JOIDES Journal

Volume 28, No. 2
Fall 2002

Joint Oceanographic Institutions
for Deep Earth Sampling

In this issue:

ODP Leg 196: Logging-While-Drilling and Advanced CORKs at the Nankai Trough Accretionary Prism

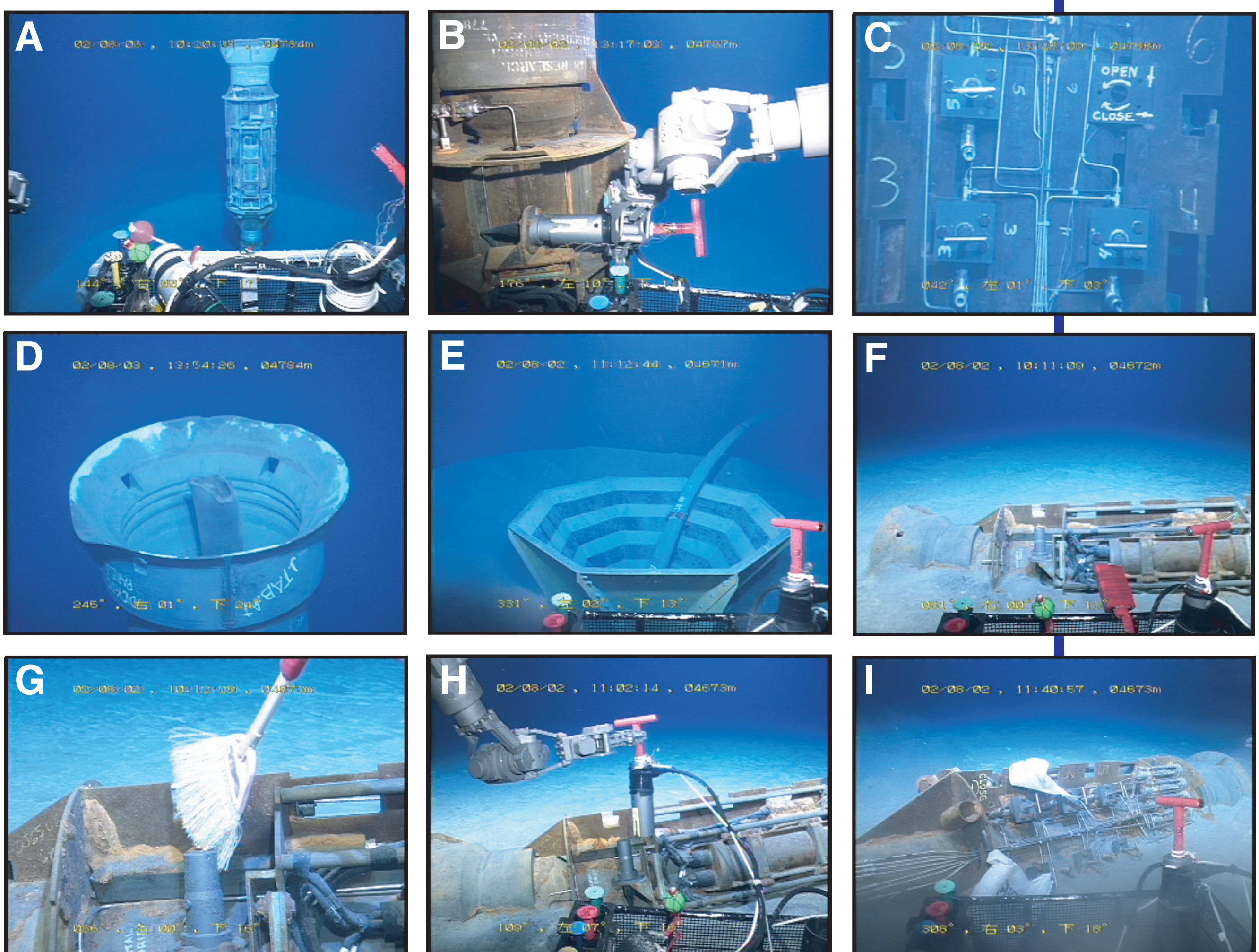

Figure Caption for Cover Illustration from the Leg 196 Science Report:

Figure 3. *Video still images taken during August 2002 operations with the JAMSTEC* ROV Kaiko *at the Leg 196 ACORKS at Hole 1173B (images A-D), and Hole 808I (images E-I).* ***A.*** *The standing ACORK head above the reentry cone at Hole 1173B.* ***B.*** *Mating the underwater-mateable connector for data download.* ***C.*** *The sampling valves in closed position at the end of operations.* ***D.*** *Top of the ACORK showing broken-off end of drill pipe 466 m above bridge plug.* ***E.*** *Reentry cone at Hole 808I showing excess 36 m of fallen ACORK casing smoothly bent and draped over cuttings pile.* ***F.*** *The ACORK head partly buried in seafloor, with underwater-mateable connector fortuitously facing straight up. After brushing the dust off the underwater-mateable connector (**G**), the connection was made (**H**), and the ACORK was found to be fully finctioning.* ***I.*** *Sampling valves in closed position near end of operations (*Kaiko *later cut away plastic bags hanging on some of the valves).*

In this issue from pages 8-12:

ODP Leg 196: Logging-While-Drilling and Advanced CORKs at the Nankai Trough Accretionary Prism

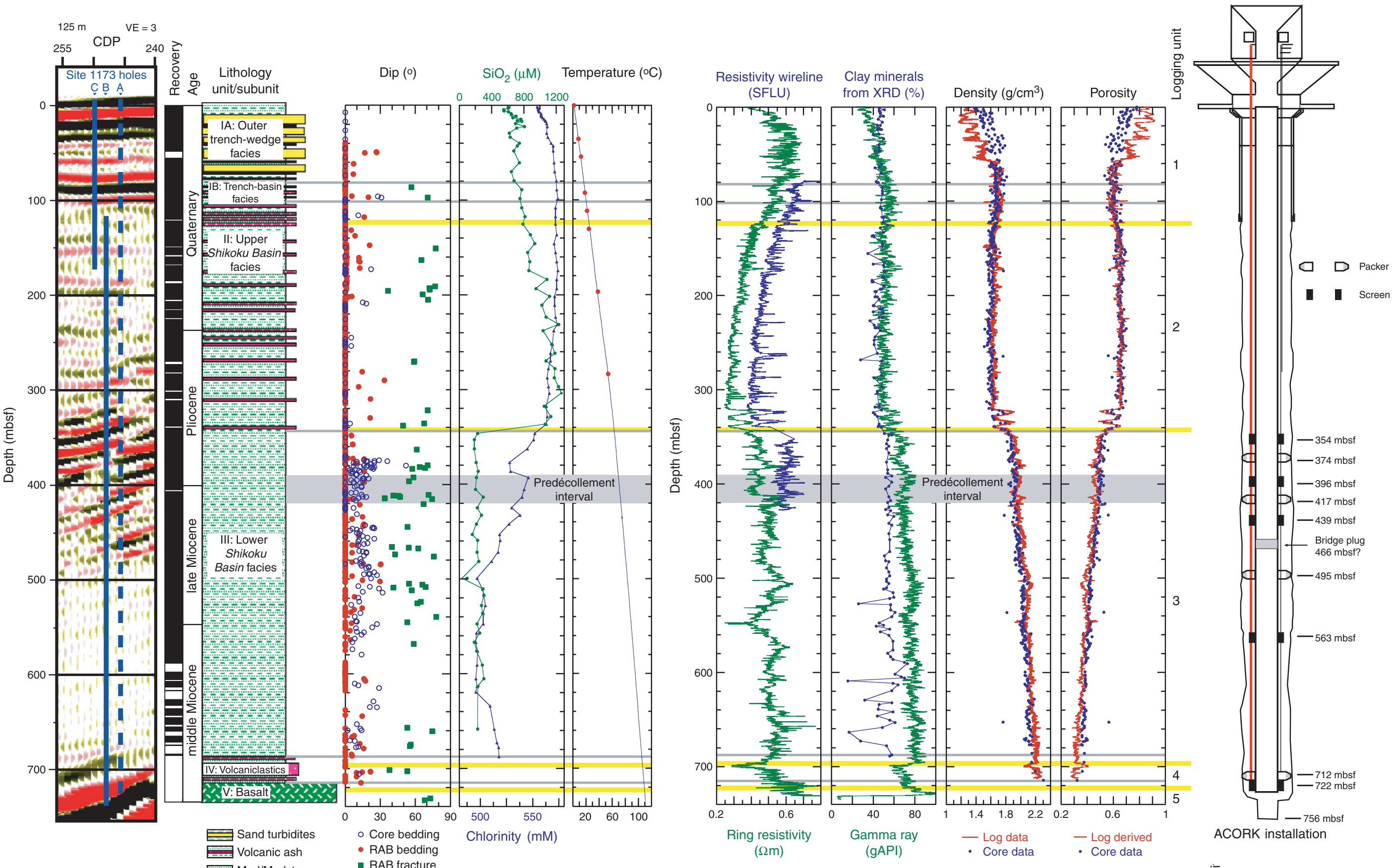

Figure 2A.

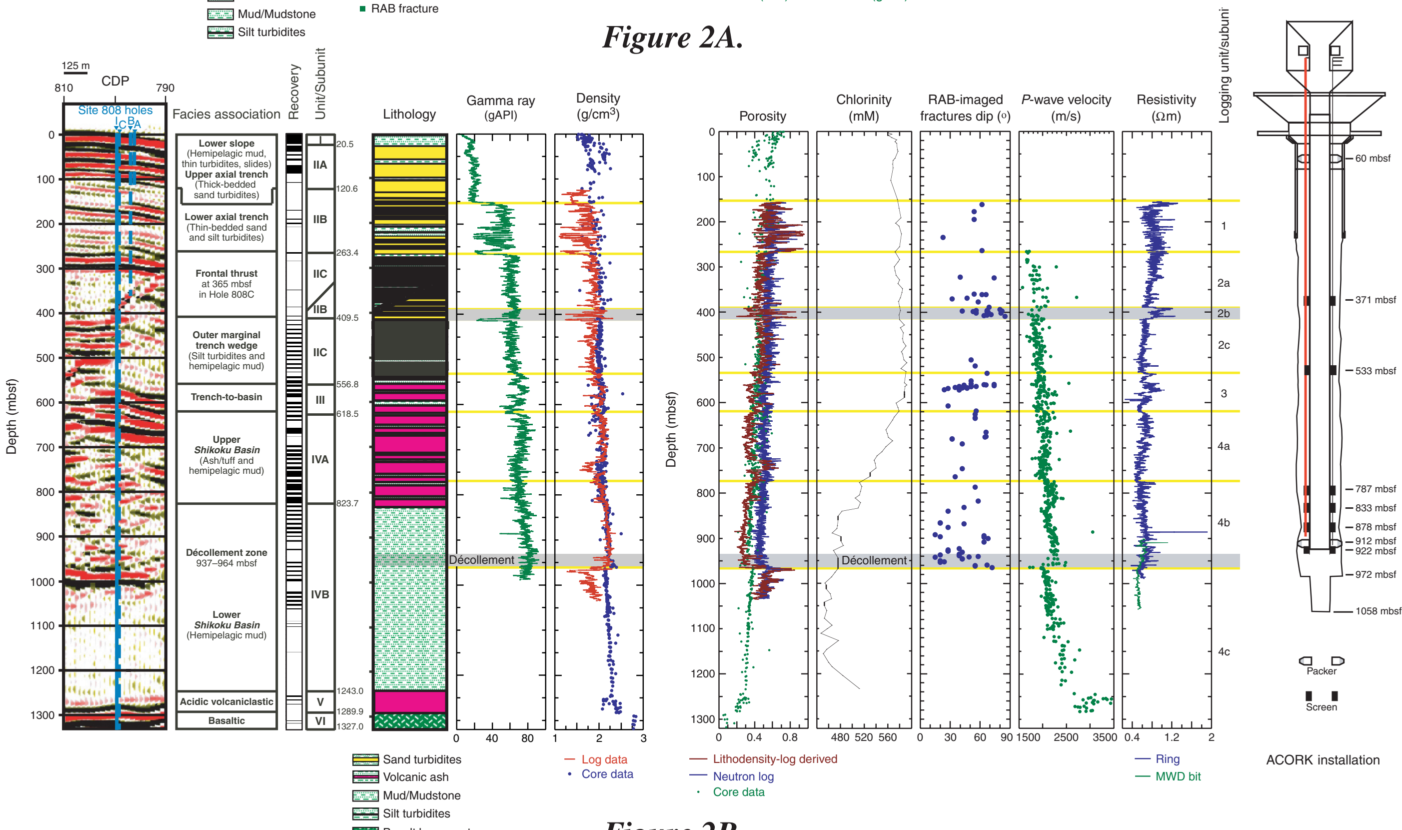

Figure 2B.

TABLE OF CONTENTS

Volume 28, No. 2
Fall 2002

In this issue:

SCIENCE - Leg Reports

PLANNING - PPG Report

Meeting Report

***JOIDES Resolution* Operations Schedule: November 2002 to September 2003**

Leg	Destination	Port (Origin)	Dates[1]	Total days[2] (Port/Sea)	Co-Chief Scientists	TAMU contact
206	Fast Spreading Crust	Balboa	6 November '02 – 5 January '03	60 (5/55)	D. Teagle D. Wilson	G. Acton
	Transit	Balboa	5 January – 13 January '03	8 (2/6)	N/A	N/A
207	Demerara Rise	Barbados	13 January – 8 March '03	54 (3/51)	J. Erbacher D.C. Mosher	M. Malone
208	Walvis Ridge	Rio de Janeiro	8 March - 9 May '03	62 (5/57)	D. Kroon J. Zachos	P. Blum
209	MAR Peridotite	Rio de Janeiro	9 May - 10 July '03	62 (5/57)	P. Kelemen E. Kikawa	J. Miller
210	Newfoundland Margin	Bermuda	10 July – 9 September '03	61 (5/56)	J.-C. Sibuet B. Tucholke	A. Klaus
	Transit	St. John's	9 September – 21 September '03	12 (1/11)	N/A	N/A
	Demobilization[3]	Galveston	21 September – 30 September '03	9 (9/0)	N/A	N/A

13 November 2002

[1] Start date reflects the first full day in port, and is the date of the ODP and ODL cross-over meetings. The *JOIDES Resolution* is expected to arrive late the preceeding day. Port call dates have been included in the dates that are listed.
[2] Although 5-day port calls are generally scheduled, the ship sails when ready.
[3] Demobilization assumes a 7-day (+2 day port call) period tentatively scheduled for Galveston.

Figure Caption for Leg 196 Inside Front Cover Illustration:

Figure 2. A (top). *Site 1173 seismic, lithologic, and logging summary, including results from Leg 190. From left to right: depth converted seismic reflection data, core recovery, core-based lithology and facies interpretation, bedding dip, pore water geochemistry, temperature-depth gradient, wireline and log resistivity, clay mineral content (solid circles) and gamma ray log, core and log density, core and log porosity (computed from the density log using core grain density values), log units, and a schematic diagram of the Advanced CORK (ACORK). CDP = common depth point, RAB = resistivity at the bit, SFLU = spherically focused resistivity, XRD = X-ray diffraction.* ***B (bottom).*** *Site 808 seismic, lithologic, and logging summary, including results from Leg 131. From left to right: depth converted seismic reflection data, core-based facies interpretation, core recovery, core-based lithologic units and lithology, log gamma ray, core and log density, core and log porosity (computed from the density log using core grain density values), pore water chlorinity, fracture dip from RAB images, core P-wave velocity, log resistivity, log units, and a schematic diagram of the ACORK. CDP = common depth point, MWD = measurement while drilling.*

SCIENCE Leg Reports

ODP

Anatomy of an Active Hydrothermal System Hosted by Felsic Volcanic Rocks at a Convergent Plate Margin: ODP Leg 193

Raymond A. Binns [1], Fernando J.A.S. Barriga [2], D. Jay Miller [3], and the Leg 193 Scientific Party

INTRODUCTION

Subseafloor hydrothermal phenomena and processes at a felsic volcanic, convergent margin were investigated during Leg 193 for comparison with those at basaltic mid-ocean ridge sites previously drilled by the Ocean Drilling Program (ODP) during Legs 139, 158, and 169. Our aim was to sample the third dimension of the dacite-hosted PACMANUS hydrothermal system, in the Manus Backarc Basin of Papua New Guinea, Southwest Pacific Ocean (Fig. 1). Our goals were to better understand factors that govern the nature and location of mineral deposition, to seek evidence relating to fluid and metal sources, and to investigate subsurface microbial life. The PACMANUS system is a modern analog of a common geological setting for ore bodies in ancient sequences where subsequent deformation and metamorphism often obscure evidence for their modes of formation.

