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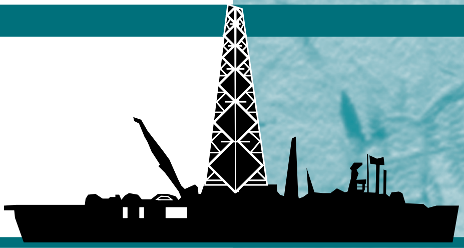

Volume 23 Number 1

Critical Boundaries in Earth's History - and the K-T Boundary

Contributed by the ODP Leg 171B Shipboard Scientific Party

Ocean Drilling Program Leg 171B was designed to recover a series of 'critical boundaries' in Earth history in which abrupt changes in climate and oceanography coincide with often drastic changes in the Earth's biota. Some of these events such as the Cretaceous-Paleogene (K-T) extinction and the late Eocene tektite layers are associated with the impacts of extraterrestrial objects, like asteroids or comets, whereas other events, including the benthic foraminifer extinction in the late Paleocene and the mid Maastrichtian extinction events, are probably related to intrinsic features of the Earth's climate system. Two of the critical boundaries, the early Eocene and the late Albian, are intervals of unusually warm climatic conditions when the Earth is thought to have experienced such extreme warmth that the episodes are sometimes described as 'super-greenhouse' periods. The major objectives of Leg 171B were to recover records of these critical boundaries at shallow burial depth where microfossil and lithological information would be well preserved, and to drill cores along a depth transect where the vertical structure of the oceans during the boundary events could be studied.

Five sites were drilled down the spine of Blake Nose, a salient on the margin of the Blake Plateau where Paleogene and Cretaceous sediments have never been deeply buried by younger deposits (Figure 1). The Blake Nose is a gentle ramp extending from about 1000 m water depth to about 2700 m depth, and is covered by a drape of Paleogene and Cretaceous strata that are largely protected from erosion by a thin veneer of manganiferous sand and nodules. A continuous, expanded, and almost complete, record of the Eocene period was recovered that shows Milankovitch-related cyclicity. In combination with the excellent magnetostratigraphic record and the presence of both calcareous and siliceous microfossils, the Milankovitch-controlled cycles will be used to recalibrate the late-middle Eocene and late Eocene timescale. Radiometric dates on ash layers, and dating by astronomical tuning, will produce an integrated timescale to recalibrate magneto- and biostratigraphy. In addition, the chemistry of the well-preserved calcareous microfossils will be used to document climate variability when the Earth's climate switched from a greenhouse to an icehouse state.

Leg 171B recovered a suite of critical events in Earth's history that includes the late Eocene radiolarian extinction, late Paleocene benthic extinction, the K-T boundary, the mid Maastrichtian event, and several episodes of organic-rich sediments in the Albian warm period. The upper Paleocene benthic foraminifer extinction occurs within an expanded interval of calcareous sediments unlike most regions of the Atlantic where calcareous fossils have been severely dissolved just above the extinction horizon.

The recovery of spectacular records of the K-T boundary attracted the attention and inagination of both the public and the international news media. The K-T boundary was recovered at three sites, each with a biostratigraphically and magnetostratigraphically complete sequence that includes the earliest part of the aftermath of the Late Cretaceous extinctions. Three copies of the boundary interval at one site were collected in a section that includes a 10-17 cm thick graded bed of green spherules capped by a fine-grained, rusty brown limonitic layer that is overlain by dark gray clay of the earliest Danian (Figure 2). This succession is interpreted as fallout from the Chicxulub impact structure on the Yucatan Peninsula and the succeeding deposition of lowermost Danian sediment following the K-T extinction event. Notably, neither of the two K-T boundary sections drilled updip from this site have well developed ejecta beds between earliest Danian and latest Maastrichtian deposits. The spherules at these sites were either slumped into deeper water

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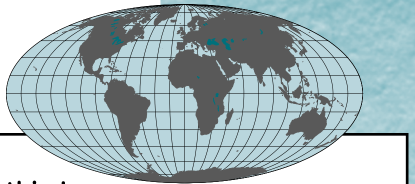

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very shortly after deposition or turbidites carrying the ejecta debris bypassed the upper slope and deposited at least part of their load near the tip of Blake Nose. The recovered sections of the K-T boundary are complete at several sites, and thus excellent for studying the response of marine biota to the extraterrestrial event. For instance, the planktonic foraminifera are extremely well preserved, and hence are ideal for stable isotope studies that hopefully will reveal the chain of climate events caused by the impact.

