, Important SP and gamma ray log anomalies explained: Oil and Gas Journal, v. 76(34), August 21, p. 70-75.

Gearhart, D.A., 1987, The effect of borehole size, mudcake, and standoff on the P_e measurement, SPE-16770, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 299-308. Later published in 1989, SPE Formation Evaluation, v. 4(2), p. 138-144.

Halyburton, R.V., and Locke, A.L., 1988, Log response in a pyrite-cemented sandstone reservoir--A case study from offshore north Western Australia, OSEA-88160, in 7th offshore South East Asia conference proceedings: Southeast Asia Petroleum Society, p. 526-530.

Hammack, G.W., and Fertl, W.H., 1974, Anomalies observed on well logs, paper V, in 15th annual logging symposium transactions: Society of Professional Well Log Analysts, 21 p. Also published in 1974, World Oil, v. 179(7), p. 69-73.

Hartley, K.B., 1979, Evaluation of wireline down-log information and effects of increased log speeds on data quality, SPE-8363: Society of Petroleum Engineers, 54th annual meeting [Las Vegas] preprint. Later published in 1980, Journal of Petroleum Technology, v. 32(7), p. 1151-1160. Also published in 1981, Oil and Gas Journal, v. 79(8 and 9), February 23, p. 66-76, and March 2, p. 99-100.

Hartmann, D.J., 1975, Effect of bed thickness and pore geometry on log response, paper Y, in 16th annual logging symposium transactions: Society of Professional Well Log Analysts.

Hedberg, H.S., and May, D.H., 1990, Gypsum determination in shallow west Texas carbonates, SPE-20106, in SPE Permian Basin oil and gas recovery conference [Midland, TX], proceedings: Society of Petroleum Engineers, p. 189-196.

Hewitt, S.T., 1989, Effects of accelerometer corrections on formation dip measurements: Oil and Gas Journal, v. 87(3), January 16, p. 71-74.

Hurst, A., 1987, Problems of reservoir characterization in some North Sea sandstone reservoirs solved by application of microscale geological data, chapter 11, in J. Kleppe, E.W. Berg, A.T. Buller, O. Hjelmeland, and O. Torsaeter, editors, North Sea oil and gas reservoirs: Graham & Totman Ltd., London, p. 153-167.

Jameson, J.B., McGhee, B.F., Blackburn, J.S., and Leach, B.C., 1976, Dual-spacing TDT applications in marginal conditions, SPE-5904: Society of Petroleum Engineers, Rocky Mountain meeting [Casper] preprint. Later published in 1977, Journal of Petroleum Technology, v. 29(9), p. 1067-1077.

Kowalski, J.J., and Asekun, S.O., 1979, It may not be shale, paper P, in 20th annual logging symposium transactions: Society of Professional Well Log Analysts, 15 p. Also published 1979, as paper G, in 7th formation evaluation symposium transactions: Canadian Well Logging Society.

Lacour-Gayet, P., 1981, The Groningen effect: The Technical Review, v. 29(1), p. 37-47.

Lau, M.N., Luquette, M.B., and Bassiouni, Z., 1989, Correction for oil-based mud effects on neutron and density tools, SPE-19611, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 411-418.

Lovell, J.R., and Chew, W.C., 1990, Effect of tool eccentricity on some electrical well-logging tools: IEEE Transactions on Geoscience and Remote Sensing, v. 28(1), January, p. 127-136.

Mathis, G.L., 1990, The effect of detector temperature on the formation density log, paper RR, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts,9 p.

Misk, A., Mowat, G.R., Goetz, J.F., Vivet, B., 1977, Effects of hole conditions on log measurement and formation evaluation, paper 22, in 5th European logging symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 16 p. Reprinted in 1978, in Measuring accuracy of parameters used in formation evaluation in the North Sea [Norwegian Petroleum Society conference, 10/30-11/2/77]: Norwegian Information Publishers, Oslo, p. 21-37.

Moore, C.V., and Kaufman, R.L., 1981, Your unsuspected problems--Fluid resistivity and water analysis, paper C, in 22nd annual logging symposium transactions: Society of Professional Well Log Analysts, 15 p.

Pachett, P.G., Berry W.R., II, Burlingame, R.W., Moore, C.V., Spalding, J.S., Wichmann, P.A., and Woodhouse, R., 1986, Problematic overview--A series of six studies on difficult log analysis, paper NNN, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 23 p.

Semmelbeck, M.E., and Holditch, S.A., 1985, The effects of mud-filtrate invasion on the interpretation of induction logs, SPE-14491, in SPE eastern regional meeting proceedings: Society of Petroleum Engineers, p. 27-38. Later published in 1988, SPE Formation Evaluation, v. 3(2), p. 386-392.

Sharma, M.M., and Wunderlich, R.W., 1985, The alteration of rock properties due to interactions with drilling fluid components, SPE-14302: Society of Petroleum Engineers, 60th annual meeting [Las Vegas], preprint 12 p. Later published in 1987, Journal of Petroleum Science and Engineering, v. 1(2), December, p. 127-143.

Shen, L.C., and Hardman, R.H., 1986, Effect of formation dip or hole deviation on induction logs, paper I, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 13 p.

Smith, M.P., 1989, Temperature effects on dual-spaced thermal neutron logging tool, paper QQ, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p.

Street, G.J., and Reid, D., 1986, Gamma radiation from steel drill casing: Exploration Geophysics v. 17(2), p. 122.

Suau, J., and Spurlin, J., 1982, Interpretation of micaceous sandstones in the North Sea, paper G, in 23rd annual logging symposium transactions: Society of Professional Well Log Analysts, 32 p.

Tilly H.P., Gallagher, B.J., and Taylor, T.D., 1981, Methods for correcting porosity data in a gypsum-bearing carbonate reservoir, SPE-9716, in 1981 SPE Permian Basin oil and gas recovery symposium, proceedings: Society of Petroleum Engineers. Later published in 1982, Journal of Petroleum Technology, v. 34(10), p. 2449-2454.

Tittle, C.W., 1989, Effect of pyrite and siderite on the response of the compensated neutron log: Nuclear Geophysics, v. 3(4), p. 335-337.

Trojan, M., 1985, Effects of diagenesis on reservoir properties and log response, Upper Jurassic Taylor Sandstone, Cotton Valley Group, Lincoln Parish, Lousisiana: Transactions Gulf Coast Association of Geological Societies, v. 35 p. 515-523.

Waid, C.C., 1987, Effect of tool rotation on the computation of dip, paper Q, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 22 p.

Wang, Z., and Nur, A., 1986, Effect of temperature on wave velocities in sands and sandstones with hydrocarbons, SPE-15645: Society of Petroleum Engineers, 61st annual meeting [New Orleans] preprint, 8 p. Also published in 1986, in Expanded abstracts with biographies, 1986 technical program [Houston]: Society of Economic Geophysicists, p. 3-5.

Williams, H., and Dunlap, H.E., 1984, Short-term variations in drilling fluid parameters; their measurement and implications: The Log Analyst, v. 25(5), September-October, p. 3.

Woodhouse, R., 1978, The laterolog Groningen phantom can cost you money, paper R, in 19th annual logging symposium transactions: Society of Professional Well Log Analysts, 17 p.

XIII. Crossplot Techniques and Applications

Burke, J.A., Campbell, R.L., Jr., and Schmidt, A.W., 1969, The litho-porosity cross plot, paper Y (abstract only), in 10th annual logging symposium transactions: Society of Professional Well Log Analysts. Later published in 1969, The

Log Analyst, v. 10(6), November-December, p. 25-43. Reprinted in 1978, in Gamma ray, neutron and density logging reprint volume, paper X: Society of Professional Well Log Analysts, 19 p. Reprinted in 1986, in Openhole well logging: Society of Petroleum Engineers, SPE Reprint Series No. 21, p. 475-503.

Clavier, C., and Rust, D.H., 1976, MID plot--A new lithology technique: The Log Analyst, v. 17(6), November-December, p. 16-24. Reprinted in 1986, in Openhole well logging: Society of Petroleum Engineers, SPE Reprint Series No. 21, p. 515-523.

Cohen, A., 1985, Enhanced lithological discrimination through application of graphical log cross-reference (crossplotting)--A case study of Shiqma 5 (Saqiye Group, Neogene, Israel): Geological Survey of Israel, Mineral Energy Infrastructure Report GSI/44/85, 22 p.

Crues, J.V., Jr., 1977, Lithology crossplots--Applications in an evaporite basin--the Maverick basin of southwest Texas, paper L, in 18th annual logging symposium transactions: Society of Professional Well Log Analysts, 23 p. Later published in 1980, Bulletin of the South texas Geological Society, v. 20(6). Reprinted in 1986, in W.L. Stapp, editor, Contributions to the geology of south Texas, 1986: South Texas Geological Society, San Antonio, p. 423-438.

Fertl, W.H., 1978, Open-hole crossplots--A powerful technique in well log analysis, SPE-8115: Society of Petroleum Engineers, European offshore petroleum conference preprint. Later published in 1981, Journal of Petroleum Technology, 33(3), p. 535-549 [See references]. Reprinted in 1986, in Openhole well logging: Society of Petroleum Engineers, SPE Reprint Series No. 21, p. 524-538.

Fertl, W.H., 1979, Practical log analysis, part 13--Hingle crossplot speeds long-interval evaluation : Oil and Gas Journal, v. 77(3), p. 110-118.

Galloway, W., and Smith W.D.M., 1981, The successful application of a neutron acoustic crossplot to the dolomite sandstone of the Belloy, paper Y, in 8th formation evaluation symposium transactions: Canadian Well Logging Society, 15 p.

Greengold, G.E., 1986, The graphical representation of bulk volume water on the Pickett crossplot: The Log Analyst, v. 27(3), May-June, p. 21-25.

Griffiths, C.M., 1988, An M-N-gamma crossplot as the basis of a numerical lithostratigraphy with geotechnical implications, in F.P. Agterberg and C.N. Rao, editors, Recent advances in quantitative stratigraphic correlation techniques [UNESCO international geological correlation programme, project 148]: Hindustan Publishing Company, Delhi, India, p. 126-135.

Heslop, A., 1978, Using cross-plots to quantify the effect of shaliness: Canadian Well Logging Society Journal, v. 10, p. 79-91.

Hrubanova, J., 1988, Contribution of the well-log overlay method in solving the lithological profile; the Broumov-1 borehole, the Intra-Sudetic basin, in J. Pesek, and J. Vozar, editors, Coal-bearing formations of Czechoslovakia: Dionyz Stur Institute of Geology, Bratislava, p. 93-98.

Kwader, T., 1985, Resistivity-porosity cross plots for determining in situ formation water quality--Case examples, in 1985 NWWA conference on surface and borehole geophysical methods in ground water investigations [Fort Worth, Texas, February 12-14], proceedings: National Water Well Association, Worthington, Ohio, p. 415-424.

Lang, W.H., Jr., 1972, Porosity-resistivity cross-plotting, paper F, in 13th annual logging symposium transactions: Society of Professional Well Log Analyts, 9 p. Later published in 1973, The Log Analyst, v. 14(1), January-Febraury, p. 16-20.

Maple, L., 1985, A crossplot approach to electromagnetic propagation tool (EPT) interpretation, paper N, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 18 p.

Mathews, D.M., and Bassiouni, Z., 1984, Resistivity-spontaneous potential crossplot for enhanced interpretation of well logs: The Log Analyst, v. 25(4), July-August, p. 14-19.

O'Brian, W.J., Brown, S.L., and Sanyal, S.K., 1982, Crossplot technique for the analysis of the carbon/oxygen log, SPE-10740, in California regional meeting, proceedings: Society of Petroleum Engineers, p. 243-266.

Pickett, G.R., 1973, Pattern recognition as a means of formation evaluation, paper A, in 14th annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p. Later published in 1973, The Log Analyst, v. 14(4), July-August, p. 3-11.

Watney, W.L., 1979, Gammaray-neutron [sic] cross-plots as an aid in sedimentological analysis, in D. Gill and D.F. Merriam, editors, Geomathematical and petrophysical studies in sedimentology: Pergamon Press, Oxford, Computers in Geology Series, p. 81-100.

Whitman, W.W., 1986, Pickett plots with approximate geologic conditions: The Log Analyst, v. 27(5), September-October, p. 11-28.

Wu, C.H., and Krudwig, M.C., 1980, Density-neutron crossplot analysis using polar coordinates: The Log Analyst, v. 21(4), July-August, p. 3-8.

XIV. Computer and Programmable Calculator Programs for Log Analysis

Asquith, G.B., 1990, NSWE.BAS--BASIC Program for determining effective water saturation in shaly sands using percentage of clay-bound water-filled microporosity: Geobyte, v. 5(3), p. 43-50.

Barba, R.E., Rubenstein, J.D., and Harder, S.M., 1989, A microcomputer-based log-analysis program in a Windows environment, SPE-19323, in SPE eastern regional conference, proceedings: Society of Petroleum Engineers, p. 165-170. Later published in 1990, by Rubenstein, J.D., Harder, S.M., and Barba, R.E., SPE Computer Applications, January-February, p. 12-15.

Bateman, R.M. and Konen, C.E., 1977, Wellsite log analysis and the programmable pocket calculator, paper B, in 18th annual logging symposium transactions: Society of Professional Well Log Analysts, 35 p. [Later expanded a into series published in The Log Analyst.]

Bateman, R.M., and Konen, C.E., 1977, The log analyst and the programmable pocket calculator, part 1--R_w from the SP and pulsed neutron log analysis: The Log Analyst, v. 18(5), September-October, p. 3-11.

Bateman, R.M., and Konen, C.E., 1977, The log analyst and the programmable pocket calculator, part 2--Crossplot porosity and water saturation: The Log Analyst, v. 18(6), November-December, p. 3-11.

Bateman, R.M., and Konen, C.E., 1978, The log analyst and the programmable pocket calculator, part 3--Dipmeter computation: The Log Analyst, v. 19(1), January-February, p. 3-9.

Bateman, R.M., and Konen, C.E., 1978, The log analyst and the programmable pocket calculator, part 4--Dual induction-laterolog 8: The Log Analyst, v. 19(3), May-June, p. 14.

Bateman, R.M., and Konen, C.E., 1978, The log analyst and the programmable pocket calculator, part 5--R_t and D_i from the dual laterolog: The Log Analyst, v. 19(4), July-August, p. 11-14.

Bateman, R.M., and Konen, C.E., 1979, The log analyst and the programmable pocket calculator, part 6--Finding true stratigraphic thickness and true vertical thickness of dipping beds cut by directional wells: The Log Analyst, v. 20(2), March-April, p. 3-6.

Cambell, D.L., Ballantyne, E.J., Jr., Mentemeier, S.H., and Wiggins, R., 1981, Manual of geophysical hand-calculator programs: Society of Exploration Geophysicists, variously paginated. Volumes for HP and TI calculators consisting of previously published programs.

Chaplow, R., 1985, Production of borehole logs using a microcomputer: The Quarterly Journal of Engineering Geology, v. 19(3), p. 291-299.

Christoffersen, K., and Whitson, C.H., 1989, TABLE--A FORTRAN subroutine for generating tables: SPE Computer Applications, May-June, p.8-10.

Crain, E.R., 1986, Calculator solutions for log analysis, chapter 13, in The log analysis handbook, volume 1--Quantitative log analysis methods: PennWell Books, Tulsa, p. 417-447.

Crain, E.R., 1986, Log analysis using electronic speadsheets, chapter 14, in The log analysis handbook, volume 1--Quantitative log analysis methods: PennWell Books, Tulsa, p. 448-462.

Crain, E.R., 1986, Computer-aided log analysis, chapter 15, in The log analysis handbook, volume 1--Quantitative log analysis methods: PennWell Books, Tulsa, p. 463-487.

Cranmer, J.L., Jr., 1982, BASIC reservoir engineering manual: PennWell Books, Tulsa, 232 p. [Programs for TRS-80 and IBM PC.]

Dudnick, R.A., 1986, Program for TI-59 to convert true dips to seismic section dips: Oil and Gas Journal, v. 84(14), April 7, p. 107-108.

Elek, I., 1990, Fast porosity estimation by principal component analysis: Geobyte, v. 5(3), p. 25-34.

Elphick, R.Y., 1987, Nuclear logging tool interpretation in hard rock formations [BASIC program]: Geobyte, v.2(3), p. 44-47.

Elphick, R.Y., 1987, Neutron/density/gr interpretation in shaley [sic] sands: Geobyte, v. 2(2), p. 51-55.

Elphick, R.Y., 1987, Dual-water model, shaly sand log analysis using Lotus 1-2-3: Geobyte, v. 2(1), p. 33-37.

Elphick, R.Y., 1987, Environmental corrections for logging tools; plus, a crossplot for the Amiga: Geobyte, v. 2(4), November, p. 44-47.

Elphick, R.Y., 1988, Digitizing well logs [IBM-PC and Amiga (Macintosh) program code]: Geobyte, v. 3(1), p. 47-52.

Elphick, R.Y., 1988, Program helps determine structure from dipmeter data: Geobyte, v. 3(2), p. 57-62.

Elphick, R.Y., 1988, Log analysis of an induction electric log: Geobyte, v. 3(3), August, p. 70-72

Elphick, R.Y., 1988, Formation mechanical properties and the sonic log: Geobyte, v. 3(4), November, p. 24-26.

Elphick, R.Y., 1989, SCAT revisited [source code for MS-DOS machines]: Geobyte, v. 4(1), p. 53-57.

Elphick, R.Y., 1989, Petrophysical software directory '89: Geobyte, v. 4(4), p. 27-37.

Elphick, R.Y., 1990, Curve fitting by regression: Geobyte, v. 5(2), April, p. 63-68.

Elphick, R.Y., 1990, A spreadsheet method of finding R_w from the SP: Geobyte, v. 5(3), p. 39-42.

Elphick, R.Y., 1990, Calculating water cut: Geobyte, v. 5(1), February, p. 15-23.

Garb, F.A., 1978, Property evaluation with hand-held computers, part 3--Clean sand log analysis and shaly formation sonic-density log analysis: Petroleum Engineer International, v. 50(3), March, p. 50-80.

Garb, F.A., 1978, Property evaluation with hand-held computers, part 4--Water saturation by five shaly sand equations and interpolation of deviated tops: Petroleum Engineer International, v. 50(4), April, p. 47-52.

Garb, F.A., 1978, Property evaluation with hand-held calculators, part 5--Neutron and neutron-density log analysis procedures: Petroleum Engineer International, v. 50(5), May, p. 52-69.

Gobran, B.D., Saldana, M.A., Brown, S.L., and Sanyal, S.K., 1980, A comprehensive mathematical approach and a hand-held calculator program for analysis of shaly gas sands: The Log Analyst, v. 21(5), September-October, p. 11-21.

Grundy, W.D., and Miesch, A.T., 1987, Brief descriptions of STATPAC and related statistical programs for the IBM personal computer, part A, documentation; part B, source code; part C, selected executable models: U.S. Geological Survey Open-File Report 87-0411(A-C), 34 p. and 15 diskettes.

Hallenburg, J.K., 1984, HP41C formation evaluation programs: PennWell Books, Tulsa, 120 p.

Hallenburg, J.K., 1985, LOGCOMP petroleum formation evaluation programs: PennWell Books, Tulsa, 104 p. [For IBM-XT.]

Heemink, G.H., Bryant, W.T., and Langenbuch, T.L., 1987, Well log analysis spreadsheet, SPE-16498, in Petroleum industry applications of microcomputers [Montgomery, Texas, June 23-26], proceedings: Society of Petroleum Engineers, p. 151-168.

Hollo, R., and Fifadara, H., 1981, TI-59 reservoir engineering manual, 2nd edition: PennWell Books, Tulsa, 249 p.

Jantzen, R.E., Foreman, R.D., Keltner, L., and McCoy, R.S., 1987, Format, content, and information transfer standards for digital rigsite data, SPE-16141, in SPE/IADC drilling conference, proceedings: Society of Petroleum Engineers, p.

793-806. Later published in 1989, as Wellsite information transfer specification (WITS) for digital rig-site data, SPE Drilling Engineering, v. 4(4), December, p. 291-300.

Keet, B., 1982, Temperature log analysis with a pocket calculator--Interpretation program for discrete temperature logs in small-diameter well: Geologie en Mijnbouw, v. 61(3), p. 293-295.

Kork, J.O., 1981, FENCE--A computer program to create files of borehole data and to construct fence sections of boreholes interactively: U.S. Geological Survey Open-File Report 81-0183, 62 p.

Kork, J.O., 1986, JKDIGIT, a program to control a digitizing board for geologists, written in BASIC for an IBM Personal Computer: U.S. Geological Survey Bulletin 1616, 69 p.

Kork, J.O., 1987, JKPLT2V--A program to make 2-variable scatter plots: U.S. Geological Survey Open-File Report 87-0442, 2 diskettes.

Kork, J.O., 1987, JKPLOT; a device-independent plotting system written in BASICA for an IBM PC: U.S. Geological Survey Open-File Report 87-0159, 48 p., 1 diskette.

Kostecke, S.T., 1980, Speed of hand-calculator programs can be improved: Oil and Gas Journal, v. 78(32), August 11, p. 107-116.

Lauman, J., 1985, Basic well log analysis using the HP-11C: Geobyte, v. 1(1), Winter, p. 108.

LeBlanc, D.P., 1982, Shaly sand and carbonate analysis on the HP-41C: Canadian Well Logging Society Journal, v. 11, p. 31-41.

LeBlanc, D.P., 1983, Enhanced shaly sands and carbonate analysis on the HP-41C: Canadian Well Logging Society Journal, v. 12, p. 135-145.

Linehan, J.M., and Sutterlin, P.G., 1986, WSULOG, microcomputer-based well-log evaluation for carbonate reservoirs in Kansas [with source code in Fortran 77]: Computers & Geosciences, v. 12(4B), p. 499-517.

McCoy, R.L., 1983, PETROCALC 1--Reservoir engineering and formation evaluation: Gulf Publishing Co., Houston, 144 p. [For IBM, Apple, and HP.]

Meehan, D.N., and Vogel, E.L., 1982, HP-41 reservoir engineering manual: PennWell Books, Tulsa, 364 p.

Mustard, P.S., and Richardson, J.M., 1990, A Lotus 1-2-3 template for triangular plots: Geobyte, v.5 (2), April, p. 47-53.

Pirson, S.J., 1983, Basic log analysis package for the HP-41CV programmable calculator, appendix 4, in Geologic well log analysis, 3rd edition: Gulf Publishing Company, Houston, p. 363-460.

Rose, R.J., Taylor, M.J., and Jantzen, R.E., 1989, Information standards for well-site data, paper F, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 4 p.

Schad, S.T., 1986, BASIC log analysis programs: Oil and Gas Journal, v. 84(18), May 5, p. 185-187.

Schad, S.T., 1987, Comprehensive log analysis software, part 1--Introduction and general routines: Oil and Gas Journal, v. 85(31), August 3, p. 58-60.

Schad, S.T., 1987, Comprehensive log analysis software, part 2--Resistivity logs: Oil and Gas Journal, v. 85(32), August 10, p. 79-80.

Schad, S.T., 1987, Comprehensive log analysis software, part 3--Single porosity logs: Oil and Gas Journal, v. 85(33), August 17, p. 81-82.

Schad, S.T., 1987, Comprehensive log analysis software, part 4--Dual porosity log crossplots: Oil and Gas Journal, v. 85(34), August 24, p. 71-73.

Schad, S.T., 1987, Comprehensive log analysis software, part 5--Ternary porosity log crossplots: Oil and Gas Journal, v. 85(36), September 7, p. 72-73.

Schoonover, L.G., and Fertl, W.H., 1979, Practical log analysis, part 17--How to find temperature, R_W, and salinity with hand calculators: Oil and Gas Journal, v. 77(27), July 2, p. 109-111.

Schoonover, L.G., and Fertl, W.H., 1979, Practical log analysis, part 18--Estimate R_{wa} and water saturation with hand calculator programs: Oil and Gas Journal, v. 77(29), July 16, p. 67-68.

Schoonover, L.G., and Fertl, W.H., 1979, Practical log analysis, part 19--Porosity and water saturation using handheld calculators: Oil and Gas Journal, v. 77(31), July 30, p. 170-172.

Schoonover, L.G., and Fertl, W.H., 1979, Practical log analysis, part 20--Calculator programs used for shaly sand log analysis: Oil and Gas Journal, v. 77(33), August 13, p. 120-126.

Schoonover, L.G., and Fertl, W.H., 1979, Practical log analysis, part 21--Using the S_w and q-factor approach to quicker shaly-sand analysis: Oil and Gas Journal, v. 77(35), August 27, p. 122-125.

Scott, J.H., 1978, A FORTRAN algorithm for correcting normal resistivity logs for borehole diameter and mud resistivity: U.S. Geological Survey Open-File Report 78-779, 12 p.

Scott, J.H., 1978, A computer program for borehole compensation of dual-detector density well logs: U.S. Geological Survey Open-File Report 78-515, 7 p.

Selner, G.I., and Taylor, R.B., 1987, GSLITH version 1.0; a program to draw cross sections and plot plan views from regional-scale drill hole data using an IBM PC (or compatible) microcomputer, digitizer, and plotter: U.S. Geological Survey Open-File Report 87-0126, 49 p., 1 diskette.

Selner, G.I., and Taylor, R.B., 1988, GSLXY version 1.0; a prototype program to draw cross sections and plot plan views from drill hole data on an X, Y, coordinate system using an IBM PC (or compatible) microcomputer, digitizer, and plotter.: U.S. Geological Survey Open-File Report 88-0387-A, B, 71 p. + 1 diskette.

Selner, G.I., and Taylor, R.B., 1988, GSSECT version 2.0; a prototype program to assist drawing of cross sections and compute gradients along a profile using a microcomputer (IBM PC or compatible), digitizer, and plotter: U.S. Geological Survey Open-File Report 88-0429-A, B, 25 p. + 1 diskette.

Selner, G.I., Smith, C.L., and Taylor, R.B., 1988, GSDIG version 2.0; a program to determine latitude/longitude coordinates, and GSDXY version 1.0; a counterpart program to determine X, Y coordinates, using a microcomputer (IBM PC or compatible) and digitizer: U.S. Geological Survey Open-File Report 88-0428-A, B, 32 p. + 1 diskette.

Selner, G.I., Smith, C.L., and Taylor, R.B., 1988, GSPOST version 2.0; a program to plot symbols and post numerical data from ASCII tables providing latitude and longitude, and GSPXY, version 1.0; a counterpart program working from X, Y coordinates using an IBM PC or compatible) microcomputer and plotter: U.S. Geological Survey Open-File Report, 88-0413-A, B, 47 p. + 1 diskette.

Smith, S.W., and Keen, D., 1979, A simplified true vertical thickness (TVT) calculation using a programmable pocket calculator: The Log Analyst, v. 20(2), March-April, p. 28-32.

Souder, W.W., and Williams, J.S., 1979, Interactive calculators can aid wellsite log analysis: Oil and Gas Journal, v. 77(47), November 26, p. 69-76.

Struyk, C., Bishop, R., Fortune, D., Foster, E., Gordon, D., d'Haene, T., Joyce, D., Kenny, S., Kowalchuk, H., and Stadnyk, M., 1989, LAS: a floppy disk standard for log data, paper J, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 16 p.

Texas Instruments, 1978, Programmable TI-59 specialty packettes--Oil, gas, energy: Texas Insturments, Inc. 40 p.

Thompson, K.D., 1978, Well log interpretation of shaly sands with the programmable calculator, paper X, in 19th annual logging symposium transactions: Society of Professional Well Log Analysts, 26 p.

Tsang, P.B., 1978, The log analyst and the programmable pocket calculator, Part I--R_w from the SP--Addendum: The Log Analyst, v. 19(1), January-February, p. 10-11.

Tsay, F.S, 1989, Use of a digitizer with microcomputers for chart conversion in induction log corrections: SPE Computer Applications Newsletter, March-April, p. 33-37.

Tsay, F.S., and Dindoruk, B., 1990, A numerical solution for CNL environmental corrections: Geobyte, v. 5(2), April, p. 69-75.

Turner, W.J., 1980, Hand-held calculator programs for frequently used formulas, part 8--Directional well surveys, radius of curvature method: Petroleum Engineer International, v. 52(7), June, p. 102-114.

Whittaker, A., 1988, Low-cost log analysis using a graphics-based microcomputer and 'off-the-shelf' software, part 2--Extending spreadsheet templates with interactive graphic tools: Geobyte, v. 3(3), August, p. 24-35.

Whittaker, A., 1988, Low-cost log analysis using a graphics-based microcomputer and 'off-the-shelf' software, part 1--A spreadsheet template to simplify mud log evaluation: Geobyte, v. 3(2), p. 76-83.

Wu, C.H., and Krug, J., 1978, Density-neutron crossplot analysis for shaly gas sands using hand-carried calculators: The Log Analyst, v. 19(4), July-August, p. 3-10.

Wu, C.H., and Krug, J., 1979, Shaly gas-sand analysis using hand-carried calculators: The Log Analyst, v. 20(3), May-June, p. 20-25.

Wu, C.H., and Krudwig, M.C., 1980, Density-neutron crossplot analysis using polar coordinates: The Log Analyst, v. 21(4), July-August, p. 3-8.

XV. Schlumberger International Well Evaluation Conferences

Alexander, I., editor, 1982, Schlumberger well evaluation developments--Continental Europe 1982 [Baden-Baden, June]: Schlumberger Technical Services, Paris, 296 p.

Boyeldieu, C., Campbell, R., de Murville, E.C., and others, 1970, Well evaluation conference--Libya [Tripoli, Autumn]: Schlumberger Technical Services, Paris, 2 volumes (text, examples), variously paginated.

Campbell, R., de Murville, E.C., and James, N., editors, 1970, Well evaluation conference--Indonesia, 1st edition [Jakarta, June]: Schlumberger Technical Services, Paris, 2 volumes (text, examples), variously paginated.

de Murville, E.C., and Dadrian, C., editors, 1970, Schlumberger well evaluation conference--Indonesia [Jakarta, June]: Schlumberger Technical Services, Paris, text + examples, variously paginated.

de Murville, E.C., and Dadrian, C., editors, 1973, Well evaluation conference--Indonesia, 2nd edition: Schlumberger Technical Services, Paris, 83 p.

Felder, B., editor, 1980, Schlumberger well evaluation conference--Venezuela 1980 [Caracas, May] [in Spanish]: Schlumberger Technical Services, Paris, variously paginated.

Felder, B.A., editor, 1987, WEC--Formation evaluation in Argentina 1987 [May][in Spanish]: Schlumberger Technical Services, Paris, variously paginated.

Logar, J.F., editor, 1983, Schlumberger well evaluation conference--West Africa 1983 [Libreville, October]: Schlumberger Technical Services, Paris, variously paginated.

Marmissolle-Daguerre, D., editor, 1984, Schlumberger well evaluation conference--Mexico 1984 [Mexico City, September] [in Spanish]: Schlumberger Technical Services, Paris, variously paginated.

Misk, A., Poupon, A., and Boyeldieu, C., 1965, Well evaluation conference--North Sea [London, Fall]: Schlumberger Technical Services, Paris, 59 p.

Misk, A., Poupon, A., Baird, D.E., Lanata, J.b., and Kucharsky, R., 1967, Well evaluation conference--Middle East [Beirut, November]: Schlumberger Technical Services, Paris, 3 volumes (text, examples, computer-processed interpretation), 162 p. + examples.

Mok, J.S., editor, 1985, Schlumberger well evaluation conference--China 1985 [Beijing, September]: Schlumberger Technical Services, Paris, 359 p.

Pinnington, D.J., editor, 1981, Schlumberger well evaluation conference--United Arab Emirates/Qatar 1981 [Abu Dhabi, November]: Schlumberger Technical Services, Paris, 271 p.

Sadras, W., editor, 1973, Well evaluation conference--Agentina [Evaluacion de formaciones en la Argentina, Buenos Aires, June, in Spanish]: Schlumberger Technical Services, Paris, 215 p.

Schlumberger, 1966, Well evaluation conference--Nigeria [Lagos, October]: Schlumberger Technical Services, Paris, 2 volumes (text and examples), 62 p. + examples.

Schlumberger, 1970, Well evaluation conference--Libya 1970 [Tripoli, Autumn]: Schlumberger Technical Services, Paris, variously paginated.

Schlumberger, 1973, Well evaluation conference--Argentina 1973 [Buenos Aires, June]: Schlumberger Technical Services, Paris, 215 p.

Schlumberger, 1974, Schlumberger well evaluation conference--North Sea 1974 [London, June]: Schlumberger Technical Services, Paris, 171 p.

Schlumberger, 1974, Schlumberger well evaluation conference--Nigeria 1974, 2nd edition, [Lagos, April]: Schlumberger Technical Services, Paris, variously paginated.

Schlumberger, 1975, Schlumberger well evaluation conference--Arabia 1975 [Bahrain, May]: Schlumberger Technical Services, Paris, 152 p.

Schlumberger, 1976, Schlumberger well evaluation conference--Iran 1976 [Tehran, May]: Schlumberger Technical Services, Paris, 179 p.

Schlumberger, 1979, Schlumberger well evaluation conference--Algeria 1979 [Algiers, December]: Paris, Schlumberger Technical Services, variously paginated.

Schlumberger, 1983, Schlumberger well evaluation conference--India 1983 [New Delhi, December]: Schlumberger Technical Services, Paris, 263 p.

Schlumberger, 1985, Well evaluation conference--Nigeria 1985 [Lagos, June]: Schlumberger Technical Services, Paris, 292 p.

Schlumberger, 1987, Well evauation conference--Italy, 1987: Schlumberger Technical Services, Paris, variously paginated.

Smith, C.M., editor, 1984, Well evaluation conference--Egypt 1984 [Cairo, March]: Schlumberger Technical Services, Paris, variously paginated.

Viro, E.J., editor, 1985, Well evaluation conference--Brazil 1985 [November] [in Portugese]: Schlumberger Technical Services, Paris, variously paginated.

Williams, R.E., editor, 1986, Formation evaluation conference--Indonesia 1986 []: Schlumberger Technical Services, Paris, variously paginated.

Winchester, A., editor, 1981, Schlumberger well evaluation conference--South East Asia 1981 [Singapore, October]: Schlumberger Technical Services, Paris, 238 p.

XVI. Reprint Volumes

American Association of Petroleum Geologists, 1974, Abnormal formation pressures: American Association of Petroleum Geologists, Reprint Series No. 11, 205 p. [Contains 14 significant papers that appeared in the AAPG Bulletin.]

Beaumont, E.A., and Foster, N.H., editors, 1990, Formation evaluation I, log evaluation: AAPG Treatise of Petroleum Geology, Reprint Series, ?? p.

Beaumont, E.A., and Foster, N.H., editors, 1990, Formation Evaluation II, log interpretation: AAPG Treatise of Petroleum Geology, Reprint Series, ?? p.

Dresser Atlas, 1981, Spectralog: Dresser Industries, Houston, Publication No. 3334, variously paginated. [Reprint volume containing papers on tool applications.]

Dresser Atlas, 1981, Carbon/Oxygen log: Dresser Industries, Houston, Publication No. 9417, variously paginated. [Reprints of papers on tool operation, interpretation and application.]

Paillet, F.L., Barton, C., Luthi, S., Rambow, F., and Zemanek, J., editors, 1990, Borehole imaging: Society of Professional Well Log Analysts Reprint Volume, 472 p. Contains an overview + 32 papers.

Society of Petroleum Engineers, 1985, Production logging: Society of Petroleum Engineers, Reprint Series No. 19, 375 p. [Contains 26 significant papers on tool design and application.]

Society of Petroleum Engineers, 1986, Openhole well logging: Society of Petroleum Engineers, Reprint Series No. 21, 575 p. [Contains 39 significant papers on tool development, application and interpretation.]

Society of Professional Well Log Analysts, 1978, Gamma ray, neutron and density logging reprint volume: Society of Professional Well Log Analysts, variously paginated. [Contains 32 significant papers in these areas.]

Society of Professional Well Log Analysts, 1979, Pulsed neutron logging reprint volume: Society of Professional Well Log Analysts, 448 p. [Contains 32 significant papers on tool operation and application.]

Society of Professional Well Log Analysts, 1982, Shaly sand reprint volume: Society of Professional Well Log Analysts, variously paginated. [Contains 38 significant papers + extensive bibliography. Excellent source for studying the shaly sand problem.]

Society of Professional Well Log Analysts, Houston Chapter, 1979, The art of ancient log analysis: Society of Professional Well Log Analysts, 131 p. + reprints of 22 classic papers on interpretation of old electric (normal and lateral) logs.

Society of Professional Well Log Analysts, 1982, Geothermal log interpretation handbook: Society of Professional Well Log Analysts, Reprint Volume, variously paginated. [Contains reprints of 17 significant papers and an extensive bibliography.]

University of Tulsa, 1985, Index to well logging literature: Petrolem Abstracts, University of Tulsa, 399 p.

XVII. Bibliographies

Connolly, E.T., 1973, Comprehensive bibliography of well logging literature 1942-1972: Canadian Well Logging Society Journal, v. 6(1), p. 51-87.

Nuhfer, E.B., and Nurmi, R.D., 1976, Bibliography of references for recognition of depositional environment from wireline log data: West Virginia Geological and Economic Survey, Mineral Briefs Series, 15 p.

Prensky, S.E., 1987, Geological applications of well logs--An introductory bibliography and survey of the well logging literature through September, 1986, arranged by subject and first-author: The Log Analyst, parts A and B, v. 28(1), January-February, p. 71-107, part C, v. 28(2), March-April, p. 219-248. (Previous editions published as U.S. Geological Survey Open-File Reports 85-441, 86-170, 87-16).

Prensky, S.E., 1987, Geological applications of well logs; An introductory bibliography and survey of the well logging literature; Annual update, October 1986 through September 1987: The Log Analyst, v. 28(6), November-December, p. 558-575.

Prensky, S.E., 1988, Geological applications of well logs--Bibliography update for October 1987 through September 1988: The Log Analyst, v. 29(6), November-December, p. 426-443.

Prensky, S.E., 1989, Bibliography of well-log applications, October 1988-September 1989, annual update: The Log Analyst, v. 30(6), November-December, p. 448-470.

Taylor, T.A., and Dey, J.A., 1985, Bibliography of borehole geophysics as applied to ground-water hydrology: U.S. Geological Survey Circular No. 926, 62 p.

XVIII. Well-Log-Response Charts

Hyne, N.J., editor, 1983, Well log response chart: PennWell Publishers, Houston, 1 sheet.

Klein, G. deV., 1984, Vertical sequences and log shapes of major sandstone reservoir systems: IHRDC Press, Boston, 1 sheet.

Petrocraft Products, 1979, Logging device response chart: Petrocraft Products, Calgary, 1 sheet. Also available through Petrocraft Products Inc., Denver.

Part B: APPLICATIONS

2. GENERAL GEOLOGICAL AND GEOTECHNICAL APPLICATIONS

Alger, R.P., 1980, Geological use of wireline logs, in G.D. Hobson, editor, Developments in petroleum geology no. 2: Applied Science Publishers Ltd., London, p. 207-272.

Allsop, J.M., Ambrose, K., and Elson, R.J., 1987, New data on the stratigraphy and geophysics in the area around Hoolwell, Northamtonshire, provided by a coal exploration borehole: Proceedings of the Geologist's Association [London], v. 98, part 2, p. 157-170.

Anderson, R.A., 1972, Fracture pressure gradient determination from well logs, SPE-4135: Society of Petroleum Engineers, 47th annual meeting [San Antonio] preprint, 15 p.

Anderson, R.N., Alt, J.C., and Malpas, J., 1989, Geochemical well logs and the determination of integrated chemical fluxes in hole 504B, eastern equatorial Pacific, section 11, in Mazzullo, E.K., editor, Proceedings of the Ocean Drilling Program, v. 111, Scientific results: Texas A & M University, Ocean Drilling Program, p. 119-132.

Anderson, R.N., Dove, R.E., Broglia, C., Silver, L.T., James, E.W., and Chappell, B.W., 1988, Elemental and mineralogical analyses using geochemical logs from Cajon Pass scientific drillhole, California, and their preliminary comparison with core analyses: Geophysical Research Letters, v. 15(9, supplement), p. 969-972.

Anderson, R.N., Jarrard, R., Pezard, P., Williams, C., and Dove, R., 1988, Logging for science: The Technical Review, v. 36(4), October, p. 4-11.

Anderson, R.N., Zoback, M.D., Hickman, S.H., and Newmark, R.L., 1985, Permeability versus depth in the upper oceanic crust--In situ measurements in Deep Sea Drilling Project hole 504B, eastern equatorial Pacific, in Initial reports of the the Deep Sea Drilling Project, v. 83: U.S. Government Printing Office, p. 429-442. Also published in 1985, Journal of Geophysical Research, v. 90(B5), p. 3659-3669.

Baker, M.R., 1988, Quantitative interpretation of geological and geophysical well data: University of Texas, El Paso, Department of Geological Sciences, Ph.D. dissertation, 144 p.

Balch, S.J., Morris, W.A., Blohm, D., and Thuma, B., 1988, Interpretation of borehole magnetic data for mineral exploration and lithological mapping, paper O, in 2nd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applications [Golden, Colorado, October 6-8, 1987], proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society Chapter-at-Large, p. 179-185.

Baldwin, A.D., Jr., and Miller, J., 1979, The use of a gamma logger to delineate glacial and bedrock stratigraphy in southwestern Ohio: Ground Water, v. 17(4), p. 385-389.

Beaudoin, B., Pinoteau, B., and Delhomme, J.P., 1983, Geological analysis of logs and dipmeter data for well-to-well correlation, paper BBB, in 24th annual logging symposium transactions: Society of Professional Well Log Analysts, 18 p. Deep-sea fan example.

Beck, A.E., and Balling, N., 1988, Determination of virgin rock temperatures, in R. Haenel, L. Rybach, and L. Stegna, editors, Handbook of terrestrial heat-flow density determination: Kluwer Academic Publishers, Dordrecht, Netherlands, p. 59-85.

Becker, K., Von Herzen, R.P., Francis, T.J.G., Anderson, R.N., Honnorez, J., Adamson, A.C., Alt, J.C., Emmermann, R., Kempton, P.D., Kinoshita, H., Laverne, C., Mottl, N.J., and Newmark, R.L., 1982, In situ electrical resistivity and bulk porosity of the oceanic crust Costa Rica rift: Nature, v. 300, December 16, p. 594-599.

Belorai, Y.L., Aimetov, C.R., Beranovskaya, A.V., and Neretin, V.D., 1988, Investigation of carbonate rocks of southern Turkmenia by the method of nuclear magnetic resonance: Moscow Univeristy Geology Bulletin, v. 43(6), p. 86-90.

Berendsen, P., Borcherding, R.M., Doveton, J., Gerhard, L., Newell, K.D., Steeples, and Watney, W.L., 1988, Log analysis of the Precambrian rocks, section IV-B, in Texaco Poersch No. 1, Washington County, Kansas; preliminary geologic report of the pre-Phanerozoic rocks: Kansas Geological Survey Open-file Report 88-22, p. 30-43.

Bleuer, N.K., 1989, Field trip No. 2, glacial terrain models in north-central Indiana, vertical sequences derived from downhole geophysics, linked to landscapes and near-surface stratigraphy; the nature of current work in downhole geophysics, in Field guidebook for the 23rd annual meeting of the north-central section of the Geological Society of America: University of Notre Dame; Notre Dame, Indiana, p. 73-93.

Bornemann E., and Doveton, J.H., 1983, Lithofacies mapping of Viola Limestone in south central Kansas based on wireline logs: AAPG Bulletin, v. 67(4), p. 609-623.

Boyeldieu, C., and Draxler, J., 1987, Deep-well formation logging; the problems, the logging tools, in H.J. Beher, editor, Observation of the continental crust through drilling [International symposium Seeheim, West Germany (October 3-6, 1983), proceedings]: Springer-Verlag, New York, p. 207-223.

Broglia, C., Schreiber, B.C., Cita, M.B., Chamley, H., and Dove, R., 1989, Mineralogical study of Upper Miocene sediments from wireline logs and core measurements, site 652, Ocea Drilling Program Leg 107 (Tyrrhenian Sea), chapter 15, in Stewart, N.J., editor, Proceedings of the Ocean Drilling Program, volume 107, scientific results: Texas A&M University Ocean Drilling Program, p. 229-243.

Brown, C.E., 1988, Determination of rock properties by borehole-geophysical and physical-testing techniques and ground-water quality and movement in the Durham Triassic basin, North Carolina: U.S. Geological Survey Professional Paper 1432, 29 p.

Brown, R.L., Cook, R.N., Lynn, D., 1989, How useful is Poisson's ratio for finding oil/gas?: World Oil, v. 209(4), October, p. 99-106.

Burns, C.S., 1986, Relating Gulf Coast sand/shale statistics to petrophysical properties as seen by seismic, SPE-15527: Society of Petroleum Engineers, 61st annual meeting [New Orleans] preprint, 8 p.

Burns, D.R., Thompson, D.R., and Cheng, C.H., 1990, Lithologic cycles and paleo fluid flow channels in old oceanic crust from geophysical logs at ODP site 418A, in Cheng, C.H., editor, Full waveform acoustic logging consortium, annual report: Massachusetts Institute of Technology, Earth Resources Laboratory, p. 273-288.

Busch, J.M., Fortney, W.G., and Berry, L.N., 1985, Determination of lithology from well logs by statistical analysis, SPE-14301: Society of Petroleum Engineers, 60th annual meeting preprint, 11 p. Later published in 1987, SPE Formation Evaluation, v. 2(4), p. 412-418.

Cann, J.R., and Von Herzen, R.P., 1983, Downhole logging at Deep Sea Drilling Project sites 501, 504, and 505, near the Costa Rica rift, in L.N. Stout and M.G. Bailey, editors, Initial reports of the Deep Sea Drilling Project, v. 69: U.S. Government Printing Office, p. 281-299.

Carlson, R.L., Snow, K.R., and Wilkens, R.H., 1988, Density of old oceanic crust; an estimate derived from downhole logging on ODP leg 102, in Proceedings of the Ocean Drilling Program, scientific results, v. 102: Texas A&M University, Ocean Drilling Program, p. 63-68.

Carlson, R.L., Wilkens, R.H., Moos, D., and Broglia, C., 1988, Correlations of sediment lithostratigraphy, downhole logs, and seismic reflectors at site 418, in Proceedings of the Ocean Drilling Program, scientific results, v. 102: Texas A&M University, Ocean Drilling Program, p. 19-26.

Carvalho, M., and Venavente, V., 1979, Application of electrical and gamma ray logging to geotechnical prospection--An example, in International symposium on the geotechnics of structurally complex formations [Capri, September 1977], supplement 1: Associazione Geotecnica Italiana, Milan, Italy, unpaginated.

Chapman, S., Colson, J.L., Flaum, C., et al., 1987, The emergence of geochemical well logging: The Technical Review, v. 35(2), p. 27-35.

Chermeninov, V.B., 1988, Mapping of hydrothermally altered rocks according to borehole sections: Soviet Geology and Geophysics, v. 29(5), p. 101-111.

Chmelik, F.B., Bouma, A.H., and Rezak, R., 1969, Comparison of electrical logs and physical parameters of marine sediment cores: Transactions of the Gulf Coast Association of Geological Societies, v. 19, p. 63-70.

Coleman, J.M., Constans, R., and Bouma, A.H., 1986, Gamma-ray well-log characteristics, Leg 96, in Initial reports of the Deep Sea Drilling Project, volume 96: U.S. Government Printing Office, p. 547-561.

Collins, D.R., and Doveton, J.H., 1988, Colour image transformations of wireline logs as a medium for sedimentary profile analysis: Bulletin of Canadian Petroleum Geology, v. 36(2), June, p. 186-190.

Collins, D.R., and Doveton, J.H., 1988, Application of color information theory to the display of lithologic images from wireline logs, paper II, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 15 p. Later published in 1989, Geobyte, v. 4(1), February, p. 16-24.

Collins, J.L., 1989, Log response as a model for production--deep Wilcox sandstones, Provident City field, Lavaca County, Texas: Transactions Gulf Coast Association of Geological Societies, v. 29, p. 27-36.

Colson, J.L., Grau, J.A., Herron, M.M., Herron, S.L., Schweitzer, J.S., Hertzog, R.C., Preeg, W.E., Nurmi, R.D., and Johnston, J., 1989, Applications using geochemical logs, SPE-17963, in SPE Middle East oil technical conference and exhibition [Manama, Bahrain], proceedings: Society of Petroleum Engineers, p. 365-372.

Conticini, F., De Scalzi, C., Mazzei, R., and Salvador, L., 1987, Seismic prospecting combined with core and log analysis to define the internal structure of a reservoir, in 12th world petroleum congress proceedings, v. 3, production: John Wiley & Sons, New York, p. 219-230.

Cowan, D.R., and Myers, K.J., 1988, Surface gamma ray logs; a correlation tool for frontier areas--Discussion: AAPG Bulletin, v. 72(5), p. 634-636.

Cratchley, C.R., 1978, Geophysical measurements in rock mechanics investigations, in Sciences de la terre et measures [Orleans, France, May 5-6, 1977]: Bureau Recherches Geologiques et Minieres, Paris, Memoir 91, p. 446-456.

Crosby, J.W., III, Konstantinidis, B., and Davis, P., 1981, Geotechnical applications of borehole physics: Journal of the Geotechnical Engineering Division, American Society of Civil Engineers, v. 107(GT10), p. 1255-1267.

Crowder, R.E., Brouillard, L, and Irons, L., 1988, Utilizing a borehole geophysical logging program in poorly consolidated sediments for a hazardous waste investigation, paper H, in 2nd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applications [Golden, Colorado, October 6-8, 1987], proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society Chapter-at-Large, p. 65-97.

Crowder, R.E., Yearsley, E.N., and Irons, L.A., 1989, Monitor well completion evaluation with borehole geophysical density logging, paper B, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 3-13.

Daly, L., and Tabbagh, A., 1988, Towards the in situ measurement of the remnant magnetization of oceanic basalts: The Geophysical Journal of the Royal Astronomical Society, v. 95(3), p. 481-489.

Dobecki, T.L., and Romig, P.R., 1985, Geotechnical and groundwater geophysics: Geophysics, v. 50(12), p. 2621-2636.

Douglas, A.C., and Millett, M.R., 1978, Total intensity magnetometer logging as a stratigraphic tool in Tertiary volcanic rock: Lawrence Livermore Laboratory Report No. UCRL-52617, 11 p.

Doveton, J.H., 1986, Log analysis of subsurface geology--Concepts and computer methods: John Wiley & Sons, New York, 273 p.

Doveton, J., 1989, Subsurface lithofacies mapping from geophysical logs in Kansas, in Steeples, D.W., editor, Geophysics in Kansas: Kansas State Geological Survey Bulletin No. 226, p. 177-184.

Doveton, J.H., Ke-An, Z., and Davis, J.C., 1984, Three-dimensional trend mapping using gamma-ray well logs--Simpson Group, south-central Kansas: AAPG Bulletin, v. 68(6), p. 690-703.

Dusseault, M.B., 1987, Determination of geomechanical parameters from geophysical logs, in R.F. Myer, editor, Exploration for heavy crude oil and natural bitumen [AAPG/UNITAR research conference (Santa Maria, California, October 29-November 2, 1984), proceedings]: AAPG Studies in Geology No. 25, p. 415-421.

Dusseault, M.B., and Scott, J.D., 1987, Coring and sampling in heavy-oil exploration; difficulties and proposed cures, in R.F. Myer, editor, Exploration for heavy crude oil and natural bitumen [AAPG/UNITAR research conference (Santa Maria, California, October 29-November 2, 1984), proceedings]: AAPG Studies in Geology No. 25, p. 437-442.

Dutta, N.C., 1986, Shale compaction, burial diagenesis, and geopressures; a dynamic model, solution and some results, in J. Burrus, editor, Thermal modeling in sedimentary basins [1st IPF exploration research conference (Carcans, France, June 3-7, 1985) proceedings]: Editions Technip, Paris, Collection Colloques et Seminaires No. 44, p. 149-172.

Dyck, J.H., 1973, Some applications of borehole logging to Quaternary research--A study in southern Saskatchewan: Geoexploration, v. 11(4), p. 233-247.

Edwards, D.P., 1983, Zones of sand production identified by log-derived mechanical properties--A case study, paper S, in 8th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, London Chapter, 23 p.

Edwards, D., Joranson, H., and Spurlin, J., 1988, Field normalization of formation mechanical properties for use in sand control management, paper Y, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 24 p.

El-Sheikh, T.S., and Syiam, M.M., 1989, An efficient technique for lithology classification: IEEE Transactions on Geoscience and Remote Sensing, v. 27(5), September, p. 629-632

Elkington, P.A.S., Stouthamer, P., and Brown, J.R., 1982, Rock strength predictions from wireline logs: International Journal of Rock Mechanical Mineral Science and Geomechanical Abstracts, v. 19, p. 91-97. Reprinted in 1986, in Buchanan, D.J., and Jackson, L.J., editors, Coal geophysics: Tulsa, Society of Exloration Geophysicists, Geophysics reprint series no. 6, p. 45-51.

Elphick, R.Y., 1988, Formation mechanical properties and the sonic log: Geobyte, v. 3(4), November, p. 24-26.

Entwisle, D.C., and McCann, D.M., 1990, An assessment of the use of Christensen's equation for the prediction of shear wave velocity and engineering parameters, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 347-354.

Ervine, W.B., and Bell, J.S., 1987, Subsurface in situ stress magnitudes from oil-well drilling records--An example from the Venture area, offshore eastern Canada: Canadian Journal of Earth Sciences, v. 24(9), p. 1748-1759.

Esmilla, A.B., Phipps, M.B., and Slosson, J.E., 1987, Application of oil well technology and continuous coring to landslide investigations, in P.J. Fischer, editor, Geology of the Palos Verdes peninsula and San Pedro Bay: Pacific Section of SEPM and AAPG, Los Angeles, guidebook, p. 2-7 - 2-12.

Fons, L., 1969, Geological applications of well logs, paper AA, in 10th annual logging symposium transactions: Society of Professional Well Log Analysts, 44 p.

Foote, R.S., 1987, Correlations of borehole rock magnetic properties with oil and gas producing areas: Bulletin Association of Petroleum Geochemical Explorationists, v. 3(1), December, p. 114-134.

Gandl, L.A., and Flaniken, J.A., 1986, The use of limited geophysical log data to delineate and characterize disposal and confining zones, in NWWA FOCUS conference on Southeastern ground water issues [Tampa, October 6-8], proceedings: National Water Well Association, Dublin, Ohio, p. 304-311.

Gera, D.F., 1983, The use of gamma-gamma logging for detecting quartz veins in borehole sections [translated from the 1974 Russian paper]: Geological Survey of Canada Translations, No. 798658, 8 p.

Goldberg, D., Moos, D., and Anderson, R.N., 1985, Attenuation changes due to diagenesis in marine sediments paper KK, in 26th annual well logging symposium transactions: Society of Professional Well Log Analysts, 18 p.

Gorshkov, Y.M., Kochetkov, P.F., and Nikoleva, T.M., 1986, Experience of geological-engineering investigations of andesite-basaltic lavas of Armenia by seismoacoustic and radiation logging methods, in 5th international congress, International Association of Engineering Geologists [Buenos Aires, October 20-25], proceedings v. 1: A.A. Balkema, Boston, p. 365-369.

Greenhouse, J.P., and Pehme, P., 1986, Stratigraphy and physical properties of unconsolidated glacial deposits useing borehole geophysics, in P. Kileen, editor, Borehole geophysics for mining and geotechnical applications [International symposium and workshop, (Toronto, August 29-31, 1983), proceedings]: Geological Survey of Canada Paper 85-27, p. 7-12.

Griffiths, C.M., 1989, An example of the use of a fuzzy-set based pattern recognition approach to the problem of strata recognition from drilling response, in Oleynikov, A., and Rubel, M., editors, Quantitative stratigraphy--restrospective evaluation and future development [IGCP Project No. 148]: Academy of Sciences, Estonian Socialist Republic, Tallinn, p. 83-100.

Grimnes, J.P., 1988, Brage--The "invisible" reservoir, paper C, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 17 p.

Halker, A., Kuznir, N.J., Mellor, D.W., and Whitworth, K.R., 1982, The synthesis of fracture/strength logs using borehole geophysics--A new geotechnical service: The Quarterly Journal of Engineering Geology [London], v. 15, p. 15-28. Reprinted in 1986, in Buchanan, D.J., and Jackson, L.J., editors, Coal geophysics: Tulsa, Society of Exloration Geophysicists, Geophysics reprint series no. 6, p. 52-64.

