ODP

Logging Manual

4/2004

Welcome to the

ODP Logging Manual

- How to use this manual
- What is downhole logging?

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Welcome to Version 2.0 of the ODP Logging Services Electronic Manual.

There are several ways to navigate through this manual. Clicking on the Home page will take you to a Table of Contents organized along rough chronological lines. Four main groups of issues are presented; Pre-cruise Planning, Data Acquisition & Shipboard Operations, Data Processing & Analysis, and Data Presentation & Post-Cruise Activities. In addition, a separate Index of Toolstrings and Tools is provided on this page.

A navigation banner containing a link to the Home page is provided at the top of most of the pages in this manual. Also in this banner are links to the Acronyms page, a Glossary of Logging Terms page and an Index of Topics page. The latter is particularly useful when you are seeking information about a specific topic but may not be sure where to find it in the chronological menu.

Version 2 of this manual includes several significant enhancements that were not available in the previous version. Among these is a summary chart, accessible from the Tool Selection page, that lists all of the available logging tools and their principal scientific applications. The Data Processing & Analysis section has been augmented, and contains updated sections on FMS and GHMT processing. New information on integration of log data with other data types, such as core information and seismic profiles, is now included. The Glossary has also been significantly expanded.

We are always interested in your feedback, as our goal is to make this document as helpful as possible to site proponents, shipboard and shore-based scientists, and JOIDES panel members. Please feel free to contact us anytime with comments, suggestions or questions.

- ODP Logging Services

ODP Logging Manual

Pre-Cruise Planning
Data Acquisition & Shipboard Operations
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Data Acquisition & Transfer

The objective of this chapter is to provide a short description of how the loggers collect data onboard the *JOIDES Resolution*. It focuses on the techniques and formats employed to produce proprietary (also called "field") and customer (also called "field edit") tapes and how both data and the information necessary for its processing are transmitted via satellite to ODP Logging Services at the Lamont-Doherty Earth Observatory. For further information about these procedures, contact the following personnel:

Data Handling and Processing

- Cristina Broglia
  Data Services Supervisor
  Tel: (845)-365-8343
  Fax: (845)-365-3182
  chris@ldeo.columbia.edu

- Trevor Williams
  Log Analyst
  Tel: (845)-365-8626
  Fax: (845)-365-3182
  trevor@ldeo.columbia.edu

Satellite Transmission

- James Murray
  Database Assistant
  Tel: (845)-365-8639
  Fax: (845)-365-3182
  jmurray@ldeo.columbia.edu

- Greg Myers
  Technical Operations Manager
  Tel: (845)-365-8772
  Fax: (845)-365-3182
  gmyers@ldeo.columbia.edu

Customer, Proprietary & Backup Tapes

Once the Schlumberger log data have been acquired, they are routinely loaded on DAT tapes.

Three types of DAT tapes are produced onboard:

1. **Proprietary** tapes (also called field tapes);
2. **Customer** tapes (also called field edit tapes); and
3. **Backup** copies of the proprietary tapes.

Proprietary tapes (field tapes) contain the original log data recorded by the Schlumberger engineer, as well as the calibration counts necessary for some onshore processing of the original count rates. The original proprietary data are not depth shifted because: 1) depth shifting can alter the sonic and geochemical waveforms recorded with the other data; and 2) accurate depth shifting is performed on shore.

Customer tapes (field edit tapes) contain the data necessary to perform the processing and preliminary interpretation.

Backup tapes are produced for each leg and kept on the ship for a maximum of six months. The Logging Staff Scientist makes sure that the backup copy/copies of the proprietary data are safely stored onboard, in case the tapes brought onshore get lost or damaged during transport to LDEO-BRG. Every six months, these backup tapes are brought back or sent to LDEO-BRG to be included in the permanent archive.

Satellite Data Transmission

Digital log data are routinely transmitted via satellite to LDEO-BRG after the completion of logging operations at each hole. This allows log analysts at the LDEO-BRG Log Analysis Center to perform routine processing of the conventional logs and transmit the data back to the ship in ASCII format along with documentation of the processing performed. It currently takes 2-5 days (depending on the complexity of the processing) to perform the initial processing of a hole logged with a full suite of logs; complete FMS, GHMT, and geochemical data processing are performed at a later date.

Shipboard Data Availability & Utility

Logging data are made available to the entire scientific shipboard party immediately after the acquisition and preliminary processing are completed. The digital data are placed on the centralized data disk, called UserVol, and paper copies are available for the Core Lab and Science Lounge.

The resistivity, gamma-ray, magnetic susceptibility, and density logs are useful to sedimentologists and petrologists for reconstruction of gaps in the lithostratigraphy (especially in cases of poor core recovery), compiling a complete stratigraphic sequence in the area of interest, and determining the thickness of individual units.

The FMS and BHTV images allow structural geologists to orient the structural features observed in the cores and relate these features to the current principal stresses associated with the present tectonic environment.

The DSI-2, VSP, porosity, and density logs allow geophysical properties specialists to correlate core and log results with seismic properties and improve the interpretations of regional and local seismic data.

The GHMT logs provide paleomagnetists with the capabilities of producing continuous magnetostratigraphic and polarity inversion records.

All data except FMS images are usually made available to the scientific party within 48 hours of acquisition. They are stored as ASCII files -- usually one file per logging run --and can be opened by any spreadsheet application (such as Synergy Software's KaleidaGraph or Microsoft Excel). Before placing the data on the Uservol server, the Logging Staff Scientist converts the depths to meters below sea floor (mbsf) and uses the gamma ray curves to perform a preliminary depth matching between successive runs. More accurate depth correction is available with the return of the processed data about a week later. For more information, see the section on data processing.

FMS images are now also made available on the Uservol server in the form of GIF images produced by the Logging Scientist after preliminary processing with GeoFrame. These images, usually produced at several different scales to maximize their utility, can be opened in any graphic application (such as Adobe Photoshop) or browser. Because the interpretation of FMS images is greatly enhanced by the ability to identify and characterize structural features with Geoframe, shipboard scientists are encouraged to familiarize themselves with this software package in order to be able to perform their own interpretation and correlation on the Downhole Measurements Lab workstation – provided they don't interfere with the critical work of the logging scientists, of course.

Schlumberger Log Plots (Playbacks)

Schlumberger prints out detailed, expanded-scale log plots for use by shipboard scientists. These images complement the regular page-scale plots commonly used to define broad trends and general log units. The fine scale resolution of the larger plots aids in detailed stratigraphic correlation with the core. Schlumberger plots are particularly valuable to the shipboard sedimentologists, stratigraphers, and physical properties specialists who use them to help reconstruct the complete stratigraphic sequence of the cored material and estimate how much, and what type, of material is missing from the recovered section. For example, cyclic sequences with periodic or fining upward lithologies that are difficult to recover completely with coring can be well defined by the addition of the detailed log information. In addition, when a number of sites are logged in a given region, these plots are useful for inter-site correlation and can be used to map the lateral continuity of individual beds and units.

The Schlumberger log plots are produced by the Schlumberger engineer after completion of logging operations. Each playback consists of three parts: **Header**, **Logs** and **Trailer**.

1. Header:
The header includes information such as the hole location (latitude and longitude), water depth, the interval drilled and logged, type of drilling fluid, etc., which are all used later during processing.

The new Minimum Configuration MAXIS presentation also includes a sketch of the tool string, along with the position, from the bottom of the string, of the different sensors.

2. Logs:
This is a display vs. depth of the main curves recorded. The Logging Staff Scientist can follow every step of the recording on the screen of the MCM unit and thus has the option of choosing the best type of display. Should she decide to change the type of display, the data can be played back on the screen at the end of logging operations before producing final blueprints.

Logs are usually displayed with depth referred to the rig floor (mbrf).

3. Trailer:
The bottom portion of the blueprints includes the after and before-survey calibration summary as well as the shop calibration, a list of the sensor measure points for each tool, and a list of logging parameters.

Data Acquisition | Logging Operations | Stuck/Lost Tool Policy | Shipboard Reports

Logging Operations

When the total depth of a hole scheduled for logging has been reached, a series of activities is initiated to prepare the hole and rig floor for the logging operation. The borehole is conditioned by pumping a viscous mud into the hole to flush remnant cuttings from the borehole, running the bit up and down to break through any bridges or swelling clays and finally filling the hole with a drilling mud such as sepiolite to stabilize the hole. Based on data collected from the capillary suction test (CST), the hole may be filled with fluids containing potassium chloride to inhibit the swelling of re-hydrated clays. The next step is determined by the type of bottom hole assembly (BHA) used. If the APC/XCB BHA and core barrel assembly is deployed, logging can commence directly through the bit with the use of a go-devil and the lockable flapper valve (LFV). If the RCB BHA and core barrel are deployed, the drill bit must be removed using one of three methods listed below:

1. The drill bit may be dropped at the bottom of the hole (if hole deepening will not occur)
2. The drill bit may be dropped at the seafloor but a reentry cone or Free Fall Funnel (FFF) is required to reenter the hole
3. A pipe trip may be used to remove the bit at the rig floor and the hole reentered assuming a reentry cone or FFF is deployed.

Next, the base of drill pipe is placed at a depth of 50 - 80m below the sea floor to provide confining pressure to the upper regions of the hole and to prevent the pipe from pulling out of the hole. Once the pipe is set, the rig floor is converted from drilling operations to logging operations.

To prepare the rig floor for logging, the top drive is pushed back and the wireline is threaded through the derrick, winch and wireline heave compensator (WHC). The first logging string, typically the Triple Combo, is now prepared for rig up. The tools are assembled from the bottom up; therefore the DIT-E is rigged up first, then the Lamont TAP tool is attached to the bottom of the DIT-E. These two tools are placed in the pipe and successive tools are added to the top. After the tool string is assembled, the cablehead is attached and the tool zero point is established by pulling the bottom of the DIT-E to the level of the rig floor. The tool string is then lowered, the fluid seal is fastened and the tool is run into the hole. The tool descent speed is typically 10,000 ft/hr. Once the sea floor is reached, the tool string is held stationary for 2-3 minutes to allow the TAP tool to equilibrate. The tool is run down to the bottom of the hole and then pulled up at a constant rate to complete the first pass. A second pass can be completed if desired. As the first toolstring is being pulled back to the surface, the Schlumberger engineer may slow the ascent speed as the tool string crosses the mud line to measure the depth of the sea floor accurately.

The first toolstring is rigged down and the TAP tool is cleaned by the logger and returned to the Downhole Measurements Lab for the retrieval of the data. The next toolstring (typically the FMS/Sonic) is then prepared. The same logging procedure is followed for running the FMS/Sonic toolstring. The third toolstring deployed may be a specialty tool such as the GHMT, WST or other.

During the logging process, the Logging Staff Scientist is involved in many steps including:

1. Taking detailed operations notes on the Logging Event forms and including all listed depths and times.
2. Discussing toolstring configurations with the Schlumberger Engineer.
3. Initializing the Lamont TAP tool and operating the data acquisition system.
4. Connecting the TAP tool to the bottom of the DIT-E.
5. Disconnecting, cleaning and downloading the data from the TAP tool.
6. Remaining with the Schlumberger engineer to monitor tool progress and to inspect the data in real-time.

Introduction

Stuck and lost tools are a normal occupational hazard of logging. In spite of our best efforts to avoid tool loss, Schlumberger strings have been lost on Legs 101, 113, 117, 122, and 175. These strings are expensive and therefore are insured against loss in a hole; however, the shipboard loggers obviously try their best to avoid sticking a tool, to recover a stuck tool, and to fish for a lost tool.

If a tool is lost downhole, a reasonable effort must be made to recover it in order to satisfy obligations to Schlumberger and the insurance provider. The recovery effort should follow accepted practices and include multiple recovery attempts if technically feasible. The shorebased ODP Logging Services representative must be notified of the stuck or lost tool situation by the Logging Staff Scientist or the drilling superintendent.

If all reasonable efforts have been made to recover a stuck or lost tool without success, then the decision to abandon the tool must be made collectively by the Logging Staff Scientist, Operations Superintendent, Rig Superintendent and the Schlumberger engineer. A report must be filed by the Operations Superintendent and delivered to the Logging Staff Scientist. In the event of loss involving a radioactive source, the tool and hole must be abandoned with cement to safely entomb the sources.

There are four main types of tool "sticking" situations:

1. The tool is either stuck in a bridge or stuck by cavings (possibly beneath a bridge).
2. The tool is not stuck but cannot be pulled up past a bridge.
3. The tool is stuck in the base of pipe.
4. The tool is not stuck but cannot get into pipe.

Strategies

There are several available strategies for dealing with stuck tools:

1. Pulling harder on the cable

Pulling harder on the cable is recommended as the first course of action when a tool appears to be stuck. Pulling may not exceed the combined cable weight plus weak point strength, or 50% of cable strength, whichever is less. With this method, situations #2 and #4 have a higher chance of recovery than #1 and #3.

2. Adding pipe (if using the CSES)

If the CSES is in the tool string, stands of pipe may be added to break through a bridge or cuttings (situations #1 and #2). Cable tension should be maintained when lowering pipe to prevent: (A) cutting through or kinking a slack cable with the pipe; or (B) sudden dropping of the tool when the tool is freed (a l0'-30' free fall of the tool may be enough to snap the weak point). Once the tool is free, you can pull it well into pipe, raise pipe, and go back down to resume logging.

3. Cutting and stripping

Cutting and stripping involves clamping the cable at the drill floor, cutting it, then either adding or removing a stand of pipe. For every 30m of pipe added or removed, the cable must be threaded in or out of the pipe and re-clamped. For sticking types #1 or #2, one would add pipe to break through the bridge. For sticking types #3 and #4, one would remove pipe, eventually pulling the tool on deck with the bottom hole assembly. One disadvantage of cutting and stripping is that all of the cut cable will be discarded (perhaps 1000-3000m) and this may not leave enough cable on the spool for subsequent logging. The Logging Staff Scientist is responsible for making this determination. Cutting and stripping is also not the most favorable alternative because it is time consuming. Cutting and stripping is not needed for situations #1 and #2 if the CSES is in the string, but a modified type of cutting and stripping may be possible with situations #3 and #4 with the CSES.

4. Using the Kinley crimper/cutter

The Kinley crimper and cutter system greatly increases the safety of downhole tool recovery operations. The crimper/cutter procedure is

extremely sequence sensitive. The crimper slides down the wireline and stops about 10m above the base of the bottom hole assembly (BHA), then a hammer is sent down to fire the crimper which crimps the logging cable against the BHA. A successful crimp **must** be observed by the Schlumberger engineer by checking for an electrical short inside the cable. If successful, the cutter is dropped and the cut logging cable is reeled in. The tool is held inside the BHA and recovered by pulling pipe to the rig floor. Crimping and cutting works well for situation #4 but is no guarantee of success. During Leg 175, the Kinley crimper was used to secure the tool in the pipe but it failed to adequately crimp the cable. As the tool and drill pipe were being pulled to the surface, the toolstring dislodged itself and fell to the seafloor where it could not be retrieved.

5. Additional strategies

In 1988, Glen Foss (Operations Superintendent at ODP/TAMU), put together a detailed memo on wireline stripping operations. This is **highly recommended reading**. The part relevant to recovery of stuck tools is given here.

In addition, ODP Logging Services has compiled a list of very dangerous situations to avoid when logging, along with strategies to avoid and cope with them.

To some degree, each stuck/lost tool situation is unique, and it is impossible for any guidelines we give to always be appropriate. Thus, the recommendations given in the following table should be considered as suggestions only, not requirements:

CSES					
PROBLEM	**SOLUTIONS**				**COMMENTS**
	add pipe	cut & strip	crimp & cut	pull cable to failure	
#1. Stuck in bridge and cuttings	YES	--	--	--	--

#2. Cannot pull past bridge	YES	--	--	--	--
#3. Stuck in base of pipe	--	YES[a]	YES[b,f]	YES[e]	d
#4. Cannot get into pipe	--	YES[a]	YES[b]	--	c

NO CSES					
PROBLEM	SOLUTIONS				COMMENTS
	add pipe	cut & strip	crimp & cut	pull cable to failure	
#1. Stuck in bridge and cuttings	--	YES	NO	--	--
#2. Cannot pull past bridge	--	YES	YES	--	--
#3. Stuck in base of pipe	--	YES	YES[f]	YES[e]	d
#4. Cannot get into pipe	--	YES	YES	--	c

a - if a feasible technique can be worked out

b - after pulling the CSES on deck, and detaching it from the drill string

c - first figure out what is hanging up, circulate while trying (especially with lockable flapper), rotate the drillstring half a turn, and keep trying to pull out (a centralizer or bow spring can sometimes be snapped deliberately by repeated trials)

d - first try circulating to free the tool, with a slightly slack cable

e - a last resort if cutting and stripping is rejected; hopefully the tool will break free before failure or, if not, be so well stuck that it will be pulled up with the BHA

f - if the tool is too far into the pipe, the crimper will not be able to seat

Shipboard Reports

1. Logging Chapter (Initial Reports)

The scientific results of the cruise are initially presented in the Initial Reports (IR) volume, which is organized by site. The Logging Staff Scientist is responsible for presenting the results of any downhole measurements made during the leg. Any site for which logging operations are conducted requires a chapter on downhole measurements. In this section the Logging Scientist will:

1. Present the operational details for the site. If more than one toolstring is run, then the operations will be summarized in a table organized by toolstring with the following information: start and stop time, logging speed, pipe depth, mudline measured depth, interval logged for each pass, and the tools on the string. The text will also contain general information about the site, such as total penetration, core recovery, muds that were circulated etc. Finally, the conditions of the hole during logging will be discussed, as well as any obstacles or difficulties encountered which affect data quality.
2. Present the results of the logging. This section is usually similar to the data results of a paper in which log data are presented (in plot form) and the pertinent features described. The presentation of results will be tailored to the science of the leg and integrated as much as possible with the results from other groups (physical properties, sedimentology, biostratigraphy, magnetics, geochemistry, etc.). Frequently a summary figure containing all of the log curves, caliper curve, stratigraphy, sedimentology, etc., is presented. This is then followed by a breakdown of each of the records describing them in the context of the other data, including plots where necessary.
3. Discuss the detailed comparisons with other data, core-log comparisons, and definitions of stratigraphic intervals. Finally, the results of any analysis or scientific highlights of the logs will be presented. This section may be included in each of the tool results sections if it is not significant enough to merit an independent section.

2. Seismic Stratigraphy Chapter (Initial Reports)

Occasionally, the Logging Staff Scientist will collaborate with other shipboard scientists in producing the seismic stratigraphy chapter of the Initial Reports volume. Seismic sequence analysis is usually outlined in this chapter to describe the structural boundaries between layers of different ages and to provide scientific context for the proper interpretation of drilling and logging results. The seismic profiles included in this chapter are usually collected during pre-cruise site surveys; occasionally, seismic profiles from industry sources are also available. The quality and density of the seismic data are usually a function of the scientific objectives of the drilling leg. For legs on which seismic stratigraphic sequence analysis is most important, multichannel seismic (MCS) data are frequently available; for the others, single-channel seismic (SCS) data are usually the norm. The specifications for the seismic data are usually given in this chapter, including acquisition and processing.

On certain legs -- such as those on which vertical seismic profiling is performed -- the Logging Staff Scientist will be more involved in the collection and interpretation of seismic profiles, and thus will have a more active role in the production of the stratigraphy chapter of the IR volume.

Geological information derived from the stratigraphic sequences is used to define in detail the geological or tectonic setting of the leg, to design the leg operation, and to tie seismic boundaries with core and log depths, both during the leg and post-cruise. Proper use of the results of seismic sequence analyses can help in the integration of core, log and seismic data and can enhance the spatial interpretation of high-resolution profiles of structural, physical, and chemical properties from the core and log data.

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3. Explanatory Notes (Initial Reports)

The purpose of the explanatory notes chapter of the IR volume is to provide the reader with the technical and operational background for the wireline logging operations conducted during the leg. Although there are an infinite number of ways to present this material, a typical downhole logging section of the Explanatory Notes would contain the following sections:

Introduction

This section should introduce the reader to what wireline logging is and how it is conducted (e.g. the in situ measurement of physical, chemical, and structural properties). It is tailored to the science relevant to the leg under discussion and may include general principles of how these measurements can contribute to the scientific goals of the leg. Other points frequently included are:

- The particular advantages of wireline measurements and how they complement the other types of analysis that will be made.
- Past examples of applications and pertinent references.
- Information about who provides the logging services (e.g. ODP Logging Services & Schlumberger) and the role that each plays.

Operations

This section will provide operational details for the reader. Some typical topics are as follows:

- Hole is flushed with fluid.
- Wiper trip is conducted.
- Pipe pulled to logging depth (e.g., 90m).
- Tools assembled and lowered on 7 conductor cable.
- WHC employed.
- Details on data acquisition system and satellite transfer methods.

Because the operations section is site specific, it is possible to cover the general operational techniques in the introduction, specific operational details in the site chapter, and omit this as a separate section.

Logging Tools

This section will introduce the tools and how they were combined during the leg. Usually, figures and tables are employed to present the information more coherently. Typically, a figure of the toolstrings employed on the leg and a table of the tools and their depth of investigation, sample interval, and vertical resolution are presented in this section. In the text, the names of the tools, their acronyms, and the measurements they make are introduced, and the theory behind the measurements may be summarized. This will essentially amount to a paragraph about each tool. If new tools were used or conventional tools employed in an unconventional way, then a more detailed explanation of the tool and the way it makes its measurements will be provided.

Data Quality

Any environmental (borehole conditions, excessive heave etc.) or technical problems encountered on the leg will be discussed here in the context of how they affect data quality.

Data Processing

This section is somewhat optional, but it is usually included, especially if the logging operation employed new tools, new techniques, or data were applied in new ways. The basics of depth shifting and correlation between the passes are briefly presented. Then details of how particular estimates are derived from the data will be given. For example, these may include the onboard generation of a magnetostratigraphy (using the GHMT) or clay typing (using natural gamma ray and photoelectric effect).

The above sections are meant to provide guidelines for the type of information to be conveyed in the Explanatory Notes. As the specific operations and science of each leg is different, it may be beneficial to refer to previous examples of explanatory notes from legs with similar scientific objectives and/or tool deployments (e.g. 162,167,172, 175 for paleoceanography, or 118, 140, 148 or 176 for hard rock environments).

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4. Logging Operations (Preliminary Report)

The preliminary report is meant to supply operational details and highlights of the data which is recovered. Operational details that are usually presented include: BHA depth, tools used and depths logged during each pass, number of passes, problems encountered, highlights of the recovered data and its potential utility (e.g., potential for core-log integration, cyclicity related to climate, good magnetics that allow reversal stratigraphy etc.).

ACRONYMS

- Acronyms for Schlumberger Tools
- Acronyms for Third Party Tools
- Acronyms and Units used for Schlumberger Logs
- Additional Acronyms and Units

ACRONYMS FOR SCHLUMBERGER TOOLS	
ACT	Aluminum Clay Tool
APS	Accelerator Porosity Sonde
ARI	Azimuthal Resistivity Imager
ASI	Array Seismic Imager
BHC	Borehole Compensated Sonic Tool
CNT	Compensated Neutron Tool
CALI	Caliper
CA_	Caliper
C_	Caliper
DIT	Dual Induction Tool
DLL	Dual Laterolog
DSI-2	Dipole Sonic Imager
FMS	Formation µscanner
GHMT	Geological Magnetic Tool
GLT	Geochemical Tool
GPIT	General Purpose Inclinometer Tool
GR	Natural Gamma Ray
GST	Induced Gamma Ray Spectrometry Tool
HLDS	Hostile Environment Lithodensity Sonde

HNGS	Hostile Environment Gamma Ray Sonde
LDT	Lithodensity Tool
LSS	Long Spacing Sonic Tool
LWD-ADN	Logging While Drilling - Azimuthal Density Neutron Tool
LWD-CDN	Logging While Drilling - Compensated Density Neutron Tool
LWD-CDR	Logging While Drilling - Compensated Dual Resistivity Tool
LWD-RAB	Logging While Drilling - Resistivity-at-the-Bit Tool
MCD	Mechanical Caliper Tool
M_	Miscellaneous
NGT	Natural Gamma Ray Spectrometry Tool
N_	Natural Gamma Ray Spectrometry Tool
SDT	Digital Sonic Tool
S_	Digital Sonic Tool
SP	Spontaneous Potential
UBI	Ultrasonic Borehole Imager
WST	Well Seismic Tool
WST-3 component	Well Seismic Tool-3 Component

ACRONYMS FOR THIRD PARTY TOOLS	
BHTV	Borehole Televiewer
MCS	Multichannel Sonic Tool
SST	Shear Sonic Tool
TAP	High Resolution Temperature/Acceleration/Pressure Tool
TLT	Temperature Logging Tool

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ACRONYMS AND UNITS USED FOR SCHLUMBERGER LOGS	
AFEC	APS Far Detector Count Rate (cps)
APLC	APS Near/Array Limestone Porosity Corrected (decimal fraction)
C1	Caliper 1 (in, from FMS)

C2	Caliper 2 (in, from FMS)
CALI	Caliper (in, from HLDT)
CFEC	Corrected Far Epithermal Counts (cps)
CFTC	Corrected Far Thermal Counts (cps)
CGR	Computed (Th+K) Gamma Ray (API units)
CNEC	Corrected Near Epithermal Counts (cps)
CNTC	Corrected Near Thermal Counts (cps)
DEVI	Hole Deviation (degrees)
DIFF	Difference Between MEAN and MEDIAN in Transit Time Proc. (µsec/ft)
DRH	HLDS Bulk Density Correction (g/cm^3)
DRHO	Bulk Density Correction (g/cm^3)
DT	Short Spacing Transit Time (10'-8' spacing; µsec/ft)
DTCO	Compressional Wave Transit Time (µsec/ft)
DTL	Long Spacing Transit Time (12'-10' spacing; µsec/ft)
DTLF	Long Spacing Transit Time (12'-10' spacing; µsec/ft)
DTLN	Short Spacing Transit Time (10'-8' spacing; µsec/ft
DTSM	Shear Wave Transit Time (µsec/ft)
DTST	Stoneley Wave Transit Time (µsec/ft)
ENPH	Epithermal Neutron Porosity (%)
ENRA	Epithermal Neutron Ratio
FINC	Magnetic Field Inclination (degrees)
FNOR	Magnetic Field Total Moment (oersted)
FX	Magnetic Field on X Axis (oersted)
FY	Magnetic Field on Y Axis (oersted)
FZ	Magnetic Field on Z Axis (oersted)
GR	Natural Gamma Ray (API units)
HALC	High Res. Near/Array Limestone Porosity Corrected (decimal fraction)
HAZI	Hole Azimuth (degrees)
HBDZ	High Res. Bulk Density Correction (g/cm^3)
HBHK	HNGS Borehole Potassium (dec. fraction)
HCFT	High Resolution Corrected Far Thermal Counts
HCGR	HNGS Computed Gamma Ray (GAPI)
HCNT	High Resolution Corrected Near Thermal Counts
HD	Hole Diameter (in)
HDEB	High Res. Enhanced Bulk Density (g/cm^3)

HDRH	High Resolution Density Correction (g/cm3)
HFEC	High Res. Far Detector Count Rate (cps)
HFK	HNGS Formation Potassium (dec. fraction)
HFLC	High Res. Near/FarLimestone Porosity Corrected (decimal fraction)
HLCA	High Res. Caliper (in)
HLEF	High Res. Long-spaced Photoelectric Effect (barns/e-)
HNEC	High Res. Near Detector Count Rate (cps)
HNPO	High Resolution Enhanced Thermal Nutron Porosity (%)
HNRH	High Resolution Bulk Density (g/cm3)
HPEF	High Resolution Photoelectric Effect (barns/e-)
HRHO	High Resolution Bulk Density (g/cm3)
HROM	High Res. Corrected Bulk Density (g/cm3)
HSGR	HNGS Standard (total) Gamma Ray (GAPI)
HSIG	High Res. Formation Capture Cross Section (cu)
HSTO	High Res. Computed Standoff
HTHO	HNGS Thorium (ppm)
HTNP	High Resolution Thermal Neutron Porosity (%)
HURA	HNGS Uranium (ppm)
IDPH	Phasor Deep Induction (ohm-m)
IIR	Iron Indicator Ratio [CFE/(CCA+CSI)]
ILD	Deep Resistivity (ohm-m)
ILM	Medium Resistivity (ohm-m)
IMPH	Phasor Medium Induction (ohm-m)
LCAL	HLDS Caliper (in)
LDOC	HLDS Density quality Indicator
LIR	Lithology Indicator Ratio [CSI/(CCA+CSI)]
LLD	Laterolog Deep (ohm-m)
LLS	Laterolog Shallow (ohm-m)
LTT1	Transit Time (10'; µsec)
LTT2	Transit Time (8'; µsec)
LTT3	Transit Time (12'; µsec)
LTT4	Transit Time (10'; µsec)
MAGB	Earth's Magnetic Field (nTes)
MAGC	Earth Conductivity (ppm)
MAGS	Magnetic Susceptibility (ppm)

MEDIAN	Median Transit Time Recomputed (μsec/ft)
MEAN	Mean Transit Time Recomputed (μsec/ft)
NMST	Magnetometer Temperature (°C)
NMSV	Magnetometer Signal Level (V)
NPHI	Neutron Porosity (%)
NRHB	LDS Bulk Density (g/cm^3)
P1AZ	Pad 1 Azimuth (degrees)
PEF	Photoelectric Effect (barns/e-)
PEFL	LDS Long-spaced Photoelectric Effect (barns/e-)
PIR	Porosity Indicator Ratio [CHY/(CCA+CSI)]
POTA	Potassium (wet wt. %)
RB	Pad 1 Relative Bearing (degrees)
RHL	LDS Long-spaced Bulk Density (g/cm^3)
RHOB	Bulk Density (g/cm^3)
RHOM	LDS Corrected Bulk Density (g/cm^3)
RMGS	Low Resolution Susceptibility (ppm)
SFLU	Spherically Focused Log (ohm-m)
SGR	Spectroscopy Gamma Ray (API units)
SIGF	APS Formation Capture Cross Section (cu)
SP	Spontaneous Potential (mv)
STOF	APS Computed Standoff
SURT	Receiver Coil Temperature (°C)
SXRT	NMRS differential Temperature (°C)
THOR	Thorium (ppm)
TNRA	Thermal Neutron Ratio
TT1	Transit Time (10' spacing; μsec)
TT2	Transit Time (8' spacing; μsec)
TT3	Transit Time (12' spacing; μsec)
TT4	Transit Time (10' spacing; μsec)
URAN	Uranium (ppm)
VP1	Compressional Wave Velocity (Short Spacing or Mean Transit Time; km/s)
VP2	Compressional Wave Velocity (Long Spacing or Median Transit Time; km/s)
VPCO	Compressional Wave Velocity (from DTCO; km/s)
VPSH	Shear Wave Velocity (from DTSM; km/s)
VPST	Stonely Wave Velocity (from DTSM; km/s)

#POINTS	Number of Transmitter-Receiver Pairs Used in the Processing

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ADDITIONAL ACRONYMS AND UNITS (PROCESSED LOGS FROM GEOCHEMICAL TOOL STRING)	
AL2O3	Computed Al_2O_3 (dry weight %)
AL2O3MIN	Computed Al_2O_3 standard deviation (dry weight %)
AL2O3MAX	Computed Al_2O_3 standard deviation (dry weight %)
CAO	Computed CaO (dry weight %)
CAOMIN	Computed CaO standard deviation (dry weight %)
CAOMAX	Computed CaO standard deviation (dry weight %)
CA2O3	Computed $CaCO_3$ (dry weight %)
CA2O3MIN	Computed $CaCO_3$ standard deviation (dry weight %)
CA2O3MAX	Computed $CaCO_3$ standard deviation (dry weight %)
CCA	Calcium Yield (decimal fraction)
CCHL	Chlorine Yield (decimal fraction)
CFE	Iron Yield (decimal fraction)
CGD	Gadolinium Yield (decimal fraction)
CHY	Hydrogen Yield (decimal fraction)
CSI	Silicon Yield (decimal fraction)
CSIG	Capture Cross Section (capture units)
CSUL	Sulfur Yield (decimal fraction)
CTB	Background Yield (decimal fraction)
CTI	Titanium Yield (decimal fraction)
FEO*	Computed FeO* (dry weight %)
FEO*MIN	Computed FeO* standard deviation (dry weight %)
FEO*MAX	Computed FeO* standard deviation (dry weight %)
FE2O3	Computed Fe_2O_3 (dry weight %)
FE2O3MIN	Computed Fe_2O_3 standard deviation (dry weight %)
FE2O3MAX	Computed Fe_2O_3 standard deviation (dry weight %)
GD	Gadolinium (dry weight %)
GDMIN	Gadolinium standard deviation (dry weight %)
GDMAX	Gadolinium standard deviation (dry weight %)

K2O	Computed Fe_2O_3 (dry weight %)
K2O	Computed Fe_2O_3 standard deviation (dry weight %)
SIO2	Computed SiO_2 (dry weight %)
SIO2MIN	Computed SiO_2 standard deviation (dry weight %)
SIO2MAX	Computed SiO_2 standard deviation (dry weight %)
THORMIN	Thorium standard deviation (ppm)
THORMAX	Thorium standard deviation (ppm)
TIO2	Computed TiO_2 (dry weight %)
TIO2MIN	Computed TiO_2 standard deviation (dry weight %)
TIO2MAX	Computed TiO_2 standard deviation (dry weight %)
URANMIN	Uranium standard deviation (ppm)
URANMAX	Uranium standard deviation (ppm)
VARCA	Variable $CaCO_3$/CaO calcium carbonate/oxide factor

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GLOSSARY

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A

Acoustic log: A generic term for well logs which display any of several aspects of acoustic-wave propagation. In some acoustic logs (sonic log, continuous velocity log), the travel time of the compressional wave between two points is measured. In others (amplitude log), the amplitude of part of the wave train is measured. Other acoustic logs (character log, three-D log, VDL-log, microseismogram log, signature log) display part of the wave train in wiggle or variable density form. Still others (cement-bond log, fracture log) are characterized by the objective of measurements rather than their form. The borehole televiewer is also an acoustic log.

Acoustic wave: 1) Sonic wave. An elastic wave train, sometimes restricted to propagation through a fluid. 2) The wave train generated and detected by a sonic-logging sonde. The wave train is a composite of various modes of energy transfer. The first arrival usually results from compressional (P- or longitudinal) waves traveling in the formation; the inverse of its velocity is measured by the sonic log. A second arrival is sometimes identified as shear (S-) wave travel in the formation; it represents a pseudo-Rayleigh wave which travels at approximately the velocity of S-waves. Compressional waves traveling through the mud usually have relatively high frequency content; they are sometimes called fluid waves. One or more modes of high-amplitude, low frequency tube waves (sometimes called Stonely waves) are usually very distinct arrivals. 3) More generally, an elastic wave or seismic wave.

Advanced Piston Corer (APC): A coring device used to obtain near-complete core recovery when sediments are very soft (usually the uppermost 100-200 m of section).

API Units: (1) A unit of counting rate for the gamma-ray log. The difference between the high and low radioactivity sections in the API calibration pit is defined as 200 API units. (2) A unit of counting rate for the neutron log. The reading in the Indiana limestone portion of the API neutron log calibration pit which has 19% porosity and is saturated with fresh water is defined as 1000 API units.

Auxiliary Measuring Sonde (AMS): A Schlumberger tool that can be added to any digital string, yielding measurements of hole temperature and head tension.

B

Borehole effect: A distortion of a well log because of the size and influence of the borehole or (sometimes) the invaded zone.

Bottom Hole Assembly (BHA): The lowest 70-100 m portion of the drillstring, made of thicker steel with a smaller inner diameter than normal pipe. Different BHAs are used for APC/XCB coring and RCB coring.

Bridge: A hole constriction too small for the logging tool to pass through, caused sometimes by clay swelling and sometimes by caving of fractured formations.

Bridle: (1) The insulation covered lower portion of the cable to which a logging tool is connected. (2) To connect in parallel a group of amplifiers to a common input. (3) An arrangement for towing a seismic streamer.

C

Caliper: A tool used for measuring the diameter of a borehole. The measurements are displayed as a caliper log. Open hole caliper logging tools often have four or more arms.

Casing: Tubes or pipes used in boreholes to keep them from caving in. Usually made in pieces of ten feet lengths that screw together.

Cement-bond log: A well log of the amplitude of the acoustic wave which indicates the degree of bonding of cement to the casing and formations. If the casing is poorly cemented, energy which travels through the casing at the fast speed of acoustic waves in steel is strong and little energy travels in the formation; if the casing is well cemented, the casing signal nearly disappears and the formation signal is strong. The log may consist of: (1) an amplitude log (CBL) which represents the amplitude of a portion of the longitudinal acoustic wave train; or (2) a display of the acoustic wave train such as the character log, 3-D, microseismogram, VDL, or acoustic signature log.

Check Shot Survey: Seismic sources shot into a borehole where a seismic recording tool records travel times for checking results of integrating a continuous velocity or sonic log.

Compensated log: A well log made with a sonde designed to correct unwanted effects. The compensated density log uses the signal from a secondary detector to correct for the effect of mud cake and small irregularities in the borehole wall. The compensated sonic log uses a special arrangement of the transducers to correct for irregularities in the borehole size and sonde tilt.

Continuous velocity log: A sonic log; a log of formation velocity against depth. The quantity recorded and graphed is usually the reciprocal of the velocity, the travel time over a short interval, often expressed in μsec/ft.

Customer tape: Tape containing the data used in the processing of standard logs.

Cycle skipping: In acoustic or sonic logging, the first arrival is sometimes strong enough to trigger the receiver closest to the transmitter but not the farthest receiver, which may then be triggered by a later cycle resulting in an erroneously high transit time. This situation is called cycle skipping. Its onset is characterized by an abrupt deflection corresponding to an added cycle of travel between receivers. Short cycle skipping, where the near receiver is triggered by a cycle too late, also can occur, resulting in an abnormally short travel-time.

D

Density log: A well log which records the formation density. The logging tool consists of a gamma ray source (e.g., Cs^{137}) and a detector so shielded that it records backscattered gamma rays from the formation. This secondary radiation depends on the density of electrons, which is roughly proportional to the bulk density. The source and detector are on a skid which is pressed against the borehole wall. Compensated density logging tools include a secondary detector which responds more to the mud cake and small borehole irregularities; the response of the second detector is used to correct the readings of the main detector.

Depth of investigation: The radius about a logging sonde within which material contributes significantly to the readings from the sonde.

Dipmeter: A well log from which the magnitude and azimuth of formation dip can be determined. The resistivity dipmeter includes: (a) three or more microresistivity readings made using sensors distributed in azimuth about the logging sonde; (b) a reading of the azimuth of one of these; (c) a reading of the hole deviation or drift angle; (d) its bearing; and (e) one or two caliper measurements. The microresistivity curves are correlated to determine the differences in depth of bedding markers on different sides of the borehole and dip calculations are based on such correlations.

E

Eccentralize: To push a logging tool from the center of the borehole to the borehole wall. This is often accomplished by a mechanical arm in the logging tool, actuated at the beginning of the upward logging run. Nuclear logging tools, for example, need to be eccentralized to make correct measurements.

Environmental Corrections: Log data are adversely influenced by downhole conditions such as pressure, salinity, drilling mud, filter cake, etc. The effects of these environmental conditions on the data may be eliminated post-cruise though environmental correction software.

Extended Core Barrel (XCB): A thin bit which extends beyond the normal bit, for high core recovery when sediments are too firm for use of the advanced piston corer.

F

Flowmeter: A device that measures the flow of fluid in the borehole or casing at specified depth intervals. Sometimes the flowmeter is lowered through the flow stream in a borehole and sometimes it is set in one spot with a packer.

G

Gamma-ray log: A well log which records the natural radioactivity. 1) In sediments the log mainly reflects shale content because minerals containing radioactive isotopes (the most common of which is potassium) tend to concentrate in clays and shales. Volcanic ash, granite wash, and some salt deposits also give significant gamma-ray readings. The log often functions as a substitute for the SP for correlation purposes in cased holes, in conductive muds in open holes, and for thick carbonate intervals.

H

Hydraulic Bit Release (HBR): Equipment inserted next to the bit while "making up" (putting together) an RCB bottom hole assembly, to permit dropping the bit for logging. A "go-devil" is sent down the pipe to release bit latches and seal the bit opening, then the bit is pumped off by applying hydraulic pressure. The HBR usually does not release immediately but needs a fair amount of work to get off; sometimes it refuses to release, and we either cannot log or have to wash a new hole for logging.

I

Induction log: An electrical conductivity/resistivity well log based on electromagnetic-induction principles. A high-frequency alternating current of constant intensity induces current flow in the formation. This Foucault current flowing in the formation ground loop causes an alternating magnetic field which produces a current in a receiving coil. The receiving-coil current is nearly proportional to the conductivity of the formation. Induction sondes may have several transmitting and receiving coils to produce a highly focused log. An induction log can be recorded where the borehole fluid is conductive or nonconductive, as in oil-base muds or gas. A dual induction log measures different depths of penetration.

Interval transit-time: The travel time of a compressional sonic (seismic) wave over a unit distance, hence proportional to the reciprocal of P-wave velocity. Measured in the sonic log, usually in microseconds per foot.

Invaded zone: The portion about a wellbore into which drilling fluid has penetrated, displacing some of the formation fluids. Invasion takes place in porous, permeable zones because the pressure of the mud is kept greater than that of the formation fluids. A mud cake builds on the formation wall, limiting further flow of mud fluid (filtrate) into the formation. Directly behind the mud cake is a flushed zone from which almost all of the formation water and most of the hydrocarbons have been displaced by filtrate. The invasion process alters the distribution of resistivities and other properties and consequently the value which logs read. The depth of invasion is the equivalent depth in an idealized model rather than the maximum depth reached by filtrate. In oil-bearing intervals, the filtrate may push a bank of formation water ahead of it to produce a relatively low-resistivity annulus which is especially important with deep-investigation induction logs.

J

K

L

Logging-While-Drilling (LWD): Process by which downhole geophysical logs are acquired during drilling operations. LWD acquires data from sensors integrated into the drill string immediately above the drill bit. LWD records data minutes after cutting the hole, closely approximating in situ conditions. This forefront industry technology provides high quality logging information in environments where standard wireline systems previously acquired either no data or poor quality data. Specifically, LWD provides excellent quality results in deviated holes or unstable environments that may preclude wireline log runs. In addition to the acquisition of logging data in potentially unstable boreholes where high-quality wireline data cannot be acquired, LWD measurements also offer at least two other operational advantages over standard coring and wireline operations: (1) in situ logs and azimuthal borehole images are acquired over the entire drilled interval, providing data over the critical section; and (2) data is either saved in memory or transmitted during drilling, hence data can be obtained without dismantling the drill string and the chances of borehole wall collapse are reduced.

M

MBSF: meters below sea floor.

MBRF: meters below rig floor.

Measurement-While-Drilling (MWD): Drilling and logging technology very similar to LWD (Logging-While-Drilling). MWD data is telemetered to a surface acquisition system in real-time, while LWD data is stored in downhole memory until the tool is pulled to the surface and the data retrieved. The MWD tools are now routinely used in industry, often together with LWD tools, to monitor drilling parameters in real time. A significant advantage of measuring downhole weight-on-bit is that it allows for changes in the rate of penetration to be quantified in terms of formation strength through a simple transform. When calibrated to shear strength measurements on core, this estimate of downhole formation strength together with LWD and core measurements of porosity, density and lithology provides an improved determination of the pore-pressure and effective stress at depth.

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N

Neutron Activation: Radioactive sources in density and porosity tools emit neutrons into the formation as part of the routine density and porosity measurements. If a toolstring with radioactive sources is stationary in the hole for any amount of time, residual neutrons will remain in the borehole for a small period of time in the location adjacent to source. This neutron activation does not usually last more than a few hours, but it is detectable with the gamma tool and can be falsely interpreted as a high gamma count interval.

Neutron log: A porosity well log which measures mainly hydrogen density. Fast neutrons emitted by a source in the tool are slowed to thermal speed by collisions with (mainly) hydrogen atoms. The thermal neutrons are then captured by atomic nuclei of the surrounding material (mainly chlorine atoms) at which time a characteristic gamma ray of capture is given off. Porosity calculated from the neutron log is affected somewhat by the formation matrix and by the presence of gas. Neutron logs are used in crossplots to detect gas and determine lithology. Neutron logs are sometimes scaled in API units, sometimes in porosity units assuming a limestone matrix. The neutron log can be recorded in cased holes.

O

P

Permeability: A measure of the ease with which a fluid can pass through the pore spaces of a formation. Measured in millidarcy (1/1000 darcy) units. The permeability constant k is expressed by Darcy's law as $\mu q/(dp/dx)$, where μ is fluid viscosity, q is linear rate of flow, and dp/dx is the hydraulic pressure gradient.

Pigtail: A 4-foot long piece of logging cable, modified with electrical connectors at each end, which converts the rope socket (Schlumberger cable termination) via the torpedo to the

Gearhart Owen (G.O.) cablehead used on the specialty tools.

Processed Data: Logging data that has been processed using a specific log analysis system (such as GeoFrame or Logos). Processing includes depth shifting, environmental corrections, quality control and the creation of ASCII files for the online database.

Proprietary Data: The entirety of logging data collected by the Schlumberger acquisition system aboard the *JOIDES Resolution*.

Proprietary Tape: A tapes containing the original log data recorded by the Schlumberger engineer, as well as the calibration counts necessary for some onshore processing of the original count rates.

Pull Out of Hole (POOH): A term used to describe the upward trip of either a logging tool or the drillstring. Most commonly, it refers to the distance from the bottom of the hole to the drill floor, but distances to specific depths below the seafloor can also be specified (e.g., "POOH to 70 mbsf" means raising pipe from the bottom of the hole to 70 mbsf).

Q

R

RCB: Rotary Core Barrel. Used after the APC/XCB core barrels to drill hard rocks. Logging tools cannot pass through an RCB bit; therefore, the bit must be removed prior to logging.

Resistivity: The property of a material which resists the flow of electrical current. Also called specific resistance. The ratio of electric-field intensity to current density. The reciprocal of resistivity is conductivity.

Resistivity logs: Well logs which depend on electrical resistivity: normal, lateral, laterolog and induction log. Most resistivity logs derive their readings from 10 to 100 ft^3 of material about the sonde. Microresistivity logs on the other hand derive their readings from a few cubic inches of material near the borehole wall.

Rigup (RU): To assemble a toolstring or piece of equipment in preparation for deployment.

Rigdown (RD): To disassemble a toolstring following deployment.

ROP: Rate of penetration.

Run Into Hole: The opposite of POOH.

S

Schlumberger Workshop: A room on the *JOIDES Resolution* immediately beneath the logging winch, containing Schlumberger supplies and the ozalid machine for paper copies of logs.

Scintillation Counter: An instrument for measuring radioactive radiation, especially from gamma rays. Gamma radiation impinging on a sensitive phosphor causes it to emit light (scintillations) which is measured by a photo-multiplier tube.

Secondary porosity: Porosity resulting from the alteration of the formation such as by fractures, vugs, solution channels, dolomitization, etc.

Seismic Source: The sound source used for the collection of seismic reflection data. In the early days of seismic exploration of watered covered areas, the source was always a form of unconfined explosion. However, an unacceptable level of environmental damage resulted from this method and it was soon clear that there was a pressing need to generate seismic waves that did not have sufficiently high peak pressures to cause damage to marine fauna. In addition, explosive sources created a so-called "bubble effect" – an undesirable artifact in a seismic record caused by oscillations of gas bubbles generating repetitions of first arrivals. Because of the consistency of the water medium, it is possible to generate energy within the frequency band used for seismic exploration by a more controlled release of gas pressure (air gun) or by other means of producing a sudden volume increase within the water column (water gun) while at the same time minimizing the bubble effect. The requirements for a marine seismic source are:

1. Ability to generate a discrete powerful pulse or signal that can be subjected to later compression in time.
2. A rechargeable or repeatable system which can be used in a sequence of operations at short intervals of time (10 seconds or so).
3. A relatively simple system that will operate consistently, trouble-free, and have a long life between overhauls.
4. A system that can be used in constant depth below the water surface and results in a minimum drag on the vessel carrying it.
5. A system that does not injure marine life.
6. A system that minimizes the bubble effect.

Seismic guns currently available on the *JOIDES Resolution*:

- 3 /80 cu. in. SSI water guns.
- 2 /200 cu. in. Hamco water guns.
- 1 /400 cu. in. SSI water gun.
- 1 /1500 Bolt Airgun capable of 120 to 1000 cu. in.

Shoulder-bed effect: Effect of adjacent beds on a log reading. Also called the adjacent bed effect. For example, high resistivity beds adjacent to a low resistivity bed may result in more current flowing in the low-resistivity bed than if the high-resistivity bed were not present, thus changing the apparent resistivity of the low-resistivity bed.

Sonic log: A well log of the travel time for acoustic waves over a unit distance, and hence the reciprocal of the longitudinal wave (P-wave) velocity. Also called acoustic velocity log and continuous velocity log. Usually measured in microseconds per foot. Especially used for porosity determination by the Wyllie relationship. The interval transit time is integrated down the borehole to give the total travel time. For the compensated sonic log, two transmitters are pulsed alternately; averaging the measurements tends to cancel errors due to sonde tilt or changes in hole size.

Spontaneous Potential (SP): Also called self potential. 1) A well log of the difference between the potential of a movable electrode in the borehole and a fixed reference electrode at the surface. The SP results from electrochemical SP and electrokinetic potentials which are present at the interface between permeable beds adjacent to shale. In impermeable shales, the SP is fairly constant at the shale base-line value. In permeable formations the deflection depends on the contrast between the ion content of the formation water and the drilling fluid, the clay content, the bed thickness, invasion, and bed-boundary effects, etc. In thick, permeable, clean nonshale formations, the SP has the fairly constant sand line value, which will change if the salinity of the formation water changes. In sands containing disseminated clay (shale), the SP will not reach the sand line and a pseudostatic SP value will be recorded. The SP is positive with respect to the shale base-line in sands filled with fluids fresher than the borehole fluid. 2) The DC or slowly varying natural ground voltage observed between nearby nonpolarizing electrodes in field surveying. In many mineralized areas this is caused by electrochemical at the electrically conducting sulfide body.

Stand: A 30-meter segment of pipe, made up of 3 10-meter pipe joints. This is the usual increment for adding or removing pipe.

Stoneley wave: 1) A type of seismic wave propagated along an interface. 2) A surface wave in a borehole.

Synthetic Seismogram: An artificial seismic reflection record manufactured from velocity-log data by convolving the reflectivity function with a waveform which includes the effects of filtering by the Earth and recording system. Used to compare with an actual seismogram to aid in identifying events or predicting how stratigraphic variation might affect a seismic record. Often constructed from sonic log data alone although density data may also be incorporated. Generally assumes plane interfaces and plane waves, sometimes a point source. Synthetic seismograms sometimes show primary events only, primaries plus selected multiples, or primaries plus all multiples; they may be constructed by analog, digital, or manual methods.

T

Tadpole Plot: A type of plot of dipmeter or drift results, also sometimes called an arrow plot. The position of a dot gives the dip angle versus depth and a line segment pointing from the dot gives the direction of dip, using the usual map convention of North being up.

Telemetry: Communication with a remote acquisition system. Logging tools usually transmit acquired data in real-time via wireline telemetry.

Temperature log: A well log of temperature, often made with a resistance thermometer (thermistor). Used for locating cement behind the casing (because the setting of cement is exothermic and hence raises temperature), intervals which are producing gas (because the expansion of gas as it enters the borehole lowers the temperature), and fluid flows (particularly behind the casing).

Total depth: Final depth achieved during drilling operations.

U

V

Vertical Seismic Profile (VSP): A VSP differs from a conventional reflection profile in that the receiver is clamped successively at different borehole depths within the Earth. The seismometer records both the direct, downgoing waves and upgoing waves reflected from acoustic impedance changes below the clamping depth. Interval velocities may be calculated from the difference in arrival time of the direct wave between receiver depths. Processing techniques can be applied to separate the upgoing and downgoing wavefields, which can then be analyzed for attenuation properties of rock, prediction of acoustic properties below the bottom of the hole, and correlation with borehole lithology, wireline logs, and events on conventional seismic reflection profiles.

W

Washout: A borehole feature where the gauge of the hole increases substantially due to caving or erosion during the drilling processes.

Wavelet: A seismic pulse usually consisting of 1-1/2 to 2 cycles.

Wiper Trip: The action of pulling pipe from the bottom of the hole to logging depth, then lowering pipe back to bottom, or the opposite. Wiper trips are always pipe round trips to clean the hole for logging, usually at a much slower speed than normal pipe trips to avoid damaging the hole.

Wireline: A cable comprising one or conductors which is lowered into a borehole and provides for real-time communication between a tool and the surface.

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How to contact us:

Mailing Address:	Borehole Research Group Lamont-Doherty Earth Observatory Rt. 9W Palisades, NY 10964
E-Mail:	borehole@ldeo.columbia.edu
Fax:	(845)-365-8132
Phone:	(845)-365-8674 (Director) (845)-365-8672 (Deputy Director) (845)-365-8772 (Manager, Technical Services)
Web:	http://www.ldeo.columbia.edu/BRG/ODP/

Data Processing - Overview

The main purpose of shore-based log processing is to provide scientists with a comprehensive quality controlled downhole log data set. This data set can then be used for comparison and integration with core and seismic data from each ODP leg: the Sagan in-house software is used to put cores and logs on the same depth scale; and IESX software is used to analyze seismic sections and generate synthetic seismograms from the logs. Shore-based log processing comprises:

- Depth adjustments to remove depth offsets between data from different logging runs
- Corrections specific to certain tools and logs
- Documentation for the logs, with an assessment of log quality
- Conversion of the data to a widely accessible format (ASCII for the conventional logs, GIF for the FMS images and summary diagrams)
- Assembling the data for inclusion in the ODP Logging Services on-line and tape databases.

Log analysts at ODP Logging Services carry out the processing, mostly using Schlumberger GeoQuest's "GeoFrame" software package. Conventional log data (natural gamma radioactivity, resistivity, density, porosity, sonic velocity, magnetic susceptibility logs) are transmitted via satellite from the ship, processed, and returned to the ship, usually within a week of logging. Processing of other log data (FMS images, GHMT magnetic polarities, etc.) is done after the cruise, either because the file sizes are too large to transmit via satellite, and/or the processing time is longer.

For details on the various types of processing, click on the appropriate link:

- Log Processing
- Core/Log Integration (Splicer & Sagan)
- Log/Seismic Integration (IESX)

Log Processing

Conventional Log Processing

Depth adjustments

The main processing task is to remove depth discrepancies between the different logging runs. Such discrepancies are caused by cable stretch, incomplete heave compensation, and by tides. The natural gamma ray log (SGR and HSGR) is generally used to match between the logging runs, as this log is recorded on all toolstrings. One gamma log is chosen as the reference, on the basis of the length of the logged interval and data quality. The other gamma logs are matched to the reference using an automatic routine; the match of each log is checked to make sure distinctive peaks and troughs line up, and the match is adjusted, as necessary, by the log analyst. The resulting depth shifts are then applied to the other logs on the tool strings. The depth reference is then shifted from the rig floor to sea floor, which is determined from the step in the natural gamma log seen at the sediment-water interface.

Environmental corrections

Environmental corrections are designed to remove any effect from the borehole (size, roughness, temperature, tool standoff) or the drilling fluids that may partially mask or disrupt the log response from the formation. Onshore, only the natural gamma (NGT) logs are generally corrected. The logs from the HNGS, HLDS, and APS tools are corrected in near-real time during log acquisition.

Sonic log corrections

Sonic slowness logs from the SDT, LSS, and DSI-2 sonic tools are routinely edited to remove noise and cycle-skips that are often present in the raw log. The travel times are converted into sonic velocities.

Quality control and documentation

The quality of the data is assessed in terms of reasonable values for the logged formation, repeatability between different passes of the same tool, and correspondence between logs affected by the same formation property (e.g., the resistivity log should show similar features to the sonic velocity log). Invalid data at the top (affected by the bottom hole assembly) and bottom of the logs are removed. Depth adjustments, corrections, and data quality are documented in the processing report.

Data delivery

The processed data are saved as ASCII files and transmitted via satellite back to the ship. They are also put in the on-line database, the Initial Reports CD-ROM, and are archived to tape in LIS/DLIS format.

FMS Processing

Processing is required to convert the 64 electrical current traces recorded by the FMS into a color-scale image representative of the conductivity changes in the formation.

BorEID corrections

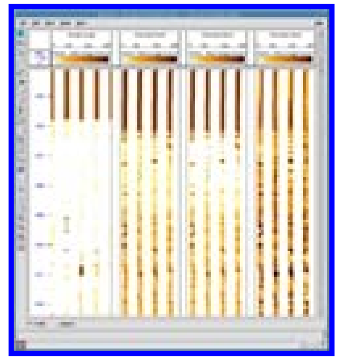
Several corrections are applied using the BorEID module of GeoFrame:

1. **Speed Correction.** The data from the z-axis accelerometer are used to correct the vertical position of the data for variations in the speed of the tool ("GPIT speed correction"), including "stick and slip." In addition, "image-based speed correction" is also applied to the data, based on reducing any offset between the data from two rows of button electrodes on each FMS pad.
2. **Equalization.** The responses of the button electrodes on the pads of the tool are equalized to correct for various tool and borehole effects which affect individual buttons differently.
3. **Button Correction.** If the measurements from a button electrode are unreasonably different from its neighbors (e.g., "dead buttons"), the defective trace is replaced by traces from adjacent good buttons.
4. **EMEX voltage correction.** During logging, the voltage that drives the current is continuously regulated so that current flows even through very resistive formations. The button response is divided by the EMEX voltage so that the response corresponds more closely to the conductivity of the formation.

Depth adjustment

The natural gamma log (SGR) resulting from the BorEID speed correction is matched to the SGR log from the same pass after conventional log depth shifting. The logs are checked for a good match, and then the resulting depth shifts are applied to FMS images and their associated logs (pad azimuth, etc.). The resulting FMS images are then on a comparable depth scale to the conventional logs.

Image normalization



Using the BorNor module of GeoFrame, "static" and "dynamic" normalizations of the image are applied. In the static normalization, the resistivity range of the entire interval of data is computed, and is partitioned into 256 color levels; this image is good for examining large-scale resistivity variations. In the dynamic normalization, the full range of color levels is assigned to resistivity range of short intervals (e.g., 2m); thus the color contrast is increased, enhancing the fine details of the resistivity structure.

Data delivery

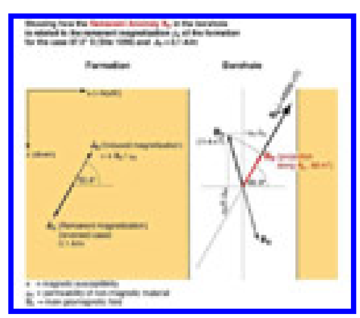
Static images are output as GIF files and added to the on-line database and the Initial Reports CD-ROM. In the future, dynamic images will be treated in a similar manner. The FMS data are also saved in DLIS format and archived.

GHMT Processing

Once the GHMT logs have been depth shifted, the magnetic polarity stratigraphy is determined as follows:

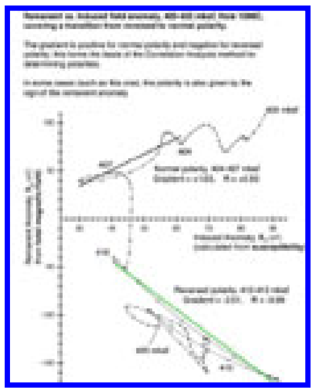
1. The Earth's main field and the field of the metal drill pipe are subtracted from the total magnetic field log (MAGB) to isolate the field anomaly caused by the local formation.

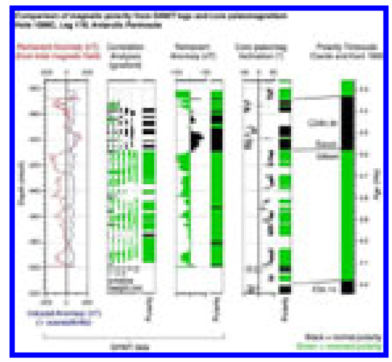
2. The local field anomaly is caused by the induced and remanent magnetizations of the local formation (see figure). The induced anomaly can be calculated from the magnetic susceptibility log (MAGS), and so the remanent



anomaly can also be isolated. Prior to this step, the logs are smoothed so that they have comparable vertical resolutions.

3. The induced and the remanent anomalies are correlated over depth intervals of varying heights ("correlation analysis"). If the induced and remanent anomalies correlate, then the magnetic polarity of the formation is normal; if they anti-correlate, the polarity is reversed (below left). This polarity interpretation can then be related to the geomagnetic polarity timescale (below right).





4. The processed data are included along with a summary diagram in the on-line database and the Initial Reports CD-ROM.

Processing of Other Log Data

Temperature data

Time vs. temperature logs recorded by Lamont's TAP tool are merged with time vs. depth data recorded during logging by the Schlumberger MCM unit to give the variations of borehole temperature with depth. The temperature data are added to the Initial Reports CD-ROM.

Sonic waveform data

During logging, sonic travel-times are picked from the waveform data acquired by the DSI-2 and LSS sonic tools; these picks are used in the conventional log processing. It is anticipated that the waveform data from the DSI-2 sonic tool can be reprocessed after the leg (using newly acquired GeoFrame waveform processing modules) to derive compressional, shear, and Stonely wave velocities, and seismic anisotropy data.

WST (checkshot and VSP) data

WST data, both individual shot records and the stacks for each station, are archived in DLIS format. First arrival times are picked on the ship and are not generally re-picked onshore. Where there are enough stations for a vertical seismic profile, a corridor stack can be produced and compared to the synthetic seismogram and seismic section.

Other data

Processing of data from tools that are used, or have been used, only occasionally -- Geochemical tool (GLT), Borehole televiewer (BHTV), Azimuthal Resistivity Imager (ARI), third party logging tools, etc. -- is determined on a per-leg basis and may be outsourced.

Core/Log Integration (Splicer & Sagan)

Introduction

The Core-Log Integration Platform (CLIP) software provides the ODP community with a set of graphic, interactive data analysis products for depth-merging and integrating core and downhole log data. These graphically oriented and intuitive products are for use on the ship or on shore-based Unix workstations. Splicer (current version: 2.2) and Sagan (current version: 1.2) have expanded data handling flexibility considerably, allowing for access to a variety of non standard data types and formats in addition to current Janus database output files.

Splicer

Splicer is installed on Sun workstations on the *JOIDES Resolution* and allows interactive depth-shifting of multiple holes of core data to build composite sections using an optimized cross-correlation approach. Multiple data types can be compared simultaneously in order to quickly determine the best correlation for all variables. On legs where it is important to recover complete "spliced" sediment sections, a "Stratigraphic Correlator" will be staffed in order to provide real time feedback on the completeness of the recovered sediment record to help determine operational and drilling plans. Splicer has been used routinely on the JOIDES Resolution to build continuous sediment records since Leg 151 (1993). Metadata files generated by this program are now formally included in the JANUS database. Splicer also allows the composite section to be compared or tied to reference records such as insolation and isotope curves.

Some example applications are:

- Simultaneous comparison of multiple data types from multiple holes.
- Tying holes together to build a common "composite" depth scale.

- Build a continuous sediment section by "splicing" overlapping cores.
- Enter and compare stratigraphic data from various holes down the splice.
- Output data on the new composite depth scale (mcd) as well as mbsf.
- Output a continuous "spliced" records for further analysis.
- Tie the downhole spliced record to reference data such as insolation or isotope curves

---

Sagan

The addition of the Sagan program now allows the composite sections output by Splicer to be mapped to their true stratigraphic depths, unifying core and log records and providing a crosscheck on the completeness of the composite section. Sagan generates a single metafile that defines a set of precise depth correlations between core and log datasets at any given site. This metafile provides the foundation for core-log data integration, as it establishes the unique mapping function linking the two independent depth scales. The program performs the core-log depth merging using physical parameters which are measured on both cores by logs (e.g. natural gamma, bulk density, porosity, magnetic susceptibility, sonic velocity). The core-log depth correlations are conducted either manually (e.g., core-by-core from single or multiple holes) or automatically. Sagan can also perform smoothing, decimation, and culling procedures to modify the data. The program can manage up to 10 holes of core data, 5 data types, nearly an infinite number of cores and data points and up to 3 reference log curves. The resulting core-log timelines can be applied across equivalent mcd depths in different holes or just for individual cores.

Some specific example applications are:

- Compare multiple core data types (in mbsf or mcd space) to downhole log records (log mbsf).
- Automatically or manually map core data back to log data to determine original stratigraphic depths.
- Accurately estimate the size and position of coring gaps, as well as the accuracy of the composite section.
- After mapping core data into the logs, the core data can be saved versus Estimated Log Depth (eld) as well as mcd and mbsf.

Log/Seismic Integration

IESX is used to display and interpret seismic surveys, and to generate synthetic seismograms from sonic velocity and density data. It is part of Schlumberger GeoQuest's GeoFrame software, which has been used for several years by the ODP downhole logging groups to display and process ODP log data, particularly FMS images. We anticipate that it will become a very powerful interpretation tool, able to integrate until now disparate data sets. IESX is available at each of the ODP Logging Services offices; an "IESX Cookbook" has been produced to guide new users in the use of this powerful but non-intuitive software.

Currently, IESX is being employed primarily for post-cruise work. However, a pilot study is underway (Legs 194 and 196) to determine the effectiveness of using this tool on the drillship.

The log and seismic data are organized into GeoFrame "projects," usually one project for each ODP leg. The user must log in to the project to gain access to the data and the application modules that are used to load, process, and view the data. Within IESX are the following applications:

- IESX Data Manager (for loading seismic data into the project)
- Basemap (for viewing maps of the survey lines and site locations)
- Seis2DV (for viewing and interpreting seismic data, and adding downhole log data)
- Synthetics (for generating synthetic seismograms)
- Geoviz (for viewing and interpreting data in 3 dimensions)

Initially, the available seismic navigation and trace (SEG-Y) data for the area are loaded into the project. The latitude and longitude of existing and proposed sites are also entered. The examples shown in the links above are based on ODP Leg 119 (Prydz Bay, Antarctica) and the 1982 BMR (Australian Bureau of Mineral Resources) seismic surveys of the area.

The log and core physical property data can also be imported into the project. A synthetic seismogram can be generated to provide the link between the logs (and core) and the seismic section. The basic idea is to achieve a match between the reflections that we expect the formations to create (the synthetic) and the reflections in the seismic data. The seismic can then be interpreted in terms of the actual formations, and, conversely, you can find out how deep into the seismic the borehole penetrated.

Before being used in the IESX Synthetics application, the data must be extended to the sea floor and bad data must be edited out. (We use the GeoFrame application "WellEdit" for this.) For example, in the Hole 742A data the log density has some bad values due to hole washouts; core-based density measurements, interpolated onto even spacing, can be used instead.

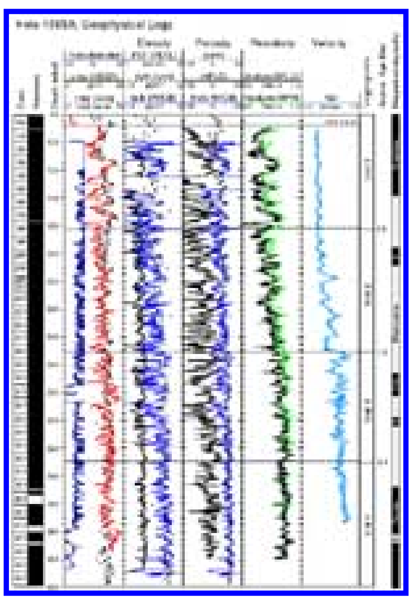
In the Synthetics application, a depth–two way travel time relation is generated from the sonic velocity data or a checkshot survey. An acoustic impedance log and reflection coefficients are calculated from the sonic and density logs. Then a source wavelet (extracted from the seismic survey data) is convolved with the reflection coefficients to produce the synthetic seismogram. The synthetic seismogram and the logs can be plotted on the seismic section in the Seis2DV application.

To make a hardcopy plot of the seismic section, the plot can be exported in the seismic CGM graphics format, and plotted. For page-size plots, a screen dump is usually acceptable.

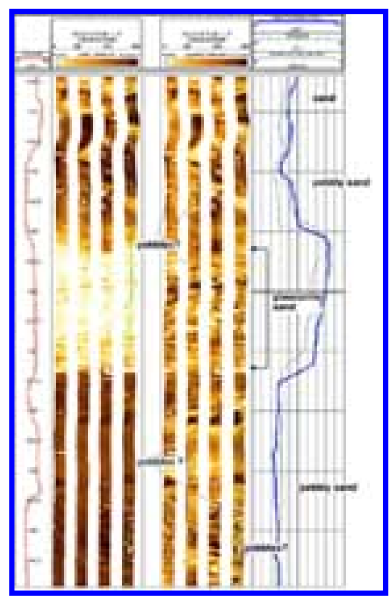
The project can be saved to tape for backup or for loading into another computer (e.g., the Downhole Measurements Lab Unix workstation).

Post-Cruise Meetings

The first post-cruise meeting is usually held in College Station about three to six months after the leg is completed. Prior to the meeting, the Logging Staff Scientist reviews all text and figures generated for the ODP Initial Reports (IR) volume. During the meeting, the Logging Staff Scientist revises the text, figures, and tables as needed. Corrections and additions are made to the IR Explanatory Notes and Site chapters in order to finalize these sections for publication. All figures include depth shifted log plots and any additional processing performed immediately after the cruise. The Co-Chiefs and TAMU Staff Scientist will generally review the text and figures and discuss any potential changes with the Logging Staff Scientist.



Typical IR figure of downhole logs and core recovery column



Typical IR figure of FMS image with downhole logs

The second post-cruise meeting focuses on the preparation of the ODP Scientific Reports volume and the coordination of publishing strategies in other scientific journals. During this meeting, the ODP Logging Staff Scientist, as well as the JOIDES Logging Scientist, prepares a 10-15 minute presentation that describes any post-cruise work performed with the logging data or with samples obtained for physical properties or chemical analyses. If the Logging Scientist (or any other shipboard scientist) obtains samples for post-cruise work, ODP requirements stipulate that a manuscript must be submitted on the work performed with the samples. Collaborations and scientific discussions between the Logging Staff Scientist and other shipboard participants are an integral part of the second post-cruise meeting. At this time, preliminary manuscript titles for publication in the Scientific Reports volume should be provided to the ODP/TAMU Staff Scientist.

Shore-based investigators with an approved sample or data request are also usually invited to participate in the second post-cruise meeting, where they too present their results and submit manuscript titles.

Post-Cruise Meetings | Data Distribution | On-line Data | Log Data CD-ROM

Data Distribution

Shipboard Participants

Shipboard data distribution

Log data are distributed onboard the *JOIDES Resolution* to all shipboard scientific participants, both digitally and in paper format. Details can be found in the shipboard data availability section of the data acquisition page. Shipboard integration of logs with core data and seismic sections is possible using the Sagan software package; more information on data processing and analysis can be found on the data processing page of this manual, which also describes the corrections that are applied to various log data types.

Shore-based data distribution

After the drilling leg is completed, processed digital log data are placed on-line by ODP Logging Services for use by the shipboard scientific party. The data are considered proprietary for one year, accessible only to shipboard scientists via a password security system implemented after the cruise. One year after the conclusion of the cruise, the password is lifted and data are accessible to all interested investigators. For additional details, see the on-line data section of this manual.

ODP Logging Services also creates a CD-ROM of log data that is distributed with each volume of the Initial Reports. Details can be found on the log data CD-ROM page.

Shore-based Investigators

Shore-based investigators whose requests for log data have been approved by the shipboard scientific party may obtain log data during the one year data moratorium. It is strongly suggested that such requests be submitted **before** the drilling leg, in order to expedite the request approval process. Shore-based investigators who obtain either core or log data are subject to the same publishing restrictions and obligations as members of the shipboard scientific party. A detailed discussion of the ODP publication policy can be found on the publications page of the Science Operator's web site:

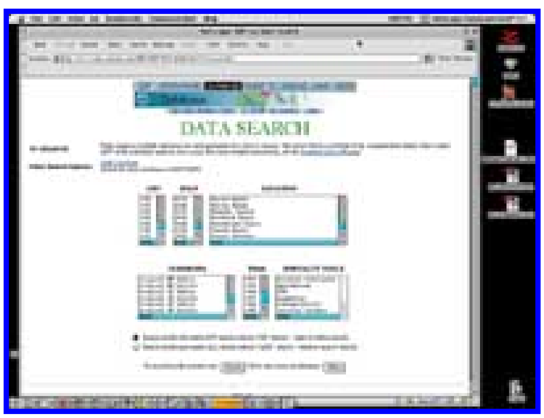
http://www-odp.tamu.edu/publications/policy.html

On-line Data

Over the last four years, ODP Logging Services has undertaken a major effort to create an easily accessible, on-line database of the log data collected by the Ocean Drilling Program. Currently, the ODP Log Database contains the majority of the log data collected by ODP, and in the future will provide access to all ODP log data. It can be accessed and searched through the internet, providing a convenient method for downloading large amounts of data, as well as educational and technical information about the applications of log data to scientific problems. The ODP Log Database can be accessed at:

http://www.ldeo.columbia.edu/BRG/ODP/DATABASE/

The ODP Log Database provides access to log data 24 hours a day, 7 days a week from any computer in the world. Using the database, a user has the ability to search by leg, hole, location, ocean/sea, or tool:



The Data Search screen on the ODP Logging Services web site.

