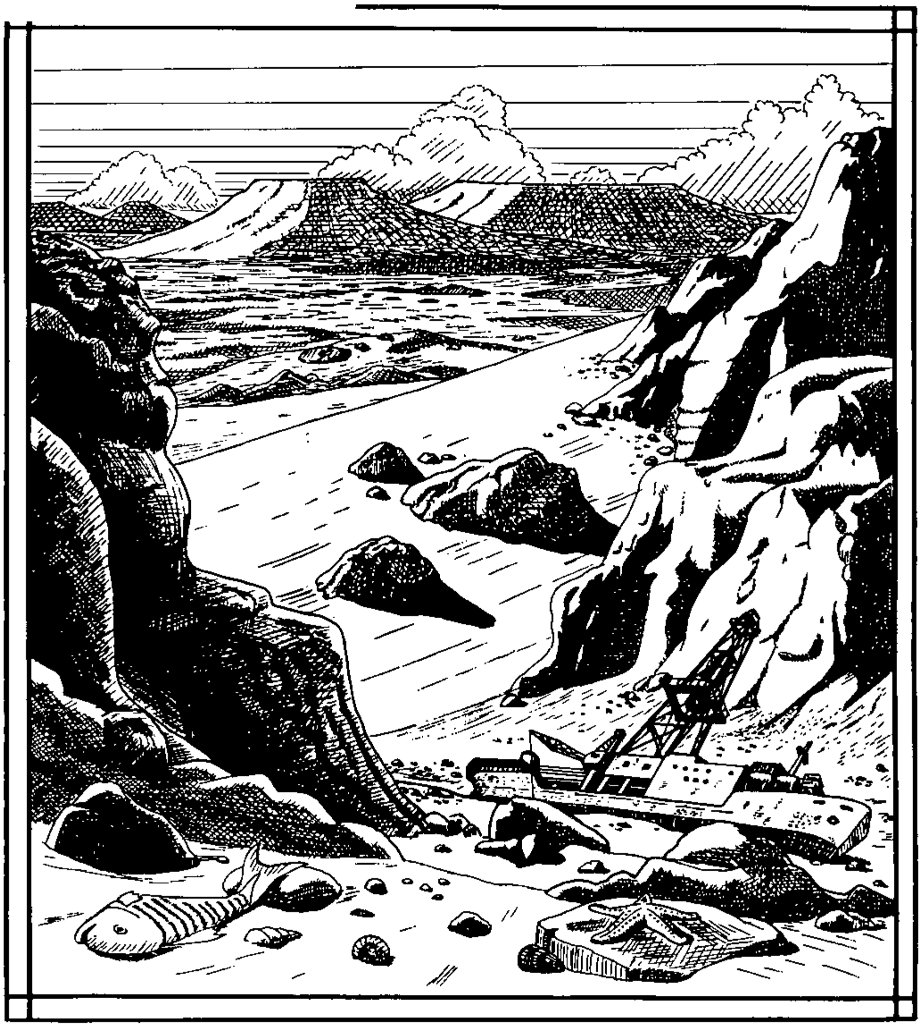
Joint Oceanographic Institutions for Deep Earth Sampling

JOIDES Journal

Volume 18, Number 3, October 1992

ng Program - Leg 143

SEDCO/BP 471



JOIDES Resolution

HAVING DRILLED THE DEEPEST-PENETRATION SINGLE-LEG HOLE, OUR INTREPID CREW DISCOVERS THEY ACCIDENTALLY DRAINED THE PACIFIC OCEAN. NEVERTHELESS, THEY ARE AFFORDED AN EXCELLENT VIEW OF THE PREVIOUSLY UNSEEN MID-PACIFIC MOUNTAINS.

Honolulu to Majuro
1992

Front Cover: Leg 143 (Atolls & Guyots I) Logo

The logo designed by Will Sager, Leg 143 Co-Chief Scientist, is based on the frontispiece of the 1956 monograph *Sunken Islands of the Mid-Pacific Mountains* (Geological Society of America Memoir 64, 97p.) by Edwin L. Hamilton. Artist Chesley Bonestell, a well-known scientific illustrator, painted the original depiction of how the Mid-Pacific Mountains might look if the ocean was drained away. This updated version commemorates drilling of Site 866 at Resolution (formerly "Huevo") Guyot in the Mid-Pacific Mountains. A record penetration of 1743.6 m made Hole 866A the deepest hole drilled in a single leg by either DSDP or ODP. See Leg 143 Preliminary Report (page 2) for further information.

[Logo design and supporting information provided by Dr. W.W. Sager, Texas A&M University.]

Joint Oceanographic Institutions for Deep Earth Sampling

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Contents

Focus

This is the University of Texas Institute for Geophysics JOIDES Office last "official" communiqué. The horse has already left the barn, so to speak. Most of the shipping boxes are gone, and even as this is being written, the University of Washington has picked up the ball and JOIDES planning is being run smoothly from that new location. On behalf of the UTIG team—Peter Blum (who has already moved on to be a Staff Scientist at ODP-TAMU), Craig Fulthorpe, Art Maxwell, Kathy Moser and myself, I want to wish Brian Lewis, Karen Schmitt and Bill Collins the very best of luck.

In the last issue of the *JOIDES Journal* (v. 18, no. 2, June 1992), I expressed the belief that ODP was at a crossroads - in engineering development, computing and data handling, and in the use of alternate/additional drilling platforms. Recent events have underscored that perspective. At its August (1992) meeting in Corner Brook, Newfoundland (see summary, this issue), PCOM expressed continued philosophical and financial support for the Diamond Coring System (DCS), but the accent was on the philosophical. In truth, without financial support originally anticipated from the former Soviet Union (*Note:* Russia was put on "inactive" ODP status as of October 1.), the level of current DCS funding may prevent another field test of the system until 1995. In the matter of data handling, PCOM commissioned a canvassing of the community by ODP-TAMU, in concert with a Data Handling Evaluation Committee, in order to ascertain levels of interest in participation before a Request for Proposals (RFP) for the task is generated by the Science Operator. That RFP may be circulated late this year or sometime next year. Although PCOM debated the merits of the issue intensely in Corner Brook, the fact remains that available financial resources to accomplish a thorough renovation of shipboard and shorebased data handling in ODP in a timely manner (2-3 years) simply do not exist, given current budgets. The same is true of funding for additional platforms, which will certainly run into millions of dollars/deployment.

Where does ODP go from here, given this situation? On the bright side, renewal with six international partners (Canada/Australia, European Science Foundation, Great Britain, France, Germany, Japan) seems assured as of this writing, at least through 1998. That gives scientific ocean drilling time to make a significant start on some exciting (but complex) initiatives - North Atlantic Rifted Margins, Offset (Section) Drilling of the oceanic lithosphere, Sea-Level transects. Everyone connected with the (long!) renewal effort is to be congratulated. Names like John Malpas, Margaret Leinen, Nick Pisias and (especially) Paul Worthington come to mind. Never has any scientific initiative had such eloquent spokesprofessionals. On the down side, ODP must convince its funders that some highly important science now in the planning stages simply will not occur unless support for scientific ocean drilling is augmented. Such a request comes at a time when budgets are tight everywhere, but the effort must be made. Furthermore, ODP must begin a search in earnest for new international partners, to augment both the level of effort and the excitement that such increased international participation will bring to the program.

In conclusion, let me say that it has been the rarest of professional pleasures to serve ODP as PCOM Chair over the past two years. I have been a part of what I truly believe is one of the world's greatest scientific endeavors. That is both a humbling and exhilarating experience - one I will never forget. Thank you all for your support.

Jamie

James A. Austin, Jr.
(ex) Planning Committee Chair

Science Operator Report

[Reports presented below are summaries. Complete reports are available from ODP, Texas A&M University, 1000 Discovery Drive, College Station, TX 77845-9547.]

Leg 143: Atolls & Guyots I

Abstract

Leg 143 drilled summits of two guyots in the Mid-Pacific Mountains (Sites 865, 866 and 867/868), the archipelagic apron adjacent to an atoll-guyot pair in the Marshall Islands (Site 869), and within the lagoon of a modern Marshall Islands atoll (Site 870). Scientific objectives were to study development, growth and drowning of Cretaceous Pacific carbonate platforms, examine their record of sea-level change and decipher the tectonic and volcanic history of these edifices. At Site 870, the purpose was mainly a test of the shallow-water drilling capability of *JOIDES Resolution.*

Deep holes drilled into Cretaceous lagoonal limestone caps of Allison (Hole 865A) and Resolution (formerly "Huevo"; Holes 866A and 866B) guyots yielded histories of the guyots from submergence of the volcanic pedestal through final drowning of the carbonate platform. Both guyots have alternated between subsidence and uplift. The carbonate platform on Resolution Guyot first formed during the Barremian, on a small, rapidly-subsiding volcanic pedestal, which accumulated ~1350 m of carbonate sediments by early to middle Aptian time. After a hiatus of perhaps as much as10-15 m.y., during which time the carbonate platform either drowned, with currents sweeping the summit clear of pelagic sediment, or was uplifted and eroded, ~270 m of late Albian sediments accumulated. Allison Guyot formed during late Albian time and also accumulated a late Albian shallow-water limestone cap, 731 m of which were drilled. Despite rapid subsidence, lagoonal facies of both guyots indicate very shallow water throughout most of their carbonate platform histories. Furthermore, limestone sections are often characterized by meter-scale facies shifts that imply short-period cycles of emergence and submergence. Cores from both guyot summits also show evidence of dissolution and mineralization (by manganese and phosphate), indicating emergence and karsting at some time after the late Albian. Pelagic sediments infilling dissolution cavities from Hole 866B imply that this event occurred before mid-Turonian time. Drilling results and guyot morphology indicate that the relative sea-level drop was at least 160 m.

Holes drilled into (867A and 867B) and next to (868A) the perimeter mound surrounding the summit on Resolution Guyot failed to find expected abundant reefal material, suggesting that these mounds, commonly seen on guyot profiles, are not necessarily reefs like those on Cenozoic atolls. These results point out important differences between Cretaceous and Cenozoic atolls—the former were probably more open platforms with low relief.

An entirely different geologic history was recorded at Site 869, on the apron adjacent to atoll-guyot pair Pikinni and Wodejebato. At this site, little shallow-water debris was encountered. Instead, abundant volcaniclastic material was delivered by turbidity currents, grain flows and mass flows from late Cenomanian to Maastrichtian time. Especially large influxes during Cenomanian and Campanian imply the existence of nearby land and shallow-water carbonate shoals. During the Cenozoic, volcanism ceased and pelagic sedimentation prevailed, interrupted by turbidity currents carrying debris from shallow water.

Introduction

Across the western Pacific Ocean are scattered scores of Cretaceous seamounts. Their source is uncertain, but may have been a large-scale intraplate volcanic episode, perhaps related to overturn in the mantle. Many of these seamounts have flat summits and are called "guyots"; still others are surmounted by modern atolls. Though some guyots may have formed by wave planation, many clearly have limestone caps. Because of this and morphologic resemblances to modern atolls, the classic Darwinian model for atoll formation has often been extended to account for them. For reasons unknown, the atoll reefs apparently were unable to grow apace with subsidence of the underlying edifice and drowned.

A corollary of the idea that guyot summits are created by waves or reefs is that they must have been at sea level. They can be thought of as giant "dipsticks" that measure the level of the ocean at the time they drowned. This idea has been used in the western Pacific to connect guyot summits of the same depth and infer a large region of Cretaceous uplift, termed "Darwin Rise". Guyot sediments may also preserve records of sea level during their formation. Because their sediments are usually deposited close to sea level, they record relative sea level rises and falls caused by subsidence or uplift in addition to eustatic fluctuations. Climate shifts also leave imprints on biota, facies, compositions and textures of guyot carbonates, so drilling offers the promise of answering fundamental questions about Cretaceous climate, sea level, biotic assemblages and tectonics.

Leg 143 was the first of two ODP legs whose purpose was to drill western Pacific atolls and guyots. Eight atolls and guyots and one site on an archipelagic apron were to be drilled on Legs 143 and 144, spanning nearly 35° of longitude and 30° of latitude. Provinces to be sampled were the Mid-Pacific Mountains, Marshall Islands, Marcus-Wake Guyots and Japanese guyots. Two-thirds of the time for Leg 143 was concentrated on two guyots in the Mid-Pacific Mountains (Fig. 1): Allison (Site 865), and Resolution (formerly "Huevo"; Sites 866 and 867/868). Remainder of the time was spent in the Marshall Islands, where Site 869 was drilled in the basin adjacent to Wodejebato Guyot (formerly Sylvania) and Pikinni Atoll (formerly Bikini) and Site 870 was drilled in the lagoon of Anewetak Atoll (formerly Eniwetak) to test *JOIDES Resolution's* shallow-water drilling capability.

Drilling Objectives

Drilling of limestone pedestals and pelagic caps of guyots in the Mid-Pacific Mountains had the following goals:

- Develop a history of Cretaceous carbonate platform growth and evolution by determining lithologic, biostratigraphic, isotopic, geochemical and seismic stratigraphic succession within the limestone cap, for use in:
  - a) direct correlation with other drilled guyots (legs 143 and 144);
  - b) correlations via reflection seismology among guyots in the northwest Pacific;
  - c) comparisons of timing and magnitude of relative sea-level

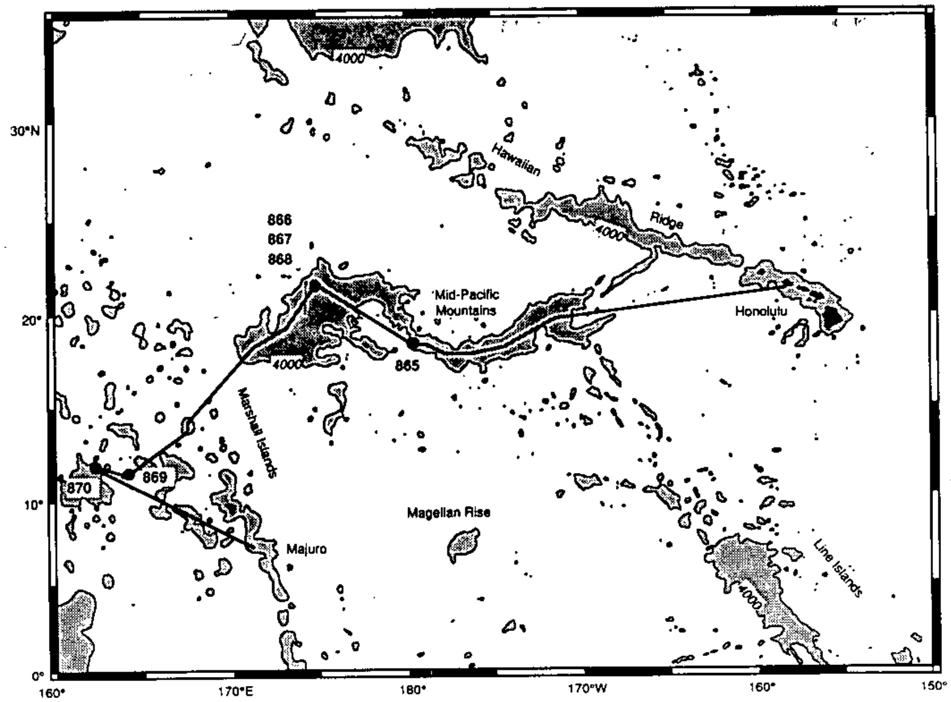

Figure 1. Map of western Pacific showing Leg 143 drill sites and survey track between Honolulu and Majro (formerly Majuro). Stippled areas denote regions above 4000 m water depth. Larger islands are shown in black.

changes recorded in guyot limestones with sea-level curves developed elsewhere in the world;

- Provide constraints on timing and cause(s) of reef platform drowning;
- Examine timing and extent of emergence and karstification event(s) evident in morphology and in seismic reflection profiles of Allison, "Huevo," and other western Pacific guyots;
- Recover the oldest and deepest lagoonal sediments, providing constraints on age of platform formation;
- Study diagenetic history of guyot platform carbonates;
- Compare shallow-water reef biotic assemblages to others of similar age elsewhere as a clue to migration patterns;
- Gather pore water samples, to infer residence times and chemical evolution of interstitial waters;
- Examine pelagic sediments, deposited above the CCD atop the guyots, for Late Cretaceous and Paleogene stable isotope and biostratigraphic data as well as additional constraints on timing of platform drowning;
- Obtain a suite of downhole logs to illuminate structure, stratigraphy and composition of the carbonate cap and upper volcanic layers; and
- Collect data on seismic wave velocities in Cretaceous platform carbonates to use in interpretation and correlation of seismic reflection and refraction data from Pacific guyots.

At Resolution Guyot (Sites 866-868), drilling of the volcanic pedestal addressed additional goals:

- Determine a reliable Early Cretaceous paleolatitude for constraining the tectonic history of the guyot and the Pacific Plate as a whole;
- Obtain a reliable radiometric date for the volcanic pedestal for evidence of timing of volcanism in the Mid-Pacific Mountains; and
- Compare geochemical and isotopic signatures of basalts to those of other seamounts for evidence of magma source.

Drilling in the basin adjacent to Wodejebato Guyot (Site 869) also addressed the following specific goals:

- Calculate paleolatitudes for constraining the tectonic history of the Marshall Islands and Pacific Plate;
- Refine magnetic polarity reversal time scale for the Early to Late Cretaceous;
- Study the diagenetic history of deep-water sediments;
- Determine seismic wave velocities in Cretaceous to Tertiary deep sea sediments for use in interpretation and correlation of seismic reflection and refraction data;
- Obtain a suite of downhole logs that illuminate structure, stratigraphy and composition of deep-sea sediments in the vicinity of atolls and guyots;
- Determine history of volcanism on nearby Pikinni Atoll and Wodejebato Guyot;
- Develop a model of Cretaceous, mid-ocean guyot/atoll carbonate platform formation and evolution for the Marshall Islands; and
- Decipher cause(s) of drowning(s) of some Marshall Islands guyots (such as Wodejebato) versus existence of Cenozoic reefs on nearby atolls (such as Pikinni).

Results

Site 865

Site 865 is located atop Allison Guyot (Fig. 1). Allison is typical of Mid-Pacific Mountain guyots because it has a thick limestone cap with a seismic reflection signature that implies a sequence of ponded lagoonal sediments enclosed by a perimeter reef. The limestones are surmounted by a thick cap of pelagic sediments to provide a post-drowning history.

Pre-Leg 143 site-survey seismic profiles showed several prominent and many minor reflectors beneath the surface of the guyot. Strong reflections were thought to represent tops of shallow-water limestone and volcanic basement. Between those reflectors, lesser seismic horizons may have resulted from sea-level oscillations. Beneath the "basement" reflector, several additional weak returns suggested layered volcanics, or interlayered sediments and volcanics.

Although the pre-cruise plan was to drill a single hole, three were drilled. Hole 865A was the primary deep hole, drilled using a single RCB bit. APC coring was postponed for use in Holes 865B and 865C because it was feared that hard chert layers were present in the pelagics. Hole 865A penetrated 139.7 m of pelagic sediments ranging from mid-Paleocene to Quaternary age, but contained an expanded mid-Paleocene to upper Eocene section. Core recovery through the pelagic section averaged 55%, but sediments were pervasively disturbed by rotary coring. Below 139.7 mbsf, upper Albian shallow-water limestones were drilled to within a few meters of total depth (TD), at 870.9 mbsf. Basalt intrusives interlayered with limestone were recovered in the last five cores, from 831.8 mbsf to TD. Recovery in much of the shallow-water limestone section was 1%-2%; however, it improved (10%-100%) in clayey limestones and basalts within the lowermost 100 m. Holes 865B and 865C were APC/XCB-cored to obtain the expanded Paleocene-Eocene pelagic cap sediments for paleoceanographic and biostratigraphic study. Hole 865B penetrated 165.5 mbsf, ending with five XCB cores attempting to retrieve material from the mineralized zone near the top of the limestones. Hole 865C was APC-cored to 136.3 mbsf.

Lithostratigraphy

Using combined micro- and macro-fossil biostratigraphy, visual core descriptions augmented with smear-slide and thin section data and physical properties/downhole logging data, four stratigraphic units were distinguished *(Note: boundary depths given to tenths of meters were determined from cores; integer depths determined from logs)*. From bottom upward, these are as follows:

Unit IV (870.9-621.9 mbsf). Upper Albian clayey organic-rich limestone with decreasing amounts of clay and organic matter upward. Limestones contain a varied biota of benthic foraminifers, ostracodes, snails, bivalves, solitary corals, sponges and dasycladacean and red algae. Mudstones are commonly extensively burrowed. Pyrite is common in dark-colored clay layers; gypsum has been identified in several clay layers. Carbonaceous fragments of land plants are common, particularly near the bottom of the hole, and decrease in abundance upward. The lowest 30 m of drilled section contains alkali basalt, thought to be one or more sills intruded into sediments, rather than volcanic basement. Lithologic subunits were distinguished based on varying amounts of, clay, organic matter, dolomite and bioclastic debris. Good core recovery (10-100%) in Unit IV allowed recognition of depositional shallowing-upward cycles, repeating on a scale of about half a meter. These cycles were shown exceptionally well on formation microscanner (FMS) logs, which could often be matched very satisfactorily with cores themselves.

Unit III (621.9-207.3 mbsf). Upper Albian white limestones of several facies: peloidal mudstone, wackestone, packstone, and rare grainstone with molds of formerly aragonitic mollusks. High-spired gastropods, small bivalves, sponges and large sponge spicules are common; benthic foraminifers are relatively abundant; ostracodes and dasycladacean algae occur sporadically. Rudists and corals occur in a few layers. Subunit IIIB is richer in lime mud than overlying Subunit IIIA. Induration is variable; limestone ranges from chalky to hard. Dissolution has removed most molluscan shells. Episodic subaerial exposure is suggested by occurrence of erosional surfaces, reddish stains and brecciated well-indurated wackestones. FMS logs show continuation of cyclic alternations seen in Unit IV.

Unit II (207.3-139.7 mbsf). Upper Albian phosphatized, karstified limestone, riddled in the upper 40 m with internal cavities encrusted with phosphatic pelagic limestone and manganese oxyhydroxides. Cavities are partly filled with geopetal sediment containing nannofossils and planktonic foraminifers of Late Cretaceous age. This unit is genetically like Unit III, except for the mineralization. Unit II is silicified at the very top; logs show concentrations of uranium.

Unit I (139.7-0 mbsf). Middle Paleocene/Quaternary foraminiferal nannofossil ooze and foraminiferal sand. Approximately 90% of this section is of middle Paleocene to late Eocene age and probably formed as the guyot drifted beneath the equatorial high productivity zone. These sediments generally contain a large fraction of sand-sized foraminifers, suggesting winnowing by currents.

Recovery of pelagic sections at Site 865 was good, averaging 61%, 90% and 84% for Holes 865A, 865B and 865C, respectively. Core recovery in shallow-water limestones of Holes 865A and 865B was disappointing for some intervals, particularly in Units II and III, where values of 1%-2% were typical. In Unit IV of Hole 865A, recovery improved in basalts and clayey limestones and ranged from 7% to 100% in the deepest 200 m.

Despite overall low core recovery, it was possible to reconstruct the lithologic sequence by comparing cored material with a suite of geophysical, geochemical and FMS logs. Logs, compared with measurements of sonic velocity and density on cored speci-

Table 1. Leg 143 Operations Summary

Hole	Latitude	Longitude	Water Depth[1] (m)	No. of Cores	Interval Cored (m)	Recovered Core (m)	Percent Recovered	Interval Drilled (m)	Total Penetration	Time (hrs)
865A	18°26.410'N	179°33.339'W	1529.1/1518.4	94	870.90	132.07	15.16	0.0	870.90	159.00
865B	18°26.415'N	179°33.349'W	1527.0/1516.2	19	165.50	123.66	74.72	0.0	165.50	26.25
865C	18°26.425'N	179°33.339'W	1528.2/1517.4	15	136.30	114.11	83.72	0.0	136.30	12.75
Site 865 totals				128	1172.70	369.84	31.54	0.0	1172.70	198.00
866A	21°19.953'N	174°18.844'E	1372.6/1361.8	189	1743.60	268.98	15.43	0.0	1743.60	406.00
866B	21°19.952'N	174°18.870'E	1357.1/1346.1	13	117.40	23.06	19.64	0.0	117.40	17.50
Site 866 totals				202	1861.00	292.04	15.69	0.0	1861.00	423.50
867A	21°20.963'N	174°18.550'E	1363.2/1352.2	1	10.00	0.07	0.70	0.0	10.00	10.50
867B	21°20.959'N	174°18.561'E	1363.2/1352.2	14	76.80	22.47	29.26	0.0	76.80	49.50
Site 867 totals				15	86.80	22.54	25.97	0.0	86.80	60.00
868A	21°21.171'N	174°18.564'E	1396.0/1384.9	5	20.30	9.40	46.31	0.0	20.30	40.00
Site 868 totals				5	20.30	9.40	46.31	0.0	20.30	40.00
869A	11°00.091'N	164°44.969'E	4837.8/4826.7	18	166.50	129.27	77.64	0.0	166.50	41.00
869B	11°00.093'N	164°45.019'E	4837.8/4826.7	69	656.20	252.04	38.41	140.0	796.20	260.00
Site 869 totals				87	822.70	381.31	46.35	140.0	962.70	301.00
870A	11°20.829'N	162°15.788'E	49.8/38.6	1	0.20	0.19	95.00	0.0	0.20	10.75
870B	11°20.833'N	162°15.775'E	48.7/37.5	3	31.30	0.41	1.31	0.0	31.30	6.75
Site 870 totals				4	31.50	0.60	1.90	0.0	31.50	17.50
Leg 143 totals				441	3995.00	1075.73	26.93	140.0	4135.00	1040.00

1 Seafollor depths in m from driller's datum at dual elevator stool/seafloor depth in m below sea level.

mens, allowed a satisfactory correlation to be made between seismic reflectors and the drilled sequence.

Pelagic Cap Biostratigraphy

Biostratigraphic studies of the pelagic cap show the Paleogene section to be relatively complete, spanning nannofossil zones NP4-NP21 and foraminiferal zones P2-P17 (early Paleocene to early Oligocene). The section is rare, not only because it contains sediments from an epoch (the Paleocene) rarely cored in Pacific pelagic sediments, but also because the guyot was near the equator and its summit had a paleodepth of ~1000 m. The section also appears to contain the Paleocene/Eocene boundary, a transition of interest to paleoceanographers studying the shift of warm Cretaceous to cold late Tertiary climates.

Geochemistry

Organic geochemistry measurements showed, as expected, that percentage of $CaCO_3$ from Site 865 is typically >95%. A small percentage of lower values (as low as 27%) was found in clay-rich intervals in Unit IV. Despite abundance of plant remains in the lowest sedimentary unit, total organic-carbon (TOC) values were typically very low to low (<0.5%). Moderate to high percentages (as much as 35.6%) were found in Unit IV in small, organic-rich beds. Analyses of inorganic compounds in interstitial waters throughout all holes showed values consistent with seawater. This suggests that both pelagic cap and limestones have high permeability and are essentially open to seawater circulation. With the exception of samples from the very bottom of Hole 865A, sulfate concentrations stay relatively constant and imply that sulfate reduction is not occurring quickly enough to deplete sulfate concentrations.

Density and Seismic Velocity

Physical properties show a discontinuity from pelagic cap to limestone: porosities drop from >60% to ~10%-20%, and bulk densities jump from 1.6-1.7 g/cm³ to 2.3-2.7 g/cm³. Furthermore, seismic velocities increase sharply in the limestones, with values >4 km/s from 140-400 mbsf and decreasing to typically 2.0-3.5 km/s below 500 mbsf. Downhole physical logs give similar trends in bulk density, but show that shipboard velocity readings are biased to the high side by selective recovery of harder layers. In limestone between 140 and 350 mbsf, the sonic log displays large variations in velocity, from ~2.0 km/s to 4.5 km/s, apparently resulting from alternating hard and soft layers. Velocities below 350 mbsf are more consistent, but average from ~2.9 km/s to 3.5 km/s with short excursions to higher values. Overall, both sonic log and physical properties measurements demonstrate that velocities used to calculate depths to seismic reflectors during pre-cruise planning, based mainly on plateau carbonate sediments, are too low.

Downhole Logs

Downhole logs yield valuable information about structure and composition of shallow-water limestones. Gamma-ray logs show higher counts in the upper 60 m of the shallow-water limestone, possibly a result of scavenging of uranium by phosphorite. Resistivity logs give numerous short-wavelength variations that probably result from thin beds. Finally, FMS gives a unique view of the structure of the limestone section. In the lowermost portion of Hole 865A, it is possible to make a detailed correlation of beds in cores and imaged beds in the borehole wall. Moreover, structures such as vugs are often visible in the FMS recording. Clearly, low recovery has biased the limestone samples, but FMS data will compensate for much of the missing section.

Interpretation

Data from Site 865 paint a classic Darwinian picture of carbonate atoll evolution from early formation to final drowning. Deepest recovered sediments (Subunit IVD) contain abundant fossil oyster specimens and evidence of intense burrowing, suggesting a restricted, shallow lagoonal environment. Abundant plant remains imply a nearby shoreline and marshy conditions. Presence of pyrite with associated organic matter indicates bacterial sulfate reduction in anoxic sediments, but the water must have been oxygenated enough for shallow infaunal activity. Gypsum and early diagenetic dolomite occur in some layers and may be due to seasonally evaporative conditions. Basaltic dikes intruded these sediments, probably at shallow depths. This event may represent late-stage volcanics or rejuvenation of volcanism.

Subunit IVC shows periods of more open-marine conditions. Land-derived organic matter wanes through this sequence and disappears at the top of this subunit. Dolomite was not observed in sediments above Subunit IVB, and clay disappears by the top of Subunit IVA, implying that the shoreline gradually retreated. Episodic concentrations of clay seams in these subunits suggest cyclic variations in water depth, caused either by autocyclic processes such as sedimentary-lobe switching, by allocyclic mechanisms such as irregular subsidence of the seamount foundation, by eustatic sea-level fluctuations, or by combinations of all of these.

Facies of Unit III suggest a quiet-water lagoonal environment. Degree of faunal diversity is not high, but occurrence of rudists and corals higher in the section indicates conditions evolving from more restricted (Subunit IIIB) to open marine (Subunit IIIA). Winnowed carbonate sands suggest sporadic storm activity, whereas scattered reddish stains attest to periods of subaerial exposure. Evidence for prolonged emergence occurs at the top of shallow-water carbonates in Unit II. Although these limestones are genetically the same as those in Unit III, they display mineralization, dissolution and infilling of cavities by fine, possibly eolian, sediments as well as by Upper Cretaceous pelagic sediments. High gamma-ray log readings imply concentrations of uranium either from eolian deposits or from association with phosphorite. High uranium values suggest that thickness of the exposed layer is ~68 m. Biostratigraphic data (primarily benthic and planktonic foraminifers) suggest that the reef evolved and died quickly; the 731 m drilled section of shallow-water limestones appears to have been deposited within the last half of the Albian (~105-97.5 Ma).

Following exposure near the end of the Albian, the carbonate reefs drowned. Oldest pelagic fossils, in cracks and cavities, are between mid-Turonian and late Coniacian in age. Some time during the 5-10-m.y. interval between uplift and installation of pelagic conditions over the guyot, the emergent carbonate cap subsided below sea level, but without reestablishment of reefs. Since the seamount was probably located in low southern latitudes during this time, unusual conditions are required, perhaps a rapid and substantial rise in sea level such as that postulated for the Cenomanian-Turonian boundary. During the remainder of the Cretaceous, after the carbonate platform drowned, the environment was mainly non-depositional, leaving only a thin veneer of sediment. It is not yet clear whether later Cretaceous sediments were simply not deposited or removed by subaerial erosion.

During the Paleogene, the guyot rode the Pacific Plate northward across the equator. As it passed beneath the equatorial high-productivity zone, it acquired a substantial pelagic cap, consisting mainly of late Paleocene and early to mid-Eocene nannofossil and foraminiferal ooze and sand. Currents eroded some of the cap and produced winnowed foraminiferal sands.

Neogene sedimentation was slow, producing only a thin frosting that appears to rest unconformably on top of the thick Paleogene pile.

Site 866

Sites 866 and 867/868 were drilled on the north rim of Resolution Guyot in the western Mid-Pacific Mountains (Fig. 2) and were conceived as part of a transect. Together with Site 463, drilled on DSDP Leg 62 and located ~24 nmi (44.4 km) away in the basin to the east, they form a transect from lagoon to perimeter reef to basin. Site 866 was placed to penetrate lagoonal facies limestones just behind (~1.5 km) the perimeter mound, to enable correlation of lagoonal sediment facies, ages and horizons with those drilled at Site 865 on Allison Guyot. It was also to be a multiple-reentry site to penetrate the entire limestone cap and significantly into the volcanic pedestal.