THE PACMANUS HYDROTHERMAL FIELD

The Manus Backarc Basin lies within a zone of complex oblique convergence between the major Indo-Australian and Pacific plates and opposed fossil and active subduction zones (Fig. 1). Northward subduction of the oceanic Solomon Microplate beneath the South Bismarck Microplate, a complex formed by earlier Tertiary arc volcanism and backarc spreading, currently occurs along the New Britain Trench with formation of a chain of

[1] CSIRO Exploration and Mining, P.O. Box 136, North Ryde, NSW 1670 Australia
[2] Department of Geology and CREMINER, University of Lisbon, Edificio C2, Piso 5, Campo Grande, 1749-016 Lisboa, Portugal
[3] Ocean Drilling Program, Texas A&M University, 1000 Discovery Drive, College Station, TX 77845-9547 USA

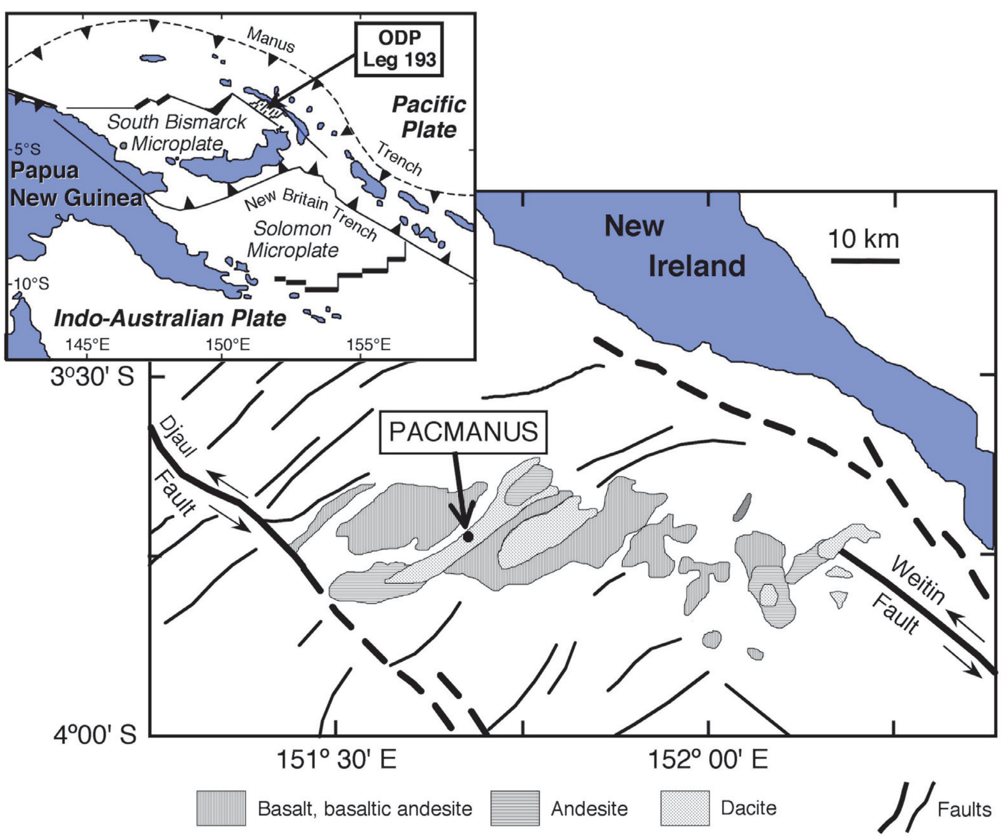

***Figure 1.** The PACMANUS hydrothermal system, at the crest of a fork-shaped edifice of dacite (Pual Ridge), was drilled during ODP Leg 193. The inset shows the regional setting of the Manus Basin in the Southwest Pacific Ocean. The eastern Manus Basin consists of a series of elevated neovolcanic edifices that link the active ends of the Djual and Weitin Transform Faults, and overlie Early Tertiary arc crust thinned by northeast-trending extensional faults and graben filled with Pliocene to Recent sediments.*

young arc volcanoes at the concave northern side of New Britain. Present-day structure of the basin is dominated by spreading in the center and west, and by extensional rifting in the east; the various segments are delineated by sinistral transform faults (Martinez and Taylor, 1996).

The eastern Manus Basin, a pull-apart rift zone, consists of an east-west trending belt of mostly high-standing neovolcanic edifices overlying Early Tertiary to Pleistocene crust. This edifice belt links the active ends of the bounding Djual and Weitin Transform Faults (Fig. 1). The compositions of individual edifices range from picritic basalt to dacite-rhyodacite, and their isotopic and trace element geochemistries are similar to that of the subaerial volcanoes of New Britain to the south. Pual Ridge, aligned north-northeast towards the center of this belt, stands some 500 m to 600 m above basaltic andesite- and sediment-floored valleys to either side. It is predominantly dacitic in composition though consanguineous andesites and rhyo-dacites occur locally. The eastern side of Pual Ridge has a terraced structure, suggesting a sequence of subhorizontal dacite flows 10 m to 30 m thick. Glassy flows along the crest have negligible sediment cover and vary in structure from lobate to block lava.

Isolated hydrothermal deposits occur for ~13 km along the crest of Pual Ridge (Binns and Scott, 1993; Scott and Binns 1995; Binns et al., 1995). The more significant active deposits extend for 2 km across two elongate highs on the ridge crest, lie between 1650 and 1750 meters below sea level (mbsl), and were collectively named the PACMANUS (Papua New Guinea–Australia–Canada–Manus Basin) hydrothermal field after the 1991 discovery expedition. Three hydrothermal centers within this field were examined during Leg 193 (Fig. 2). Roman Ruins and Satanic Mills are 100 m- to 200 m-wide sites of focussed, high-temperature activity to 280ºC (Douville et al., 1999), with sulfide chimneys up to 20 m high. By contrast, Snowcap is a low knoll (10 to 15 m high, 150 m across) where fresh and altered dacite-rhyodacite outcrops are interspersed with patches of gravely to sandy sediment derived from altered dacite, metalliferous hemipelagic ooze, and dark surficial Mn-Fe oxide crust. Some sulfide chimneys occur on Snowcap's lower southwestern flank, diffuse low-temperature venting (measured at 6ºC but likely locally higher) is extensive across the crest, and more intense shimmer occurs at the edges of rock outcrops. The Snowcap vent sites are surrounded by white- to cream-colored deposits that include microbial mat and, possibly, methane hydrate. PACMANUS chimneys are rich in chalcopyrite and sphalerite with high levels of gold and silver (Moss and Scott, 2001).

DRILLING STRATEGY

Drilling operations during Leg 193 were unusual for ODP in that they were confined to a very small area less than 1 km across (Fig. 2). Our strategy was to drill deep holes into both the Snowcap area of low-temperature diffuse venting through altered dacite (Site 1188), and the Roman Ruins high-temperature chimney site (Site 1189). Penetration to 387 meters

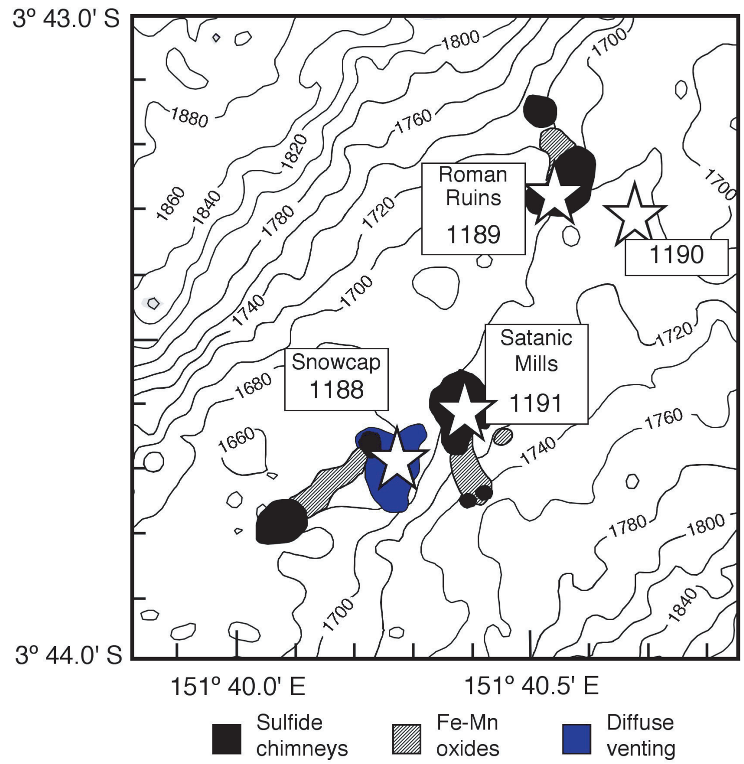

Figure 2. Distribution of hydrothermal deposits along the crest of Pual Ridge, and location of Leg 183 sites (stars). Bathymetry in meters.

SCIENCE Leg Reports

ODP

below sea floor (mbsf) with six Site 1188 boreholes and to 206 mbsf with three Site 1189 holes allowed comparison of mineralization and alteration patterns below these different seafloor settings (Fig. 2). Deep penetration planned at a deep hole at a "background" region lacking evidence of hydrothermal activity (Site 1190) was not achieved. A shallow rotary hole was drilled to 20 mbsf at Satanic Mills (Site 1191) for comparison with the Roman Ruins section. Although spudded beside a chimney, only dacite was recovered.

The priority assigned to deep penetration resulted in a generally low average core recovery of 11%. Deployment of the advanced diamond core barrel yielded longer sections of continuous core than rotary drilling in extensively altered rocks, but these had a tendency to auto-fragment after extraction from the barrel following expansion of fluids trapped at high pressure in hairline fractures. We conducted wireline logging of the deep holes at Sites 1188 and 1189 and obtained valuable, continuous *in situ* physical properties data as well as formation microscanner (FMS) images along the borehole walls. Ancillary holes also were drilled near each deep hole to accommodate logging-while-drilling (LWD) experiments to elucidate near-seafloor structure and lithology. This was the first hard rock application by ODP of LWD, and we achieved the first direct comparison of LWD and FMS imagery and geophysical profiles in the same hole (Fig. 3).

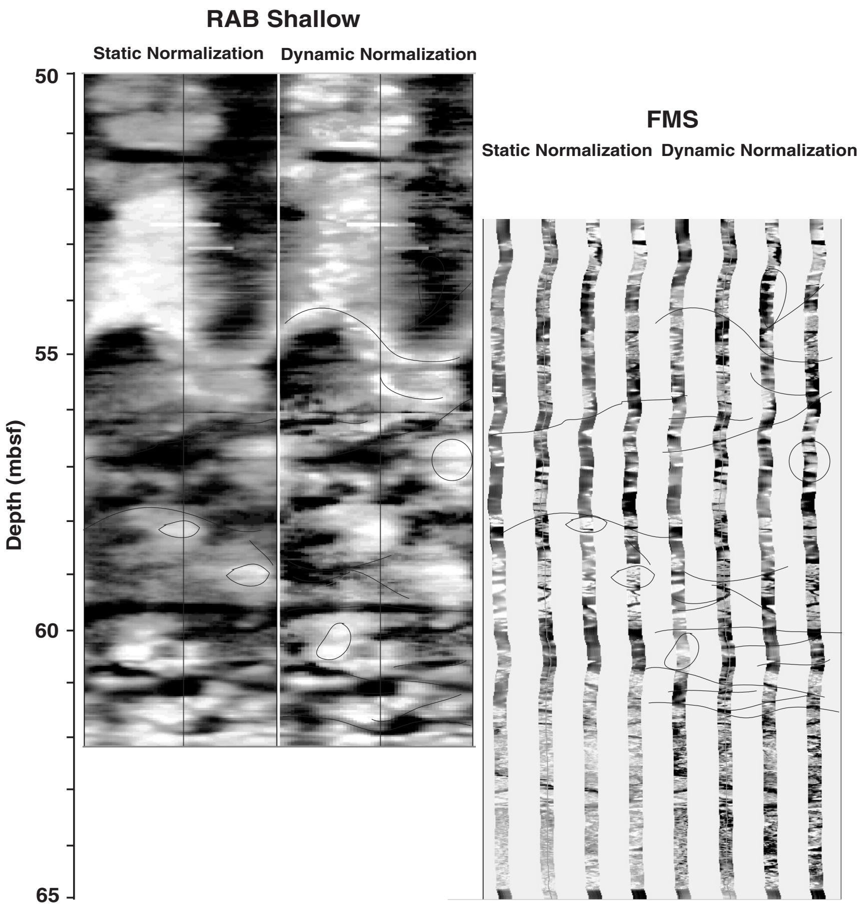

Figure 3. *Comparison of resistivity images of the borehole wall obtained by logging-while-drilling (LWD) resistivity-at-bit (RAB), and by formation microscanner (FMS) during subsequent wireline logging of Hole 1189C. Correlated features are marked.*

RESULTS

Volcanic Architecture

Although deep penetration at the planned "background" location (Site 1190) was not realized, generally excellent preservation of volcanic structures and textures in the altered rocks recovered from Site 1188 and Site 1189 boreholes allowed reconstruction of the architecture of the upper two-thirds of Pual Ridge under PACMANUS (Fig. 4A). We unequivocally established that this edifice is built up by a sequence of felsic lavas variously characterized by perlitic (formerly glassy), conspicuously to sparsely vesicular, spherulitic, flow-banded, and autoclastic fabrics. All were formerly aphyric or only sparsely porphyritic. No large intrusive bodies or plutonic rocks were encountered. The presence of thin dikes was not ruled out, and one interval with subvertical vesicle elongation was interpreted as a possible example.

Given poor core recovery and the likelihood that hydrothermal brecciation and alteration prevented recognition of some cored paleoseafloor horizons, the number of flows intersected by drilling cannot be accurately estimated. The minimum average flow thickness at Site 1189 is around 50 m, comparable with the 30 m thickness observed on the external terraces of Pual Ridge.

Alteration Patterns

A major surprise of Leg 193 was the extent of subsurface alteration at PACMANUS. Beneath a cap of unaltered dacite-rhyodacite 35 m thick at Site 1188 and a few meters thick at Site 1189, a rapid change occurred to pervasively altered rocks that continued to the deepest cores taken (Fig. 4B). Three main alteration styles were defined: soft argillaceous assemblages dominated by illite and clay-chlorite, acid sulfate bleaching characterized by pyrophyllite and anhydrite as well as illite, and silicification.

Local repetitive superimposition of these alteration styles denotes multiple episodes of fluid flux with differing compositions. There was no conclusive evidence for cyclic eruption and hydrothermal events. Rather, the overall impression was of a single, major alteration event commencing after the bulk of Pual Ridge had been built up by submarine felsic volcanism, and continuing to the present time. Evidence for this includes vertical zoning in alteration assemblages that extends across many flows. Vertical zoning was most prominently represented at both Site 1188 and Site 1189 by a change in the dominant silica mineral species, from cristobalite at shallow levels to deeper quartz. Parallel but subtle changes in clay mineralogy were suspected from shipboard observations and are a subject of post-cruise research. The cristobalite-quartz transition occurred in the interval from 70 mbsf to 120 mbsf at Snowcap Site 1188, and more sharply at 25 mbsf in Hole 1189A towards the fringe of Roman Ruins Site 1189. The differing transition depths were interpreted to reflect higher thermal gradients below Site 1189, consistent with the presence at Roman Ruins of high temperature chimney venting. The maximum borehole temperature measured in Hole 1188F eight days after drilling was 313°C at 360 mbsf. Collection of comparative data at Site 1189 was not successful.

Cristobalite also was significant in a less altered sequence with preserved igneous plagioclase below 127 mbsf in Hole 1189B (Fig. 4B). In borehole imagery this sequence showed a more widely spaced, blocky fracture pattern. Smaller intersections of similar material occurred at 160 mbsf in Hole 1188A and 180 mbsf in Hole 1188F. These zones were interpreted as regions of low fluid penetration and low fluid-wallrock

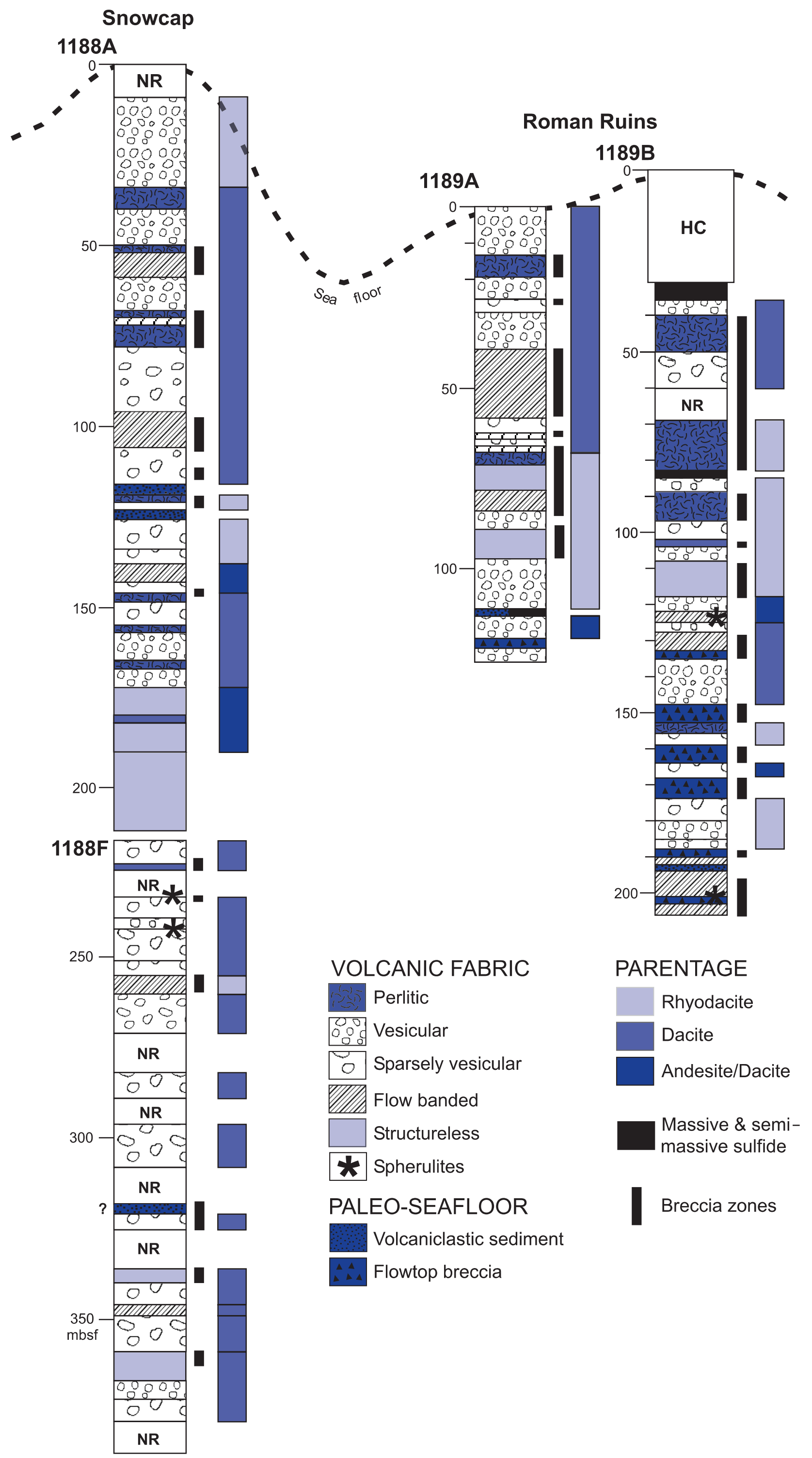

Figure 4. A.** Lithologic profiles of the three deep holes drilled during Leg 193 at PACMANUS with schematic seafloor topography. Parentage is based on the immobile element ratio Zr/Ti and referred to unaltered surficial lavas from Pual Ridge.* ***B (right, next page).

reaction ratios, and also characterized by lower porosities than the intensely altered sequences, complex mixed-layer clay minerals, and local magnetite mostly as igneous relicts. Hydrothermal magnetite as vein selvages and vesicle fillings occurred deep in Hole 1188F (Fig. 4B). The intensely altered rocks showed high measured porosities, averaging 25%, and their capacity to soak up water indicated they also are very permeable. These characteristics, and the widespread fracturing evident in cores and borehole imagery, indicate a setting favorable for extensive diffuse fluid flow throughout the subseafloor PACMANUS hydrothermal system.

Mineralization

The scarcity of sulfide mineralization, apart from widespread disseminated pyrite at depth below PACMANUS, was another surprise during Leg 193. Pyrite is part of the mineral assemblage in all three main alteration styles, and also occurs with anhydrite or quartz, or both, in partly-filled vesicles, amygdules, and veins. At Site 1189 disseminated pyrite is accompanied in places by traces of chalcopyrite and sphalerite. Pyrrhotite is very rare, occurring locally as small inclusions in pyrite.