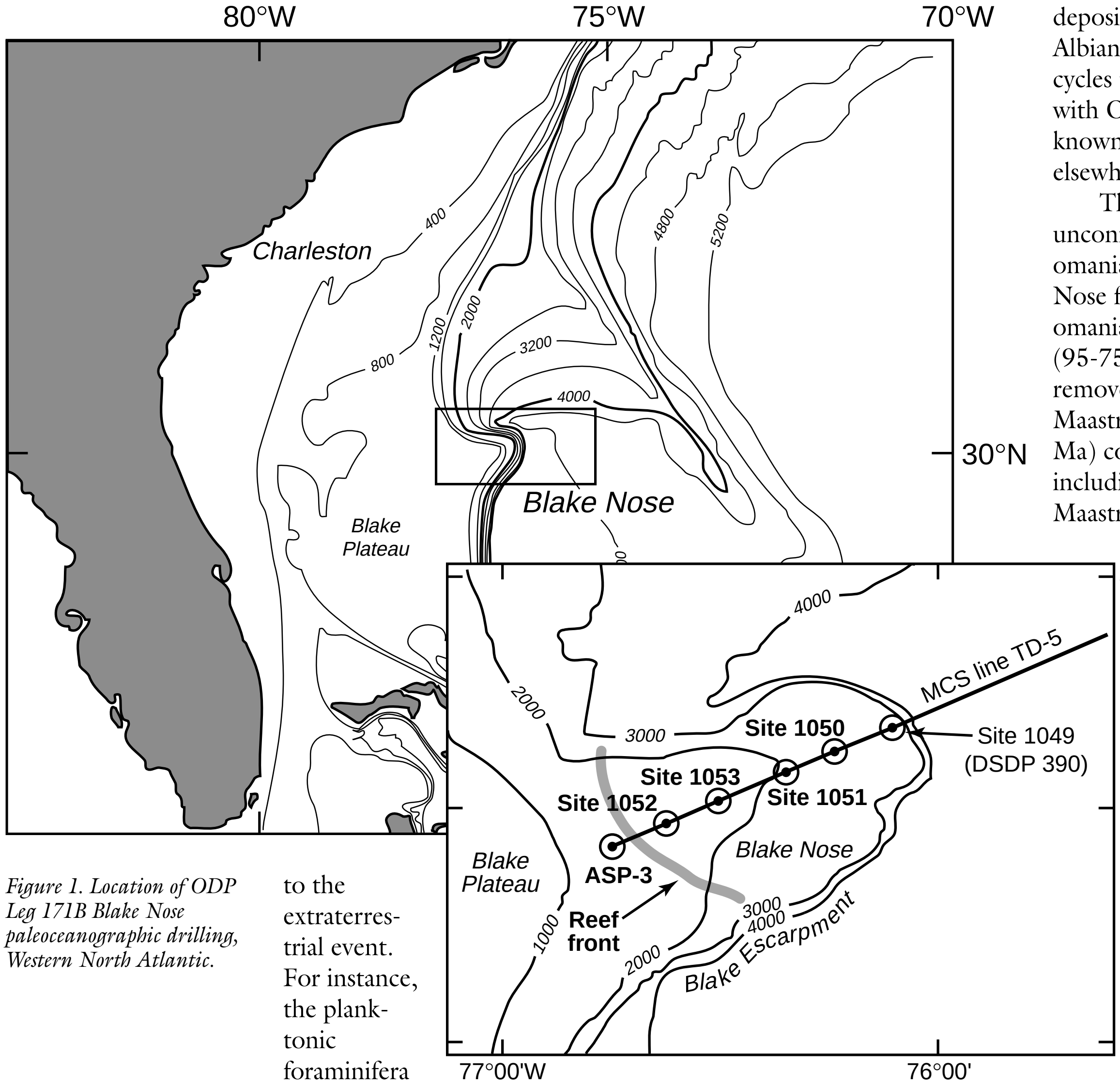

Figure 1. Location of ODP Leg 171B Blake Nose paleoceanographic drilling, Western North Atlantic.

Based on the results from drilling, the shipboard scientific party has derived a preliminary geologic history of Blake Nose. The Blake Nose is composed largely of Jurassic to mid Cretaceous carbonate platform deposits. The platform rests on basement rocks formed by intrusion and volcanism through attenuated continental crust during the rifting stage of the Atlantic. As much as 10 km of carbonates accumulated in this area. By about 110 Ma, the reef tract stepped back 40-50 km from the lower Cretaceous margin and formed a long tract of coral-rudist reefs. These reefs ceased growth a few Ma later, and the deposition of green and red variegated clays began. Black shales of latest Aptian age (about 105 Ma) found at Site 1049 suggest that the disaerobic conditions associated with the organic rich sediments extended to a water depth of at least 1500 m. Black shale deposition returned in the late Albian-Cenomanian in a series of cycles that are age-correlative with Oceanic Anoxic Event 1d known from Europe and elsewhere.

There is a widespread, major unconformity above the Cenomanian (100 Ma) on Blake Nose from which upper Cenomanian to lower Campanian (95-75 Ma) strata were largely removed. In addition, the Maastrichtian sequence (65-70 Ma) contains numerous slumps, including one at the Maastrichtian-Cenomanian contact at Site 1052, so it is possible that Campanian sediments were removed from the area of Site 1052 by down slope transport. Despite the slumping, much of the Maastrichtian appears to be present as a drape of nannofossil chalk and ooze. The preserved record has a well-developed color banding that may record orbital cycles.

The end of the Cretaceous and earliest events of the Cenozoic (K-T boundary) are well preserved on Blake Nose. Deposition of a nearly uniform drape of pelagic sediment continued into the Paleocene. Paleocene strata are the first to preserve geochemical and lithological evidence for abundant volcanic ash on Blake Nose – a trend that continued throughout the Eocene.

By the latest Paleocene, deposition was concentrated into a major clinoform stack that reached its greatest thickness near the center of the Blake Nose transect. At least two hiatuses are present in this sequence. One is within the uppermost Paleocene, and occurs close to the upper Paleocene 'Thermal Maximum' when the deep oceans appear to have abruptly warmed for a few hundred thousand years. However, the hiatus is either absent or very short near the center of the clinoform stack where the Paleocene-Eocene transition is biostratigraphically complete. A second hiatus is present near the lower-middle Eocene transition where about two million years of the Eocene are absent across the whole of Blake Nose. The locus of sedimentation apparently backstepped up the slope of Blake Nose during the middle and late Eocene. Sediments are mostly green siliceous nannofossil chalks and ooze with well-preserved calcareous and siliceous microfossils. Volcanic ash beds are common throughout the sequence and probably record major eruptions in the Lesser Antilles. The combination of good magnetostratigraphy, biostratigraphy, and color cycles should result in great improvements in the chronology for this part of the Eocene. In addition, sediments correlative with the Upper Eocene meteorite impact event in the Chesapeake Bay were recovered.

It is probably no coincidence that the youngest Eocene sediments are of latest Eocene age. The Oligocene is associated with widespread hiatuses in the North Atlantic. The Gulf Stream assumed its present course for the most part in the Oligocene and cut into the surface of the Florida Straits and the Blake Plateau. A highstand of sea level in the late Oligocene shifted sedimentation from the shelf to the coastal plain starving the outer shelf and slope landward of the Blake Escarpment. In the Blake Basin, Oligocene cooling at high latitudes intensified the southward flow of deep water along the Blake Escarpment and formed the widespread seismic reflector that represents a unconformity distributed over most of the western North Atlantic.

Shore-based research will focus on studies of the sequence of events surrounding both the K-T and Upper Eocene impact events and the paleoceanographic history of the Paleogene and Cretaceous sequences. The excellent magnetostratigraphy record from Blake Nose will be used to determine the polar-wander path of North America from the Aptian to the Eocene. Major research effort will be devoted to analysis of history of orbital forcing of both Cretaceous and Cenozoic climate and the dynamics of both the Cenomanian and lower Eocene warm periods. Finally, the depth transect of cores will be used to reconstruct the vertical structure of the oceans in the distant past when patterns of ocean circulation were much different from today.

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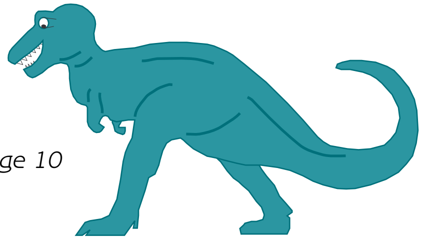