The Search Results screen. Data are organized by hole number.

A keyword search will soon be available as well. This feature will greatly enhance the search capability of the database. For example, scientists will be able to search for all holes where basement was penetrated, or search for all the holes where fluid processes were an important objective.

The log database is useful not only for scientific research, but also for cruise planning. If a proponent is writing a proposal for drilling in an accretionary prism, for instance, the keyword feature can be used to search for all holes logged in accretionary prisms and determine what tools were used in each. The links to the on-line logging summaries would reveal that the traditional coring and logging techniques used in the early cruises were not very successful. Recent cruises (such as Legs 170 and 171A) that used logging-while-drilling (LWD) techniques, however, delivered very satisfactory results. Links are also available to a "Guide to Logging" section, where in-depth information on the tools is provided, and to "Proponent’s Helper," a section that provides assistance in completing the required site forms.

While the log database is an important asset to most ODP research, its value is greatly enhanced when the data can be integrated and compared with core data. For this reason, a link is provided from each listing of log data collected in a hole to the corresponding core data set at the TAMU web site.

The ODP log database consists of profiles and images of geophysical measurements – e.g., density, gamma ray, porosity, resistivity, and acoustic properties – recorded as a function of depth in a drill hole. There are two basic data formats currently available on-line: ASCII and GIF. ASCII can be opened in a variety of applications, although spreadsheet and graphing programs are most often used. Image data, such as the FMS, are provided as GIF files. The easiest way to view these files is in a web browser such as Netscape Navigator or Internet Explorer. They can also be imported into graphics programs or included in word processing documents.

Along with these files, the log database contains explanatory documentation and log summary plots. The documentation provides an overview of operations for each hole as well as information about processing procedures and quality control. The file dictionaries provide a list of data file names for each hole and the corresponding data type contained within it. The log summary plots show various types of log data and core recovery plotted versus depth. They are available only for the more recent legs (Leg 155 and later).

For one year after the drilling leg, log data from the leg can be accessed by members of the shipboard scientific party only; a username and password unique to each leg are distributed about two weeks after the leg. After a one year moratorium the password is lifted and the data become available to the rest of the scientific community.

Log Data CD-ROM

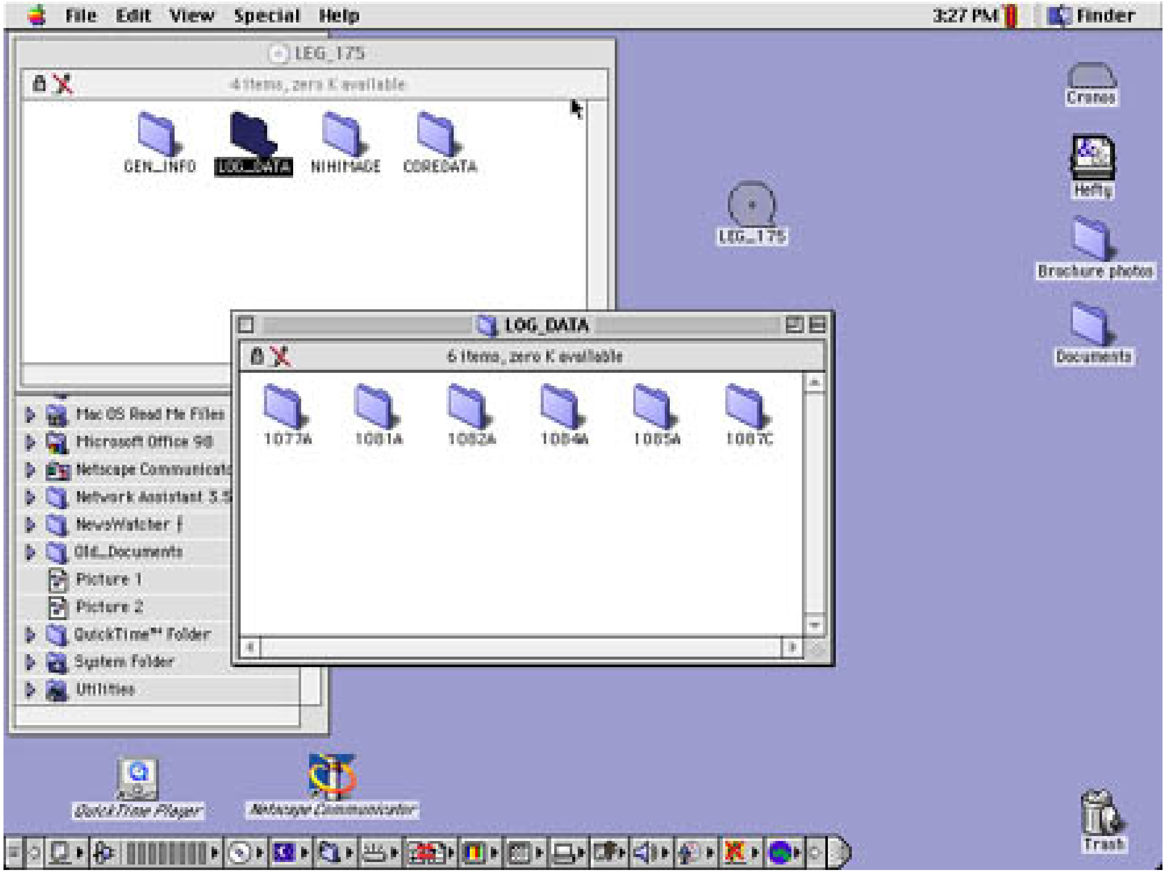
ODP Logging Services creates a CD-ROM for distribution with each ODP Initial Reports volume. The CD is readable on PC, Mac and Unix platforms. All data are in ASCII format except the FMS images, which are stored as GIF files. In addition to being available with each volume, CD-ROMs are available directly from ODP Logging Services. For further information, contact Jim Murray at jmurray@ldeo.columbia.edu.

The log data CD-ROM organizes the data by site and typically includes, along with relevant documentation:

- Processed conventional logs
- Processed FMS images
- Processed Dipmeter data
- Processed GHMT data
- Processed temperature data
- Sonic waveforms

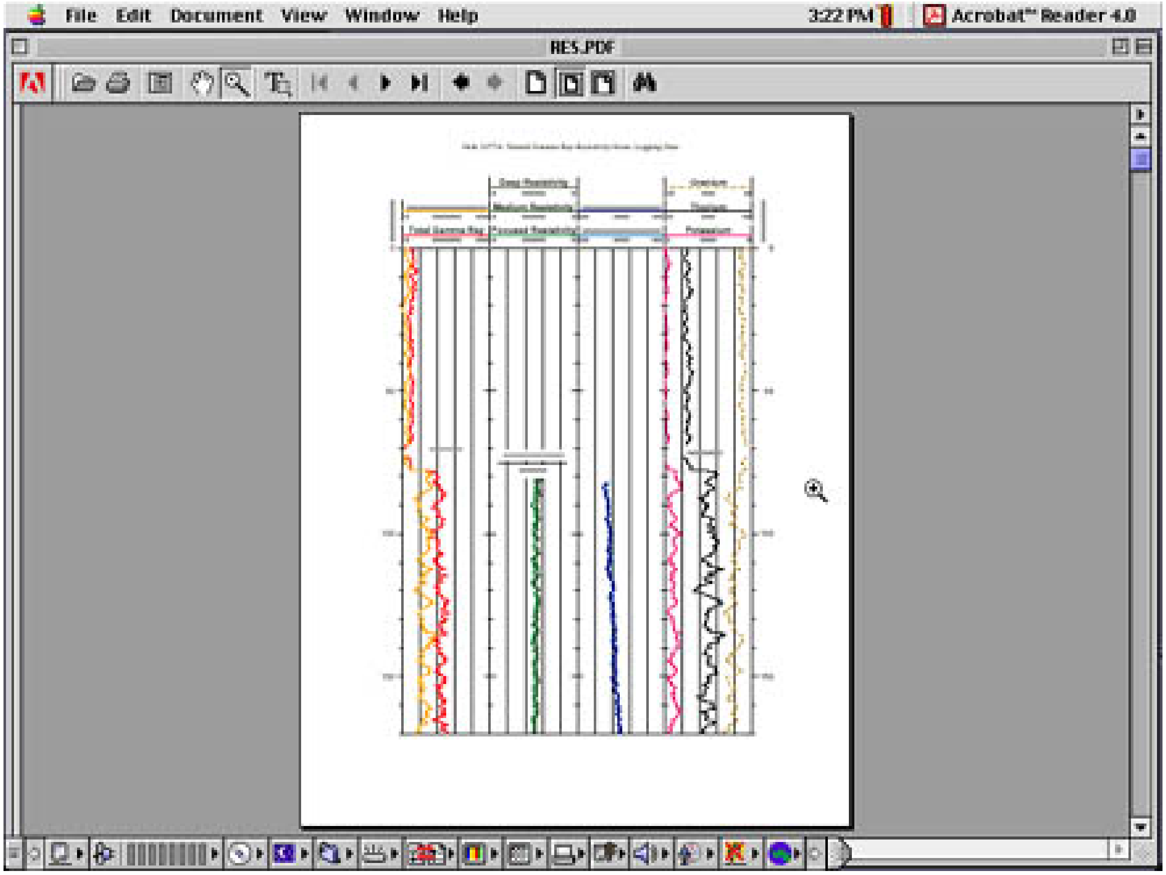
In addition to the log data on the CD, a subset of core data are also included for integration with the log data set. The following data types are routinely included as part of the core data set:

- GRAPE (gamma ray attenuation porosity evaluation)
- Moisture and density system
- Magnetic susceptibility
- Natural gamma
- Paleomagnetic data
- Compressional wave velocity



Screen shot showing opening windows of a representative log data CD-ROM

Log summary figures are available as postscript (.PS) or portable document format (.PDF) files:

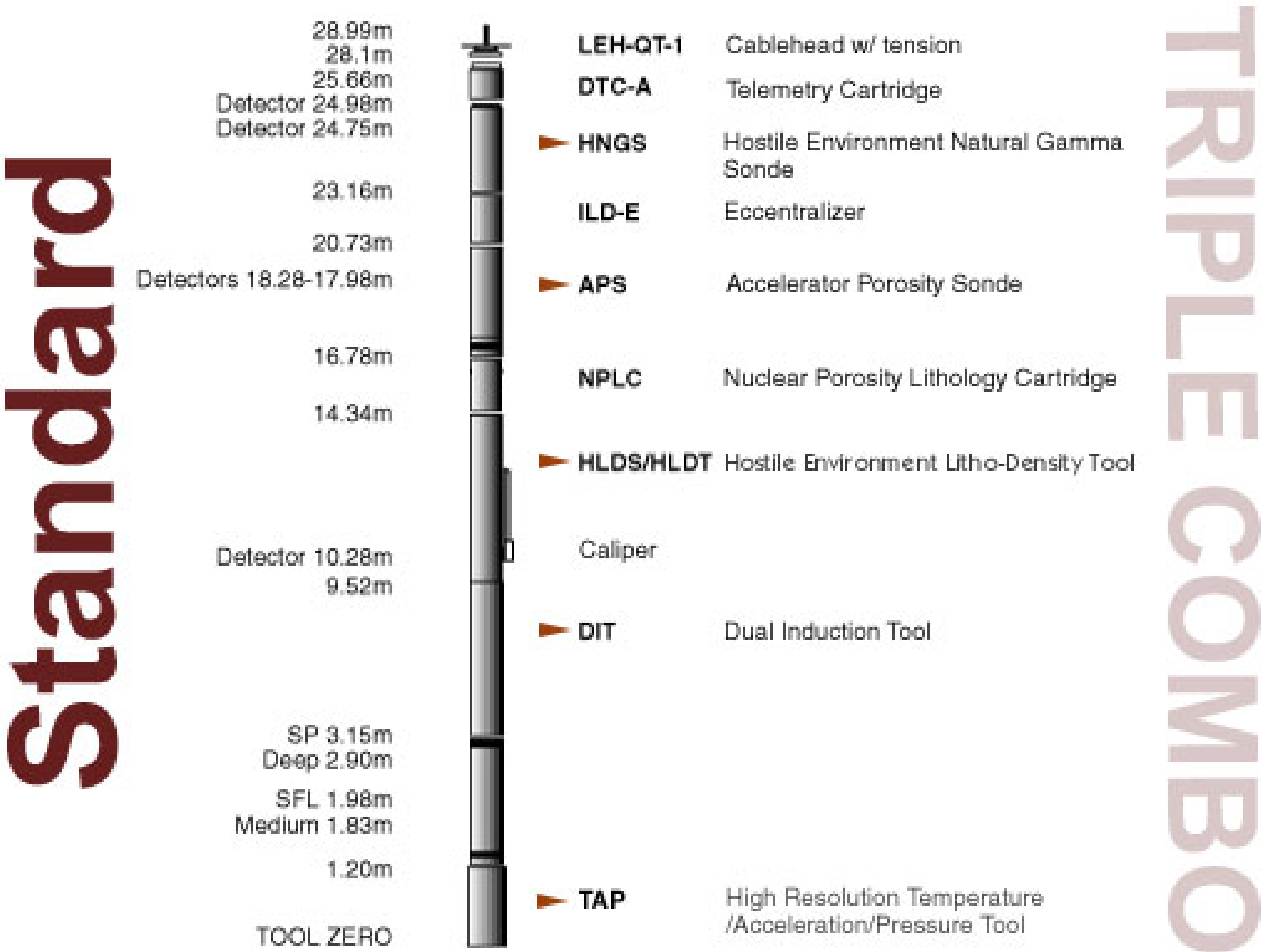


Log summary figure displayed as a portable document format (.PDF) file

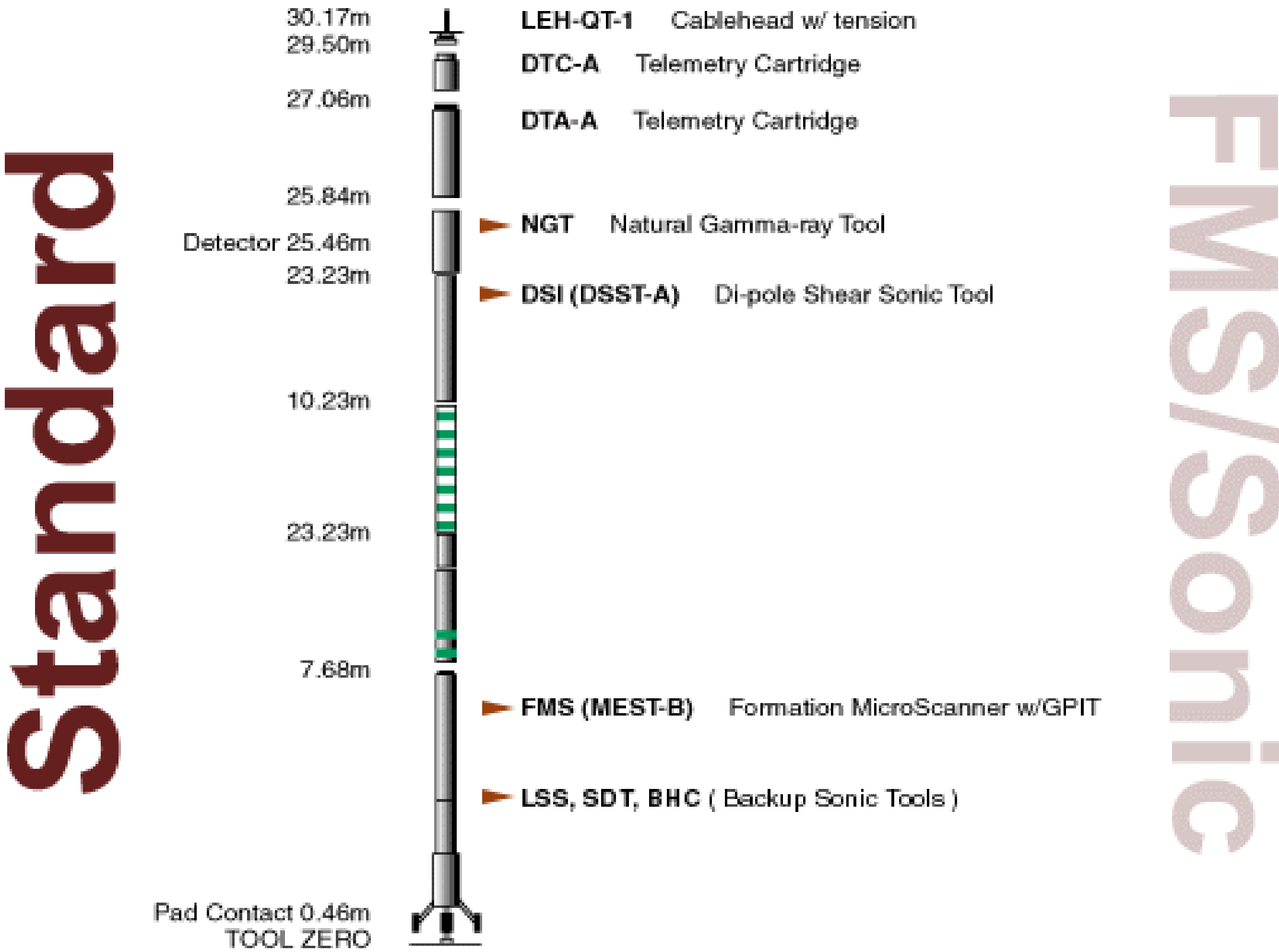
At the request of the Co-Chief Scientists, additional information such as third party tool data can also be included on the CD-ROM, subject to space availability. Other data sets are included as available on a leg-by-leg basis.

ODP Logging Services is currently investigating new and innovative log data visualization software for use in future CD-ROMs.

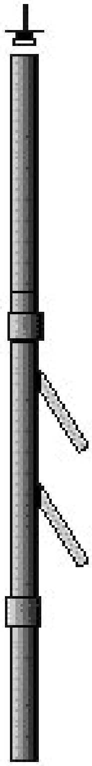
Post-Cruise Meetings | Data Distribution | On-line Data | Log Data CD-ROM



Triple Combo FMS/Sonic Specialty Other Toolstring Index



Triple Combo FMS/Sonic Specialty Other Toolstring Index



Specialty

- ARI
- ASI
- CNT-G
- DLL
- GHMT
- HTT
- LWD-ADN
- LWD-CDR
- LWD-RAB
- LWD-Isonic
- MGT
- UBI
- WST
- WST-3 component

Other

- WHC
- Hole Finder
- Cable Heads
- Wireline
- Sheaves
- Sources
- Fluid Seal
- Torpedo
- MCM
- DHML
- CSES
- Miscellaneous

Triple Combo FMS/Sonic Specialty Other Toolstring Index

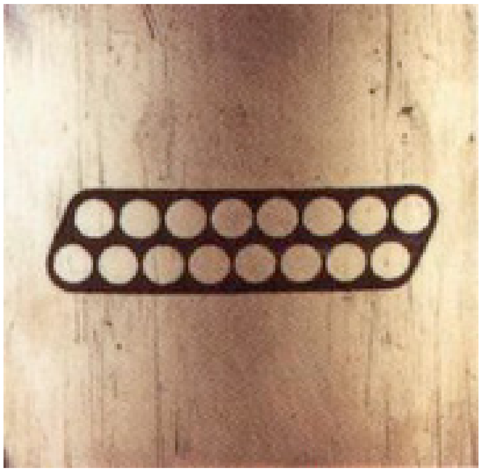
Formation MicroScanner (FMS*)

Description

The Formation MicroScanner sonde (FMS) consists of four orthogonal imaging pads each containing 16 microelectrodes which are in direct contact with the borehole wall during the recording. The button current intensity is sampled every 0.1 in (2.5 mm). The tool works by emitting a focused current from the four 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 gray or color images of variable intensity. Black and white (darkest or lightest color) indicate low and high microresistivity, respectively. The tool also includes a General Purpose Inclinometry Cartridge (GPIT) which provides accelerometer and magnetometer data in order to allow one to define the tool position and spatial orientation of the data.

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).



<---- Sixteen-electrode arrangement for the four-pad tool.

Applications

- Mapping of bedding planes, fractures, faults, foliations, and other formation structures and dip determination.
- Detailed correlation of coring and logging depths.
- Precise positioning of core sections where core recovery is less than 100%.
- Analysis of depositional environments.

Environmental Effects

To produce high-quality FMS images, the pads must be pressed firmly against the borehole wall. 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 (not all four pads touching the wall) and the FMS images can be blurred. The maximum borehole deviation where good data can be recorded with this tool is 10°. Irregular borehole walls will also adversely affect the images because the pads can not make sufficient contact with the borehole wall.

Log Presentation

FMS images can be plotted with identical vertical and horizontal scales to see features without exaggeration. However, due to physical constraints, different vertical and horizontal scales are commonly used. 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. The calipers or other curves can be plotted alongside the images as well.

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

FMS output plot

Specifications

Temperature Rating:	175° C / 350° F
Pressure Rating:	20 kpsi (13.8 kPa)
Tool Diameter:	3.625 in (9.2 cm)
Tool Length:	25.3 ft (7.72 m)
Sampling Interval:	0.1 in (2.5 mm)
Max. Logging Speed:	1,800 ft/hr
Vertical Resolution:	0.2 in. (5 mm)
Depth of Investigation:	10 in (25 cm)

Deployment Notes

Stuck/lost tool information

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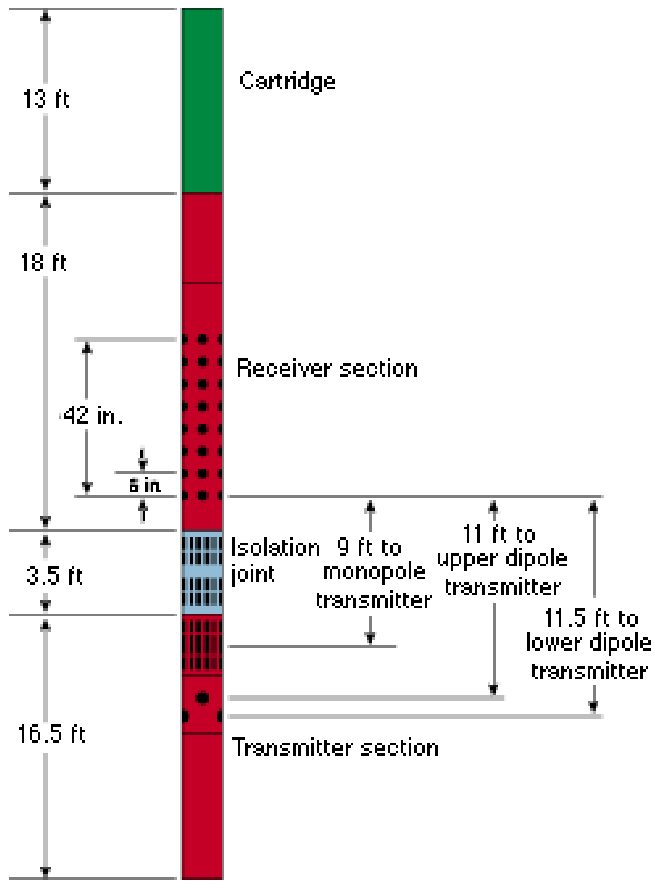
* ®trademark of Schlumberger

Dipole Shear Sonic Tool (DSI-2*)

Description

The Dipole Shear Sonic (DSI-2) tool combines high-speed telemetry with simultaneous, 12-bit dynamic range digitization of an eight-receiver array. The sonde incorporates both monopole and crossed-dipole transmitters with an eight-station array of electronically configurable hydrophones for monopole and dipole reception. The MAXIS wellsite unit acquires and processes these data.



The DSI-2 tool combines new dipole-based technology with the latest monopole developments into one system, providing the best method available today for obtaining borehole compressional, shear and Stoneley slownesses. (Slowness is the reciprocal of velocity and corresponds to the interval transit time measured by standard sonic tools.)

Dipole technology allows borehole shear measurements to be made in "soft" rock as well as "hard" rock formations. Limited by borehole physics, monopole tools can detect only shear velocities that are faster than the borehole fluid velocity -- or in hard rocks only. Dipole tools overcome this fluid velocity barrier.

The DSI-2 is a multireceiver tool with a linear array of eight receiver stations, a monopole transmitter and two dipole transmitters. The receiver array provides more spatial samples of the propagating wavefield for full waveform analysis. The arrangement of the transmitters and receivers allows measurement of wave components propagating deeper into the formation.

The DSI-2 tool is distinguished from the DSI by an upgraded receiver section. The upgrade improves the shear measurements in slow formations. The unimproved DSI is no longer available on board the JOIDES Resolution.

The DSI-2 can be combined with most ODP tools.

Tool Operation Modes

The DSI-2 tool has several data acquisition operating modes, any of which may be combined to acquire digitized waveforms over each 6-in. logging interval. For waveforms, eight channels are digitized simultaneously with a 12-bit dynamic range.

1. Upper and lower dipole modes
Eight dipole waveforms from firings of either of the dipole transmitters -- 40 sec per sample, 512 samples/waveform.

2. Crossed dipole mode
Standard acquisition of 32 total waveforms, in-line and cross-line from both transmitters.

3. Stoneley mode
Eight monopole waveforms from firings of the monopole transmitter driven with a low-frequency pulse -- 40 sec per sample, 512 samples/ wave form.

4. P and S mode
Eight monopole waveforms from firings of the monopole transmitter driven with a high-frequency pulse -- 10 sec per sample, 512 samples/ waveform.

5. First-motion mode

Eight sets of monopole threshold-crossing data from firings of the monopole transmitter driven with a high-frequency pulse -- primarily for compressional first-arrival applications.

Features

New fast tool bus and data reduction techniques have allowed double the maximum logging speed in most instances.

A switchable power regulator has enabled a one-third reduction in power needs, resulting in broader combinability with other tools.

Additional human-interface engineering has improved field acquisition quality and efficiency.

A new low-frequency transmitter driver improves signal-to-noise ratio and allows successful logging of extremely slow formations and greatly enlarged holes.

Improved waveform processing techniques have greatly improved vertical resolution.

New answer products utilize Stoneley slowness to evaluate fractures and indicate permeability.

In addition to the new dipole features, acquisition of the Stoneley wave velocity utilizes a low-frequency monopole energy pulse for highest-quality Stoneley measurements. Stoneley-derived permeability is useful for evaluating fractures as well as investigating deeply into the formation.

A new technique for detecting compressional wave arrival--digital first-motion detection (DFMD)--provides measurements that are compatible with previous sonic logs, in addition to a 6-in. vertical resolution compressional sonic.

Processing with the MAXIS wellsite unit displays a full wave and its component characteristics. Its high-speed array processor uses the slowness-time-coherence (STC) method to determine compressional, shear and Stoneley slowness values. A choice of band-pass filters permits utilization of the optimum frequency range within a mode. The process reliably provides unambiguous transit times even in difficult borehole conditions. The resulting values are useful inputs for mechanical properties, formation evaluation and seismic applications.

Tool Components

1) Transmitter section

The transmitter section contains three transmitter elements: one omnidirectional monopole ceramic transducer and two unidirectional wide-band electrodynamic dipole transducers oriented perpendicular to each other. Wide-band transducers are preferable to a single narrow-band source because they allow examination of the entire frequency spectrum without phase-matching problems at their resonant frequencies and are not subject to reduced output because of aging. A low-frequency pulse drives the monopole transducer for Stoneley wave excitation, and a high-frequency pulse drives it for compressional and shear measurements. A low-frequency pulse drives each dipole transducer for the creation of shear waves. In addition, a new low-frequency source option provides excitation below 1 kHz for extremely large holes and for very slow formations and shear waves.

2) Isolation joint

The isolation joint is a mechanical filter that keeps the transmitter signals from traveling up the tool.

3) Receiver section

The receiver section contains eight receiver stations spaced 6 in. apart and spanning 3.5 ft. Each station contains two hydrophone pairs: one oriented in line with the upper dipole transmitter and the other in line with the lower dipole transmitter. The outputs from each pair are differenced for dipole reception and summed for monopole reception. Receivers are carefully matched during manufacture.

4) Acquisition cartridge

The acquisition cartridge contains the circuitry to perform automatic gain control, digitize eight separate waveforms simultaneously, stack these waveforms from more than one firing and then transmit the signals uphole. Threshold detectors for recording amplitude threshold crossing times for each waveform are also present. These are for compressional first-motion detection and allow derivation of compressional slowness in a manner similar to the analog threshold detection scheme used in conventional sonic tools.

Explanation of Acoustic Wave Propagation

1. Monopole compressional and shear

Compressional and shear waves (sometimes referred to as p- and s-waves) are excited in the formation, along with various modes in the borehole, by a monopole source operating at high frequencies (typically 10-20 kHz). They propagate as body waves in the formation and along the borehole. As they do so, they leak energy (refract) back into the borehole, creating headwaves in the borehole fluid. Compressional waves propagate along the borehole in the direction of the borehole axis with minute vibrations (or displacements) of the formation in the same direction. Shear waves propagate in the direction of the borehole axis with minute radial vibrations of the formation.

Monopole shear waves have a lower velocity (higher t), generally a larger amplitude, and a slightly lower frequency than the compressional waves. Shear waves have a larger refraction angle than the compressional waves. The mud speed is usually nearly constant, so that the refraction angle depends on the phase velocity of the body wave in the formation. As the shear t becomes large (soft formations), less shear energy is refracted back into the hole. If the shear t surpasses the mud slowness (typically 190 sec/ft), none of the shear waves will be detected by the receivers.

2. Monopole Stoneley

At low frequencies, perhaps a few kHz, where typical wavelengths in the mud are greater than the borehole size, monopole signals are dominated by the Stoneley wave, a dispersive mode of the borehole. Stoneley waves are guided waves associated with the solid-fluid boundary at the borehole wall, and their amplitude decays exponentially away from the boundary in both the fluid and formation. At extremely low frequencies, the slowness of this mode approaches that of the tube wave, while at higher frequencies, it approaches that of the Scholte (planar interface) wave. It is most easily excited using a low-frequency monopole source. For all frequencies, the Stoneley slowness is determined predominantly by the mud and to a lesser extent by the formation compressional and shear slownesses, formation permeability, and other variables.

3. Dipole shear

In a dipole shear sonic tool, a directional (dipole) source and directional receivers are employed. The source is operated at low frequencies, usually below 4 kHz. Compressional and shear waves are excited along with a dispersive flexural mode of the borehole. The slowness of this mode has the same high-frequency limit as the Stoneley wave, but at low frequencies it approaches the formation shear slowness rather than the tube wave slowness.

The amplitudes of both the flexural and the shear wave are peaked in frequency, the flexural generally peaking higher. They fall off very rapidly toward low frequencies and more gradually toward high frequencies. The flexural mode dominates the response down to very low frequencies where the shear wavelength is several times the borehole diameter. At such low frequencies, the direct shear wave is the only appreciable feature on the waveform. However, the amplitude of the waves at these frequencies (below 1 kHz for a typical slow formation) is very low and noise is likely to be a problem. A practical frequency range is 1-4 kHz. In this range, the flexural mode dominates the signals, but travels at nearly the shear slowness. A continuous shear log then is obtained by measuring the flexural slowness at as low a frequency as is practical and applying a small correction.

In very fast formations, the dipole compressional signal is usually very weak and may not be visible. The flexural mode is very dispersive in fast formations, there being as much as a factor of two difference in slowness between low frequencies (shear slowness) and high frequencies (Scholte slowness, approximately the mud slowness). The flexural arrival is therefore quite long in duration and spreads rapidly as the transmitter receiver spacing is increased. Low-frequency components traveling near the shear slowness become well separated from the slower higher frequency components. Often the (nondispersive) shear headwave is detectable in fast formations.

In slow formations, the flexural mode is again dispersive, but to a much lesser extent. Typically, the ratio between the high- and low-frequency limiting values of the flexural slownesses is about 1.2 or less. The flexural arrival is shorter in time duration and the spectral content is concentrated at lower frequencies. As in the figure, a higher frequency compressional arrival is often visible in slow formations, and in large boreholes and very slow formations can become the largest amplitude event. A distinct shear headwave arrival cannot be detected in slow formations.

Slowness Time Coherence (STC) Analysis Acquisition Software

Slowness-Time Coherence examines each waveform set for coherent arrivals across the array. It does this by stepping a time window of fixed duration through a range of times across the waveforms and a range of slowness across the array. For each time and slowness step, the waveforms within the window are added or stacked and the corresponding stacked or coherent energy is computed. When the window moveout or slowness aligns with a particular component moveout across the array, the waveforms within the window add in phase, maximizing the coherent energy. Coherent arrivals are thus identified by maxima in the coherent energy.

The STC module is used to find and extract slowness (Dt) and other information about various coherent arrivals in the sonic waveforms. Then the STC computation performs a sequence of operations on a set of waveforms aimed at identifying coherent arrivals in the set and extracting their slownesses. The following steps taken are: Waveform filtering, Waveform stacking, Peak searching, and Labeling.

An additional step is needed to identify and separate the desired arrivals (flexural, compressional, shear, or Stoneley) from any others. This is done by the labeling algorithm part of the STC computation. The slowness, arrival time, and coherence of each arrival are examined and compared with the propagation characteristics expected of the compressional, shear or Stoneley waves for the given physical conditions. Classifying the arrivals in this manner gives a continuous log of wave-component slowness versus depth.

STC processing of high-frequency monopole waveforms generally results in compressional and shear slowness estimates in fast formations. Narrow band filtering is applied to low-frequency monopole (Stoneley) waveforms, since this mode is dispersive and we want to estimate slowness within a consistent band of frequencies. In slow formations, no shear slowness estimate is available from monopole waveforms.

1. Dipole labeling bias correction

In STC processing of dipole waveforms, a coherence peak corresponding to the dispersive flexural mode occurs at a slowness near that of the frequency of peak excitation after filtering. The estimate is therefore biased slower than the true shear, and must be corrected. The bias depends on the time signature of the source excitation, the filter characteristics, the borehole size and shear slowness. In slow formations, the correction is less than 10%, and usually much less. In fast formations, where the dispersion of the flexural mode is greater, a large correction is required only in large (>17 in.) boreholes. In a fast formation with a moderate hole size (<12 in.), very little or no bias is found.

2. Depth-derived borehole compensation

One way to obtain borehole compensation is to derive slowness (delta t) measurements from both upward and downward propagating waves. The effects of borehole size changes tend to have an opposite effect on the slownesses derived from each. The standard BHC tool accomplishes this by having a transmitter above and below the receivers. The Long Spaced Sonic (LSS) tool, though, simulates this with depth-derived borehole compensation. The DSI-2 employs the same depth-derived technique. Instead of having transmitters above and below the array, it constructs a pseudo-transmitter array from several tool positions as it moves up the hole. The pseudo-transmitter array looks like an array of transmitters with one receiver above. This approximates a single transmitter on top with a receiver array below.

Depth of Investigation/Eccentering Effects

Depths of investigation for sonic devices depend on the formation type, shear and compressional slowness, the transmitter-to-receiver spacing, wavelength of the wave considered and whether it is a head wave or a guided wave, the source frequency and signal types.

Frequency determines the wavelength that drives the depth of investigation of the measurement.

Typical sonic wavelengths at different frequencies and slownesses are shown in the "Additional Specifications" table. Low frequency penetrates deeper into the formation and helps read beyond altered zones.

Numerical simulations verified by measurements from scale models show that when eccentering is small compared to the borehole radius, there is little change in the character of the dipole waveforms or in the

STC-processed slowness values. Large eccentering, on the order of 2 to 4 in. in a 12-in. borehole, increases the flexural wave amplitude relative to the compressional. For the DSI-2 tool, the variation in the shear slowness estimate is ± 2 percent over the normal slowness range.

Log Presentation

Output plot of DSI-2 data

Specifications

Temperature Rating:	350° F (175° C)
Pressure Rating:	20 kpsi (13.8 kPa)
Tool Diameter:	3.375 in (8.57 cm)
Minimum Tool Length:	280 ft (85 m)
Sampling Interval:	1, 2 and 4 msec
Max. Logging Speed:	Stationary
Vertical Resolution:	N/A

Additional Specifications

Minimum Hole Size:	5.5 in (13.9 cm)
Maximum Hole Size:	21 in (53.3 cm)
Tool Length:	51 ft (15.5 m)
Maximum Logging Speed:	
One eight-waveform set (single mode)	3600 ft/hr
All six modes simultaneously, without 6-in delta t	1000 ft/hr
All six modes simultaneously, with 6-in delta t	900 ft/hr
Digitizer Precision:	12 bits
Digitizer Sampling Interval Limits:	Variable from 10 to 32,700 µsec per sample
Digitized Waveform Duration Limits:	Up to 15,000 samples / all waveforms

Acoustic Bandwidth:	
Dipole and Stoneley	80 Hz to 5 kHz
High-frequency Monopole	8 to 30 kHz
Combinability:	All MAXIS tools, any resistivity tool

Deployment Notes

Stuck/lost tool information

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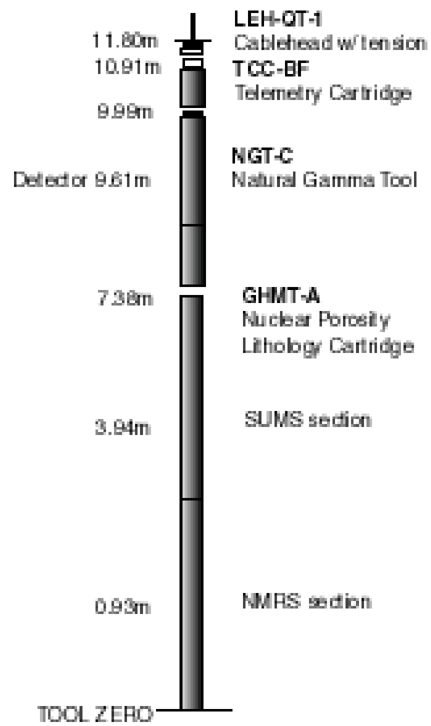
Triple Combo FMS/Sonic Specialty Other Toolstring Index

Geological High-Resolution Magnetic Tool (GHMT*)

Description



The Geological High-Resolution Magnetic Tool (GHMT) provides magnetic susceptibility and total magnetic induction measurements. The main use of the GHMT is to provide a magnetic reversal sequence in sediment.

The GHMT consists of two sondes. The Susceptibility Measurement Sonde (SUMS) makes an induction-type measurement to record a signal related to formation susceptibility. Its depth of investigation and vertical resolution are about 80 cm and 40 cm, respectively. The Nuclear Resonance Magnetometer Sonde (NMRS) is a high-precision nuclear magnetic resonance device, which accurately measures the total magnetic induction in the borehole. Its depth of investigation is theoretically infinite (most of the Earth's field is generated in the Earth's core) and its vertical resolution is about 45 cm.

Applications

Magnetostratigraphy

In order to obtain a magnetic reversal sequence, the total induction and the susceptibility are processed and combined to reveal the polarity of the remanent magnetization in the sediment. Normal polarity is in the direction of the present Earth's magnetic field; reverse polarity is in the opposite direction. The magnetic reversal sequence can be correlated to the geomagnetic polarity time scale (GPTS) for absolute formation dating, giving a formation depth-to-age conversion and sedimentation rates.

Paleoclimate

Magnetic susceptibility is often a good indicator of climatically induced lithological changes. It has been used in studies of sediment cyclicity, and usually represents either varying terrestrial sediment input, or varying dilution by, for example, carbonate.

Core-log correlation

Magnetic susceptibility measurements on both core and log are reliable and often display correlatable peaks, troughs, and trends. Thus it is a good parameter to use for correlation between core and log.

Environmental Effects

The method works best when the sediment's remanent magnetization is strong. The working range of the NMRS is from 27100 to 69400 nTesla. The magnetic field in some areas off South America is below this range. When the Earth's field inclination is + or - 35 degrees (approximately + or - 20 degrees of latitude), the susceptibility effect is zero and the polarity cannot be determined.

Log Presentation

Magnetostratigraphy is compiled from the susceptibility and total induction measurements, and is usually plotted to show the correlation or anticorrelation between the susceptibility and the remanence effects.

Magnetostratigraphy plot

Specifications

Temperature Rating:	125° C / 257° F
Pressure Rating:	20 kpsi (13.8 kPa)
Tool Diameter:	4 in (10.2 cm)

Tool Length:	27.4 ft (8.34 m)
Weight:	286 lb.
Range Full Scale:	NMRS from 27100 to 69400 nT
Accuracy:	NMRS 0.1 nT SUMS 0.000005

Deployment Notes

As of Leg 189, the GHMT can be combined with the DSI-2. The main advantages of this combination are: 1) it adds weight to the GHMT; 2) it avoids using the FMS in high heave and difficult hole conditions; and 3) it saves rig up time if the DSI-2 is run twice.

Stuck/lost tool information

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* ®trademark of Schlumberger

Other Equipment (cont.)

Fluid Seal and Torpedo

The fluid seal is used to prevent drilling fluid from being released in large quantities on the rig floor. The device consists of rubber packing element surrounded by a steel enclosure. The logging cable is passed through the seal prior to logging, and the tool string is then rigged up. Following the completion of tool rigup, the seal is slid down the cable and fastened to the logging pipe.

The torpedo is a small stainless steel connector used for connecting two pieces of logging cable. A good example is the connection between the cablehead pigtail and the logging cable. The torpedo consists of two symmetrical halves which make a small enclosure for establishing conductor continuity between each cable. Each piece of cable must contain a rope-socket and exposed conductors for the torpedo connection to be complete. A torpedo connection should not pass over a sheave.

MCM

Acquisition of log data is completed in the Minimum Configuration MAXIS (Multitask Acquisition & Imaging System) located just port and forward of the helipad. Presently, the MCM contains two VAX processors and numerous control and power modules which communicate with the downhole tools during logging. Real time displays of all log data may be viewed from here; thus, you will usually find the loggers here during logging operations. The MCM is capable of communicating with all labs and workplaces on the ship and an intercom link exists with the winch shack. A color plotter is available for producing log reprints.

Two views of the Minimum Configuration MAXIS (MCM) system.

Downhole Measurements Lab (DHML)

The logger's scientific domain aboard the *JOIDES Resolution* is the Downhole Measurement Lab (DHML). Located atop the lab stack, the DHML contains two Mac Computers, one PC for data acquisition, one Sun Ultra-Sparc and a Laserjet printer. The third party data acquisition system is housed in the DHML, as well as additional rack space for other equipment deployments.

Hand tools and supplies are furnished by LDEO-BRG.

Conical Sidewall Entry Sub (CSES)

The CSES was tested successfully on Leg 108. When inserted into the drill string, it allows one to add or remove drill pipe while a logging tool is downhole. The CSES 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.

Drill String Acceleration Tool / Core Barrel Temperature Tool

The Drill String Acceleration tool (DSA) is a modular downhole tool designed to acquire data near the bit in memory. The DSA is attached to virtually any core where it measures drillbit acceleration and vibration signals while drilling. The DSA tool contains a single axis high sensitivity accelerometer for heave measurements, a three-axial high frequency accelerometer for drillbit vibrations and a high resolution pressure sensor. For ease of deployment, the DSA has been designed as a removeable extension of the APC/XCB/RCB core barrels. Using standard threaded connections, the DSA will be attached to the top of a selected core barrel by a Core Tech prior to core barrel deployment. Except for the connection and disconnection of the DSA, coring activities will not be affected by the presence of the DSA. Upon DSA/core barrel retrieval, the DSA will be disconnected and the data downloaded to the third party data acquisition system in the DHML for immediate analysis.

The modular design of the DSA allows for customization of the sensor packages. The acceleration and pressure measurements may be swapped for high fluid temperature measuring equipment. In the high temperature fluid temperature monitoring mode, the tool name changes to the Core Barrel Temperature Tool (CBTT). Many additional measurement possibilities exist but have not been designed and implemented do date.

Other Equipment Continued

Triple Combo FMS/Sonic Specialty Other Toolstring Index

Other Equipment (cont.)

Miscellaneous

Winch

The winch is located at the aft end of the pipe racker and is controlled by either the assistant driller (AD) or the core tech (CT). An intercom link is used between the MCM and winch during logging operations. In contrast to most oilfield winches, the winch on the *JOIDES Resolution* is powered by electricity, not a diesel motor. This affords much smoother slow speed operation. The winch contains several cable sensing mechanisms, including two calibrated wheel depth encoders, which measure deployed cable length and cable speed. It also contains a tension gauge for surface cable tension.

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Calibration Equipment

Prior to the logging of each hole, the logging tools are subjected to calibrations to ensure that reliable quantitative data are obtained from the tools. The Schlumberger engineer will place sleeves on some tools to expose the sensors to known values of radiation, electrical resistance, distance etc. Other tools are placed within a tank for the calibration process. Seen in the picture are the radiation calibration tanks with tools inserted. The tools are routinely subjected to calibrations during the course of a leg. A master calibration is performed at the beginning of the leg and subsequent standard calibrations are performed before each logging run.

Density calibration tank.

Schlumberger engineer performing calibration tests.

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Lockable Flapper Valve and Go-Devil

The lockable flapper valve (LFV) is a component of the APC/XCB Bottom Hole Assembly (BHA). It is hinged and sprung on one side and is designed to prevent fluids from backflowing up the drill pipe.

Lockable flapper valve in the closed position.

Close-up view of the lockable flapper valve in the open position.

The LFV presents an obstacle for the logging operation, as a closed LFV could snag a tool string as it is withdrawn from the open hole into pipe. The LFV is engineered to pass tools through a diameter of 3-5/8" (3.625"), but to lock open or release with the passage of a 3-3/4" (3.75") tool. For this reason a go-devil (an attachment at the end of the tool string) is deployed to open the valve as the tool passes through downward. As the tool is withdrawn to the surface, the go-devil again closes the LFV. Certain tools (the GHMT, for example) can work as a go-devil because their diameter is very close to 3 3/4". Remember, when the RCB BHA is used, the LFV is not an issue. In RCB logging operations the bit is released either in the hole or on the seafloor, or is removed at the surface so logging tools pass through pipe with no other obstructions.

There are two methods for running the go-devil:

1. The go-devil is attached to the bottom of each toolstring (except the GHMT, which acts as its own go-devil), and the LFV is opened and closed for each logging run. The disadvantage of this is that it sometimes takes a few attempts to get the go-devil through the LFV.

2. The go-devil is pumped down on its own before logging, and the LFV stays open for all logging runs until closed by the GHMT passing upwards though it (the WST would either have to be run before the GHMT, or after, with another go-devil attached to it). The disadvantage here is that the hole cannot be deepened, because the go-devil is sitting at the bottom of it.

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Capillary Suction Tester

The Capillary Suction Testing (CST) equipment is used to measure the propensity of a clay to swell once it is introduced to fresh water. A slurry consisting of a portion of the core catcher with distilled water is prepared. This slurry is placed in the small stainless steel beaker seen in the picture at right. A piece of blotting paper is located underneath the beaker and below the clear plastic frame, which includes two electrodes. The slurry makes contact with the blotting paper and a "liquid front" moves outward from the beaker. The liquid front passes the first electrode and starts a timer (the black box seen in the picture). The liquid front passes the second electrode and stops the timer. The recorded time is directly related to the sample's swelling potential -- the greater the time, the higher the swelling potential is. This time can be reduced by adding KCl to the slurry. In samples where the clays are predicted to swell, KCl may be added to the drilling fluid in a percentage determined by the CST to inhibit swelling. The Operations Superintendent may ask the logger to conduct a CST on several samples to determine the likelihood of encountering a swelling clay during logging.

Other Equipment

Wireline Heave Compensator (WHC)

The wireline heave compensator (WHC) is an extremely important component in the wireline logging program, due to its role in preventing degraded data as a result of ship's heave. The WHC is a large hydraulic ram with a wireline sheave on one end and is designed to reduce the effect of ship's heave on the downhole tool. As the ship heaves with the billowing sea, an accelerometer located near the ship's center of gravity measures the movement and feeds the data in real time to the WHC. The WHC responds to the ship's heave by adding or removing cable slack to decouple the movement of the ship from the desired movement of the toolstring.

The WHC can adequately compensate in seas of 10 meters or less. Aborting the logging effort should be considered if the seas are greater than 10 meters, as the WHC could reach the end of its operating limits and automatically shut down. This could place the toolstring at risk. Should you be caught in a situation where the ship's heave is greater than 10m and a tool is downhole, you should increase logging speed to 1500 ft/hr to prevent the tool from traveling too far downward as the ship reaches the wave trough.

The WHC is LDEO property and therefore its status should be known and monitored by the logger. However, during logging events the assistant driller or Coretech will operate the WHC, so the logger will not always be directly involved. Also, ODP Logging Services employs a SEDCO mechanic to perform routine maintenance on the unit.

Hole Finder

The hole finder is a solid rubber extension that may be run at the end each tool string, excluding the GHMT, to assist the tool past ledges. Experience has shown that it only provides a real benefit in deviated holes, as it closely follows the curves of the borehole and guides the tool down. The Schlumberger engineer is responsible for maintaining and deploying this device. It is important to note that the TAP and TLT cannot be run when the hole finder is deployed.

Cableheads

Cableheads are used by all wireline logging tools to make a physical connection between the wireline and the tool string. Several different cablehead models exist, including ones with a cablehead tension measurement. The LEH-QT is the most widely used cablehead with tension measuring capability. Tension data are only available when the cablehead is connected to digital tools; therefore, tension data is not available for the WST.

Wireline

In ODP wireline logging operations, three types of logging cable are typically used. All are 15/32" in diameter and all contain 7 copper conductors. Differences in the cable insulation determine temperature rating.

The standard 7 conductor cable used in ODP is the Vector 7-46P. For moderately high temperature boreholes a short length of Vector 7-46NA is spliced to the main wireline.

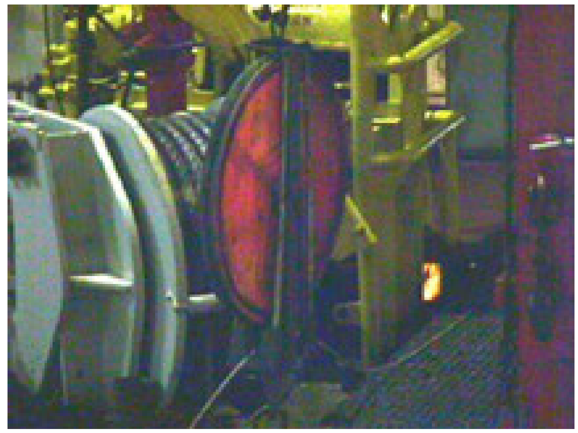
For detailed specs, click on the relevant cable type:

Cable	Insulation	Capacitance	Breaking Strength	Temp Rating
7-46P	Propylene	40 pf/ft	16,700 Lbf	300° F
7-46NT	Teflon	55 pf/ft	16,700 Lbf	450° F
7-46NA	Fluoropolymer	55 pf/ft	16,700 Lbf	450° F; 500° F up to 2 hrs

Sheaves

Sheaves (or pulleys) are used during the logging operation to route the wireline around bends and curves on the rig floor. Sheaves are located at the WHC, at the crown block and adjacent to the pipe racker. It is extremely important that these be given plenty of clearance when rigged to avoid personal injury!

Logging tool string with rigged-up sheave.



Another view of a sheave. (This is a night photo.)

Sources

Chemical and electrical radioactive sources are commonplace in ODP logging. Sources include:

Name	Type	Uses
Cesium 137	Chemical	LithoDensity tool and LWD-CDN
Americium-beryllium	Chemical	Compensated Neutron Porosity tool and LWD-CDN
Californium 252	Chemical	Geochemical tool
Minitron	Electrical	Accelerator Porosity tool and Geochemical tool

Sources are handled only by the Schlumberger engineer, including all permitting and paperwork. Should a tool containing a radio-source become stranded or lost downhole, appropriate actions such as tool fishing and well abandonment would occur. Please see the stuck/lost tool section.

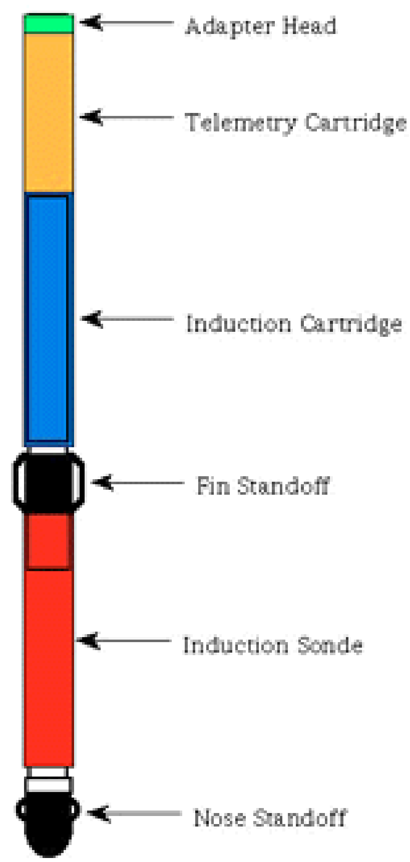
Other Equipment Continued

Triple Combo FMS/Sonic Specialty Other Toolstring Index

Phasor Dual Induction - Spherically Focused Resistivity Tool (DIT-E*)

Description

The Phasor Dual Induction - Spherically Focused Resistivity tool (DIT-E) 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. The induction sonde consists of a series of transmitter and receiver coils mounted on the sonde axis. The high frequency, alternating current of constant intensity sent through the transmitter coil produces an alternating magnetic field which in turn induces currents in the formation around the borehole. These currents flow in circular ground loops coaxial with the sonde. 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.



Sensor Geometry

In homogeneous formations with resistivity higher than 100 ohm m 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 ohm-m resistivities.

The thin bed resolution over a full range of formation conductivities has been greatly improved, due to an enhanced signal processing technique and real time correction for the effect of adjacent formations (shoulder effect).

Applications

- **Porosity estimate**
  In sediments that do not contain clay or other conductive minerals, the relationship between resistivity and porosity has been quantified by Archie's Law. Archie's Law relates the resistivity to the inverse power of porosity. This relationship has also been used to estimate 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.

- **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. In a particular example, the decrease in resistivity toward the top of a carbonate unit, coupled with a decrease in velocity, allowed one to interpret this unit 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.

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 it 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.

Log Presentation

Deep (ILD or IDPH) and medium (ILM or IMPH) induction, and spherically focused resistivity (SFLU), are usually plotted in ohm-m on a logarithmic scale along with gamma ray and caliper logs.

Output plot of DIT-E data

Specifications

Temperature Rating:	350° F (175° C)
Pressure Rating:	20 kpsi (13.8 kPa)
Tool Diameter:	3.375 in (9.21 cm)
Tool Length:	31.3 ft (9.6 m)
Sampling Interval:	6 in (15.24 cm)
Max. Logging Speed:	10,000 ft/hr
Vertical Resolution:	5-6 ft (1.5 m) and 7-8 ft (2m) for medium and deep induction logs; 2.5 ft (76) cm for spherically focused log.
Depth of Investigation:	(see discussion in "Description" section)
Formation Ohm Limits:	0-150 ohm-m

Output

ILD	Deep Induction (ohm)
ILM	Medium Induction (ohm)
IDPH	Phasor Deep Induction (ohm)
IMPH	Phasor Medium Induction (ohm)
SFLU	Spherically Focused Log (ohm)
ITEM	Internal Temperature (°C)

Deployment Notes

Typically run with IPLT components, the DIT can be substituted for the DLL or ASI if additional funding is available. The DIT has an internal temperature measurement which may be useful in high temperature environments.

Stuck/lost tool information

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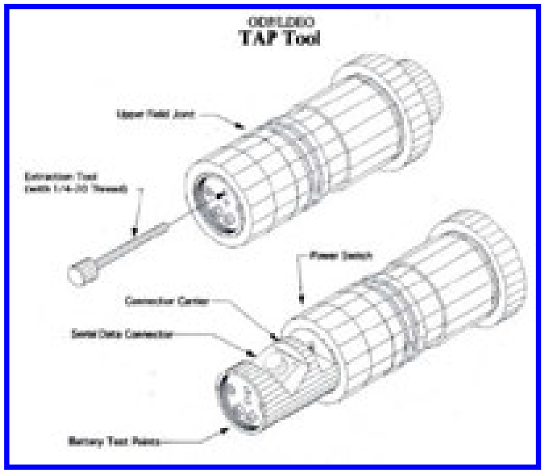
Temperature/Acceleration/Pressure Tool (TAP)

Description

The TAP (High Resolution Temperature / Acceleration / Pressure) tool was designed to acquire borehole temperature, tool acceleration and hydrostatic pressure data. It is the successor tool to the Lamont Temperature Tool (TLT).



The TAP tool may be run in either memory mode, where the tool is fastened to the bottom of the Triple Combo and data stored in the onboard memory, or it may be run in telemetry mode, where the tool is run alone and data is recorded in real-time by the third-party DAS (data acquisition system).

Fast and slow response thermistors are mounted near the bottom of the tool to detect borehole fluid temperatures at two different rates. The thinner, fast-response is able to detect small abrupt changes in temperature, the thicker, slow-response thermistor is used to estimate temperature gradient and thermal regimes more accurately. One pressure transducer is included to turn the tool on and off at specified depths when used in memory mode. Typically data acquisition is programmed to begin 100m above the seafloor.

A 3-axis accelerometer is also included to measure tool movement downhole. These data are expected to be instrumental in analyzing the effects of heave on a deployed tool string which will lead to the fine tuning of the WHC (wireline heave compensator).

When the tool is run in memory mode, the stored data are dumped to the third party DAS upon the tool's return to the rig floor.

At a meeting in January, 1999, the Scientific Measurements Panel (SCIMP) recommended **"that BRG-LDEO use the TAP tool routinely for the purpose of acquiring acceleration data and testing the efficiency of the WHC under different cable length and heave conditions. The Co-Chief scientists must be informed at the pre-cruise meeting at TAMU of the potential use of this tool and additional logging time that may result from the use of the tool."** Thus, the TAP tool must be run routinely in every hole. The acceleration log can aid in deconvolving heave effects post-cruise and it has proven at times to be critical data. In almost ALL cases, the 5-ft of log data that is missed can be compensated by drilling a rat hole below the target horizon. If hole depth is so tightly constrained that this is not possible, then a truly compelling reason should be provided (e.g. fault at TD, etc.).

Applications

Geothermics:
The recording of temperature provides an insight into the thermal regime of the formation surrounding the borehole. The vertical heat flow is estimated from the vertical temperature gradient combined with the measurements of the thermal conductivity from logs or core samples.

Hydrogeology:
Crust at mid-ocean ridge crests must be permeable to a considerable depth to allow for the efficient removal of heat by hydrothermal systems. Temperature logs in such an environment can clearly differentiate between the advective (hydrothermal) and conductive heat transfer regimes.

Environmental Effects

Drilling and circulation operations considerably disturb the temperature distribution inside the borehole thus preventing equilibrated temperature conditions. The amount of time elapsed between the end of drilling fluid circulation and the beginning of logging operations is not long enough to allow the borehole to recover thermally. Therefore the data recorded is not representative of the thermal equilibrium of that environment. In addition, the thermistors may become fouled with sediment from the drilled formation which reduces the sensitivity and accuracy of the recorded temperature data.

Log Presentation

Temperature data acquired by the fast and slow thermistors may be presented with resistivity, density and porosity log data. Temperature data may also be imported into GeoFrame for inclusion in plots made during the leg.

Specifications

Tool Length:	8.895 ft (2.71 m)
Tool Diameter:	3.25 in (8.26 cm)
Temperature Rating:	105° C / 220° F
Acceleration Measurement Range:	-2g to +2g
Acceleration Resolution:	1 mm/s^2
Acceleration Sampling Rate:	
Low Resolution Mode (LR):	4 Hz
High Resolution Mode (HR):	8 Hz
Temperature Measurement Range:	-4°C to +85°C
Temperature Resolution:	0.005 °C
Pressure Measurement Range:	0 to 10,000 psi
Pressure Resolution:	1 psi
Pressure Measurement Precision:	0.1% FS
Temperature / Pressure Sampling Rate:	1 Hz
Total Data Recording Time:	
HR mode	5 hrs.
LR mode	8 hrs.
Power Source:	8 alkaline batteries (D type)
Operation Time From One Set of Batteries:	approx. 40 hrs.

Deployment Notes

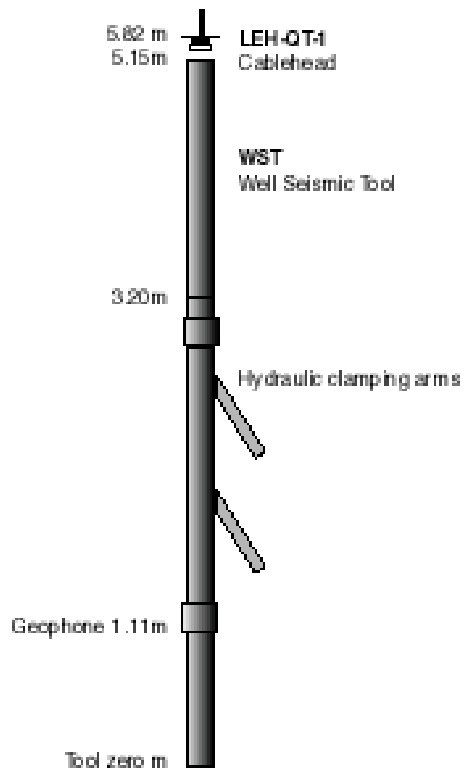
The TAP tool can be deployed in two modes, memory mode and telemetry mode. In memory mode, the TAP is deployed in the same fashion as the superseded TLT. This requires the logger to initialize the tool approximately 1/2 hour prior to rig up of the lower most Triple Combo tool, typically the DIT. Once initialized, the TAP tool should be placed on the deck outside of the DHML to be picked up by the roughnecks. The logger then must connect it to the bottom of the triple combo using a pin and rotating ring assembly. When the Triple Combo is retrieved to the rig floor, the Lamont logger must remove the TAP tool, wash it off and download the data.

When the telemetry cartridge is completed in mid FY 00, the TAP tool may be run in telemetry mode which precludes from running it with the triple combo. In telemetry mode, the TAP tool will be deployed in a similar fashion as a Schlumberger tool. The tool will be placed outside the DHML door for rigging by the rig floor crew. A tugger will hoist the tool for insertion into pipe where it will be held by the Schlumberger make-up plate. From here, the Schlumberger cable head will be fastened to the TAP tool with a standard Schlumberger field joint. The Logging Staff Scientist will then be responsible for conducting the entire logging operation for this tool. This includes coordination with the winch shack, rig floor and Schlumberger engineer. Detailed instructions for the telemetry mode deployment will be available following prototype field testing.

Well Seismic Tool (WST*)

Description

The WST is a Schlumberger single axis check shot tool used for zero offset vertical seismic profiles (VSP). The WST consists of a single geophone, pressed against the borehole wall, that is used to record the acoustic waves generated by an air gun located near the sea surface. A 120 in^3 air gun is suspended by buoys at a depth of 3 mbsl, offset 48.5 m from the hole on the portside. The WST is clamped against the borehole wall at intervals of approximately 50m, and the air gun fired five to seven times. The resulting waveforms are stacked and a traveltime is determined from the median of the first breaks in each trace. These check shot experiments attempt to reproduce the seismic reflection profiling by simulating a similar geometry and source frequency. In general, the acoustic velocities, and resulting depth-traveltime pairs, determined from the sonic tool differ significantly from the seismic velocities because of frequency dispersion (e.g. the sonic tool works at 10-20 kHz vs. 50-100 Hz in seismic data) and because the sound is forced to travel along the borehole wall, a path this is quite different from the one taken by the air gun signal generated during a seismic reflection survey. In addition, sonic logs are not obtained above the bottomhole assembly, and the traveltime to the uppermost logging point has to be estimated by some other means.



WST

Applications

Depth-traveltime pairs determined from check shots can be used to produce a depth-traveltime plot and to calibrate the sonic logs and determine accurate drilling depths and their relative position with respect to targets on the seismic reflection profiles.

Log Presentation

The first arrival times are plotted against depth (the time vs. depth data derived from core and log sonic velocity measurements can be displayed on the same plot). The interval velocities (gradients of the time vs. depth plot between WST stations) can be plotted in the same track as the sonic velocity log. Velocities are given in km/sec; arrival times are measured in either milliseconds or seconds.

If the WST waveforms have been processed as a zero-offset VSP by the Schlumberger engineer on the Maxis, the resulting seismogram can be plotted vs. two-way-time alongside the seismic section and the synthetic seismogram.

Specifications

Temperature Rating:	350° F (175° C)
Pressure Rating:	20 kpsi (13.8 kPa)
Tool Diameter:	3.625 in (9.21 cm)
Tool Length:	16.9 ft (5.15 m)
Sampling Interval:	~ 50m
Max. Logging Speed:	Stationary
Vertical Resolution:	N/A

Deployment Notes

The WST is run alone and placed at stations at regular intervals. At each station a seismic shot is produced at the sea surface using either air or water guns provided by TAMU. Schlumberger provides a blast hydrophone for synchronizing the gun pulse with the system timer.

The WST and other downhole seismic tools are sensitive to pipe noise and ringing of pipe following a shot. Efforts should be made to reduce pipe noise at each station. If time and resources permit, a drill string packer may be deployed to dampen the banging motion of the pipe against the borehole. Also it is always prudent to leave 50 to 75 m distance between the tool and the bottom of pipe.

For FY 99, the WST is a standard tool and can be deployed on any leg. The WST requires TAMU involvement to provide air or water guns as the energy source. At the beginning of each leg, meet with the TAMU techs to ensure that the guns can/will be ready for use. Typically, one week's notice is required before the guns can be used. If a WST tool deployment is not initially scheduled, plan on meeting with the co-chiefs to let them know that running the WST will require at least 7 days' notice prior to deployment.

The CSES should not be used with the WST for three primary reasons:

1. If the bottom of pipe is kept near the tool, it is likely that the tool will measure ringing in the pipe each time the gun is fired.
2. If a significant amount of pipe is downhole, there is a possibility that the pipe could generate noise in the data as the pipe bangs in the hole.
3. The WST is inherently risky to run because the tool is routinely stationary in a deteriorating borehole and must be clamped to the borehole creating additional risks. Use of the CSES may only exacerbate these risks by providing access to a hole that may be unsafe for the WST.

Stuck/lost tool information

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Triple Combo FMS/Sonic Specialty Other Toolstring Index

November 22, 1988

To: Operations Superintendents
From: Glen Foss
Subject: Wireline stripping operations

There are four basic scenarios for the recovery of a logging tool stuck in open hole:

1. The side entry sub is in the string and the cablehead weak point has not failed.
2. The cablehead weak point has failed (CSES not relevant in this situation).
3. The CSES is not deployed, and the cablehead weak point has not failed.
4. Both the tool and drill string are stuck (presence of CSES is very relevant).

Though there are risks to the tool in all the above situations, situation 1 is by far the least undesirable. The hazard to the tool is minimized, the cable is saved and very little operating time is consumed in the freeing of the tool. Pipe is simply added at the rig floor to bring the end of the drill string to the top of the stuck tool. The circulating head is installed, and the drill string is "washed over" the logging tool to free it. Care must be exercised to avoid putting too much tension on the cable if the tool does not enter the pipe easily. This can be tricky if there is any amount of vessel heave involved. Normally, it is prudent to start the tool into the pipe and then hold the pipe stationary and try to work the tool loose with the winch. That minimizes chances of damaging the tool or pulling out the weak point as the drill string is lowered past bow springs, retractable arms, etc.

Situation 2 is to be avoided if possible, but, if the weak point has failed in the open hole, an open hole fishing job is required. Depending on the circumstances, a wireline fishing job may be attempted before the more drastic round trip/reentry step is taken. In one case, an expensive logging tool was recovered by washing over the tool with the bit release top connector and then engaging the fishing neck of the tool with a "Larson" slip-type core catcher. There are risks of damaging the logging tool by applying too much string weight, deforming the fishing neck (jeopardizing subsequent fishing attempts), or bypassing the tool with the BHA and pushing it into the side of the hole. The conformation of the lower end of a bit release top connector makes it a less-than-optimum washover shoe. The wireline attempt is not recommended in a cased reentry hole, where chances of successful overshot fishing are excellent. In a single-bit hole, however, a free-fall funnel (FFF) and reentry into an uncased hole are required, with greatly reduced chances of reaching the fish in a clean hole. It is therefore an on-the-spot judgment call, and a wireline attempt before pulling out of the hole may be the more prudent course of action. ODP stocks grapples in 2-1/2" (fishing neck) and 3-3/8" (tool body) sizes for logging tools for the Bowen 9-1/2" overshot. The overshot is installed in place of a bit, a reentry is made and the entire drill string is lowered over the tool to engage the grapple. Circulation is maintained through this process, and successful engagement is signaled by increased pump pressure.

Situation 3 calls for a pipe-stripping operation by means of the Bowen ropesocket method. The cable must be cut at the rig floor, and that portion in the pipe is thereby sacrificed. Once the pipe has been stripped into the hole to just above the fish, the circulating head is installed and the washover operation is conducted as with the CSES. The logging tool and cable then can be recovered by the logging winch.

In situation 4 (without the CSES), the only alternative is to pull on the logging tool until it comes free or the weak point fails. If the weak point fails, a core barrel with slip-type core catcher can be run into open hole to attempt to engage the fishing neck. More pull can then be exerted with the coring line than with the logging line. If the CSES is installed, the situation is serious. With the current equipment and techniques, it would be necessary to pull on the cable until the weak point fails, pull the logging line until the torpedo connection reaches the CSES packoff and then drop the Kinley cutter and cut the logging line at the SES. The drill pipe severing tool could then be lowered as far as the logging line inside the pipe would permit to salvage as much drill pipe as possible. The logging tool would be lost. Note that this is the case even if the logging tool is not stuck, but the pipe is. The weak point simply does not enter into the operation, as there is no way to pull on it.

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Stuck/Lost Tools

Dangerous Logging Situations

Tool trapped between two closely spaced (<30m) bridges:
If the troolstring breaks through one bridge and then encounters another one less than about 30m beyond the first, cavings will accumulate between the two bridges while it is trying to get through the second bridge. The cavings can fill up the short interval between the two bridges. Then it is extremely difficult to even pull up again through the upper bridge, because there is nowhere to displace the cavings.

Solution:
Spend very little time trying to break through the second bridge. If unsuccessful after 5 minutes, give up and POOH (pull out of hole). In fact, when there are two bridges within a short interval, there are probably many more deeper in the hole. Alternative solutions: (a) switch to using the CSES; (b) do a wiper trip, then set pipe beneath the two bridges for further logging; (c) if the bridges are near the bottom of the hole, give up logging the deeper portion with this tool string, do a wiper trip, and start logging with the next tool string.

Tool stuck near hole bottom:
Getting the tool stuck between the bottom of the hole and a bridge near the bottom of the hole; or getting stuck by cavings at the bottom of the hole.

Solution:
Whether or not any deep bridges exist, spend as little time as possible near the bottom of the hole. As soon as bottom is reached while logging down, start moving upward slowly and continue upward during the time it takes for the Schlumberger engineer to set parameters for the upcoming run. When ready, go back down to bottom and immediately start logging up. Remember, cavings will almost always be accumulating at the bottom of the hole.

Getting trapped downhole by a bridge:
Getting trapped downhole by a bridge forming after you've already gone

down through it.

Solution:
This is always a risk and is not easily avoided. Bridges usually take 2-5 hours to form, so if you break down through a bridge, try to minimize the time spent by the logging tool beneath it. One risk that can be somewhat avoided is bridge formation at the bottom of the bottom hole assembly (BHA); this results from ship heave which causes the BHA to pack down the soft sediments. Move the pipe up 10-15m whenever possible (e.g., during tool run up and down and during logging) and then if a bridge forms, lower the pipe 10-15m to punch through it.

Tool breakoff during circulation:
Pumping mud or circulating with high water pressure while the tool is in the BHA can break off the tool at the weak point (e.g., Leg 114). The inside diameter of the BHA is only slightly larger than that of the logging tool, so fluid flow is highly constricted between the two. Rapid pressure buildup occurs, blowing off the tool.

Solution:
Don't pump mud while the tool is in the BHA. Either raise the tool into the larger-diameter pipe above the BHA, or (less desirably) lower the tool into open hole. Occasionally it can be difficult getting the BHTV out the end of pipe, and an extra push was needed from circulating sea water to get it out. When using the CSES and moving the pipe up and down, mud plugs form within the BHA or even higher in the pipe. There is no choice but to run the tool down while circulating cautiously, to try to punch out.