Only three small pieces from all recovered cores qualified as massive or semi-massive sulfide, and all were from Site 1189. Two sulfide-rich samples from the upper section of Hole 1189B, where core recovery was especially poor and the penetration rate unusually fast, have fabrics suggesting they are thicker representatives of the numerous coarse pyrite veins in soft, altered volcanic rock that form a stockwork-breccia zone extending 70 m below the cased section of the hole (Fig. 4B). The favored interpretation for the rapidly penetrated stockwork zone in Hole 1189B, though constrained by poor core recovery, is as a discharge conduit traversed by chimney-generating fluids venting to the seafloor at Roman Ruins.

Deep Biosphere

A major success of Leg 193 was confirmation that microbes flourish in the subsurface portion of the PACMANUS hydrothermal system. Bacteria were found by direct counting and adenosine triphosphate (ATP) analysis in cores recovered up to ~100 mbsf under Site 1188, where low temperature venting occurs at the seabed, and up to 80 mbsf under the

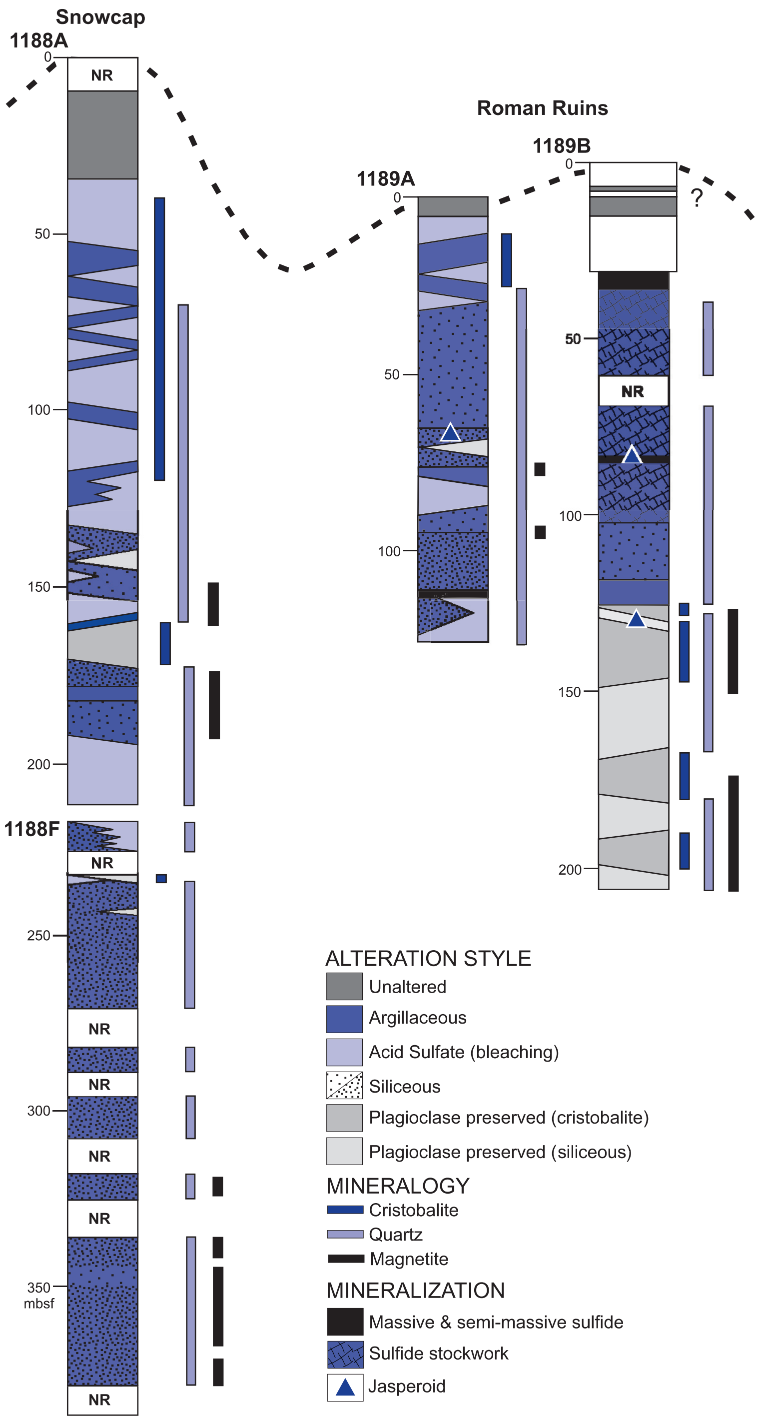

Figure 4. B. Distribution of dominant alteration styles and mineralization in the three deep holes at PACMANUS.

high temperature chimney field at Site 1189, where the thermal gradient is presumably higher. Cultivation experiments on board, also conducted on samples from slightly deeper in the boreholes, confirmed that the bacteria multiplied under anaerobic conditions up to 90°C, with best results at increasingly higher temperatures for progressively deeper samples. The preferred habitats are volcanic glass close to the seabed, and clay minerals at deeper levels within the intensely altered zone.

ACKNOWLEDGEMENTS

We thank the drilling engineers and crew on the *JOIDES Resolution* for their successful efforts in confronting the many technical challenges posed by Leg 193. Site survey cruises were funded by CSIRO Australia, JAMSTEC, and the German Federal Ministry for Research and Technology. For further information on shipboard science during Leg 193, visit http://www-odp.tamu.edu/publications/193_IR.

LEG 193 SCIENTIFIC PARTY

Raymond A. Binns, Co-Chief Scientist; Fernando J.A.S. Barriga, Co-Chief Scientist; D. Jay Miller, Staff Scientist; Ryuji Asada, Wolfgang Bach, Anne C.M. Bartetzko, Liane G. Benning, Terje Bjerkgård, Lizet Brokner Christiansen, Erika R. Elswick, Robert H. Findlay, Gerardo J. Iturrino, Hiroyuki Kimura, John B. Kulange, Klas S. Lackschewitz, Sang-Mook Lee, Andrew Masta, Holger Paulick, Álvero M. Pinto, Stephen Roberts, Steven D. Scott, David A. Vanko, Ian Warden, and Christopher J. Yeats.

REFERENCES

Binns, R.A. and Scott, S.D., 1993. Actively forming polymetallic sulfide deposits associated with felsic volcanic rocks in the eastern Manus back-arc basin, Papua New Guinea. *Economic Geol.*, 88:2226-2236.

Binns, R.A., Parr, J.M., Scott, S.D., Gemmell, J.B. and Herzig, P.M., 1995. PACMANUS: An active seafloor hydrothermal field on siliceous rocks in the Eastern Manus Basin, Papua New Guinea. *In* Mauk, J.L. and St. George, J.D. (Eds.), *Proc. 1995 Pacific Rim Congress*, Australasian Institute of Mining and Metallurgy, Melbourne, 49-54.

Douville, E., Bienvenu, P., Charlou, J.-L., Donval, J.-P., Fouquet, Y., Appriou, P. and Gamo, T., 1999. Yttrium and rare earth elements in fluids from various deep-sea hydrothermal systems. *Geochim. Cosmochim. Acta*, 63:627-643.

Martinez, F. and Taylor, B., 1996. Fast backarc spreading, rifting and microplate rotation between transform faults in the Manus Basin, Bismarck Sea. *In* Auzende, J.-M. and Collot, J.-Y. (Eds.), Seafloor Mapping in the West, Southwest and South Pacific. *Marine Geophys. Res.* Spec. Issue, 18:203-224.

Moss, R. and Scott, S.D., 2001. Geochemistry and mineralogy of gold-rich hydrothermal precipitates from the eastern Manus Basin, Papua New Guinea. *Can. Mineralogist*, 39:957-978.

Scott, S.D. and Binns, R.A., 1995. Hydrothermal processes and contrasting styles of mineralization in the western Woodlark and eastern Manus basins of the western Pacific. *In* Parson, L.M., Walker, C.L. and Dixon, D.R. (Eds.), *Hydrothermal Vents and Processes*. Spec. Pub. 87, Geol. Soc. London, 191-205.

SCIENCE Leg Reports

ODP

ODP Leg 196: Logging-While-Drilling and Advanced CORKs at the Nankai Trough Accretionary Prism

Hitoshi Mikada [1], Keir Becker [2], J. Casey Moore [3], Adam Klaus [4], and the Leg 196 Shipboard Scientific Party

INTRODUCTION

The Nankai Trough marks the location where the Philippine Sea Plate begins subducting beneath the Eurasian Plate. The Nankai Trough subduction system has played an important role in causing many catastrophic earthquakes, a phenomenon observed at many other subduction zones (Ando, 1975). Recent studies have established that fluids play a major role in the physical and chemical evolution of subduction zones and, hence, their seismogenic behavior (e.g., Hyndman et al., 1995). The Philippine Sea Plate is relatively young but carries sediments ~1 km thick into the Nankai subduction zone. These sediments, as well as underlying oceanic crust, must influence the role of fluids around the plate interface and the generation of megathrust earthquakes at depth.

Leg 196 operations were based on prior Ocean Drilling Program (ODP) coring and logging at six sites along the "Muroto Transect" (Fig. 1). Drilling during Leg 131 penetrated through the décollement and into oceanic basement at Site 808 (Hill et al., 1993); coring at Sites 1173 through 1176 and 1178 occurred during Leg 190 (Moore et al., 2001). Leg 196 was designed to define the interrelationship of deformation, structure, and hydrogeology in the toe of the Nankai accretionary prism. These objectives were achieved by acquiring continuous *in situ* physical properties profiles with Logging-While-Drilling (LWD) instrumentation, and installing ODP's first "Advanced CORK" (ACORK) long-term hydrogeological observatories at Sites 808 and 1173 (Mikada et al., 2002).

LOGGING-WHILE-DRILLING AND ACORK EXPERIMENTS

Leg 196 revisited Site 1173, a reference site on the Philippine Sea Plate ~12 km seaward of the deformation front of the Nankai accretionary prism, and Site 808, ~2 km landward of the deformation front. Site 808 is located between frontal and secondary thrust faults where several hundred meters of hemipelagic and trench fill materials were scraped off as frontal accretion at the prism toe (Fig. 1). LWD tools were used at both sites to measure resistivity at

[1] Japan Marine Science and Technology Center, 2-15 Natsushima-cho, Yokosuka 237-0061, Japan
[2] Marine Geology & Geophysics, Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149 USA
[3] Earth Sciences Board of Studies, University of California at Santa Cruz, 1156 High Street, Santa Cruz, CA 95064 USA
[4] Ocean Drilling Program, Texas A&M University, 1000 Discovery Drive, College Station, TX 77845-9547 USA

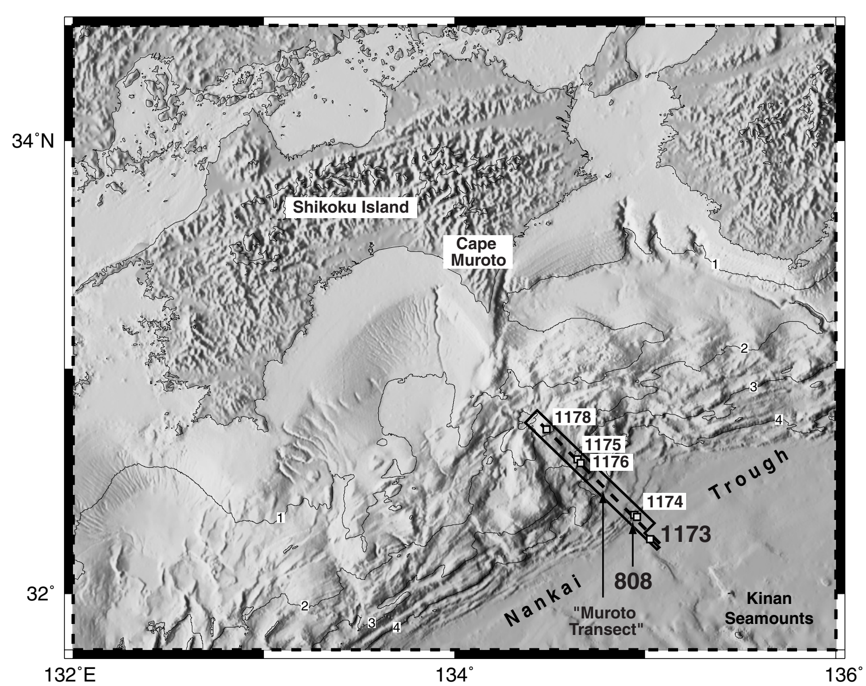

Figure 1. Map showing sites drilled along the "Muroto Transect" during ODP Leg 131 (Site 808) and Leg 190 (Sites 1173-1176, 1178), and revisited during Leg 196 (Sites 808 and 1173). The box surrounding the numbered drilling sites outlines the three-dimensional seismic survey conducted by the R/V Maurice Ewing *in 1999.*

the bit (RAB), sonic velocity, density, porosity, natural gamma ray production, and photoelectric effect.

Site 1173

Site 1173 was chosen as a reference site to obtain physical and chemical properties of undeformed sediments prior to any effects of subduction. More than 700 m into basement was cored in these holes during Leg 190, and a limited set of wireline logs were recovered from the shallow sediments. During Leg 196, an excellent set of LWD logs was recorded from the seafloor to oceanic basement. The LWD data were processed using multivariate statistical analyses. Five log units that account for the lithologic variations observed in the cores were defined:

- Log Unit 1 (0 to 122 meters below sea floor [mbsf]), characterized by high neutron porosity and low density values reflecting silt and sand turbidites of the outer trench-wedge to trench-basin facies;
- Log Unit 2 (122 to 340 mbsf), equivalent to Upper Shikoku Basin facies and characterized by low densities likely resulting from a cementation effect due to the formation of cristobalite in hemipelagic mud with abundant interbeds of volcanic ash;
- Log Unit 3 (340 to 698 mbsf), equivalent to Lower Shikoku Basin facies and characterized by gradually increasing resistivity and gamma ray values;
- Log Unit 4 (698 to 731 mbsf), characterized by broad variations in photoelectric effect, resistivity, neutron porosity, and gamma ray logs reflecting the presence of the volcaniclastic facies; and
- Log Unit 5 (731 to 735 mbsf), characterized by an abrupt increase in resistivity and decrease in gamma ray and representing the basaltic oceanic basement.

The Log Unit 2-Log Unit 3 boundary showed a change in average values of gamma ray, density, and photoelectric effect log values, and may represent a diagenetic boundary of phase transition between cristobalite and quartz.

After LWD operations, a four-packer, five-screen, 728-m-long ACORK casing assembly (Fig. 2A, inside front cover) was deployed through the sediment section in Hole 1173B. The ACORK was configured to record long-term pressure data in three principal zones:

- Oceanic basement below 731 mbsf, to determine permeability and assess the role of oceanic crust in the overall hydrogeology of the Nankai Trough;
- Lowermost Shikoku Basin deposits well below the stratigraphic projection of the décollement zone, to assess the hydrological properties of a reference section of the lower Shikoku Basin; and
- The stratigraphic equivalent of the décollement zone at about 390 to 420 mbsf in the upper part of the lower Shikoku Basin deposits, to assess the role of fluid in and around this layer.

A bridge plug was set inside the casing to isolate the basement section monitored by the deepest pressure sensor. In the process, the drill pipe above the bridge plug and the top of the ACORK accidentally broke off. This had no adverse effect other than precluding use of the inner bore for additional sensors.

Site 808

Poor borehole conditions at Site 808 precluded penetration deeper than about 100 m below the décollement zone. The overall quality of the LWD logs was fair except along the two depth intervals with poor hole conditions (725 to 776 mbsf and 967 to 1057 mbsf). Interpretation was based on a comparison with data acquired and measured during Leg 131. Four main log units were identified based on a multivariate statistical analysis (Fig. 2B, inside front cover):

- Log Unit 1 (156 to 268 mbsf), characterized by the lowest mean values of gamma ray, density, and photoelectric effect and highest mean values of resistivity and neutron porosity corresponding to fine grained sandstone, siltstone, and clayey siltstone/silty claystone;
- Log Unit 2 (268 to 530 mbsf), characterized by a constant range of values in

gamma ray and neutron porosity and a decrease in resistivity;

- Log Unit 3 (530 to 620 mbsf), marked by a significant increase in mean values of gamma ray, density, and photoelectric effect logs; and
- Log Unit 4 (620 to 1035 mbsf), characterized by the highest mean values of gamma ray, photoelectric effect, and density and the lowest mean values of resistivity and neutron porosity.

A continuous increase in gamma ray and photoelectric effect along the entire section may indicate an increase in clay and carbonate contents. Further interpretation of the logs led us to identify log subunits shown in Fig. 2B.

After the LWD operations, a 964-m-long ACORK casing string was installed in Hole 808I that incorporated two packers and six screens for long-term observations of pressures in three principal zones. These are the décollement zone and overlying section of the lower Shikoku Basin deposits, a fractured interval at 560 to 574 mbsf in the upper Shikoku Basin deposits, and the frontal thrust zone centered at about 400 mbsf. Since we anticipated poor drilling conditions, only two packers (the largest-diameter component) were included at ~100 and ~940 m. Drilling conditions during installation of the ACORK were even worse than expected, and progress stopped 37 m short of the intended installation depth. The 37 m of the installation above seafloor fell gently to the seafloor when released, but video inspection showed the key components intact and accessible for future submersible operations. Thus, although we did not achieve the ideal installation, the system appeared to be viable in terms of scientific objectives.

RETURN TO ACORKS WITH ROV *KAIKO* IN AUGUST, 2002

The JAMSTEC ROV *Kaiko* visited the ACORKs at Holes 808I and 1173B in August 2002, more than a year after Leg 196. Data were downloaded and the instruments reprogrammed during JAMSTEC cruise KR02-10. Both ACORKs, including the fallen unit at Hole 808I, were left fully functional (Fig. 3, outside front cover). A surprise was that several of the sampling valves to the monitoring zones had opened during the ACORK installation operations. These valves were closed during *Kaiko* operations, and the zones were verified to be hydrologically isolated, with measured pressures equilibrating toward *in situ* values. The valve situation delayed recovery of any scientifically useful data until the next proposed revisit in a few years. Nevertheless, the new ACORK concept has been validated to the great credit of the ODP. The two Nankai Trough ACORKs should provide important pressure data for years, if not decades, to come.