Hamano, Y., and Kinoshita, H., 1990, Magnetization of the oceanic crust inferred from magnetic logging in hole 395A, chapter 18, in Stewart, N.J., editor, Proceedings of the Ocean Drilling Program, volume 106/109, scientific results: Texas A&M University, Ocean Drilling Program, p. 223-229.

Hamano, Y., and Ohno, M., 1990, Remnant magnetization of cement cores from hole 648B; a possible logging tool for the downhole measurments of magnetic field, chapter 24, in Stewart, N.J., editor, Proceedings of the Ocean Drilling Program, volume 106/109, scientific results: Texas A&M University, Ocean Drilling Program, p. 275-281.

Hawkins, J.M., Snyder, R.W., and Pahwa, S.B., 1977, How well logs were used to improve evaluation of a gas storage project, SPE-6429: Society of Petroleum Engineers, 52nd annual meeting [Denver] preprint. Later published in 1977, Journal of Petroleum Technology, v. 29(12), p. 1550-1558.

Hearst, J.R., 1987, Investigation of subsurface structure with borehole gravimetry: Transactions of the Society of Mining Engineers of AIME, v. 282, p. 1,817-1,824.

Hearst, J.R., Conaway, J.G., Mathews, M.A., and Barber, J.W., 1989, In-situ equivalent CO_2 estimates using a neutron-induced gamma-ray spectroscopy logging system, paper BB, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 501-538.

Herron, M.M., 1986, Mineralogy from geochemical well logging: Clays and Clay Minerals, v. 34(2), p. 204-213.

Herron, M.M., 1987, Future applications of elemental concentrations from geophysical logging: Nuclear Physics, v. 1(3), p. 197-211.

Herron, M.M., 1988, Geochemical classification of terrigenous sands and shales from core or log data: Journal of Sedimentary Petrology, v. 58(5), September, p. 820-829.

Herron, M.M., and Herron, S.L., 1990, Geological applications of geochemical well logging, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 165-175.

Hess, J.W., Wheatcraft, S.W., Spencer, D.D., and Adams, W.M., 1984, Evaluation of the applicability of some existing borehole instruments to hazardous waste site characterization and monitoring, in D.M. Nielsen and M. Curl, editors, 1984 NWWA/EPA conference on surface and borehole geophysics methods in ground water investigations, proceedings: National Water Well Association, Worthington, Ohio, p. 762-787.

Hilchie, D.W., 1984, Reservoir description using well logs: Journal of Petroleum Technology, v. 36(7), p. 1067-1073. A discussion and reply published in 1984, Journal of Petroleum Technology, v. 36(12), p. 2195-2196. Reprinted in 1988, in 1988 California regional meeting proceedings: Society of Petroleum Engineers, p. 35-41.

Hinrichs, D.R., 1986, Utilization of geophysical logs in the evaluation of subsurface conditions from mine subsidence studies, in J.L. Hynes, editor, 1985 conference on coal mine subsidence in the Rocky Mountain region: Colorado Geological Survey Report No. 31, p. 121-131.

Holmes, M.A., 1988, Evidence for continuous and discontinuous alteration in DSDP hole 418A basalts and its significance to to natural gamma-ray log readings, in Proceedings of the Ocean Drilling Program, scientific results, v. 102 : Texas A&M University, Ocean Drilling Program, p. 135-151.

Holt, R.M., and Fjaer, E., 1987, Acoustic behavior of sedimentary rocks during failure, chapter 23, in J. Kleppe, E.W. Berg, A.T. Buller, O. Hjelmeland, and O. Torsaeter, editors, North Sea oil and gas reservoirs: Graham & Totman Ltd., London, p. 311-316.

Holt, R.M., Fjaer, E., and Raaen, A.M., 1988, New elements of sand failure prediction, paper BB, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 18 p.

Holt, R.M., Ingsoy, P., and Mikkelsen, M., 1987, Rock mechanical analysis of North Sea reservoir formations, SPE-16796, in 1987 SPE annual meeting and technical exhibition proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 483-490. Later published in 1989, SPE Formation Evaluation, v. 4(1), p. 33-37.

Horseman, S.T., McCann, D.M., McEwen, T.J., Brightman, M.A., 1984, Determination of the geotechnical properties of mudrocks from geophysical logging of the Harwell boreholes: British Geological Survey, Fluid Processes Research Group Report No. FLPU 84-14, 33 p.

Howsam, P., Brassington, F.C., and Lucey, P.A., 1989, The examination of encrustations in an unlined borehole using the sidewall sampling technique: Quarterly Journal of Engineering Geology, v. 22(2), p. 139-144.

Hsiang-Huan, L., 1987, Porosity and hydrothermal alteration determined from wireline logs from the Salton Sea: University of California Riverside, unpublished MS thesis, 168 p.

Hurst, A., Lovell, M.A., and Morton, A.C., editors, 1990, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, 357 p.

Ierubino, J.V., and Ginest, N.H., 1989, Use of pulsed neutron logging techniques to prove protection of underground sources of drinking water, SPE-19616, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 459-464.

Irons, L.A., 1989, Using a borehole geophysical logging program in poorly consolidated sediments for a hazardous waste investigation: The Leading Edge, v. 8(1), January, p. 24-32.

Jarrard, R.D., and Arthur, M.A., 1989, Milankovich paleoceanographic cycles in geophysical logs, Leg 105, Labrador Sea and Baffin Bay, section 38, in Stewart, S.K., editor, Proceedings of the Ocean Drilling Program, v. 105, Scientific results: Texas A & M University, Ocean Drilling Program, p. 757-772.

Jarrard, R.D., Dadey, K.A., and Busch, W.H., 1989, Velocity and density of sediments of Eirik Ridge, Labrador Sea; control by porosity and mineralogy, section 43, in Stewart, S.K., editor, Proceedings of the Ocean Drilling Program, v. 105, scientific results, Baffin Bay and Labrador Sea: Texas A&M University, Ocean Drilling Program, p. 811-835.

Johnson, R.B., and Johnson, L.A., 1978, Investigation of a damsite utilizing drill-hole, down-hole geophysical and surface geophysical data: Association of Engineering Geologists Bulletin, v. 15(3), p. 285-294.

Kennedy, W.J., 1985, Sedimentology versus log response in central graben shales, in North Sea chalk symposium proceedings: Norwegian Petroleum Society, Stavanger, v.1, 14 p.

Killeen, P.G., editor, 1986, Borehole geophysics for mining and geotechnical applications [International symposium and workshop, (Toronto, Ontario, August 29-31, 1983), proceedings]: Geological Survey of Canada Paper 85-27, 400 p.

King, D.E., 1990, Incorporationg geological data in well log interpretation, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 45-55.

Kinoshita, H., Furuta, T., and Pariso, J., 1989, Downhole magnetic field measurements and paleomagnetism, hole 504B, Costa Rica ridge, chapter 13, in Mazzullo, E.K., editor, Proceedings of the Ocean Drilling Program, volume 111, scientific results: Texas A&M University Ocean Drilling Program, p. 147-156.

Kissenpfennig, J.F., Motherwell, J.T., and LaFountain, L.J., 1984, Integrity testing of bored piles using sonic logging: Journal of Geotechnical Engineering, v. 110(8), August, p. 1079-1090. Discussion by K.K. Shen and V.A. Sowa published in 1987, v. 113(3), p. 267-268.

Kowalski, J.J., 1975, Formation strength parameters from well logs, paper N, in 16th annual logging symposium transactions: Society of Professional Well Log Analysts, 19 p. Reprinted 1978, paper Z, in Acoustic logging reprint volume: Society of Professional Well Log Analysts, 19 p.

Krammer, K., 1990, Magnetic susceptiblity log measured in hole 395A, Leg 109, chapter 19, in Stewart, N.J., editor, Proceedings of the Ocean Drilling Program, volume 106/109, scientific results: Texas A&M University, Ocean Drilling Program, p. 231-235.

Lang, W.H., Jr., 1978, Determination of prior depth of burial using interval transit time, paper B, in 19th annual logging symposium transactions: Society of Professional Well Log Analysts. Later published in 1980, Oil and Gas Journal, v. 78(4), January 28, p. 222-232.

Lapointe, P., Morris, W.A., and Harding, K.L., 1986, Interpretation of magnetic susceptibility--A new approach to geophysical evaluation of the degree of rock alteration: Canadian Journal of Earth Sciences, v. 23(3), p. 393-401.

Leckie, D.A., Singh, C., Goodarzi, F., and Wall, J.H., 1990, Organic-rich, radioactive marine shale; a case study of a shallow-water condensed section, Cretaceous Shaftesbury Formation, Alberta, Canada: Journal of Sedimentary Petrology, v. 60(1), p. 101-117.

Lew, M., and Campbell, K.W., 1985, Relations between shear wave velocity and depth of overburden, in R.D. Woods, editor, Measurement of use of shear wave velocity for evaluating dynamic soil properties [Proceedings of a ASCE convention session (Denver, May 1, 1985)]: American Society of Civil Engineers, New York, p. 63-76.

Lowe, D.J., 1989, Log evaluation required for permitting of a Class I hazardous waste injection well; a case history, paper P, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 261-267.

Luthi, S.M., 1990, Sedimentary structures of clastic rocks identified from electrical borehole images, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 3-10.

Magara, K., 1976, Thickness of removed sedimentary rocks, paleopore pressure, and paleotemperature, southwestern part of western Canada basin: AAPG Bulletin, v. 60(4), p. 554-565. Valuable uses of sonic log data.

Magara, K., 1978, Compaction and fluid migration--Practical petroleum geology: Elsevier Scientific Publishing Company, New York, Developments in Petroleum Science, No. 9, 319 p.

Magara, K., 1979, Formation water salinity and its exploration application, paper S, in 7th formation evaluation symposium transactions: Canadian Well Logging Society, 8 p.

Magara, K., 1986, Porosity-depth relationship during compaction in hydrostatic and non-hydrostatic cases, in J. Burrus, editor, Thermal modeling in sedimentary basins [1st IPF exploration research conference (Carcans, France, June 3-7, 1985) proceedings]: Editions Technip Collection Colloques et Seminaires No. 44, Paris, p. 129-147.

Magara, K., 1986, Geological models of petroleum entrapment: Elsevier Applied Science Publishers, London, 328 p.

Major, R.P., and Holtz, M.H., 1989, Effects of geologic heterogeneity on waterflood efficiency at Jordan field, University Lands, Ector and Crane Counties, Texas, SPE-19874, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 633-640.

Martin, G.C., 1988, Well log interpretation and lithostratigraphy, chapter 6, in Turner, R., editor, Geological and operational summary, north Aleutian shelf COST No. 1 well, Bering Sea, Alaska: U.S. Minerals Management Service OCS Report No. 88-0089, p. 117-158.

Martinez, R.D., Cornish, B.E., and Seymour, R.H., 1989, An integrated approach for reservoir description using seismic, borehole, and geologic data, SPE-19581,in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 99-108.

Mathew, P.J., and Anderson, M.R., 1986, A gamma-gamma method for measuring the diameters of air-filled holes, in P.G. Killeen, editor, Borehole geophysics for mining and geotechnical applications [international symposium and workshop, (Toronto, Ontario, August 29-31, 1983), proceedings]: Geological Survey of Canada Paper 85-27, p. 260-276.

Maxant, J., 1975, Distribution and regional variation of density in the western Canada basin: Geophysics, v. 40(1), p. 56-78.

Maxant, J., 1980, Variation of density with rock type, depth, and formation in Western Canada basin from density logs: Geophysics, v. 45(6), p. 1061-1076.

McCann, D.M., and McCann, C., 1976, The application of borehole acoustic logging techniques in engineering geology, paper N, in 4th european formation evaluation symposium transactions: Society of Professional Well Log Analysts, London Chapter, 22 p. Later published in 1977, The Log Analyst, v. 18(3), May-June, p. 30-37.

McGlew, P.J., and Elliot, J., Jr., 1986, Methods of conducting contamination investigations in fractured bedrock aquifers, in Exploration and investigation for ground water contamination [HazPro '86 symposium (Baltimore, April 1-4), proceedings: Association of Engineering Geologists, Symposium Series No. 2, p. 15-22.

Mendelson, J., 1989, Inversion of geophysical logs to determine lithology, in Cheng, C.H., editor, Full waveform acoustic logging consortium, annual report: Massachusetts Institute of Technology, Earth Resources Laboratory, p. 172-188.

Menghini, M.L., 1988, Compaction monitoring in the Ekofisk area chalk fields, OTC-5620, in 20th annual offshore technology conference proceedings, v. 1: Society of Petroleum Engineers, p. 31-38. Later published in 1989, Journal of Petroleum Technology, v. 41(7), p. 735-739.

Mikkelsen, M., and Indehaug, O.H., 1988, Sand strength evaluation from logs and cores, paper AA, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 16 p.

Miller, C.H., and Odum, J.K., 1986, A review of concepts and techniques for obtaining shear-wave velocities from measured Rayleigh- and compressional-wave velocities at engineering sites: Bulletin of the Association of Engineering Geologists, v. 23(3), p. 317-324.

Mitchell-Tapping, H.J., 1988, Exploration petrophysics of the "serpentine" plugs of Texas: The Log Analyst, v. 29, No. 3, May-June, p. 196-203.

Montgomery, R.J., Taylor, R.W., Koch, H.A., 1985, Use of downhole geophysical methods in determining the internal structure of a large landfill, in 1985 NWWA conference on surface and borehole geophysical methods in ground water investigations [Fort Worth, Texas, February 12-14], proceedings: National Water Well Association, Worthington, Ohio, p. 377-386.

Moos, D., 1990, Petrophysical results from logging in DSDP hole 109A, OPD Leg 109, chapter 20, in Stewart, N.J., editor, Proceedings of the Ocean Drilling Program, volume 106/109, scientific results: Texas A&M University, Ocean Drilling Program, p. 237-253.

Moos, D., Anderson, R.N., Broglia, C., Goldberg, D., and Williams, C.F., 1985, The Ocean Drilling Program V--Logging for the Ocean Drilling Program-results from the first two legs, in Ocean engineering and the environment conference, Oceans '85 [San Diego, November 12-14, 1985], proceedings, v. 1: IEEE, p. 160-169.

Morin, R.H., 1985, Physical properties of calcareous sediments from the southwest Pacfic, chapter 31, in J.P. Kennett and C.C. von der Borch, editors, Initial reports of the Deeep Sea Drilling project, volume 90: U.S. Government Printing Office, p. 1239-1246.

Mwenifumbo, C.J., Thorleifson, L.H., Killeen, P.G., and Elliott, B., 1989, Preliminary results on the use of borehole geophysics in overburden stratigraphic mapping near Geraldton, northern Ontario, in Current research, part C: Geological Surevey of Canada Paper 89-1C, p. 305-311.

Norris, S.E., 1972, The use of gamma logs in determining the character of unconsolidated sediments and well construction features: Ground Water, v. 10(6), p. 14-21.

Nurmi, R., Charara, M., Waterhouse, M., and Park, R., 1990, Heterogeneities in carbonate reservoirs; detection and analysis using borehole electrical imagery, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 95-111.

Ohya, S., 1986, In situ P and S wave velocity measurement, in S.P. Clemence, editor, Use of in situ tests in geotechnical engineering [In situ '86 conference (Blacksberg, Virginia, June 23-25), proceedings]: American Society of Civil Engineers, Geotechnical Special Publication, No. 6, p. 1218-1235.

Onyia, E.C., 1988, Relationships between formation strength, drilling strength, and electric log properties, SPE-18166, in 1988 SPE annual technical conference and exhibition proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 605-618.

Oyeneyin, M.B., 1987, Formation sand size prediction from well-log correlations, SPE-16345: Society of Petroleum Engineers, unsolicited paper, 18 p.

Paillet, F.L., 1985, Applications of borehole-acoustic methods in rock mechanics, in E. Ashworth, editor, Research and engineering applications in rock masses [26th U.S. symposium on rock mechanics, South Dakota School of Mines and Technology, Rapid City, 26-28 June, proceedings]: A.A. Balkema, Boston, p. 207-220.

Pariso, J.E., and Johnson, H.P., 1989, Magnetic properties of an analog of the lower oceanic crust; magnetic logging and paleomagnetic measurements from drill hole CY-4 in the Troodos ophiolite, in Gibson, I.L., Malpas, J., Robinson, P.T., and Xenophontos, C. eds., Cyprus crustal study project; initial report, hole CY-4: Geological Survey of Canada Paper 88-9, p. 279-292.

Penn, I.E., 1987, Geophysical logs in the stratigraphy of Wales and adjacent offhsore and onshore areas: Proceedings of the Geologist's Association [London], v. 98, part 4, p. 275-314.

Penn, I.E., Cox, B.M., and Gallois, R.W., 1986, Towards precision in stratigraphy--Geophysical log correlation of Upper Jurassic (including Callovian) strata of the eastern England shelf: Journal of the Geological Society [London], v. 143, p. 381-410.

Pennebaker, E.S., 1968, An engineering interpretation of seismic data, SPE-2165: Society of Petroleum Engineers, 43rd annual meeting [Houston] preprint, 12 p. Also published, in part, 1968, World Oil, v. 166(7), June, p. 73-77. [Important uses and interpretations of sonic log data.]

Pezard, P.A., and Anderson, R.N., 1989, Morphology and alteration of the upper oceanic crust from in-situ electrical experiments in DSDP/ODP hole 504B, section 12, in Mazzullo, E.K., editor, Proceedings of the Ocean Drilling Program, v. 111, Scientific results: Texas A & M University, Ocean Drilling Program, p. 133-146.

Pirson, S.J., 1983, Geostatic equilibrium, chapter 9, in Geologic well log analysis, 3rd edition: Gulf Publishing Co., Houston, p. 259-290.

Pirson, S.J., 1983, Hydrodynamics of infiltration, chapter 10, in Geologic well log analysis, 3rd edition: Gulf Publishing Company, Houston, p. 291-332.

Pirson, S.J., 1983, SP and Eh curves as redoxomorphic logs, chapter 1, in Geologic well log analysis, 3rd edition: Gulf Publishing Company, Houston, p. 1-43.

Plint, A.G., Walker, R.G., and Bergman, K.M., 1986, Cardium Formation, part 6--Stratigraphic framework of the Cardium in subsurface: Bulletin of Canadian Petroleum Geology, v. 34(2), June, p. 213-225.

Poncetta, J.H., Torres, A.G., and MacPherson, J.D., 1989, Basin prospecting using porosity and permeability from surface outcrop samples, paper T, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 10 p.

Possi, J.P., Martin, J.P., Pocachard, J., Feinberg, H., and Galdeano, A., 1988, In-situ magnetostratigraphy; interpretation of magnetic logging in sediments: Earth and Planetary Science Letters, v. 88(3-4), p. 357-373.

Prensky, S.E., 1986, Geologic implications of large-scale trends in well-log response, northern Green River basin, Wyoming, paper EEE, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 24 p.

Prensky, S.E., 1989, Gamma-ray well-log anomaly in the northern Green River of Wyoming, chapter H, in Law, B.E., and Spencer, C.W., eds., Geology of tight gas reservoirs in the Pinedale anticline area, Wyoming, and at the Multiwell Experiment site, Colorado: U.S. Geological Survey Bulletin 1886, p. H1-H21.

Priisholm, S., and Michelsen, O., 1979, The use of porosity logs in lithology determination, lithostratigraphy and basin analysis, in D.Gill and D.F. Merriam, editors, Geomathematical and petrophysical studies in sedimentology: Pergamon Press, Oxford, Computers in Geology Series, p. 71-79.

Ramirez, A.L., Lytle, R.J., and Harben, P., 1984, Crosshole geophysical methods used to investigate the near vicinity of high level waste repositories: Lawrence Livermore National Laboratory Report NUREG/CR-3758 [UCID-20060], 65 p.

Reeves, F.M., 1989, Borehole geophysical logging techniques for geotechnical investigations; a trans-Atlantic review, paper R, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 271-306.

Reyment, R., 1982, Correlating between electrical borehole logs in paleocology, in J.M. Cubitt and R.A. Reyment, editors, Quantitative stratigraphic correlation: John Wiley, New York, p. 233-240.

Reyment, R., and Sturesson, U., 1987, Correlation of chemical and physical environmental fluctuations in a Late Cretaceous borehole sequence--A multivariate study: Sedimentary Geology, v. 53, p. 311-325.

Rider, M.H., 1986, The geological interpretation of well logs: John Wiley & Sons, Inc., New York, 175 p.

Rissler-Akesson, G., 1988, Early results of the electric wireline logging in the Gravberg-1 well, in A. Boden, and K.G. Eriksson, editors, Deep drilling in bedrock, volume 1, The deep gas drilling in the Siljan impact structure, Sweden and astroblemes: Springer-Verlag, New York, 105-112.

Robertson, H.A., Stapp, D., Harville, D., and Philipson, C., 1989, Determining lithology from continuously collected drill cuttings, using Fourier transform infrared spectroscopy, paper T, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 16 p.

Robinette, M.S., and Williams, R.E., 1980, Geophysical techniques for selection, analysis and monitoring uranium waste disposal sites, chapter 10, in C.O. Brawner, editor, First international conference on uranium mine waste disposal, proceedings [May 19-21, Vancouver, British Columbia, Canada]: Society of Mining Engineers of AIME, New York, p. 93-99.

Rolle, F., 1985, Late Cretaceous-Tertiary sediments offshore central west Greenland--Lithostratigraphy, sedimentary evolution, and petroleum potential: Canadian Journal of Earth Science, v. 22, p. 1001-1019.

Rupp, J., Hertzog, R., and Schweitzer, J., 1989, Using log-derived elemental concentrations in stratigraphic correlation of argillaceous sediments, paper W, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 385-396.

Schlumberger, 1986-Present, Middle East Well Evaluation Review: Schlumberger Technical Services, semi-annual journal.

Schmoker, J.W., and Hester, T.C., 1989, Oil generation inferred from formation resistivity--Bakken Formation, Williston Basin, North Dakota, paper H, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p. Later published in 1990, as Formation resistivity as an indicator of oil generation; Bakken Formation of North Dakota and Woodford Shale of Oklahoma: The Log Analyst, v. 31(1), January-February, p. 1-9.

Schmoker, J.W., and Hester, T.C., 1989, Formation resistivity as an indicator of the onset of oil generation in the Woodford Shale, Anadarko basin, Oklahoma, in Johnson, K.S., editor, Anadarko basin symposium, 1988: Oklahoma Geological Survey Circular No. 90, p. 262-266.

Senger, J.A., 1985, Defining glacial stratigraphy with the neutron log, in 1985 NWWA conference on surface and borehole geophysical methods in ground water investigations [Fort Worth, Texas, February 12-14], proceedings: National Water Well Association, Worthington, Ohio, p. 355-368.

Sethi, D.K., 1981, Well log applications in rock mechanics, SPE/DOE-9833, in 1981 SPE/DOE symposium on low permeability gas reservoirs, proceedings: Society of Petroleum Engineers, p. 45-53.

Shell Oil Company, 1987, Atlas of seismic stratigraphy, geometric analysis of a depositional sequence, part 3, Well log sequence, in A.W. Bally, editor, Atlas of seismic stratigraphy, v. 1: AAPG Studies in Geology No. 27, p. 28-30.

Shier, D.E., 1989, Reconaissance mapping of stratigraphic traps in sandstones; depositional energy maps and diagenetic maps: The Log Analyst, v. 30(4), July-August, p. 225-242.

Singh, R.N., Hassani, F.P., and Elkington, P.A.S., 1983, The application of strength and deformation index testing to the stability assessment of coal measures excavations, in Mathewson, C.C., editor, Rock mechanics, theory-experiment-practice [24th U.S. symposium on rock mechanics, proceedings]: Association of Engineering Geologists, p. 599-609.

Sinha, A., Lawrence, T., Simmons, B., 1989, An advanced interpretation technique integrates well log and core data fro thin-bed reservoir evaluation: Transactions Gulf Coast Association of Geological Societies, v. 29, p. 267-274.

Slack, H.A., and Otte, C., 1960, Electric log interpretation in exploration for stratigraphic traps in shaly sands: AAPG Bulletin, v. 44(12), p. 1874-1894.

Smith, D., 1990, Predicting a down-dip water level using capillary pressure relationsips, paper Z, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 11 p.

Spencer, T.W., and Wu, R.C., 1985, Polarization method for the determination of Poisson's ratio in boreholes: Geophysics, v. 50(12), p. 2808-2816.

Stein, N., 1975, Mechanical properties of friable sands from conventional log data, SPE-5500: Society of Petroleum Engineers, 50th annual meeting [Dallas] preprint. Later published in 1976, Journal of Petroleum Technology, v. 28(7), p. 757-763. Discussion and reply published in 1976, Journal of Petroleum Technolgy, v. 28(11), p. 1303-1304.

Stein, N., 1987, Estimate formation strength using log data: World Oil, v. 205(5), November, p. 39-40.

Stein, N., 1988, How to calculate fracture pressures from well logs: Petroleum Engineer International, v. 60(8), August, p. 36-38.

Stein, N., 1988, Determine properties of friable formation sands: World Oil, v. 206(3), March, p. 33-37.

Stein, N., 1989, Porosity of friable sand using acoustic wave velocity, paper LL, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 715-729.

Stein, N., 1989, Mud weight correction gives better sand strength estimates: World Oil, v. 208(3), March, p. 61-63.

Stowell, J.R., 1989, An overview of borehole geophysical methods for solving engineering and environmental problems, in 3rd national outdoor action conference on aquifer restoration, ground water monitoring and geophysical methods [Orlando, Florida], proceedings: National Well Water Association, Dublin, Ohio, p. 871-890.

Takahashi, K., and Ishikawa, K., 1974, Geological investigation and judgment of engineering nature, utilizing borehole measurements: Rock Mechanics in Japan, v. 2, p. 158-160.

Tixier, M.P., Loveless, G.W., and Anderson, R.A., 1973, Estimation of formation strength from the Mechanical Properties Log, SPE-4532: Society of Petroleum Engineers, 48th annual meeting [Las Vegas] preprint, 14 p. Later published in 1975, Journal of Petroleum Technology, v. 27(12), p. 283-293. Reprinted 1978, paper X, in Acoustic logging: Society of Professional Well Log Analysts, Reprint Volume, 11p.

Tokle, K., Horsrud, P., and Bratli, R.K., 1986, Predicting uniaxial compressive strength from log parameters, SPE-15645: Society of Petroleum Engineers, 61st annual meeting [New Orleans] preprint, 8 p.

Toksoz, M.N., Wilkens, R.H., and Cheng, C.H., 1985, Shear wave velocity and attenuation in ocean bottom sediments from acoustic log waveforms: Geophysical Research Letters, v. 12(1), p. 37-40.

Torres, D., Strickland, R., and Gianzero, M., 1990, A new approach to determining dip and strike using borehole images, paper K, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts,20 p.

Turner, W.S., and Black, J.H., 1988, The use of geophysical logs in the characterization of a structurally complex site, in 3rd national outdoor action conference on aquifer restoration, ground water monitoring and geophysical methods [Orlando, Florida], proceedings: National Well Water Association, Dublin, Ohio, p. 909-919.

Vail, P.R., 1987, Seismic stratigraphy interpretation using sequence stratigraphy, Part 1, Seismic stratigraphy interpretation procedure, in A.W. Bally, editor, Atlas of seismic stratigraphy, v. 1: AAPG Studies in Geology No. 27, p. 1-10.

Veneziani, I.I., Pirson, S.J., Colombo, U., and Broome, M.B., 1972, The Redox log, paper D, in 13th annual logging symposium transactions: Society of Professional Well Log Analysts, 18 p.

Vuataz, F-D., Brach, M., Criaud, A., Fouillac, C., 1990, Geochemical monitoring of drilling fluids; a powerful tool to forecast and detect formation waters: SPE Formation Evaluation, v. 5(2), June, p. 177-184.

Weber, K.J., 1989, Delineation of the reservoir by identification of environmental types and early estimation of reserves, chapter 4, in Mason, J.F., and Dickey, P.A., editors, Oil field development techniques: AAPG Studies in Geology No. 28, p. 31-47.

Weber, K.J., and van Geuns, L.C., 1989, Framework for constructing clastic reservoir simulation models, SPE-19582, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 109-118.

Wendlandt, R.F., and Bhuyan, K., 1990, Estimation of mineralogy and lithology from geochemical log measurements: AAPG Bulletin, v. 74(6), p. 837-856.

Wetzel, A., 1987, Sedimentological significance of strain and sonic velocity anisotropy in fine-grained turbiditic and hemipelagic deep-sea sediments--an example from the Mississippi Fan: Marine Geology, v. 74, p. 191-207.

Whittaker, A., Holliday, D.W., and Penn, I.E., 1985, Geophysical logs in British stratigraphy: Blackwell Scientific Publications, London, Geological Society Special Report No. 18, 74 p.

Wilkens, R.H., Schreiber, B.C., Caruso, L., and Simmons, G., 1987, The effects of diagenesis on the microstructure of Eocene sediments bordering the Baltimore Canyon trough, in K.L. Turner, editor, Initial reports of the Deep Sea Drilling Project, volume 95: U.S. Government Printing Office, p. 527-547.

Willink, R.J., 1989, A methodical approach to critical well re-evaluation: APEA [Australian Petoleum Exploration Association] Journal, v. 29, part 1, p. 269-286.

Wolfsburger, R.T., Welychka, E.P., and Standen, E.J.W., 1988, Formation MicroScanner applications in southwestern Ontario, in 27th annual conference transactions: Ontario Petroleum Institute, London, Ontario, Canada, p. 22 p.

Woods, R.D., editor, 1985, Measurement of use of shear wave velocity for evaluating dynamic soil properties [Proceedings of a ASCE convention session (Denver, May 1, 1985)]: American Society of Civil Engineers, New York, 78 p.

Worthington, P.F., 1990, Sediment cyclicity from well logs, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 123-132.

Worthington, P., Anderson, R.N., Bell, S., Becker, K., Jarrard, R.D., Salisbury, M., and Stephen, R., 1988, Downhole measurements for the Ocean Drilling Programme, in 2nd conference on scientific ocean drilling [Strasbourg, France], report: European Science Foundation, p. 131-136.

Worthington, P., Anderson, R.N., Jarrard, R.D., Becker, K., Bell, J.S., Salisbury, M.H., and Stephen, R.A., 1988, Scientific applications of downhole measurements in the ocean basins: Basin Analysis, v. 1, p. 223-236.

3. DETERMINATION OF FACIES AND DEPOSITIONAL ENVIRONMENT

Abrahao, D., 1988, Well-log signatures of alluvio-lacustrine reservoir and source rocks of the Lagoa Feia Formation, Lower Cretaceous Campos basin, offshore Brazil: Colorado School of Mines, Golden, Department of Geology, Ph.D. thesis no. 3589, 279 p.

Adams, S.C., and Kullerud, G., 1984, Depositional patterns of Pennsylvanian sediments in Sullivan County, west-central Indiana, USA: International Journal of Coal Geology, v. 3, p. 349-373.

Allan, D.R., 1975, Identification of sediments--Their depositional environment and degree of compaction from well logs, in G.V. Chilingarian and K.H. Wolf, editors, Compaction of coarse-grained sediments, part I: Elsevier, New York, Developments in Sedimentology Series No. 18A, p. 349-401.

Allen, G., and Mercier, F., 1988, Subsurface sedimentology of deltaic systems: PESA [Petroleum Exploration Society of Australia] Journal, No. 12, p. 30-44.

Arditto, P.A., 1987, Potential hydrocarbon plays in the Late Permian succession of the southern Sydney Basin based on well log and seismic sequence analysis: Exploration Geophysics [Bulletin of the Australian Society of Exploration Geophysicists], v. 18(4), December, p. 355-365.

Awal, M.R., and Arnold, F.C., 1990, DENIS--an expert system for identification of depositional environments, in 1990 conference on artificial intelligence in petroleum exploration and production [College Station, TX, May 16-18], proceedings: Texas A&M University, College Station, p. 143-153.

Bashem, W.H.M., and Dorfman, M.H., 1983, Facies characterization of carbonates by use of well logs, Sligo Formation (Lower Cretaceous), south Texas, paper SS, in 24th annual logging symposium transactions: Society of Professional Well Log Analysts, 17 p.

Berg, R.R., 1986, Interpretation of reservoir morphology, chapter 3, in Reservoir sandstones: Prentice-Hall Inc., Englewood Cliffs, New Jersey, p. 75-103.

Berteig, V., Helgeland, J., Mohn, E., Langeland, T., and van der Wel, D., 1985, Geofacies determination by logging data, paper TT, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Bertrand, J.P., Bot, P., Pizon, J., and others, 1986, The well logs, chapter 2, in Sedimentary bodies--seismic and well logging examples [in French]: Editions Technip, Paris, p. 33-57.

Bifani, R., 1986, Esmond gas complex, in J. Brooks, J.C. Goff, and B. van Hoorn, editors, Habitat of Paleozoic gas in NW Europe: Geological Society of London, Special Publication No. 23, p. 209-221.

Bigelow, E.L., 1989, Modelling fluvial depositional environments, paper CC, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 14 p.

Bigelow, E.L., and Easton, S.B., 1986, Electrofacies fingerprints of eolian desert environments, paper V, in 10th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Aberdeen Chapter, 19 p.

Black, C.E., and Berg, R.R., 1987, Fan-delta reservoirs in the lower Cotton Valley Group (Jurassic), Kildare field, northeastern Texas: Gulf Coast Association of Geological Societies Transactions, v. 37, p. 35-42.

Bristow, C.S., and Bristow, C.S., 1989, Detailed sedimentology and gamma-ray log characteristics of a Namurian deltaic succession, part II, gamma-ray logging, in Whateley, M.K.G., and Pickering, K.T., editors, Deltas--sites and traps for fossil fuels: Geological Society of London, Special Publication No. 41, p. 81-88.

Brown, S., and Richards, P.C., 1989, Facies and development of the Middle Jurassic Brent delta near the northern limit of its progradation, U.K. North Sea, in Whateley, M.K.G., and Pickering, K.T., editors, Deltas--sites and traps for fossil fuels: Geological Society [London] Special Publication No. 41, p. 253-267.

Bulling, T.P., and Breyer, J.A., 1989, Exploring for subtle traps with high-resolution paleogeographic maps--Reklaw 1 interval (Eocene), south Texas: AAPG Bulletin, v. 73(1), p. 24-39.

Cant, D.J., 1983, Subsurface sedimentology: Geoscience Canada, v. 10(3), p. 115-121.

Chauvel, Y., Seeburger, D.A., and Castro-Orjuela, A., 1984, Applications of the SHDT (Stratigraphic High Resolution Dipmeter) to the study of depositional environments, paper G, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 23 p.

Chauvin, A., and Valachi, L., 1980, Sedimentology of the Brent and Statfjord Formations of Statfjord field, in The sedimentation of the North Sea reservoir rocks [Proceedings of a conference, May 11-14, Geilo, Norway]: Norwegian Petroleum Society, Oslo, 17 p.

Choen, A., 1987, Determination of fluvial-deltaic marine facies in the Helez and Telamim Formations (Lower Cretaceous, Israel), in McKenzie, K.G., editor, Shallow Tethys 2 [Proceedings of the international sympsoium on shallow Tethys 2 (Wagga Wagga, September 15-17, 1986)]: A.A. Balkema, Rotterdam, p. 261-286.

Coleman, J.M., and Prior, D.B., 1982, Deltaic environments of deposition, in P.A. Scholle and D. Spearing, editors, Sandstone depositional environments: American Association of Petroleum Geologists, Memoir No. 31, p. 139-178.

Davis, R.J., Johnson, C.A., Gilreath, J.A., 1990, Interpretation of depositional systems in the Lower Silurian Medina Group of western New York, paper N, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Dorfman, M.H., and Dupree, J., 1985, New techniques for facies determination of carbonates by use of well logs, in Third AGIP improved oil recovery European meeting [Rome, 4/16-18], proceedings, volume 1: Azienda Generale Italiana Petroli, Rome, p. 13-23.

Dorfman, M.H., Newey, J.J., and Coates, G.R., 1990, New techniques in lithofacies determination and permeability prediction in carbonates using well logs, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 113-120.

Ethridge, F.G., 1985, Surface and subsurface methods of investigation and classification of fluvial environments, in Recognition of fluvial depositional systems and their resource potential: Society of Economic Paleontologists and Mineralogists, Short Course No. 19, p. 9-32.

Everett, R.V., Herron, M., Pirie, G., Schweitzer, J., and Edmundson, H., 1985, Faja case study results on a single well MFM-7S, paper A, in 10th formation evaluation symposium transactions: Canadian Well Logging Society, 20 p. Also presented in 1985, 60th annual meeting: Society of Petroleum Engineers, preprint, SPE-14176. Later published in 1987, SPE Formation Evaluation, v. 2(3), September, p. 361-375. Also published in 1987, in R.F. Myer, editor, Exploration for heavy crude oil and natural bitumen [AAPG/UNITAR research conference (Santa Maria, California, October 29-November 2, 1984), proceedings]: AAPG Studies in Geology No. 25, p. 423-436.

Ferrante, R., and Minetto, C., 1988, The use of deconvolution curves in paleoenvironmental determination, paper JJ, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 16 p.

Fett, T.H., 1987, A practical method of identifying and exploiting clastic depositional environments using wireline parameters, paper KK, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 19 p. Later reprinted in 1988, Bulletin Corpus Christi Geological Society, February, p. 35-52. Later reprinted in 1989: Bulletin of the South Texas Geological Society, v. 29(7), p. 11-24.

Fisher, W.L., 1969, Facies characterization of Gulf Coast basin delta systems with some Holocene analogues: Gulf Coast Association of Geological Societies Transactions, v. 19, p. 239-261.

Flach, P.D., and Mossop, G.D., 1985, Depositional environments of Lower Cretaceous McMurray Formation, Athabasca oil sands, Alberta: AAPG Bulletin, v. 69(8), p. 11195-1207.

Flores, R.M., Toth, J.C., and Moore, T.A., 1982, Use of geophysical logs in recognizing depsositional environments in the Tongue River Member of the Fort Union Formation, Powder River Area, Wyoming and Montana: U.S. Geological Survey Open-File Report 82-756, 22 p.

Galloway, W.E., 1968, Depositional systems of the Lower Wilcox Group, north-central Gulf Coast Basin: Transactions of the Gulf Coast Association of Geological Societies, v. 18, p. 275-289.

Galloway, W.E., and Hobday, D.K., 1983, Terrigenous clastic depositional systems: Springer-Verlag, New York, 423 p.

Geehan, G.W., Lawton, T.F., Sakurai, S., Klob, H., Clifton, T.R., Inman, K.F., and Nitzberg, K.E., 1986, Geologic prediction of shale continuity, Prudhoe Bay field, in L.W. Lake and H.B. Carroll, Jr., editors, Reservoir characterization: Academic Press, New York, p. 63-81.

Gilreath, J.A., Healy, J.S., and Yelverton, J.N., 1969, Depositional environments defined by dipmeter interpretation: Transactions of the Gulf Coast Association of Geological Societies, v. 19, p. 101-111.

Gilreath, J.A., and Stephens, R.W., 1971, Distributary front deposits: Transactions of the Gulf Coast Association of Geological Societies, v. 21, p. 233-243.

Goodchild, M.W., and Bryant, P., 1986, The geology of the Rough gas field, in J. Brooks, J.C. Goff, and B. van Hoorn, editors, Habitat of Paleozoic gas in NW Europe: Geological Society of London, Edinburgh, Special Publication No. 23, p. 223-235.

Griffiths, C.M., 1990, The language of rocks; an example of the use of syntactic analysis in the interpretation of sedimentary environments from wireline logs, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 77-94.

Hamilton, D.S., Galloway, W.E., and Reynolds, S.A., 1987, Depositional systems of the Narrabeen Group, in Advances in the study of the Sydney basin, in 21st symposium [April 10-12] proceedings, : University of Newcastle, Newcastle, N.S.W., Australia, Department of Geology, p. 115-122.

Harker, S.D., and Maher, C.E., 1988, Late Jurassic sedimentation and tectonics, main area Claymore reservoir, North Sea, in A.J. Lomando and P.M. Harris, editors, Giant oil and gas fields; a core workshop: Society of Economic Paleontologists and Mineralogists, Core Workshop No. 12, p. 391-458.

Harris, P.M., Dodman, C.A., and Bliefnick, D.M., 1984, Permian (Guadalupian) reservioir facies, McElroy Field, west Texas, in Harris, P.M., editor, Carbonate sands--A core workshop: Society of Economic Paleontologists and Mineralogists, Core Workshop No. 5, p. 136-174.

Helland-Hansen, W., Steel, R., Nakayama, K., Kendall, C.G. St. C., 1989, Review and computer modelling of the Brent Group stratigraphy, in Whateley, M.K.G., and Pickering, K.T., editors, Deltas--sites and traps for fossil fuels: Geological Society [London] Special Publication No. 41, p. 237-252.

Hobson, G.D., 1989, Carbonate deposits and oil accumulations, chapter 12, in Mason, J.F., and Dickey, P.A., editors, Oil field development techniques: AAPG Studies in Geology No. 28, p. 159-174.

Hobson, G.D., 1989, Production from carbonate reservoirs, chapter 14, in Mason, J.F., and Dickey, P.A., editors, Oil field development techniques: AAPG Studies in Geology No. 28, p. 193-207.

Hocker, C., Eastwood, K.M., Herweijer, J.C., and Adams, J.T., 1990, Use of dipmeter data in clastic sedimentological studies: AAPG Bulletin, v. 74(2), p. 105-118.

Honarpour, M.M., Szpakiewicz, M.J., Schatzinger, R.A., Tomutsa, L., Carroll, H.B., Jr., and Tillman, R.W., 1988, Integrated geological/engineering model for barrier island deposits in Bell Creek field, Montana, SPE-17366, in 6th SPE/DOE Enhanced oil recovery symposium proceedings: Society of Petroleum Engineers, p. 491-512.

Kamon, K., and Dorfman, M.H., 1986, Identification of carbonate depositional texture from well-log response; West Seminole field, Gaines County, Texas, in D.G. Bebout and P.M. Harris editors, Hydrocarbon reservoir studies, San Andres/Grayburg Formations, Permian basin [Proceedings of research conference, Midland, Texas, October 7-9, 1986]: Society of Economic Mineralogists and Paleontologists, Permian Basin Chapter Publication 86-26, p. 75-77.

Kennedy, W.J., 1985, Sedimentology versus log response in central graben shales, in North Sea chalk symposium proceedings: Norwegian Petroleum Society, Stavanger, v.1, 14 p.

Kennedy, W.J., 1987, Sedimentology of Late Cretaceous-Paleocene chalk reservoirs, North Sea central graben, chapter 41, in J. Brooks, and K. Glennie, editors, Petroleum geology of north west Europe: Graham & Trotman, London, p. 469-481.

Klein, G. deV., 1980, Sandstone depositional models for exploration for fossil fuels: Burgess Publishing Co., Cepco Division, Minneapolis, 149 p.

Kramers, J.W., Bachy, S., Cuthiell, D., and others, 1988, The Provost Upper Mannville B pool; an integrated analysis for reservoir characterization, paper 88-39-112, in 39th annual technical meeting, preprints, volume 3: Petroleum Society of CIM [Canadian Institute of Mining], Calgary, 27 p.

Krueger, W.C., 1968, Depositional environments of sandstones as interpreted from electrical measurements--An introduction: Transactions of the Gulf Coast Association of Geological Societies, v. 18, p. 226-241.

Lalouel, P., 1979, Log interpretation in deltaic sequences, in 8th annual convention, proceedings: Indonesian Petroleum Association, Jakarta, p. 247-290.

Lawrence, T.D., Ball, S., and Harris, M., 1984, Continuous carbon/oxygen and neutron lifetime log proposed interpretation for organic and/or shaly depositional environments, paper QQ, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 19 p.

LeBlanc, R.J., Sr., 1976, Distribution and continuity of sandstone reservoirs, part I and part II, SPE-6137A, B: Society of Petroleum Engineers, 51st annual meeting [New Orleans] preprint. Later published in 1977, Journal of Petroleum Technology, v. 29(9), p. 776-804.

Levell, B.K., Braakman, J., and Rutten, K.W., 1988, Oil-bearing sediments of Gondwana glaciation in Oman: AAPG Bulletin, v. 72(7), p. 776-796.

Lindquist, S.J., 1988, Practical characterization of eolian reservoirs for development--Nugget Sandstone, Utah-Wyoming thrust belt: Sedimentary Geology, v. 54(1-4), p. 315-339.

Lorenz, J.C., Sattler, A.R., and Stein, C.L., 1989, The effects of depositional environment on petrophysical properties of Mesaverde reservoirs, northwestern Colorado, SPE-19583, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 119-132.

Lucia, F.J., and Conti, R.D., 1987, Rock fabric, permeability, and log relationships in an upward-shoaling, vuggy carbonate sequence: Texas Bureau of Economic Geology Geological Circular 87-5, 22 p.

Luthi, S.M., and Banavar, J.R., 1988, Application of borehole images to three-dimensional geometric modeling of eolian sandstone reservoir: AAPG Bulletin, v. 72(9), p. 1074-1089.

MacFarlane, P.A., Doveton, J.H., and Coble, G., 1989, Interpretation of lithologies and depositional environments of Cretaceous and Lower Permian rocks by using a diverse suite of logs from a borehole in central Kansas: Geology, v. 17(4), April, p. 303-306.

Magara, K., 1979, Identification of sandstone body types by computer method: Journal of the International Association for Mathematical Geology, v. 11(3), p. 269-283.

Magara, K., 1986, Identification of sandstone body types by the computer method, chapter 11, in Geological models of petroleum entrapment: Elsevier Applied Science Publishers, London, p. 217-234.

Martin, J.H., and Evans, P.F., 1988, Reservoir modeling of marginal aeolian/sabkha sequences, southern North Sea (U.K. sector), SPE-18155, in 1988 SPE annual technical conference proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 473-486.

Marzano, M.S., Pense, G.M., and Andronaco, P., 1988, A comparison of the Jurassic Norphlet Formation in Mary Ann field, Mobile Bay, Alabama, to onshore regional Norphlet trends: Transactions Gulf Coast Association of Geological Societies, v. 38, 85-100.

Mathis, B., Augier, C., Serra, O., Clermonte, J., Lanau, M., 1988, The hypersiliceous deposits of the Gabon offshore; lithologic identification from well logging analysis--paleoenvironmental implications [in French]: Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine, v. 12(2), p. 493-512.

Mathis, B., Bourquin, S., Didelot, B., Alkhaddour, G., and Clermonte, J., 1989, Lithologic identification and sequential organization in the Paris basin and in the Rhine graben, paper DD, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 12 p.

McGovney, J.E., and Radovich, B.J., 1985, Seismic stratigraphy and facies of the Frigg fan complex, in O.R. Berg and D.G. Woolverton, editors, Seismic stratigraphy II--An integrated approach to hydrocarbon exploration: American Association of Petroleum Geologists, Memoir No. 39, p. 139-154.

Mitchell-Tapping, H.J., 1986, Depositional environment determination using a SSP-resistivity method: The Log Analyst, v. 27(2), March-April, p. 15-20.

Mohn, E., Berteig, V., and Helgeland, J., 1987, A review of statistical approaches to lithofacies determination from well data, chapter 22, in J. Kleppe, E.W. Berg, A.T. Buller, O. Hjelmeland, and O. Torsaeter, editors, North Sea oil and gas reservoirs: Graham & Totman Ltd., London, p. 301-309.

Muwais, W., and Smith, D.G., 1990, Types of channel-fills interpreted from dipmeter logs in the McMurray Formation, northeast Alberta: Bulletin of Canadian Petroleum Geology, v. 38(1), March, p. 53-63.

Myers, K.J., and Bristow, C.S., 1989, Detailed sedimentology and gamma-ray log characteristics of a Namurian deltaic succession, part I, sedimentology and facies analysis, in Whateley, M.K.G., and Pickering, K.T., editors, Deltas--sites and traps for fossil fuels: Geological Society of London, Special Publication No. 41, p. 75-80.

Norwood, E.M., 1974, Lithofacies mapping--A descriptive tool for ancient delta systems of the Louisiana outer continental shelf: Transactions of the Gulf Coast Association of Geological Societies, v. 24, p. 175-188.

Nuhfer, E.B., and Nurmi, R.D., 1976, Bibliography of references for recognition of depositional environment from wireline log data: West Virginia Geological and Economic Survey, Mineral Briefs Series, 15 p.

Nurmi, R.D., 1985, Eolian sandstone reservoirs--bedding facies and production geology modeling, SPE-14172: Society of Petroleum Engineers, 60th annual meeting [Las Vegas], preprint, 8 p.

Olsen, R.S., 1982, Depositional environment of Jurassic Smackover Sandstones, Thomasville Field, Rankin County Mississippi: Transactions of the Gulf Coast Association of Geological Societies, v. 32, p. 59-66.

Ouyand, J., Ma, Z, He, D., Tian, H., and Xiao, Y., 1988, Sedimentary facies recognition in China with well-logging data, in Wagner, H.C., Wagner, L.C., Wang, F.F.H., and Wong, F.L., editors, Petroleum resources of China and related subjects [Beijing petroleum symposium (September 20-25, 1984)]: Circum-Pacific Council for Energy and Mineral Resources, Houston, Texas, Earth Science Series v. 10, p. 467-474.

Palomino Cardenas, J.R., and Carozzi, A.V., 1979, Sedimentology and electric log interpretation of the Cabo Blanco Sandstone (Lower Eocene), Talara Basin, northeast Peru: Archives des Sciences [Societe de Physique et d'Histoire Naturelle de Geneve], v. 32(2), p. 127-149.

Petricola, M., Jumardi, and Saito, K., 1985, Formation evaluation in deltaic sand deposits--The effect of lignite debris on logs--Integration of sand-body analysis, in 14th annual convention proceedings: Indonesian Petroleum Association, Jakarta, p. 517-541.

Pirie, G., 1984, Computer-generated interpretations of stratigraphy and depositional environments from a logging/core study--Cotton Valley Group, East Texas, in W.P.S. Ventress, D. Bebout, B.F. Perkings and C.H. Moore, editors, The Jurassic of the Gulf rim: Gulf Coast Section of the Society of Economic Paleontologists and Mineralogists p. 323-331.

Pirie, G., 1985, Geology of a single well (Maraven SDZ-86X) from cores and logs, Orinoco heavy oil belt, Venezuela, in 3rd international UNITAR/UNDP heavy oil crude and tar sands conference [Long Beach, California, July 22-31, 1985), preprints: United Nations Institute for Training and Research, New York, Information Center for Heavy Crude and Tars, 54 p. Also published in 1985, as Geological evaluation of a single well from cores and logs Faja petrolifera del Orinoco, eastern Venezuela, paper B, in 10th formation evaluation symposium transactions: Canadian Well Logging Society, 35 p.

Pirson, S.J., 1983, Paleo-facies logging and mapping, chapter 6, in Geologic well log analysis, 3rd edition: Gulf Publishing Company, Houston, p. 163-190.

Priisholm, S., and Michelsen, O., 1979, The use of porosity logs in lithology determination, lithostratigraphy and basin analysis, in D.Gill and D.F. Merriam, editors, Geomathematical and petrophysical studies in sedimentology: Pergamon Press, Oxford, Computers in Geology Series, p. 71-79.

Proctor, C.V., 1980, Distribution of Middle Jurassic facies in the east Shetlands basin and their control of reservoir capability, in The sedimentation of the North Sea reservoir rocks [Proceedings of a conference, May 11-14, Geilo, Norway]: Norwegian Petroleum Society, Oslo, 22 p.

Ramli, N., 1986, Depositional model of a Miocene barred wave- and storm-dominated shoreface and shelf, southeastern Malay Basin, offshore west Malaysia: AAPG Bulletin, v. 70(1), p. 34-47.

Ranganathan, V., and Tye, R.S., 1986, Petrography, diagenesis, and facies controls on porosity in Shannon Sandstone, Harztog Draw field, Wyoming: AAPG Bulletin, v. 70(1), p. 56-69.

Ronning, K., and Steel, R.J., 1987, Depositional sequences within a "transgressive" reservoir sandstone unit; the Middle Jurassic Tarbet Formation, Hild area, northern North Sea, chapter 12, in J. Kleppe, E.W. Berg, A.T. Buller, O. Hjelmeland, and O. Torsaeter, editors, North Sea oil and gas reservoirs: Graham & Totman Ltd., London, p. 153-167.

Russell, D.J., 1985, Depositional analysis of a black shale by using gamma-ray stratigraphy--The Upper Devonian Kettle Point Formation of Ontario: Bulletin of Canadian Petroleum Geology, v. 33(2), June, p. 236-253.

Saito, K., Tono, S., and Kamili, Z.A., 1985, Sand body correlation in deltaic setting, East Ketaling field, Sumatra basin, in 14th annual convention proceedings: Indonesian Petroleum Association, Jakarta, p. 499-515.

Saitta, B.S., and Visher, G.S., 1968, Subsurface study of the southern portion of the Bluejacket delta, in A guidebook to the geology of the Bluejacket-Bartlesville Sandstone, Oklahoma: Oklahoma Geological Society, p. 52-65.

Sakurai, S., and Melvin, J., 1988, Facies discrimination and permeability estimation from well logs for the Endicott field, paper FF, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 18 p.

Schmoker, J.W., and Schenk, C.J., 1988, Facies composition calculated from the sonic, neutron, and density log suite, upper part of the Minnelusa Formation, Powder River basin, Wyoming: The Mountain Geologist, v. 25(3), July, p. 103-112.

Schultz, A.L., and Coppinger, W.W., 1990, Identification of point bar reservoirs within units of the Fall River Formation through comprehensive electric log interpretation; Powder River basin, Wyoming, in Eisert, J.L., editor, Gas resources of Wyoming: Wyoming Geological Association, 40th Field Conference Guidebook, p. 143-153.

Self, G.A., Breard, S.Q., Rael, H.P., Stein, J.A., Traugott, M.O., Thayer, P.A., and Eason, W.D., 1986, Lockhart Crossing field--New Wilcox trend in southeastern Louisiana: AAPG Bulletin, v. 70(5), p. 501-515. Later published in 1986, in abridged form in, Oil and Gas Journal, v. 84(33), p. 81-87.

Selley, R.C., 1974, Environmental analysis of subsurface sediments, paper J, in 3rd European formation evaluation symposium transactions: Society of Professional Well Log Analysts, London Chapter, 15 p. Later published in 1976 as, Subsurface environmental analysis of North Sea sediments: AAPG Bulletin, v. 60(2), p. 184-195. Also published in 1976, The Log Analyst, v. 17(1), January-February, p. 3-11.

Selley, R.C., 1975, Subsurface diagnosis of deltaic deposits with reference to the northern North Sea, in Jurassic of the northern North Sea symposium, paper JNNSS/13: Norwegian Petroleum Society, Stavanger, 22 p.

Selley, R.C., 1978, Ancient sedimentary environments, 2nd edition: Cornell University Press, New York, 287 p.

Selley, R.C., 1979, Dipmeter and log motifs in North Sea submarine-fan sands: AAPG Bulletin, v. 63(6), p. 905-917.

Selley, R.C., 1985, Methods of exploration, chapter 3, in Elements of petroleum geology: W.H. Freeman & Company, San Francisco, p. 37-131.

Selley, R.C., 1989, Deltaic reservoir prediction from rotational dipmeter patterns, in Whateley, M.K.G., and Pickering, K.T., editors, Deltas--sites and traps for fossil fuels: Geological Society of London, Special Publication No. 41, p. 81-88.

Serra, O., 1985, Sedimentary environments from wireline logs: Schlumberger Technical Services, Paris, Document No. M-081030/SMP-7008, 211 p. [extracted from Serra, O., 1986, Fundamentals of well-log interpretation volume 2--The interpretation of logging data, chapters 4-6: Elsevier Science Publishers, Amsterdam, Developments in Petroleum Science No. 15B, 684 p.]

Serra, O., 1986, Stratigraphy, tectonics and multiwell studies using wireline logs: Schlumberger Well Services, Houston, Document No. M-090029, 127 p. [extracted from Serra, O., 1986, Fundamentals of well-log interpretation volume 2--The interpretation of logging data, chapters 13-15: Elsevier Science Publishers, Amsterdam, Developments in Petroleum Science No. 15B, p. 557-652]

Serra, O., 1987, Sedimentological applications of wireline logs to reservoir studies, chapter 21, in J. Kleppe, E.W. Berg, A.T. Buller, O. Hjelmeland, and O. Torsaeter, editors, North Sea oil and gas reservoirs: Graham & Totman Ltd., London, p. 277-299.

Serra, O., and Abbott, H.T., 1980, The contribution of logging data to sedimentary sedimentology and stratigraphy, SPE-9270: Society of Petroleum Engineers, 55th annual meeting [Dallas] preprint, 19 p. Later published in 1982, Society of Petroleum Engineers Journal, v. 22(1), p. 117-131.