Originally, one hole to a depth of ~950 m was planned, but two were actually drilled. The first, Hole 866A, was RCB-drilled to a TD of 1743.6 mbsf, bottoming in basalt. Its depth resulted from basalt being far deeper than estimated and from stability of the hole in limestones of the carbonate cap. Coring recovered 1620 m of mostly shallow-water limestone and 124 m of subaerial basalt. Recovery in the limestone section was poor at the top (average 1.4% in the top 300 mbsf) but increased downhole (average 34% in the bottom 220 m of limestone). The second hole, 866B, located ~30 m away from 866A, was drilled in the upper part of the limestone platform, where recovery was poor in the first hole, using a diamond drill bit rather than RCB. The pelagic ooze section, missed in 866A, was cored in 866B, showing that the mud line was incorrectly placed in 866A and that the seafloor was actually 15.5 m shallower than assumed. Hole 866B reached 117.4 mbsf, bottoming in limestone. Drilling took only 16.5 hr. Average recovery was low (4.3%), but far better than that achieved in the same section of 866A.

Ages range from Barremian to Pliocene. Most of the section is Barremian to upper Albian shallow-water limestone, dated primarily from benthic foraminifers, resting upon basalt of uncertain age. Foraminiferal assemblages in limestones indicate Barremian from 1620 to 1200 mbsf, early to middle Aptian from 1200 to 270 mbsf and late Albian from 270 to 13 mbsf. The break at 270 mbsf appears to be a hiatus encompassing the late Aptian and early Albian, a period of perhaps 10-15 m.y. Another possible hiatus is suggested at about 1400 mbsf by an abrupt change in paleodepth implied by foraminifers. Basalt below the limestone is reversely polarized, implying that it formed during, or prior to, Chron M0. Shallow-water limestones are capped by a thin veneer of winnowed and reworked pelagic sediments containing both calcareous nannofossils and planktonic foraminifers ranging in age from Maastrichtian to Pliocene.

Lithostratigraphy

Using combined micro- and macro-fossil biostratigraphy, visual core descriptions augmented with smear-slides and thin-sections, physical properties data and downhole logs, eight stratigraphic units were recognized above volcanic basement. Because core recovery was low in some intervals, downhole logs were invaluable in constructing a stratigraphic framework and in correlating sedimentary layers with seismic horizons. From bottom to top, lithologic divisions are as follows:

Unit VIII (1620.0-1399.7 mbsf). Barremian dolomitized and undolomitized oolitic/oncoidal grainstone. Unit VIII is divided into two subunits on the basis of dolomitization: the lowest 19 m, overlying basalt, is almost undolomitized, whereas the upper 202 m is pervasively dolomitized and tan in color with lighter-colored, unreplaced oncoids in parts. Common biogenic components are gastropods, bivalve fragments, echinoid spines and green algae. Coral fragments and bryzoans occur rarely. Dolomitization decreases upward and becomes patchy near the top.

Unit VII (1399.7-1203.4 mbsf). Barremian dolomitized oolitic/peloidal grainstone, oncoidal wackestone and algal laminites, with clay/organic-rich layers. Main characteristic is pervasive sucrosic dolomitization and abundance of oncoids. Four subunits are defined by an interval of bright white dolomitized peloidal grainstone overlying a layer of coral peloidal grainstone in the middle part of Unit VII. Components include oncoids, benthic foraminifers, peloids, fragments of rudist and other bivalve shells, serpulid worm tubes, echinoids, corals, nerineiid gastropods, stromatoporoids and dasycladacean algae. Intergranular and moldic porosity is common near the bottom.

Unit VI (1203.4-791.8 mbsf). Lower to middle Aptian cyclic packstone/wackestone with algal laminites, clay/organic-rich layers and patchy dolomitization. Primary characteristic is cyclic repetition of lithologies in meter-scale, shallowing-upward sequences that imply fluctuations in relative sea level. Cycles typically begin with peloidal wackestone or packstone and grade upward into wackestone or mudstone. Tops of these sequences are commonly truncated and show small-scale desiccation cracks, implying emergence and erosion. Unit VI is subdivided into three parts based on occurrence of a caprinid rudist biostrome in the middle.

Unit V (791.8-676.6 mbsf). Lower to middle Aptian oolitic grainstone. Unit V consists of massive, well-sorted, oolitic grainstone

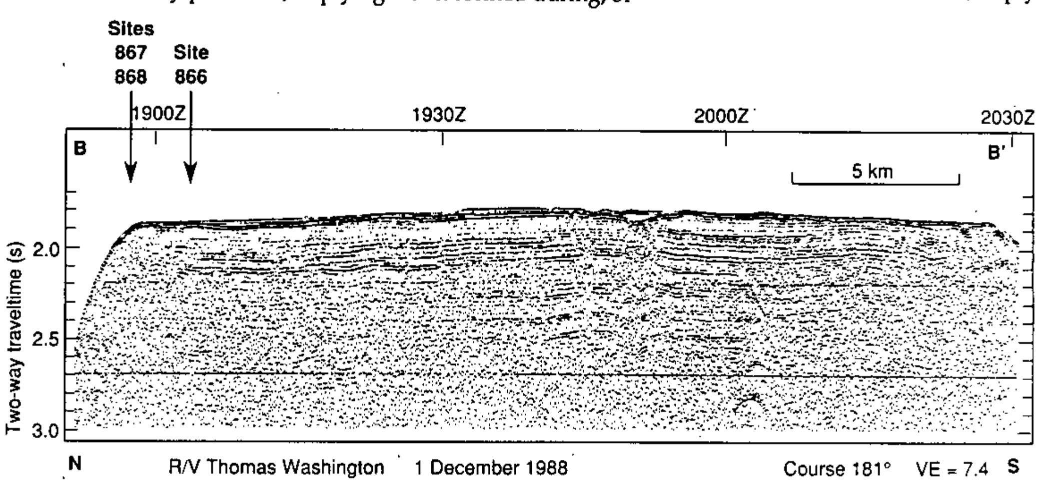

Figure 2. Seismic reflection profile across Resolution Guyot, taken by *R/V Thomas Washington* during Roundabout Leg 10. Locations of sites 866, 867 and 868 were projected to this line from their actual locations ~0.5 to 1.2 nmi. (0.9 to 1.9 km) to the east.

which is cross-laminated in some places. Though grainstone is predominant, there are short intervals with rudstone, where large fossils occur, and wackestone, where micrite is abundant. Other components are peloids, grapestones, intraclasts, rare oncoids, bivalve debris, corals and gastropods. Locally, ooids and peloids are blackened by manganese oxides. Oolitic grainstones exhibit a high degree of overpacking and grain interpenetration.

Unit IV (676.6-434.5 mbsf). Lower to middle Aptian cyclic packstone/wackestone with scattered clay/organic-rich layers. Bioturbated peloidal packstone, wackestone and grainstone with gastropods and foraminifers are characteristic. Meter-scale submergence-emergence cycles, similar to those in Unit VI, occur, with laminated wackestone and packstone decreasing in frequency upward. Other components are bivalve fragments, dasycladacean algae and scattered lignite fragments. Smectite clay layers occur in the lower part and decrease upward.

Unit III (434.5-19.6 mbsf, Hole 866A; 117.4-32.8 mbsf, Hole 866B). Middle Aptian to upper Albian wackestone and mudstone. Unit III is predominantly wackestone with lesser amounts of mudstone, packstone and grainstone. Common components are gastropods, bivalves, benthic foraminifers, echinoids, ostracodes, sponges and dasycladacean algae. Rare components are corals, serpulid worm tubes and bryozoans. Aragonitic fossils have been largely dissolved to create moldic porosity. Calcrete layers decrease upward. Three subunits were distinguished, based on porosity and occurrence of calcrete zones. A significant hiatus occurs between Subunits IIIB and IIIC (271 mbsf), with a gap between the Aptian and upper Albian.

Unit II (19.6-0.9 mbsf, Hole 866A; 32.8-23.5 mbsf, Hole 866B). Cretaceous manganiferous limestone. This poorly recovered unit is known from only a few small pebbles of manganese-encrusted limestone and from comparison with the mineralized limestone unit of Allison Guyot (Site 865). It represents the mineralized surface layer of the shallow-water limestones.

Unit I (0.9-0.0 mbsf, Hole 866A; 23.5-0.0 mbsf, Hole 866B). Maastrichtian to upper Pliocene foraminiferal nannofossil ooze. Unit I is the thin pelagic layer representing part of the post-drowning history of Resolution Guyot. It has been winnowed and reworked and contains iron-manganese micronodules.

Biostratigraphy

Most of the preliminary, shipboard biostratigraphy is based on benthic foraminifers because planktonic foraminifers, calcareous nannofossils and palynomorphs are absent from the shallow-water limestones. Deepest sediments from Hole 866A (1619-1200 mbsf) contain a Barremian foraminiferal assemblage. A gradual shift to an early to middle Aptian assemblage occurs at ~1200 mbsf. Higher up in the sequence, at ~271 mbsf, an abrupt change to late Albian foraminifers marks a hiatus encompassing the late Aptian and early Albian. The thin layer of pelagic sediment atop the guyot has nannofossils and foraminifers of Maastrichtian to late Pliocene age, some of which are in reworked layers.

Physical Properties

Bulk density and sonic velocity measurements in the shallow-water limestone sequence show remarkable trends. The shallowest 420 m exhibit relatively high seismic velocities and densities, with values of 4.4-6.5 km/s and 2.4-2.7 g/cm^3, respectively. In the lower part, from 1619 to 1200 mbsf, high velocities and densities are also found, but there is a much larger range, ~2.1-6.8 km/s and 2.15-2.75 g/cm^3, respectively. The large scatter is evidently caused by alternating harder dolomite and softer limestone layers. In the middle of the section, from ~1200 to 420 mbsf, is a low-velocity/density zone with velocities of 1.8-4.5 km/s and densities of 2.1-2.4 g/cm^3. These trends are a significant departure from the common monotonic increase in seismic velocity and bulk density observed in most deep-sea sediments. Their cause is undoubtedly related to a complex diagenetic history.

Downhole Logs

As at Site 865, downhole logs from Hole 866A provided a valuable framework for understanding core material. Unfortunately, collapse of the basement section prevented significant penetration of logging tools into the basalt. In limestones, sonic velocity and density logs showed trends similar to those in physical properties data, but values were generally lower, indicating that the cores are a preferential sample of more-indurated material. Resistivity logs displayed excellent correlation with lithology. High-resistivity layers between 271 and 434 mbsf correspond to dense, high-seismic-velocity mudstones and wackestones of lithologic Unit III. Likewise, high-resistivity layers in lithologic units VII and VIII appear to correlate with pervasively dolomitized sediments. Geochemical and FMS logs were also recorded in Hole 866A. Geochemical logs require additional processing and interpretation, but appear to show small variations probably related to clay content. FMS logs show variations in borehole-wall resistivity that suggest correlations to porosity and structure. Some variations appear cyclic.

Igneous Geology

Drilling in Hole 866A penetrated 124.8 m of basalt with 37% overall recovery. The basalt/limestone contact is at 1619.7 mbsf. Basalt is subaerial and lightly to heavily altered. Red clay zones were cored in several intervals, indicating subaerial weathering and development of lateritic soils. Poorly recovered rubbly zones imply that basalt flows were of clinkery aa type. Twelve flow units are recognized, separated on the basis of intervening lateritic or rubbly intervals. Above the basalt/limestone contact, volcaniclastic grains are generally small, not very abundant, and restricted to within 40 m above the basalt. This suggests that any exposed volcanic remnant was small and not close to the site.

Paleomagnetism

Magnetic measurements of the basalt section at the bottom of Hole 866A show that basalts have reversed polarity, indicating that they are older than Chron M0 (~118 Ma; Kent and Gradstein, 1985), since the basalt is overlain by Barremian-age sediments.

Geochemistry

Studies of inorganic compounds from interstitial waters in the pelagic cap and limestones show that these waters are mostly indistinguishable from normal seawater. On the other hand, sulfate and ammonium concentrations indicate a slight amount of reaction with buried organic matter. Carbonate content is typically 97%-99% in limestones, but decreases locally in clay layers, where values as low as 22% were measured. Low (<0.3%) TOC values are typical of most of the limestones. In clay-rich layers and algal laminites, TOC was typically, but not always, higher.

Interpretation

Hole 866A records virtually the entire history of carbonate platform formation, drowning and diagenesis on Resolution Guyot. The story begins with the waning eruptive stages of the volcanic pedestal. Reversed magnetic polarity implies that it formed during or prior to Chron M0 (~118 Ma). Pedestal height was much smaller than expected. A comparison of extrapolated

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depth to basement at DSDP Site 463 with depth of basement in Hole 866A implies that the volcanic edifice had a relief of only ~500 m above the basaltic plateau that underlies most of the western Mid- Pacific Mountains. An implication of this result is that a very large region of the western Mid-Pacific Mountains was at depths <~1 kmbsf in Barremian time. Volcanic underpinnings were quickly submerged and added little sediment to limestones above.

The carbonate cap on Resolution is surprisingly thick, with ~1620 m of shallow-water limestone ranging in age from Barremian to late Albian, with perhaps two hiatuses. One possible lacuna, at ~1400 mbsf, in the Barremian, was recognized solely on the basis of an abrupt change in paleodepth implied by foraminiferal assemblages. Consequently, it is of uncertain duration and significance. The other, at ~271 mbsf, shows a distinct change in foraminiferal assemblages from early to middle Aptian below to late Albian above. Evidently, the carbonate platform formed in two stages: a thick sequence during rapid subsidence in the Barremian and early to middle Aptian, and a thinner cap during slower subsidence in the late Albian.

During its active growth stage, the carbonate platform stayed at or near sea level. Generally, facies show that most sediments were deposited in shallow, often restricted, lagoonal environments that gradually deepened and became more open marine. Meter-scale facies cycles in much of the limestone section imply small-amplitude, short-term fluctuations in relative sea level.

Cause of the gap in carbonate platform history, perhaps as great as 10-15 m.y., is uncertain. Two plausible end-member models are: 1) Aptian subsidence and drowning followed by Albian uplift into shallow water and reestablishment of growing reefs, and 2) Aptian reef growth followed by uplift to sea level, subaerial erosion, resubmergence, and reestablishment of a late Albian reef. Final drowning occurred between late Albian and Maastrichtian time, when the first preserved pelagic sediments were deposited atop the shallow-water limestones. Sometime during this period, the platform was emergent and subjected to karsting, as suggested by sinkhole and other karstic features seen on 3.5-kHz and seismic profiles. This is also shown by freshwater dissolution and cave deposits in the uppermost part of shallow-water limestones at Sites 866 and 867/868. Subaerial exposure, and increased porosity it caused, also led to phosphatization.

Diagenesis was important in modifying shallow-water carbonates. In general, three effects were noted: differential lithification, dolomitization and karstification. Differential lithification created alternating layers of harder and softer limestone, so that density and porosity do not increase monotonically downward. A notable interval is that of denser wackestone layers at the top of the Aptian section from ~431 to 271 mbsf. Dolomitization was locally pervasive, but patchy. Although deeper limestone layers show the most dolomitization, some interbedded layers and the overlying layers were unaffected or only lightly dolomitized. Timing of dolomitization is uncertain, but indications are that it occurred soon after burial. Post-Albian subaerial exposure and creation of a lens of fresh water within the uppermost limestone layers caused widespread dissolution and formation of cavities and cavity deposits in the vadose zone. Many cavities were later filled by fine-grained sediments and permeated with phosphate and iron-manganese oxyhydroxides.

Drilling at Site 866 changed the way we view Cretaceous, carbonate-capped guyots. For years, geophysical ships have crossed these features and brought back profiles that were fitted to the classic picture of modern atolls. A prominent, deep seismic reflector was commonly seen and assumed to be volcanic basement upon which a fringing reef grew. This volcanic pedestal was generally thought to make up most of the guyot, capped with <1 km of limestone. Furthermore, prominent mounds around guyot perimeters, and scattered seismic energy at guyot edges, were presumed to show a drowned fringing reef. Layered seismic horizons in the interior were interpreted as lagoonal limestones with relatively low seismic velocities and densities, both of which should nominally increase with depth.

Hole 866A showed that, in the Mid-Pacific Mountains at least, the original volcano had much less relief than the final guyot. What is more, estimates of thickness of the carbonate cap were off by a factor of 2 because the "basement" reflector was not associated with the top of the volcanic pedestal, and acoustic velocities of the limestones were underestimated. Both errors are a result of diagenesis of the limestone cap.

The modern atoll model may also be inadequate. Despite drilling nearly 2 km of carbonate material at Site 866, a location only ~1.5 km from the edge of the guyot, little reef-derived material was recovered. Instead, open-water platform components, such as oolites, were common.

Sites 867/868

Site 867 is on the perimeter mound of Resolution Guyot nearest Site 866. It was envisaged as a single, shallow hole to penetrate only the karsted upper 300 m of the atoll perimeter reef. Site 868 is on a terrace, ~33 m deeper and 400 m outside the perimeter mound. Because of shallow water depth, a separate beacon had to be used for Site 868; hence, it is catalogued as a different site from 867. Because of their proximity in space and in scientific theme, the sites are joined for reporting purposes (Fig. 2).

The perimeter mound drilled at Site 867 was assumed to be a Cretaceous reef that had drowned and perhaps even been emergent owing to relative sea-level fall. Site 868 was drilled because results from previous Leg 143 sites suggested that there is a significant time gap between the youngest platform carbonates and the first pelagic sediments to accumulate atop the platform. It was thought that the lower terrace might be a sea-level lowstand reef complex, which might help fill that gap.

Two holes were drilled at Site 867; both were spudded-in with no guide base on hard limestone. Hole 867A consisted of a single core drilled with a diamond bit. The small-diameter bottom-hole assembly sheared off at the outer core barrel, so the hole was terminated. Hole 867B recovery would have been higher, but the section contained a 9-m cavity. Slow drilling rates and time constraints did not allow accomplishment of 300 mbsf penetration.

Lithostratigraphy

Cores from Sites 867/868 consist of shallow-water limestone with a thin veneer of pelagic limestone. Based primarily on benthic foraminifers, the shallow-water limestone is late Albian, whereas planktonic foraminifers and nannofossils indicate an Eocene age for overlying pelagics. Two lithologic units were recognized at Site 867, and core from Site 868 is equivalent to the second, stratigraphically lower, unit from Site 867. In stratigraphic order these units are:

Unit II (10.0-0.0 mbsf, Hole 867A; 76.9-0.29 mbsf, Hole 867B; 20.3-0.0 mbsf, Hole 868A). Albian bivalve/gastropod/echinoid wackestone to packstone, grainstone to floatstone beach deposits, and oolitic grainstone. A variable amount of skeletal material is present, including rudists, sponges and corals. These limestones have two outstanding characteristics. First, they display meter-scale, fining-upward, transgressive-regressive sequences modulating an overall shift from restricted lagoon to open-marine shoreface upsection. Second, virtually the entire sequence, down to at least 62 mbsf, contains centimeter-scale dissolution cavities, many of which contain speleothems and imply dissolution in the lower vadose zone. Some cavities may be much larger; one section of ~9-m length gave no resistance to the drill string and is thought to be a cavity. Unit II is subdivided into three subunits, the uppermost of which is distinguished by multiple generations of internal sediment (mudstone) of different colors and compositions, the most prominent of which is dark brown, fine-grained phosphatic material. This subunit also gives high readings on gamma-ray logs, as did the upper limestone layers of Allison Guyot, probably owing to pervasive phosphatization. The second subunit is essentially the same, except for absence of cavity infilling and pervasive phosphatization. Notable features of this subunit are coarse-grained intervals of floatstone to rudstone interbedded with finer-grained wackestone, packstone and grainstone. Coarser grained sediments are composed mainly of caprinid rudist and gastropod shell fragments, intraclasts and peloids. The entire section drilled at Hole 868A is distinguished as the third subunit because it is characterized by intervals of boundstone consisting of calcareous sponge fragments. The boundstone is interbedded with floatstone and grainstone containing rudists, gastropods, sponge fragments, possible oyster fragments and oncoidally coated particles. This subunit also contains a layer of red-stained limestone that suggests emergence.

Unit I (0.29-0.0 mbsf, Hole 867B). Eocene foraminiferal nannofossil limestone, heavily replaced and impregnated with phosphate and manganese dendrites. Unit I represents the first permanent pelagic sedimentation.

Interpretation

Facies evolution of Sites 867/868 implies an overall opening of environment, from restricted lagoon to open-marine foreshore. This trend is modulated by meter-scale transgressive-regressive cycles. Many of the cycles begin with storm deposits, typically with an erosive base, and grade to lagoon, tidal flat or beach. The most obvious diagenetic process is dissolution, probably due to subaerial exposure and karsting. Cavities formed by this process in the upper part of the section were partially or wholly filled by a later generation of fine-grained sediment. Final stage of carbonate platform evolution was deposition of a thin cover of pelagic sediment.

Results from Sites 867/868 have two important implications. First, dissolved cavities with speleothems are strong evidence of emergence and confirm inferences of karsting based on seismic reflection profiles and multibeam echo-sounder data over Resolution and other Pacific guyots. Furthermore, depth of dissolution, 62 mbsf at Site 867, combined with nearly 100 m of limestone relief above the site in the guyot center, together imply a relative sea-level fall of at least 160 m. Second, cores contain much less reefal material than expected. The perimeter mound, once thought to be a reef, may be only a perimeter island chain instead. Furthermore, the volume contribution from reefs to building of the carbonate platform may be smaller than previously thought.

Site 869

Site 869 is situated 45 nmi (83 km) southwest of the atoll-guyot pair Pikinni Atoll and Wodejebato Guyot. Drilling was planned to provide a basinal reference section for comparison to Leg 144 drill holes on the summit of Wodejebato and prior drilling on Pikinni. Site-survey data suggested a thick, layered succession of sediments, consisting mainly of turbidites. Volcanic basement is not obvious in site-survey seismic lines, so drilling was not expected to encounter basement basalt. Penetration of ~850 m was planned, and the expectation was to bottom in Cretaceous volcaniclastics produced by constructional volcanism on either or both Wodejebato and Pikinni.

Two holes were drilled, APC/XCB Hole 869A and RCB Hole 869B, the latter located ~30 m east of the former. The operational plan was to use the APC/XCB combination to obtain relatively undisturbed cores from the upper 300-400 m of the sedimentary column. In analogy to Site 462, hard chert layers were expected to frustrate drilling at about 300-400 mbsf, and a round-trip was planned to change to RCB bit and begin a second hole. Chert and porcellanite were encountered at much shallower depths than expected and Hole 869A was terminated at TD of only 166.5 mbsf. Hole 869B was washed to 140.0 mbsf and cored continuously to TD of 796.2 mbsf.

Core recovery in Hole 869A was >100% for APC cores and 77.6% overall. In Hole 869B, recovery was variable. In cherty sections, recovery was generally low, obtaining only a few pebbles of chert in some cores. In contrast, recovery in Cretaceous volcaniclastic turbidites was typically >60%. In general, recovery increased downhole, averaging ~20% from 200 to 500 mbsf and increasing to 70% at the bottom of the hole.

Lithology

Using combined micro- and macrofossil biostratigraphy, visual core descriptions augmented with smear-slide and thin-section data, physical properties data and downhole logs, threel stratigraphic units were recognized. From bottom to top, lithologic divisions are as follows:

Unit III (796.2-217.2 mbsf). Middle/upper Cenomanian to upper Campanian/lower Maastrichtian volcaniclastics interlayered with nannofossil and radiolarian claystone. Numerous gray to green volcaniclastic sandstones and breccias are intercalated with lighter colored claystones. Seven subunits are recognized on the basis of changes in mix, grain sizes or depositional style. Subunits IIIE (780.7-653.3 mbsf), IIIF (653.3-536.1 mbsf), IIIC (487.8-458.8 mbsf) and IIIA (381.5-217.2 mbsf) consist mostly of volcaniclastic sandstone interbedded with claystone. These similar subunits are punctuated by Subunits IIIG (796.2-780.7 mbsf), volcanic siltstone with calcareous claystone, IIID (536.1-487.8 mbsf), a volcanic breccia, and IIIB (458.8-381.5 mbsf), consisting mainly of radiolarian-rich claystone. Volcaniclastic layers consist mainly of sand-size grains, deposited by turbidites. Basaltic clasts are common, in places forming breccias, but also occurring within a fine-grained matrix and implying transportation by grain-flow. Most clasts are subangular to subrounded, suggesting a moderate transport distance. Largest clasts are up to 80 mm in diameter; most have been affected by light to moderate alteration. Volcaniclastic layers contain clinopyroxene, palagonite, feldspar, zeolite, epidote and chlorite grains, attesting to a basaltic parentage. Zeolites are a common cement. Claystone occurs abundantly in some parts of the section (e.g., Subunit IIIB), but rarely in others (e.g., Subunit IIIF), and is locally calcareous, siliceous and/or zeolitic. Radiolarian and nannofossil concentrations are variable; in some layers, these fossils are dispersed and in others they are concentrated in millimeter-scale beds. Shallow-water biogenic fragments occur only rarely but are most abundant in Subunits IIIA, IIIB, and IIIC. Bivalve shell, gastropod, echinoid, red-algal and recrystallized skeletal fragments were found, as were orbitolinid foraminifers, micritic ooids, peloids and glauconite. Coalified woody fragments were found at a 618 mbsf.

Unit II (217.2-88.2 mbsf, Hole 869A; 217.2-140.0 mbsf, Hole 869B). Upper Campanian/upper Maastrichtian to upper Eocene radiolarian-nannofossil ooze and nannofossil-radiolarian ooze with porcellanites and chert. Recovery was low, but Unit II appears to consist of alternating layers of hard chert and soft ooze. Porcellanites and cherts make up a significant fraction in the bottom of the unit and decrease in abundance upward. Layers of nannofossil limestone and chalk occur in places.

Unit I (88.2-0.0 mbsf). Upper Eocene to lower Miocene clayey nannofossil ooze and radiolarian-nannofossil ooze. Major components are nannofossils, radiolarians, sponge spicules and clay. Color and compositional changes show cycles, on various scales. Unit I is divided into two subunits by a stratigraphic gap between upper Oligocene and lower Miocene.

Biostratigraphy

Nannofossils provided most of the datable biomarkers for constructing an age framework. Abundance increases uphole, from few to absent in volcaniclastic turbidites to abundant in the ooze section. Preservation is generally moderate to poor. Foraminifers are few to rare and also generally increase in abundance uphole; however, they are missing from all but the Oligocene section of Hole 869A. Their preservation is typically poor. Radiolarians are common, but there was no specialist on board to study them, so they did not contribute to the shipboard biostratigraphy.

The lower portion of Hole 869B consists of ~320 m of intercalated turbidites and claystones of late Cenomanian age. Extremely rapid sedimentation rates are indicated, as virtually the entire Cenomanian sequence is within the uppermost Cenomanian biozone CC10. Above the Cenomanian strata, up to 207 mbsf, are more volcaniclastic turbidites and intercalated claystones ranging in age from Turonian to late Campanian/early Maastrichtian. This interval contains an expanded Campanian section, from ~400 to 225 mbsf. Into the Cenozoic, there is a change in lithology to cherts and radiolarian-nannofossil oozes. The uppermost cored interval of Hole 869B is late Paleocene to early Eocene in age. Hole 869A yielded entirely Cenozoic-age sediments, ranging from middle Eocene to early Miocene. The stratigraphic progression is punctuated by five recognized hiatuses: upper Coniacian to lower Santonian, upper Maastrichtian to lower Paleocene, part of the upper Paleocene, a section including the Oligocene/Miocene boundary and post-lower Miocene sediments missing at the seafloor. Of these, the most prominent is the upper Maastrichtian-lower Paleocene hiatus, which spans up to 10 m.y. and includes the Cretaceous/Tertiary boundary.

Paleomagnetism

Paleomagnetic measurements of Hole 869A sediments were ruined by pervasive rust contamination. Measurements of discrete samples and archive-half samples from the Hole 869B Cretaceous section showed normal polarity down to Core 143-869B-21R, reversed polarity from Cores 143-869B-21R to -26R, and normal polarity below. This reversed zone is interpreted as Chron 33R, the first reversed polarity epoch after the Cretaceous Quiet Period (Cretaceous Normal Superchron, K-N). Paleolatitudes from Hole 869B samples are 10-20° south.

Sedimentation Rates

Calculated sedimentation rates were based solely on biostratigraphy. Sediments accumulated in the Cenomanian section, from TD up to ~470 mbsf, at the rapid rate of 60 m/m.y or greater. In the Cretaceous section above, up to ~207 mbsf, the overall rate was ~15 m/m.y. A hiatus of ~10 m.y. duration separates Cenozoic and Mesozoic parts of the sedimentation curve; average sedimentation rate in the Cenozoic was ~4.5 m/m.y.

Geochemistry

Marked downhole concentration trends of cations reflect diagenetic changes within the volcanogenic sediments: Ca and Sr are released by feldspars, whereas Mg, K, Na and Rb are decreased by incorporation into alteration products. High silica concentrations in Hole 869A result from high biogenic silica concentrations. $CaCO_3$ percentage varied from highs of >97% to lows of <1% in some cherts, claystones and volcaniclastic layers. In Hole 869A, $CaCO_3$ increases with depth from ~50% through lithologic Subunit IA, is >90% through Subunit IB, and decreases with depth to ~20% at the bottom of Unit II. In Hole 869B, $CaCO_3$ concentration is typically <10%. Peaks of $CaCO_3$ content, commonly >20%, occur within chalk and claystone layers intercalated between volcanogenic layers. TOC in both Holes 869A and 869B is low to very low, with the greatest values <0.8%.

Physical Properties

Physical property trends are what would be expected for basinal sediments: bulk density and sonic velocity increase slightly downhole (from ~1.5 to 2.1 g/cm^3 and 1.5 to 2.6 km/s), whereas porosity and water content decrease (from 70% to 35% and 60% to 20%, respectively). Superimposed upon these trends are fluctuations caused by variations in composition and layering of turbidites and volcanic breccias. Radiolarian and nannofossil-rich oozes of Hole 869A show remarkable variations in bulk density, apparently owing to variable carbonate content; however, sonic velocity remains nearly constant throughout except for intercalated chert layers. Physical properties are more variable in cores from Hole 869B because they have highly variable compositions, consisting mostly of volcaniclastic turbidites and breccias interlayered with marly, nannofossil and radiolarian-rich claystone. Sonic velocities as high as 4 to 5 km/s and anisotropies >15% are measured from samples taken out of cores from the lower 300 m of Hole 869B.

Downhole Logs

Four logging runs were performed in Hole 869B. The first, with the quad tool (gamma-ray, sonic-velocity, neutron-porosity, resistivity and temperature), extended from 777 mbsf to the base-of-pipe at 112 mbsf. For the second and third, FMS and Japanese magnetometer, hole-penetration problems dictated lowering the pipe to 235 mbsf, below Cenozoic chert layers. FMS and magnetometer were then lowered to 775 and 724 mbsf, respectively, and run up to the base-of-pipe. The final run, with the geochemical tool string, was abbreviated because of time constraints, but it recorded data from 560 to 360 mbsf.

The quad tool produced excellent correlation of resistivity, density and gamma-ray reflectance with lithology and seismic reflection record. In particular, several prominent volcaniclastic turbidite-breccia layers show up as upward-fining sequences. The Japanese magnetometer showed prominent anomalies that also correspond to some of these units. Interpretation of FMS and geochemical tool data awaits processing, but preliminary FMS data in particular promise a good record of structure of the borehole wall.

Seismic Stratigraphy

Combining downhole sonic velocity logs with lithologic and physical properties data, changes in acoustic impedance can be determined that correlate with most seismic reflectors. In general, Cenozoic layers show hummocky forms that suggest turbidite channels, and strong reflectors appear to be caused by silicified layers of porcellanite or chert. Upper Mesozoic layers appear more flat-lying, and reflectors come in packets that are probably caused by volcaniclastic turbidites. The strongest and most continuous reflector, at a two-way traveltime of 0.44 s, appears to correlate with the sharp base of a unit of coarse volcanic breccia and turbidites cored from 509 to 543 mbsf. Reflectors beneath this depth become increasingly intermittent and show more relief, corresponding to massive volcaniclastic turbidites and breccias of the rapidly deposited Cenomanian section. Drilling terminated short of at least two additional reflectors at two-way traveltimes of 0.89 and 1.05 s, with extrapolated depths of 1000 and 1230 mbsf. There is no indication on seismic records of true basaltic basement, suggesting that the sedimentary section may be quite thick.

Interpretation

Site 869 shows rapid deposition of Cretaceous sediments, mainly volcaniclastic sandstones, siltstones and breccias, against a background of pelagic sedimentation. A section, >300 m thick, of Cenomanian volcaniclastics was cored and no bottom reached, which suggests that volcanism on nearby seamounts (probably Wodejebato or Pikinni) contributed a large volume of material to the adjacent basin. Interestingly, dredges from nearby Wodejebato Guyot yielded Albian shallow-water carbonates, implying that the underlying seamount formed during or prior to the Albian, a chapter of depositional history not sampled at Site 869.