STRUCTURAL GEOLOGY

Several structural investigations using the RAB images are underway, including studies of bedding dips, fracture analysis, and stress analysis using borehole breakouts. Sparse deformation and predominantly subhorizontal bedding dips were observed at Site 1173, except for increases in bedding dips to 5° to 35° at 50 to 200 mbsf and below ~370 mbsf (Fig. 2A). An increase in fracture intensity from 380 to 520 mbsf corresponds to the stratigraphic projection of the décollement zone and underlying Lower Shikoku Basin sediments. At ~500 mbsf, bands of heterogeneous high resistivity probably represent zones of intense deformation or brecciation. In general, deformation observed in Holes 1173B and 1173C is consistent with extensional faulting that is probably related to basin compaction and burial, and not to compressional deformation propagating from the accretionary wedge.

Fracture populations and clear borehole breakouts were identified throughout much of the section at Site 808 (Fig. 4). Fractures are concentrated in discrete areas of deformation along the frontal thrust zone from 389 to 414 mbsf, along a fractured interval from 559 to 574 mbsf, and along the décollement zone from ~940 to 960 mbsf. Relatively sparse deformation occurs between these zones. The major deformation zones are characterized by fractures with strikes predominantly in east-northeast to west-southwest directions, nearly perpendicular to the convergence vector (Seno et al., 1993). Highly deformed zones are identified in the frontal thrust zone (389 to 414 mbsf) and in the fractured interval at 559 to 574 mbsf. Deformation at the décollement zone is more subdued and is represented by a series of discrete fracture zones. Borehole breakouts are recorded throughout Hole 808I and are particularly strongly developed within log Unit 2 (270 to 530 mbsf), suggesting lithologic control on sediment strength and breakout formation. The breakouts indicate a northwest-southeast orientation for the maximum horizontal compressive stress, consistent with the northwest-southeast convergence vector.

IMPORTANCE FOR FUTURE STUDIES

ODP has had many successes in subduction zone drilling. Important problems remain unsolved and, accordingly, are highlighted in the Initial Science Plan for the Integrated Ocean Drilling Program (IODP). Understanding the role of fluids in controlling the deformational style of the accretionary prism and with respect to seismogenic processes remain two central issues. In three legs at Nankai Trough, ODP has demonstrated that two types of fluids are involved at the toe of the accretionary prism: deeply-sourced fluids, as in other subduction zones, and diagenetically produced *in situ* fluids. Episodic fluid flow events are hypothesized to be linked with major earthquake ruptures in and around the accretionary prism, and with maintaining the observed chemical and thermal anomalies in the sediments (Saffer and Bekins, 1998; Moore and Silver, 2002). Seismogenic behavior at depth is hypothesized to be controlled by geochemical and thermal conditions (Hyndman, et al., 1995). Therefore, episodic fluid flow is of great importance in studying earthquake processes at subduction zones. Elucidation of the physical state of the toe of the prism from core and log analyses, and long-term monitoring of fluid pressure with the ACORK systems, will provide essential boundary conditions for understanding steady and episodic fluid migration processes and constraining conditions surrounding the Nankai seismogenic zone.

LEG 196 SCIENTIFIC PARTY

Hitoshi Mikada, Co-Chief Scientist; Keir Becker, Co-Chief Scientist; J. Casey Moore, Co-Chief Scientist; Adam Klaus, Staff Scientist; Gary L. Austin, Nathan L. Bangs, Sylvain Bourlange, Julien Broilliard, Warner Bruckmann, Ernest Ray Corn, Earl E. Davis, Peter B. Flemings, David S. Goldberg, Sean S. Gulick, Martin Bak Hansen, Nathan Hayward, Denise J. Hills, Sabine Hunze, Masanori Ienaga, Hiroyasu Ishiguro, Masataka Kinoshita, Robert D. Macdonald, Lisa

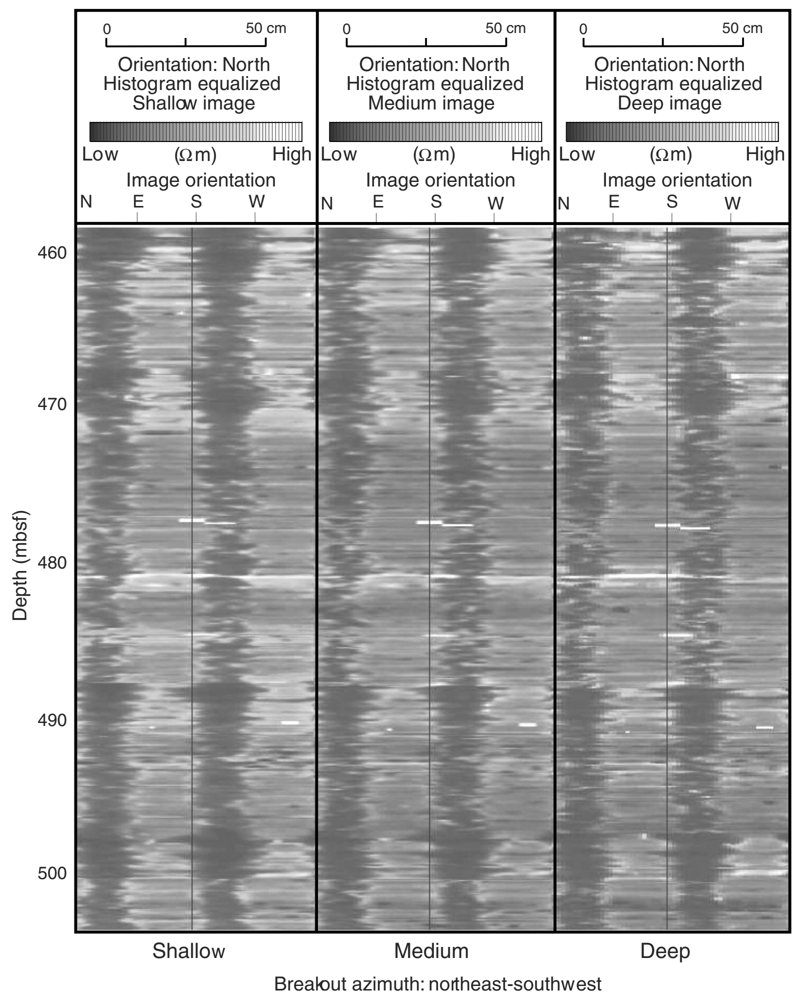

Figure 4. *Borehole breakouts observed using RAB (Resistivity at the Bit) images in Hole 808I at 460 to 505 mbsf. Resistivity values decrease with increasing darkness. Vertically aligned dark belts represent borehole breakouts that indicate orientation of the minimum horizontal compressive stress is ~northeast-southwest. This orientation is in good agreement with the plate convergence vector.*

SCIENCE
Leg Reports

ODP

McNeill, Shinichi Obana, Ong Swee Hong, Sheila Peacock, Thomas L. Pettigrew, Saneatsu Saito, Takao Sawa, Nophawit Thaiprasert, Harold J. Tobin, and Hikaru Tsurumi.

REFERENCES

Ando, M., 1975. Source mechanisms and tectonic significance of historical earthquakes along the Nankai Trough, Japan. *Tectonophys.*, 27: 119-140.

Hill, I.A., Taira, A., and Firth, J.V., et al., 1993. *Proc. ODP, Sci. Results*, 131, College Station, TX (Ocean Drilling Program).

Hyndman, R.D., Wang, K., and Yamano, M., 1995. Thermal constraints on the seismogenic portion of the southwestern Japan subduction thrust, *J. Geophys. Res.*, 100:15,373-15,392.

Moore, G.F., Taira, A., Klaus, A., et al., 2001. *Proc. ODP, Init. Repts.*, 190, College Station, TX (Ocean Drilling Program), [CD-ROM].

Mikada, H., Becker, K., Moore, J.C., Klaus, A., et al., 2002. *Proc. ODP, Init. Repts.*, 196, College Station, TX (Ocean Drilling Program), [CD-ROM].

Moore, J.C., and Silver, E., 2002. Fluid flow in accreting and eroding convergent margins, *JOIDES J.*, 28:91-96.

Saffer, D.M., and Bekins, B.A., 1998. Episodic fluid flow in the Nankai accretionary complex: Timescale, geochemistry, flow rates and fluid budget. *J. Geophys. Res.*, 103:30,351-30,370.

Seno, T., Stein, S., and Gripp, A.E., 1993. A model for the motion of the Philippine Sea plate consistent with NUVEL-1 and geological data. *J. Geophys. Res.*, 98:17,941-17,948.

ODP Leg 198: New Evidence for Rapid Climate Change in the Cretaceous and Paleogene from the Shatsky Rise, Northwest Pacific Ocean

SCIENCE
Leg Reports
ODP

Timothy J. Bralower [1], Isabella Premoli Silva [2], Mitchell J. Malone [3], and the Leg 198 Scientific Party

INTRODUCTION

Shatsky Rise is a medium-sized, large igneous province in the Pacific Ocean (Fig. 1, inside back cover) that serves as a pedestal for an impressive 140-million-year package of pelagic sediment. The primary objectives of Ocean Drilling Program (ODP) Leg 198 were to use cores obtained from these sediments to understand long-term transitions into and out of the warm Cretaceous and early Paleogene climate "greenhouse", as well as transient but critical events that involved major changes in oceanic environments, geochemical cycling, and marine biotas. Drilling on Shatsky Rise was conducted at sites on topographic highs, including the North and Central Highs (Sites 1207 and 1208, respectively) and the Southern High (Sites 1209 to 1214). Boreholes were cored to depths between 170 and 623 meters below sea floor (mbsf).

The sedimentary column is predominantly calcareous and includes a general transition with increasing burial depth from ooze to chalk to limestone (Fig. 2). The Neogene section is more clay-rich and siliceous than the Paleogene and Cretaceous sections. The Cenozoic section on the Southern High is almost complete except for a hiatus in the early Miocene and latest Oligocene (17 to 25 Ma). This section showed a strong signature of orbital cycles that involve minor fluctuations in the amount of clay and dissolution of the host carbonate. Multiple occurrences of the Paleocene-Eocene thermal maximum (PETM) and Cretaceous/Tertiary boundary were cored. In addition, a previously undetected late Paleocene biotic event was identified.

The uppermost Cretaceous (Maastrichtian-Campanian) section consists of pure white ooze and chalk and contains records of the mid-Maastrichtian oceanographic event.

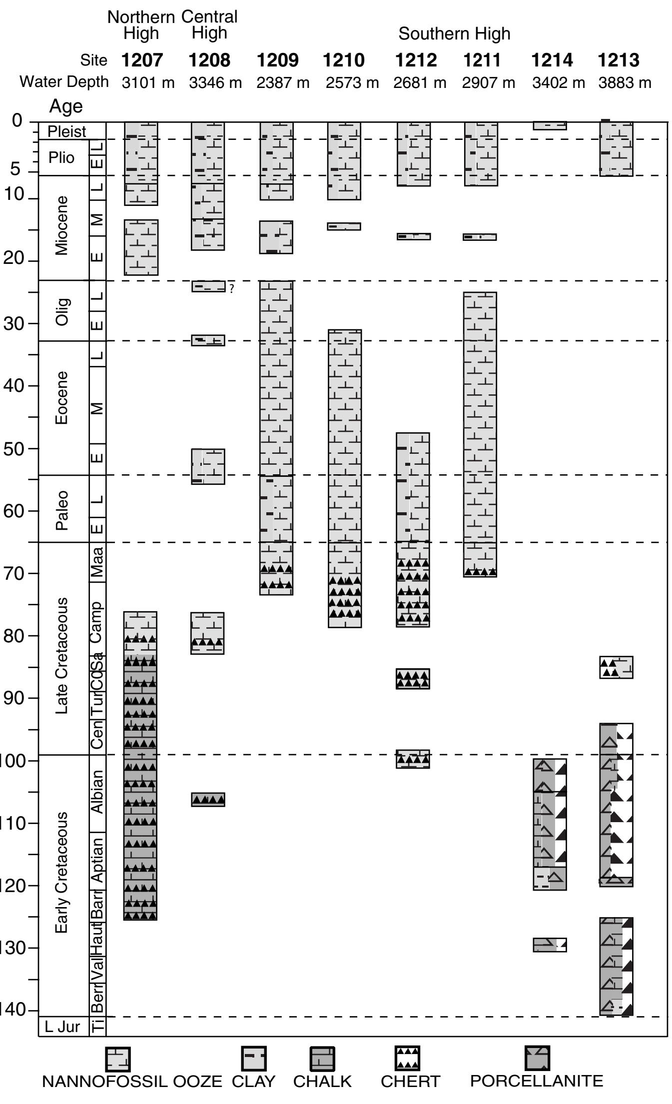

Figure 2. Summary of stratigraphy and lithologic succession from Sites 1207 to 1214. Lithology is plotted against time to show duration of periods of deposition and location of unconformities. Southern High Sites 1209 to 1214 are arranged by water depth.

[1] Department of Geological Sciences, University of North Carolina, Chapel Hill, NC 27599-3315 USA
[2] Dipartmento di Scienza della Terra, University of Milan, Via Mangiagalla 34, 201B3 Milan, Italy
[3] Ocean Drilling Program, Texas A&M University, 1000 Discovery Drive, College Station, TX 77845-9547 USA

SCIENCE Leg Reports

ODP

Thin chert layers were found in most of the Cretaceous section (Campanian-Berriasian), impeding the recovery of the softer interbedded carbonates. However, intervals without significant chert had higher recovery rates and resulted in the fortuitous recovery of black shales in the lower Aptian (OAE1a) and Valanginian. Although several diabase sills were cored at Site 1213, "true basement" was not penetrated.

A CLASSIC RECORD OF THE EARLY APTIAN OCEANIC ANOXIC EVENT

Organic carbon (C_{org})-rich sedimentary rocks recovered in Site 1207 and 1213 cores (Fig. 3) provide evidence for an Oceanic Anoxic Event (OAE) during the early Aptian (OAE1a; 120 Ma) (Arthur et al., 1990). OAE1a at Site 1207 is found within 45 cm of a finely laminated, dark brown radiolarian claystone with up to 34.7 wt.% C_{org}. The Site 1213 C_{org}-rich sedimentary rocks include clayey porcellanites, radiolarian porcellanites with up to 25.2 wt.% C_{org}, and associated minor tuff. Logging data suggest that approximately 50% of the C_{org}-rich unit was recovered at Site 1207, and less than 30% at Site 1213. At Site 1214, a distinctive radiolarian assemblage contained in a black laminated claystone unit with low C_{org} contents suggests correlation to OAE1a (e.g., Erbacher and Thurow, 1997). The Shatsky Rise C_{org}-rich units represent the most pelagic records outside of Tethys (Coccioni et al., 1992).

Rock-Eval analyses and gas chromatography-mass spectrometry (GC-MS) of extractable hydrocarbons and ketones indicate that organic matter from the C_{org}-rich sedimentary rocks at Sites 1207 and 1213 is almost exclusively algal and bacterial in origin. GC-MS data, in particular, were used to identify biomarkers associated with cyanobacteria. The prevalence and character of bacterial biomarkers suggest the existence of microbial mats at the time of deposition. Compounds produced by haptophyte algae include the oldest known alkenones (Brassell et al., in review). Lamination at Site 1207, and the exceptional preservation of organic compounds in the lower Aptian samples from Sites 1207 and 1213, indicate that conditions were highly dysoxic or anoxic during deposition.

At Sites 1207 (~1.3 km paleodepth during OAE1a) and 1213 (~2.8 km paleodepth), the C_{org}-rich units lack carbonate, but calcareous sediments are found directly underneath the C_{org}-rich sediments at Site 1213, indicating that the carbonate compensation depth (CCD) shoaled by at least 1.5 km during the event. The magnitude of the change of the CCD during OAE1a likely results from oxidation of a steady flux of organic matter over a fairly

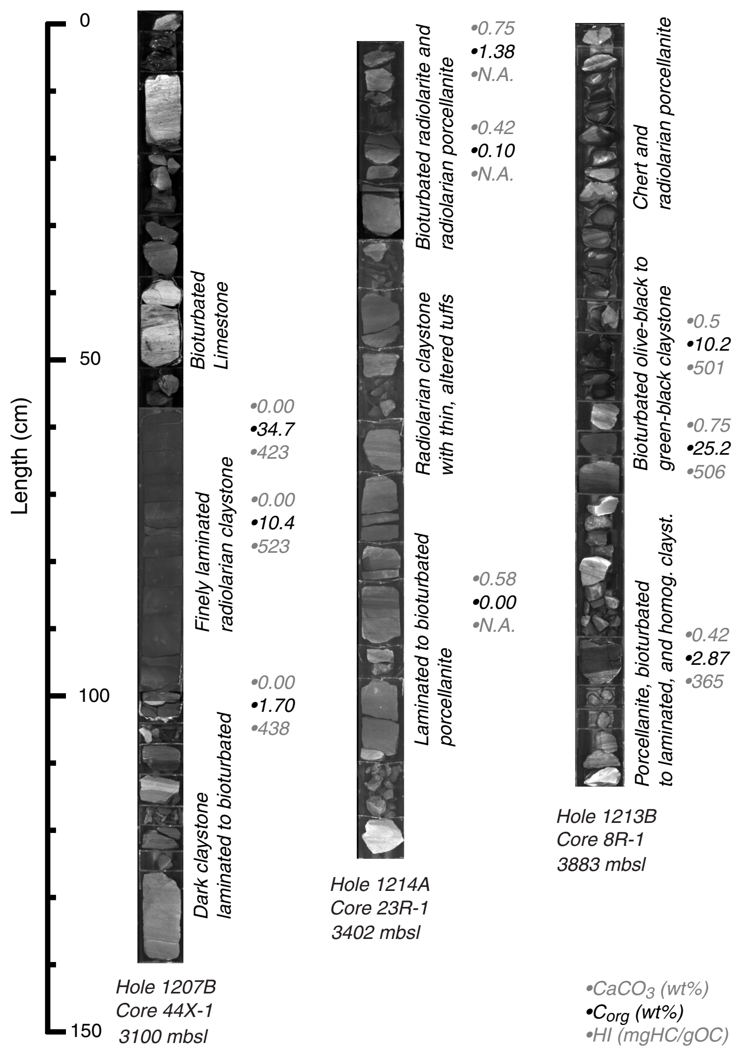

Figure 3. Lithology, organic carbonate (% C_{org}), and pyrolysis hydrogen indices for lower Aptian sedimentary rocks recovered at Sites 1207, 1213, and 1214, Shatsky Rise. Note that C_{org}-rich intervals representing OAE1a were recovered from Site 1207 and 1213 boreholes.

long time period (~1 m.y.) and increased rates of CO_2 outgassing (e.g., Arthur et al., 1985). C_{org}-rich horizons of OAE1a age have been found at Deep Sea Drilling Project (DSDP) Site 463 (Mid-Pacific Mountains) and ODP Site 866 (Resolution Guyot). Both of these sites have a shallow-water influence. Early Aptian OAE1a in Tethys corresponds to a prominent C_{org}-rich unit. Recovery of highly carbonaceous OAE1a horizons on Shatsky Rise strongly suggests a global extent of this oceanic anoxic event.