Serra, O., Delfiner, P., Levert, J.C., 1985, Lithology determination from well-logs--Case studies, paper WW, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 19 p.

Serra, O., and Sulpice, L., 1975, Sedimentological analysis of sand-shale series from well logs, paper W, in 16th annual logging symposium transactions: Society of Professional Well Log Analysts, 23 p.

Sharma, B., Honarpour, M.M., Jackson, S.R., Schatzinger, R., and Tomutsa, L., 1989, Determining the productivity of a barrier island sandstone deposit from integrated facies analysis based on log and core data and fluid production, SPE-19584, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 133-148.

Shell Oil Company, 1987, Atlas of seismic stratigraphy, geometric analysis of a depositional sequence, part 3, Well log sequence, in A.W. Bally, editor, Atlas of seismic stratigraphy, v. 1: AAPG Studies in Geology No. 27, p. 28-30.

Shields, C., 1974, The dipmeter used to recognize and correlate depositional environment, paper, H, in 3rd European formation evalution symposium transactions: Society of Professional Well Log Analysts, London Chapter, 15 p. Also published in 1974: APEA [Australian Petroleum Exploration Association] Journal, v. 14, part 1, p. 181-188.

Shier, D.E., 1989, Reconaissance mapping of stratigraphic traps in sandstones; depositional energy maps and diagenetic maps: The Log Analyst, v. 30(4), July-August, p. 225-242.

Slatt, R.M., Boak, J.M., Goodrich, G.T., Lagoe, M.B., Vavra, C.L., Bishop, J.M., and Zucker, S.M., 1988, Depositional facies, paleoenvironments, reservoir quality, and well log characteristics of Mio-Pliocene deep water sands, Long Beach unit, Wilmington field, California, in A.J. Lomando and P.M. Harris, editors, Giant oil and gas fields; a core workshop: Society of Economic Paleontologists and Mineralogists, Core Workshop No. 12, p. 31-88.

Sneider, R.M., Tinker, C.N., and Meckel, L.D., 1977, Deltaic environment reservoir types and their characteristics, SPE-6701: Society of Petroleum Engineers, 52nd annual meeting preprint. Later published in 1978, Journal of Petroleum Technology, v. 30(11), p. 1538-46.

Standen, E., 1985, The use of dipmeter synthetic data to determine rock texture and depositional environment, paper AA, in 10th formation evaluation symposium transactions: Canadian Well Logging Society, 12 p.

Stowe, I., and Hock, M., 1988, Facies analysis and diagenesis from well logs in the Zechstein carbonates of northern Germany, paper HH, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 24 p.

Swanson, D.C., 1980, Handbook of deltaic facies--A collection of practical and useful information and exercises for the subsurface geologist: Lafayette Geological Society, Lafayette, Louisiana, 125 p.

Tizzard, P.G., and Lerbekmo, J.F., 1975, Depositional history of the Viking Formation, Suffield area, Alberta, Canada: Bulletin of Canadian Petroleum Geology, v. 23(4), p. 715-752.

Tyler, N., and Ambrose, W.A., 1985, Facies architecture and production characteristics of strandplain reservoirs in the Frio Formation, Texas: Texas Bureau of Economic Geology Report of Investigations No. 146, 42 p. Later published in 1986, AAPG Bulletin, v. 70(7), 809-829.

Vail, P.R., 1987, Seismic stratigraphy interpretation using sequence stratigraphy, Part 1, Seismic stratigraphy interpretation procedure, in A.W. Bally, editor, Atlas of seismic stratigraphy, v. 1: AAPG Studies in Geology No. 27, p. 1-10.

Visher, G.S., 1965, Use of vertical profile in environmental reconstruction: AAPG Bulletin, v. 49(1), p. 41-61. Paper generally cited as the basis of environmental interpretation of the SP curve.

Weber, K.J., 1971, Sedimentological aspects of oil fields in the Niger Delta: Geologie en Mijnbouw, v. 50(3), p. 559-576.

Wetzel, A., 1987, Sedimentological significance of strain and sonic velocity anisotropy in fine-grained turbiditic and hemipelagic deep-sea sediments--an example from the Mississippi Fan: Marine Geology, v. 74, p. 191-207.

Whittaker, A., Holliday, D.W., and Penn, I.E., 1985, Geophysical logs in British stratigraphy: Blackwell Scientific Publications, London, Geological Society Special Report No. 18, 74 p.

Wilson, M.D., and Pittman, E.D., 1977, Authigenic clays in sandstones--recognition and influence on reservoir properties and paleoenvironmental analysis: Journal of Sedimentary Petrology, v. 47(1), p. 3-31. Reprinted 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. I137-I165.

Witherbee, L.J., Godfrey, R.D., and Dimelow, T.E., 1983, Predicting turbidite-contourite reservoir intervals in tight gas sands--A case study from the Mancos B Sandstone, SPE/DOE-11609, in 1983 SPE/DOE symposium on low permeability gas reservoirs, proceedings: Society of Petroleum Engineers, p. 87-94.

Woodruff, K.D., 1976, Geophysical log characteristics of coastal plain units in Delaware, in A.M. Thompson, editor, Guidebook to the stratigraphy of the Atlantic coastal plain in Delaware [third annual field trip]: Petroleum Exploration Society, New York, p. 81-92.

Woodruff, K.D., 1976, Selected logging data and examples of geophysical logs for the coastal plain of Delaware: Delaware Geological Survey Report of Investigation No. 25, 40 p.

Worthington, P.F., 1990, Sediment cyclicity from well logs, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 123-132.

Zelt, F.B., 1985, Natural gamma-ray spectrometry, lithofacies and depositional environments of selected Upper Cretaceous marine mudrocks, western United States, including Tropic Shale and Tununk Member of Mancos Shale: Princeton University, unpublished PhD. dissertation, 354 p.

Zelt, F.B., 1985, Paleo-oceanographic events and lithologic/geochemical facies of the Greenhorn marine cycle (Upper Cretaceous) examined using natural gamma-ray spectroscopy, in L. Pratt, E.G. Kaufmann, F.B. Zelt, editors, SEPM field trip guidebook no. 4, 1985 midyear meeting, Golden, Colorado: Society of Economic Paleontologists and Mineralogists, p. 49-59.

4. IDENTIFICATION OF DEPOSITIONAL ENVIRONMENTS BY SP AND GR PATTERN

Allen, G., and Mercier, F., 1988, Subsurface sedimentology of deltaic systems: PESA [Petroleum Exploration Society of Australia] Journal, No. 12, p. 30-44.

Bertrand, J.P., Bot, P., Pizon, J., and others, 1986, The well logs, chapter 2, in Sedimentary bodies--seismic and well logging examples [in French]: Editions Technip, Paris, p. 33-57.

Bulling, T.P., and Breyer, J.A., 1989, Exploring for subtle traps with high-resolution paleogeographic maps--Reklaw 1 interval (Eocene), south Texas: AAPG Bulletin, v. 73(1), p. 24-39.

Cant, D.J., 1983, Subsurface sedimentology: Geoscience Canada, v. 10(3), p. 115-121.

Coleman, J.M., Constans, R., and Bouma, A.H., 1986, Gamma-ray well-log characteristics, Leg 96, in Initial reports of the Deep Sea Drilling Project, volume 96: U.S. Government Printing Office, p. 547-561.

Coppinger, W.W., and Schlutz, A.L., 1983, Using the self-potential curve to define depositional trends in Lower Wilcox sands, McMullen County, Texas: Bulletin of the South Texas Geological Society, v. 23(6), p. 16-28.

Hamilton, D.S., Galloway, W.E., and Reynolds, S.A., 1987, Depositional systems of the Narrabeen Group, in Advances in the study of the Sydney basin, in 21st symposium [April 10-12] proceedings, : University of Newcastle, Newcastle, N.S.W., Australia, Department of Geology, p. 115-122.

Klein, G. deV., 1984, Vertical sequences and log shapes of major sandstone reservoir systems: IHRDC Press, Boston, 1 sheet.

Pirson, S.J., 1983, Sedimentological studies by log curve shapes, chapter 2, in Geologic well log analysis, 3rd edition: Gulf Publishing Company, Houston, 475 p.

Rider, M.H., 1990, Gamma-ray log shape used as a facies indicator--critical analysis of an oversimplified methodology, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 27-37.

Ruoff, W.A., 1976, A technique for interpreting depositional environments of sandstone from the SP log using a computer: The Log Analyst, v. 17(4), July-August, p. 3-10.

Snedden, J.W., 1984, Validity of the use of the spontaneous potential curve shape in the interpretation of sandstone depositional environments: Transactions Gulf Coast Association of Geological Societies, v. 34. p. 255-263.

Sneider, R.M., Tinker, C.N., and Meckel, L.D., 1977, Deltaic environment reservoir types and their characteristics, SPE-6701: Society of Petroleum Engineers, 52nd annual meeting preprint. Later published in 1978, Journal of Petroleum Technology, v. 30(11), p. 1538-46.

Swanson, D.C., 1980, Handbook of deltaic facies--A collection of practical and useful information and exercises for the subsurface geologist: Lafayette Geological Society, Lafayette, Louisiana, 125 p.

Throckmorton, H.C., and Al-Shaieb, Z., 1986, Core-calibrated logs utilization in recognition of depositional facies and reservoir rock of the Henryhouse Formation (Silurian), Anadarko Basin, paper L, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 17 p.

Tyler, N., and Ambrose, W.A., 1985, Facies architecture and production characteristics of strandplain reservoirs in the Frio Formation, Texas: Texas Bureau of Economic Geology Report of Investigations No. 146, 42 p. Later published in 1986, AAPG Bulletin, v. 70(7), 809-829.

Visher, G.S., 1965, Use of vertical profile in environmental reconstruction: AAPG Bulletin, v. 49(1), p. 41-61. Paper generally cited as the basis of environmental interpretation of the SP curve.

Woodruff, K.D., 1976, Selected logging data and examples of geophysical logs for the coastal plain of Delaware: Delaware Geological Survey Report of Investigation No. 25, 40 p.

Woodruff, K.D., 1976, Geophysical log characteristics of coastal plain units in Delaware, in A.M. Thompson, editor, Guidebook to the stratigraphy of the Atlantic coastal plain in Delaware [third annual field trip]: Petroleum Exploration Society, New York, p. 81-92.

5. DIPMETER APPLICATIONS

Adams, J., Bourke, L., Frisinger, R., 1987, Strategies for dipmeter interpretation, part 2: The Technical Review, v. 35(4), p. 20-31.

Anonymous, 1988, Dipmeter helps in siting successful Wilcox offsets: World Oil, v. 206(3), March, p. 29-32.

Babcock, E.A., 1978, Measurement of subsurface fractures from dipmeter logs: AAPG Bulletin, v. 62(7), p. 1111-1126.

Baker, J.D., 1984, Dipmeter Advisor--an expert log analysis system at Schlumberger in P.H. Winston and K.A. Prendergast, editors, The AI business; the commercial uses of artificial intelligence: MIT Press, Cambridge, Massachussetts, p. 51-65.

Banerjee, I., 1987, Interpretation of dipmeter logs of the Lower Cretaceous Cutbank Sandstone, Mannville Group, southern Alberta: Canadian Geological Survey Paper 87-1A, part 1, p. 337-348.

Bateman, R.M., 1986, Determination of high angle fracture plane orientations from SHDT dipmeter recordings using a microcomputer: Canadian Well Logging Society Journal, v. 15(1), p. 85-100.

Beinkafner, K.J., 1988, Computer processing of dipmeter log data; enhancement of a subsurface exploration tool, in D.F. Merriam, editor, Current trends in geomathematics: Plenum Press, New York, p. 181-206.

Bengston, C.A., 1981, Statistical curvature analysis techniques for structural interpretation of dipmeter data: AAPG Bulletin, v. 65(2), p. 312-332. Reprinted in 1988, Geobyte, v. 3(2), p. 63-75.

Bengston, C.A., 1982, Structural and stratigraphic uses of dip profiles in petroleum exploration, in M.T. Halbouty, editor, The deliberate search for the subtle trap: American Association of Petroleum Geologists, Memoir 32, p. 31-45.

Bigelow, E.L., 1982, Application of dip-related measurements to a complex-carbonate-clastic depositional environment: The Log Analyst, v. 23(2), p. 9-30.

Bigelow, E.L., 1985, Making more intelligent use of log derived dip information, Part I--Suggested guidelines: The Log Analyst, v. 26(1), January-February, p. 41-51.

Bigelow, E.L., 1985, Making more intelligent use of log derived dip information, Part II--Wellsite data gathering considerations: The Log Analyst, v. 26(2), March-April, p. 25-41.

Bigelow, E.L., 1985, Making more intelligent use of log derived dip information, Part III--Computer processing considerations: The Log Analyst, v. 26(3), May-June, p. 18-31.

Bigelow, E.L., 1985, Making more intelligent use of log derived dip information, Part IV--Structural interpretation: The Log Analyst, v.26(4), July-August, p. 21-43.

Bigelow, E.L., 1985, Making more intelligent use of log derived dip information, Part V--Stratigraphic interpretation: The Log Analyst, v. 26(5), September-October, p. 25-64.

Bigelow, E., 1987, Fundamentals of Diplog analysis: Atlas Oilfield Services, Houston, 210 p.

Cameron, G.I.F., 1986, Confidence and the identification of foresets in stratigraphic dipmeter surveys, paper O, in 10th European formation evaluation symposium transactions, : Society of Professional Well Log Analysts, Aberdeen Chapter, 17 p.

Campbell, R.J., Jr., 1968, Stratigraphic applications of dipmeter data in Mid-Continent: AAPG Bulletin, v. 52(9), p. 1700-1719.

Chauvel, Y., Seeburger, D.A., and Castro-Orjuela, A., 1984, Applications of the SHDT (Stratigraphic High Resolution Dipmeter) to the study of depositional environments, paper G, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 23 p.

Chemali, R., Su., S.M., and Goetz, J.F., 1989, Measuring Rxo and dip in oil-based mud with the six-arm dipmeter, paper O, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Cox, J.W., 1970, The high resolution dipmeter reveals dip-related borehole and formation characteristics paper D, in 11th annual logging symposium transactions: Society of Professional Well Log Analysts, 26 p.

Curial, A., 1988, Multiple applications of dipmeter curves for analyzing evaporite formations--Examples from paleogene of Bresse Trough, France: AAPG Bulletin, v. 72(11), p. 1323-1333.

Delhomme, J-P., Pilenko, T., Cheruvier, E., and Cull, R., 1986, Reservoir applications of dipmeter logs, SPE-15485: Society of Petroleum Engineers, 1986 annual meeting preprint, 8 p. Later published in 1988, Journal of Petroleum technology, v. 40(2), p. 180-186.

Devilliers, M.C., and Werner, Ph., 1990, Example of fault identification using dipmeter data, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 287-295.

Donovan, M.P., and Nelson, R.F., 1985, The Dual Dipmeter service in high-resistivity formations, SPE-14492, in Eastern regional meeting proceedings, : Society of Petroleum Engineers, p. 39-46.

Elphick, R.Y., 1989, SCAT revisited [source code for MS-DOS machines]: Geobyte, v. 4(1), p. 53-57.

Enderlin, M.B., and Hansen, D.K.T., 1987, A fundamental approach to dipmeter analysis, paper D, in 11th formation evaluation symposium transactions: Canadian Well Logging Society, 14 p.

Fitzgerald, D.D., Theriot, J.C., and York, P.L, 1980, Dipmeter validity in deviated boreholes: The Log Analyst, v. 21(3), May-June, p. 8.

Frank, W., 1986, The Dipmeter Advisor is field tested, in Expert systems and knowledge engineering [Gottlieb Duttweiler Institute of Technological Assessment and management (April 25-26, 1985), conference proceedings]: Elsevier Science Publishers, New York, p. 167-175. Also published in 1986, in T. Bernold, editor, Expert systems and knowledge engineering (essential elements of advanced information technology): Elsevier Science Publishers, B.V., Amsterdam, pp. 111-120.

Franke, M., and Hepp, V., 1973, Dipmeter outlines pertroleum entrapment on flanks of diapiric shale dome, paper J, in 14th annual logging syposium transactions: Society of Professional Well Log Analysts.

Georgi, D.T., 1986, Guides for the interpretation of dipmeter fracture logs, paper TT, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p.

Gilreath, J.A., 1977, Dipmeter, chapter 22, in L.W. LeRoy, D.O. LeRoy and J.W. Raese, editors, Subsurface geology, 4th edition: Colorado School of Mines, Golden, CO., p. 389-396.

Gilreath, J.A., 1987, Strategies for dipmeter interpetation: The Technical Review, v. 35(3), p. 28-39.

Gilreath, J.A., 1987, Dipmeter interpetation rules: The Technical Review, v. 35(3), supplement, 6 p. Also published as Schlumberger Document No. SMP-6007.

Gilreath, J.A., Cox, J.W., Fett, T.H., and Grace, L.M., 1985, Practical dipmeter interpretation: Schlumberger Educational Services, Houston, variously paginated.

Gilreath, J.A., Healy, J.S., and Yelverton, J.N., 1969, Depositional environments defined by dipmeter interpretation: Transactions of the Gulf Coast Association of Geological Societies, v. 19, p. 101-111.

Gilreath, J.A., and Maricelli, J.J., 1964, Detailed stratigraphic control through dip computations: AAPG Bulletin, v. 48(12), p. 1902-1910.

Gilreath, J.A., and Stephens, R.W., 1971, Distributary front deposits: Transactions of the Gulf Coast Association of Geological Societies, v. 21, p. 233-243.

Goetz, J.F., Chemali, R., and Seifert, D.J., 1989, Thin bed resolution and the determination of flushed zone resistivity in oil-based mud, paper I, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 14 p.

Goetz, J.F., Prins, W.J., and Logar, J.F., 1977, Reservoir delineation by wireline techniques: The Log Analyst, v. 18(5), September-October, p. 12-40.

Goldstein, B.A., and Hubbard, J.J., 1984, Comparison and geologic interpretation of alternative dipmeter analyses from a Permo-Carboniferous sequence in the Fitroy graben, in P.G. Purcell, editor, The Canning Basin, Western Australia [symposium proceedings]: Geological Society of Australia, Perth, p. 505-519. Reprinted in 1986, The Log Analyst, v. 27(6), November-December, p. 6-25.

Grace, L.M., Luthi, S.M., and Pirie, R.G., 1986, Stratigraphic interpretation using formation imaging and dipmeter analyses, SPE-15611: Society of Petroleum Engineers, 61st annual meeting [New Orleans] preprint, 4 p.

Herweijer, J.C., Hocker, C.F.W., Williams, H., and Eastwood, K.M., 1990, The relevance of dip profiles from outcrops as reference for the interpretation of SHDT dips, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 39-43

Hewitt, S.T., 1989, Effects of accelerometer corrections on formation dip measurements: Oil and Gas Journal, v. 87(3), January 16, p. 71-74.

Hocker, C., Eastwood, K.M., Herweijer, J.C., and Adams, J.T., 1990, Use of dipmeter data in clastic sedimentological studies: AAPG Bulletin, v. 74(2), p. 105-118.

Holt, O.R., 1972, Structural geologic considerations in diplog interpretation, paper Q, in 13th annual logging symposium transactions: Society of Professional Well Log Analysts, 30 p. Later published in 1973, The Log Analyst, v. 14(2), March-April, p. 3-9.

Holt, O.R., 1983, Relating diplogs to practical geology: Dresser Industries, Houston, Publication No. 1603, 69 p.

Jageler, A.H., and Matuszak, D.R., 1972, Use of well logs and dipmeters in stratigraphic-trap exploration, in R.E. King, editor, Stratigraphic oil and gas fields--Classification, exploration methods and case histories: American Association of Petroleum Geologists, Memoir No. 16, p. 107-135.

Jancikovic, B., and Cizelj, I., 1988, Determination of structural forms by dipmeter interpretation in southwestern part of Pannonian basin, paper N, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 20 p.

Jorgensen, S.D., and James, S.W., 1988, Integration of Stratigraphic High Resolution Dipmeter data into the development of the Minnelusa "B" sand reservoir in Hawk Point field, Campbell County, Wyoming, in R.P. Diedrich, M.A.K. Dyka, and W.R. Miller, editors, Eastern Powder River Basin-Black Hills: Wyoming Geological Association, 39th Field Conference Guidebook, p. 105-116.

Kemp, F., 1980, An algorithm for automatic dip computation: Computers and Geoscience, v. 6(2), p. 193-209.

Kerzner, M.G., 1983, Formation dip determination--An artificial intelligence approach: The Log Analyst, V. 24(5), September-October, P. 10-22.

Kerzner, M.G., 1986, Obtaining structural and stratigraphic dip information from dipmeter logs using segmentation trees and hierarchical multilevel optimization, SPE-15539: Society of Petroleum Engineers, 61st annual meeting preprint, 15 p. Later published in 1988, SPE Formation Evaluation, v. 3(1), p. 47-54.

Mair, B.F., and Adams, J.T., 1986, An approach to the sedimentological interpretation of dipmeter results, paper N, in 10th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Aberdeen Chapter, 22 p.

Muwais, W., and Smith, D.G., 1990, Types of channel-fills interpreted from dipmeter logs in the McMurray Formation, northeast Alberta: Bulletin of Canadian Petroleum Geology, v. 38(1), March, p. 53-63.

Nurmi, R.D., 1984, Geological evaluation of high resolution dipmeter data, paper YY, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 23 p.

Payre, X., and Serra O., 1979, Turbidites recognized through dipmeter, paper K, in 6th European logging symposium transactions: Society of Professional Well Log Analysts, London Chapter, 26 p.

Pelissier-Combescure, 1988, Advances in dipmeter acquisition and interpretation, in 3rd Bolivian symposium--Petroleum exploration in the sub-Andean basin [Caracas, Venezuela, March 13-16], proceedings: Venezuela Geological Society, Caracas, p. 916-939.

Phillips, S., 1987, Dipmeter interpretation of turbidite-channel reservoir sandstones, Indian Draw field, New Mexico, in R.W. Tillman and K.J. Weber, editors, Reservoir sedimentology: Society of Economic Paleontologists and Mineralogists, Special Publication No. 40, p. 113-128.

Pirson, S.J., 1983, Continuous dipmeter as a structural and sedimentation tool, chapters 4 and 5, in Geologic well log analysis, 3rd edition: Gulf Publishing Company, Houston, p. 97-162.

Poulton, H.N., and Strozeski, B.B., 1989, Ultrasonic Diplog; a system for measuring dips in wells drilled with oil-base mud, paper GG, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 15 p.

Rider, M.H., 1978, Dipmeter log analysis--An essay, paper G, in 19th annual logging symposium transactions: Society of Professional Well Log Analysts, p.

Ronningsland, T.M., 1990, Structural interpretation of dipmeter results in Gullfaks field, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 273-286.

Sallee, J.E., and Wood, B.R., 1982, Use of microresistivity from the dipmeter to improve formation evaluation in thin sands, northeast Kalimantan, Indonesia, SPE-10462, in Offshore South East Asia conference, proceedings: Society of Petroleum Engineers, 24 p. Later published in 1984, Journal of Petroleum Technology, v. 36(9), p. 1535-1544.

Schlumberger, 1986, Dipmeter interpretation--Fundamentals: Schlumberger Well Services, Houston, Document No. SMP-7002, 76 p.

Schneider, W.A., Jr., and Whitman, W.W., 1990, Dipmeter analysis by a Monte Carlo technique: Geophysics, v. 55(3), p. 320-326.

Schoonover, L.G., and Holt, O.R., 1973, Computer methods of dip log correlations, SPE-3566: Society of Petroleum Engineers Journal, v. 13(1), February, p. 31-38.

Selley, R.C., 1979, Dipmeter and log motifs in North Sea submarine-fan sands: AAPG Bulletin, v. 63(6), p. 905-917.

Selley, R.C., 1989, Deltaic reservoir prediction from rotational dipmeter patterns, in Whateley, M.K.G., and Pickering, K.T., editors, Deltas--sites and traps for fossil fuels: Geological Society of London, Special Publication No. 41, p. 81-88.

Shanor, G.G., 1987, The Dipmeter Advisor; a dipmeter interpretation workstation: Bulletin of the Geological Society of Malaysia, v. 21, Special Issue on Petroleum Geology v. 2, December, p. 37-54.

Shields, C., 1974, The dipmeter used to recognize and correlate depositional environment, paper, H, in 3rd European formation evalution symposium transactions: Society of Professional Well Log Analysts, London Chapter, 15 p. Also published in 1974: APEA [Australian Petroleum Exploration Association] Journal, v. 14, part 1, p. 181-188.

Smith, R.G., and Baker, J.D., 1983, The Dipmeter Advisor system, a case study in commerical expert system development, in 8th international joint conference on artifical intelligence, proceedings: International Joint Conference on Artificial Intelligence, p. 122-129.

Standen, E., 1982, Correlating the dipmeter to EPT moved-oil plots: The Technical Review, v. 30(3), December, p. 43-49.

Standen, E., 1985, The use of dipmeter synthetic data to determine rock texture and depositional environment, paper AA, in 10th formation evaluation symposium transactions: Canadian Well Logging Society, 12 p.

Strozeski, B.B., Hilliker, D.J., and Oliver, D.W., 1989, Theoretical and experimental development of the ultrasonic DIPLOG System, paper DD, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 21 p.

Stuart-Bruges, W.P., 1984, A dipmeter for use in oil based muds, paper 32, in 9th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 8 p.

Vincent, Ph., Gartner, J.E., and Attali, G., 1977, An approach to detailed dip determination using correlation by pattern recognition, SPE-6823: Society of Petroleum Engineers, 52nd annual meeting [Denver] preprint. Later published in 1979, Journal of Petroleum Technology, v. 31(2), p. 232-240.

Wahab, A., 1975, An analysis of dipmeter survey results in the Langkat area, in 4th annual convention proceedings, volume 1: Indonesian Petroleum Association, Jakarta, p. 83-112.

Waid, C.C., 1987, Effect of tool rotation on the computation of dip, paper Q, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 22 p.

Waid, C.C., Easton, S.B., and Weissman, G.S., 1988, An algorithm for determining stratigraphic dip: Journal of Petroleum Science and Engineering, v. 1(4), p. 301-314.

Waid, C.C., Easton, S.B., and Weissman, G.S., 1988, Advances in Diplog data processing for stratigraphic analysis: Bulletin Geological Society of Malaysia [Buletin Persatuan Geologi Malaysia], no. 22, p. 85-99.

Waterhouse, M., 1989, The evolution of a dipmeter analysis; a case study from Pakistan, paper J, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 22 p.

6. APPLICATIONS OF ARTIFICIAL INTELLIGENCE (AI) AND EXPERT SYSTEMS

(See also 7. Well-Log Data Processing)

Awal, M.R., and Arnold, F.C., 1990, DENIS--an expert system for identification of depositional environments, in 1990 conference on artificial intelligence in petroleum exploration and production [College Station, TX, May 16-18], proceedings: Texas A&M University, College Station, p. 143-153.

Baker, J.D., 1984, Dipmeter Advisor--an expert log analysis system at Schlumberger in P.H. Winston and K.A. Prendergast, editors, The AI business; the commercial uses of artificial intelligence: MIT Press, Cambridge, Massachussetts, p. 51-65.

Baker, P.L., 1989, Log analysis systems incorporating artificial intelligence techniques; some examples: Exploration Geophysics [Bulletin Australian Society of Exploration Geophysicists], v. 20(1-2), p. 331-334.

Baker, P.L., and Smoliar, S.W., 1984, Applying artifical intelligence to the interpretation of petroleum well logs, in Proceedings, first conference on artificial intelligence applications: The Institute of Electrical and Electronics Engineers Computer Society Press, p. 558-561.

Baldwin, J.L., Bateman, R.M., and Wheatley, C.L., 1989, Application of a neural network to the problem of mineral identification from well logs, paper U, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 337-347.

Baldwin, J.L., Otte, D.N., and Bateman, R.M., 1989, Computer emulation of human mental processes; application of neural network simulators to problems in well log interpretation, in Artificial intelligence in petroleum exploration and production, proceedings: Texas A&M University, College Station, p. 145-175. Also published in 1989 as SPE-19619, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 481-493.

Bonnet, A., and Dahan, C., 1983, Oil-well interpretation using expert system and pattern recognition technique, in 8th international joint conference on artificial intelligence, proceedings: American Association on Artificial Intelligence, Palo Alto, p. 185-189.

Citerne, A., and Yu, K., 1988, Knowledge-based well data management and graphical interface, SPE-17611, in SPE international meeting on petroleum engineering [Tianjin, China], proceedings: Society of Petroleum Engineers, p. 633-640.

Crain, E.R., 1985, A primer on artificial intelligence and expert systems in the petroleum industry: Canadian Well Logging Society Journal, v. 14, p. 17.

Crain, E.R., 1989, A knowledge-based spreadsheet system to reduce complexity in log analysis, paper Y, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 30 p.

Davis, J.C., and Olea, R.A., 1989, Artificial intelligence for the correlation of well logs, in Agterberg, F.P. and Bonhamn-Carter, G.F., editors, Statistical applications in the earth sciences: Geological Survey of Canada, Paper No. 89-9, p. 389-394.

Davis, R., Austin, H., Carlbom, I, Frawley, B., Pruchnik, P., Sneiderman, R., and Gilreath, J.A., 1981, The Dipmeter Advisor--Interpretation of geological signals, in 7th international joint conference on artificial intelligence, [Vancouver, British Columbia, Canada], proceedings: ?? p. 846-849.

Derek, H., Johns, R., and Pasternack, E., 1990, Comparative study of backpropagation neural network and statistical pattern recognition techniques in identifying sandstone lithofacies, in 1990 conference on artificial intelligence in petroleum exploration and production [College Station, TX, May 16-18], proceedings: Texas A&M University, College Station, p. 41-49.

Einstein, E.E., and Edwards, K.W., 1988, Comparison of an expert system to human experts in well log analysis and interpretation, SPE-18129, in 1988 SPE annual technical conference proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 253-262. Later published in 1990, SPE Formation Evaluation, v. 5(1), March, p. 39-45.

Einstein, E.E., and Sutherland, L., 1989, An expert system for assistance in well log analysis; an overview: SPE Computer Applications, July-August, p. 20.

Frank, W., 1986, The Dipmeter Advisor is field tested, in Expert systems and knowledge engineering [Gottlieb Duttweiler Institute of Technological Assessment and management (April 25-26, 1985), conference proceedings]: Elsevier Science Publishers, New York, p. 167-175. Also published in 1986, in T. Bernold, editor, Expert systems and knowledge engineering (essential elements of advanced information technology): Elsevier Science Publishers, B.V., Amsterdam, pp. 111-120.

Gershman, A., 1982, Building a geological expert system for dipmeter interpretation, in European conference on artificial intelligence [Orsay, France, July 12-14], proceedings: ?, p. 139-140.

Griffiths, C.M., 1989, An example of the use of a fuzzy-set based pattern recognition approach to the problem of strata recognition from drilling response, in Oleynikov, A., and Rubel, M., editors, Quantitative stratigraphy--restrospective evaluation and future development [IGCP Project No. 148]: Academy of Sciences, Estonian Socialist Republic, Tallinn, p. 83-100.

Harker, S.D., McGann, G.J., Bourke, L.T., and Adams, J.T., 1990, Methodology of Formation MicroScanner image interpretation in Claymore an Scapa fields (North Sea), in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 11-25.

Josso, M., 1986, The Dipmeter Advisor--An expert system comes to South-East Asia, in 6th SPE offshore South East Asia conference [Singapore, January 28-31], proceedings: South East Asia Petroleum Exploration Society, p. 461-466.

Kerzner, M.G., 1983, Formation dip determination--An artificial intelligence approach: The Log Analyst, V. 24(5), September-October, P. 10-22.

Kerzner, M.G., 1988, A rule-based approach to dipmeter processing, SPE-18128, in 1988 SPE annual technical conference proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 239-251.

Korth, H.F., and Peltier, X., 1990, Query processing issues in knowledge bases, in 1990 conference on artificial intelligence in petroleum exploration and production [College Station, TX, May 16-18], proceedings: Texas A&M University, College Station, p. 121-128.

Kuo, T-B., 1986, Well log correlation using artificial intelligence: Texas A&M University, unpublished PhD thesis, 138 p.

Kuo, T-B., and Startzman, R.A., 1987, Field-scale stratigraphic correlation using artificial intelligence: Geobyte v. 2(2), 30-35.

Lineman, D.J., Mendelson, J.D., and Toksoz, M.N., 1987, Well to well log correlation using knowledge-based systems and dynamic depth warping, paper UU, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Lineman, D.J., Mendelson, J.D., and Toksoz, M.N., 1989, An expert system for well-to-well log correlation, in Simaan, M., and Aminzadeh, F., editors, Artificial intelligence and expert systems in petroleum exploration: JAI Press, Inc., Greenwich, CT, Advances in Geophysical Data Processing, v. 3, p. 235-278.

Luthi, S.M., 1990, Sedimentary structures of clastic rocks identified from electrical borehole images, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 3-10.

Nurmi, R., Charara, M., Waterhouse, M., and Park, R., 1990, Heterogeneities in carbonate reservoirs; detection and analysis using borehole electrical imagery, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 95-111.

Olea, R.A., and Davis, J.C., 1986, An artificial intelligence approach to lithostratigraphic correlation using geophysical well logs, SPE-15603: Society of Petroleum Engineers, 61st annual meeting [New Orleans] preprint, 12 p.

Olea, R.A., and Davis, J.C., 1989, An expert system for the correlation of geophysical well logs, in Simaan, M., and Aminzadeh, F., editors, Artificial intelligence and expert systems in petroleum exploration: JAI Press, Inc., Greenwich, CT, Advances in Geophysical Data Processing, v. 3, p. 279-307.

Pajot, D.J., Paul, A., Winchester, A.J., 1989, Knowledge representation in a workstation for reservoir analysis, paper PP, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 21 p.

Peveraro, R.C.A., and Lee, J.A., 1988, HESPER--An expert system for petrophysical formation evaluation, paper R, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 22 p. Also published in 1988, SPE-18375, in SPE European petroleum conference [London] proceedings: Society of Petroleum Engineers, p. 361-370.

Shanor, G.G., 1987, The Dipmeter Advisor; a dipmeter interpretation workstation: Bulletin of the Geological Society of Malaysia, v. 21, Special Issue on Petroleum Geology v. 2, December, p. 37-54.

Smith, R.G., and Baker, J.D., 1983, The Dipmeter Advisor system, a case study in commerical expert system development, in 8th international joint conference on artifical intelligence, proceedings: International Joint Conference on Artificial Intelligence, p. 122-129.

Smith, R.G., and Young, R.L., 1984, The design of the dipmeter advisor system, in ACM annual conference [October, 1984], proceedings: Association for Computing Machinery, New York, p. 15-23.

Startzman, R.A., and Kuo, T.B., 1986, An artificial intelligence approach to well log correlation, paper WW, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 21 p. Also published in 1986 as, A rule-based system for well log correlation, SPE-15295, in Symposium on petroleum industry applications of microcomputers [Silver Creek, Colorado, June 18-20], proceedings: Society of Petroleum Engineers, p. 113-124. Later published in 1987, The Log Analyst, v. 28(2), March-April, p. 175-183, and SPE Formation Evaluation, v. 2(3), September, p. 311-319.

Startzman, R.A., and Kuo, T.B., 1989, A knowledge-based approach to the interpretation of well-bore images, in Artificial intelligence in petroleum exploration and production, proceedings: Texas A&M University, College Station, p. 35-42.

Wu, X., and Nyland, E., 1986, Well log data interpretation using artificial intelligence technique, paper M, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p.

Zivy, G.M., 1984, The role of expert systems in producing log interpretation software: Expert Systems, v. 1(1), p. 57-62.

7. WELL-LOG DATA PROCESSING
(Including Log Correlation and Analysis)

Alcocer, C.F., and Hayatdavoudi, A., 1989, A practical and comprehensive well logging evaluation technique for modern computers, SPE-18524, in SPE eastern regional meeting, proceedings: Society of Petroleum Engineers, p. 21-26.

Anderson, R.N., Broglia, C., Pezard, A., Williams, C.F., 1988, Lithostratigraphy determined from discriminant analysis of geochemical well logs from the Cajon Pass scientific drillhole, California: Geophysical Research Letters, v. 15(9, supplement), p. 957-960.

Anxionnaz, H., Delfiner, P., and Delhomme, J.P., 1990, Computer-generated corelike descriptions from open-hole logs: AAPG Bulletin, v. 74(4), p. 375-393.

Asten, M.W., 1983, Borehole log analysis using an interactive computer: Australian Society of Exploration Geophysicists Bulletin, v. 14, p. 3-10.

Baker, M.R., 1987, Quantitative log interpretation using probablistic internally consistent inversion (PICI), in Geosciences collequium [February 27-28], proceedings: Univeristy of Texas at El Paso, Department of Geological Sciences, p. 49-60.

Ball, S.B., Chace, D.M., and Fertl, W.H., 1987, The Well Data System (WDS)--An advanced formation evaluation concept in a microcomputer environment, SPE-17034, in 1987 SPE eastern regional meeting proceedings: Society of Petroleum Engineers, p. 61-85.

Berteig, V., Helgeland, J., Mohn, E., Langeland, T., and van der Wel, D., 1985, Geofacies determination by logging data, paper TT, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Bigelow, E.L., and Easton, S.B., 1986, Electrofacies fingerprints of eolian desert environments, paper V, in 10th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Aberdeen Chapter, 19 p.

Boichot, G., 1983, Non linear programming applied to stratigraphic log analysis: Sciences de la Terre, Informatique Geologique, v. 16, p. 59-72.

Bolviken, E., Helgeland, J., Storvik, G., Siring, E., and van der Wel, D., 1988, Statistical permeability prediction from wireline logs by switching and Markov regime models, paper Q, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 17 p.

Bornemann E., and Doveton, J.H., 1983, Lithofacies mapping of Viola Limestone in south central Kansas based on wireline logs: AAPG Bulletin, v. 67(4), p. 609-623.

Bowdon, R.D., 1985, Advantages of microcomputer log analysis: Bulletin of the West Texas Geological Society, v. 24(9), p. 8-10.

Bowler, J., 1987, Why the MacIntosh? A case study: Geobyte, v. 2(4), November, p. 48-53.

Branisa, F., 1974, Filtering of well-log curves: Geophysics, v. 39(4), August, p. 545-549.

Busch, J.M., Fortney, W.G., and Berry, L.N., 1985, Determination of lithology from well logs by statistical analysis, SPE-14301: Society of Petroleum Engineers, 60th annual meeting preprint, 11 p. Later published in 1987, SPE Formation Evaluation, v. 2(4), p. 412-418.

B‚scher, M., 1985, Interpretation of structure analyzing logs (GEODIP and SABIS) of the research borehole Konzen, Hohes Venn (West Germany): Neues Jahrbuch f‚r Geologie und Pal‰ontologie, v. 1711-3), p. 95-104.

Charara, M., and Rabadi, N., 1987, Lithological and sedimentological evaluation using computerized interpretation programs, SPE-15731, in 5th SPE Middle East oil show [Manama, Bahrain], proceedings: Society of Petroleum Engineers, p. 341-350.

Collins, D.R., and Doveton, J.H., 1986, Color images of Kansas subsurface geology from well logs: Computers & Geosciences, v. 12(4B), p. 519-526.

Collins, D.R., and Doveton, J.H., 1988, Application of color information theory to the display of lithologic images from wireline logs, paper II, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 15 p. Later published in 1989, Geobyte, v. 4(1), February, p. 16-24.

Collins, D.R., and Doveton, J.H., 1988, Colour image transformations of wireline logs as a medium for sedimentary profile analysis: Bulletin of Canadian Petroleum Geology, v. 36(2), June, p. 186-190.

Collins, H.N., 1984, Regression analysis - some loose ends: Canadian Well Logging Society Journal, v. 13, p. 61-65.

Crain, E.R., 1986, Computer-aided log analysis, chapter 15, in The log analysis handbook, volume 1--Quantitative log analysis methods: PennWell Books, Tulsa, p. 463-487.

Day, R.B., Tucker, E.V., and Wood, L.A., 1987, A quantified approach to the lithostratigraphic correlation of site investigation borehole logs: Computers & Geosciences, v. 13(2), p. 161-184.

Delfiner, P., Delhomme, J.P., and Pelissier-Cobescure, J., 1983, Application of geostatistical analysis to the the evaluation of petroleum reservoirs with well logs, paper WW, in 24th annual logging symposium transactions: Society of Professional Well Log Analysts, 26 p.

Delfiner, P.C., Peyret, O., and Serra, O., 1984, Automatic determination of lithology from well logs, SPE-13290: Society of Petroleum Engineers, 59th annual meeting [Houston] preprint, 8 p. Later published in 1987, SPE Formation Evaluation, v. 2(3), September, p. 303-310.

Descalzi, C., Rognoni, A., and Cigni, M., 1988, Synergetic log and core data treatment through cluster analysis; a methodology to improve reservoir description, SPE-17637, in SPE international meeting on petroleum engineering [Tianjin, China], proceedings: Society of Petroleum Engineers, p. 913-920.

Dimitrakopoulas, R., 1988, Stochastic modelling of space dependent reservoir-rock properties, paper 88-39-113, in 39th annual technical meeting, preprints, volume 3: Petroleum Society of CIM [Canadian Institute of Mining], Calgary, 19 p.

Ditzhuijen, P.J.D., and Massan, D., 1984, A multilog-evaluation package using linear programming techniques to evaluate porosity and lithology in hydrocarbon bearing complex lithologies, SPE-12376, in 5th offshore South East Asia conference [February 21-24, Singapore], proceedings: Society of Petroleum Engineers, 17 p.

Doveton, J.H., 1983, Automated lithofacies analysis from well logs, in 12th annual geochautauqua short course notes, November 8, 1983: Kansas Geological Survey/University of Kansas, Lawrence, 188 p.

Doveton, J.H., 1986, Log analysis of subsurface geology--Concepts and computer methods: John Wiley & Sons, New York, 273 p.

Doveton, J.H., 1988, Automated well-log analysis and correlation: Interstate Oil and Gas Compact Commission Bulletin, v. 2(2), p. 94-98. Later published in 1989 in abridged form, Advances aid computer log analysis: American Oil and Gas Reporter, v. 32(11), p. 17-21.

Doveton, J., 1989, Subsurface lithofacies mapping from geophysical logs in Kansas, in Steeples, D.W., editor, Geophysics in Kansas: Kansas State Geological Survey Bulletin No. 226, p. 177-184.

Doveton, J.H., and Bornemann, E., 1981, Log normalization by trend surface analysis: The Log Analyst, v. 22(4), July-August, p. 3-8.

Doveton, J.H., and Cable, H.W., 1979, Fast matrix methods for the lithological interpretation of geophysical logs, in D. Gill and D.F. Merriam, editors, Geomathematical and petrophysical studies in sedimentology: Pergamon Press, Oxford, Computers in Geology Series, p. 101-116.

Doveton, J.H., Ke-An, Z., and Davis, J.C., 1984, Three-dimensional trend mapping using gamma-ray well logs--Simpson Group, south-central Kansas: AAPG Bulletin, v. 68(6), p. 690-703.

El-Sheikh, T.S., and Syiam, M.M., 1989, An efficient technique for lithology classification: IEEE Transactions on Geoscience and Remote Sensing, v. 27(5), September, p. 629-632

Elek, I., 1988, Some applications of principle component analysis; well-to-well correlation, zonation: Geobyte, v. 3(20), p. 46-55.

Etnyre, L.M., 1982, Statistical detection of hydrocarbons from well logs, paper Z, in 23rd annual logging symposiums transactions: Society of Professional Well Log Analysts, 29 p. Later published in 1984 as, Practical application of weighted least squares method to formation evaluation, part I--The logarithmic transformation of non-linear data and selection of dependent variable: The Log Analyst, v. 25(1), January-February, p. 11-21. Part II--Evaluating the uncertainty in least squares results: The Log Analyst, v. 25(3), May-June, p. 11-20.

Frank, W., 1986, Sand-shale identification by computer: Transactions Gulf Coast Association of Geological Societies, v. 36, p. 111-119.

Gill, D., 1970, Application of a statistical zonation method to reservoir evaluation and digitized-log analysis: AAPG Bulletin, v. 54(5), p. 719-729.

Griffiths, C.M., 1982, A proposed geologically consistent segmentation and reassignment algorithm for petrophysical borehole logs, in J.M. Cubitt and R.A. Reyment, editors, Quantitative stratigraphic correlation: John Wiley & Sons, New York, p. 287-298.

Griffiths, C.M., and Bakke, S., 1988, Semi-automated well matching using gene-typing algorithms and a numerical lithology derived from wire-line logs, paper GG, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 24 p.

Griffiths, C.M., and Bakke, S., 1990, Interwell matching using a combination of petrophysically derived numerical lithologies and gene-typing techniques, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 133-151.

Gysen, M., Mayer, C., and Hashmy, K.H., 1987, A new approach to log analysis involving simultaneous optimization of unknowns and zoned parameters, paper B, in 11th formation evaluation symposium transactions: Canadian Well Logging Society, 20 p.

Heckel, B.H., 1985, Enhanced hydrocarbon recognition--A new approach to well evaluation for sand-shale sequences, paper 85-36-45, in 36th annual technical meeting, Petroleum Society of CIM [Edmonton], preprints, volume 2, : Petroleum Society of CIM, Calgary, p. 645-661. Also published in 1986, in 10th formation evaluation symposium transactions, paper L: Calgary, Canadian Well Logging Society, 17 p.

Hempkins, W.B., 1977, Multivariate statistical approaches in formation evaluation, paper DD, in 18th annual logging symposium transactions: Society of Professional Well Log Analysts, 23 p.

Hoyle, I.B., 1986, Computer techniques for the zoning and correlation of well-logs: Geophysical prospecting, v. 34(5), August, p. 648-664.

Jensen, J.L., and Lake, L.W., 1985, Optimization of regression-based porosity-permeability predictions, paper R, in 10th formation evaluation symposium transactions: Canadian Well Logging Society, 22 p.

Johnson, N.M., and Dreiss, S.J., 1989, Hydrostratigraphic interpretation using indicator geostatistics: Water Resources, v. 25(12), p. 2,501-2,510.

Kassenaar, D., and Dusseault, M.B., 1986, Development of a PC-based interactive geophysical log interpretation system, in 25th annual conference, proceedings: Ontario Petroleum Institute, Ontario, Canada, 22 p.

Kemp, F., 1982, An algorithm for the stratigraphic correlation of well logs: Mathematical Geology, v. 14(3), p. 271-285.

Kerzner, M.G., 1986, Obtaining structural and stratigraphic dip information from dipmeter logs using segmentation trees and hierarchical multilevel optimization, SPE-15539: Society of Petroleum Engineers, 61st annual meeting preprint, 15 p. Later published in 1988, SPE Formation Evaluation, v. 3(1), p. 47-54.

Kerzner, M.G., 1986, Image processing in well log analysis: IHRDC Press, Boston, 140 p.

Kerzner, M.G., and Frost, E., Jr., 1982, Blocking--A new technique for well log interpretation, SPE-11093: Society of Petroleum Engineers, 57th annual meeting [New Orleans] preprint. 14 p. Later published in 1984, Journal of Petroleum Technology, v. 36(2), p. 267-275.

Keys, W.S., 1985, Use of a microcomputer to analyze geophysical logs of a water well in a carbonate aquifer, in G. Gunay and A.I. Johnson, editors, Karst water resources [proceedings of a symposium in Ankara, Turkey, July, 1985]: International Association of Hydrological Sciences, Washington, D.C., Publication No. 161, p. 249-260.

King, D.E., and Quirein, J., 1987, Systematic incorporation of geologic data in the log interpretation process with applications to lithlogy analysis, paper N, in 11th formation evaluation symposium transactions: Canadian Well Logging Society, 14 p.

Lanning, E.N., and Johnson, D.M., 1983, Automated identification of rock boundaries--An application of the Walsh transform to geophysical well-log analysis: Geophysics, v. 48(2), p. 197.

Leaney, W.S.P., and Ulrych, T.J., 1987, Multiple dynamic matching; a new apprach to well log correlation: Geoexploration, v. 24(6), p. 503-515.

Lineman, D.J., Mendelson, J.D., and Toksoz, M.N., 1987, Well to well log correlation using knowledge-based systems and dynamic depth warping, paper UU, in 28th annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Looyestijn, W.J., 1982, Deconvolution of petrophysical logs--Applications and limitations, in 23rd annual logging symposium transactions, paper W: Society of Professional Well Log Analysts, 20 p. A discussion of improving the vertical resolution of different logging tools.

Magara, K., 1979, Identification of sandstone body types by computer method: Journal of the International Association for Mathematical Geology, v. 11(3), p. 269-283.

Magara, K., 1986, Lithostatistical study of Frio Formation in Texas Gulf Coast, chapter 12, in Geological models of petroleum entrapment: Elsevier Applied Science Publishers, London, p. 235-263.

Magara, K., 1986, Identification of sandstone body types by the computer method, chapter 11, in Geological models of petroleum entrapment: Elsevier Applied Science Publishers, London, p. 217-234.

Mann, C.J., 1979, Obstacles to quantitative lithostratigraphic correlation, in D. Gill and D.F. Merriam, editors, Geomathematical and petrophysical studies in sedimentology: Pergamon Press, New York, p. 149-165.

Mann, C.J., and Dowell, T.P.L., Jr., 1977, Quantitative lithostratigraphic correlation of subsurface sequences: Computers and Geosciences, v. 4, p. 295-306.

Mason, T.R., and Arnold, A.R., 1985, A computer-based archive for storage and correlation of geological borehole logs: Petros, v. 12, p. 22-37.

Mathews, M., and LaDelfe, C., 1981, Log comparison and quantification, paper I, in 8th formation evaluation syposium transactions: Canadian Well Logging Society.

Matuszak, D.R., 1972, Stratigraphic correlation of subsurface geologic data by computer: Mathematical Geology, v. 4(4), p. 331-343. Discussion of Holgate crossplots.

Merkel, R.H., and Head, W.J., 1977, The use of computerized log analysis to determine in situ lithologic characteristics pertinent to secondary recovery: Bulletin of Canadian Petroleum Geologists, v. 25(2), May, p. 291-304.

Messineo, A.V., 1980, The use of computers in log interpretation to evaluate complex reservoirs, in Tenth world petroleum congress, proceedings, volume 3: Heyden, London, p. 171-179.

Mezzatesta, A., Rodriguez, Frost, E., 1988, OPTIMA--A statistical approach to well log analysis: Geobyte, v. 3(3), August, p. 56-69.

Mitchell, W.K., and Nelson, R.J., 1988, A practical approach to statistical log analysis, paper S, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 20 p.

Moghaddamjoo, A., 1989, Constraint optimum well-log signal segmentation: IEEE Transactions on Geoscience and Remote Sensing, v. 27(5), September, p. 633-641.

Mohn, E., Berteig, V., and Helgeland, J., 1987, A review of statistical approaches to lithofacies determination from well data, chapter 22, in J. Kleppe, E.W. Berg, A.T. Buller, O. Hjelmeland, and O. Torsaeter, editors, North Sea oil and gas reservoirs: Graham & Totman Ltd., London, p. 301-309.

Moinard, L., 1987, Application of kriging to the mapping of a reef from wireline logs and seismic data, a case history, in G. Matheron and M. Armstrong, editors, Geostatistical case studies: D. Reidel Publishers, Dordrecht, Netherlands, Quantitative Geology and Geostatistics Series, p. 93-103.

Morin, R.H., LeBlanc, D.R., and Teasdale W.E., 1988, A statistical evaluation of formation disturbance produced by well-casing installation methods: Ground Water, v. 26(2), p. 207-217.

Mosa, M.M., 1983, Lithology computer program--Three minerals plus shale contamination and porosity, appendix 2, in S.J. Pirson, Geologic well log analysis, 3rd edition: Gulf Publishing Company, Houston, p. 343-362.

Moss, B.P., 1990, Stochastic reservoir description; a methodology, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 57-75.

Mulhern, M.E., Laing, J.E., Senecal, J.E., Widdicombe, R.E., Isselhart, C., and Bowersox, J.R., 1986, Electrofacies identification of lithology and stratigraphic trap, southeast Lost Hills fractured shale pool, Kern County, California: Geobyte, v. 1(4), p. 48-56.

Olea, R.A., 1988, CORRELATOR--An interactive computer system for lithostratigraphic correlation of wireline logs: Kansas Geological Survey Petrophysical Series No. 4, 85 p.

Olea, R.A., and Davis, J.C., 1986, An artificial intelligence approach to lithostratigraphic correlation using geophysical well logs, SPE-15603: Society of Petroleum Engineers, 61st annual meeting [New Orleans] preprint, 12 p.

Oliveira, A., and Dufour, J., 1989, Estimating petrophysical parameters from a probabilistic database, paper Z, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 14 p.

Pande, K.N., 1987, Use of physical properties of shale for evaluating reliable correlation between electrofacies and chronostratigraphic correlation, paper S, in 11th formation evaluation symposium transactions: Canadian Well Logging Society, 18 p.

Poelchau, H.S., 1987, Coherence mapping--An automated approach to display goodness-of-correlation between wells in a field: Mathematical Geology, v. 19(8), p. 833-850.

Quirein, J., Kimminau, S., Lavigne, J., Singer, J., and Wendel, F., 1986, A coherent framework for developing and applying multiple formation evaluation models, paper DD, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p.

Reid, I., Linsey, T., and Frostick, L.E., 1989, Automatic bedding discriminator for use with digital wireline logs: Marine and Petroleum Geology, v. 6(4), November, p. 364-369.

Reyment, R., 1982, Correlating between electrical borehole logs in paleocology, in J.M. Cubitt and R.A. Reyment, editors, Quantitative stratigraphic correlation: John Wiley, New York, p. 233-240.

Reyment, R., and Sturesson, U., 1987, Correlation of chemical and physical environmental fluctuations in a Late Cretaceous borehole sequence--A multivariate study: Sedimentary Geology, v. 53, p. 311-325.

Rider, M.H., and Laurier, D., 1979, Sedimentology using a computer treatment of well logs, paper J, in 6th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, London Chapter, 12 p.

Robinson, J.E., 1977, Pitfalls in automatic lithostratigraphic correlation: Computers and Geosciences, v. 4, p. 273-275.

Robinson, J.E., 1982, Computer analysis of well logs, chapter 12, in Computer applications in petroleum geology: Hutchinson Publishing Company, New York, p. 143-151. [Discussion of unusual graphic displays of log data.]

Robinson, J.E., 1986, Correcting well-log information for computer processing and analysis: Computers & Geosciences, v. 12(4B), p. 493-498.

Robinson, M.C., and Reeves, J.J., 1989, Cluster analysis of geophysical well-log data in the North Riley unit, Gaines County, Texas, paper BG 2.7, in Expanded abstracts with biographies 59th annual meeting, v. 1: Society of Exploration Geophysicists, p. 51-54.

Rodriguez, E., Tetzlaff, D.M., Mezzatesta, A., and Frost, E., 1988, Estimating rock properties by statistical methods, SPE-17603, in SPE international meeting on petroleum engineering [Tianjin, China], proceedings: Society of Petroleum Engineers, p. 539-552.

Sahu, B.K., and Satyanarayana, C., 1986, Multivariate factor model for well log analysis of Bombay High area, India: Bulletin of the Oil and natural Gas Commission [India], v. 23(1), p. 153-162.

Schoonover, L.G., and Holt, O.R., 1973, Computer methods of dip log correlations, SPE-3566: Society of Petroleum Engineers Journal, v. 13(1), February, p. 31-38.

Serra, O., and Sulpice, L., 1975, Sedimentological analysis of sand-shale series from well logs, paper W, in 16th annual logging symposium transactions: Society of Professional Well Log Analysts, 23 p.

Shaw, B.R., 1977, Parametric interpolation of digitized log segments: Computers and Geosciences, v. 4, p. 277-283.

Shaw, B.R., and Cubitt, J.M., 1979, Stratigraphic correlation of well logs--An automated approach, in D. Gill and D.F. Merriam, editors, Geomathematical and petrophysical studies in sedimentology: New York, Pergamon Press, p. 127-148.

Skandsen, J., Backe, K.R., Lile, O.B., and Griffiths, C.M., 1989, A knowledge-based system for interpretation of wireline logs, in Artificial intelligence in petroleum exploration and production, proceedings: Texas A&M University, College Station, p. 51-58.

Somturk, A.R., and Des Ligneris, S., 1985, LITHO; a computerized approach to lithofacies determination: Geological Society of Malyasia Bulletin [Buletin Persatuan Geologi Malaysia], v. 18, p. 101-118.