Breaking off the tool by pulling too hard:
The tool can be broken off the weak point by pulling too hard when it is stuck either on a bridge or entering pipe. This can happen inadvertently, if the winch operator is not watching cable tension and neither the Logging Scientist nor the Schlumberger engineer notices the tension increase on the dial or oscilloscope log display. It can happen deliberately, if you get stuck on a bridge or at the base of pipe and try too hard to pull your way out.

Solution:
Watch the log oscilloscope display while logging up for any quick ramping up of tension. When entering the pipe, watch the tension gauge instead of the oscilloscope, because there is a substantial delay before tension data are displayed on the scope. Remember that many pulls will weaken the weak

point.

Breaking the tool when turning on the WHC:

Turning on the WHC (wireline heave compensator) when the tool is in the air or barely lowered into the pipe can break the tool. Very rarely, the WHC will jerk when it is turned on, and this jerk can sever the tool at the weak point.

Solution:

Wait until the tool is several hundred meters down the pipe (but not in the BHA) or well into open hole (not barely past the bit) before turning on the WHC.

Jamming the BHA with mud:

When using the CSES, the bottom hole assembly becomes jammed with mud while lowering pipe with the logging tool in open hole.

Solution:

The tool must always be up in pipe when lowering the pipe.

Severing the cable by rotating the pipe while the cable is clamped to the CSES:

When rigging up the LDT combo with the CSES in place, the rig hands twist the pipe string to join it to the CSES. Because the LDT bow spring prevents free rotation of this tool in pipe, rotating the pipe while the cable is clamped to the CSES will unravel and possibly sever the cable. Yet the pipe must be rotated to tighten the threads between pipe and CSES.

Solution:

There is no easy solution at present. Fortunately, the LDT is seldom used now that we have the HLDT, and most of the other tools do not drag on pipe (the neutron eccentralizer could be a problem, but it, too, is seldom used. Option 1 is to put the swivel into the top of the tool string. Before logging, ask the Schlumberger engineer whether there is a working swivel aboard, filled with oil. The disadvantage of a swivel is that sometimes it will short out downhole. Option 2 is to make up the pipe to the CSES horizontally, with the pigtail unclamped at the CSES so that it can rotate freely to avoid torquing the cable. Then clamp the pigtail and pick up everything, joining the drillstring to this pipe joint.

Excess cable spooling after the tool has set down:
Sometimes cable continues to spool out inadvertantly after the logging tool has set down on a bridge. At 600 m/hr, a one-minute delay in detecting tool setdown means 10m of excess cable that will accumulate just above the logging tool. The cable may fold (so that it cannot get back into pipe) or it may kink (causing a short or greatly decreasing breaking strength). Yet tool setdown is not always easy to detect, since in a tight hole the effective weight of a tool string varies from several hundred pounds to zero (compared to 5-10,000 pounds cable weight).

Solution:
If logging down with Schlumberger tools, setdown is easy to see on the oscilloscope as a sudden straight-lining of log responses. However, straight-lining of the deepest tool on the string will not be visible until about 15m of excess cable is unspooled, because of recording delay. With specialty tools or when not logging while going down, setdown is detected only on the tension meter (especially on the increment dial). Fortunately, bridges are most likely on the first run (seismic stratigraphic combo) and the gamma ray can be monitored while the winch operator watches the tensiometer. The increment dial must be watched carefully through the last 200m of pipe and BHA if the CSES is in use. Mud plugs are likely, and pipe diameter is so narrow (compared to open hole) that even a few meters of excess cable can cause a kink.

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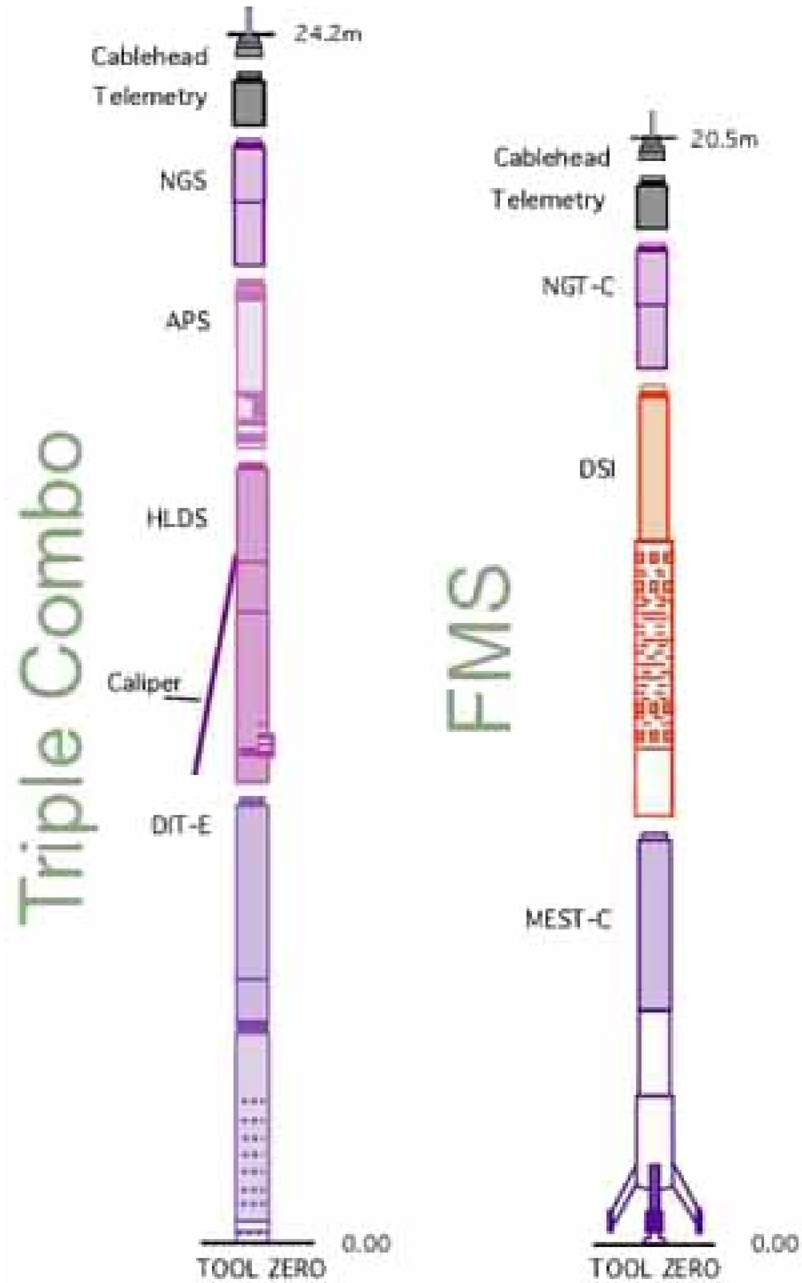

24.2m
Cablehead
Telemetry
NGS
APS
HLDS
Caliper
DIT-E
Triple Combo
0.00
TOOL ZERO
20.5m
Cablehead
Telemetry
NGT-C
DSI
FMS
MEST-C
0.00
TOOL ZERO

Table 1 : Specifications of downhole tools employed during Leg 178

Tool String	Tool	Measurement	Sample Interval (cm)	Approx. Vertical Resolution (cm)
Triple Combo (total length ~ 32m)	HNGS* APS* HLDS* DIT-E* TLT	Natural Gamma Porosity Bulk Density, PEF Resistivity Temperature	15 5 and 15 2.5 and 15 2.5 and 15 1 per second	45 30 15 / 45 200 / 150 / 75 ---
FMS/Sonic (total length ~ 26m)	NGT* GPIT* SDT* FMS*	Natural Gamma Tool orientation Sonic Velocity Resistivity Image	15 15 15 0.25	45 --- 120 0.5
GHMT	NGT* SUMS* FMS*	Natural Gamma Susceptibility Total Field	15 5 and 15 5 and 15	45 35 45
WST	WST*	Sonic Travel Time	---	---

* ®trademark of Schlumberger

Table 2 : Schlumberger tool and measurement acronyms

Tool	Output	Explanation	Units
HNGS*		**Hostile Environment Natural Gamma Sonde**	
	HSGR	Standard (total) Gamma Ray	gAPI
	HCGR	Computed Gamma Ray (HSGR minus U contribution)	gAPI
	HFK	Formation Potassium	fraction
	HTHO	Thorium	ppm
	HURA	Uranium	ppm

Tool	Mnemonic	Description	Units
NGT*		**Natural Gamma Ray Tool**	
	SGR	Standard (total) Gamma Ray	gAPI
	CGR	Computed Gamma Ray (SGR minus U contribution)	gAPI
	POTA	Potassium	%
	THOR	Thorium	ppm
	URAN	Uranium	ppm
APS*		**Accelerator Porosity Sonde**	
	APLC	Near/Array Porosity (Limestone Corrected)	fraction
	FPLC	Near/Far Porosity (Limestone Corrected)	fraction
	SIGF	Neutron capture cross section of the formation	c. units
	STOF	Tool Standoff (computed distance from borehole wall)	inches
HLDS*		**High Temperature Litho-Density Sonde**	
	RHOM	Bulk density (corrected)	g/cm^3
	PEFL	Photoelectric effect	barns/e-
	LCAL	Caliper -- measure of borehole diameter	inches
	DRH	Bulk density correction	g/cm^3
DIT-E*		**Dual Induction Tool**	
	IDPH	Deep Induction Phasor-Processed Resistivity	ohm-m
	IMPH	Medium Induction Phasor-Processed Resistivity	ohm-m
	SFLU	Spherically Focussed Resistivity	ohm-m
GHMT*		**Geologic Magnetic Tool**	
	MAGS	Magnetic Susceptibility (limited range)	ppm
	RMGS	Low Resolution Magnetic Susceptibility (wider range)	ppm
	MAGC	Earth Conductivity	ppm
	MAGB	Earth Total Magnetic Field	nT
SDT*		**Digital Sonic Tool**	
	LTT1-4	Transit times (10, 8, 12, 10 ft spacings)	µsec
	DTLF	Slowness (12 minus 10 ft travel times	µsec
	DTLN	Slowness (10 minus 8 ft travel times)	µsec

* ®trademark of Schlumberger

Accelerator Porosity Sonde (APS*)

Description

The APS sonde is the key module in the Triple Combo's IPL components. The powerful electronic neutron source (minitron) allows epithermal neutron measurements and detector shielding, resulting in porosity values that are less influenced by environmental conditions. The near-array ratio epithermal porosity is the primary porosity measurement. Its source-to-detector spacing is optimized to yield a formation hydrogen index measurement that is essentially free of formation matrix density effects. Five detectors provide information for porosity, gas detection, shale evaluation, improved vertical resolution and borehole corrections.

Applications

Porosity

In reservoir engineering the importance of porosity measurements is quite evident. In the study of the volcanic rocks that make up the upper oceanic crust, a good in-situ porosity measurement is critical to the correct understanding of the crustal structure, for two reasons: 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 second, 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.

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).

Environmental Effects

Eccentralization of the tool by a bow spring is the most important requirement to obtain reliable porosity measurements. The triple combo string utilizes an in-line eccentralizer to maintain consistent contact with the borehole wall. The eccentralizer is vital in preventing poor contact of the tool with the borehole wall, which can lead to attenuation of the formation signal by the borehole fluid and, in turn, the overestimation 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, an increased porosity reading will result, its degree depending on the thickness of the pipe.

Log Presentation

The APS is recorded in linear porosity units for a particular lithology (limestone, sandstone, dolomite). The Near/Array Limestone Porosity Corrected (APLC) is usually displayed. When APS is run in combination with the lithodensity and spectral gamma ray tool the porosity and density curves are usually displayed in the same track, with gamma ray and caliper curves in a separate track.

Specifications

Temperature Rating:	175° C / 350° F
Pressure Rating:	20 kpsi (13.8 kPa)
Tool Diameter:	3.625 in (9.2 cm)
Tool Length:	13 ft (3.96 m)
Sampling Interval:	6 in (15.24 cm)
Max. Logging Speed:	1,800 ft/hr
Vertical Resolution:	2 in. (5.08 cm)

Output

APLC	Near/Array Limestone Porosity Corrected (decimal fraction)
STOF	Computed Standoff
SIGF	Formation Capture Cross Section (cu)
AFEC	Far Detector Count Rate (cps)
ANEC	Near Detector Count Rate (cps)

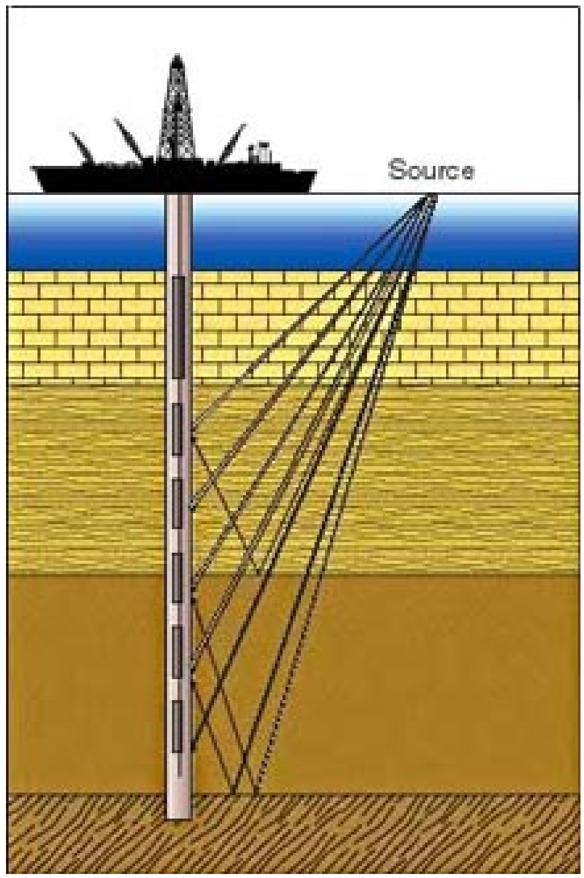
Deployment Notes

Stuck/lost tool information

* ®trademark of Schlumberger

Array Seismic Imager (ASI*)

Description



The Array Seismic Imager (ASI) consists of an array of five seismic shuttles linked by a bridle to a signal-conditioning cartridge. Each shuttle sensor package contains three mutually orthogonal geophones fixed relative to the sensor package geometry. One geophone lies along the axis of the package (z-axis); the other two geophones (x- and y-axes) form a 45°angle relative to the clamping direction. This design allows the ASI tool to operate in wells with a 90° deviation while not exceeding the 45°limitation of the X and Y geophones. For the study of anisotropy and analysis of split shear, these features make the ASI tool reliable in both vertical and deviated wells, with consistent X and Y component response.

The ASI tool is unique in that it ensures consistent, lengthy coupling periods during downhole seismic acquisition, both in vertical and deviated wells. This feature makes the ASI tool ideal for 2D and 3D time-lapse borehole seismic surveys, reservoir monitoring applications and amplitude variation with offset (AVO) calibration walkaways.

Applications

The ASI can acquire three-dimension walkaway vertical seismic profile (VSP) surveys in both vertical and deviated wells. One of the primary benefits to ODP is its low deployment time, since multiple geophones are deployed simultaneously.

Specifications

Temperature Rating:	350° F (175° C)
Pressure Rating:	20 kpsi (13.8 kPa)
Tool Diameter:	3.375 in (8.57 cm)
Minimum Tool Length:	280 ft (85 m)
Sampling Interval:	1, 2 and 4 msec
Max. Logging Speed:	Stationary
Vertical Resolution:	N/A

Deployment Notes

The standard ASI tool can be used in cased holes without special equipment. Adding a bowspring assembly allows surveying of open holes from 8 1/2 to 13 in.

Stuck/lost tool information

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* ®trademark of Schlumberger

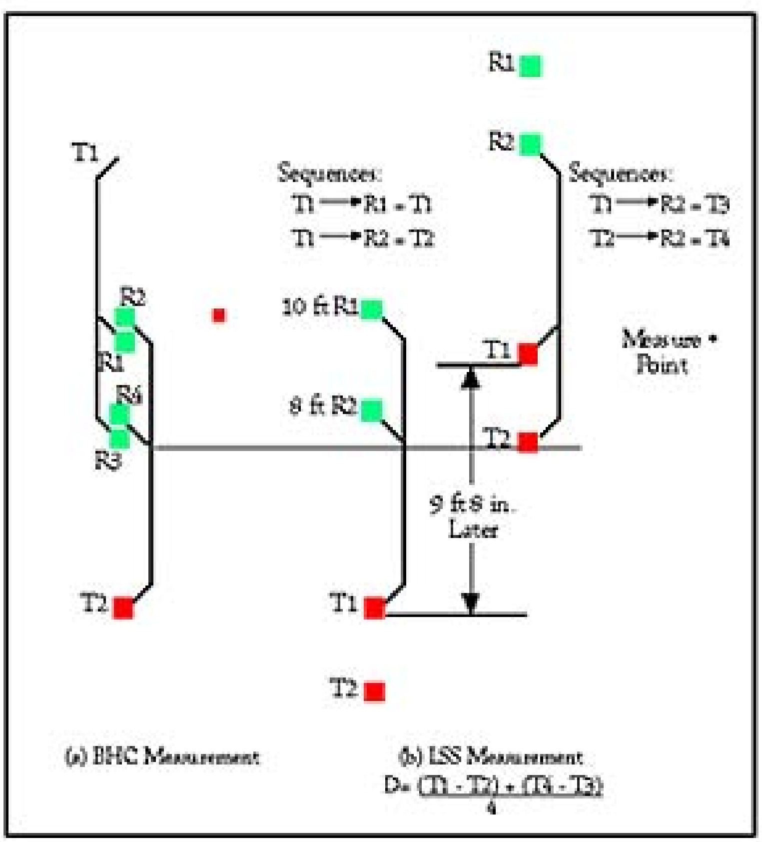
Backup Sonic Tools

Description

Borehole Compensated Tool (BHC*)

The BHC sonde measures the time required for a compressional sound wave to travel through one foot of formation. The BHC consists of an upper and lower transmitter arranged symmetrically on either side of two pair of receivers. The spacings 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:

$$dt=1/2\ (T_1R_3-T_1R_1+T_2R_2-T_2R_4)$$

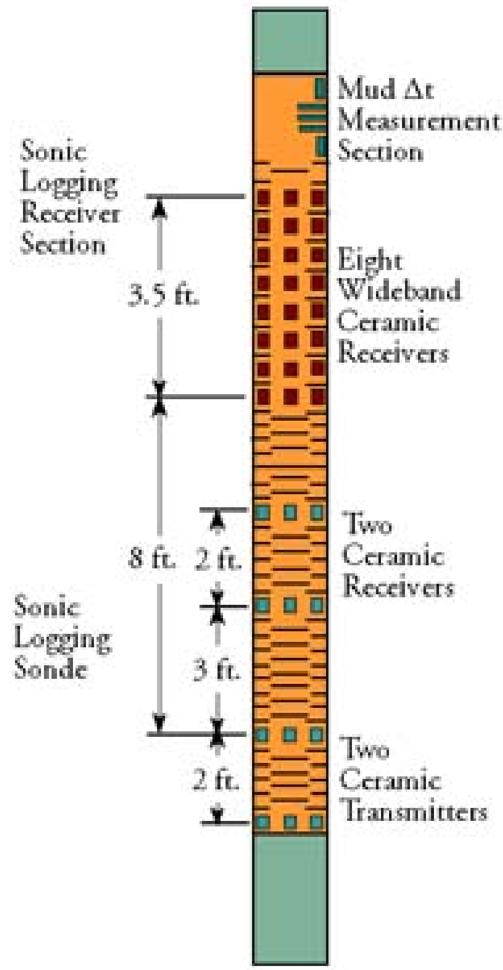


Long Spacing Sonic (LSS*)

The LSS relies on the "depth derived" borehole compensation principle because the sonde would be too long if it used the same configuration as the BHC tool. Two transmitters spaced two feet apart are located eight feet below two receivers which are also two feet apart. Hole size compensation is obtained by memorizing the first DT reading and averaging it with a second reading measured after the sonde has been pulled up to a fixed distance along the borehole. The LSS provides an improved measurement of the sonic travel time. Thanks to its longer spacing (10-12 feet) the sonde has a deeper investigation depth and the measurement is not influenced by the altered zone close to the borehole. In fact, drilling operations in the altered zone produce a decrease of acoustic velocity below that of the virgin zone. Full waveforms are always recorded for each receiver. Shear velocity can be recorded with delay beyond P-wave arrival during a separate run.

Array Sonic (SDT*)

In a fast formation, where shear velocity is faster than the velocity of the drilling fluid, the SDT obtains direct measurements for shear, compressional, and Stoneley wave values. In a slow formation, the SDT obtains real-time measurements of compressional, Stoneley, and mud wave velocities. Shear wave values can then be derived from these velocities. The multireceiver sonic tool, with its linear array of eight receivers, provides more spatial samples of the propagating wavefield for full waveform analysis than the standard two-receiver tools. This arrangement allows measurements of wave components propagating deeper into the formation past the altered zone.



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 ft, 8-10 ft, and 10-12 ft the depth of investigation ranges from 2 in to 10 in (altered/invaded and undisturbed formation, respectively), 5 in to 25 in, and 5 in to 30 in. The vertical resolution is 2 ft (61 cm).

Applications

Porosity and "pseudodensity" log

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

Seismic impedance

The product of compressional velocity and density is useful in computing synthetic seismograms for time-depth ties of seismic reflectors.

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.

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.

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 dt to be too high. This problem can also be related to the presence of fractures or gas.

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 dt to be too low.

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

Log Presentation

DT and DTL are interval travel-times in microseconds per foot for the near and far receiver pairs, respectively. In very slow formations DTL provides the more reliable measurement as the refracted wave is not seen at the near receivers. The acoustic data is usually presented as compressional (Vp) velocity and, where available, as shear velocity (Vs) in km/s.

Output plot of acoustic data (shallow depth)
Output plot of acoustic data (deep water).

Specifications

Temperature Rating:	175° C / 350° F
Pressure Rating:	20 kpsi (13.8 kPa)
Tool Diameter:	3.625 in (9.2 cm)
Tool Length:	37.9 ft (11.6 m)
Acoustic Bandwidth:	5 kHz to 18 kHz
Waveform Duration:	5 ms nominally, 10 ms maximum
Sampling Interval:	6 in (15.24 cm)
Max. Logging Speed:	1,700 ft/hr for eight-receiver array

Deployment Notes

Stuck/lost tool information

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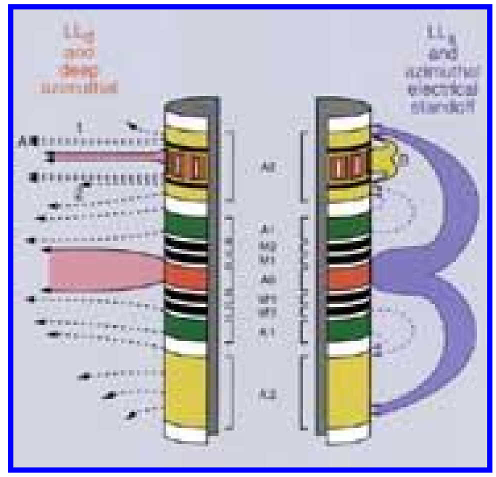
* ®trademark of Schlumberger

Azimuthal Resistivity Imager (ARI*)

Description



The Azimuthal Resistivity Imager (ARI) is a new generation of laterolog tool that makes deep measurements and azimuthal resistivity images around the borehole. Using these data it is possible to analyze features and details that escape conventional resistivity measurements: thin beds (down to 8 inches), borehole formation heterogeneity, formation dip, resistivity in dipping beds, and fracture position and orientation. The ARI produces images similar to the FMS with coarser vertical resolution, but complete azimuthal coverage. Whereas FMS electrodes are pad-mounted and in contact with the borehole surface, the ARI provides a remote image of the formation in a similar way to that of the BHTV.

The ARI electrode array operates at 35 Hz for the deep readings and focuses currents that flow from the 12 electrodes to the grounded logging cable. The sum of these 12 readings produces a high-resolution measurement, equivalent to a single laterolog electrode of the same height. To correct for tool eccentralization and variations in borehole shape, a shallow auxiliary measurement of electrical resistivities is performed at a much higher frequency of 71 kHz. This measurement responds primarily to the volume of borehole fluid affecting each electrode. If the borehole fluid resistivity is independently measured, then borehole size and shape can be deduced from the auxiliary array measurements. While the vertical resolution of the standard laterolog readings is about 0.60 m, the high-resolution array can reduce this by up to a factor of 6, depending on the formation resistivity.

Preliminary processing of ARI images may be accomplished using

GeoFrame, a software package developed by Schlumberger and GeoQuest, in a similar manner to FMS image processing. Comparison of image data from different logging tools can also be displayed using this software, which may provide information about fracture and fault orientation and aperture, formation dip and heterogeneity, and borehole shape. As the FMS is less sensitive to features near the borehole than the FMS, such as drilling-induced fractures, the origin and lateral extent of such features may be determined from the comparison of FMS and ARI images.

Applications

Fractures
The response of each of the 12 electrodes is strongly influenced by conductive fluid-filled fractures, and each log trace is affected by its position and orientation in relation to the fractures. Deep fractures can be clearly identified and are differentiated from the shallow drilling-induced cracks to which the tool is insensitive.

Formation heterogeneity
Average resistivity can be strongly affected by formation heterogeneities. In such cases, the azimuthal images from the ARI tool help interpret the resistivity log.

Formation dip
ARI images can give a good estimate of formation dip, although they cannot provide dipmeter accuracy. They may detect unexpected structural features such as unconformities and faults, and they help confirm expected features.

Resistivity in dipping beds
ARI electrodes facing along the strike of the formation dip are barely affected by anistropy of the apparently dipping layers. Selecting the readings from these electrodes gives a much more accurate resistivity in thin dipping formations.

Specifications

Temperature Rating:	350° F (175° C)
Pressure Rating:	20 kpsi (13.8 kPa)

Tool Diameter:	3.625 in (9.21 cm)
Tool Length:	33.2 ft (10.12 m)
Sampling Interval:	6 in (15.24 cm)
Max. Logging Speed:	1800 ft/hr (550 m/hr)
Resistivity Range:	0.2 to 100,000 ohm-m
Vertical Resolution:	8 in.

Output

ARI output plot

Deployment Notes

The ARI may be deployed in the Triple Combo, where it replaces the Dual Induction Tool (DIT-E), in several other combinations, or deployed independently. However the ARI must be used with the GPIT for image orientation, as is the case for the FMS tool. Repeat passes of the ARI may be useful to obtain consistent azimuth measurements.

Stuck/lost tool information

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Cyclicity in Logs

Introduction

Milankovitch orbital cycles (eccentricity at periods of 95K, 123K, and 410K; obliquity at 41K; and precession at 19K and 23K) are expected in logs of pelagic sediments for the following reasons:

1. Orbital changes cause global or regional climatic changes.
2. Climatic changes affect the mineralogy or porosity of the sediments.
3. Logs detect mineralogy and porosity changes.

(See figure)

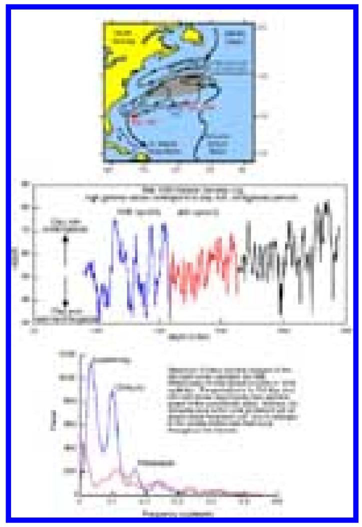
The cycles may appear on different logs in different regions (so far we have had success with gamma, density, resistivity, magnetic susceptibility, and sonic logs), and it is possible that different logs from the same well will show energies at different Milankovitch periods.

The climate system also varies on sub-orbital time scales, and this climate variability is similarly reflected in the composition and physical properties of the sediments. In regions where the sedimentation rate is high enough, or conversely in logs with sufficient vertical resolution, the millennial scale variability can also be documented.

There are several prerequisites to successfully identifying any climate cycle through spectral analysis. First, log display makes a difference. A log plot that shows broad compaction trends may obscure fine-scale Milankovitch cycles. Second, accurate sedimentation rates are needed for confirmation that any detected periodicity is at Milankovitch frequencies. Reversal stratigraphy gives more accurate sedimentation rates than paleontology, because the latter has errors at both datums that blow up when calculating a sedimentation rate. Lacking precise sedimentation rates, one will need to detect at least two Milankovitch periods (preferably in more than one log) before any confidence can begin to be placed in them. Third, a high sedimentation rate is needed for logging tools with 0.5 vertical resolution to detect high frequencies (e.g. 19K, 23K, and 41K). Fourth, beware of cycles caused by local sedimentary phenomena (e.g. turbidites) rather than climate: the depth period of the latter will change with the sedimentation rate, but not the former. Keep in mind that the 41K cycle is the only truly constant period for all ages. Eccentricity strength varies somewhat between 95K and 123K as a function of time, and precession strength varies between 19K and 23K (although ideally one would find separate eccentricity peaks and separate precession peaks). Also, the shortest periods are the most likely to be smeared by small changes in sedimentation rate within a log interval.

Spectral analysis is the most common means of characterizing periodicity in logs and can be undertaken with either depth or age as the independent variable. Ultimately, however, a conversion from depth scale to age must be performed in order to understand the driving forces behind the variability. There are a large number of programs available on various platforms that easily allow spectral analysis to be performed. Perhaps the easiest and most commonly employed (and accepted) method is to use the Macintosh program Analyseries to perform the analysis. In order to generate power spectra in Analyseries you need to do the following:

1. Generate a tab delimited text data file for the mac with the first column as depth (or age)
2. Import it to Analyseries (open it from within the application)
3. Select (click on) the data you wish to analyze and choose a method from the "Math" menu. Blackman Tukey is the most common method used by geologists/paleoceanographers, but a variety of methods should be compared to insure that the results are robust. The Blackman-Tukey method is nice because, unlike some other methods, it gives confidence estimates for the results.
4. The resulting (frequency vs. power spectra) output can be copied and pasted into any spreadsheet program or plotted directly in Analyseries.



Example of spectral analysis figure. (Click to enlarge.)

Tuning

Once Milankovitch cycles have been positively identified in the logs, the regular pacing of these records can be used to refine or "tune" the timescale by correlating the climate driven cycles to the astronomical forcing. Such correlations are capable of producing much more accurate and highly resolved age models than are obtainable by other methods. Furthermore, with a high-resolution timescale, it becomes possible to make phase estimates for the relative responses of the different components of the climate system, and to determine the rates of various geologic processes.

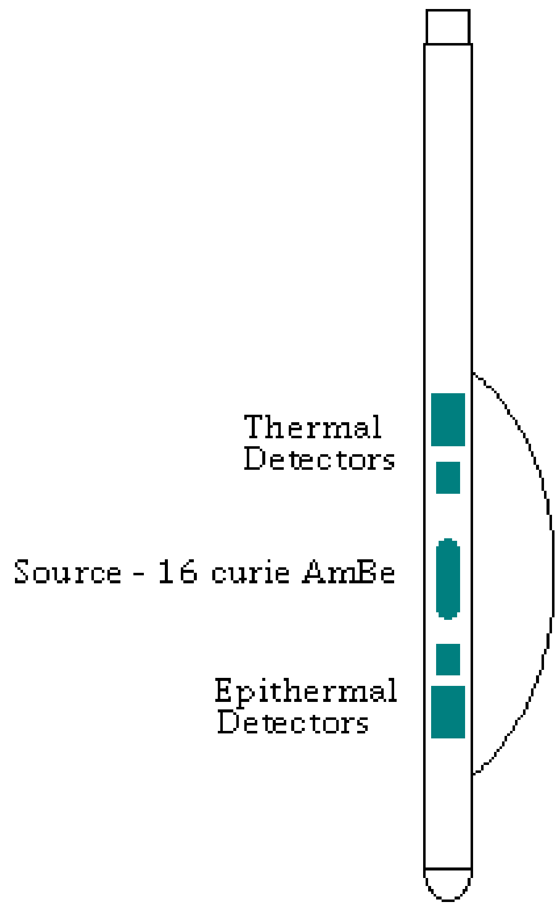
The SAGAN program, designed to correlate core and downhole log records, is also capable of automatically (by maximizing coherence) or manually (by graphical selection of tie points) correlating logs to insolation records. In this way it is possible to generate a highly resolved age-depth model for a well in a matter of minutes. However, any age model generated by tuning in this fashion should be considered tentative because although a high coherence is good for estimating the success of tuning, it is not necessarily an indication of the degree of common amplitude modulation (a basic test of whether the tuning is correct). Instead, other methods such as complex demodulation, which assesses the relationship between amplitude modulation in both the data and the inferred forcing, are necessary to evaluate the validity of the timescale [Shackleton et al., 1995].

Back to
Toolstring Selection

ODP Logging Staff Scientist | Selecting Toolstrings | Estimating Log Times | Pre-Cruise Meeting

Dual Porosity Compensated Neutron Log (CNT-G*)

Description



In the Dual Porosity Compensated Neutron log (CNT-G) a radioactive source mounted on the sonde emits fast neutrons which are scattered and slowed down by collisions with the nuclei in the formation. Whenever they reach the "thermal"energy level they are captured by the nuclei of atoms such as hydrogen, chlorine and silicon, and gamma rays of capture are emitted. Two pairs of detectors measure both epithermal (intermediate) and thermal (slow) neutrons. The epithermal detectors are spaced closer to the source than the thermal detectors in order to maintain a good statistical precision in the count rates. A new data processing method utilizing the individual count rates rather than their ratios is used to derive porosity. This technique minimizes the environmental effects on the response of the epithermal detectors due to their closer spacing from the source and provides better porosity measurements in shaly formations.

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 porosities ranging from 0 to

30% the depth of investigation varies from 2 ft (61 cm) to about 6 in (15 cm). The vertical resolution is 1.5 ft (46 cm).

Applications

Porosity

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.

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).

Environmental Effects

Eccentralization of the tool by a bow spring is the most important requirement to obtain reliable porosity measurements. This is not routinely performed in ODP boreholes because of the increased risk of getting the tool stuck in the drill pipe. 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 pipe.

Log Presentation

The CNT-G is recorded in linear porosity units for a particular lithology (limestone, sandstone, dolomite). The thermal porosity curve (NPHI or TNPH) is usually displayed. When the CNT-G is run in combination with the lithodensity and spectral gamma ray tool the neutron and density curves are usually displayed in the same track with Gamma Ray and Caliper curves in a separate track.

CNT-G output plot

Specifications

Temperature Rating:	400° F (205° C)
Pressure Rating:	20 kpsi (13.8 kPa)
Tool Diameter:	3.375 in (8.6 cm)
Tool Length:	16.6 ft (5.06 m)
Sampling Interval:	6 in (15.24 cm)
Max. Logging Speed:	1,800 ft/hr
Vertical Resolution:	1.5 ft (46 cm)
Depth of Investigation:	See text in "Description" section

Deployment Notes

Stuck/lost tool information

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Triple Combo FMS/Sonic Specialty Other Toolstring Index

Dual Laterolog (DLL*)

Description

The Dual Laterolog (DLL) 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); 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 has a response range of 0.2 to 40,000 ohm-m, whereas the DIT has a range of 0.2 to 2,000 ohm-m. The DLL is recommended for igneous environments (e.g., oceanic basalts and gabbros) because the resistivities can be higher than the upper limit of what the DIT can measure (e.g., Hole 735B). However, in upper crustal environments (seismic Layers 2A and 2B), the resistivities are usually low enough that you can use the DIT. This was the case in data from, for example, Legs 104 and 152 as well as Holes 395A and 504B.

The DLL is usually run in combination with the Natural Gamma Ray Spectrometry tool (NGT), but may be run with the Triple Combo or alone.

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).

Applications

Porosity estimate
Because of the inverse relationship between resistivity and porosity, the dual laterolog can be used to compute 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.

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 ft in diameter.

Log Presentation

The LLd and LLs curves are usually displayed on a resistivity logarithmic scale, along with the gamma ray log.

Output plot of DLL data

Specifications

Temperature Rating:	350° F (175° C)
Pressure Rating:	20 kpsi (13.8 kPa)
Tool Diameter:	3.625 in (9.21 cm)
Tool Length:	30.6 ft (9.35 m)
Sampling Interval:	6 in (15.24 cm)

Max. Logging Speed:	10,000 ft/hr
Vertical Resolution:	2 ft (61 cm)
Depth of Investigation:	(see discussion in "Description" section)

Output

LLD	Deep Laterolog (ohm)
LLS	Shallow Laterolog (ohm)

Deployment Notes

As noted above, the DLL is usually run in combination with the Natural Gamma Ray Spectrometry tool (NGT), but may be run with the triple combo or alone. Obviously, combining the DLL with the Triple Combo will save an additional run.

Stuck/lost tool information

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* ®trademark of Schlumberger

Estimating Logging Times

Introduction

Logging times are calculated by the Logging Staff Scientist prior to her initial contact with the Co-Chief Scientists and are revised, if necessary, before the pre-cruise meeting. At the meeting, the Logging Staff Scientist will discuss the logging plan and logging time estimates with the Co-Chiefs, TAMU Staff Scientist and other cruise participants as part of the leg planning process. The logging time estimates, together with time estimates for drilling, transit and other operations, are commonly published in the leg scientific prospectus, which is distributed among the leg participants and is also available on the prospectus page of the Science Operator web site. During the cruise, the Logging Staff Scientist will continuously monitor and modify logging time estimates. Drilling and logging plans are commonly altered during the course of the leg in order to accommodate changes in the original plan due to unforeseen hole conditions or the dynamics of the scientific drilling process. The purpose of this document is to provide shipboard scientists with the basic information the Logging Staff Scientist incorporates in the course of preparing logging time estimates.

Logging Time Calculation

Logging time depends on several variables, such as water depth, length of logged interval, logging speed, and type and number of tool strings used. Logging speed is an important variable because it may affect logging data quality. Slower logging speeds usually result in better counting statistics for nuclear tools (such as the NGT, AACT and GST). Faster logging speeds on the other hand usually lead to less tool sticking that adversely affects all logs. Table 2.1, shown immediately below, provides some guidelines regarding the logging speeds commonly used for logging on the *JOIDES Resolution*. High-resolution logs (neutron porosity and bulk density data sampled every 2 and 1 inches respectively) can only be obtained by logging at the lower logging speeds (typically 900 ft/hr or less). The currently available logging winch onboard the *JOIDES Resolution* (as of January 1995) is capable of stable minimum logging speeds of 600 ft/hr. However, even at speeds of a few hundred feet per hour, the effect of only partially compensated ship's heave achieved by the WHC system may lead to the tool string undergoing significant oscillatory motion in the hole during logging.

TABLE 2.1 -- Typical Logging Speeds						
Log Quality:	Fair		Good		Excellent (Hi-Res)	
Tool	m/hr	ft/hr	m/hr	ft/hr	m/hr	ft/hr
Triple	549	1800	335	1100	274	900
GLT	183	600	137	450	91	300
FMS/Sonic	549	1800	488	1600	274	900
GHMT	549	1800	488	1600	274	900

A spreadsheet (logtime.xls) has been created to facilitate standardized estimation of logging times for all loggers and logging proponents. The spreadsheet provides the means for calculating times for both standard and specialty tools. Some borehole experiments with specialty tools, such as vertical seismic profiling, case inspection logs, "CORKS" and others, may require consultation with the scientists involved in order to accurately estimate the times.

Invariably, real-time decisions have to be made in response to changes in conditions uphole and downhole; thus, knowing how the condition changes affect the estimates is important. In considering the time required for operations it is important to note that the Operations Superintendent assumes that hole preparation time, including mud circulation, wiper trip, bit release and pulling pipe to logging depth, is not included in the logger's estimate. In this spreadsheet, note that Logging Time is counted as the time between the positioning of the base of the bottom-hole assembly at the logging depth and the time when tools and wireline are rigged down and the pipe can begin to be pulled out of the hole.

The spreadsheet has been continually updated. It allows for easy calculation of the logging times for an individual hole, as well as for input of different logging speeds, retrieval speeds and the addition of repeat logging runs. The input variables are outlined in Table 2.2. The user simply inputs the values for water depth, pipe depth, hole depth, tool strings run and their respective logging speeds, whether the conical side entry sub (CSES) is used or not, whether the bit is released or not (bit is released only when RCB is used in drilling) and the tool retrieve speed in pipe, and the total time is automatically calculated. (See Table 2.2, immediately below.) All the variable inputs to the spreadsheet are separated from the detailed outline of logging operations. This detailed outline can be tailored for or changed according to the specifics of an individual leg, or from experience of actual logging times as a leg progresses.

TABLE 2.2 -- Variable Input

HOLE: SCS-8		Logs	Tool Deployed? (Yes/No)	Speed (m/hr)	Repeat?	Rep. Speed	Rep. Interval
		Triple Combo	Yes	488	Yes	488	100
Variables	(in meters)	FMS/Sonic	Yes	250	Yes	250	250
Water Depth:	1800	GHMT	Yes	500	Yes	500	100
Pipe Depth:	150	BHTV (UBI)	No	250	Yes	250	100
Hole Depth:	400	GLT	Yes	183	Yes	183	100
Open Hole Int. Logged:	250	LDEO TLT	Yes	180	No	N/A	N/A
Pipe Length:	1950	RSMAS Hi Temp Tool	Yes	180	No	N/A	N/A
				Station Interval (meters)		Time/Station (min)	
		WST	Yes	50		20	
Can CSES be used?	**OK to use CSES**						
			with SES (hrs)		without SES (hrs)		
	Total Time:		55.5		47.3		

Estimation Concerns

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 when it 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. With the routine use of sepiolite muds, the clay swelling problems have significantly diminished. Bridges can also form in heavily fractured formations, but these types of situations have been much rarer.

Deep basalt holes rarely 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. The drilling engineers and operations superintendent usually have a good "feel" for hole conditions prior to logging from their observations during the wiper trip.

If a bridge is encountered that stops the logging tool, there are two options: 1) simply log the interval above the bridge and cancel plans to log beneath the bridge; or 2) 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.

To prevent lost time or lost logs associated with bridges, the *JOIDES Resolution* has the capability of using a conical sidewall entry sub (CSES) during logging. When inserted into the drill string, the CSES allows for the addition or removal of drill pipe while a logging tool is downhole. The CSES 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 by minimizing the time between pipe removal and logging so substantial bridges cannot develop. Even though the use of the CSES is not ordinarily planned for, the Logging Scientist will estimate logging which incorporates its use. If the CSES is planned for but not needed, logging operations will take 4-12 hours less than planned at a site.

Estimation Assumptions

1. The spreadsheet calculations assume that the entire interval below the

pipe depth is logged for all toolstring combinations.
2. Logging rates as specified are constant for the duration of logging.
3. Time estimation is not required for the rig up and rig down of the TAP tool. Actual rig time required for this tool is negligible (approximately 5 min).
4. "Fixed" time estimates for operations such as retrieval speeds (while tool is in drill pipe), tool rig-up and rig-down may vary from leg to leg.

Contingencies Not Included in Estimations

The logging times provided in the spreadsheet do not include three contingencies that commonly occur:

1. Time required to punch through bridges or change to the sidewall entry sub if one starts logging without the CSES.
2. For reentry holes in which it is not permissible to drop the bit at the bottom of the hole, time to pull the drillstring, take off the bit, and reenter the hole.
3. Time beyond 1 hour to drop the bit, due to problems with the bit release 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.

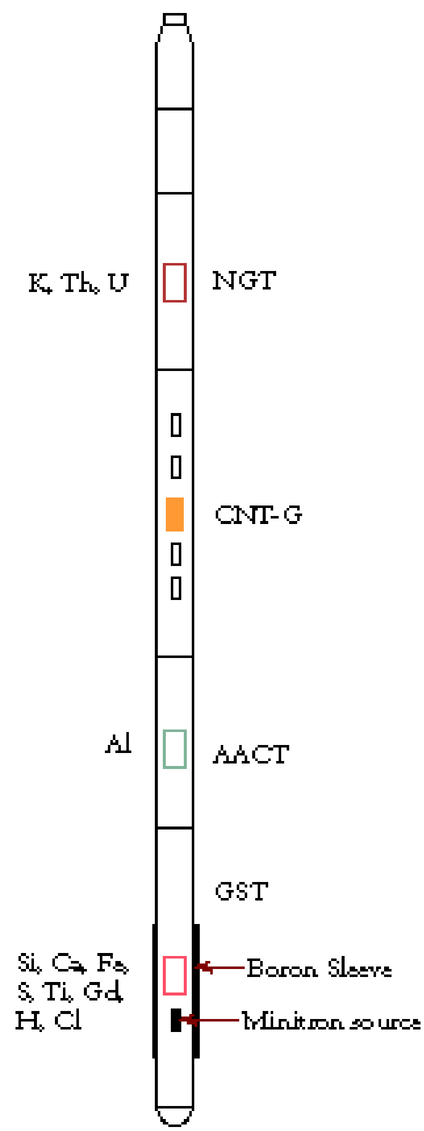
"Safety" margins have not been included but can be by increasing the fixed time necessary for certain operations (e.g., item 3 above), or by decreasing logging speeds.

Geochemical Tool (GLT*)

Note: the GLT is no longer in use in the ODP logging program. This page is included to provide assistance to investigators working with GLT data.

Description

The Geochemical Logging Tool (GLT) uses three separate modes of gamma-ray spectroscopy to obtain measurements of most of the major oxides which make up sedimentary and igneous rocks. Initial measurements provide estimates of Si, Al, Fe, Ca, K, U and Th (together with H and Cl). Estimates of Ti, S and Gd are obtained later with further processing. The GLT provides gross geochemical information about the formation which is particularly useful when combined with other logs. The data can be used directly for the characterization of geological sequences and phenomena, and are excellent for geotechnical zoning. However, due to its relatively low measurement precision (see Environmental Effectssection below), the GLT is best employed in environments where there is a marked variation in the geochemistry of the rocks.



The GLT consists of four components. At the top is a Natural Gamma Ray Tool (NGT). Beneath this is a Compensated Neutron Porosity Tool

(CNT-G), which in the GLT is used solely as a carrier for a Californium (^{252}Cf) source. Californium is used instead of the conventional AmBe source because its spectrum has a lower energy (2 MeV instead of 4.5 MeV), thus reducing the number of fast neutron reactions which would interfere with measurements taken by the tools below. Next is the aluminium activation clay tool, which is essentially a Natural Gamma Ray Tool with a modified spectrometer (7 windows instead of 5) to allow a more detailed analysis of the spectrum. Finally, a gamma ray spectrometry tool is located at the bottom of the string. A boron exclusion sleeve surrounds the gamma ray spectrometry tool and increases the signal-to-noise ratio by shielding the path of fast neutrons from borehole fluid and reducing the number of capture reactions in the borehole itself, thus counteracting the effects of chlorine and water present in the borehole. The sleeve also reduces the interference of iron from the tool housing.

The natural gamma ray tool measures the abundance of K, U, and Th from the natural gamma radiation given out by these elements. A sodium iodide detector is used for the measurement and this also provides a spectrum of the background radiation, which is required for subsequent processing. Data are collected as the tool string is pulled up the borehole so that natural gamma-ray measurements are made before the formation is activated by the neutron and gamma spectroscopy tools.

The next two tools in the string allow the measurement of the Al concentration. The ^{252}Cf source in the Compensated Neutron Porosity Tool causes the neutron activation of Al, in which the natural isotope ^{27}Al absorbs thermal neutrons and produces the isotope ^{28}Al, which decays with a half life of 2.24 minutes and emits 1.78 MeV gamma rays. The aluminium activation clay tool measures the gamma spectrum of the activated formation and the Al component is determined by subtracting the input from the natural gamma ray tool spectrum. There is some spectral interference in the aluminium measurement from silicon, which is corrected during the land-based processing.

The gamma ray spectrometry tool can operate in two timing modes: inelastic, which mainly measures the neutron reactions in the high energy range; and capture-tau mode, which employs prompt neutron capture reactions to measure elemental concentrations. This report describes how the gamma ray spectrometry tool functions in capture-tau mode, which is how it is normally used in the ODP. For an example of its use in inelastic mode the reader should refer to the BRG Leg Summary for ODP Leg 164.

The gamma ray spectrometry tool uses a "minitron" tritium source to bombard the formation with pulsed 14 MeV neutrons. Through scattering reactions with the atoms in the formation, the neutrons progressively lose energy until they reach a thermal energy at which they can be captured by elemental nuclei in the rock. When this occurs the nucleus emits a gamma ray at a unique energy, characteristic for each element. The emitted gamma rays are measured by a spectrometer consisting of a sodium iodide detector and a 256-channel analyzer. During logging, the gamma ray spectrometry tool provides estimates of Si, Fe, Ca, Cl and H. In ODP boreholes the Cl and H relate virtually entirely to the sea water in the borehole. Later land-based processing permits the removal of Cl and H from the spectra, and the additional extraction of estimates for Ti, S and Gd.

The elements measured by the GLT account for the bulk of the chemistry of most common rocks; the only significant elements not measured are Na, Mg and possibly Mn. Under favorable circumstances an estimate of these missing elements may be obtained by comparing a calculation of the photoelectric factor (P_e) from the elements measured above, with the direct measurement of P_e made by the Hostile Environment Lithodensity Tool (HLDS). The difference in these P_e values is, within limits of error, due to the unmeasured elements, and may be recast as either Na or Mg, or some combination, where a fixed ratio of the elements has to be assumed.

Applications

Lithology

In basement, variations in elemental concentrations will help delineate flow boundaries and characterize alteration vein-filling. In sedimentary environments, where there is a reasonable chemical variation in the rocks, GLT data can be used as an effective indicator of changes in the lithostratigraphy.

Cyclically interbedded lithologies can be identified and analyzed using geochemical logging, and changes in the provenance of sediments can be shown. For example, the FeO, SiO_2 and $CaCO_3$ results from ODP Hole 950A on the Madeira abyssal plain show distinct downhole alternations (see figure). Horizons which are generally rich in FeO, rich in SiO_2 and poor in $CaCO_3$ show the position of clay-rich organic and volcanic distal turbidites, sourced from volcanic islands and the African margin, to the east of the drill-site. Horizons generally poor in FeO, poor in SiO_2, and rich in $CaCO_3$ show the position of calc-turbidites, sourced from a chain of seamounts to the west of the plain.

The ratio of certain elemental yields can also be used to emphasize fluctuations or distinct marker horizons in the stratigraphy. For example, elemental yield ratios were used to analyze data from ODP Hole 999B, drilled beneath the Caribbean Sea. The lithology (Si/(Si + Ca)), iron (Fe/(Si + Ca)) and porosity (H/(Si + Ca)) indicator ratios all help to highlight the position of tephra horizons within the formation (see figure).

Geochemistry.

Downhole fluctuations in the elemental yields reflect gross variations in geochemistry, which can be used to help categorize the formation. The GLT results from Hole 735B, logged during Leg 118, show a good example of this. This hole penetrated basement of the Southwest Indian Ridge, which between 50-400 mbsf can be subdivided into four distinct units (see figure). The geochemical data clearly delineate Unit 4, which is a Fe-Ti oxide-rich gabbro. Generally low and uniform FeO and TiO_2 values occur in Unit 5, which is a relatively uniform olivine gabbro.

Quantitative Mineralogy and lithology

The oxide data, in combination with data from other logs if appropriate, can be inverted to estimate the proportions of the main minerals in the rock. This information, which can be displayed as mineralogical logs, can often be used to derive other physical properties of the formation, such as magnetic susceptibility or cation exchange capacity (CEC).

Environmental Effects

During data acquisition the signal-to-noise ratio of the gamma ray measurement can be affected by the following:

- Logging speed. This is normally between 400 and 600 ft/hr, with measurements being made every six inches. The slower the logging speed the greater the measurement precision.
- Borehole fluids and porosity. Due to the large capture cross-

section of chlorine and hydrogen more than half of the gamma ray spectrometry tool signal may come from the borehole fluid (normally seawater). This can adversely affect the measurement precision of the other element yields. High porosity rocks can have a similar affect on precision, and it is recommended that the GLT only be used in rocks with less than 40% porosity.

- Hole size. This is of particular importance as oversized holes cause an increase in the signal derived from the borehole fluids, and a decrease in the signal from the formation. The interpretation of geochemical logs should, therefore, always be undertaken in conjunction with caliper logs. Because the aluminium activation clay tool has a low activation energy (2 MeV), aluminium is measured in a much smaller volume of rock than those elements measured by the gamma spectroscopy tool. As a result, with increasing hole size, the aluminium signal decreases rapidly and may reach background levels, whereas the gamma spectroscopy tool elements can still be measured. This problem is compounded by the oxide closure procedure, which forces the major oxides to a constant sum (usually 100%).
- Temperature. Temperature effects can significantly reduce the efficiency of the NaI detector in the gamma ray spectrometry tool, with higher temperatures resulting in a poor signal-to-noise ratio and decreased resolution. Poor resolution will result in gamma-ray peaks appearing in the wrong window and lead to incorrect identification of the element represented. It is recommended that the GLT not be used in temperatures greater than 150°C.

The quality of the data can also be reduced during processing. This can occur due to errors in the spectral inversion of the raw data, inaccuracies in the oxide closure model caused by the presence of unmeasured elements and incorrect oxide factor assumptions. In the ODP, shipboard data (particularly petrographic, chemical and diffraction) can often be used to minimize these errors.

One limitation of the GLT is its relatively low spatial resolution. The volume sampled by the GLT approximates to a sphere, with a radius varying from around 0.3-1.0 m, depending on lithology, porosity, composition of the pore fluids and the elemental spectra being determined. At each measurement point (every 15 cm) a number of these spherical samples are averaged. The raw data from the GLT have, therefore, already undergone a certain amount of smoothing. This accentuates the shoulder effect on the logs, which tends to smooth the log responses over sharp lithological boundaries.

Comparisons between GLT derived oxide estimates and similar data obtained from conventional geochemical analyses (e.g. XRF) on core samples should be treated with extreme caution. The two techniques measure substantially different volumes of rock. Furthermore, it is always difficult to precisely match the depths of the core samples with those of the log values, especially when core recovery is low.

Log Presentation

Following data acquisition, the elemental concentrations measured by the GLT are expressed as decimal fractions and the elements are normalized to unity. Further processing, sometimes referred to as the "oxide closure procedure," converts the major elements (Si, Al, Ca, Fe, S, Ti, K, Cl and H) to weight percent oxides. The trace elements (U, Th and Gd) are expressed in parts per million. Post-cruise processing also allows the expected errors on the GLT data to be calculated (see figure).

GLT plot examples

Specifications

Temperature Rating:	150° C / 300° F
Pressure Rating:	20 kpsi (13.8 kPa)
Tool Diameter:	3.875 in (10 cm)
Tool Length:	9.25 ft (2.82 m)
Sampling Interval:	6 in (15.24 cm)
Max. Logging Speed:	600 ft/hr

Deployment Notes

Stuck/lost tool information

* ®trademark of Schlumberger

High Temperature Operations

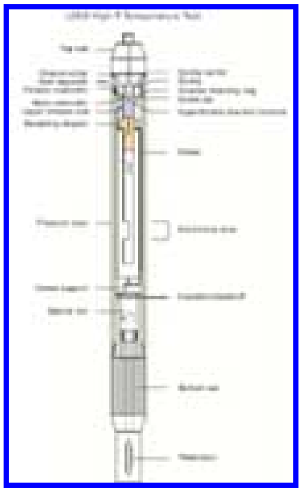
Moderate-to-High Temperatures

In moderate-to-high temperature environments (i.e., a sheeted dike complex), the measurement of borehole temperatures with either wireline or memory tools should precede any other logging operation in order to determine the temperature of the borehole fluids, estimate the geothermal gradient, and approximate the time of post-drilling temperature rebound. Schlumberger tools rated to 175°C can often be deployed with adequate hole cooling by circulating cold fluids for approximately 2-3 hours. If temperatures rebound quickly, however, these tools are at risk and logs may only be recorded in cases where the side-entry sub (SES) could be used. After circulating for several hours, a Schlumberger tool string should be lowered into the hole as quickly as possible and in combination with an Auxiliary Measurement Sonde (AMS) to monitor borehole fluid temperatures.

High Temperatures

In high-temperature environments (i.e. hydrothermal systems or lower crustal settings), temperature logs can be recorded using the wireline slim-hole Hi-T Temperature Tool (HTT) developed at LDEO for operation at the TAG hydrothermal mound in 1994, or the University of Miami third-party GRC memory temperature tool.

Tools

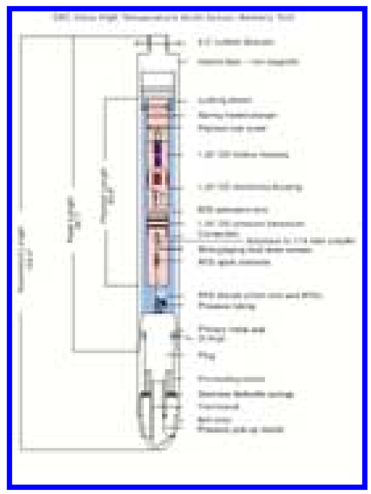


LDEO High-T Temperature Tool (HTT)

The HTT can be used in temperature conditions of up to 275°C although the Teflon insulation in the wireline will begin to degrade beyond 232°C. Generally, this can present a problem after extended use in temperature conditions exceeding 235°C; however, the HTT measuring system is only frequency dependant. Therefore, the tool can still transmit reliable measurements even after the cable has been considerably degraded.

GRC Ultra-High T Temperature Tool

The GRC was developed with NSF funds by the University of Miami. Although this tool is available, arrangements need to be made for maintenance if it is desired for future use. This tool can be deployed on the sandline if temperatures exceed 232°C, as occurred during Leg 169 when the tool was successfully deployed in Hole 858G. However, since this is a memory tool, the loggers will be unable to monitor temperature or tool problems in real time.



Operations

Following drilling, circulation operations must occur to cool the hole. At this point, the Triple Combo with the AMS can be deployed. If the AMS records temperatures in the 175°C range, then the tool string must be retrieved immediately to avoid damage. In this case, additional hole cooling operations must occur, and a deployment using a modified string with only the Hostile Environment Natural Gamma Sonde (HNGS) and the Hostile-Environment Litho-Density Tool (HLDT) can be attempted. The tool's built-in temperature sensors must be monitored carefully in order to avoid exposing the electronics to harmful temperatures. In additions, downhole magnetic field measurements are also possible with the German (BGR) third-party three-component fluxgate magnetometer. This tool measures the three orthogonal components of the magnetic field up to 100 microTesla with a resolution of ± 0.1 nT. The tool also contains two inclinometers that measure tilt with a resolution of 0.1°. The probe is mounted inside a dewar flask and contains heat sinks that allow measurements at temperatures of up to 300°C. This magnetometer was previously used during ODP Leg 148 however, as it is the case with most third-party tools, any future deployments must obtain additional funds prior to the cruise for maintenance, shipping, and training.

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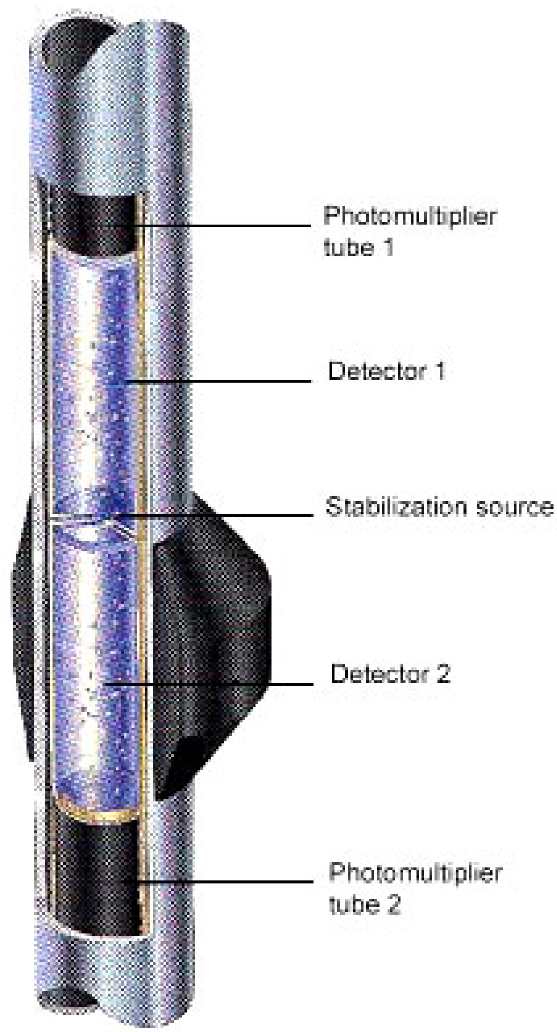
Toolstring Selection

ODP Logging Staff Scientist | Selecting Toolstrings | Estimating Log Times | Pre-Cruise Meeting

Hostile Environment Gamma Ray Sonde (HNGS*)

Description



The Hostile Environment Natural Gamma Ray Sonde (HNGS) utilizes two bithmus-germanate (BGO) scintillation detectors to measure the natural gamma ray radiation of the formation. The larger detector volume and higher gamma ray stopping power of BGO makes the HNGS a very effective spectral gamma tool. The HNGS makes similar measurements to the NGT; however, the HNGS is more accurate and capable of making measurements in difficult hole conditions. The HNGS employs a larger and better scintillation detector than the NGT which affords better nuclear decay statistics. The HNGS measures total gamma and 256-window spectroscopy to resolve the detected spectrum into the three most common components of 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, a uranium-free gamma ray measurement, and the concentrations of potassium, thorium, and uranium.

The radius of investigation depends on several factors: hole size, mud density, formation bulk density (denser formations display a slightly lower radioactivity) and the energy of the gamma rays (a higher energy gamma ray can reach the detector from deeper in the formation).

Only the high-energy gamma rays are used in the analysis, thereby eliminating sensitivity to mud barite content. The MAXIS system provides real-time corrections for borehole size and the borehole potassium contribution.

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.

- **Ash layer detection**
  Thorium is frequently found in ash layers. The ratio of Th/U can also help detect these ash layers.

  Additional applications of gamma ray logs

Environmental Effects

The HNGS response is affected by borehole size, mud weight, and by the presence of bentonite or KCl in the mud. In ODP boreholes KCl is sometimes added to the mud to stabilize freshwater 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 of these effects are accounted for during the processing of the HNGS data onshore.

Log Presentation

The HNGS log is routinely recorded with each logging string for correlation between logging runs. To this purpose HSGR (total gamma ray in API units) and HCGR (computed gamma ray -- HSGR minus Uranium component, in API units) are usually displayed along with other curves (resistivity, sonic, density, etc.). A full display of the data with HSGR, HCGR, and HTHO (in ppm), HURA (in ppm), and HFK (dec fraction) is usually provided separately.

Output plot of HNGS data combined with DIT-E and TLT data

Specifications

Temperature Rating:	260° C / 500° F
Pressure Rating:	25 kpsi
Tool Diameter:	3.75 in.
Tool Length:	8.5 ft.
Sampling Interval:	6 in.
Max. Logging Speed:	3600 ft/hr
Accuracy Thorium:	+/- 2%
Accuracy Uranium:	+/- 2%
Accuracy Potassium:	+/- 5%

Output

HSGR	Standard (total) Gamma Ray (GAPI)

HCGR	Computed Gamma Ray (GAPI)
HFK	Formation Potassium (dec. fraction)
HTHO	Formation Thorium (ppm)
HURA	Uranium (ppm)
HBHK	Borehole Potassium (dec. fraction)

Deployment Notes

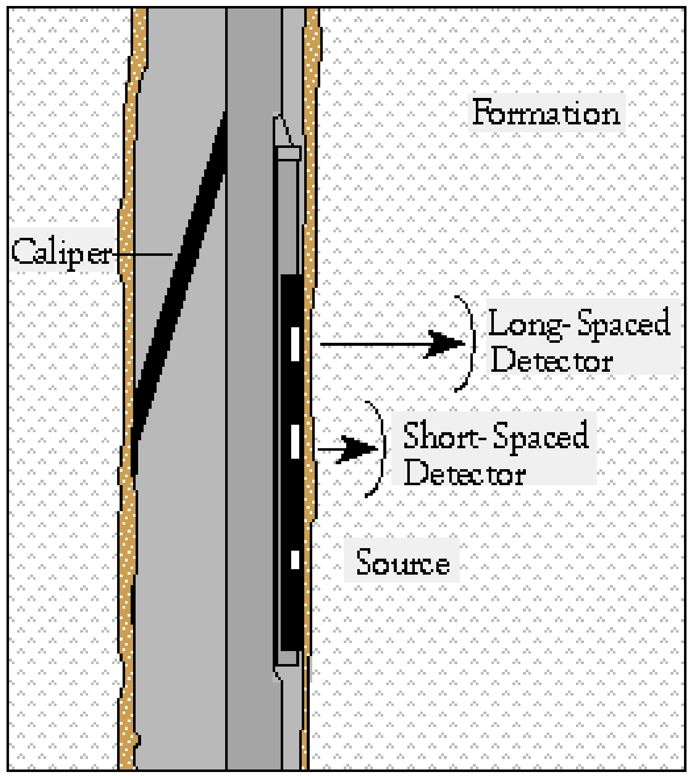
The HNGS is always run near the top of the triple combo tool string. Several passes are made with the HNGS past the mudline for improved depth control.

Stuck/lost tool information

* ®trademark of Schlumberger

Hostile Environment Litho-Density Sonde (HLDS*)

Description



The Hostile Environment Litho-density sonde (HLDS) consists of a Cs_{137}radioactive source and two detectors mounted on a shielded skid which is pressed against the formation by a hydraulically activated eccentering arm. 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 absorption.

Compton scattering 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 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 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.

As with 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. The vertical resolution is 16 in (38 cm).

Applications

Porosity estimate

If grain density is known, 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 log, the density log allows for the definition of the lithology and of lithologic boundaries. Because each element is characterized by a different photoelectric factor, this can be used, alone or in combination with other logs, to determine the lithologic type. Both density and photoelectric effect index are input parameters to some of the geochemical processing algorithms used onshore.

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 mudcake 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 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. These corrected data are typically located in the DRHO data column.

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.). They are usually displayed along with the neutron curve NPHI. Also, DPHI (density porosity) can be computed and displayed by assuming a constant grain density of 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.

Specifications

Temperature Rating:	260° C / 500° F
Pressure Rating:	25 kpsi (17.25 kPa)
Tool Diameter:	3.5 in (9 cm)
Tool Length:	23.08 ft (7.03 m)
Sampling Interval:	6 in (15.24 cm)
Max. Logging Speed:	1,800 ft/hr
Vertical Resolution:	1.25 ft (38 cm)
Depth of Investigation:	(see last paragraph of "Description" section)

Output

RHOM	Corrected Bulk Density (g/cm^3)
DRH	Bulk Density Correction (g/cm^3)
PEFL	Long-spaced Photoelectric Effect (barns/e-)
NRHB	Bulk Density (g/cm^3)

Deployment Notes

Typically run with IPLT components (HNGS, APS). Can be combined with DIT, DLL and ASI. The Density section is capable of measuring internal temperature which may be useful in high temperature holes.

Stuck/lost tool information

* ®trademark of Schlumberger

The ODP Logging Staff Scientist

The role of the ODP Logging Staff Scientist encompasses a number of responsibilities:

- Coordination of all leg-related logging activities - pre-cruise, cruise, and post-cruise
- Training of any new logging scientists sailing on the cruise
- Interfacing with the Co-Chief Scientists, TAMU Staff Scientist, and the Operations and Drilling Superintendents
- Pre-cruise, cruise, and post-cruise reporting of logging objectives and operations
- Participation in and supervision of at-sea logging operations

Logging scientists aboard ODP Leg 188

Formation of the Project Team

Shortly after the drillship schedule has been set by SCICOM at the August meeting, ODP Logging Services appoints a Logging Staff Scientist for each scheduled leg. Following the appointment, the Logging Staff Scientist will contact the Co-Chief Scientists (when named) and the TAMU Staff Scientist to introduce himself and explain his role on the drilling leg.

The Logging Staff Scientist is considered to be the leader of the Logging Services project team. In addition to any people sailing, the team usually consists of:

- Manager of Technical Services (Greg Myers) for tool deployment and engineering issues
- Engineering Assistant (Walt Masterson) for shipping issues
- Manager of Information Services (Cristina Broglia) for data handling issues
- Log Analysts (Trevor Williams and Caroline Philippot) for log processing services
- CD-ROM coordinator (Jim Murray) for issues involving the Log Data CD
- Systems Analyst (Ted Baker) for any computer or software issues

In addition, there may be other engineering or scientific personnel involved if special projects are planned for the cruise. The Deputy Director of Operations (Mary Reagan) is responsible for coordinating the activities of the leg project managers. She and the Director (Dave Goldberg) are available to assist as needed.

Following the initial consultations between the Logging Staff Scientist, the Co-Chief Scientists and the TAMU Staff Scientist, there should be general agreement on the following issues:

- At what sites logging is required.
- The general science plan for the leg.
- What tools are funded for the leg.
- The preliminary details of the logging plan.

At this point, the science and logging plans undergo refinement through numerous discussions with LDEO-BRG, TAMU, Schlumberger and the Co-Chief Scientists. Meanwhile, the Logging

Staff Scientist, in consultation with the Logging Services project team, prepares a logging presentation for the pre-cruise meeting. It is at the pre-cruise meeting that the involved parties discuss every detail of the leg and the time allocation for each drill site. The Logging Staff Scientist represents the ODP logging program; therefore she will describe the available toolstrings and the integration of the logging plan with the overall science plan. The result of the pre-cruise meeting is the creation of a comprehensive Scientific Prospectus which serves as the operational guide for the leg.

Prior to the pre-cruise meeting the Logging Staff Scientist will:

1. Contact the members of the Logging Services project team to begin acquiring specific information about the leg.
2. Contact the Co-Chief Scientists, once named, to review the current plan.
3. Be apprised of tool condition and availability and toolstring deployment details specific to the leg. Greg Myers serves as the liaison between ODP Logging Services and Schlumberger.
4. Generate logging time estimates using the estimation spreadsheets.
5. Prepare a logging template for the leg.
6. Prepare a short presentation with overheads on the tools to be deployed and the respective time requirements.

Division of Responsibilities bewteen the Logging Staff Scientist and JOIDES Logger

The other shipboard participant with whom the Logging Staff Scientist has extensive contact is the JOIDES Logging Scientist. This position is selected by the co-chiefs. The person who is selected may or may not have had previous logging experience. ODP Logging Services offers to provide pre-cruise training to any JOIDES logger who wants it; an invitation is issued by the Deputy Director of Operations. The Logging Staff Scientist will contact the JOIDES Logger before the cruise to discussed planned operations, shipboard responsibilities and post-cruise research interests.

The division of responsibilities between the Logging Staff Scientist and JOIDES Logger is quite flexible, and is usually worked out between the individuals involved on a leg-by-leg basis. A general summary of the respective responsibilities is given below. The rule of thumb is that the Logging Staff Scientist is responsible for data acquisition (with both Schlumberger standard tools and specialty tools) and preliminary processing. Log interpretation responsibilities are shared between the Logging Staff Scientist and JOIDES Logger and should be divided in a mutually agreed-upon manner.