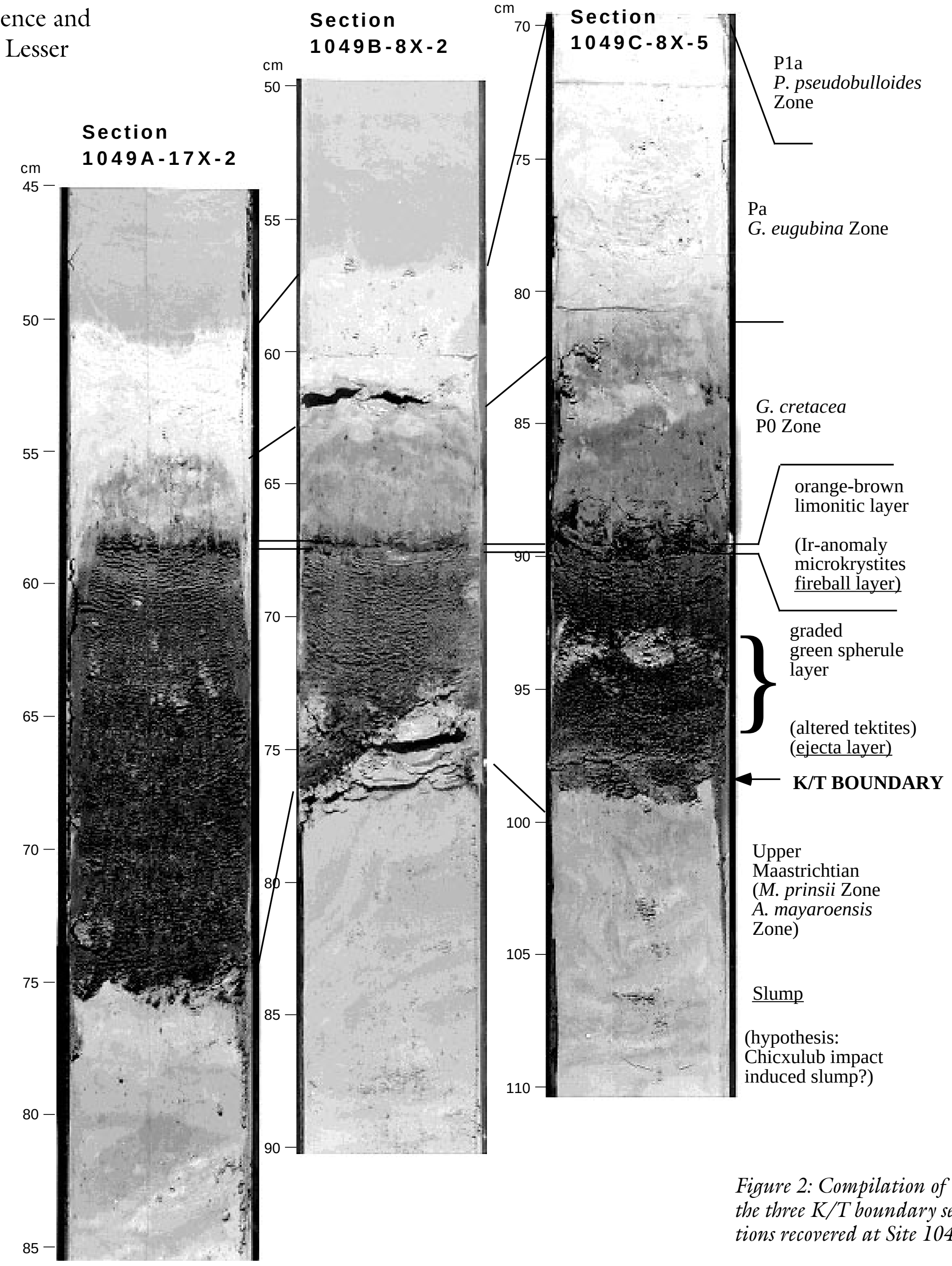

Figure 2: Compilation of the three K/T boundary sections recovered at Site 1049.

Leg 169 Drills a Major Massive Sulfide Deposit on a Sediment-Buried Spreading Center

by Yves Fouquet, Robert Zierenberg, Jay Miller and Leg 169 Scientific Party

OPD Leg169 was the second ODP leg designed to investigate the genesis and evolution of Fe-Cu-Zn deposits formed at sediment-covered spreading centers, with the ultimate goal of quantifying the transfer of mass and energy during hydrothermal circulation. This Leg built on results from drilling at Middle Valley on the Juan de Fuca Ridge during Leg 139 (Davis et al., 1992) with additional drilling in this area, and also investigated hydrothermal sites at Escanaba Trough on the Southern Escanaba Ridge (Figure 1).

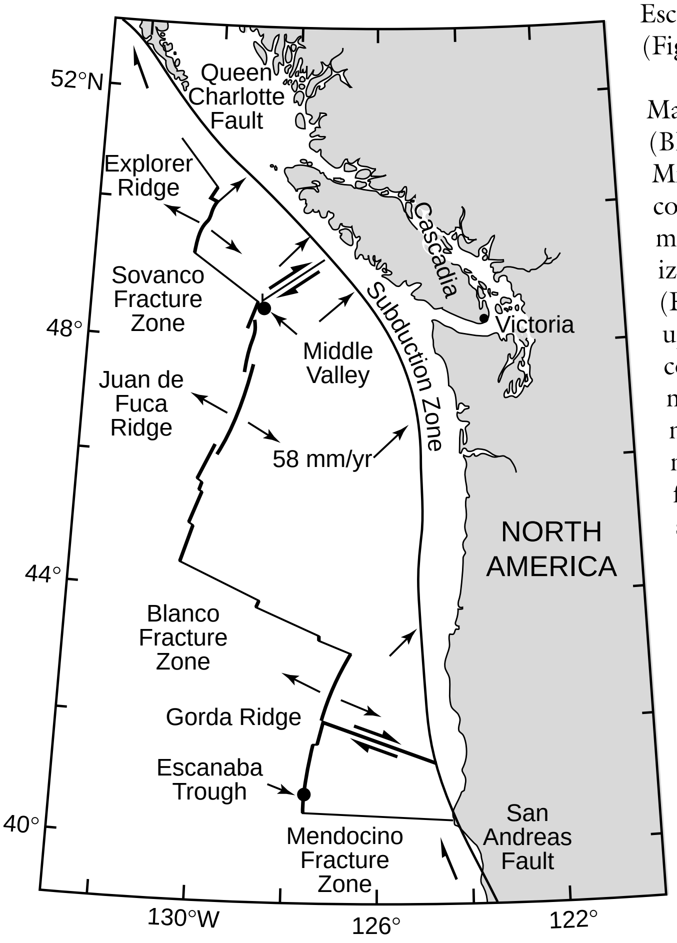

Figure 1. Location map showing tectonic setting of the sediment-covered spreading centers at Middle Valley and Escanaba Trough on the Juan de Fuca-Gorda Ridge spreading system.

The Bent Hill Massive Sulfide (BHMS) in Middle Valley comprises three major mineralized parts (Figure 2). The uppermost zone consists of a 100 m thick conical mound of massive sulfide formed at the seafloor and subsequently buried by sediment. Underlying this is a 100 m thick feeder zone consisting of subvertical crosscutting veins filled with Cu-Fe sulfide and pyrrhotite. The intensity of veining decreases with depth and the style of mineralization changes to predominantly subhorizontal impregnation and replacement of sediment. At the base of the feeder zone there is a 4 m thick strongly silicified horizon underlain by a 13 m thick zone of intense alteration and replacement of the host sandstones by Cu-Fe sulfides and chlorite (Deep Copper Zone). This zone of high grade (up to 16% Cu) stratiform copper mineralization may represent a zone where hydrothermal fluid flowed laterally into a permeable sedimentary horizon during stages of the development of the deposit when the pathways to the seafloor, represented by the feeder zone mineralization, were sealed. This zone is capped and isolated by an impermeable silicification front that may have formed in response to *in situ* cooling of the hydrothermal fluid. Pore fluid derived from below this horizon is distinct from that sampled above and has the low chlorinity signal typical of the only vent known in the area prior to Leg 169 indicating that the hydrothermal system underlying the Bent Hill area is separated from the hydrothermal system that delivers higher salinity fluids to the Dead Dog vent field, which is located 3 km to the northwest. Hole 1035F penetrated this horizon and was vigorously venting hydrothermal fluid after the drilling.