Startzman, R.A., and Kuo, T.B., 1986, An artificial intelligence approach to well log correlation, paper WW, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 21 p. Also published in 1986 as, A rule-based system for well log correlation, SPE-15295, in Symposium on petroleum industry applications of microcomputers [Silver Creek, Colorado, June 18-20], proceedings: Society of Petroleum Engineers, p. 113-124. Later published in 1987, The Log Analyst, v. 28(2), March-April, p. 175-183, and SPE Formation Evaluation, v. 2(3), September, p. 311-319.

Swamy, V.V.L.N., 1988, Computer interpretation of well-logging data, topic 13.2, in Murty, B.V.S., Nandakumar, G., Reddy, P.C., and Rao, S.M.V., editors, Geophysical technology for coal prospecting [national workshop lectures]: Osmania University, Centre for Exploration Geophysics, Hyderabad, India, p. p. 185-203.

Szendro, D., 1983, A statistical method for lithologic interpretation from well logs: The Log Analyst, v. 24(3), May-June, p. 16-23.

Tsay, F.S., and Lai, P.F., 1988, Stratigraphic correlation of well logs using relational tree representation, SPE-17604, in SPE international meeting on petroleum engineering [Tianjin, China], proceedings: Society of Petroleum Engineers, p. 553-558.

Vincent, Ph., Gartner, J.E., and Attali, G., 1977, An approach to detailed dip determination using correlation by pattern recognition, SPE-6823: Society of Petroleum Engineers, 52nd annual meeting [Denver] preprint. Later published in 1979, Journal of Petroleum Technology, v. 31(2), p. 232-240.

Waid, C.C., Easton, S.B., and Weissman, G.S., 1988, An algorithm for determining stratigraphic dip: Journal of Petroleum Science and Engineering, v. 1(4), p. 301-314.

Wolff, M., and Pelissier-Combescure, J., 1982, FACIOLOG--Automatic electrofacies determination, paper FF, in 23rd annual logging symposium transactions: Society of Professional Well Log Analysts, 22 p.

Wu, X., and Nyland, E., 1987, Automated stratigraphic interpretation of well-log data: Geophysics, v. 52(12), p. 1665-1676.

8. NATURAL GAMMA-RAY SPECTROMETRY

Anderson, J.A., Pearson, C.M., Abou-Sayed, A.S., and Myers, G.D., 1986, Determination of fracture height by spectral gamma log analysis, SPE-15439: Society of Petroleum Engineers, 61st annual meeting [New Orleans] preprint, 8 p.

Atwater, J.E., 1984, Spectrometric gamma ray logging of core: Canadian Well Logging Society Journal, v. 13, p. 29-39.

Bristow, Q., and Killeen, P.G., 1982, Natural gamma-ray spectral logging using scintillation detectors, in Symposium on uranium exploration methods [Paris, June 1-4, 1982], proceedings: Nuclear Energy Agency, Organization for Economic Cooperation and Development, Paris, p. 777-791.

Bristow, Q., Killeen, P.G., and Mwenifumbo, J.C., 1982, Comparison of standardized gamma-ray log calibration measurements--Ottawa, Adelaide and Grand Junction, in Symposium on uranium exploration methods [Paris, June 1-4, 1982], proceedings: Nuclear Energy Agency, Organization for Economic Cooperation and Development, Paris, p. 715-727.

Dickson, B.L., and Ramsden, A.R., 1986, Significance of the Toolebuc gamma ray anomaly in the search for and evaluation of oil shale in the Eromanga Basin: Australian Journal of Earth Sciences, v. 33(4), p. 429-441.

Dion, E.P., and Allen, L.S., 1985, The accuracy of commercial natural gamma-ray spectral logs, in 1985 technical program abstracts and biographies: Society of Exploration Geophysicists, Tulsa, p. 283-285.

Donovan, W.S., and Hilchie, D.W., 1979, Natural gamma ray emission in the Muddy J Formation in eastern Wyoming, paper B, in 7th formation evaluation symposium transactions: Canadian Well Logging Society, 11 p. Later published in 1981, The Log Analyst, v. 22(2), February-March, p. 17-22.

Dresser Atlas, 1981, Spectralog: Dresser Industries, Houston, Publication No. 3334, variously paginated. [Reprint volume containing papers on tool applications.]

Dyck, A.V., Auchincloss, P.V., and Atherton, D.L., 1989, High-resolution magnetic-susceptibility logger and dipmeter for mineral exploration boreholes; concept and initial progress (Grant 332), in Milne, V.G., editor, Geoscience research grant program summary of research 1988-1989: Ontario [Canada] Geological Survey Miscellaneous Paper 143, p.146-159.

Dypvik, H., and Eriksen, D.O., 1983, Natural radioactivity of clastic sediments and the contribution of U, Th, and K: Journal of Petroleum Geology, v. 5(4), April, p. 409-416.

Feely, M., and Madden, J., 1986, A quantitative regional gamma-ray survey on the Main Galway Granite, in Andrew, C.J., Crowe, R.W.A., Finlay, S., Pennell, W.M., and Pyne, J.F., editors, Geology and genesis of mineral deposits of Ireland: Irish Association for Economic Geology, p. 195-199.

Felder, P.J., and Boonen, L.G.M., 1988, Gamma-ray measurements of Upper Cretaceous to Pleistocene deposits in south Limburg (SE Netherlands) and northern Liege (NE Belgium), in M. Streel, and M.J.M. Bless, editors, The chalk district of the Euregio Meuse-Rhine; selected papers on Upper Cretaceous deposits: Naturhistorisch Museum, Maastricht, Netherlands, p. 17-24.

Fertl, W.H., 1979, Gamma ray spectral data assists in complex formation evaluation, paper Q, in 6th European formation evaluation symposium transactions, : Society of Professional Well Log Analysts, London Chapter. Later pubished in 1979, The Log Analyst, v. 20(5), September-October, p. 3-37. Reprinted in 1981, in Spectralog: Dresser Industries, Houston, Publication No. 3334.

Fertl, W.H., 1983, Gamma ray spectral logging--A new evaluation frontier, part I--Principles : World Oil, v. 196(4), March, p. 79-91. [A seven-part series. See References.]

Fertl, W.H., 1983, Gamma ray spectral logging--A new evaluation frontier, part II--Application in carbonates: World Oil, v. 196(5), April, p. 87-98.

Fertl, W.H., 1983, Gamma ray spectral logging--A new evaluation frontier, part III--Measuring source rock potential: World Oil, v. 196(6), May, p. 147-155.

Fertl, W.H., 1983, Gamma ray spectral logging--A new evaluation frontier, part IV--Application in fractured shale: World Oil, v. 196(7), June, p. 189-204.

Fertl, W.H., 1983, Gamma ray spectral logging--A new evaluation frontier, part V--Application in clastic reservoirs: World Oil, v. 197(2), August 1, p. 57-63.

Fertl, W.H., 1983, Gamma ray spectral logging--A new evaluation frontier, part VI--Clay analysis in shaly sands: World Oil, v. 197(4), October, p. 99-112.

Fertl, W.H., 1983, Gamma ray spectral logging--A new evaluation frontier, part VII--Application in workovers/recompletions: World Oil, v. 197(5), November, p. 85-88.

Fertl, W.H., 1986, Log-derived evaluation of shaly clastic reservoirs, SPE-14061, in 1986 SPE international meeting on petroleum engineering [Beijing, March 17-20], proceedings: Society of Petroleum Engineers. Later published in 1987, Journal of Petroleum Technology, v. 39(2), p. 175-194.

Fertl, W.H., and Chilingar, G.V., 1988, Determination of volume, type, and distribution modes of clay minerals from well logging data, SPE-17145, in 8th SPE symposium on formation damage control, proceedings: Society of Petroleum Engineers, p. 13-28.

Fertl, W.H., Chilingarian, G.V., and Yen, T.F., 1982, Use of natural gamma ray spectral logging in evaluation of clay minerals: Energy Sources, v. 6(4), p. 335-360.

Fertl, W.H., and Rieke, H.H., III, 1979, Gamma ray spectral evaluation techniques identify fractured shale reservoirs and source-rock characteristics, SPE-8454: Society of Petroleum Engineers, 54th annual meeting [Las Vegas] preprint. Later published in 1980, Journal of Petroleum Technology, v. 32(11), p. 2053-2062.

Gendron, C.R., Cahill, R.A., and Gilkeson, R.H., 1988, Comparison of spectral gamma ray (SGR) well logging data with instrumental neutron activation analysis (INAA) data for rock types in northern Illinois: The Log Analyst, v. 29(5), September-October, p. 345-357.

Hurst, A., 1990, Natural gamma-ray spectrometry in hydrocarbon-bearing sandstones from the Norwegian continental shelf, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 211-222.

Koizumi, C.J., 1985, Computer determination of calibration and environmental corrections for a natural spectral gamma ray logging system, SPE-14186: Society of Petroleum Engineers, 60th annual meeting preprint, 12 p. Later published in 1988, SPE Formation Evaluation, v. 3(3), p. 637-650.

Kozhevnikov, D.A., and Shagin, V.L., 1989, A method of treating the spectral response of a tool in open and cased boreholes to determine the natural radioactivity of rocks: Nuclear Geophysics, v. 3(1), p. 17-29.

Mathis, G.L., 1987, Smoothing spectral gamma logs--A simple but effective technique: Geophysics, v. 52(3), p. 363-367.

Mickam, J.T., Levy, B.S., and Lee, G.W., Jr., 1984, Detection of fractures and solution channels in karst terranes using natural gamma ray and hole caliper borehole logs, in D.M. Nielsen and M. Curl, editors, 1984 NWWA/EPA conference on surface and borehole geophysics methods in ground water investigations, proceedings: National Water Well Association, Worthington, Ohio, p. 801-811.

Moll, S.H., 1980, Spectral gamma logging in the Copper Mountain uranium distric--A case study in fractured quartz monzonite, paper O, in, 21st annual logging symposium transactions: Society of Professional Well Log Analysts, 18 p.

Moore, D.C., 1980, Interpretation of total gamma logs in thin and dipping beds: Geophysics, v. 45(1)2, p. 1847-1856.

Mwenifumbo, C.J., and Killeen, P.G., 1987, Natural gamma ray logging in volcanic rocks; the Mudhole and Clementine base metal prospects, in R.V. Kirkham, editor, Buchans Geology, Newfoundland, paper 16: Geological Survey of Canada Paper 86-24, p. 263-272.

Mwenifumbo, C.J., Urbancic, T.I., and Killeen, P.G., 1983, Preliminary studies on gamma ray spectral logging in exploration for gold, in Current Research, part A: Geological Survey of Canada Paper no. 83-1A, p. 391-397.

Passaretti, M., Eslinger, E., and Hinterlong, G., 1986, High gamma ray zone from a core within a Permian dolostone sequence, SPE-15333: Society of Petroleum Engineers, unsolicited paper, 12 p.

Schlumberger, 1982, Essentials of natural gamma ray spectrometry interpretation: Schlumberger Technical Services, Paris, Document No. M-081025, 69 p.

Taylor, T.A., 1986, Application of gamma-spectral logging to ground-water investigations, in Surface and borehole geophysical methods and ground water instrumentation conference and exposition [Denver, October 15-17], proceedings: National Water Well Association, Dublin, Ohio, p. 527-544.

Taylor, T.A., 1989, Correlation of abnormal gamma readings with fluid movement through fractures in a formation by use of gamma-spectral logs, paper AA, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 472-499.

Woodward, D.G., 1984, Areal lithologic changes in bedrock aquifers in southeastern Minnesota as determined from natural-gamma borehole logs, in D.M. Nielsen and M. Curl, editors, 1984 NWWA/EPA conference on surface and borehole geophysics methods in ground water investigations, proceedings: National Water Well Association, Worthington, Ohio, p. 788-800.

Zelt, F.B., 1985, Natural gamma-ray spectrometry, lithofacies and depositional environments of selected Upper Cretaceous marine mudrocks, western United States, including Tropic Shale and Tununk Member of Mancos Shale: Princeton University, unpublished PhD. dissertation, 354 p.

Zelt, F.B., 1985, Paleo-oceanographic events and lithologic/geochemical facies of the Greenhorn marine cycle (Upper Cretaceous) examined using natural gamma-ray spectroscopy, in L. Pratt, E.G. Kaufmann, F.B. Zelt, editors, SEPM field trip guidebook no. 4, 1985 midyear meeting, Golden, Colorado: Society of Economic Paleontologists and Mineralogists, p. 49-59.

9. ORGANIC CARBON DETERMINATION AND SOURCE ROCK EVALUATION

Abdel-Rahman, E.M., and Wali, A., 1984, Determination of density and organic content of Matruh shales in the Western Desert of Egypt from density logs: Bulletin of the Faculty of Science, Cairo University [Egypt], v. 52(2), p. 589-600.

Abrahao, D., 1988, Well-log signatures of alluvio-lacustrine reservoir and source rocks of the Lagoa Feia Formation, Lower Cretaceous Campos basin, offshore Brazil: Colorado School of Mines, Golden, Department of Geology, Ph.D. thesis no. 3589, 279 p.

Abrahao, D., 1989, Well-log evaluation of lacustrine source rocks of the Lagoa Feia Formation, Lower Cretaceous, Campos Basin, offshore Brazil, paper I, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 22 p.

Autric, A., and Dumensil, P., 1985, Resistivity, radioactivity and sonic transit time logs to evaluate the organic content of low permeability rocks: The Log Analyst, v. 26(3), May-June, p. 36-45.

Carpentier, B., Bessereau, G., and Huc, A.Y., 1989, Well logs and source rocks; assessing organic carbon content by the CARBOLOG technique [in French, English abstract]: Revue de l'Institut Francais du Petrole, v. 44(6), November-December, p. 699-719.

Chilingar, G.V., Fertl, W.H., and Yen, T.F., 1984, Classification of source rocks on the basis of shale resistivity ratio parameter: Energy Soures, v. 7(3), p. 271-274.

Dellenbach, J., Espitalie, J., and Lebreton, F., 1983, Source rock logging, paper D, in 8th European logging symposium transactions: Society of Professional Well Log Analysts, London Chapter, 19 p.

Duba, A. Huenges, E., Nover, G., Will, G., and Jodicke, H., 1988, Impedance of black shale from Munsterland 1 borehole; an anomalously good conductor?: Geophysical Journal, v. 94(3), September, p. 413-419.

Fertl, W.H., and Chilingar, G.V., 1986, Total organic carbon content determined from well logs, SPE-15612: Society of Petroleum Engineers, 61st annual meeting preprint, 14 p. Later published in 1988, SPE Formation Evaluation, v. 3(2), p. 407-419.

Fertl, W.H., Chilingarian, G.V., and Yen, T.F., 1986, Organic carbon content and source rock identification based on geophysical well logs: Energy Sources, v. 8(4), p. 381-439.

Herron, S.L., 1986, A total organic carbon log for source rock evaluation, paper HH, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 11 p.

Hester, T.C., and Schmoker, J.W., 1987, Determination of organic content from formation-density logs, Devonian-Mississippian Woodford Shale, Anadarko Basin, Oklahoma: U.S. Geological Survey Open-File Report 87-20, 11 p.

Hester, T.C., Schmoker, J.W., and Sahl, H.L., 1990, Log-derived regional source-rock characteristics of the Woodford Shale, Anadarko basin, Oklahoma: U.S. Geological Survey Bulletin 1866-D, 38 p.

Hussain, F.A., 1987, Source rock identification in the State of Kuwait using wireline logs, SPE-15747, in 5th SPE Middle East oil show [Manama, Bahrain (March 7-10)], proceedings: Society of Petroleum Engineers, p. 477-488.

Krystinik, K.B., and Charpentier, R.R., 1987, Statistical model for source rock maturity and organic richness using well-log data, Bakken Formation, Williston Basin, United States: AAPG Bulletin, v. 71(1), p. 95-102.

Lawrence, T.D., Ball, S., and Harris, M., 1984, Continuous carbon/oxygen and neutron lifetime log proposed interpretation for organic and/or shaly depositional environments, paper QQ, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 19 p.

Mann, U., Leythaeuser, D., and Muller, P.J., 1986, Relation between source rock properties and wireline log parameters--An example from Lower Jurassic Posidonia Shale, NW-Germany, in Advances in organic geochemistry 1985, part II [12th international meeting on organic geochemistry (Julich, West Germany, 16-20 September) proceedings]: Organic Geochemistry, v. 10(4/6), p. 1105-1112.

Meissner, F.F., 1978, Petroleum geology of the Bakken Formation Williston basin, North Dakota and Montana, in Williston basin symposium: Montana Geological Society, p. 207-227. Reprinted in 1984, in G.Demaison and R.J. Murris, editors, Petroleum geochemistry and basin evaluation: American Association of Petroleum Geologists, Memoir No. 35, p. 159-179. Reprinted in 1987, in N.C. Dutta, editor, Geopressure: Society of Exploration Geophysicists, Geophysics Reprint Series No. 7, p. 203-223.

Mendelson, J.D., 1985, Petroleum source rock logging: Massachusetts Institute of Technology, unpublished MS thesis, 96 p.

Mendelson, J.D., and Toksoz, M.N., 1985, Source rock characterization using multivariate analysis of log data, paper UU, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 21 p.

Mendelson, J.D., and Toksoz, M.N., 1986, In-situ determination of organic richness in sediments by geophysical logging, in Biochemistry of black shales [international workshop, Hamburg, West Germany, May 28-31, 1985]: Mitteilungen aus dem Geologisch-Palaontologischen Institut der Universitat Hamburg, No. 60, p. 23-36.

Meyer, B.L., and Nederlof, M.H., 1984, Identification of source rocks on wireline logs by density/resistivity and sonic transit time/resistivity crossplots: AAPG Bulletin v. 68(2), p. 121-129.

Russell, D.J., 1985, Depositional analysis of a black shale by using gamma-ray stratigraphy--The Upper Devonian Kettle Point Formation of Ontario: Bulletin of Canadian Petroleum Geology, v. 33(2), June, p. 236-253.

Schmoker, J.W., 1979, Determination of organic content of Appalachian Devonian shales from formation-density logs: AAPG Bulletin, v. 63(9), p. 1504-1509.

Schmoker, J.W., 1981, Determination of organic-matter content of Appalachian Devonian shales from gamma-ray logs: AAPG Bulletin, v. 65(7), p. 1285-1298.

Schmoker, J.W., and Hester, T.C., 1983, Organic carbon in Bakken Formation, U.S. Portion of Williston Basin: AAPG Bulletin, v. 67(12), p. 2165-2174.

Schmoker, J.W., and Hester, T.C., 1989, Oil generation inferred from formation resistivity--Bakken Formation, Williston Basin, North Dakota, paper H, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p. Later published in 1990, as Formation resistivity as an indicator of oil generation; Bakken Formation of North Dakota and Woodford Shale of Oklahoma: The Log Analyst, v. 31(1), January-February, p. 1-9.

Schmoker, J.W., and Hester, T.C., 1989, Formation resistivity as an indicator of the onset of oil generation in the Woodford Shale, Anadarko basin, Oklahoma, in Johnson, K.S., editor, Anadarko basin symposium, 1988: Oklahoma Geological Survey Circular No. 90, p. 262-266.

Smagala, T.M., Brown, C.A., and Nydegger, G.L., 1984, Log-derived indicator of thermal maturity, in J. Woodward, F.F. Meissner, J.L. Clayton, editors, Hydrocarbon source rocks of the greater Rocky Mountain region: Rocky Mountain Association of Geologists, Denver, p. 355-363.

Stocks, A.E., and LAwrence, S.R., 1990, Identification of source rocks from wireline logs, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 241-252.

Sweeney, J.J., Burnham, A.K., and Braun, R.L., 1986, A model of hydrocarbon maturation in the Uinta basin, Utah, USA, in J. Burrus, editor, Thermal modeling in sedimentary basins [1st IPF exploration research conference (Carcans, France, June 3-7, 1985) proceedings]: Editions Technip, Paris, Collection Colloques et Seminaires No. 44, p. 547-561.

10. TIGHT (LOW-PERMEABILITY) GAS SANDSTONES
(See also VII. Shaly Sands)

Autric, A., and Dumensil, P., 1985, Resistivity, radioactivity and sonic transit time logs to evaluate the organic content of low permeability rocks: The Log Analyst, v. 26(3), May-June, p. 36-45.

Boardman, C.R., Hammack, G.W., Fertl, W.H., and Atkinson, C.H., 1972, Evaluation of low-permeability gas-bearing formations in Rio Blanco County, Colorado, SPE-4097: Society of Petroleum Engineers, 47th annual meeting [San Antonio] preprint. Later published in 1973, Journal of Petroleum Technology, v. 25(10), p. 1125-1129.

Brown, J.A., Jackson, J.A., and Koelle, A.R., 1985, Western gas sands project Los Alamos NMR well logging tool development: Los Alamos National Laboratory, Report LA-10374-PR, March, 77 p.

CER Corporation, 1984, Multiwell experiment--Well log analysis of the paludal interval: CER Corporation [Prepared for Sandia National Laboratory], Las Vegas, Nevada, 103 p.

CER Corporation, 1986, Multiwell experiment--Well log analysis of coastal interval: CER Corporation [Prepared for Sandia National Laboratory], Las Vegas, Nevada, 98 p.

Chisholm, J.L., Schenewerk, P.A., and Donaldson, E.C., 1985, A comparison of shaly-sand inteperpretation techniques in the Mesaverde Group of the Uinta Basin, Utah, SPE-14281: Society of Petroleum Engineers, 60th annual meeting preprint. Later published in 1987, SPE Formation Evaluation, v. 2(4), p. 478-486.

Chowdiah, P., 1987, Effects of pore-water distribution and stress on the laboratory measurement of tight sandstone properties, SPE-15210, in 1986 SPE unconventional gas technology symposium proceedings: Society of Petroleum Engineers, p. 35-47. Later published in 1988 as, Influence of water-desaturation technique and stress on laboratory measurement of hydraulic properties of tight sandstones: SPE Formation Evaluation, v. 3(4), December, p. 679-685.

Collier, H.A., 1989, Recognizing high porosity-low permeability sandstone reservoirs with routine logs; a case history, paper W, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Crain, E.R., 1981, Log evaluation results in the Deep Basin area of Alberta, paper A, in 8th formation evaluation symposium transactions: Canadian Well Logging Society, 14 p.

Dawson-Grove, G.E., 1979, Log analysis in tight gas sands--A reconnaissance study, paper H, in 7th formation evaluation symposium transactions: Canadian Well Logging Society, 14 p.

Haase, C.S., and King, H.L., 1986, Application of borehole geophysics to fracture identification and characterization in low permeability limestones and dolostones, in Surface and borehole geophysical methods and ground water instrumentation conference and exposition [Denver, October 15-17], proceedings: National Water Well Association, Dublin, Ohio, p. 487-506.

Heinze, D.M., 1985, Clay identification and amount measured by laboratory techniques compared to well log responses--Application to tight gas sands and shales: Sandia National Laboratory Report SAND/85-0312, March, 36 p.

Howard, W.E., and Hunt, E.R., 1986, Travis Peak--An integrated approach to formation evaluation, SPE-15208, in 1986 unconventional gas technology symposium, proceedings: Society of Petroleum Engineers, p. 7-17.

Howard, W.E., and Hunt, E., 1989, Travis Peak formation evaluation, chapter 5, in Staged field experiment No. 2, application of advanced geological, petrophysical, and engineering technologies to evaluate and improve gas recovery from low permeability sandstone reservoirs, Travis Peak Formation, North Appleby field, Nacogdoches County, Texas: Gas Research Institute Report No. GRI-89/0140, p. 91-152.

Hunt, E.R., Raymond, D.H., Haskett, C.E., and Pirie, R.G., 1981, Application of new well logs and geology to fracturing and producibility in tight gas sands, Cotton Valley Group, SPE/DOE-9832, in 1981 SPE/DOE symposium on low permeability gas reservoirs, proceedings: Society of Petroleum Engineers, p. 35.

Hunt, E.R., Walls, J.D., and Scala, C., 1985, An integrated log and core analysis study of an east Texas tight gas well, paper HHH, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 18 p.

Jackson, J.A., Brown, J.A., and Crawford, T.R., 1981, Remote characterization of tight gas formations with a new NMR logging tool, SPE/DOE-9860, in 1981 SPE/DOE symposium on low permeability gas reservoirs, proceedings: Society of Petroleum Engineers, p. 313-320.

Jennings, J.B., and Carroll, H.B. Jr., editors, 1982, Western tight gas sands advanced logging workshop [March 17-18, 1981], proceedings: U.S. Department of Energy Report CONF-8103113, April 1982, 253 p.

Knutson, C.F., 1984, Reservoir evaluation and geologic modeling for the Clinton eastern tight gas formation, phase I final report: U.S. Department of Energy Report DOE/MC/21148, 73 p.

Knutson, C.F., and Boardman, C.R., 1978, Continuity and permeability development in the tight gas sands of the eastern Uinta Basin, Utah: U.S. Department of Energy Report NVO/0011-1, 54 p.

Kukal, G.C., 1978, Log evaluation of compacted shaly sands of the Mesaverde Group, Unita Basin, Utah, in 4th annual DOE symposium on enhanced oil and gas recovery and improved drilling methods, proeceedings, volume 2, paper E-1: U.S. Department of Energy, 18 p.

Kukal, G.C., 1979, Formation evaluation and gas detection in shallow, low-permebility shaly sands of the Northern Great Plains province, SPE-7920, in 1979 SPE symposium on low permeability gas reservoirs, proceedings: Society of Petroleum Engineers, p. 85-98. Later published in 1981, Journal of Petroleum Technology, v. 33(10), p. 1976-1984.

Kukal, G.C., 1981, Determination of fluid corrected porosity in tight gas sands and in formations exhibiting shallow invasion profiles, SPE-9856, in 1981 SPE symposium on low permeability gas reservoirs, proceedings: Society of Petroleum Engineers, p. 289-299.

Kukal, G.C., 1983, Log analysis in low-permeability gas sand sequence--Correcting for variable unflushed gas saturation, paper F, in 23rd annual logging symposium transactions: Society of Professional Well Log Analysts, 18 p.

Kukal, G.C., 1984, A systematic approach for the effective log analysis of tight gas sands, SPE/DOE/GRI-12851, in SPE/DOE/GRI unconventional gas recovery symposium, proceedings: Society of Petroleum Engineers, p. 209-220.

Kukal, G.C., 1990, Log analysis, chapter 4, in Multiwell Experiment final report, part 4, volume A, The fluvial interval of the Mesaverde Formation: Sandia National Laboratories Report SAND89-2612/A, 173 p.

Kukal, G.C., Biddison, C.L., Hill, R.E., Monson, E.R., and Simons, K.E., 1983, Tight gas sands log interpretation--Problem study: Gas Research Institute, Chicago, Final Report GRI-82/0094, July 1982, 181 p.

Kukal, G.C., Biddison, C.L., Hill, R.E., Monson, E.R., and Simons, K.E., 1983, Critical problems hindering accurate log interpretation of tight gas sand reservoirs, SPE/DOE-11620, in 1983 SPE/DOE symposium on low permeabilty gas reservoirs, proceedings: Society of Petroleum Engineers, p. 181-190.

Kukal, G.C., and Hill, R.E., 1986, Log analysis of clay volume--An evaluation of techniques and assumptions used in an Upper Cretaceous sand-shale sequence, paper RR, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 21 p.

Kukal, G.C., and Simons, K.E., 1985, Log analysis techniques for quantifying the permeability of sub-millidarcy sandstone reservoirs, SPE/DOE-13880, in 1985 SPE/DOE symposium on low permeability reservoirs, proceedings: Society of Petroleum Engineers, p. 303-310. Later published in SPE Formation Evaluation, v. 1(6), December, p. 609-622.

Laubach, S.E., Baumgardner, T.W., Jr., Monson, E.R., Hunt, E., and Meador, K.J., 1988, Fracture detection in low-permeability reservoir sandstone; a comparison of BHTV and FMS logs to core, SPE-18119, in 1988 SPE annual technical conference proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 129-139.

Leeth, R., and Cossette, B., 1979, The velocity ratio plot in tight Canadian carbonate formations, paper X, in 7th formation evaluation symposium transactions: Canadian Well Logging Society, 17 p.

Luffel, D.L., and Howard, W.E., 1987, Reliability of laboratory measurement of porosity in tight gas sands, SPE-16401, in 1987 SPE/DOE joint symposium on low permeability reservoirs proceedings: Society of Petroleum Engineers, p. 115-124. Later published in 1988, SPE Formation Evaluation, v. 3(4), December, p. 705-710.

Luffel, D.L., Howard, W.E., and Hunt, E.R., 1989, Relationships of permeability, porosity, and overburden stress derived from extensive core analysis data base in the Travis Peak Formation, SPE-19008, in SPE joint Rocky Mountain regional/low permeability reservoirs symposium [Denver], proceedings: Society of Petroleum Engineers, p. 729-740.

Lysne, P., 1988, Neutronic properties of Mesaverde sands, part II, Results: Nuclear Geophysics, v. 2(2), p. 113-122.

Murphy, W.F., III, 1984, Acoustic measures of partial gas saturation in tight sandstones: Journal of Geophysical Research, v. 89(B13), p. 11,549-11,559.

Nur, A., and Raible, C., 1983, Sonic and electrical properties of partially saturated tight gas sands: U.S. Department of Energy Report DOE/BC/10498-5, March 1983, 54 p.

Nydegger, G.L., Rice, D.D., and Brown, C.A., 1979, Development of shallow gas reserves in low-permeability reservoirs of Late Cretaceous age, Bowdoin Dome area, north-central Montana, SPE-7945, in 1979 SPE symposium on low permeability gas reservoirs, proceedings: Society of Petroleum Engineers, p. 315-323. Later published in 1980, Journal of Petroleum Technology, v. 32(12), p. 2111-2120.

Osoba, J., Gist, R., and Carroll, H., 1980, Porosity determination from density logs in western gas sands, paper JJ, in 21st annual logging symposium transactions: Society of Professional Well Log Analysts, 10 p. Later published in abridged form in 1981, as, Log evaluation techniques in Uinta basin found faulty: World Oil, v. 192(6), June, p. 235-244.

Osoba, J.S., and Raible, C.J., 1982, Study of sonic, neutron and density logging of low permeability gas sands: U.S. Department of Energy Report DOE/BC/00010-33, May 1982, 63 p.

Pirie, G., 1982, Geology and log study of tight gas sandstones--Cotton Valley Group: Transactions of the Gulf Coast Association of Geological Societies, v. 32, p. 77-88.

Rosepiler, M.J., 1981, Calculation and significance of water saturations in low porosity shaly gas sands, paper C, in 23rd annual logging symposium transactions: Society of Professional Well Log Analysts, 21 p. Also published in condensed form 1981, Oil and Gas Journal, v. 79(28), July 13, p. 180-187.

Sattler, A.R., 1989, Core analysis in a low permeability sandstone reservoir; results from the Multiwell Experiment: Sandia National Laboratory Report No. SAND 89-07/10, 64 p.

Sattler, A.R., 1989, Comparison of the in-situ stress information from core and log analysis, SCA-8911, part III, paper K, in Annual technical conference reprints, v. 1 (1987-89): Society of Professional Well Log Analysts, Society of Core Analysts SPWLA Chapter-at-Large, 27 p.

Sattler, A.R., 1990, Core analysis, chapter 5, in Multiwell Experiment final report, part 4, volume A, The fluvial interval of the Mesaverde Formation: Sandia National Laboratories Report SAND89-2612/A, 76 p.

Streeter, R.W., and Hunt, E.R., 1989, Prefracture analysis of Red Mountain sands--An integrated analysis of openhole and cased hole logs, SPE-19003, in SPE joint Rocky Mountain regional/low permeability reservoirs symposium [Denver], proceedings: Society of Petroleum Engineers, p. 695-706.

Suau, J. Boyeldieu, C. Roccabianca, R., Cigni, M., and Spila, M., 1978, Evaluation of very low-porosity carbonates (Malossa, Italy), paper W, in 19th annual logging symposium transactions: Society of Professional Well Log Analysts.

Tsay, F.S., and Fang, J.H., 1986, A core-log study of the Hastselle Sandstone in north Alabama with emphasis in log interpretation problems in tight gas sands, SPE-15211, in 1986 unconventional gas technology symposium, proceedings: Society of Petroleum Engineers, p. 47-62.

Volk, L.J., Carroll, H.B., and Raible, C.J., 1979, Influence of shale conductivities on the electrical conductivity of low-permeability rocks, SPE-7918, in 1979 symposium on low-permeability gas reservoirs [Denver], proceedings: Society of Petroleum Engineers, p. Later published in 1980, Journal of Petroleum Technology, v. 32(5), p. 865-867.

Wescott, W.A., 1983, Diagenesis of Cotton Valley Sandstone (Upper Jurassic), east Texas--Implications for tight gas formation pay recognition: AAPG Bulletin, v. 67(6), p. 1002-1013. A discussion and reply published in 1985, AAPG Bulletin v. 69(5), p. 813-816.

Whitehead, W.S., Hunt, E.R., Finley, R.J., and Holditch, S.A., 1986, In-situ stresses--A comparison between log-derived values and actual field-measured values in the Travis Peak Formation of east Texas, SPE-15209, in 1986 unconventional gas technology symposium, proceedings: Society of Petroleum Engineers, p. 19-34.

Whitehead, W.S., Hunt, E.R., and Holditch, S.A., 1987, The effects of lithology and reservoir pressure on the in-situ stresses in the Waskom (Travis Peak) field, SPE/DOE-16403, in 1987 SPE/DOE low permeability reservoirs symposium, proceedings, : Society of Petroleum Engineers, p. 139-152.

Witherbee, L.J., Godfrey, R.D., and Dimelow, T.E., 1983, Predicting turbidite-contourite reservoir intervals in tight gas sands--A case study from the Mancos B Sandstone, SPE/DOE-11609, in 1983 SPE/DOE symposium on low permeability gas reservoirs, proceedings: Society of Petroleum Engineers, p. 87-94.

Yiwu, Z., 1989, Pore texture of a sandstone reservoir with low permeability, chapter 16, in Mason, J.F., and Dickey, P.A., editors, Oil field development techniques: AAPG Studies in Geology No. 28, p. 223-236.

11. ABNORMAL PRESSURE DETECTION AND DETERMINATION

Aldred, W., Bergt, D., Rasmus, J., Voisin, B., 1989, Real-time overpressure detection: Schlumberger Oilfield Review, v. 1(3), October, p. 17-27.

Alixant, J.L., Desbrandes, R., and Delahaye, T., 1989, A new approach to real-time pore pressure evaluation, SPE-19336, in SPE eastern regional conference, proceedings: Society of Petroleum Engineers, p. 281-290.

Allan, D.R., 1975, Identification of sediments--Their depositional environment and degree of compaction from well logs, in G.V. Chilingarian and K.H. Wolf, editors, Compaction of coarse-grained sediments, part I: Elsevier, New York, Developments in Sedimentology Series No. 18A, p. 349-401.

American Association of Petroleum Geologists, 1974, Abnormal formation pressures: American Association of Petroleum Geologists, Reprint Series No. 11, 205 p. [Contains 14 significant papers that appeared in the AAPG Bulletin.]

Barron, J.G., Weakley, R.R., and Haas, M.A., 1990, Pore pressure analysis indicates abnormal pressure as reason for shale instability in offhsore California field, IADC/SPE-19993, in IADC/SPE drilling conference, proceedings: Society of Petroleum Engineers, p. 687-693.

Blackburn, J.S., and Brimage, R.C., 1978, Estimation of formation pressures in clean gas sands from the dual-spacing TDT log, paper V, in 19th annual logging symposium transactions: Society of Professional Well Log Analysts, 14 p.

Boardman, W.A., 1967, Measuring and using shale density to aid drilling wells in high-pressure areas: American Petroleum Institute, southern district, spring meeting preprint. Later published in 1967, Journal of Petroleum Technology, v. 19(11), p. 1423-1429. Reprinted in 1987 in, N.C. Dutta, editor, Geopressure: Society of Exploration Geophysicists, Geophysics Reprint Series No. 7, p. 319-326.

Buhrig, C., 1989, Geopressured Jurassic reservoirs in the Viking Graben; modelling and geological significance: Marine and Petroleum Geology, v. 6(1), February, p. 31-48.

Campbell, R., 1974, Abnormal pressure detection using log data, paper T, in 3rd European formation evaluation symposium transactions: Society of Professional Well Log Analysts, London Chapter, 16 p.

Carstens, H., and Dypvik, H., 1981, Abnormal formation pressure and shale porosity: AAPG Bulletin, v. 65(2), p. 344-350.

Chiarelli, A., Serra, O., Gras, C., Masse, P., and Tison, J., 1973, ...tude automatique de la sous-compactions des argiles par diagraphies diffÈrÈes, mÈthodologie et applications: Revue de L'Institut Francais du Petrole, v. 28, no. 1, p. 19-36. English-language version published in 1975, Use of compaction profiles to predict abnormal pressure: World Oil, v. 180, no. 6, May, p. 107-110.

Constant, W.D., and Bourgoyne, A.T., Jr., 1986, Fracture gradient prediction for offshore wells, in 56th SPE California regional meeting, proceedings, SPE-15105: Society of Petroleum Engineers, p. 125-128. Also published in 1986 as, Method predicts frac gradient for abnormally pressured formations: Petroleum Engineer International, v. 58(1), January, p. 38-46.

Davis, T.B., 1984, Subsurface pressure profiles in gas-saturated basins, in J.A. Masters, editor, Elmworth--Case study of a Deep Basin gas field: American Association of Petroleum Geologists,, Memoir No. 38, p. 189-203.

Dickey, P.A., 1986, Subsurface pressures, chapter 13, in Petroleum development geology, 3rd edition: Petroleum Publishing Co., Tulsa, p. 287-352.

Dickey, P.A., 1989, Application of pressure measurements to development geology, chapter 9, in Mason, J.F., and Dickey, P.A., editors, Oil field development techniques: AAPG Studies in Geology No. 28, p. 105-117.

Dutta, N.C., 1986, Shale compaction, burial diagenesis, and geopressures; a dynamic model, solution and some results, in J. Burrus, editor, Thermal modeling in sedimentary basins [1st IPF exploration research conference (Carcans, France, June 3-7, 1985) proceedings]: Editions Technip, Paris, Collection Colloques et Seminaires No. 44, p. 149-172.

Dutta, N.C., editor, 1987, Geopressure: Society of Exploration Geophysicists, Geophysics Reprint Series No. 7, 363 p.

Eaton, B.A., 1972, The effect of overburden stress on geopressure prediction from well logs, SPE-3719, in 3rd symposium on abnormal pore pressure, proceedings: Society of Petroleum Engineers. Later published in 1972, Journal of Petroleum Technology, v. 24(8), p. 929-934.

Eaton, B.A., 1975, The equation for geopressure prediction from well logs, SPE-5544: Society of Petroleum Engineers, 50th annual meeting [Dallas] preprint, 9 p.

Evers, J.F., and Ezeanyim, R., 1983, Prediction of abnormal pressures in Wyoming sedimentary basins using well logs, SPE-11859, in Rocky Mountain regional meeting [Salt Lake City], proceedings: Society of Petroleum Engineers, p. 363-374.

Fertl, W.H., 1976, Geophysical well-logging techniques detect and evaluate abnormal formation pressures, chapter 5, in Abnormal formation pressures: Elsevier, New York, p. 177-274.

Fertl, W.H., 1977, Shale density studies and their application, in G.D. Hobson, editor, Developments in petroleum geology no. 1: Applied Science Publishers, London, p. 293-327.

Fertl, W.H., 1987, Pulsed neutron capture logs evaluate geopressure environments, OTC-5572, in 19th annual offshore technology conference proceedings, : Offshore Technology Conference, Houston, p. 175-187.

Fertl, W.H., 1988, Detection and evaluation of geopressured subsurface formations based on dielectric (electomagnetic wave propagation) measurements: Energy Sources, v. 10(3), p. 195-200.

Fertl, W.H., and Chilingarian, G.V., 1987, Abnormal formation pressures and their detection by pulsed neutron capture logs: Journal of Petroleum Science and Engineering, v. 1, p. 23-28.

Fertl, W.H., and Chilingarian, G.V., 1989, Prediction of tectonically-caused overpressures by using resistivity and density measurements of associated shales: Journal of Petroleum Science and Engineering, v. 3(3), p. 203-208.

Fertl, W.H., and Leach, W.G., 1988, Economics of hydrocarbon reserves in overpressured reservoirs below 18,000 ft in south Louisiana, SPE-18146, in 1988 SPE annual technical conference proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 397-412.

Finch, W.C., 1968 , Abnormal pressure in the Anteleope field, North Dakota, SPE-2227: Society of Petroleum Engineers, 43rd annual meeting [Houston] preprint. Later published in 1969, Journal of Petroluem Technology, v. 21(7), p. 821-826.

Forbes, P.L., Mudford, B.S., and Ungerer, P., 1989, 2-D modeling of overpressure generation and gas accumulation in the Venture gas field (Canada), paper RES 1.5, in Expanded abstracts with biographies 59th annual meeting, v. 1: Society of Exploration Geophysicists, p. 599-601.

Foster, J., Jr., 1990, Pore-pressure plot accuracy increased by multiple trend lines: Oil and Gas Journal, v. 88(19), May 7, p. 100-108.

Foster, J.B., and Whalen, H.E., 1965, Estimation of formation pressures from electrical surveys; offshore Louisiana, SPE-1200: Society of Petroleum Engineers, 40th annual meeting preprints. Later published in 1966, Journal of Petroleum Technology, v. 18(2), p. 165-171. Reprinted in 1987 in, N.C. Dutta, editor, Geopressure: Society of Exploration Geophysicists, Geophysics Reprint Series No. 7, p. 278-284.

Gregory, A.R., and Backus, M.M., 1980, Geopressured formation parameters, geothermal well, Brazoria County, Texas, in M.H. Dorfman and W.L. Fisher, editors, 4th U.S. Gulf Coast geopressured-geothermal energy conference, proceedings, volume 1: Center for Energy Studies, University of Texas, Austin, p. 235-311.

Ham, H.H., 1966, A method of estimating formation pressures from Gulf Coast well logs: Transactions Gulf Coast Association of Geological Societies, v. 16, p. 185-197. Reprinted in 1987 in, N.C. Dutta, editor, Geopressure: Society of Exploration Geophysicists Geophysics Reprint Series No. 7, p. 295-308.

Hamouz, M.A., and Mueller, S.L., 1984, Some new ideas for well log pore-pressure prediction, SPE-13204: Society of Petroleum Engineers, 59th annual meeting [Houston] preprint, 11 p.

Herring, E.A., 1973, Estimating abnormal pressures fromdata in the North Sea, SPE-4301: Society of Petroleum Engineers, 2nd annual European meeting [London, April 2-3], preprint, 8 p.

Hottman, C.E., and Johnson, R.K., 1965, Estimation of formation pressures from log-derived shale properties, SPE-1110: Journal of Petroleum Technology, v. 17(6), p. 717-722. Reprinted 1971 in, Well logging: Society of Petroleum Engineers, Reprint Series No. 1, p. 299-305. Reprinted 1987 in, N.C. Dutta, editor, Geopressure: Society of Exploration Geophysicists, Geophysics Reprint Series No. 7, p. 272-277.

Hottman, C.E., Smith, J.H., and Purcell, W.R., 1978, Relationship among earth stresses, pore pressure, and drilling problems offshore Gulf of Alaska, SPE-7501: Society of Petroleum Engineers, 53rd annual meeting [Houston] preprint. Later published in 1979, Journal of Petroleum Technology, v. 31(11), November, p. 1477-1484.

Hunt, J.M., 1990, Generation and migration of petroleum from abnormally pressured fluid compartments: AAPG Bulletin, v. 74(1), p. 1-12.

Jones, P.H., 1968, Hydrodynamics of geopressure in the northern Gulf of Mexico Basin, SPE-2207: Society of Petroleum Engineers, 43rd annual meeting [Houston] preprint. Later published in 1969, Journal of Petroleum Technology, v. 21(7), p. 803-810.

Jones, P.H., 1977, Geopressured geothermal energy in the south-central United States--Frontier areas and exploration techniques, chapter 11, in M.D. Campbell, editor, Geology of alternate energy resources in the south-central United States: Houston Geological Society, p. 215-250.

Kutasov, I.M., Caruthers, R.M., Targhi, A.K., and Chaaban, H.M., 1988, Prediction of downhole circulating and shut-in pressures: Geothermics, v. 17(4), p. 607-618. Also published in 1989, in abridged form, Oil and Gas Journal, v. 87(28), July 10, p. 94-95.

Lane, R.A., and MacPherson, L.A., 1974, A review of geopressure evaluation from well logs--Louisiana Gulf Coast, SPE-5033: Society of Petroleum Engineers, 49th annual meeting [Houston] preprint, 16 p. Later published in 1976, Journal of Petroleum Technology, v. 28(9), p. 963-971.

Lindberg, P.H., and Fertl, W.H., 1980, Occurrence and distribution of overpressures in the northern North Sea, SPE-9339: Society of Petroleum Engineers, 55th annual meeting [Dallas] preprint, 21 p.

Magara, K., 1978, Compaction and fluid migration--Practical petroleum geology: Elsevier Scientific Publishing Company, New York, Developments in Petroleum Science, No. 9, 319 p.

Magara, K., 1986, Thickness of erosion, chapter 7, in Geological models of petroleum entrapment: Elsevier Applied Science Publishers, London, p. 129-151.

Magara, K., 1986, Geological models of petroleum entrapment: Elsevier Applied Science Publishers, London, 328 p.

Magara, K., 1986, Porosity-depth relationship during compaction in hydrostatic and non-hydrostatic cases, in J. Burrus, editor, Thermal modeling in sedimentary basins [1st IPF exploration research conference (Carcans, France, June 3-7, 1985) proceedings]: Editions Technip Collection Colloques et Seminaires No. 44, Paris, p. 129-147.

Mann, D.M., and MacKenzie, A.S., 1990, Prediction of pore pressures in sedimentary basins: Marine and Petroleum Geology, v. 7(1), p. 55-65.

Matthews, W.R., McClendon, R.T., and Soucek, C.R., 1972, How to predict formation pressures of Cretaceous-Jurassic age sediments in Mississippi, SPE-3895, in 3rd symposium on abnormal subsurface pore pressure, proceedings: Society of Petroleum Engineers, p. 137-144.

McGregor, J.R., 1965, Quantitative determination of reservoir pressures from conductivity logs: AAPG Bulletin, v. 49(9), p. 1502-1511. Reprinted in 1974, in Abnormal subsurface pressure: American Association of Petroleum Geologists, Reprint Series No. 11, p. 37-46. Reprinted in 1987, in N.C. Dutta, editor, Geopressure: Society of Exploration Geophysicists, Geophysics Reprint Series No. 7, p. 285-294.

Menghini, M.L., 1988, Compaction monitoring in the Ekofisk area chalk fields, OTC-5620, in 20th annual offshore technology conference proceedings, v. 1: Society of Petroleum Engineers, p. 31-38. Later published in 1989, Journal of Petroleum Technology, v. 41(7), p. 735-739.

Mudford, B.S., 1990, A one-dimensional, two-phase model of overpressure generation in the Venture gas field, offshore Nova Scotia: Bulletin of Canadian Petroleum Geology, v. 38(2), June, p. 246-258.

Nyein, R.K., MacLean, L., and Warris, B.J., 1977, Occurrence, prediction and control of geopressures on the northwest shelf of Australia: APEA [Australia Petroleum Exploration Association] Journal, v. 17, part 1, p. 64-72.

Obah, B., 1989, Overpressure--a drilling hazard in the Niger delta: Erdol und Khole Erdgas, v. 42(9), p. 339-343.

Pennebaker, E.S., 1968, An engineering interpretation of seismic data, SPE-2165: Society of Petroleum Engineers, 43rd annual meeting [Houston] preprint, 12 p. Also published, in part, 1968, World Oil, v. 166(7), June, p. 73-77. [Important uses and interpretations of sonic log data.]

Pickering, L.A., and Indelicato, G.J., 1985, Abnormal formation pressure--A review: The Mountain Geologist, v. 22(2), April, p. 78-89.

Prensky, S.E., 1986, Geologic implications of large-scale trends in well-log response, northern Green River basin, Wyoming, paper EEE, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 24 p.

Prensky, S.E., and Dickinson, W.W., 1986, Computer-generated well-log data plots assist in regional subsurface evaluation, northern Green River basin, Wyoming: Geobyte, v.1(2), Spring, p. 52-58.

Pritchett, W.C., 1978, Physical properties of shales and possible origins of high pressures, SPE-7506: Society of Petroleum Engineers, 53rd annual meeting [Houston] preprint. Later published in 1980, Society of Petroleum Engineers Journal v. 20(5) p. 341-348.

Ransom, R.C., 1986, A method for calculating pore pressures from well logs: The Log Analyst, v. 27(2), March-April, p. 72-76.

Rathbun, F.C., 1968, Abnormal pressures and conductivity anomaly, northern Green River basin, Wyoming, SPE-2205: Society of Petroleum Engineers, 43rd annual meeting [Houston] preprint, 8 p. Later reprinted under Rathbun, F.C., and Dickey, P., in 1969, as, Abnormal pressures and conductivity anomaly, northern Green River basin, Wyoming: The Log Analyst, v. 10(4), July-August, p. 3-8.

Reynolds, E.B., Timko, D.J., Zanier, A.M., 1972, Potential hazards of acoustic-log shale pressure plots, SPE-4020: Society of Petroleum Engineers, 47th annual meeting [San Antonio] preprint. Later published in 1973, Journal of Petroleum Technology, v. 25(9), p. 1039-1044.

Saavedra, L.L., 1985, A review of the methods of detection and estimation of geopressure from well logs: South Texas Geological Society Bulletin, v. 26(2), p. 21-37.

Sahay, B., and Fertl, W.H., 1989, Origin and evaluation of formation pressures: Kluwer Academic Publishers, Dordrecht, The Netherlands, 292 p.

Serra, O., 1986, Compaction study, chapter 8, in Fundamentals of well-log interpretation volume 2--The interpretation of logging data: Elsevier Science Publishers, Amsterdam, Developments in Petroleum Science No. 15B, p. 367-407.

Sherwood, K.W., 1988, Abnormal formation pressure, chapter 10, in Turner, R., editor, Geological and operational summary, north Aleutian shelf COST No. 1 well, Bering Sea, Alaska: U.S. Minerals Management Service OCS Report No. 88-0089, p. 203-218.

Society of Petroleum Engineers, 1972, Third symposium on abnormal subsurface pore pressure, transactions: Society of Petroleum Engineers, 159 p. [preprints of 16 papers.]

Spencer, C.W., 1987, Hydrocarbon generation as a mechanism for overpressuring in Rocky Mountain region: AAPG Bulletin, v. 71(4), p. 368-388.

Taneja, P.K., and Carroll, J.F., 1985, Abnormal pressure detection using a pulsed neutron log, paper MM, in 26th annual well logging symposium transactions: Society of Professional Well Log Analysts, 10 p.

Timko, D.J., and Fons, L.C, 1971, Definition, identification and measurement of normal and abnormal subsurface pressures, in Abnormal subsurface pressures, a study group report, 1969-1971: Houston Geological Society, p. 20-30.

Turner, R.F., Lynch, M.B., and others, 1987, Abnormal formation pressure, chapter 10, in Turner, R.F., editor, Geological and operational summary, Kodiak Shelf stratigraphic test wells, western Gulf of Alaska: U.S. Minerals Management Service OCS Report MMS 87-0109, p. 229-252.

Wallace, W.E., 1965, Abnormal subsurface pressures measured from conductivity or resistivity logs, paper I, in 6th annual logging symposium: Society of Professional Well Log Analysts, 13 p. Also published in 1965, The Log Analyst, v. 5(4), February-March, p. 26-38, and in 1965, Oil and Gas Journal, v. 63, July 5, p. 102-106.

Ward, G.S., and Pendergast, R.D., 1979, Evaluation of pressures and salinities of the Cardium Formation in Western Canada, paper R, in 7th formation evaluation syposium transactions: Canadian Well Logging Society.

Weakley, R.R., 1989, Recalibration techniques for accurate determinations of formation pore pressures from shale resitivity, SPE-19563, in 1989 SPE annual technical conference and exhibition, proceedings, volume delta, Drilling: Society of Petroleum Engineers, p. 457-466.

Weakley, R.R., 1989, Use of surface seismic data to predict formation pore pressures (sand shale depositional environments), SPE/IADC-18713, in 1989 SPE/IADC drilling conference, proceedings: Society of Petroleum Engineers, p. 791-806

Weakley, R.R., 1990, Plotting sonic logs to determine formation pore pressures and creating overlays to do so worldwide, IADC/SPE-19995, in IADC/SPE drilling conference, proceedings: Society of Petroleum Engineers, p. 703-712.

Whittaker, A., editor, 1985, Theory and evaluation of formation pressures, a pressure detection reference handbook: International Human Resources Development Corporation, Boston, 92 p.

Wichmann, P.A., 1973, A review of the use of logs to determine abnormal pressures: Canadian Well Logging Society Journal, v. 6(1), December, p. 7-32. Later published in 1974, paper C, in 15th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p.

12. OIL AND GAS SHALES

Abdel-Rahman, E.M., and Wali, A., 1984, Determination of density and organic content of Matruh shales in the Western Desert of Egypt from density logs: Bulletin of the Faculty of Science, Cairo University [Egypt], v. 52(2), p. 589-600.

Bardsley, S.R., and Algermissen, S.T., 1963, Evaluating oil shale by log analysis: Journal of Petroleum Technology, v. 15(1), p. 81-84. Later published in 1963, Colorado School of Mines Quarterly, v. 58(4), p. 175-184.

Campbell, R.L., 1987, A Devonian shale-specific formation evaluation log: Eastern Devonian Gas Shales Technology Review, v. 4(1), October, p. 19-29.

Campbell, R.L., Jr., and Truman, R.B., 1986, Formation evaluation in the Devonian shale, in 1986 unconventional gas technology symposium, proceedings, SPE-15212: Society of Petroleum Engineers, p. 63-74.

Curtis, J.B., 1986, Geochemical evaluation of Devonian shale wells: Eastern Devonian Gas Shales Technology Review, v. 3(3), December, p. 13-17.

Curtis, J.B., and Fingleton, W.G., 1979, A preliminary evaluation of various log analysis techniques for the eastern Devonian shales, paper I, in 20th annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p.

Curtis, J.B., and McBane, R.A., 1987, Use of geochemistry to improve identification of completion intervals, SPE-17032, in SPE eastern regional meeting [Pittsburgh], proceedings: Society of Petroleum Engineers, p. 45-51. Later published in 1989, SPE Formation Evaluation, v. 4(2), p. 163-166.

Duba, A. Huenges, E., Nover, G., Will, G., and Jodicke, H., 1988, Impedance of black shale from Munsterland 1 borehole; an anomalously good conductor?: Geophysical Journal, v. 94(3), September, p. 413-419.

Evans, K.F., and Engelder, J.T., 1986, A study of stress in Devonian Shale, part I--3D stress mapping using a wireline microfrac system, SPE-15609: Society of Petroleum Engineers, 61st annual meeting [New Orleans] preprint, 12 p.

Fertl, W.H., 1976, Evaluation of oil shales using geophysical well-logging techniques, chapter 10, in F.F. Yen, editor, Oil shale: Elsevier Scientific Publishing Company, New York, p. 199-213.

Flower, J.G., 1981, Use of sonic-shear-wave/resistivity overlay as a quick-look method for identifying potential pay zones in the Ohio (Devonian) Shale, SPE-10366: Society of Petroleum Engineers, eastern regional meeting preprint. Later published in 1983, Journal of Petroleum Technology, v. 35(3), p. 638-642.

Gatens, J.M., III, Lancaster, D.E., Harrison, C.W., III, and Guidry, F.K., 1988, Using in-situ tests and acoustic logs to determine mechanical properties and stress profiles in the Devonian shales, SPE-18523, in SPE eastern regional meeting, proceedings: Society of Petroleum Engineers, p. 7-20. Reprinted in 1989, Devonian Gas Shales Technology Review, v. 6(1), July, p. 8-24.

Graham, R.L., Walbe, K., and McBane, R.A., 1986, Application of the borehole TV camera: Eastern Devonian Gas Shales Technology Review, v. 3(3), December, p. 19-23.

Guidry, F.K., Luffel, D.L., and Olszewski, A.J., 1990, Devonian shale formation-evaluation model based on logs, new core-analysis methods, and production test, paper NN, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p.

Habiger, R., and Robinson, R.H., 1983, Using a multiple log approach to evaluate Green River oil shale in the Piceance Creek Basin, in J.H. Gary, editor, 16th oil shale symposium, proceedings: Colorado School of Mines, Golden, p. 45-67.

Hashmy, K.H., Hefter, T., and Chicko, R., 1982, Quantitative log evaluation in the Devonian shales of the northeast United States, SPE/DOE-10795, in 1982 SPE/DOE unconventional gas recovery symposium proceedings: Society of Petroleum Engineers, p. 55-66.