THE MID-MAASTRICHTIAN EVENT: DEATH ON THE SEAFLOOR

An unusual record of the mid-Maastrichtian (69 Ma) event was observed in the sedimentary record recovered from boreholes on the Southern High of Shatsky Rise. Clusters of large *Inoceramus* prisms observed for several meters in the cores recovered at Sites 1209 and 1210 disappear abruptly in the same stratigraphic position in both holes. Furthermore, *Inoceramus* prisms were washed from samples within the same foraminiferal zone at Site 1211. The significance of the short range of visible specimens in this open ocean setting is not currently understood. However, the position of the event is similar to that of the *Inoceramus* extinction and the isotopic shifts that mark the mid-Maastrichtian event at DSDP Site 305 and other deep-sea locations (e.g., MacLeod and Huber, 1996). Benthonic and planktonic foraminiferal data from Shatsky Rise will help to characterize accurately the changes in deep- and surface-water properties, and their relationship with the extinction event.

A MULTI-CORE RECORD OF THE CRETACEOUS/TERTIARY BOUNDARY

Although the Cretaceous/Tertiary (K/T) boundary was not a prime focus of investigation during Leg 198, a remarkable set of cores was taken across this critical interval at Sites 1209, 1210, 1211, and 1212 on the Southern High, and nine separate K/T records were recovered. The boundary succession includes an uppermost Maastrichtian (nannofossil Zone CC26) white to very pale orange, slightly indurated nannofossil ooze overlain by lowermost Paleocene (foraminiferal Zone Pα) grayish-orange foraminiferal ooze. The boundary between the uppermost Maastrichtian and the lowermost Paleocene is clearly bioturbated. The contact surface is irregular and pale orange burrows extend 10 cm into the white Maastrichtian ooze. Sampling of the deepest sections of these burrows yielded highly abundant, minute planktonic foraminiferal assemblages dominated by *Guembelitria* with rare *Hedbergella holmdelensis*, suggesting a possible Zone P0 age (Smit, 1982). The substantial thicknesses of the uppermost Maastrichtian *M. prinsii* (CC26) Zone and the lowermost Danian *P. eugubina* (Pα) Zone indicate that the K/T boundary is expanded compared to the majority of deep sea sites, and represents one of the best preserved, least disrupted, deep sea records of the K/T extinction event and susequent biotic radiation.

A BIOTIC EVENT IN THE LATE PALEOCENE

A new event of evolutionary and paleoclimatological significance in the early late Paleocene (~58.4 Ma) was discovered during Leg 198. A prominent clay-rich ooze found at Sites 1209, 1210, 1211, and 1212 coincides with the evolutionary first occurrences of *Heliolithus kleinpellii* and primitive discoasters, two important, and often dominant, components of late Paleocene and younger nannoplankton assemblages. Planktonic foraminifers in the clay-rich layer are characterized by a low diversity, largely dissolved assemblage dominated by representatives of the genus *Igorina* (mainly *I. pusilla* and *I. tadjikistanensis*).

The clay-rich layer contains common crystals of phillipsite, fish teeth, and phosphatic micronodules, and corresponds to a prominent peak in magnetic susceptibility that probably reflects Fe-Mn coating of grains. The abundance of phillipsite and fish teeth indicates very slow sedimentation or intervals of seafloor exposure, possibly resulting from pervasive dissolution of carbonate. Even though microfossil assemblages are clearly altered by dissolution, the biotic event appears to have been triggered by a significant environmental perturbation in surface waters.

A DEPTH TRANSECT OF THE PALEOCENE-EOCENE THERMAL MAXIMUM

Shatsky Rise sediment cores show evidence of a strong deep-ocean response to warming in the Paleocene-Eocene thermal maximum (PETM; ~55 Ma). In nine holes at Sites 1209, 1210, 1211, and 1212 on the Southern High, the PETM corresponds to an 8- to 23-cm-thick layer of clayey nannofossil ooze with a sharp base and a gradational upper contact (Fig. 4, inside back cover).

Preliminary biostratigraphy and stable isotope stratigraphy suggest that the PETM is complete. The biostratigraphy also shows that the PETM interval at the Southern High sites is condensed compared to continental margin records from the Atlantic and Tethys (e.g., Kennett and Stott, 1991), but somewhat expanded compared to other deep sea sites. At the relatively deep Site 1208, biostratigraphic and bulk stable isotopic data confirm that the recovered PETM is a highly condensed (~3 cm) record.

The depth transect strategy of Leg 198 was designed to address the response of the ocean to the greenhouse forcing mechanism proposed for the PETM. This warming is generally thought to have resulted from input of a massive release of methane into the ocean-atmosphere system (e.g., Dickens et al., 1997). Oxidation of this methane would generate CO_2, which would lower the saturation state of seawater with respect to calcite and cause a dramatic shoaling in the depth of the lysocline and CCD. This response should be recorded in changes in carbonate content and preservation in sections below the mid-slope. Shallower sections should show less change in dissolution and carbonate content than deeper sections.

Nannofossil preservation below the PETM at all of the Southern High sites is moderate, indicating that the sites were located in the upper part of the lysocline. All sites show a short-lived deterioration in preservation at the onset of the event. Carbonate contents were measured in detail across the PETM at Site 1210. These data show a decrease from ~96 to ~86 wt.% $CaCO_3$ at the base of the event that would involve a substantial increase in dissolution.

The general changes in lithology suggest a transition from paleodepths at the shallower Sites 1209, 1210, and 1212 that were less sensitive to changes in carbonate solubility of the deep ocean to paleodepths at Sites 1208 and 1211 that were at depth ranges highly sensitive to such changes across the PETM (Fig. 4). The decrease in carbonate content and deterioration in nannofossil preservation are evidence for an abrupt rise in the level of the CCD and lysocline during the PETM, and support the predicted ocean response to massive methane input.

THE EOCENE-OLIGOCENE TRANSITION IN THE TROPICAL PACIFIC OCEAN

Sediments recording the response of the tropical Pacific Ocean to cooling in the Eocene-Oligocene (E-O) boundary transition were recovered across a large depth range from nine holes at Sites 1208, 1209, 1210, and 1211. This cooling that signaled the end of the warm Paleogene occurred largely in a rapid step in the earliest Oligocene at ~33.5 Ma (Zachos et al., 1996). Nannofossil and planktonic foraminiferal biostratigraphy suggest that the boundary interval is complete. At the Southern High (Sites 1209, 1210, and 1211), a gradual but distinctive change from light brown to tan nannofossil ooze with clay, to a light gray to white nannofossil ooze, is observed over a 4 to 7.5 m interval. The lithologic record of the E-O transition at Site 1208 on the Central High is much more condensed than that at the Southern High sites. A change from a dark brown zeolitic claystone with extremely low carbonate content to a gray-orange nannofossil ooze was observed over a 1 to 2 cm interval.

The distinctive color change in all of the Leg 198 records reflects an increase in carbonate content and a pronounced deepening of the CCD during the E-O transition. In the latest Eocene, the CCD in the Shatsky Rise region was between the paleodepths of Sites 1208 and 1211, and probably closer to the former based on the sporadic occurrence of nannofossils. After the event, the CCD was substantially deeper than Site 1208. This significant change is observed in other ocean basins and is likely related to cooling that increased mechanical erosion rates and riverine flux of Ca (e.g., Zachos et al., 1996).

LEG 198 SCIENTIFIC PARTY

Timothy J. Bralower, Co-Chief Scientist; Isabella Premoli Silva, Co-Chief Scientist; Mitchell J. Malone, Staff Scientist; Michael A. Arthur, Kristin Averyt, Simon C. Brassell, Paul R. Bown, James E.T. Channell, Leon J. Clarke, Andrea Dutton, Jason W. Eleson, Tracy D. Frank, Susanne Gylesjö, Heidi Hancock, Harumasa Kano, R. Mark Leckie, Kathleen M. Marsaglia, K.T. Moe, Jennifer McGuire, Maria Rose Petrizzo, Stuart Robinson, Ursula Röhl, William W. Sager, Kotaro Takedo, Deborah Thomas, Trevor Williams, and James C. Zachos.

REFERENCES

Arthur, M.A., Brumsack, H.-J., Jenkyns, H.C., and Schlanger, S.O., 1990. Stratigraphy, geochemistry, and paleoceanography of organic carbon-rich Cretaceous sequences. *In* Ginsburg, R.N., and Beaudoin, B. (Eds.), *Cretaceous Resources, Events and Rhythms*, Kluwer Academic Publishers, 75-119.

Arthur, M.A., Dean, W.E., Schlanger, S.O., 1985. Variations in the global carbon cycle during the Cretaceous related to climate, volcanism, and changes in atmospheric CO_2. *In* Sundquist, E.T., and Broecker, W.S. (Eds.), The Carbon Cycle and Atmospheric CO_2: Natural Variations Archean to Present. *Geophys. Monogr., Am. Geophys. Union*, 32:504–529.

Brassell, S.C., and the ODP Leg 198 Shipboard Scientific Party, in review. Alkenones in lower Aptian black shales from the Pacific: Organic geochemistry. *Proc. ODP, Sci. Results,* 198, College Station, TX (Ocean Drilling Program).

Coccioni, R., Erba, E., and Premoli Silva, I., 1992. Barremian-Aptian calcareous plankton biostratigraphy from the Gorgo Cerbara section, Marche, central Italy, and implications for plankton evolution. *Cretaceous Res.*, 13: 517-537.

Dickens, G.R., Castillo, M.M., and Walker, J.G.C., 1997. A blast of gas in the latest Paleocene: simulating first-order effects of massive dissociation of oceanic methane hydrate. *Geology*, 25:259-262.

Erbacher, J., and Thurow, J., 1997. Influence of oceanic anoxic events on the evolution of mid-Cretaceous radiolaria in the North Atlantic and western Tethys. *Mar. Micropaleontol.*, 30: 139-158.

Kennett, J.P., and Stott, L.D., 1991. Abrupt deep-sea warming, palaeoceanographic changes, and benthic extinctions at the end of the Palaeocene. *Nature*, 353:225-229.

MacLeod, K.G., and Huber, B.T., 1996. Reorganization of deep-sea circulation accompanying a Late Cretaceous extinction event. *Nature*, 380: 422-425.

Smit, J., 1982. Extinction and evolution of planktonic foraminifera after a major impact at the Cretaceous/Tertiary boundary. *In* Silver, L.T., and Schultz, H. (Eds.), Geological Implications of Impacts of Large Asteroids and Comets on the Earth. *Spec. Paper Geol. Soc. Am.,* 190: 329-352.

Smith, W.H.F., and Sandwell, D.T., 1997. Global sea floor topography from satellite altimetry and ship depth soundings. S*cience,* 277: 1956-1962.

Zachos, J.C., Quinn, T.M., and Salamy, K.A., 1996. High resolution deep-sea foraminiferal stable isotope records of the Eocene-Oligocene climate transition. *Paleoceanogr.,* 11:251-266.

SCIENCE
Leg Reports

ODP

ODP Leg 200: Drilling at the Hawaii-2 Observatory (H2O) and Nuuanu Landslide

Ralph A. Stephen [1], Junzo Kasahara [2], Gary D. Acton [3], and the Leg 200 Scientific Party

INTRODUCTION

Leg 200 investigations targeted two distinct projects in the Pacific Ocean east of Hawaii. The drilling and preparation of long-term measurement boreholes at the Hawaii-2 Observatory (Site 1224) was the primary objective (Fig. 1). A test borehole into the distal portions of the Nuuanu landslide (Site 1223) was the secondary objective.

The Hawaii-2 Observatory (H2O) site satisfied three scientific objectives of crustal drilling: (1) it is located in a high priority region for the Ocean Seismic Network (OSN) (Butler, 1995; Purdy, 1995); (2) its proximity to the Hawaii-2 cable and H2O junction box makes it a unique site for real time, continuous monitoring of geophysical and geochemical experiments in the crust (Sutton et al., 1965; Nagumo and Walker, 1989; Kasahara et al., 1998); and (3) it is on fast-spread Pacific crust (7.1 cm/yr half-rate), which represents one end-member for models of crustal generation and evolution and crust/mantle interaction (Atwater, 1989).

Cores were recovered from the Nuuanu Landslide site on the Hawaiian Arch, ~300 km northeast of Honolulu. The upper 100 m of sediment at this site was thought to contain a record of the Nuuanu Landslide, a catastrophic event or series of events that removed ~40% (3000 to 4000 km^3) of the Koolau Volcano on the island of Oahu (Normark et al., 1983; Herrero-Bervera et al., 2002).

[1] Earthquake Research Institute, University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo 113-0032, Japan
[2] Department of Geology and Geophysics, Woods Hole Oceanographic Institution, MS 24, 360 Woods Hole Road, Woods Hole, MA 02543-1542 USA
[3] Ocean Drilling Program, Texas A&M University, 1000 Discovery Drive, College Station, TX 77845-9547 USA

THE HAWAII-2 OBSERVATORY (SITE 1224)

The primary objective of the cruise was to prepare a borehole in basaltic crust for the installation of a broadband borehole seismo-

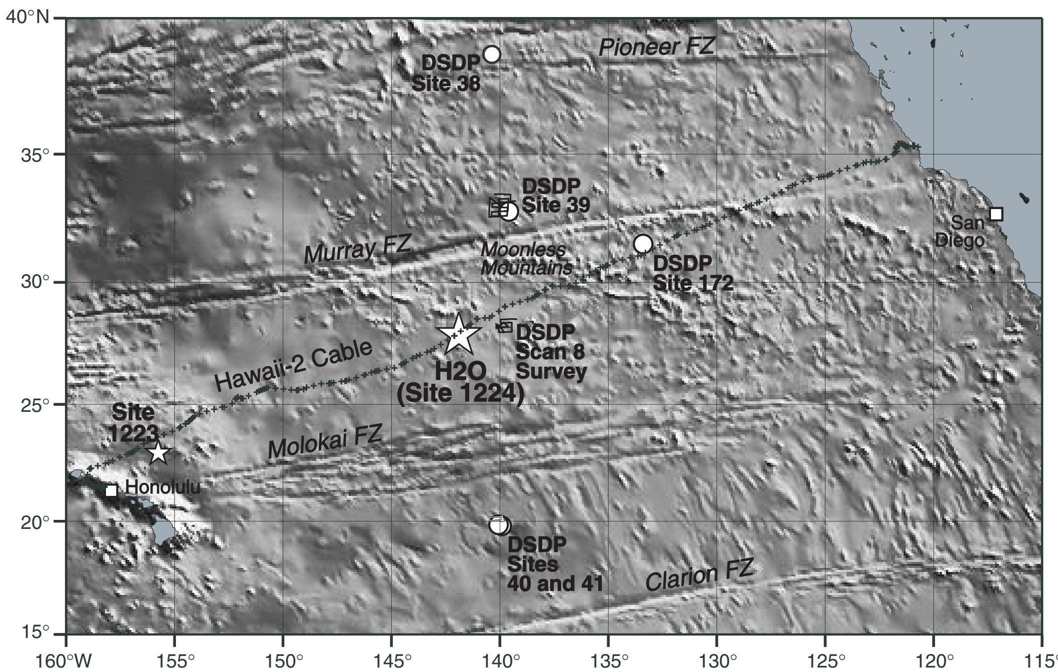

Figure 1. The repeater locations of the Hawaii-2 cable (plus signs), the Nuuanu landslide drill site (Site 1223, small star), the location of the H2O junction box and drill site (Site 1224, large star), and the location of previous drilling on Legs 5 and 18 of DSDP are shown. Superimposed on the map is the satellite derived bathymetry. The locations of the major fracture zones are marked.

meter that will be connected to the Hawaii-2 Observatory, and the existing seafloor installation, for continuous, real time data transmission to the University of Hawaii (Collins et al., 2001; Duennebier et al., 2002). Previous tests have shown that improved signal-to-noise ratios for earthquakes can be obtained with borehole installations (Collins et al., 2001). Since the cruise, the U.S. National Science Foundation has funded a project to develop the borehole seismometer system and to deploy it in Hole 1224D in 2004. From Hawaii, the data will be made available to seismologists worldwide through the IRIS (Incorporated Research Institutions for Seismology) Data Management Center in Seattle.

Hole 1224D is a cased and cemented hole, located 1.48 km northeast of the H2O junction box. The 10.75" casing suspended below the reentry cone is 58.5 m long, and it was cemented into a 30 m thick, well-consolidated, massive basalt flow underlying 28 m of soft, red clay (Fig. 2).

After setting the reentry cone and casing at Hole 1224D, a single-bit hole, Hole 1224F, was drilled to 174.5 mbsf to acquire sediment and basalt samples for shipboard and shore-based analysis as well as to run a logging program. Hole 1224F is less than 20 m to the southeast of Hole 1224D. Measurements at Hole 1224F can be used to infer the structure surrounding both holes. A free fall funnel was dropped at Hole 1224F so that future borehole experiments using wireline reentry technology can be carried out. Since this hole is open to the formation, it is available for continuous, long-term measurements of hydrothermal, geochemical and microbiological processes.

Sedimentary Section

The sediment thickness at Site 1224 is 28 to 30 m. Paleontological analysis of the calcareous nannofossils indicates that essentially the whole sedimentary sequence was deposited within a few million years of the crustal age of ~46 Ma (middle Eocene).

Hard Rock Section

The basalts are differentiated N-MORB (Normal Mid-Ocean Ridge Basalt) with 2 to 3.5% TiO_2. We divided the basaltic section into three lithologic units as follows:

- Unit 1: Massive basalt flows. This unit includes all basalt cores of Holes 1224A, D, and E. The base of the unit in Hole 1224F is curated at 62.7 meters below sea floor (mbsf), and its thickness in Hole 1224F as curated is 34.7 m. Recovery of Unit 1 from all holes was 52.6%. The logs show a change in porosity and density at the curated depth of the base of Unit 1.