The metal zonation observed in ancient massive sulfide deposits is also present in the BHMS. Continued hydrothermal circulation through the massive sulfide after its initial deposition converted much of the primary pyrrhotite to pyrite ± magnetite. In addition, remobilized metals, such as zinc, have been reprecipitated at the top and on the sides of the mound at lower temperatures. Much of the copper transported in the hydrothermal fluid was deposited below the seafloor in the stockwork zone and in the Deep Copper Zone.

A second mound, the Ore Drilling Program (ODP) mound, occurs 350 m south of the BHMS (Figure 2). A single hole was drilled near the top of the mound, 50 meters south of the only known natural active vent. The results were spectacular! Hole 1035H penetrated three stacked zones of massive and semi-massive sulfide along with their feeder zones. Metal grades are much higher than those encountered at BHMS with some samples exceeding 40% Zn and 15% Cu. Most mining geologists will never have the experience of drilling a hole that intersects as much high grade ore as 1038H. However, the true value of this deposit is in the complex record of deposition, recrystallization, and remobilization of metal recorded through the multiple hydrothermal stages that remained focused beneath this mound throughout its history. Although the continuity of mineralization between the ODP mound and BHMS could not be tested, a zone of high-grade stratiform copper mineralization was intersected at approximately the same stratigraphic horizon as the zone under BHMS. Hole 1038H is also now the third known hydrothermal vent in the Bent Hill area. An NSF sponsored "event response" cruise using the R/V *Thompson* and the Canadian ROPOS ROV sampled 272°C hydrothermal fluids from this vent just weeks after its creation (D.S. Kelley and M.D. Lilley, personal communication).

Although creating new vents in the Bent Hill area was not a goal of this Leg, conducting active hydrological experiments in the Dead Dog vent field, which is located 4 km to the northwest, was a high priority objective. The existing CORK from Hole 858G was successfully removed and recovered the first CORK-hosted hydrothermal chimney deposits in the process, and 272°C hydrothermal fluids were sampled from the borehole. The borehole was then reinstrumented with a new temperature string and pressure transducer and a new CORK was installed. The damaged CORK in Hole 857D was recovered and replaced with an 898 m long thermistor string and a new CORK in a technologically difficult operation that was efficiently executed by the ODP engineering group and the SEDCO staff. The recovered CORK data logger contains an important record of the initial recovery of this drill hole from drilling induced disturbance (E. Davis, personal communication). Rapid downflow of cold bottom water in this hole was confirmed, and this may lead to both a pressure pulse that is potentially detectable in Hole 858G, 1.6 km to the north, and to induced seismicity, which may be detected by an array of OBSs deployed prior to drilling by Spahr Webb and colleagues at Scripps Institution of Oceanography. A transect of short holes across the Dead Dog active hydrothermal mound demonstrated that the mound is young and was formed by build-up and collapse of anhydrite chimneys, rather than by subsurface deposition and internal inflation.

A high priority scientific objective was to establish the differences between the mature hydrothermal system developed at Bent Hill in Middle Valley and the young hydrothermal system in Escanaba Trough. These systems differ in more than their state of evolution. Metals in the Middle Valley sulfide deposits seem to be dominantly derived from basaltic rocks, whereas in Escanaba Trough, the composition of the deposits shows extensive contribution of metals from the sediment. Massive sulfide recovered from the Central Hill at

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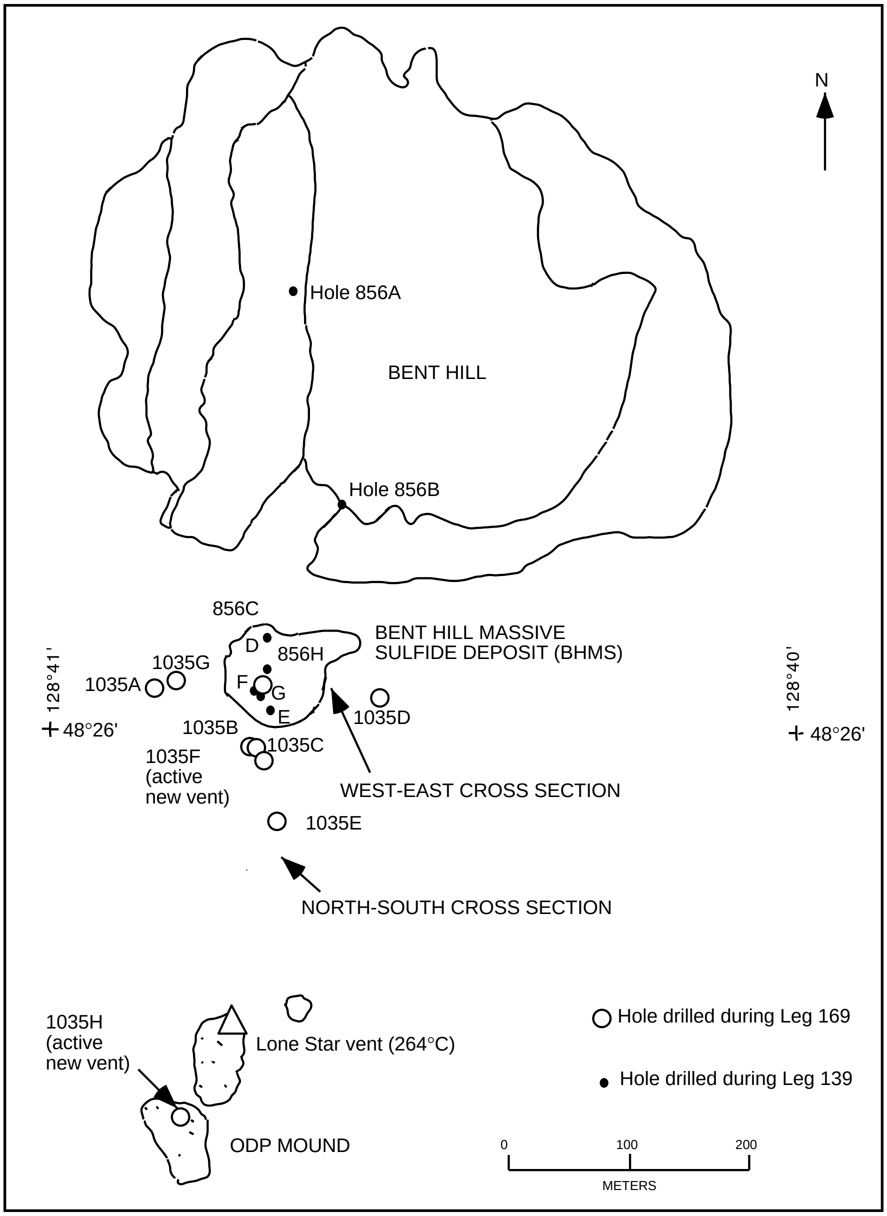

Figure 2. Map of Bent Hill (Middle Valley area) showing the location of Bent Hill and the two mounds (Bent Hill and Ore Drilling Program massive sulfide) to the south. The positions of holes drilled during Leg 139 (black circles) and Leg 169 (white circles) are shown. Modified from Goodfellow and Peter (1994).