Hester, T.C., Schmoker, J.W., and Sahl, H.L., 1990, Log-derived regional source-rock characteristics of the Woodford Shale, Anadarko basin, Oklahoma: U.S. Geological Survey Bulletin 1866-D, 38 p.

Hilton, J., 1978, Wireline evaluation of the Devonian shale, in G.L. Schott, W.K. Overbey, Jr., A.E. Hunt, and C.A. Komar, editors, 1st eastern gas shales symposium, proceedings: U.S. Department of Energy Report MERC/SP-77/5, p. 68-79.

Knutson, C.F., 1984, Reservoir evaluation and geologic modeling for the Clinton eastern tight gas formation, phase I final report: U.S. Department of Energy Report DOE/MC/21148, 73 p.

Lancaster, D.E., Guidry, F.K., Graham, R.L., Curtis, J.B., Shaw, J.S., and Blake, T.H., 1987, A case study of the evaluation, completion, and testing of a Devonian Shale gas well, SPE-17037, in 1987 eastern regional meeting proceedings: Society of Petroleum Engineers, p. 87-99. Later published in 1989, Journal of Petroleum Technology, v. 41(5), p.509-518.

Leckie, D.A., Singh, C., Goodarzi, F., and Wall, J.H., 1990, Organic-rich, radioactive marine shale; a case study of a shallow-water condensed section, Cretaceous Shaftesbury Formation, Alberta, Canada: Journal of Sedimentary Petrology, v. 60(1), p. 101-117.

Luffel, D.L., and Guidry, F.K., 1989, Reservoir rock properties of Devonian shale from core and log analysis, SCA-8910, part III, paper J, in Annual technical conference reprints, v. 1 (1987-1989): Society of Professional Well Log Analysts, Society of Core Analysts SPWLA Chapter-at-Large, 15 p.

McBane R.A., Campbell, R.L., and Truman, R.B., 1986, Comparison of diagnostic tools for selecting completion intervals in Devonian shale wells, SPE-15948, in 1986 eastern regional meeting proceedings, p. 259-270. Later published in 1988, Journal of Petroleum Technology, v. 40(2), p. 187-196.:

McCoy, R.L., Kumar, R.M. and Pease, R.W., 1980, Fracture identification in Devonian shales using conventional well logs, in 11th annual Appalachian petroleum geology symposium: West Virginia Geological and Economic Survey Circular C-16, p. 16-28. A condensed version published in 1980 as, Identifying fractures with conventional well logs: World Oil, v. 191(7), December, p. 91-98.

Myung, J.I., 1976, Fracture investigation of the Devonian shale using geophysical well logging techniques, SPE-6366: Society of Petroleum Engineers, Eastern region annual meeting preprint, 16 p. Also published in 1976 in R.C. Shumaker and W.K. Overbey, Jr., editors, 7th Appalachian petroleum geology symposium, proceedings: U.S. Department of Energy Report MERC/SP-76/2, p. 212-238, [these proceedings were also published by West Virginia Geological and Economic Survey, p. 1-29.]

Schmoker, J.W., 1977, The relationship between density and gamma-ray intensity in the Devonian shale sequence, Lincoln County, West Virginia, in G.L. Schott, W.K. Overbey, Jr., A.E. Hunt, C.A. Komar, editors, First eastern gas shales symposium, proceedings: U.S. Department of Energy Morgantown Energy Research Center, p. 266-271.

Schmoker, J.W., and Hester, T.C., 1989, Oil generation inferred from formation resistivity--Bakken Formation, Williston Basin, North Dakota, paper H, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p. Later published in 1990, as Formation resistivity as an indicator of oil generation; Bakken Formation of North Dakota and Woodford Shale of Oklahoma: The Log Analyst, v. 31(1), January-February, p. 1-9.

Schmoker, J.W., and Hester, T.C., 1989, Formation resistivity as an indicator of the onset of oil generation in the Woodford Shale, Anadarko basin, Oklahoma, in Johnson, K.S., editor, Anadarko basin symposium, 1988: Oklahoma Geological Survey Circular No. 90, p. 262-266.

Smith, J.W., Thomas, H.E., and Trudell, L.G., 1968, Geologic factors affecting density logs in oil shale, paper P, in 9th annual logging symposium transactions: Society of Professional Well Log Analysts, 17 p. Reprinted 1978, as paper CC, in Gamma ray, neutron and density logging: Society of Professional Well Log Analysts, 17 p.

Soeder, D.J., 1986, Porosity and permeability of eastern Devonian gas shale, SPE-15213, in 1986 unconventional gas technology symposium proceedings: Society of Petroleum Engineers, p. 75-88. Later published in 1988, SPE Formation Evaluation, v. 3(1), p. 116-124.

Tixier, M.P., and Curtis, M.R., 1967, Oil shale yield predicted from well logs, in 7th world petroleum congress, proceedings, volume 3: Elsevier, New York, p. 713-715.

Truman, R.B., and Campbell, R.L., Jr., 1985, Devonian shale well log analysis: Eastern Devonian Gas Shales Technology Review [Gas Research Institute], v. 2(3), December, p. 6-17.

Walbe, K., 1986, Utilization of the borehole television camera in conjunction with regular open and cased-hole logging in the Devonian shale of the Applachian Basin, SPE-15610: Society of Petroleum Engineers, 61st annual meeting [New Orleans] preprint, 4 p.

Yost, A.B., II, Frohne, K., Komar, C.A., and Ameri, S., 1980, Techniques to determine natural and induced fracture relationships in Devonian shale, SPE-9271: Society of Petroleum Engineers, 55nd annual meeting [Dallas] preprint. Later published in 1982, Journal of Petroleum Technology, v. 34(6), p. 1371-1377.

Yost, A.B., II, Komar, C.A., and Ameri, S., 1980, Application of core and log data to determine producible hydrocarbon intervals in the Devonian shale, SPE-9271: Society of Petroleum Engineers, 55th annual meeting [Dallas] preprint, 8 p.

13. HEAVY OIL AND TAR SANDSTONES

Britton, M.W., 1987, Problems frequently encountered in evaluating tar sand resources; the south Texas San Miguel deposit, in R.F. Myer, editor, Exploration for heavy crude oil and natural bitumen [AAPG/UNITAR research conference (Santa Maria, California, October 29-November 2, 1984), proceedings]: AAPG, Studies in Geology No. 25, p. 489-506.

Brown, J.S., 1965, Formation evaluation in heavy oil sands: Journal of Petroleum Technology, v. 4(4), p. 177. Later published in 1966, as paper B, in 7th annual logging symposium transactions: Society of Professional Well Log Analysts, 14 p.

Carrigy, M.A., 1971, Deltaic sedimentation in Athabasca tar sands: AAPG Bulletin, v. 55(8), p. 1155-1169.

Chestnut, D.A., and Cox, D.O., 1978, Log analysis in a Rocky Mountain heavy oil reservoir, paper F, in 19th annual logging symposium transactions: Society of Professional Well Log Analysts, 15 p.

Collins, H.N., 1974, Log-core correlations in the Athabasca oil sands, SPE-5037: Society Petroleum Engineers, 49th annual meeting [Houston] preprint, 17 p. Later published in 1976, Journal of Petroleum Technology, v.28(10), p. 1157-1168.

Cossette, B.B., 1981, Well log analysis in heavy oil sands, paper K, in 8th formation evaluation symposium transactions: Canadian Well Logging Society, 18 p.

Dusseault, M.B., 1987, Determination of geomechanical parameters from geophysical logs, in R.F. Myer, editor, Exploration for heavy crude oil and natural bitumen [AAPG/UNITAR research conference (Santa Maria, California, October 29-November 2, 1984), proceedings]: AAPG Studies in Geology No. 25, p. 415-421.

Dusseault, M.B., and Scott, J.D., 1987, Coring and sampling in heavy-oil exploration; difficulties and proposed cures, in R.F. Myer, editor, Exploration for heavy crude oil and natural bitumen [AAPG/UNITAR research conference (Santa Maria, California, October 29-November 2, 1984), proceedings]: AAPG Studies in Geology No. 25, p. 437-442.

Everett, R.V., Herron, M., Pirie, G., Schweitzer, J., and Edmundson, H., 1985, Faja case study results on a single well MFM-7S, paper A, in 10th formation evaluation symposium transactions: Canadian Well Logging Society, 20 p. Also presented in 1985, 60th annual meeting: Society of Petroleum Engineers, preprint, SPE-14176. Later published in 1987, SPE Formation Evaluation, v. 2(3), September, p. 361-375. Also published in 1987, in R.F. Myer, editor, Exploration for heavy crude oil and natural bitumen [AAPG/UNITAR research conference (Santa Maria, California, October 29-November 2, 1984), proceedings]: AAPG Studies in Geology No. 25, p. 423-436.

Fertl, W.H., 1981, Evaluation of heavy oil and tar sands deposits using geophysical well logging techniques in open and cased boreholes, in R.F. Meyer, C.T. Steele and J.C. Olson, editors, Heavy crude oils and tar sands [1st international UNITAR conference proceedings, 1979]: McGraw-Hill, Inc., Mineral Information Service, New York, p. 283-294.

Fertl, W.H., 1984, Recent advances in the evaluation of heavy oil reservoirs based on geophysical well-logging concepts, in R.F. Meyer, J.C. Wynn and J.C. Olson, editors, The future of heavy crude and tar sands [2nd international UNITAR conference proceedings, 1982]: McGraw-Hill Inc., Coal Age Mineral Information Service, New York, p. 313-317.

Fertl, W.H., 1987, Well log assisted evaluation of heavy-oil resources; a status report, in R.F. Myer, editor, Exploration for heavy crude oil and natural bitumen [AAPG/UNITAR research conference (Santa Maria, California, October 29-November 2, 1984), proceedings]: AAPG Studies in Geology No. 25, p. 443-452.

Fertl, W.H., and Chilingarian, G.V., 1978, Formation evaluation of tar sands using geophysical well-logging techniques, chapter 11, in G.V. Chilingarian and T.F. Yen, editors, Bitumens, asphalts and tar sands: Elsevier, New York, Developments in Petroleum Science No. 7, p. 259-276.

Fertl, W.H., and Elliott, D.B., 1984, Well log assisted evaluation of heavy oil resources--A status report, in AAPG research conference on exploration for heavy crude oil and bitumen, proceedings, volume 1: American Association of Petroleum Geologists, 28 p.

Fetzner, R.W., Henson, W.L., and Feigl, F.J., 1966, Athabasca oil sand evaluation using core and log analysis and geological data processing methods, paper A, in 7th annual logging symposium transactions: Society of Professional Well Log Analysts, 13 p.

Flach, P.D., and Mossop, G.D., 1985, Depositional environments of Lower Cretaceous McMurray Formation, Athabasca oil sands, Alberta: AAPG Bulletin, v. 69(8), p. 11195-1207.

Freedman, R., and Studlick, J.R.J., 1981, Evaluation of a heavy oil prospect Bandera Tank area Maverick and Zavala Counties, Texas, paper Y, in 22nd annual logging symposium transactions: Society of Professional Well Log Analysts, 39 p. Later published in 1981, Oil and Gas Journal, v. 79,(48), November 30, p. 63-76.

Laramie Energy Research Center, 1981, A bibliography of publications dealing with tar sands: U.S. Department of Commerce, National Technical Information Service, Report DOE/LETC/RI-81-2 (DE81-026146), 294 p.

Logan, D., Kovacs, J., and Morriss, C., 1989, Identification of mobile water in bitumen reservoirs using the nuclear magnetic log, paper 89-40-71, in Building on 40 years of achievement [annual meeting preprints, volume II]: Petroleum Society of CIM, Calgary, 16 p.

Mraz, T.J., Rajeshwar, K., and Dubow, J.B., 1982, Thermophysical characterization of oil sands, part 2, acoustic properties: Fuel, v. 61(3), p. 240-244.

Nelson, H.W., and Glaister, R. P., 1978, Subsurface environmental facies and reservoir relationships of the McMurray oil sands, northeastern Alberta: Bulletin of Canadian Petroleum Geology, v. 26(2), June, p. 177-207.

Neuman, C.H., 1983, Application of the nuclear magnetism log and electromagnetic propagation tool to define steam potential in heavy oil reservoirs, in 12th annual convention proceedings, volume 2: Indonesian Petroleum Association, Jakarta, p. 265-273.

Nickel, B.I., Edgson, J.J., and Howes, E.J., 1985, Productivity potential indicator in a heavy oil reservoir, paper 85-36-42, in 36th annual technical meeting, Petroleum Society of CIM [Edmonton], preprints, volume 2: Petroleum Society of CIM, Calgary, p. 689-704. Later published in 1986, Journal of Canadian Petroleum Technology, v. 25(6), December, p. 55-59.

Pilman, D., 1985, Petrophysical evaluation of the Orinoco heavy oil belt, Hamaca-Pao area Venezuela, in 3rd international UNITAR/UNDP heavy oil crude and tar sands conference [Long Beach, California, July 22-31, 1985), preprints: United Nations Institute for Training and Research, New York, Center for Heavy Crude and Tars, 29 p.

Pirie, G., 1985, Geology of a single well (Maraven SDZ-86X) from cores and logs, Orinoco heavy oil belt, Venezuela, in 3rd international UNITAR/UNDP heavy oil crude and tar sands conference [Long Beach, California, July 22-31, 1985), preprints: United Nations Institute for Training and Research, New York, Information Center for Heavy Crude and Tars, 54 p. Also published in 1985, as Geological evaluation of a single well from cores and logs Faja petrolifera del Orinoco, eastern Venezuela, paper B, in 10th formation evaluation symposium transactions: Canadian Well Logging Society, 35 p.

Putnam, P.E., 1982, Aspects of the petroleum geology of the Lloydminster heavy oil fields, Alberta and Saskatchewan: Bulletin of Canadian Petroleum Geology, v. 30(2), June, p. 81-111.

Roux, C., Fertl, W.H., Frost, E., Stedman, D., and Elliott, D., 1981, Well logs evaluate and monitor heavy oil steam flood in Kern County, California, paper II, in 22nd annual logging symposium transactions: Society of Professional Well Log Analysts, 17 p.

Sah, R.C., Chase, A.E., and Wells, L.E., 1974, Evaluation of the Alberta tar sands, SPE-5034: Society of Petroleum Engineers, 49th annual meeting [Houston] preprint 15 p.

Vogel, A.W., Jr., 1982, Predicting possibility of oil production from tar sand deposits based on geologic, logging and chemical composition, SPE-10884: Society of Petroleum Engineers, Rocky Mountain regional meeting [Billings] preprint, 15 p.

Woodhouse, R., 1976, Athabasca tar sand reservoir properties derived from cores and logs: Canadian Well Logging Society Journal, v. 9(1), p. 83. Also published 1976, paper T, in 17th annual logging symposium transactions: Society of Professional Well Log Analysts, 13 p.

14. COAL AND COALBED METHANE

Abshier, J.F., McBride, G.E., and Beardsmore, S.F., 1979, Saving money with coal geophysics: Coal Age, v. 84(9), p. 100-110.

Adams, S.C., and Kullerud, G., 1984, Depositional patterns of Pennsylvanian sediments in Sullivan County, west-central Indiana, USA: International Journal of Coal Geology, v. 3, p. 349-373.

Agostini, A., 1977, Correlation of high resolution density log counts and ash content of coal: Australian Society of Exploration Geophysicists Bulletin, v. 8(2), p. 26-31.

Bond, L.O., Alger, R.P., and Schmidt, A.W., 1971, Well log applications in coal mining and rock mechanics: Transactions of the Society of Mining Engineers AIME, v. 250, December, p. 355-362. Reprinted in 1986, in Buchanan, D.J., and Jackson, L.J., editors, Coal geophysics: Society of Exloration Geophysicists, Geophysics reprint series No. 6, p. 28-35.

Borsaru, M., Ceravolo, C., Charbucinski, J., Eisler, P., and Youl, S., 1986, Ash determination of black coal in exploration boreholes by neutron-gamma, in P. Kileen, editor, Borehole geophysics for mining and geotechnical applications [International symposium and workshop, (Toronto, August 29-31, 1983), proceedings]: Geological Survey of Canada, Paper 85-27, p. 261-268.

Borsaru, M., Charbucinski, J., Eisler, P.L., Rawling, J.R., and Snider, B., 1987, A spectrometric gamma-gamma borehole logging method for ash measurement in rough holes, in 57th annual meeting expanded abstracts with biographies: Society of Exploration Geophysicists, p. 29-31.

Borsaru, M., Charbucinski, J., Eisler, P.L., and Youl, S.F., 1985, Determination of ash content in coal by borehole logging in dry boreholes using gamma-gamma methods: Geoexploration, v. 23, p. 503-518.

Borsaru, M., Eisler, P.L., and Charbucinski, J., 1988, Quantitative nuclear borehole logging based on neutron excited gamma reactions, in Current trends in nuclear borehole logging techniques for elemental analysis [consultants meeting (Ottawa, Canada, November 2-6, 1987), proceedings]: International Atomic Energy Agency, Vienna, Report IAEA-TECDOC-464, p. 31-53.

BPB Instruments Limited, 1981, Coal interpretation manual: BPB Instruments, Ltd., Loughborough, England, 100 p.

Brom, R.W.C., and Driedonks, F., 1981, Applications of petrophysical logging in the evaluation of coal deposits, paper KK, in 22nd annual logging symposium transactions: Society of Professional Well Log Analysts, 29 p.

Buchanan, D.J., and Jackson, L.J., editors, 1986, Coal geophysics: Society of Exloration Geophysicists, Geophysics reprint series no. 6, p. 25-85. [Reprints of 6 papers relating to identification and evaluation of coal via borehole logging.]

Cairncross, B., and McCarthy, T.S., 1986, A Fortran IV computer program for displaying coal seam data: Geological Society of South Africa Transactions, v. 89, part 3,, p. 409-414.

Charbucinski, J., Youl, S.F., Eisler, P.L., and Borsaru, M., 1986, Prompt neutron-gamma logging for coal ash in water-filled boreholes: Geophysics, v. 51(5), p. 1110-1118.

Chironis, N.P., 1982, Better methods aid exploration of coal sites: Coal Age, v. 87(10), p. 82-88.

Chrusciel, E., Kaczmanski, S.M., Kopec, M., Niewodniczanski, J., Palka, K.W., and Wojda, F., 1987, In situ analysis of coal by scintillation gamma-ray spectrometry in deep boreholes: Nuclear Geophysics, v. 1(4), p. 345-352.

Clark, W.J., and Copper, D.M., 1985, Sedimentological and wireline log aspects of the Walloon coal measures in GSQ Dalby 1 and GSQ Chincilla 3, Surat Basin, Queensland: Queensland Government Mining Journal, v. 86(1006), p. 386-394.

Clayton, C.G., 1977, Applications of nuclear techniques in the coal industry, in Symposium on nuclear techniques in exploration, extraction and processing of mineral resources, 1977, proceedings: International Atomic Energy Agency, Vienna, Austria, p. 85-117.

Clayton, C.G., Hassan, A.M., and Wormald, M.R., 1983, Multi-element analysis of coal during borehole logging by measurement of prompt gamma-rays from thermal neutron capture, in C.G. Clayton, editor, Nuclear geophysics--Selected papers on applications of nuclear techniques in mineral exploration, mining and process control: Pergamon Press, Oxford, England, p. 83-93. Reprinted in 1986, in Buchanan, D.J., and Jackson, L.J., editors, Coal geophysics: Society of Exloration Geophysicists, Geophysics Reprint Series No. 6, p. 74-84.

Clayton, C.G., and Wormald, M.R., 1983, Coal analysis by nuclear methods, in C.G. Clayton, editor, Nuclear geophysics--Selected papers on applications of nuclear techniques in mineral exploration, mining and process control: Pergamon Press, Oxford, England, p. 3-22.

Cobb, J.C., and Smath, R., 1981, Geophysical well logging for coal exploration in the eastern Kentucky coal field, in Coals and coal-bearing rocks of eastern Kentucky [annual Geological Society of America coal division field trip]: Kentucky Geological Survey, p. 74-81.

Daniels, J.J., and Scott, J.H., 1980, Computer-assisted interpretation of geophysical well logs in a coal depositional environment, Illinois Basin, Kentucky: U.S. Geological Survey Bulletin No. 1509, 44 p.

Daniels, J.J., and Scott, J.H., 1982, Automated lithologic interpretation from geophysical well logs in a coal depositional environment, Carbon County, Wyoming, in K.D., Gurgel, editor, 5th Rocky Mountain coal symposium, proceedings: Utah Geological and Mineral Survey, Bulletin no. 118, p. 220-232.

Daniels, J.J., Scott, J.H., and Liu, J., 1983, Estimation of coal quality parameters from geophysical well logs, paper KK, in 24th annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p.

Davis, D., 1977, Geophysical logging of coal, in D.K. Murray, editor, Geology of Rocky Mountain coal: Colorado Geological Survey Resource Series No. 1, p. 115-119.

Dyck, J.H., and McKenzie, C.T., 1979, Estimating certain analytical properties of lignite in Saskatchewan from gamma-gamma borehole density logs, paper Z, in 7th formation evaluation symposium transactions: Canadian Well Logging Society, 16 p.

Edwards, K.W., and Banks, K.M., 1978, A theoretical approach to the evaluation of in-situ coal: Canadian Institute of Mining and Metallurgy [CIM] Bulletin, v. 71(792), p. 124-131.

Eisler, P., Borsaru, M., Youl, S.F., and Charbucinski, J., 1988, Quantitative spectrometric borehole logging techniques for coal mining: Nuclear Physics, v. 2(1), p. 43-54.

Ferm, J.C., 1984, Geology of coal, chapter 5, in C.R. Ward, editor, Coal geology and coal technology: Blackwell Scientific Publishers, Boston, p. 151-176.

Fertl, W.H., and DeVries, M.R., 1977, Coal evaluation using geophysical well logs, paper F, in 6th formation evaluation symposium transactions: Canadian Well Logging Society, 17 p.

Fishel, K.W., and Mayer, R., Jr., 1979, Extremely high resolution density coal logging techniques, in G.O. Argall Jr., editors, Coal exploration 2 [2nd international coal exploration symposium, (Denver, 1978), proceedings]: Miller Freeman Publications Inc., San Francsico, p. 490-504. Also published in 1979 as, Mayer, R., Jr., and Fishel, K.W., Applications of electric logs in Applachian coal exploration, in 6th European logging symposium transactions, paper DD: Society of Professional Well Log Analysts, London Chapter, 18 p.

Haigh, J.E., and Edwards, I.H., 1982, Computer processing of geophysical logging data in coal deposits, in C.W. Mallett, editor, Coal resources; origin, exploration, and utilization in Australia [Melbourne, November 15-19], proceedings, part 2: Geological Society of Australia, Coal Group, p. 364-380.

Hoffman, G.L., Jordan, G.R., and Wallis, G.R., 1982, Geophysical logging handbook for coal exploration: The Coal Mining Research Centre, Edmonton, Alberta, Canada, 270 p. [The best single source for information on the tools, techniques and qualitative interpretation of logs for coal exploration.]

Hoffman, L.J.B., 1984, Determination of pyritic sulphur in coal using induced polarisation, paper III, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 12 p.

Huppert, P., Borsaru, M., Charbucinski, J., Ceravolo, C., and Eisler, P.L., 1989, Combined natural-gamma/gamma-gamma borehole lithology logging: Nuclear Geophysics, v. 3(4), p. 381-386.

Kayal, J.R., 1979, Electrical and gamma-ray logging in Gondwana and Tertiary coal fields of India: Geoexploration, v. 17, p. 243-258.

Kayal, J.R., 1981, Correlation of T-log with E-log in coal-bearing formations: Pure and Applied Geophysics, v. 119, p. 349-355.

Kayal, J.R., 1981, In situ analysis of coal from single electrode resistance, self-potential and gamma-ray logs: Geophysical Research Bulletin, v. 19(2), p. 117-121.

Kayal, J.R., and Christoffel, D.A., 1982, Relationship between electrical and thermal resistivities for differing grades of coal: Geophysics, v. 47(1), p. 127-129. Discussion and Reply in 1982, Geophysics, v. 47(10), p. 1461.

Kayal, J.R., and Christoffel, D.A., 1989, Coal quality from geophysical logs; Southland lignite region, New Zealand: The Log Analyst, v. 30(5), September-October, p. 343-352.

Kayal, J.R., and Das, L.K., 1981, A method of estimating ash content of coal from combined resistivity and gamma-ray logs: Geoexploration, v. 19, p. 193-200.

Kholin, S.V., 1984, Location of outburst prone zones within coal beds from correlation functions of well logs: Geophysical Journal, v. 5(6), p. 945-950.

Kloosterman, R.A., and Brom, R.W.C., 1977, Application of wireline logging techniques in the assessment of surface mineable coal, in A. Prijono, C. Long, and R. Sweatman, editors, The Indonesian mining industry, its present and future [1st Indonesian mining symposium, (Jakarta, June 14-16), proceedings]: Indonesian Mining Association, Jakarta, p. 408-429.

Kowalski, J., and Fertl, W.H., 1977, Application of geophysical well logging to coal mining operations: Energy Sources, v. 3(2), p. 133-147.

Kowalski, J., and Holter, M.E., 1975, Coal analysis from well logs, SPE-5503: Scoiety of Petroleum Engineers, 50th annual meeting reprint. Later published in 1976, Canadian Well Logging Society Journal, v. 9(1), p. 97-113.

Lavers, B.A., and Smits, L.J.M., 1976, Recent developments in coal petrophysics, paper S, in 17th annual logging symposium transactions: Society of Professional Well Log Analysts, 19 p. Reprinted in 1976 in W.L.G. Muir, editor, Coal exploration [1st international coal exploration symposium, (London, May 18-21), proceedings]: Miller Freeman Publications Inc., San Francisco, p. 129-152. Later published in 1977, The Log Analyst, v. 18(1), January-February, p. 6-16.

McCabe, P.J., 1984, Depositional environments of coal and coal-bearing strata in R.A. Rahmani and R.M. Flores, editors, Sedimentology of coal and coal-bearing sequences: Blackwell Publishers, Oxford, England, International Association of Sedimentologists, Special Publication No. 7, p. 13-42.

McNally, G.H., 1987, Estimation of coal measures rock strength using sonic and neutron logs: Geoexploration v. 24(4-5), p. 381-395.

Merritt, R.D., 1986, Depositional modeling methods, chapter 5, in Coal exploration, mine planning and development: Noyes Publications, Park Ridge, New Jersey, p. 74-116.

Merritt, R.D., 1986, Exploration and mapping methods, chapter 3, in Coal exploration, mine planning and development: Noyes Publications, Park Ridge, New Jersey, p. 33-68.

Miller, M.S., and Moore, M., 1980, Geophysical logging and exploration techniques in the Appalachian coal fields, SPE-9466: Society of Petroleum Engineers, 55th annual meeting [Dallas] preprint.

Moule, K.J., Peterson, M.S., and Webster, V.J., 1987, Latest international trends in applying computer-based techniques to the prediction of coal quality, in Advances in the study of the Sydney basin symposium, proceedings: University of Newcastle, Newcastle, N.S.W., Australia, Department of Geology, p. 19-25.

Mullen, M.J., 1988, Log evaluation in wells drilled for coal-bed methane, in Fassett, J.E., editor, Geology and coalbed methane resources of the northern San Juan basin, Colorado and New Mexico: Rocky Mountain Association of Geologists, Denver, p. 113-124. Also published in 1989 as GRI-8953, in 1989 coalbed methane symposium, proceedings: Gas Research Institute, Chicago, p. 167-184.

Mullen, M.J., 1989, Coalbed methane resource evaluation from wireline logs in the northeastern San Juan Basin; a case study, SPE-18946, in SPE joint Rocky Mountain regional/low permeability reservoirs symposium [Denver], proceedings: Society of Petroleum Engineers, p. 161-172.

Mumme, I.A., 1987, Some useful nuclear techniques for deriving important characteristics of coal deposits during the exploration phase, in Advances in the study of the Sydney basin symposium, proceedings: University of Newcastle, Newcastle, N.S.W., Australia, Department of Geology, p. 159-162.

Mwenifumbo, C.J., 1989, The symmetrical lateral resistivity log in coal seam mapping, Highvale mine, Alberta: Geological Survey of Canada Paper 89-1D, p. 1-8.

Negoita, V., 1983, A new method for quantitative evaluation of coal seams passed through by hydrocarbon wells [1983 Congress of the Carpathian-Balkan geological association, Bucharest]: Annuaire de l'Institut de Geologie et de Geophysique, v. 63, p. 123-133.

Nelms, C.A., 1976, Application of electric well logging techniques to identifying coal beds in the Powder River Basin, Wyoming: U.S. Geological Survey Open-File Report 76-581, 20 p.

Norris, J.O., and Thomas, R., 1980, An in situ coal quality prediction technique, SPE-9467: Society of Petroleum Engineers, 55th annual meeting [Dallas] preprint, 9 p.

Otto, K., 1979, Coal exploration in West Germany by well logging, paper H, in 6th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, London Chapter, 30 p.

Petricola, M., Jumardi, and Saito, K., 1985, Formation evaluation in deltaic sand deposits--The effect of lignite debris on logs--Integration of sand-body analysis, in 14th annual convention proceedings: Indonesian Petroleum Association, Jakarta, p. 517-541.

Prensky, S.E., 1988, Well-log determination of ash content in Fruitland Formation coals, Southern Ute Indian Reservation, southwest Colorado, in Fassett, J.E., editor, Geology and coalbed methane resources of the northern San Juan basin, Colorado and New Mexico: Rocky Mountain Association of Geologists, Denver, p. 91-112.

Psilovikos, A. and Karistineos, N., 1986, A depositional sedimentary model for the Neogene uraniferous lignites of the Serres Graben, Greece: Paleongeography, Paleoclimatology, Paleoecology, v. 56(1-2), p. 1-16.

Rao, K.V., 1988, Geophysical well-logging techniques and their applications in coal prospecting, topic 10, in Murty, B.V.S., Nandakumar, G., Reddy, P.C., and Rao, S.M.V., editors, Geophysical technology for coal prospecting [national workshop lectures]: Osmania University, Centre for Exploration Geophysics, Hyderabad, India, p. 116-138.

Reeves, D.R., 1971, In-situ analysis of coal by borehole logging techniques: Canadian Institute of Mining and Metallurgy [CIM] Bulletin, v. 64(706), p. 67-75. Reprinted in 1971, CIM Transactions, v. 74, p. 61-69. Reprinted in 1986, in Buchanan, D.J., and Jackson, L.J., editors, Coal geophysics: Society of Exloration Geophysicists, Geophysics Reprint Series No. 6, p. 36-44.

Reeves, D.R., 1976, Application of wireline logging techniques to coal exploration, in W.L.G. Muir, editor, Coal exploration [1st international coal exploration symposium, (London, May 18-21), proceedings]: Miller Freeman Publications Inc., San Francisco, p. 112-128.

Reeves, D.R., 1979, Some improvements and developments in coal wireline logging techniques, in G.O. Argall, Jr., editors, Coal exploration 2 [2nd international coal exploration symposium, (Denver, 1978), proceedings]: Miller Freeman Publications Inc., San Francisco, p. 468-489.

Rieke, H.H., Rightmire, C.T., and Fertl, W.H., 1979, Evaluation of gas bearing coal seams, SPE-8359: Society of Petroleum Engineers, 54th annual meeting [Las Vegas] preprint. Later published 1981, Journal of Petroleum Technology, v. 33(1), p. 195-204.

Rightmire, C.T., Eddy, G.E., Kirr, J.N., editors, 1984, Coalbed methane resources of the United States: American Association of Petroleum Geologists, Studies in Geology Series No. 17, 378 p. [A collection of 14 papers containing overviews of the geology and coalbed methane resources of 13 basins in the U.S.]

Smith, G.G., 1989, The required use of coal density values for calculating average composition of in situ coals, in Contributions to Canadian coal geoscience: Geological Survey of Canada Paper 89-8, p. 131-136.

Stanley, C.B., and Schultz, A.P., 1983, Coal-bed methane resource evaluation, Montgomery County, Virginia: Virginia Division of Mineral Resources, Publication No. 46, 59 p.

Suau, J., 1981, Logging methods for coal exploration: Bulletin des Centres de Recherchese Exploration-Production Elf-Aquitain, v. 5(2), p. 621-633.

Swamy, V.V.L.N., 1988, Computer interpretation of well-logging data, topic 13.2, in Murty, B.V.S., Nandakumar, G., Reddy, P.C., and Rao, S.M.V., editors, Geophysical technology for coal prospecting [national workshop lectures]: Osmania University, Centre for Exploration Geophysics, Hyderabad, India, p. p. 185-203.

Till, V.S., 1987, Coal quality from geophysical logs; methods and ideas, in Advances in the study of the Sydney basin: University of Newcastle, Newcastle, N.S.W., Australia, Department of Geology, 21st symposium proceedings, p. 149-157.

Verma, R.K., and Bhuin, N.C., 1979, Use of electrical resistivity methods for study of coal seams in parts of the Jharia coalifield, India: Geoexploration, v. 17(2), p. 163-176.

Ward, C.R., 1984, Coalfield exploration, chapter 6, in C.R. Ward, editor, Coal geology and coal technology: Blackwell Scientific Publishers, Boston, p. 177-219.

Weltz, L.S., 1976, Log evaluation of sub-bituminous coals in Magallenes--Chile, paper K, in 17th annual logging symposium transactions: Society of Professional Well Log Analysts, 33 p.

Williams, C.C.G., 1983, Development of borehole logging, in G.O. Argall, editor, 4th international coal exploration symposium [Sydney, Australia, May 15-20], proceedings: Miller Freeman Publications Inc., San Francisco, 19 p.

Zuohua, H., 1987, Application of geophysical logging to coal prospecting, in Mining science and technology [international symposium on mining and technology, China Institue of Mining and Technology (Xuzhou, September 1985), proceedings]: Claus-Zellerfeld, West Germany, Trans Tech Publications, p. 978-985.

15. FRACTURE DETECTION AND EVALUATION; WELLBORE BREAKOUTS AND IN SITU STRESS ANALYSIS

(See also 19. Ground water; 20. Igneous rocks; 21. Geothermal logging)

Aguilera, R., 1973, Analysis of naturally fractured reservoirs from sonic and resistivity logs, SPE-4398: Society of Petroleum Engineers, Rocky Mountain regional meeting preprint. Later published in 1974, Journal of Petroleum Technology, v. 26(11), p. 1233-1238.

Aguilera, R., 1975, Analysis of naturally fractured reservoirs from conventional well logs, SPE-5342: Society of Petroleum Engineers, Rocky Mountain regional meeting preprint. Later published in 1976, Journal of Petroleum Technology, v. 28(7), p. 764-772. Discussion and reply published in 1976, Journal of Petroleum Technology, v. 28(10), p. 1183-1184.

Aguilera, R., 1980, Formation evaluation by well log analysis, chapter 3, in Naturally fractured reservoirs: Petroleum Publishing Co., Tulsa, p. 125-232. See references.

Aguilera, R., 1980, Fractured shales, chapter 5, in Naturally fractured reservoirs: Petroleum Publishing Company, Tulsa, p. 355-414.

Aguilera, R., 1981, A computerized well log interpretation process for the evaluation of naturally fractured reservoirs: Petroleum Society of CIM 32nd Annual Technical Meeting [Calgary] preprint 81-32-6, 8 p.

Aguilera, R., 1983, Exploring for naturally fractured reservoirs, paper C, in 24th annual logging symposium transactions: Society of Professional Well Log Analysts, 28 p.

Aguilera, R., and Acevedo, L., 1982, FCL--A computerized well-log interpretation process for the evaluation of naturally fractured reservoirs: Journal of Canadian Petroleum Technology, v. 21(1), p. 31-37.

Aguilera, R., and Van Poolen H.K., 1977, Current status on the study of naturally fractured reservoirs: The Log Analyst, v. 18(3), p. 3-23.

Aguilera, R., and Van Poolen, H.K., 1978, How to evaluate naturally fractured reservoirs from various well logs: Oil and Gas Journal, v. 76, December 25, p. 202-208.

Aguilera, R., and Van Poolen, H.K., 1979, Porosity and water saturation can be estimated from logs: Oil and Gas Journal, v. 77, January 8, p. 101-108.

Ahmed, U., 1987, Fracture-height predictions and post-treatment measurements, chapter 10, in M.J. Economides and K.G. Nolte, editors, Reservoir stimulation: Schlumberger Educational Services, Houston, Document No. SMP-7018, 13 p.

Allison M.L., and Nielson, D.L., 1988, Application of borehole breakouts to geothermal exploration and development; an example from Cove Fort-Sulphurdale, Utah: Geothermal Resources Council Transactions, v. 12, p. 213-219.

Anderson, J.A., Pearson, C.M., Abou-Sayed, A.S., and Myers, G.D., 1986, Determination of fracture height by spectral gamma log analysis, SPE-15439: Society of Petroleum Engineers, 61st annual meeting [New Orleans] preprint, 8 p.

Anderson, R.A., 1972, Fracture pressure gradient determination from well logs, SPE-4135: Society of Petroleum Engineers, 47th annual meeting [San Antonio] preprint, 15 p.

Anderson, R.N., and O'Malley, H., 1985, Frequency response and attenuation changes across highly altered fracture zones crosscutting a fast formation--The oceanic crust of the Mid-Atlantic Ridge, paper LLL, in 26th annual well logging symposium transactions: Society of Professional Well Log Analysts, 12 p.

Anderson, R.N., O'Malley, H., and Newmark, R.L., 1984, Use of geophysical logs for quantitative determination of fracturing, alteration, and lithology in the upper oceanic crust, in C.B. Raleigh, editor, Observation of the continental crust through drilling, volume I [international symposium (Tarrytown, N.Y., May 20-25), proceedings]: Springer-Verlag, New York, p. 182-234. Also published in 1985 as, Use of geophysical logs for quantitative determination of fracturing, alteration and lithostratigraphy in the upper oceanic crust, Deep Sea Drilling Project, holes 504B and 556, in Initial reports of the the Deep Sea Drilling Project, v. 83: U.S. Government Printing Office, p. 443-478. Also published in 1985 as, Nuclear, multichannel-sonic, ultrasonic analyses for determination of degree of fracturing and alteration in a fast formation--the deep oceanic crust, paper Y, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 22 p.

Andersson, P., and Stenberg, L., 1985, Geophysical borehole logging in Lavia borehole--Results and interpretation of sonic and tube wave measurements: Nuclear Waste Commission of Finnish Power Commission, Helsinki, Report No. YJT-85-07, 46p.

Armstead, H.C.H., and Tester, J.W., 1987, Rock fracturing practice--reservoir diagnostics, chapter 9, in Heat mining: E. & F.N. Spon, London, p.172-189.

Astbury, S., and Worthington, M.H., 1986, The analysis and interpretation of full waveform sonic data, part 1--Dominant phases and shear wave velocity: First Break, v. 4(4), p. 7-16.

Astbury, S., and Worthington, M.H., 1986, The analysis and interpretation of full waveform sonic data, part 2--Multiples, mode conversions and reflections: First Break, v. 4(6), June, p. 15-24.

Avasthi, J.M., Nolen-Hoeksema, R.C., El Rabaa, A.W.M., and Wilson, L.E., 1990, In-situ stress evaluation in the McElroy field, west Texas, SPE-20105, in SPE Permian Basin oil and gas recovery conference [Midland, TX], proceedings: Society of Petroleum Engineers, p. 189-196.

Babcock, E.A., 1978, Measurement of subsurface fractures from dipmeter logs: AAPG Bulletin, v. 62(7), p. 1111-1126.

Barlai, Z., 1989, Micro-Lambda logging; a new tool for detecting and analysing fractures in hard rocks, paper U, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 19 p.

Barton, C.A., and Zoback, M.D., 1988, Determination of in situ stress orientation from borehole guided waves: Journal of Geophysical Research, v. 93(B7), p. 7,834-7,844.

Barton, C.A., and Zoback, M.D., 1989, Utilization of interactive analysis of digital borehole televiewer data for studies of macroscopic fracturing, paper GG, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 623-653.

Barton, C.A., Zoback, M.D., and Burns, K.L., 1988, In-situ stress orientation and magnitude at the Fenton geothermal site, New Mexico, determined from wellbore breakouts: Geophysical Research Letters, v. 15(5), p. 467-470.

Bateman, R.M., 1986, Determination of high angle fracture plane orientations from SHDT dipmeter recordings using a microcomputer: Canadian Well Logging Society Journal, v. 15(1), p. 85-100.

Baumgartner, J., Rummel, F., Haimson, B.C., and Lee, M.Y., 1989, In situ stress measurements and natural fracture logging in drill hole CY-4, the Troodos ophiolite, Cyprus, in Gibson, I.L., Malpas, J., Robinson, P.T., and Xenophontos, C. eds., Cyprus crustal study project; initial report, hole CY-4: Geological Survey of Canada Paper 88-9, p. 315-330.

Bell, J.S., 1990, Investigating stress regimes in sedimentary basins using information from oil industry wireline logs and drilling records, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 305-325.

Bell, J.S., and Gough, D.I., 1979, Northeast-southwest compressive stress in Alberta--Evidence from oil wells: Earth and Planetary Science Letters, v. 45, p. 475-482.

Bell, J.S., and Gough, D.I., 1982, The use of borehole breakouts in the study of crustal stress, in M.D. Zoback and B.C. Haimson, editors, Workshop on hydraulic fracturing stress measurements [December 2-5], proceedings: U.S. Geological Survey Open-file Report 82-1075, p. 539-557.

Bergosh, J.L., and Lord, g.d., 1988, New developments in the analysis of cores from naturally fractured reservoirs, SPE-16805, in 1987 SPE annual technical conference proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, P. 563-570. Reprinted in 1988, in Permian basin oil and gas recovery symposium proceedings: Society of Petroleum Engineers, p. 57-64.

Beyer, L.A., 1987, Porosity of unconsolidated sand, diatomite, and fractured shale reservoirs, South Belridge and West Cat Canyon oil fields, California, in R.F. Myer, editor, Exploration for heavy crude oil and natural bitumen [AAPG/UNITAR research conference (Santa Maria, California, October 29-November 2, 1984), proceedings]: AAPG, Studies in Geology No. 25, p. 395-413.

Blumling, P., Fuchs, K., and Schneider, T., 1983, Orientation of the stress field from breakouts in a crystalline well in a seismic active area: Physics of the Earth and Planetary Interiors, v. 33, p. 250-254.

Botter, B.J., 1982, Circumferential acoustic waves in boreholes for the delineation of vertical fractures, paper S, in 23rd annual logging symposium: Society of Professional Well Log Analysts, 21 p.

Boyeldieu, C., 1982, Evaluating fracture porosity in hard carbonate formations: The Technical Review, v. 30(2), September, p. 15-22.

Boyeldieu, C., and Martin, C., 1984, Fracture dectection and evaluation, paper 21, in 9th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 9 p.

Boyeldieu, C., and Winchester, A., 1982, Use of the Dual Laterolog for the evaluation of the fracture porosity in hard carbonate formations, SPE-10464: Society of Petroleum Engineers, Offshore South East Asia 82 conference preprint, 11 p.

Brevetti, J.C., Greer, G., and Weis, B.R., 1985, Evaluation of fractured carbonates in the Mid-Continent region, paper III, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 19 p.

Brie, A., Hsu, K., Eckersley, C., 1988, Using the Stoneley normalized differential energies for fractured reservoir evaluation, paper XX, in 29th annual symposium transactions: Society of Professional Well Log Analysts, 25 p. Also published in 1988, paper F, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 25 p.

Brown, R.O., 1978, Application of fracture identification logs in the Cretaceous of north Louisiana and Mississippi: Gulf Coast Association of Geological Societies Transactions, v. 28, p. 75-91.

Burns, K.L., 1985, Information extraction from noisy televiewer logs of inclined wellbores in hard rock: Geothermal Resources Council Transactions, v. (, part 2, p. 441-445.

Burns, K.L., 1988, Televiewer measurement of the orientation of in situ stress at the Fenton Hill hot dry rock site, New Mexico: Los Alamos National Laboratory Report LA-UR-88-1775, 6 p. Also published in 1988, Geothermal Resources Council Transactions, v. 12, p. 229-235.

Butler, M. Phelan, M.J., and Wright, A.W.R., 1976, Buchan field--Evaluation of a fractured sandstone reservoir, paper A, in 4th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, London Chapter, 18 p. Later published in 1977, The Log Analyst, v. 18(2), March-April, p. 23-31.

Butsch, R.J., 1982, Identifying fractured reservoirs through casing: The Technical Review, v. 30(2), September, p. 23-31.

Cannon, D.E., 1979, Log evaluation of a fractured reservoir--Monterey Shale, paper Q, in 20th annual logging symposium transactions: Society of Professional Well Log Analysts, 13 p. Later reprinted in 1981, in R.E. Garrison and R.G. Douglas, editors, The Monterey Formation and related siliceous rocks of California: Pacific Section Society of Economic Mineralogists and Paleontologists, Los Angeles, p. 249-255.

Casarta, L.J., McNaughton, D.A., Bornemann, E., and Bettis, F.E., 1989, Fracture identification and matrix characterization using a new borehole imaging device in the Lisburne carbonate, Prudhoe Bay, Alaska, paper XX, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 10 p.

Cheung, P.S.Y., 1984, Fracture detection using the sonic tool, paper 42, in 9th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 8 p.

Chilingarian, G., and Fertl, W.H., 1987, Fracture detection using circumferential acoustic logs: Energy Sources, v. 9(3), p. 149-160.

Chilingarian, G.V., and Yen, T.F., 1986, Notes on carbonate reservoir rocks, no. 3--Fractures: Energy Sources, v. 8(2/3), p. 261-275.

Clavier, C., 1985, Accuracy and limitations with special log data, in 1985 technical program abstracts and biographies: Society of Exploration Geophysicists, p. 286-289.

Cornet, F.H., 1989, Survey by various logging techniques of natural fractures, paper DD, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 559-569.

Cox, J.W., 1982, Long-axis orientation in elongated boreholes: The Technical Review, v. 30(3), December, p. 15-25.

Cox, J.W., 1983, Long axis orientation in elongated boreholes and its correlation with rock stress data, paper J, in 24th annual logging symposium transactions: Society of Professional Well Log Analysts, 17 p.

Crampin, S., Lynn, H.B., and Booth, D.C., 1987, Shear-wave VSP's; a powerful new tool for fracture and reservoir description, SPE-16866, in 1987 SPE annual technical conference and exhibition proceeding, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers. Later published in 1989, Journal of Petroleum Technology, v. 41(3), p. 283-288.

Crary, S., Dennis, B., Denoo, S., et al., 1987, Fracture detection with logs: The Technical Review, v. 35(1), April, p. 22-34.

Cross, J.W., 1986, Fracture detection in a volcanic oil reservoir using discriminant analysis of well log data: Old Dominion University, unpublished MS thesis, 1`13 p.

Cruden, D.M., Lau, J.S.O., Auger, L.F., and Bisson, J.G., 1987, Subsurface fracture surveys using a borehole television camera and acoustic televiewer: Canadian Geotechnical Journal, v. 24, p. 499-508.

Dart, R., 1985, Horizontal-stress directions in the Denver and Illinois basins from the orientations of borehole breakouts: U.S. Geological Survey Open-File Report 85-733, 41 p.

Dart, R.D., 1989, Horizontal stresses from well-bore breakouts and lithologies associated with their formation, Oklahoma and Texas Panhandle, in Johnson, K.S., editor, Anadarko basin symposium, 1988: Oklahoma Geological Survey Circular No. 90, p. 97-120.

Dart, R.D., and Zoback, M.L., 1987, Principal stress directions on the Atlantic Continental Shelf inferred from the orientations of borehole elongations: U.S. Geological Survey Open-File Report 87-283, 43 p.

Dart, R.D., and Zoback, M.L., 1988, Well-bore breakout-stress analysis within the continental United States, paper L, in 2nd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applications [Golden, Colorado, October 6-8, 1987], proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society Chapter-at-Large, p. 139-149. Later published in 1989 as, Wellbore breakout stress analysis within the central and eastern continental United States: The Log Analyst, v. 30(1), January-February, p. 12-24.

Dearborn, J.L., 1988, Borehole geophysical investigation of fractured rock at an EPA superfund site in Massachusetts, in 2nd national outdoor action conference on aquifer restoration, ground water monitoring, and geophysical methods [Las Vegas, May 23-26] proceedings, volume 2: Association of Ground Water Scientists and Engineers (AAAS), p. 875-895.

Dearborn, L.L., Baker, P.S., and Davis, J.B., 1989, Preliminary interpretation of geophysical logs and in-situ hydrologic properties in fractured limestone at Loring Air Force Base, paper FF, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 595-622.

Delhomme, J.P., Panci, G., Leslie, D., Cigni, M., and Spila, M., 1981, An integrated approach to fracture detection from multipad sensors, paper 26, in 7th European logging symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 17 p.

DeLuca, R.J., and Buckley, B.K., 1985, Borehole logging to delineate fractures in a contaminated bedrock aquifer, in 1985 NWWA conference on surface and borehole geophysical methods in ground water investigations [Fort Worth, Texas, February 12-14], proceedings: National Water Well Association, Worthington, Ohio, p. 387-398.

Dennis, B., 1985, Digital Sonic (SDT) - full waveform logging applications in western Canada: Canadian Well Logging Society Journal, v. 14, p. 63.

Dennis, B., and Standen, E., 1988, Fracture identification techniques in carbonates, paper 88-39-110, in 39th annual technical meeting, preprints, volume 3: Petroleum Society of CIM [Canadian Institute of Mining], Calgary, p. 19 p.

Dennis, B., Standen, E., Georgi, D.T., and Callow, G.O., 1987, Fracture identification and productivity predictions in a carbonate reef complex, SPE-16808, in 1987 SPE annual meeting proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 579-588. A similar version also published in 1987 as, Fracture identification techniques in carbonates, paper Y, in 11th formation evaluation symposium transactions: Canadian Well Logging Society, 27 p.

Do Rozario, R.F., and Baird, B.W., 1987, The detection and significance of fractures in the Palm Valley gas field: APEA [Australian Petroleum Exploration Association] Journal, v. 27, part 1, p. 264-280.

Dreier, R.B., and Leat, M.B., 1988, Fracture zone identification in the Applachian fold and thrust belt determined from geophysical logs: U.S. Department of Energy Report No. CONF-880583-4, 22 p.

Drury, M.J., 1989, Fluid flow in crystalline crust; detecting fractures by temperature logs, in Beck, A.E., Garven, G., and Stegena, editors, Hydrological regimes and their subsurface thermal effects: American Geophysical Union Geophysical Monograph 47, p. 129-135.

Emmendorfer, A., 1989, Fracture orientation; use of the dipmeter-type fracture log: The Mountain Geologist, v. 26(2), April, 63-67.

Engelhard, L., 1985, Shear wave well logging from wavetrain analysis, chapter 5, in G.P. Dohr, editor, Seismic shear waves, seismic exploration volume 15A, part A--Theory: Geophysical Press, London, p. 283-351.

Ervine, W.B., and Bell, J.S., 1987, Subsurface in situ stress magnitudes from oil-well drilling records--An example from the Venture area, offshore eastern Canada: Canadian Journal of Earth Sciences, v. 24(9), p. 1748-1759.

Etnyre, L., 1981, Fracture detection identification in the Panoma Field, Council Grove Formation: The Log Analyst, v. 22(6), November-December, p. 3-6.

Evans, C.J., and Brereton, N.R., 1990, In situ crustal stress in the United Kingdom from borehole breakouts, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 327-338.

Evans, K.F., and Engelder, J.T., 1986, A study of stress in Devonian Shale, part I--3D stress mapping using a wireline microfrac system, SPE-15609: Society of Petroleum Engineers, 61st annual meeting [New Orleans] preprint, 12 p.

Evans, K.F., Engelder, T., and Plumb, R.A., 1989, Appalachian stress study, part 1, A detailed description of in situ stess variations in Devonian shales of the Appalachian plateau: Journal of Geophysical Research, v. 94B96), June 10, p. 7,129-7,154.

Evans, K.F., Engelder, T., and Plumb, R.A., 1989, Appalachian stress study, part 2, Analysis of Devonian shale core; some implications for the nature of contemporary stress variations and Alleghanian deformation in Devonian rocks: Journal of Geophysical Research, v. 94B96), June 10, p. 7,155-7,170.

Fertl, W.H., 1980, Evaluation of fractured reservoirs using geophysical well logs, SPE/DOE-8938, in SPE/DOE unconventional gas recovery symposium, proceedings: Society of Petroleum Engineers, p. 131-136.

Fertl, W.H., 1987, Recent advances in fracture evaluation, SPE-16226, in 1987 SPE production operations symposium [Oklahoma City, March 8-10, 1987], proceedings: Society of Petroleum Engineers, p. 403-419.

Fertl, W.H., 1990, Circumferential acoustics logs detect natural fractures and determine their orientation, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 255-262.

Fertl, W.H., and Rieke, H.H., III, 1979, Gamma ray spectral evaluation techniques identify fractured shale reservoirs and source-rock characteristics, SPE-8454: Society of Petroleum Engineers, 54th annual meeting [Las Vegas] preprint. Later published in 1980, Journal of Petroleum Technology, v. 32(11), p. 2053-2062.

Fordjor, C.K., Bell, J.S., and Gough, D.I., 1983, Breakouts in Alberta and stress in the North American plate: Canadian Journal of Earth Science, v. 20; p. 1445-1455

Frank, R.W., and Simonson, R.B., 1983, Identification and interpretation of naturally fractured reservoirs in north Texas, in Exploration in a mature area [AAPG Southwest section annual meeting (Abilene, Texas, March 6-80), proceedings]: Abilene Geological Society, Abilene, Texas, 143-167.

Frisinger, M.R., and Gyllensten, A., 1986, Fracture detection in North Sea reservoirs, paper Q, in 10th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Aberdeen Chapter, 18 p.

Gatens, J.M., III, Lancaster, D.E., Harrison, C.W., III, and Guidry, F.K., 1988, Using in-situ tests and acoustic logs to determine mechanical properties and stress profiles in the Devonian shales, SPE-18523, in SPE eastern regional meeting, proceedings: Society of Petroleum Engineers, p. 7-20. Reprinted in 1989, Devonian Gas Shales Technology Review, v. 6(1), July, p. 8-24.

Georgi, D.T., 1986, Guides for the interpretation of dipmeter fracture logs, paper TT, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p.

Goldberg, D., Speed, D., Wilkinson, C., and Scholz, E., 1990, A correlation of hydraulic conductivity from pulse tests with sonic log amplitudes, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 297-302.

Gonfalini, M., and Anxionnaz, H., 1990, A complete use of structural information from borehole imaging techniques [FMS]; a case history for a deep carbonate reservoir, paper J, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Gough, D.I., and Bell, J.S., 1981, Stess orientations from oil-well fractures in Alberta and Texas: Canadian Journal of Earth Sciences, v. 18, p. 638-645.

Gough, D.I., and Bell, J.S., 1982, Stress orientations from borehole fractures with examples from Colorado, east Texas, and northern Canada: Canadian Journal of Earth Sciences, v. 19(7), p. 1358-1370.

Gough, D.I., and Gough, W.I., 1987, Stress near the surface of the earth, in G.W. Wetherill, A.L. Albee, and F.G. Stehli, editors, Annual review of earth and planetary sciences, volume 15: Annual Reviews Inc., Palo Alto, p. 545-66.

Grove, G.P., and Whittaker, J.L., 1985, Continuous fracture probability determination as applied to the Monterey Formation, SPE-13652, in 55th annual California regional meeting proceedings: Society of Petroleum Engineers, p. 591-598.

Haase, C.S., and King, H.L., 1986, Application of borehole geophysics to fracture identification and characterization in low permeability limestones and dolostones, in Surface and borehole geophysical methods and ground water instrumentation conference and exposition [Denver, October 15-17], proceedings: National Water Well Association, Dublin, Ohio, p. 487-506.

Haimson, B.C., and Herrick, C.G., 1985, In situ stress evaluation from borehole breakouts, experimental studies, in E. Ashworth, editor, Research and engineering applications in rock masses [26th U.S. symposium on rock mechanics, South Dakota School of Mines and Technology, Rapid City, 26-28 June, proceedings], volume 2: A.A. Balkema, Boston, p. 1207-1218.

Haimson, B.C., and Herrick, C.G., 1986, Borehole breakouts--A new tool for estimating in situ stress, in I. Stephansson, editor, Rock Stress and rock stress measurements [international symposium on rock stress and rock stress measurements [Stockholm, September 1-3], proceedings]: Centek Publishers, Stockholm, p. 271-280.

Haimson, B.C., and Herrick, C.G., 1989, Borehole breakouts and in situ stress, in Rowley, J.C., editor, Drilling symposium 1989 [12th annual energy-sources technology conference and exhibition (Houston, January 22-25): American Society of Mechanical Engineers, New York, PD-Vol. 22, p. 17-22.