The Cenomanian section is essentially devoid of shallow-water material, suggesting that massive influx of volcaniclastics overwhelmed input of such material. Conversely, higher in the section, shallow-water debris becomes more important, although it is never abundant. Volcaniclastic material waxed and waned through the rest of the Cretaceous, with a significant influx during early to late Campanian, perhaps signalling another phase of volcanism on a nearby seamount. Grain sizes and distributions vary in volcaniclastic layers. There are large-grained breccias (with clasts up to 80 mm in diameter), sand- and silt-sized turbidites and grain flows with large clasts surrounded by fine-grained matrix. These structures imply energetic, probably channelized, transport by turbidites, grain flows and mass flows from relatively nearby sources.

At the end of the Cretaceous, volcaniclastic input waned and sediments changed to nannofossil and radiolarian-rich oozes, some of which were silicified into chert and porcellanite layers. Cenozoic sedimentation was episodic, with numerous hiatuses and low sedimentation rates. Many Cenozoic sedimentary layers are turbidites, probably shed from nearby Wodejebato-Pikinni. Sediments younger than early Miocene are not found, and seafloor morphology suggests they have been removed, probably by bottom currents.

Site 870

Site 870 was drilled in the lagoon of Anewetak Atoll in the Marshall Islands. The main purpose was a test of shallow-water station-keeping and drilling capabilities of *JOIDES Resolution*. Anewetak has been extensively surveyed and drilled by the U.S. Geological Survey, and its location close to Site 869 made it a convenient location for the shallow-water test. The location for drilling was to be in a water depth of <40 m near the southern

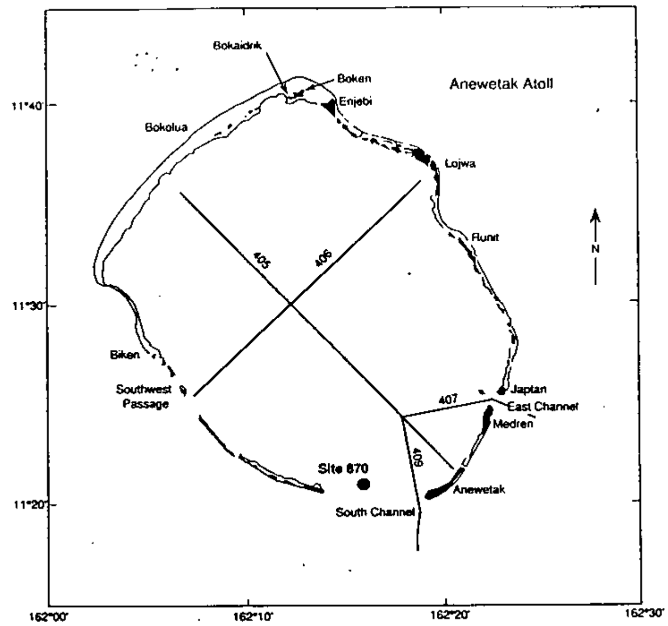

Figure 3. Location of Site 870 in Anewetak lagoon.

end of the lagoon (Fig. 3), near the cross point of USGS lines 405, 407 and 409. Actual position was based on finding the clearest spot away from shallow coral knolls, which could pose a hazard to the ship. Because this was an engineering test, scientific goals were considered secondary; nevertheless, it was hoped that core could be retrieved from the upper 100 m of this modern atoll and provide a contrast and comparison with Cretaceous shallow-water carbonates drilled at other Leg 143 sites.

Station-keeping tests provided valuable insights into handling of the drill ship in shallow water with variable currents. The taut-wire system was able to hold the ship on position for a period of hours, although an abrupt change in current speed and direction caused an unacceptable excursion at one point. Changing the ship heading by small angles caused insignificant pipe-angle deflections, but heading changes of 45° gave rise to 5-7° deflections. A modified deep-water beacon was tried as a backup position reference, but it saturated the hydrophones. Additionally, the taut-wire tugger-winch was damaged by stress on the taut-wire arm at high wire angles. Overall, the positioning tests were successful and indicated areas where improvements can be made.

Drilling at Site 870 produced little core material. Hole conditions were unstable, probably owing to loose sand, and eventually caused drilling to be terminated. In all, 0.6 m of material was recovered from 31.5 m of coring. Hole 870A was cored with an APC/XCB BHA to a sub-bottom depth of 0.2 m. Core 143-870A-1H had 0.19 m recovery and consists of unconsolidated bioclastic sand and gravel with foraminifers, gastropods, bivalves, bryozoans and encrusting red and green algae. Hole 870B was cored with an APC/XCB BHA to a sub-bottom depth of 31.3 m. Cores 143-870B- 1X to -3X had <1% recovery, consisting of more indurated bioclastic rudstone and grainstone and coral debris. Age of the sediments is Holocene.

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Anouncement: Santa Barbara Basin Drilling on Leg

Subject to a successful review by PPSP on 22-23 October 1992, *JOIDES Resolution* will complete APC coring operations in Santa Barbara Basin during Leg 146. The main objective is to recover a continuous stratigraphic sequence to examine high-resolution climatic fluctuations using both marine biogenic and terrigenous clastic signals.

One day has been allocated for Santa Barbara operations at the end of Leg 146. The sedimentation rate (0.5 to 1 m/1000 yr.) is such that double-APC coring to 200 mbsf should retrieve a substantial portion of the Quaternary record (last 0.5 m.y.). Triple-APC coring will be carried out if time permits to ensure continuous recovery of the sequence.

During Leg 146, cores will be collected and sectioned. Only chemistry and paleontology (core-catcher) samples will be collected. These samples will be shipped from San Diego following the cruise. Core sections will remain on *JOIDES Resolution* for analysis during Leg 147. Cores will be run through the Multi-Sensor Track system for GRAPE, P-Wave and Magnetic susceptibility measurements. Resulting data and cores will be shipped to ODP-TAMU (College Station) following Leg 147.

Selected interested scientists (a total of 12) will meet in College Station in early March 1993 to split, describe and sample coortu-collected from the Santa Barbara site. Results will be inclucan the Initial Reports volume (Leg 146 and/or Leg 147). Sampxet-taken will be circulated to interested individuals with the ur standing that results from analysis will be incorporated into Leg 146 or Leg 147 Science Results volumes.

The purpose of this announcement is to publicize the opp nity to participate in this research effort. Interested persons ca get involved in this program either by attending the mini-mee ing to describe the cores or by submitting a sample request for post-cruise analysis.

Letters of interest for attending the mini-description meeting should be received by 1 November 1992. They should be mailed to:

Jack Baldauf, Manager
Science Operations
Ocean Drilling Program
Texas A&M University Research Park
College Station, Texas 77845-9547

Sample requests should be sent to the above address and should be received no later than 1 December 1992.

Leg 147 Prospectus: Hess Deep

Abstract

Primary objective of Leg 147 will be to recover a long continuous core of gabbros and, possibly, shallow mantle generated at the fast-spreading East Pacific Rise (EPR). Hess Deep is the deepest part of a westward-propagating rift valley that is opening up the eastern flank of equatorial EPR in advance of the propagating Cocos-Nazca spreading center. Exposure in Hess Deep rift valley floor has provided a unique opportunity to sample a representative section of normal ocean crust formed at fast-spreading EPR that is far from any fracture zone. The highest priority site is located on the crest of an intra-rift ridge where gabbro outcrops have been identified during a *DSRV Nautile* dive program. Recovery of gabbros and peridotites is critical in order to characterize igneous, metamorphic and structural evolution of lower crust and upper mantle generated at a fast-spreading ridge, as well as vertical variation in its physical and magnetic properties. Leg 147 represents the first of a proposed multi-leg program.

Introduction

Investigation of the global ocean-ridge system during the past decade has greatly changed our view of oceanic crust. To test the models that have emerged and to understand better the interplay etween magmatic, tectonic and hydrothermal processes at mid-cean ridges, it is necessary to sample complete sections of oce-ic lithosphere. Current drilling technology, however, precludes overy of continuous sections through the upper crust down to d mantle. An alternative approach, developed during a JOI/ miAC Workshop on Drilling the Oceanic Lower Crust and bettle, proposes that tectonic exposures be used as the basis for oceng composite sections of ocean crust with a series of strateanicy-chosen offset drill holes. vations have shown that the dike/gabbro transition, massive sections of gabbros, and peridotites crop out on the walls and floor of this rift. Leg 147 is the first of a multi-leg drilling program proposed to reconstruct a composite section of oceanic lithosphere by drilling a combination of holes. Primary objective will be to drill the first long, continuous section of gabbros, possibly down to the gabbro/peridotite transition (petrologic Moho), formed in a fast-spreading environment. This long gabbro core will be compared to the section of oceanic gabbro drilled at Hole 735B, in a slow-spreading environment, to test various models of magmatic, tectonic and hydrothermal processes at mid-oceanic ridges.

Background and Scientific Objectives

Detailed bathymetric, petrologic and geophysical surveys conducted along the global mid-ocean-ridge system have modified our conception of the generation oceanic crust. The simple layer-cake model that requires a continuous, elongate magma chamber has been replaced by a model of segmented volcanism, in which magma chambers are discontinuous features fed intermittently from below at regularly spaced points. Our current view of how rate of magma supply and, thus, spreading rate influence internal stratigraphy of oceanic crust has been developed primarily on the basis of remote geophysical techniques and can be tested through petrologic and structural study of drill core.

Deep rift valleys of slow-spreading ridges suggest that there is a low rate of magma supply and that magmatism is ephemeral. Although there is no seismic evidence for presence of a magma chamber at slow spreading ridges, gravity anomalies along the Mid-Atlantic Ridge (MAR) suggest that magmatic accretion is focused and/or that the crust is thicker at discre discontinuities between segments. Variation of ridge morphology within and between individual segments along MAR reflects cyclicity of tectonic extension and magmatism.

A study of earthquake focal mechanisms at MAR indicates that brittle failure under extension occurs to depths as great as 7-8 kmbsf, presumably where lithosphere has had a chance to cool between magmatic episodes. If crust created at slow-spreading centers is built by small, short-lived magmatic intrusions, it may be predicted that both brittle and ductile deformation occurs in Layer 3 while the crust is within the vicinity of a ridge. Because deformation would enhance hydrothermal flow, it is possible that the lower crust undergoes significant high-temperature alteration at a ridge. Ductile shear zones within the plutonic sequence recovered at the slow-spreading Southwest Indian Ridge (SWIR) during Leg 118 are interpreted as zones of enhanced permeability that acted as conduits for hydrothermal flow to the lower plutonics. Lower crust seismic reflectors in old Atlantic crust may represent zones of deformation and hydrothermal flow similar to those observed in the gabbroic core of SWIR and in the Bay of Islands ophiolite.

Until recently, it has been predicted that large, steady-state magma chambers would be maintained at fast-spreading ridges, producing a thick layered sequence in lower crust similar to layered sequences in the Oman ophiolite and continental layered intrusions. New geophysical data predict a narrow, thin lens of melt underlain by an extensive crystal-mush zone that may extend down to the base of the crust. Igneous stratigraphy of the lower crust at fast-spreading ridges should vary with relative size and geometry of the chamber and crystal-mush zone and may or may not show evidence for anhydrous ductile deformation. Evolution of cumulates and mechanism of melt extraction from long-lived crystal-mush zones is not known, but it must differ from crystal-mush zones in small, ephemeral magma chambers, as documented at SWIR. For example, a long-lived crystal-mush zone may explain why magmas erupted at fast-spreading ridges are generally more fractionated than magmas at slow-spreading ridges.

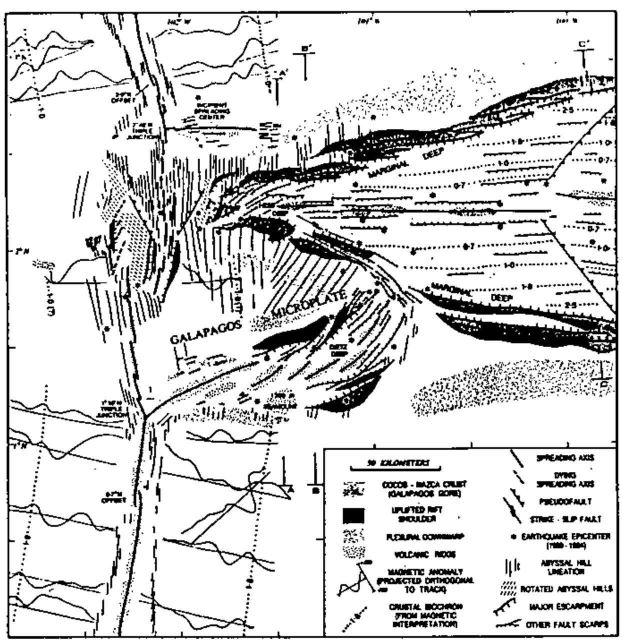

Figure 1. Location of Hess Deep at the western end of the propagating Cocos-Nazca spreading axis. (from Lonsdale, P., 1988, Structural pattern of the Galapagos microplate and evolution of the Galapagos triple junction, *J. Geophys. Res.*, 94, 251-293. Copyright by the American Geophysical Union.)

Presence of long-lived axial magma chambers at fast- spreading ridges would probably fix the brittle-ductile transition at the top of the thin melt lens, with extension within the magma chamber being taken up by laminar flow of the crystal mush. Because absence of ductile deformation should preclude early penetration of seawater into the lower crust, high-temperature hydrothermal alteration may not be a significant process beneath fast-spreading ridges, producing a pattern of hydrothermal alteration in the lower crust that is different from slow-spreading ridges. Thus, it is probable that lower crust generated at fast-spreading ridges is strikingly different from that formed at slow-spreading ridges. We anticipate that gabbroic core recovered during Leg 147 will provide not only important new insights into processes of crustal formation at fast-spreading ridges, but will also be an important comparison to gabbroic core recovered at SWIR.

Geological Background

Regional setting

Hess Deep is the deepest part of a westward-propagating oceanic rift valley that is opening up the eastern flank of the equatorial EPR in advance of the westward-propagating Cocos-Nazca spreading center (Fig. 1). The western end of the rift valley is 30 km from the EPR axis, where ~0.5 Ma EPR crust is broken by two 5 km-wide east-west grabens, which join a few kilometers farther east. As the rift valley is traced eastward, it broadens to 20 km and deepens to >5400 mbsl; its uplifted shoulders rise to <2200 mbsl. Approximately 70 km east of the EPR axis, the Cocos-Nazca spreading center begins to build a volcanic ridge in the rift valley, and rift escarpments are locally uplifted an additional 500 m at narrow horsts. Farther east, the wedge of newly accreted crust formed by north-south spreading expands to a mature, medium-rate (50 mm/yr total) spreading center, and the rift escarpments become the "rough-smooth boundary" of the Galapagos gore.

Hess Deep rift valley is propagating into a random part of EPR at a rate that matches the 65 km/m.y. half rate of EPR spreading. A steady-state interpretation of the present topography indicates that growth of the rift escarpments is correspondingly fast, with the 3250 m of total relief of the Hess Deep area being created as a rift propagates ~30 km, i.e., in 0.5 m.y. Because there are no obvious effects of the presence of Hess Deep on the EPR accretion process, Hess Deep crustal window is very different from a fracture-zone trough. This part of the EPR axis is not exactly typical, however, as it has been the western boundary of a Galapagos Microplate for the past 1 m.y., rather than part of the Pacific-Cocos or Pacific-Nazca boundary. Between 2°20' N and 1°50' N, this microplate is affected by a southward-migrating non-transform offset; whose pseudofault "wake" has recently been intersected by the western end of Hess Deep rift valley.

Fault scarps that bound the rift valley are seismically active, exposing 0.5 to 1.0 Ma EPR crust. Rocks observed on these scarps appear to have been freshly exposed and are not encrusted with manganese oxides. The rift valley is asymmetric, with Hess Deep ridge axis occurring closer to the southern than the northern wall. The southern wall rises in large steps to a crest of ~2200 mbsl, ~7 km south of the deep. The EPR plateau is fairly flat, and abyssal-hill lineations intersect the scarp. The northern scarp is twice as far from the deep. Abyssal-hill lineations generally extend up to the scarp except in the area of a rift-shoulder horst,

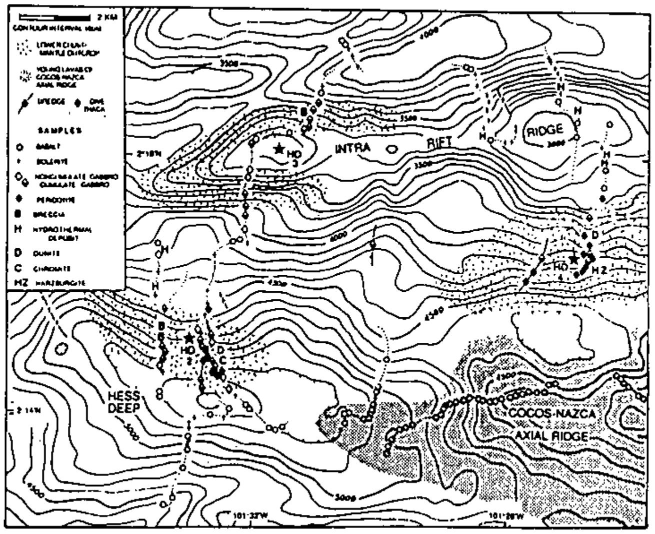

Figure 2. Geologic and bathymetric map of Hess Deep rift valley. Geology is based upon *DSRV Nautile* dive series and dredge results from *R/V Sonne* and *R/V Atlantis II*. Stars indicate locations of the three proposed drill sites. (From Francheteau et al., 1990, 1 Ma East Pacific Rise oceanic crust and uppermost mantle exposed by rifting in Hess Deep (equatorial Pacific Ocean), *Earth Planet. Sci. Lett.*, 101, 281-295.)

where a crustal block has been rotated. Soviet multichannel reflection profiling along the EPR flanks indicates that seismic layers 2A (lava sequence) and 2B (dike complex) are of normal thickness (~2 km) and that Layer 3 (gabbroic complex) may be somewhat thinner than usual (3-3.5 km). A major intra-rift ridge occurs between Hess Deep and the northern scarp and extends eastward, overlapping the western end of the Cocos-Nazca Ridge.

Geology of Hess Deep

Geology of the Hess Deep region was investigated during two submersible cruises: in 1988, floor and walls of the rift valley were studied with *DSRV Nautile* during a series of 22 dives; in 1989, rift valley walls were investigated with *DSRV Alvin* in a series of 11 dives. The following is a summary of results of these field programs.

Volcanics, sheeted dikes and, locally, gabbros crop out along scarps that bound Hess Deep rift valley. A talus ramp intersects the scarps within the ~1200 m-thick sheeted-dike complex. Dikes are generally subvertical and strike north-south, parallel to the EPR fabric. Gabbros underlie sheeted dikes within a rift shoulder horst along the northern scarp. In this region, dikes are locally rotated. Typically, a 100-300 m-thick layer of pillow lavas is separated from sheeted dikes by an intermediate zone of variable thickness (50-500 m), consisting of a mixture of extrusives and intrusives, including thick horizontal layers that may represent sills.

A complete, albeit dismembered, crustal section of EPR, including volcanics, sheeted dikes, gabbros and peridotites, is exposed on the floor of Hess Deep rift valley (Fig. 2). The slope that rises southward from the axis of Hess Deep averages 45° and is covered with basaltic and diabasic rubble. A 15-20° slope, stepped with secondary high-angle faults, extends north of Hess Deep for 5-6 km. Lower crustal rocks with rare peridotites crop out in ledges that dip into the lower slope from 5400 and 4500 mbsl. Mineralogical and geochemical data for plutonic rocks show that the most magnesian gabbros lie at the greatest depths, which may reflect formation within the lower level of a magma chamber. Semi-horizontal ledges of dolerite occur in a mainly sedimented terrain between 4500 and 4000 mbsl. A change in slope at 4000 mbsl marks the southern edge of the east-west-trending intra-rift ridge, which culminates at 2900 mbsl. At the western end of this ridge, gabbroic rocks crop out with isolated occurrences of volcanics. Further east, pillow lavas and dikes crop out along the crest of the ridge, and low-temperature hydrothermal activity has been observed.

Farther east, north of the tip of the Cocos-Nazca Ridge, plutonic and ultramafic rocks crop out between 4500 and 3500 mbsl along a gentle slope that is locally ≤10°. Cr-spinel-bearing dunites and harzburgites (up to 50% serpentinized) have been sampled from subhorizontal ledges that dip to the north. Gabbros have been recovered by dredges due west of this area (Fig. 3). Geology and structure between these two areas are not known.

Two alternative rifting models have been proposed for Hess Deep rift valley. One emphasizes vertical movement of mantle horsts or serpentine diapirs to expose mantle rocks. The other postulates rupture of the lithosphere by low-angle detachment faults similar to those mapped and imaged at rifting sites in continental lithosphere and recently postulated for regenerating axial rift valleys of slow-spreading ridges. Both models are compatible with observed bathymetry and outcrop distribution (Fig. 3). Preliminary interpretation of on-bottom gravity and seismic data recently collected across the intra-rift ridge indicates that the ridge is composed of high-density, high-velocity material. These new data suggest that the intra-rift rift ridge is a block of unserpentinized lower crustal rocks, supporting the latter model.

In both models, dolerites and basalts sampled along the western transect between 4500 and 4000 mbsl are interpreted as dismembered fragments of upper EPR crust. These dolerites and basalts are consistently poor in titanium, overlapping the field of Cocos-Nazca basalts but not the field of EPR basalts from the area, which are systematically richer in titanium. They do however, fall within the range of basalts from 13°N EPR. Therefore, it is not possible to determine unequivocally the origin of basalts exposed on the rift-valley floor. Whatever interpretation is preferred for formation of the intra-rift ridge, it is probable that opening of the rift left some imprint of previously-formed EPR crust.

Proposed Drill Sites

Primary scientific objective of Leg 147 is to recover a long, continuous section of gabbros and possibly the transition across petrologic Moho. HD-3 (Fig. 2) has been selected as the highest priority site on the basis of technical constraints (shallowest water depth, flat-lying outcrops). HD-2 and HD-4 are proposed as alternate sites in the event that HD-3 does not fulfill this objective.

HD-3: Crest of the intra-rift ridge (2°18′N, 101°31.6′W; 3075 m water depth)

Primary objective of HD-3 is to recover a long continuous core of plutonic rocks and possibly the transition across petrologic Moho into shallow mantle. HD-3 is located at the crest of the western end of the intra-rift ridge, in the vicinity of *DSRV Nautile* dive 5. Plutonic rocks are exposed as discontinuous, flat-lying outcrops, several meters in size, separated by sediment with sparse rock fragments. It is probable that the sedimented areas are underlain by a thin (1-5 m?) zone of talus. A hard-rock guidebase (HRB) would be required.

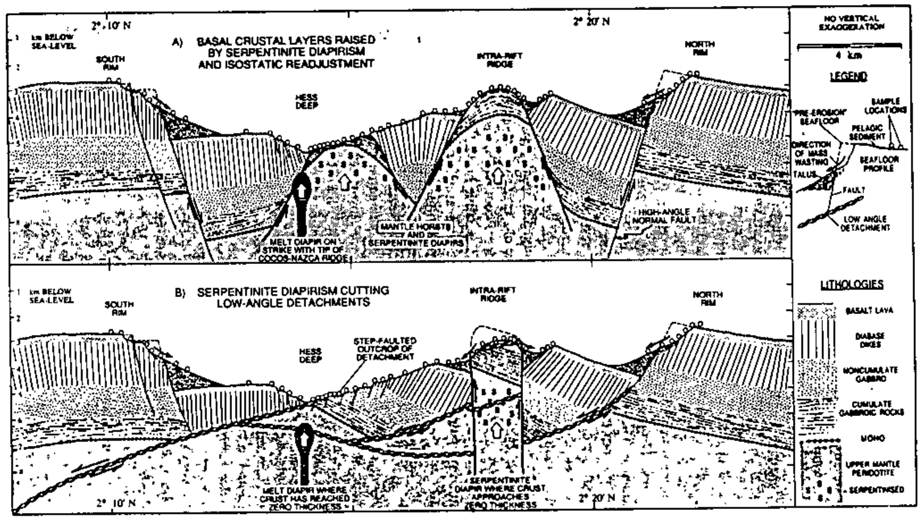

Figure 3. Interpretive cross sections depicting two models for surficial geology and topography of Hess Deep rift valley. Model A implies that the basal crustal layers have been raised by serpentine diapirism and isostatic readjustment. Model B invokes low-angle detachments with only restricted diapirism. Small open circles shown on the surface represent places where samples have been taken. Models are drawn with no vertical exaggeration. (From Francheteau et al., 1990, 1 Ma East Pacific Rise oceanic crust and uppermost mantle exposed by rifting in Hess Deep (equatorial Pacific Ocean), *Earth Planet. Sci. Lett.*, 101, 281-295.)

HD-2: South of the intra-rift ridge and north of the deep, south of HD-3 (2°15.2'N, 101°33'W; 5000 m water depth)

Objective of HD-2 is to recover a long, continuous section of plutonics and possibly the transition across petrologic Moho into shallow mantle. HD-2 is located in an area where plutonic rocks are exposed as subhorizontal outcrops, along a 15-20° slope. These outcrops are separated by sedimented areas and talus piles, some of which appear to be fairly recent. Plutonic rocks look more fragmented than at HD-3 and, therefore, will probably be more difficult to drill. There is evidence of low-temperature hydrothermal alteration. Some mylonites were recovered by submersible. HRB would be required.

HD-4: South of the intra-rift ridge and north of the Cocos-Nazca Ridge (2°16.8'N, 101°26.6'W; 4100 m water depth)

Objective of HD-4 is to recover a continuous section of shallow mantle. In the area of HD-4, dunites with Cr-spinels and foliated harzburgites (up to 50% serpentinized) are exposed along a gentle slope. Degraded outcrops are separated by 30-50-m-wide ponds of sediment. Presence of dunites in the section, by analogy with similar sections in ophiolites, suggests that this area may expose the transition zone across lower plutonics into the mantle. A hole at this site will be the first opportunity to recover the transition zone and upper mantle beneath a fast-spreading ridge. Petrofabrics and strain-stress history will provide information on flow and creep processes in the shallow mantle beneath a ridge. HRB would be required.

Operations

Drilling strategy and time estimates

JOIDES Resolution will depart from San Diego on 26 November 1992 and return to Panama on 21 January 1993. It will be on site for 42.6 days (39.1 days drilling and 3.5 days logging), and there will be 8.1- and 5.3-day transits at the beginning and end of the cruise, respectively.

Once in the Hess Deep region, the drill ship will drop a beacon and proceed to drill site HD-3. The TV camera system will be lowered on the drill string, and a ~500 m by 500 m survey will be conducted to determine potential locations for HD-3. Once the best target is determined, a HRB will be deployed. Slope of the guide-base will be determined, and the local area will be viewed to ensure that the site offers optimal drilling conditions. If it is satisfactory, the hole will be started with a conventional rotary bit. Once coring commences, drilling will continue at HD-3 until the end of the leg, saving appropriate time for logging (penetration of ~500 mbsf anticipated).

In the event that the initial drill site is not satisfactory, or that initiation of the hole fails for technical reasons, the HRB will be moved to another location within the surveyed area, the new area will be surveyed, and drilling will re-commence. This procedure will continue until a hole is initiated and core is recovered.

In the event that no suitable location can be found at site HD-3 or that HD-3 does not meet the scientific objectives, the ship will proceed to HD-2 and the same site survey plan will be followed. Similarly, if drilling problems are encountered at HD-2 or if the scientific objectives are not met at HD-2, the ship will move to HD-4.

Downhole measurements

Downhole measurements will be conducted at the end of the leg to determine structure and seismic stratigraphy within the borehole, refine lithostratigraphy and extent of alteration and determine crustal magnetization. A total of 3.5 days have been scheduled for the logging program, which will include, in order of priority: (1) standard tools, including FMS (formation microscanner), quad-combo (resistivity, sonic, density) and geochemical tool; (2) digital BHTV (bore-hole televiewer); (3) VSP (vertical seismic profile); and (4) magnetic susceptibility (depending on tool availability). In the event that logging time is lost due to tool failure or other technical problems, the lowest priority logs will not be run. If more than the allotted time is available for logging because of drilling problems late in the cruise, a packer experiment will be run.

Leg 148 Prospectus: Deepening Hole 504B

Introduction

During Leg 148, *JOIDES Resolution* will return to deepen Hole 504B in the eastern equatorial Pacific (Fig. 1). Primary purpose is to core through the dike/gabbro and/or layer 2/3 transition. Hole 504B is now the deepest hole ever drilled by DSDP/ODP, and extends almost three times as deep into oceanic basement as any other hole. Leg 148 is scheduled for 26 January to 10 March, 1993. About 39 days on site will be devoted to coring and downhole measurements.

Located in 5.9-m.y.-old crust formed at the Costa Rica Rift, Hole 504B presently extends to a depth of 2 km and is the only DSDP/ODP borehole that unequivocally penetrates through extrusive pillow lavas into sheeted dikes predicted from studies of ophiolites (Fig. 2). It therefore represents the most important reference hole for the structure and composition of "normal" oceanic crust, and provides the best opportunity for sampling the transition between sheeted dike complex and underlying gabbros in the context of a complete crustal section.

Leg 148 will be the eighth DSDP/ODP expedition to occupy Hole 504B (Fig. 2). The hole was originally spudded during Leg 69 in 274.5 m of sediments overlying basaltic basement, and was then deepened and/or logged during parts of six other DSDP/ODP legs: 70, 83, 92, 111, 137 and 140.

Although previous coring, logging and geophysical programs at Hole 504B achieved unprecedented scientific success, the operational history of the hole has been marred by downhole hardware losses and relatively low rates of core recovery. Leg 111, in particular, experienced several premature bit failures, an overall core recovery rate of <13%, and loss of a large-diameter diamond coring assembly at the end of the leg. Lack of time and proper equipment forced temporary abandonment of the hole before lost junk could be removed. Leg 137 cleaned Leg 111 junk out of Hole 504B, but left an 18-m outer core barrel with a diamond drilling bit at the bottom of the hole. After successfully cleaning the hole again, operations during Leg 140 deepened Hole 504B to 2000.4 m. Coring with improved RCB bits was straightforward. At the end of Leg 140, Hole 504B was stable, open and clean.

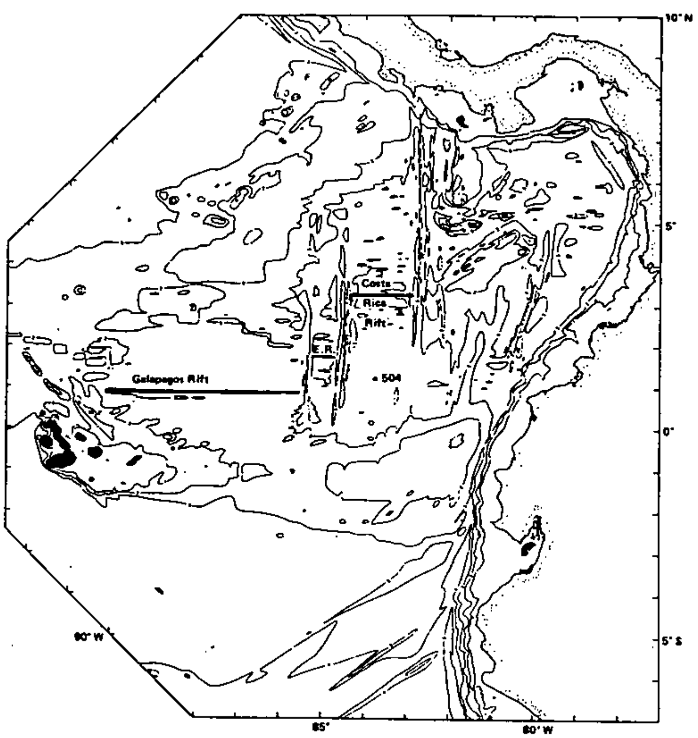

Figure 1. Location map. (After Hobart, M.A., Langseth, M.G., and Anderson, R.N., 1985, A geothermal and geophysical survey on the south flank of the Costa Rica Rift: sites 504 and 505, In Anderson, R.N., Honnorez, J., Init. Repts. DSDP, 83: Washington, D.C., US Govt. Printing office, 517-528.)

Summary of DSDP/ODP Results From Hole 504B

[This summary is based upon in an appended bibliography available in the complete preliminary report.]

Hole 504B is located about 200 km south of the Costa Rica Rift (Fig. 1) and presently extends through 274.5 m of sediment and 1725.9 m of basement, for a total penetration of 2000.4 m.

Seismic surveys, heat-flow measurements, downhole temperature (Fig. 3), porosity and permeability data indicate that the crust at Site 504 is at an interesting stage in its evolution. At a relatively young crustal age, thick, even sediment cover has mostly sealed basement against pervasive hydrothermal circulation, and crustal temperatures vary closely about values consistent with predicted, conductive plate heat transfer. Recent detailed heat flow work and numerical simulations indicate that convection still occurs in the permeable, uppermost 500 m of basement beneath impermeable sediment cover, partly controlled by presence of isolated basement faults and topographic highs.