Hydrogeology of the Upper Oceanic Crust

by Earl Davis, Andy Fisher, John Firth and the ODP Leg 168 Shipboard Scientific Party

Hydrothermal circulation through the oceanic crust is known to carry a significant portion of the heat from cooling lithospheric plates, to exert a strong influence on the chemistry of the oceans, and to modify the composition of oceanic crust before it is recycled by subduction. Among the primary objectives of Ocean Drilling Program Leg 168 were 1) to determine just how this circulation takes place, and 2) to establish how rapidly fluids move through the sediments and upper igneous crust of mid-ocean ridge flanks. This was accomplished with a transect of drill sites on the eastern flank of the northern Juan de Fuca Ridge on crust ranging in age from 0.6 to 3.6 Ma (Fig. 1).

In most oceans, burial and the resultant hydrologic isolation of the permeable upper igneous crust takes place over a time spanning tens of millions of years; on the eastern Juan de Fuca Ridge flank, burial is accelerated as a consequence of the proximity of the ridge to the abundant supply of turbidite sediments shed from the adjacent North American continental margin during the Pleistocene. Drilling sites were placed in context of distance from the position of sediment/igneous-basement onlap, and of the local hydrothermal regime that had been defined previously by seismic reflection profiles and by heat-flow and sediment pore-fluid geochemical variations (e.g., Davis et al., 1992; 1997; Wheat and Mottl, 1994).

Clues concerning Long-Distance Transport in the Upper Igneous Crust

This article focuses on those observations that document the extreme efficiency with which buoyancy-driven fluid circulation moves heat and solutes laterally in the uppermost igneous crust. Perhaps the most surprising result of Leg 168 was the distance over which the influence of locally ventilated circulation in the igneous crust appears to extend beneath the relatively continuous sediment cover on the eastern ridge flank. The three youngest Sites 1023, 1024, and 1025 were drilled to characterize the local transition from igneous crust that is exposed in outcrop on the seafloor,where generally unrestricted fluid discharge and recharge can occur, to crust buried by a continuous sediment layer that is sufficiently thick to provide a hydrologically resistive barrier to local fluid exchange across the seafloor. Previous observations along this transect had suggested that the effects of ventilated circulation were felt over a distance of about 20 km. Seafloor heat flow measurements increased systematically with distance from outcropping basement and approached that believed to be representative of the total lithospheric heat flow (Davis et al., 1992), and seismic velocities in the upper crust were found to increase from values of less than 3 to over 5 km/s over this same distance (Rohr, 1994). Major changes in the hydrothermal regime over this 20 km scale were confirmed by drilling at these three sites, but they were seen as only part of a much larger scale regional pattern.

This large-scale pattern is illustrated in Figure 1, where upper basement temperatures and pore-fluid compositions are plotted against distance from the ridge crest, or more importantly from a hydrologic perspective, against the distance from the last point of basement outcrop and potential seawater recharge. Upper basement temperature variations (Fig. 1B) are the result of several factors. The general increase in the thickness of the insulating sediment cover with crustal age tends to increase the basement temperature, although this effect is partly offset by the decrease with age of the background heat flow from the cooling lithosphere. The magnitude of these effects has been estimated, and it leads to the conclusion that basement temperatures are anomalously low along the entire transect, but most noticeably so at the western end. Advective heat loss to lateral hydrothermal flow in the upper basement is the most plausible mechanism for removal of heat, resulting in the anomalously low basement temperatures.

Variations in magnesium concentration are controlled by temperature-sensitive rock-water reactions, and are much less influenced by recharge. The correlation between Mg concentration and temperature along the transect (compare Fig. 1B and 1C) provides an excellent “calibration” for the temperature dependence of Mg concentration that can be applied to any ocean basin setting where the thermal regime is known but fluid sampling is not possible. At Site 1030/31, the Mg concentration is anomalously low relative to the simple Mg-temperature relationship defined by other sites. This, together with the anomalous high chlorinity at these sites (Fig. 1D) suggest an influence of deeper, higher temperature water-rock interactions.

The chlorinity of basement water (Fig. 1D), determined from pore waters squeezed from basal sediment, shows clear signs of “contamination” by fresh post-glacial seawater recharge and lateral fluid flow. The variation in cholrinity along the transect suggests flow rates on the order of meters per year.

The systematic variation in basement-water sulfate (Fig. 1E) tells a similar story; values decrease systematically with distance from the most likely source of sulfate (i.e., recharging seawater in the region of basement outcrop). This source, perhaps together with the dissolution of relic anhydrite precipitated by high-temperature hydrothermal circulation at the time of crustal formation, is required to balance the strong sink for sulfate present in the sediments that bury the crust.

What Drives the Regional Fluid Flow?

There are two possible mechanisms for the transport of heat and solutes that may cause the regional variations in composition and temperatures observed along the Leg 168 drilling transect. Recharge of cool, dense water in sediment-free areas close to the ridge crest could result in persistent lateral fluid flow to the east in the uppermost crust. The head of cool water in the region of recharge would force distributed seepage upwards through the sediment section on the ridge flank. A second method of producing net transport of heat and solutes may be efficient mixing by local but vigorous hydrothermal convection. We anticipate that long-term observations of basement fluid temperature and pressure, to be provided by borehole observatory instruments at Sites 1024 and 1025, will provide critical information about the relative importance of these two modes of transport.

The Nature of Local Convection

Drilling at the oldest two Sites 1026 and 1027 targeted a buried basement ridge-trough pair, an environment where buoyancy-driven fluid circulation in the uppermost crust is modified and enhanced by basement relief (e.g., Fisher and Becker, 1995; Davis et al., 1997; Wang et al., 1997). The sites were drilled to investigate quantitatively the