Haimson, B.C., and Lee, M.Y., 1987, The state of stress and natural fractures in a jointed Precambrian rhyolite in south-central Wisconsin, in I.W. Farmer, J.J.K. Daemen, C.S. Desai, C.E. Glass, and S.P. Neuman, editors, Rock mechanics; proceedings of the 28th U.S. symposium: A.A. Balkema, Boston, 231-240.

Hansen, K.S., and Purcell, W.R., 1986, Earth stress measurements in the South Belridge oil field, Kern County, California, SPE-15641: Society of Petroleum Engineers, 61st annual meeting [New Orleans] preprint, 15 p. Later published in 1989, SPE Formation Evalution, v. 3(4), December, p. 541-549.

Harvey, A.H., Koederitz, L.F., and Honarpour, M., 1988, How well logs detect fractures, part 1--Techniques used in identification: Petroleum Engineer International, v. 60(7), p. 45-51.

Harvey, A.H., Koederitz, L.F., and Honarpour, M., 1988, How well logs detect fractures, part 2--Logging tools: Petroleum Engineer International, v. 60(8), August, p. 40-45.

Healy, J.H., Hickman, S.H., Zoback, M.D., and Ellis, W.L., 1984, Report on televiewer log and stress measurements in core hole USW-G1, Nevada test site, December 13-22, 1981: U.S. Geological Survey Open-File Report 84-15, 47 p.

Heflin, J.D., 1979, Fracture detection in West Coast reservoirs using well logs, SPE-7976: Society of Petroleum Engineers, California Regional meeting preprint, 16 p.

Heflin, J.D., and Frost, E., Jr., 1981, Some novel approaches in the use of wireline logs for fracture detection, paper 22, in 7th European logging symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 42 p. Later published 1983, in C.M. Isaacs, R.E. Garrison, editors, Petroleum generation and occurrence in the Miocene Monterey Formation, California: Pacific Section, Society of Economic Paleontologists and Mineralogists, p. 131-149.

Heflin, J.D., Neill, B.E., and DeVries, M.R., 1976, Log evaluation in the California Miocene, SPE-6160: Society of Petroleum Engineers, 51st annual meeting [New Orleans] preprint, 17 p. Reprinted in 1981, Spectralog: Dresser Industries, Houston, Publication No. 3334.

Hensel, W.M., Jr., 1987, A perspective look at fracture porosity, SPE-16806, in 1987 SPE annual technical conference proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 571-578. Reprinted in 1988, in Permian basin oil and gas recovery symposium, proceedings: Society of Petroleum Engineers, p. 65-72. Later published in 1989, SPE Formation Evalution, v. 3(4), December, p. 531-534.

Hess, A.E., and Paillet, F.L., 1989, Characterizing flow paths and permeability distribution in fractured-rock aquifers using a sensitive, thermal, borehole flowmeter, in Conference on new field techniques for quantifying the physical and chemical properties of heterogeneous aquifers [March 20-23, Dallas, TX], proceedings: National Water Well Association, Dublin, OH, p. 155-172.

Hickman, S.H., Healy, J.H., and Zoback, M.D., 1985, In situ stress, natural fracture distribution and borehole elongation in the Auburn geothermal well, Auburn, New York: Journal of Geophysical Research, v. 90(B7), p. 5497-5512.

Hirsch, J.M., 1981, Recent experience with wireline fracture detection logs, SPE-10333: Society of Petroleum Engineers, 56th annual meeting [San Antonio] preprint, 10 p.

Holbrook, P.W., 1989, A new method for predicting fracture propagation pressure from MWD or wireline log data, SPE-19566, in SPE annual technical conference and exhibition, proceedings, volume delta, Drilling: Society of Petroleum Engineers, p. 475-487.

Holditch, S.A., 1989, Pretreatment formation evaluation, chapter 2, in Gidley, J.L., Holditch, S.A., Nierode, D.E., and Veatch, R.W., Jr., editors, Recent advances in hydraulic fracturing: Society of Petroleum Engineers, p. 39-56.

Hornby, B.E., Johnson, D.L., Winkler, K.W., and Plumb, R.A., 1987, Fracture evaluation from the borehole Stonely wave, in 57th annual meeting expanded abstracts with biographies: Society of Exploration Geophysicists, p. 688-691. Later published in 1989, Geophysics, v. 54(10), p. 1,274-1,288.

Hornby, B.E., Luthi, S.M., and Plumb, R.A., 1990, Comparison of fracture apertures computed from electrical borehole scans and reflected Stoneley waves--an automated interpretation, paper L, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Hottman, C.E., Smith, J.H., and Purcell, W.R., 1978, Relationship among earth stresses, pore pressure, and drilling problems offshore Gulf of Alaska, SPE-7501: Society of Petroleum Engineers, 53rd annual meeting [Houston] preprint. Later published in 1979, Journal of Petroleum Technology, v. 31(11), November, p. 1477-1484.

Howard, K.W.F., 1986, The influence of fissuring on saline incursion in a limestone aquifer as revealed by fluid logging, in P.G. Killeen, editor, Borehole geophysics for mining and geotechnical applications [international symposium and workshop, (Toronto, Ontario, August 29-31, 1983), proceedings]: Geological Survey of Canada Paper 85-27, p. 217-226.

Howard, K.W.F., Hughes, M., and Thompson, M.J., 1986, Down-hole geophysical methods of fracture detection in low resistivity bedrock, in Surface and borehole geophysical methods and ground water instrumentation conference and exposition [Denver, October 15-17], proceedings: National Water Well Association, Dublin, Ohio, p. 507-524.

Hsu, K., Brie, A., and Plumb, R.A., 1985, A new method for fracture identification using array sonic tools, SPE-14397: Society of Petroleum Engineers, 60th annual meeting [Las Vegas], preprint, 8 p. Later published in 1987, Journal of Petroleum Technology, v. 39(6), p. 677-683.

Irish, J.P.R., and Kempthorne, R.H., 1987, The study of natural fractures in a reef complex, Norman Wells oil field, Canada, in R.W. Tillman and K.J. Weber, editors, Reservoir sedimentology: Society of Economic Paleontologists and Mineralogists, Special Publication No. 40, p. 153-167.

Jamtlid, A., Manusson, K., Olsson, O., and Stenberg, L., 1984, Electrical borehole measurements for the mapping of fracture zones in crystalline rock: Geoexploration, v. 22, p. 203-216.

Jianmin, D., Guoping, L., Qiliang, G., and Jianli, G., Shouye, C., Zhenxian, J., Zhaohui, J., and Jilin, Y., 1988, The orientation of crustal stress determined from borehole breakouts: Acta Seismologica Sinica, v. 1(2), p. 33-43.

Jones, J.W., Simpson, E.S., and Neuman, S.P., 1984, Geophysical investigation of fractured crystalline rock near Oracle, Arizona, in D.M. Nielsen and M. Curl, editors, 1984 NWWA/EPA conference on surface and borehole geophysics methods in ground water investigations, proceedings: National Water Well Association, Worthington, Ohio, p. 877-896.

Julian, P.J., 1982, Fracture detection techniques in the Georgetown and Austin chalk formations, SPE-11035: Society of Petroleum Engineers, 57th annual meeting [New Orleans] preprint.

Kern, J.W., Sinha, A.K., and Sookram, V.A., 1983, Geophysical techniques for coalbed evaluation, final report: Gas Research Institute, Chicago, Report 83-0055 [preprared by Dresser Petroleum Engineering Services under contract no. 5081-214-0587], variously paginated.

Keys, W.S., 1982, Location and character of fractures in geothermal wells, in Fractures in geothermal reservoirs: Geothermal Resources Council, Special Report No. 12, p. 17-27.

Keys, W.S., 1984, A synthesis of borehole geophysical data at the Underground Research Laboratory, Manitoba, Canada: U.S. Department of Energy Report BMI/OCRD-15, 43 p.

Kierstein, R.A., 1984, True location and orientation of fractures logged with the acoustic televiewer (including programs to correct fracture identification): U.S. Geological Survey Water-Resources Investigations Report 83-4275, 73 p.

King, M.S., and McConnell, B.V., 1975, Fracture evaluation with acoustic log in dry borehole, in E.R. Hoskins, Jr., editor, Applications of rock mechanics [15th symposium on rock mechanics, (September 17-19, 1973) proceedings] : American Society of Civil Engineers, New York, p. 273-292

Kleinberg, R.L., Chow, E.Y., Plona, T.J., Orton, M., and Canady, W.J., 1982, Sensitivity and reliability of fracture detection techniques for borehole application, SPE-11036: Society of Petroleum Engineers, 57th annual meeting [New Orleans] preprint. 8 p.

Knize, S., 1989, Evaluation of full wave sonic data by analysis of instantaneous characteristics and colorgrams, paper II, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 14 p.

Knize, S., and Patton, B., 1989, Application of complex waveform analysis and color displays, paper H, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 20 p.

Koederitz, L.F., Harvey, A.H., and Honarpour, M., 1989, Naturally fractured reservoir, chapter 6, in Introduction to petroleum reservoir analysis: Gulf Publishing Company, Houston, Contributions in Petroleum Geology & Engineering, No. 6, p. 128-151.

Koerperich, E.A., 1977, Investigation of acoustic boundary waves and interference patterns as techniques for detecting fractures, SPE-6820: Society of Petroleum Engineers, 52nd annual meeting [Denver] preprint. Later published in 1978, Journal of Petroleum Technology, v. 30(8), p. 1199-1207.

Lacy, L.L., and Smith M.B., 1989, Fracture azimuth and geometry determination, chapter 16, in Gidley, J.L., Holditch, S.A., Nierode, D.E., and Veatch, R.W., Jr., editors, Recent advances in hydraulic fracturing: Society of Petroleum Engineers, p. 341-356.

Lamb, C.F., and Ferguson, D.G., 1988, The role of core analysis in fractured reservoir evaluation, paper 88-39-86, in 39th annual technical meeting, preprints, volume 3: Petroleum Society of CIM [Canadian Institute of Mining], Calgary, p. 10 p.

Lau, J.S.O., Auger, L.F., and Bisson, J.G., 1987, Subsurface fracture surveys using a borehole television camera and acoustic televiewer: Canadian Geotechnical Journal, v. 24(4), November, p. 499-508.

Lau, M.N., and Bassiouni, Z., 1989, Oil detection in fractured carbonates of Chapayal basin, Guatemala: The Log Analyst, v. 30(4), July-August, p. 261-269.

Laubach, S.E., 1989, Fracture analysis of the Travis Peak Formation, eastern flank of the Sabine arch, east Texas: Texas Bureau of Economic Geology Reprot of Investigations No. 185, 55 p.

Laubach, S.E., Baumgardner, T.W., Jr., Monson, E.R., Hunt, E., and Meador, K.J., 1988, Fracture detection in low-permeability reservoir sandstone; a comparison of BHTV and FMS logs to core, SPE-18119, in 1988 SPE annual technical conference proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 129-139.

Lehne, K.A., 1988, Fracture detection from logs of North Sea chalk, paper E, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 18 p. Later published in 1990, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 263-271.

Levine, E.N., Cybriwsky, Z.A., and Toksoz, M.N., 1984, Detection of permeable rock fractures and estimation of hydraulic conductivity by 3-D vertical seismic profiling, in D.M. Nielsen and M. Curl, editors, 1984 NWWA/EPA conference on surface and borehole geophysics methods in ground water investigations, proceedings: National Water Well Association, Worthington, Ohio, p. 853-876.

Liu, O.Y., 1985, Fracture evaluation using borehole sonic velocity measurements, SPE-14399: Society of Petroleum Engineers, 60th annual meeting [Las Vegas], preprint, 8 p.

Lui, O.Y., 1986, A new method of fracture detection using borehole sonic velocity, paper R measurements, in 10th European formation evaluation symposium transactions : Society of Professional Well Log Analysts, Aberdeen Chapter, 13 p.

Martin, M., and Davis, T.L., 1987, Shear-wave birefringence; a new tool for evaluating fractured reservoirs: Geophysics--The leading edge [Society of Exploration Geophysicists], v. 6(10), p. 22-28.

Mastin, L., 1988, Effect of borehole deviation on breakout orientations: Journal of Geophysical Research, v. 93(B8), p. 9,187-9,195.

Mathieu, F., and Toksoz, M.N., 1984, Determination of fracture permeability using acoustic logs, paper 47, in 9th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 39 p.

Mathieu, G., Yver, J-P., Cheung, P., Brie, A., Hornby, B., and Hsu, K., 1985, Applying sonic data; fracture detection: The Technical Review, v. 33(1), p. 69-79.

McCoy, R.L., Kumar, R.M. and Pease, R.W., 1980, Fracture identification in Devonian shales using conventional well logs, in 11th annual Appalachian petroleum geology symposium: West Virginia Geological and Economic Survey Circular C-16, p. 16-28. A condensed version published in 1980 as, Identifying fractures with conventional well logs: World Oil, v. 191(7), December, p. 91-98.

McDougall, J., 1988, Advances in fracture detection using petrophysical data, in 27th annual conference transactions: Ontario Petroleum Institute, London, Ontario, Canada, p. 1-37.

McEwen, T.J., McCann, D.M., and Shedlock, S., 1985, Fracture analysis from borehole geophysical techniques in crystalline rocks: The Quarterly Journal of Engineering and Geology, v. 18(4), p. 413-436.

Merin, I.S., 1989, Characterization of fractures in Devonian siltstones, northern Appalachian plateau; implications for ground water flow, in 3rd national outdoor action conference on aquifer restoration, ground water monitoring and geophysical methods [Orlando, Florida], proceedings: National Well Water Association, Dublin, Ohio, p. 921-934.

Michalski, A., and Klepp, G.M., 1990, Characterization of transmissive fractures by simple tracing of inwell flow: Ground Water, v. 28(2), p. 191-198.

Mickam, J.T., Levy, B.S., and Lee, G.W., Jr., 1984, Detection of fractures and solution channels in karst terranes using natural gamma ray and hole caliper borehole logs, in D.M. Nielsen and M. Curl, editors, 1984 NWWA/EPA conference on surface and borehole geophysics methods in ground water investigations, proceedings: National Water Well Association, Worthington, Ohio, p. 801-811.

Minne, J.C., and Gartner, J., 1979, Fracture detection in the Middle East, SPE-7773, in 1979 Middle East oil technical conference, proceedings: Society of Petroleum Engineers, p. 183-190.

Moos, D., 1984, A case study of vertical seismic profiling in fractured crystalline rock, in M. Simaan, editor, Advances in geophysical data processing, volume 1: JAI Press, Greenwich, Connecticut, p. 9-37.

Moos, D., and Zoback, M.D., 1983, In situ studies of velocity in fractured crystalline rocks: Journal of Geophysical Research, v. 88(B3), March 10, p. 2345-2358.

Morin, R.H., Anderson, R.N., and Barton, C., 1989, Analysis and interpretation of the borehole televiewer log; information on the state of stress and the lithostratigraphy at hole 504B, chapter 10, in Mazzullo, E.K., editor, Proceedings of the Ocean Drilling Program, v. 111, Scientific results: Texas A & M University, Ocean Drilling Program, p. 109-118.

Morin, R.H., and Barrash, W., 1986, Defining patterns of ground water and heat flow in fractured Brule Formation, western Nebraska, using borehole geophysical methods, in Surface and borehole geophysical methods and ground water instrumentation conference and exposition [Denver, October 15-17], proceedings: National Water Well Association, Dublin, Ohio, p. 545-569.

Morin, R.H., Hess, A.E., and Paillet, F.L., 1988, Determining the distribution of hydraulic conductivity in a fractured limestone aquifer by simultaneous injection and geophysical logging: Ground Water, v. 26(5), October, p. 587-595.

Morris, R.L., Grine, D.R., and Arkfeld, T.E., 1964, Using compressional and shear acoustic amplitudes for the location of fractures: Journal of Petroleum Technology, v. 16(6), p. 623-632.

Mount, V.S., 1989, Present-day stress directions in California, chapter 2, in State of stress in California and a seismic structural analysis of the Perdido fold belt, northwest Gulf of Mexico: Princeton University unpublished Ph.D. dissertation, p. 20-56.

Mwenifumbo, C.J., 1988, Cross-borehole mise-a-la-masse mapping of fracture zones at the Bells Corners borehole geophysical test area, Ottawa, Canada, paper M, in 2nd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applications [Golden, Colorado, October 6-8, 1987], proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society Chapter-at-Large, p. 151-165.

Myung, J.I., 1976, Fracture investigation of the Devonian shale using geophysical well logging techniques, SPE-6366: Society of Petroleum Engineers, Eastern region annual meeting preprint, 16 p. Also published in 1976 in R.C. Shumaker and W.K. Overbey, Jr., editors, 7th Appalachian petroleum geology symposium, proceedings: U.S. Department of Energy Report MERC/SP-76/2, p. 212-238, [these proceedings were also published by West Virginia Geological and Economic Survey, p. 1-29.]

Myung, J.I., and Baltosser, R.W., 1977?, Fracture evaluation by the borehole logging method: Birdwell Division, Seismograph Service Corporation, Tulsa, 28 p.

Nelson, R.A., 1985, Geologic analysis of naturally fractured reservoirs: Gulf Publishing Company, Houston, Contributions in Petroleum Geology and Engineering Series, volume 1, 320 p.

Nelson, R.A., 1987, Fractured reservoirs--Turning knowledge into practice: Journal of Petroleum Technology, v. 39(4), p. 407-414.

Newmark, R.L., Anderson, R.N., Moos, D., and Zoback, M.D., 1985, Sonic and ultrasonic logging of hole 504B and its implications for the structure, porosity, and stress regime of the upper 1 km of the oceanic crust, in Initial reports of the the Deep Sea Drilling Project, v. 83: U.S. Government Printing Office, p. 479-510. Also published in 1985 as, Structure, porosity and stress regime of the upper oceanic crust--Sonic and ultrasonic logging of DSDP hole 504B: Tectonophysics, v. 118, p. 1-42.

Newmark, R.L., Zoback, M.D., and Anderson, R.N., 1984, Orientation of in situ stresses in the oceanic crust: Nature, v. 311, October 4, p. 424-429.

Newmark, R.L., Zoback, M.D., and Anderson, R.N., 1985, Orientation of the in situ stresses near the Coast Rica rift and Peru-Chile trench--Deep Sea Drilling Project Hole 504B, in Initial reports of the Deep Sea Drilling Project, v. 83: U.S. Government Printing Office, p. 511-515.

Noblett, B.R., Fertl, W.H., and Guy, J.O., 1987, Recent advances in fracture evaluation, SPE-16226, in Production operations symposium [Oklahoma City] proceedings: Society of Petroleum Engineers, p. 403-419. A condensed version published in 1987 as, Circumferential acoustic log finds vertical fractures: World Oil, v. 205(5), November, p. 37-38.

Noblett, B.R., and Howard, L.P., 1989, New resistivity fracture detection concepts for the evaluation of shale formations, paper X, in 30th annual logging symposium transactions: Society of Professional Well Log Analysts, 12 p.

Norman, D.K., and Garrett, C.H., 1988, Advances in fractured reservoir characterization, paper 88-39-111, in 39th annual technical meeting, preprints, volume 3: Petroleum Society of CIM [Canadian Institute of Mining], Calgary, p. 22 p.

Olsson, O., Falk, L., Forslund, O., Niva, B., and Sandberg, E., 1989, Borehole radar applied to characterization of fracture zones: Exploration Geophysics [Bulletin Australian Society of Exploration Geophysicists], v. 20(1-2), p. 149-152.

Olsson, O., Falk, L., Sandberg, S., Carsten, S., and Magnusson, K-A, 1985, Results from borehole radar reflection measurements, in Radioactive waste disposal in situ experiments in granite [Proceedings of 2nd NEA/Stripa Project symposium, June 1985]: Nuclear Energy Agency, Paris, p. 190-202.

Olsson, O., Falk, L., Sandberg, E., Forslund, O., and Lundmark, L., 1989, Radar measurements with a directional borehole antenna, paper E/G 1.4, in Expanded abstracts with biographies 59th annual meeting, v. 1: Society of Exploration Geophysicists, p. 222-225.

Olsson, O., Forslund, O, Lundmark, L, Sandberg, E., and Falk, L., 1985, The design of a borehole radar system for detection of fracture zones, in Radioactive waste disposal in situ experiments in granite [Proceedings of 2nd NEA/Stripa Project symposium, June 1985]: Nuclear Energy Agency, Paris, p. 172-189.

Overby, W.K., Jr., Yost, L.E., and Yost, A.B., II, 1988, Analysis of natural fractures observed by borehole video camera in a horizontal well, SPE-17760, in SPE gas technology symposium [Dallas], proceedings: Society of Petroleum Engineers, p. 9-16.

Paillet, F.L., 1981, A comparison of fracture characterization techniques applied to near-vertical fractures in a limestone reservoir, paper XX, in 22nd annual logging symposium transactions: Society of Professional Well Log Analysts, 29 p.

Paillet, F.L., 1985, Problems in fractured-reservoir evaluation and possible routes to their solution: The Log Analyst, v. 26(6), November-December, p. 26-41.

Paillet, F.L., 1988, Fracture characterization and fracture-permeability estimation at the underground research laboratory in southeastern Manitoba, Canada: U.S. Geological Survey Water Resources Investigations Report 88-4009, 42 p.

Paillet, F.L., Keys, W.S., and Hess, A.E., 1985, Effects of lithology on televiewer log quality and fracture interpretation, paper JJJ, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 31 p.

Paillet, F.L., and Hess, A.E., 1986, Geophysical well-log analysis of fractured crystalline rocks at East Bull lake, Ontario Canada: U.S. Geological Survey Open-File Report 86-452, 37 p.

Paillet, F.L., and Hess, A.E., 1987, Geophysical well log analysis of fractured granitic rocks at Atikokan, Ontario, Canada: U.S. Geological Survey Water Resources Investigations Report No. 87-4154, 36 p.

Paillet, F.L., and Keys, W.S., 1984, Applications of borehole geophysics in characterizing the hydrology of fractured rocks, in D.M. Nielsen and M. Curl, editors, 1984 NWWA/EPA conference on surface and borehole geophysics methods in ground water investigations [San Antonio, February 7-9], proceedings: National Water Well Association, Worthington, Ohio, p. 743-761.

Paillet, F.L., and Kim, K., 1985, The character and distribution of borehole breakouts and their relationship to in situ stresses in deep Columbia River basalts: Rockwell Hanford, Richland, Washington, Operations Report RHO-BW-CR-155, December, 27 p. Later published in 1987, Journal of Geophysical Research, v. 92(B7), p. 6223-6234.

Paillet, F.L., and Turpening, R., 1984, Borehole and surface-to-borehole seismic applications in fracture characterization, in Expanded abstracts with biographies, 1984 technical program: Society of Exploration Geophysicists, p. 333-334.

Paillet, F.L., Cheng, C.H., Hess, A.E., and Hardin, E.L., 1986, Comparison of fracture permeability estimates based on tube-wave generation in vertical seimic profiles, acoustic waveform-log attenuation, and pumping-test analysis, in Surface and borehole geophysical methods and ground water instrumentation conference and exposition [Denver, October 15-17], proceedings: National Water Well Association, Dublin, Ohio, p. 398-416.

Paillet, F.L., Hess, A.E., Cheng, C.H., and Hardin, E.A., 1987, Characterization of fracture permeability with high-resolution vertical flow measurements during borehole pumping: Ground Water, v. 25(1), February, p. 28-40.

Peeters, M., and Hartley, R., 1984, Induced fracture height detection from wireline logs, paper GGG, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p.

Pezard, P.A., and Anderson, R.N., 1990, In situ measurements of electrical resistivity, formation anisotropy, and tectonic context, paper M, in 31st annual logging symposium transactions: Society of Professional Well Log Analysts, 24 p.

Pezard, P.A., Anderson, R.N., Howard, J.J., and Luthi, S.M., 1988, Fracture distribution and basement structure from measurements of electrical resistivity in the basement of the Cajon Pass scientific drillhole, California: Geophysical Research Letters, v. 15(9, supplement), p. 1,021-1,024.

Pezard, P.A., and Luthi, S.M., 1988, Borehole electrical images in the basement of the Cajon Pass scientific drillhole, California; fracture identification and tectonic implications: Geophysical Research Letters, v. 15(9, supplement), p. 1,017-1,020.

Pirhonen, V.O., 1988, Combined geophysical and hydraulic methods for 3D mapping of fractures and siting rock caverns in granite: Engineering Geology, v. 25(1), p. 45-68.

Pirson, S.J., 1983, Fracture intensity logging and mapping, chapter 7, in Geologic well log analysis, 3rd edition: Gulf Publishing Co., Houston, p. 191-215.

Plumb, R.A., and Hickman, S.H., 1985, Stress-induced borehole elongation--A comparison between the four-arm dipmeter and the borehole televiewer in the Auburn geothermal well: Journal of Geophysical Research, v. 90(B7), p. 5513-5521.

Rasmus, J.C., 1981, Determining the type of fluid contained in the fractures of the Twin Creek limestone by using the Dual Laterolog tool, paper C, in 1981 SPE/DOE low-permeability symposium [Denver], proceedings: Society of Petroleum Engineers, p. Later published in 1982, Journal of Petroleum Technology, v. 34(11), p. 2673-2682.

Reiss, L.H., 1980, Well logging in fractured reservoirs, appendix 1, in The reservoir engineering aspects of fractured formations: Gulf Publishing Co., Houston, p. 47-53.

Rieke, H.H., III, Oliver, D.W., and Fertl, W.H., McCord, J.P., 1980, Successful application of carbon/oxygen logging to coalbed exploration, SPE-9464: Society of Petroleum Engineers, 55th annual meeting [Dallas] preprint, 11 p. Later published in 1983, Journal of Petroleum Technology, v. 35(2), p. 421-428. Reprinted 1981, in Carbon/Oxygen Log: Dresser Industries, Houston, Publication No. 9417.

Rigby, F.A., 1980, Fracture identification in an igneous geothermal reservoir, Surprise Valley, California, paper Z, in 21st annual logging symposium transactions: Society of Professional Well Log Analysts, 9 p. Reprinted 1982, in Geothermal log interpretation handbook: Society of Professional Well Log Analysts, p. VII-111-VII-119.

Saksa, P., 1985, Borehole geophysical investigations of Lavia deep testhole, Finland: Nuclear Waste Commission of Finnish Power Commission, Helsinki, Report No. YJT-85-06, 100 p.

Sandberg, E., Olsson, O., and Falk, L., 1989, Combined interpretation of fracture zones in crystalline rock using single hole, crosshole, tomography, and directional borehole radar data, paper G, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 97-116.

Sattler, A.R., 1989, Comparison of the in-situ stress information from core and log analysis, SCA-8911, part III, paper K, in Annual technical conference reprints, v. 1 (1987-89): Society of Professional Well Log Analysts, Society of Core Analysts SPWLA Chapter-at-Large, 27 p.

Schafer, J.N., 1979, A practical method of well evaluation and acreage development for the naturally fractured Austin Chalk Formation, paper U, in 20th annual logging symposium transactions: Society of Professional Well Log Analysts, 27 p. Later published in 1980, The Log Analyst, v. 21(1), January-February, p. 10-23.

Senecal, J.E., and Mulhern, M.E., 1985, Monterey Formation analysis--State-of-the-art interpretation of lithology, fractures and fluid identification in fine-grained mineralogically variable rocks, paper KKK, in 26th annual logging symposium transactions,: Society of Professional Well Log Analysts, 16 p.

Setser, G.G., 1981, Fracture detection by circumferential propagation of acoustic energy, SPE-10204: Society of Petroleum Engineers, 56nd annual meeting [San Antonio] preprint, 8 p.

Shamir, G., and Zoback, M.D., 1989, Detailed analysis of wellbore breakout in the Cajon Pass scientific drillhole, in Rowley, J.C., editor, Drilling symposium 1989 [12th annual energy-sources technology conference and exhibition (Houston, January 22-25): American Society of Mechanical Engineers, New York, PD-Vol. 22, p. 11-15.

Shamir, G., Zoback, M.D., and Barton, C.A., 1988, In situ stress orientation near the San Andreas fault--Preliminary results to 2.1 km depth from the Cajon Pass scientific drillhole: Geophysical Research Letters, v. 15(9, supplement), p. 989-992.

Shanks, T.R., Kwon, B.S., DeVries, M.R., and Wichmann, P.A., 1976, A review of fracture detection with well logs, SPE-6159: Society of Petroleum Engineers, 51nd annual meeting [New Orleans] preprint, 17 p.

Sibbit, A., and Faivre, O., 1985, The Dual Laterolog response in fractured rocks, paper T, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 34 p.

Snodgrass, J.J., 1989, Sonic full-waveform applications to stress evaluation in coal mines, paper MM, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 731-745.

Springer, J.E., 1987, Stress orientations from well bore breakouts in the Coalinga region: Tectonics, v. 6(5), p. 667-676.

Springer, J.E., Thorpe, R.K., and McKague, H.L., 1984, Borehole eleongation and its relation to tectonic stress at the Nevada test site: Lawrence Livermore National Laboratory Report UCRL-53528, 43 p.

Standen, E., 1989, The analysis of fracture anomalies on electrical wellbore images, paper G, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 20 p.

Stang, C.W., 1989, Alternative electronic logging technique locates fractures in Austin chalk horizontal well: Oil and Gas Journal, v. 87(45), November 6, p. 42-45.

Stein, N., 1988, How to calculate fracture pressures from well logs: Petroleum Engineer International, v. 60(8), August, p. 36-38.

Stewart, G., Wittman, M.J., and van Golf-Racht, T., 1981, The application of the repeat formation tester to the analysis of naturally fractured reservoirs, SPE-10181: Society of Petroleum Engineers, 56th annual meeting [San Antonio] preprint, 19 p.

Suau, J., and Gartner, J., 1980, Fracture detection from well logs: The Log Analyst, v. 21(2), March-April, p. 3-13.

Suter, M., 1987, Orientational data on the state of stress in northeastern Mexico as inferred from stress-induced borehole elongations: Journal of Geophysical Research, section B, v. 92(3), p. 2,617-2,626.

Teufel, L.W., 1985, Insights into the relationship between wellbore breakouts, natural fractures, and in situ stress, in E. Ashworth, editor, Research and engineering applications in rock masses [26th U.S. symposium on rock mechanics, South Dakota School of Mines and Technology, Rapid City, 26-28 June, proceedings], volume 2: Boston, A.A. Balkema, p. 1199-1206.

Tselentis, G., 1985, A study of the hydrogreophysical properties of fissured aquifers using a double porosity model: Journal of Hydrology, v. 78, p. 331-344.

Van Golf-Racht, T.D., 1982, Logging versus fracture evaluation, chapter 5, in Fundamentals of fractured reservoir engineering: Elsevier, Amsterdam, Developments in Petroleum Science No. 12, p. 255-294.

Verbovsek, R., 1985, Determination of fractured zones by well logging in low transmissivity geothermal reservoirs in Kochani Valley, Macedonia, Yugoslavia: Geothermal Resources Council Transactions, v. 9, part 2, p. 481-484.

Westermark, R.V., and Scholes, P., 1987, Fracture identification in openhole from a Cement Evaluation Tool, SPE-16387, in SPE California regional meeting, proceedings: Society of Petroleum Engineers, p. 601-607.

Whitehead, W.S., Hunt, E.R., Finley, R.J., and Holditch, S.A., 1986, In-situ stresses--A comparison between log-derived values and actual field-measured values in the Travis Peak Formation of east Texas, SPE-15209, in 1986 unconventional gas technology symposium, proceedings: Society of Petroleum Engineers, p. 19-34.

Whitehead, W.S., Hunt, E.R., and Holditch, S.A., 1987, The effects of lithology and reservoir pressure on the in-situ stresses in the Waskom (Travis Peak) field, SPE/DOE-16403, in 1987 SPE/DOE low permeability reservoirs symposium, proceedings, : Society of Petroleum Engineers, p. 139-152.

Williams, D.M., Leavitt, E.M., and Theriot, D.G., 1988, Estimation of in-situ stress variations for fracture height calculations using Mobil's shear wave acoustic log, paper CC, in 11th European formation evaluation symposium transactions: Society of Professional Well Log Analysts, Norwegian Chapter, 23 p.

Williams, G.B., 1970, Sonic principles applied to formation fracture location and cement bond logging: Canadian Well Logging Society Journal, v. 3, p. 7.

Williams, J.H., Carswell, L.D., Lloyd, O.B., Jr., and Roth, W.C., 1984, Characterization of ground water circulation in selected fractured rock aquifers using borehole temperature and flow logs, in D.M. Nielsen and M. Curl, editors, 1984 NWWA/EPA conference on surface and borehole geophysics methods in ground water investigations, proceedings: National Water Well Association, Worthington, Ohio, p. 842-852.

Xu, X., Colpitts, R., and Bretz, R.E., 1988, A fractured/matrix model for estimating water saturations in reservoir rocks, SPE-17562, in SPE international meeting on petroleum engineering [Tianjin, China], proceedings: Society of Petroleum Engineers, p. 99-111

Yale, D.P., and Sprunt, E.S., 1989, Prediction of fracture direction using shear acoustic anistropy, SCA-8711, paper K, in Annual technical conference reprints, part I, v. 1 (1987-1989): Society of Professional Well Log Analysts, Society of Core Analysts, Chapter-at-Large, 6 p. Later published in 1989, The Log Analyst, v. 30(2), March-April, p. 65-70.

Yamaguchi, S., and Hirakawa, S., 1983, A method for well log interpretation of a fractured oil reservoir: Butsuri-Tanko [Geophysical Exploration], v. 36(1), p. 16-22 p.

Yost, A.B., II, Frohne, K., Komar, C.A., and Ameri, S., 1980, Techniques to determine natural and induced fracture relationships in Devonian shale, SPE-9271: Society of Petroleum Engineers, 55nd annual meeting [Dallas] preprint. Later published in 1982, Journal of Petroleum Technology, v. 34(6), p. 1371-1377.

Zheng, Z, Kemeny, J., and Cook, N.G.W., 1989, Analysis of borehole breakouts: Journal of Geophysical Research, v. 94B(6), June 10, p. 7,171-7,182.

Zoback, M.D., Moos, D., Mastin, L., and Anderson, R.N., 1985, Well bore breakouts and in situ stress: Journal of Geophysical Research, v. 90(B7), p. 5523-5530. Discusssion and reply in 1986, Journal of Geophysical Research, v. 91(B14), p. 14,161-14,164.

16. PERMAFROST AND GAS HYDRATES

Bily, C., and Dick, J.W.L., 1974, Naturally occurring gas hydrates in the McKenzie Delta, N.W.T.: Bulletin Canadian Petroleum Geology, v. 22(3), September, p. 340-352.

Collett, T.S., 1983, Detection and evaluation of natural gas hydrates from well logs, Prudhoe Bay, Alaska, in 4th international permafrost conference proceedings: National Academy Press, Washington, D.C., p. 169-174.

Collett, T.S., Bird, K.J., Kvenvolden, K.A., and Magoon, L., 1988, Geologic interrelations relative to gas hydrates within the North Slope of Alaska: U.S. Geological Survey Open-File Report 88-389, 150 p.

Collett, T.S., and Ehlig-Economides, C.A., 1983, Detection and evaluation of the in-situ natural gas hydrates in the north slope region, SPE-11673, in 53rd annual California regional meeting, proceedings: Society of Petroleum Engineers p. 97-106.

Collett, T.S., and Godbole, S.P., and Ehlig-Economides, C., 1984, Quantification of in-situ gas hydrates with well logs, in 35th annual meeting transactions, volume 2: Petroleum Society of CIM and Canadian Association of Drilling Engineers, Calgary, p. 571-582.

Cox, J.W., 1973, A short note on resistivity measurement in permafrost: Canadian Well Logging Society Journal, v. 6, p. 47.

Davidson, D.W., Elf-Defrawy, M.K., Fuglem, M.O., and Judge, A.S., 1978, Natural gas hydrates in northern Canada, in Third international conference on permafrost, proceedings, volume 1: National Research Council of Canada, Ottawa, p. 938-943.

Desai, K.P., and Morre, E.J., 1967, Well log interpretation in permafrost, paper N, in 8th annual logging symposium transactions: Society of Professional Well Log Analysts, 27 p.

Godbole, S.P., Kamath, V.A., and Ehlig-Economides, C., 1985, Natural gas hydrates in the Alaskan arctic, SPE-13593, in California regional meeting proceedings: Society of Petroleum Engineers. Later published in 1988, SPE Formation Evaluation, v. 3(1), p. 263-266.

Goodman, M.A., and Giussani, A.P., and Alger, R.P., 1982, Detection and evaluation methods for in-situ gas hydrates, SPE/DOE-10831, in SPE/DOE unonventional gas recovery symposium, proceedings: Society of Petroleum Engineers, p. 355-371.

Hnatiuk, J., and Randall, A.G., 1977, Determination of permafrost thickness in wells in northern Canada: Canadian Journal of Earth Sciences, v. 14(3), p. 375-383.

Hoyer, W.A., Simmons, S.O., Spann, M.M., and Watson, A.T., 1975, Evaluation of permafrost with logs, paper AA, in 16th annual logging symposium transactions: Society of Professional Well Log Analysts, 15 p.

Hunter, J.A., 1975, Borehole geophysical methods in permafrost, in A.V. Dyck, editor, Borehole geophysics applied to metallic mineral prospecting--A review: Geological Survey of Canada Paper 75-31, p. 67.

Katz, D.L., 1970, Depths to which frozen gas fields (gas hydrates) may be expected, SPE-3061: Society of Petroleum Engineers, 45th annual meeting [Houston] preprint. Later published in 1971, Journal of Petroleum Technology, v. 23(4), p. 419-423.

Kiefte, H., Clouter, M.J., and Gagnon, R.E., 1985, Determination of acoustic velocities of clathrate hydrates by Brillouin spectroscopy: Journal of Physical Chemistry, v. 89, p. 3103-3108.

Kuustraa, V.A., and Hammershaimb, E.C., 1983, Handbook of gas hydrate properties and occurrence: U.S. Department of Energy Report DOE/MC/19239-1546, 234 p.

Kvenvolden, K.A., and McDonald, T.J., 1985, Gas hydrates of the Middle America Trench--Deep Sea Drilling Project leg 84, in S. Orlofsky, editor, Initial Reports of the Deep Sea Drilling Project, v. 84: U.S. Government Printing Office, p. 667-682.

Lachenbruch, A.H., and Marshall, B.V., 1986, Changing climate--Geothermal evidence from permafrost in the Alaskan Arctic: Science, v. 234, November 7, p. 689-696.

Malone, R.D., Mroz, T.H., and Dominic, K.L., 1986, Geologic analysis of gas hydrate deposits, SPE-15224, in 1986 unconventional gas technology symposium, proceedings: Society of Petroleum Engineers, p. 193-202.

Mathews, M., 1985, Logging characteristics of methane hydrate, paper K, in 10th formation evaluation symposium transactions: Canadian Well Logging Society, 62 p. Later published in 1986, The Log Analyst, v. 27(3), May-June, p. 26-63.

Mathews, M.A., and von Huene, R., 1985, Site 570 methane hydrate zone, in S. Orlofsky, editor, Initial reports of the Deep Sea Drilling Project, v. 84: U.S. Government Printing Office, p. 773-790.

McKay, A.S., and O'Connell, L.P., 1976, The permafrost density logger: The Journal of Canadian Petroleum Technology, v. 15(1), p. 69-74.

Mel'nikov [sic], P.I., Mel'nikov, V.P., Tsarev, V.P., Degtyarev, B.V., Mizulina, N.B., Popov, A.P., Bereznyakov, A.I., and Svechnikov, A.M., 1989, Natural gas generation in permafrost: International Geology Review, v. 31(3), p. 317-326.

Merritt, R.K., 1979, Geophysical measurements in the permafrost zone, Canadian Arctic Islands, in W.J. Scott and R.J.E. Brown, editors, Permafrost field methods and permafrost geophysics [Saskatoon, Canada, October 3-4, 1977], proceedings: Associate Committee on Geotechnical Research, Ottawa, Canada, Technical Memorandum No. 124, p. 56-72.

Osterkamp, T.E., and Payne, M.W., 1981, Estimates of permafrost thickness from well logs in northern Alaska: Cold Regions Science and Technology, v. 5, p. 13-27.

Pearson, C.F., Halleck, P.M., McGuire, P.L., Hermes, R., and Mathews, M., 1983, Natural gas hydrate deposits--A review of in-situ properties: Journal of Physical Chemistry, v. 87, p. 4180-4185.

Peterson, J.K., 1985, Quantitative nuclear well logging in permafrost for geotechnical purposes: University of Alaska, unpublished MS thesis, 173 p.

Pollard, D.E., and Nash, R.G., 1971, Observations on permafrost logging in the Canadian Arctic: Canadian Well Logging Society Journal, v. 4(1), p. 37-84.

Scott, J.H., Petersen, J.K., Osterkamp, T.E., and Kawasaki, K., 1985, Interpretation of geophysical well logs in permafrost: University of Alaska Geophysical Institute Report UAG-R(303) (Prepared for U.S. Department of Energy, Morgantown Energy Technology Center, contract DE-AI19-83 BC 10810), 125 p.

Snegirev, A.M., 1984, Resistivity logging of frozen rocks, in Permafrost 4th international conference [Fairbanks, Alaska, July 17-22, 1983], proceedings: National Academy Press, Washington, D.C., p. 295-299.

Stewart, J.M., and Weaver, J.S., 1983, Permafrost and hydrates under the Beaufort Sea, paper K, in 24th annual logging symposium transactions: Society of Professional Well Log Analysts, 18 p.

Stoll, R.D., and Bryan, G.M., 1979, Physical properties of sediments containing gas hydrates: Journal of Geophysical Research, v. 84(B4), p. 1629-1634.

Taylor, A., Judge, A., and Allen, V., 1989, Recovery of precise offshore permafrost temperatures from a deep geotechnical hole, Canadian Beaufort Sea: Geological Survey of Canada Paper 89-1D, p. 119-124.

Taylor, A.E., and Judge, A.S., 1981, Measurement and prediction of permafrost thickness, Arctic Canada: Society of Exploration Geophysicists, 51st annual meeting technical paper, v. 6, p. 3964-3977.

Trofimuk, A.A., Makogon, Y.F., Tolkachev, M.V., and Cherskii, N.V., 1984, Some distinctive features of the discovery, prospecting, and exploitation of gas-hydrate bodies: Soviet Geology and Geophysics, v. 25,(9), p. 1-7.

Walker, J.H.D., and Stuart, A.J., 1976, Permafrost investigations by crystal cable surveys, McKenzie Delta, N.W.T., paper J, in 17th annual logging convention transactions: Society of Professional Well Log Analysts, 10 p.

Zimmerman, R.W., and King, M.S., 1986, The effect of the extent of freezing on seismic velocities in unconsolidated permafrost: Geophysics, v. 51(6), p. 1285-1290.

17. EVAPORITES

Alger, R.P., and Crain, E.R., 1966, Defining evaporite deposits with electrical well logs, in J.L. Rau, editor, Second symposium on salt, volume 2: Northern Ohio Geological Society, Cleveland, p. 116-130.

Bidgood, D.E.T., and Blanchard, J.E., 1970, Geophysical investigations of evaporites in Nova Scotia, in L.W. Morely, editor, Mining and groundwater geophysics--1967: Geological Survey of Canada Economic Report No. 26, p. 497-503.

Carter, D.C., 1989, Downhole geophysics as an aid to the interpretation of an evaporite sequence; examples from Nova Scotia: CIM Bulletin, v. 82(925), p. 58-64.

Costello, J.T., and Norquay, I.P., 1970, Logging the Prairie evaporite formation in Saskatchewan, in L.W. Morely, editor, Mining and groundwater geophysics--1967: Geological Survey of Canada Economic Report no. 26, p. 492-496.

Crain, E.R., and Anderson, W.B., 1966, Quantitative log evaluation of the Prairie Evaporite Formation in Saskatchewan: Canadian Journal of Petroleum Technology, v. 5(3), p. 145-152.

Crues, J.V., Jr., 1977, Lithology crossplots--Applications in an evaporite basin--the Maverick basin of southwest Texas, paper L, in 18th annual logging symposium transactions: Society of Professional Well Log Analysts, 23 p. Later published in 1980, Bulletin of the South texas Geological Society, v. 20(6). Reprinted in 1986, in W.L. Stapp, editor, Contributions to the geology of south Texas, 1986: South Texas Geological Society, San Antonio, p. 423-438.

Curial, A., 1988, Multiple applications of dipmeter curves for analyzing evaporite formations--Examples from paleogene of Bresse Trough, France: AAPG Bulletin, v. 72(11), p. 1323-1333.

Daniels, J.J., Scott, J.H., and Hite, R.J., 1979, Analysis of borehole geophysical data in an evaporite sequence at Salt Valley, Utah, paper M, in 20th annual logging symposium transactions: Society of Professional Well Log Analysts, 19 p.

Haile, P.M., and Blunden, H.A., 1984, Zechstein magnesium rich evaporite deposits of northern Netherlands and their volumetric analysis by GLOBAL, paper 37, in 9th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 9 p.

Huurdeman, A.J.M., Breunese, J.N., Al-Asbahi, A., Lutgert, J.E., and Floris, F.J.T., 1989, Assessment of halite-cemented reservoir zones with a combined geological/engineering approach; a case study, SPE-19603, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 335-343.

Nurmi, R.D., 1978, Use of well logs in evaporite sequences, in W.E. Dean and B.C. Schreiber, editors, Marine evaporites: Society of Economic Paleontologists and Mineralogists, Short Course Notes No. 4, p. 144-176.

Nurmi, R.D., 1988, Geologic intepretation of well logs and seismic measurements in reservoirs associated with evaporites, chapter 8, in B.C. Schreiber, editor, Evaporites and hydrocarbons: Columbia University Press, New York, 405-459.

Ramondetta, P.J., and Merritt, R.M., 1982, Use of geophysical well logs for the determination of mud and anyhdrite content in bedded salt, in Geology and geohydrology of the Palo Duro Basin, Texas panhandle: Texas Bureau of Economic Geology Circular No. 82-7, p. 105-108.

Ruppel S.C., and Ramondetta, P.J., 1982, Determination of salt purity using gamma-ray logs--San Andres Formation, Palo Duro Basin, in Geology and geohydrology of the Palo Duro Basin, Texas panhandle: Texas Bureau of Economic Geology Circular 82-7, p. 183-200.

Serra, O., 1980, Aspects of logging in evaporites [in French]: Bulletin des Centres Recherches Exploration-Production Elf-Aquitaine, v. 4(1), p. 411-431.

Serra, O., 1986, Evaporites and computed well logs [...vaporites et diagraphies diffÈrÈes], in Evaporite series in petroleum exploration [Les sÈries ‡ Èvaporites en exploration pÈtroliÈre], volume 1, Geologic Methods [Chambre Syndicale de la Recherche et de la Production du PÈtrole et du Gaz Nautrel] [in French]: ...ditions Technip, Paris, p. 13-71.

Serra, O., and Curial, A., 1985, Recent progress in evaporite recognition through well logs [in French]: Bulletin Societe Geologique de France, v. 8(6), p. 797-806. [The use of newer logging tools and computer software for evaporite recognition.]

18. MINERAL EXPLORATION AND EVALUATION
(See also VI. Nuclear logging)

Aigner, H., 1989, Logging in hard formations with the method of induced polarization, paper QQ, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 10 p.

Anderson, W.B., 1974, Potential uses for borehole logs in mineral exploration: CIM [Canadian Institute Mining Metallurgy] Bulletin, v. 67(743), p. 164-168.

Aylmer, J.A., Charbucinski, J., Eisler, P.L., and Youl, S.F., 1984, Quantitative borehole logging of manganese ore by prompt neutron-gamma and neutron activation methods, paper D, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p.

Aylmer, J.A., Eisler, P.L., Mathew, P.J., and Wylie, A.W., 1976, The use of natural gamma radiation for estimating the iron content of sedimentary iron formations containing shale bands, in Nuclear techniques in geochemistry and geophysics: International Atomic Energy Agency, Vienna, Austria, p. 53-74.

Baicker, J.A., Stone, J.M., Lister, D.E., Schneider, G., Senftle, F., and Tanner, A., 1982, In-situ ore grade determination and other applications of high-resolution gamma ray spectroscopy in mineral and oil logging: Society of Mining Engineers of AIME, Fall meeting [Honolulu] preprint SME-AIME 82-365, 9 p.

Balch, S.J., Morris, W.A., Blohm, D., and Thuma, B., 1988, Interpretation of borehole magnetic data for mineral exploration and lithological mapping, paper O, in 2nd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applications [Golden, Colorado, October 6-8, 1987], proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society Chapter-at-Large, p. 179-185.

Balogh, I., and Horvath, J., 1983, Quantitative determination of Al_2O_3 content in bauxite-prospecting boreholes by means of neutron activation logging: Geophysical Transactions [Eotvos Lorand Geophysical Institute of Hungary], v. 29(2), June, p. 173-185.

Baltosser, R.W., and Lawrence, H.W., 1970, Application of well logging techniques in metallic mineral mining: Geophysics, v. 35(1), p. 143-152.

Bernard, J., Hentinger, R., Lebert, F., and Straub, A., 1985, Improvements in logging methods for mineral exploration: Transactions of the Institution of Mining and Metallurgy, Section B [Applied Earth Sciences], v. 94, February, B32-B38.

Bosum, W., 1985, Magnetic measurements under use of a 3-D drillhole magnetometer in the research borehole Konzen, Hohes Venn (West Germany): Neues Jahrbuch f,r Geologie und Pal%ontologie, v. 1711-3), p. 145-155.

Bosum, W., Eberle, E., and Rehli, H.J., 1988, A gyro-oriented 3-component borehole magnetometer for mineral prospecting with examples of its applications: Geophysical Prospecting, v. 36(8), p. 933-961.

Bristow, Q., and Killeen, P.G., 1982, Natural gamma-ray spectral logging using scintillation detectors, in Symposium on uranium exploration methods [Paris, June 1-4, 1982], proceedings: Nuclear Energy Agency, Organization for Economic Cooperation and Development, Paris, p. 777-791.

Bristow, Q., Killeen, P.G., and Mwenifumbo, J.C., 1982, Comparison of standardized gamma-ray log calibration measurements--Ottawa, Adelaide and Grand Junction, in Symposium on uranium exploration methods [Paris, June 1-4, 1982], proceedings: Nuclear Energy Agency, Organization for Economic Cooperation and Development, Paris, p. 715-727.

Brott, C.A., Millard, W.A., Lively, J.M., and Goff, D.D., 1986, In-situ mineral analysis in boreholes, in P. Kileen, editor, Borehole geophysics for mining and geotechnical applications [International symposium and workshop, (Toronto, August 29-31, 1983), proceedings]: Geological Survey of Canada Paper 85-27, p. 277-284.

Chapman, B.H., and Thompson, D.T., 1984, Applications of geophysical logging within skarn-type deposits: The Log Analyst, v. 25(2), March-April, p. 13-24.

Charbucinski, J., 1983, A universal gamma-gamma method for simultaneous determination of rock and ore properties, in C.G. Clayton, editor, Nuclear geophysics--Selected papers on applications of nuclear techniques in mineral exploration, mining and process control: Pergamon Press, Oxford, England, p. 353-361.

Chauvet, P., 1987, The comparison between the gamma logs and the grades in the estimation of a uranium deposit, in G. Matheron and M. Armstrong, editors, Geostatistical case studies: D. Reidel Publishers, Dordrecht, Netherlands, Quantitative Geology and Geostatistics Series, p. 23-37.

Chermeninov, V.B., 1988, Mapping of hydrothermally altered rocks according to borehole sections: Soviet Geology and Geophysics, v. 29(5), p. 101-111.

Chomyn, B.A., Lapointe, P., Morris, W.A., and Coles, R.L., 1986, Application of magnetic susceptibility within crystalline rocks, in P.G. Killeen, editor, Borehole geophysics for mining and geotechnical applications [International symposium and workshop, (Toronto, Ontario, August 29-31, 1983), proceedings]: Geological Survey of Canada Paper 85-27, p. 226-236.

Chrusciel, E., Niewodniczanski, J., Palka, K.W., and Roman, S., 1977, Determination of sulphur content in boreholes by neutron capture, in Nuclear techniques and mineral resources 1977 [International symposium on nuclear techniques in exploration, extraction and processing of mineral resource, 1977, proceedings]: International Atomic Energy Agency, Vienna, Austria, p. 301-311.

Clayton, C.G., 1977, Some recent applications of nuclear techniques in the exploration and mining of metalliferous minerals, in Nuclear techniques and mineral resources 1977: International Atomic Energy Agency, Vienna, Austria, p. 185-213.

Conaway, J.G., 1979, Problems in gamma-ray logging--The effect of dipping beds on the accuracy of ore grade determinations: Geological Survey of Canada Paper 79-1A, p. 41-44.

Conaway, J.G., 1980, Uranium concentrations and the system response function in gamma ray logging: Geological Survey of Canada Paper 80-1A, p. 77-87.

Conaway, J.G., 1982, Principles of inverse filtering applied to gamma ray logs, in Symposium on uranium exploration methods [Paris, June 1-4, 1982], proceedings: Nuclear Energy Agency, Organization for Economic Cooperation and Development, Paris, p. 753-766.

Conaway, J.G., 1983, Digital filtering of geophysical logs in A.A. Fitch, editor, Developments in geophyscial methods--5: Applied Science Publishers, London, p. 65-105.

Conaway, J.G., Bristow, Q., Killeen, P.G., 1980, Optimization of gamma-ray logging techniques for uranium: Geophysics, v. 45(2), p. 292-311.

Conaway, J.G., and Killeen, P.G., 1980, Gamma-ray spectral logging for uranium: Canadian Mining and Metallurgical Bulletin, v. 73(813), p. 115-123.

Conaway, J.G., Killeen, P.G., and Bristow, Q., 1981, Variable formation parameters and nonlinear errors in quantitative gamma ray log interpretation, paper M-11, in 50th annual meeting technical papers, : Society of Exploration Geophysicists, v. 5, p. 2523-2534.

Cossy, S.P.J., and Frank, H.J., 1983, Uranium mineralization and use of resistance log character in deltaic point bars--Franklin Mines, Karnes County, Texas: AAPG Bulletin, v. 67(1), p. 131-151.

Cowan, D.R., and Myers, K.J., 1988, Surface gamma ray logs; a correlation tool for frontier areas--Discussion: AAPG Bulletin, v. 72(5), p. 634-636.

Crone, J.D., 1988, Case histories of borehole pulse EM surveys, paper K, in 2nd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applications [Golden, Colorado, October 6-8, 1987], proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society Chapter-at-Large, p. 133-138.

Czubek, J.A., 1979, Modern trends in mining geophysics and nuclear borehole logging methods for mineral exploration, in P.J. Hodd, editor, Geophysics and geochemistry in the search for metallic ores [Exploration 77, Ottawa, Canada, October 1977, proceedings]: Geological Survey of Canada, Economic Geology Report No. 31, p. 231-272.

Czubek, J.A., 1983, Advances in gamma-gamma logging, in C.G. Clayton, editor, Nuclear geophysics--Selected papers on applications of nuclear techniques in mineral exploration, mining and process control: Pergamon Press, Oxford, England, p. 153-172.

Czubek, J.A., 1986, Quantitative interpretation of gamma-ray logs in presence of random noise, paper KKK, in 27th annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Czubek, J.A., and Loskiewicz, J., 1976, Optimum conditions for uranium detection in delayed neutron well logging, in Exploration for uranium deposits [Exploration of uranium ore deposits, (Vienna, Austria, March 29-April 2), symposium proceedings]: International Atomic Energy Agency, Vienna, Proceedings Series, p. 471-498.

Czubek, J.A., Loskiewicz, J., Gyurcsak, J., Lenda, A., Umiastowski, K., and Zorski, T., 1977, Geostatistical method of interpretation of nuclear well logs, in Nuclear techniques and mineral resources 1977: International Atomic Energy Agency, Vienna, Austria, p. 313-332.

Daniels, J.J., and Dyck, A.V., 1984, Borehole resistivity and electromagnetic methods applied to mineral exploration: IEEE Transactions on Geoscience and Remote Sensing, v. GE-22(1), January, p. 80-87.

Daniels, J.J., Olhoeft, G.R., and Scott, J.H., 1983, Interpretation of core and well log physical property data from drill hole UPH-3, Stephenson County, Illinois: Journal of Geophysical Research, v. 88(B9), September 10, p. 7346-7354.

Daniels, J., and Scott, J., 1978, The role of borehole electrical measurements in uranium exploration: U.S. Geological Survey Open-File Report 78-326, 18 p.