The 1725.9 m of basement cored in Hole 504B consists of 571.5 m of pillow lavas and minor flows, underlain by a 209-m zone of transition into 945.4 m of sheeted dikes and massive units (Fig. 2). Lithostratigraphy has been determined from core recovery averaging ~20% (25% in the pillows, 10-15% in the dikes); it is generally corroborated by an extensive suite of geophysical logs, except that logs suggest a sharper transition between pillows and dikes. To date, lithostratigraphy sampled in Hole 504B is the best direct verification of the ophiolite model of oceanic crust. However, this verification is only partial, as the lowermost 3-4 km of oceanic crust has never yet been sampled *in situ*.

Basement rocks recovered are fine- to medium-grained, plagioclase-olivine + clinopyroxene + chrome spinel phyric basalts, with aphyric types more abundant with depth. Coarsest unit recovered during Leg 140 has an average grain size of 1.5 mm, but, in terms of texture and grain-size, is clearly a diabase and not a gabbro. While there is not a simple, systematic increase in grain size with depth, coarser-grained diabases do become more common, whereas glassy chilled margins virtually disappear, consistent with generally deeper dike emplacement at higher temperatures.

All recovered basalts are mineralogically and chemically altered to some extent. Detailed studies of downhole variation of secondary minerals and mineral assemblages document existence of three major alteration zones:

1. Upper alteration zone in pillows (274.5-584.5 mbsf) displaying typical effects of oxidative alteration commonly observed in DSDP cores.
2. Lower alteration zone in pillows (584.5-836 mbsf) presumably produced by reactions with reducing, low-temperature solu-

tions at low seawater/rock ratios. This zone is characterized by smectite and pyrite.

3. Hydrothermally altered zone (898-2000.4 mbsf) producing the first *in situ* samples of ocean floor basalt containing greenschist-facies alteration minerals.

Pronounced changes in alteration mineralogy observed from 836 to 898 mbsf are interpreted to have resulted from a steep temperature gradient across the top of the transition from pillow lavas to underlying dikes. This is attributed to mixing of high-temperature (~ 300°C) hydrothermal fluids upwelling through relatively "tight" dikes with larger volumes of lower temperature (~100°C) seawater fluids circulating in the pillow lavas, which have orders of magnitude greater values of bulk porosity and permeability than the underlying dikes.

Rocks in the dike section are generally only partly altered (~20%), but are more extensively recrystallized (up to 100%) along veins and in cm-sized patches around former pore space, indicating permeability and porosity controls on alteration. Some significant variations in mineralogy and chemistry occur with depth in the dikes, however. Fibrous actinolite in the upper dikes gives way to well-crystallized pleochroic green amphibole in the lower 300 m. In the upper dikes, plagioclase is altered to albite and pyroxene is mostly unaltered, whereas in the lower 400 m plagioclase is only slightly altered and pyroxene is extensively replaced by actinolite and amphibole. Olivine is totally altered in the upper dikes, but relict olivine is present locally in the lower 350 m, particularly in the interval 1710-1790 mbsf, reflecting locally more restricted circulation and lower water-rock ratios in the lower dikes.

Changes in mineralogical effects with depth in the dikes are consistent with increasing temperatures of hydrothermal alteration downward, and with penetration into the top of the transition from dikes to underlying gabbros.

Despite effects of alteration, primary composition and variation of recovered basalts can be reliably established. Lavas and dikes recovered are remarkably uniform in composition. The rocks can be classified as olivine tholeiites with compositions that are similar to moderately evolved mid-ocean ridge basalts (Leg 140: MgO = 7.7-10.1%, Fe_2O_3total = 8.1-11.4%, Ni = 79-189 ppm, Mg value = 0.60-0.75). However, they are strongly depleted in incompatible elements (Leg 140: TiO_2 = 0.67-1.1%, Nb ~0.3- 0.7 ppm, Zr = 35-58 ppm), suggesting that they may be products of multistage melting of a normal MORB source. These characteristics encompass >98% of all investigated samples recovered, through 2000 mbsf. There appear to be no major igneous enrichment or depletion trends with depth, nor are there large-scale fractionation trends, suggesting the presence of a steadily replenished magma chamber.

The transition zone is enriched in Cu, Zn and S due to sulfide mineralization, whereas there is a systematic Zn loss with depth at the bottom of the hole, from an average of 70 ppm at 1500 mbsf to 30 ppm at 2000 mbsf. This Zn depletion is similar to metal depletion observed in basal dikes of ophiolites and may be a source for hydrothermal Zn and Zn-enrichment in the mineralized transition zone.

Hole 504B has been surveyed with the most extensive suite of *in situ* geochemical and geophysical experiments in any submarine borehole. Geophysical data indicate that *in situ* physical properties of the crust change dramatically across the transition from pillow lavas to sheeted dikes: *in situ* sonic and seismic velocities and electrical resistivity increase sharply, while bulk porosity and permeability drop by orders of magnitude. Sonic and seismic data are generally consistent with a sharp layer 2B/

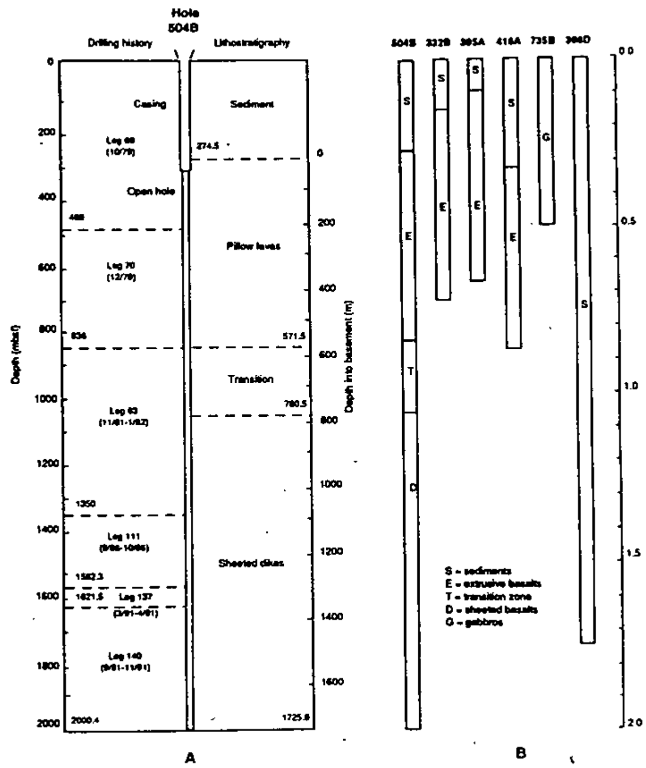

Figure 2. A. Schematic drilling history and lithostratigraphy of Hole 504B through Leg 140. B. Generalized lithostratigraphy of selected DSDP/ODP holes.

2C boundary at the top of the sheeted dikes. Sonic data, but not the much longer-wavelength seismic data, indicate a thin layer 2A, consisting of the uppermost 100-200 m of highly porous pillow lavas. This layer corresponds to a highly permeable, underpressured zone into which ocean bottom water has been drawn since the hole was drilled (Fig. 3). Layer 2B comprises the lowermost 500 m of pillows, in which the original porosity has been partially sealed by alteration products.

Temperature profiles measured on several previous legs indicate variable drawdown of bottom seawater through the hole and into the upper 100 m of basement. Rate of flow decreased from Leg 69 through Leg 111, but was found to be vigorous again on Leg 137, and then decayed to Leg

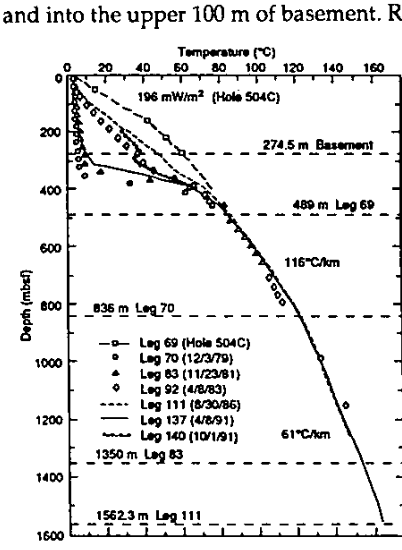

Figure 3. Composite of temperature logs obtained in Hole 504B during legs 69, 70, 83, 92, 111, 137 and 140. The depressed temperatures in the upper 400 m reflect the downhole flow of cold ocean bottom water through the casing into the upper 100-150 m of basement.

140 values (Fig. 3). A gradient inversion between 283 and 288 mbsf measured prior to operations on Leg 140 may be due to differential thermal rebound of the wallrock or possibly to local fluid inflow from basement into the borehole. The linear temperature gradient in the deeper hole is still 61°C/km, which extrapolates to a temperature of 195°C at 2000 mbsf.

A vertical seismic profile (VSP) experiment conducted during Leg 111 shows a relatively weak seismic reflector between 1660 and 1860 mbsf, which was interpreted as the transition between sheeted dikes in seismic Layer 2C and gabbros in Layer 3. Leg 140 clearly penetrated through this depth, but the "boundary" was not the transition from dike complex into gabbros. Observed changes in intensity of alteration and in physical rock properties may have caused an impedance difference somewhere around 1750 mbsf, which resulted in the observed reflector. Changes in alteration mineralogy, increasing average grain-size, general increase in amphibole abundance and absence of glassy chilled dike margins in the newly drilled section all suggest that Leg 140 reached the lower part of the sheeted dike section.

Operations Plan

Leg 148 is scheduled to leave Panama City on 26 January 1993 for a two-day transit to Hole 504B and return to Panama City on 10 March. The schedule includes a total of 4 days of transit between Hole 504B and Panama City, and 39 days on site for coring, logging and special experiments. Prior to coring, borehole temperatures will be measured and water samples will be taken.

Legs 137 and 140 demonstrated that Hole 504B can be cored using improved RCB bits at a penetration rate of 1.0-1.5 m/hr, and recovery of ~10-15%. Recovery was better (50%) using the Christensen core barrel and diamond bits, but drilling rates were low. During Leg 137, penetration with the Christensen core barrel was limited to 2 m/round trip of the drill string, because cores cut using Christensen core barrels are retrieved by tripping the entire drill string and not by wireline. Diamond bits used with the Christensen core barrel were made of the hardest matrix material available, but were worn smooth after only 2 hr rotation.

For Leg 148, the RCB system will be used exclusively. Operations on Leg 148 will employ RCB bits specially hardened to increase rotating time from ~15 to 40-45 hr/bit. In this way, Leg 148 should continuously core at least 300-400 m deeper in the time available, with acceptable levels of core recovery inferred from past experience.

Hole 504B

1°13.611'N, 83°43.818'W; sed. thickness: 274.5 m; water depth 3460 m.

Proposed Drilling Program: Reenter existing reentry cone. Run temperature logs and borehole water sampling (~2 days). RCB core into basement to deepen through the layer 2/3 transition (~32 days).

Logging: Temperature measurements and borehole water sampling prior to coring. After coring, run quad combo (gamma-ray, velocity, resistivity, density/porosity), FMS, geochemical combination, digital borehole televiewer, magnetometer and possibly temperature log (~3 days). Then, conduct VSP (~1 day) and test permeability with packer and a flowmeter tool (~1 day). Spike borehole with NaBr tracer if time allows. Depending on coring progress, logs and experiments may be conducted slightly before the end of allocated coring time, allowing for a final coring trip at the end of operations. Logs are to be run only in previously unlogged sections (DMP recommendation). Order of logging may be adjusted depending on thermal conditions. Possible additional logs include shear wave tool, WHOI high-temperature borehole instrument and CSM high-temperature resistivity tool, all pending time availability, successful land tests before Leg 148 and endorsement by Scientific Party.

Objectives: Coring through the layer 2/3 transition.

Nature of Rock Anticipated: Basalt (sheeted dikes) and gabbro.

Wireline Services Report

Leg 140: Hole 504B

The downhole measurement program comprised two phases. Phase 1 preceded fishing operations and involved two separate runs: temperature and Formation MicroScanner (FMS). This short program was run after re-entry in order to monitor renewed vigorous downflow of ocean-bottom water into basement detected six-months earlier during Leg 137. Phase 2 followed coring and involved five runs, including temperature, geochemical and geophysical combinations, borehole televiewer (BHTV), and a flowmeter experiment. Except for the flowmeter, whose measurements were restricted to the upper 200 m of basement, all downhole measurements were made in the newly-drilled section.

Phase 1 Logging (Pre-Fishing/Coring)

High-Resolution Temperature

Downhole sensor was the same as that used during legs 111 and 137. Measurements were made from sea-floor to 550 mbsf, where recorded temperature was identical to that measured at the same depth on previous legs.

FMS

Recording started at 1575.0 mbsf, well within the dikes and ~20 m above the top of the fish left in the hole at the end of Leg 137. Shortly thereafter (at 1563.0 mbsf), the telemetry link with the tool was lost owing to high downhole temperature (~165°C). While pulling out of the hole, communications were reestablished in the cooler, upper part of the hole and recording was resumed at 985.5 mbsf. A series of FMS images were consequently recorded over the extrusive section of the volcanic pile, up to 280.5 mbsf (5.0 m below the casing shoe).

Phase 2 Logging (Post-Coring)

High-Resolution Temperature

Downhole sensor was identical to that used in Phase 1. The goal was to measure bottom hole temperature after 6 weeks of fishing and coring activity and set up a strategy for further downhole measurements. A temperature of 143.6°C was measured at total depth (2000 mbsf) and logging was, therefore, able to continue without further cooling of the hole between runs. In order to evaluate equilibrium temperature at total depth, a stationary recording was made and indicated a 2.0°C temperature increase over a period of 60 minutes.

Geochemical Combination

The geochemistry tool, limited to 150°C, is the most heat-sensitive of the Schlumberger sensors used on *JOIDES Resolution*. It was, therefore, run immediately after the temperature tool, and was not run in the bottom 100 m. Data were recorded from 1896 to 1811 mbsf, where the neutron generator stopped operating due to high temperature. It revived at 1686 mbsf and logging resumed up to 1350 mbsf (into the Leg 111 dataset). At the end of logging operations, the remaining 6 hours were used to run the geochemical combination back into the hole, and log from 1826 to 1648 mbsf, yielding continuous data in the newly-cored interval.

Geophysical Combination (Acoustic Velocity/Resistivity)

As even higher temperatures were expected, heat-sensitive nuclear sensors were removed from the string, which therefore comprised dual laterolog (DLL) and long-spacing velocity sensor (LSS). Although two passes at different recording velocities were made over the cored interval (from 1990 to 1480 mbsf), velocity data were of extremely poor quality.

BHTV

Digital BHTV data were recorded from 1985 to 1885 mbsf and from 1685 to 1485 mbsf. Continuous telemetry interruptions between surface panel and downhole tool prevented coverage of the entire interval.

Flowmeter Experiment

A flowmeter experiment was performed in the upper part of basement. Four passes (two upward and two downward) were recorded at different logging velocities over the most permeable part of basement (256 to 468 mbsf), followed by calibration in the drillpipe.

Data Analysis

Temperature (recorded prior to coring)

The temperature profile recorded immediately after re-entry between 200 and 550 mbsf is characterized by a gradient inversion in the uppermost basement (283 to 288 mbsf), probably due to local fluid inflow from basement into the hole. Below this upper section, the temperature gradient locally reaches values as high as 500°C/km, explicable by borehole fluid intake into fractured basement. Profiles recorded during legs 111, 137 and 140 (Figure 1) show large temporal variability of upper basement hydrological activity. Strong drawdown of cold ocean-bottom water is indicated by the Leg 137 profile. Leg 111 and 140 profiles show much weaker downflow in the cased interval (sedimentary section), with a magnitude of ~1.2 m/hr in both cases.

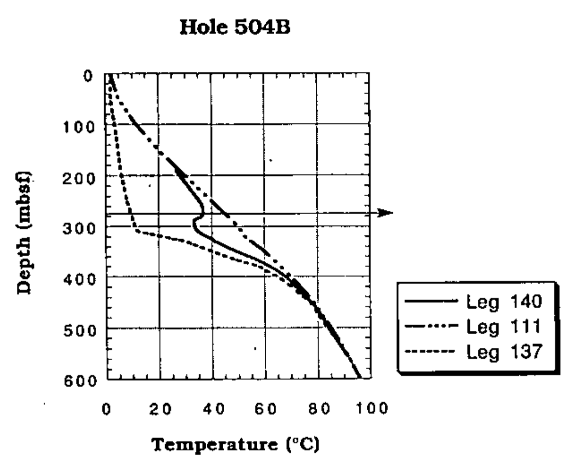

Fig.1 Temperature profiles recorded in Hole 504B with the BRGM high-resolution temperature probe during legs 111, 137 and 140.

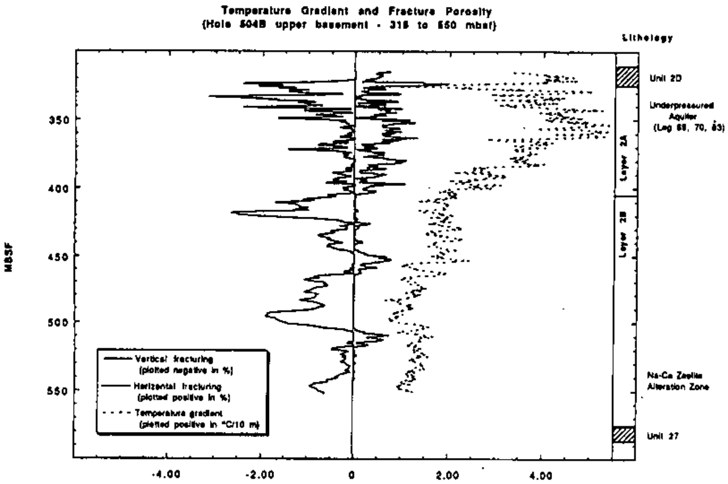

Fig. 2 Temperature gradient (expressed in °C/10 m) and fracture porosity (expressed in %) plotted versus depth over the section of upper basement constituting the main site of water influx after initial drilling (e.g. during DSDP legs 70, 83, and 92). Horizontal fracture porosity is plotted as positive values and vertical fracture porosity is plotted as negative values.

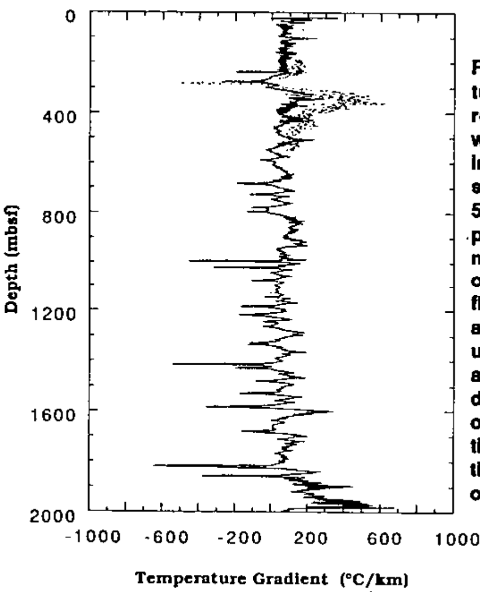

Fig. 3 Temperature gradient recorded after 4 weeks of coring in the lower section of Hole 504B and computed with a moving average of 2.0 m. Active fluid movements are still visible in upper basement, as well as over discrete regions of the dike section where negative values are obtained.

Below 250 mbsf, departure of the Leg 140 profile from that recorded during Leg 111 suggests some cold fluid inflow from upper basement to the borehole. This recent upper basement hydrological activity contrasts with the previous gradual re-equilibration of underpressure observed between 1979 and 1986. The previously-unseen and pronounced anomaly on the Leg 137 profile was reduced significantly in <1 year. Such rapid, short-lived variations are associated with modifications of hydraulic conductivity of upper basement, due either to local tectonic activity or to stresses associated with previous reduction of underpressure. Below 450 mbsf, the three profiles coincide and indicate a relatively constant (over 10 years) thermal regime in the least permeable section of Hole 504B.

Fracturing in Upper Basement

In an effort to investigate the relationship between fracturing, heat and fluid flow around Hole 504B, the Leg 140 temperature gradient recorded after re-entry was compared to fracture porosity profiles derived from analysis of electrical resistivity data obtained with DLL during Leg 111. Such data outline the principal mode of fracturing (either horizontal or vertical), and a minimum value for fracture porosity is computed.

The zone of thermal gradient inversion located in the upper 15 m of basement corresponds to a region where horizontal fractures dominate. Similarly, the 1.0 m-thick pillow unit located just above the massive flow acting as a permeability cap on the underpressured aquifer (lithologic Unit 2D) is characterized by horizontal fracturing at 310 mbsf. This thin, fractured pillow unit was the site of the abrupt change in temperature recorded in upper basement during Leg 137 and absent from the Leg 140 profile. Observed movement of fluids (into or out of basement) is thus apparently favored by the presence of a horizontal fracture system.

Within Layer 2B, from 400 to 550 mbsf, steps in thermal gradient define three zones (Figure 2). These zones, of comparable thicknesses, are vertically fractured and separated by sections of horizontal fracturing located at 400, 450 and 510 mbsf. The deepest zone is characterized by a distinct paleoflow regime, with presence of sodic and calcic zeolites.

Such detailed analysis provides a means to study porosity structure of upper basement in great detail and to compare it with either past (e.g., alteration minerals) or present (e.g., temperature) dynamic geological parameters. Such analysis is constrained by vertical resolution of standard downhole sensors such as DLL (~1 m). In the near future, analysis of FMS data should allow even more detailed analysis, due to azimuthal orientation of borehole wall images and cm-scale resolution of the electrode array.

Borehole Electrical Images

Initial processing of raw FMS data into images was carried out onboard ship during Leg 140. Once created, resistivity images were transformed into resistivity maps of the borehole wall using calibrated shallow laterolog (LLs) data obtained during Leg 111. These resistivity maps, with resolution ~200 times that of DLL, should provide, after analysis on a dedicated workstation, an unprecedented description of fracturing throughout the extrusives.

In the lower interval of FMS images, recorded in dikes (1563 to 1575 mbsf), 81 fracture traces were identified and mapped using a transparent overlay. Fractures are mostly steep, dipping toward the south and southeast. Borehole ellipticity outlined by FMS calipers over this interval is oriented N105°E, in general agreement with minimum stress direction (N117.5°E) derived from analysis of Leg 111 BHTV images.

Temperature (recorded after coring)

Temperature profile recorded at the end of Leg 140 shows lower-than-equilibrium temperatures owing to cooling associated with coring. Active fluid movement is still observed in upper basement (Figure 3), the most permeable section of the hole, while negative temperature gradients are obtained over discrete intervals in the diabase. Such intervals probably correspond to fractured, permeable zones where fluid was injected during coring, and hence were efficiently cooled. In the bottom 200 m, a sharp increase in gradient is observed in the section where significant zinc leaching is reported. This sharp increase might result from limited time available for coring-associated cooling over this interval.

WG Reports

Offset Drilling Working Group

The report published here is a shortened version of the OD-WG report. The complete report is available from the JOIDES Office.

Definition

Offset-section drilling is a strategy to investigate complex, laterally-heterogeneous ocean crust and shallow mantle by drilling multiple partial sections of crustal and mantle rocks in tectonic windows. Such windows are provided by propagating rifts, fracture zone walls and transverse ridges, and median valley master faults.

Background and Thematic Objectives

Oceanic lithosphere underlies ~60% of the Earth's surface. Its uppermost part, seismically-defined crust, is typically no more than 6 or 7 km thick, and yet to date less than half of the oceanic crustal section has been drilled. Thus, although the plate tectonic paradigm has provided a first-order picture and model for formation of oceanic lithosphere at accretionary plate boundaries, we are still remarkably ignorant of the nature of the lower crust, the upper mantle from which it is derived, and the chemical and physical processes which take place at these depths. Potential constraints supplied by seismic studies and the ophiolite analogy only serve to underline weaknesses of these constraints and uncertainties which still surround the nature of oceanic lower crust and upper mantle.

Exposures of deep crust and uppermost mantle in oceanic areas were, until quite recently, thought to be rare and typically associated with transform fault processes. St. Paul's rocks in the equatorial Atlantic was perhaps the best-known example. The remarkable, and still largely unexplained, uplifts and faulting which produce such transverse ridges still provide some of the best prospects for drilling lower crust and upper mantle, either on fracture zone walls or on transverse ridges themselves. Several of the latter have been beveled at sea level and now provide ideal drill sites at relatively shallow depths.

Within the past decade, however, it has been realized that there are other settings in which deeper crustal levels and upper mantle have been exposed by faulting. These areas are the result of tectonic extension, either of preexisting crust ahead of a propagating ridge, or of newly-formed crust during a lengthy period of amagmatic extension at a slow spreading ridge crest. In the eastern Pacific, for example, tectonic extension and crustal thinning ahead of ridge propagators on the northeast margins of Galapagos, Easter and Juan Fernandez microplates has produced Hess, Pito and Endeavour deeps, respectively, and in each case block faulting and lower crustal exposures. Even in the fast-spread crust of the Pacific, therefore, where tectonic windows into deeper crust were once thought to be rare or non- existent, prospects for obtaining a composite section of crust and uppermost mantle by offset drilling now look good.

Along the relatively slowly spreading ridges of the Atlantic and Indian oceans, there appear to be sites at which a prolonged period of amagmatic spreading results in tectonic extension and exposure of lower crustal and upper mantle levels, probably on low-angle detachment fault surfaces which form the median valley wall. These sites, along with exposures on fracture zone walls and transverse ridges more characteristic of slow-spreading ridges, enhance opportunities for offset drilling in slow-spreading crust.

The principle of offset-section drilling is simply stated. In a particular target area (tectonic window) a number of holes, each ~1 km in depth and starting at a different 'stratigraphic' level, would be designed to produce, when 'stacked', an overlapping, composite section of the crust and upper mantle. What is less simply stated, however, is what is meant by crust and mantle, and in particular the boundary between them, the Moho. Clearly, the Moho as originally defined is an artifact of refraction seismology. Now, however, there is also reference to a "seismic reflection" Moho and a "petrologic" Moho. How do these relate to each other and how does seismic Moho relate to lithology? There is a distinct possibility that correlations vary from place to place, as does seismic character of the Moho. In places, the boundary may be gradational; in others, perhaps where the seismic signature is sharp, it may be produced by a low-angle detachment fault.

Conceptual models for the nature of oceanic lower crust and upper mantle are constrained by seismic studies and direct sampling of the ocean floor, and by analogy with ophiolites. A consensus view appears to be that crust is mafic in character and mantle ultramafic, the contrast between gabbroic lower crust and unserpentinized ultramafic mantle providing the appropriate seismic velocity contrast. However, petrologists often prefer to define crust as that part of the section that is of magmatic origin, which probably includes ultramafic cumulates beneath the mafic section. Therefore, petrologic Moho would be placed between these cumulates and residual mantle beneath. Serpentinization of the uppermost part of the ultramafic section could place seismic Moho at a variety of possible depths, depending on availability of water and ambient temperature. Indeed, seismic velocities throughout the crust are often more a function of porosity, extent of fracturing and degree of alteration than of primary lithologies. It is foolhardy, therefore, to equate particular velocities with particular lithologies.

There are also problems in equating ophiolites with oceanic lithosphere formed in main ocean basins. Most ophiolites, including those that are best exposed and studied, are now thought to have been formed above a subduction zone, i.e., in a fore-arc or back-arc/marginal sea setting. As a consequence, their lava geochemistry differs, in detail, from that of mid-ocean ridge basalts and their ultramafic cumulates are wehrlitic, i.e., pyroxene-rich, in contrast to those recovered from the ocean floor. A number of other processes and characteristics are probably different because of enhanced volatile content of supra-subduction zone magmas.

A feature of the tectonic settings outlined above, which provide windows into oceanic lithosphere, is that any ultramafics exposed are invariably serpentinized. This raises the question as to what extent serpentinization is a consequence of structure or structure a consequence of serpentinization. Either way such areas could be anomalous and it might not be possible, within the context of offset drilling, to sample a more typical seismic Moho there as a result. On the basis of existing data, it has not been possible to identify a locality at which such an objective might be met. This does not mean, however, that such a locality does not exist. Further surveys may reveal such a site.

Even if serpentinized, these ultramafics, some or all of which might form seismic mantle elsewhere, will yield information on the nature of any ultramafic cumulates and fabric and melting relations in residual petrologic mantle beneath. In this report, therefore, we have accepted common usage and equate the mafic section to crust and ultramafics to mantle, if in the appropriate stratigraphic relationships and not remobilized as a result of intense serpentinization.

Shallow oceanic mantle is the complementary residue of generation of oceanic crust. As principal component of the lithosphere, determining its composition and heterogeneity is critical in order to determine global fluxes in the Earth. Major developments in techniques, data and ideas within the past decade or so raise numerous questions regarding processes occurring in upper oceanic lithosphere. For example, while there is general agreement that magmas erupted at ocean ridges are the result of melting accompanying asthenospheric upwelling between diverging plates, little is known about how melt forms, aggregates and migrates through the mantle, and what interactions exist between it and shallow mantle as it ascends toward the crust. Numerous detailed models, based largely on conjecture, and poorly constrained by observations on mantle rocks, have been used to invert basalt compositions to infer mantle processes. For many years batch melting, in which mantle and melt have been held together throughout the melting process, was favored. More recently, another class of models, which can be best described as open system melting, where melt is continuously removed from mantle as it forms, has gained sway. Additionally, there is a growing awareness that mantle melt may react at shallow depth with mantle as it passes to the surface, perhaps substantially altering its composition, though it may not change the actual mass of melt produced.

Dredge and submersible samples from isolated outcrops and debris flows do not preserve key internal stratigraphic relationships necessary to understand melt migration, and lack orientation from which to interpolate patterns of shallow mantle flow. Moreover, detailed study of these rocks has been limited by lack of fresh samples due to surficial weathering and localized alteration associated with faults on which the rocks are exposed. These problems can be overcome by drilling long continuous sections of mantle rock below the seafloor weathering zone and through hydrothermal alteration associated with late-stage faults.

Over the past decade, there has been growing appreciation of the complexity of the internal structure of ocean crust, both igneous and tectonic. In part, this is due to new models for a segmented crust, in which ocean ridges are viewed as a series of shield volcanoes overlying regularly-spaced magmatic centers undergoing continuous extension to form ribbons of ocean crust. These models predict major lateral changes in crustal stratigraphy and composition from the central to distal portion of a ridge segment. Implicit to these models are underlying patterns of mantle flow, which require focusing of mantle flow, and therefore melt migration out of the mantle beneath the magmatic centers at midpoints of ridge segments. There is considerable controversy, however, as to whether these models can explain crustal structure at both fast- and slow-spreading ridges. Most researchers feel that a more uniform, sheet-like flow of melt and mantle exists beneath fast-spreading ridge crests. If correct, this implies significantly different crustal structure as spreading rate varies.

A test of these models can be made by looking for patterns of compositional variation in mantle rocks exposed along ocean ridges from which gradients in melting or melt extraction can be inferred. In addition, such sampling could obtain oriented samples preserving mineral fabrics, allowing direct interpolation of patterns of mantle flow, where orientation of mineral fabrics anticipated for focused diapiric mantle flow would contrast sharply to those for the more uniform sheet-like flow anticipated beneath fast-spreading ridges.

Primary agent of crustal construction at spreading centers is igneous activity, whether extrusive, forming different types of lava flow, or intrusive, forming dikes or sills at shallow levels and plutons at greater depth. Such activity is accompanied by hydrothermal and tectonic processes, which also affect the newly-formed crust. Models of these interactions are still at a preliminary stage, since there are clearly complex feedback mechanisms that link all types of process.

The general structure of interaction is considered to involve the relationship between a brittle carapace at the spreading axis, which thickens with crustal age, and a plastic substrate. These are separated from each other by a narrow brittle-ductile transition zone. The ductile zone is maintained hot and hence ductile by magma rising through underlying mantle. Mean flux of magma must be related closely to spreading rate, because overall crustal thickness is independent of spreading rate, but fluctuations of magma supply in space and time must lead to variations in heat supply across the brittle-ductile transition and perhaps to vertical movements of the transition. Heat supply drives hydrothermal circulation through the brittle, cracked carapace, in which permeability structure is largely created by faults generated by tectonic processes. Hydrothermal circulation cools and perhaps thickens the brittle carapace and thus controls the style of deformation adapted by the tectonics.

Current models for the interplay of these processes are likely to be considerable simplifications of the complexity of natural interactions. In order to evaluate these processes properly, and to set them in an overall tectonic context, as well as a local structural and stratigraphic context, penetration of the dike-gabbro boundary (or whatever other feature represents the axial brittle-ductile transition) by a series of related drill holes is necessary.