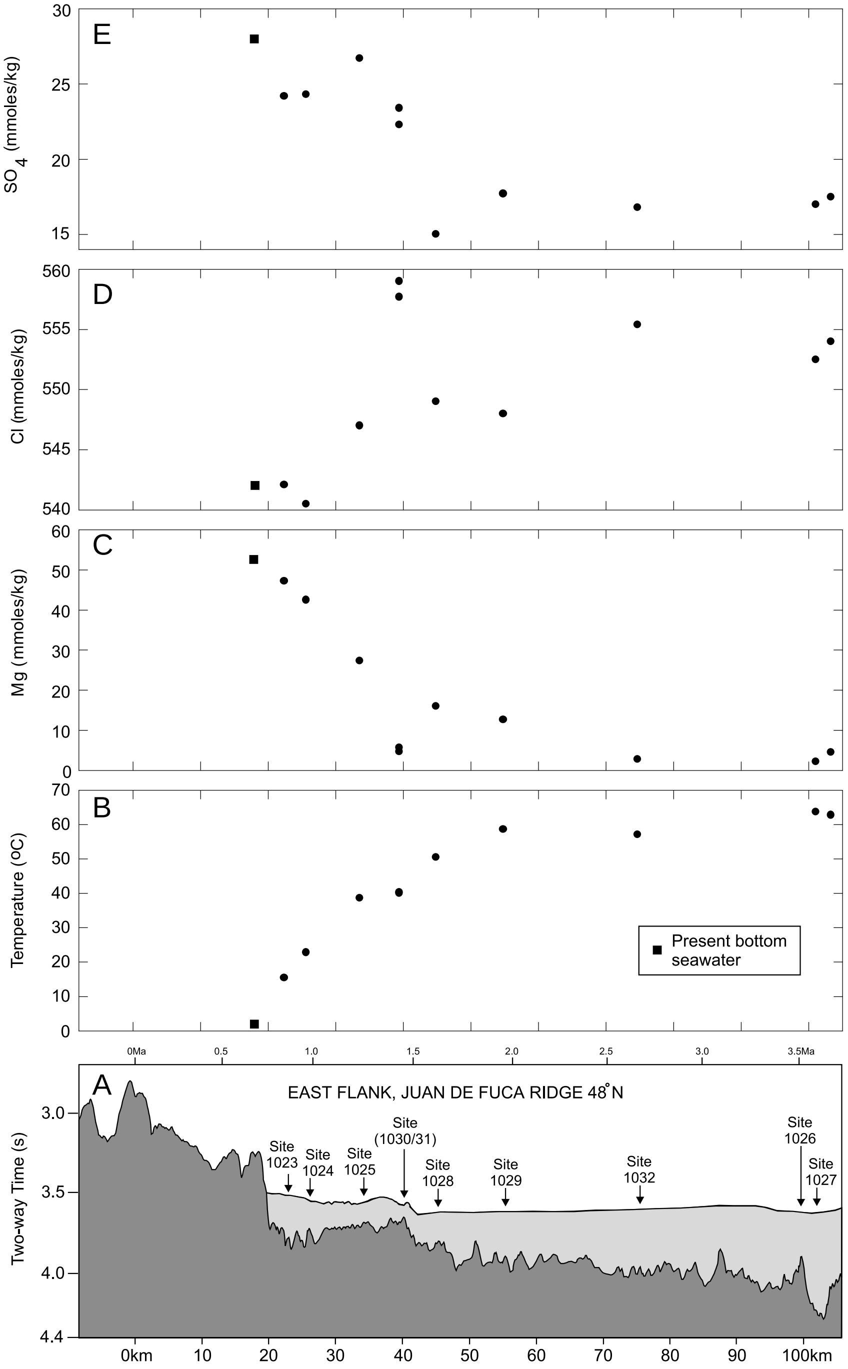

Figure 1. Section through ODP Leg 168 drilling sites showing seafloor and basement topography and crustal age. The profile, derived from seismic reflection data, crosses the ridge at 48°N and is oriented at N 107°E, perpendicular to the strike of the ridgecrest (A). Systematic variations of temperature (B), magnesium concentration (C), chlorinity (D), and sulfate concentration (E) in upper basement pore waters along the drilling transect are shown above the section.

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Neogene Evolution of the California Current System: Preliminary Results from ODP Leg 167

by the ODP Leg 167 Shipboard Scientific Party

Understanding the sedimentary record of paleoceanographic change within the California Current system is important for understanding how the North Pacific Ocean affects climate change. On a more regional scale, variations in currents along the climatically-sensitive California margin may affect precipitation in the western United States and primary productivity off the coast of California. Climate model simulations indicate that the NE Pacific surface ocean and land surface should respond strongly to Northern Hemisphere glaciation. Previous drilling at one site in the Santa Barbara Basin (Site 893) had demonstrated decadal-to-millenial-scale variations in intermediate and surface water properties linked to changes in North Atlantic climate during the last 150 ka.

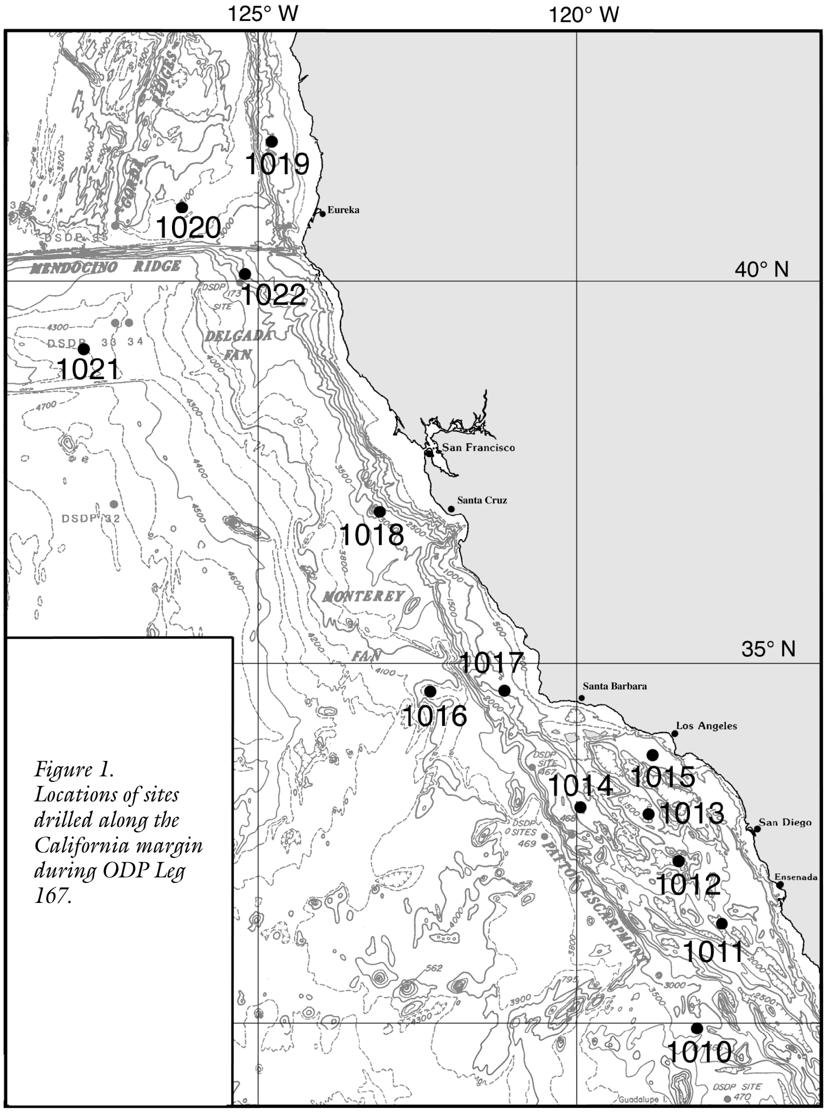

Figure 1. Locations of sites drilled along the California margin during ODP Leg 167.

ODP Leg 167 drilled thirteen sites along the California margin in a series of depth and latitudinal transects (Figure 1) to reconstruct the Neogene history of deep, intermediate, and surface ocean circulation, and to understand the paleoclimatic and geochemical history of this region. Previous piston coring and drilling along the California margin had recovered continuous records only as far as isotope stage 6 or about 150 ka. The goals of Leg 167 were to collect sedimentary records sufficiently long to study the response of the California Current system to orbital forcing, as well as to recover high resolution, continuous records from the late Pliocene to Holocene in areas with high sedimentation rates that would permit studies at submillenial time scales.