- Unit 2: Thin flows and pillows. The base of the unit is curated at 133.5 mbsf, and its

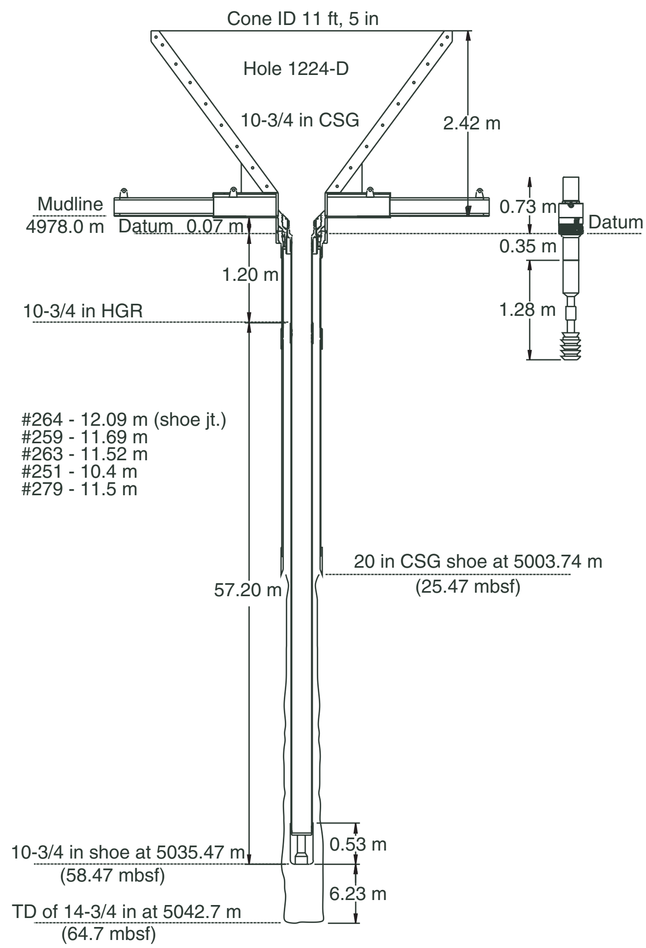

Figure 2. *Summary of the critical dimensions of the reentry cone and casing deployed at Hole 1224D during Leg 200. On re-entering the cone for the last time, it was observed that the "mudline" in this figure was actually 1.7 m below the seafloor. (Figure courtesy of Scott Pederson, Transocean/Sedco/Forex.)*

thickness as curated is 70.8 m. Recovery in Unit 2 was 14.6%. Two hyaloclastites were recovered in this unit. A change in porosity and density in the logs, that corresponds to the base of Unit 2, occurs about 140 mbsf, a few meters deeper than the curated depth. The temperature in the hole also increased at 135 to 137 mbsf, suggesting that seawater flowing down the hole entered the formation in a zone of high permeability at this depth.

- Unit 3: Basalt flows of intermediate thickness alternating with thin flows and pillows. The base of the unit is 161.7 mbsf, and its thickness as curated is 28.2 m. Recovery in Unit 3 was 21.4%.

Physical Properties, Logging and Correlation to Petrology and Geochemistry

Drilling at Site 1224 provided an excellent opportunity to understand the petrological and geophysical nature of layers 2A and 2B in fast-spread Pacific crust at an age of about 45 Ma. The correlation among physical properties, logging, petrology and geochemistry at Hole 1224F provided a new window onto at the nature of the shallow oceanic crust.

Geochemical analysis showed that lithologic Unit 1 is subdivided into two flow units. The lower of these flow units is chemically similar to Unit 2 and is, based on TiO_2 content, an extremely differentiated end-member of MORB. Lithologic Unit 2 is similar to normal MORB, but was sheared and is comprised of small pillows with chilled margins. The Formation MicroScanner (FMS) logging records show numerous fractures in lithologic Unit 2. Both physical properties and logging data indicate more altered zones than were identified lithologically. A zone of intensive fracturing at the boundary of lithologic Units 2 and 3 was identified by logging. The massive character of Unit 3 led to the interpretation of Unit 2 as a passageway for the warm water responsible for the alteration minerals.

A seismic model to 170 mbsf was developed based on velocities from physical properties measurements and logging. This model will aid in the analysis of the broadband, downhole seismometer data.

Microbiology

Sediment samples for microbiological analyses were obtained at different depths from the near-surface layer to 24.9 mbsf. Bacteria were present in all of the samples. The amount of active bacteria was assessed in two representative sediment samples taken from the near-surface layer and from a depth of 25 mbsf. Metabolically active bacteria in these sediment layers ranged from 62% in the near-surface layer to 41% at 25 mbsf.

Microscopic investigation of a thin section of basalt showed textures that resembled microbial structures. This suggests putative microbial activity may occur in deep subsurface environments.

The 3.5 KHz Deep Source Experiment

A long-standing problem in the "Red Clay Province" of the Eastern Pacific is to adequately resolve chert layers and basement in the presence of sediment layers less than 50 m thick. During Leg 200, a battery-powered, free-running 3.5 kHz pinger was lowered to the seafloor on the Vibration Isolated Television (VIT) sled. The pinger recorded the pulse on the ship's 3.5 kHz acquisition system. This method of deployment increased the sound level incident on the seafloor, improved the penetration into the subbottom, reduced the footprint of the sound on the seafloor, and increased the received signal levels. Two prominent reflections were observed at 10 and 28 mbsf, but the continuity of these reflections varied with time throughout the survey, even though the ship moved only a few meters. The origin of the first subseafloor reflection at 10 mbsf could not be clearly identified in the core. The second subseafloor reflection at 28 mbsf corresponds to basaltic basement.

Broadband Seismic Observations

Drilling-related noise from the *JOIDES Resolution* was observed on the shallow buried seismometer (frequency band 0.1 to 80 Hz) already operating at the site. Data were acquired continuously at the University of Hawaii (see

http://Imina.soest.Hawaii.edu/H2O/), and have been made available to international scientists through the IRIS. Seismic activity observed on these records could be associated with wind speed, sea state, shear resonance effects in the sediments, earthquakes, passing ships and drilling-related activities such as bit noise and running pipe.

Basement Drilling on the Pacific Plate

The spreading rate at the latitude and crustal age of the H2O area is 142 mm/yr (full rate). The presence of an instrumented reference station at Site 1224, in "normal", very fast spread, 45 to 50 Ma ocean crust, will constrain geochemical and hydrothermal models of crustal evolution.

Table 1 summarizes the boreholes drilled on "normal" crust on the Pacific plate that have 10 m or more of basement penetration and crustal ages less than 100 Ma. Boreholes in seamounts, plateaus, aseismic ridges, and fracture zones were not included. Holes with crustal ages greater than 100 Ma were not included since they would be affected by the mid-Cretaceous super plume. In over 30 years of deep ocean drilling prior to Leg 200, only 13 holes from those drilled at over 1200 drill sites have penetrated more than 10 m into "normal" igneous crust of the Pacific plate. Only one such hole was drilled during ODP, only one hole had greater than 100 m penetration, and no holes have been drilled in crust with ages between 29 and 72 Ma.

THE NUUANU LANDSLIDE (SITE 1223)

Of the 41 m of core recovered from the borehole into the Nuuanu Landslide on the Hawaiian Arch, we recovered several lithologic units that were transported to the site by a number of distinct landslide events (Fig. 3). Several unconsolidated volcaniclastic turbidites of varying thickness were recovered in the first two cores. Eight of these were more than 10 cm thick at 1, 3, and 4 mbsf for Unit 1, and 5.2, 6, 6.9, and 7.3 mbsf for Unit 2. Many were less than 1 cm thick. Paleomagnetic data indicated that all but the uppermost turbidites

Leg-Hole	Age (Ma)	Latitude/ Longitude	Basement Penetration (m)	Sediment Thickness (m)
DSDP				
16-163	72	11°N, 150°W	18	176
54-420	3.4	09°N, 106°W	29	118
54-421	3.4	09°N, 106°W	29	85
54-429A	4.6	09°N, 107°W	21	31
63-469*	17	33°N, 121°W	58	391
63-470A	15	29°N, 118°W	48	167
63-471	12	23°N, 112°W	82	741
63-472	15	23°N, 114°W	25	112
65-483B	1.7	23°N, 109°W	157	110
92-597B	29	19°S, 130°W	25	48
92-597C#	29	19°S, 130°W	91	53
ODP				
136-843B#**	110	19°N, 159°W	71	243
200-1224D#***	46.3	28°N, 142°W	36	29
200-1224F	46.3	28°N, 142°W	145	29

Table 1. *Summary of holes drilled in "normal crus" on the Pacific Plate with an age <100 Ma and penetration into basement >10 m. Notes: * = Borehole at the foot of Patton Escarpment; # = Re-entry cone emplaced at this hole; ** = Location of Hole OSN-1. [Editor's Notes: *** = Location of Hawaii-2 Observatory (H20). Two additional holes that meet these criteria have been drilled during Leg 203.]*

have an age between 1.77 and 1.95 Ma. The top turbidite has an estimated age between 0.78 and 1.77 m.y.

The recovery of two crystal vitric tuff layers containing fresh olivine was a surprise. Kink banding and fibrous structures were observed in some of these olivines. The fibrous structure may have been caused by crystallization of hematite. The textures suggest that the olivines may have been derived from the mantle under shear stress. Paleomagnetic data indicate that the vitric tuffs are older than 1.95 Ma.

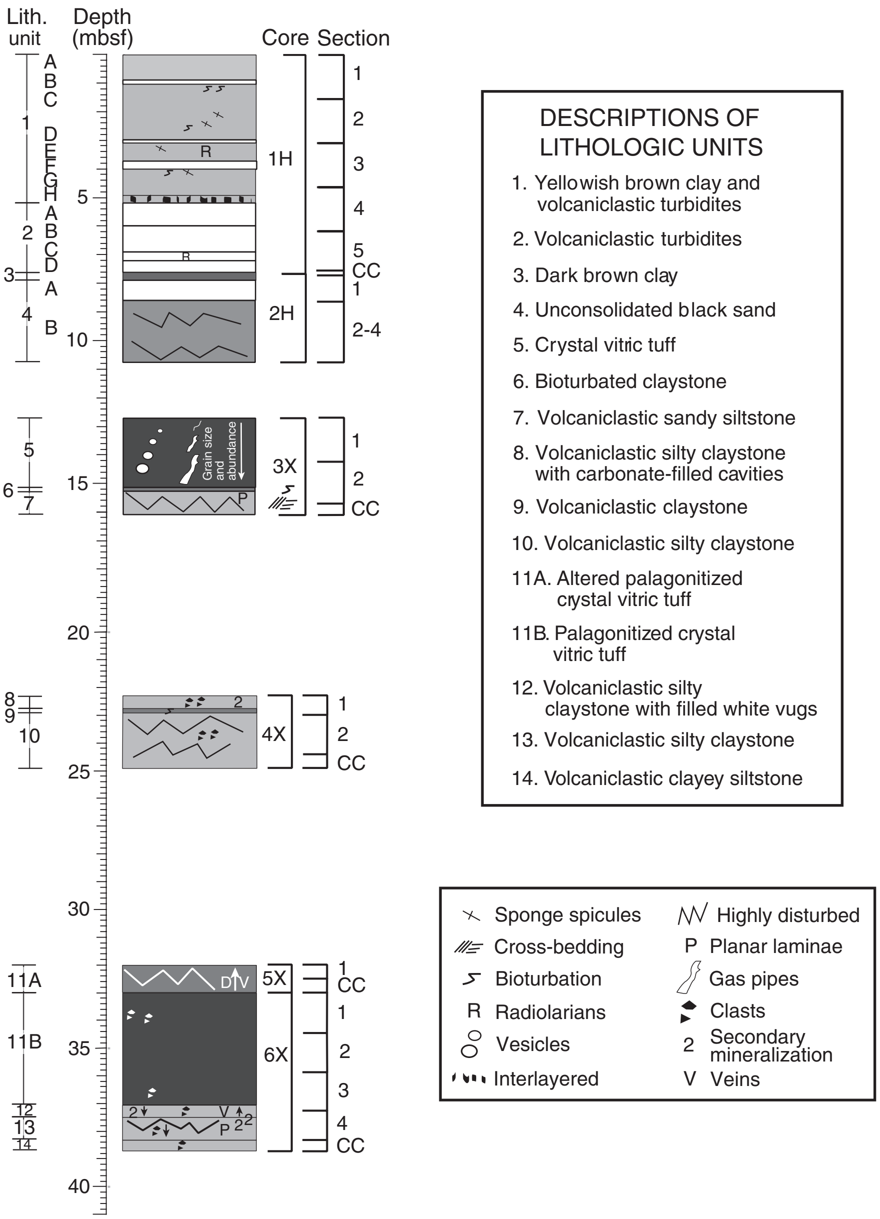

Figure 3. Lithological units of Hole 1223A. The crystal vitric tuffs (Units 5 and 11) appear to have been deposited at the seafloor at temperatures exceeding 200°C. This suggests that the Nuuanu Landslides were accompanied by pyroclastic activity similar to the Mount St. Helens eruption in 1990 but an order of magnitude larger.

Another important result is the identification of wairakite in the vitric tuff. Wairakite is stable at a temperature range from 200° to 300°C. Its presence suggests that the crystal vitric tuff was deposited under high temperatures.

Preliminary geochemical analyses indicate these tuffs are MgO-rich tholeiitic basalts, and have geochemical similarities to Hawaiian tholeiites. However, alternate sources of the crystal vitric tuffs may be the Hawaiian Arch or a nearby seamount. The genesis of crystal vitric tuffs can be complicated. For example, we do not understand why they are indurated so close to the seafloor, why they are so glassy, why they are so rich in fresh olivine, why they include kink banding and fibrous structures in the olivine crystals and why they were warm or even hot when emplaced.

Two pyroclastic events, similar to the 1980 Mt. St. Helen's eruption but an order of magnitude larger, appear to have occurred on Koolau about 2 Ma. These events may correlate with the collapse of the flank of the volcano and the formation of the Nuuanu debris field. The turbidites and pyroclastic material are of similar age to the Nuuanu Landslide (1.8 to 2.4 Ma) and are more than 38 m thick at Site 1223, located at more than 300 km from Oahu. We did not core to the bottom of the Nuuanu-related sequence. The landslide deposits may be thicker and additional landslide events may have occurred.

LEG 200 SCIENTIFIC PARTY

Ralph A. Stephen, Co-Chief Scientist; Junzo Kasahara, Co-Chief Scientist; Gary D. Acton, Staff Scientist; R. Scott Calhoun, Satoru Haraguchi, Hartley Hoskins, Michele Lustrino, Werner Manz, James H. Natland, Mikako Nakamura, Ingun Nielsen, Heather Paul, Gabriela Schumann-Kindel, Sarah Sherman, Yue-Feng Sun, and John Wilson.

REFERENCES

Atwater, T., 1989. Plate tectonic history of the northeast Pacific and western North America. *In* Winterer, E.L, Hussong, D.M., and Decker, R.W., Eds., *The Eastern Pacific Ocean and Hawaii*: Boulder, CO (Geological Society of America), 21-72.

Butler, R., 1995. Proposed station locations and rationale for the OSN component of GSN. *In* Purdy, G.M. and Orcutt, J.A., Broadband Seismology in the Oceans - Towards a Five-Year Plan: Washington, D.C. (Ocean Seismic Network, Joint Oceanographic Institutions), 20-25.

Collins, J.A., Vernon, F.L., Orcutt, J.A., Stephen, R.A., Peal, K.R., Wooding, F.B., Spiess, F.N., and Hildebrand, J.A., 2001. Broadband seismology in the oceans: Lessons from the Ocean Seismic Network Pilot Experiment. *Geophys. Res. Lett.*, 28:49-52.

Duennebier, F.K., Harris, D.W., Jolly, J., Babinec, J., Copson, D., and Stiffel, K., 2002. The Hawaii-2 observatory seismic system. *IEEE J. Oceanic Engineering*, 27:212-217.

Herrero-Bervera, E., Canon-Tapia, E., Walker, G.P.L., and Guerrero-Garcia, J.C., 2002. The Nuuanu and Wailau giant landslides: Insights from paleomagnetic and anisotropy of magnetic susceptibility (AMS) studies. *Phys. Earth Planet. Interiors*, 129:83-98.

Kasahara, J., Utada, H., Sato, T., and Kinoshita, H., 1998. Submarine cable OBS using a retired submarine telecommunication cable: GeO-TOC Program. *Phys. Earth Planet. Interiors*, 108: 113-128.

Nagumo, S., and Walker, D.A., 1989. Ocean bottom geoscience observatories: Reuse of transoceanic telecommunications cables. *EOS Trans. Amer. Geophys. Union*, 70:673-677.

Normark, W.R., Moore, J.G., and Torresan, H.-W., 1983. Giant volcano-related landslides and the development of the Hawaiian Islands. *In* Schwab, W.C., Lee, H.J., and Twichell, D.C., Eds., *Submarine Landslides: Selected studies in the U.S. Exclusive Economic Zone*. U.S. Geol. Survey Bull.: 184-196.

Purdy, G.M., 1995. A five-year plan. *In* Purdy, G.M. and Orcutt, J.A., *Broadband Seismology in the Oceans – Towards a Five-Year Plan*: Washington, D.C. (Ocean Seismic Network, Joint Oceanographic Institutions), 68-75.

Sutton, G.H., McDonald, W.G., Prentiss, D.D., and Thomson, S.N., 1965. Ocean-bottom seismic observatories. *Proc. IEEE.*, 53:1909-1921.

PLANNING
Panel Reports

ODP IODP

Hydrogeology Program Planning Group Final Report

Shemin Ge (Chair) [1], Barbara Bekins [2], John Bredehoeft [3], Kevin Brown [4], Earl E. Davis [5], Steven M. Gorelick [6], Pierre Henry [7], Henk Kooi [8], Allen F. Moench [2], Carolyn Ruppel [9], Martin Sauter [10], Elizabeth Screaton [11], Peter K. Swart [12], Tomochika Tokunaga [13], Clifford I. Voss [14], and Fiona Whitaker [15]

EXECUTIVE SUMMARY

The hydrosphere, along with the atmosphere, lithosphere, and biosphere, is an integral part of the complex Earth system. Fluids play a vital role in linking various physical and chemical processes by transporting energy and solutes in the earth at a wide range of spatial and temporal scales. Over the last decade, the Ocean Drilling Program (ODP) has made significant technological advances in measuring and monitoring hydrological parameters. However, many important questions remain on the role of fluids and associated hydrogeologic processes in subseafloor environments. Fluid flow is a critically important factor in seismogenic zone dynamics, global chemical cycles, gas hydrate formation, mid-oceanic hydrothermal systems, subseafloor biological community development, and diagenetic processes in carbonate platforms (Fig. 1).