A recurrent theme in models of ocean crust is the role of magma chambers in formation of crustal structure. Two classes of magma chamber models have been developed for ocean crust, those for slow-spreading ridges with deeply-rifted axial structures and those for fast-spreading ridges with positive axial relief. Models assume a greater rate of supply of magma at faster-spreading ridges, and depend on seismic evidence that substantial bodies of melt are present along the East Pacific Rise, whereas no such bodies of melt have been detected by similar experiments along the Mid-Atlantic Ridge.

Recent interpretations of geophysical evidence, however, indicate that melt bodies present beneath the axis of the East Pacific Rise are much smaller than previously thought. What was originally interpreted as a large magma body spanning the width of the axial topographic high, and the full thickness of the crust beneath a carapace of extrusives and dikes, has been reduced to a small melt lens only several hundred m wide and perhaps no more than 50 m thick, residing atop a body of crystal mush and hot, but solid, rock (Sinton and Detrick, 1992).

If correct, these new interpretations are very significant. Fundamental questions, once thought to be at least partially answered, must now be asked again. For instance, does magma aggregate at all to form sizable bodies in magma chambers beneath spreading ridges? Or does it simply filter through a crystal mush? If much of the zone between mantle and crust is a crystal mush, how does magma get from bottom to top? How are magmas tapped from the crystal mush for eruption? Where does magmatic differentiation take place? How do many thick gabbro sections form? Clearly, to answer these questions it will be necessary to drill long sections through the gabbroic portion of the crust in both fast- and slow-spread crust.

A large fraction of the total global mid-ocean ridge system can be assigned to one of two classes: (a) crust formed at ridges spreading in general >3 cm/yr, which exhibits well-developed magnetic anomalies and low topographic relief both laterally and longitudinally. A median valley is characteristically absent, or present as a shallow graben a few hundred m wide; (b) crust formed at rates generally <3 cm/yr in which magnetic anomalies tend to be irregular and topographic relief is high both along and at right angles to the spreading axis. Median valleys are normally deep, up to 1.5 km, and tens of km wide.

Associated with this contrast is a marked difference in style of volcanism, as imaged by high-resolution side-scan sonar. Low-relief crust is characterized by flat, smooth lava flows apparently erupted from long fissures, with few point-source constructions near the spreading axis. High-relief crust shows hummocky volcanic topography and abundant small volcanic cones near the spreading axis. As slow spreading centers of the Atlantic approach mantle plumes, such as Iceland and the Azores, crustal relief decreases, the deep median valley is replaced by a median ridge, and the seafloor takes on the aspect of crust produced at fast spreading rates, even though spreading rate remains slow. Side-scan sonar images show that these changes are not reflected in volcanic morphology, which remains typical of slow-spreading ridges, even when broad bathymetric morphology is that of fast-spread crust.

Models to explain these observations are still being developed, but typically appeal to a direct relationship between magma supply rate and spreading rate and/or plume proximity. There is a greater likelihood of faulting on slow-spreading ridges away from plumes, where magma supply rate is low. It is generally agreed, however, that the most fruitful ground for further critical observation is the plutonic section of the crust. Most predictions concur that at fast spreading rates plutonic bodies should be large and relatively simple, with little deformation or hydrothermal alteration. At slow spreading rates, the plutonic section is expected to be complex, with small bodies intersecting each other, and intense deformation and hydrothermal alteration. Deep-sea drilling of long, continuous sections of the plutonic portion of ocean crust from environments where spreading rate is known and plume influence can be estimated is thus essential.

As indicated above, the role of serpentinization in ocean crust is potentially profound but still largely unknown. Clearly, drilling of serpentinized ultramafics in a variety of contexts within an offset drilling program should enhance our knowledge of the process and importance of serpentinization. Similarly, the possible role of the plutonic section as a source region for linear oceanic magnetic anomalies is still an enigma. In principle, it has the potential to preserve a weaker but more robust magnetic record than overlying lavas and dikes, because it is less likely to have been tectonically rotated since cooling through the Curie point and is less subject to viscous decay of remanence with time. Offset drilling should resolve this problem.

Finally, relatively deep holes of an offset-section drilling program would provide ideal opportunities to measure orientation of principal horizontal stresses in the crust. Such measurements in oceanic areas are crucial in attempting to determine the relative importance of different plate driving forces. In addition, definition of local stress regimes in the vicinity of transform faults, ridge crests and ridge-transform intersections would provide important constraints on dynamic models for mechanical, thermal and rheological processes occurring in these settings.

This myriad of questions concerning oceanic lower crust and upper mantle, many of which could not have been posed ten or fifteen years ago, can be most expeditiously addressed at the present time by a strategy of offset-section drilling, which is summarized below.

Strategy

Primary scientific objective of lithospheric drilling is to investigate complex magmatic, tectonic and hydrothermal processes involved in formation and evolution of oceanic crust. Offset-section drilling is a strategy to construct composite sections of crust and upper mantle at a limited number of localities where testable models can be identified.

Key partial sections of crustal and upper mantle rocks are exposed in tectonic windows provided by propagating rifts, fracture zone walls, transverse ridges and median valley master faults. Partial sections will yield the most useful information when they can be linked together by either seismic or lithologic transitions. However, long sections of oceanic gabbro and peridotite can yield valuable information on magmatic and tectonic processes even when their stratigraphic positions are not precisely constrained.

A minimum drilling program to address the major objectives outlined above would be as follows:

1. Gross structure of the ocean crust can be determined by obtaining composite sections of crust formed at fast- and slow-spreading ridges.
2. Processes of melt formation and migration in the mantle can be addressed by sampling long peridotite sections, preferably in tectonically-constrained plume and non-plume environments.
3. Melt production can be related to local tectonic environments by sampling lower crustal and upper mantle sections near the center and at the end of a magmatic cell, preferably in a slow-spreading environment.
4. Relationships between magmatic, tectonic and hydrothermal activity can be addressed by sampling the dike-gabbro transition in slow-spreading crust. Several holes would be needed to constrain lateral and depth variations.
5. Magma chamber processes can best be studied in long sections of gabbro from fast- and slow-spreading crust where original spatial relations can be reconstructed.
6. Investigation of the relationship between crustal dynamics and spreading rate will require compilation of composite sections in fast-spreading, slow-spreading and plume-related environments.
7. Role of serpentinization in the creation of oceanic crust can best be addressed by a number of relatively short holes (~ 500 m) in a number of environments such as diapirs, rift valley walls and detachment surfaces, where peridotite is exposed.
8. Long sections of gabbro and peridotite in magnetically-constrained environments will provide data on the contribution of lower crustal rocks to magnetic anomalies.
9. Understanding state of stress in oceanic crust will require deep holes (>500 m) in areas where tectonic environment is well defined.

Given the limited amount of shiptime available for basement drilling, the following objectives for offset-section drilling are considered highest priorities:

1. To obtain composite sections of crust formed at fast- and

slow-spreading ridges. Tactical approaches to such drilling are outlined below.

2. To obtain sections which constrain variability in crust and upper mantle that occurs between geochemically enriched and depleted areas, and lateral (spatial and temporal) variations that occur within magmatic segments of spreading systems.

Hole 504B has contributed to our knowledge of the upper 2 km of a median-rate spreading center and continued drilling at 504B will provide an important reference section for comparison with upper crustal sections drilled in an offset-section approach. Another significant drilling target for understanding the origin of ocean crust has been Hole 735B, which recovered 500 m of gabbro from a very slow-spreading environment. However, lack of recovery of lithologies characteristic of lower ocean crust in a variety of environments has seriously limited our ability to answer thematic questions posed above regarding origin of oceanic crust. It is in this light that completion of at least two composite sections is regarded as the highest priority for drilling.

Construction of ocean crust exhibits first-order variations between slow- and fast-spreading ridges. Therefore, any strategy to test models for the evolution of ocean crust must include sampling sections in both kinds of crust. Furthermore, most models for crustal formation are either spreading-rate specific; e.g., detachment faulting or so-called "amagmatic" extension at slow-spreading ridges, or include end-member cases for fast- and slow-spreading environments, as in the magma chamber models of Sinton and Detrick (1992). Thus, if we are to reach a reasonable understanding of crustal genesis by an offset-section strategy, sampling of fast- and slow-spreading crust must proceed in concert.

First-order variations between slow- and fast-spreading crust, and models erected to explain those variations, require that a somewhat different approach be taken to offset-section drilling in each. Models for fast-spreading crust suggest that higher magma supply rates and more laterally-continuous melt horizons of fast-spreading ridges produce, *to a first order*, more homogeneous crust than is generated at slow-spreading ridges. In contrast, many models for evolution of slow-spread crust emphasize along-axis discontinuities in time and space, and strong interactions between tectonic and magmatic processes. Consequently, testing of models for crustal generation will require that more time be spent characterizing the slow-spreading case, because apparent complexity of the crust will require a larger number of sites. OD-WG emphasizes that this strategy is aimed at obtaining a *first order* picture of the crust in its end member varieties. It will not, and is not intended to, constrain all variability recognized to exist along both slow- and fast-spreading ridges.

Construction of composite cross-sections in both environments will require groups of holes sited in specific lithologies or lithologic transitions which can be tied together into a stratigraphic or "pseudo" stratigraphic entity. Ideally, these holes will be sited within small geographic areas and will be related in a straightforward manner. Review of potential target areas, however, suggests that it may not be possible to complete composite sections in a single area. Well-constrained transitions from dikes to gabbros and from gabbros to mantle may be particularly difficult to find; exposure and opportunity will dictate choice of sites. It is essential that the parts of a section be drilled in similar crust (in terms of spreading rate) and that their relative positions in the local geologic setting be clearly established, by correlation to regional seismic stratigraphies, clearly defined geologic cross-sections, or an obvious crustal transition. Such partial sections, if in a well-located, "ideal" setting, can be as, or more, valuable than total composite sections drilled in a poorly-understood area for addressing specific initiatives posed above.

Second-order crustal variations occur between geochemically enriched versus depleted areas of the mid-ocean ridge system and systematically within magmatic segments of all spreading systems. Establishing the nature of these variations is OD-WG's second priority.

The total program envisioned would last 8-10 years and involve ~12 two-month legs, in the hope of drilling a total of 15-18 holes. Each hole would typically be 1000±500 m in depth, depending on scientific objectives, drilling conditions and logistic considerations.

An allocation of legs to primary objectives might be as follows:

1. Composite section of fast-spreading crust: 4 legs

   This would include: nature of dike/gabbro transition, long sections in gabbro, nature of mafic/ultramafic transition and long sections within ultramafics. This would provide a first-order picture of fast-spread crust and allow evaluation of ophiolite- and seismic-type models for oceanic crust.

2. Composite section of slow-spreading crust: 6 legs

   This would include an array of holes distributed along a magmatic segment isochron and a flow line because of the apparent 3-D complexity of slow-spread crust. Among objectives that should be met with these holes are: long sections of principal lithologies exposed at slow-spread crust; transitions, structural or magmatic, between those lithologies; nature of the hypothesized median valley master fault; and emplacement mechanism of serpentinite blocks in median valley and transverse ridges.

3. Near-plume crustal sections: 2 legs

   Characterization of differences in crustal construction due to plume proximity can be addressed, to first order, by recovering "representative" long sections of gabbroic and ultramafic rocks from near-plume sites. This characterization assumes that similar sections will exist from "non-plume" slow- and fast-spread crust for comparison. Primary questions about plume effects *can* be addressed by single holes in particular lithologies at appropriate sites.

This program will produce a *first order* picture of oceanic crust in its end member varieties. It should be viewed as the initial phase of a longer-term, multidisciplinary approach to understanding what is clearly a temporally and spatially variable oceanic lithosphere.

Target areas for this first offset drilling program should be within main ocean basins, with the aim of establishing lithospheric sections and processes associated with mature, mid-ocean ridges. Should results show that sections exposed in ophiolites are not relevant to the main ocean basins, then a second program of offset-section drilling might be proposed in which primary targets would be in marginal seas, and back-arc and fore-arc basins with the objective of making the ophiolite connection.

Site Survey and Proposal Requirements

Offset section drilling seeks to determine relationships between lithologies, structures and physical properties of ocean lithosphere. Site surveys need to establish both local and regional, geological and geophysical, context of offset drilling targets. Age, tectonic history, crustal structure and potential fields associated with the region to be drilled should be determined.

The 3-D local geology, as well as nature of the offset between sites that will form a composite section, need to be defined to the extent possible with available techniques.

Suggested site survey requirements in terms of the JOIDES Site Survey Panel's (SSP) listing and guidelines are given in Table 1.

In addition to site survey requirements listed in Table 1, OD-WG suggests the following as required elements for offset- section drilling proposals:

A. Geologic Map

All available surface data should be synthesized into one or more geologic map(s), as appropriate, interpreting local and regional structure. Attempts should be made to interpolate contacts, faults and other geologic features between survey observations. In cases of ambiguous or complex regions, more than one map should be constructed to depict possible end member geologic models to be tested by drilling.

B. Cross-Sections

The geologic map or maps should be accompanied by a best attempt at characterization of the 3-D structure of the site(s) by construction, to the extent possible, of *true scale*, restorable (balanced) cross-sections. To the extent possible, these sections should represent a viable geological model. Sections should be constructed through sites and parallel to inferred spreading direction or perpendicular to major geologic features. It is recommended that an additional cross-section be constructed perpendicular to the first section to illustrate along-axis or along-strike variations. Uncertainties and ambiguities in the 3-D interpretation should be clearly spelled out, perhaps by construction of alternative sections depicting end-member geologic models.

C. Drill Site Prognosis

Each proposed drill site should be located on the geologic map or maps and cross-section(s). Using all available information and a hypothesis-testing rationale, specific predictions should be made, to the extent possible, of approximate depths, attitudes, and nature of important seismic and lithologic transitions, faults and other features. *The consequences of particular predicted observations to the hypothesis or hypotheses being tested should be clearly stated as a justification for drilling.*

Uncertainties in predictions for each hole should be clearly spelled out, in the light of uncertainties of the map(s) and cross-section(s). As appropriate, alternate drilling predictions should be made, and consequences of these alternate predictions for model(s) being tested enumerated.

D. Comment

It is expected that map and cross-section construction and drill site prognoses will be an interactive process. Thus, the original proposal may contain a first attempt at map and cross-sectional constructions. These items should be updated and made more specific as new data are acquired.

Table 1. Site Survey Requirements

1.	Deep-penetration single-channel seismic (SCS)	No
2.	High-resolution SCS	May be required[1]
3.	Multichannel seismic (MCS)	Recommended[2] May be required[9]
4.	Grid of seismic lines	See data type[3]
5a.	Refraction (surface source)	Recommended[2] May be required[9]
5b.	Refraction (near bottom source & receiver)	May be useful[3]
6a.	3.5 kHz echo sounder or equivalent	May be required[1]
6b.	12 kHz echo sounder	No
7.	Swath bathymetry	Required
8a.	Side-looking sonar (shallow-towed)	Recommended
8b.	Side-looking sonar (near-bottom towed)	Recommended
9.	Photography/video	Required[4]
10.	Heat flow	No
11a.	Magnetics	Required[5]
11b.	Gravity	Recommended[3]
12a.	Cores analyzed for paleoenvironment	No
12b.	Cores analyzed for geotechnical properties	No
13.	Rock sampling	Required[6]
14.	Water current data	May be required[7]
15.	OBS microseismicity	May be useful[8]

1 Shallow-penetration, high-resolution SCS and 3.5 kHz data will be required if sites are proposed to spud into sediment pockets.

2 A regional MCS or OBS-refraction survey is recommended to determine regional crustal structure before dismemberment. It is not necessary to have crossing seismic lines exactly over the proposed site. Site-specific reflection or refraction surveys may be required in some cases, but it is recognized that in many offset drilling settings such surveys may not provide useful subsurface information.

3 Near-bottom source/near-bottom receiver seismic refraction and near-bottom gravity are new experimental techniques that hold great promise as site survey tools for tectonic windows. JOIDES SSP is following development of this technology with great interest, and may upgrade this data type at a future date.

4 Visual observations (submersible, towed still camera, towed video camera) are required to determine detailed geological setting of sites, and to select sites for emplacing hard-rock drilling guidebases.

5 A regional magnetic survey is required to determine age of oceanic crust and plate kinematic history of sites, and surface magnetic field associated with the section to be drilled. Near-bottom is desirable.

6 A closely-spaced, precisely-positioned suite of samples is required in the immediate vicinity of sites, as well as a less-dense suite of samples over a broader region. Samples must be analyzed for geochemical/petrological and structural characteristics.

7 Data on water currents will be required for sites in shallow water or wherever swift (>1 knot) currents are anticipated.

8 Microseismicity determined from ocean bottom seismometers is useful in regions where faults that form the tectonic window are still active.

9 Some combination of 3, 5a and 9 is required to determine 3-D geology.

Technological Requirements to Implement the Strategy

One of the great attractions of an offset-section drilling strategy is that it does not require technological capabilities and developments beyond those which currently exist. However, having said this, routine provision of some hardware currently being developed could greatly enhance the degree of success achieved.

The following technological capabilities are considered to be particularly relevant to offset-section drilling:

a) 'Hard-rock' Guidebase, ideally modified to cope with slopes up to 30°.

b) 'Hard-rock' drill-in casing, which might be invaluable, e.g., on benches covered with up to 10 or 20 m of talus.

c) 'Hard-rock' spud-in with Downhole Mud Motor (DMM).

d) Commandable on-off beacon with long-life batteries (e.g., 5 years) and deployable by ROV.

e) Electronic Multishot orientation tool.

f) In principle, the Diamond Coring System (DCS) could be useful for offset-section drilling, but there is some concern that core orientation and certain crucial down-hole measurements, such as the Formation Micro Scanner (FMS), might not be available because of the narrower DCS hole. If this were to be the case, then DMM, producing a full-size hole, would be preferred, as OD-WG attaches great importance to obtaining oriented core and a full suite of downhole measurements.

Possible Target Areas

Initially, twenty-two possible target areas were identified; eleven in crust formed at slow-spreading ridges, eleven in crust formed at fast-spreading ridges:

1. *Slow-spreading ridges*

a) Sections exposed on *transverse ridges* formed within the inside or transform corner of ridge-transform intersections:

1. Atlantis II FZ, SW Indian Ocean — 32°40'S
2. Vema FZ, Mid-Atlantic Ridge — 10°40'N
3. Kane FZ, Mid-Atlantic Ridge — 23°45'N
4. Hayes FZ, Mid-Atlantic Ridge — 33°30'N
5. Oceanographer FZ, Mid-Atlantic Ridge — 35°N
6. Kurchatov FZ, Mid-Atlantic Ridge — 40°40'N

b) Sites within the *median valley:*

7. 15°20'N, Mid-Atlantic Ridge
8. MARK (Mid-Atlantic Ridge near Kane FZ) — 23°20'N
9. 45°N, Mid-Atlantic Ridge

c) Section exposed by *extension of preexisting crust:*

10. Kings Trough, NE Atlantic — 43°30'N

d) Section exposed by *thrusting of preexisting crust:*

11. Gorringe Bank, Azores-Gibralter Ridge — 36°30'N

2. *Fast-spreading ridges*

a) Exposures associated with *fracture zones:*

12. Blanco FZ, NE Pacific — 44°20'N
13. Siqueiros FZ, E Central Pacific — 8°30'N
14. Garrett FZ, E Central Pacific — 13°S
15. Eltanin FZ, S Pacific — 54°S
16. Udintsev FZ, S Pacific — 56°30'S
17. Nova Trough, W Pacific (1°S, 168°W). Extension of Clipperton FZ?

b) Sections exposed by *crustal extension ahead of propagating ridges:*

18. Hess Deep, E Central Pacific — 2°20'N, near Triple Junction
19. Pito Deep, SE Pacific (23°S), NE margin of Easter Microplate
20. Endeavour Deep SE Pacific (33°S) NE. margin of Juan Fernandez Microplate

c) Section exposed by *late-stage extension on an abandoned ridge crest:*

21. Mathematicians Ridge, E Central Pacific — 15°N, 111°W

d) Section exposed by *thrusting of preexisting crust*

22. Mussau Trough, W Pacific — 1°N, 149°E

Each of these areas was assessed according to number of objectives that might be achieved at each location and extent of existing and pending site survey data. These assessments reflected in part intrinsic potential of an area, and in part current knowledge based on existing survey information. Site survey requirements for offset-section drilling are particularly stringent and it makes good sense, therefore, to capitalize on the considerable sums already invested in certain areas.

Six areas scored very highly in this exercise, but between them did not adequately cover the full range of objectives. A further six areas were added to achieve this coverage. The resulting twelve areas were equally divided between lithosphere formed at high and low accretion rates. Following a detailed review, a final short-list of eight areas was produced. Without results of additional site surveys and preliminary drilling, OD-WG did not consider it possible to reduce this short-list further at this stage. As this additional information becomes available it will be necessary, ultimately, to identify just three or four 'natural laboratories' in which multiple offset-sections are to be drilled.

Short-listed areas

Short-listed areas may be summarized as follows:

	Rate	Composition	Segment
Rifted crust			
Hess Deep	F	N	N/A
Pito	F	N	N/A
Kings Trough	I	E	T
Transverse Ridges and Fracture Zone Walls			
Atlantis II	S	N	T, S
Vema	S	N	T
Oceanographer	S	E	T, S (?)
Median Valley Walls			
MARK	S	N	T, S
15°20'N	S	E (?)	T, S

Key:

Rate: F = fast, S = slow, I = intermediate.

Composition: N = normal MORB, E = enriched MORB.

Segment: T = temporal variability in magmatic cells, S = spatial variability in magmatic cells, N/A = not applicable

Thus, three environments have been identified for offset drilling where tectonic windows into gabbroic and ultramafic rocks are present. It is important to note that these three environments are not equally represented in slow- and fast-spreading crust, and that each has advantages and disadvantages.

Rifted Crust

Advantages:

1. In fast-spreading crust, rifted lithosphere regions appear to be the main sites where plutonic and ultramafic levels of crust are exposed.
2. As these rifts generally cut non-transform crust, they may be more representative than tectonic windows in fast- or slow-spreading transforms.
3. These rifts can sometimes produce windows into crust of different ages and provide information on temporal variations and evolution of the crust.

Disadvantage:

These rifts are usually associated with propagating rifts which may superimpose structures, alteration and magmatic effects that will be difficult to discriminate from those associated with formation of crust at the ridge axis.

Hess Deep

Hess Deep is at the tip of a propagating rift in the Cocos-Nazca Plate and exposes relatively young crust generated at the East Pacific Rise (EPR). Topography is very rugged and geology is complex. The area has been surveyed and sampled during two dive programs. Upper level gabbros, a dike complex and pillow basalts are exposed on the north wall of the rift. Peridotites, cumulate and non-cumulate gabbros, as well as basalts and dolerites are exposed on the intra-rift ridge. There is some difficulty in distinguishing what is EPR crust and what is new Cocos-Nazca crust. Geochemical data and petrographic descriptions are not well-developed as yet. Structural relationships are also poorly known and the connectivity between major zones of outcrops is not yet well-documented. Some hydrothermal activity on the lower, south-facing slope of the intra-rift ridge may be related to rift opening.

Pito Deep

As with Hess Deep, Pito Deep is formed by rift propagation into young, fast-spreading crust. Pito is ~6 km deep with 25° slopes on walls. Gabbros have been recovered from 5500 m level on wall. There may be significant crustal thinning associated with the deep. There will be a dive program in April 1993; detailed sampling will be undertaken at that time. Pito is currently viewed as a viable alternative to Hess Deep, but it needs additional study.

Kings Trough

Kings Trough is a failed rift that exposes old oceanic crust formed at ~anomaly 25 time in the North Atlantic. The spreading rate at that time was ~6 cm/yr and the area lies within the influence of a plume. The rift is part of the system that separated Iberia from Europe. Kings Trough has steep walls and a sedimented floor. Good exposures of sheeted dikes occur along the base of the walls and are up to 1 km thick. Two submersible dives in the area have recovered gabbro overlain by diabase overlain by basalt. Very few survey data exist for the area and multibeam coverage is needed as well as more dives before this becomes a mature target.

Transverse Ridges and Fracture Zone Walls

Advantages:

1. These regions produce tectonic windows that may allow assessment of crustal and upper mantle stratigraphy and temporal evolution of the lithosphere.
2. Transverse ridges may allow spatial sampling of magmatic cells over relatively short distances in both ridge-parallel and flow-line directions.
3. Because a large portion of the crust generated at slow-spreading centers is transform-affected, study of these sections may be important in documenting the more varied crustal architecture at slow-spreading centers.

Disadvantages:

1. These regions are affected by transform tectonics, which complicates reconstructions of crustal stratigraphy and creates ambiguities in the nature of lithologic contacts.
2. As transforms represent terminations of magmatic cells, there may be transform fault effects that control the thickness of units, overall magmatic budgets and alteration processes. These factors may make sections unrepresentative of the bulk of oceanic crust and upper mantle.
3. Tectonic and dynamic processes leading to formation of transverse ridges are not well known.

Atlantis II Fracture Zone

A wide, high-standing transverse ridge is developed against this slow-slipping (0.8 cm/yr half rate) transform fault on SW Indian Ocean Ridge, which exposes gabbro and ultramafics. Linear magnetic anomalies are traceable across both rock types. Hole 735B was drilled on a shallow, wave-cut platform at anomaly 5 (i.e., ~10 Ma). On the non-transform side of the ridge-transform intersection, volcanics appear to overlie unextended crust. This transverse ridge provides ideal sites for further long gabbro sections, ultramafic sections and, hopefully, the gabbro/ultramafic transition.

Vema Fracture Zone

Vema FZ is located at 11°N on MAR and has 320 km of offset. At this locality, MAR has a spreading rate of 1.2-1.6 cm/yr. Vema has a transverse ridge which is a continuous high, i.e., unlike Atlantis II. Submersible dives have surveyed and sampled two sections where all major units of oceanic upper lithosphere are represented, i.e., from base to top: mantle peridotite, gabbro, dike complex and basalts. Ferrogabbros apparently occur directly above mantle peridotites.

Vema FZ appears to be a good target for offset drilling of mantle and lower crustal sections. In addition, drilling on shallow-water limestones on the summit of the transverse ridge will address a tectonic objective, i.e., origin of the transverse ridge and processes responsible for exposure of lithospheric sections. More survey work will better constrain kinematic and tectonic settings of potential drill sites.

Oceanographer Transform Fault

Oceanographer offsets MAR by ~100 km and is adjacent to the Azores hotspot, so it has a relatively high magma supply rate. Relief is ~2500 m, and the crust appears to thin to ~2 km in the axis of the transform. There are mostly breccias exposed on the walls, with some sheeted dikes and peridotite exposed on the inner wall of the spreading ridge. Harzburgite and lherzolite have been recovered from the north wall of the transform. Ultramafic rocks and gabbros occur on the south wall, where they are overlain by pillow lavas.

Median Valley Walls

Advantages:

1. These sites lie outside areas affected by transform tectonics, alteration and effects imposed on magmatic budget, which may make these sections more representative.
2. There is access to along-axis variations in crustal stratigraphy.
3. Tectonic models of rift valley formation and unroofing of mafic and ultramafic exposures can be tested.

Disadvantages:

1. The possibility of obtaining temporal variations along a flow line is more limited when compared with transform valley walls.
2. Relief along rift valley walls is generally less than that observed along transform valley walls, so mafic plutonic and ultramafic stratigraphies exposed are more limited.

MARK Area

MARK area is one of the best-studied and best-known targets available at the present time. It has been very well surveyed and sampled and its geology is well known. Ultramafic rocks are exposed on the west wall of the ridge segment, where they are overlain by basalt. However, the nature of the peridotite/basalt contact is unknown. Apparently, ultramafic rocks were exposed by detachment faulting during a period of low magmatic activity. Basalts may have extruded directly on top of unroofed peridotite or may be part of an allochthonous block transferred from hanging wall block to footwall block. Ultramafic rocks appear to outcrop in a region of thin crust, based on mantle Bouguer anomalies. Ultramafics could also be exposed, in part, by diapiric mechanisms.

Gabbroic rocks are well exposed on the western rift valley wall closer to the transform inner corner high. They are also exposed on the south wall of the transform in the same region. Submersible work has documented >3 km of exposure of gabbroic rocks. This is the thickest section yet documented on the sea floor. Gabbro is overlain by basaltic rocks, but the transition from gabbro to basalt is obscured and there appears to be no well-documented sheeted dike section. Slickensides on gabbroic surfaces parallel surface slopes and suggest that the western rift valley wall may represent a single detachment surface.

15°20'N Fracture Zone

The 15°20'N Fracture Zone is located north of Vema on MAR. It is similar in many ways to Vema, but its attraction is its proximity to the end of a magmatic cell. Dunite and harzburgite are present, apparently unroofed by detachment faulting. Dredged rocks show some effects of low-temperature hydrothermal alteration. Rocks in the area have the geochemical signature of a hotspot, although no known hotspots occur in the vicinity.

Conclusion

The conjunction of new data and ideas relating to exposure of gabbros and ultramafic rocks in tectonic windows, and new models of the nature and spatial and temporal variability of lower oceanic crust, makes an offset-section drilling program to investigate oceanic lower crust and upper mantle timely and potentially very fruitful. Moreover, the nature and origin of these tectonic windows are also of first-order scientific interest. Offset-sections are ready to drill, using proven technology, and in temperature conditions that allow deployment of a full suite of downhole measurements.

Therefore, OD-WG recommends that a Detailed Planning Group be set up, early in 1993, to define a specific program of offset-section drilling in the light of results of legs 147 (Hess Deep) and 148 (return to Hole 504B), and responses to this OD-WG report from ODP panels and the scientific community.

Reference

Sinton, J.M., and Detrick, R.S., 1992, Mid-Ocean Ridge magma chambers, *J. Geophys. Res.*, *97*, 197-216.

Sea Level Working Group

The report published here is a shortened version of the SL-WG report. The complete report is available from the JOIDES Office.

Summary

The strategy defined by the Sea Level Working Group (SL-WG) involves a *global* drilling program that will require a minimum of one sea-level leg/year for the next decade. A Sea-Level Program should be established to oversee coordination of sea level research within ODP. The nature of the research will require a concerted, coordinated effort focused on specific time intervals, at a number of locations, by geoscientists from a wide variety of disciplines. As the program evolves, it will be important to review the criteria presented here frequently and update where necessary.

Success of the program is contingent upon global coverage in a variety of tectonic (passive, convergent, intra-oceanic), sedimentary (siliciclastic, carbonate, mixed), climatic (Icehouse, Doubthouse, Hothouse), and oceanographic (low and high latitudes) settings. The strategy is based on successful application of scientific and technical objectives to address sea-level issues outlined by SL-WG:

- *dating sea-level-related stratigraphic events*
- *establishing stratigraphic response to sea-level oscillations,* and
- *estimating magnitudes and rates of sea-level change through time.*

A fourth issue, *understanding the mechanisms of sea-level change,* is addressed, but SL-WG believes that *JOIDES Resolution* will play a lesser, although important role in increasing understanding of mechanisms of sea-level change. In fact, resolution of the first three issues listed above will be fundamental to the success of sea-level mechanism research.

JOIDES Resolution is an appropriate platform for all three issues listed above. Indeed, ODP, because of the nature of the research proposed, is in the enviable position of being able to contribute significantly to integration of continental margin, platform, deep ocean and earth-process-related research. ODP-based sea-level research will focus activities and coordinate utilization of information among a multitude of onshore, continental margin and deep-sea geoscientists. The result is a unique sharing of concepts, information and technology that cannot be addressed by any other group of geoscientists, and a better understanding of one of the key issues in sedimentary geology and global change research.

In addition to scientific coordination issues, there are a number of technical issues that will control success of the program. The first involves ability of *JOIDES Resolution* to maintain station and drill in shallow water depths (<50m). A test of that capability in shallow water (38m) in Anewetak Lagoon was undertaken during Leg 143 (see report, this issue). Although the test stopped early, the drillship was able to maintain station in variable winds and currents. A supplementary platform will be required to complete the transect begun during Leg 150; investigations are underway to find a suitable platform.

Sediment recovery from sands and alternating hard/soft units is still a major concern for proponents of sea-level proposals. As a result, the Diamond Coring System (DCS) is still regarded as a critical component of the sea-level program.

An additional technical issue that SL-WG regards as critical is development/application of an Integrated Stratigraphic Analysis System. The tool/system would integrate seismic stratigraphic tools (seismic interpretation/seismic-log calibration), log analysis/interpretation tools (including the Core/Log integration package endorsed by SMP and DMP, correlation and cross-section generation tools, etc.), backstripping software, etc. In order to address sea-level issues effectively, it is important that methodology and tools used for each approach are available to the general scientific community.

It is also imperative that a Data/Information Management System be constructed to store, display and distribute information necessary to define age, position and character of stratigraphic units and surfaces, document stratigraphic event correlations, estimate magnitudes of sea-level oscillations, and eventually begin to coordinate information necessary to understand the wide variety of mechanisms controlling sea-level.