High Resolution Studies for the Period 3-0 Ma

All of the Leg 167 sites (except Site 1015 in the Santa Monica Basin) were triple-cored to ensure collection of a long, continuous sediment sequence. The shipboard measurements and analytical program, and the wireline logging program were designed to measure a variety of physical properties at high resolution both to demonstrate the continuity of the record, and to permit reconstruction of high resolution paleoceanographic records for historical and process studies. 7.5 km of core were recovered, and several properties (e.g., magnetic susceptibility, wet bulk density and natural gamma activity) were measured at intervals of <5 cm. Collection of both color digital imagery of all of the cords, as well as ultraviolet to near infrared color spectra on much of the core, helped minimize ambiguous correlations between different holes at each site, and improved the reliability with which a continuous sedimentary sequence could be spliced together. These data will ultimately provide methods to expand discrete chemical and mineralogical data to more continuous records (e.g. Hagelberg et al., 1995; Mix et al., 1995).

The paleomagnetic signal at many Leg 167 drillsites was surprisingly stable despite a sedimentary environment sufficiently reducing to produce large quantities of biogenic methane. Site 1014, for example, has a sedimentation rate that averaged more than 80 m/m.y. since 2.6 Ma and the sediments contain about 5% organic carbon. Nevertheless a stable paleomagnetic signal was recorded for the length of the piston-cored section. These paleomagnetic records provide important age control for the sedimentation models, and will be extremely useful for understanding the processes which maintain earth's magnetic field and cause it to switch polarity.

Neogene Oceanographic Trends

Shipboard measurements have identified general trends in the evolution of Pacific climate from the relatively warm latest Miocene to the cooler climate of the Pleistocene. Between 7 and 5 Ma, siliceous microfossils decreased sharply in abundance marking a major oceanographic change similar in timing to the end of siliceous deposition in the Monterey formation. A mid-Pliocene biogenic $CaCO_3$ production event occurs, perhaps controlled by strengthened offshore upwelling beneath a stable surface ocean layer. We hypothesize that this production event to have been caused by enhanced subtropical gyral wind strength from 3.5 to 2.5 Ma, immediately prior to the appearance of major northern hemisphere ice sheets. The productivity events that we observe along the California margin are different in timing from those in either the subarctic or equatorial Pacific. The different regional responses will ultimately allow us to better understand climatic processes. Because regional oceanographic circulation patterns within the Pacific last for long periods of time (up to millions of years), stable oceanographic circulation patterns must exist even while the climate slowly drifts, or climate must respond in a stepwise fashion to the gradual tectonic changes in boundary conditions.

Geochemical Studies of the California Margin

Geochemical studies were a major part of the Leg 167 scientific program, and were designed primarily to understand diagenesis along a highly productive continental margin but also to understand the interactions between climate and the carbon cycle. The program included a high resolution interstitial water sampling program to model the oxygen isotopic composition of the last glacial maximum (Site 1010), and to study the methane hydrates that may have caused the development of a prominent bottom simulating reflector (BSR) at Site 1019 in the Eel River Basin. Interstitial waters were sampled at 9.5 m intervals from the first hole at each site to at least 100 mbsf in order to model the diagenetic processes within the sediment column. In addition, geothermal gradients were measured at all sites in order to constrain the thermal environment of diagenesis.

Site 1019, which has a moderate BSR at about 190 mbsf, was sampled at 9.5 m intervals to 240 mbsf. Although no hydrates were recovered in the core, a very strong chlorinity minimum was discovered (Figure 2). The chlorine contents decreased to about 60% of sea water, indicating perhaps 40% of hydrate in the formation, similar to profiles at Site 888 (Yuan et al, 1996). The logging records (Figure 2) identify high velocity and high resistivity anomalies that may indicate hydrate deposition, although the high resistivity zone at about 100 mbsf is not matched by a significant velocity spike.

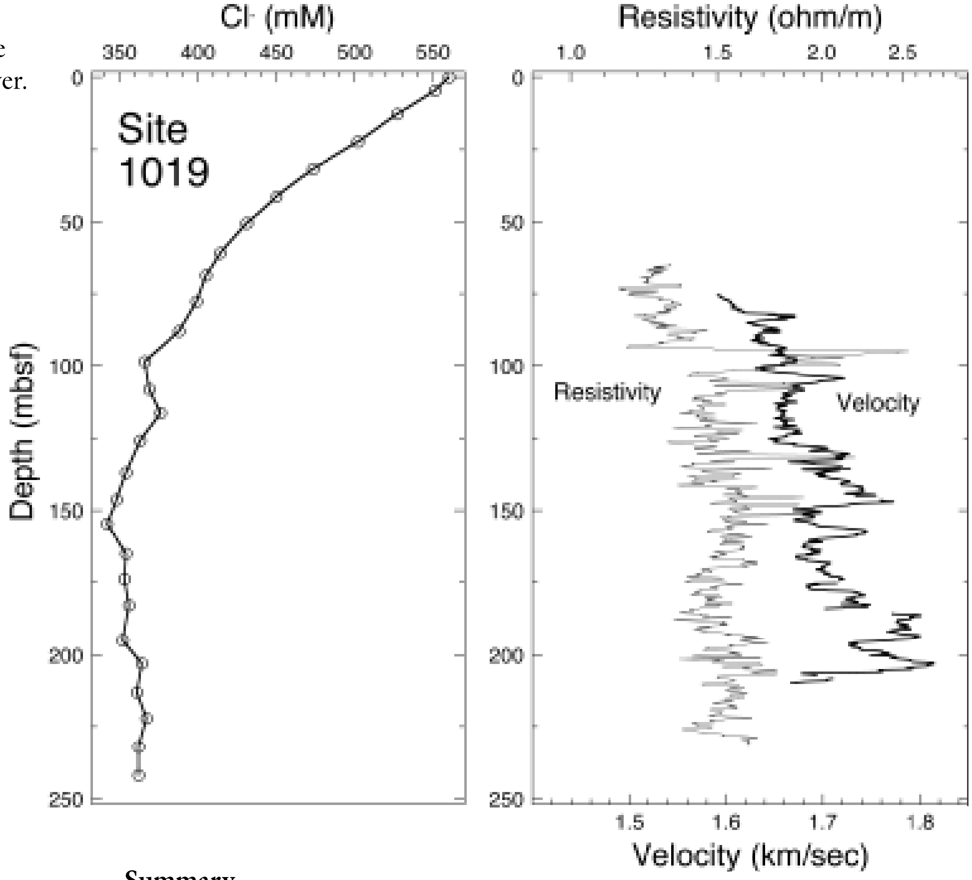

Figure 2. Downhole profile of the chlorinity of interstitial waters (left) and downhole logs of resistivity and velocity at Site 1019, ODP Leg 167.

Summary

Leg 167 represents one end-member drilling leg in which the prime shipboard concern is the recovery of a continuous sediment section and measurement of ephemeral physical properties before they degrade. The most significant scientific results will come from careful postcruise studies when details in records from different drillsites can be aligned with a high degree of confidence. This level of control will result from the development of high resolution chronostratigraphy based on radiocarbon and oxygen isotope studies on selected time intervals. These records will be used in conjunction with other shipboard and shorebased data to reconstruct the variability of the California Current system and its effects on the changing global climate.

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vigor of upper basement fluid circulation and the efficiency with which heat and solutes are transported by determining the lateral temperature, pressure, and pore-fluid compositional gradients. Temperature and fluid chemistry gradients were predicted to be small despite large local sediment thickness variations of over 3:1 (Davis et al., 1997).