The need for long-term monitoring of *in situ* pore pressure and fluid flow is well articulated in the Integrated Ocean Drilling Program's (IODP) Initial Science Plan, ODP's Long-Range Plan and the COMPLEX Report. The transition from ODP to IODP presents our scientific community with an unprecedented opportunity to develop new tools and to integrate hydrologic studies into future scientific ocean drilling endeavors. These studies will provide important new insights into the poorly understood realm of subseafloor hydrogeology, and deepen our knowledge of

[1] University of Colorado-Boulder, USA
[2] U.S. Geological Survey-Menlo Park, CA USA
[3] The Hydrodynamics Corp., USA
[4] University of California-San Diego, USA
[5] Pacific Geoscience Centre, Canada
[6] Stanford University, CA USA
[7] Ecole Normale Superieur-Paris, France
[8] Vrije Universiteit, The Netherlands
[9] Georgia Tech, USA
[10] Friedrich-Schiller-Universitaet, Germany
[11] University of Florida, USA
[12] University of Miami, FL USA
[13] University of Tokyo, Japan
[14] U.S. Geological Survey-Reston, VA USA
[15] University of Bristol, UK

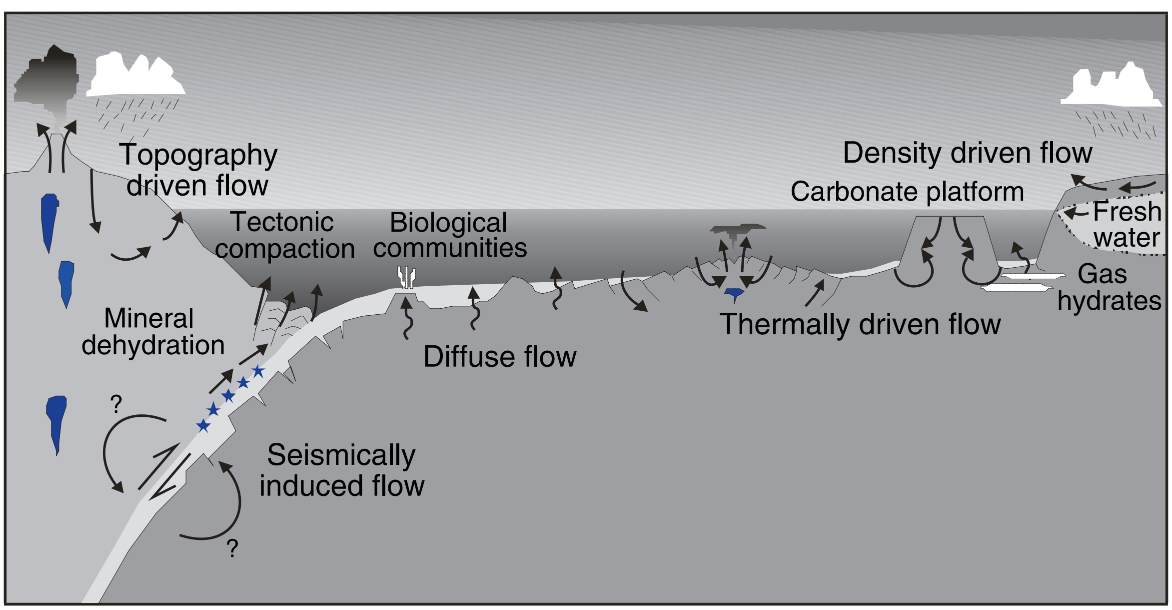

Figure 1. Schematic diagram showing the involvement of subseafloor fluid flow systems in a variety of geologic processes (modified from a figure courtesy of Earl Davis).

numerous scientific issues that have long been central to ocean drilling research.

JOIDES established the Hydrogeology Program Planning Group (PPG) at the end of 1999. The overall goal of this PPG was to define and prioritize the main problems in submarine hydrogeology. The group met three times during 2000 and 2001, and submitted a summary report to Gilbert Camoin and Tim Byrne, of the Science Steering and Evaluation Panel, in May 2002.

In this abridged version of the report, we first present important hydrogeologic questions, and then provide an overview of the fundamental principles of fluid flow in coupled geologic processes. Next we review methodologies focusing on hydrogeologic modeling and testing. Finally, we make six recommendations for addressing the scientific issues, and suggest strategies for implementation of the recommendations.

KEY SCIENTIFIC QUESTIONS

Our strong consensus is that the dynamics of geologic processes within the earth can be comprehended only if fluid movement, and how fluids transport mass and energy, are understood. Once rocks are formed in the earth's crust, moving fluids become the principal transport mechanism by which mass and energy are redistributed. It is, therefore, vital for geoscience researchers to understand the following fluid-related questions:

- What is the current state of the fluids in terms of pressure, temperature, and composition?
- What are the sources of fluid and the driving forces for fluid flow?
- What is the direction and rate of flow?
- How do the moving fluids transporting mass and heat?
- What was the past state of fluid systems (paleohydrogeology)?
- How did the paleohydrogeologic system transport mass and heat?
- What are the magnitude and distribution of porosity and permeability?

RESEARCH METHODOLOGIES IN HYDROGEOLOGIC STUDIES

The study of hydrogeologic systems begins with establishing conceptual models. A conceptual model is a description of the postulated flow system and includes the expected direction and rate of flow, the driving forces and boundary conditions, whether flow is steady or transient, the postulated sources and sinks of fluid and solutes, and the spatial variation in flow due to varying permeabilities or changes in driving forces. An important part of a conceptual model is the development of a water budget. This requires specification of water sinks, sources, and flow directions. Water inputs may involve thermally driven seawater, topographically induced flow of meteoric water, and compaction and diagenetic source of pore waters. Some fluid outputs may be readily identified based on direct observation of seafloor vents. Compared to focused flow, manifestations of diffuse flow in processes such as gas hydrate accumulations, perturbations to geothermal or geochemical profiles, seafloor mineralization, and seafloor biological communities are more subtle. By implementing the important features of the conceptual model in computer simulations, the scientific hypotheses related to fluid flow can be tested. Feasibility can be explored, which is an essential step in formulating a sample plan.

Hydrogeologic mathematical models, derived from the governing principles of hydrogeology, quantify conceptual models of subseafloor hydrogeologic flow systems. The mathematical models frequently turn into numerical or computer models in practice. Computer models of flow systems are developed from formation geometry, boundary and initial conditions, and formation properties. Such models are useful and cost effective tools for testing hypotheses and assessing conceptual model feasibilities. The complexity of hydrogeologic modeling varies. When limited data are available, it is often best to start with one- or two-dimensional analytical solutions derived from well-defined boundary value problems. In subseafloor settings, numerical models are often necessary in order to account for complex formation geometry, rock property heterogeneity, variable density fluids, simultaneous heat and solute transport, chemical reactions, and rock deformation. To incorporate as many relevant geologic features as possible, new computer models may need to be developed and tested. The broader the capability of the computer model, the greater is the range of conceptual models that can be quantified.

Hydrogeologic tests in subseafloor environments are carried out to estimate the hydraulic parameters that control the transmissive and fluid storage capacity of a formation, e.g., geometry, permeability, porosity, and compressibility. Knowledge of these characteristics is essential for successful modeling of hydrogeologic flow systems. In the past three or four decades, there have been many attempts to constrain hydrogeologic parameters through indirect means, e.g., the analysis of borehole temperature logs, seismic profiles, and fluid chemistry. Efforts to determine hydraulic parameters through direct methods by borehole hydraulic tests and naturally occurring seafloor loading processes have been quite limited. Existing methods include shipboard experiments using drill-string packers for pressurized slug and constant-rate injection or withdrawal tests, experiments using submersibles to conduct constant-drawdown and constant-discharge tests at CORKed boreholes, and interpretation of pressure fluctuations in multiple sealed boreholes due to natural variations in seafloor loading. Slug or drill-stem tests are convenient to run because they are short-lived, but yield only the permeability of material immediately adjacent to the borehole. If aquifer parameters are to be obtained with reliable accuracy multi-well hydrologic tests must be run. Long-term constant discharge or constant pressure tests should be run in sealed wells with observations made in nearby sealed boreholes.

RECOMMENDATIONS

To understand the vital role fluids play in many subseafloor processes, sufficient hydrogeologic data and modeling of complex hydrogeologic systems are key. We recommend establishment of a global suite of ocean hydrogeologic observatories for systematic long-term measurement of the nature and extent of regional groundwater circulation beneath the ocean. This should include a number of instrumented study sites in locations representative of a range of geologic settings, seven of which we explore in more detail in this report. In addition to dedicated hydrogeology legs to study these settings, a basic suite of hydrological measurements should be made on all research legs, irrespective of primary leg objectives. Six specific recommendations are described below.

1. Establishing Global Ocean Hydrogeologic Observation Stations

We recommend the establishment of a suite of ocean hydrogeologic observation stations as a long-term goal of IODP. Cost-effective strategies can be utilized to implement this task. Currently, little is known from the limited existing observations about the nature and extent of regional fluid circulation beneath the ocean, largely because limited basic hydrogeologic data exists. Shallow-depth observations of the physical and chemical state of fluid can provide insight into deep geologic anomalies, global advective heat flux, evolution of ocean chemistry, areas of potential magmatism, zones of intense deep fracturing, regions of potential petroleum accumulation, and unknown areas of enhanced subseafloor biotic activity. Collection of basic physical and chemical measurements will enable fundamental issues to be addressed, such as discovery of large-scale subseafloor fluid flow systems, detection of regional thermal and chemical convection systems, establishing a baseline of chemical and thermal signatures of fluid through the subseafloor systems, locating regions of anomalous fluid pressures in the oceanic crust, and deducing the three-dimensional hydrogeologic architecture and the global pattern of vertical flow through the ocean floor.

2. Dedicated Hydrogeology Legs in Selected Settings

We recommend IODP dedicate hydrogeology legs in seven type settings where fluid flow clearly plays an important role in subseafloor processes: 1) mid-ocean ridges and flanks, 2) subduction zones, 3) seismogenic zones,

4) coastal zones, 5) carbonate platforms and passive margins, 6) the deep biosphere, and 7) gas hydrates. Locations chosen for investigating these settings should have a limited set of identifiable driving forces that control fluid flow and transport dynamics. Previous deep-sea drilling and existing site survey data at these sites would be advantageous.

Mid-Ocean Ridges and Flanks

Subocean hydrology at mid-oceanic ridges is characterized by buoyancy-dominated flow. Water is driven through and reacts with highly permeable rocks at temperatures of 300°C to 400°C and higher. A better understanding of the fluid flow systems can shed light on a variety of processes occurring in this setting, such as cooling of lithosphere, deposition of large mineral deposits at the seafloor, and nourishment of unique vent communities and subseafloor microbial populations. All these processes are possibly a consequence of rapid exchange of water, heat, and elements between the crust and oceans.

Subduction Zones

The fate of sediments, crust, and mantle entering a subduction zone and the impact of their transformation in the subduction process are of great interest to the broad geoscience community. Water enters the system not only as interstitial fluid but also as constitutive water bound in minerals. Water is released at different stages with increasing temperature and pressure, which plays a major role in décollement formation, sediment accretion, faulting, mineral transformation, mantle alteration, intra-slab seismic rupture, and magmatism. Driving forces for fluid flow in subduction zones are complex. Compaction near the trench, mineral dehydration, diagenetic reactions, and metamorphic transformation at high temperature locations can all contribute to fluid flow by generating fluid sources or changing permeability. Furthermore, these processes often operate in concert, and are linked by upward fluid flow along the plane. The permeability along fault zones and the décollement between the subducting and overriding plates also must be known. Multi-well tests using CORKs need to be conducted to obtain permeabilities at formation scales.

Seismogenic Zones

One of the main goals for studying seismogenic zone processes is to understand the temporal relationships among stress, strain, pore pressure, and water chemistry throughout the earthquake cycle. Fully coupled models of mechanics, fluid flow, heat transfer, and chemical transport are essential to achieve this goal. The enhanced capability of the new riser ship will provide opportunities to drill deeper into the seismogenic zone. Sampling water chemistry and long-term monitoring of pore pressure or fluid flux in décollement or faults will provide valuable information for quantifying fluid migration in seismogenic zones. A dedicated hydrogeology leg could utilize one of the two sites selected for seismogenic zone experiments in Japan and Central America.

Coastal Zones

Building a comprehensive understanding of the origin and dynamics of submarine pore water requires a detailed examination of the processes that operate at ocean/continent boundaries. Unsolved scientific questions include how far offshore do continental flow systems extend, and how do such systems influence water chemistry in marine sediments? How does the distribution of fresh and brackish water offshore relate to past sea level changes? What is the relative importance of compaction driven flow? To answer these questions, a major effort must be made to obtain data from coast to shelf at depths <1 km. This effort will require shallow water drilling capabilities. The types of data needed for integrated process modeling are pore pressures, fluid density profiles, fluxes at the seafloor, temperature profiles, permeability measurements from core to formation scales, and geomorphology and biota distributions.

Carbonate Platforms

The relatively large volumes of fluids known to circulate through many carbonate platforms drive significant water-rock interaction due to the permeable and reactive nature of carbonate sediments. These processes also have an important influence on the chemistry of the atmosphere and the oceans, regulating climate, and controlling the fate of atmospheric carbon dioxide. Previous ODP investigations have provided useful sedimentological and paleoenvironmental results, and offered insights into processes controlling fluid flow, which include density contrasts due to temperature and salinity. However, a comprehensive understanding of the nature, rates, and controls on fluid flow remains elusive. Feedback between large-scale fluid flow, porosity/permeability, and diagenesis is still poorly understood, as is the effect of changing climate and sea level on fluid flow in carbonate platforms. A dedicated leg can focus on a carbonate platform where previous drilling or other studies have indicated the presence of significant fluid flow.

Flow Systems Supporting the Deep Biosphere

Studies over the last fifteen years have definitively established that large and diverse microbial populations are active below the seafloor. Although fundamental questions such as the maximum depth and temperature for habitats remain unanswered, the most compelling question for hydrogeologists is the mechanism of supplying nutrients to the subsurface population. Any drilling plan, designed to investigate nutrient supply for subseafloor microbial communities, must include a conceptual model of the flow system and describe the necessary measurements to test it. A minimum plan would include pore pressure measurements sufficient to establish the regional pore pressure gradient and superimposed local variations. Long-term monitoring may be required to determine the temporal variability in pressure, temperature, or chemistry. Characterization of relative permeabilities, ratber than absolute values, is more important in identifying zones of active flow with microbial activity. This initially may be accomplished through physical properties measurements and logging observations.

Gas Hydrates

Gas hydrates are an ice-like form of water and low-molecular weight gas (e.g., methane) stable at the pressure-temperature conditions common in continental margin marine sediments and permafrost regions. One of the fundamental objectives of gas hydrate research is to delineate the dynamics of gas hydrate deposits. Field observations, laboratory and seafloor experiments, and modeling studies have underscored the fundamental link between rapid fluid advection and the formation and concentration of gas hydrate. Taken together, these studies imply that an understanding of the hydrologic processes responsible for supplying and concentrating gas will be required to unravel hydrate system dynamics. Analysis of gas hydrate provinces as hydrologic systems also requires constraints on the driving forces for flow, pore pressure gradients, and hydraulic parameters (e.g., permeability). There is emerging evidence that free gas as well as dissolved gas migrates through these environments, sometimes within the gas hydrate stability zone. Predicting the dynamics of free gas migration will therefore require application of the techniques developed for studying multiphase flow systems.

3. Collecting Routine Hydrogeologic Data on all Legs

In order to better understand the role of fluid in heat and mass transport processes in the subseafloor, and effectively implement the recommendation of establishing the global ocean hydrogeologic observation stations, we recommend that IODP make collecting hydrogeologic data a baseline task for future legs. This effort will allow assessment of the degree to which observation sites are representative of their type settings.

State parameters necessary for hydrogeologic studies are pore pressure, fluid temperature, fluid chemistry, and stress. Other hydrogeologic properties include permeability, storativity, thermal conductivity, and porosity. Permeabilities in different directions, and different scales are needed in order to characterize flow systems. Fluid flux can be derived from pore pressure gradient and permeability, or inferred from observations of thermal or chemical variations.

4. Developing, Improving, and Maintaining Tools

Technologies and tools are crucial components of any successful hydrogeologic study. Areas in which we strongly recommend IODP invest future efforts are as follows:

- Developing expanded packer capabilities, such as a multi-set bottom-hole-assembly packer, to allow improved estimation of natural formation pressure, permeability, and stress.

- Improving shipboard low-flow pumps and real-time downhole pressure monitoring tools to better control and monitor pressures and flow delivered to packers and to the formation.

- Improving the capability and strategy for downhole water sampling to allow fluid sampling in producing holes.

- Enhancing the ability to recover fluid samples from the pressured core sampler by using a different closure design in the manifold subassembly if a larger diameter drill pipe is adopted by IODP.

- Developing and improving temperature measurement tools to allow faster time response, greater thermal isolation from the massive part of the core cutter, geater battery lifetime, and simplified data retrieval.

- Establishing new apparatus for measuring electrical conductivity on the ship in the form of a calibrated device with digital read-out that can estimate formation diffusivity from electrical conductivity measured on working halves of sediment cores.

- Improving tool maintenance and management by establishing a program for annual calibration of temperature and pressure tools, ensuring the ship carries a full set of spares including a spare data logger, and providing written guidelines for downhole tool deployment.

5. Pre-Cruise and Post-Cruise Modeling Studies

Pre-cruise hydrogeologic modeling should be carried out since modeling can give scientists a conceptual understanding of a hydrogeologic system. This can help in formulating hypotheses and defining investigative strategies when only limited data are available. At the pre-cruise stage, most of the modeling effort will likely be in developing the conceptual model, rather than on complex numerical solutions unless complex hydrogeologic features exist. Post-cruise modeling is done to synthesize and demonstrate the state of knowledge following a drilling leg. This can be accomplished by revising a pre-cruise model or by developing a completely new model. Such modeling endeavors can become an integral part of reporting the results in the open literature, and also can be used to demonstrate where understanding of processes occurring in a given setting is lacking and to point the way for future investigations.

6. Encourage Involvement of the Larger Hydrogeological Community

We recommend holding future hydrogeology-focused workshops as a way of informing and encouraging participation of the interested hydrogeology community. We recommend staffing hydrogeologists on all relevant IODP cruises and making a good-faith effort to nurture hydrogeologists who were not previously involved in ODP/IODP experiences. In addition, we suggest fostering and scheduling more research legs devoted to fluid flow studies, and supporting one or more fluid flow analyst or modeler for each of the type settings described in this report.

We also encourage bringing scientists with hydrogeology expertise into as many scientific advisory panels and committees as appropriate. Evaluation of proposals should be conducted by a multidisciplinary panel that includes land-based hydrogeologists and marine geologists.

To implement the recommendations outlined in this report, it would be prudent to provide necessary funding for hydrogeologic studies. We recommend that IODP pay special attention to the needs of developing new tools for hydrogeologic measurements, and of pre- and post-cruise modeling studies in order to achieve specific hydrogeologic objectives.

SCIENCE/ PLANNING Meeting Reports
ODP IODP

Fourth European Ocean Drilling Program (ODP) Forum: April 10-12, 2002 in Trømso, Norway

Elspeth Urquhart and Henny Gröschel, JOIDES Office

The 4th European Ocean Drilling Program (ODP) Forum, held at the Polar Environmental Centre in Trømso, was attended by participants from twenty European countries and from Canada, Japan and the USA. The meeting was convened by Juergen Mienert, Morten Hald, Nalan Koc, and Torre Vorren, and organized by Kai-Rune Mortensen (Fig. 1). The conference was successful in its primary purpose of bringing together European scientists interested in the ODP, and provided an opportunity for scientists from regions outside Europe to exchange ideas.