Here is the typical division of responsibilities:

Logging Staff Scientist:

- Schlumberger data acquisition: supervision and quality control
- Specialty tool data acquisition and processing
- Data reformatting
- Systems management
- Downhole Measurements Lab supervision

Shared between Logging Staff Scientist and JOIDES Logger:

- Daily sampling shift
- Authorship of Initial Reports chapters and Scientific Results data/ scientific report
- Seismic interpretation linked to core and log data
- Detailed interpretation of specialty logs
- Quantitative mineralogy from logs, and its interpretation
- Interaction with physical properties scientists, sedimentologists, and seismic stratigraphers
- Qualitative interpretation of lithologic units
- Qualitative interpretation of specialty tool data
- Comparison of log and laboratory measurements
- Inter-site correlation via logs
- Generation of synthetic seismograms

Name	Formula	Dens. (Log) (g/cm^3)	t_c (μsec/ft)	t_s (μsec/ft)	P_e	U	GR (API units)	Neutron Capture Cross Section (c.u.)
SILICATES								
Quartz	SiO_2	2.64	56	88	1.8	4.8		4.3
Opal (3.5% H_2O)	$SiO_2 (H_2O)_{.1209}$	2.13	58		1.8	3.7		5.0
Garnet*	$Fe_3Al_2(SiO_4)_3$	4.31			11	48		45
Hornblende*	$Ca_2NaMg_2Fe_2 AlSi_8O_{22}(O,OH)_2$	3.20	43.8	81.5	6.0	19		18
CARBONATES								
Calcite	$CaCO_3$	2.71	49	88.4	5.1	13.8		7.1
Dolomite	$CaCO_3MgCO_3$	2.85	44	72	3.1	9		4.7
Siderite	$FeCO_3$	3.89	47		15	57		52
OXIDATES								
Hematite	Fe_2O_3	5.18	42.9	79.3	21	111		101
Magnetite	Fe_3O_4	5.08	73		22	113		103
FELDSPARS -- ALKALI*								
Orthoclase	$KAlS_3O_8$	2.52	69		2.9	7.2	~220	16
Anorthoclase	$KAlS_3O_8$	2.59			2.9	7.4	~220	16
Microline	$KAlS_3O_8$	2.53			2.9	7.2	~220	16
FELDSPARS -- PLAGIOCLASE*								
Albite	$NaAlSi_3O_8$	2.59	49	85	1.7	4.4		7.5
Anorthite	$CaAl_2Si_2O_8$	2.74	45		3.1	8.6		7.2
MICAS*								
Muscovite	$KAl_2(Si_3AlO_{10})(OH)_2$	2.82	49	149	2.4	6.7	~270	17
Glauconite	$K_{0.7}(Mg,Fe_2,Al)(Si_4Al_{10})O_2(OH)$	2.86			4.8	14		21
Biotite	$K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$	~2.99	50.8	224	6.3	19	~275	30
CLAYS*								
Kaolinite	$Al_4Si_4O_{10}(OH)_8$	2.41			1.8	4.4	80-130	14

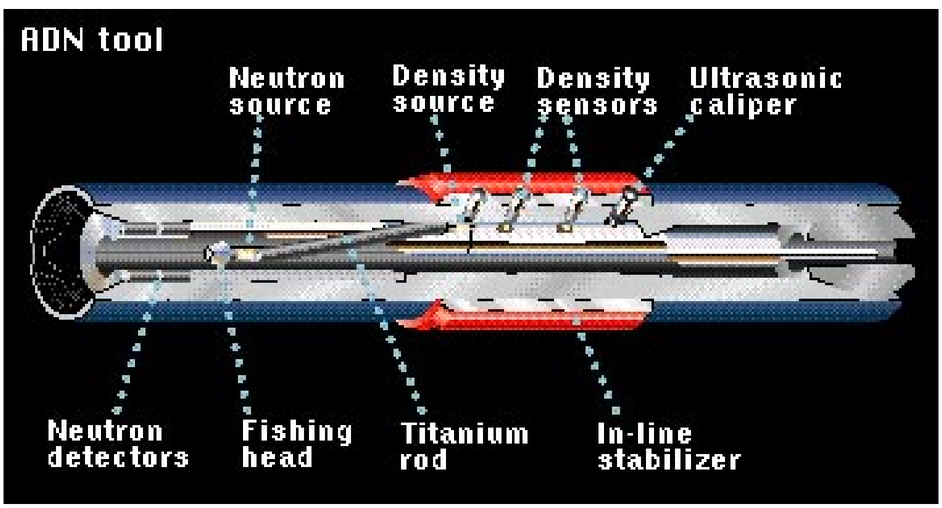
Chlorite	$(Mg,Fe,Al)_6(Si,Al)_4 O_{10}(OH)_8$	2.76			6.3	17	180-250	25
Illite	$K_{1-1.5}Al_4(Si_{7-6.5,}Al_{1-1.5}) O_{20}(OH)_4$	2.52			3.5	8.7	250-300	18
Montmorillonite	$(Ca,Na)_7(Al,Mg,Fe)_4 (Si,Al)_8O_{20}(OH)_4(H2O)_n$	2.12			2.0	4.0	150-200	14
EVAPORITES								
Halite	NaCl	2.04	67	120	4.7	9.5		754
Anhydrite	$CaSO_4$	2.98	50		5.1	15		12
Gypsum	$CaSO_4(H_2O)_2$	2.35	52		4.0	9.4		19
SULFIDES								
Pyrite	FeS_2	4.99	39.2	62.1	17	85		90

***** Mean value, which may vary for individual samples

Logging-While-Drilling
Azimuthal Density Neutron Tool (LWD-ADN*)

Description

The Azimuthal Density Neutron tool (ADN) is the latest generation density/neutron LWD tool provided by Anadrill; it supplants the CDN, which suffered from poor support and tool availability problems. It is deployed in similar fashion to the CDN and is combinable with other LWD tools. Unlike the CDN, the ADN can be configured to provide real-time apparent neutron porosity, formation bulk density and photoelectric factor data to characterize formation porosity and lithology while drilling. These nuclear measurements are borehole compensated for improved accuracy, standoff, and photoelectric factor measurements while drilling. 360-degree images of density and porosity result from the rotation of the tool's sensors through four quadrants (top, bottom, left, right). Along with the azimuthal data, average values for each parameter are also available.



Applications

The ADN provides azimuthal borehole compensated formation density, neutron porosity and photoelectric factor measurements. Given present technological capabilities, estimations of bulk porosity and permeability are best made by in situ borehole measurements, preferably at scales large enough to average the effects of irregular fracture porosity and matrix porosity. ADN measurements allow both for determining matrix and fracture porosity and locating overpressure zones.

The Power Pulse (MWD) tool can measure parameters such as annulus pressure, torque, and penetration rates. Together, MWD and ADN can render reliable measurements of effective pressure through both normal and overpressurized zones. If overpressurized zones exist within a fault zone, the magnitude and effects of fluid pressure on fault displacement and fluid flow can be assessed by estimating the amount of fluid expulsion (porosity reduction) in the immediate vicinity of the borehole.

Fault collapse and strain hardening, active fluid flow, fault-fluid interactions, and the formation of hydrofractures may occur within fault zones. Variations in fault displacement and fluid activity can be related to the in situ measurements to investigate the degree to which these processes are active. The ADN measurements of porosity and estimations of fluid pressure can illustrate the nature of the pressure seals as well as the physical processes responsible for fluid migration and redistribution along a fault zone. The determination of the Vp and bulk modulus using ISONIC and ADN data can also contribute to the understanding of the mechanical strength of the rocks within and near a fault zone. These LWD azimuthal measurements can be used to provide information regarding the spatial variation of physical properties around the borehole.

The ADN measurements can also provide porosity information as a function of borehole azimuth. To estimate strain from in situ porosity, lithological effects on these measurements must be first distinguished from the porosity effects. For this purpose, RAB resistivity and gamma-ray measurements can be used to estimate any significant changes in clay mineralogy within a fault zone. Laboratory porosity measurements and thin sections of core samples allow observations of interstitial pore structures and can serve as a correlation tool for more refined calculations of continuous porosity records from the log data. The porosity and resistivity image data can provide information about fracture density, fracture aperture, and structural orientation in the vicinity of the hole. In addition, these data may be used to distinguish fractures that are transmissive from those that are not.

Environmental Effects

Laboratory measurements and mathematical modeling have been used to define the density and photoelectric response and to quantify environmental effects. These effects include gamma ray streaming, mud weight, tool standoff and photoelectric effects of formation and mud on density.

A reliable density measurement requires good contact between stabilizer and formation. Because a statistical caliper measurement is made during the recording, it is possible to check the quality of the contact. Contact 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.

Log Presentation

(This tool has not yet been deployed by ODP Logging Services, so we have no examples at this point.)

Specifications

Tool weight:	2000 lbm (907 kg)
Tool length:	21.7 ft (6.62 m)
Min. - Max. temp:	-13° - 300°F (-25° - 150°C)
Collar OD:	6.75 in API tolerances
Stabilizer OD:	8.25 to 9.875 in.
Maximum weight on bit:	$F = 74{,}000{,}000/L^2$ lbm (where L is the distance between stabilizers in feet)
Maximum overpull (no bending):	330,000 lbf
Maximum operating pressure:	20,000 psi
Maximum flow rate:	800 gal/min

Output

RHOB	Bulk Density (g/cm^3)

DRHO	Bulk Density Correction (g/cm^3)
PEF	Photoelectric Factor (barns/e-)
TNPH	Thermal Neutron Porosity (%)
DCAL	Differential Caliper (in.)
ROMT	Max. Rotational Density (g/cm^3)
DPOR	Max. Rotational Density Porosity (p.u.)
HDIA	Horizontal Diameter (in.)
VDIA	Vertical Diameter (in.)
NTCK	Neutron Detector Sample Depth Tick Mark
DTCK	Density Detector Sample Depth Tick Mark
ROP	Rate of Penetration (ft/hr or m/hr)
TAB	Time After Bit (hr or min)

Deployment Notes

Along with the LWD collars, additional equipment such as jars must be included. Responsibility for providing this equipment is discussed at the pre-cruise meeting.

LWD deployment illustration
LWD deployment photo

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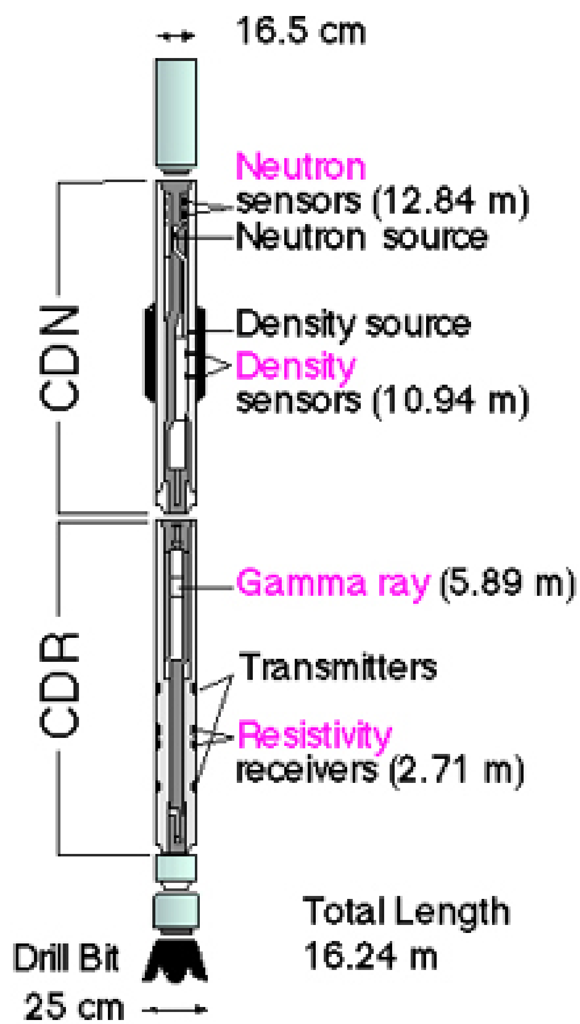
Logging-While-Drilling
Compensated Density Neutron Tool (LWD-CDN*)

Note: the LWD-CDN is no longer in use in the ODP logging program, as it has been superseded by the LWD-ADN. This page is included to provide assistance to investigators working with CDN data.

Description



The physics of the measurements made by the LWD-CDN tool are similar to those of corresponding wireline services. For the neutron porosity measurement, fast neutrons are emitted from a 7.5-curie (Ci) americium-beryllium (Am-Be) source. The quantities of hydrogen in the formation, in the form of water- or oil-filled porosity, primarily control the rate at which the neutrons slow down to epithermal and thermal energies. Neutrons are detected in near- and far-spacing detectors, and ratio processing is used for borehole compensation. The energy of the detected neutrons has an epithermal component because a high percentage of the incoming thermal neutron flux is absorbed as it passes through the 1-in. (2.5 cm) steel wall of the drill collar. Also, a wrap of cadmium under the detector banks shields them from thermal neutrons arriving from the inner mud channel. This mainly epithermal detection practically eliminates adverse effects caused by thermal absorbers in the borehole or formation.

The density section of the tool uses a 1.7-Ci 137 Cesium (Ce) gamma ray source in conjunction with two gain-stabilized scintillation detectors to provide a high-quality, borehole-compensated density measurement. The tool also measures the photoelectric effect, Pe, for lithology identification.

The density source and detectors are positioned behind a full-gauge clamp-on stabilizer, which excludes mud from the path of the gamma rays, greatly reducing borehole effect. In deviated and horizontal wells, the stabilizer may be run under gauge for directional drilling purposes. Rotational processing provides an important correction in oval holes and yields a differential caliper.

Applications - Density Measurement

Porosity estimate
If grain density is known, 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 log, the density log allows for the definition of the lithology and of lithologic boundaries. Because each element is characterized by a different photoelectric factor, this can be used, alone or in combination with other logs, to determine the lithologic type. Both density and photoelectric effect index are input parameters to some of the geochemical processing algorithms used onshore.

Applications - Neutron Porosity Measurement

Porosity
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 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.

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 have 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).

Environmental Effects

A reliable density measurement requires good contact between stabilizer and formation. Because a statistical caliper measurement is made during the recording, it is possible to check the quality of the contact. Contact 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.

Log Presentation

The primary curves are: bulk density (ROMT, in g/cc), photoelectric effect (PEF, in barns/electron) density correction (DRHO, in g/cc), and caliper (DCAL, in in.). They are usually displayed along with the neutron curve TNPH in porosity units. DRHO and DCAL are useful for quality control of the data; if the tool is operating correctly they should be less than 0.1 g/cc and 1 in., respectively. Gamma ray (GR) log in API units is also plotted.

Specifications

Tool weight:	2000 lb (907 kg)
Tool length (with savers):	30.6 ft (9.3 m)
Min. - Max temp:	-13° - 300°F (-25° - 150°C)
Maximum weight on bit:	F = 63,000,000/L^2 lbm (where L is the distance between stabilizers in feet)
Maximum flow rate:	600 gal/min
Maximum operating pressure:	18,000 psi (12.4 kPa)
Available collar sizes:	6.75 in., 8.25 in.
Available stabilizers:	8.50 in., 9.75 in.

Output

DCAL	Differential Caliper (in.)
DRHO	Bulk Density Correction (g/cm^3)
PEF	Photoelectric Effect (barns/e-)
ROMT	Max. Density Total (g/cm^3) from rotational processing
TNPH	Thermal Neutron Porosity (%)
DTAB	CDN Density Time after Bit (hr)
NTAB	CDN Neutron Time after Bit (hr)

Deployment Notes

Along with the LWD collars, additional equipment such as jars must be included. Responsibility for providing this equipment is discussed at the pre-cruise meeting.

LWD deployment illustration
LWD deployment photo

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Logging-While-Drilling
Compensated Dual Resistivity Tool (LWD-CDR*)

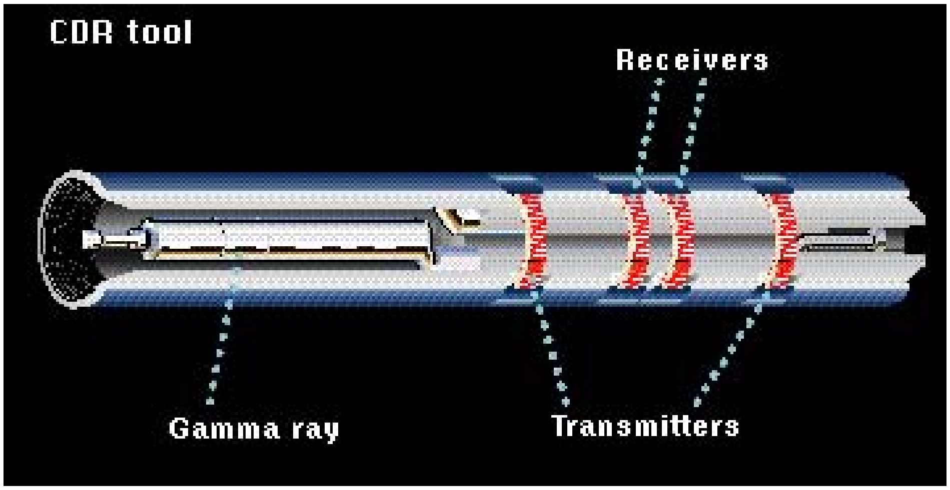
Description

The LWD-CDR is an electromagnetic propagation and spectral gamma ray tool built into a drill collar. It has many similarities to dual induction tools: it responds to conductivity rather than to resistivity, operates in water- or oil-base muds, and provides two depths of investigation. It has better vertical resolution but a shallower depth of investigation than dual induction tools.

The tool broadcasts a 2-Mhz electromagnetic wave and measures the phase shift and the attenuation of the wave between two receivers. These quantities are transformed into two independent resistivities that provide the two depths of investigation. The phase shift is transformed into a shallow resistivity (Rps, for resistivity from phase shift-shallow); the attenuation is transformed into a deep resistivity (Rad, for resistivity from attenuation-deep).

The LWD-CDR has upper and lower transmitters that fire alternately.

The average of these phase shifts and attenuations for the upward and downward propagating waves provides a measurement with borehole compensation similar in principle to that of the Borehole-Compensated Sonic Tool (BHC). Borehole compensation reduces borehole effects in rugose holes, improves the vertical response, increases measurement accuracy and provides quality control for the log. An electrical hole diameter is computed from the CDR data and is used as an input to hole size corrections.



Detection of 3 in. (7.5 cm) beds is possible with the CDR tool. However, because of shoulder bed effects, Rps and Rad will read too low in a thin, resistive bed with conductive shoulder beds, and a small correction for bed thickness is required to obtain true resistivity, Rt. A major advantage of the CDR tool is its ability to measure Rt in thin beds before invasion occurs. Once thin beds are deeply invaded, there is no reliable method for obtaining true resistivity.

Applications - Resistivity

Porosity estimate

In sediments that do not contain clay or other conductive minerals, the relationship between resistivity and porosity has been quantified by Archie's Law. Archie's Law relates the resistivity to the inverse power of porosity. This relationship has also been used to estimate 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.

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. In a particular example, the decrease in resistivity towards the top of a carbonate unit, coupled with a decrease in velocity, allowed one to interpret this unit 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.

Applications - Natural Gamma Ray

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.

Ash layer detection

Thorium is frequently found in ash layers. The ratio of Th/U can also help detect these ash layers**.**

Environmental Effects

The CDR tool provides a set of corrections for different environmental effects. These include corrections for adjacent formations, borehole signal, and invasion. Differences in the temperature of drilling fluid compared to undisturbed formation temperatures can also generate environmental effects, as conductivity in ionic fluids such as seawater is strongly temperature dependent.

Log Presentation

Attenuation Resistivity (ATR) and Phase Shift Resistivity (PSR) are usually plotted in ohm-m on a logarithmic scale along with gamma ray (GR) log in API units.

A full display of the Natural Gamma Spectroscopy data with SGR (total gamma ray in CPS), CGR (computed gamma ray -- SGR minus Uranium component -- in CPS), and THOR (in ppm), URAN (in ppm), and POTA (in wet wt%) is usually provided separately.

Specifications

Tool weight:	2000 lb (907 kg)
Tool length (with savers):	22 ft (6.7 m)
Min. - Max. temp:	-13° - 300°F (-25° - 150°C)
Maximum weight on bit:	F = 63,000,000/L^2 lbm (where L is the distance between stabilizers in feet)
Maximum flow rate:	600 gal/min
Maximum operating pressure:	18,000 psi (12.4 kPa)
Available collar sizes:	6.75 in., 8.25 in.
Available stabilizers:	8.50 in., 9.75 in.

Output

GR	Gamma Ray (API Units)
SGR	Total Gamma Ray (API units)
CGR	Computed Gamma Ray (API units)
POTA	Potassium (wet wt. %)
THOR	Thorium (ppm)
URAN	Uranium (ppm)
ATR	Attenuation Resistivity (deep; ohm-m)
PSR	Phase Shift Resistivity (shallow; ohm-m)
GTIM	CDR Gamma Ray Time after Bit (sec)
RTIM	CDR Resistivity Time after Bit (hr)

Deployment Notes

Along with the LWD collars, additional equipment such as jars must be included. Responsibility for providing this equipment is discussed at the pre-cruise meeting.

LWD deployment illustration
LWD deployment photo

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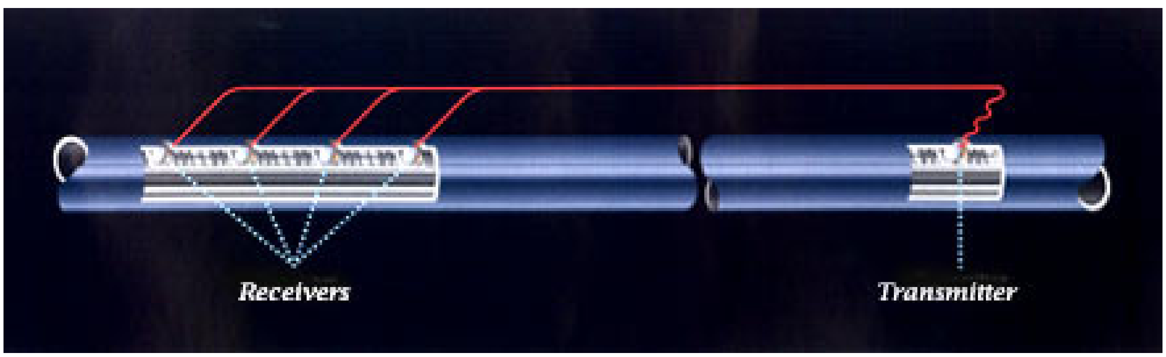
* ®trademark of Schlumberger

Logging-While-Drilling
Isonic Tool (LWD-Isonic*)

Description

Acoustic waveforms are acquired while drilling with the Anadrill Isonic tool. One transmitter and four receivers are positioned within a drill collar just above the bit to collect compressional transit times just seconds after the rock has been cut. As with all Logging-While-Drilling tools, formation data are collected before the borehole alteration or invasion occurs. The data are stored in memory and dumped upon collar retrieval, or they are pulsed in real time if an MWD sub is in use. Isonic data are then utilized in the tradional manner for sonic porosity, synthetic seismogram and correlation with wireline logs.



Applications

Porosity and "pseudodensity" log

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

Seismic impedance

The product of compressional velocity and density is useful in computing synthetic seismograms for time-depth ties of seismic reflectors.

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.

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.

Log Presentation

LWD-Isonic output

Specifications

Drill collar nominal OD:	6.75 in.
Drill collar IDs:	4.75 in. 2.38 in.
Drill collar joints:	5.5-in. FH
Pony collar and saver sub joints:	5.5-in. FH
Makeup length:	22.08 ft without saver sub
Measure point to tool bottom:	13.5 ft
Total tool weight in air:	2100 lbm
Maximum temperature:	300° F
Operating pressure:	20,000 psi
Maximum flow rate:	800 gpm
Pressure drop at maximum flow rate:	30 psi at 11 ppg
Maximum tool curvature:	
Rotating mode:	4°/100 ft
Sliding mode:	16°/100 ft
Bending strength ratio (BSR):	2.0
Equivalent bending stiffness:	23 ft of 6.5 in. x 2.81 in.

Average inertia:	85 $in.^4$
Maximum bit size:	9.875 in.
Maximum jarring load:	330,000 lbm
Maximum weight on bit:	74 million / L^2 lbm, where L = distance betweeen stabilizers in feet
Joint makeup (6.625-in. FH):	21,000 ft-lbf
Maximum rotary:	16,000 ft-lbf
Maximum torque (pin yield):	43,000 ft-lbf

Deployment Notes

The LWD-Isonic is combinable with all other Logging-While-Drilling tools with no reduction in the drilling rate.

LWD deployment illustration
LWD deployment photo

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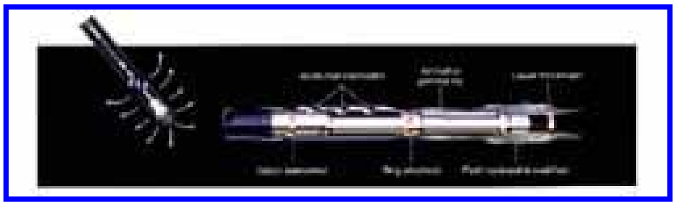
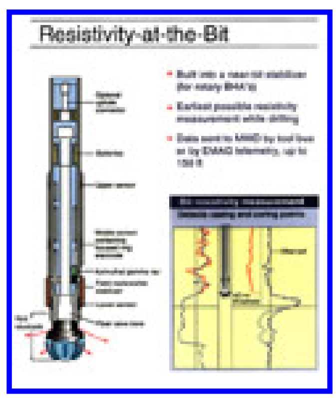
Logging-While-Drilling
Resistivity-at-the-Bit Tool (LWD-RAB*)

Description



The Resistivity-at-the-Bit (LWD-RAB) tool makes lateral resistivity measurements. As a formation evaluation tool, its application is limited to conductive muds. It may be run in several configurations and provides up to five resistivity measurements. The RAB tool contains a scintillation gamma ray detector which supplies a total gamma ray measurement. An azimuthal positioning system allows the gamma ray measurement and certain resistivity measurements to be acquired around the borehole. Additional measurements are chassis temperature and radial and longitudinal shocks.

The RAB tool has a nominal 6.75-in. diameter; it is meant to be run in 8.5-in. holes. Designed to be a flexible component of the bottomhole assembly, the RAB tool may be connected directly behind the bit or further back in the bottomhole assembly. The tool may be configured for packed or pendulum assemblies.



When connected directly to the bit, the RAB tool uses the lower portion (8-in.) of the tool and the bit as a measure electrode. In this configuration, it provides a bit resistivity measurement, RBIT, with a vertical resolution just a few inches longer than the length of the bit. A 1.5-in. tall cylindrical electrode, located 3 feet from the bottom of the tool, provides a focused lateral resistivity measurement, RING, with a 2-in. vertical resolution, independent of the location of the RAB tool in the bottomhole assembly. In addition, the RAB sub has three longitudinally spaced button electrodes that provide staggered depths of investigation. As the tool rotates, azimuthal measurements are acquired from the button electrodes.

The RAB measurements have a high vertical and azimuthal resolution. To make the most of the vertical resolution, the optimal sampling density is greater than one sample every inch. At the maximum sampling interval of 10 sec, the optimal sampling density can be achieved for rates of penetration up to 30 ft/hr. Achieving this vertical sampling is most important when imaging.

Applications

The RAB tool provides four depth of investigation measurements to detect early invasion of borehole fluids into the formation, a sensor at the bit to ensure minimum invasion, azimuthal resistivity images of the borehole to detect resistivity heterogeneity, and a gamma-ray sensor for lithology characterization.

The RAB tool can also provide a close look at structural information within a fault zone or an active tectonic are with a resolution of 15-30 cm. The RAB measures oriented resistivity images of the borehole wall, similar to an FMI or FMS wireline tools. These fracture orientations and distributions can be observed as resistivity contrasts in the image logs and are critical to recognize the extent of the deformation front along a tectonic front. Conversion of RAB images into relative porosity using Archie’s equation (Archie, 1942) can be used in combination with density and porosity data to help define the azimuthal distribution of porosity and overpressurized zones which may contribute to fluid flow along planes of structural weakness.

Environmental Effects

The button measurements have a shallow depth of investigation by design, in order to be sensitive to shallow invasion. When the RAB tool is centralized in a 8.5-in. hole, the buttons are 0.1875 in. from the formation. Controlling this standoff insures correct measurements. Therefore, proper centralization is recommended.

The RAB processing automatically corrects the resistivity measurements for frequency effects and the effects of the borehole. Routines to derive Rt from the multidepth measurements are being developed.

In impermeable zones, such as shales, and zones where insufficient time has passed for any significant invasion to take place, the measurements from the Ring, Deep Button and Medium Button will match, all reading Rt.

Log Presentation

RAB output
Comparison of RAB and Formation MicroImager (FMI)

Specifications

Tool weight:	1200 lbm
Tool length:	10.1 ft.
Min. - Max. temp:	-13° - 300°F (-25° - 150°C)
Drill collar nominal outside diameter:	6.75 in.
Drill collar maximum outside diameter (slick):	7.5 in.
Drill collar maximum outside diameter (azimuthal):	8.125 in.
Maximum flow rate:	800 gal/min
Maximum operating pressure:	18,000 psi
Maximum weight on bit:	$F = 74{,}000{,}000/L^2$ lbm (where L is the distance between stabilizers in feet)
Maximum jarring load:	330,000 lbf

Output

PGRD	Gamma ray average (API)
PGR_UP	Gamma ray up quadrant (API)
PGR_RT	Gamma ray right quadrant (API)
PGR_DN	Gamma ray down quadrant (API)
PGR_LT	Gamma ray left quadrant (API)

GTCK	Gamma ray tick
RTCK	Resistivity tick
RPM	RAB rotational speed (rpm)
ROP5	Rate of penetration (ft/hr)
RTAB	Ring time after bit (hr or min)
RTMP	RAB chassis temperature (°F / °C)
RB3	Relative bearing (deg.)
P1NO3	P1 north (deg)
P1AZ	P1 azimuth (deg)
HAZI	Azimuth (deg)

Deployment Notes

Along with the LWD collars, additional equipment such as jars must be included. Responsibility for providing this equipment is discussed at the pre-cruise meeting.

LWD deployment illustration
LWD deployment photo

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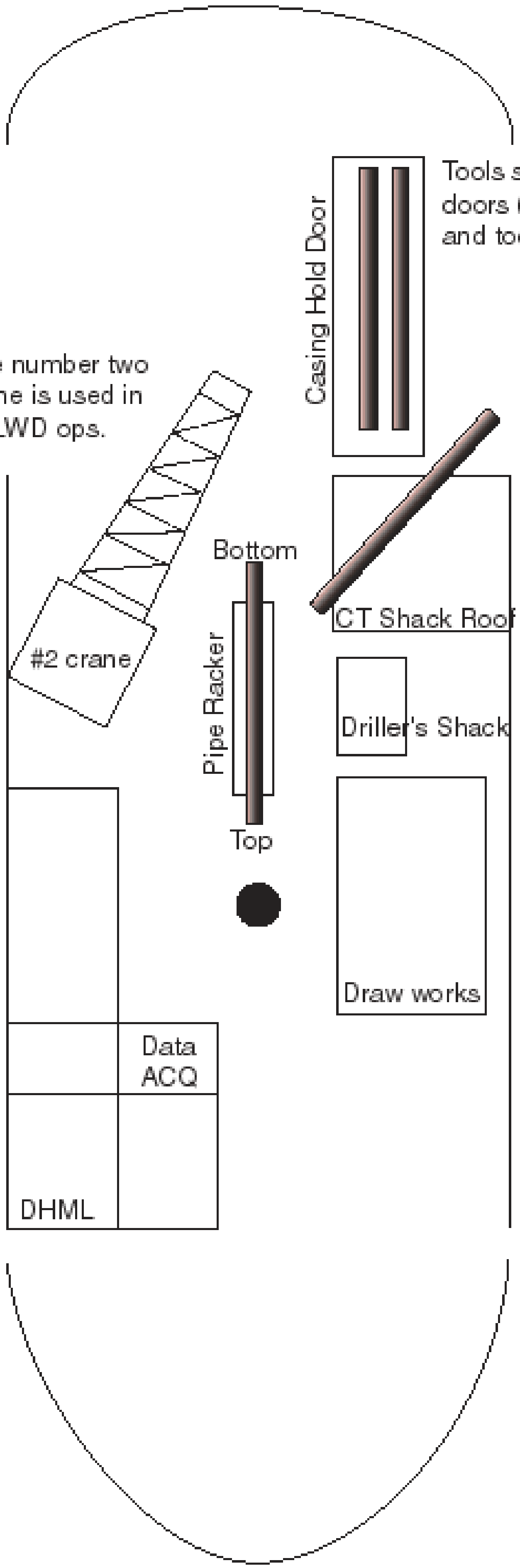
* ®trademark of Schlumberger

The number two crane is used in all LWD ops.

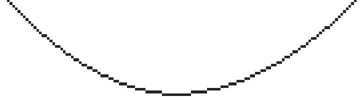


Tools stored on casing hold doors (batteries installed here and tools initialized here).

After the batteries are installed, the tools are staged on top of CT shack using the #2 crane.

When ready for logging, the CDR is layed in the pipe racker, then moved to the hole. The same procedure for the ADN. The bit is added then the sources. Once the sources are added, the ADN collar must not come above the rotary table.

Rig down occurs in the reverse sequence.



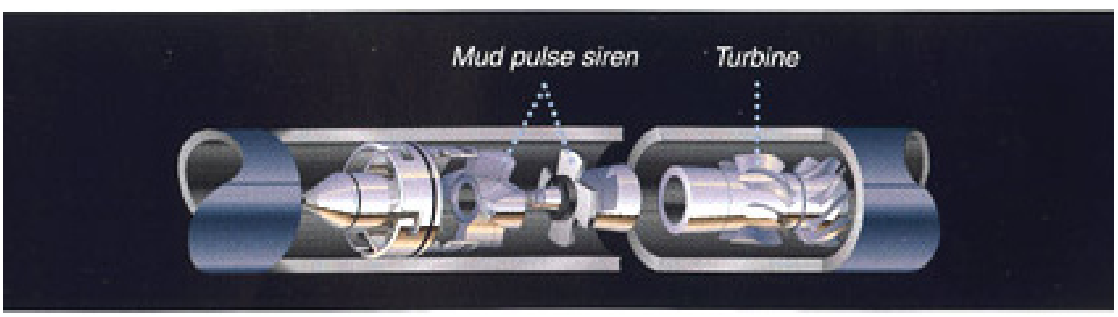
Measurement-While-Drilling (MWD*)

Description

The MWD tool is an in-line drill collar that records at-the-bit drilling parameters and telemeters the drilling parameter data as well as data from other LWD tools to the surface in real-time. MWD measurements include weight on bit (WOB), rate of penetration (ROP), torque, and pump pressure.

The tool uses a continuous mud wave, or siren-type, telemetry method and incorporates design features and software that enable it to approach data transmission rates of 6 to 10 bits per second. It measures downhole weight and torque on the bit to help the driller maintain optimal weight on bit or torque and improve the penetration rate.

The use of MWD equipment in ODP is anticipated to improve core quality and increase core recovery by reducing the variability of weight on bit (WOB). Examples of improved core quality include reduced "biscuiting," reduced core breaks, and recovery of difficult lithologies.



Specifications

Collar Size	6.75 in.	8.25-in normal flow
API collar size:	6.75 in.	8.25 in.
Collar OD:	6.89 in.	8.41 in.
Collar ID:	5.109 in.	5.109 in.
Makeup length	23 ft. (without WOB)	23 ft. (without WOB)
Collar weight without tool:	1330 (lbm)	2590 (lbm)
UH connection bending strength ratio:	2.00	2.20
DH connection bending strength ratio:	2.14	2.20
Moment of inertia:	77.4 $in.^4$	212 $in.^4$
Collar dogleg:	5 deg/100 ft, rotating at 100 rpm	4.4 deg/100 ft, rotating at 100 rpm
Max. collar dogleg:	15 deg/100 ft, sliding	12 deg/100 ft, sliding
Flow range:	225-800 gpm	300-800 gpm
Maximum operating torque:	12,000 ft-lbf	23,000 ft-lbf
Maximum weight on bit:	$71,000/L^2$	$194,000/L^2$
Maximum tensile load:	550 klbf	865 klbf

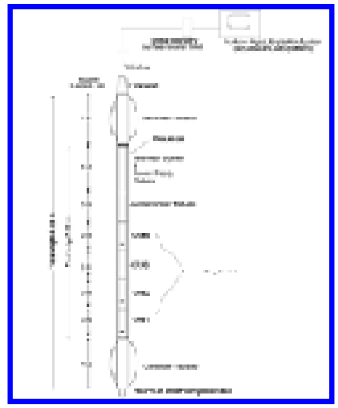
Deployment Notes

Stuck/lost tool information

* ®trademark of Schlumberger

Multi-Sensor Spectral Gamma Ray Tool (MGT)

Description



The Multi-Sensor Spectral Gamma Ray Tool (MGT) is a new third party tool developed by the Lamont-Doherty Borehole Research Group to improve the vertical resolution of natural gamma-ray logs. This is achieved in the MGT by using an array of short detector modules with approximately 2-ft spacing. Each module comprises a small 2"x4"NaI detector, a programmable 256-channel amplitude analyzer, and an Am^{241}calibration source. The spectral data are later recalculated to determine the concentration of potassium, thorium, and uranium radioisotopes or their equivalents. The spectral data from individual modules are sampled 4 times per second and stacked in real time based on the logging speed. This approach increases vertical resolution by a factor of 3-4 over conventional Schlumberger tools used in the ODP (e.g., the NGT) while preserving comparable counting efficiency and spectral resolution. The radius of investigation depends on several factors: hole size, mud density, formation bulk density (denser formations display a slightly lower radioactivity) and the energy of the gamma rays (a higher energy gamma ray can reach the detector from deeper in the formation).

The tool also includes an accelerometer channel to improve data stacking by the precise measurement of logging speed. A specialized telemetry system developed for the MGT allows it to be combined with Schlumberger toolstrings in a single logging operation, minimizing the required rig time to acquire the log.

Applications

Spectral gamma-ray logs provide one of the best means to investigate the mineralogy of thin-bedded sedimentary sequences, to correlate among different logging runs, and to compare logging data and core measurements. Increasing vertical resolution over currently available tools provides new opportunities for log analysis in reservoirs with rapidly changing lithology and for finer resolution of thin layering and in areas with low sedimentation rates. The added resolution provided by the MGT will be of particular use in paleoclimate studies.

Environmental Effects

The MGT response is affected by borehole size, mud weight, and by the presence of bentonite or KCl in the mud. In ODP boreholes KCl is sometimes added to the mud to stabilize freshwater 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 of these effects are accounted for during the processing of the MGT data onshore.

Specifications

Temperature Rating:	85° C operational / 100° C maximum
Pressure Rating:	10,000 psi (~6.8 km)
Tool Length	
Telemetry module:	9.0 ft (2.75 m)
MGT module:	9.5 ft (2.90 m)
Tool Outer Diameter:	3.375 in. (8.6 cm)
Maximum logging speed:	900 ft/hr
Energy Measurement Range:	0.2 - 0.3 MeV

Deployment Notes

The MGT is always run at the top of the Schlumberger toolstring. The downhole switch in the MGT telemetry module provides switching of the signal and power lines between the MGT and the Schlumberger logging system.

Stuck/lost tool information

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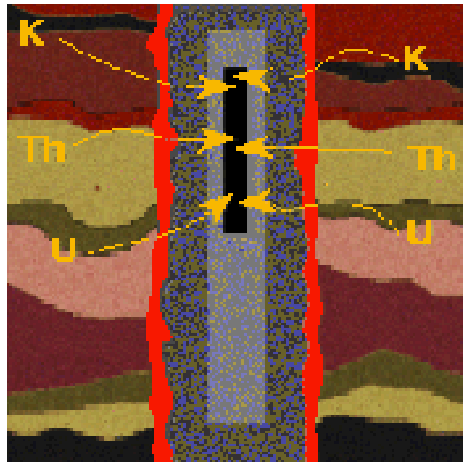
* ®trademark of Schlumberger

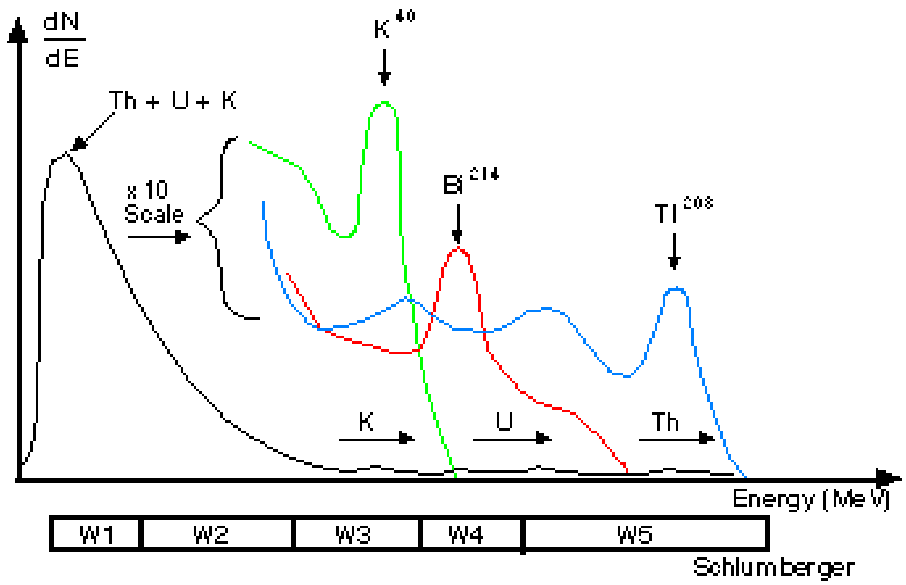
Triple Combo FMS/Sonic Specialty Other Toolstring Index

Natural Gamma Ray Tool (NGT*)

Description



The Natural Gamma Ray Tool (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, a uranium-free gamma ray measurement, and the concentrations of potassium, thorium, and uranium.



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).

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.

Ash layer detection

Thorium is frequently found in ash layers. The ratio of Th/U can also help detect these ash layers**.**

Additional applications of gamma ray logs

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 sometimes added to the mud to stabilize freshwater 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 of these effects are accounted for during the processing of the NGT data onshore.

Log Presentation

The NGT log is routinely recorded for correlation between logging runs. To this purpose SGR (total gamma ray in API units) and CGR (computed gamma ray - SGR minus Uranium component - in API units) are usually displayed along with other curves (resistivity, sonic, density etc.). A full display of the data with SGR, CGR, and THOR (in ppm), URAN (in ppm), and POTA (in wet wt %) is usually provided separately.

Output plot of NGT data

Specifications

Temperature Rating:	149° C / 300° F
Pressure Rating:	20 kpsi (13.8 kPa)
Tool Diameter:	3.625 in (9.2 cm)
Tool Length:	8.58 ft (2.61 m)
Sampling Interval:	6 in (15.24 cm)
Max. Logging Speed:	900 ft/hr
Vertical Resolution:	.75 - 1 ft (20 - 31 cm)
Depth of Investigation:	1.5 ft (46 cm)

Output

SGR	Standard (total) Gamma Ray (GAPI)
CGR	Corrected Gamma Ray (GAPI)
THOR	Thorium (ppm)
URAN	Uranium (ppm)
POTA	Potassium (dec. fraction)
W1NG	Window 1 (0.2 - 0.5 MEV) Counts (cps)
W2NG	Window 2 (0.5 - 1.1 MEV) Counts (cps)
W3NG	Window 3 (1.1 - 1.59 MEV) Counts (cps)
W4NG	Window 4 (1.59 - 2.0 MEV) Counts (cps)
W5NG	Window 5 (2.0 - 3.0 MEV) Counts (cps)

Deployment Notes

Stuck/lost tool information

* ®trademark of Schlumberger

Triple Combo FMS/Sonic Specialty Other Toolstring Index

The Pre-Cruise Meeting

Pre-cruise meetings usually last two days and are always held at ODP/TAMU in College Station, Texas. The goal of the pre-cruise meeting is to prepare a detailed scientific and planning prospectus for the upcoming leg. This prospectus is available on the relevant page of the Science Operator's web site.

The scientific prospectus contains the following information:

1) Leg objectives.
2) Operations plan, including:

- Operation details of each site to be drilled
- Coring/logging tools to be deployed
- Specific objectives to be achieved at the site
- Sampling plan, if any

3) A time table for the leg operations.
4) A list of scientific participants.

At the pre-cruise meeting, the Logging Staff Scientist will make a presentation on the tools available for logging, the rationale for tool selection and the estimated logging times for specific sites to be drilled on the leg. Typically, this presentation follows those of the Co-Chief Scientists (on general scientific objectives) and the Operations Superintendent (on operations and engineering issues). Other topics covered by additional speakers include sampling and curatorial procedures, computing equipment and services, and publications policy and procedures.

A sample agenda for a pre-cruise meeting can be found at the end of this page.

The Logging Staff Scientist will contact the Co-Chief Scientists several weeks prior to the pre-cruise meeting in order to learn what issues the Co-Chiefs would like to have addressed at the meeting. The Logging Scientist's contribution can range from minimal (a short talk on time calculation) to comprehensive (a crash course on logging). Typically, the Logging Scientist will have several overheads describing recent applications of particular tools and/or measurements from recent legs, ideally from legs in similar geologic environments or legs with similar scientific objectives. Overheads showing the standard tool strings available, along with alternative tool combinations, will also be available.

The ODP/TAMU Drilling Superintendent will also prepare a preliminary timetable prior to the pre-cruise meeting. In that table he will also often include the logging times. The Logging Staff Scientist will work closely with both the Drilling Superintendent and the Co-Chiefs prior to the pre-cruise meeting to make sure all is well-coordinated and everyone is on the same page, more or less, before the meeting begins.

During the meeting there will normally be discussion of how to "fit" the program into a single leg -- by reducing the target depth, for example, or by cutting down the number of holes and/or sites, or cutting down the logging program (less runs, no runs). The Logging Staff Scientist will provide detailed information on the utility and rationale of logging measurements for each scheduled hole on the leg, but will also be prepared to re-compute logging times if necessary.

At the end of the meeting, the Logging Staff Scientist will write the logging section of the prospectus.

OCEAN DRILLING PROGRAM

Pre-Cruise Meeting -- Draft Agenda

Leg 183: Kerguelen Plateau

ODP Conference Room 106, Texas A&M Research Park,
College Station, Texas

April 20-21, 1998

April 20

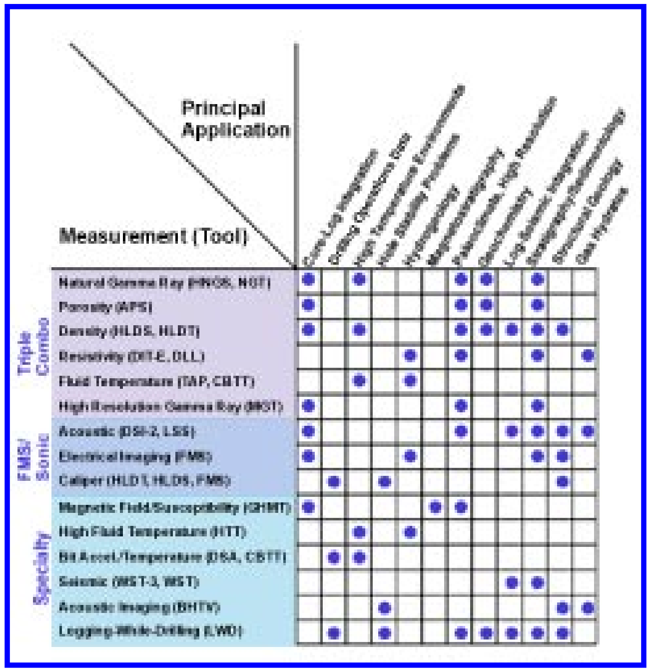
8:30 A.M.	Introduction/Coffee	Paul Wallace (ODP/TAMU Staff Scientist)
	Science Overview	Mike Coffin / Fred Frey (Co-Chiefs)
	Operations and Engineering Discussion	Mike Storms (ODP/TAMU Operations Superintendent)

	Logging Information	Heike Delius (ODP Logging Staff Scientist)
Noon	Lunch	
1:00 P.M.	Technical Support	Brad Julson (ODP/TAMU Supervisor of Logistics & Technical Support)
	Logistics	Pat Thompson (ODP/TAMU Material Services Team)
	Public Relations	Aaron Woods (ODP/TAMU Coordinator for Public Information)
	Science Staffing	Tom Davies (ODP/TAMU Manager, Science Services)
	Scientific Prospectus	Karen Graber / Paul Wallace (Staff Researcher / Staff Scientist)
April 21		
8:30 A.M.	Coffee	
	Curation & Sampling	John Firth (ODP/TAMU Curator, Science Services)
	Computers	Ken Emery (ODP/TAMU Supervisor, Computer Network Development & Support)
	Publications	Ann Klaus (ODP/TAMU Manager, Publication Services)
	Photography	John Beck (ODP/TAMU Senior Photographer)
Noon	Lunch	
1:00 P.M.	Scientific Prospectus	Paul Wallace / Mike Coffin / Fred Frey

ODP Logging Staff Scientist | Selecting Toolstrings | Estimating Log Times | Pre-Cruise Meeting

Selecting Logging Tools

Introduction



The selection of specific downhole logging tools for a particular leg is an ongoing procedure that starts with the proponents and (usually) ends when the Program Plan is approved. The standard toolstrings (Triple Combo and FMS/ Sonic) are always on the ship, often accompanied by one or more of the specialty toolstrings (GHMT, ARI, etc.). Specialty tool use is dictated by the scientific objectives of the cruise leg, and (inevitably) by the size of the year's budget for specialty tools. The operational plan for logging is determined at the pre-cruise meeting, usually held 6 to 8 months before the cruise, and is included in the cruise prospectus. Confirmation of the logging plan and time estimates are made onboard before each site at the "pre-site" meetings.

The Triple Combo is **always** run first, because it collects most of the basic petrophysical and lithological logs. It also measures borehole width, an important indicator of borehole and log quality. The FMS/ Sonic is usually run next: the FMS resistivity image reveals the fine details of the formation, and the sonic velocity completes the basic logs. Then the specialty tools are run, usually in order of scientific importance. The WST is usually the final tool to be run, because the fact that it is clamped against the borehole wall means it can destabilize the hole, and it is perhaps the one tool most prone to getting stuck.

When time is short, or when there are adverse logging conditions, the Logging Staff Scientist has the responsibility of preserving the integrity of the logging plan and making appropriate changes to it if necessary. He will keep in regular contact with the Operations Superintendent and the Co-Chiefs, so as to be up to date with the latest operational developments. Shipboard scientists should understand that it is the Logging Staff Scientist's job to act as an advocate for the logs, based on their scientific merit -- not just because they are part of the logging plan in the prospectus.

The principles to keep in mind when prioritizing toolstrings are:

1. To get the logs most relevant to the leg's scientific objectives.
2. To run the toolstrings most likely to get good results.
3. To minimize the risk of harming the tools or getting them stuck down the hole.

The scientific, environmental, and technical issues relevant to toolstring selection are described briefly below.

Science Issues

Lithology

The natural gamma, magnetic susceptibility, and PEF logs yield information on aspects of the chemical and mineralogical composition of the formation, which can be used to infer lithology (see individual tool summaries). This information can then be used to fill gaps in the core record, to pinpoint boundaries, etc. The absence of gaps in the logs makes them particularly useful for studies of sediment cyclicity, where a complete record is essential.

Petrophysics

The porosity, density, resistivity, and sonic velocity logs collect petrophysical and geotechnical information about the penetrated formations. In sediments, the general trend in these logs is of consolidation with depth. Deviations from this trend are caused by lithological change, lithification (cementation), under-consolidation (due, for example, to high fluid pressure, or a framework provided by microfossils), or the presence of gas hydrates. (Hydrate in the pore space increases resistivity and sonic velocity.) The principal advantage of these logs over the equivalent core measurements is that the logs record the in-situ property, whereas the cores are expanded and depressurized, and can suffer from end-effects and biscuiting.

Relation to the seismic section, synthetic seismograms

The Well Seismic Tool (WST) and air gun are used for checkshot surveys (to obtain a depth-traveltime relation) and zero-offset VSP experiments (to obtain seismograms at the site). The depth-traveltime relation can also be derived from the sonic velocity log, which together with the density log and seismic source wavelet combine to make a synthetic seismogram. Thus, reflectors on the seismic section can be identified with lithological or petrophysical changes in the borehole.

For almost every leg there is an extensive (and extensively interpreted) set of site survey seismic sections, and so it is of great importance that the borehole information can be associated with seismic reflectors and mapped along the seismic lines.

Structure and fabric

FMS data provide resistivity images of the borehole wall, showing detailed structural (faults, fractures), sedimentological (turbidites, beds, bioturbation, concretions, clasts), and igneous (veins, alteration, and basalt pillows, breccias, and flows) features. Moreover, the orientation of these features can be analyzed, since the GPIT is on the same toolstring. Under favorable circumstances, a borehole televiewer (BHTV) or azimuthal resistivity imager (ARI) can provide images of the same features.

Crustal stress and anisotropy

Borehole televiewers measure the shape of the borehole, which can be interpreted in terms of crustal stress (the borehole is deformed according to the maximum horizontal stress direction). The FMS caliper arms will tend to follow the major and minor axes of the borehole if it is elliptical, and thus can also be used to infer stress orientation.

The Dipole Sonic Imager (DSI-2) can reveal sonic S-wave anisotropy, which may be due to crustal stress or a preferential rock fabric.

Magnetic polarity

The GHMT total field and magnetic susceptibility measurements are processed to find the magnetic polarity of the remanent magnetization of the sediment, which can then be used for magnetostratigraphic dating. Note that the GHMT can log when descending the hole, as well as while going up the hole, unlike the other toolstrings.

Heat flow, fluid flow

The Temperature/Acceleration/Pressure (TAP) tool records the temperature of the borehole fluid, which increases downhole. The borehole fluid temperature equilibrates towards the actual formation temperature over the course of the logging run, and thus gives a lower limit to the actual formation temperature. Where formation fluids locally enter the borehole, they will cause an anomaly in the temperature log.

Environmental Issues

The state of the hole for logging can be assessed from the conditions experienced during coring. Before logging, the Logging Staff Scientist will confer with the Operations Superintendent and drillers about the general condition of the hole, and whether there are any "tight spots" or likely washouts. The Schlumberger Engineer, the Operations Superintendent, the Drilling Superintendent, the drillers, and the core-techs all have a wealth of experience in dealing with adverse hole conditions, and should be able to advise on specific matters such as how long to spend trying to break through bridges, what the risk to tools might be, how to retrieve stuck tools, and so on.

Logging-while-drilling (LWD) tools may be assigned to legs where hole conditions are anticipated to be unsuitable for conventional logging. Available LWD tools include the Azimuthal Density Neutron Tool (ADN), the Compensated Dual Resistivity Tool (CDR), and the Resistivity-at-the-Bit (RAB) Tool. In cases where real time acquisition of downhole data are required, Measurement-while-drilling (MWD) tools may be utilized.

Time-limited logging

Although adequate time for logging is usually allocated in the leg prospectus, it is not uncommon for unforeseen events (bad weather, difficult formations slowing the pace of coring, etc.) to reduce the actual time available for the logging program at a given hole. In this case, the Logging Staff Scientist will discuss with the Co-Chiefs the relative merits of allocating extra time to carry out the original program, cutting back on repeat runs or even forgoing a toolstring entirely. The Triple Combo will still be run first, but the others should be prioritized according to the leg objectives.

Bridged holes

Some holes may contain constrictions (bridges) that slow the toolstring’s descent into the hole. The heavier toolstrings (Triple Combo and FMS/Sonic) have a better chance of passing through a bridge than the lighter toolstrings (GHMT, WST); therefore, these are run first. One cause of bridges is swelling clays; this phenomenon can be combated by adding KCl to the drilling mud, although this will degrade the natural gamma potassium log. The capillary suction test equipment should be employed when swelling clays are suspected.

Blocked holes

There are various options if the toolstring cannot penetrate beyond a certain depth in the hole. If the blockage is near the base of the hole, it is probably best to just log the open interval above the blockage. If the blockage is midway down the hole, several options exist: 1) log only above the blockage; 2) dismantle the logging cable and lower the BHA to tag the blockage, then raise the BHA back to the original position; or 3) tag the blockage and only log below it. If the blockage is near the top of the hole, it is likely that there will be similar blockages further down and the hole is unloggable, but dismantling the wireline cable and re-reaming the hole is always an option.

Wide holes

Wide holes can result in poor contact between the tool sensor and the borehole wall, and hence degraded logs. Affected tools are the HLDS and APS (max caliper extension 18"), the FMS (max 16"), and the WST (max ~18"). The borehole width is measured by caliper during the first (Triple Combo) run. Depending on the scientific objectives, it is sometimes preferable to run the GHMT (which is relatively insensitive to borehole width) before the FMS/Sonic.

High heave conditions

The wireline heave compensator (WHC) reduces the effect of ship heave on tool motion, but higher heave conditions lead to increased uncertainty in the downhole tool depth, particularly if the heave is too great (more than 6m) for the WHC to be used. Increased tool motion (up-down oscillation) poses a risk to those tools with caliper arms (e.g., the HLDT and FMS), as there may be downward tool movement even when logging upwards; higher logging speeds will help. Additionally, high heave makes the process of bringing the tools back into the pipe from the open hole after logging more difficult.

There is an increased risk of the wireline cable slipping on the cable reel when lowering the tools down though the pipe, especially at the start of the descent, because initially there is only a small weight to provide tension in the cable. Tools must be lowered slowly, adding to the logging time particularly in deep waters. The risk of cable slip is worse with the lighter toolstrings (GHMT, WST).

High temperature conditions

When in a high temperature environment (such as a hydrothermal ridge system), careful attention is paid to the temperature channels on (for example) the DIT-E. It is important not to exceed the tool temperature ratings. Circulating water in the hole immediately prior to logging will cool the hole for a period of time. Some measurements are temperature dependent (e.g., resistivity).

Technical Issues

Logging tool limitations

The logging operation is limited to downhole tools with a diameter of 3.75 inches or less. All tools listed in the tool section of this document can be deployed in a standard bottom hole assembly (BHA). The absolute maximum tool diameter which can be run in a standard BHA is 3.81 inches, but this is pushing the tolerances to unsafe limits. To run tools up to 4.0 inches in diameter, the BHA can be modified by removing the Kinley crimper landing sub. This is strongly discouraged and formal approval would be necessary since this action would severely limit stuck tool recovery efforts.

Stuck/lost tools

This issue is discussed in more detail on the stuck/lost tools page. Needless to say, every effort should be made to avoid getting any of the tools stuck in the hole. The loggers are required to fish for any tool that is stuck or lost. It is particularly undesirable to lose the HLDT, as that tool contains a radioactive source; losing it would require cementing of the hole, a process that would take days and sour the mood on the ship considerably. Don't lose the GHMT either, as there are only two of them in existence.

In summation, losing a tool is awkward and unpleasant. Try very hard not to do it.

Conical side-entry sub (CSES)

The CSES makes it less risky to log under unstable hole conditions, however, it can increase the logging time by 50% or more, and cannot be used in shallow water depths. A more detailed discussion can be found in the CSES section on the Other Equipment page.

Dedicated logging holes

The more time spent coring a hole, the wider and more unstable it will become. For this reason, a fresh hole should provide better logs. However, the time involved is usually prohibitive.

Logging APC/XCB vs. RCB holes

The logging tools can pass through the APC/XCB bit, whereas the RCB bit has to be "dropped" at the bottom of the hole before logging tools can pass through. The hole cannot be deepened or bridges tagged after the RCB bit has been dropped. The RCB bit is about 2 inches narrower than the APC/XCB bit, so the RCB hole is less likely to be wide, and consequently better for the FMS.

The go-devil

It is important to understand the principles behind the deployment and operation of the go-devil. For details, see the go-devil section on the Other Equipment page.

Third Party Tool Support

ODP Logging Services provides support for broad aspects of third-party downhole tool deployment. Third party tools are designed and developed by investigators at other institutions involved with ODP and are reviewed by the JOIDES Scientific Committee (SCICOM) and the Scientific Measurements Panel (SCIMP) for deployment on the *JOIDES Resolution*. ODP Logging Services provides support to third party investigators in the areas of data acquisition systems and software, tool design and manufacturing assistance, and tool testing. Recently, successful deployments of the Lamont Shear Sonic tool (SST) and the WHOI Vertical Seismic Profile tool have been completed.

The need for custom-designed surface instrumentation, acquisition systems, and specialized power supplies has been addressed through the development of a multipurpose data acquisition system installed in the Downhole Measurements Lab (DHML). This system offers numerous benefits, including a standard computer platform from which to launch acquisition software, several power supplies, and a work space in the acquisition area devoted to third party equipment. Data telemetry software currently available includes modules utilizing a Windows 3.11/LabView4.0 graphic environment for acquisition of the following data types:

- Temperature
- Acoustic
- Depth and Heave
- Acceleration

Third-party tool support also includes the design and production of a cablehead crossover that allows third party tools to connect to the Schlumberger cablehead via an inexpensive, modified off-the-shelf connector. Hardware components currently available for third party tool support at LDEO include:

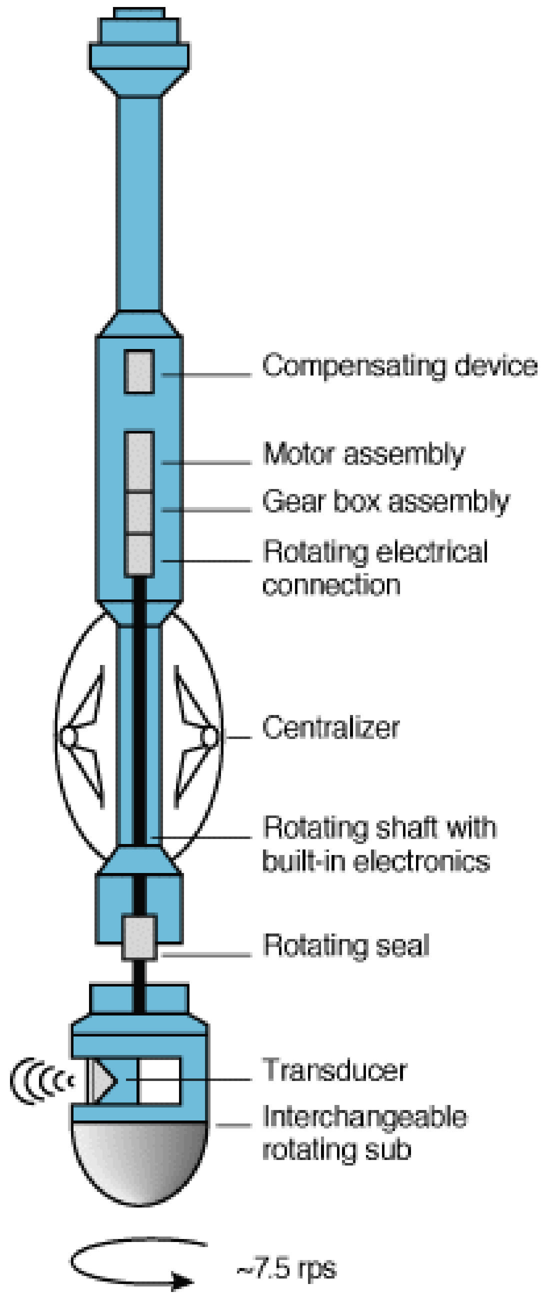
- PC-based data acquisition system at LDEO and on the *JOIDES Resolution*
- Multiple power supplies in a wide variety of voltage and amperage outputs
- Crossover for connecting third party tools to a Schlumberger-style cablehead
- Telemetry connection to a depth measurement system
- Access to pressure test vessel capable of 10,000 psi
- Access to 740 foot test hole at LDEO
- 22,000 feet of 7-46 wireline with terminations

Assistance during the development of third party tools is provided through ODP Logging Services personnel and the facilities available at LDEO. On-site facilities are available to assist in manufacturing, assembly, and pressure and field testing. Interested investigators should contact ODP Logging Services' Technical Services Manager, Greg Myers, at gmyers@ldeo.columbia.edu.

ODP Logging Staff Scientist | Selecting Toolstrings | Estimating Log Times | Pre-Cruise Meeting

Ultrasonic Borehole Imager (UBI*)

Description



The UBI Ultrasonic Borehole Imager features a high-resolution transducer that provides acoustic images of the borehole. Critical borehole stability and breakout information can be derived from the accurate borehole cross section measured by the tool. The high-resolution image from the transducer is also ideal for measuring casing internal geometry. The rotating transducer incorporated in the UBI sonde is both a transmitter and a receiver. The transducer subassembly is available in a variety of sizes for logging the complete range of normal openhole sizes. The subassembly is also selected to optimize the distance traveled by the ultrasonic sound pulse in the borehole fluid by reducing attenuation in heavy fluids and maintaining a good signal-to-noise ratio. For openhole applications, the UBI tool is logged with the transducer operating at either 250 or 500 kHz. The higher frequency has better image resolution, but the lower frequency provides a more robust measurement in highly dispersive muds.

The UBI tool measures amplitude and transit time. An innovative processing technique improves accuracy, avoids cycle skips and reduces echo losses, which makes the UBI transit-time measurement as reliable as that of the amplitude. The tool is relatively insensitive to eccentralization up to 1/4 in. and yields images that are clean and easy to interpret, even in highly deviated wells. Processing software available both in MAXIS surface units and at Data Services Centers further enhances UBI images by correcting amplitude and transit-time information for the effects of logging speed variations and tool eccentering and by applying noise filtering. Transit times are converted to borehole radius information using the velocity of the ultrasonic signal in mud, measured by the tool on the way down. The images are oriented with inclinometry data from the combinable GPIT inclinometry tool and then enhanced by dynamic normalization and displayed as an image for visual interpretation. Amplitude and radius image data can be loaded on a geology workstation for analysis and interpretation. Major events can be automatically extracted from the radius data for wellbore stability evaluation.

Applications

- **High-resolution geological interpretation**
  The high resolution of openhole borehole wall images with 360° coverage makes the UBI tool suitable for fracture evaluation, even in oil-base mud.

- **Accurate shape analysis**
  Borehole stability problems can lead to stuck pipe, lost time and even the loss of equipment or part of the well, resulting in added drilling costs. The UBI radius and the cross-section analysis accurately report the shape of the borehole, enabling a clear and detailed analysis of the problem.

- **Mechanical properties evaluation**
  The UBI tool indications of stress anisotropy and orientation characterize borehole deformations such as breakouts for predicting perforation stability in unconsolidated formations. Shear sliding along a fracture or bedding plane can be detected with UBI radius measurements and cross-section plots, providing strong evidence of potential borehole and drilling problems.

- **Casing and mechanical wear**
  An additional run in the hole to monitor the internal surface of the casing can be avoided by acquiring data while pulling the UBI tool out of the hole after an openhole survey.

Log Presentation

The UBI presentation usually consists of an amplitude image on the left and a borehole radius image on the right on a 1:40 depth scale. Dynamic normalization, usually over a 1-m interval, is applied to both images to highlight borehole features. Dark colors represent low amplitudes and large radii, indicating borehole rugosity, enlargements and attenuative material. These center tracks display dynamically scaled images. The two edge tracks show the upper 25%, median and lower 25% values of the amplitude and radius information at each depth. The colored areas on the edge tracks indicate the range of amplitude and radius data represented by the image color scales at each depth.

With advanced processing techniques, choice of operating frequencies and low sensitivity to eccentralization, the UBI tool offers unequaled quality of amplitude and precision of radius measurements for high-resolution acoustic borehole images.

Specifications

Temperature Rating:	350° F (175° C)
Pressure Rating:	20 kpsi (13.8 kPa)
Tool Diameter (varies according to subassembly):	3.6 to 112 in.
Weight (varies according to subassembly):	Sonde 188 - 210 lbm
Tool Length (sonde and cartridge only):	20 ft. 8 in. (6.3 m)
Maximum Mud Weight:	Water-base mud 16 lbm/gal
Recommended Logging Speed:	1 in. vertical sampling rate 2100 ft/h 0.4 in. vertical sampling rate 800 ft/hr 0.2 in. vertical sampling rate 400 ft/hr

Hole Size Range	5.5 - 12.5 in.
Approximate Image Resolution:	250 kHz operating frequency 0.4 in 500 kHz operating frequency 0.2 in

---

Deployment Notes

The UBI is run only with the NGT, and after the Triple Combo.

Stuck/lost tool information

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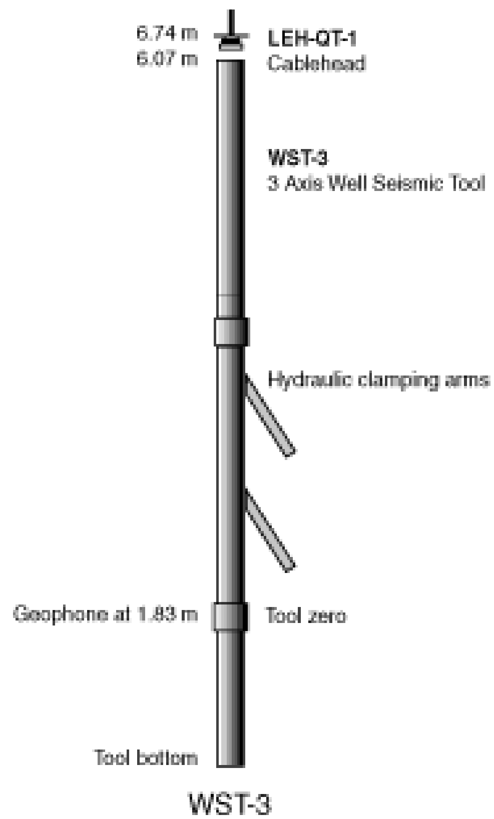
* ®trademark of Schlumberger

Triple Combo   FMS/Sonic   Specialty   Other   Toolstring Index

WST-3* Component

Description

The WST-3 is a Schlumberger three axis check shot tool used for both zero offset (check shot) and offset vertical seismic profiles (VSP). The WST-3 consists of three geophones which press against the borehole wall and record the acoustic waves generated by an air gun located near the sea surface. The tool was designed specifically for use in an offset VSP experiment, where a remote seismic source would be fired from a second ship. The tool is compatible with Schlumberger's latest data acquisition system, and data output is in SEG-Y format.



Applications

Offset VSP data acquired by the WST-3 are useful for:

- Providing seismic interval velocities which can be compared to the rock sequence intersected by the borehole.
- Placing the borehole results in their proper setting with respect to the seismically defined structure of the oceanic crust and mantle.
- Correlating borehole lithology with the up-going seismic reflected wavefield.
- Predicting structure and lithology changes below the drill hole.

- Estimating physical properties of rock on seismic scales by studying particle motion and downhole seismic attenuation.

In check shot mode, the WST-3 data can be used to produce a depth-traveltime tie and to calibrate the sonic logs and determine accurate drilling depths and their relative position with respect to targets on the seismic reflection profiles.

Log Presentation

The WST-3 has not yet been run in the Ocean Drilling Program, so no examples of data output are available yet. (It is scheduled for deployment during Leg 194, beginning January, 2001.) Data from the WST and WST-3 are similar in "check shot" mode; however, the WST-3's offset VSP mode is quite different. Updated information on the WST-3 will be posted to the ODP Logging Services web site as soon as it is available.

Specifications

Mechanical:

Temperature Rating:	350° F (175° C)
Pressure Rating:	20 kpsi (13.8 kPa)
Tool Diameter:	3.625 in (9.21 cm)
Tool Length:	19.9 ft (6.07 m)
Tool Weight:	310 lbs. (141 kg)
Min. Hole Diameter:	5 in. (12.7 cm) with "short" arms
Max. Hole Diameter:	19 in. (48.3 cm) with "long" arms
Max. Logging Speed:	Stationary
Vertical Resolution:	N/A

Sensors:

Axis:	3 axis
Geophone:	One per axis
Geophone type:	SM4 (3ea gimbaled)
Geophone frequency:	10 Hz
Damping:	60 dB

Sensitivity per axis:	83 V/m/sec or .80 V/in./sec at 25°C
Low-cut frequency:	0.2 Hz
Low-cut slope:	18 dB per octave
High-cut frequency:	250 Hz for 1 ms or 125 Hz for 2 and 4 ms sampling
High-cut slope:	36 dB per octave
Digitization:	Downhole
Sampling rate:	1, 2 or 4 ms (selectable)
ADC resolution:	11 bit + sign
Autoranger steps:	Five 6 dB steps
Preamplifier gain:	40 - 160 dB by 6 dB steps for each axis
Dynamic range per waveform (shot):	90 dB
Total dynamic range:	156 dB
Input noise level:	2µV
Anti-aliasing filters:	330 Hz / 24 dB per octave
Data format:	16 bit FP (12 bits mantissa, 4 bits exponent

Deployment Notes

The WST-3 can be used in both checkshot and offset vertical seismic profile experiments. A remote seismic source is required for an offset survey, while a traditional check shot survey can be completed with existing equipment on the *JOIDES Resolution*. For each type of experiment, the deployment routine for the WST-3 is approximately the same. The main difference is simply the location of the source and the handling of the trigger pulse.

For a check shot, a 120 in^3 air gun is suspended by buoys at a depth of 3 mbsl, offset 48.5m from the hole on the portside. The WST-3 is clamped against the borehole wall at intervals of approximately 50m, and the air gun fired five to seven times. The resulting waveforms are stacked and a travel-time is determined from the median of the first breaks in each trace. These check shot experiments attempt to reproduce the seismic reflection profiling by simulating a similar geometry and source frequency.

The WST-3 is always the last tool run and it is always run alone. At each selected station, a seismic shot is produced at the sea surface using either air or water guns provided by TAMU. Schlumberger provides a blast hydrophone for synchronizing the gun pulse with the system timer.

The WST-3 and other downhole seismic tools are sensitive to pipe noise and ringing of pipe following a shot. Efforts should be made to reduce pipe noise at each station. If time and resources permit, a drill string packer may be deployed to dampen the banging motion of the pipe against the borehole. In addition, it is always prudent to leave at least 50 to 75 m distance between the tool and the bottom of pipe.

The WST-3 must be powered with a 400hz power supply to avoid 60hz noise generated when a 60hz power supply is used.

The CSES should not be used with the WST-3 for three primary reasons:

1. If the bottom of pipe is kept near the tool, it is likely that the tool will measure ringing in the pipe each time the gun is fired.
2. If a significant amount of pipe is downhole, there is a possibility that the pipe could generate a noise in the data as the pipe bangs in the hole.
3. The WST-3 is an inherently risky tool to deploy because the tool is held in a stationary position in a deteriorating borehole. Use of the CSES may only exacerbate these risks by providing access to a hole that may be unsafe for the WST-3.