Introduction

The JOI/USSAC Workshop held in El Paso, Texas from October 24-26, 1988 (Watkins and Mountain, 1988) laid the foundation for the role of ODP in investigation of global changes of sea level. The workshop stimulated a number of investigations of stratigraphic response to eustatic changes on a number of margins of the world.

SL-WG, commissioned by JOIDES PCOM in 1991, was charged with the task to reassess strategy for sea-level-related research, to encourage proposal writing and to establish further criteria for proponents.

SL-WG's mission was to formulate a global ocean-drilling strategy for:

1) estimating timing, magnitude and rate of eustatic changes as they are recorded in sediments and sedimentary rocks,
2) investigating stratigraphic response to sea-level oscillations, and
3) determining mechanisms of eustatic change.

SL-WG agrees that *JOIDES Resolution* is an excellent platform to address sea-level issues. The most important result is recognition that it will require a coordinated, concerted effort on a number of margins around the world to achieve all tests conceived in the El Paso workshop and presented here. Coordination of ODP related sea-level research is at present handled jointly by the JOIDES Ocean History Panel (OHP) and Sedimentary and Geochemical Processes Panel (SGPP). In future, coordination will have to be integrated even further.

Eustatic fluctuations are inferred to constitute an important control on the stratigraphic record that should be addressed by ODP. However, neither timing and amplitudes nor causes of eustatic change are well known. For instance, possible relations between eustasy, tectonics, climate, origin and deposition of siliciclastic versus carbonate sediments, ocean chemistry and circulation, and organic evolution are largely a matter of speculation. Similarly, little is known about feedbacks between sedimentary, climatic, tectonic or eustatic phenomena, or possible offsets in leads and lags between them. Understanding rates and effects of sea-level related processes and their interaction with other Earth system processes is a fundamental component of the US Global Change Program.

Despite interest in and understanding of sea-level issues (synchrony, magnitudes, rates, shape of curve) developed at the El Paso workshop, very few proposals submitted to ODP specifically to test eustatic concepts have been drilled. In general, previous legs have not been able to provide an adequate test of the concept (by concept SL-WG means all aspects of stratigraphy that are influenced by eustatic oscillations). Recent legs, and a number scheduled for 1993, may well contribute significantly to solving certain aspects of sea level issues mentioned above. However, after an initial flurry, there has been a steady decrease in the number of sea-level proposals. For example, there was only one mature sea level proposal in the North Atlantic Prospectus (1991). Although a number of immature sea-level proposals in the southwest Pacific have been submitted, many tests of sea-level concepts are appropriate for *JOIDES Resolution* and it is imperative to alert and encourage potential proponents elsewhere. There is a significant opportunity to coordinate onshore, continental shelf, slope and deep sea geological activities to resolve some key, topical, geological questions.

In the following sections, four distinct sea level research issues involving *JOIDES Resolution* are discussed, including a number of strategies and criteria for proposals. It is important that clear tests of various aspects of sea level be proposed and that there is understanding and consistency among proponents of legs on different margins or areas of the world. It is apparent that there are still significant gaps in understanding of the terms used in sequence stratigraphy, methods employed by Vail and his colleagues to generate eustatic cycle charts, and possible mechanisms for changing relative sea level. Discussions below address some of these gaps and will hopefully generate better insights into sea level research, resulting in new and better ODP proposals.

Strategy

The strategy defined by SL-WG involves a global drilling program that will require a minimum of 1 sea-level leg/year for the next decade. Success of the program is contingent upon global coverage in a variety of tectonic (passive, convergent, intraoceanic) sedimentary (siliciclastic, carbonate, mixed), climatic (Icehouse, Doubthouse, Hothouse), and oceanographic (low and high latitudes) settings. Strategy is based on successful application of scientific and technical objectives to address sea level issues outlined by SL-WG: dating stratigraphic events, establishing stratigraphic response to sea-level oscillations, and estimating magnitudes and rates of sea-level change through time.

An additional, but important, component of this strategy is geared toward stimulating potential proponents to write specific sea-level-related proposals to meet objectives outlined by SL-WG. Watchdogs among SL-WG members for potential areas have been named and potential proponents will be contacted to obtain initial estimates of whether respective areas may meet requirements for the Sea-Level Program.

Strategy is divided into short- and long-term components to take advantage of ODP's drilling schedule in the Atlantic. Although the emphasis is initially on the Neogene Icehouse, for reasons outlined below, sea level objectives in the Paleogene "Doubthouse" and Cretaceous "Hothouse" are also regarded as critical components of the program.

Short Term

SL-WG recommends that an integrated Sea-Level Program should begin by testing synchrony of stratigraphic events in the Neogene, where optimum age control and a calibrated signature of sea level are best constrained. Leg 150 on the New Jersey (NJ) margin represents the first step in the program. Transect design on the NJ margin is focused on establishing the age of several Miocene sequences. Secondary objectives include estimating magnitudes of sea level oscillations and understanding stratigraphic response to sea level changes. It is important to note that site locations required to achieve the latter objectives would be significantly different from those designed for dating stratigraphic surfaces in the same geographical area.

Leg 150 will establish a control point that could be augmented by another leg in the Atlantic within the next two years. SL-WG believes that an appropriate next step would be to drill the Neogene of the Bahamas, because it offers a geographically close test of the ability to correlate stratigraphic events between two areas of contrasting sedimentary settings. In an effort to solicit other potential tests in the Atlantic, SL-WG has undertaken an initial evaluation of potential locations and initiated communication with possible sea-level proponents (Fig. 1; see Appendix A, complete report). It is also important to remember that following completion of Leg 150, the strategy outlined here may change. The stratigraphic framework developed during Leg 150 could form the basis for locating additional sites to constrain sea-level magnitude estimates better and improve understanding of processes controlling distribution of sediment across the NJ margin.

Long Term

An essential component of the Sea-Level Program is to demonstrate degree of synchrony of sea-level-related stratigraphic events between a number of continents. After an initial assessment of possible candidate locations, SL-WG believes that existing proposals for the southern Australian and eastern New Zealand Neogene may provide an adequate test. SL-WG is also

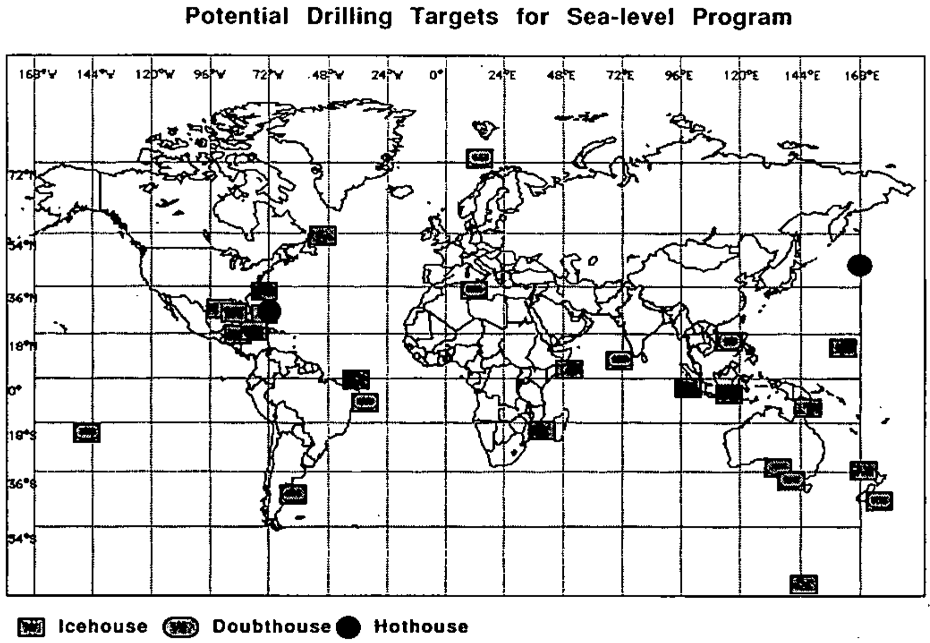

Figure 1. Areas suggested by members of SL-WG as potential targets for a Sea-Level Program. Brief descriptions of the areas, including names of SL-WG watchdogs and potential proponents, are contained in Appendix A of the complete SL-WG report.

encouraging proponents to submit proposals for other potential Neogene test locations (Fig. 1; see Appendix A, complete report). The targets in Australia and New Zealand also include Paleogene strata, as does Leg 150. Adequate testing of synchrony of sea-level-related events in the Neogene (Icehouse) will provide confidence and understanding of the methods required to investigate Paleogene and Cretaceous sea-level-related processes and effects. To begin to understand stratigraphic response to sea-level oscillations, SL-WG believes that 6 legs will be required: 3 in siliciclastic settings and 3 in carbonate settings (including 2 platforms of different ages and 1 atoll/guyot) in different time-slices.

Target Intervals

SL-WG suggests that proponents focus on specific time-intervals with greatest chronologic resolution, so that the "global" nature of events can be tested within a reasonable period of time. With a limited number of legs available, it is imperative that there be a coordinated effort among groups of researchers on selected target intervals. Target intervals include late Miocene-Recent, late Oligocene-middle Miocene, latest Paleocene-middle Eocene, and Aptian-Coniacian (for a more detailed description of these time periods see Watkins and Mountain, 1988, and complete SL-WG report). In addition, there are advantages to selecting intervals that are associated with second-order sea-level rises and highstands. Many classic, intensely studied, outcrop sections span the climatic intervals targeted. They represent sediments deposited during major transgressions related to second- and third-order relative sea-level rises. It is important to take advantage of as many of these land-based studies as possible in order to formulate questions that can be addressed by *JOIDES Resolution*.

Sea-level Research Issues

Four sea level issues can be addressed by *JOIDES Resolution* during the next few years. Three of them were discussed at the El Paso workshop:

- testing synchrony of sea-level events,
- estimating amplitudes and rates of sea-level changes, and
- understanding mechanisms of sea-level change.

The fourth issue that could be studied by ODP is:

- understanding stratigraphic response(s) to sea-level oscillations

Outlined below are some criteria for selecting margins suitable for tackling each issue. Criteria are generally similar, with a number of exceptions specific to each approach. Success of the sea-level drilling program is contingent upon adherence to most of these criteria. It is important that each test of a sea-level-related problem be well formulated, with every effort being made to constrain parameters to be measured for sea-level estimation and correlation. Margins or areas that do not meet, or adequately address, criteria should not be drilled solely for sea-level-related reasons. However, SL-WG realizes that new tests of sea-level concepts will be developed as our understanding of problems evolves; Sl-WG cannot provide an exhaustive list of criteria that *must* be met. Criteria listed for each approach serve as a checklist to help establish ground rules and improve communication between proponents and JOIDES thematic panels. The criteria checklist should be reviewed from time to time and updated accordingly. Responsibility for evaluation of the criteria must rest with OHP and SGPP or another group commissioned to oversee a Sea-Level Program.

Dating Of Stratigraphic Events

One of the primary products of ODP drilling of sea-level targets will be firm constraints on ages of major stratigraphic surfaces, particularly unconformities (sequence boundaries). This will allow interregional correlations of sequence boundaries and provide a test (although potentially incomplete) of synchrony of their cause(s). Ages of surfaces may be slightly different and the cause globally synchronous, but the stratigraphic response involves leads and lags of up to a quarter cycle (approximately 400 k.y. for a third-order cycle). In addition, ODP drilling will provide chronologic control needed to compare sequence stratigraphic estimates with other proxies of sea-level change. Firm age constraints are also needed to estimate rates of sea-level change and evaluate causal mechanisms. Close dating of sequence boundaries is the first step required to decipher the history of sea-level changes.

Strategy

Objective of this drilling strategy is to test synchrony of sea-level-related stratigraphic events in three selected time intervals characterized by different climatic regimes and potentially different sea-level signatures. Transects from marginal marine to deep basin environments are required in a variety of settings (such as passive continental margins, seamounts and perhaps basins in more complex settings associated with plate convergence). These settings should be characterized by stratigraphic sections with sufficient resolution to date surfaces in selected target intervals.

Determining Stratigraphic Response To Sea Level Changes

An essential component of the Sea-Level Program will be to understand stratigraphic response, in a variety of settings and climatic regimes, to inferred eustatic oscillations using sequence stratigraphy as a tool to provide a framework for observations. What role does eustasy play in the origin of sedimentary cyclicity? It is important to select widely-separated basins for which sequence geometry and rates of subsidence and sediment supply are similar, as well as basins in which they are different.

Sedimentary response may be different for siliciclastic and carbonate margins. In end-members of the two settings, time of maximum sediment supply can be 180° out of phase. For example, carbonate platforms may shed sediment during relative sea-level highstands, while siliciclastic shelves shed during lowstands. The result is that internal architecture and geometry of carbonate versus siliciclastic sequences differ widely so that high-quality data sets for both settings are necessary to calibrate their respective responses to relative sea-level changes. Emphasis should be on understanding processes that control sedimentation in a variety of settings, not on descriptive comparisons of stratal geometry and tectonic/sedimentary setting.

Eustatic fluctuations may also affect the stratigraphic record of portions of the ocean far from continental margins. Responses in open-ocean sedimentation processes to eustatic changes are not well documented; there is an opportunity to better quantify nature and timing of such responses.

Strategy

SL-WG proposes marginal marine to deep basin transects in a variety of settings, such as passive continental margins, seamounts and perhaps basins in more complex settings associated with plate convergence. Targeted intervals must have well-developed sedimentary cyclicity and well-defined sequences. Objective of this drilling strategy is to calibrate the sedimentary record and to document the variability of depositional sequences. This should allow us to quantify the influence of sea-level fluctuations on stratal geometry, lithofacies distribution and other stratigraphic/lithologic attributes.

Since the strategy is dependent on whether sea level is known or not, proposals must contain a clear statement of whether the targeted program applies to a time of known or uncertain sea-level change, type of geologic and sedimentary setting and whether nominated sites fall within Icehouse, Doubthouse or Hothouse time periods. They must define periodicity of sea-level oscillations thought to drive the stratigraphic response. Proponents should strongly consider taking advantage of areas and time periods (such as the Neogene) that have already been evaluated in detail by other sea-level legs. Such studies would reveal changes in lithologic response to similar sea-level forcing in different sedimentological and tectonic settings.

Two general approaches are suggested depending on availability, or absence, of eustatic records.

a) Eustatic record already known with some degree of certainty based on other sea-level proxies (e.g., $\partial^{18}O$).

By comparing stratigraphic response to sea-level changes on different margins in time intervals where there exists a reliable signal of sea level, one can understand the precise relationship between facies and sea-level change. In particular, it may be possible to identify leads and lags between sediment facies and a sea-level signal and to identify processes responsible. Studies within the Neogene Icehouse period are most appropriate for this approach because of the existence of a eustatic, ice-volume-driven forcing mechanism. Neogene sections offer the possibility of directly correlating depositional sequences with the deep-sea record, from which a number of eustatic proxies have been generated.

Eustatic records provide a model that can be used to formulate tests of the sequence stratigraphic approach. For example, how much of the stratal geometry on a specific margin can be explained by processes related to a specific eustatic history? On the basis of available data, various stratigraphic models can be constructed which predict facies, in both two and three dimensions, and their timing. Reliability of eustatic proxy records varies considerably, primarily as a function of construction method, and this must be discussed by proponents. The most reliable eustatic records have been obtained from the last 3 m.y. Understanding the stratigraphic record of these events is important to understanding sedimentary processes associated with sea-level change. While sea level fluctuations in this time period are often large and occur frequently, it must be recognized that this time interval is not characteristic of all of earth history.

b) Eustatic record not known with any precision, even by proxy.

In such cases, eustasy constitutes an additional unknown which has to be inferred from the sedimentary record being studied. It is essential to attempt to quantify effects of processes that control sediment deposition and distribution during time intervals where a preexisting independent eustatic record is not available or mechanisms are unknown.

Estimating Magnitudes And Rates Of Sea Level Changes

Estimation of magnitudes and rates of sea-level fluctuations will require a variety of geological, geophysical and geochemical models. *JOIDES Resolution* can be an effective component of an integrated effort to estimate magnitudes and rates of sea-level fluctuations by selectively sampling environments ranging from shallow shelf to deep (open ocean) settings. Importance of *JOIDES Resolution* to a program to estimate sea-level magnitudes and rates cannot be overemphasized. The drillship provides the ability, in suitable locations, to correlate chronostratigraphic units (depositional sequences) between the open ocean, where calibrated signatures of sea-level are available, and shallower environments where geometric and geochemical estimates of magnitudes and rates are traditionally estimated. Integration and calibration of the variety of methods currently available can be achieved via a coordinated effort by ODP-sponsored research.

Two fundamentally different approaches have been suggested for estimating magnitude of sea-level change and, when integrated with appropriate geochronolgy, rate of change. One approach is to analyze subsidence history at a given site or transect and to attempt to make corrections for variations in water depth through time, compaction/lithification, isostatic response of the lithosphere to loading and unloading and the tectonic component of observed subsidence. In detail, nature of the corrections depends to some extent on local geology (e.g., passive continental margins versus atolls). Different techniques have been employed to provide an approximation of changes in paleobathymetry (e.g., physical sedimentology and paleoecology, seismic geometry, evidence for subaerial exposure and freshwater diagenesis of sediments that accumulated close to sea level). A second approach is to attempt to gauge the glacio-eustatic component of the sea-level signal from analysis of oxygen isotopic ratios in foraminifera.

Sea-level magnitude and rate estimates are inherently difficult because of the large number of variables that must be quantified. For this reason, a number of researchers have questioned whether realistic estimates are possible. Most members of SL-WG are of the opinion that constraints can be placed on both amplitude and rates of eustatic change by means of a coordinated drilling program utilizing the capabilities of *JOIDES Resolution,* coupled with analysis of seismic and existing borehole data and modeling. Computer simulations are useful for examining sensitivity of the stratigraphic record to variations in key parameters, even if the parameters themselves cannot be estimated uniquely from the geologic record (for a more complete discussion of computer simulations, see Appendix B in complete report).

It is very important that magnitude and rate proposals are coordinated with those selected to estimate synchrony of stratigraphic events. Drilling strategy for estimating magnitude of sea-level change may differ from that employed to date and correlate stratigraphic events. However, accurate estimates of rates of sea level change require accurate dating of surfaces and depositional sequences produced by sea-level oscillations. It is critical that the efforts required for both approaches not be compromised. Coordination of effort within specific time-intervals and on selected margins will result in a more efficient and successful use of the drillship.

It is also important to explain the appropriateness of *JOIDES Resolution* (as a tool to estimate sea-level magnitudes) relative to other efforts (land-based, alternate platforms, other time periods, etc.). Advantages of using *JOIDES Resolution* for this task are not as obvious as in the other approaches and it is appropriate that proponents document these advantages, relative to other platforms and areas. For example, a good case can be made for modifying the technique used by Greenlee et al. (1988) and Greenlee and Moore (1988) to estimate eustatic change in the Neogene of the US mid-Atlantic margin, as well as for updating basic stratigraphic constraints and assumptions. Many assumptions can be evaluated through the ability of *JOIDES Resolution* to obtain samples from specific sites and depths. The US mid-Atlantic margin, because of these previous studies, provides a well-constrained "test", in contrast to many other areas that have been proposed for sea-level research.

Strategy

Drilling strategy is to estimate magnitudes and rates of sea-level fluctuations using a variety of geological, geophysical and geochemical models. Best results can be expected to be achieved for known periods of well-defined sea-level excursions and regions of well-defined tectonic movement.

ODP needs to drill selected marginal marine to basin transects in a variety of known sedimentary settings and environments with: 1) well-constrained tectonic behavior, and 2) sections of sufficient geometric, paleobathymetric and time-stratigraphic resolution for selected target intervals to allow correlation to a geochronologic time scale.

Determining Mechanisms Of Sea Level Change

Introduction

Our understanding of sea-level forcing mechanisms ranges from fair to nil. Short-period (0.01-0.1 m.y.) sea-level cycles are probably the best documented. They have been shown to match orbital frequencies closely. Linkages between orbital perturbations and sea-level changes remain clouded, however. The next best understood part of the sea-level spectrum is that with periods ranging from ~0.1 to 1 m.y. Sea-level changes in this range appear to be mainly due to glacial removal of water from the world's oceans and its subsequent restoration. Although the basic mechanism is well known, much remains to be determined regarding specifics of rates, durations and amplitudes of these cycles. Sea-level events with periods 1-10 m.y. are the most enigmatic. Many of these events have been reported from periods of geological time when glaciation is neither known nor likely. Although no mechanism has as yet been demonstrated to account adequately for cycles in this frequency range, several mechanisms have been suggested. A variety of mechanisms appears capable of explaining cycles with periods of 10-300 m.y. With the exception of changes in ocean basin volume due to changes in global spreading rates, the effectiveness of these mechanisms has not been demonstrated.

To understand fully mechanics of sea-level change, we must:

- Test and confirm proposed mechanisms,
- Fully understand those mechanisms shown to be active,
- Discover unrecognized mechanisms, especially those responsible for changes of 1-10 m.y. duration, and finally
- Develop a strategy for attaining the above objectives.

In order to accomplish the above, we herein review known and potential mechanisms and summarize their salient features, including inferred polarity (rise, fall or both), duration, probable amplitudes and near- and far-field variation in signature. We then suggest steps that might be taken to clarify and define these mechanisms, together with objectives of experiments that have highest priorities in terms of understanding sea-level mechanisms.

Mechanisms

There are two families of mechanisms, one consisting of those due to changes in the volume of water in the ocean basins, and the other due to changes in volume of the world-ocean basin. In the first case, we know that waxing/waning of ice sheets may cause rapid, large-amplitude changes in sea level. According to benthic foraminiferal $\partial^{18}O$ studies, ice sheets developed at least intermittently during the Oligocene to early Miocene. Calibration of $\partial^{18}O$ record against a "known" eustatic record from terraces/atolls suggests that glacial mechanisms are capable of producing magnitude changes of ~30-120 m with cycles that range from a few tens of thousands of years to perhaps a few million years. No other mechanisms capable of significant changes in ocean water-volume over periods commensurate with sea-level changes are known.

Estimates of eustatic changes due to tectonic alteration of the volume of the world-ocean basin rely on model predictions and, as a result, there is much controversy about the magnitude and periods of these mechanisms. However, some general patterns emerge. For example, it has been shown that changes in volume of mid-ocean ridges can cause large-amplitude sea-level rises and falls of up to 250 ± 50 m on a cycle scale of up to 70 m.y.

Mechanisms such as compressional and extensional tectonics, sediment loading, and volcanic loading appear capable of producing long-frequency cycles. Results of recent seismic tomographic studies suggest that there may be bumps in the lithosphere-asthenosphere boundary due to temperature variations in the asthenosphere. Most of these variations in temperature appear associated with entombed segments of old subducted slabs, plumes or mid-ocean spreading ridges. These bumps may be capable of changing global sea level as well as causing apparent sea level changes on a megaregional scale as the asthenosphere rotates relative to the lithosphere.

Preliminary analysis of ODP Leg 143 drilling and associated geophysical surveys in the Western Pacific suggest that vertical motion of the sea floor due to construction and subsidence of oceanic plateaus and seamount groups during the mid-Cretaceous may have been of sufficient areal extent and vertical magnitude to displace volumes of water capable of causing rises and falls of sea level of 10-40 m on continental shelves. Time scale of these events appears to be in the range of 1-10 m.y.

Although eustatic variations are generally thought of as being of the same magnitude worldwide, observed magnitudes vary widely. Some variations are probably due to poor data or observational errors, but other variations may be inherent in the mechanism. For example, deglaciation models of a self-gravitating earth show several different fields in which observed sea-level curves differ. Most prominent is the region of ice sheets and their immediate surroundings which are uplifting from post-glacial rebound and which, therefore, see a net sea-level fall. This region constitutes a "near field" where the observed sea-level signal is significantly different from that in the rest of the world. In "far field" and "near field" regions relative to ice sheet locus, adjustment of the earth to melting and redistribution of water will be different. Sea-level changes will be greater in the near field, and polarity will vary with distance from the ice sheet.

During movement of asthenospheric bumps beneath continental margins and desiccation of isolated basins, local observations of apparent sea-level change will also differ from distant observations. Similarly, near-field and far-field signatures will differ in the case of uplift of mid-plate swells. For other mechanisms, such as changes in spreading rates, there will only be a global far field signal caused by volume change of the ocean basins.

For a third class of mechanisms, there will be local or regional effects but no uniform global signal. These mechanisms, e.g., in-plane stress and dynamic topography, are tectonic processes that produce "eustatic-like" signal in the near field but no uniform far field response. It has been proposed that they are capable of generating sequence boundaries that may be otherwise mistaken for eustatic events.

Strategy

A detailed list of distinguishing features of many individual mechanisms, or correlation of timing of associated geologic and eustatic events, is not appropriate at this time. For these processes, uncertainties in magnitude and timing of sea-level response are still too large to define tests of mechanisms. As new data enable refinement of their eustatic effects, tests will become feasible. We can, however, identify a suite of studies that will contribute to an improved understanding of many mechanisms. In this context, we would like to see studies that improve our understanding of:

a) Timing of inception, growth and decay of ice sheets.

b) Timing and volume changes associated with additions of large thicknesses of sediments to the oceanic crust, especially deep sea fan deposits that form adjacent to rapidly-eroding continents.

c) Timing and volume changes associated with additions of large thicknesses of volcanic material to the oceanic lithosphere through processes of deep-water volcanism, underplating and emplacement of seaward-dipping reflector sequences.

d) Timing and volumes of formation of mid-plate oceanic swells or plateaus. This requires a systematic evaluation of water-displacement volume and timing of emplacement and subsidence of oceanic plateaus and swells and of deep-water flood basalts. This includes emplacement in both mid-plate (e.g., Ontong-Java Plateau, Cape Verde Rise) and ridge-crest (e.g., Iceland-Reykyanes Ridge, Easter Microplate) settings.

e) Timing and volume changes associated with connection and/or isolation of individual basins (e.g., Mediterranean and Gulf of Mexico).

f) Timing and magnitude of shortening (through compression) and lengthening (through extension) of continental crust during orogeny and rifting.

In addition to improving determination of the contribution of different mechanisms to sea level fluctuations, it may be possible to distinguish effects of individual components in the stratigraphic record. Some processes should yield distinctive stratigraphic signals that may be investigated via drilling. For example, it appears that inception of large mid-plate swells is a geologically rapid event. If so, they would produce a rapid sea level rise but only a slow fall as the lithosphere cools. When ODP dating of mid-ocean swells matures, one could examine the stratigraphic record of sea-level change for rapid eustatic rises, not coupled to sea level falls, that are coeval with times of swell initiations.

Summary

Assuming that magnitudes of sea-level changes can be estimated from the stratigraphic record with an accuracy of ±5 m or better, it should be possible to constrain current models of the causes of sea-level change. Drilling proposals must discuss the capability of various mechanisms to contribute to sea-level changes. Would they produce a rise or fall, smooth or oscillatory changes? How would they be expressed in different parts of the world?

SL-WG cannot overemphasize the necessity for accurate estimates of sea level change from widely distributed areas of the world. Good estimates of magnitudes, durations and rates of sea-level fluctuations are critical to constraining mechanisms responsible for sea-level change.

Criteria for Proponents

Topics discussed below summarize some of the transect requirements for sea-level research utilizing capabilities of *JOIDES Resolution*. Issues not discussed in detail, but of concern to proponents, include tracking down licensing roadblocks, understanding territorial jurisdiction, locating potential aquifers, recognizing potential hazards that *JOIDES Resolution* may pose to shipping or commercial ventures, and environmental concerns that may require special drilling muds and close-out procedures.

Clearly define the issues to be addressed

Proponents should clearly define sea-level research issues that are to be addressed by ODP drilling. Four issues are outlined in this paper and any others should be identified and described in proposals. It will be difficult to address more than one sea-level issue per leg because of differences in transect design required to obtain samples for age estimation, stratigraphic response to sea-level oscillations, and estimating sea-level rates and magnitudes.

Clearly define nature of the test, including methods to be used or evaluated

Each sea-level research issue may be addressed by a variety of methods. Each method has a number of assumptions that must be clearly outlined and addressed.

For example, proponents addressing the stratigraphic response issue should describe the model or working hypothesis that is being applied to predict sediment architecture (including facies patterns, unconformities, etc.). In addition, a discussion should be included about parameters that are utilized in the model and how these parameters relate and respond to sea-level fluctuations, with particular emphasis on leads and lags that may exist within the system. It is likely that reference to geometric modeling simulations would form part of such a discussion.

Summarize the status and availability of data/ information

Illustrate scope of the transect and the reason for individual site selection

At the El Paso workshop, the need for drilling non-marine to "deep" basin transects was recognized because transects allow: 1) dating of bounding unconformities of individual sequences; and 2) estimation of the magnitude of sea-level events. In particular, there are two positions within depositional sequences that are critical for dating surfaces.

The first is associated with "toes of clinoforms" within a sequence. Because sedimentation rates are generally lower than in the overlying and underlying systems tracts, microfossils tend to be found in greater abundance (i.e., condensed section). Within a depositional sequence, there may be two sites of significant downlap: 1) downlap at the base of the lowstand wedge near the basinward edge of a sequence, and 2) downlap at the base of the highstand system tract. The first, while physically most continuous and closer in time to the age of the sequence boundary, poses challenges in dating owing to downslope transport, scarcity of pelagic microfossils and problems with sand recovery. The second significant downlap location, in the middle of the sequence and removed (in time) from the sequence boundary, may also provide good chronostratigraphic control. To estimate magnitudes of sea-level oscillations, it will be important to date as many horizons as possible within a sequence, not just at specific locations such as condensed sections and unconformities.

The second critical area is in the open-ocean basin. The deep (open-ocean) basin potentially contains more complete pelagic sections that are suitable for detailed magnetobiostratigraphy; typically the best sections are associated with paleodepths greater than 200 m and often greater than 1000 m. Even in deep basins, it is critical to locate the most continuous section using high-resolution seismic profiles.

Dating stratigraphic surfaces in margin and platform successions represents a major challenge. The key is to project the excellent age-control provided by open-ocean, integrated chronostratigraphy into more fragmented, but expanded, sections on margins and platforms.

Define chronologic resolution that is expected at each site and with respect to age of target intervals

It is important to demonstrate that ages of stratigraphic events, delineated in a particular area, can be determined with chronologic tools that have been or might be effective in the area. Industry results, data from nearby outcrop and/or deep-sea studies may all contribute to making an estimate of the degree of stratigraphic resolution attainable. For example, biostratigraphic information from industry wells, plotted with respect to sequence boundary positions ("biostratigraphic time-distance grids") could provide a framework for more accurately establishing local biozone boundaries prior to designing specific transect locations. This step will be particularly important in some of the middle to higher latitude sites, where paleobiogeographic effects may decrease resolution to the point that ability to date individual sequences using biostratigraphic criteria is difficult. Chemo- and magneto-chronologic (e.g. strontium isotopes, magnetic susceptibility, etc.) tools, in addition to logging, will play an even more critical role in these areas.

Define/illustrate the tectonic/sedimentary setting and justify selection of these areas relative to other possible candidates.

A complete test of the eustatic concept must involve recognition, dating and correlation of surfaces in a variety of tectonic/ sedimentary settings with both similar and differing tectonic histories. The character of stratigraphic surfaces such as sequence boundaries depends on a number of factors but perhaps most significantly on the interplay between eustasy (position of sea surface) and tectonic subsidence (shape of container) through time. In areas with more complex subsidence histories, it should be possible to recognize the eustatic component if subsidence history is carefully documented using geohistory analysis and backstripping techniques. The advantage of using the drillship in complex tectonic settings again relates to the ability to design a sampling strategy that will precisely date surfaces that may coalesce or split due to effects of multiple geologic processes.

Demonstrate that the geophysical data grid is sufficient to resolve the sedimentary targets

A critical component in the effort to date stratigraphic events, represented by unconformities (e.g., sequence boundaries, etc.) is the ability to resolve target surfaces adequately ahead of the drill. The term "adequately resolve" is difficult to define and may best be illustrated by the use of an example from the NJ margin. Key points are the importance of acquiring seismic reflection profiles of sufficient resolution to image target stratigraphic units, looptying around a regional seismic grid to define stratal and reflection termination patterns, calibrating seismic reflections to reflectors via synthetics and delineating seismic facies of systems tracts within depositional sequences.

Industry, government and academic studies of the NJ margin provide a comprehensive stratigraphic framework that will form the basis for sea-level related research on Leg 150. In order to improve stratigraphic resolution and to determine best possible locations for drill sites on Leg 150, proponents have collected multichannel (MCS) and single channel (SCS) seismic data to supplement existing published data. Seven middle to uppermost Miocene sequence boundaries have been defined on previously-published profiles and as many as eight additional sequences have been recognized on newly-acquired profiles. Boreholes have been sited to target specific portions of a number of depositional sequences in order to obtain best possible sections to date sequence boundaries. In this particular example, third- to fourth-order depositional sequences have been "adequately resolved" prior to designing the strategy for locating drill sites. Proponents of Leg 150 noted that their MCS survey, in combination with industry data, provided a minimum degree of control for locating sites. They also suggested that industry specialists be involved in interpretation and location of appropriate sites.