Daniels, J.J., Scott, J.H., and Smith, B.D., 1979, Analysis of bore hole geophysical information across a uranium deposit in the Jackson Group, Karnes County, Texas: U.S. Geological Survey Open-File Report 79-585, 31 p.

de Bourayne, A.M., 1988, High resolution spectroscopy for direct uranium ore grade assay in exploration, development, and production, paper T, in 2nd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applications [Golden, Colorado, October 6-8, 1987], proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society Chapter-at-Large, p. 227-240.

Dodd, P.H., 1966, Quantitative logging and interpretation systems to evaluate uranium deposits, paper P, in 7th annual logging symposium transactions: Society of Professional Well Log Analysts, 21 p. Reprinted in 1978, paper DD, in Gamma ray, neutron and density logging: Society of Professional Well Log Analysts, Reprint volume, 21 p.

Dodd, P.H., Droullard, R.F., and Lathan, C.P., 1970, Borehole logging methods for exploration and evaluation of uranium deposits, in L.W. Morely, editor, Mining and groundwater geophysics--1967: Geological Survey of Canada, Economic Geology Report No. 26, p. 401-415.

Dodd, P.H., and Eschliman, D.H., 1972, Borehole logging techniques for uranium exploration and evaluation, in S.H.U. Bowie, M. Davis and D.Ostle, editors, Uranium prospecting handbook [1971 NATO-sponsored advanced study institute, proceedings]: Institution of Mining and Metallurgy, London, p. 244-276.

Doyle, H.A., 1990, Geophysical exploration for gold--a review: Geophysics, v. 55(2), p. 136-146.

Drew, L.J., Bawiec, W.J., Page, N.J., and Schuenemeyer, J.H., 1985, The copper-nickel concentration log--A tool for stratigraphic interpretation within the ultramafic and basal zones of the Stillwater Complex, Montana: Journal of Geochemical Exploration, v. 23, p. 117-137.

Duray, J.R., 1982, Direct-uranium logging; neutron-based techniques, in Uranium exploration methods: Organization for Economic Cooperation and Development, Paris, p. 807-810.

Dyck, A.V., editor, 1975, Borehole geophysics applied to metallic mineral prospecting--A review: Geological Survey of Canada Paper 75-31, 67 p. [Eight separate review papers each with a bibliography.]

Dyck, A.V., 1975, Electrical borehole methods applied to mineral prospecting, in A.V. Dyck, editor, Borehole geophysics applied to metallic mineral prospecting--A review: Geological Survey of Canada Paper No. 75-31, p. 13-30.

Dyck, A.V., Auchincloss, P.V., and Atherton, D.L., 1989, High-resolution magnetic-susceptibility logger and dipmeter for mineral exploration boreholes; concept and initial progress (Grant 332), in Milne, V.G., editor, Geoscience research grant program summary of research 1988-1989: Ontario [Canada] Geological Survey Miscellaneous Paper 143, p.146-159.

Dyck, A.V., and Young, R.P., 1979, Physical characterization of rock masses using borehole methods: Geophysics, v. 50(12), p. 2530-2541.

Edwards, E.H., 19??, Computerised bore-hole logging for minerals, in Mineral exploration, v. 5, Geophysics and other exploration techniques [papers presented to a post-graduate course in mineral exploration]: Western Australia School of Mines, Kalgoorlie, Australia, p. 117-136.

Edwards, J.M., Ottinger, N.H., and Haskell, R.E., 1967, Nuclear log evaluation of potash deposit, paper L, in 8th annual logging symposium transactions: Society of Professional Well Log Analysts, 12 p.

Eisler, P.L., Charbucinski, J., Borsaru, M. and Indrans, A.P., 1988, Spectrometric gamma-gamma borehole methods for iron-ore mining, paper P, in 2nd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applications [Golden, Colorado, October 6-8, 1987], proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society Chapter-at-Large, p. 189-201.

Eisler, P.L., Huppert, P., Mathew, P.J., Wylie, A.W., and Youl, S.F., 1977, Use of neutron capture gamma radiation for determining grade of iron ore in blast hole and exploration holes, in Nuclear techniques and mineral resources 1977: International Atomic Energy Agency, Vienna, Austria, p. 215-228.

Eisler, P.L., Mathew, P.J., and Youl, S.F., 1979, Nuclear activation logging for aluminum in iron ores and coal: Geoexploration, v. 17(1), p. 43-53.

Fokin, A.F., and Kalvarskaya, V.P., 1987, Borehole geophysics in the exploration of ore deposits in the USSR, in Drilling techniques in mineral and groundwater explorations and development [Proceedings of seminar on drilling, sampling, and logging, Donetsk, USSR September 16-26, 1981]: United Nations Economic and Social Commission for Asia and the Pacific, Bangkok, p. 270-281.

Frignet, B., 1986, Induction logs applied to mineral exploration and development, in P.G. Killeen, editor, Borehole geophysics for mining and geotechnical applications [international symposium and workshop, (Toronto, Ontario, August 29-31, 1983), proceedings]: Geological Survey of Canada Paper 85-27, p. 89-100.

Furlong, V.L.R., 1982, Converting the numerical values to geologic reality, in Symposium on uranium exploration methods [Paris, June 1-4, 1982], proceedings: Nuclear Energy Agency, Organization for Economic Cooperation and Development, Paris, p. 767-775.

George, D.C., 1982, Total count gamma-ray logging--Correction factors and logging model grade assignments, in Symposium on uranium exploration methods [Paris, June 1-4, 1982], proceedings: Nuclear Energy Agency, Organization for Economic Cooperation and Development, Paris, p. 729-751.

George, D.C., and Scott, J.H., 1982, Review of magnetic susceptibility logging and its application to uranium exploration, in Symposium on uranium exploration methods [Paris, June 1-4, 1982], proceedings: Nuclear Energy Agency, Organization for Economic Cooperation and Development, Paris, p. 837-856.

Givens, W.W., Mills, W.R., Dennis, C.L., and Caldwell, R.L., 1976, Uranium assay logging using a pulsed 14-MEV neutron source and detection of delayed fission neutrons: Geophysics, v. 41(3), p. 468-490.

Givens, W.W., and Stromswold, D.C., 1989, Prompt fission neutron logging for uranium: Nuclear Geophysics, v. 3(4), p. 299-307.

Glenn, W.E., and Hohmann, G.W., 1981, Well logging and borehole geophysics in mineral exploration: Economic Geology, 75th anniversary volume, p. 850-862.

Glenn, W.E., and Nelson, P.H., 1979, Borehole logging techniques applied to base metal ore deposits, in P.J. Hodd, editor, Geophysics and geochemistry in the search for metallic ores [Exploration 77, Ottawa, Canada, October 1977, proceedings]: Geological Survey of Canada Economic Geology Report No. 31, p. 273-294.

Goldsmith, L.H., 1966, Some fundamentals of potash geology as a guide to exploration, paper O, in 7th annual logging symposium transactions: Society of Professional Well Log Analysts, 15 p.

Hafen, P.L., Adams, S.S., Secor, G.B., 1976, Application of magnetic susceptibility measurements to uranium exploration in sandstones, in Exploration for uranium deposits [Exploration of uranium ore deposits, (Vienna, Austria, March 29-April 2), symposium proceedings]: International Atomic Energy Agency, Vienna, Proceedings Series, p. 367-378.

Hale, L.A., 1967, Phosphate exploration using gamma-radiation logs, Dry Valley, Idaho, in Anatomy of the western phosphate field--Intermountain Association of Geologists 15th annual field conference: Intermountain Association of Geologists, Salt Lake City, Utah, p. 147-159.

Hallenburg, J.K., 1973, Interpretation of gamma-ray logs, paper G, in 14th annual logging symposium transactions: Society of Professional Well Log Analysts, 28 p. Reprinted in the 1973, The Log Analyst, v. 14(6), November-December, p. 3. [Quantitative use of the gamma ray curve for uranium assay.]

Hallenburg, J.K., 1978, Use of the spontaneous potential curve in a mineral mapping technique, paper U, in 19th annual logging symposium transactions: Society of Professional Well Log Analysts, 12 p.

Hallenburg, J.K., 1984, Geophysical logging for mineral and engineering applications: PennWell Books, Tulsa, 254 p.

Halleux, I., 1986, Contribution of the quantitative interpretation of gamma-ray logs to the study of limestone exploitation, a case-study at Maizeret, Belgium: Geoexploration, v. 24(6), p. 461-470.

Hawkins, W.K., and Gearhart, M., 1968, Use of logging in uranium prospecting, paper T, in 9th annual logging symposium transactions: Society of Professional Well Log Analysts.

Hearst, J.R., and Nelson, P.H., 1985, Well logging for physical properties: McGraw-Hill, New York, 576 p.

Hill, D.G., 1986, Geophysical well log calibration and quality control, in P.G. Killeen, editor, Borehole geophysics for mining and geotechnical applications [international symposium and workshop, (Toronto, Ontario, August 29-31, 1983), proceedings]: Geological Survey of Canada Paper 85-27, p. 379-392.

Hood, P.J., editor, 1979, Geophysics and geochemistry in the search for metallic ores [Exploration 77, Ottawa, Canada, October 1977, proceedings]: Geological Survey of Canada, Economic Geology Report No. 31, p. [See the case histories.]

Hood, P.J., and Dyck, A.V., 1975, Magnetic drillhole measurements in mineral exploration, in A.V. Dyck, editor, Borehole geophysics applied to metallic mineral prospecting--A review: Geological Survey of Canada Paper No. 75-31, p. 35-38.

Houseman, G.A., Cull, J.P., Muir, P.M., and Paterson, H.L., 1989, Geothermal signatures and uranium ore deposits on the Stuart shelf of South Australia: Geophysics, v. 54(2), p. 158-170.

Howell, E.P. Grant, O.J., Jr., and Crebs, T.J., 1978, Slim hole logging and analysis for uranium exploration, SPE-7434: Society of Petroleum Engineers, 53nd annual meeting [Houston] preprint. Later published 1980, Journal of Petroleum Technology, v. 32(7), p. 1144-1150.

Humphreys, D.R., Barnard, R.W., Bivens, H.M., Jensen, D.H., Stephenson, W.A., and Weinlein, J.H., 1983, Uranium logging with prompt fission neutrons, in C.G. Clayton, editor, Nuclear geophysics--Selected papers on applications of nuclear techniques in mineral exploration, mining and process control: Pergamon Press, Oxford, England, p. 261-268.

International Atomic Energy Agency, 1986, Practical borehole logging procedures for mineral exploration with emphasis on uranium: International Atomic Energy Agency, Vienna, Technical Reports Series No. 259, 44 p.

IRT Corporation, 1976, Future research in borehole assaying technology, volume 1--Technology assessment of borehole logging techniques: U.S. Bureau of Mines Open-File Report 119(1)-76 (Contract J0255018, Final Report, March 18, 1976), 325 p.

IRT Corporation, 1976, Future research in borehole assaying technology, volume 2--Bibliography of borehole assaying techniques, 1965-75: U.S. Bureau of Mines Open-File Report 119(2)-76 (Contract J0255018, Final Report, March 18, 1976), 325 p.

Jessop, A.M., and Judge, A.S., 1975, Temperature measurement in boreholes for the mining industry, in A.V. Dyck, editor, Borehole geophysics applied to metallic mineral prospecting--A review: Geological Survey of Canada Paper 75-31, p. 55-66.

Karus, E.V., and Shimelevich, Y.S., 1983, Nuclear geophysics in prospecting, exploration and development of oil and gas fields, in C.G. Clayton, editor, Nuclear geophysics--Selected papers on applications of nuclear techniques in mineral exploration, mining and process control: Pergamon Press, Oxford, England, p. 95-117.

Kayal, J.R., Datta, S., and Madhusudan, I.C., 1982, Resistance and self-potential logging for copper deposits: Geophysical Research Bulletin, v. 20(4), p. 157-161.

Keller, G.W., 1970, Application of resistivity methods in mineral and groundwater exploration programs, in L.W. Morely, editor, Mining and groundwater geophysics--1967: Geological Survey of Canada Economic Geology Report 26, p. 51-66.

Killeen, P.G., 1975, Nuclear techniques for borehole logging in mineral exploration, in A.V. Dyck, editor, Borehole geophysics applied to metallic mineral prospecting--A review: Geological Survey of Canada Paper 75-31, p. 39-52.

Killeen, P.G., 1979, Gamma ray spectrometric methods in uranium exploration--Application and interpretation, in P.J. Hodd, editor, Geophysics and geochemistry in the search for metallic ores [Exploration 77, Ottawa, Canada, October 1977, proceedings]: Geological Survey of Canada Economic Geology Report No. 31, p. 163-229.

Killeen, P.G., 1982, Gamma-ray logging and interpretation, in A.A. Fitch, editor, Developments in geophysical exploration methods--3: Applied Science Publishers, London, p. 95-150.

Killeen, P., 1983, Borehole logging for uranium by measurement of natural gamma-radiation: International Journal of Applied Radioactive Isotopes, v. 34(1), p. 231-260. Also published in 1984, in C.G. Clayton, editor, Nuclear geophysics--Selected papers on applications of nuclear techniques in mineral exploration, mining and process control: Oxford, England, Pergamon Press, p. 231-260.

Killeen, P.G., editor, 1986, Borehole geophysics for mining and geotechnical applications [International symposium and workshop, (Toronto, Ontario, August 29-31, 1983), proceedings]: Geological Survey of Canada Paper 85-27, 400 p.

Killeen, P.G., and Mwenifumbo, C.J., 1988, Downhole assaying in Canadian mineral deposits with the spectral gamma-gamma method, in Current trends in nuclear borehole logging techniques for elemental analysis [consultants meeting (Ottawa, Canada, November 2-6, 1987), proceedings]: International Atomic Energy Agency, Vienna, Report IAEA-TECDOC-464, p. 23-29.

Killeen, P.G., and Mwenifumbo, C.J., 1988, Interpretation of new generation geophysical logs in Canadian mineral exploration, paper N, in 2nd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applications [Golden, Colorado, October 6-8, 1987], proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society Chapter-at-Large, p. 167-178.

Killeen, P.G., Schock, L.D., and Elliott, B.E., 1989, A slim-hole assaying technique for base metals and heavy elements, based on spectral gamma-gamma logging, paper Y, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 435-454.

Koizumi, C.J., 1980, Thin, dipping ore zone logging models--Log studies: U.S. Department of Energy Report GJBX-54(80), March, 43 p.

Kuchurin, E.S., Zaramenskikh, N.M., and Lebrezon, L.M., 1976, The geologic efficiency of using nuclear geophysical well-logging methods to study boreholes in the main types of gold ore deposits in the eastern Transbaikal region [translated from the Russian]: Geological Survey of Canada Library Report No. 461877, January 15, 1985, 6 p.

Lovborg, L., 1972, Assessment of uranium by gamma-ray spectrometry, in S.H.U. Bowie, M. Davis and D.Ostle, editors, Uranium prospecting handbook [1971 NATO advanced study institute, proceedings]: The Institution of Mining and Metallurgy, London, p. 157-173.

Lovborg, L., Nyegaard, P., Christiansen, E.M., Nielsen, B.L., 1980, Borehole logging for uranium by gamma-ray spectrometry: Geophysics, v. 45(6), p. 1077-1090.

Lubecki, A., Doebele, R., and Herrmann, W., 1982, Direct uranium logging using X-ray flourescence technique, in Symposium on uranium exploration methods [Paris, June 1-4, 1982], proceedings: Nuclear Energy Agency, Organization for Economic Cooperation and Development, Paris, p. 821-835.

Marett, G., Chevalier, P., Souhaite, P., and Suau, J., 1976, Shaly sand evaluation using gamma ray spectrometry applied to the North Sea Jurassic, paper DD, in 17th annual logging symposium transactions: Society of Professional Well Log Analysts, 20 p. Reprinted 1982, in Shaly sand reprint volume: Society of Professional Well Log Analysts, p. IV43-IV63.

McGuire, J.A., Rogers, L.T., and Watson, J.T., 1985, Improved lithology and hydrocarbon saturation determination using the gamma spectrometry log, SPE-14465: Society of Petroleum Engineers, 60th annual meeting [Las Vegas], preprint, 9 p.

Mikesell, J.L., Senftle, F.E., Lloyd, T.A., Tanner, A.B., Meritt, C.T., and Force, E.R., 1987, Borehole field calibration and measurement of low-concentration manganese by decay gamma rays: Geophysics, v. 51(12), p. 2219-2224.

Moll, S.H., 1980, Spectral gamma logging in the Copper Mountain uranium distric--A case study in fractured quartz monzonite, paper O, in, 21st annual logging symposium transactions: Society of Professional Well Log Analysts, 18 p.

Mwenifumbo, C.J., 1985, Application of borehole geophysics in exploration of gold, paper DD, in 26th annual logging symposium transactions: Society of Professional Well Log Analysts, 24 p.

Mwenifumbo, C.J., 1988, Cross-borehole mise-a-la-masse mapping of fracture zones at the Bells Corners borehole geophysical test area, Ottawa, Canada, paper M, in 2nd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applications [Golden, Colorado, October 6-8, 1987], proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society Chapter-at-Large, p. 151-165.

Mwenifumbo, C.J., 1989, Optimization of logging parameters in continuous time-domain induced polarization measurements, paper N, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 201-232.

Mwenifumbo, C.J., and Killeen, P.G., 1987, Natural gamma ray logging in volcanic rocks; the Mudhole and Clementine base metal prospects, in R.V. Kirkham, editor, Buchans Geology, Newfoundland, paper 16: Geological Survey of Canada Paper 86-24, p. 263-272.

Mwenifumbo, C.J., Urbancic, T.I., and Killeen, P.G., 1983, Preliminary studies on gamma ray spectral logging in exploration for gold, in Current Research, part A: Geological Survey of Canada Paper no. 83-1A, p. 391-397.

Nargowalla, S.S., Kung, A., Legrady, O.J., Strever, J., Csillag, A., and Seigel, H.O., 1977, Nuclear Metalog grade logging in mineral deposits, in Nuclear techniques and mineral resources 1977: International Atomic Energy Agency, Vienna, p. 229-265.

Nelson, P.H., and Glenn, W.E., 1975, Influence of bound water on the neutron log in mineralized igneous rock, paper M, in 16th annual logging symposium transactions: Society of Professional Well Log Analysts, 9 p.

Newnham, L.A., and Packer, T.W., 1983, Development and application of energy-dispersive X-ray flourescence borehole loggers and drill core analysers at the Renison tin mine in Tasmania, in C.G. Clayton, editor, Nuclear geophysics--Selected papers on applications of nuclear techniques in mineral exploration, mining and process control: Pergamon Press, Oxford, England, p. 345-352.

Ogilvy, R.D., 1985, Down-hole IP/resistivity prospecting in mineral drill-holes--Some illustrative field examples: Geoexploration, v. 23, p. 257-273.

Olsson, O., and Nilsson, B., 1986, Some examples from borehole radar measurements, in P.G. Killeen, editor, Borehole geophysics for mining and geotechnical applications [international symposium and workshop, (Toronto, Ontario, August 29-31, 1983), proceedings]: Geological Survey of Canada Paper 85-27, p. 197-206.

Paul, J.M., Venuto, P.B., and Lundahl, R.B., 1984, In-Situ leaching of south Texas uranium ores, part 3--Post-leach assessment of recovery and sweep efficiency, SPE-11044: Society of Petroleum Engineers, 57th annual meeting [New Orleans], preprint. Later published in 1984, Journal of Petroleum Technology, v. 36(10), p. 1018-1026.

Peters, W.C., 1987, Logging of drill-hole data, section 15.3, in Exploration and mining geology, second edition: John Wiley & Sons, New York, p. 458-463.

Pinault, J.-L., 1988, Nuclear quantitative analysis of P, Si, Ca, Mg, Fe, and Al in boreholes on a phosphate mine, in Current trends in nuclear borehole logging techniques for elemental analysis [consultants meeting (Ottawa, Canada, November 2-6, 1987), proceedings]: International Atomic Energy Agency, Vienna, Report IAEA-TECDOC-464, p. 93-104. Also published in 1988: Nuclear Geophysics, v. 3(2), p. 191-199.

Reynolds, R.L., Fishman, N.S., Scott, J.H., and Hudson, M.R., 1986, Iron-titanium oxide minerals and magnetic susceptibility anomalies in the Marion Lake-Lake Valley cores--Constraints on conditions of uranium mineralization in the Morrison Formation, San Juan Basin, New Mexico, in C.E. Turner-Peterson, E.S. Santos, and N.S. Fishman, editors, A basin analysis case study--The Morrison Formation, Grants Uranium District, New Mexico: AAPG Studies in Geology No. 22, p. 303-313.

Robinette, M.S., and Williams, R.E., 1979, Delineation of hydrostratigraphic units using borehole geophysical techniques, in Symposium on uranium mill tailings management, geotechnical engineering program [November 19-20]: Colorado, Colorado State University, Fort Collins, Civil Engineering Department, p. 3-12.

Robinette, M.S., and Williams, R.E., 1980, Geophysical techniques for selection, analysis and monitoring uranium waste disposal sites, chapter 10, in C.O. Brawner, editor, First international conference on uranium mine waste disposal, proceedings [May 19-21, Vancouver, British Columbia, Canada]: Society of Mining Engineers of AIME, New York, p. 93-99.

Schlein, N., and Spivak, D., 1986, A log interpreted mineralogical composition for solution mining of underground caverns in Mount Sedom, in Y. Arkin, editor, Engineering geology in Israel: Israel Journal of Earth-Sciences, v. 35(2), p. 136-148.

Scott, J.H., 1974, Well-logging techniques for mineral deposit evaluation--A review: U.S. Bureau of Mines Information Circular 8627, 45 p.

Scott, J.H., 1986, Analysis of geophysical well logs from the Mariano Lake-Lake Valley drilling project, San Juan Basin, northwest New Mexico, in C.E. Turner-Peterson, E.S. Santos, N.S. Fishman, editors, A basin analysis case study--The Morrison Formation, Grants uranium region, New Mexico: AAPG Studies in Geology No. 22, p.241-256.

Scott, J.H., and Daniels, J.J., 1976, Non-radiometric borehole geophysical detection of geochemical haloes surrounding sedimentary uranium deposits, in Exploration for uranium deposits [Exploration of uranium ore deposits, (Vienna, Austria, March 29-April 2), symposium proceedings]: International Atomic Energy Agency, Vienna, Proceedings Series, p. 379-390.

Scott, J.H., Daniels, J.J., Habrouck, W.P., and Guu, J.Y., 1975, Hole-to-hole geophysical measurement for mineral exploration, paper KK, in 16th annual logging symposium transactions: Society of Professional Well Log Analysts, 14 p.

Scott, J.H., Daniels, J.J., Reynolds, R.L., and Seeley, R.L., 1983, Magnetic-susceptibility logging in sedimentary uranium environments: The Log Analyst, v. 24(2), March-April, p. 16-21.

Scott, J.H., and Sena, J., 1974, Acoustic logging for mining applications, paper P, in 15th annual logging symposium transactions: Society of Professional Well Log Analysts, 10 p.

Seigel, H.O., 1983, An overview of mining geophysics, in Symposium on exploration geophysics in India [Calcutta, November 21-24, 1978], proceedings: Geological Survey of India, Special Publication Series No. 2, v. 1, p. 113-167.

Senftle, F.E., 1980, Field studies of borehole gamma-ray spectrometer methods for mineral exploration--A selected bibliography: U.S. Geological Survey Open-File Report 80-503, 41 p.

Smith, R.J., 1985, Geophysics in Australian mineral exploration: Geophysics, v. 50(12), p. 2637-2665. Case histories.

Snyder, D.D., and Merkel, R.H., 1977, Induced polarization measurements in and around boreholes, in Induced polarization for exploration geologists and geophysicists [short course, March 14-16, 1977]: University of Arizona Department of Geosciences, p. 161-220.

Snyder, D.D., Merkel, R.H., and Williams, T.T., 1977, Complex formation resistivity--The forgotten half of the resistivity log, paper Z, in 18th annual logging symposium transactions: Society of Professional Well Log Analysts, 39 p.

Staub, A., Lebert, F., and Valla, P., 1989, ELIAS: a slimhole electrical imaging probe, pape K, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 161-181.

Sumner, J.S., 1976, Principles of induced polarization for geophysical exploration: Elsevier Scientific Publishing Company, New York, Developments in Economic Geology No. 5, 277 p.

Sumner, J.S., 1979, The induced-polarization exploration method, in P.J. Hood, editor, Geophysics and geochemistry in the search for metallic ores [Exploration 77, (Ottawa, Canada, October 1977), proceedings]: Geological Survey of Canada Economic Geology Report No. 31, p. 123-133.

Tanner, A.B., 1982, Direct uranium logging by high-resolution gamma-ray spectrometry, in Symposium on uranium exploration methods [Paris, June 1-4, 1982], proceedings: Nuclear Energy Agency, Organization for Economic Cooperation and Development, Paris, p. 793-810.

Threadgold, P., 1970, Applications of well-logging techniques to mining exploration boreholes, in Mining and petroleum geology [9th Commonwealth mining and metallurgical congress, 1969, proceedings]: The Institution of Mining and Metallurgy, London, p. 731-747.

Tixier, M.P., and Alger, R.P., 1967, Log evaluation of non-metallic mineral deposits, paper R, in 8th annual logging symposium transactions: Society of Professional Well Log Analysts, 22 p. Later published in 1970, Geophysics, v. 35(1), p. 124-142. Reprinted 1971, in Well Logging: Society of Petroleum Engineers, Reprint Series nno. 1, p. 368-390. Reprinted 1986, in Openhole well logging: Society of Petroleum Engineers, SPE Reprint Series No. 21, p. 397-419.

Tyne, E.D., 1981, Drill hole resistivity and induced polarization logging at Woodlawn, in R.J. Whiteley, editor, Geophysical case study of the Woodlawn orebody, NSW, Australia: Pergamon Press, New York, p. 531-553.

Tyne, E.D., 1988, The development of a computer controlled system for continuous IP logging and spectral IP measurements in exploration boreholes: University of New South Wales, Kensington, NSW, Australia, Ph.D. thesis, 345 p.

Tyne, E.D., Thorburn, M.J., Daggar, D.H., 1985, A major advance in borehole IP logging technology: Exploration Geophysics [Bulletin of the Australian Society of Exploration Geophysicists], v. 16(2/3), p. 303-309.

Urbancic, T., and Mwenifumbo, C.J., 1986, Multiparameter logging techniques applied to gold exploration, in P. Kileen, editor, Borehole geophysics for mining and geotechnical applications [International symposium and workshop, (Toronto, August 29-31, 1983), proceedings]: Geological Survey of Canada Paper 85-27, p. 13-28.

Wilson, R.D., and Cosby, M.S., 1980, Field evaluation of direct uranium borehole logging methods, paper S, in 21st annual logging symposium transactions: Society of Professional Well Log Analysts, 35 p.

Wylie, A.W., 1984, Nuclear assaying of mining boreholes: Elsevier, New York, Methods in Geochemistry and Geophysics No. 21, 344 p.

Wylie, A.W., and Eisler, P.L., 1978, Determining the grade, bulk density and porosity of iron ores by the methods of nuclear geophysics: Atomic Energy in Australia, v. 21, p. 2-13.

Zablocki, C.J., 1966, Some applications of geophysical logging methods in mineral exploration drill holes, paper U, in 7th annual logging transactions: Society of Professional Well Log Analysts, 13 p.

Zeller, E.J., Dreschhoff, G., Holdoway, K., and Saunders, D.F., 1976, Use of gamma-ray logs from wells drilled for petroleum exploration to define uranium provinces in subsurface formations, in Exploration for uranium deposits [Exploration of uranium ore deposits, (Vienna, Austria, March 29-April 2), symposium proceedings]: International Atomic Energy Agency, Vienna, Proceedings Series, p. 415-425.

19. GROUND WATER APPLICATIONS

(See also 15. Fracture detection; 20. Igneous rocks)

Abd Allatif, T.A., 1982, Determination of the discharge of various individual aquifers from temperature logging: Desert Institute Bulletin [Egypt], v. 32(1-2), p. 13-17.

Alger, R.P., 1966, Interpretation of electric logs in fresh water wells in unconsolidated formations, paper CC, in 7th annual logging sumposium transactions: Society of Professional Well Log Analysts, p.

Alger, R., and Harrison, C.W., 1988, Improved fresh water assessment in sand aquifers utilizing geophysical well logs, paper I, in 2nd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applications [Golden, Colorado, October 6-8, 1987], proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society Chapter-at-Large, p. 99-118. Also published in 1988, in FOCUS conference on southwestern ground water issues [Albuquerque, New Mexico, March 23-35], proceedings: National Well Water Association, Dublin, Ohio, p. 281-309. Also published in 1988, in 2nd national outdoor action conference on aquifer restoration, ground water monitoring, and geophysical methods [Las Vegas, May 23-26] proceedings, volume 2: Association of Ground Water Scientists and Engineers (AAAS), p. 939-968. Later published in 1989, The Log Analyst, v. 30(1), January-February, p. 31-44.

American Water Works Association, 1989, Evaluation of regional groundwater conditions, chapter 2, in Groundwater, 2nd edition: American Water Works Association, AWWA Manual M21, p. 21-38.

Anderson, B.C., 1987, Use of temperature logs to determine intra-wellbore flows, Yucca Mountain, Nevada: Colorado School of Mines, Golden, unpublished MS thesis, 112 p.

Andersson, K.P., Andersson, P.M., Gustafsson, E., and Olsson, O., 1989, Mapping groundwater flow paths in crystalline bedrock using differential radar crosshole tomography measurements utilizing saline tracers, paper H, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 117-125.

Bachu, S., 1985, Influence of lithology and fluid flow on the temperature distribution in a sedimentary basin--A case study from the Cold Lake area, Alberta, Canada: Tectonophysics, v. 120, p. 257-284.

Batt, L.S., 1973, The use of well logging techniques in water resources development, paper 7, in 2nd annual logging symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 25 p.

Besenecker, H., and Lillich, W., 1978, The determination of permeability rates of acquifer-separating layers from non-hydrological data, in Hydrogeology of great sedimentary basins [Conference of May/June 1976, Budapest]: Hungarian Geological Institute, Budapest, p. 108-116.

Bevc, D., and Morrison, H.F., 1989, Borehole-to-surface electrical resistivity monitoring of a salt water injection experiment, paper E/G 1.2, in Expanded abstracts with biographies 59th annual meeting, v. 1: Society of Exploration Geophysicists, p. 216-218.

Brown, C.E., 1988, Determination of rock properties by borehole-geophysical and physical-testing techniques and ground-water quality and movement in the Durham Triassic basin, North Carolina: U.S. Geological Survey Professional Paper 1432, 29 p.

Buckley, D.K., and Oliver, D., 1990, Geophysical logging of water exploration boreholes in the Deccan Traps, central India, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 153-161.

Clemmens, C.B., 1989, Geophysical borehole logging, applications (and limitations) to groundwater investigations in shallow and small diameter wells, in Ground water issues and solutions in the Potomac River Basin/Chesapeake Bay regions [Washington, D.C., March 14-16], proceedings: Association of Ground Water Scientists and Engineers, p. 47-68.

Collier, H.A., and Alger, R.P., 1988, Recommendations for obtaining valid data from borehole geophysical logs, in 2nd national outdoor action conference on aquifer restoration, ground water monitoring, and geophysical methods [Las Vegas, May 23-26] proceedings, volume 2: Association of Ground Water Scientists and Engineers (AAAS), p. 897-923.

Conaway, J., 1988, Temperature logging as an aid to understanding groundwater flow in boreholes, paper F, in 2nd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applications [Golden, Colorado, October 6-8, 1987], proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society Chapter-at-Large, p. 51-59.

Crosby, J.W., III, and Anderson, J.V., 1971, Some applications of geophysical well logging to basalt hydrogeology: Ground Water, v. 9(5), Septermber-October, p. 12-20.

Davis, B.K., 1981, Log analysis in the search for brackish water in the Kurnub and Arad Groups in the northeastern Negev: Israel Journal of Earth Sciences, v. 30, p. 93-101.

Dearborn, J.L., 1988, Borehole geophysical investigation of fractured rock at an EPA superfund site in Massachusetts, in 2nd national outdoor action conference on aquifer restoration, ground water monitoring, and geophysical methods [Las Vegas, May 23-26] proceedings, volume 2: Association of Ground Water Scientists and Engineers (AAAS), p. 875-895.

Dearborn, L.L., Baker, P.S., and Davis, J.B., 1989, Preliminary interpretation of geophysical logs and in-situ hydrologic properties in fractured limestone at Loring Air Force Base, paper FF, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 595-622.

DeLuca, R.J., and Buckley, B.K., 1985, Borehole logging to delineate fractures in a contaminated bedrock aquifer, in 1985 NWWA conference on surface and borehole geophysical methods in ground water investigations [Fort Worth, Texas, February 12-14], proceedings: National Water Well Association, Worthington, Ohio, p. 387-398.

Dobecki, T.L., and Romig, P.R., 1985, Geotechnical and groundwater geophysics: Geophysics, v. 50(12), p. 2621-2636.

Drury, M.J., Jessop, A.M., and Lewis, T.J., 1983, Geothermal logging for the detection of groundwater flow, in International conference on groundwater and man [Sydney, Australia], proceedings, volume 1, Investigation and assessment of groundwater resources: Australian Water Resources Council Conference Series No. 8, p. 79-87.

Dyck, J.H., Keys, W.S., and Meneley, W.A., 1972, Application of geophysical logging to groundwater studies in southeastern Saskatchewan: Canadian Journal of Earth Sciences, v. 9, p. 78-94.

Emerson, D.W., and Haines, B.M., 1972, Sampling and geophysical logging of water bores in unconsolidated sediments: Australian Society of Exploration Geophysicists Bulletin, v. 3(4), p. 17-32.

Ernston, K., and Scherer, H.U., 1986, Self-potential variations with time and their relation to hydrogeologic and meteorological parameters: Geophysics, v. 51(10), p. 1967-1977.

Fetter, C.W., 1988, Geophysical logs, chapter 12, Field methods, in Applied hydrology, 2nd edition: Merrill Publishing Company, Columbus, Ohio, 506-518.

Fligg, K., and Rodrigues, E., 1981, Case histories in the application of geophysical well logging in ground-water applications: Ontario Ministry of the Environment, Water Resources Branch, Water Resources Paper No. 12, 19 p.

Goldberg, D., Speed, D., Wilkinson, C., and Scholz, E., 1990, A correlation of hydraulic conductivity from pulse tests with sonic log amplitudes, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 297-302.

Guo, Y.A., 1986, Estimation of TDS in sand aquifer water through resistivity log: Ground Water, v. 24(5), p. 598-600.

Henrich, W.J., 1986, Delineation of transmissive layers by borehole geophysics, in Surface and borehole geophysical methods and ground water instrumentation conference and exposition [Denver, October 15-17], proceedings: National Water Well Association, Dublin, Ohio, p. 570-578.

Hess, A.E., 1984, Use of a low-velocity borehole flowmeter in the study of hydraulic conductivity in fractured rock, in D.M. Nielsen and M. Curl, editors, 1984 NWWA/EPA conference on surface and borehole geophysics methods in ground water investigations, proceedings: National Water Well Association, Worthington, Ohio, p. 812-832.

Hess, A.E., and Paillet, F.L., 1989, Characterizing flow paths and permeability distribution in fractured-rock aquifers using a sensitive, thermal, borehole flowmeter, in Conference on new field techniques for quantifying the physical and chemical properties of heterogeneous aquifers [March 20-23, Dallas, TX], proceedings: National Water Well Association, Dublin, OH, p. 155-172.

Hill, F.L., III, Barnette, J.C., Koenn, L.D., and Chace, D.M., 1989, New instrumentation and interpretive methods for identifying shielded waterflow using pulsed neutron technology, paper S, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 14 p.

Hodges, R.E., 1988, Calibration and standardization of geophysical well-logging equipment for hydrologic applications: U.S. Geological Survey Water-Resource Investigations Report 88-4058, 25 p.

Howard, K.W.F., 1986, The influence of fissuring on saline incursion in a limestone aquifer as revealed by fluid logging, in P.G. Killeen, editor, Borehole geophysics for mining and geotechnical applications [international symposium and workshop, (Toronto, Ontario, August 29-31, 1983), proceedings]: Geological Survey of Canada Paper 85-27, p. 217-226.

Hunt, E.R., 1987, FRACLOG - an integrated log analysis approach to completion and hydraulic fracture design: In Focus--tight Gas Sands, v. 4(1), March, p. 9-22.

Huntley, D., 1986, Relations between permeability and electrical resistivity in granular aquifers: Ground Water, v. 24(4), p. 466-474.

Ierubino, J.V., and Ginest, N.H., 1989, Use of pulsed neutron logging techniques to prove protection of underground sources of drinking water, SPE-19616, in SPE annual technical conference and exhibition, proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 459-464.

Jarrell, M., and Lyle, R., 1987, Application of the temperature survey in demonstrating the mechanical integrity of injection wells, in NWWA FOCUS conference on Midwestern ground water issues [Indianapolis, April 21-23], proceedings: National Water Well Association, Dublin, Ohio, p. 569-590.

Javandel, I., 1989, On the field determination of effective porosity, in Conference on new field techniques for quantifying the physical and chemical properties of heterogeneous aquifers [March 20-23, Dallas, TX], proceedings: National Water Well Association, Dublin, OH, p. 155-172.

Johnson, N.M., and Dreiss, S.J., 1989, Hydrostratigraphic interpretation using indicator geostatistics: Water Resources, v. 25(12), p. 2,501-2,510.

Jones, F.W., and Majorowicz, J.A., 1987, Some aspects of the thermal regime and hydrodynamics of western Canadian sedimentary basins, in J.C. Goff, and B.P.J. Williams, editors, Fluid flow in sedimentary basins and aquifers: Geological Society of London Special Publication No. 34, p. 79-85.

Jorgensen, D.G., 1988, Estimating permeability in water-saturated formations: The Log Analyst, v. 29(6), November-December, p. 401-409.

Jorgensen, D.G., 1989, Using geophysical logs to estimate porosity, water resistivity, and intrinsic permeability: U.S. Geological Survey Water-Supply Paper 2321, 24 p.

Kartawidjaja, F., and Luciani, J.P., 1985, The streaming SP--A flow indicator, in 14th annual convention proceedings: Indonesian Petroleum Association, Jakarta, p. 611-633.

Keller, G.W., 1970, Application of resistivity methods in mineral and groundwater exploration programs, in L.W. Morely, editor, Mining and groundwater geophysics--1967: Geological Survey of Canada Economic Geology Report 26, p. 51-66.

Keys, W.S., 1970, Borehole geophysics as applied to groundwater, in L.W. Morley, editor, Mining and grounwater geophysics--1967: Geological Survey of Canada Economic Geology Report No. 26, p. 598-614.

Keys, W.S., 1980, The application of the acoustic televiewer to the characterization of hydraulic fractures in geothermal wells, in Raft River well stimulation experiments, geothermal reservoir well stimulation program: U.S. Department of Energy Report DOE/AL/10563-T7, p. A1-A11.

Keys, W.S., 1985, Use of a microcomputer to analyze geophysical logs of a water well in a carbonate aquifer, in G. Gunay and A.I. Johnson, editors, Karst water resources [proceedings of a symposium in Ankara, Turkey, July, 1985]: International Association of Hydrological Sciences, Washington, D.C., Publication No. 161, p. 249-260.

Keys, W.S., 1986, Analysis of geophysical logs of water wells with a microcomputer: Ground Water, v. 24(6), p. 750-760.

Keys, W.S., 1988, Borehole geophysics applied to ground-water hydrology: U.S. Geological Survey Open-File Report 87-539, 305 p. Later published in 1989: National Water Well Association, Dublin, Ohio, 313 p.

Keys, W.S., and MacCary, L.M., 1971, Application of borehole geophysics to water-resources investigations: U.S. Geological Survey, Techniques of Water-Resources Investigations, book 2, chapter E1, 126 p.

Keys, W.S., and MacCary, L.M., 1973, Location and characteristics of the interface between brine and fresh water from geophysical logs of boreholes in the upper Brazos River basin, Texas: U.S. Geological Survey Professional Paper 809-B, 23 p.

Knutson, C.F., Harrison, W.E., and Smith, R.P., 1989, Petrophysical characterization of basalt in the vadose zone, Idaho Noational Engineering Laboratory, eastern Snake River plain, Idaho, paper E, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 53-93

Kovacs, G., 1981, Exploration and exploitation of deep groundwaters, section 14, in Subterranean hydrology: Water Resources Publications, Littleton, Colorado, p.609-683.

Kwader, T., 1982, Interpretation of geophysical logs in shallow carbonate environments and their applications to ground water resource investigations: T. Kwader Inc., 201 p.

Kwader, T., 1984, Estimating acquifer permeability from formation resistivity factors, in D.M. Nielsen and M. Curl, editors, 1984 NWWA/EPA conference on surface and borehole geophysics methods in ground water investigations, proceedings: National Water Well Association, Worthington, Ohio, p. p.713-721.

Kwader, T., 1984, The use of geophysical logs for determining formation water quality, in D.M. Nielsen and M. Curl, editors, 1984 NWWA/EPA conference on surface and borehole geophysics methods in ground water investigations, proceedings: National Water Well Association, Worthington, Ohio, p. 833-841. Later published in 1986, Ground Water, v. 24(1), p. 11-15.

Kwader, T., 1985, Resistivity-porosity cross plots for determining in situ formation water quality--Case examples, in 1985 NWWA conference on surface and borehole geophysical methods in ground water investigations [Fort Worth, Texas, February 12-14], proceedings: National Water Well Association, Worthington, Ohio, p. 415-424.

Lancaster, J.R., and Atkinson, A., 1987, Computer processing of selected drilling, lithologic, and geophysical log data produces accurate permeability values and comprehensive aquifer analysis, including specific yield: COGS [Computer Oriented Geological Society] Computer Contributions, v. 3(1), February, p. 13-36.

Levine, E.N., Cybriwsky, Z.A., and Toksoz, M.N., 1984, Detection of permeable rock fractures and estimation of hydraulic conductivity by 3-D vertical seismic profiling, in D.M. Nielsen and M. Curl, editors, 1984 NWWA/EPA conference on surface and borehole geophysics methods in ground water investigations, proceedings: National Water Well Association, Worthington, Ohio, p. 853-876.

MacCary, L.M., 1980, Use of geophysical logs to estimate water-quality trends in carbonate aquifers: U.S. Geological Survey Water-Resources Investigations no. 80-57, 23 p.

MacCary, L.M., 1984, Relation of formation factor to depth of burial in aquifers along the Texas Gulf Coast, in D.M. Nielsen and M. Curl, editors, 1984 NWWA/EPA conference on surface and borehole geophysics methods in ground water investigations, proceedings: National Water Well Association, Worthington, Ohio, p. 722-742.

Mares, S., and Eldunia, A., 1989, Partial inflow yields in water wells determined by fluid resitivity logs, paper HH, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 655-669.

McConnell, C.L., 1983, Spontaneous potential corrections for ground-water salinity calculations; Carter County, Oklahoma, U.S.A.: Journal of Hydrology, v. 65, p. 363-372.

McConnell, C.L., 1985, Time dependence of the quivalent water resistivity in fresh water wells: The Log Analyst, v. 26(3), May-June, p. 12-17.

McConnell, C.L., 1986, Equivalent mud filtrate resistivities in fresh water wells: The Log Analyst, v. 27(2), March-April, p. 85-90.

McConnell, C.L., 1987, A natural inverted groundwater salinity profile in southern Oklahoma: Shale Shaker, v. 38(1), July-August, p. 2-6.

McConnell, C.L., 1988, A general correction for spontaneous potential well logs in fresh water: Journal of Hydrology, v. 101(1-4), p. 1-13.

McConnell, C.L., 1989, Characterization of wellhead protection areas using spontaneous potential well log analysis, paper II, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 671-697.

McKay, W.A., and Kepper, J., 1988, Estimating hydraulic parameters using wildcat oil and gas data; a feasibility study in east-central Nevada: University of Nevada, Water Resources Center, Desert Research Institute, Reno, Publiction No. 41117, 48 p.

Merin, I.S., 1989, Characterization of fractures in Devonian siltstones, northern Appalachian plateau; implications for ground water flow, in 3rd national outdoor action conference on aquifer restoration, ground water monitoring and geophysical methods [Orlando, Florida], proceedings: National Well Water Association, Dublin, Ohio, p. 921-934.

Michalski, A., 1989, Application of temperature and electrical conductivity logging in ground water monitoring: Ground Water Monitoring Review, v. 9(3), p. 112-118.

Michalski, A., and Klepp, G.M., 1990, Characterization of transmissive fractures by simple tracing of inwell flow: Ground Water, v. 28(2), p. 191-198.

Morin, R.H., and Barrash, W., 1986, Defining patterns of ground water and heat flow in fractured Brule Formation, western Nebraska, using borehole geophysical methods, in Surface and borehole geophysical methods and ground water instrumentation conference and exposition [Denver, October 15-17], proceedings: National Water Well Association, Dublin, Ohio, p. 545-569.

Morin, R.H., Hess, A.E., and Paillet, F.L., 1988, Determining the distribution of hydraulic conductivity in a fractured limestone aquifer by simultaneous injection and geophysical logging: Ground Water, v. 26(5), October, p. 587-595.

Newman, J., and McDuff, J., 1988, Electric wireline methods for in situ capture of wellbore samples and determining their flow rates and direction, in 2nd national outdoor action conference on aquifer restoration, ground water monitoring, and geophysical methods [Las Vegas, May 23-26] proceedings, volume 1: Association of Ground Water Scientists and Engineers (AAAS), p. 97-122.

Ogbe, D., and Bassiouni, Z., 1978, Estimation of aquifer permeabilities from electric well logs: The Log Analyst, v. 19(5), September-October, p. 21-27.

Oteri, A., 1988, Electric log interpretation for the evaluation of salt water intrusion in the eastern Niger Delta: Hydrological Sciences Journal, v. 33(1), p. 19-30.

Overton, H.L., 1978, Appraisal of water movement from subsurface data: The Log Analyst, v. 19(5), September-October, p. 3-20.

Paillet, F.L., and Keys, W.S., 1984, Applications of borehole geophysics in characterizing the hydrology of fractured rocks, in D.M. Nielsen and M. Curl, editors, 1984 NWWA/EPA conference on surface and borehole geophysics methods in ground water investigations [San Antonio, February 7-9], proceedings: National Water Well Association, Worthington, Ohio, p. 743-761.

Paillet, F.L., Hess, A.E., Cheng, C.H., and Hardin, E.A., 1987, Characterization of fracture permeability with high-resolution vertical flow measurements during borehole pumping: Ground Water, v. 25(1), February, p. 28-40.

Paillet, F., and Morin, R., 1986?, Quantitative analysis of geophysical well-log data: U.S. Geological Survey Short Course Notes, 105 p.

Paillet, F.L., Waltz, J., and Boyle, R.E., 1989, Geophysical log investigation of formation changes produced by hydraulic fracture stimulation in a crystalline bedrock aquifer, paper EE, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 571-594.

Pirson, S.J., 1983, Hydrodynamics of infiltration, chapter 10, in Geologic well log analysis, 3rd edition: Gulf Publishing Company, Houston, p. 291-332.

Poeter, E.P., 1987, Perched water identification with radiation logs, in NWWA FOCUS conference on northwestern ground water issues proceedings: National Water Well Association, Dublin, Ohio, p. 313-327. Later published in 1988, Ground Water, v. 26(1), January-February, p. 15-21.

Poole, V.L., Cartwright, K., and Leap, D., 1989, Use of geophysical logs to estimate water quality of basal Pennsylvanian sandstones, southwestern Illinois: Ground Water, v. 27(5), September-October, p. 682-688.

Prasada, S.V.V., Rao, G., Varadarajan, P., Prasad, P.P., Subrahmanyam, K., and Seshunarayana, T., 1989, Borehole resistivity logging in PVC screened well, in Gupta, C.P., editor, Appropriate methodologies for development and management of groundwater resources in developing countries [Hyperabad, India, February 28-March 4], proceedings, volume 1: Oxford & IBH Publishing Company, New Delhi, p. 457-460.

Rao, S.V.V.P., 1985, Aquifer and aquiclude delineation and correlation of Quaternary sediments by borehole geophysical logs in Banganga River basin, Rajasthan: Geophysical Research Bulletin, v. 23(9), p. 169-176.

Repsold, H., 1989, Well logging in groundwater development: International Association of Hydrogeologists, International Contributions to Hydrogeology, v. 9, 136 p.

Robinette, M.S., and Williams, R.E., 1979, Delineation of hydrostratigraphic units using borehole geophysical techniques, in Symposium on uranium mill tailings management, geotechnical engineering program [November 19-20]: Colorado, Colorado State University, Fort Collins, Civil Engineering Department, p. 3-12.

Roscoe Moss Company, 1989, Geophysical borehole logging, chapter 4, in Handbook of ground water development: John Wiley & Sons, New York, p. 52-84.

Sciacca, J., 1989, Operational and quality assurance considerations for borehole geophysical logging in hydrogeologic investigations, in 3rd national outdoor action conference on aquifer restoration, ground water monitoring and geophysical methods [Orlando, Florida], proceedings: National Well Water Association, Dublin, Ohio, p. 891-907.

Shuter, E., and Teasdale, W.E., 1989, Application of drilling, coring, and sampling techniques to test holes and wells, chapter F1, in Collection of environmental data: U.S. Geological Survey Techniques of Water-Resource Investigations, Book 2, 97 p.

Sorensen, K., 1989, A method for measurement of the electrical formation resistivity while auger drilling: First Break, v. 7(10), p. 403-407.

Stegner, R., and Becker, A., 1988, Borehole geophysical methodology; analysis and comparison of new technologies for ground water investigation, in 2nd national outdoor action conference on aquifer restoration, ground water monitoring, and geophysical methods [Las Vegas, May 23-26] proceedings, volume 2: Association of Ground Water Scientists and Engineers (AAAS), p. 987-1011.

Tanwar, B.S., 1980, Electric logging techniques applied to ground water exploration and waterwells: Irrigation Power [New Delhi], v. 37(2), p. 233-240.

Taylor, K.C., 1987, Application of borehole geophysical methods to shallow groundwater investigations: University of Nevada, unpublished PhD dissertation, 186 p. [Includes source code.]

Taylor, K., Molz, F., and Hayworth, J., 1988, A single well electrical tracer test for the determination of hydraulic conductivity and porosity as a function of depth, in 2nd national outdoor action conference on aquifer restoration, ground water monitoring, and geophysical methods [Las Vegas, May 23-26] proceedings, volume 2: Association of Ground Water Scientists and Engineers (AAAS), p. 925-938.

Taylor, K., and Wheatcraft, S., 1986, Use of borehole geophysics to define hydrologic conditions; a field example, in Surface and borehole geophysical methods and ground water instrumentation, conference proceedings: National Well Water Association, Dublin, Ohio, p. 215-238.

Taylor, K.C., Wheatcraft, S.W., and McMillion, L.G., 1985, A strategy for the hydrologic interpretation of well logs, in 1985 NWWA conference on surface and borehole geophysical methods in ground water investigations [Fort Worth, Texas, February 12-14], proceedings: National Water Well Association, Worthington, Ohio, p. 314-323.

Taylor, T.A., 1986, Application of gamma-spectral logging to ground-water investigations, in Surface and borehole geophysical methods and ground water instrumentation conference and exposition [Denver, October 15-17], proceedings: National Water Well Association, Dublin, Ohio, p. 527-544.

Taylor, T.A., 1989, Correlation of abnormal gamma readings with fluid movement through fractures in a formation by use of gamma-spectral logs, paper AA, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 472-499.

Taylor, T.A., and Dey, J.A., 1985, Bibliography of borehole geophysics as applied to ground-water hydrology: U.S. Geological Survey Circular No. 926, 62 p.

Testa, S.M., 1988, Benefits of downhole geophysical methods in low permeability hydrogeologic environments, in 2nd national outdoor action conference on aquifer restoration, ground water monitoring, and geophysical methods [Las Vegas, May 23-26] proceedings, volume 2: Association of Ground Water Scientists and Engineers (AAAS), p. 969-985.

Tselentis, G., 1985, A study of the hydrogreophysical properties of fissured aquifers using a double porosity model: Journal of Hydrology, v. 78, p. 331-344.

Tselentis, G., 1985, The processing of geophysical well logs by microcomputers as applied to the solution of hydrogeological problems: Journal of Hydrology, v. 80, p. 215-236.

Tucci, P., and Pool, D.R., 1986, Use of geophysics for geohydrologic studies in the alluvial basins of Arizona, in Regional aquifer systems of the United States, southwest alluvial basins of Arizona [21st annual conference and symposium (Tuscson, August 11-16, 1985), proceedings]: American Water Resources Association, Bethesda, Maryland, p. 37-56.

Tulipano, L., 1988, Temperature log intepretation for the identification of preferential flow pathways in the coastal carbonatic and karstic aquifer of the Salento peninsula (southern Italy), in 21st congress [Guilin, China, (October 10-15)], proceedings, volume 2, Karst hydrogeology and karst environment protection: International Association of Hydrogeologists, Publication No. 176

Vaish, J.P., and Saini, I.S., 1982, Application of geophysical well-logging technique for detection of aquifers, in S.S. Merh, First national seminar on Quaternary environments [Baroda, India, November, 1977]: Hindustan Publishing Corporation, Delhi, India, p. 115-20.

Vonhof, J.A., 1966, Water quality determination from spontaneous-potential electric log curves: Journal of Hydrology, v. 4, p. 341-347.

Waller, P.L., 1986, Use of geophysical logs in conjunction with concentrated acid injection to improve water yields from limestone wells in Tampa, Florida, in NWWA FOCUS conference on southeastern ground water issues [Tampa, October 6-8], proceedings: National Water Well Association, Dublin, Ohio, p. 377-388.

Walters, M., and Lloyd, J.W., 1985, The use of a microcomputer for recording and analysis of borehole logging data in hydrogeological investigations: The Quarterly Journal of Engineering and Geology, v. 18(4), p. 381-389.

Williams, J.H., Carswell, L.D., Lloyd, O.B., Jr., and Roth, W.C., 1984, Characterization of ground water circulation in selected fractured rock aquifers using borehole temperature and flow logs, in D.M. Nielsen and M. Curl, editors, 1984 NWWA/EPA conference on surface and borehole geophysics methods in ground water investigations, proceedings: National Water Well Association, Worthington, Ohio, p. 842-852.

Wilson, H.C., Michel, F.A., Mewnifumbo, C.J., and Killeen, P.G., 1989, Application of borehole geophysics to groundwater energy resources, paper T, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 317-335.

Woodward, D.G., 1984, Areal lithologic changes in bedrock aquifers in southeastern Minnesota as determined from natural-gamma borehole logs, in D.M. Nielsen and M. Curl, editors, 1984 NWWA/EPA conference on surface and borehole geophysics methods in ground water investigations, proceedings: National Water Well Association, Worthington, Ohio, p. 788-800.

Working Group on Nuclear Techniques in Hydrology, 1971, Nuclear well logging in hydrology: Vienna, Austria, International Atomic Energy Agency, Technical Reports Series, No. 126, 90 p.

20. IGNEOUS AND METAMORPHIC ROCKS (Including DSDP and ODP Results)

(See also 15. Fracture detection; 19. Ground water; 21. Geothermal)

Anderson, B.C., 1987, Use of temperature logs to determine intra-wellbore flows, Yucca Mountain, Nevada: Colorado School of Mines, Golden, unpublished MS thesis, 112 p.

Anderson, R.N., Alt, J.C., and Malpas, J., 1989, Geochemical well logs and the determination of integrated chemical fluxes in hole 504B, eastern equatorial Pacific, section 11, in Mazzullo, E.K., editor, Proceedings of the Ocean Drilling Program, v. 111, Scientific results: Texas A & M University, Ocean Drilling Program, p. 119-132.

Anderson, R.N., Dove, R.E., and Pratson, E., 1990, Geochemical well logs; calibration and lithostratigraphy in basaltic, granitic, and metamorphic rocks, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 177-194.

Anderson, R.N., and O'Malley, H., 1985, Frequency response and attenuation changes across highly altered fracture zones crosscutting a fast formation--The oceanic crust of the Mid-Atlantic Ridge, paper LLL, in 26th annual well logging symposium transactions: Society of Professional Well Log Analysts, 12 p.