Stuck/lost tool information

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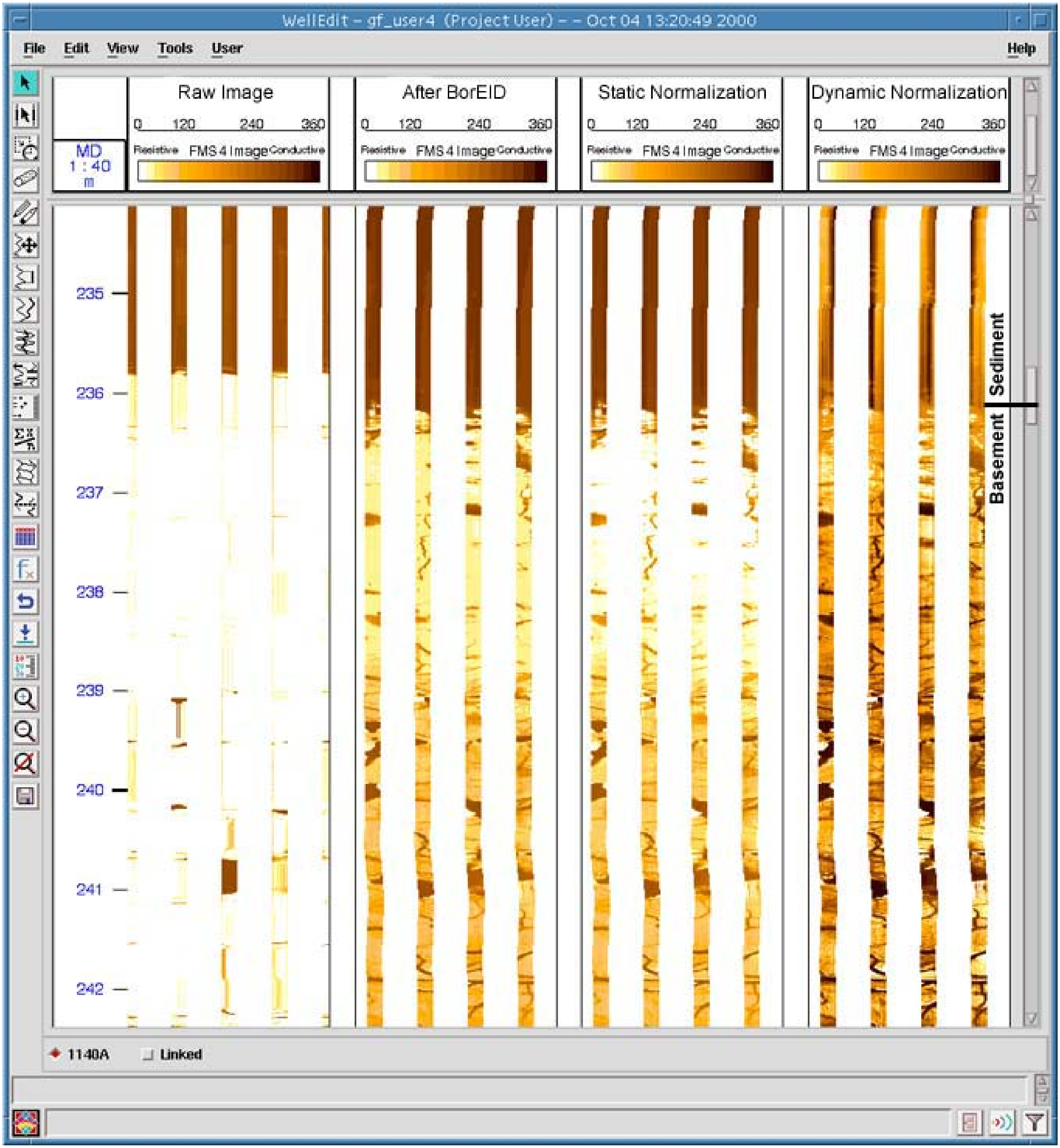
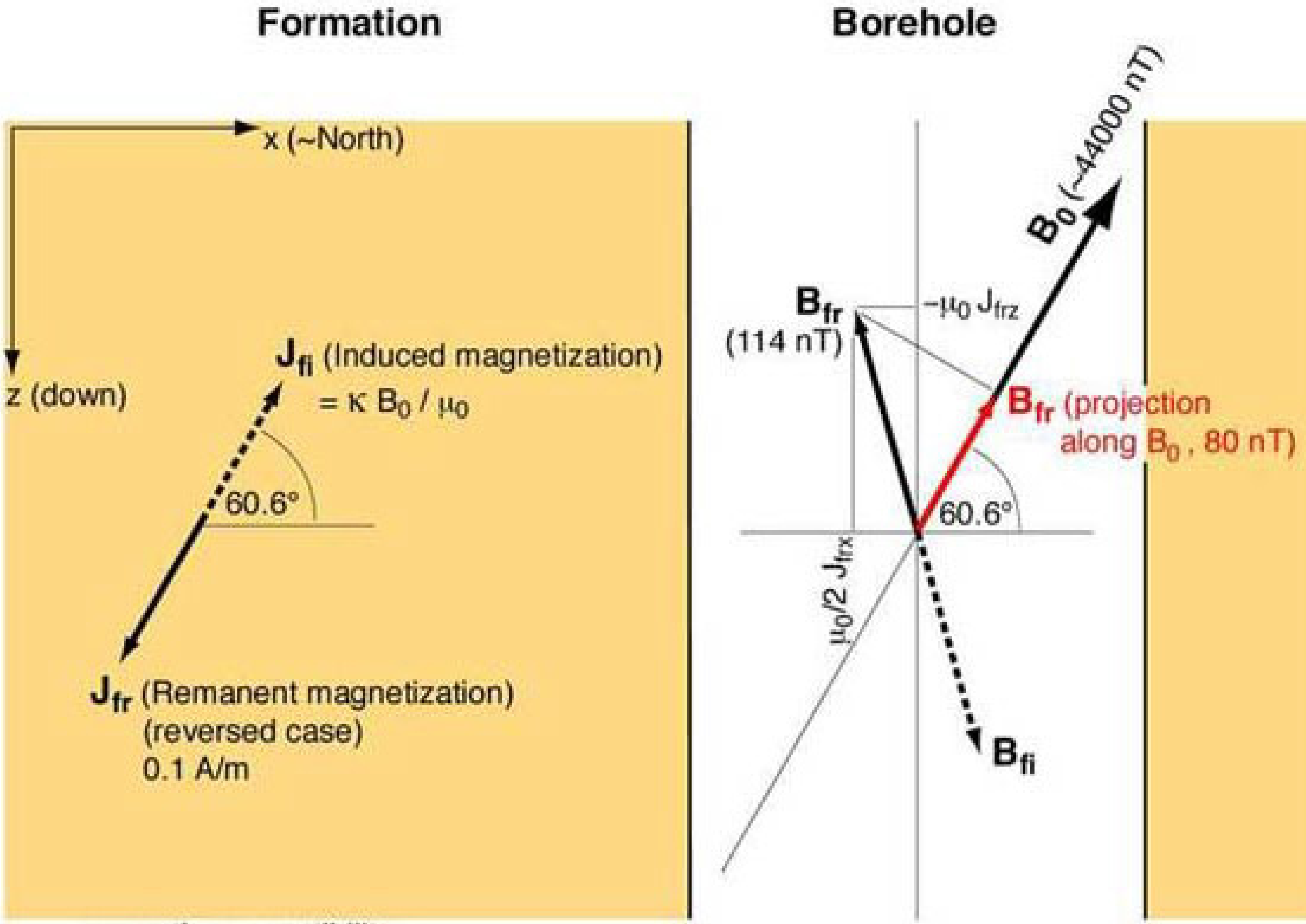
* ®trademark of Schlumberger

Testing the WST hydraulic arms during rig-up on Leg 183.



FMS images after successive processing steps

Showing how the Remanent Anomaly B_{fr} in the borehole is related to the remanent magnetization J_{fr} of the formation for the case 67.5° S (Site 1096) and J_{fr} = 0.1 A/m



κ = magnetic susceptibility

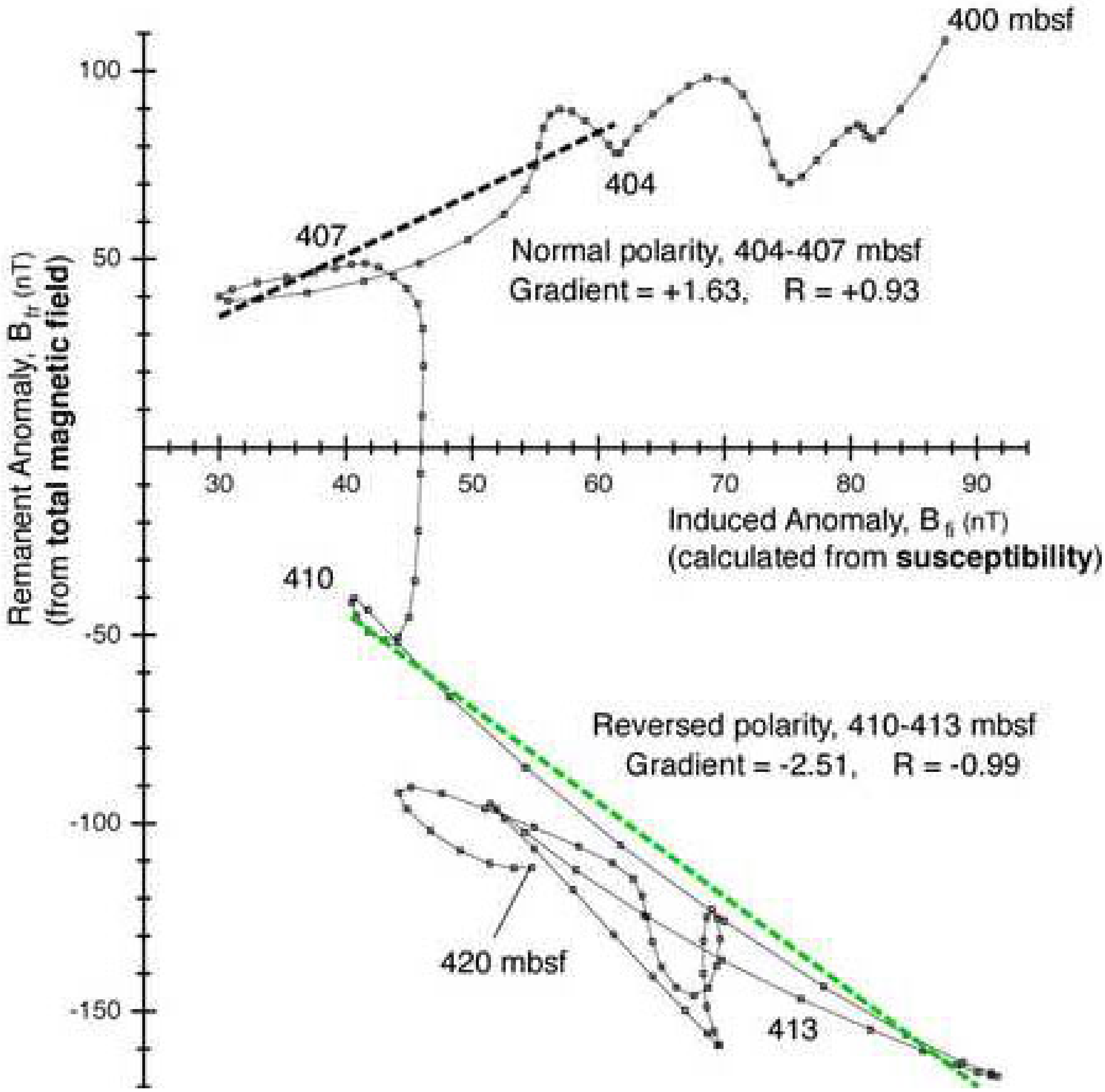
μ_0 = permeability of non-magnetic material

B_0 = main geomagnetic field

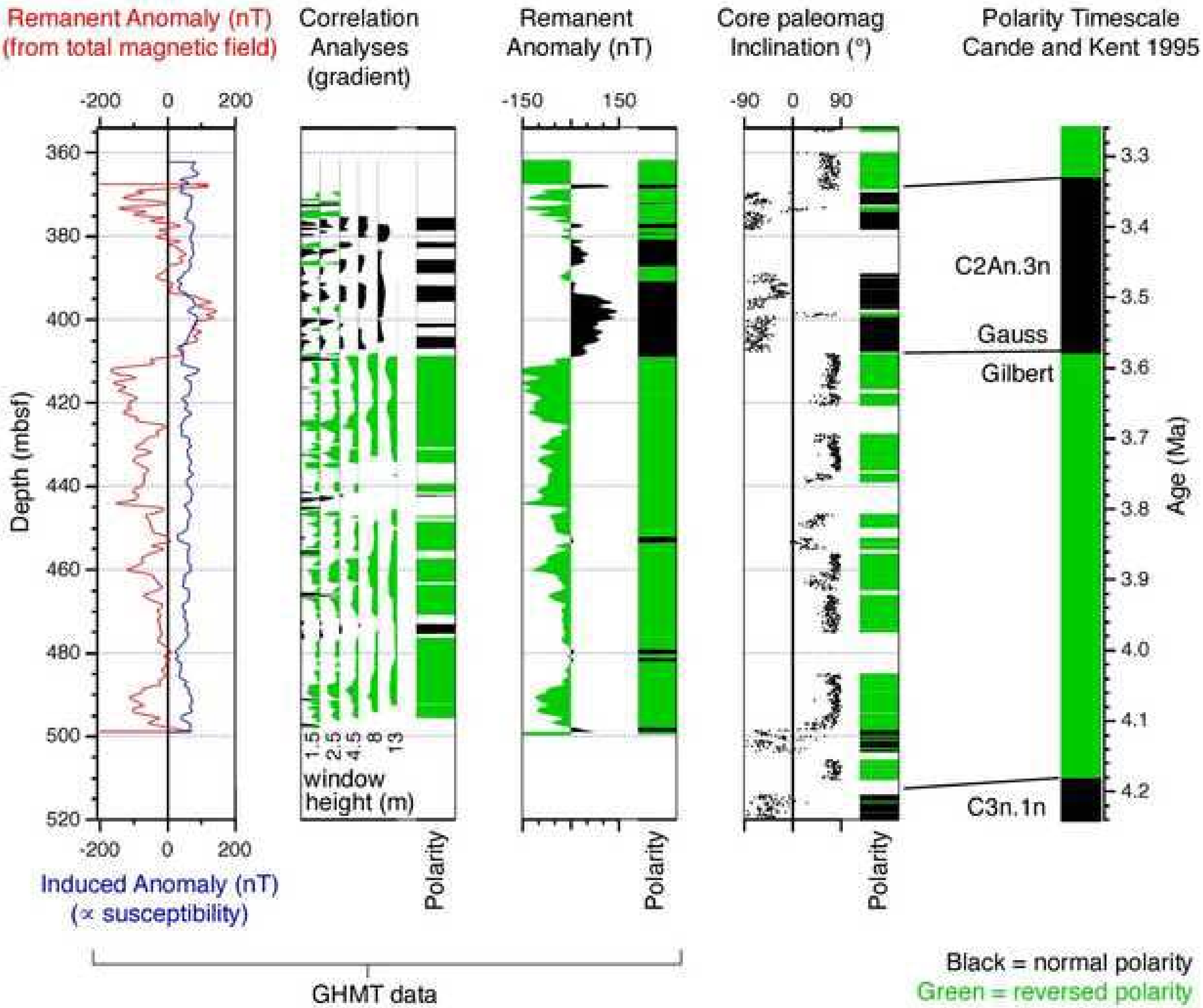
Remanent vs. Induced field anomaly, 400-420 mbsf, Hole 1096C, covering a transition from reversed to normal polarity.

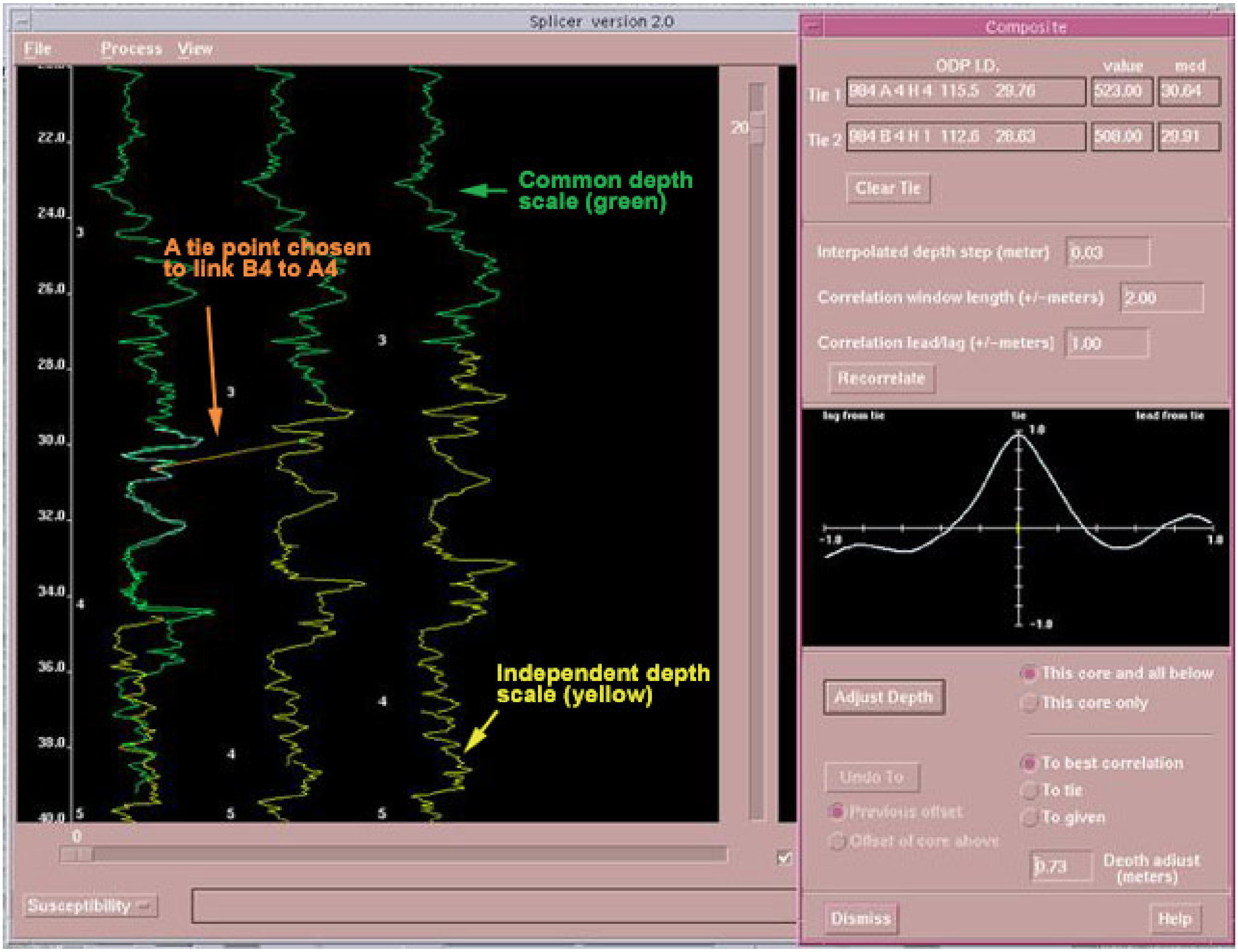
The gradient is positive for normal polarity and negative for reversed polarity; this forms the basis of the Correlation Analysis method for determining polarities.

In some cases (such as this one), the polarity is also given by the sign of the remanent anomaly.

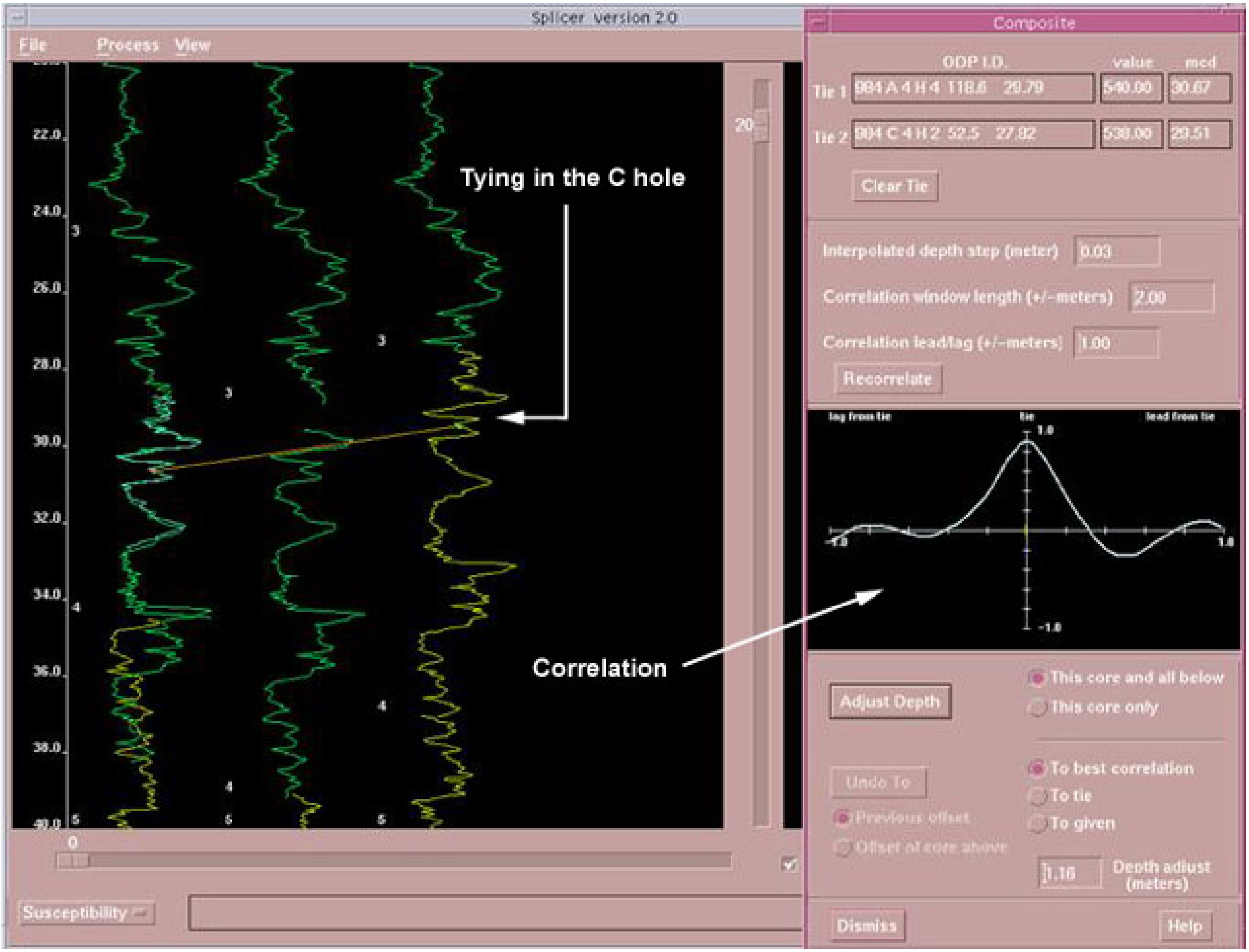


Comparison of magnetic polarity from GHMT logs and core paleomagnetism
Hole 1096C, Leg 178, Antarctic Peninsula

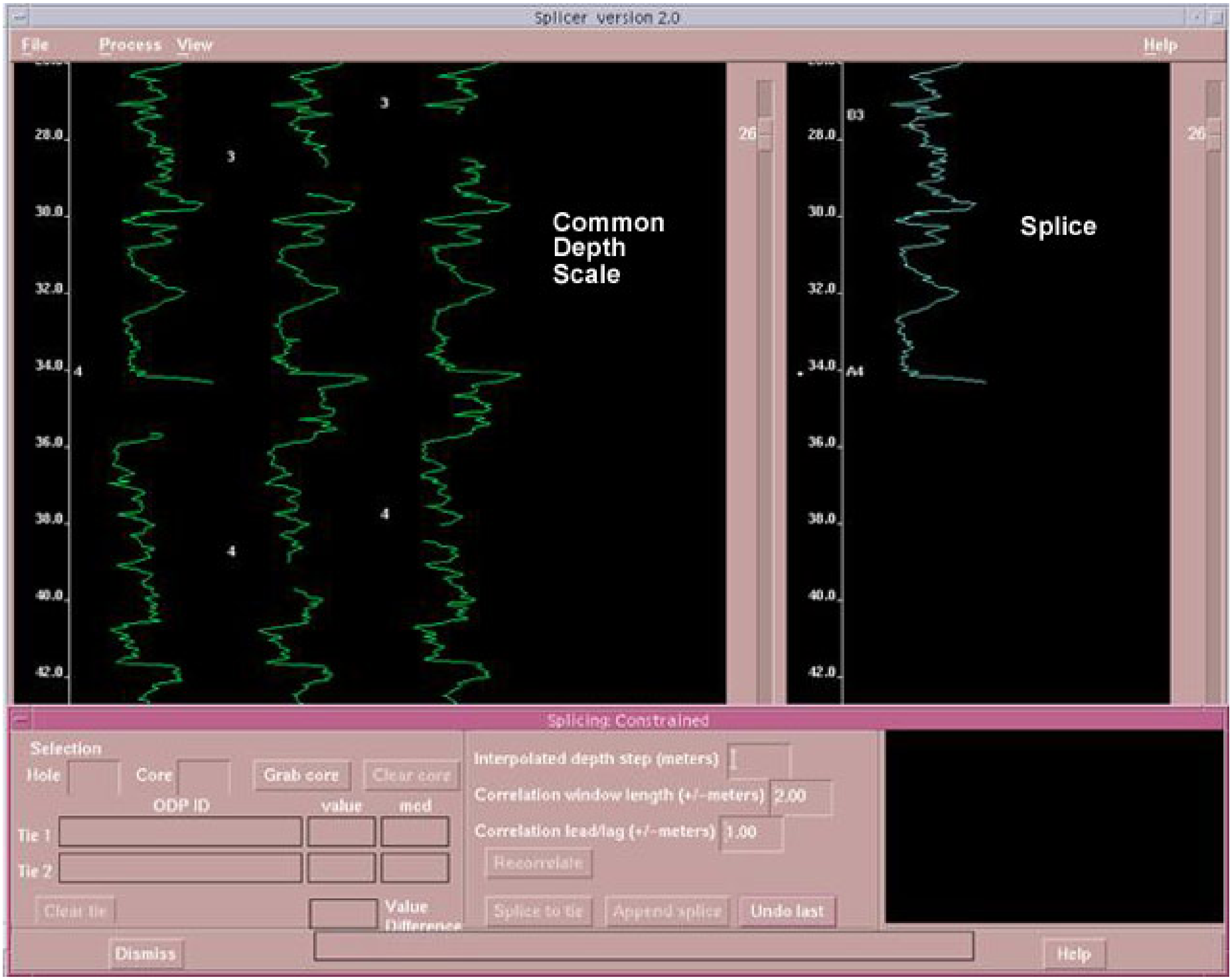




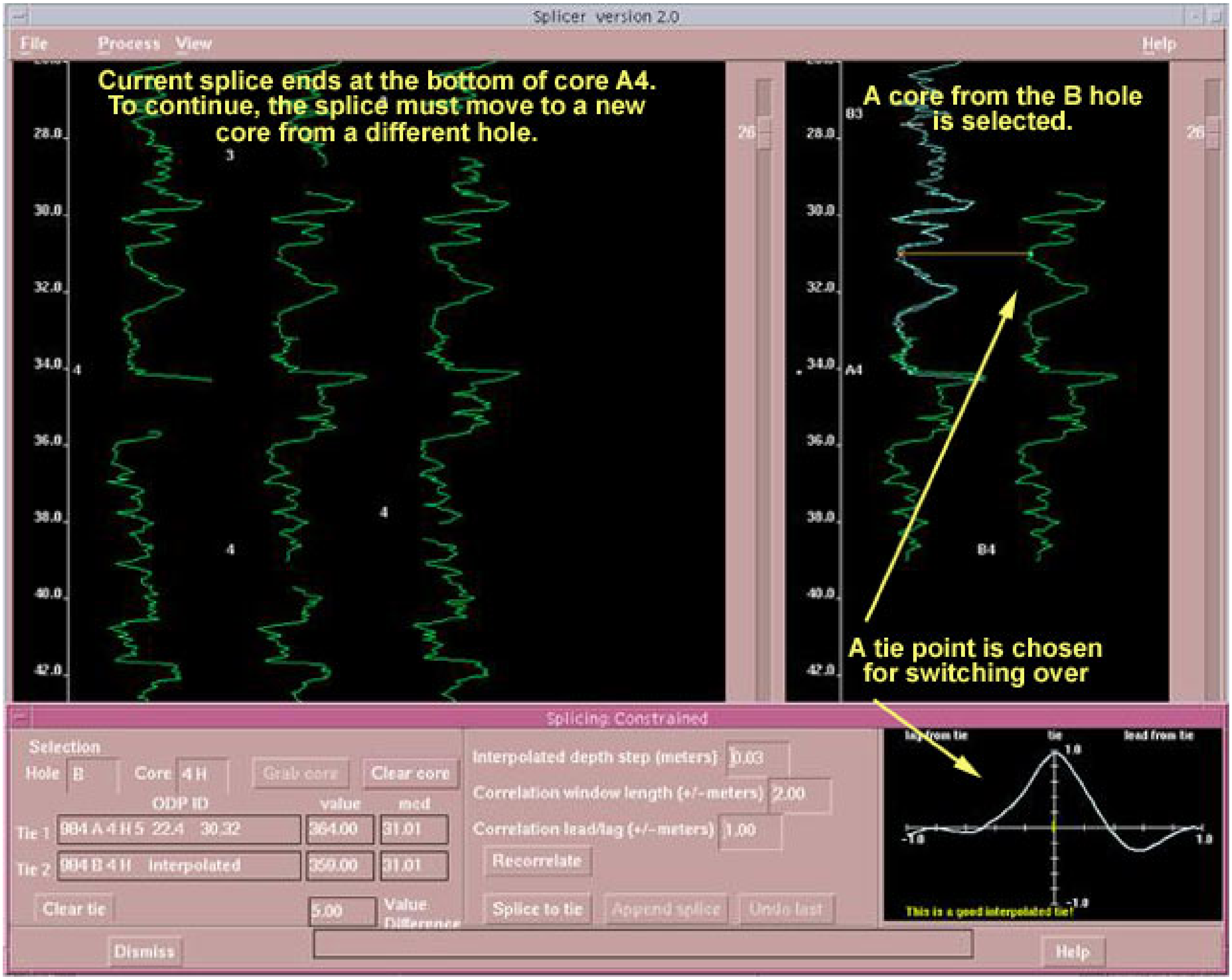
Tying Hole B to Hole A.



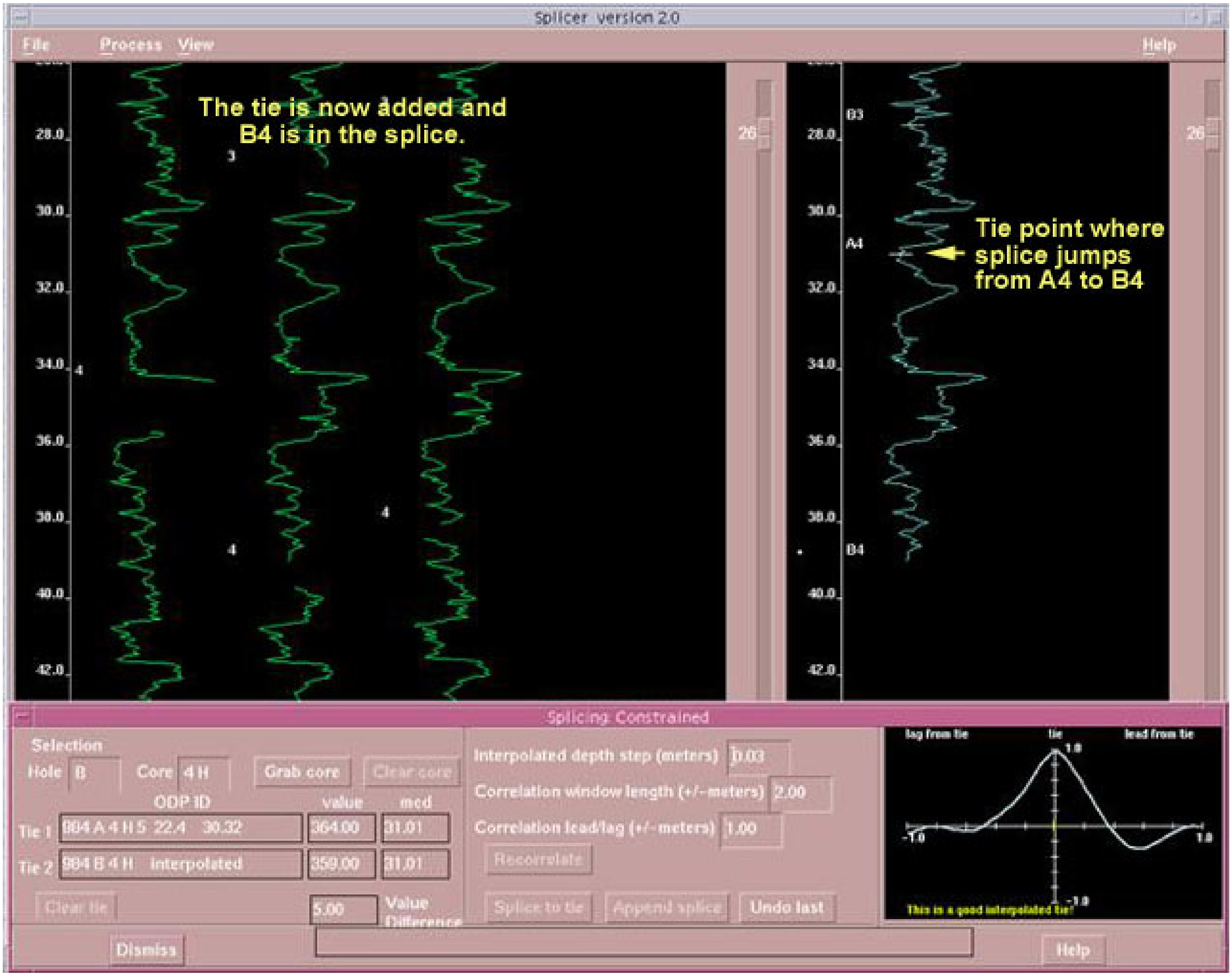
Tying in Hole C so that all holes are in the composite.



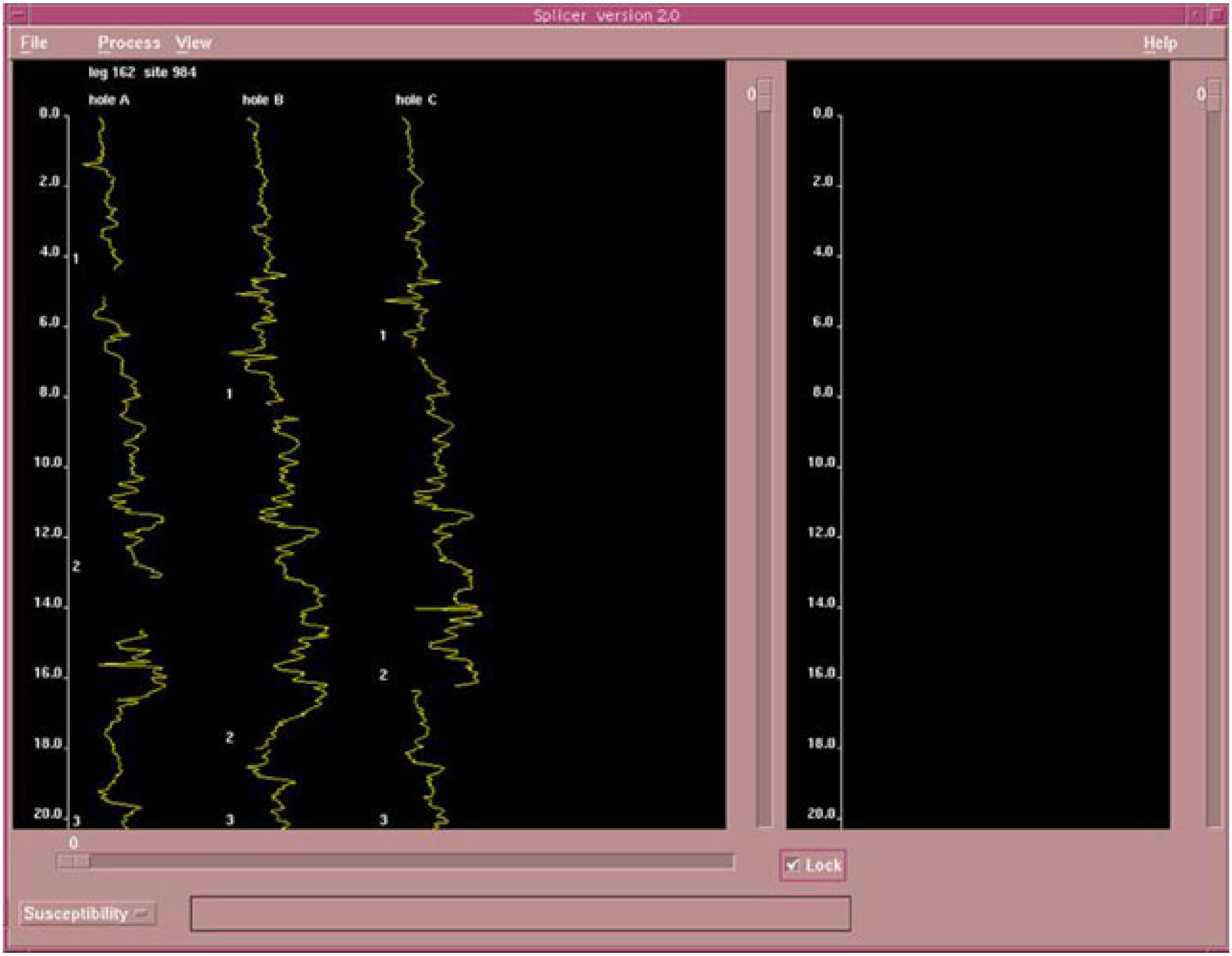
The splice complete to 34 mcd.



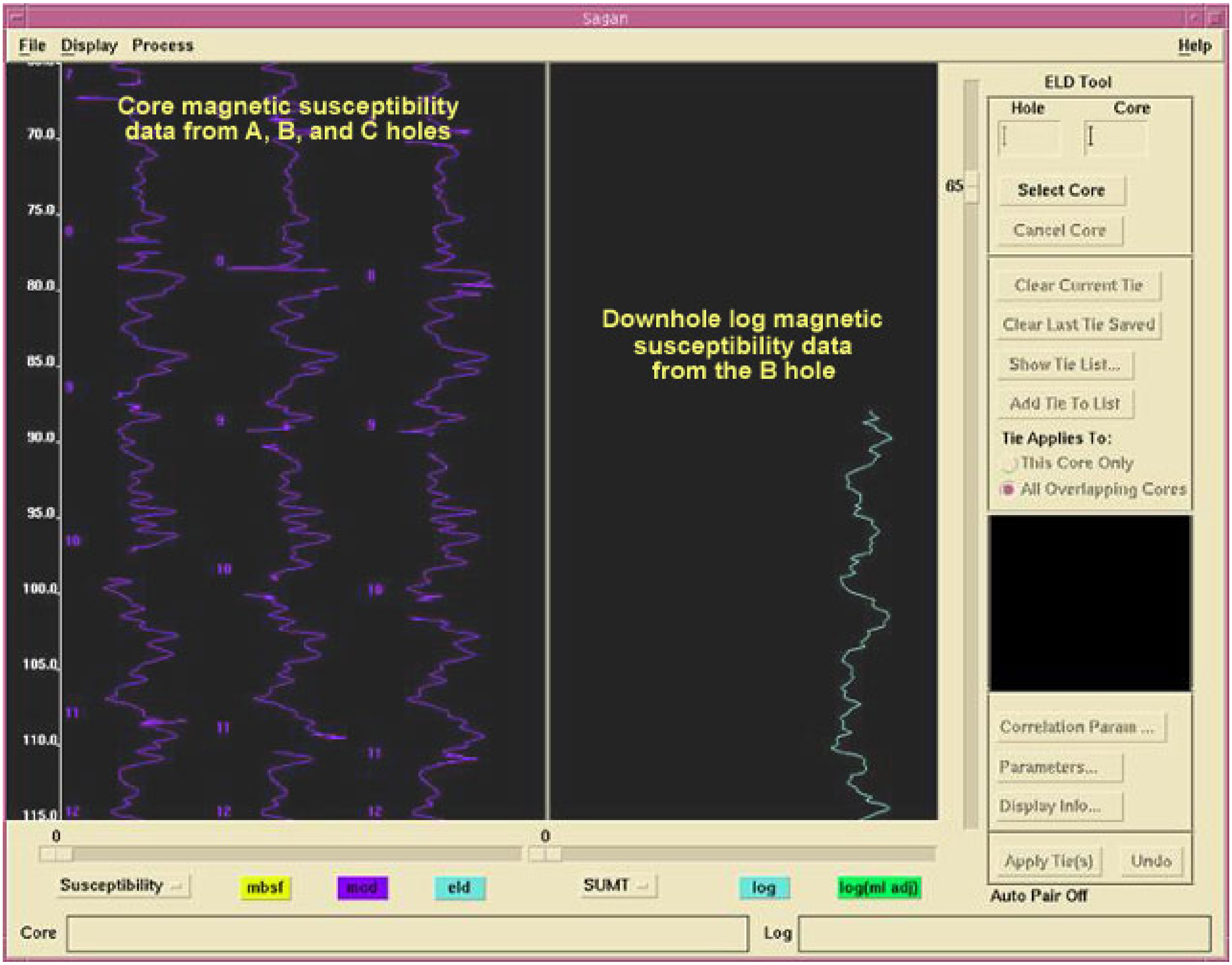
An overlapping core from the B hole is chosen to extend the splice.



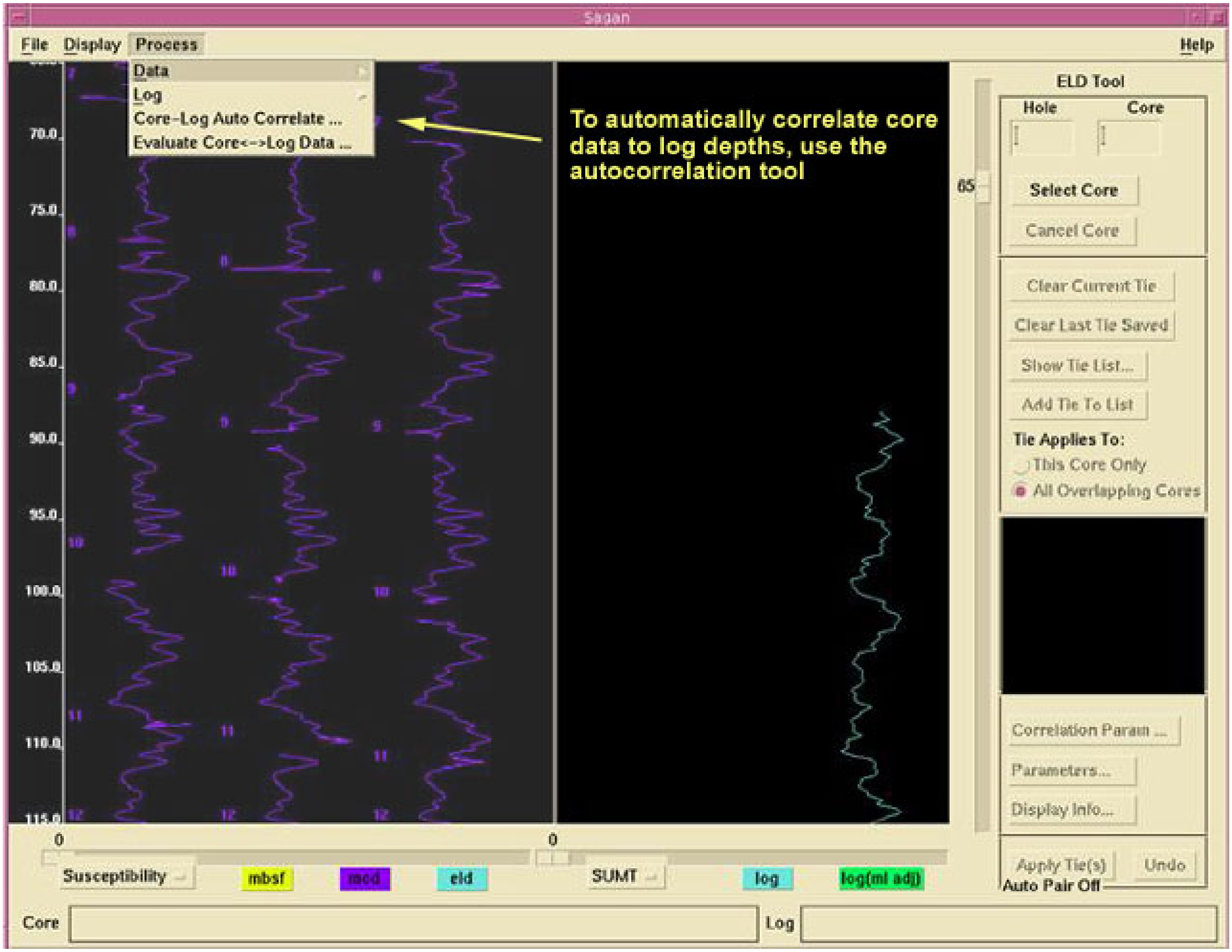
After the tie point is chosen, the splice continues in the B hole.



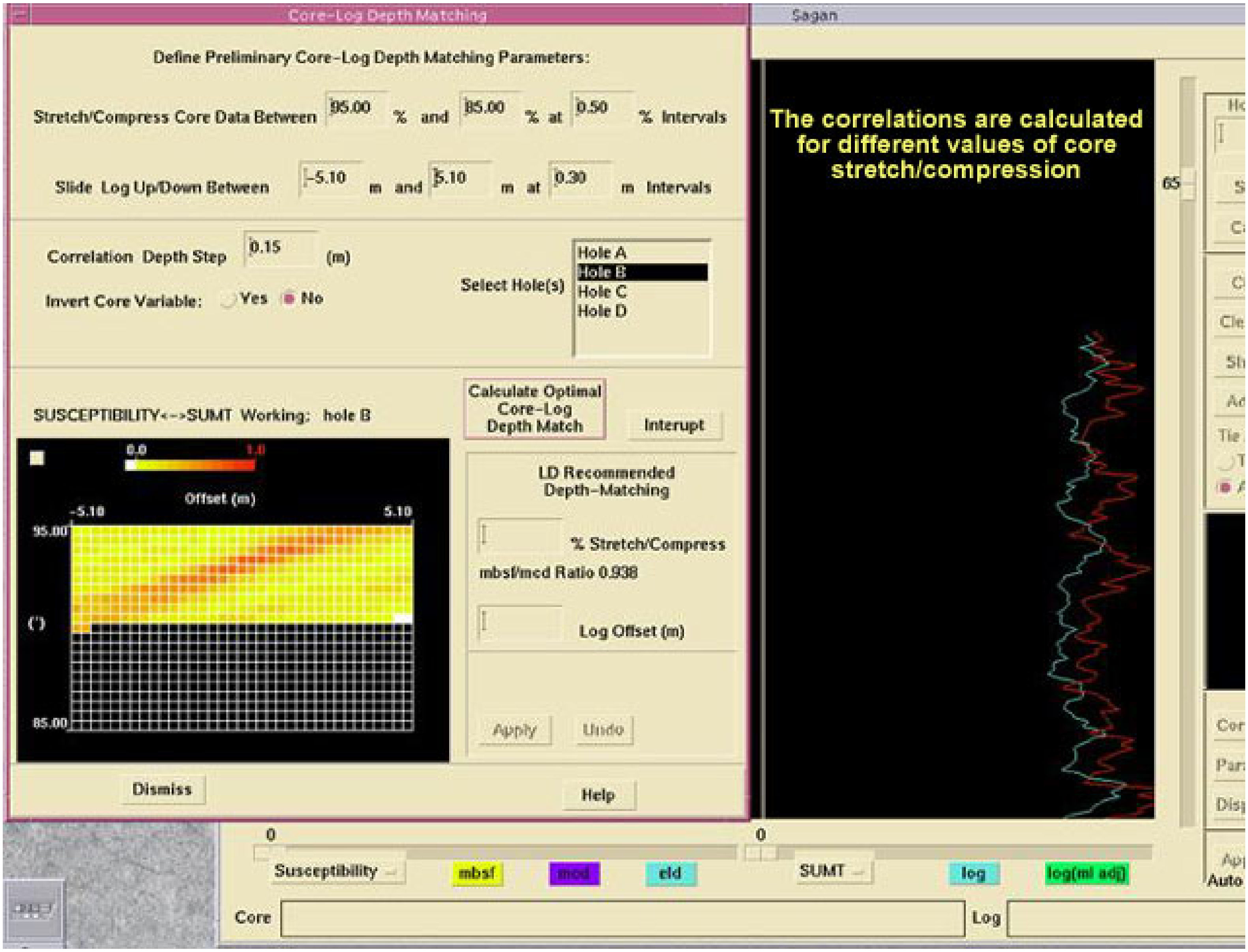
Core magnetic susceptibility data is loaded from three different ODP holes (A, B, C) at Site 984 and appears vs. mbsf.



Core magnetic susceptibility data from three holes are compared to downhole magnetic susceptibility from the B hole.

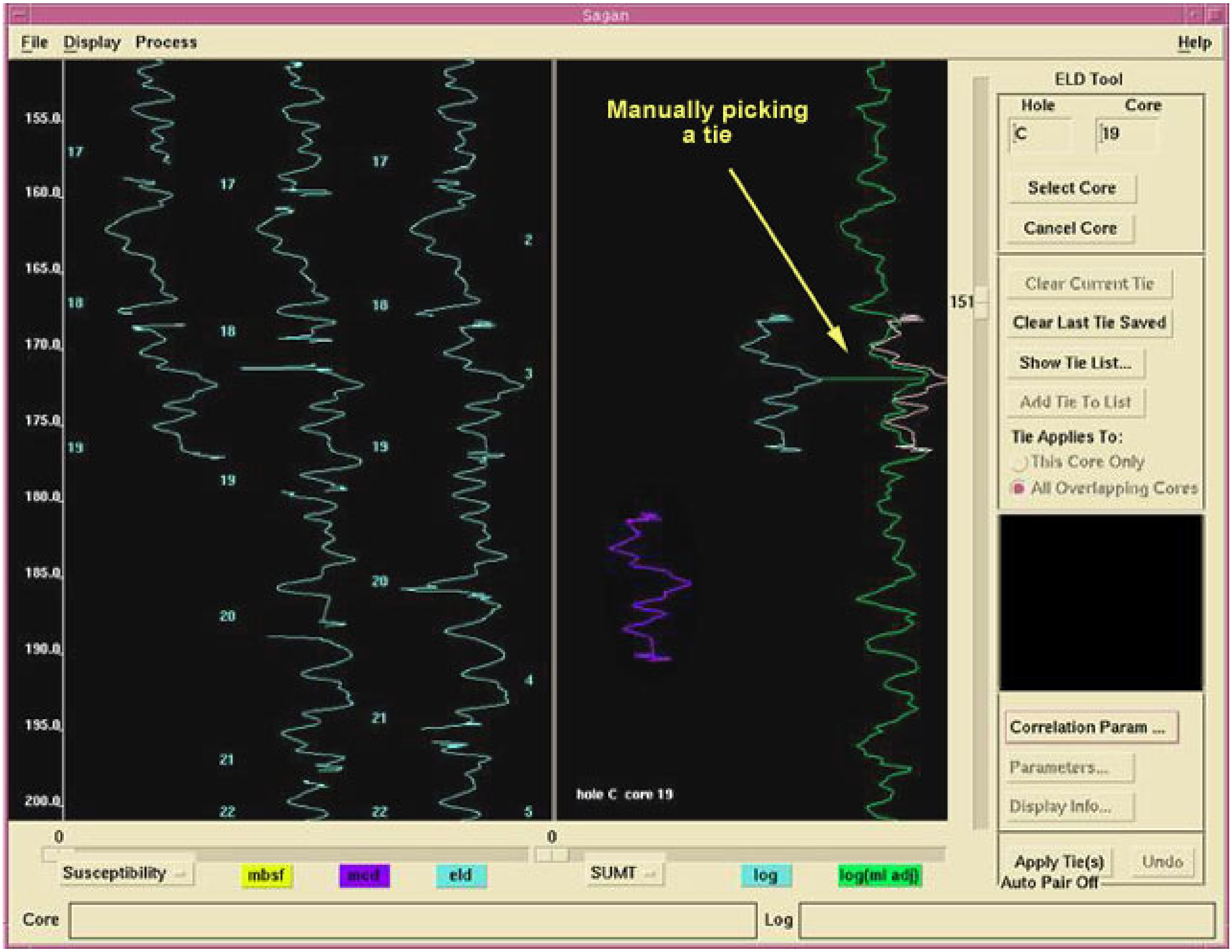


Core data versus mcd and downhole log data before correlation.

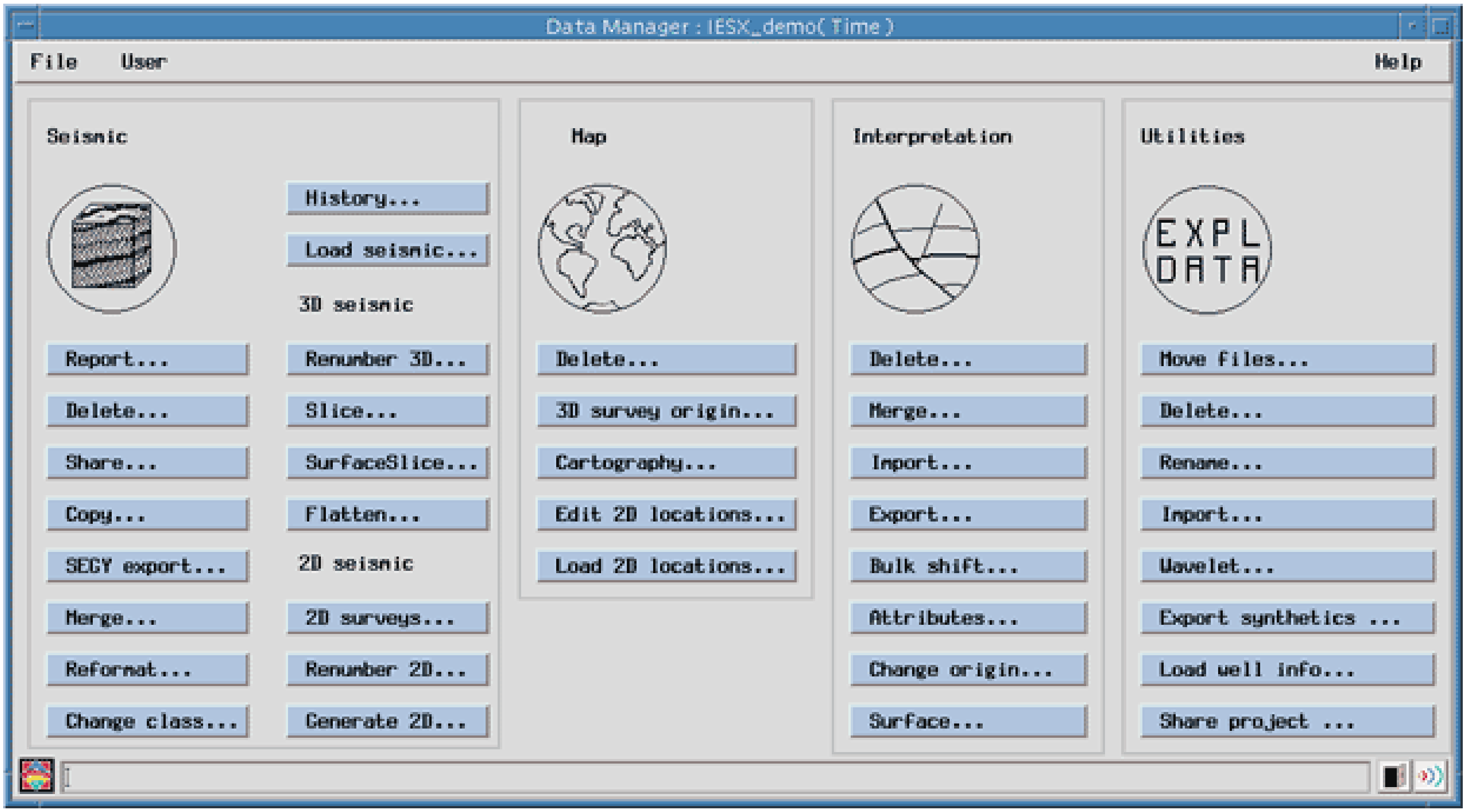


A hole is chosen for correlating core data to the logs and the best overall correlation is calculated.

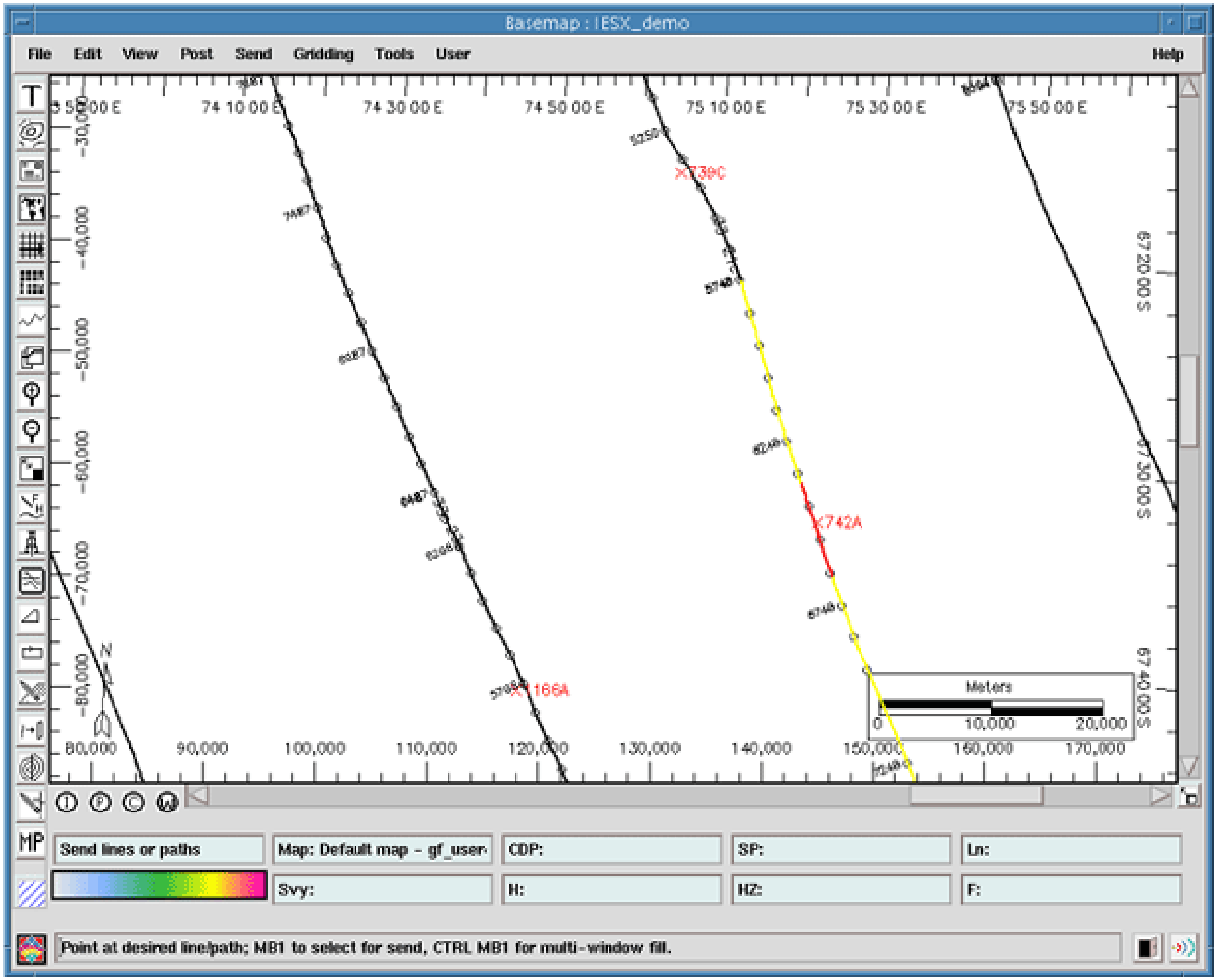
Continue



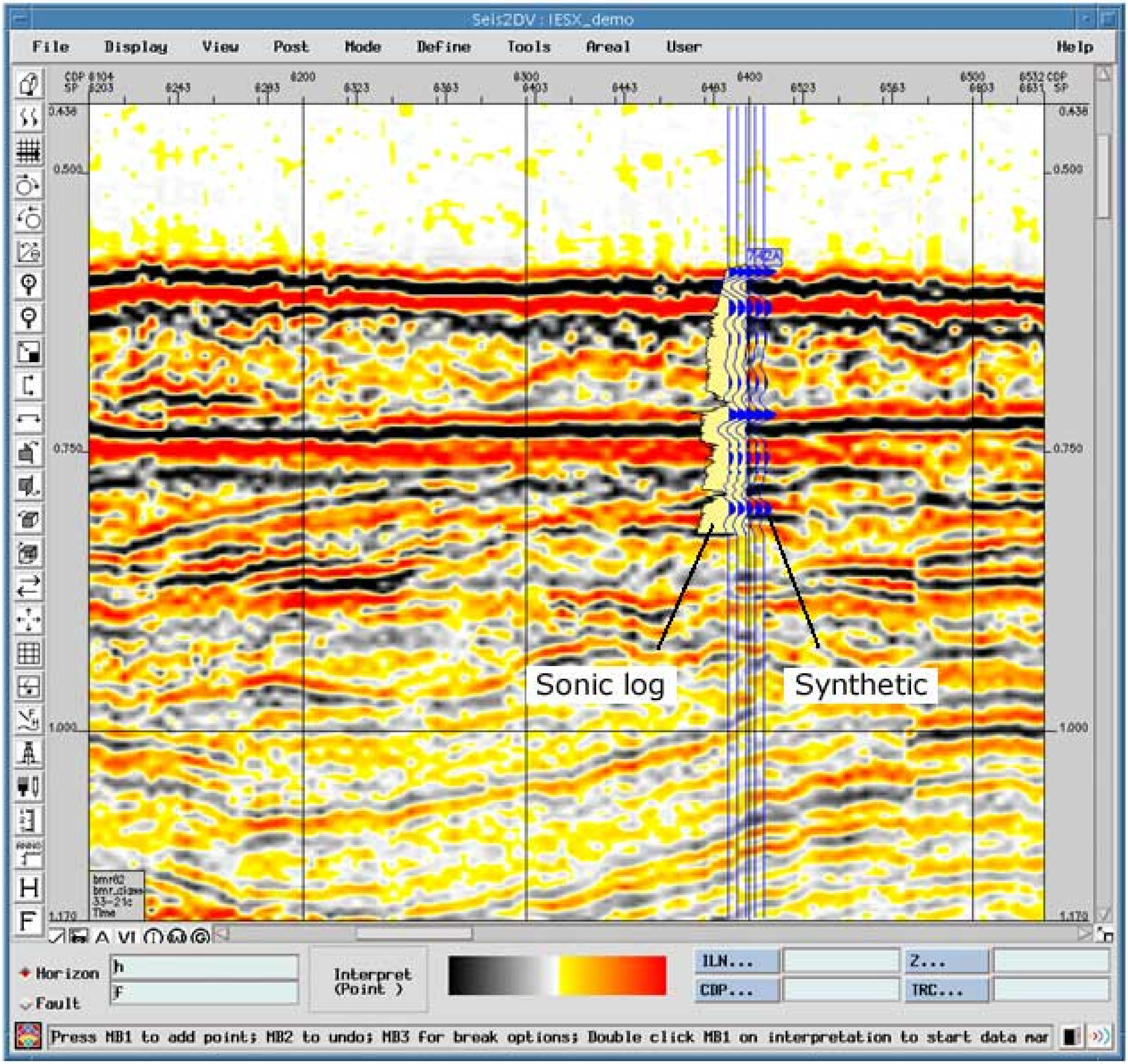
Manually tying the core data to the logs.