Another important function of the geophysical data grid is to help with evaluation of safety hazards. Lack of shallow-penetration SCS data along the proposed Leg 150 transect has made it difficult to demonstrate that there is no risk of shallow gas deposits.

Try to select targets that are at moderate burial depths

Selection of target intervals for *JOIDES Resolution* at moderate burial depths (<1000m or so) has significant implications for efficiency of the drilling program, frequency bandwidth of seismic reflection profiles (hence stratigraphic resolution), success of chemostratigraphic dating techniques, preservation of microfossils and construction of calibrated signatures of sea level.

Explain the appropriateness of* JOIDES Resolution *drilling

Some sea-level research issues may be better handled by outcrop studies than open-ocean drilling, particularly for the Mesozoic, where there is an abundance of outcrops. Proponents should make it clear to JOIDES thematic panels how *JOIDES Resolution* drilling could improve, complement or provide new approaches to sea-level issues.

Technical Issues

Supplemental platform selection

Study of sea-level change requires drilling in all settings, from onshore to deep sea. One of the more critical and challenging settings is nearshore (water depths 0-50 m). Although *JOIDES Resolution* has documented its ability to position dynamically in water depths of 38 m (see Leg 143 Preliminary Report, this issue), it is not clear that it can maintain position long enough to obtain significant penetration (100's m). Furthermore, the drillship may not be able to recover unconsolidated sands, particularly in the nearshore zone. In contrast, stable platforms such as jack-up rigs and anchored drillships (e.g., *Glomar Conception*) provide near-continuous recovery in the nearshore setting. Jack-up rigs are best in water depths <30 m, while anchored drillship capability overlaps with dynamically positioned drilling (~30-400 m). Because adding anchoring capability to *JOIDES Resolution* will be prohibitively expensive (~$5,000,000; T. Francis, ODP-TAMU, personal communication, 1992), a supplementary platform will be required to meet all sea-level objectives. JOIDES should consider funding options for supplementary platforms in these critical nearshore settings. For example, completion of two extant sea-level transects (New Jersey/Mid-Atlantic Transect, Leg 150; Bahamas Transect, JOIDES proposal #412) may require supplementary platform drilling in 1994-1995. Future transects of continental margins, drilling on atolls, and other shallow-water drilling targets are expected to have similar requirements.

Maximize sediment recovery

In order to resolve a number of sea level issues, recovery must be maximized in a number of sediment types, some of which have proven difficult to recover with existing tools. Technological improvements are paramount. A number of these issues were raised during the El Paso workshop, but have not yet been resolved. Failure to achieve high core recovery will seriously impact investigations of sea-level change, because both carbonates and unconsolidated clastic sediments will make up a high percentage of sediments being investigated. Early correction of the core recovery problem is essential if planning for drilling on margin sites is to proceed. Also, because hole stability often limits penetration and logging, SL-WG supports efforts to improve hole stability.

Sidewall coring may provide a tool to obtain key sediment targets that may have been missed, after downhole coring and logging operations have ceased.

Carbonates

SL-WG requires far higher recovery rates in carbonate sequences than are currently obtained. Using XCB, RCB technology, ODP Legs 133,134 and 143 drilled shallow water carbonates of ages ranging from Tertiary to Mesozoic. Recovery was typically low, ~5%, at shallow depths, with some improvement with greater depth and consolidation. Better results have been obtained in the Bahamas and on Anewetak Atoll using other coring tools. Fixed platform drilling of shallow carbonate banks has routinely obtained recovery rates >80%, in contrast to ~10% averaged by *JOIDES Resolution*. SL-WG believes that higher recovery rates can be achieved by *JOIDES Resolution*. Core recovery can perhaps be improved through use of alternate bits, but highest recovery will probably require a diamond coring system (DCS). So far, efforts with DCS have not been successful. SL-WG strongly supports continued efforts to make DCS operational.

Sands

SL-WG also requires recovery of unconsolidated clastic sediments. Since use of rubber-sleeve liners in core barrels is impractical on *JOIDES Resolution*, VPC (vibra-percussive corer), currently under development, needs to be completed and put into operation *before* Leg 150.

Soft/hard alternations

A method is required for recovering a higher percentage of sections exhibiting alternating hard and soft layers, e.g., cherts and chalks in the deep ocean. Sediment recovery in alternating hard/soft layers is critical to the success of sea level efforts on carbonate margins, carbonate platforms, and atolls and guyots. The best candidate for improving core recovery in these environments appears to be DCS.

Deep sea sediments

Be prepared to double-APC to obtain required recovery.

Stratigraphic Analysis Tools

SL-WG believes that efficiency of a global effort to investigate sea-level issues would be improved immensely by developing and integrating stratigraphic analysis tools and information management systems on *JOIDES Resolution* and also making them available onshore for proponents and cruise participants. Individual investigators have built many of the components of such a system and SL-WG recommends that every effort be made to coordinate/integrate components into a loosely-linked analysis scheme. Requirements of sea level investigators are varied: seismic stratigraphic analysis, structural interpretation, well log analysis and stratigraphy, sedimentology, sequence biostratigraphy and low-temperature geochemistry, to name but a few disciplines. The goal of all disciplines is to recognize and correlate (globally) stratigraphic events, such as depositional sequence boundaries, quantify effects of sea level oscillations on the stratigraphic record and understand processes that control sea-level oscillations. Thus, a Sea-Level Program will require tremendous coordination, not just among investigators, but of all available methods and information, in order to succeed. It will be important to make every effort to release, in a form that can be used, all information utilized by the Sea-Level Program. The petroleum industry is often accused of withholding proprietary information required to support scientific findings. A similar situation could arise, for different reasons, if ODP sea-level data, information, methods and tools are not broadly available to the scientific community.

The stratigraphic analysis scheme could eventually evolve into a state-of-the-art stratigraphic analysis tool that would dramatically improve shipboard operations. Recent efforts to generate a core-log integration implementation plan by JOIDES Downhole Measurements Panel (DMP) and Shipboard Measurements Panel (SMP), as well as recent efforts to upgrade the ODP shipboard computer systems, represent critical steps toward achieving the goal of an integrated system, but there is still a long way to go.

Seismic/Core/Log integration

Calibration of seismic reflections to specific reflectors is a key step in seismic/sequence stratigraphic analysis and is crucial for documenting degree of synchrony of stratigraphic events on continental margins. SL-WG would like to see this capability on board *JOIDES Resolution* in time for Leg 150. Programs to generate synthetics and tie seismics to logs were used on legs 130 and 138 and SL-WG would like to see similar capabilities, plus ability to define/extract seismic wavelets, added to shipboard facilities. Much of the calibration of survey or industry seismic is, of course, done prior to a drilling leg, but ability to select pulses (e.g., Ricker or sine wavelets), adjust frequencies or extract pulses onboard the drillship, after logging runs to tie cores to seismics, is important for sea-level related research and to guide Co-Chief Scientists with operational decisions.

Core-log integration is a critical component of continental margin subsurface studies recommended by SL-WG. Therefore, SL-WG strongly supports the implementation plan prepared by DMP and SMP during a joint meeting in October,1991. Core-log integration procedures, initiated during Leg 138, to correlate cores from multiple holes will need to be modified to handle core/lithology/depth calibration. Recommendations to generate user-friendly, interactive graphics for curve matching and calibration and to create, for appropriate legs, a position of Data Correlation Specialist onboard are also strongly endorsed by SL-WG. For sea-level legs, the position should be filled by a Sequence Stratigrapher (two are necessary on board to handle daily tasks) to undertake sequence stratigraphic interpretation (and prediction) in real-time.

Information Management/Database issues

Dating and correlation of stratigraphic events will require a coordinated program among scientists on a variety of margins. An important feature of this effort must be the ability to share all available data utilized on each margin between groups of researchers. At present, data/information sharing is restricted to data/information captured from Initial Reports or by an informal process of digital data transfer. In addition, integration of analysis tools within the stratigraphic analysis process and linkages to official databases are not optimal.

ODP also has an opportunity, during the course of a Sea-Level Program, to coordinate geological information from continental margins of the world. At present, seismic and well databases required for preliminary selection of sea-level study areas are poorly organized, with some exceptions due to specific government regulations requiring curation and publication of information. SL-WG recommends that data/information required to support ODP sea-level legs become part of an evolving, coordinated (by ODP) package of information (digital/hardcopy) available for sea-level researchers.

Recognition/description of events (depositional sequences, unconformities, etc.) - physical stratigraphy database

SL-WG suggests that a stratigraphic events database be constructed for capturing information on location and age of surfaces or markers encountered in ODP holes.

Chronostratigraphic database

SL-WG also recommends that a chronostratigraphic database be constructed to record position, character and age of depositional sequences penetrated by ODP holes. The chronostratigraphic database represents an interpreted dataset that is derived from raw data stored in the stratigraphic events database.

Correlation of events, including graphic displays documenting precision and accuracy of correlations

An important feature in the stratigraphic tools arsenal is ability to display graphically the precision and accuracy of ages of depositional sequences around the globe. Graphic correlation tools and displays should be attached to databases mentioned above to allow rapid extraction and evaluation of chronologic data used to date chronostratigraphic units and surfaces.

Oriented cores

High-resolution age determination in low latitudes requires oriented cores for determining magnetostratigraphic orientation. Characterization and orientation of sedimentary structures will be an important component of sea-level-related research. Oriented XCB cores will be required. At present, no orientation tool for XCB cores is under development. An orientation system for RCB cores was tested on Leg 143, but had several flaws. Further development work is encouraged. An electronic orientation tool for APC (also part of RCB) was tested on Leg 143. The tool has potential, but computer hardware and software are needed to handle the several orders-of-magnitude increase in data. Multiple orientation tools will also be needed to speed up orientation operations. Orientation of cores may also be accomplished through correlations between recovered cores and logs such as FMS.

Shipboard Core Analysis

SL-WG encourages more detailed routine core description through use of new technology, especially color scanners and whole-core X-ray. SL-WG also supports suggestions by JOIDES SMP to upgrade shipboard core analysis processes.

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Third Party Tools

Revised Guidelines for Development and Deployment of Third Party Tools

Introduction

Downhole measurements form an integral part of the technology that is routinely deployed in ODP. In addition to standard downhole tools that are run on all ODP scientific expeditions or legs, ODP has historically drawn upon tools developed outside the framework of its primary contractors. These tools are known as "third party tools".

Support for development of third party tools can come from a variety of sources. In the United States, third party tool development has generally been supported by the National Science Foundation, using funds earmarked for ODP and allocated to highly-ranked, unsolicited proposals. International partners operate a similar procedure. Tools developed with this type of funding are specifically intended for deployment in ODP. However, ODP sometimes wishes to use existing tools that have been developed externally for different purposes. In both cases, it is important that third party tools are certified as satisfying all operational and safety criteria that ODP applies to in-house tools.

Third-party tools are required to make a transition from the development stage to being certified for deployment downhole in ODP, under management of either the ODP Logging Contractor (for wireline tools) or the Science Operator (for all others). To facilitate this transition, a set of guidelines has been formulated for the overall process of bringing third party tools to deployment stage. The aim is to improve communications between ODP and those outside investigators who wish to develop a third party tool, with the object of preserving ODP's safe, secure and scientifically beneficial operations.

These revised guidelines, completed by JOIDES Downhole Measurements Panel (DMP) in February 1992 and approved by Planning Committee (PCOM) in April 1992, supersede those published in the February 1991 issue of *JOIDES Journal*.

Definitions

There are three types of third party tool:

- A "Development Tool" is either one under development externally for use specifically in ODP or one developed outside ODP for other purposes and being considered for ODP deployment.
- A "Certified Tool" is one developed outside ODP, either for specific ODP application or for other purposes, and now deemed to satisfy all the criteria for scientific deployment in ODP. Where there is likely to be a long-term requirement for data provided by a Certified Tool, it may be a candidate to become an ODP Mature Tool.
- A "Mature Tool" is one that has become part of the range of ODP tools operated routinely by the Science Operator or the Logging Contractor. Such a tool will effectively be owned by ODP and will, therefore, no longer be a third party tool.

Development Tools

For a tool to be considered an ODP Development Tool, several criteria must be satisfied:

(i) There must be an identified Principal Investigator who is the primary proponent for use of the tool in ODP.

(ii) The Principal Investigator should formulate a Development Plan in consultation with the Science Operator or the Logging Contractor, as appropriate.

(iii) The Development Plan should:

- indicate the usefulness of the proposed measurements and the financial and technical feasibility of making them;
- include a brief description of the tool, schematic diagram(s), details of the operational procedure, and technical specifications such as dimensions, weight, temperature and pressure ratings, cable-length restrictions, cable type, etc.;
- identify development milestones in terms of both level and timing of technical achievements;
- make provision for initial testing on land;
- satisfy safety considerations;
- specify shipboard requirements such as data processing necessary to make the information accessible on board ship, any special facilities (emphasizing areas where the tool is not compatible with existing hardware/software), and appropriate technical support;
- make provision for transporting tools for shipboard testing, in terms of both cost and time;
- contain a signed (pro-forma) statement of (a) accedence with these requirements and (b) intent that the tool will be available for post-development deployment in ODP.

(iv) The Development Plan must be submitted for approval to DMP. This submission should be made by the Science Operator or the Logging Contractor, as appropriate, on behalf of the Principal Investigator, who may be invited to present the Development Plan to DMP in person.

(v) If DMP endorses the Development Plan, DMP will appoint a coordinator to monitor on behalf of DMP the tool's progress through the Development Plan. The DMP monitor will receive reports from the Principal Investigator on request and will present these to DMP. Day-to-day liaison with the Principal Investigator will be the responsibility of the Science Operator or the Logging Contractor.

(vi) An ODP Development Tool can be scheduled for testing during an upcoming leg. Development tools must be deployed in test mode, i.e., by their very definition, they are not certified or mature tools. Therefore, the scientific success of a leg should not be contingent upon the proper functioning of such a tool.

(vii) Where it becomes apparent that the Development Plan is seriously behind schedule and that the tool is unlikely to have satisfied all the above criteria prior to its planned deployment, the shipboard test should be canceled and a revised schedule agreed. In particular, if a Development Tool has failed to satisfy all the above criteria six months prior to commencement of a scheduled test leg, the tool should be withdrawn immediately from that leg.

(viii) It is incumbent upon the Principal Investigator to ensure that the ODP Science Operator or Logging Contractor, as appropriate, is fully advised as to tool status prior to the six-month deadline.

(ix) A tool cannot be regarded as an ODP Development Tool, and therefore cannot be scheduled for testing on future legs, if the above procedure has not been followed. A Development Tool cannot be deployed on an ODP leg unless the Science Operator and/or Logging Contractor are fully satisfied that the terms of the Development Plan have been fully met.

Certified Tools

For a tool to be considered an ODP Certified Tool, the following criteria must be met:

(i) The tool must have satisfied all requirements for an ODP Development Tool.

(ii) The tool has been tested at sea during ODP legs and has performed satisfactorily in the opinion of the Science Operator and/or Logging Contractor.

(iii) The Principal Investigator must formulate a Request for Certification in consultation with the Science Operator or Logging Contractor, as appropriate.

(iv) The Request for Certification should:

- indicate cost of routine operations, including shipboard data processing;
- outline the operational requirements for routine deployment and data processing;
- detail the availability of spare components;
- provide information on adequate maintenance facilities;
- include an operating/maintenance manual;
- satisfy safety considerations;
- confirm the long-term usefulness of the collected data.

(v) The Request for Certification must be submitted for approval to DMP. This submission should be made by the Science Operator or the Logging Contractor, on behalf of the Principal Investigator, who may be invited to present the Request for Certification to DMP in person.

(vi) If DMP endorses the Request for Certification, a certificate confirming the satisfactory conclusion of tests and compliance with all other requirements will be issued to the Principal Investigator by the Science Operator or the Logging Contractor. A copy of this certificate should be forwarded to the DMP Chair.

(vii) An ODP Certified Tool remains in the charge of a third party. It can be scheduled for deployment during an upcoming leg and would be expected to contribute to the scientific success of that leg.

(viii) Tools that do not possess a certificate cannot be programmed for scientific deployment on future legs.

Mature Tools

For a tool to be considered an ODP Mature Tool, the following criteria must be met.

(i) The tool must satisfy all the requirements for an ODP Certified Tool.

(ii) A Mature Tool Proposal should be submitted for approval to DMP. This submission should be made by the Science Operator or the Logging Contractor, as appropriate. DMP will advise on the long-term scientific benefits of the proposal.

(iii) If DMP proposes and PCOM endorses the Mature Tool Proposal, the Science Operator or Logging Contractor will progress the acquisition of the tool for ODP, provided funds are available.

(iv) Where several Certified Tools are competing for the same Mature Tool slot, DMP will require the appropriate contractor to evaluate all these tools and to submit their multiple-tool evaluations to DMP for panel consideration. DMP will advise on the most suitable option(s).

(v) Tools that have not undergone this process cannot be adopted by ODP as Mature Tools and will therefore remain third party tools.

JOIDES Committee Report

Planning Committee

PCOM met in Corner Brook, Newfoundland, on 11-13 August 1992. The following decisions, with broad relevance to the scientific community, were made.

Diamond Coring System/Data Handling

- In light of the continuing requirement for a coring system that is capable of recovering rock types that cannot be effectively drilled by standard rotary bits, PCOM reconfirms its commitment to development and deployment of a Diamond Coring System (DCS).
- PCOM requests that the Science Operator (ODP-TAMU) issue a RFP to the ODP community to provide a shipboard and shorebased computing facility which meets performance specifications set by DH-WG at its Toronto meeting (March 1992). Responses to the RFP are to be evaluated by an impartial expert committee including PCOM Chair, DH-WG Chair, representative of the Science Operator, representative of JOI, Inc., and two other PCOM-appointed members. This evaluation committee will report to PCOM at its December 1992 meeting.
- PCOM recognizes that both the DCS and upgrade of the ODP computing system are of great importance to ODP science. PCOM further notes that some savings for the Leg 151 ice-support vessel may be possible. If such savings are realized, DCS should be funded at a level of $400,000 and any additional overflow (possibly several hundred thousand dollars) will go toward computing upgrades in FY93. PCOM realizes that this may delay land testing of the DCS to FY94 and sea testing to FY95.

In Situ Pore-Fluid Sampling

- PCOM commends the Steering Group for *In Situ* Pore-Fluid Sampling for identifying important opportunities in advancing research on pore fluid sampling and outlining technology developments required. PCOM is strongly in favor of pursuing this research and development and intends to issue the necessary RFP in spring 1993 for funding 1 October 1993. *[Note: Consensus]*

Core Repositories

- In order to help ODP-TAMU provide JOI, Inc. and PCOM with least-cost procedures/policy for expanding quality core repository facilities, which will be discussed at the December 1992 PCOM meeting, PCOM requests its member institutions, and especially international partners, to provide ODP-TAMU with information on their interest and ability to host such facilities.

FY93 Program Plan

- After consultation with interested members of the community, including Panel Chairs, members of PCOM and others, PCOM has reconsidered its decision made at the April 1992 PCOM meeting and endorses the original recommendation of NARM-DPG to drill a transect across the Iberian margin, in the priority order IAP-4, IAP-2, IAP-3, and alternates. PCOM furthermore charges the Co-Chiefs to attempt penetration of the basement to several hundred meters in order to increase the chances of recovering diverse lithologies containing a record of tectonic evolution.

FY94 Prospectus

- After discussion of proposals highly-ranked and considered drillable in FY94 by the four thematic panels and on the general ship track defined by PCOM at its April 1992 meeting, PCOM decided that the following programs, for which SSP considered that the required site survey data exist or that surveys could be completed by November 1992, should be included in the FY94 Atlantic Prospectus:

323-Rev2	Alboran Basin evolution
346-Rev3	Eastern equatorial Atlantic transform
361-Rev2	TAG hydrothermal system
369-Rev2	MARK
380-Rev3	VICAP/MAP (only MAP ready for FY94)
388/-Add	Ceara Rise
391-Rev	Mediterranean sapropels
405-Rev	Amazon Fan
414-Rev	North Barbados Ridge
NARM-DPG	Non-volcanic margins II
NARM-DPG	Volcanic margins II

Thematic Panel Issues

- Acknowledging the great importance and impact of large, thematic, multi-leg programs, PCOM charges thematic panels to follow continuously and evaluate such programs by naming watchdogs as appropriate and by making annual written reports to PCOM on program progress and performance and the possible need for program changes at the scale from drilling leg priority to detailed siting.
- PCOM charges the relevant thematic panels to evaluate the reports of the Offset(-Section)-Drilling and Sea-Level working groups in the immediate future. The two working groups will remain alive, but inactive, until the December 1992 PCOM meeting when a final decision on their fate will be made.

Proposal/Data Submission

- In response to a request from SSP, PCOM establishes a 1 November 1992 deadline for submission to the ODP Site Survey Data Bank of available data and schedules for completion of survey work for proposals to be considered for drilling in FY94. Decisions on FY94 scheduling will be based on proponents' compliance with this deadline. *[Note: Consensus]*
- Because SSP was concerned that the lead-time from data submission deadline to PCOM meeting had been too short to ensure full compilation in the Site Survey Data Bank, PCOM sets a future deadline of 1 July for submission of proposals to the JOIDES Office and of site survey data to the Site Survey Data Bank. *[Note: Consensus]*

Proposal News

Deadlines for proposal submission

1 January 1993

Thematic panels will review all active proposals, including new submissions received at the JOIDES Office not later than 1 January 1993, during their early spring meetings and globally rank those proposals within their mandate and interest. Highly-ranked proposals will be reviewed by the Site Survey Panel (SSP) at its April 1993 meeting and monitored from then on. In order to give SSP enough time to evaluate site survey data of (resubmissions of) highly-ranked proposals before the August PCOM Meeting, PCOM has changed the **Summer Deadline** for proposal submission to the JOIDES Office, and site survey data packages to the Site Survey Data Bank (Lamont-Doherty Geological Observatory), from 1 August (as advertised in the previous *JOIDES Journal*) to:

1 July 1993

Proposals must be submitted to the JOIDES Office.

Proposals submitted directly to thematic panels are not reviewed.

Active Proposals

Proponents of JOIDES drilling proposals are reminded that the statute of limitations for proposals (PCOM motion, August 1991) renders proposals inactive after a certain period. Inactive proposals are not considered for planning.

By 1 January 1993, all proposals submitted before 1 January 1990 and not updated since then, become inactive.

To keep a proposal active, or to reactivate a proposal, a revised version or an addendum must be submitted to the JOIDES Office.

Drilling proposals received since 1 June 1992

JOIDES Office, UTIG

Ref.No	Received	Abbreviated Title	Contact	Status
417—	06/30/92	Gas hydrate in vicinity of gas plume, Okhotsk Sea	Soloviev, V.	In Review
338-Add	07/13/92	Sea-level fluct., Marion carbonate plateau, NE Australia	Pigram, C.J.	*1992
400-Add	07/20/92	NSF proposal: fluid paths in Costa Rica Acc. wedge	Silver, E.A.	*1992
384-Rev2	07/21/92	Pacific-Atlantic connection, Venezuela basin, Aruba Gap	Mauffret, A.	In Review
086-Rev2	07/27/92	Drilling in the Red Sea	Bonatti, E.	In Review
334-Rev2	07/27/92	Galicia margin S reflector	Boillot, G.	In Review
376-Rev2	07/27/92	Vema F.Z.: Upper mantle, gabbro/dyke, limestone cap	Bonatti, E.	*1992, 1991, 1990
418—	07/27/92	Miocene biomagnetostrat. reference section, Menorca Rise	Cita-Sironi, M.B.	In Review
403-Rev2	07/28/92	KT Boundary Drilling in the Gulf of Mexico	Alvarez, W.	*1992
419—	07/28/92	Convergence at Azores-Gibraltar plate boundary	Zitellini, N.	In Review
347-Add	07/30/92	L. Cenozoic paleoceanography, south-equatorial Atlantic	Wefer, G.	*1992, 1991
354-Add	07/30/92	Benguela Current and Angola/Namibia upwelling	Wefer, G.	*1992, 1991
380-Rev3	07/30/92	Clastic apron, Gran Canaria, and Madeira Abyssal Plain	Schmincke, H.U.	*1992, 1991, 1990
420—	07/30/92	The evolution of oceanic crust	Purdy, G.M.	In Review
421—	07/30/92	Alkali-acidic rocks of the Volcano Trench	Vasiliev, B.I.	In Review
079-Rev	07/31/92	Tethys and the birth of the Indian Ocean	Coffin, M.F.	In Review
323-Rev2	07/31/92	Tectonic evolution of the Alboran Sea	Comas, M.C.	*1992, 1991, 1990
330-Rev	07/31/92	Mediterranean Ridge accretionary complex (Phase 1)	Camerlenghi, A.	*1992, 1991
346-Rev3	07/31/92	Ivory Coast - Ghana transform margin	Mascle, J.	*1992, 1991, 1990
361-Rev2	07/31/92	TAG active hydrothermal system, slow spreading ridge	Thompson, G.	*1992, 1991, 1990
369-Rev2	07/31/92	Generation of oceanic lithosphere, MARK area	Mevel, C.	*1992, 1991, 1990
405-Rev	07/31/92	Amazon fan growth and climate, denudation, sea-level	Flood, R.D.	*1992
414-Rev	07/31/92	Structural and fluid processes, N Barbados acc. prism	Moore, J.C.	*1992
415-Rev	07/31/92	Caribbean ocean history and KT-boundary	Sigurdsson, H.	*1992
422—	07/31/92	Santa Monica Basin	Stott, L.D.	In Review
423—	07/31/92	Gas hydrate sampling, Blake Ridge and Carolina Rise	Paull, C.K.	In Review
424—	07/31/92	To "cork" Hole 395A	Becker, K.	In Review
425—	07/31/92	MAR at 15°37'N: crust generation at magma-poor MOR	Cannat, M.	In Review
300-Rev	08/01/92	Return to Site 735: very slow-spread. lower ocean crust	Dick, H.J.B.	In Review
391-Rev	08/01/92	Formation of sapropels in the Mediterranean	Zahn, R.	*1992, 1991
333-Rev	08/05/92	Evolution of pull-apart basin, Cayman Trough	Mercier de Lepina	*1992, 1991, 1990
426—	08/20/92	Mantle reservoirs/migration, Australia-Antarctic rifting	Christie, D.	In Review

*Previous version(s) reviewed and globaly ranked in the indicated years

Bulletin Board

ANNOUNCEMENTS

JOI/USSAC OCEAN DRILLING GRADUATE FELLOWSHIPS

JOI/US Science Advisory Committee is seeking doctoral candidates of unusual promise and ability who are enrolled in U.S. institutions to conduct research compatible with that of the Ocean Drilling Program. Both one- and two-year fellowships are available. The award is $20,000 per year to be used for stipend, tuition, benefits, research costs and incidental travel, if any. Applicants are encouraged to propose innovative and imaginative projects. Research may be directed toward the objectives of a specific leg or to broader themes.

Applications are available from the JOI office and should be submitted according to the following schedule:

Shorebased Research (regardless of leg): 12/1/92

For more information and to receive an application packet, contact:
JOI/USSAC Ocean Drilling Fellowship Program
Joint Oceanographic Institutions, Inc.
1755 Massachusetts Ave., NW, Suite 800
Washington, DC 20036-2102.
For additional information,call: Andrea Leader, 202-232-3900.

RESULTS OF DRILLING IN WESTERN PACIFIC ACTIVE MARGINS AND MARGINAL BASINS

A JOI-USSAC Sponsored ODP Results Symposium

Asilomar Conference Center, Monterey CA

January 18-21, 1993

The goal of the symposium is to assemble scientists from all nations to develop an inter-leg synthesis of, and to prepare summary papers on, the results of ODP legs 124-128, 131, 132, 134, and 135, and to discuss future drilling objectives in the light of these results. Highlighted themes will include:

Arc-forearc processes
Rifting and basin evolution
Collision-accretion processes

The meeting will be limited to a maximum of 72 participants, of which about one third will be invited US scientists supported by JOI-USSAC, one third will be invited non-US scientists supported by their national organizations, and one third will be other interested persons. For more details contact:

Dr. Brian Taylor
Department of Geology & Geophysics
University of Hawaii, 2525 Correa Road, Honolulu, HI 96822
Fax: (808) 956-2538, Tel: (808) 956-6649
Internet: taylor@kiawe.soest.hawaii.edu
Omnet: B. Taylor

Registration deadline is 1 September 1992

JOI/USSAC Distinguished Lecturer Series

JOI/USSAC is pleased to announce the institutions selected to participate in the 1992-1993 Distinguished Lecturer Series.

Warren Prell (Brown University)

Evolution of the Indian Ocean Monsoon: Results from ODP Drilling and Climate Modelling

- MIT
- Univ. of Northern Colorado
- Saint Louis University
- UC, Berkeley

J. Casey Moore (UC, Santa Cruz)

Investigating the Plumbing of Accretionary Prisms using the JOIDES Resolution, Alvin *and a Rock Hammer*

- University of Nebraska
- University of North Carolina
- University of Texas at Dallas
- Virginia Tech

James Kennett (UC, Santa Barbara)

Cenozoic Climate Change: Paleoceanography and Event Stratigraphy

- University of Montana
- University of North Dakota
- University of Utah
- University of Wyoming

Susan Humphris (WHOI)

Hydrothermal Systems of the Mid-Atlantic Ridge

- Bryn Mawr College
- Humboldt State University
- University of New Hampshire
- College of William & Mary

Robert Zierenberg (U.S. Geological Survey)

Seafloor Hydrothermal Systems on the Gorda and Juan de Fuca Ridges

- Ohio Wesleyan University
- University of Idaho
- University of Minnesota
- University of Oklahoma

Janet Haggerty (University of Tulsa)

The Cretaceous through Cenozoic History of the Atolls and Guyots of the West Central Pacific

- Cornell University
- Purdue University
- University of South Florida

For more information please contact Mary Reagan at Joint Oceanographic Institutions, Inc., 1755 Massachusetts Avenue, NW, Suite 800, Washington, DC 20036-2102. Phone: (202) 232-3900

Now Available!

The JOI/USSAC Workshop Report, *Paleogene Paleoceanography*, is now available from JOI, Inc.

For a free copy, contact Johanna Adams
Joint Oceanographic Institutions, Inc. 1755 Massachusetts Ave, NW, Suite 800, Washington, DC 20036-2102

Don't miss JOI/USSAC at the fall AGU meeting! We'll be at booth #415.

CENOZOIC GLACIATION: THE MARINE RECORD ESTABLISHED BY OCEAN DRILLING

A SUPPLEMENT TO UNDERGRADUATE CURRICULA

Eugene Domack and Cynthia Domack, Hamilton College

A new course supplement, *Cenozoic Glaciation: The Marine Record Established by Ocean Drilling*, will be available for use in the fall 1991 semester. The booklet, sponsored by JOI/USSAC, covers the results of five ODP high-latitude legs: two in the northern hemisphere (legs 104 and 105) and three in the southern hemisphere (legs 113, 119 and 120). Cenozoic Glaciation is intended for use as a supplement to regular class materials in courses such as oceanography, glacial geology, marine geology and sedimentology, and is designed specifically for undergraduates. A coordinated color poster illustrating the core intervals described in the text is included.

Copies of the booklet and poster are available from JOI.

If you would like a sample copy, contact Mary Reagan, Joint Oceanographic Institutions, Inc., 1755 Massachusetts Ave., NW, Suite 800, Washington, DC 20036-2102; (202) 232-3900.

Available from: Karen Riedel, ODP, Public Relations, Texas A&M University, 1000 Discovery Drive, College Station, TX 77840.

Coring Poster

ODP has a poster: "Scientific Coring Beneath the Sea," available for distribution. The poster features individual coring systems developed for scientific ocean drilling, including the rotary core bit, advanced piston coring and extended core barrel. Eric Schulte of Engineering and Drilling Operations designed and produced the poster.

Brochures

Updated ODP brochures in English, French, Spanish and German are now available. A brochure featuring engineering developments is also available.

Reprints

Reprints of the 1990 Offshore Technology Conference paper, *"The Ocean Drilling Program: After five years of field operations,"* is available from Karen Riedel. The paper, written by P.D. Rabinowitz, L.E. Garrison, et al., features the significant results of Legs 100-124. The paper also describes in detail Legs 124E-135. An ODP Operations Summary outlines the data from each cruise, including number of sites, number of holes and percent recovery.

ODP Long Range Plan

The ODP Long Range Plan portfolio is available from the JOI office. If you would like to receive a copy, contact:

Jenny Ramarui, JOI, Inc.
1755 Massachusetts Ave., NW, Suite 800
Washington, DC 20036-2102
Phone: 202-232-3900, FAX: 202-232-8203

Report on National Workshop on Gas Hydrates

Workshop held in April 1991, organized by: US Navy, Naval Research Laboratory; USGS; US Dept. of Energy, Morgantown Energy Technology Center.