Anderson, R.N., O'Malley, H., and Newmark, R.L., 1984, Use of geophysical logs for quantitative determination of fracturing, alteration, and lithology in the upper oceanic crust, in C.B. Raleigh, editor, Observation of the continental crust through drilling, volume I [international symposium (Tarrytown, N.Y., May 20-25), proceedings]: Springer-Verlag, New York, p. 182-234. Also published in 1985 as, Use of geophysical logs for quantitative determination of fracturing, alteration and lithostratigraphy in the upper oceanic crust, Deep Sea Drilling Project, holes 504B and 556, in Initial reports of the the Deep Sea Drilling Project, v. 83: U.S. Government Printing Office, p. 443-478. Also published in 1985 as, Nuclear, multichannel-sonic, ultrasonic analyses for determination of degree of fracturing and alteration in a fast formation--the deep oceanic crust, paper Y, in 25th annual logging symposium transactions: Society of Professional Well Log Analysts, 22 p.

Anderson, R.N., Zoback, M.D., Hickman, S.H., and Newmark, R.L., 1985, Permeability versus depth in the upper oceanic crust--In situ measurements in Deep Sea Drilling Project hole 504B, eastern equatorial Pacific, in Initial reports of the the Deep Sea Drilling Project, v. 83: U.S. Government Printing Office, p. 429-442. Also published in 1985, Journal of Geophysical Research, v. 90(B5), p. 3659-3669.

Andersson, K.P., Andersson, P.M., Gustafsson, E., and Olsson, O., 1989, Mapping groundwater flow paths in crystalline bedrock using differential radar crosshole tomography measurements utilizing saline tracers, paper H, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 117-125.

Andersson, P., and Stenberg, L., 1985, Geophysical borehole logging in Lavia borehole--Results and interpretation of sonic and tube wave measurements: Nuclear Waste Commission of Finnish Power Commission, Helsinki, Report No. YJT-85-07, 46p.

Barton, C., Moos, D., and Blangy, J-P., 1989, Analysis of full waveform acoustic logging data at ODP site 642--Outer Voring plateau, section 45, in Winkler, W.R., editor, Proceeding of the Ocean Drilling Program, volume 104, Norwegian Sea, scientific results: Texas A&M University, Ocean Drilling Program, p. 953-964.

Baumgartner, J., Rummel, F., Haimson, B.C., and Lee, M.Y., 1989, In situ stress measurements and natural fracture logging in drill hole CY-4, the Troodos ophiolite, Cyprus, in Gibson, I.L., Malpas, J., Robinson, P.T., and Xenophontos, C. eds., Cyprus crustal study project; initial report, hole CY-4: Geological Survey of Canada Paper 88-9, p. 315-330.

Becker, K., Langseth, M.G., Von Herzen, R.P., Anderson, R.N., and Hobart, M.A., 1985, Deep crustal geothermal measurements, hole 504b, Deep Sea Drilling Project legs 69, 70, 83, and 92, in Initial reports of the Deep Sea Drilling Project, v. 83: U.S. Government Printing Office, p. 405-418.

Becker, K., Sakai, H., Merrill, R.B., and others, 1988, Site 504, chapter 3, in Proceedings of the Ocean Drilling Program, volume 111, part A-Initial report, Costa Rica rift: Texas A&M University, Ocean Drilling Program, p. 94-186.

Becker, K., Von Herzen, R.P., Francis, T.J.G., Anderson, R.N., Honnorez, J., Adamson, A.C., Alt, J.C., Emmermann, R., Kempton, P.D., Kinoshita, H., Laverne, C., Mottl, N.J., and Newmark, R.L., 1982, In situ electrical resistivity and bulk porosity of the oceanic crust Costa Rica rift: Nature, v. 300, December 16, p. 594-599.

Berendsen, P., Borcherding, R.M., Doveton, J., Gerhard, L., Newell, K.D., Steeples, and Watney, W.L., 1988, Review of wireline-log responses in igneous and igneous-derived sedimentary rocks, appendix 5, in Texaco Poersch No. 1, Washington County, Kansas; preliminary geologic report of the pre-Phanerozoic rocks: Kansas Geological Survey Open-file Report 88-22, p. 113-116.

Berendsen, P., Borcherding, R.M., Doveton, J., Gerhard, L., Newell, K.D., Steeples, and Watney, W.L., 1988, Log analysis of the Precambrian rocks, section IV-B, in Texaco Poersch No. 1, Washington County, Kansas; preliminary geologic report of the pre-Phanerozoic rocks: Kansas Geological Survey Open-file Report 88-22, p. 30-43.

Berlitz, R., Pirie, G., Brideson, C., and others, 1988, Log interpretation in igneous and metamorphic rocks: The Technical Review, v. 36(3), p. 30-46.

Blackwood, D.J., and Peveraro, R.C.A., 1983, Determination of rock properties in a metamorphic/igneous formation by integrated formation evaluation, paper AAA, in 24th annual logging symposium transactions: Society of Professional Well Log Analysts, 25 p.

Bosum, W., 1985, Magnetic measurements under use of a 3-D drillhole magnetometer in the research borehole Konzen, Hohes Venn (West Germany): Neues Jahrbuch f,r Geologie und Pal‰ontologie, v. 1711-3), p. 145-155.

Bosum, W., Eberle, E., and Rehli, H.J., 1988, A gyro-oriented 3-component borehole magnetometer for mineral prospecting with examples of its applications: Geophysical Prospecting, v. 36(8), p. 933-961.

Bosum, W., and Scott, J.H., 1988, Interpretation of magnetic logs in basalt, hole 418A, in Proceedings of the Ocean Drilling Program, scientific results, v. 102: Texas A&M University, Ocean Drilling Program, p. 77-95.

Boyce, R.E., 1980, Determination of the relationships of electrical resistivity, sound velocity, and density/porosity of sediment and rock by laboratory techniques and well logs from Deep Sea Drilling Project sites 415 and 416 off the coast of Morocco, in Initial reports of the Deep Sea Drilling Project, v. 50: U.S. Government Printing Office, p. 305-318.

Boyce, R.E., 1984, Deep Sea Drilling Project drill sites 530 and 532 in the Angola Basin and on the Walvis Ridge--Interpretation of induction log data, and laboratory sound velocity, density, porosity-derived reflection coefficients, and vane shear strength, in Initial reports of the Deep Sea Drilling Project, v. 75, part 2: U.S. Government Printing Office, p. 1137-1187.

Brewer, T.S., Lovell, M.A., Harvey, P.K., Pelling R., Atkin, B.P., and Adamson, A., 1990, Preliminary geochemical results from DSDP/ODP hole 504B; a comparison of core and log data, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 195-202.

Broglia, C., and Moos, D., 1988, In-situ structure and properties of 110-Ma crust from geophysical logs in DSDP hole 418A, in Proceedings of the Ocean Drilling Program, scientific results, v. 102: Texas A&M University, Ocean Drilling Program, p. 29-47.

Burns, D.R., Thompson, D.R., and Cheng, C.H., 1990, Lithologic cycles and paleo fluid flow channels in old oceanic crust from geophysical logs at ODP site 418A, in Cheng, C.H., editor, Full waveform acoustic logging consortium, annual report: Massachusetts Institute of Technology, Earth Resources Laboratory, p. 273-288.

Burns, K.L., 1985, Information extraction from noisy televiewer logs of inclined wellbores in hard rock: Geothermal Resources Council Transactions, v. (, part 2, p. 441-445.

B,scher, M., Schmitz, D., Wohlenberg, J., 1985, Standard logs of the research borehole Konzen, Hohes Venn (West Germany): Neues Jahrbuch f,r Geologie und Pal‰ontologie, v. 1711-3), p. 83-94.

Cann, J.R., and Von Herzen, R.P., 1983, Downhole logging at Deep Sea Drilling Project sites 501, 504, and 505, near the Costa Rica rift, in L.N. Stout and M.G. Bailey, editors, Initial reports of the Deep Sea Drilling Project, v. 69: U.S. Government Printing Office, p. 281-299.

Carlson, R.L., Snow, K.R., and Wilkens, R.H., 1988, Density of old oceanic crust; an estimate derived from downhole logging on ODP leg 102, in Proceedings of the Ocean Drilling Program, scientific results, v. 102: Texas A&M University, Ocean Drilling Program, p. 63-68.

Carlson, R.L., Wilkens, R.H., Moos, D., and Broglia, C., 1988, Correlations of sediment lithostratigraphy, downhole logs, and seismic reflectors at site 418, in Proceedings of the Ocean Drilling Program, scientific results, v. 102: Texas A&M University, Ocean Drilling Program, p. 19-26.

Carroll, R.D., 1968, Applications of inhole geophysical logs in volcanic rocks, Nevada Test Site, in E.B. Eckel, editor, Nevada Test Site: Geological Society of America, Memoir No. 110, p. 125-134.

Carroll, R.D., 1989, Density logging and density of rocks in Ranier Mesa area, Nevada test site: U.S. Geological Survey Open-File Report No. 89-329, 180 p.

Carroll, R.D., 1990, Electric logging and electrical properties of rocks in Ranier Mesa area, Nevada test site, Nevada: U.S. Geological Survey Open-File Report 90-31, 90 p.

Carroll, R.D., and Magner, J.E., 1988, Velocity logging and seismic velocity of rocks in the Ranier Mesa area, Nevada test site, Nevada: U.S. Geological Survey Open-File Report 88-380, 85 p. + appendices.

Chomyn, B.A., Lapointe, P., Morris, W.A., and Coles, R.L., 1986, Application of magnetic susceptibility within crystalline rocks, in P.G. Killeen, editor, Borehole geophysics for mining and geotechnical applications [International symposium and workshop, (Toronto, Ontario, August 29-31, 1983), proceedings]: Geological Survey of Canada Paper 85-27, p. 226-236.

Coleman, J.M., Constans, R., and Bouma, A.H., 1986, Gamma-ray well-log characteristics, Leg 96, in Initial reports of the Deep Sea Drilling Project, volume 96: U.S. Government Printing Office, p. 547-561.

Crosby, J.W., III, and Anderson, J.V., 1971, Some applications of geophysical well logging to basalt hydrogeology: Ground Water, v. 9(5), September-October, p. 12-20.

Cross, J.W., 1986, Fracture detection in a volcanic oil reservoir using discriminant analysis of well log data: Old Dominion University, unpublished MS thesis, 1`13 p.

Cull, R., 1988, Formation Microscanner tool imaging and laterolog resistivity measurements in interpretation of crystalline terrains, in A. Boden and K.G. Eriksson, editors, Deep drilling in crystalline bedrock, volume 2: Springer-Verlag, Berlin, p. 315-327.

Czubek, J.A., 1985, Slowing down of fast neutrons in magmatic rocks: Acta Geophysica Polonica, v. 33(1), p. 45-54.

Daly, L., and Tabbagh, A., 1988, Towards the in situ measurement of the remnant magnetization of oceanic basalts: The Geophysical Journal of the Royal Astronomical Society, v. 95(3), p. 481-489.

Daniels, J.J., Scott, J.H., and Olhoeft, G., 1981, Interpreting Precambrian metamorphic geology, paper T, in 22nd annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p.

Davison, C.C., Keys, W.S., and Paillet, F.L., 1982, Use of borehole-geophysical logs and hydrologic tests to characterize crystalline rocks for nuclear-waste storage, Whiteshell nuclear research establishment, Manitoba, and Chalk River nuclear laboratory, Ontario, Canada: Battelle National Laboratory, Office of Nuclear Waste Isolation, Technical Report ONWI-418, 103 p.

Dearborn, J.L., 1988, Borehole geophysical investigation of fractured rock at an EPA superfund site in Massachusetts, in 2nd national outdoor action conference on aquifer restoration, ground water monitoring, and geophysical methods [Las Vegas, May 23-26] proceedings, volume 2: Association of Ground Water Scientists and Engineers (AAAS), p. 875-895.

Douglas, A.C., and Millett, M.R., 1978, Total intensity magnetometer logging as a stratigraphic tool in Tertiary volcanic rock: Lawrence Livermore Laboratory Report No. UCRL-52617, 11 p.

Drew, L.J., Bawiec, W.J., Page, N.J., and Schuenemeyer, J.H., 1985, The copper-nickel concentration log--A tool for stratigraphic interpretation within the ultramafic and basal zones of the Stillwater Complex, Montana: Journal of Geochemical Exploration, v. 23, p. 117-137.

Drury, M.J., 1985, The Iceland research drilling project crustal section; physical properties of some basalts from the Reydarfjordur borehole, Iceland: Canadian Journal of Earth Sciences, v. 22(11), p. 1588-1593.

Dyck, A.V., Auchincloss, P.V., and Atherton, D.L., 1989, High-resolution magnetic-susceptibility logger and dipmeter for mineral exploration boreholes; concept and initial progress (Grant 332), in Milne, V.G., editor, Geoscience research grant program summary of research 1988-1989: Ontario [Canada] Geological Survey Miscellaneous Paper 143, p.146-159.

Feely, M., and Madden, J., 1986, A quantitative regional gamma-ray survey on the Main Galway Granite, in Andrew, C.J., Crowe, R.W.A., Finlay, S., Pennell, W.M., and Pyne, J.F., editors, Geology and genesis of mineral deposits of Ireland: Irish Association for Economic Geology, p. 195-199.

Gable, R., Morin, R.H., and Becker, K., 1989, Geothermal state of hole 504B; ODP Leg 111 overview, chapter 8, in Mazzullo, E.K., editor, Proceedings of the Ocean Drilling Program, volume 111, scientific results: Texas A&M University Ocean Drilling Program, p. 87-96.

Genter, A., Cautru, J-P., Montaggioni, P., and Traineau, H., 1989, Geological interpretaton of well logging data from the granitic section of the Soultz-sous-Forets well GPK1, paper EE, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 12 p.

Gorshkov, Y.M., Kochetkov, P.F., and Nikoleva, T.M., 1986, Experience of geological-engineering investigations of andesite-basaltic lavas of Armenia by seismoacoustic and radiation logging methods, in 5th international congress, International Association of Engineering Geologists [Buenos Aires, October 20-25], proceedings v. 1: A.A. Balkema, Boston, p. 365-369.

Grau, J.A. Ellis, D.V., Herron, M.M., Schweitzer, J.S., and Rissler-Akesson, G., 1988, Geochemical logging in the Siljan ring, in A. Boden, and K.G. Eriksson, editors, Deep drilling in bedrock, volume 1, The deep gas drilling in the Siljan impact structure, Sweden and astroblemes: Springer-Verlag, New York, 230-252.

Haimson, B.C., and Lee, M.Y., 1987, The state of stress and natural fractures in a jointed Precambrian rhyolite in south-central Wisconsin, in I.W. Farmer, J.J.K. Daemen, C.S. Desai, C.E. Glass, and S.P. Neuman, editors, Rock mechanics; proceedings of the 28th U.S. symposium: A.A. Balkema, Boston, 231-240.

Hamano, Y., and Kinoshita, H., 1990, Magnetization of the oceanic crust inferred from magnetic logging in hole 395A, chapter 18, in Stewart, N.J., editor, Proceedings of the Ocean Drilling Program, volume 106/109, scientific results: Texas A&M University, Ocean Drilling Program, p. 223-229.

Harvey, P.K., and Lovell, M.A., 1989, Basaltic litho-stratigraphy of Ocean Drilling Program hole 504B: Nuclear Geophysics, v. 3(2), p. 87-96.

Holloway, A.L., 1989, Rock mass characterization studies in granite using borehole radar at Canada's underground research laboratory, paper DD, in 12th formation evaluation symposium transactions: Canadian Well Logging Society, 4 p.

Holmes, M.A., 1988, Evidence for continuous and discontinuous alteration in DSDP hole 418A basalts and its significance to to natural gamma-ray log readings, in Proceedings of the Ocean Drilling Program, scientific results, v. 102 : Texas A&M University, Ocean Drilling Program, p. 135-151.

Hyndman, R.D., and Ade-Hall, J.M., 1972, Electrical resistivity of basalts, in T.A. Davies, editor, Initial reports of the Deep Sea Drilling Project, v. 26: U.S. Government Printing Office, 505-508.

Hyndman, R.D., and Salisbury, M.H., 1984, The physical nature of young upper oceanic crust on the Mid-Atlantic Ridge, Deep Sea Drilling Project Hole 395A, in Initial reports of the Deep Sea Driling Project, v. 78A: U.S. Government Printing Office, p. 839-848.

Iizuka, Y., Ishii, T., Nagata, K., Matsumoto, Y., Murakami, O., and Noguchi, K., 1987, New system for borehole TV logging and evaluation of weathered granites according to their colour indices, in Herget, G., and Vongpaisal, S., editors, 6th international congress on rock mechanics, proceedings, v. 1: International Society for Rock Mechanics, p. 393-396.

Itoh, T., Kato, S., and Miyairi, M., 1982, A quick method of log interpretation for very low resistivity volcanic tuff by the use of CEC data, paper NN, in 23rd annual logging symposium transactions: Society of Professional Well Log Analysts, 26 p.

Jamtlid, A., Manusson, K., Olsson, O., and Stenberg, L., 1984, Electrical borehole measurements for the mapping of fracture zones in crystalline rock: Geoexploration, v. 22, p. 203-216.

Jones, J.W., Simpson, E.S., and Neuman, S.P., 1984, Geophysical investigation of fractured crystalline rock near Oracle, Arizona, in D.M. Nielsen and M. Curl, editors, 1984 NWWA/EPA conference on surface and borehole geophysics methods in ground water investigations, proceedings: National Water Well Association, Worthington, Ohio, p. 877-896.

Katsube, T.J., and Hume, J.P., 1987, Permeability determination in crystalline rocks by standard geophysical logs: Geophysics, v. 52(3), p. 342-352.

Keys, W.S., 1979, Borehole geophysics in igneous and metamorphic rocks, paper OO, in 20th annual logging symposium transactions: Society of Professional Well Log Analysts, 26 p. Later published in 1979, The Log Analyst, v. 20(4), July-August, P. 14-28. Reprinted 1982, in Geothermal log interpretation handbook: Society of Professional Well Log Analysts, p. III-177 - III-191.

Keys, W.S., 1984, A synthesis of borehole geophysical data at the Underground Research Laboratory, Manitoba, Canada: U.S. Department of Energy Report BMI/OCRD-15, 43 p.

Khatchikian, A., 1982, Log analysis of oil-bearing igneous rocks, paper AA, in 23rd annual logging symposium transactions: Society of Professional Well Log Analysts, 34 p. Later published in condensed form 1983, World Oil v. 197(7), December, p. 79-98.

Khatchikian, A., and Lesta, P, 1973, Log evaluation of tuffites and tuffaceous sandstones in southern Argentina, paper K, in 14th annual logging symposium transactions: Society of Professional Well Log Analysts, 23 p.

Kinoshita, H., Furuta, T., and Pariso, J., 1989, Downhole magnetic field measurements and paleomagnetism, hole 504B, Costa Rica ridge, chapter 13, in Mazzullo, E.K., editor, Proceedings of the Ocean Drilling Program, volume 111, scientific results: Texas A&M University Ocean Drilling Program, p. 147-156.

Kirkpatrick, R.J., 1979, Results of downhole geophysical logging hole 396b, DSDP leg 46, in Initial reports of the Deep Sea Drilling Project, v. 46: U.S. Government Printing Office, p. 401-407. Also published in 1979 as The physical state of the oceanic crust--Results of downhole geophysical logging in the mid-Atlantic ridge at 23°N: Journal of Geophysical Research, v. 84(B1), p. 178-188.

Kiss, B., and Toth, J., 1985, Well log interpretation of metamorphic hydrocarbon-bearing formations: First Break, v. 3(5), may, p. 24-31.

Knutson, C.F., Harrison, W.E., and Smith, R.P., 1989, Petrophysical characterization of basalt in the vadose zone, Idaho Noational Engineering Laboratory, eastern Snake River plain, Idaho, paper E, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 53-93

Krammer, K., 1990, Magnetic susceptiblity log measured in hole 395A, Leg 109, chapter 19, in Stewart, N.J., editor, Proceedings of the Ocean Drilling Program, volume 106/109, scientific results: Texas A&M University, Ocean Drilling Program, p. 231-235.

Krammer, K., Pohl, J, and Franken, D., 1985, Magnetic susceptiblity measurements in the borehole Konzen and rockmagnetic [sic] investigations on selected core samples: Neues Jahrbuch f,r Geologie und Pal%oontologie, v. 1711-3), p. 157-168.

Lapointe, P., Morris, W.A., and Harding, K.L., 1986, Interpretation of magnetic susceptibility--A new approach to geophysical evaluation of the degree of rock alteration: Canadian Journal of Earth Sciences, v. 23(3), p. 393-401.

Lebreton, F., and Vaubourg, P., 1983, Contribution of well logs to determining permeability and porosity in crystalline rocks, in J.B.W. Day, editor, Recent advances in hydrogeological research in France: Natural Environment Research Council, Institute of Geological Sciences, Report 82-6, p. 21-30.

Lovell, M.A., and Pezard, P.A., 1990, Electrical properties of basalts from DSDP hole 504B; a key to the evaluation of pore space morphology, in Hurst, A., Lovell, M.A., and Morton, A.C., editors, Geological applications of wireline logs: Geological Society of London Special Publication No. 48, p. 339-345.

Mathews, M., Salisbury, M.H., and Hyndman, R., 1984, Basement logging on the Mid-Atlantic Ridge, Deep Sea Drilling Project hole 395A, in Initial reports of the Deep Sea Drilling Project, v. 78A: U.S. Government Printing Office, p. 717-730.

Mathews, M.A., Scott, J.H., and LaDelfe, C.M., 1985?, Test pits for calibrating well logging equipment in fractured hard-rock environment: Los Alamos National Laboratory Report LA-UR 85-859, variously paginated.

McCann, D.M., Barton, K.J., and Hearn, K., 1983, Geophysical well logging in a crystalline rock mass, paper G, in 8th formation evaluation symposium transactions: Society of Professional Well Log Analysts London Chapter, 25 p.

McEwen, T.J., McCann, D.M., and Shedlock, S., 1985, Fracture analysis from borehole geophysical techniques in crystalline rocks: The Quarterly Journal of Engineering and Geology, v. 18(4), p. 413-436.

Mikesell, J.L., Senftle, F.E., Anderson, R.N., and Greenberg, M., 1989, Elemental concentrations in diabase determined by high-resolution borehole gamma-ray spectrometry: Nuclear Geophysics, v. 3(4), p. 501-519.

Mitchell-Tapping, H.J., 1988, Exploration petrophysics of the "serpentine" plugs of Texas: The Log Analyst, v. 29, No. 3, May-June, p. 196-203.

Moos, D., 1984, A case study of vertical seismic profiling in fractured crystalline rock, in M. Simaan, editor, Advances in geophysical data processing, volume 1: JAI Press, Greenwich, Connecticut, p. 9-37.

Moos, D., 1988, Elastic properties of 110-Ma oceanic crust from sonic full waveforms in DSDP hole 418A, in Proceedings of the Ocean Drilling Program, scientific results, v. 102: Texas A&M University, Ocean Drilling Program, p. 49-62.

Moos, D., 1990, Petrophysical results from logging in DSDP hole 109A, OPD Leg 109, chapter 20, in Stewart, N.J., editor, Proceedings of the Ocean Drilling Program, volume 106/109, scientific results: Texas A&M University, Ocean Drilling Program, p. 237-253.

Moos, D., and Zoback, M.D., 1983, In situ studies of velocity in fractured crystalline rocks: Journal of Geophysical Research, v. 88(B3), March 10, p. 2345-2358.

Moos, D., Goldberg, D., Hobart, M.A., and Anderson, R.N., 1986, Elastic wave velocities in Layer 2A from full waveform sonic logs at Hole 504B, in M. Bailey, editor, Intitial reports of the Deep Sea Drilling Project, volume 92: U.S. Government Printing Office, p. 563-570.

Morgan, F.D., Williams, E.R., and Madden, T.R., 1989, Streaming potential properties of Westerly Granite with applications: Journal of Geophysical Research, v. 94B(9), September 10, p. 12,449-12,461.

Morin, R.H., Anderson, R.N., and Barton, C., 1989, Analysis and interpretation of the borehole televiewer log; information on the state of stress and the lithostratigraphy at hole 504B, chapter 10, in Mazzullo, E.K., editor, Proceedings of the Ocean Drilling Program, v. 111, Scientific results: Texas A & M University, Ocean Drilling Program, p. 109-118.

Muller, D.C., and Spengler, R.W., 1989, Bulk porosity in lithophysal zones above the static water level at Yucca Mountain Nevada, calculated from the borehole gravity and gamma-gamma density logs, paper D, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 29-51.

Musgrave, J.A., Goff, F., Shevenell, L., and others, 1989, Selected data from continental scientific drilling core holes VC-1 and VC-2a, Valles caldera, New Mexico: Los Alamos National Laboratory Report LA-11496-OBES, 71 p.

Mwenifumbo, C.J., and Killeen, P.G., 1987, Natural gamma ray logging in volcanic rocks; the Mudhole and Clementine base metal prospects, in R.V. Kirkham, editor, Buchans Geology, Newfoundland, paper 16: Geological Survey of Canada Paper 86-24, p. 263-272.

Nelson, P.H., and Glenn, W.E., 1975, Influence of bound water on the neutron log in mineralized igneous rock, paper M, in 16th annual logging symposium transactions: Society of Professional Well Log Analysts, 9 p.

Newmark, R.L., Anderson, R.N., Moos,D., and Zoback, M.D., 1985, Sonic and ultrasonic logging of hole 504B and its implications for the structure, porosity, and stress regime of the upper 1 km of the oceanic crust, in Initial reports of the the Deep Sea Drilling Project, v. 83: U.S. Government Printing Office, p. 479-510. Also published in 1985 as, Structure, porosity and stress regime of the upper oceanic crust--Sonic and ultrasonic logging of DSDP hole 504B: Tectonophysics, v. 118, p. 1-42.

Olsson, O., Falk, L., Sandberg, S., Carsten, S., and Magnusson, K-A, 1985, Results from borehole radar reflection measurements, in Radioactive waste disposal in situ experiments in granite [Proceedings of 2nd NEA/Stripa Project symposium, June 1985]: Nuclear Energy Agency, Paris, p. 190-202.

Paillet, F.L., 1985, Acoustic-televiewer and acoustic-waveform logs used to characterize deeply buried basalt flows, Hanford site, Benton County, Washington: U.S. Geological Survey Open-File Report 85-419, 90 p.

Paillet, F.L., 1988, Fracture characterization and fracture-permeability estimation at the underground research laboratory in southeastern Manitoba, Canada: U.S. Geological Survey Water Resources Investigations Report 88-4009, 42 p.

Paillet, F.L., and Hess, A.E., 1986, Geophysical well-log analysis of fractured crystalline rocks at East Bull lake, Ontario Canada: U.S. Geological Survey Open-File Report 86-452, 37 p.

Paillet, F.L., and Hess, A.E., 1987, Geophysical well log analysis of fractured granitic rocks at Atikokan, Ontario, Canada: U.S. Geological Survey Water Resources Investigations Report No. 87-4154, 36 p.

Paillet, F.L., Waltz, J., and Boyle, R.E., 1989, Geophysical log investigation of formation changes produced by hydraulic fracture stimulation in a crystalline bedrock aquifer, paper EE, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 571-594.

Pariso, J.E., and Johnson, H.P., 1989, Magnetic properties of an analog of the lower oceanic crust; magnetic logging and paleomagnetic measurements from drill hole CY-4 in the Troodos ophiolite, in Gibson, I.L., Malpas, J., Robinson, P.T., and Xenophontos, C. eds., Cyprus crustal study project; initial report, hole CY-4: Geological Survey of Canada Paper 88-9, p. 279-292.

Peterson, F.L., 1974, Neutron well logging in Hawaii: University of Hawaii, Water Resources Research Technical Report 75, 42 p.

Pezard, P.A., and Anderson, R.N., 1989, Morphology and alteration of the upper oceanic crust from in-situ electrical experiments in DSDP/ODP hole 504B, section 12, in Mazzullo, E.K., editor, Proceedings of the Ocean Drilling Program, v. 111, Scientific results: Texas A & M University, Ocean Drilling Program, p. 133-146.

Pezard, P.A., Howard, J.J., and Lovell, M.A., 1989, Clay conduction and pore structure of oceanic basalts from DSDP/ODP hole 504B, chapter 9, in Mazzullo, E.K., editor, Proceedings of the Ocean Drilling Program, volume 111, scientific results: Texas A&M University Ocean Drilling Program, p. 97-108.

Pirhonen, V.O., 1988, Combined geophysical and hydraulic methods for 3D mapping of fractures and siting rock caverns in granite: Engineering Geology, v. 25(1), p. 45-68.

Ponomarev, V.N., and Nechoroshkov, V.L., 1983, Downhole magnetic measurements in oceanic crustal hole 395a on the Mid-Atlantic Ridge, in Initial reports of the Deep Sea Drilling Project, v. 78A: U.S. Government Printing Office, p. 731-739.

Rabinowitz, P.D., and Borella, P.E., 1984, Well logging of the sediments and basement complex on the Walvis Ridge, in Initial reports of the Deep Sea Drilling Project, v. 74: U.S. Government Printing Office, p. 827-838. Also published in 1984, as, A sonic well log of the basement complex of the Walvis Ridge: Geo-Marine Letters, v. 3(1), p. 1-7.

Rigby, F.A., 1980, Fracture identification in an igneous geothermal reservoir, Surprise Valley, California, paper Z, in 21st annual logging symposium transactions: Society of Professional Well Log Analysts, 9 p. Reprinted 1982, in Geothermal log interpretation handbook: Society of Professional Well Log Analysts, p. VII-111-VII-119.

Rissler-Akesson, G., 1988, Early results of the electric wireline logging in the Gravberg-1 well, in A. Boden, and K.G. Eriksson, editors, Deep drilling in bedrock, volume 1, The deep gas drilling in the Siljan impact structure, Sweden and astroblemes: Springer-Verlag, New York, 105-112.

Ritch, H.J., 1975, An open hole logging evaluation in metamorphic rocks, paper V, in 16th annual logging symposium transactions: Society of Professional Well Log Analysts, 11 p.

Saksa, P., 1985, Borehole geophysical investigations of Lavia deep testhole, Finland: Nuclear Waste Commission of Finnish Power Commission, Helsinki, Report No. YJT-85-06, 100 p.

Salisbury, M.H., Christensen, N.I., Becker, K., and Moos, D., 1985, The velocity structure of layer 2 at Deep Sea Drilling Project site 504 from logging and laboratory experiments, in Initial reports of the Deep Sea Drilling Project, v. 83: U.S. Government Printing Office, p. 529-539

Salisbury, M.H., Christiansen, N.I., Vine, F.J., Smith, G.C., and Eleftheriou, S., 1989, Geophysical structure of the Troodos ophiolite from downhole logging, in Gibson, I.L., Malpas, J., Robinson, P.T., and Xenophontos, C. eds., Cyprus crustal study project; initial report, hole CY-4: Geological Survey of Canada Paper 88-9, p. 331-349.

Salisbury, M.H., Donnelly, T.W., and Francheteau, J., 1980, Geophysical logging in Deep Sea Drilling Project hole 417D, in Initial reports of the Deep Sea Drilling Project, v. 51-53, part 1, : U.S. Government Printing Office, p. 705-713.

Salisbury, M.H., Scott, J.H., Auroux, C. Becker, K., Bosum, W., Broglai, C., Carlson, R., Christienson, N.I., Fisher, and others, 1988, Old oceanic crust--synthesis of logging laboratory, and seismic data from Leg 102, in Proceedings of the Ocean Drilling Program, scientific results, v. 102: Texas A&M University, Ocean Drilling Program, p. 155-180.

Salisbury, M.H., Scott, J.H., Becker, K., Bosum, W., Broglia, C., Carlson, R., Fisher, A., Gieskes, J., Holmes, M., Hoskins, H., Legrand, J., Moos, D., Rio, D, Stephen R., Wilkens, R., 1985, Ocean drilling program--looking down an old hole: Nature, v, 316(6030), August 22, p. 682.

Salisbury, M.H., Stephen, R., Christensen, N.I., Francheteau, J., Hamano, Y., Hobart, M., and Johnson, D., 1980, The physical state of the upper levels of Cretaceous oceanic crust from the results of logging, laboratory studies, and the oblique seismic experiment at Deep Sea Drilling Project Sites 417 and 418, in Initial reports of the Deep Sea Drilling Project, v. 51-53, part 2: U.S. Government Printing Office, p. 1579-1597.

Sandberg, E., Olsson, O., and Falk, L., 1989, Combined interpretation of fracture zones in crystalline rock using single hole, crosshole, tomography, and directional borehole radar data, paper G, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 97-116.

Sarmiento, Z.F., and Aquino, B.G., 1985, Lithologic and fracture response to geophysical logs in the andesite, metamorphic and diorite intrusive rocks in two geothermal wells in the Phillipines: Geothermal Resources Council Transactions, v. 9, part 2, p. 475-480.

Schmoker, J.W., 1977, Density variations in a quartz diorite determined from borehole gravity measurements, San Benito County, California: The Log Analyst, v. 18(2), March-April, p. 32-38.

Soonawala, N.M., 1983, Geophysical logging in granites: Geoexploration, v. 21(3), p. 221-230.

Stefansson, V., Gudmundsson, A., and Emmerman, R., 1982, Gamma ray logging in Icelandic rocks: The Log Analyst, v. 23(6), November-December, p. 11-16.

Vernik, L., 1989, Effects of hydrothermal zeolitization on reservoir properties and fluid flow in crystalline rock, paper C, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 15-28.

West, F.G., and Laughlin, A.W., 1976, Spectral gamma logging in crystalline basement rocks: Geology, v. 4(10), p. 617-618.

Wilkens, R., Schultz, D., Carlson, R., 1988, Relationship of resistivity, velocity, and porosity for basalts from downhole well-logging measurements in hole 418A, in Proceedings of the Ocean Drilling Program, scientific results, v. 102 : Texas A&M University, Ocean Drilling Program, p. 69-75

Worthington, P., Anderson, R.N., Bell, S., Becker, K., Jarrard, R.D., Salisbury, M., and Stephen, R., 1988, Downhole measurements for the Ocean Drilling Programme, in 2nd conference on scientific ocean drilling [Strasbourg, France], report: European Science Foundation, p. 131-136.

Worthington, P., Anderson, R.N., Jarrard, R.D., Becker, K., Bell, J.S., Salisbury, M.H., and Stephen, R.A., 1988, Scientific applications of downhole measurements in the ocean basins: Basin Analysis, v. 1, p. 223-236.

Zoback, M.D., and Anderson, R.N., 1982, Ultrasonic borehole televiewer investigation of oceanic crustal layer 2a, Costa Rica rift: Nature, v. 295, February 4, p. 375-379.

21. GEOTHERMAL WELL-LOG EVALUATON

(See also XI. Temperature logging; 15. Fracture detection; 19. Ground water; 20. Igneous rocks)

Allison M.L., and Nielson, D.L., 1988, Application of borehole breakouts to geothermal exploration and development; an example from Cove Fort-Sulphurdale, Utah: Geothermal Resources Council Transactions, v. 12, p. 213-219.

Armstead, H.C.H., and Tester, J.W., 1987, Rock fracturing practice--reservoir diagnostics, chapter 9, in Heat mining: E. & F.N. Spon, London, p.172-189.

Baker, L.E., Campbell, A.B., and Hughen, R.L., 1975, Well-logging technology and geothermal applications--A survey and assessment with recommendations: Sandia Laboratory, Report SAND 75-0275, 75 P.

Benoit, W.R., Sethi, D.K., Fertl, W.H., and Mathews, M., 1980, Geothermal well log analysis at Desert Peak, Nevada, paper AA, in 21st annual logging symposium transactions: Society of Professional Well Log Analysts, 41 p. Reprinted in 1982, Geothermal log interpretation handbook: Society of Professional Well Log Analysts, p. VII-69-VII-109.

Carlson, N.R., and Barnette, J.C., 1988, Determining a reliable estimate of the geothermal gradient from shut-in temperature recordings, SPE-18144, in 1988 SPE annual technical conference proceedings, volume omega, formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 375-387.

Carson, C.C., and Bauman, T., 1987, Use of an acoustic borehole televiewer to investigate casing corrosion in geothermal wells: Materials Performance, v. 26(6), p. 53-59.

Chilingar, G.V., Edwards, L., Fertl, W.H., and Rieke, H.H., III, 1982, Introduction, chapter 1, in L.M. Edwards, G.V. Chilingar, H.H. Rieke, III, W.H. Fertl, editors, Handbook of geothermal energy: Gulf Publishing Company, Houston, p. 1-43

Cochran, L.E., 1979, Formation evaluation in the geothermal environment--The Geysers steam field, California, SPE-8452: Society of Petroleum Engineers, 54th annual meeting [Las Vegas] preprint, 12 p.

Davarzani, J., and Roesner, R.E., 1985, Surveying steam injection wells using production logging instruments: Geothermal Resources Council Transactions, v. 9, part 2, p. 451-456.

Davarzani, J., and Sloan, M.L., 1987, Analysis of geothermal wells with simultaneous logging instruments, SPE-16818, in 1987 annual technical conference and exhibition proceedings, volume omega, Formation evaluation and reservoir geology: Society of Petroleum Engineers, p. 691-702. Later published in 1989, SPE Formation Evaluation, v. 4(3), September, p. 455-458.

Davarzani, J., and Sloan, M., 1988, Simultaneous TPS logging system: Geothermal Resources Council Transactions, v. 12, p. 441-448.

Dennis, B.R., 1984, Logging technology for high-temperature geothermal boreholes, in C.B. Raleigh, editor, Observation of the continental crust through drilling, volume I [international symposium (Tarrytown, N.Y., May 20-25), proceedings]: Springer-Verlag, New York, p. 174-181.

Dennis, B., Jemance, R., and Lawton, R., 1989, Results of well logging operations at the Ahuachapan geothermal field: Los Alamos National Laboratory Report NO. LA-UR-88-4257, 7 p.

Dreesen, D.S., Malzhan, M.V., Fehler, M.C., and Dash, Z.V., 1987, Identification of MHF fracture planes and flow paths; a correlation of well log data with patterns in locations of induced seismicity: Geothermal Resources Council Transactions, v. 11, p. 339-348.

Drury, M.J., 1989, Fluid flow in crystalline crust; detecting fractures by temperature logs, in Beck, A.E., Garven, G., and Stegena, editors, Hydrological regimes and their subsurface thermal effects: American Geophysical Union Geophysical Monograph 47, p. 129-135.

Dunlap, H.F., and Dorfman, M.H., 1981, Problems and partial solutions of using the SP log to predict water salinity in deep hot wells, in D.G. Bebout and A.L. Bachman, editors, 5th conference on geopressured-geothermal energy, proceedings: Louisiana State University, Baton Rouge, p. 189-192. Also published in 1981, Geothermal Resource Council Transactions, v. 5, October, p. 283-286.

Ehring, T.W., Lusk, L.A., Grubb, J.M., Johnson, R.B., DeBries, M.R., and Fertl, W.H., 1978, Formation evaluation concepts for geothermal reservoirs, paper FF, in 19th annual logging symposium transactions: Society of Professional Well Log Analysts, 14 p.

Ershaghi, I., and Abdassah, D., 1983, Interpretation of some wireline logs in geothermal fields of the Imperial Valley, California, SPE-11745, in California regional meeting [Ventura), proceedings: Society of Petroleum Engineers, p. 727-736.

Ershaghi, I., Dougherty, E.L., Herzberg, D., and Ucok, H., 1981, Permeability determination in liquid dominated geothermal reservoirs using the Dual Induction Laterolog, in I. Ershaghi, E.E. Dougherty, L.L. Handy, editors, Formation evaluation in liquid dominated geothermal reservoirs: U.S. Department of Energy Report No. DOE/ET/28384-T1, p. 41-59.

Ershaghi, I., Dougherty, E.L., Ucok, H., and Ghassemi, F., 1981, Problems in estimation of salinity profile in liquid dominated geothermal systems, in I. Ershaghi, E.E. Dougherty, L.L. Handy, editors, Formation evaluation in liquid dominated geothermal reservoirs: U.S. Department of Energy Report No. DOE/ET/28384-T1, p. 36-38.

Ershaghi, I., Ghaemian, S., and Abdassah, D., 1981, Lithology and hydrothermal alteration determination from well logs for the Cerro Prieto wells, Mexico: Los Alamos National Laboratory Report No. LA-9075-MS, 28 p. Reprinted in 1982, in Geothermal log interpretation handbook: Society of Professional Well Log Analysts, p. III-75-III-106.

Ershaghi, I., Ghaemian, U., and Mathews, M., 1980, Detection of hydrothermal alteration in a sedimentary type geothermal system using well logs, SPE-9499: Society of Petroleum Engineers, 55th annual meeting [Dallas] preprint, 11 p.

Ershaghi, I., Phillips, L.B., Dougherty, E.L., and Handy, L.L., 1979, Application of oil-field well log interpretation techniques to the Cerro Prieto Geothermal Field: Los Alamos Scientific Laboratory Report No. LA-8130-MS, 142 p.

Fertl, W.H., 1980, Geophysical well logs applied to geothermal resource evaluation, in P.F. Burollet and V. Ziegler, editors, Energy resources, colloqium C2, 26th international geological congress: Editions Technip, Paris, p. 461-468.

Fertl, W.H., Miller, J.E., and Wilson, B.F., 1985, Well logging technology for vapor-dominated (Geysers) resource evaluaton: Geothermal Resources Council Transactions, v. (, part 2, p. 457-462.

Fertl, W.H., and Overton, H., 1982, Formation evaluation, chapter 8, in L.M. Edwards, G.V. Chilingar, H.H. Rieke, III, W.H. Fertl, editors, Handbook of geothermal energy: Gulf Publishing Company, Houston, p. 326-425.

Fialka, B.N., Pyszka, M.H., and Chhina, H.S., 1990, The evaluation of temperature logging in thermal application, SPE-20084, in SPE California regional meeting, proceedings: Society of Petroleum Engineers, p. 571-580.

Galbraith, R.M., 1978, Geological and geophysical analysis of Coso geothermal exploration hole no. 1 (CGEH-1), Coso Hot Springs KGRA, California: Department of Energy, Division of Geothermal Energy, Report IDO-1701-2 [Prepared by the Earth Science Laboratory, University of Utah Research Institute], 42 p.

Genter, A., Cautru, J-P., Montaggioni, P., and Traineau, H., 1989, Geological interpretaton of well logging data from the granitic section of the Soultz-sous-Forets well GPK1, paper EE, in 12th international formation evaluation symposium transactions: Society of Professional Well Log Analysts, Paris Chapter (SAID), 12 p.

Glenn, W.E., and Ross, H.P., 1982, A study of well logs from Cove Fort-Sulpurdale KGRA, Millard and Beaver Counties, Utah: Earth Science Laboratory Division, University of Utah Research Institute, Report No. 75, 51 p.

Glenn, W.E., Ross, H.P., and Atwood, J.W., 1980, Review of well logging in the Basin and Range known geothermal resource areas, SPE-9496: Society of Petroleum Engineers, 55th annual meeting [Dallas] preprint. Later published in 1982, Journal of Petroleum Technology, v. 34(5), p. 1104-1118. Reprinted in 1982, in Geothermal log interpretation handbook: Society of Professional Well Log Analysts, p. VII-121-VII-135.

Gregory, A.R., and Backus, M.M., 1980, Geopressured formation parameters, geothermal well, Brazoria County, Texas, in M.H. Dorfman and W.L. Fisher, editors, 4th U.S. Gulf Coast geopressured-geothermal energy conference, proceedings, volume 1: Center for Energy Studies, University of Texas, Austin, p. 235-311.

Haenel, R., Pearson, R.A., and Pine, R.J., 1987, Borehole measurements in the field of hot dry rock experiments [1st EEC/US workshop on geothermal hot dry rock technology, Brussels, May 28-30, 1986, proceedings]: Geothermics, v. 16(4), p. 433-439.

Halfman, S.E., Lippman, M.J., and Gilreath, J.A., 1984, Cerro Prieto case history--Use of wireline logs to characterize a geothermal reservoir, SPE-12739, in 1984 SPE California regional meeting, proceedings: Society of Petroleum Engineers, p. 113-122.

Halfman, S.E., Lippman, M.J., Zelwer, R., and Howard, J.H., 1984, Geologic interpretation of geothermal fluid movement in Cerro Prieto Field, Baja California, Mexico: AAPG Bulletin, v. 68(1), p. 18-30.

Hill, D.G., 1985, Maximizing geothermal exploration drilling information with wire-line geophysical logs: Bulletin Geothermal Resources Council, v. 14(3), p. 19-22.

Hirakawa, S., and Yamaguchi, S., 1982, Geothermal well logging and its interpretation, in P. Kruger, H.J. Ramey and others, editors, 7th DOE geothermal reservoir engineering workshop [Stanford, California], proceedings: U.S. Department of Energy Report CONF-811201, p. 115-119.

Hsiang-Huan, L., 1987, Porosity and hydrothermal alteration determined from wireline logs from the Salton Sea: University of California Riverside, unpublished MS thesis, 168 p.

Hyndman, R.D., Langseth, M.G., and Von Herzen, R.P., 1984, A review of Deep Sea Drilling Project geothermal measurements through leg 71, in Initial reports of the Deep Sea Drilling Project, v. 78A: U.S. Government Printing Office, p. 813-837.

Itoh, T., 1983, High-temperature well logging techniques in Japan, in S.T. Watson, editor, 3rd circum-Pacific energy and mineral resources conference [Honolulu, August 22-28, 1982], transactions: American Association of Petroleum Geologists, p. 407-413.

Jones, F.W., Lam, H.L., and Majorowicz, J.A., 1985, Temperature distributions at the Paleozoic and Precambrian surfaces and their implications for geothermal energy recovery in Alberta: Canadian Journal of Earth Science, v. 22, p. 1774-1780.

Jones, P.H., 1977, Geopressured geothermal energy in the south-central United States--Frontier areas and exploration techniques, chapter 11, in M.D. Campbell, editor, Geology of alternate energy resources in the south-central United States: Houston Geological Society, p. 215-250.

Kehle, R.O., Schoeppel, R.J., and Deford, R.K., 1970, The AAPG geothermal survey of North America [U.N. symposium on the development and utilitization of geothermal resources (Pisa, Italy)]: Geothermics, special issue no. 2, part 1, p. 358-367.

Keys, W.S., 1980, The application of the acoustic televiewer to the characterization of hydraulic fractures in geothermal wells, in Raft River well stimulation experiments, geothermal reservoir well stimulation program: U.S. Department of Energy Report DOE/AL/10563-T7, p. A1-A11.

Keys, W.S., 1982, Location and character of fractures in geothermal wells, in Fractures in geothermal reservoirs: Geothermal Resources Council, Special Report No. 12, p. 17-27.

Keys, W.S., 1982, Borehole geophysics in geothermal exploration, in A.A. Fitch, editor, Developments in geophysical exploration methods--3: Applied Science Publishers, London, p. 239-268.

Keys, W.S., and Sullivan, J.K., 1979, Role of geophysics in defining physical characteristics of the Raft River geothermal reservoir, Idaho: Geophysics, v. 44(6), p. 1116-1141.

Littleton, R.T., and Burnett, E.E., 1976, The salinity profile of the East Mesa Field as determined from dual induction resistivity and SP logs, in 1st EPA workshop on sampling geothermal effluents, proceedings: U.S. Environmental Protection Agency Report No. EPA-600/9-76-011, p. 114-125.

Lyons, D.J., and van de Kamp, P.C., 1980, Subsurface geological and geophysical study of the Cerro Prieto Geothermal Field, Baja California, Mexico: Lawrence Berkeley Laboratory Report No. LBL-10540, 95 p.

Masse, P.J., Gosney, T.C., and Long, D.L., 1990, The use of pulsed neutron capture logs to identify steam breakthrough--case study; South Belridge middle expansion steamflood project, SPE/DOE-20252, in SPE/DOE symposium on enhanced oil recovery, proceedings: Society of Petroleum Engineers, p. 773-784.

McDowell, S.D., 1987, Geothermal alteration of sediments in the Salton Sea scientific drill hole--Petrophysical properties and mass changes during alteration: U.S. Department of Energy Report No. DOE/ER/13409-1, 62 p.

McNitt, J.R., Sanyal, S.K., and Peterson, C.A., 1981, Synergistic interpretation of formation characteristics of a low temperature geothermal well in Susanville, California: Geothermal Resources Council Transactions, v. 5, p. 303-306.

Morgan, F.D., Williams, E.R., and Madden, T.R., 1989, Streaming potential properties of Westerly Granite with applications: Journal of Geophysical Research, v. 94B(9), September 10, p. 12,449-12,461.

Muramoto, F.S., and Elders, W.A., 1984, Identification of zones of progressive hydrothermal metamorphism from wireline logs and their correlation to reservoir temperatures in the Salton Sea and Westmorland geothermal systems, Imperial Valley, California, in C.A. Rigsby, editor, The Imperial basin tectonics, sedimentation, and thermal aspects: Pacific Section Society of Economic Paleontologists and Mineralogists, p. 87-95.

Musgrave, J.A., Goff, F., Shevenell, L., and others, 1989, Selected data from continental scientific drilling core holes VC-1 and VC-2a, Valles caldera, New Mexico: Los Alamos National Laboratory Report LA-11496-OBES, 71 p.

Noble, J.E., and Abril G.A., 1979, Analysis of Cerro Prieto well logs--Some results and problems: Geothermics, v. 8, p. 191-200.

Paillet, F.L., editor, 1986, Preliminary report on geophysical well-logging activity on the Salton Sea scientific drilling project, Imperial Valley, California: U.S. Geological Survey Open-File Report 86-544, 99 p.

Paillet, F. L., and Morin, R. H., 1988, Analysis of geophysical well logs obtained in the State 2-14 borehole, Salton Sea geothermal area, California: Journal of Geophysical Research, v. 93(B11), November, 10, p. 12,981-12,994.

Quinn, T.H., Hashimoto, N., Suzuki, M., and Takagi, S., 1989, Mineralogy evaluation in a geothermal well using statistical probabilistic log evaluation techniques: Geothermal Resources Council Transactions, v. 13, p. 277-287.

Rigby, F.A., 1980, Fracture identification in an igneous geothermal reservoir, Surprise Valley, California, paper Z, in 21st annual logging symposium transactions: Society of Professional Well Log Analysts, 9 p. Reprinted 1982, in Geothermal log interpretation handbook: Society of Professional Well Log Analysts, p. VII-111-VII-119.

Rigby, F.A., 1981, Applications of geothermal well log data for evaluation of reservoir potential: Los Alamos Scientific Laboratory Report LA-8778-MS, 69 p. Reprinted 1982, in Geothermal log interpretation handbook: Society of Professional Well Log Analysts, p. III-3-III-73.

Rigby, F., and McEuen, R.B., 1980, An example of resistivity log extrapolation with magnetoteulluric data for a geothermal site, SPE-9497: Society of Petroleum Engineers, 55nd annual meeting [Dallas] preprint. Later published in 1982, Journal of Petroleum Technology, v. 34(11), p. 2683-2688.

Rigby, F.A., and Zebal, G.P., 1981, Case history on geothermal well log interpretation Surprise Valley, California: Los Alamos Scientific Laboratory Report no. LA-8598-MS, 58 p.

Ross, E.W., Vagelatos, N., Dickerson, J.M., and Nguyen, V., 1982, Nuclear logging and geothermal log interpretation--Formation temperature sonde evaluation: Los Alamos National Laboratory Report No. LA-9159-MS, 56 p. Reprinted 1982, in Geothermal log interpretation handbook: Society of Professional Well Log Analysts, p. V-3-V-60.

Rudman, A.J., 1978, Analysis of geophysical logs from the Hawaii geothermal project well: Hawaii Institute of Geophysics, Geothermal Resources Exploration in Hawaii No. 6, 26 p.

Ryley, D.J., 1980, Well logging, in R. DiPippo, H.E. Khalifa, D.J. Ryley, editors, Sourcebook on the production of electricity from geothermal energy: U.S. Department of Energy Report DOE/RA/4051-1, p. 155-172.

Sanyal, S.K., 1981, Estimation of steam saturation and rock alteration from geothermal well logs--A theoretical inquiry: Geothermal Resources Council, Transactions, v. 5, p. 373-376.

Sanyal, S.K., and Jusbasche, J.M., 1979, Calculation of geothermal water salinity from well logs--A statistical approach: Geothermal Resources Council Transactions, v. 3, September, p. 613-616.

Sanyal, S.K., Che, M., Dunlap, R.E., and Twichell, M.K., 1982, Theoretical nuclear log responses of the components of the Geysers geothermal reservoir, California: Geothermal Resources Council Transactions, v. 6, p. 165-168.

Sanyal, S.K., Che, M., Dunlap, R.E., and Twichell, M.K., 1982, Qualitative patterns on geophysical well logs from the Geysers, California: Geothermal Resources Council Transactions, v. 6, p. 313-316.

Sanyal, S.K., Juprasert, S., and Jusbasche, M., 1979, An evaluation of a rhyolite-basalt-volcanic ash sequence from well logs, paper TT, in 20th annual logging symposium transactions: Society of Professional Well Log Analysts, 14 p. Later published in 1980, The Log Analyst, v. 20(1), January-February, p. 3-9. Reprinted 1982, in Geothermal log interpretation handbook: Society of Professional Well Log Analysts, p. III-169-III-175.

Sanyal, S.K., Wells, L.E., and Bickham, R.E., 1980, Geothermal well log interpretation state of the art--Final report: Los Alamos Scientific Laboratory Report LA-8211-MS, 330 p.

Sanyal, S.K., Wells, L.E., and Mathews, M., 1979, Classification of geothermal reservoirs from the viewpoint of log analysis, in 20th annual logging symposium transactions, paper HH: Society of Professional Well Log Analysts, 20 p. Reprinted 1982, in Geothermal log interpretation handbook: Society of Professional Well Log Analysts, p. II-3-II-22.

Sarmiento, Z.F., and Aquino, B.G., 1985, Lithologic and fracture response to geophysical logs in the andesite, metamorphic and diorite intrusive rocks in two geothermal wells in the Phillipines: Geothermal Resources Council Transactions, v. 9, part 2, p. 475-480.

Seamount, D.T., Jr., and Elders, W.A., 1982, Use of wireline logs at Cerro Prieto in the identification of the distribution of hydrothermally altered zones and dike locations and their correlation with reservoir temperatures, in 3rd symposium on the Cerro Prieto Geothermal Field, Baja California, Mexico, [1981], proceedings: Lawrence Berkeley Laboratory Report No. LBL-11967 (DOE Report CONF-810399), p. 123-133.

Sethi, D.K., and Fertl, W.H., 1980, Geophysical well logging operations and log analysis in geothermal well Desert Peak no. B-23-1: Los Alamos National Laboratory Report LA-8254-MS, 69 p.

Silva, P., and Bassiouni, Z, 1981, Accurate determination of geopressured aquifer salinity from the SP log, in D.G. Bebout and A.L. Bachman, editors, 5th conference on geopressured-geothermal energy, proceedings: Louisiana State University, p. 193-196. Also published in 1981, Geothermal Resources Council Transactions, v. 5, p. 737-740.

Society of Professional Well Log Analysts, 1982, Geothermal log interpretation handbook: Society of Professional Well Log Analysts, Reprint Volume, variously paginated. [Contains reprints of 17 significant papers and an extensive bibliography.]

Stefansson, V., and Steingrimsson, B., 1980, Geothermal logging, part I--An introduction to techniques and interpretation: National Research Council of Iceland, Reykjavik, Scientific and Technical Information Service, Report OS80017/JHD09, 117 p.

Stefansson, V., Gudmundsson, A., and Emmerman, R., 1982, Gamma ray logging in Icelandic rocks: The Log Analyst, v. 23(6), November-December, p. 11-16.

Syms, M.C., Syms, P.H., and Bixley, P.F., 1982, Interpretation of flow measurements in geothermal wells without caliper data: The Log Analyst, v. 23(2), March-April, p. 34-45.

Ucok, H., 1981, A laboratory study of the effect of temperature gradient on the development of spontaneous-potential in geothermal wellbore, paper K, in 22nd annual logging symposium transactions: Society of Professional Well Log Analysts, 16 p.

Urban, T.C., and Diment, W.H., 1982, An interpretation of precision temperature logs in a deep geothermal well near Desert Peak, Churchill County, Nevada: Geothermal Resources Council Transactions v. 6, p. 317-321.

Verbovsek, R., 1985, Determination of fractured zones by well logging in low transmissivity geothermal reservoirs in Kochani Valley, Macedonia, Yugoslavia: Geothermal Resources Council Transactions, v. 9, part 2, p. 481-484.

Vernik, L., 1989, Effects of hydrothermal zeolitization on reservoir properties and fluid flow in crystalline rock, paper C, in 3rd international symposium on borehole geophysics for minerals, geotechnical, and groundwater applicatons, proceedings: Society of Professional Well Log Analysts, Minerals and Geotechnical Logging Society, Chapter-at-Large, p. 15-28.

Wright, P.M., Ward, S.H., Ross, H.P., and West, R.C., 1985, State of the art geophysical exploration for geothermal resources: Geophysics, v. 50(12), p. 2666-2696.