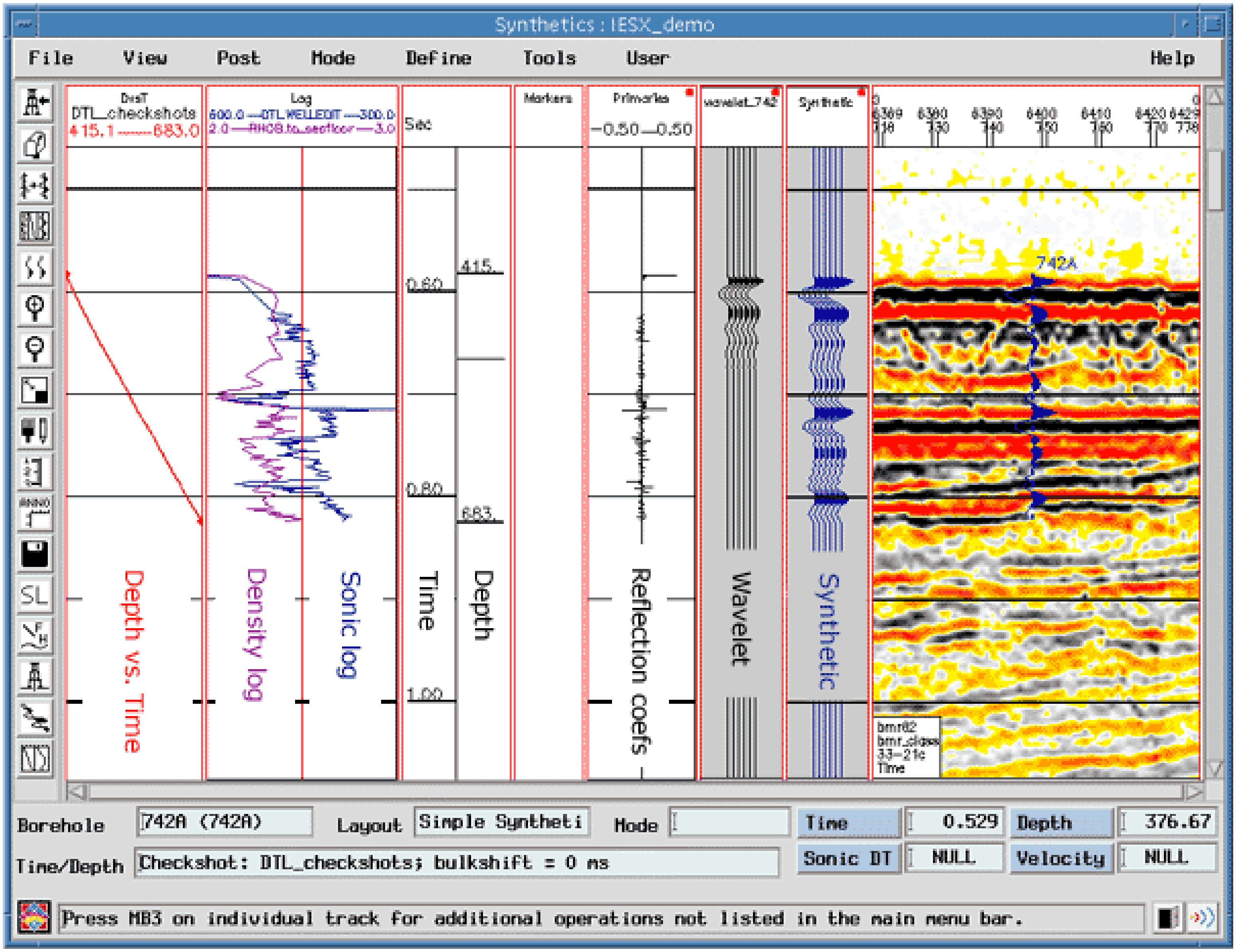
Screen shot of the Data Manager application within IESX



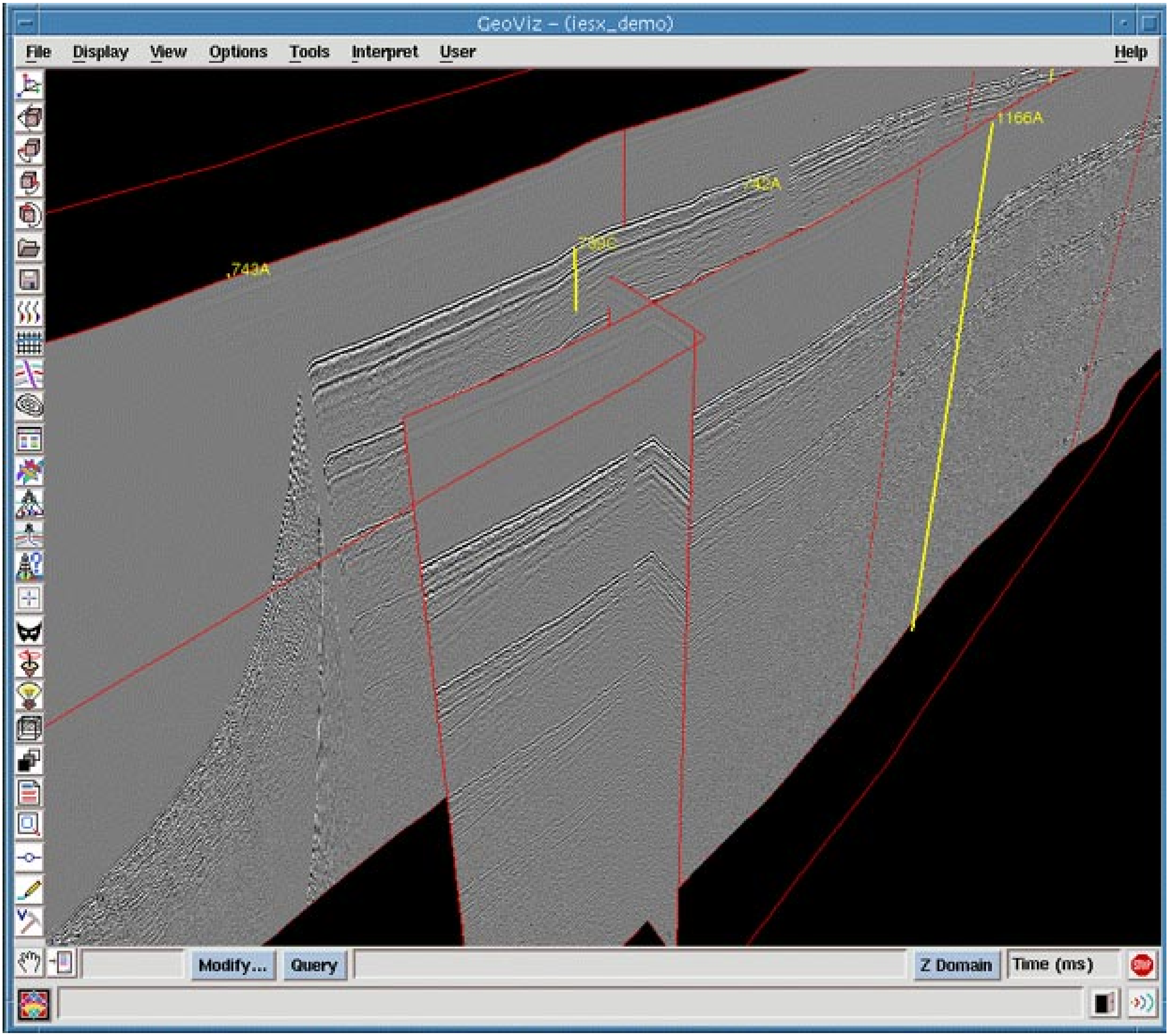
Screen shot of the Basemap application within IESX



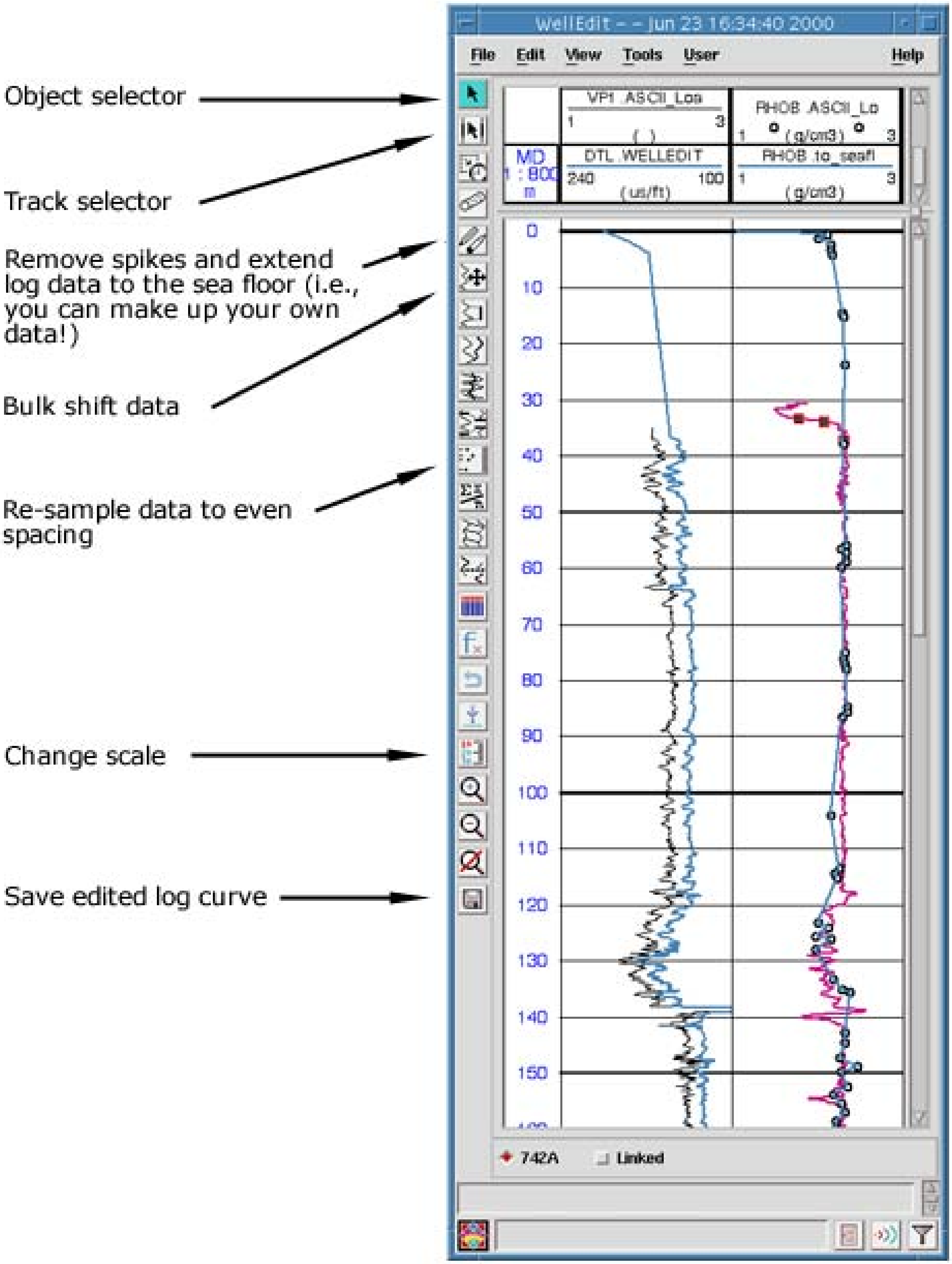
Screen shot of the Seis2DV application within IESX



Screen shot of the Synthetics application within IESX

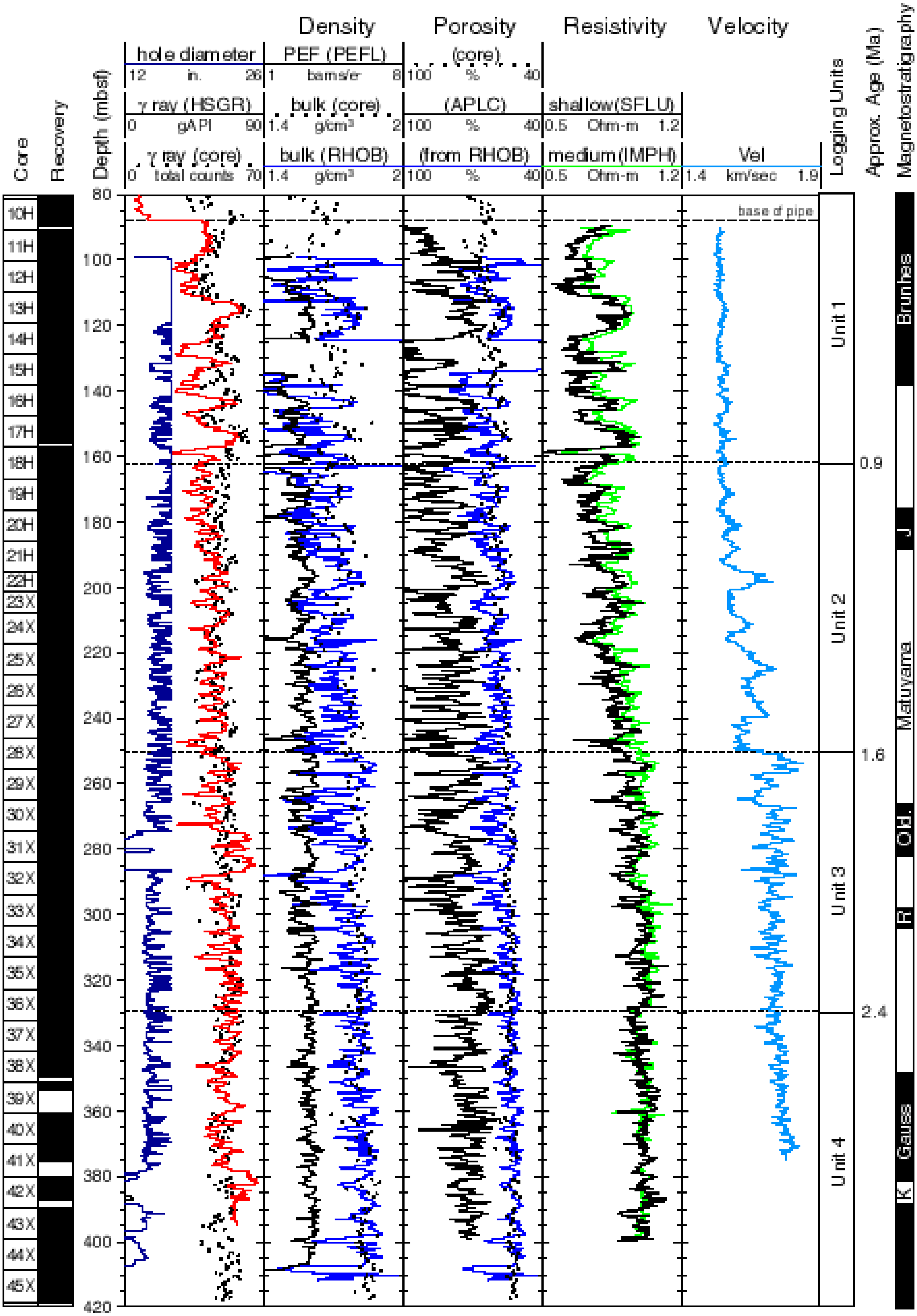


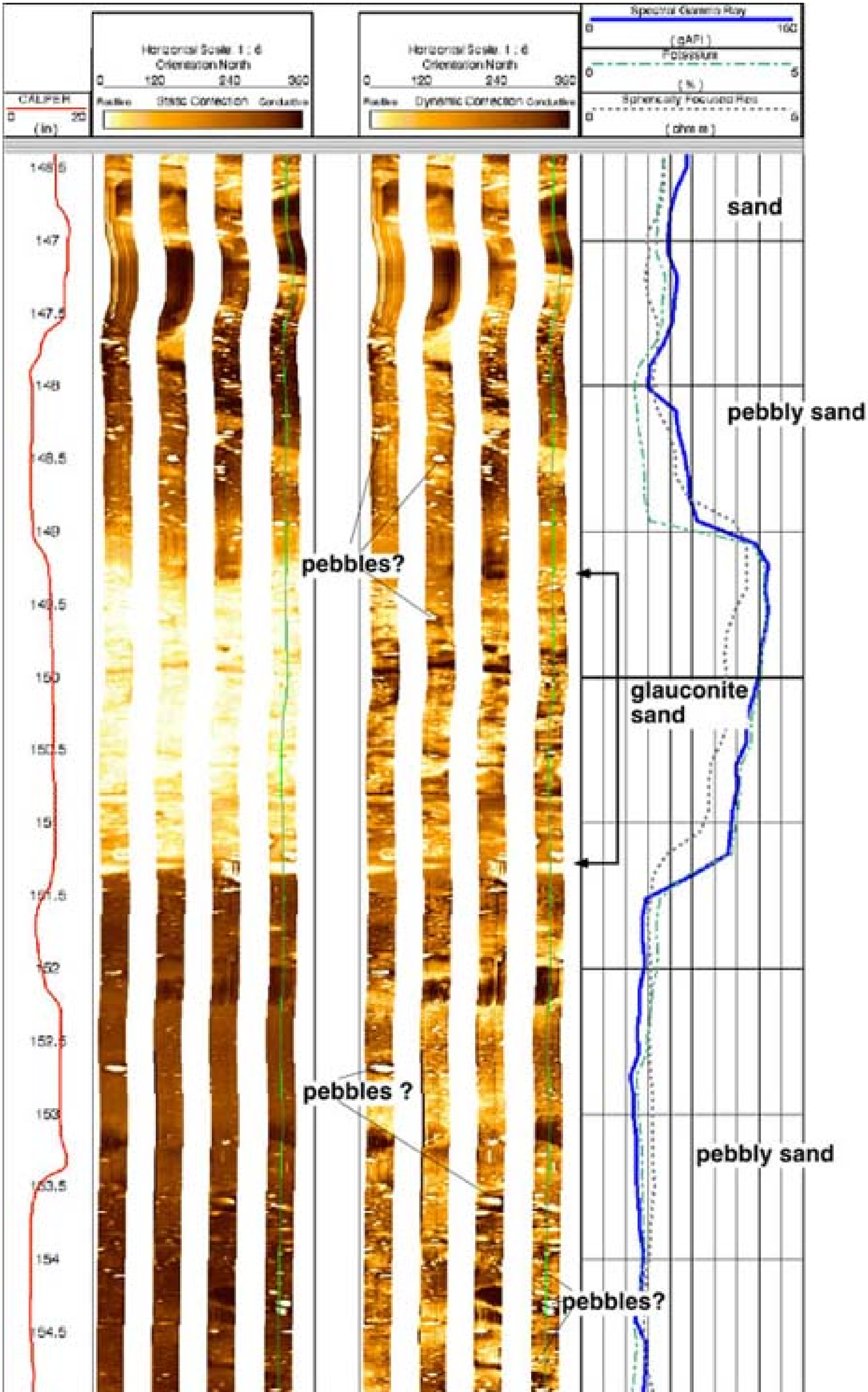
Screen shot of the Geoviz application within IESX

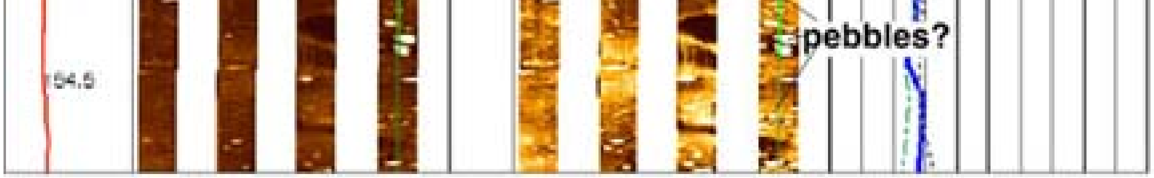


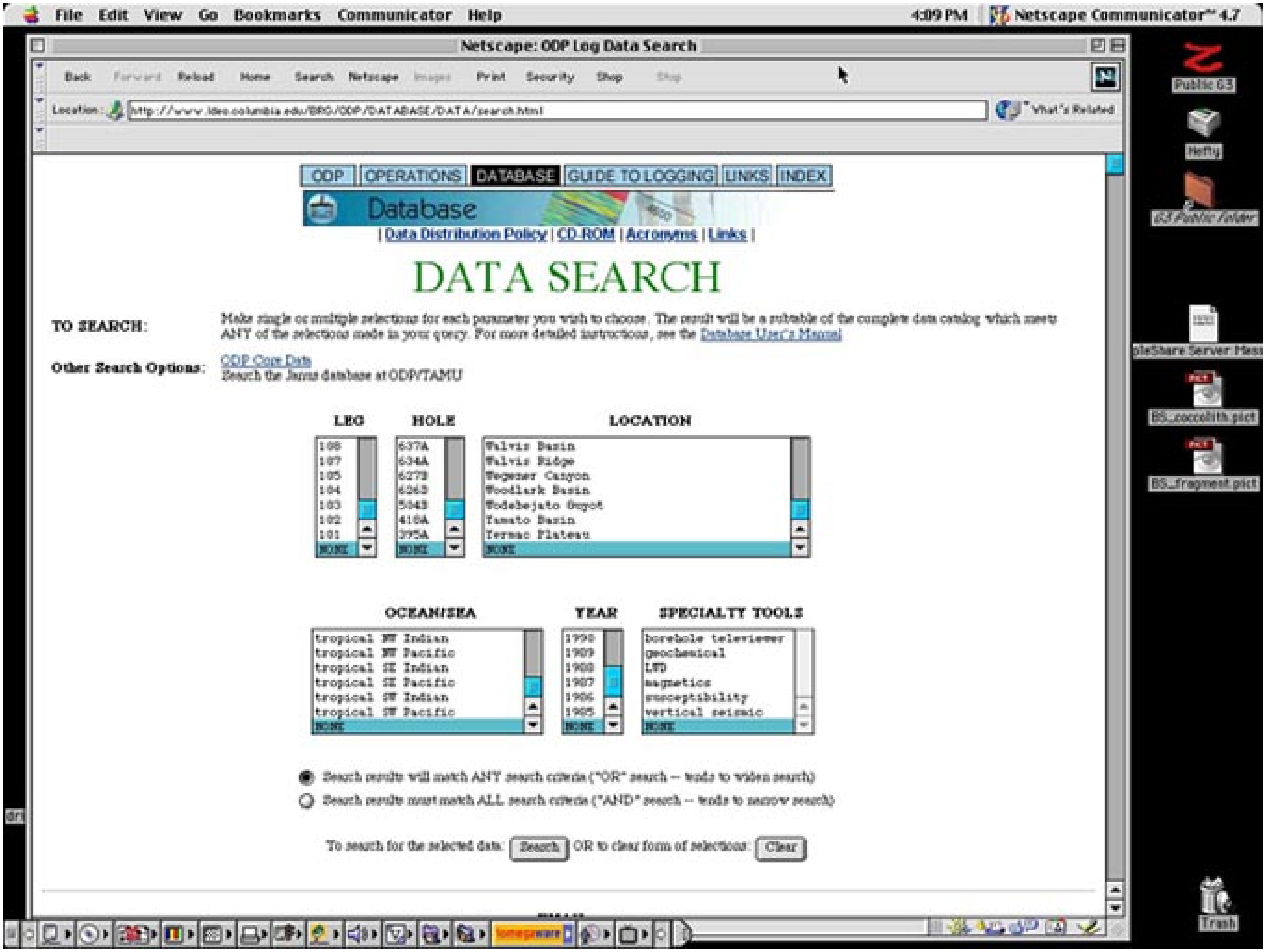
Screen shot of the Well Edit application within IESX

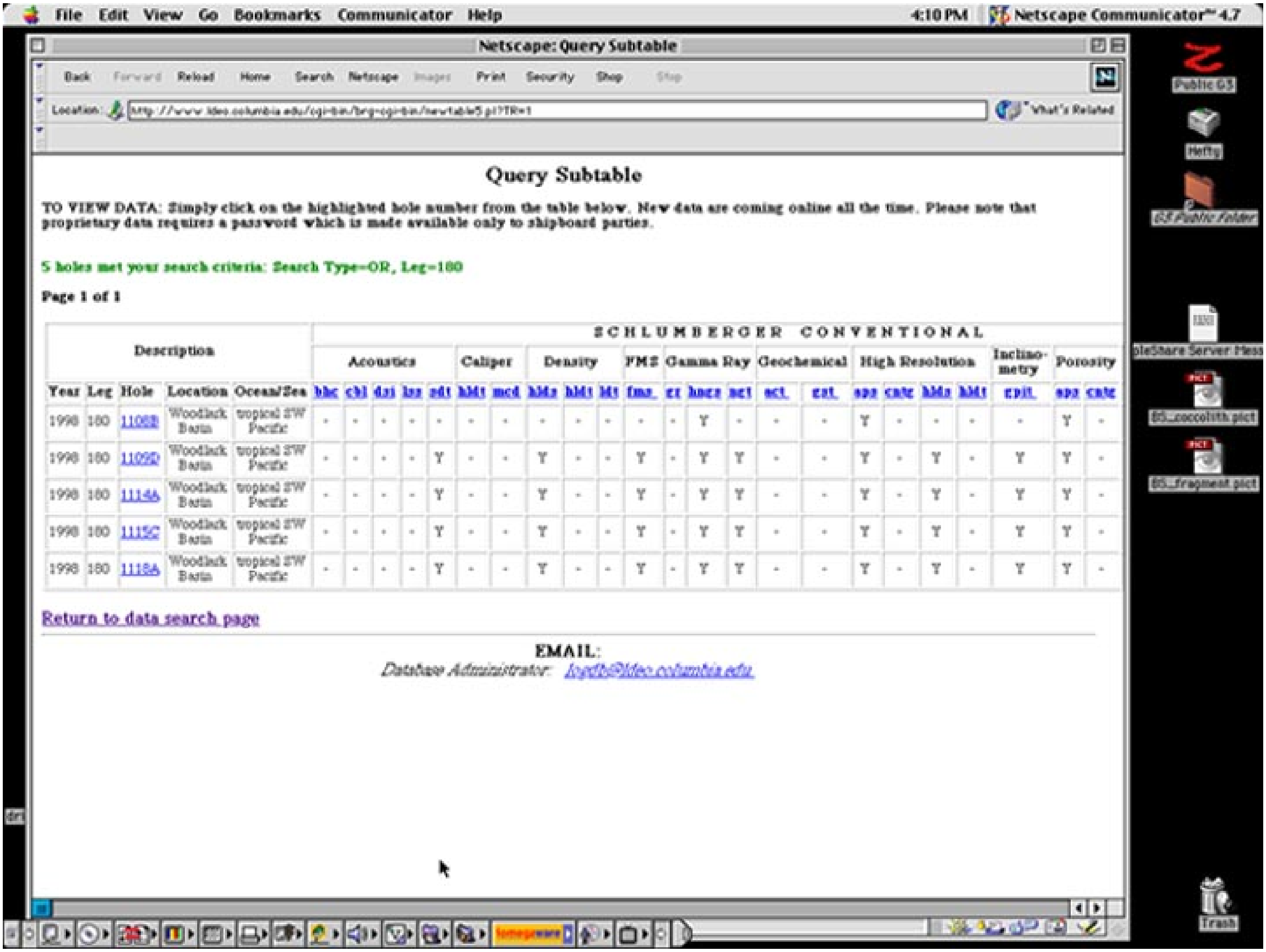
Hole 1063A: Geophysical Logs




CALIPER
(in)
Horizontal Scale 1 : 6
Orientation North
Static Correction
Horizontal Scale 1 : 6
Orientation North
Dynamic Correction
Spectral Gamma Ray
(gAPI)
Potassium
(%)
Spherically Focused Res
(ohm m)
146.5
147
147.5
148
148.5
149
149.5
150
150.5
151
151.5
152
152.5
153
153.5
154
154.5
sand
pebbly sand
pebbles?
glauconite sand
pebbles ?
pebbly sand
pebbles?


104.5
pebbles?


File Edit View Go Bookmarks Communicator Help
4:09 PM
Netscape Communicator™ 4.7
Netscape: ODP Log Data Search
Back Forward Reload Home Search Netscape Images Print Security Shop Stop
Location: http://www.ldeo.columbia.edu/BRG/ODP/DATABASE/DATA/search.html
What's Related
ODP OPERATIONS DATABASE GUIDE TO LOGGING LINKS INDEX
Database
| Data Distribution Policy | CD-ROM | Acronyms | Links |
DATA SEARCH
TO SEARCH:
Make single or multiple selections for each parameter you wish to choose. The result will be a subtable of the complete data catalog which meets ANY of the selections made in your query. For more detailed instructions, see the Database User's Manual
Other Search Options:
ODP Core Data
Search the Janus database at ODP/TAMU
LEG
HOLE
LOCATION
108 107 105 104 103 102 101 NONE
637A 634A 627B 626D 504B 418A 395A NONE
Walvis Basin
Walvis Ridge
Wegener Canyon
Woodlark Basin
Wodejebato Guyot
Yamato Basin
Yermac Plateau
NONE
OCEAN/SEA
YEAR
SPECIALTY TOOLS
tropical NW Indian
tropical NW Pacific
tropical SE Indian
tropical SE Pacific
tropical SW Indian
tropical SW Pacific
NONE
1990 1989 1988 1987 1986 1985 NONE
borehole televiewer
geochemical
LWD
magnetics
susceptibility
vertical seismic
NONE
Search results will match ANY search criteria ("OR" search -- tends to widen search)
Search results must match ALL search criteria ("AND" search -- tends to narrow search)
To search for the selected data: Search OR to clear form of selections: Clear
Public G3
Hefty
G3 Public Folder
BS_coccolith.pict
BS_fragment.pict
Trash



Query Subtable

TO VIEW DATA: Simply click on the highlighted hole number from the table below. New data are coming online all the time. Please note that proprietary data requires a password which is made available only to shipboard parties.

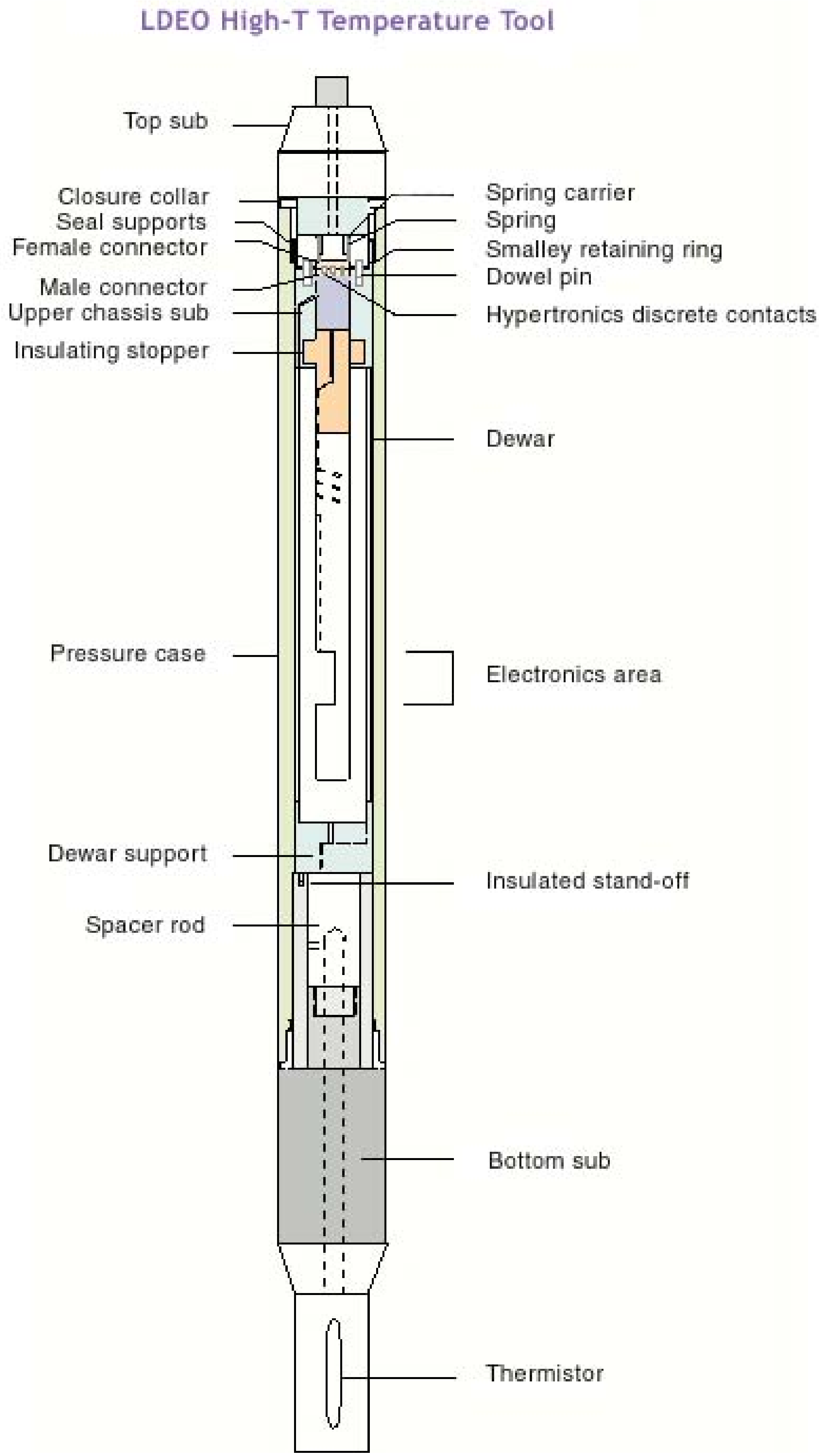
5 holes met your search criteria: Search Type=OR, Leg=180

Page 1 of 1

Description					SCHLUMBERGER CONVENTIONAL																						
					Acoustics					Caliper		Density			FMS	Gamma Ray			Geochemical		High Resolution				Inclino-metry	Porosity	
Year	Leg	Hole	Location	Ocean/Sea	bhc	cbl	dsi	lss	sdt	hlt	mcd	hlds	hldt	ldt	fms_	gr	hngs	ngt	act	gst	aps	cntc	hlds	hldt	gpit	aps	cntc
1998	180	1108B	Woodlark Basin	tropical SW Pacific	-	-	-	-	-	-	-	-	-	-	-	-	Y	-	-	-	Y	-	-	-	-	Y	-
1998	180	1109D	Woodlark Basin	tropical SW Pacific	-	-	-	-	Y	-	-	Y	-	-	Y	-	Y	Y	-	-	Y	-	Y	-	Y	Y	-
1998	180	1114A	Woodlark Basin	tropical SW Pacific	-	-	-	-	Y	-	-	Y	-	-	Y	-	Y	Y	-	-	Y	-	Y	-	Y	Y	-
1998	180	1115C	Woodlark Basin	tropical SW Pacific	-	-	-	-	Y	-	-	Y	-	-	Y	-	Y	Y	-	-	Y	-	Y	-	Y	Y	-
1998	180	1118A	Woodlark Basin	tropical SW Pacific	-	-	-	-	Y	-	-	Y	-	-	Y	-	Y	Y	-	-	Y	-	Y	-	Y	Y	-

Return to data search page

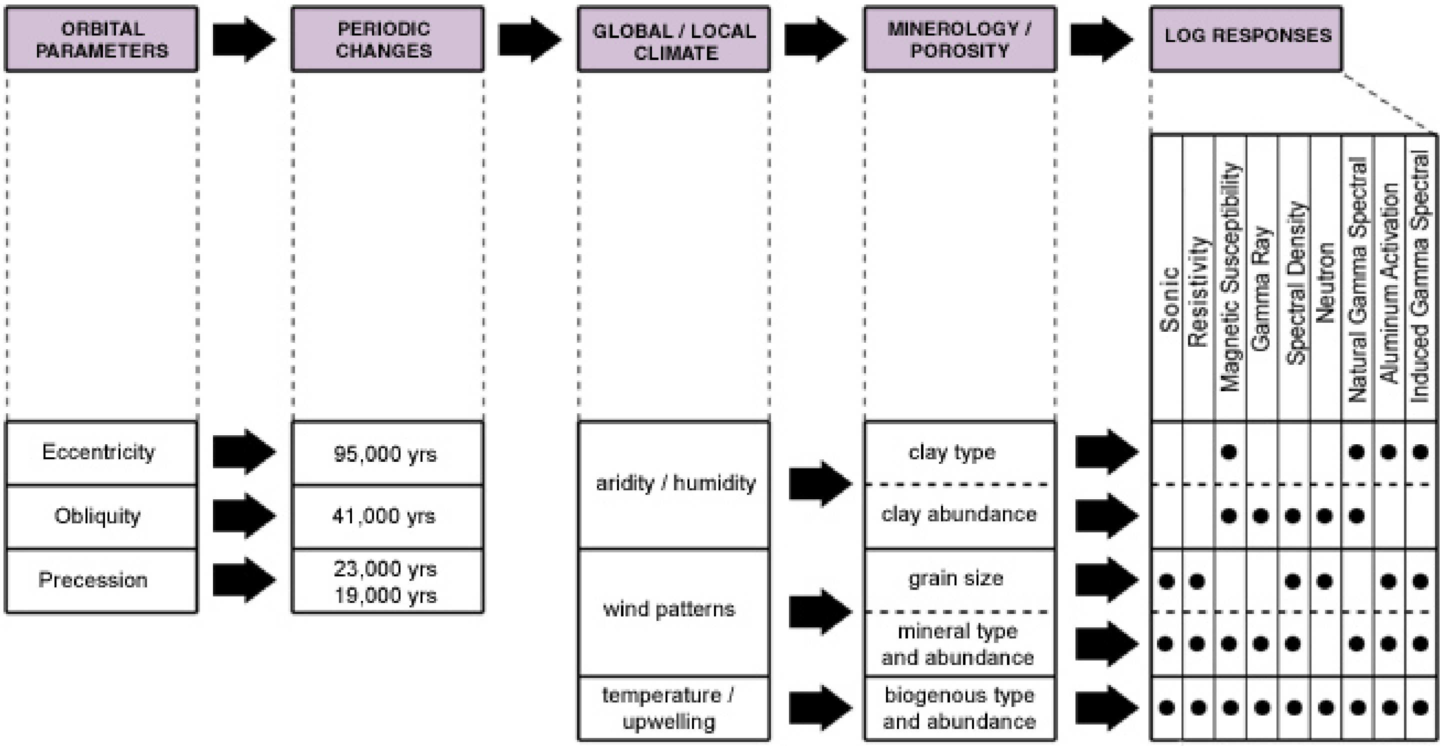
EMAIL:
Database Administrator: logdb@ldeo.columbia.edu


LDEO High-T Temperature Tool
Top sub
Closure collar
Seal supports
Female connector
Male connector
Upper chassis sub
Insulating stopper
Spring carrier
Spring
Smalley retaining ring
Dowel pin
Hypertronics discrete contacts
Dewar
Pressure case
Electronics area
Dewar support
Insulated stand-off
Spacer rod
Bottom sub
Thermistor

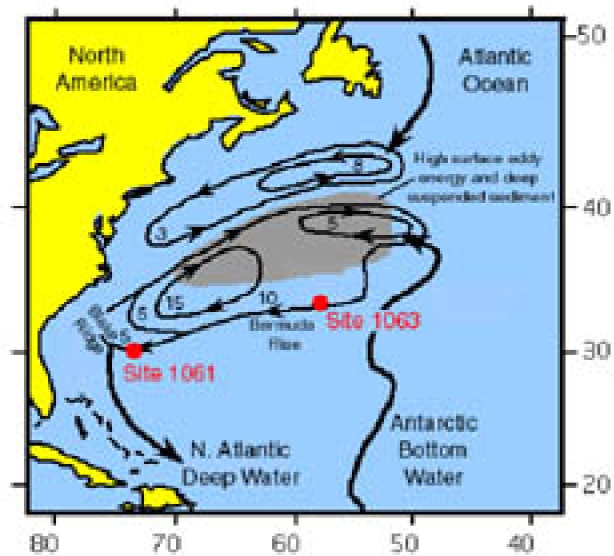
Principal Application

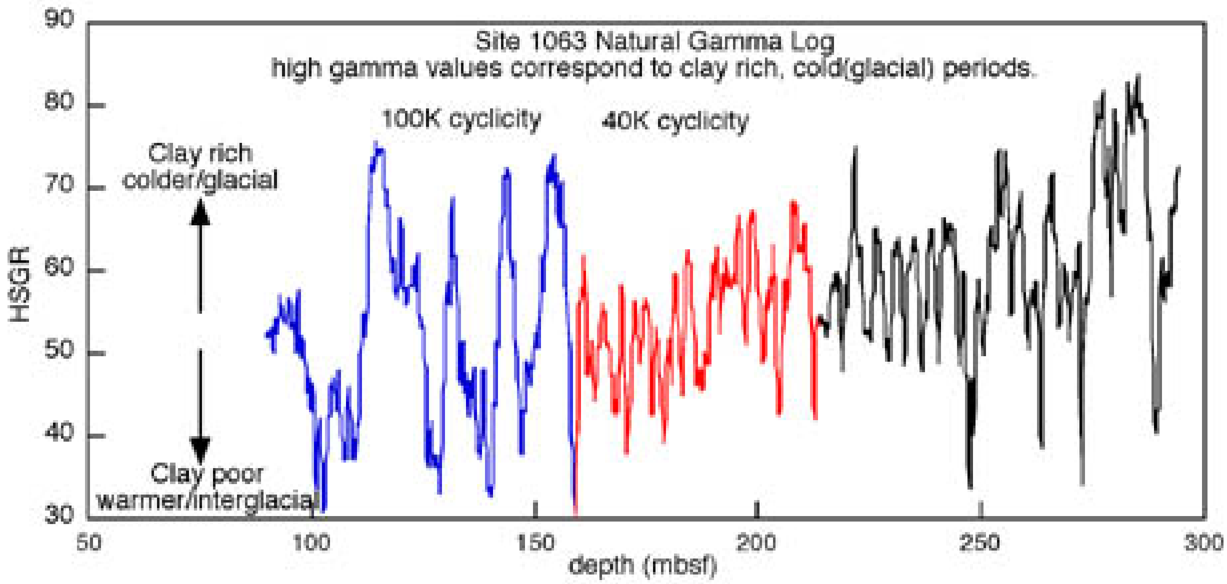
Measurement (Tool)
[Click on tool name for further information]

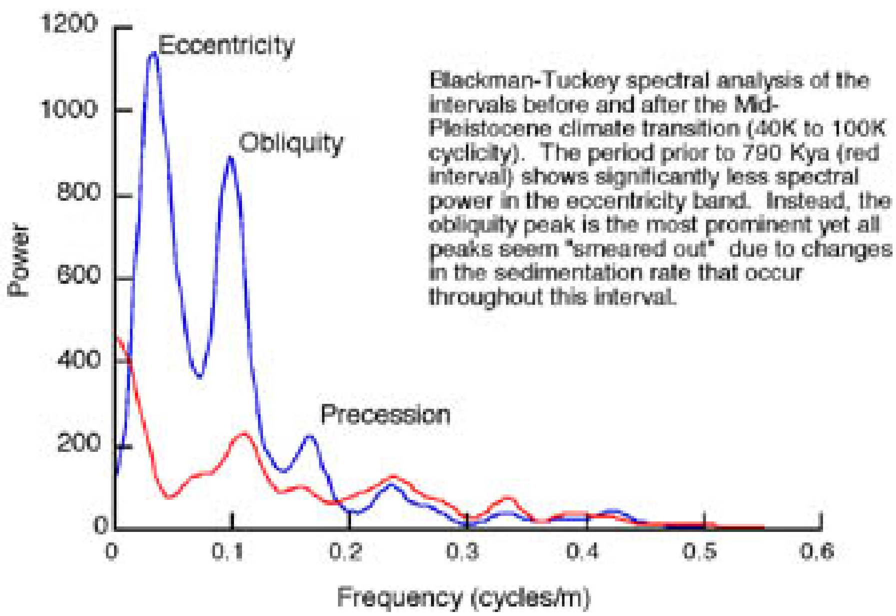
Group	Measurement (Tool)	Core-Log Integration	Drilling Operations Data	High Temperature Environments	Hole Stability Problems	Hydrogeology	Magnetostratigraphy	Paleoclimate, High Resolution	Geochemistry	Log-Seismic Integration	Stratigraphy/Sedimentology	Structural Geology	Gas Hydrates
Triple Combo	Natural Gamma Ray (HNGS, NGT)	●		●				●	●		●		
	Porosity (APS)	●						●	●		●		
	Density (HLDS, HLDT)	●		●				●	●	●	●	●	
	Resistivity (DIT-E, DLL)					●		●			●		●
	Fluid Temperature (TAP, CBTT)			●		●							
	High Resolution Gamma Ray (MGT)	●						●			●		
FMS/ Sonic	Acoustic (DSI-2, LSS)	●						●		●	●	●	●
	Electrical Imaging (FMS)	●				●					●	●	
	Caliper (HLDT, HLDS, FMS)		●		●							●	
Specialty	Magnetic Field/Susceptibility (GHMT)	●					●	●					
	High Fluid Temperature (HTT)			●		●							
	Bit Accel./Temperature (DSA, CBTT)		●	●									
	Seismic (WST-3, WST)									●	●		
	Acoustic Imaging (UBI)				●							●	●
	Logging-While-Drilling (LWD)		●		●			●	●	●	●	●	

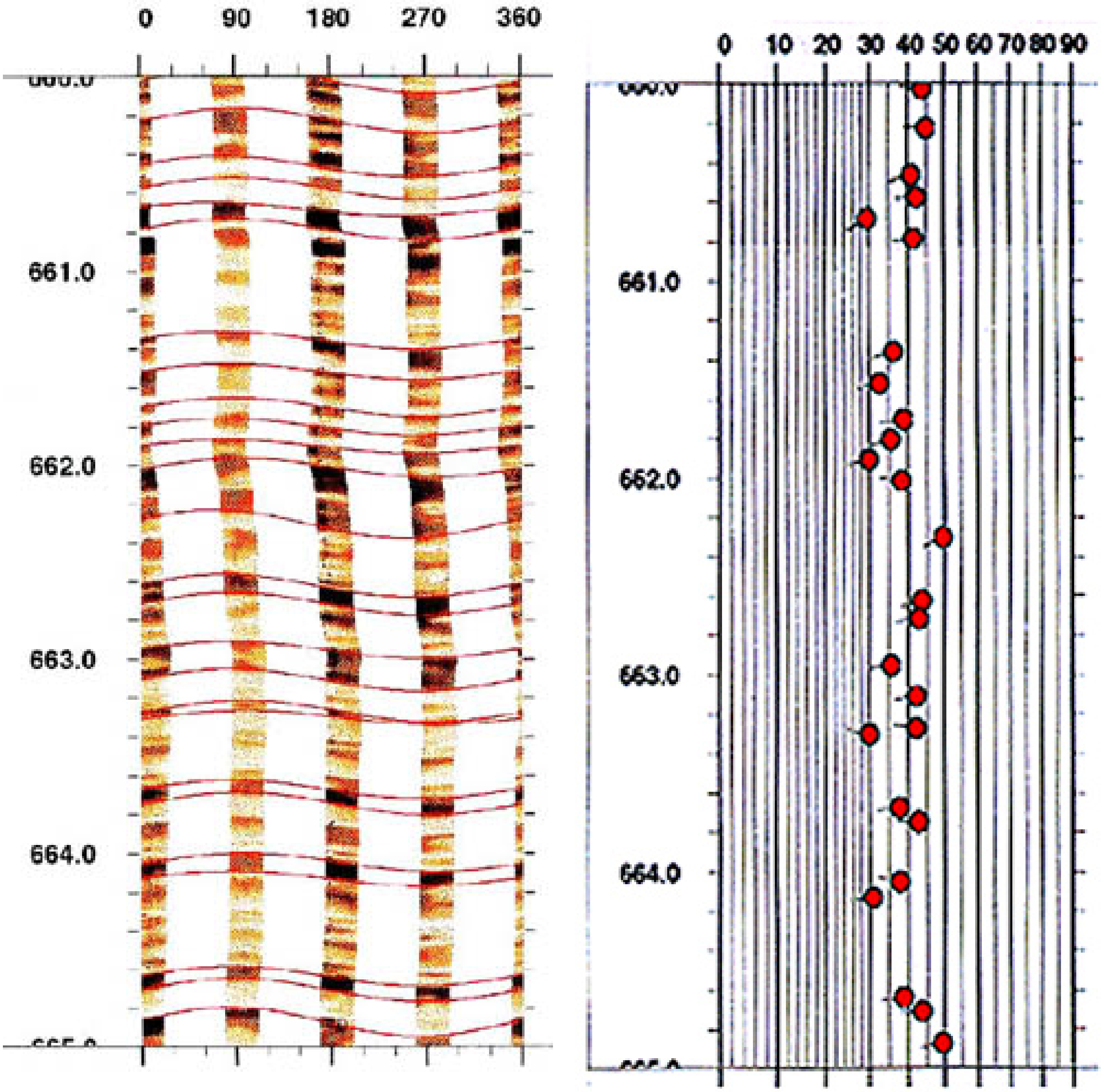


ORBITAL PARAMETERS
PERIODIC CHANGES
GLOBAL / LOCAL CLIMATE
MINEROLOGY / POROSITY
LOG RESPONSES
Sonic
Resistivity
Magnetic Susceptibility
Gamma Ray
Spectral Density
Neutron
Natural Gamma Spectral
Aluminum Activation
Induced Gamma Spectral
Eccentricity
Obliquity
Precession
95,000 yrs
41,000 yrs
23,000 yrs
19,000 yrs
aridity / humidity
wind patterns
temperature / upwelling
clay type
clay abundance
grain size
mineral type and abundance
biogenous type and abundance

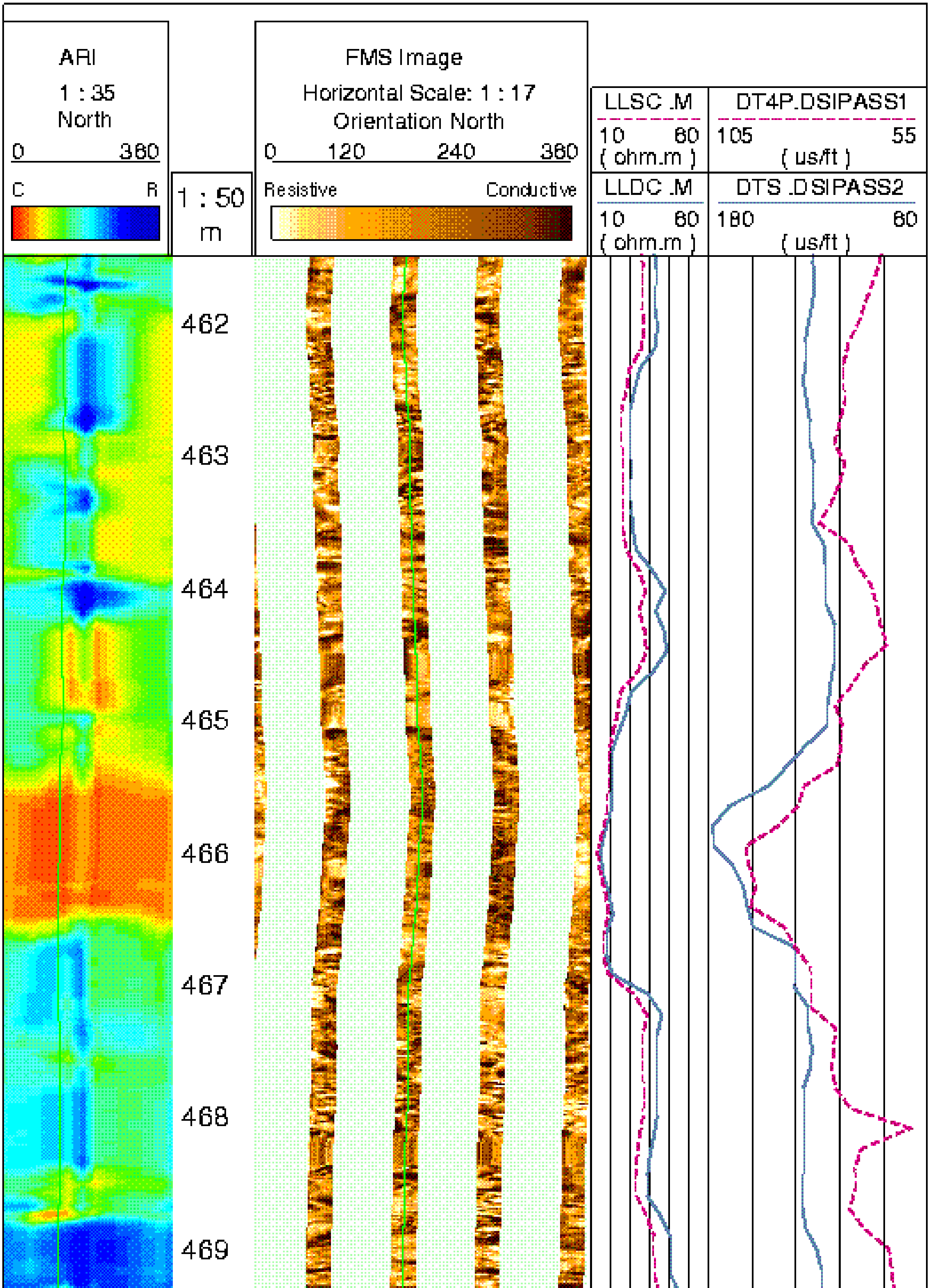

North America
Atlantic Ocean
High surface eddy energy and deep suspended sediment
Bermuda Rise
Site 1063
Site 1061
N. Atlantic Deep Water
Antarctic Bottom Water
50
40
30
20
80
70
60
50
40


Site 1063 Natural Gamma Log
high gamma values correspond to clay rich, cold(glacial) periods.
100K cyclicity
40K cyclicity
Clay rich
colder/glacial
Clay poor
warmer/interglacial
HSGR
depth (mbsf)
90
80
70
60
50
40
30
50
100
150
200
250
300

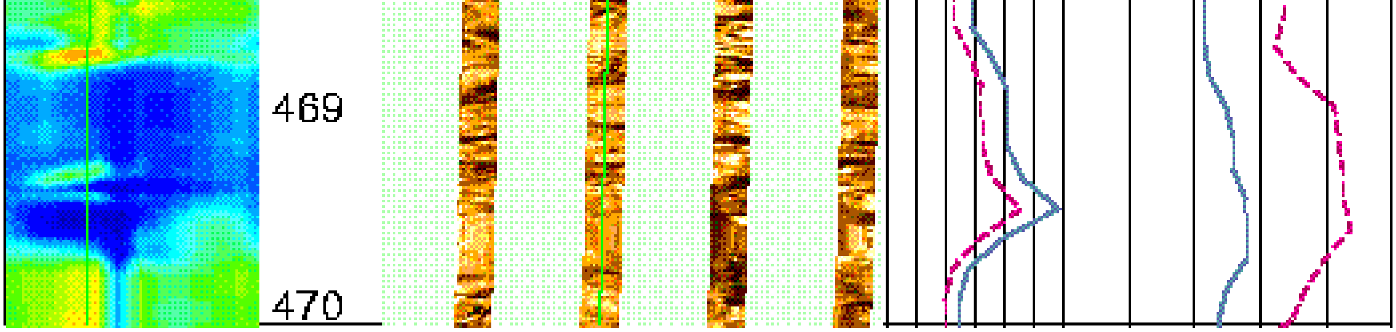

Eccentricity
Obliquity
Precession
Power
Frequency (cycles/m)
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Blackman-Tuckey spectral analysis of the intervals before and after the Mid-Pleistocene climate transition (40K to 100K cyclicity). The period prior to 790 Kya (red interval) shows significantly less spectral power in the eccentricity band. Instead, the obliquity peak is the most prominent yet all peaks seem "smeared out" due to changes in the sedimentation rate that occur throughout this interval.



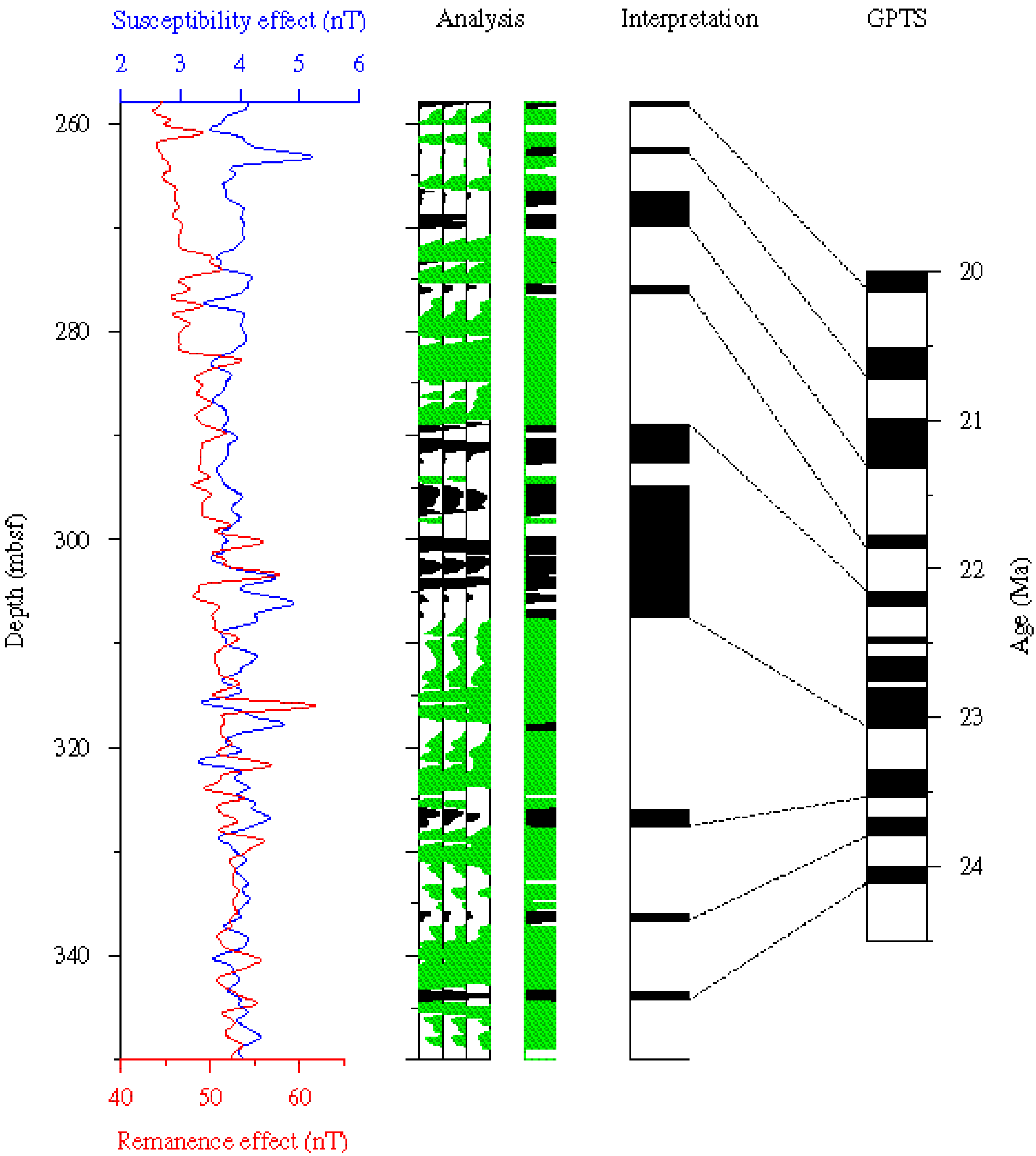
Turbidite sequences are imaged here by the FMS data. Red sine waves on the images trace bedding planes.The corresponding "tadpole" plot shows the average dip is roughly 40 degrees to the west. Interpretive work of the FMS data can be performed either on the ship or onshore with the GeoFrame software.



ARI
1 : 35
North
0 360
C R
1 : 50
m
FMS Image
Horizontal Scale: 1 : 17
Orientation North
0 120 240 360
Resistive Conductive
LLSC .M
10 60
(ohm.m)
LLDC .M
10 60
(ohm.m)
DT4P.DSIPASS1
105 55
(us/ft)
DTS .DSIPASS2
180 60
(us/ft)
462
463
464
465
466
467
468
469



469
470

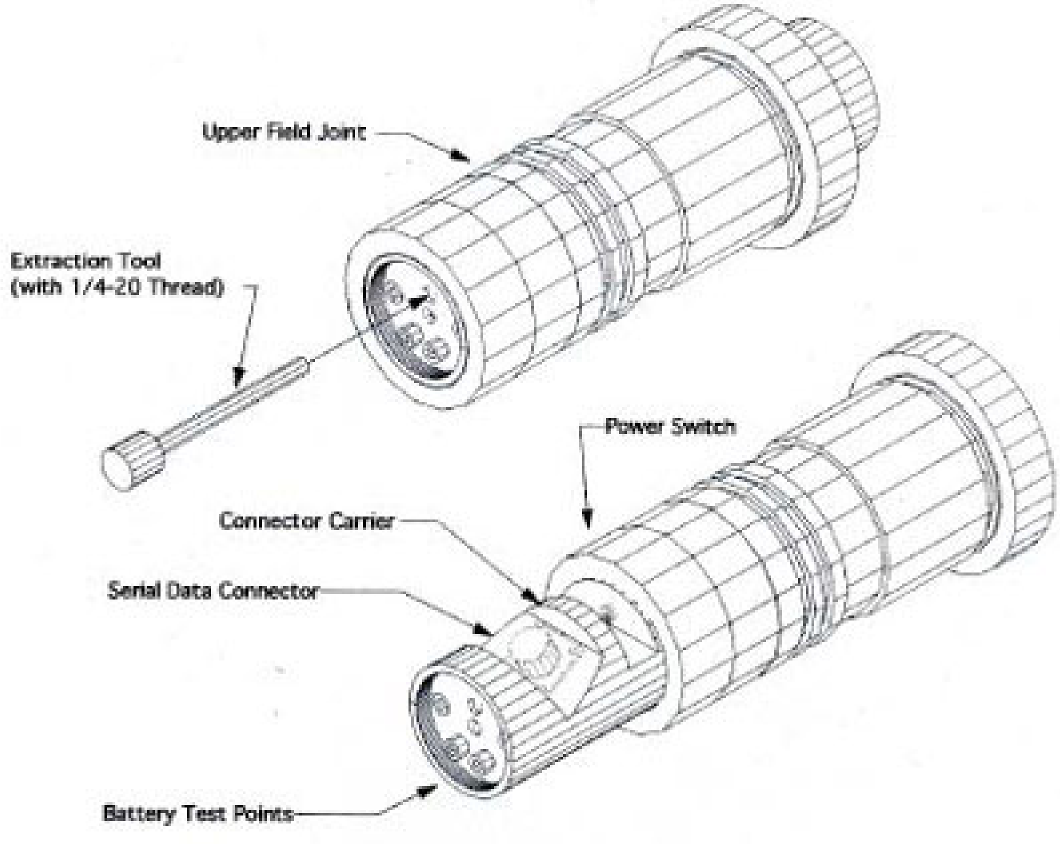


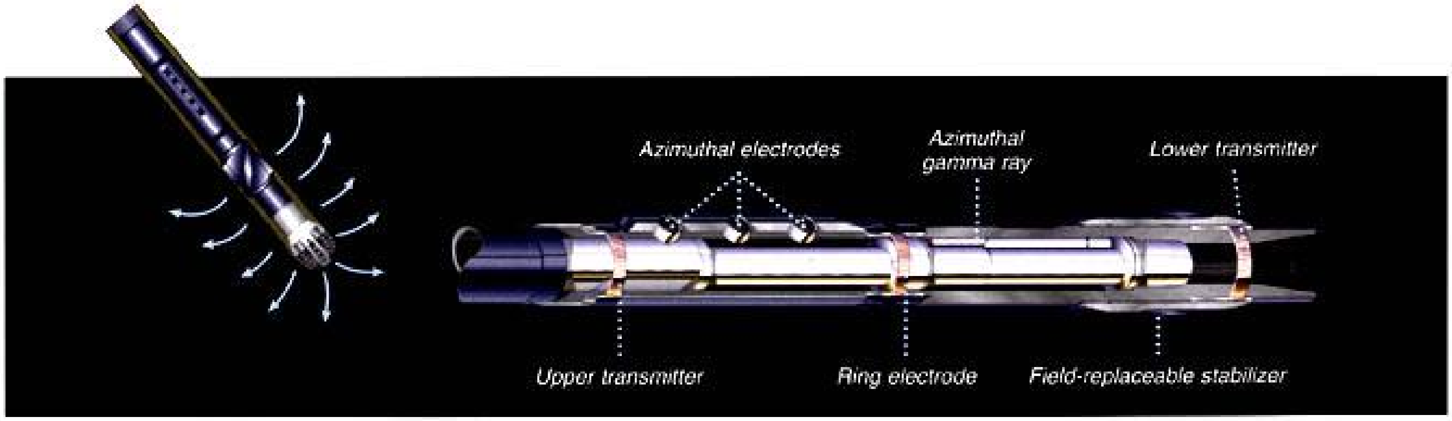
Susceptibility effect (nT)
2
3
4
5
6
Analysis
Interpretation
GPTS
260
280
300
320
340
Depth (mbsf)
40
50
60
Remanence effect (nT)
20
21
22
23
24
Age (Ma)

Example of magnetostratigraphy (from ODP Leg 165):

The figure above shows the derivation of magnetostratigraphy from the susceptibility and total induction measurements. The analysis column shows the correlation (black) or anticorrelation (green) between the susceptibility and the remanence effects in three sliding windows of different sizes. Correlation indicates normal magnetic polarity zones, anti-correlation indicates reverse magnetic polarity zones. The interpretation column is then compared to a standard geomagnetic polarity time scale.

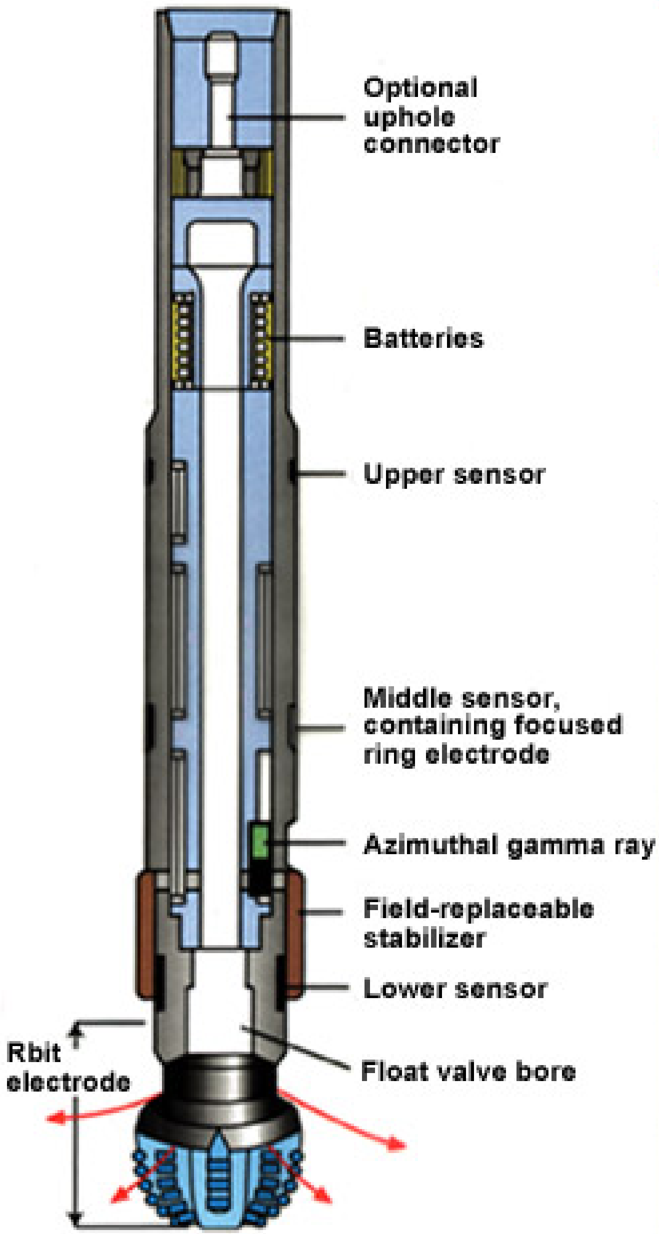
ODP/LDEO
TAP Tool



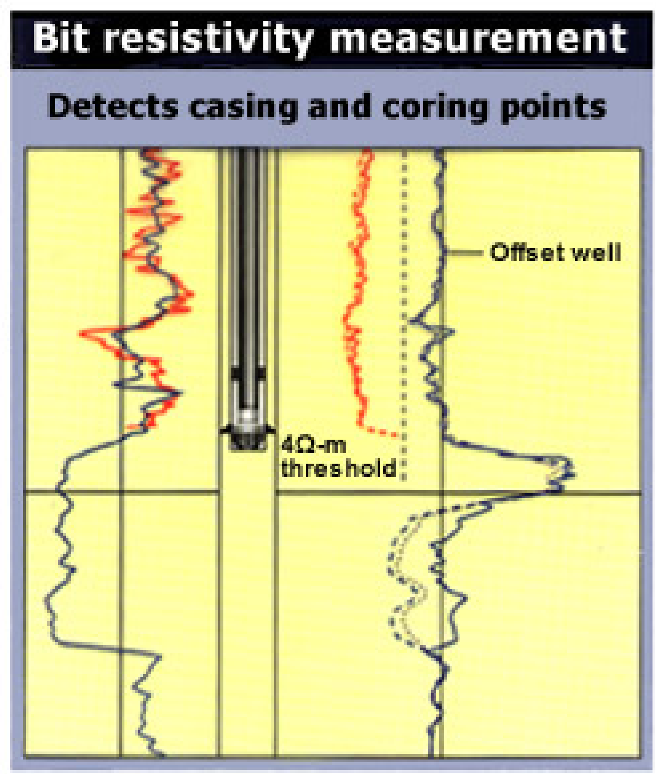


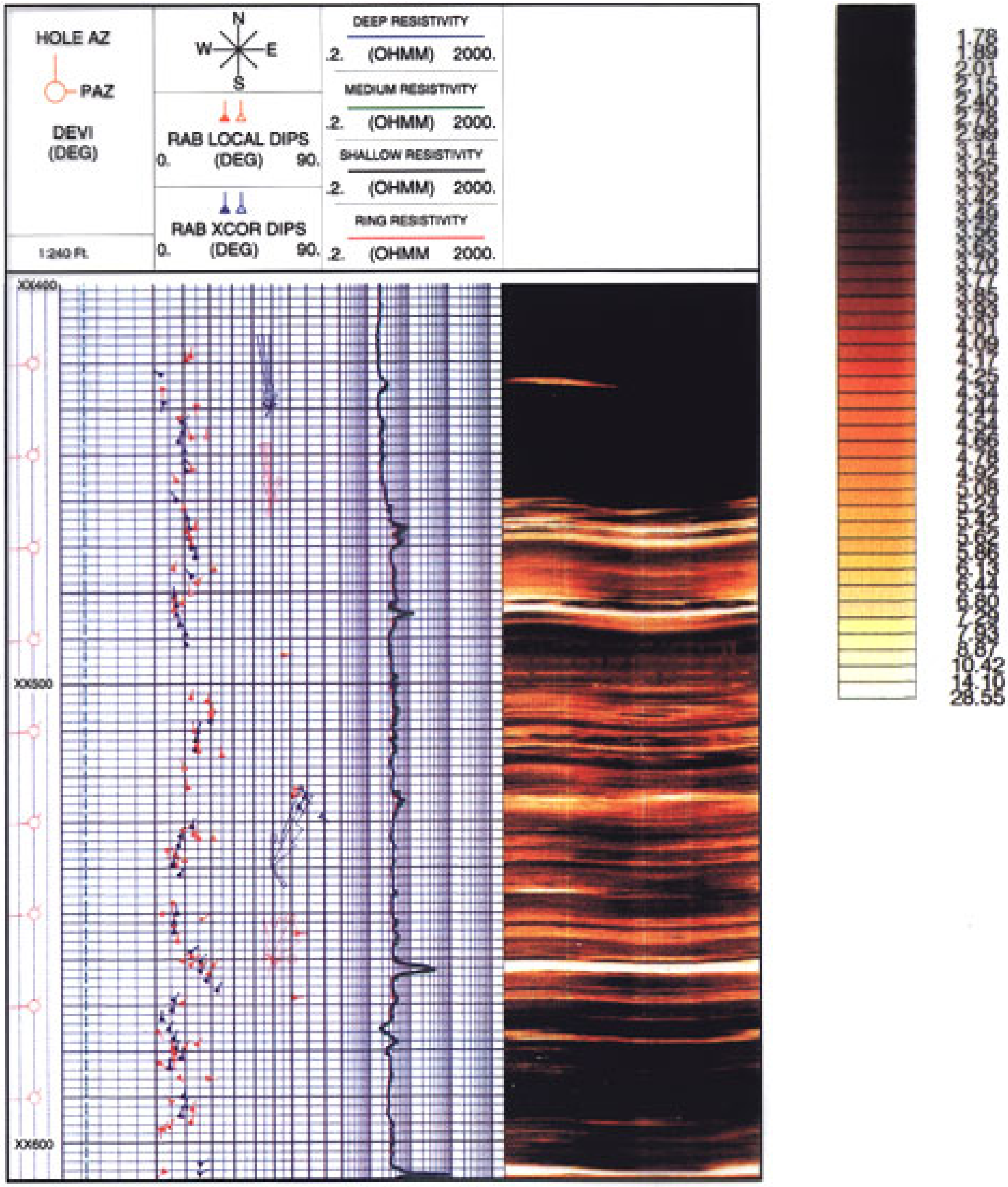
Azimuthal electrodes
Azimuthal gamma ray
Lower transmitter
Upper transmitter
Ring electrode
Field-replaceable stabilizer

Resistivity-at-the-Bit

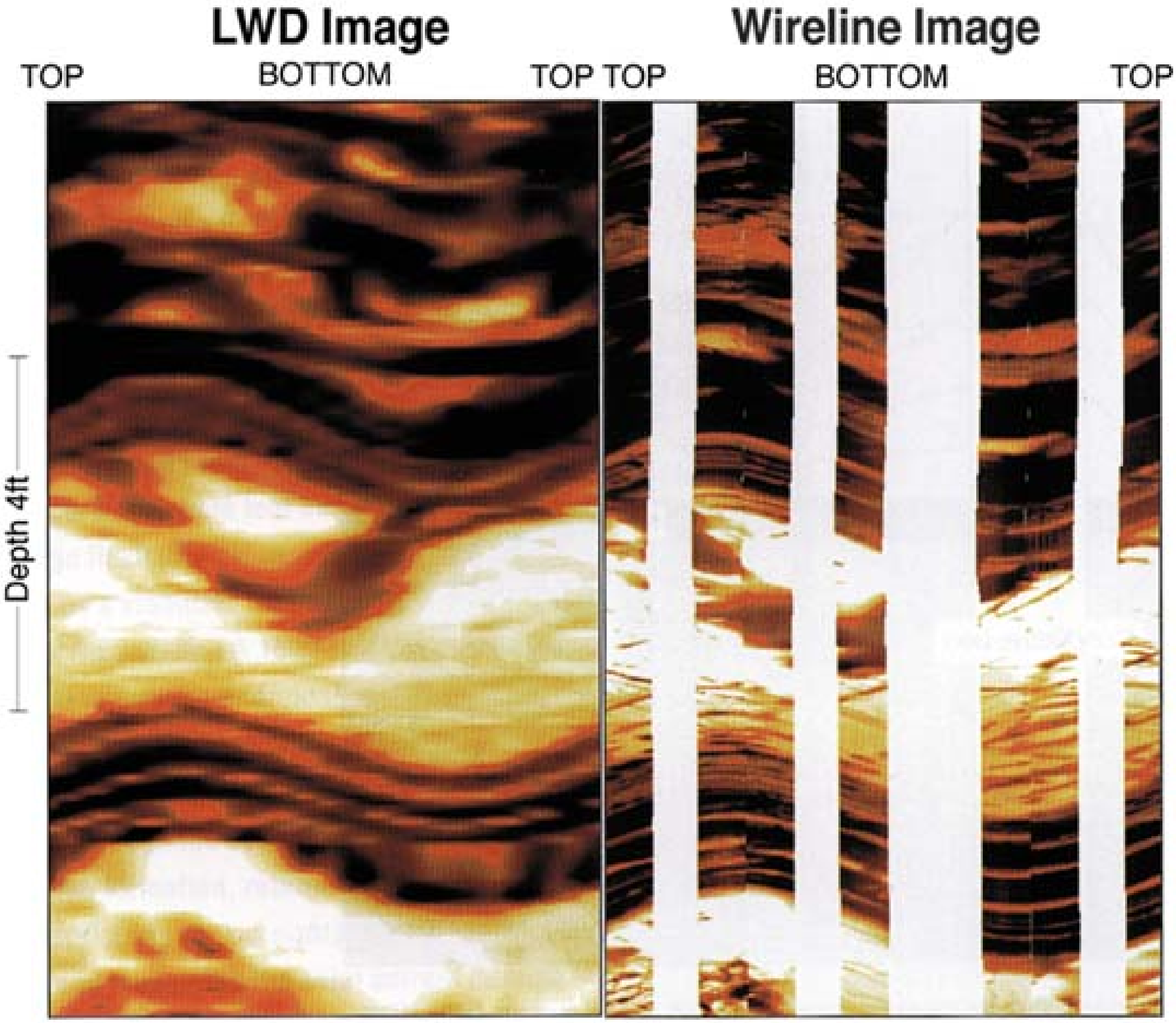


- Built into a near-bit stabilizer (for rotary BHAs)
- Earliest possible resistivity measurement while drilling
- Data sent to MWD by tool bus or by EMAG telemetry, up to 150 ft





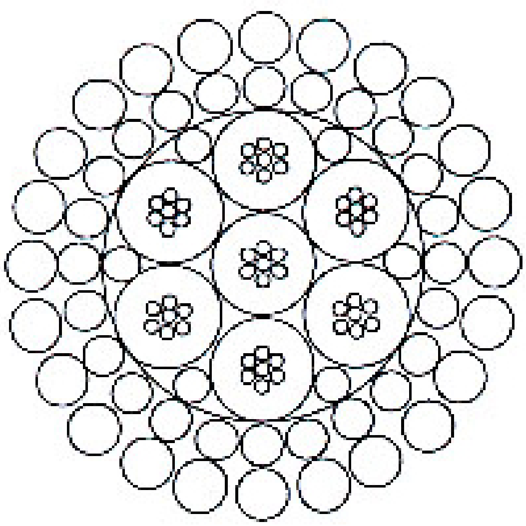
HOLE AZ
PAZ
DEVI
(DEG)
1:240 Ft.
N
W
E
S
RAB LOCAL DIPS
0. (DEG) 90.
RAB XCOR DIPS
0. (DEG) 90.
DEEP RESISTIVITY
.2. (OHMM) 2000.
MEDIUM RESISTIVITY
.2. (OHMM) 2000.
SHALLOW RESISTIVITY
.2. (OHMM) 2000.
RING RESISTIVITY
.2. (OHMM 2000.
XX400
XX500
XX600
1.78
1.89
2.01
2.15
10.42
14.10
28.55



Comparison of LWD Resistivity-at-the-Bit (RAB) tool and wireline electrical imaging FMI tool measurements of dense fracturing in consolidated sediments. Both images of the interior of the borehole wall are oriented to the top and bottom of the deviated hole. Although the LWD tool has inferior bed resolution (by a factor of 30), it offers the advantage of data coverage around the entire circumference of the borehole and measurements within minutes after the hole has been drilled.

7-46 P

Seven conductor armored cable, designed and specially manufactured for use in well logging. The armor wires are high tensile, galvanized improved plow steel, pre-formed and pre-stressed. The armor is coated with an anticorrosion compound.