Report available from: National Technical Information Service, US Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

ODP Open Discussion via Bitnet

The ODP BITNET LISTSERVER is an open discussion service to which individuals subscribe *via* Bitnet. It permits exchange of information among all subscribers. Currently, the list administrator sends a report of the previous week's shipboard scientific and operations activities to all subscribers. Site summaries are distributed as soon as they are received at ODP from the ship, usually the day after a site is completed. Periodically, an updated cruise schedule and brief descriptions of upcoming cruises are sent out. Any subscriber may send files to the list for distribution. A file sent *via* Bitnet to the list address (ODP-L@TAMVM1) will be distributed automatically to all subscribers.

Anyone with a Bitnet computer link can subscribe. At present there are subscribers in the U.S., Canada, Europe, Australia and Japan. There is no charge for subscribing to the listserver.

To subscribe, send a brief Bitnet command to LISTSERV@TAMVM1 consisting of the words "SUBSCRIBE ODP-L YOUR_NAME" (where YOUR_NAME really is your first and last names). For example, people on VAX/VMS systems using the JNET networking software will send a command that looks like this: $SEND LISTSERV@TAMVM1 "SUBSCRIBE ODP-L YOUR_NAME" but it may be different according to the command language your computer system uses. If you have any questions, your own friendly local system manager should be able to help. As a last resort, you may send a message to Joan Perry (PERRY@TAMODP or perry@odpvax.tamu.edu) requesting that you be added to the ODP-L subscription list.

Funding for Site Survey Augmentation

JOI/U.S. Science Support Program has Site Survey Augmentation funds available to supplement drilling site data sets that are in all phases of planning. This program element includes support for:

- acquiring and/or processing data for sites being considered by JOIDES;
- mini-workshops that would bring together scientists to coordinate site-specific data for integration into a mature drilling proposal;
- "augmentation" surveys on ships of opportunity that would significantly enrich drilling-related science and/or acquire needed site survey data;
- U.S. scientists to participate in non-U.S. site surveys.

Site Survey Augmentation proposals may be submitted at any time. Priority will be given to augmentation of sites and/or themes that are high priority within JOIDES. As with all JOI/USSSP activities, it is important to clearly state how the work would contribute to U.S. plans or goals related to the Ocean Drilling Program. Note that the Site Survey Augmentation funds cannot be used to supplement NSF/ODP funded work.

Contact Ellen Kappel, JOI office, for further information and proposal guidelines: (202) 232-3900.

Micropaleontological Reference Centers

Located at eight sites on four continents, Micropaleontological Reference Centers (MRC) provide scientists around the world an opportunity to examine, describe and photograph microfossils of various geological ages and provenance. The collections contain specimens from four fossil groups—foraminifers, calcareous nannofossils, radiolarians and diatoms—selected from sediment samples obtained from the Deep Sea Drilling Project (DSDP). Processing of samples from DSDP legs 1 through 82 has been overseen by John Saunders, Supervisor of the Western Europe Center, and William Riedel, Supervisor of the facility on the US West Coast. These samples have been prepared, divided into eight identical splits, and distributed to each MRC. Future plans include addition of samples from later legs of DSDP and from the Ocean Drilling Program (ODP) as well.

All fossil material maintained by MRCs remains the property of the US National Science Foundation and is held by the MRCs on semipermanent loan.

Establishment of identical paleontological reference collections around the world will help researchers to unify studies on pelagic biostratigraphy and paleoenvironments, and to stabilize taxonomy of planktonic microfossils. Researchers visiting these centers may observe quality of preservation and richness of a large number of microfossils, enabling them to plan their own requests for either ODP or DSDP deep-sea samples more carefully. Visitors to MRCs also may compare actual, prepared faunas and floras (equivalent to type material) with figures and descriptions published in DSDP *Initial Reports* or ODP *Proceedings* volumes.

Facilities at MRCs

All MRCs maintain complete, identical collections of microfossil specimens.
In addition, the following materials and equipment are available for visitor use:

- secure storage and display areas
- binocular microscope and work space
- reference set of DSDP *Initial Reports* and ODP *Proceedings* volumes
- lithologic smear slides accompanying each fossil sample
- microfiche listings of samples available.

For more information about MRCs, or to schedule a visit, contact the supervisor on site.

Locations of MRCs

US East Coast
Lamont-Doherty Geological Observatory
Palisades, NY 10964
Supervisor: Ms. Rusty Lotti
Phone: (914) 359-2900
Telex: 7105762653 LAMONTGEO

US National Museum
US National Museum of Natural History
Dept. of Paleobiology
Smithsonian Institution
Washington, D.C. 20560
Supervisor: Dr. Brian Huber
Phone: (202) 786-2658
Telex: 264729
Fax: (202) 786-2832

US Gulf Coast
Texas A&M University
Dept. of Oceanography
College Station, TX 77843
Supervisor: Dr. Stefan Gartner
Phone: (409) 845-8479

US West Coast
Scripps Institution of Oceanography
La Jolla, CA 92093
Supervisor: Dr. William Riedel
Phone: (619) 534-4386
Telex: 910337127 IUC WWD SIOSDG

Western Europe
Natural History Museum
CH-4001 Basel
Switzerland
Supervisor: Mr. John Saunders
Phone: 061-29-55-64

Russia
Institute of the Lithosphere
Staromonet 22
Moscow 109180, Russia
Supervisor: Dr. Ivan Basov
Phone: 231-48-36

Japan
National Science Museum
Dept. of Geology
3-23-1 Hyakunin-cho
Shinjuku-ku
Tokyo, 160, Japan
Supervisor: Dr. Y. Tanimura
Phone: 03-364-2311
Telemail: 03-364-2316

New Zealand
DSIR Geology & Geophysics
PO Box 30 368
Lower Hutt, New Zealand
Supervisor: Dr. C.P. Strong
Phone: (04) 569-9059
Fax: (04) 569-5016

JOI/USSAC Workshop Reports and other ODP-Related Reports

Joint Oceanographic Institutions, Inc.
1755 Massachusetts Ave. NW, Suite 800, Washington, D.C. 20036-2102, Tel (202) 232-3900

Scientific Seamount Drilling, A.B. Watts and R. Batiza, conveners.
Vertical Seismic Profiling (VSP) and the Ocean Drilling Program (ODP), J. Mutter and A. Balch, conveners.
Dating Young MORB?, R. Batiza, R. Duncan and D. Janecky, conveners.
Downhole Seismometers in the Deep Ocean, G.M. Purdy and A. Dziewonski, conveners.
Science Opportunities Created By Wireline Reentry of Deep-Sea Boreholes, M.G. Langseth and F.N. Spiess, conveners.
Wellbore Sampling, R.K. Traeger and B.W. Harding, conveners
South Atlantic and Adjacent Southern Ocean Drilling, J.A. Austin, Jr., convener.
Measurements of Physical Properties and Mechanical State in the Ocean Drilling Program, D.K. Karig and M.H. Salisbury, conveners.
Paleomagnetic Objectives for the Ocean Drilling Program, K.L. Verosub, M. Steiner and N. Opdyke, conveners.
Cretaceous Black Shales, M.A. Arthur and P.A. Meyers, conveners.
Caribbean Geological Evolution, R.C. Speed, convener.
Drilling the Oceanic Lower Crust and Mantle, H.J.B. Dick, convener.
Role of ODP Drilling in the Investigation of Global Changes in Sea Level, J.S. Watkins and G.S. Mountain, conveners.
Ocean Drilling and Tectonic Frames of Reference, R. Carlson, W. Sager and D. Jurdy, conveners.
ODP Shipboard Integration of Core and Log Data, K. Moran and P. Worthington, conveners.
Drilling of the Gulf of California, B. Simoneit and J.P. Dauphin, Conveners.
East Pacific Rise Petrology Data Base (Vols. I-III), C. Langmuir, compiler.
Report on the Conference on Scientific Ocean Drilling (COSOD I), JOIDES, sponsor.
Report of the Second Conference on Scientific Ocean Drilling (COSOD II), JOIDES, sponsor.
Geochemistry Progress and Opportunities, M. Kastner and G. Brass, Conveners.
Proceedings of a Workshop on the Physical Properties of Volcanic Seafloor, G.M. Purdy and G.J. Fryer, Conveners.
Data Synthesis on Rejuvenescent Mid-Plate Volcanism in the Pacific Basin, compiled by S.O. Schlanger, R.G. Gordon, E. Okal, and R. Batiza (available in flat ASCII format on Mac or IBM disks, or Sun tapes[150MB 1/4 in. cartridge or 9-track TAR])..
Large Igneous Provinces, M. Coffin, convener.
Cretaceous Resources, Events and Rhythms, M.A. Arthur, convener.
Paleogene Paleoceanography, L. Stott, convener.

ODP BIBLIOGRAPHY AND DATABASES

ODP Science Operator

Texas A&M University, 1000 Discovery Drive, College Station, Texas 77845-9547

Cumulative Index to 96 DSDP Volumes Now Available

A cumulative index to all 96 volumes of the Initial Reports of the Deep Sea Drilling Project is now available from ODP/TAMU. The index is presented in two formats: an electronic version on CD-ROM, and a printed version. Both are packaged together in a sturdy slipcase.

The index is in three parts: (1) a subject index, (2) a paleontological index, and (3) a site index. The three parts reflect the interwoven nature of the marine geoscience subdisciplines.

The electronic version of the index is the more complete of the two, containing up to eight hierarchies of entries. The 1072-page printed index volume contains three hierarchies of entries and was condensed from the electronic version. Both versions of the index were prepared by Wm. J. Richardson Associates, Inc.

The CD-ROM containing the electronic index was manufactured under the auspices of the Marine Geology and Geophysics Division of the National Geophysical Data Center, National Oceanic and Atmospheric Administration, and U.S. Department of Commerce. In addition to the three-part index, the CD-ROM contains (1) a bibliography of authors and titles, (2) citations to DSDP exclusive of the Initial Reports, (3) proposals to DSDP, (4) site-summary information, (5) an inventory of DSDP underway geophysical data, (6) an inventory of downhole-logging data, and (7) data-documentation files.

Many persons contributed to the indexing project, including those at Scripps Institution of Oceanography and Texas A&M University. The U.S. National Science Foundation funded preparation and publication.

Index sets (US$50), Proceedings (US$45 each, plus postage), Prospectuses, Preliminary Reports and Technical notes (free) can be obtained from:

Publications Distribution Center
Ocean Drilling Program
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.
Phone, (409) 845-2016; Fax, (409) 845-4857;
Bitnet: FABIOLA@TAMODP

Proceedings of the Ocean Drilling Program, Initial Reports and Scientific Results

	Initial Reports		Scientific Results	
	Vol.	Published	Vol.	Publ.
Leg 101	101/102	Dec 86	101/102	Dec 88
Leg 102	101/102	Dec 86	101/102	Dec 88
Leg 103	103	Apr 87	103	Dec 88
Leg 104	104	July 87	104	Oct 89
Leg 105	105	Aug 87	105	Oct 89
Leg 106	106/109/111	Feb 88	106/109	Jan 90
Leg 107	107	Oct 87	107	Feb 90
Leg 108	108	Jan 88	108	Dec 89
Leg 109	106/109/111	Feb 88	106/109	Jan 90
Leg 110	110	Apr 88	110	May 90
Leg 111	106/109/111	Feb 88	111	Dec 89
Leg 112	112	Aug 88	112	May 90
Leg 113	113	Sept 88	113	Aug 90
Leg 114	114	Nov 88	114	Feb 91
Leg 115	115	Nov 88	115	Sept 90
Leg 116	116	Jan 89	116	Sept 90
Leg 117	117	June 89	117	Feb 91
Leg118	118	May 89	118	July 91
Leg 119	119	Sept 89	119	Sept 91
Leg 120	120	Nov 89	120	May 92
Leg 121	121	Nov 89	121	Nov 91
Leg 122	122	Jan 90	122	Dec 91
Leg 123	123	June 90	123	May 92
Leg 124	124	June 90	124	Sept 91
Leg 125	125	Aug 90	125	Apr 92
Leg 126	126	Aug 90	126	Aug 92
Leg 127	127	Sept 90		
Leg 128	128	Sept 90		
Leg 129	129	Dec 90		
Leg 130	130	Mar 91		
Leg 131	131/132	June 91		
Leg 132	131/132	June 91		
Leg 133	133	Sept 91		
Leg 134	134	Mar 92		
Leg 135	135	May92		
Legs136/137	136/137	Jan 92		
Leg 138	138	Sept 92		

Scientific Prospectuses and Preliminary Reports

	Prospectuses		Prelimin. Rpts.	
	Vol.	Published	Vol.	Published
Leg 139	39	Mar 91	39	Nov 91
Leg 140	40	June 91	40	Jan 92
Leg 141	41	Aug 91	41	Mar 92
Legs143/144	43/44	Jan 92	43	Sept 92
Leg 145	45	Apr 92		
Leg 146	46	July 92		
Leg 147	47	Sept 92		

Engineering Prospectuses and Preliminary Reports

	Prospectus		Prelimin. Rpts.	
	Vol.	Published	Vol.	Published
Leg 142	3	Nov 91	3	June 92

Technical Notes

No. 1: Preliminary time estimates for coring operations (Revised Dec 86)
No. 3: Shipboard Scientist's Handbook (Revised 1990)
No. 6: Organic Geochemistry aboard *JOIDES Resolution*- An Assay (Sept 86)
No. 7: Shipboard Organic Geochemistry on *JOIDES Resolution* (Sept 86)
No. 8: Handbook for Shipboard Sedimentologists (Aug 88)
No. 9: Deep Sea Drilling Project data file documents (Jan 88)
No. 10: A Guide to ODP Tools for Downhole Measurement (June 88)
No. 11: Introduction to the Ocean Drilling Program (Dec 88)
No. 12: Handbook for Shipboard Paleontologists (June 89)
No. 14: A Guide to Formation Testing using ODP Drillstring Packers (1990)
No. 15: Chemical Methods for Interstitial Water Analysis on *JOIDES Resolution*
No. 16: Hydrogen Sulfide-High Temperature Drilling Contingency Plan (1991)

Other Items Available

Brochure: The Data Base Collection of the ODP - Database Information

Ocean Drilling Program brochure (English, French, Spanish, German or Japanese)

ODP Sample Distribution Policy

Micropaleontology Reference Center brochure

Instructions for Contributors to ODP *Proceedings* (Revised Oct 90)

ODP Engineering and Drilling Operations (New)

Multilingual brochure with a synopsis of ODP (English, French, Spanish, German and Japanese)

ODP Posters (Ship and coring systems posters)

ODP After Five Years of Field Operations (Reprinted from the 1990 Offshore Technology Conference proceedings)

Brochure: On Board *JOIDES Resolution*
Public Information Office, Karen Riedel
Phone: (409) 845-9322; Fax: (409) 845-0876
Bitnet: KAREN@TAMODP

Sample Distribution

The materials from Legs 135 through 139 are now available for sampling by the general scientific community. This means that the twelve-month moratorium on cruise-related sample distribution is complete for Ocean Drilling Program legs 101-139. Scientists who request samples from these cruises are no longer required to contribute to *ODP Proceedings* volumes, but must publish in the open literature.

All sample requests received at ODP are entered into the Sample Investigations Database. Anyone may request a search. Some common types of searches include: on-going research from particular holes or legs, current research in a specified field of interest, or publications resulting from DSDP or ODP samples. For details contact:

Assistant Curator, Chris Mato
Phone: (409) 845-4819, Fax: (409) 845-4857
Bitnet: CHRIS@TAMODP

The Assistant Curator takes an average of 1.5 weeks to review each request.

Repository	No. Weeks Processing	Total No. Samples
East Coast	7	11,538
Gulf Coast	3	12,812
West Coast	3	3,777

ODP Data Available

ODP data currently available include all DSDP data files (Legs 1-96), geological and geophysical data from ODP Legs 101-137, and all DSDP/ODP core photos (Legs 1-137). More data are available as paper and microfilm copies of original data collected aboard the *JOIDES Resolution*. Underway geophysical data are on 35 mm microfilm; all other data are on 16 mm microfilm.

All DSDP data and most ODP data are contained in a computerized database (contact the ODP Librarian to find out what data are available electronically). Data can be searched on almost any specified criteria. Files can be cross-referenced so a data request can include information from multiple files.

Computerized data are currently available on Macintosh- or PC-formatted disks, magnetic tape, hard-copy printouts, or through BITNET or internet.

Photos of ODP/DSDP cores and seismic lines are available. Seismic lines, whole core and close-up core photos are available in black and white 8x10 prints. Whole core color 35-mm slides are available.

The following are also available: (1) ODP Data Announcements containing information on the database; (2) Data File Documents containing information on specific ODP data files; (3) ODP Technical Note No. 9, "Deep Sea Drilling Project Data File Documents," which includes all DSDP data file documents.

Data Librarian
Phone: (409) 845-8495, Fax: (409) 845-0876
BITNET: DATABASE@TAMODP
Internet: database@nelson.tamu.edu

Small requests can be answered quickly, free of charge. If a charge is made, an invoice will be sent and must be paid before the request is processed.

Data Available from the National Geophysical Data Center (NGDC)

Computerized data from the DSDP are now available through NGDC in compact-disc read-only-memory (CD-ROM) format. The DSDP CD-ROM data set consists of two CD-ROMs and custom, menu-driven, access software developed by NGDC with support from JOI/USSSP. 500 complimentary copies of the DSDP CD-ROMs are being offered to U.S. researchers in academia and government, courtesy of JOI/USSSP. An additional 200 copies of the set are available on a cost recovery basis.

Volume I of the 2-disc set contains all computerized sediment/hardrock files, the Cumulative Index (Paleontology, Subject, and Site), bibliographic information, age and fossil codes dictionaries, an index of DSDP microfilm, sediment chemistry reference tables, and copies of DSDP documentation for each data and reference file.

Volume II contains all digital downhole logging data from the DSDP, including some data digitized for the CD-ROM set by the Woods Hole Oceanographic Institution under contract to JOI/USSSP. All of the data are in the Schlumberger Log Information Standard (LIS) format, some ASCII and Gearhart-Owen data have been translated to LIS by WHOI for the CD-ROM. All DSDP underway and geophysical data are on disc 2, including bathymetry, magnetics, and navigation in the MGD77 format (no data for Legs 1-3; navigation only for Legs 4, 5, 10, 11; SEG-Y single channel seismic data not included). Volume II also contains the DSDP Core Sample Inventory and color/monochrome shaded relief images from several ocean views.

DSDP data files can be provided on magnetic tape according to user specifications (see table below). NGDC can also provide correlative marine geological and geophysical data from other sources. NGDC will provide a complimentary inventory of data available on request. Inventory searches are tailored to users' needs.

Information from DSDP Site Summary files is fully searchable and distributable on floppy diskette, as computer listings and graphics, and on magnetic tape. NGDC is working to make all DSDP data files fully searchable and available in PC-compatible form. Digital DSDP geophysical data are fully searchable and available on magnetic tape. In addition, NGDC can provide analog geological and geophysical information from DSDP on microfilm. Two summary publications are available: (1) *Sedimentology, Physical Properties, and Geochemistry in the Initial Reports of Deep Sea Drilling Project Vols. 1-44: An Overview*, Rept. MGG-1; (2) *Lithologic Data from Pacific Ocean Deep Sea Drilling Project Cores*, Rept. MGG-4.

Costs for services are: $90/2-disc CD-ROM data set, $90/magnetic tape, $30/floppy diskette, $20/microfilm reel, $12.80/copy of Rept. MGG-1, $10/copy of Rept. MGG-4. Costs for computer listings and custom graphics vary. Prepayment is required by check or money order (drawn of a U.S. bank), or by charge to VISA, Mastercard, or American Express. A $10 handling fee is added to all shipments ($20 for foreign shipments), and a $15 fee is added to all rush orders. Data Announcements describing DSDP data sets are available at no charge, as are inventory searches of correlative (non-DSDP) geological and geophysical data available from NGDC. For details contact:

Marine Geology and Geophysics Division, NOAA/NGDC, E/GC3, Dept. 334, 325 Broadway, Boulder, CO 80303; Tel (303) 497-6339; Fax 303-497-6513); Internet cjm@ngdc1.colorado.edu.

AVAILABLE DATA

Data Available	Data Source	Description	Comments
1. LITHOLOGIC and STRATIGRAPHIC DATA			
Visual Core Descriptions			
-Sediment/sedimentary rock	Shipboard data	Information about core solor, sedimentary structures, disturbance, large minerals and fossils, etc.	
-Igneous/metamorphic rock	Shipboard data	Information about lithology, texture, structure, mineralogy, alteration, etc.	
Smear slide descriptions	Shipboard data	Nature and abundance of sedimentary components.	
Thin section descriptions	Shipboard data	Petrographic descriptions of igneous and metamorphic rock. Includes information on mineralogy, texture, alteration, vesicles, etc.	
Paleontology	*Initial Reports, Proceedings*	Abundance, preservation and location for 26 fossil groups The "dictionary" consists of more than 12,000 fossil names.	
Screen	Processed data	Computer-generated lithologic classifications. Basic composition data, average density, and age of layer.	
2. PHYSICAL PROPERTIES			
G.R.A.P.E. (gamma ray attenuation porosity evaluator)	Shipboard data	Continuous whole-core density measurements.	
Grain Size	Shore laboratory	Sand-silt-clay content of a sample.	Legs 1-79 only
Index properties: bulk and grain density, water content, and porosity	Shipboard data	Gravimetric and volumetric measurements from a known volume of sediment	
Liquid and plastic limits	Shipboard data	Atterberg limits of sediment samples.	
Shear-strength measurements	Shipboard data	Sediment shear-strength measurements using motorized and Torvane instruments.	
Thermal conductivity	Shipboard data	Thermal conductivity measurements of sediments using a thermal probe.	
Velocity measurements	Shipboard data	Compressional and shear-wave velocity measurements.	
Downhole measurements			
-Heatflow	Shipboard data	*In-situ* formation temperature measurements.	
-Pressure	Shipboard data	*In-situ* formation and hydrostatic pressure.	
3. SEDIMENT CHEMICAL ANALYSES			
Carbon-carbonate	Shipboard data, shore laboratory	Percent by weight of the total carbon, organic carbon, and carbonate content of a sample.	Hydrogen percents for Legs 101,103, 104, 106-108; nitrogen percents for Legs 101, 103, 104, 107, 108.
Interstitial water chemistry	Shipboard data, shore laboratory	Quantitative ion, pH, salinity, and alkalinity analyses of interstitial water.	
Gas chromatography	Shipboard data	Hydrocarbon levels in core gases.	
Rock evaluation	Shipboard data	Hydrocarbon content of a sample.	
4. IGNEOUS AND METAMORPHIC CHEMICAL ANALYSES			
Major element analyses	Shipboard data, shore laboratory	Major element chemical analyses of igneous, metamorphic, and some sedimentary rocks composed of volcanic material.	
Minor element analyses	Shipboard data, shore laboratory	Minor element chemical analyses of igneous, metamorphic, and some sedimentary rocks composed of volcanic material.	
5. X-RAY MINERALOGY			
X-ray mineralogy	Shore laboratory	X-ray diffraction	Legs 1-37 only
6. PALEOMAGNETICS			
Paleomagnetics	Shipboard data, shore laboratory	Declination, inclination, and intensity of magnetization for discrete samples and continuous whole core. Includes NRM and alternating field demagnetization.	
Susceptibility	Shipboard data	Discrete sample and continuous whole-core measurements.	
7. UNDERWAY GEOPHYSICS			
Bathymetry	Shipboard data	Analog records of water-depth profile	Available on 35-mm continuous microfilm
Magnetics	Shipboard data	Analog records and digital data.	Available on 35-mm continuous microfilm
Navigation	Shipboard data	Satellite fixes and course and speed changes that have been run through a navigation smoothing program, edited on the basis of reasonable ship and drift velocities, and later merged with the depth and magnetic data.	Available in MGD77 exchange format
Seismics	Shipboard data	Analog records of sub-bottom profiles and unprocessed signal on magnetic tape	Available on 35-mm continuous microfilm
8. SPECIAL REFERENCE FILES			
Leg, site, hole summaries	Shipboard data initial core descriptions	Information on general leg, site, and hole characteristics (i.e. cruise objectives, location, water depth, sediment nature, drilling statistics).	
DSDP Guide to Core Material	*Initial Reports,* prime data files	Summary data for each core: depth of core, general paleontology, sediment type and structures, carbonate, grain size, x-ray, etc.	Legs 1-85 only
AGEPROFILE	*Initial Reports,* hole summaries	Definition of age layers downhole.	
COREDEPTH	Shipboard summaries	Depth of each core. Allows determination of precise depth (in m) of a particular sample.	
9. AIDS TO RESEARCH			
ODASI	A file of ODP-affiliated scientists and institutions. Can be cross-referenced and is searchable.		
Keyword Index	A computer-searchable bibliography of DSDP- and ODP-related papers and studies in progress.		
Sample Records	Inventory of all shipboard samples taken.		
Site Location Map	DSDP and ODP site positions on a world map of ocean topography.		
Thin Section Inventory	Inventory of all shipboard thin sections taken.		

ODP Site Survey Data Bank

Lamont-Doherty Geological Observatory, Palisades, NY 10964.

The JOIDES/ODP Data Bank received the following data between 1 May 1992 and 31 July 1992. For additional information on the ODP Data Bank, please contact Mr. Carl Brenner.

- From R. Whitmarsh (IOS, UK): contoured magnetic anomaly chart of the Iberian Abyssal Plain area.
- From K. Hinz (BGR, Germany): MCS profiles NGT-42, BGR 88-13 and BGR 75-14, documenting proposed NAAG East Greenland Margin sites.
- From Y. Kristoffersen (U. Of Bergen, Norway): migrated copy of MCS line 77-3, along with navigation charts, documenting proposed NAAG/ICEP and /GREEN sites.
- From L. Kulm (OSU): MCS line OR-25, documenting proposed Oregon Margin Cascadia site OM-8A.
- From L. Kulm (OSU): processed copy of MCS line OM-25, documenting proposed Oregon Margin Cascadia site OM-8A.
- From S. Srivastava (AGC, Canada): *R/V Farnella* 381 SCS lines 16, 17, 17B, 18, 20, 21, 22 and 23 in Newfoundland Basin, along with magnetic anomaly chart and *R/V Agnich* MCS lines 85-4 and 85-4A.
- From K. Hinz (BGR, Germany): MCS profiles NGT-39/1, NGT-39/2 and NGT-46, documenting propossed NAAG sites.
- From D. Mann (USGS, Menlo Park): digital navigation for USGS *R/V Farnella* cruise 92-4, along with corresponding SCS and 3.5 kHz profiles.
- From E. Silver (UCSC): 2D swath lines 10, 20, 30 and 40 (migrated time sections) and 3D line 177 (depth section) from *R/V Fred Moore* cruise 35-2, documenting proposed Costa Rica Margin sites.
- From T. Shipley (UT, Austin): SeaBeam bathymetry and navigation charts, along with processed SCS and 3.5 kHz data from *R/V Ariadne* cruise 3, plus track charts and books of 3D sections from *R/V Fred Moore* cruise 35-2, documenting proposed Costa Rica Margin sites.
- From B. Tucholke and P. Mills (WHOI): seismic velocity plot derived from *R/V Conrad* MCS cruise, and core descriptions, both from Newfoundland Basin area.
- From R. Hyndman (PGC, Canada): migrated depth sections of PGC MCS profiles 89-4, 89-8 and 89-10 in Vancouver Margin area.
- From G. Thompson (WHOI): SeaBeam base maps, sample location maps, bibliography and site survey proposals for TAG area.
- From C. Mevel (Université Pierre et Marie Curie, France): report of *Hydrosnake* dive cruise in MARK area.
- From H. Schminke (GEOMAR, Germany): selected seismic profiles documenting proposed VICAP sites.
- From K. Kastens (LDGO): SeaBeam maps and SeaMARC I mosaic acquired during *R/V Conrad* 2506 cruise in Mediterranean Ridge area.
- From M. Comas (U. of Granada, Spain): MCS, SCS and high-frequency seismic profiles, with corresponding track charts, depth-to-basement maps and well log data documenting proposed Alboran Sea sites (AL-1 and AL-2.
- From K. Kastens (LDGO): SeaBeam base maps, selected reprints on seismic reflection and refraction data, side-looking sonar, underway geophysics, sampling and heat flow data, plus dive transcripts from *DSRV Nautile* dives, all documenting proposed Vema Fracture Zone drilling.

ODP EDITORIAL REVIEW BOARDS (ERB)

For each ODP cruise, an editorial board is established to handle review of the manuscripts intended for publication in the "Scientific Results" volume of the *Proceedings of the Ocean Drilling Program.* These boards consist of the Co-Chief Scientists (*) and the ODP Staff Scientist (**) for that cruise, one outside scientist (***) selected by the Manager of ODP Science Operations in consultation with the cruise Co-Chief Scientists, and an ODP Editor. These boards are responsible for obtaining adequate reviews and for making decisions concerning the acceptance or rejection of papers. The names of scientists serving on ERBs for Legs 123 through 141 are listed below.

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A chairman for each ERB, usually a Co-Chief Scientist, has been elected since Leg 120.

ODP Wireline and Logging Services

Lamont-Doherty Geological Observatory, Palisades, NY 10964.

Wireline Logging Manual (New Edition, Sept 1990).

To obtain a copy, contact Dave Roach (Tel: (914) 359-2900, ext. 330. Fax: (914) 365-3182).

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ODP/JOIDES Directory

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JOIDES Office Rotation

The JOIDES Office rotated, on 1 October 1992, to the University of Washington, Seattle. Brian Lewis is the new PCOM Chair. The other staff members are: Karen Schmitt, Science Coordinator; Bill Collins, Executive Assistant and Non-US Liaison. All proposals and other communications should be sent to:

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• Comments and suggestions concerning the content of this or future issues of the *JOIDES Journal* should be directed to the editorial staff:

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Special Issue No. 1: Manual on Pollution Prevention and Safety, 1976 (Vol. II)
Special Issue No. 2: Initial Site Prospectus, Supplement One, April 1978 (Vol. III)
Special Issue No. 3: Initial Site Prospectus, Supplement Two, June 1980 (Vol. VI)
Special Issue No. 4: Guide to the Ocean Drilling Program, September 1985 (Vol. XI)
Special Issue No. 4: Guide to the Ocean Drilling Program, Suppl. One, June 1986 (Vol. XII)
Special Issue No. 5: Guidelines for Pollution Prevention and Safety, March 1986 (Vol. XII)
Special Issue No. 6: Guide to the Ocean Drilling Program, December 1988 (Vol. XIV)
Special Issue No. 7: Ocean Drilling Program Guidelines for Pollution Prevention and Safety, October, 1992 (Vol. 18)

JOIDES Resolution Operations Schedule

Leg	Program	Cruise Dates	Days Transit	Days On Site	Total	In Port†
145	North Pacific Transect	25 July-21 Sept.	18	41	59	Victoria, 21-25 Sept.
146	Cascadia	26 Sept.-22 Nov.	6	51	57	San Diego, 22-26 Nov.
147	Hess Deep	27 Nov. '92-22 Jan. 1993	14	42	56	Panama, 22-25 Jan. 1993
148	Hole 504B	26 Jan.-10 March	4	39	43	Panama, 10-13 March
149A	Transit	14 March-1 April	18	0	18	Lisbon, 1 April
148B	Iberian Abyssal Plain*	2-21 April	2	17	19	Lisbon, 21 April
149C	Iberian Abyssal Plain*	22 April-27 May	2	33	35	Lisbon 27-31 May
150	New Jersey Sea Level	1 June-27 July	16	40	56	St. John's, 27-31 July
151	Atlantic Arctic Gateway	1 Aug.-26 Sept.	14	42	56	Reykjavik, 26-30 Sept.
152	East Greenland Margin	1 Oct.-26 Nov.			56	

* Scientific Party on board for 149A&B. Sedco-Forex crews rotate on 10 March, 21 April and 27 May 1993.
† Although 5-day port calls are generally scheduled, the ship sails when ready.

JOIDES Meeting Schedule

Date	Place	Committee/Panel
1992		
9-11 September	Marseilles, France	IHP
21-23 September	Victoria, B.C.	SMP
23-25 September	Victoria, B.C.	DMP
22-27 September	Granada, Spain	TECP
26-28 September	Kiel, Germany	SGPP
30 Sept.-2 Oct.	Marseille, France	OHP
7-9 October	Cambridge, UK	TEDCOM
14-16 October	Paris, France	LITHP
22-23 October	London, UK	PPSP
1 December	Bermuda	PANCHM
2-5 December	Bermuda	PCOM
1993		
27-28 January	Coff's Harbor, Australia	EXCOM
January*	College Station, Texas	DMP
26-28 April	Palisades, NY	PCOM
22-24 June	College Station, TX	EXCOM
10-12 August	Brisbane, Australia	PCOM

* Meeting not yet formally requested and/or approved

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