Participants were welcomed by Are Carlson from the Research Council of Norway, and by Tore Vorren, Dean of the University of Trømso. Mary von Knorring (Sweden), Chair of the European Science Foundation Management Committee for the ODP (EMCO), gave a brief outline of the history of European involvement in deep ocean drilling. Jeroen Kenter (Netherlands), Chair of the European Science Foundation Science Committee for ODP (ESCO), presented a progress report on planning for future exploration with the Integrated Ocean Drilling Program (IODP). Europe is currently assessing the technical and financial requirements necessary to provide Mission Specific Platforms for IODP, and may become a third lead agency with Japan and the USA.

Henny Gröschel (*JOIDES Journal* Editor) and Elspeth Urquhart (International Liaison) represented the JOIDES Office at the forum and presented posters on the ODP legacy issue (Fig. 2), and the second volume of *ODP's Greatest Hits*. Promotional activities included distribution of CD-ROMs of the galley proofs of the "Achievements and Opportunities of Scientific Ocean Drilling". This collection of invited manuscripts was subsequently published in June 2002 as a Special Issue of the *JOIDES Journal* (Vol. 28, No. 1), and is available online at **http://www.joides.rsmas.miami.edu**. Contributions to *ODP's Greatest Hits, Volume 2*, were encouraged (Fig. 3). The volume is available online at **http://www.joiscience.org/greatesthits2JOIDES**.

The oral sessions of the conference program were divided into four categories: European

Figure 1. *Conveners of the 4th European ODP Forum, Trømso. From left to right: Morton Hald, Nalan Koc, Tore Vorren, Karin Andreassen and Juergen Mienert. Not pictured is Kai-Rune Mortensen.*

Figure 2. *Dick Kroon points to his contribution on a poster about the* JOIDES Journal *special issue titled "Achievements and Opportunities of Scientific Ocean Drilling".*

Figure 3. *JOIDES Office representatives Elspeth Urquhart (left) and Henny Gröschel (right) recruit a new author for Volume 2 of* ODP's Greatest Hits.

and International Scientific Programs; Arctic/Antarctic Research - Tectonics and Climate; Dynamics of the Earth's Interior, and Dynamics of the Earth's Exterior. We focus here on the first session of presentations on the next stages of ocean drilling.

Steve Bohlen, President of Joint Oceanographic Institutions (JOI), chaired the first session of presentations designed to inform the community of the current status of developments in planning for the IODP (Fig. 4). He cited the IODP Initial Science Plan, *Earth Oceans, and Life*, as the driving force for the new program. Copies are available from the International Working Group Support Office (IWGSO) at **http://www.iodp.org**.

Jamie Austin, of the interim Planning Committee (iPC) for the IODP, presented a summary of the IODP planning progress, described the conceptual design of the program, and then outlined the proposed science plan. The focus of this program is on processes, and its three main science themes are The Deep Biosphere and the Subseafloor "Ocean"; Environmental Change, Processes, and Effects; and Solid Earth Cycles and Geodynamics. Dr. Austin emphasized to all, and especially to the students and young researchers in the audience, that IODP is geared to the science and to the scientists of the future. Dr. Austin commented that the international ocean drilling community was gratified to see how much effort and enthusiasm was being contributed to the planning of IODP by European members (Fig. 5).

Figure 4. *Steve Bohlen, JOI President, mentioned the IODP Initial Science Plan during his talk.*

The centerpiece of the IODP presentations was the *Chikyu*, the new riser drilling vessel being constructed in Japan that will be ready for its first shakedown cruise in 2006. Yoshiro Miki, from the Japanese Marine Science and Technology Center (JAMSTEC), gave a summary of the ship's construction and showed a video of the launching ceremony that took place on January 18, 2002 (Fig. 6). Miki-san continued with an update on the construction of the new Marine Core Research center in Kochi, Shikoku, Japan. He emphasized that the new ship and the new facilities at Kochi are part of the Japanese contribution in their role as one of the lead agencies to IODP. Proposal submissions, cruise participation and scientific contributions are welcome from the entire international community. Information is available at the interim Science Advisory Structure (iSAS) website at **http://www.isas-office.jp**. Miki-san concluded his presentation by making an international call for personnel to fill positions at the Institute for Frontier Research on Earth Evolution (IFREE) at JAMSTEC (**http:**

Figure 5. *A toast to ODP from (left to right) Izumi Sakamoto (IODP, USA), Yoshiro Miki (JAMSTEC, Japan), John Ludden (ECORD/JEODI, France), Andy Kingdon (ESCOD/JEODI, UK) and Jamie Austin (IODP iPC, USA).*

Figure 6. *New IODP riser vessel* Chikyu *being maneuvered by tugs immediately after her launch in Japan on January 18, 2002. (Photo courtesy of E. Fish, IWGSO.)*

//www.jamstec.go.jp/jamstec-j/IFREE/). Andy Kingdon (UK), IODP coordinator on behalf of the European Standing Committee for Ocean Drilling (ESCOD) and the Joint European Ocean Drilling Initiative (JEODI), reported on the latest developments of the European initiative to become the third lead agency in IODP. Further information can be found at **http://www.bgs.ac.uk/odp/iodp.html**. Menchu Comas (Spain), reported on the activities of JEODI working groups. John Ludden (France), Chair of the European Consortium on Ocean Research Drilling (ECORD), also reported on JEODI activities and urged people to keep themselves informed by using the JEODI web site at **http://www.jeodi.org**. Reports from other European scientific programs were given by Ulrich Harms (Germany) on the International Continental Drilling Project (ICDP); Jörn Thiede (Germany) on the proposed new vessel *Aurora Borealis*; Michael Sarnthein (Germany) on the International Marine Global Change Study (IMAGES); Serge Berne (France) on Profiles across Mediterranean Sedimentary Systems (PROMESS); and Juergen Mienert (Norway) on the Ocean Margin Deep Water Research Cluster (OMARC).

The meeting continued with excellent oral presentations and poster displays. The scientific quality of the presentations was very high and included contributions from frontier research groups on a wide variety of topics.

Scientific business and social events during the three-day meeting were beautifully orchestrated. Highlights included an icebreaker party (Fig. 7), delicious Norwegian food at the smorgasbord-style lunches, and a conference dinner in a snowswept mountaintop restaurant on the "roof of Trømso" accessible only by cable car (Fig. 8). Participants also were able to enjoy the local sights and sounds of Trømso between sessions (Fig. 9).

Abstracts of the meeting are available and published as Norsk Geologisk Forening Abstracts and Proceedings No. 3, 2002, 4th European ODP Forum, 113 pp., and edited by Juergen Mienert and Kai-Rune Mortensen. The volume is available from the Norwegian Geological Society, c/o NGU, 7491 Trondheim, Norway, or can be requested via email at **ngf@ngu.no**, or on the Internet at **http://www.geologi.no**. The program and participant list are still available at **http://www.ibg.uit.no/geologi/konferanser/odpforum/index**.

We all extend a special "Thank You" to Kai-Rune Mortensen for his excellent logistical help. The meeting was sponsored by the European Science Foundation, The Research Council of Norway, Statoil, Norsk Hydro and the University of Trømso.

***Figure 8.** Jeroen Kenter, ESCO Chair from the Netherlands, and Judy Mackenzie (Switzerland), at the conference dinner.*

***Figure 9.** Peter Barker (left), of the British Antarctic Survey, enjoying a cold drink with Jamie Austin (center) and Jonathan Snow (far right, Germany). Beautiful Trømso harbor provides the backdrop.*

***Figure 7.** Senior ODP scientists enjoy the icebreaker. From left to right: Olav Eldholm (Norway), Dave Falvey (ODP UK), and Michael Sarnthein (Germany).*

In this issue from pages 13-17:

ODP Leg 198: New Evidence for Rapid Climate Change in the Cretaceous and Paleogene from the Shatsky Rise, Northwest Pacific Ocean

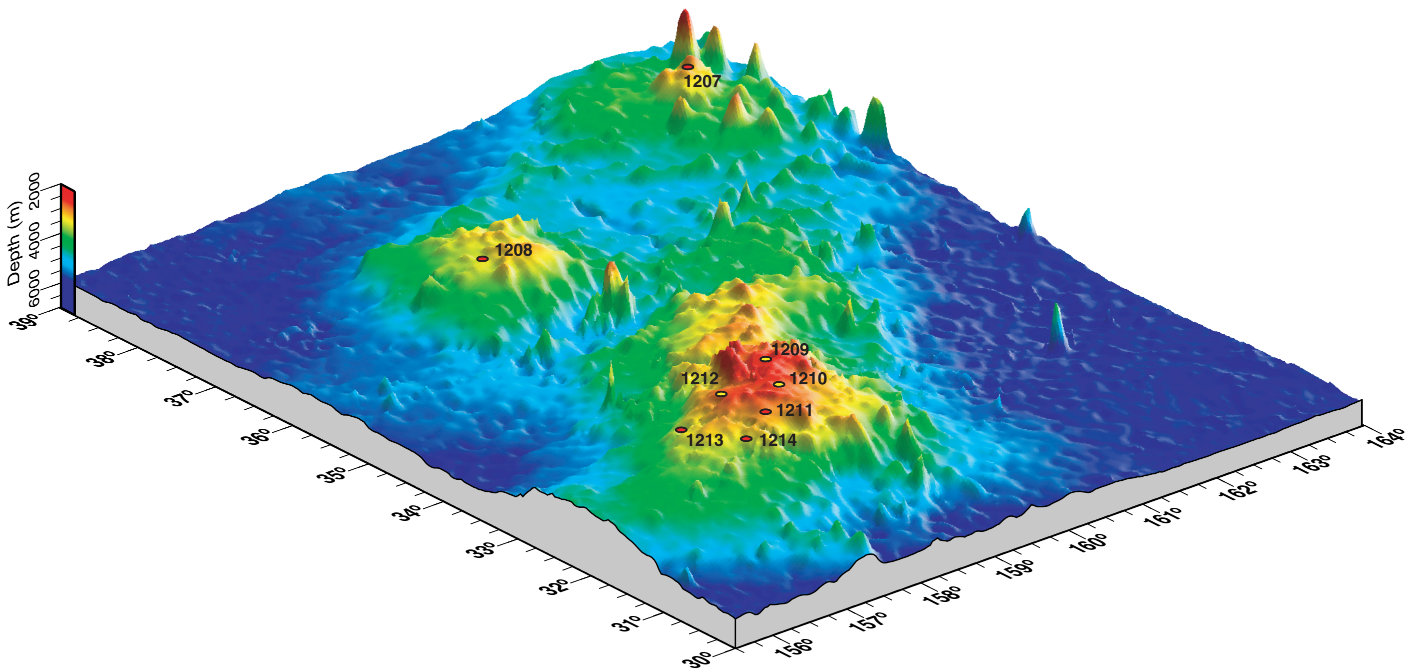

Figure 1. Bathymetric map of Shatsky Rise in the Northwest Pacific Ocean showing locations of Leg 198 drill sites. Site 1207 is located on the Northern High, Site 1208 is on the Central High, and Sites 1209 to 1214 are on the Southern High. Altimetry-derived bathymetry from Smith and Sandwell (1997).

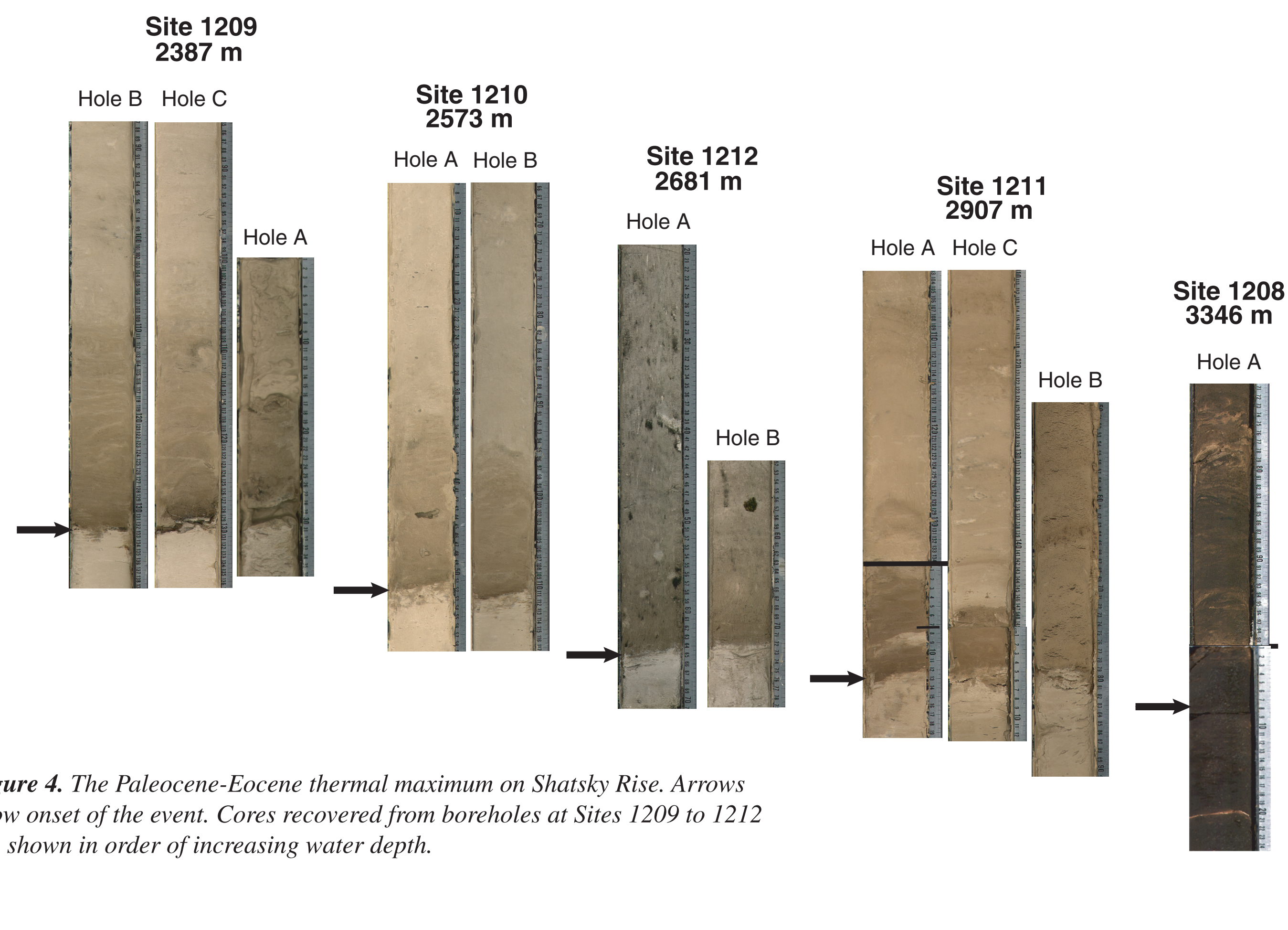

Figure 4. *The Paleocene-Eocene thermal maximum on Shatsky Rise. Arrows show onset of the event. Cores recovered from boreholes at Sites 1209 to 1212 are shown in order of increasing water depth.*

ODP CONTRACTORS

Joint Oceanographic Institutions (JOI)

Prime Contractor
Program Management
Public Affairs
***JOIDES Journal* Distribution**
1755 Massachusetts Avenue, N.W.
Suite 700
Washington, D.C. 20036-2102 USA
Tel: (202) 232-3900
Fax: (202) 462-8754
Email: info@joiscience.org
http://www.joiscience.org

JOIDES Office

Science Planning and Policy
***JOIDES Journal* Publication**
Marine Geology & Geophysics
Rosenstiel School of Marine and Atmospheric Science
University of Miami
4600 Rickenbacker Causeway
Miami, FL 33149-1031 USA
Tel: (305) 361-4668
Fax: (305) 361-4632
Email:joides@rsmas.miami.edu
http://joides.rsmas.miami.edu

Ocean Drilling Program (ODP) - TAMU

Science Operations
Leg Staffing
ODP/DSDP Sample Requests
ODP Publications
Texas A&M University
1000 Discovery Drive
College Station, TX 77845-9547 USA
Tel: (979) 845-2673
Fax: (979) 845-4857
Email: moy@odpemail.tamu.edu
http://www-odp.tamu.edu

ODP - LDEO

Wireline Logging Services
Logging Information
Logging Schools
Log Data Requests
Borehole Research Group
Lamont-Doherty Earth Observatory
P.O. Box 1000, Route 9W
Palisades, N.Y. 10964 USA
Tel: (845) 365-8672
Fax: (845) 365-3182
Email: borehole@ldeo.columbia.edu

ODP Site Survey Data Bank

Site Survey Data Submission
Site Survey Data Requests
Lamont-Doherty Earth Observatory
P.O. Box 1000, Route 9W
Palisades, N.Y. 10964 U.S.A.
Tel: (845) 365-8542
Fax: (845) 365-8159
Email: odp@ldeo.columbia.edu

ODP/IODP TRANSITION

Integrated Ocean Drilling Program (IODP)

http://www.iodp.org

Interim Science Advisory Structure (iSAS) Office

Proposal Submission
Japan Marine Science and Technology Center
2-15 Natsushima-cho,
Yokosuka-city 237-0061 JAPAN
Tel: +81-468-67-5562
Fax: +81-468-66-5351
Email: isasoffice@jamstec.go.jp
http://www.isas-office.jp

International Working Group Support Office (IWGSO)

1755 Massachusetts Avenue, N.W.
Suite 700
Washington, D.C. 20036-2102 USA
Tel: (202) 232-3900, Ext. 262
Fax: (202) 232-3426
Email: iwgso@joiscience.org

JOIDES Journal

The *JOIDES Journal* is printed and distributed twice a year by Joint Oceanographic Institutions, Inc., Washington, D.C., for the Ocean Drilling Program under the sponsorship of the National Science Foundation and participating member countries. The material is based upon research supported by the National Science Foundation under prime contract OCE-9308410.

The purpose of the *JOIDES Journal* is to serve as a means of communication among the JOIDES advisory structure, the National Science Foundation, the Ocean Drilling Program, JOI subcontractors thereunder, and interested geoscientists. Any opinions, findings, conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Editor & Designer: Henrike Gröschel

Published by the:

JOIDES Office
Division of Marine Geology & Geophysics
Rosenstiel School of Marine and Atmospheric Science
University of Miami
4600 Rickenbacker Causeway
Miami, FL 33149-1031 U.S.A.
Tel: (305) 361-4668 / Fax: (305) 361-4632
Email: joides@rsmas.miami.edu

RSMAS UNIVERSITY OF Miami
ROSENSTIEL SCHOOL OF MARINE & ATMOSPHERIC SCIENCE