20 AWG copper	6 / 0.014"	6 / 0.36 mm
EPC insulation	0.102"	2.59 mm
20 AWG copper	7 / 0.013"	7 / 0.32 mm
EPC insulation	0.098"	2.49 mm
Filler rods, filler compound & tape binder -- Compressed Diameter	0.288"	7.32 mm
Inner armor	24 / 0.039"	24 / 0.99 mm
Outer armor	24 / 0.049"	24 / 1.24 mm
Nominal Diameter	0.464"	11.79 mm

Nominal Properties

ELECTRICAL

DC Resistance @ 68° F	Conductor:	10.9 ohm/kFt	36 ohm/km
or 20° C	Armor:	1.2 ohm/kFt	4 ohm/km
Insulation Resistance	at 500 VDC	15000 M ohm/kFt	5000 M ohm/km
Capacitance	at 1 KHz	40 pf/Ft	131 pf/km
Voltage Rating		880 Vrms	880 Vrms

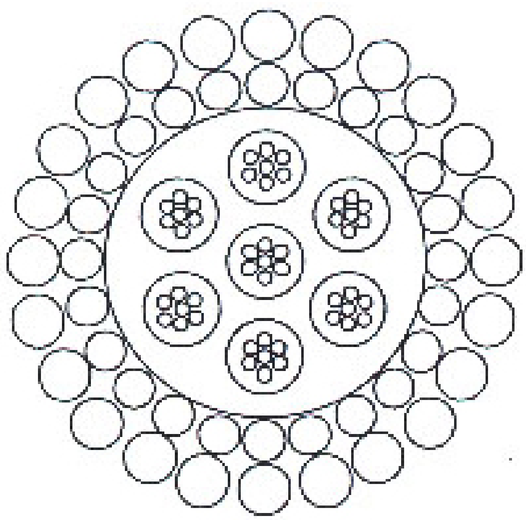
MECHANICAL

Calculated Weight	In air	335 Lbs/kFt	498 kg/km
	In fresh water	264 Lbs/kFt	393 kg/km
Temperature Rating	Min.	- 40° F	- 40° C
	Max.	300° F	150° C
Break Strength	Ends fixed	16700 Lbf	74 kN
	Ends free	11600 Lbf	52 kN
Maximum end to end variation		0.010 Inch	0.254 mm

Triple Combo FMS/Sonic Specialty Other Toolstring Index

7-46 NA

Seven conductor armored cable, designed and specially manufactured for use in well logging. The armor wires are high tensile, galvanized improved plow steel, pre-formed and pre-stressed. The armor is coated with an anticorrosion compound.



20 AWG copper	6 / 0.014"	6 / 0.36 mm
PFA* insulation	0.073"	1.85 mm
20 AWG copper	7 / 0.013"	7 / 0.32 mm
PFA* insulation	0.070"	1.78 mm
Conductive Neoprene Compressed Diameter	0.288"	7.32 mm
Inner armor	24 / 0.039"	24 / 0.99 mm
Outer armor	24 / 0.049"	24 / 1.24 mm
Nominal Diameter	0.464"	11.79 mm

* ®trademark of Dupont

Nominal Properties

ELECTRICAL

DC Resistance @ 68° F or 20° C	Conductor:	10.9 ohm/kFt	36 ohm/km
	Armor:	1.2 ohm/kFt	4 ohm/km
Insulation Resistance	at 500 VDC	15000 M ohm/kFt	5000 M ohm/km
Capacitance	at 1 KHz	55 pf/Ft	180 pf/km
Voltage Rating		560 Vrms	560 Vrms

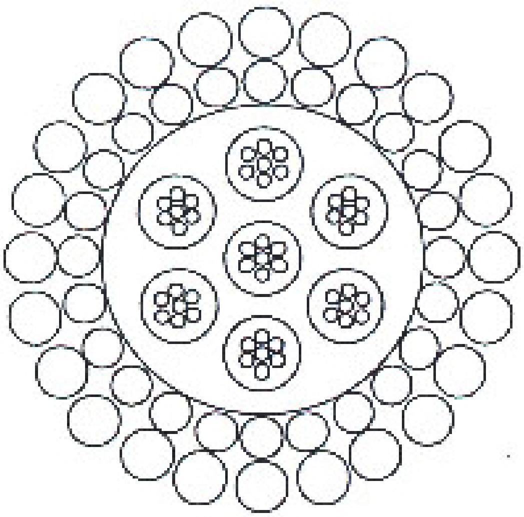
MECHANICAL

Calculated Weight	In air	350 Lbs/kFt	521 kg/km
	In fresh water	277 Lbs/kFt	412 kg/km
Temperature Rating	Min.	- 40° F	- 40° C
	Max.	450° F; 500° F up to 2 hrs	260° C
Break Strength	Ends fixed	16700 Lbf	74 kN
	Ends free	11600 Lbf	52 kN
Maximum end to end variation		0.010 Inch	0.254 mm

Triple Combo FMS/Sonic Specialty Other Toolstring Index

7-46 NT

Seven conductor armored cable, designed and specially manufactured for use in well logging. The armor wires are high tensile, galvanized improved plow steel, pre-formed and pre-stressed. The armor is coated with an anticorrosion compound.



20 AWG copper	6 / 0.014"	6 / 0.36 mm
Teflon* insulation	0.073"	1.85 mm
20 AWG copper	7 / 0.013"	7 / 0.32 mm
Teflon* insulation	0.070"	1.78 mm
Conductive Neoprene Compressed Diameter	0.288"	7.32 mm
Inner armor	24 / 0.039"	24 / 0.99 mm
Outer armor	24 / 0.049"	24 / 1.24 mm
Nominal Diameter	0.464"	11.79 mm

* ®trademark of Dupont

Nominal Properties

ELECTRICAL

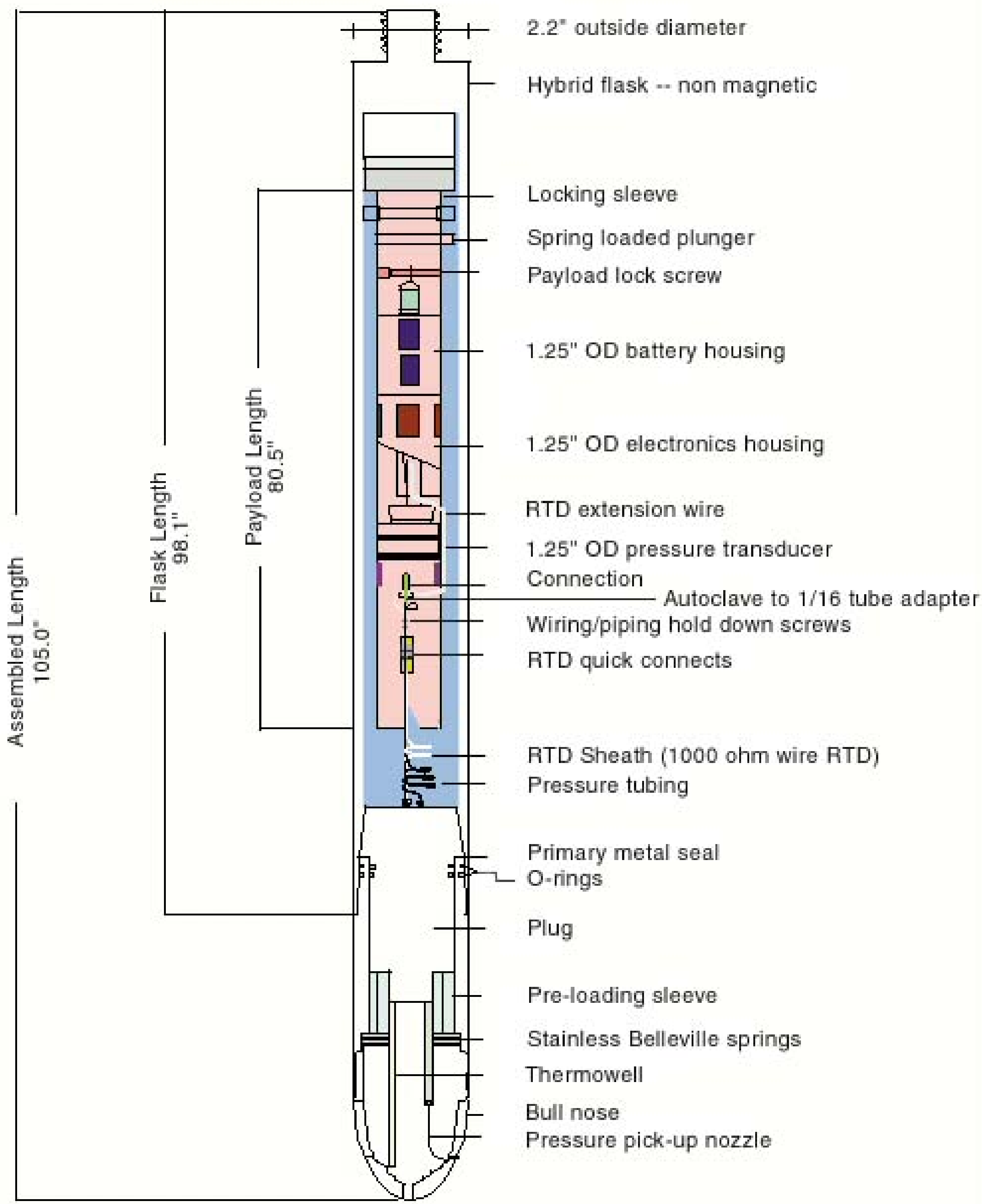
DC Resistance @ 68° F or 20° C	Conductor:	10.9 ohm/kFt	36 ohm/km
	Armor:	1.2 ohm/kFt	4 ohm/km
Insulation Resistance	at 500 VDC	15000 M ohm/kFt	5000 M ohm/km
Capacitance	at 1 KHz	55 pf/Ft	180 pf/km
Voltage Rating		560 Vrms	560 Vrms

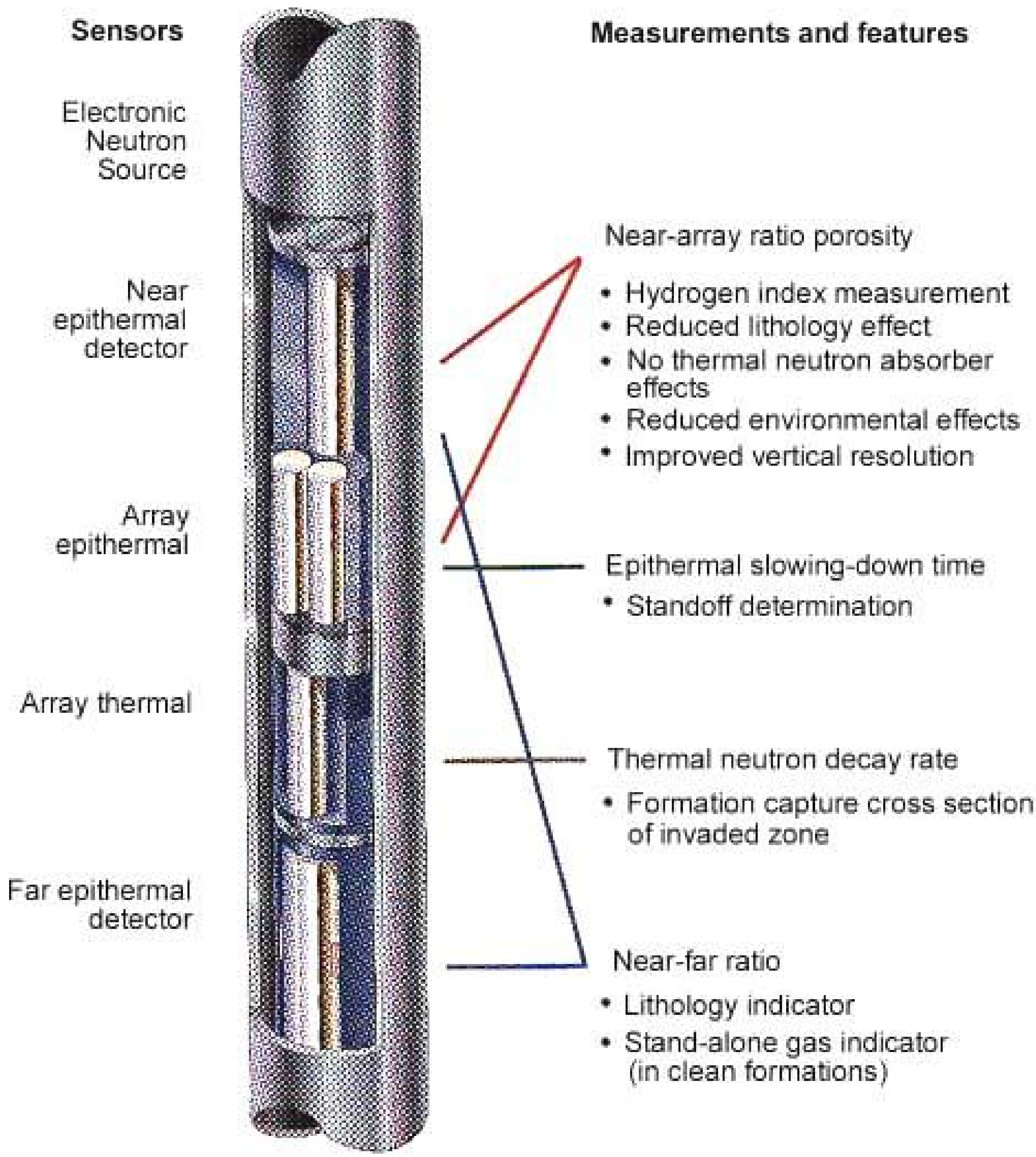
MECHANICAL

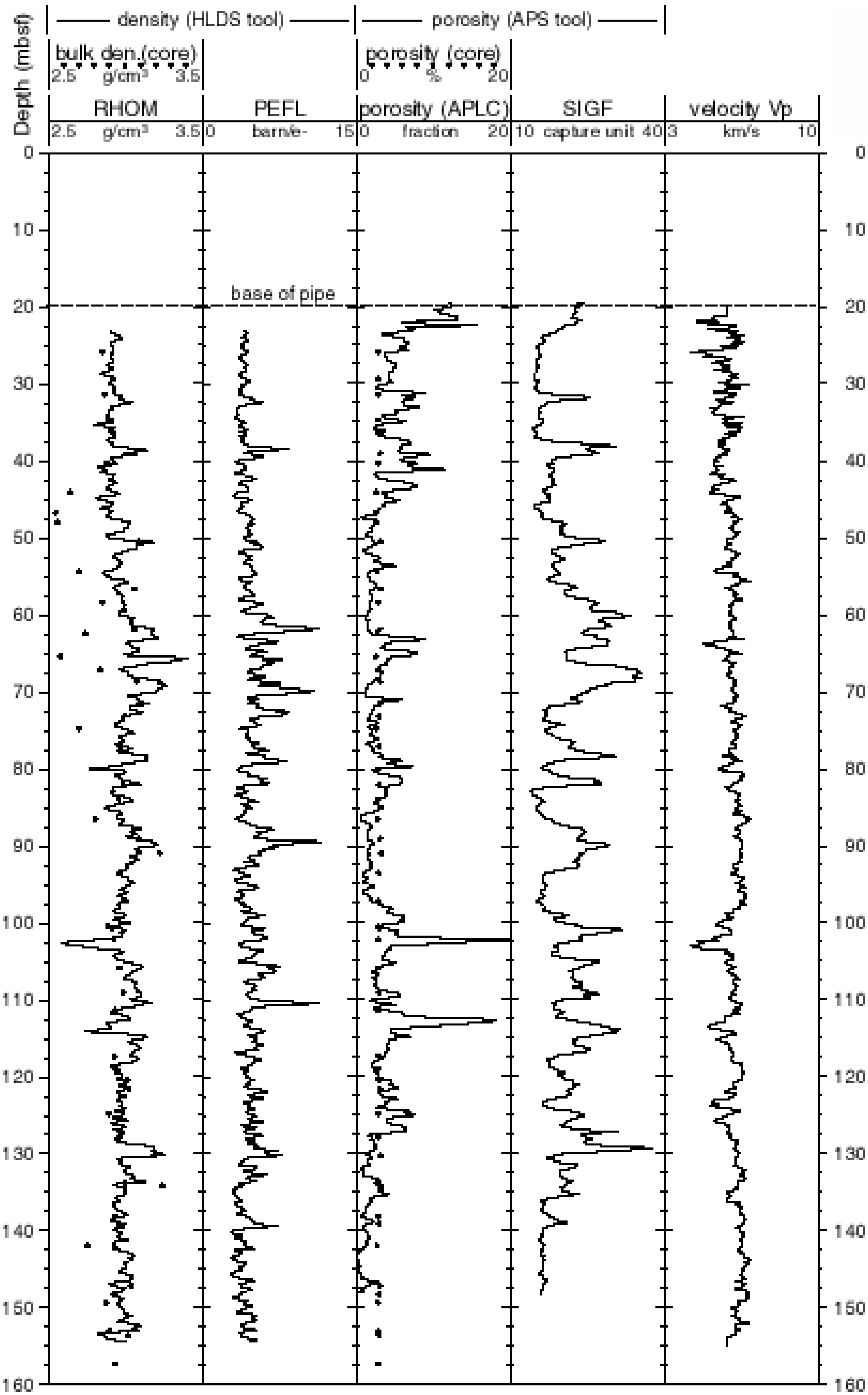
Calculated Weight	In air	350 Lbs/kFt	521 kg/km
	In fresh water	277 Lbs/kFt	412 kg/km
Temperature Rating	Min.	- 40° F	- 40° C
	Max.	450° F	260° C
Break Strength	Ends fixed	16700 Lbf	74 kN
	Ends free	11600 Lbf	52 kN
Maximum end to end variation		0.010 Inch	0.254 mm

Triple Combo FMS/Sonic Specialty Other Toolstring Index

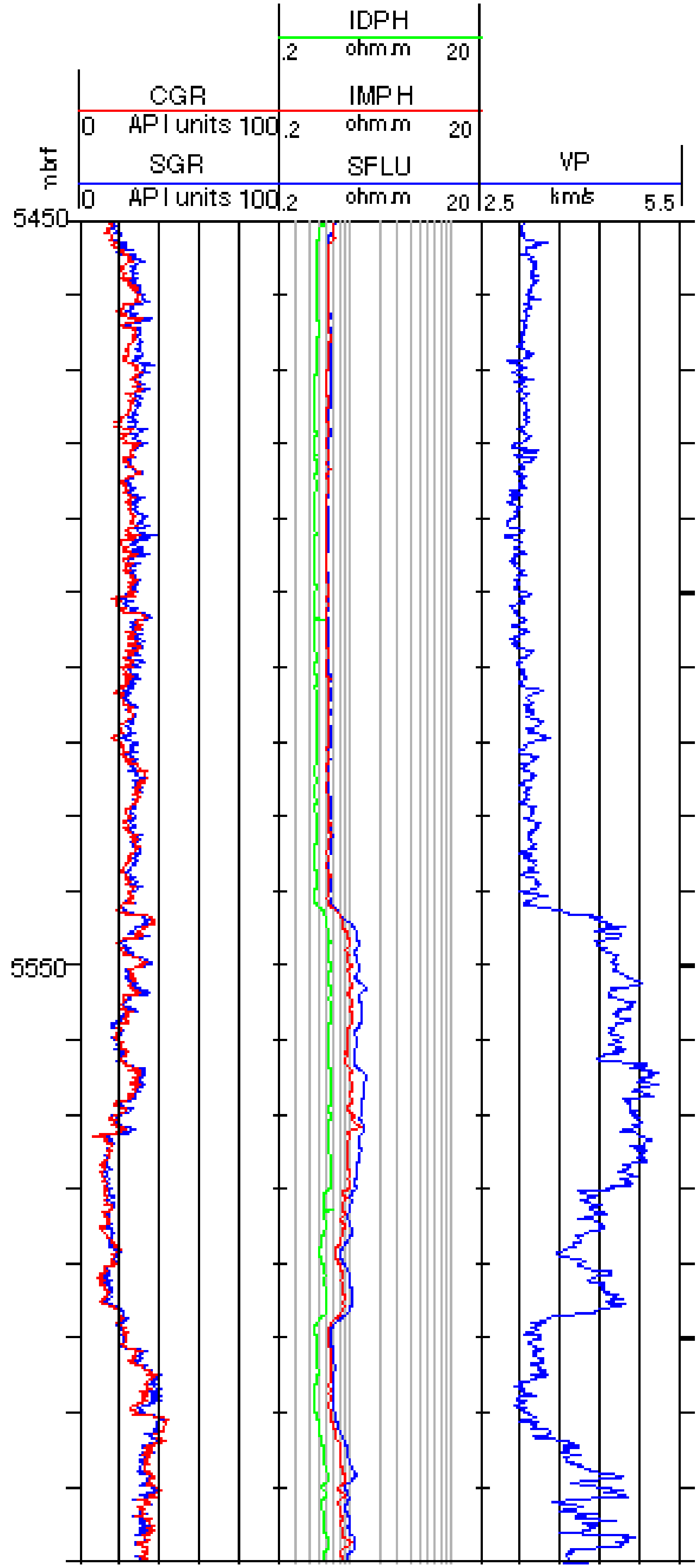
GRC Ultra High Temperature Multi Sensor Memory Tool



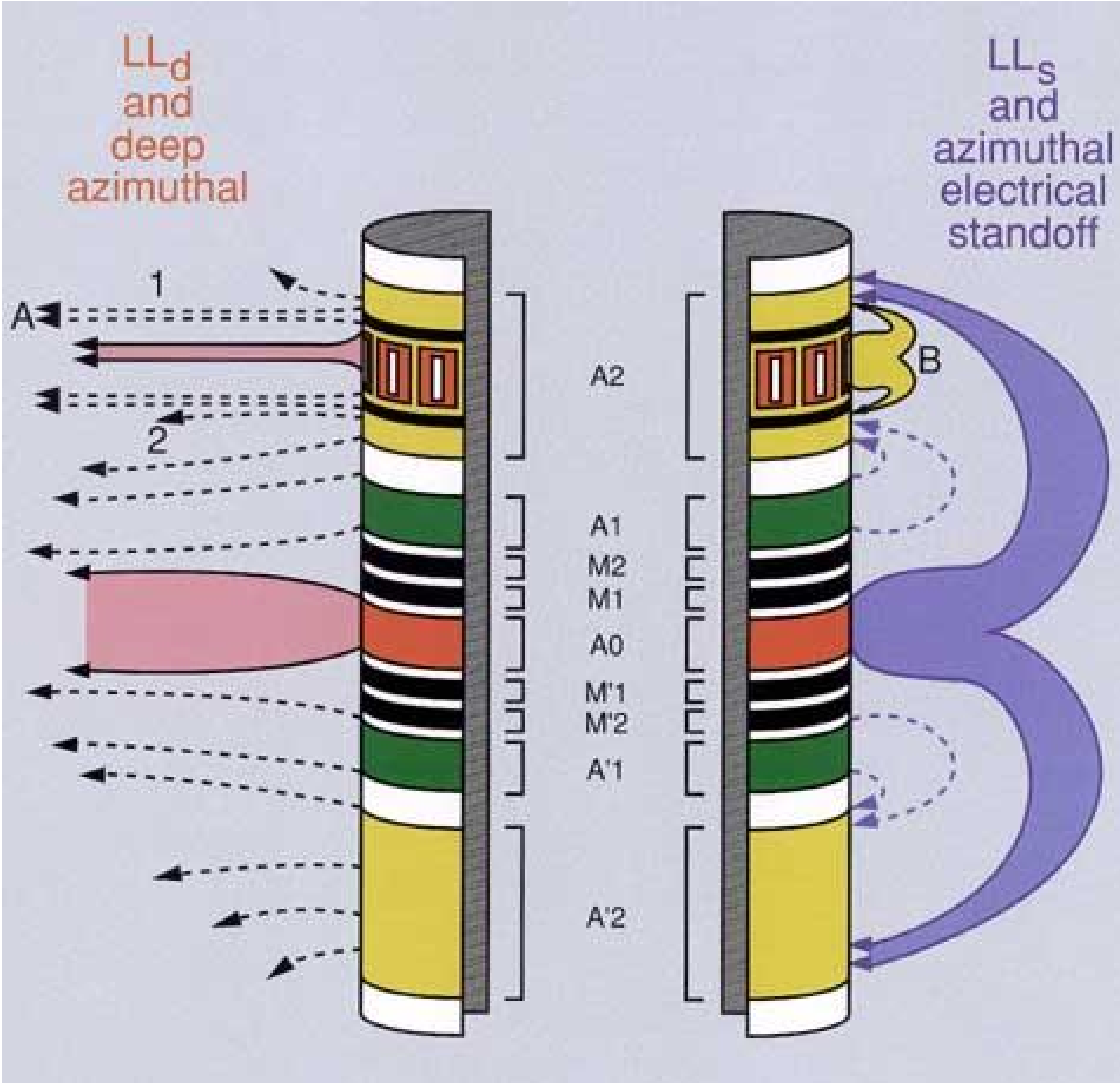

Sensors
Measurements and features
Electronic Neutron Source
Near epithermal detector
Array epithermal
Array thermal
Far epithermal detector
Near-array ratio porosity
• Hydrogen index measurement
• Reduced lithology effect
• No thermal neutron absorber effects
• Reduced environmental effects
• Improved vertical resolution
Epithermal slowing-down time
• Standoff determination
Thermal neutron decay rate
• Formation capture cross section of invaded zone
Near-far ratio
• Lithology indicator
• Stand-alone gas indicator (in clean formations)



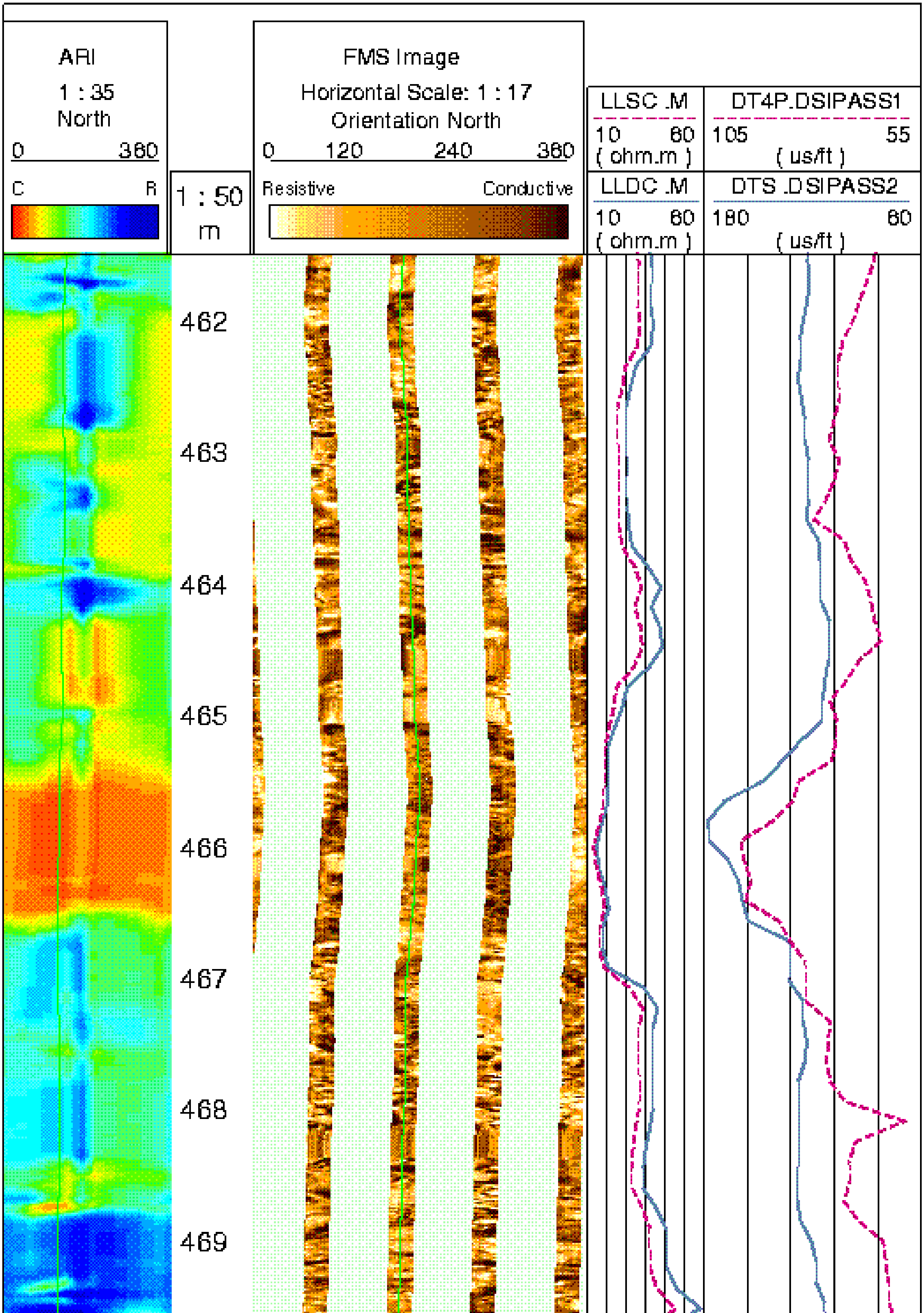
Depth (mbsf)
density (HLDS tool)
porosity (APS tool)
bulk den.(core)
2.5 g/cm³ 3.5
porosity (core)
0 % 20
RHOM
2.5 g/cm³ 3.5
PEFL
0 barn/e- 15
porosity (APLC)
0 fraction 20
SIGF
10 capture unit 40
velocity Vp
3 km/s 10
base of pipe
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160

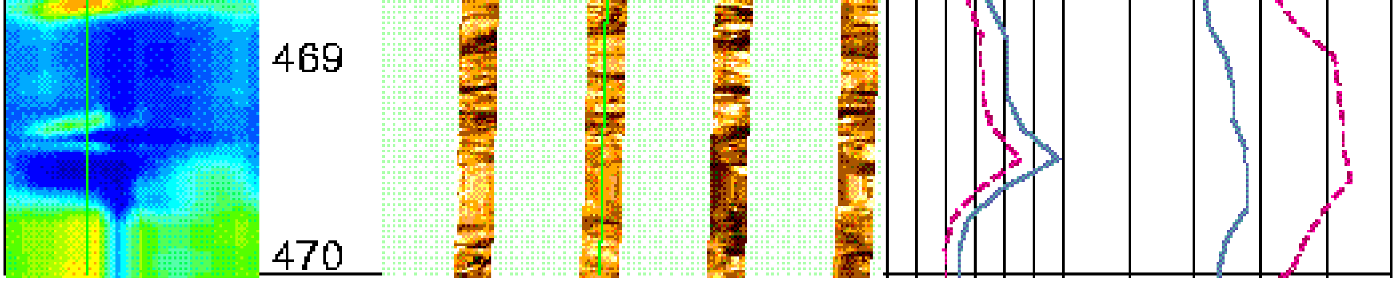


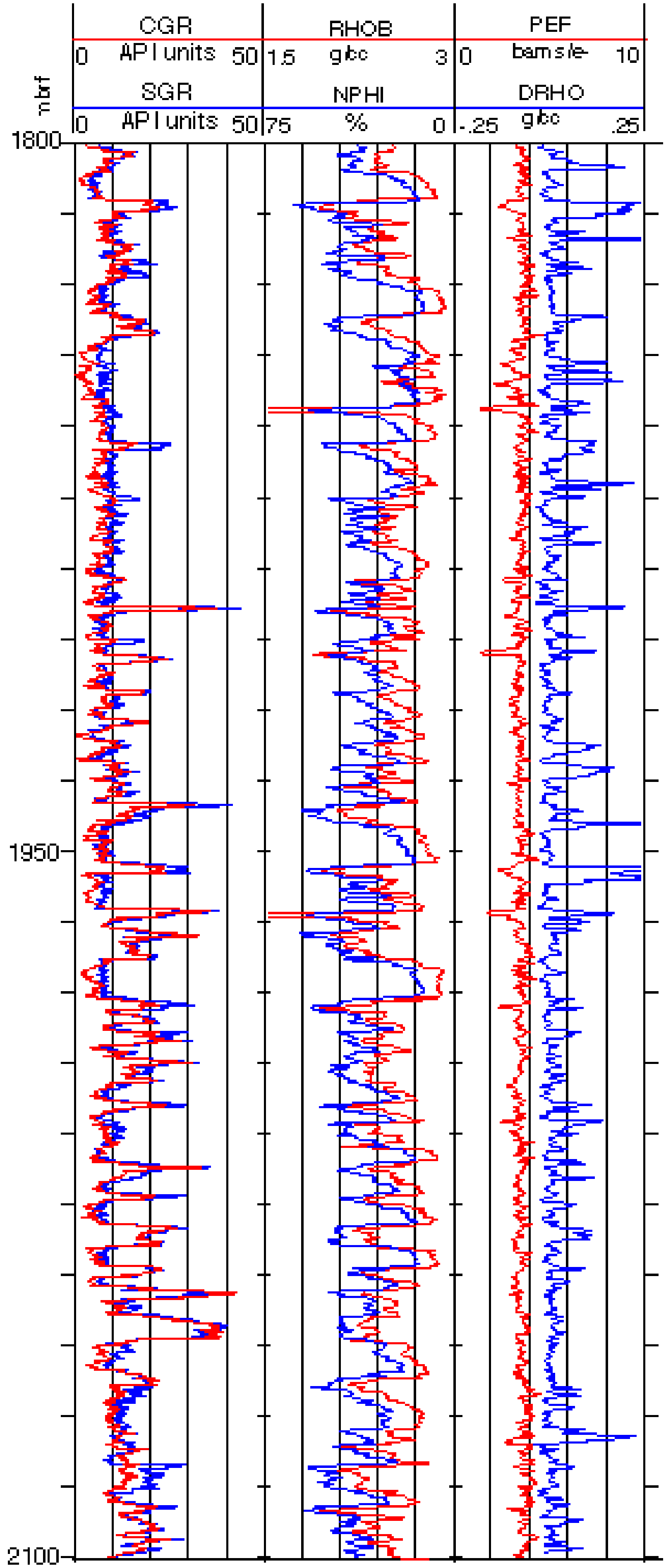
IDPH
.2 ohm.m 20
CGR
0 API units 100
IMPH
.2 ohm.m 20
mbrf
SGR
0 API units 100
SFLU
.2 ohm.m 20
VP
2.5 km/s 5.5
5450
5550



LLd
and
deep
azimuthal
LLs
and
azimuthal
electrical
standoff
1
A
2
B
A2
A1
M2
M1
A0
M'1
M'2
A'1
A'2

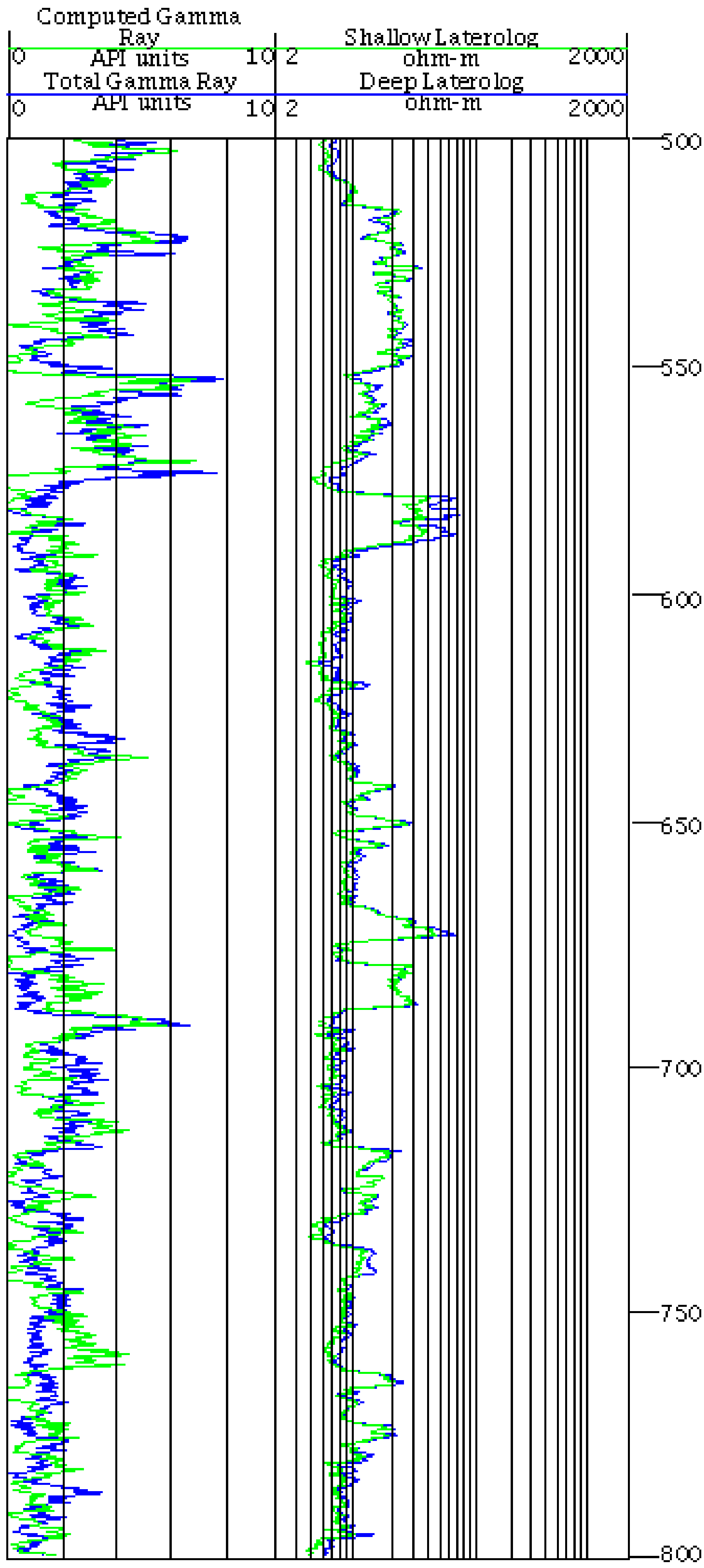

ARI
1 : 35
North
0 360
C R
1 : 50
m
FMS Image
Horizontal Scale: 1 : 17
Orientation North
0 120 240 360
Resistive Conductive
LLSC .M
10 60
(ohm.m)
DT4P.DSIPASS1
105 55
(us/ft)
LLDC .M
10 60
(ohm.m)
DTS .DSIPASS2
180 60
(us/ft)
462
463
464
465
466
467
468
469


469
470

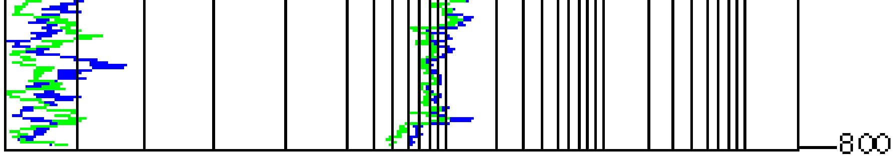


CGR
0 API units 50
SGR
0 API units 50
RHOB
1.5 g/cc 3
NPHI
75 % 0
PEF
0 barns/e- 10
DRHO
-.25 g/cc .25
mbrf
1800
1950
2100


2100



Computed Gamma Ray
0 API units 10
Total Gamma Ray
0 API units 10
Shallow Laterolog
2 ohm-m 2000
Deep Laterolog
2 ohm-m 2000
500
550
600
650
700
750
800


800

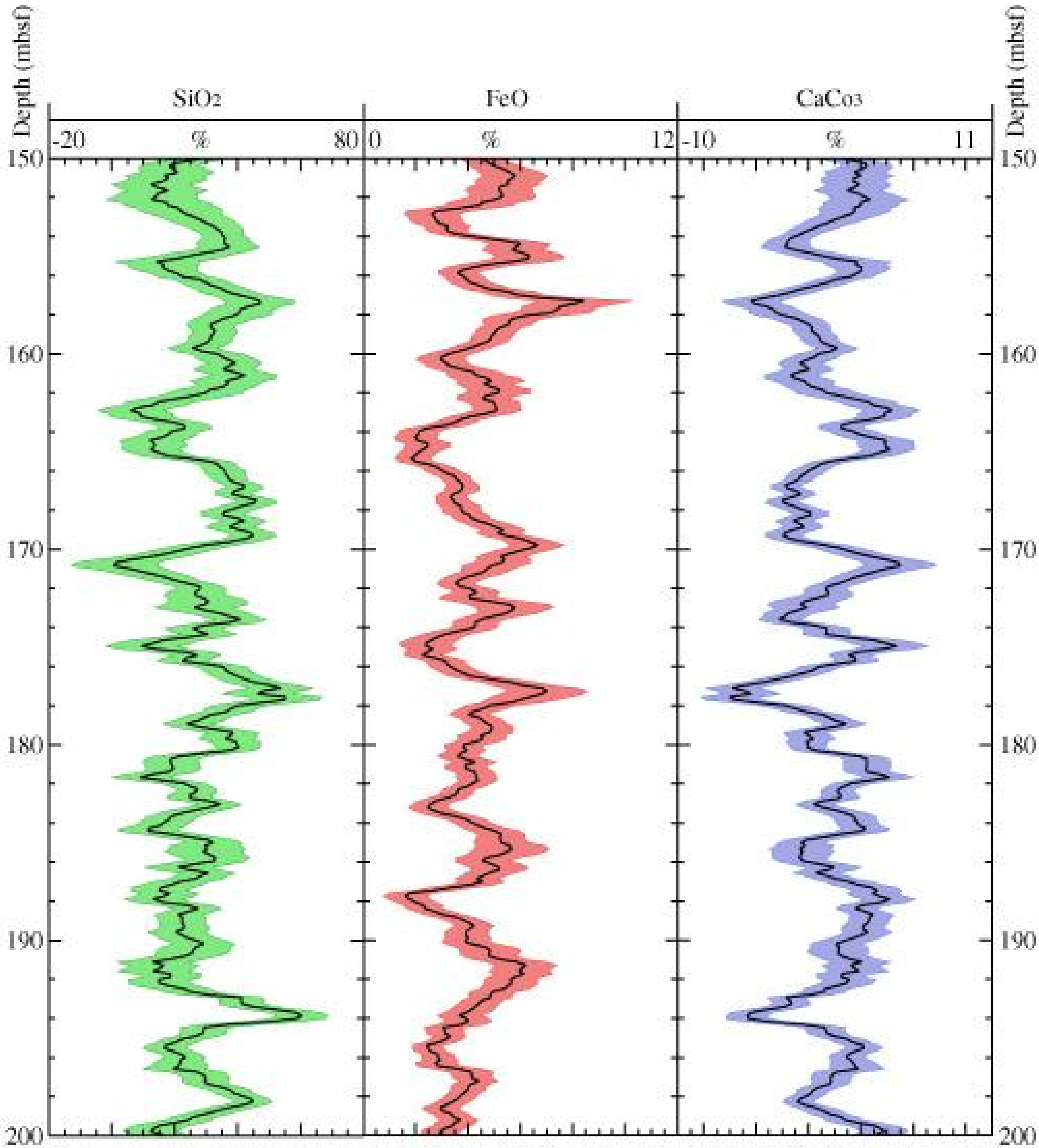


Figure 2 A selection of the geochemical logging results from ODP Hole 950A. Downhole fluctuations in SiO_2, Fe0 and $CaCO_3$ (shown with calculated errors) reflect regular variations in the lithology.

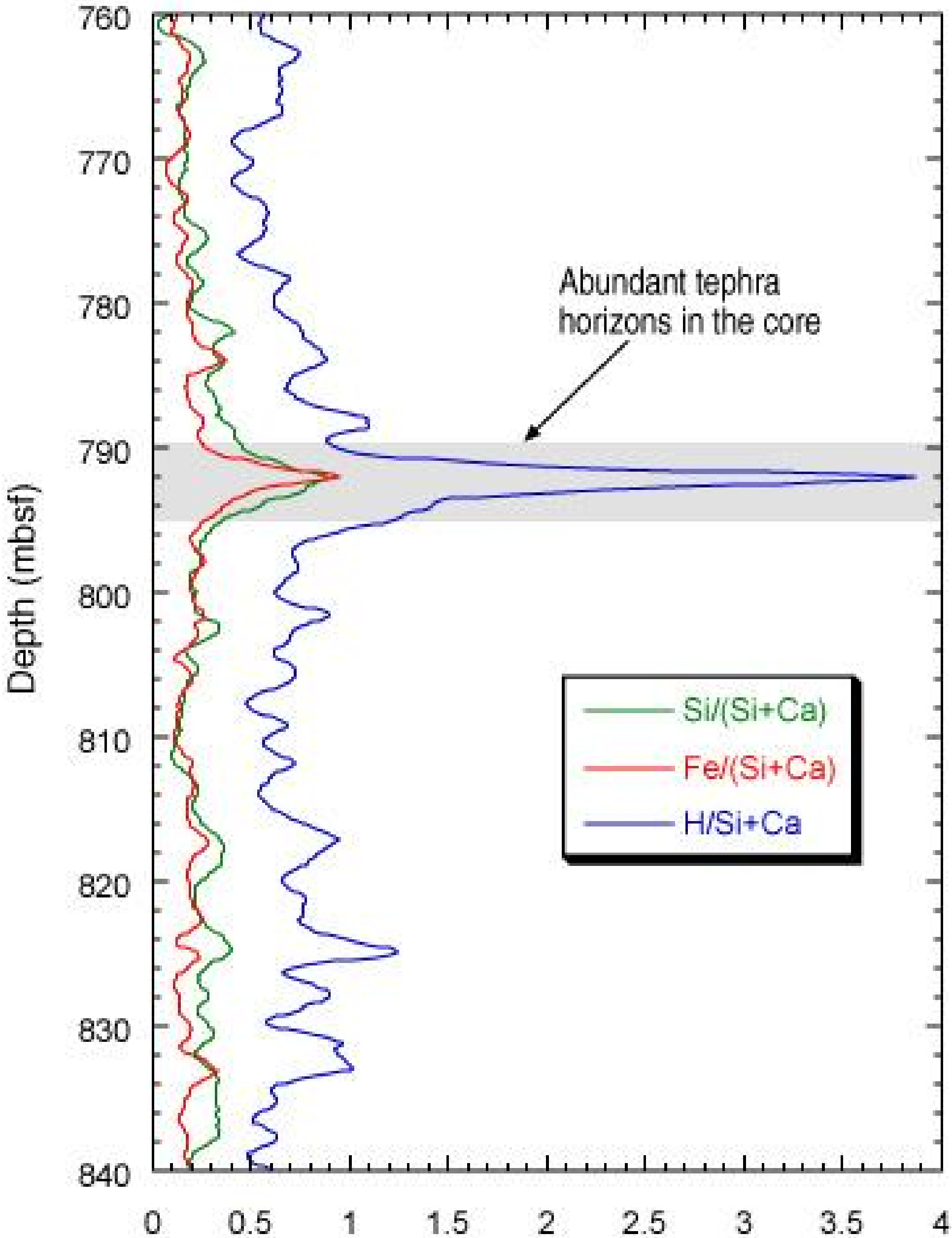


Figure 3 Elemental yield ratios from ODP Hole 999B. Increases in all the data, but particlulrly the porosity indicator(H/(Si + Ca), correlate with the occurrence of abundant tephra horizons in the core.

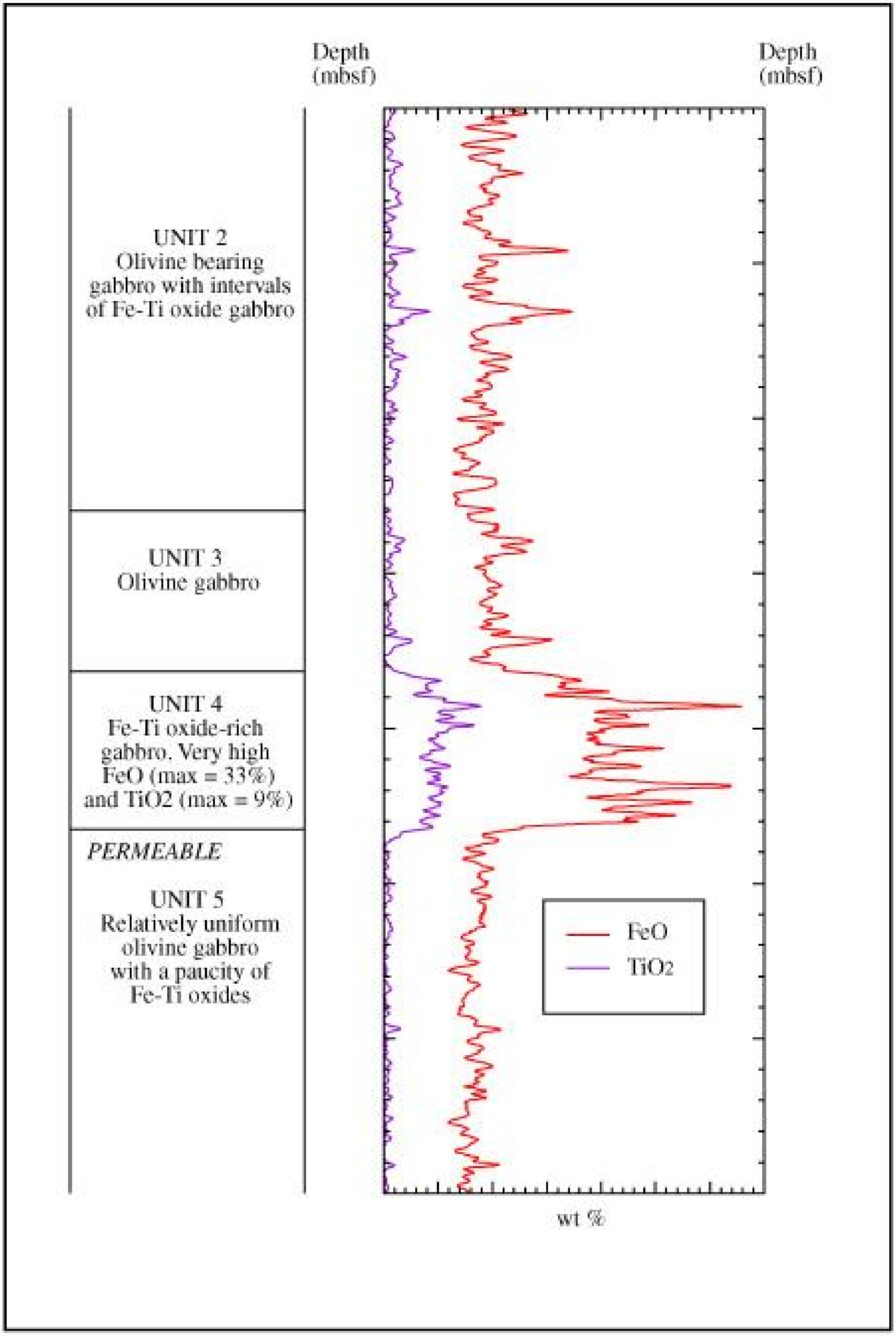
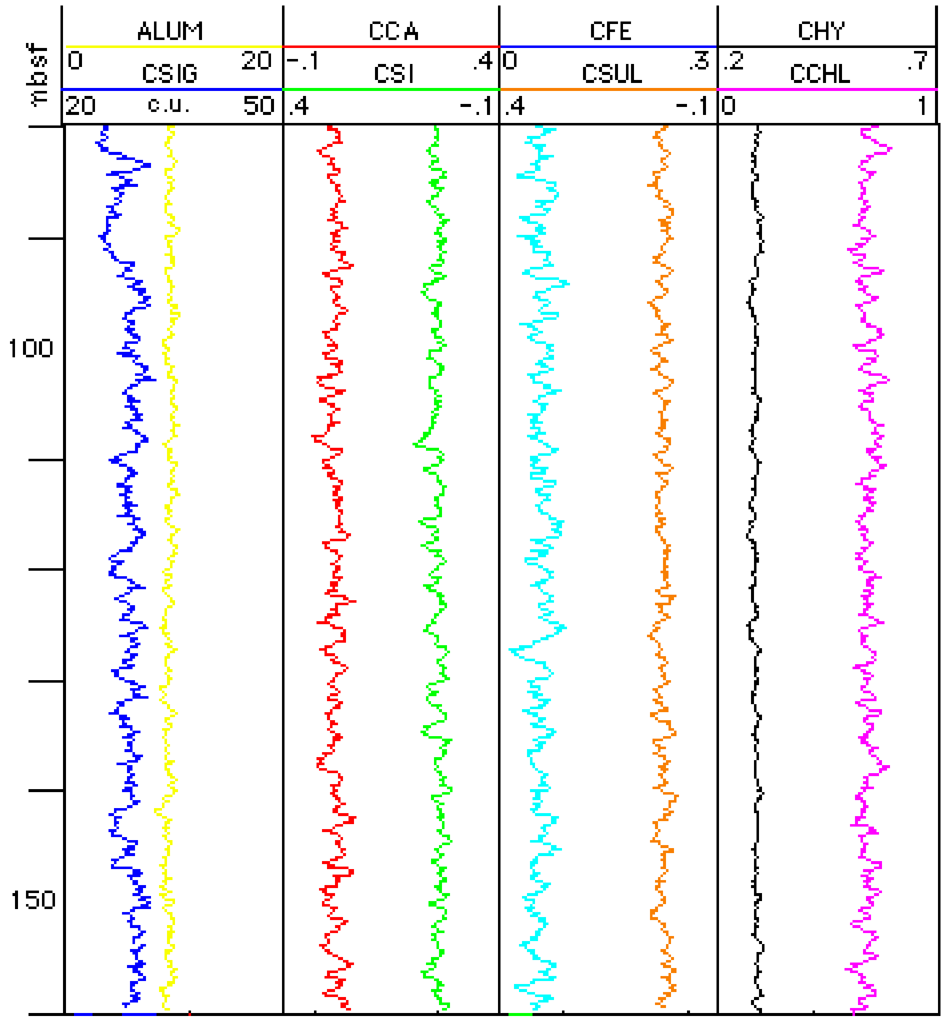
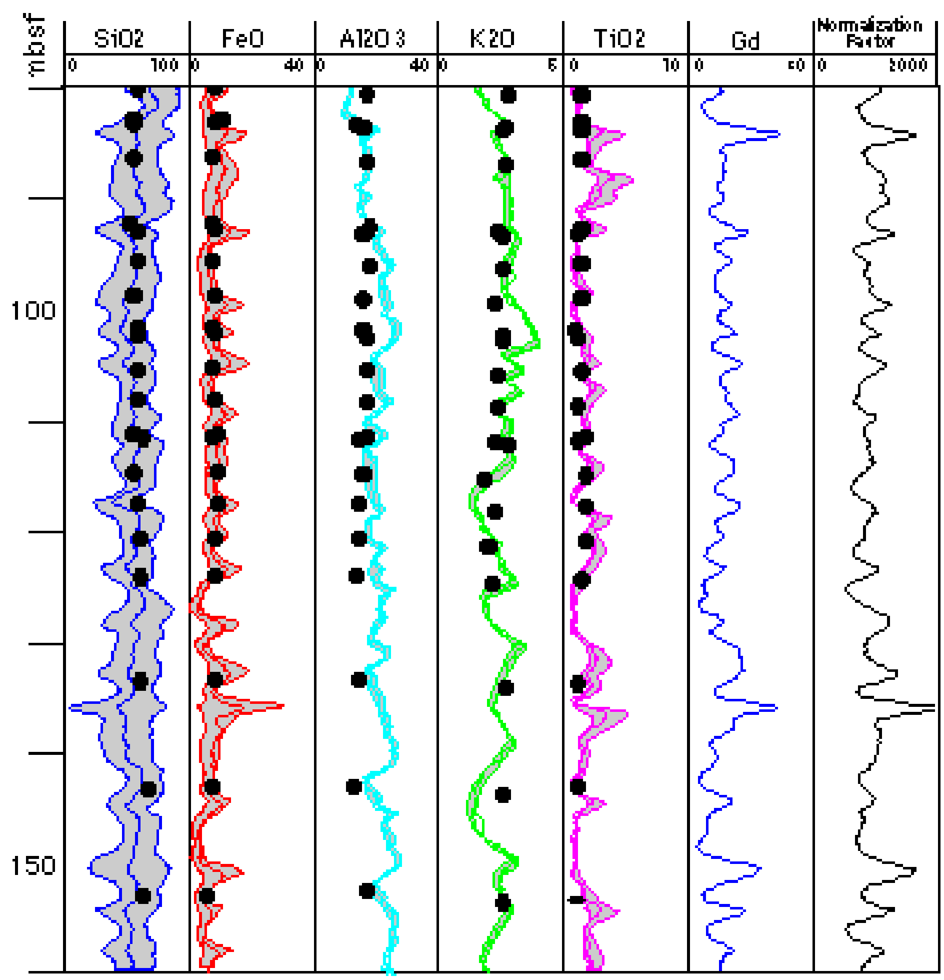
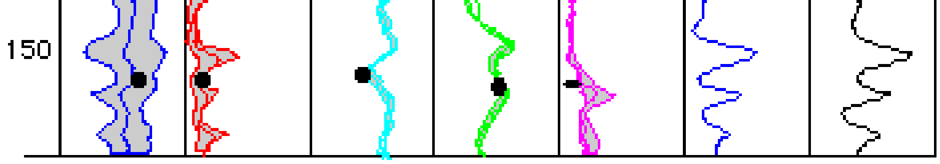


Figure 4 Geochemical results from ODP Hole 735B clearly show a unit of iron-titanium oxide-rich gabbro in the formation.

Figure 4 Geochemical results from ODP Hole 735B clearly show a unit of iron-titanium oxide-rich gabbro in the formation.


mbsf
ALUM
0
20
CSIG
20
c.u.
50
CCA
-.1
.4
CSI
.4
-.1
CFE
0
.3
CSUL
.4
-.1
CHY
.2
.7
CCHL
0
1
100
150


mbsf
SiO2
0
100
FeO
0
40
Al2O3
0
40
K2O
0
5
TiO2
0
10
Gd
0
Normalization Factor
0
2000
100
150


150

Applications of gamma ray logs

Depth correlations and core-log integration

Total gamma-ray log curves, which are acquired with every toolstring combination, are normally used to depth match all of the logs obtained in any one hole. The HSGR log from the Triple Combo is used as the base curve, and the SGR logs from all the other toolstrings are interactively matched to it. The depth shift applied to each SGR curve is propagated to all other logs acquired by that toolstring.

Gamma ray data can also be used for core-log integration, by correlating the natural gamma results from the whole core multisensor track (WC-MST) with the HSGR and SGR curves. Furthermore, because the gamma ray log responds principally to fluctuations in the formation's mineralogy, rather than physical properties such as lithification, it is particularly useful for making regional, inter-hole comparisons between major lithostratigraphic units (**Figure 1**).

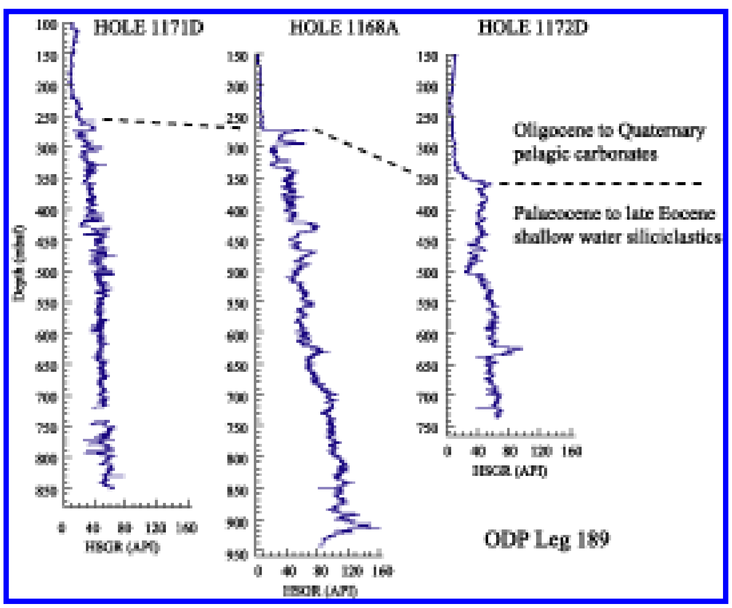


Figure 1: Regional correlation of major lithostratigraphic units, using total gamma ray data from Leg 189.

Identification of lithology, facies and depositional environment

Naturally radioactive elements tend to have a far greater concentration in shales than in other sedimentary lithologies, and therefore the total gamma-ray log and, in particular, the corrected gamma-ray log (HCGR and CGR) and the Th log are frequently used to derive a "shale volume" (see Ellis 1987 and Rider 1996). In addition, the shape of the gamma log curve may be used to reconstruct downhole fluctuations in grain size, and infer changes in sedimentary facies: the standard approach is to interpret bell shaped gamma curves as a fining-upwards sequence and funnel shaped gamma curves as a coarsening-upward sequence (Serra & Sulpice 1975). However, these methods are only likely to be of use in simple sandstone/shale formations, and are subject to error when a significant proportion of the gamma ray radioactivity originates from the sand sized detrital fraction of the rock (see Heslop 1974 and Rider 1990).

Gamma ray data may also be used to help interpret the environment of deposition. Unconformities can result in the accumulation of phosphatic nodules, which may be evident in the spectral gamma log as an anomalous spike in U. Increased U values, and in particular low Th/U ratios, may also be associated with marine condensed sequences (Myers & Wignall 1987). Doveton (1991) used Th/U ratios to estimate paleo-redox conditions at the time of deposition, which he used to identify generally transgressive and regressive intervals.

Mineralogy / Geochemistry

The concentrations of the three main radioactive elements in the formation can often be used to give an indication of the mineralogy and/or geochemistry. For example, high Th values may be associated with the presence of heavy minerals, particularly in channel sand deposits overlying an erosional unconformity. Increased Th values may also be associated with an increased input of terrigenous clays (Hassan *et al.* 1976) (**Figure 2**).

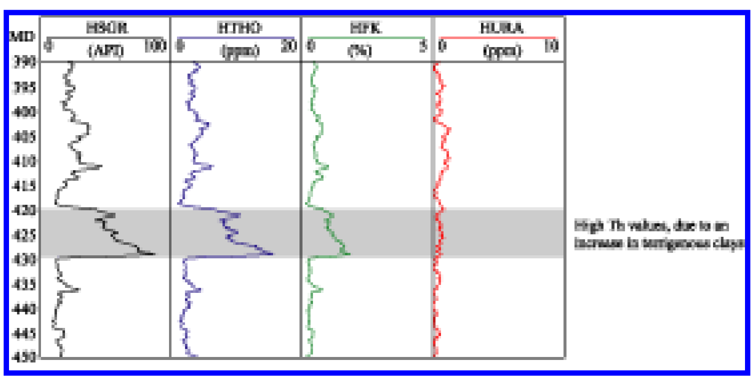


Figure 2: Spectral gamma-ray data from Hole 1124C, showing high Th values in a mudstone unit between 420-430 mbsf.

Increases in U are frequently associated with the presence of organic matter. For example, particularly high U concentrations (>~5 ppm) and low Th/U ratios (<~2) occur in black shale deposits (Adams & Weaver 1958). In the Ocean Drilling Program, a correlation can often be observed between the U log and the total organic carbon values measured in the core (**Figure 3**)

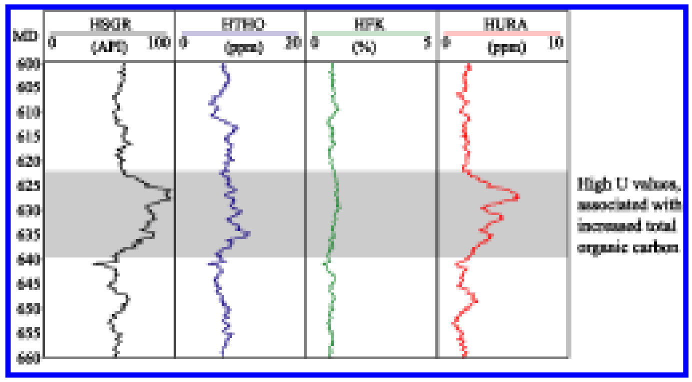


Figure 3: Spectral gamma-ray data from Hole 1172D, showing high U values in an organic-bearing claystone unit between ~622-640 mbsf.

In sandstones, high K values may be caused by the presence of potassium feldspars or micas (Humphreys & Lott 1990, Hurst 1990). Glauconite usually produces a very distinctive, almost diagnostic spike in the K log (**Figure 4**).

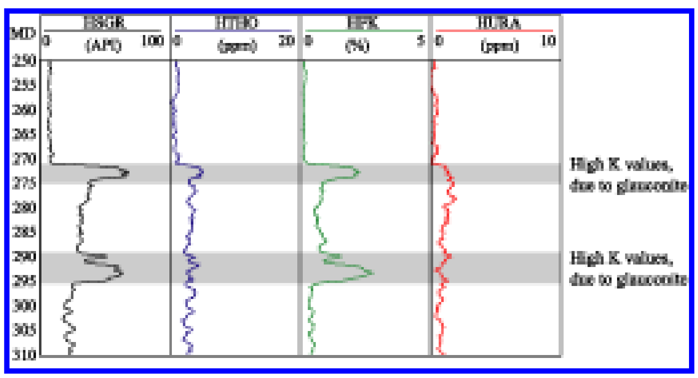


Figure 4: Spectral gamma-ray data from Hole 1171D, showing high K values due to the presence of glauconite.

In ocean floor volcanics, K can become significantly enriched in secondary alteration minerals, which are typically found where the formation is more permeable and intense fluid-rock interactions can occur (Brewer *et al.* 1992). An example of this can be seen in ODP Hole 896A, where the lowest K values occur in relatively impermeable massive flows, whereas higher and more variable K concentrations can be correlated with the more permeable pillow lavas and breccias (Brewer et al, 1998).

More quantitative attempts have been made to derive a mineralogy from the spectral gamma-ray log, which generally involve cross-plotting Th against K (Quirein 1982), PEFL against K (Schlumberger 1991), or PEFL against Th/K (Schlumberger 1991). However, the validity of these methods is questionable (Hurst 1990), and it is unlikely that they are applicable in a wide variety of sedimentary environments.

Cyclostratigraphic analysis

Spectral gamma-ray data can also be used for cyclostratigraphic analysis of the formation, to help identify the frequency of paleoceanographic and/or climatic change (**Figure 5**). Data acquired by the recently developed Lamont Multisensor Gamma ray Tool will be particularly valuable for time series analysis, due to its very high resolution (~8 cm).

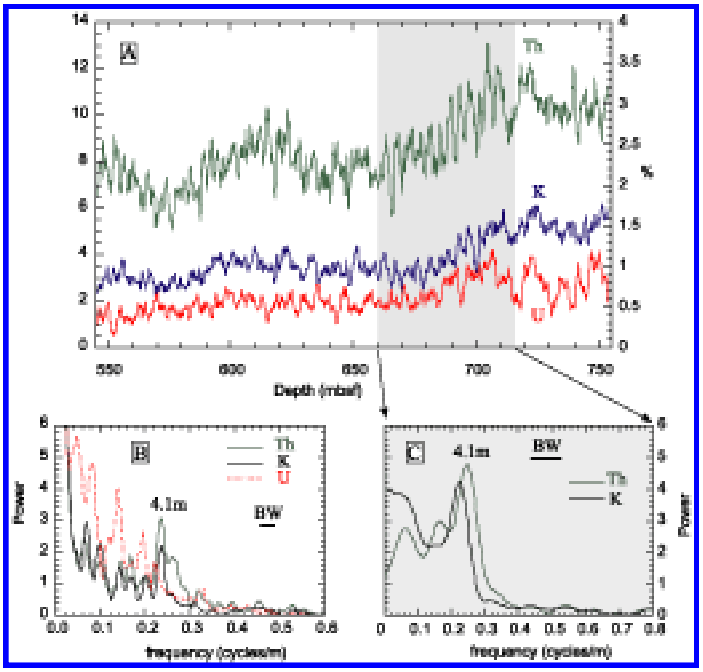


Figure 5: Spectral gamma-ray data (A) and preliminary spectral analysis (B and C) from 1170D. The power spectrum show the results of spectral analysis over the entire logged section (B) and the interval where the Th and K data show the most pronounced cyclicity (C).

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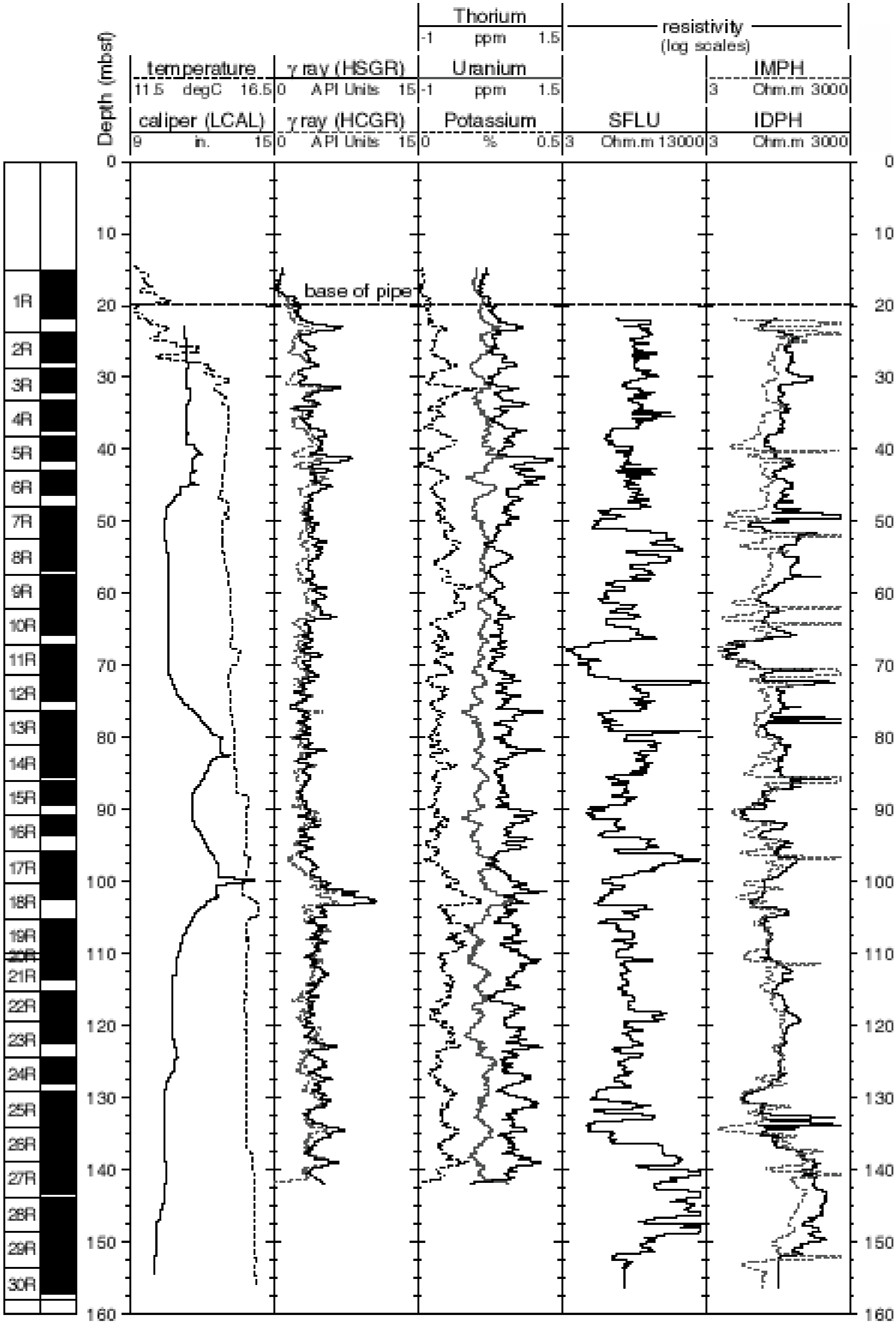

Depth (mbsf)
temperature
11.5 degC 16.5
caliper (LCAL)
9 in. 15
γ ray (HSGR)
0 API Units 15
γ ray (HCGR)
0 API Units 15
Thorium
-1 ppm 1.5
Uranium
-1 ppm 1.5
Potassium
0 % 0.5
resistivity
(log scales)
SFLU
3 Ohm.m 13000
IMPH
3 Ohm.m 3000
IDPH
3 Ohm.m 3000
base of pipe
1R
2R
3R
4R
5R
6R
7R
8R
9R
10R
11R
12R
13R
14R
15R
16R
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HOME
How to use this manual
What is downhole logging?

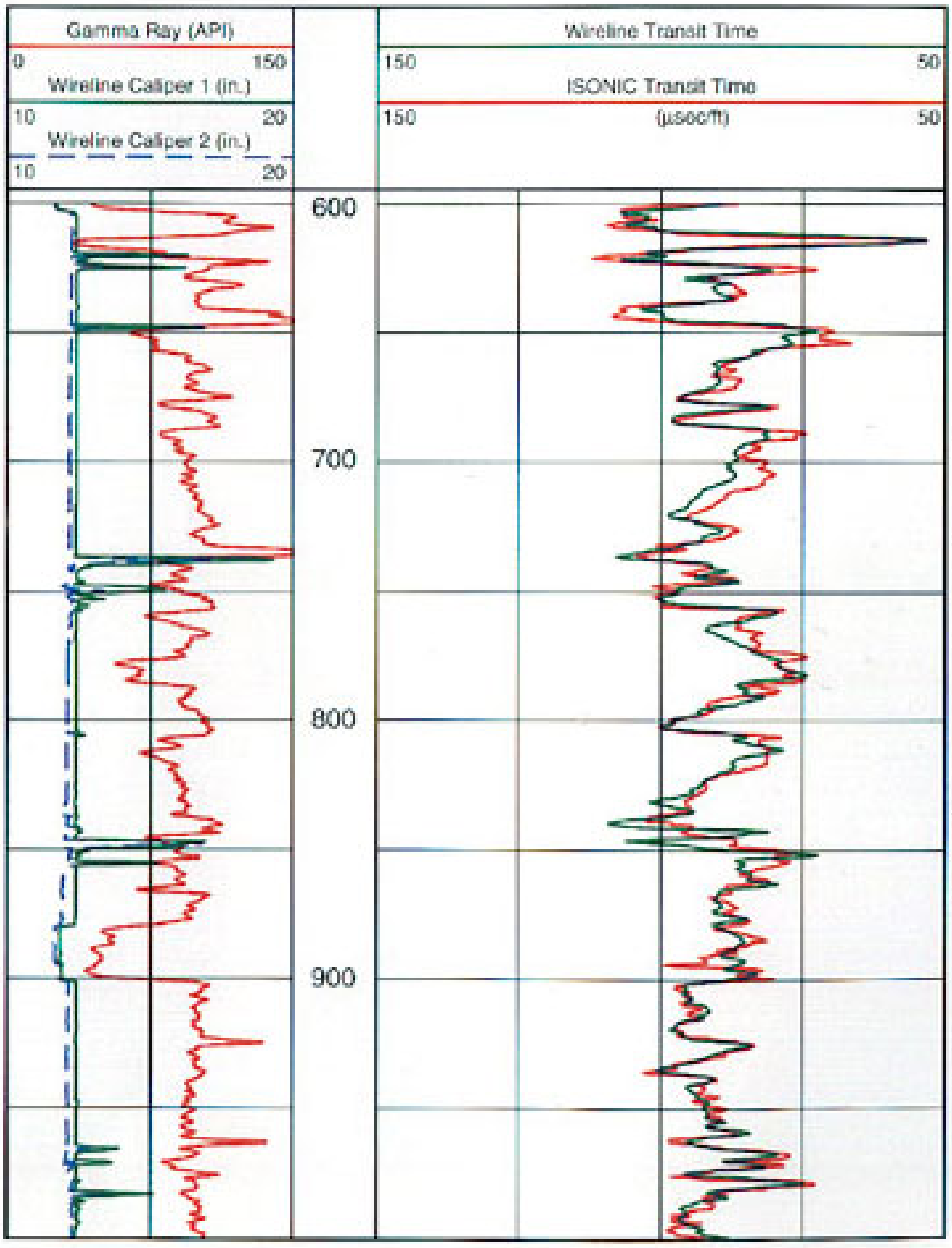
What is downhole logging?

Downhole logging is the process of measuring physical, chemical, and structural properties of penetrated geological formations using logging tools that are either lowered into the borehole on a wireline cable (wireline logging) or placed just behind the drill bit as part of the drill pipe itself (logging-while-drilling). The tools employ various acoustic, nuclear, and electrical measurement techniques to acquire downhole logs of properties such as sonic velocity, density, and electrical resistivity. The wireline cable provides real-time communication between the tools and the surface; logging-while-drilling tools typically record the logs in downhole memory devices, which are subsequently downloaded when the tool returns to the ship.

The downhole logs are rapidly collected, are continuous with depth, and measure in situ properties. They can be interpreted in terms of the formation's stratigraphy, lithology, and mineralogy. The sampling interval is typically 15 cm, with a vertical resolution of about 35 cm. Some tools have a higher sampling interval and resolution; for example, the FMS can electrically image sub-cm-scale features. Logging tools are generally designed to measure formation properties some distance into the formation, in order to minimize the effects of variable borehole diameter and roughness. Logs also provide the major link between borehole and seismic section: sonic velocity logs and checkshots improve depth to travel-time conversion, and synthetic seismograms may be compared directly to the seismic section.

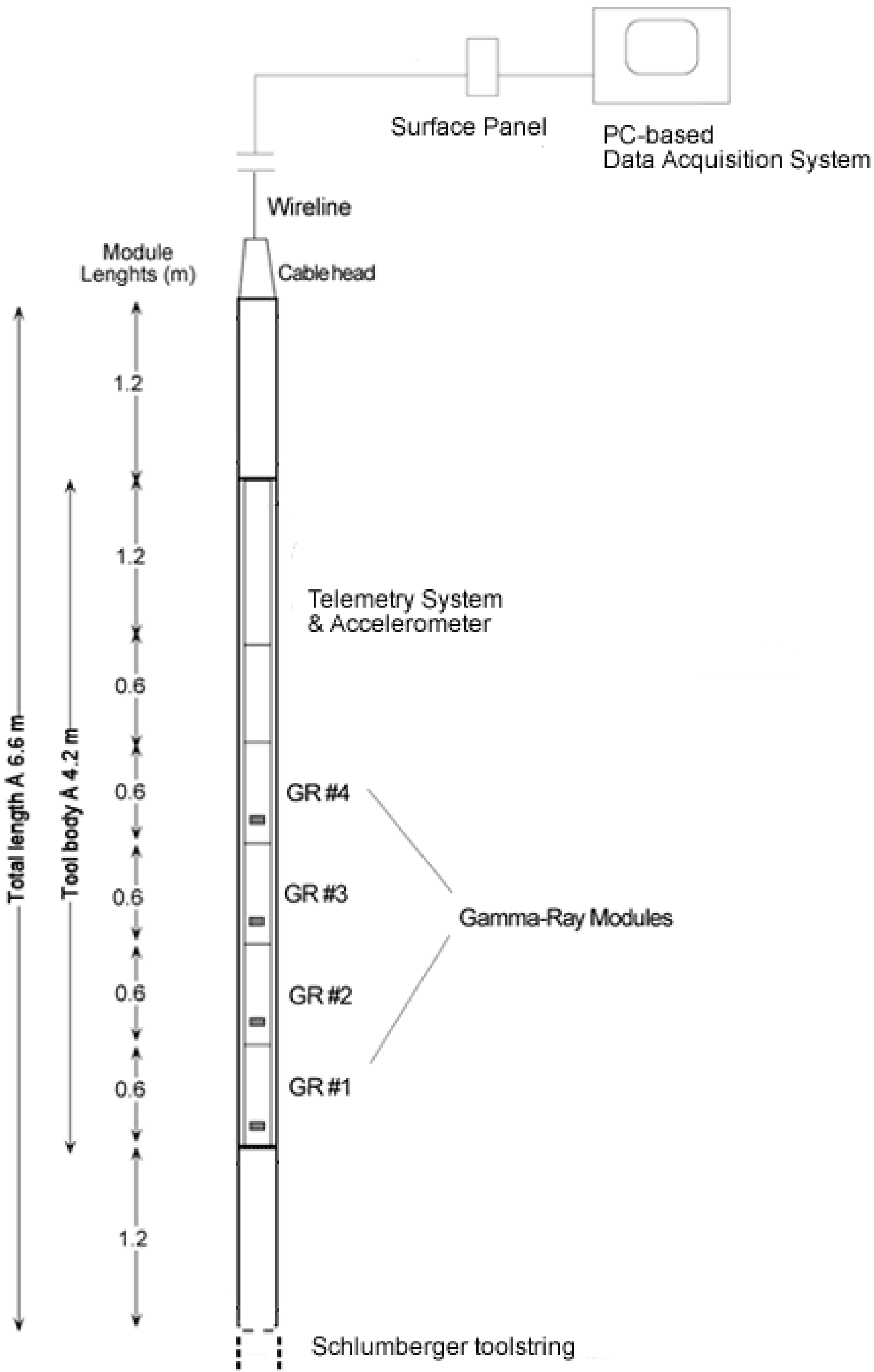
While downhole logs are complementary to core measurements, they also offer certain advantages. In a hole where there is only limited core recovery, the depth location of the incomplete cores can be uncertain; logs provide a continuous depth record of formation properties. Where there is preferential recovery of a certain rock type -- for example, basalt pillows can be more easily recovered than breccia -- the logs can reveal a more realistic stratigraphy. The in-situ nature of the downhole measurements is in contrast to measurements on recovered core: when material is no longer under the high-pressure conditions that exist at depth, it can physically expand and gas hydrates can dissociate. The core may also be degraded by the coring process: rotary coring can grind up sediment, resulting in "biscuits" of coherent sediment in a ground-up matrix.

Readers interested in an in-depth introduction to the role of downhole measurements in marine geology and geophysics, with examples, are invited to read the enclosed review paper, published in Reviews of Geophysics and reprinted by permission of the American Geophysical Union.



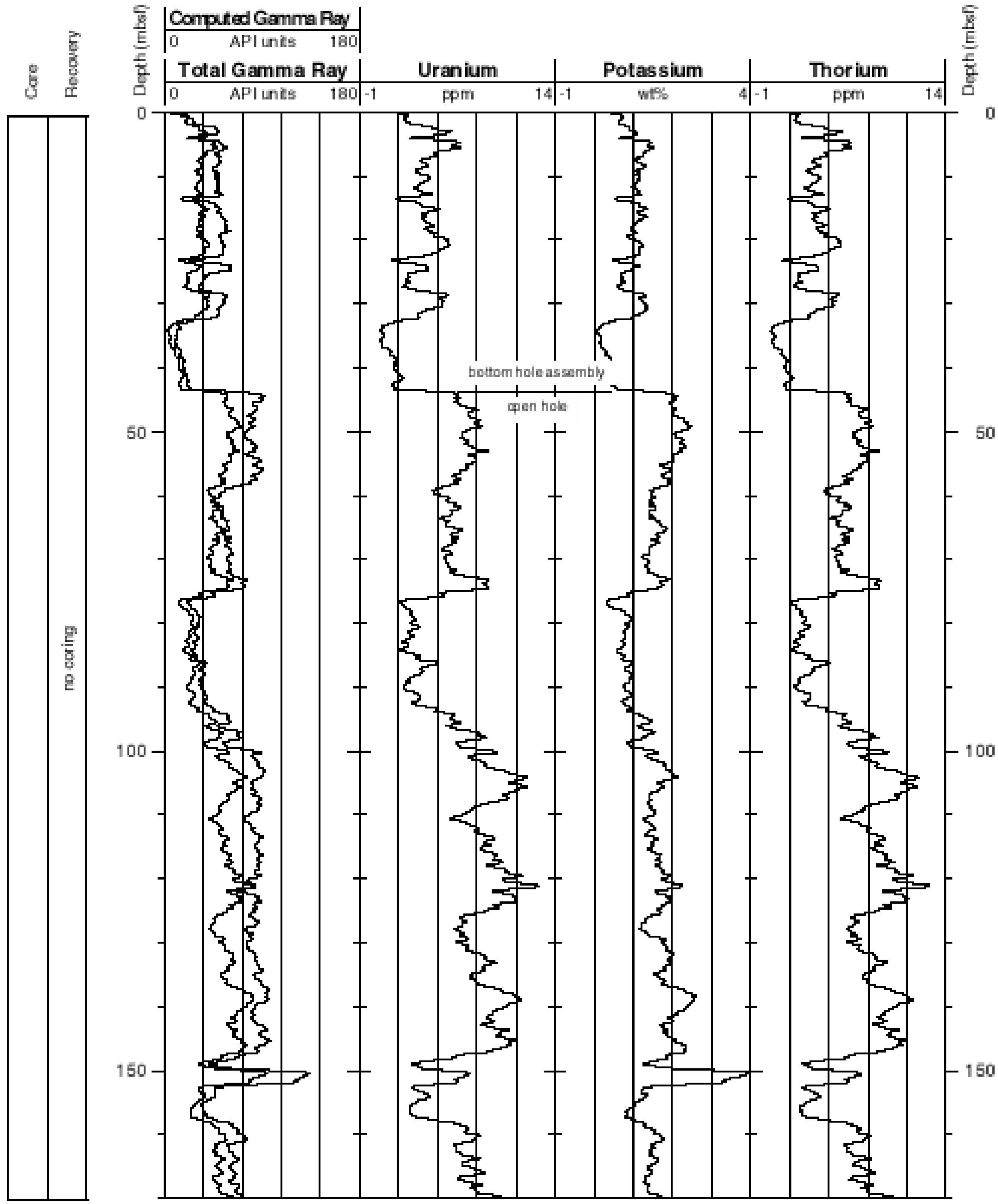
Note shale swelling by time of wireline logging

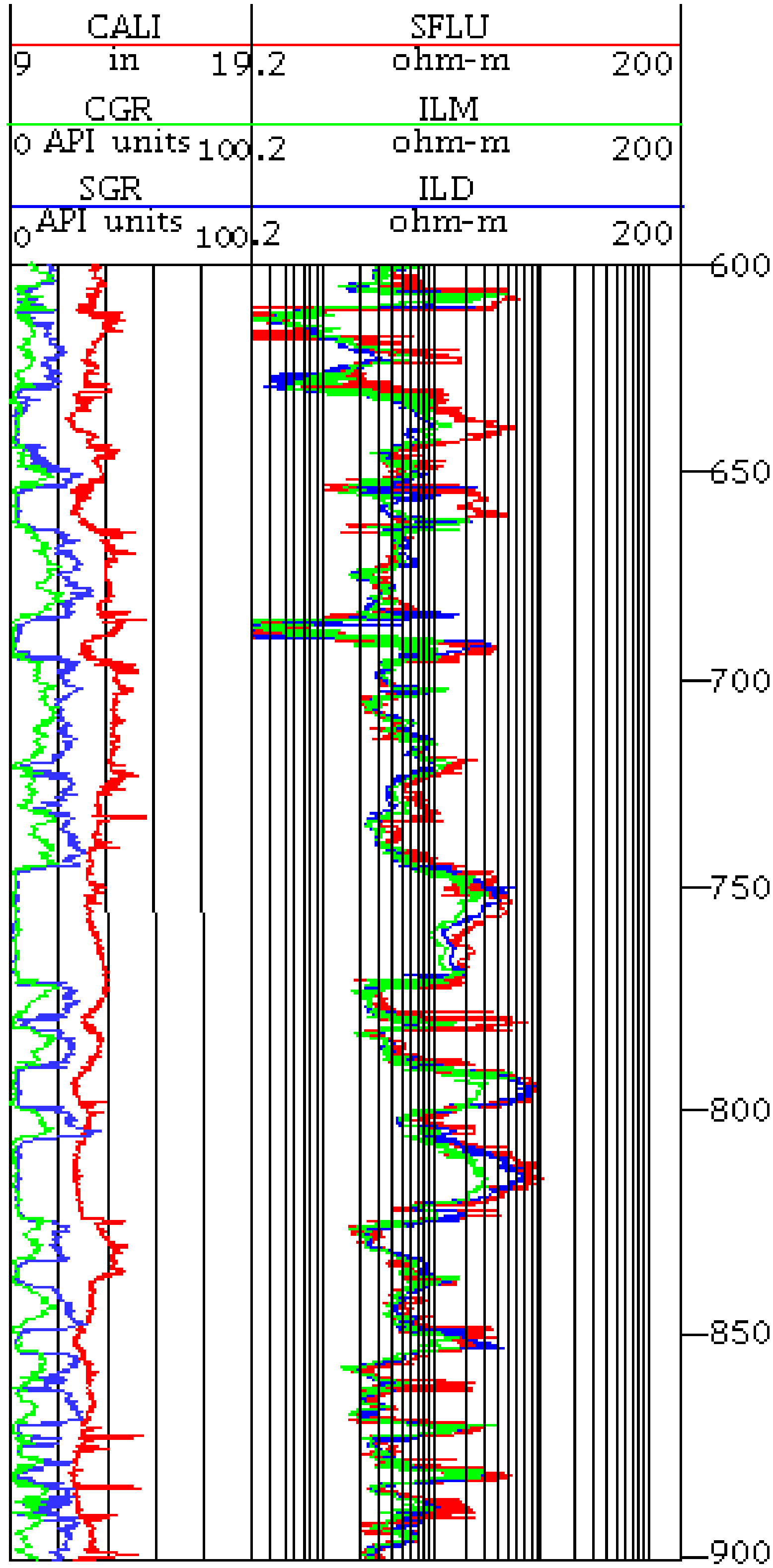
Disagreement caused by deteriorated hole condition at time of wireline logging (note wireline caliper indicating washout)



Surface Panel
PC-based
Data Acquisition System
Wireline
Module
Lenghts (m)
Cable head
1.2
1.2
Telemetry System
& Accelerometer
0.6
0.6
GR #4
0.6
GR #3
Gamma-Ray Modules
0.6
GR #2
0.6
GR #1
1.2
Total length A 6.6 m
Tool body A 4.2 m
Schlumberger toolstring

Hole 1072B: Natural Gamma Ray Logging Data




CALI
9 in 19
CGR
0 API units 100
SGR
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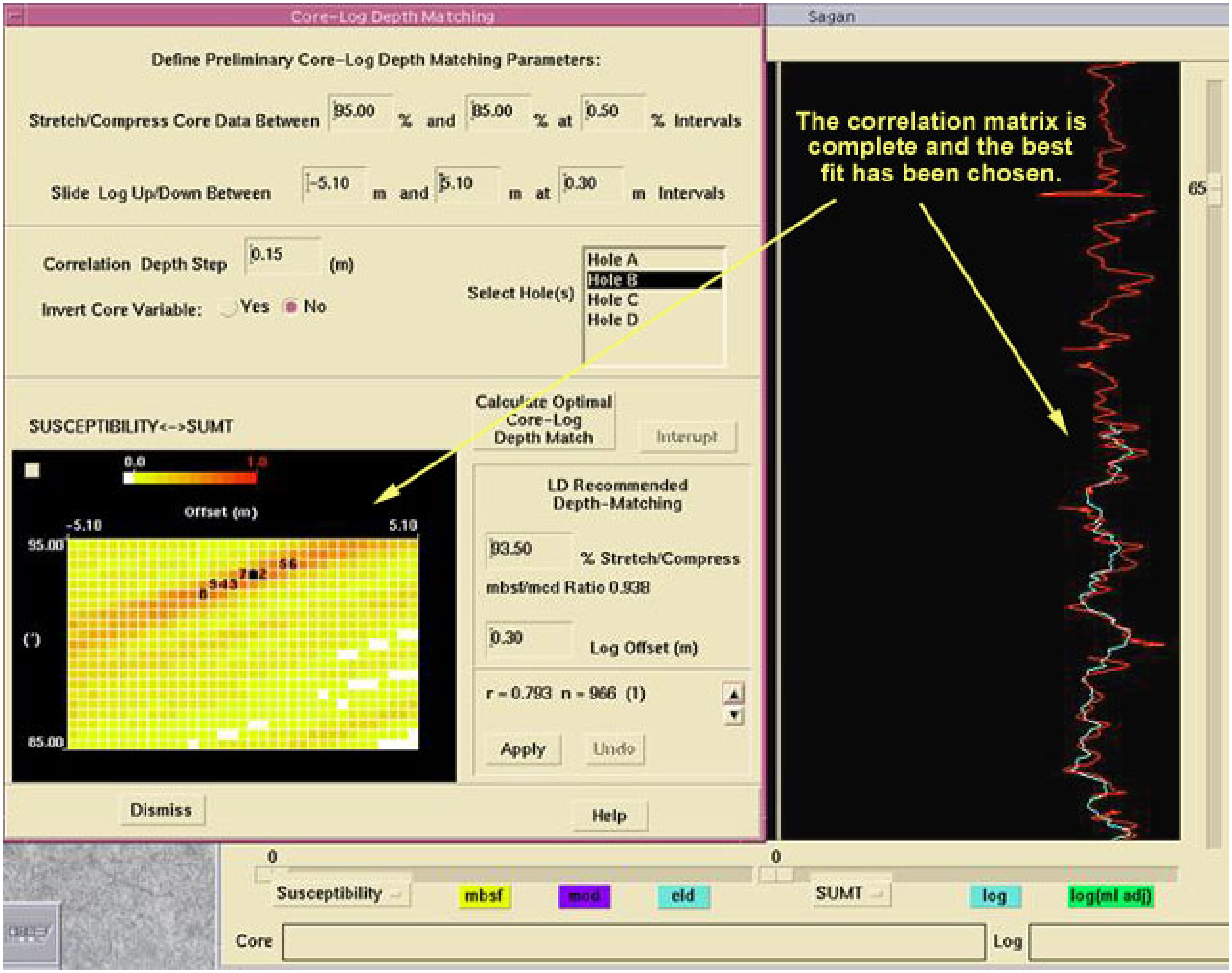
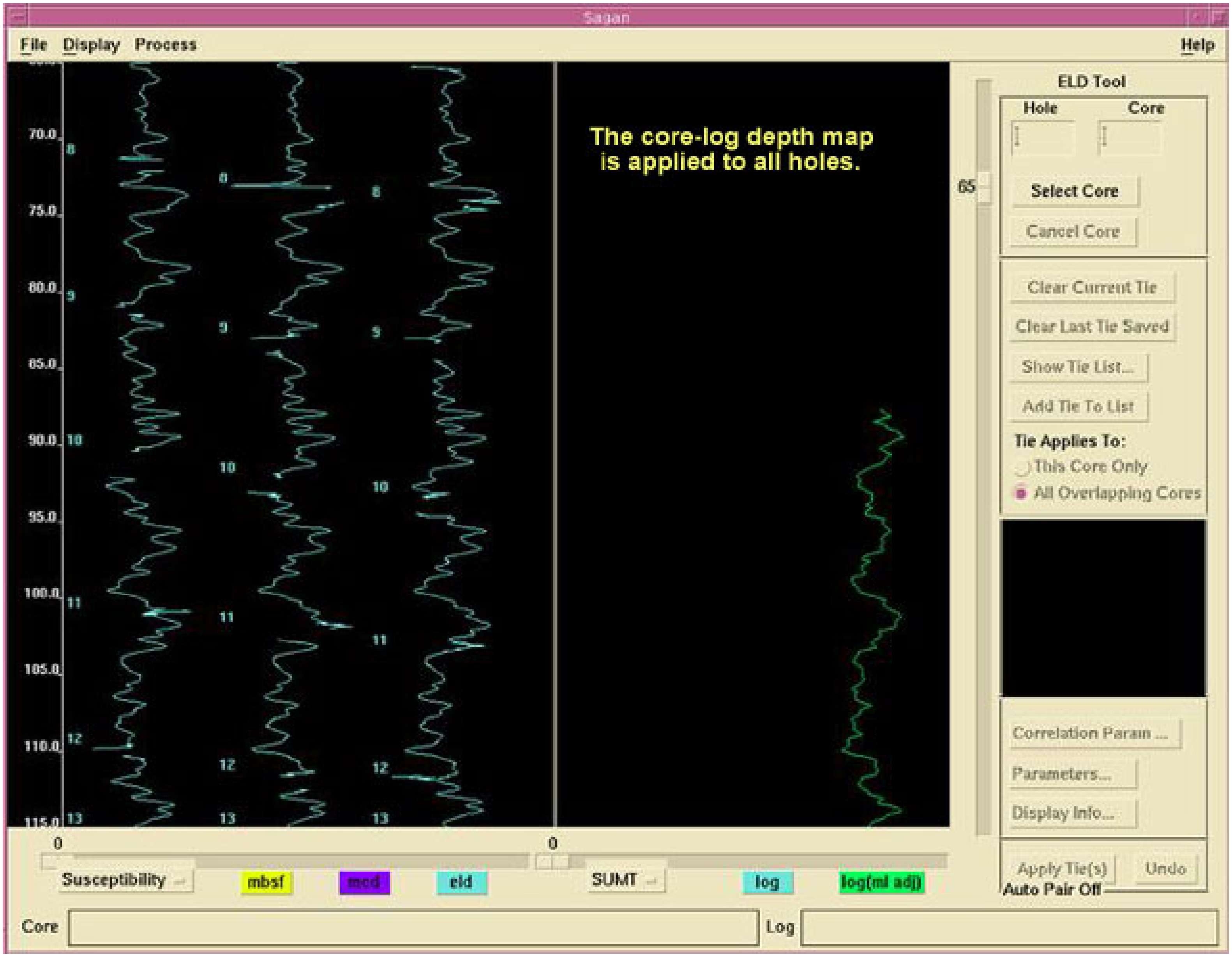


The user chooses the preferred correlation.



Once this is applied to the core data, they can now be shown versus estimated log depth (eld).

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Figure 1: Regional correlation of major lithostratigraphic units, using total gamma ray data from Leg 189.

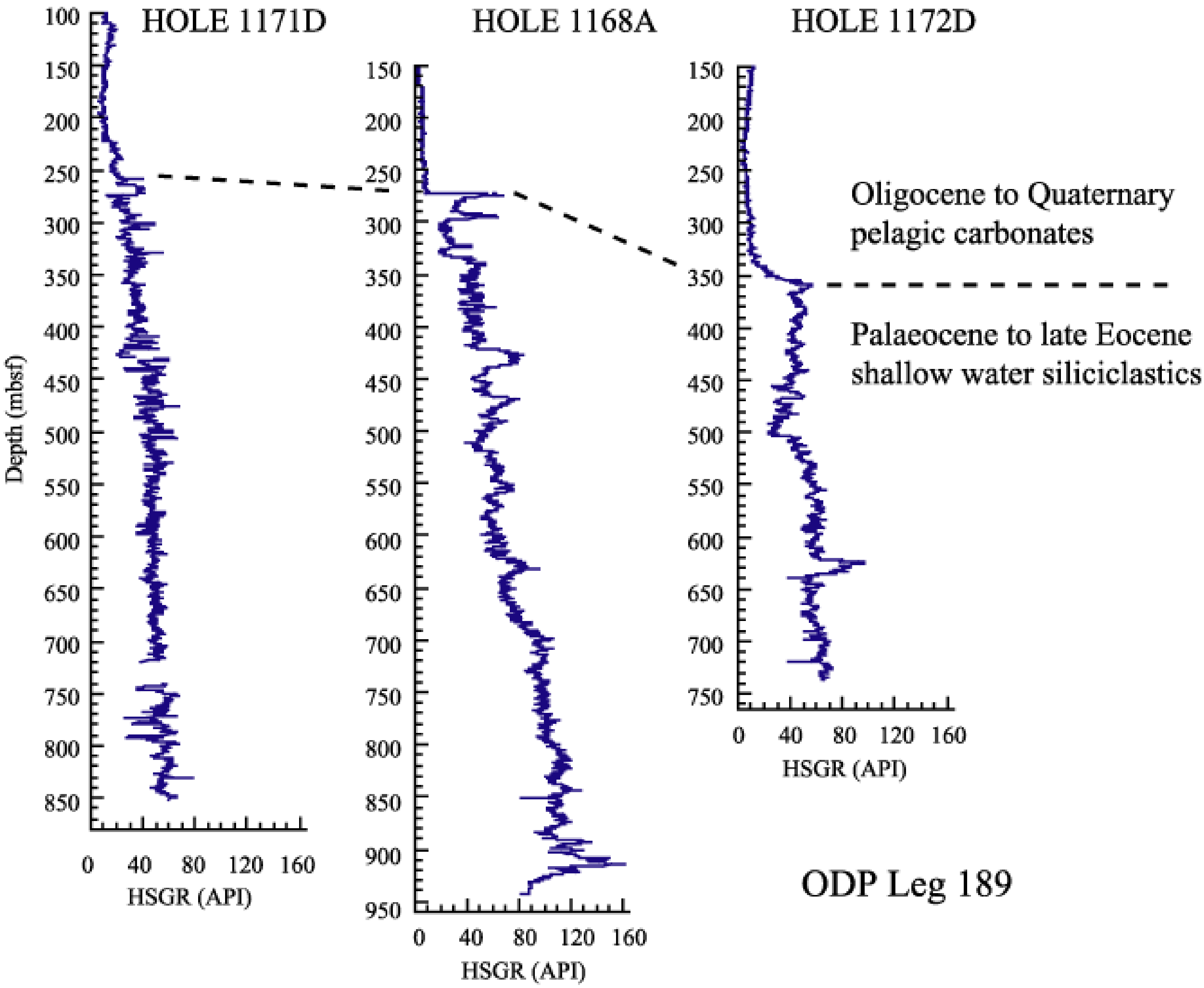

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Figure 2: Spectral gamma-ray data from Hole 1124C, showing high Th values in a mudstone unit between 420-430 mbsf.

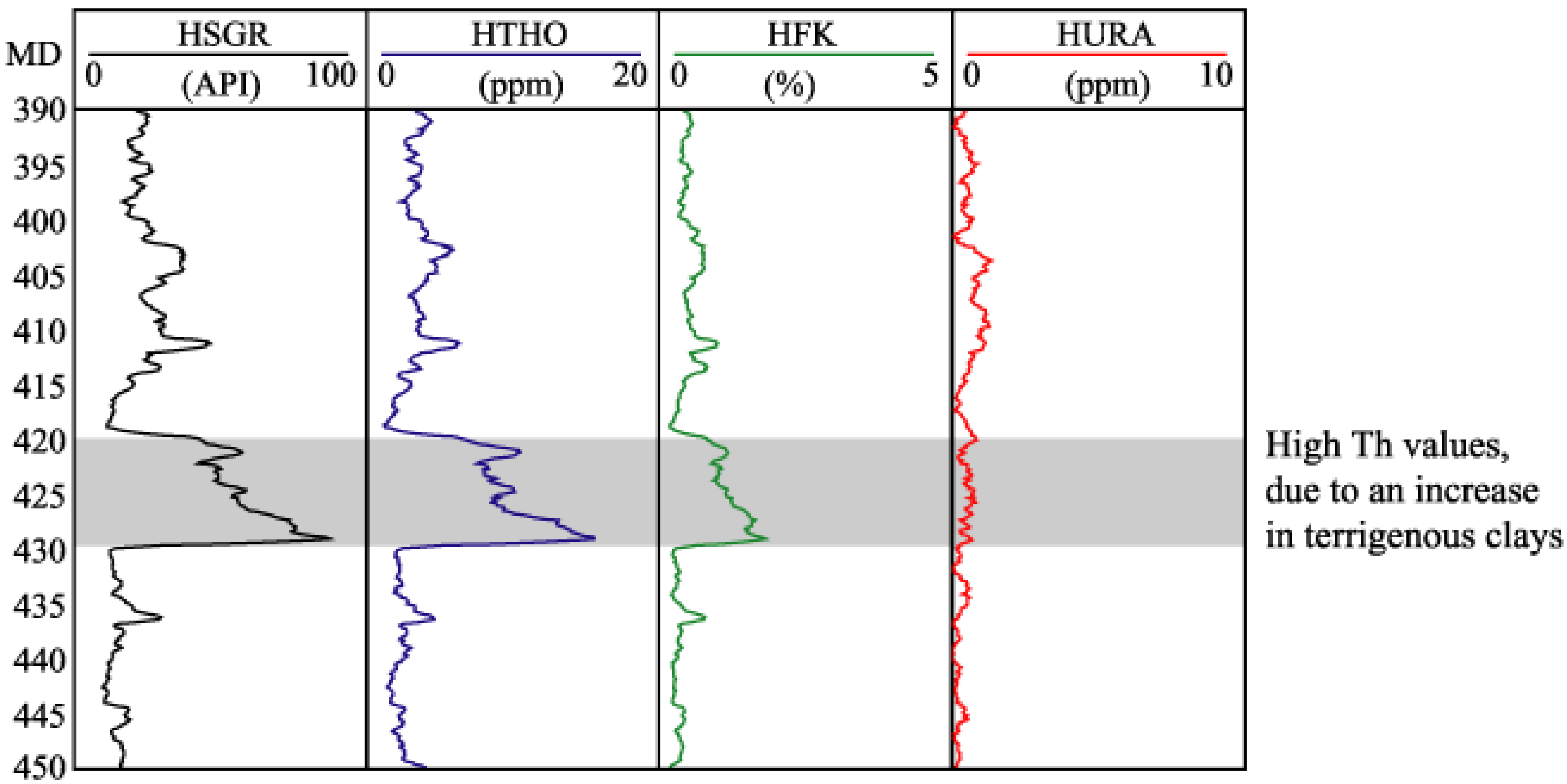

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Figure 3: Spectral gamma-ray data from Hole 1172D, showing high U values in an organic-bearing claystone unit between ~622-640 mbsf.

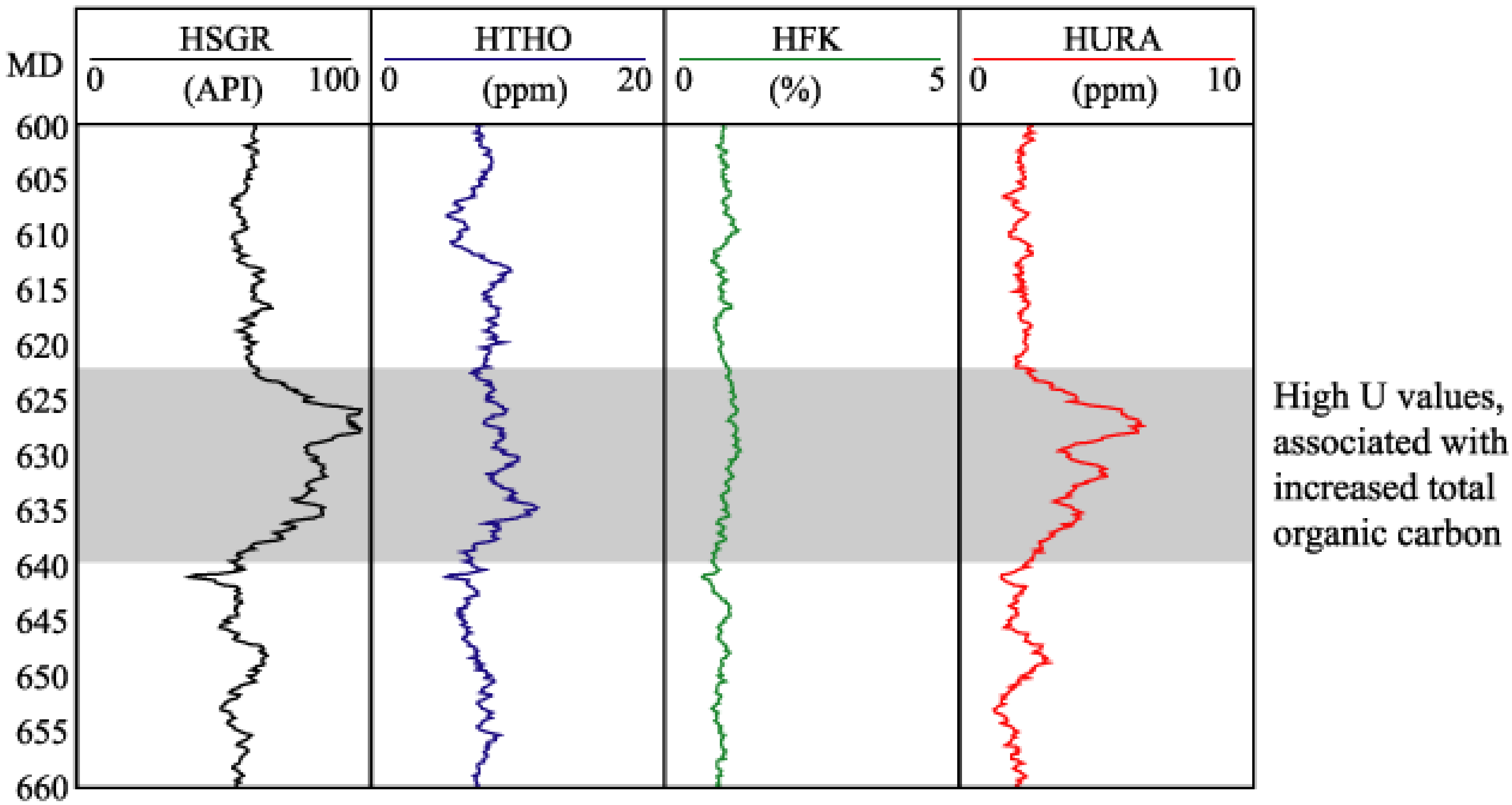

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Figure 4: Spectral gamma-ray data from Hole 1171D, showing high K values due to the presence of glauconite.

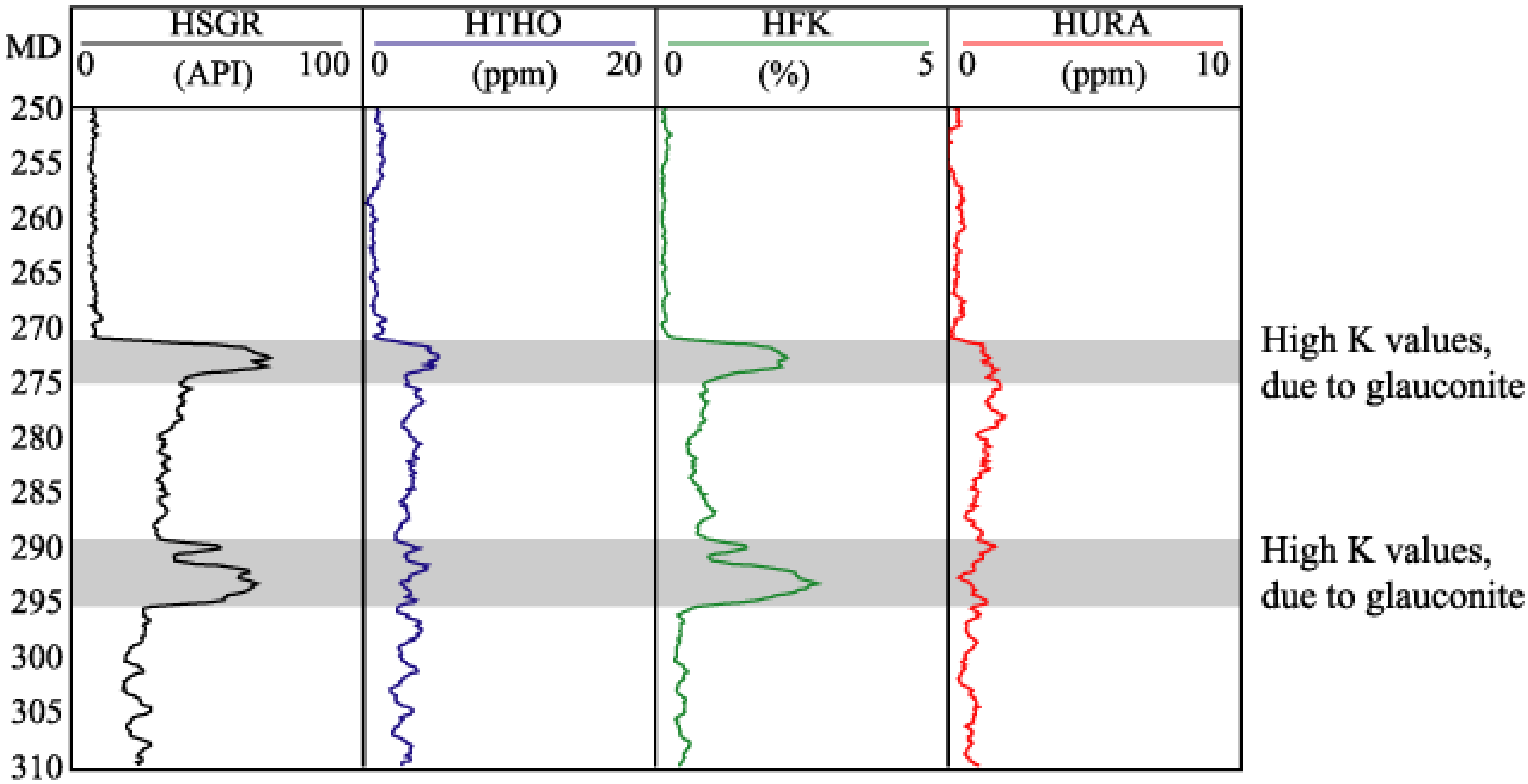

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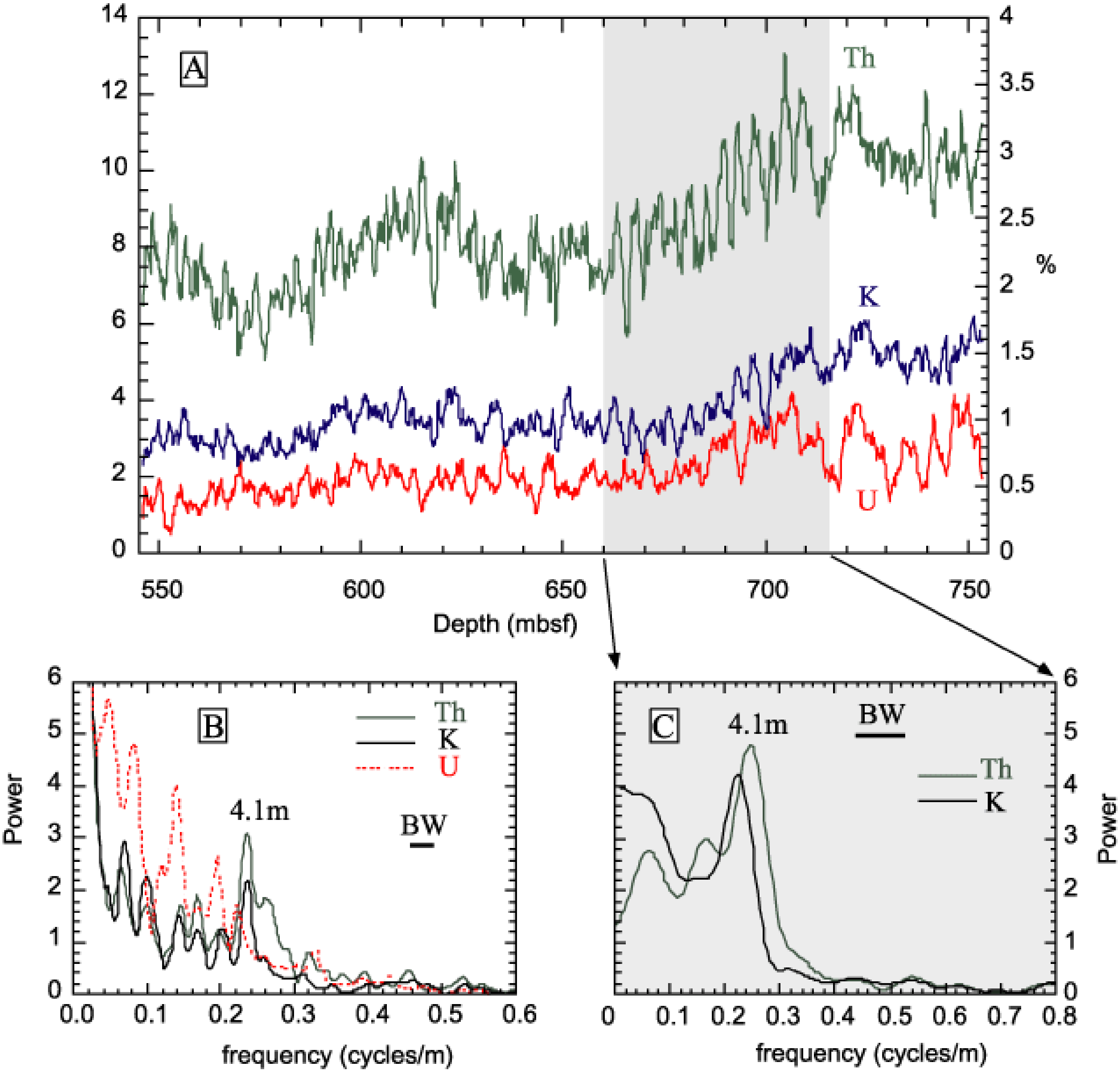
Figure 5: Spectral gamma-ray data (A) and preliminary spectral analysis (B and C) from 1170D. The power spectrum show the results of spectral analysis over the entire logged section (B) and the interval where the Th and K data show the most pronounced cyclicity (C).



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THE ROLE OF DOWNHOLE MEASUREMENTS IN MARINE GEOLOGY AND GEOPHYSICS

David Goldberg
Borehole Research Group, Lamont-Doherty Earth Observatory, Palisades, New York

Abstract. During the last 25 years, downhole measurements have been increasingly used for scientific applications in marine geology and geophysics, particularly in deep-sea drilling operations. Used mostly by the oil industry to map promising formations for exploration and production of hydrocarbons, a variety of instruments have been developed that can be lowered down drill holes to extract information about the subsurface geology. In the last decade, advances in computers, software, and data transmission have greatly increased the amount and quality of data that such instruments can provide. Relatively new instruments that image the borehole wall with high resolution can reveal layers and faults that previously could be seen only in core sections. Downhole measurements play a crucial role in linking core data with regional geophysical surveys and in providing data where core sections could not be obtained. Examples of recent scientific applications and approaches are presented that address previous problems with data quality and changes in properties over time after a hole is drilled. The role of downhole measurements is discussed for two broad areas of research: the structure and composition of the Earth's crust, most of which is formed at mid-ocean ridges, and past changes in Earth's environment recorded in the deep-sea sediments overlying the crust. Finally, new emerging technologies and experiments that promise significant advantages over current methods for downhole measurements in marine geology and geophysics are discussed.

INTRODUCTION

The scientific use of downhole measurements in marine geology and geophysics has become increasingly important in recent years. The methods and tools are derived largely from those developed for oil and gas exploration and are applied to recent scientific problems in the Earth's oceans. The purpose of this review is twofold: first, to present applications of state-of-the-art downhole measurements in recent marine science problems, and second, to review both existing and new methodologies for downhole measurements with new scientific directions. During the last 25 years, the Deep-Sea Drilling Project (DSDP) and its successor since 1984, the Ocean Drilling Program (ODP), have been progressively expanding the role of downhole measurements. These programs have successfully fulfilled their scientific missions by drilling holes in nearly all the different geologic settings of the world's oceans. A total of 170 drilling expeditions, or "legs," around the world's oceans have been successfully completed at the time of this writing. More than 1000 drill holes have been cored, after which many have in turn been logged using downhole instruments. While downhole measurements were conducted in less than 14% of all marine holes drilled during the DSDP, they have been made in more than 56% of the holes drilled by ODP. This dramatic increase in ODP's use of logging is due to several causes, including permanent shipboard systems for routine operations, vast improvements in downhole instrumentation technology and drilling methods, and new measurements made on core samples that allow for one-to-one correlation with similar measurements made downhole.

There have been numerous published discussions of the scientific goals and overviews of DSDP and ODP that include elements of specific downhole measurement capabilities, their successes, and their failures. For general and historical background of the DSDP and ODP, the interested reader is referred to *Revelle* [1981] and the proceedings of the International Conference on Scientific Ocean Drilling (COSOD) in 1987 [*Joint Oceanographic Institutions for Deep Earth Sampling and Joint Oceanographic Institutions, Inc.*, 1987]. For more detailed information on specific drilling locations, the Initial Reports and Scientific Results of the ODP and DSDP offer summaries, and various monographs of the American Geophysical Union present synthesis articles for sites around the globe. For a more detailed discussion of particular downhole measurements, a number of smaller proceedings outline various specific applications [e.g., *Worthington et al.*, 1987; *Hyndman*, 1991; *Cullen*, 1994]. Reviews of current downhole technologies are also periodically published in industry journals [e.g., *Snyder and Fleming*, 1985; *Prensky*, 1994].

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Continental scientific drilling programs have also successfully used downhole measurements to achieve their objectives. Downhole experiments support and enhance core-related studies of the subsurface in almost every environment and in nearly every scientific discipline. During the last decade, several continental scientific drilling programs conducted by Germany, Japan, Sweden, the United States, Russia, and Ukraine have relied on the extensive use of downhole measurements [*Zoback et al.*, 1994]. Often the results of these efforts complement the goals of the ODP in advancing new scientific applications of downhole measurements, and together, these programs are moving researchers toward a global scientific investigation using downhole instruments to measure in situ properties of the Earth.

The scope of this review focuses on past, present, and future scientific applications that have used or will use "short-term" experiments, that is, measurements that themselves do not require instruments to be deployed for more than several hours or days in the subseafloor. Such measurements can be repeated over longer periods for time series studies. This class of downhole measurements is commonly referred to as "logging" and is distinct from the class of instruments deployed below the seafloor for long-term studies. The latter class may be referred to as in situ "observatories" and is discussed in less detail (the reader is referred to recent workshop reports by *Hyndman* [1991] and *Carson et al.* [1994] for an overview of and further references to a variety of downhole observatory applications in marine research). The reason for this distinction is methodological, not scientific, as both types of deployments are complementary. The short-term logging measurements that are primarily addressed include (1) measurements made in a borehole by instruments lowered on a wireline, (2) measurements made while drilling, and (3) measurements repeated over time. A short background is given first to define the current types and range of measurements that can be made by logging. Then a discussion of strategies for downhole measurements is presented, followed by a discussion of various scientific achievements of downhole measurements over the past several years. Within this last section, two broad disciplinary areas are discussed: the Earth's crust and Earth's environment. The applications of many different downhole measurements fall into these two categories, both of which contain several subdisciplines that illustrate the broad range of questions which can be addressed using downhole methods.

The scientific objectives for the future of marine scientific drilling have recently been outlined in the ODP Long Range Plan [*Joint Oceanographic Institutions, Inc.* (*JOI*), 1996]. This plan describes the directions for marine scientific drilling from now through 2008 and the new technologies that will be required to accomplish them. The plan relies heavily on downhole experiments "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." Given these views of the future, the summary provided here of recent scientific applications and new methods for downhole measurements leads to the conclusion that downhole data are irreplaceable assets in marine geology and geophysics; planning and use of downhole experiments in the future should expand, both while drilling and in existing holes. The scientific legacy of new downhole data will undoubtedly continue to advance marine science in several disciplines.

BACKGROUND

During the previous decade, downhole measurements have become viewed as essential and complementary to measurements made on recovered core. They are critical for measurements, such as temperature, that must be made in situ. The scientific objectives at most study sites are addressed with a multidisciplinary strategy, integrating measurements made on core samples with those made downhole and placing both in the context of regional geophysical and seismic studies. *Worthington et al.* [1991] summarize this multiscale approach to drilling investigations and suggest that data integration will be the hallmark of the geosciences in the 1990s. Figure 1 shows their illustration of the range of experimental scales of investigation used today. The multiple scales of investigation used with seismic, downhole, and core data acquired in the same geological environment complement each other extremely well. Seismic sections are the basis for a regional description, downhole measurements are of an intermediate scale and give continuous information in the region surrounding the borehole, and core samples provide detailed information on physical properties and age. Downhole, core, and seismic data used jointly also contribute to the confidence in each individual data set. Unlike measurements on core samples, which are often disturbed during the process of recovery, downhole data provide a set of continuous logs of information and sample a larger volume of rock than core measurements. Because logs have much greater vertical resolution than surface data but little lateral resolution, the combination of the two defines subsurface geological structures far better than either data type can alone. The difference in the scale of physical phenomena affecting each type of measurement may be extreme. The scale ratio from core to log may be greater than 2×10^3; the ratio from log to seismic section may be 10^6 to 10^7 times larger. In most integrated scientific applications, there-

Long Range Plan [*Joint Oceanographic Institutions, Inc.* (*JOI*), 1996]. This plan describes the directions for marine scientific drilling from now through 2008 and the new technologies that will be required to accomplish them. The plan relies heavily on downhole experiments to achieve its scientific objectives. It also maintains the historical premise that [*Worthington et al*., 1987, p. 135]

difference in the scale of physical phenomena affecting each type of measurement may be extreme. The scale ratio from core to log may be greater than 2×10^3; the ratio from log to seismic section may be 10^6 to 10^7 times larger. In most integrated scientific applications, therefore, downhole measurements provide three complementary advantages: (1) data are acquired under in situ

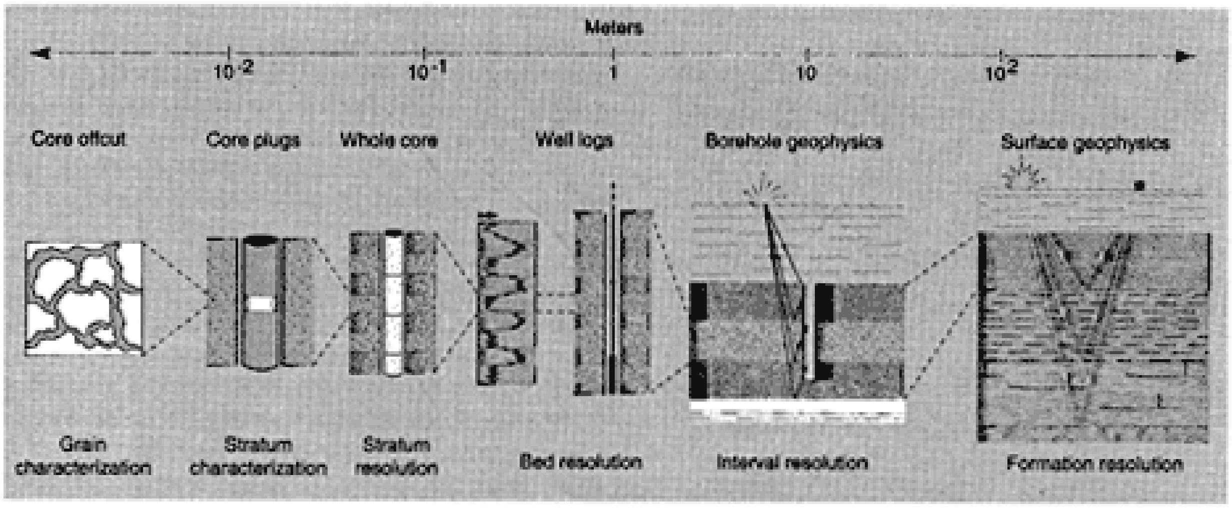

Figure 1. Schematic diagram illustrating the different scales of measurement in geophysics [after *Worthington et al.*, 1991]. The span of measurements from core samples to seismic surveying is greater than 10^4, complicating the interpretation of data from samples to regional geology without intermediate-scale logging and borehole measurements.

conditions, (2) data are acquired in continuous profiles measured throughout the interval with no missing sections, and (3) data are sampled at a larger scale, intermediate between core and seismic measurements.

In most drilling environments, continuous coring does not result in continuous core recovery. In fact, core recovery by techniques other than piston coring is less than 50% on average, and this proportion is often disturbed by the drilling process [*Hyndman*, 1991]. As a result, the true core depth becomes ambiguous. Drilling disturbances within a recovered section can be corrected, however, by correlation with continuous logs, so that preferential recovery of particular rock types can be documented. In Figure 2 a nonrepresentative section of interlayered basalt and sediment near the Juan de Fuca ridge in the northeastern Pacific would have been interpreted from the recovered core alone, but the continuous log profiles reveal layers of sediment between basalt that were not recovered through coring. Despite such successes, complete recovery of continuous log profiles is still not possible. With current wireline technology, the interval immediately below the seafloor is not logged because the drill pipe must be lowered 80–100 m to ensure hole stability in the softest sediments for logging to begin. To benefit from core-log correlation, the stratigraphic interpretation from logs is limited to below this depth and only where high-quality data are recorded.

Downhole Measurements: Logging

In 1927, C. and M. Schlumberger made the first well log near Paris. It was a simple electrical current experiment that used an electrode placed at a series of horizontal points on the ground to make measurements and detect variations in geological structure below the sur-

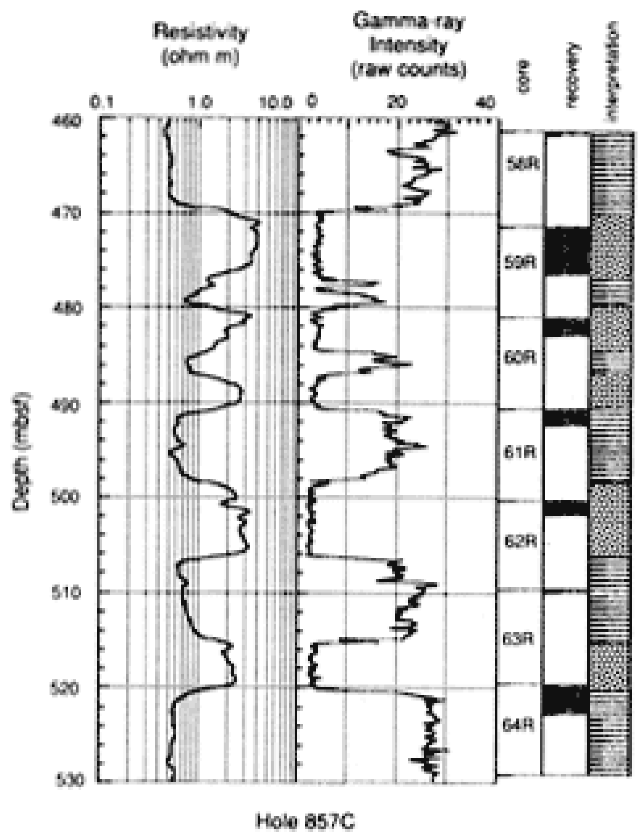

Figure 2. Logs of electrical resistivity and natural gamma radiation in a layered basalt-sediment sequence in ODP Hole 857C near the Juan de Fuca ridge in the north eastern Pacific [from *ODP Leg 139 Scientific Drilling Party*, 1992]. Core recovery (black zones) is partial and is arbitrarily set at the top of each core section, biasing any subsequent geologic interpretation. The complete interpretation (dotted zones are basalt) is based on the logs. Depth is in meters below sea floor (left).

Downhole Measurements: Logging

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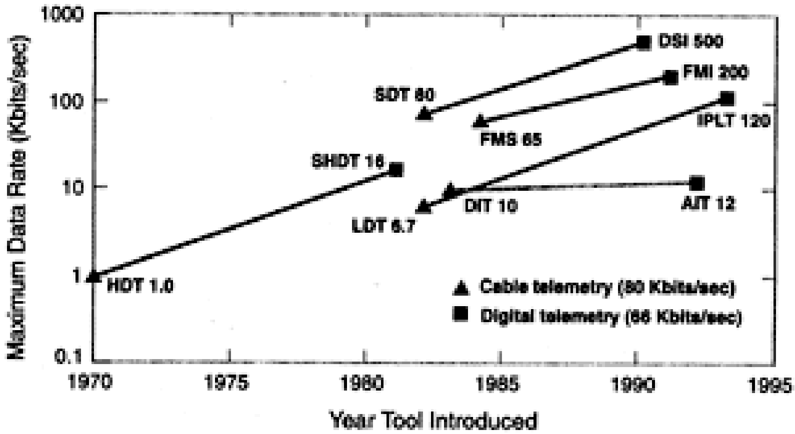

Figure 3. Telemetry rates for common wireline tools showing the steady increase in data rates over the past 25 years (after *Prensky* [1994]; data from Schlumberger). See Table 1 for list of abbreviations.

face. During the 1930s, they evolved this method into a simple tool consisting of an electrode and a current source that made continuous measurements of the subsurface resistivity with each lowering into a borehole. Depth was determined by measuring the length of the cable run into the hole, as it is today. The interpretation of these continuous logs for oil exploration helped to determine bed thicknesses, identify clay-rich and hydrocarbon-bearing zones, and provided a rough estimate of formation permeability, all qualities that could be correlated between holes. In the 1940s, *Archie* [1942] linked laboratory measurements of resistivity to the amount of water and hydrocarbon in pore space, which greatly improved log interpretation. In various modifications his empirical relationship is still used to calculate porosity and fluid saturation from resistivity logs. In the mid-1940s through the 1970s, rapid technological advances made it possible to estimate porosity using nuclear activation, gamma radiation, and acoustic techniques. The resolution of the logging measurements also improved with the development of sensors that extended close to the borehole wall. In the 1980s, continued advances in digital data acquisition and signal processing have made it possible to evaluate logging data as they are collected, so that decisions can be made on site to enhance data quality and interpretation. With these improvements, logging has become the standard for evaluating subsurface geology in the oil industry; it is now often the sole source of data used for geological interpretation because of the difficulty and expense of routine coring.

Over the past 10 years, researchers in academia and industry have steadily improved the accuracy and sophistication of geophysical and geochemical logging measurements. Most downhole experiments use technology developed by industry; a small, yet significant, number use technologies developed for scientific research. The recent history of advances in all of these technologies parallels advances in data transmission and computer capabilities, which have led to a remarkable increase in the quantity and speed of downhole data acquisition and of a number of commercial instruments over the past 10 years. Advances in acquiring scientific data for marine geology and geophysics have followed closely from these new technological developments.

Prensky [1994] provides an excellent summary of current downhole technologies; *Doveton* [1986], *Serra* [1987], *Ellis* [1987], and the *Borehole Research Group* [1990], among others, have summarized the principles of downhole measurements and the interpretation of logging data in scientific applications. The interested reader is referred to these publications for a more detailed discussion. The following summary of downhole logging measurements is included only to present a general overview of the methods used and the range of data and their measurement resolutions.

Typically, logs made downhole fall into three general categories: electrical, nuclear, and acoustic. In addition, borehole imaging, temperature, and various other in situ properties can be measured downhole using wireline logging tools. Although the accuracy, resolution, and applications differ for each type of measurement, together they provide a comprehensive data set that can be used as a proxy for the subsurface geology. Each type of measurement is discussed briefly below; a summary of the vertical resolutions of several common devices which range from a few millimeters to over a meter is presented in Figure 4 (see Table 1 for abbreviations). Most typical logging devices have a vertical resolution of at least 0.5 m, so that beds thinner than this are difficult to study [*Allen et al.*, 1988; *Tittman*, 1991].

To maximize the vertical resolution of logging data, it is important to minimize effects that may introduce additional uncertainties in the correlation between the recorded data and depth, such as motion due to ship heave. In 1988 a hydraulic heave compensator that moves the wireline opposite to heave motion while logging was first developed and used on the ODP drill ship. *Goldberg* [1990] measured the effectiveness of this wireline heave compensator by comparing measurements of the acceleration of a downhole tool with the displace-developed by industry; a small, yet significant, number use technologies developed for scientific research. The recent history of advances in all of these technologies parallels advances in data transmission and computer capabilities, which have led to a remarkable increase in the quantity and speed of downhole data acquisition and processing [*Prensky*, 1994]. Figure 3 shows how increases in data transmission have accompanied the introduction

heave. In 1988 a hydraulic heave compensator that moves the wireline opposite to heave motion while logging was first developed and used on the ODP drill ship. *Goldberg* [1990] measured the effectiveness of this wireline heave compensator by comparing measurements of the acceleration of a downhole tool with the displacement of the motion compensator on the ship. The measurements indicate that heave amplitudes reach about

2.5 m with vertical accelerations of up to 8% of G in seas with 3–4 m waves. As the ship's dominant period was about 8.5 s, the maximum downhole displacement and velocity due to heave were reduced to 1.5 m and 1.0 m/s, respectively, using the wireline compensator. Since typical logging speeds are 0.2 m/s or less, in high seas it is possible that a tool could move downward even when it is being pulled uphole on the wireline. Much of this motion is probably stopped by friction between the tool and the borehole wall; however, recent corrections in the control of the heave compensator further reduce the effects of heave by a factor of 2–3, eliminating the possibility that wireline motion could be reversed for most logging operations. As a result, downhole logs obtained at different times are consistent under most sea conditions, and the residual heave effects on vertical resolution are negligible for most downhole tools.

Electrical resistivity logging tools. Devices that gather data on a formation's electrical properties measure currents that propagate through the borehole and pore fluids in the surrounding rock and sediment layers. Water is a ubiquitous and conductive fluid underground; its electrical conductivity increases with the concentration of Na^+ and Cl^- ions and with temperature, which increases the mobility of the ions. Electrical resistivity measurements in a formation therefore allow one to estimate its porosity, fluid content, and often the degree of fracturing. Clays also contribute to the measured electrical conductivity because of the negative ions commonly associated with the molecular structure of various Al-bearing minerals found in many clays [*Ellis*, 1986]. Self-potential devices measure the electrical potential generated by ions flowing between the borehole and pore fluids. This measurement is related to clay content in a formation; it is high where resistivities are low. In most ocean drill holes, however, seawater fills both borehole and pore space, and the self-potential measurement is poor. Induction devices are used to measure lower (<100 ohm-m) resistivities; current-generating devices (laterologs) are used to measure higher resistivities (>100 ohm-m) that may occur in the calcareous and igneous rocks encountered in ocean drilling. Most measurements of electrical resistivity are made by induction tools, with vertical resolutions ranging between 0.5 m and 2.0 m. The varying spacing between electrodes on these tools measures resistivity at different depths in the borehole wall. If drilling fluids have invaded significantly into the formation, these measurements are not equal, and their difference allows one to make an estimate of formation permeability.

Acoustic logging tools. Acoustic tools record compressional, shear, and surface waves in the borehole environment, much like a seismic refraction experiment that operates in the kilohertz frequency range [e.g., *Paillet et al.*, 1992]. Energy generated by one or more sources in an acoustic instrument is transmitted into the borehole fluid and then propagates as refracted and surface waves at the borehole wall. Energy is received at one or more sensors on the logging tool at a transit time proportional to their distance from the source. Wave velocities can be determined by comparing arrival times of different waves. Using asymmetric acoustic sources in the borehole, acoustic tools can now be used to estimate shear wave velocities in most marine environments [e.g., *Zemanek et al.*, 1991]. Compressional and shear wave velocity measurements can be used together to compute the elastic properties of a formation, such as the Poisson's ratio, which depend on lithology and porosity. Wave amplitudes can be measured directly at each sensor or between sensors and primarily reflect the coupling

TABLE 1. Abbreviations for Downhole Tools and Logs

Abbreviation	*Definition*
AIT*	Array Induction Imager Tool
BHTV	Borehole Televiewer
CNL*	Compensated Neutron Log
DIL*	Dual Induction Log
DSI*	Dipole Shear Sonic Imager
FMS*	Formation MicroScanner*
FMI*	Fullbore Formation MicroImager
GST*	Gamma Ray Spectroscopy Tool
HDT*	High Resolution Dipmeter Tool
ILD	Induction Log, Deep
ILM	Induction Log, Medium
IPLT*	Integrated Porosity Lithology Tool
LDT*	Litho-density* Tool
LSS*	Long Spacing Sonic Tool
MDT*	Modular Formation Dynamics Tester
NGT*	Natural Gamma Ray Tool
NMR	Nuclear Magnetic Resonance Tool
RAB*	Resistivity-At-Bit Tool
SDT*	Sonic Digital (Array-Sonic*) Tool
SFL*	Spherically Focussed Resistivity Tool
SHDT*	Stratigraphic Dual-Dipmeter* Tool

*Trademark of Schlumberger.

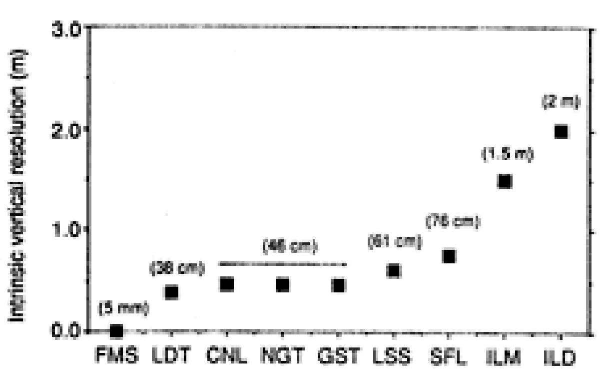

Figure 4. Intrinsic vertical resolution of various wireline tools representing the minimum depth interval for which a mean-

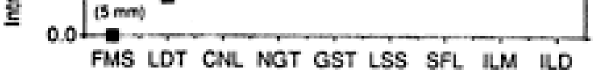

Figure 4. Intrinsic vertical resolution of various wireline tools representing the minimum depth interval for which a meaningful log measurement can be obtained (after *deMenocal et al.* [1992]; data from *Allen et al.* [1988]). See Table 1 for list of abbreviations.

velocity measurements can be used together to compute the elastic properties of a formation, such as the Poisson's ratio, which depend on lithology and porosity. Wave amplitudes can be measured directly at each sensor or between sensors and primarily reflect the coupling of energy between the formation and the borehole. In fractured and heterogeneous formations the coupling of energy decreases, and wave amplitudes can be used to indicate fracturing and heterogeneity at the scale of centimeters to meters in the formation. Most acoustic logging tools measure compressional waves which penetrate 0.1–0.5 m into the borehole wall, with vertical resolutions of 0.5–1.5 m. Other instruments that clamp geophones downhole and record energy from seismic sources on the surface penetrate through hundreds of meters of the formation. Such vertical seismic profiles (VSPs) typically provide acoustic velocity and amplitude profiles with vertical resolution of 5.0–50 m.

Nuclear logging tools. This class of instruments measures naturally occurring radioisotopes and mineral constituents of the formation, as well as the fluid content in pore space. They are sophisticated devices that rely on statistical counting of subatomic particles and advanced computer analysis for interpretation. Three types of nuclear measurements are typically used in marine scientific applications: natural gamma ray activity, gamma ray scattering, and neutron scattering.

Gamma ray activity tools are perhaps the most common nuclear measurement instruments and detect the radioactive decay of natural isotopes of potassium, uranium, and thorium using a scintillation counter and a crystal detector. The response of the detector is a simple function of the concentration by weight of the radioisotopes and the formation density. The average depth of penetration of the measurement into the borehole wall is about 0.5 m, and vertical resolution is approximately 0.3 m [*Allen et al.*, 1988]. The natural gamma ray log usually responds to clay content in a formation, where naturally radioactive elements concentrate, or to alteration minerals that have these minerals present within oxides and other compounds. The concentration of the natural radioisotopes is therefore largely controlled by depositional environments and diagenesis.

Density tools use a gamma ray source, usually ^{137}Cs, to bombard the formation with gamma rays that are scattered through the rock and gradually lose energy. Sensors pressed against the borehole wall measure the energy flux of gamma rays returned to a scintillation counter and crystal detector which captures photons emitted by Compton scattering. The radiation returned is directly related to the electron density in the formation, which in turn is related to the bulk density of the rock [*Doveton*, 1986; *Ellis*, 1987]. The electron density is low for most pore-filling fluids and can therefore be used as an indicator of rock composition. The depth of investigation into the borehole wall of density tools depends on the density of the formation; greater density reduces the penetration of emitted gamma rays into the borehole wall. In porous and permeable formations, densities are typically measured to approximately 0.5 m into the borehole wall, and the vertical resolution of the measurement is approximately 0.4 m.

Neutron tools employ either a Am-Be radioisotope or an electrical generator source to bombard the formation

is transferred to slow the neutrons down enough to drop below 0.1 eV energy, constituting the epithermal-thermal neutron transition. Neutron responses are therefore strongly affected by the porosity and pore fluids in the formation and by minerals such as clay that have considerable water bound in their molecular structure [*Broglia and Ellis*, 1990]. Some neutron tools utilize a pulsed-neutron accelerator to bombard the nuclei of minerals in the formation. The spectrum of gamma ray energies emitted by these interactions is recorded using a crystal detector and provides a measure of the abundance of the major mineral-forming elements, such as Fe, Si, Ca, and Al [*Herron et al.*, 1993]. The elemental abundances may be used to estimate mineral concentration when core materials can be combined to provide sufficient calibration [*Kerr et al.*, 1992; *Myers*, 1992]. Nuclear magnetic resonance (NMR) tools measure the H present in the formation and pore fluid by inducing proton movement around a pulsed magnetic field [*Brown and Gamson*, 1960; *Jackson*, 1984]. The time decay of the resonance signal is also directly related to the pore size distribution and can be used to indicate formation permeability. Neutron measurements penetrate 0.5–1.0 m into the formation, and the vertical resolution of the measurement is approximately 0.4 m.

Borehole imaging tools. Imaging tools deliver high-resolution pictures of the wall of a borehole using precision measurements of either electrical conductivity, optical variation, or acoustic reflectivity. These three imaging techniques are complementary, since conductivity (electrical), color (optical), and reflectivity (acoustic) are controlled by different physical and chemical characteristics of the rock. The images are always oriented to a magnetic reference measured downhole. Electrical imaging provides approximately 5-mm resolution of the borehole wall by sensing contrasts between high- and low-conductivity features, such as water-filled fractures or fine-scale bedding variations [*Serra*, 1989]. Devices such as the Formation MicroScanner™ (FMS) and Full-bore Formation MicroImager™ (FMI) measure the borehole's surface conductivity on four pads pressed against the borehole wall with vertical resolution 10^2 times finer than most other downhole measurements (see Figure 4). Optical imaging also offers high vertical resolution but is limited to holes containing transparent borehole fluids. Ultrasonic imaging devices generate a complete 360° image of the reflectivity of the borehole wall, an advantage over the four-pad electrical method, with a vertical resolution of 2–3 cm. The dip, strike, width, and depth of geological features intersecting a borehole may be measured using any of these imaging devices [e.g., *Paillet et al.*, 1990; *Luthi and Souhaite*, 1990]. Images can be visually used to compare logs with cores for bedding orientation and to study fracturing, structure, and borehole shape.

Temperature tools. Temperature logging typically

typically measured to approximately 0.5 m into the borehole wall, and the vertical resolution of the measurement is approximately 0.4 m.

Neutron tools employ either a Am-Be radioisotope or an electrical generator source to bombard the formation with neutrons. After the neutrons collide with molecules of like mass in the formation, such as H, sufficient energy

devices [e.g., *Paillet et al.*, 1990; *Luthi and Souhaite*, 1990]. Images can be visually used to compare logs with cores for bedding orientation and to study fracturing, structure, and borehole shape.

Temperature tools. Temperature logging typically involves measuring a continuous profile of borehole fluid temperature as a proxy for the in situ formation