Observations made during drilling attested to an even greater degree of homogenization in upper basement than anticipated. Basement was encountered by drilling at 240 m below the seafloor at the buried ridge (Site 1026), and at 600 m in the buried valley (Site 1027). Temperatures of circulating fluid, roughly 64°C, appeared to be nearly identical at the two sites despite their separation and the contrasting depths of burial. Borehole observatories installed at this pair of sites should improve the accuracy to which the lateral upper-basement temperature difference is known, and allow the pressure gradients that drive the flow to be determined.

A serendipitous outcome of drilling at the buried ridge (Site 1026) was that basement fluids were sufficiently overpressured to reverse the tendency for the cool water circulated during drilling to sink into the formation. During the two weeks that elapsed between drilling and observatory installation operations, the hole began to produce formation water. This provided a unique opportunity to sample basement water directly, and it also provided an unusual hydrologic test. A detailed temperature log allowed the rate of fluid flow from uppermost basement into and up the hole to be determined (about 100m/hr), thereby allowing the permeability of upper basement to be estimated (about 10^{-12} m^2). This estimate is particularly valuable in that it is representative of a much larger volume of the formation than is normally sampled by relatively short-term packer testing, and suggests that the upper igneous crust at this site is permeable over a scale of several kilometers or more.

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Leg 171 continued from page 3

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The Cause and Effect of Sea Level Change - Unraveling the Stratigraphic Yarn

by Gregory S. Mountain and Kenneth G. Miller

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Sea level divides the Earth into two realms, land and ocean. Despite such apparent simplicity, processes controlling this partition are complexly intertwined, and include global sea-level change, sediment supply, and subsidence (the sum of simple thermal subsidence, active tectonics, isostasy, flexure, and sediment compaction) acting on time scales from tens to tens of millions of years. Sea-level fluctuations are a primary influence on how, where, when, and what type of sediment is preserved in the geologic record. Consequently, one of five goals spelled out in the ODP Long Range Plan is to learn the history of global sea-level and gain from it an understanding of how these processes work.

By drilling and logging continuously cored holes almost anywhere in the ocean, ODP has the unique ability to unravel global sea-level history using three integrated strategies: 1) derive glacioeustasy from marine oxygen isotopic records; 2) recover direct indicators of sea-level change contained in the shallow-water sediments of carbonate platforms and atolls; and 3) sample depositional sequences in transects across passive continental margins. No one approach stands on its own. While oxygen isotopic studies provide reliable ages of ice volume changes, the magnitudes of eustatic change are less certain. Carbonate sediments can yield excellent measures of the amplitude of sea-level change, but these materials are very difficult to date with precision. Lastly, passive margins provide extensive evidence of the effects of sea-level change on the stratigraphic record, but unwinding the eustatic signal from those of local subsidence and sediment supply is especially challenging.

The continental margin approach requires choosing a region where subsidence and sediment supply histories are well known. A transect of sample locations across the margin improves the reliability of: 1) ages of depositional sequences and their bounding surfaces; 2) inverse subsidence (backstrip) models; and 3) paleobathymetric estimates derived from the recovered sediments. Nonetheless, the uncertainties imposed by local effects can obscure the eustatic record, and transects from more than one margin are needed to determine the global signal with confidence. Furthermore, transect records from times of contrasting global climate such as the Oligocene-Recent "Icehouse" and the mid-Cretaceous "Greenhouse" worlds are needed because rates and magnitudes of the processes driving these two systems must have been very different. Ironically, the stratigraphic record from these times are remarkably similar, and this inconsistency needs explanation.

This transect approach was begun along the NE Australia margin during ODP Leg 133, and most recently continued on Leg 166 in the

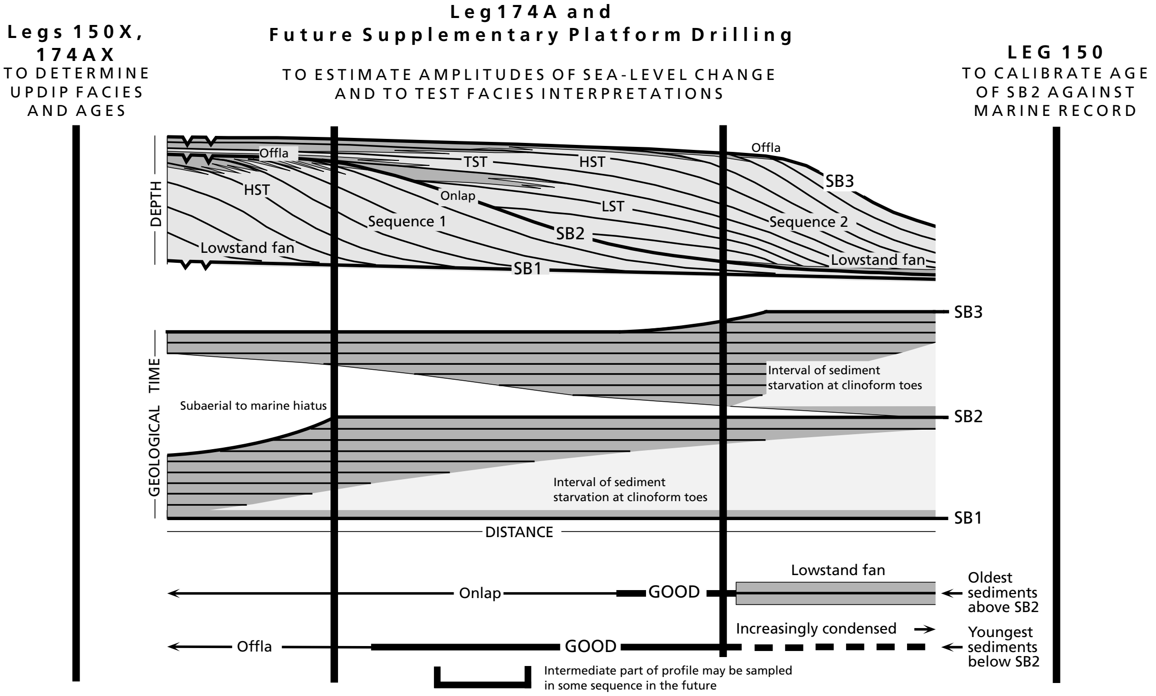

Figure 1 - Idealized stratal geometries prograding seaward across a continental margin such as New Jersey. Seismic data detect surfaces such as "SB2" that mark a downward shift in deposition to a position seaward of a major clinoform, followed by landward onlap onto and subsequent re-burial of the clinoform, and thus define sequence boundaries formed by a rapid fall in sea level. The age of this fall is best determined by drilling seaward of the fan at the foot of the clinoform (ODP Leg 150). The same stratal surface far updip provides added age control and facies to determine the extent of marine flooding during sea-level highstands (Legs 150X and 174AX.) Shelf drilling to either side of the SB2 rollover is the only way to accurately measure the amplitude of sea-level change associated with SB2. This will be done across middle Miocene sequence boundaries during Leg 174A. Determining the amplitudes of remaining Icehouse sea-level falls will have to await a supplementary drilling platform, as these clinoform rollovers are in water too shallow for safe JOIDES Resolution operations.

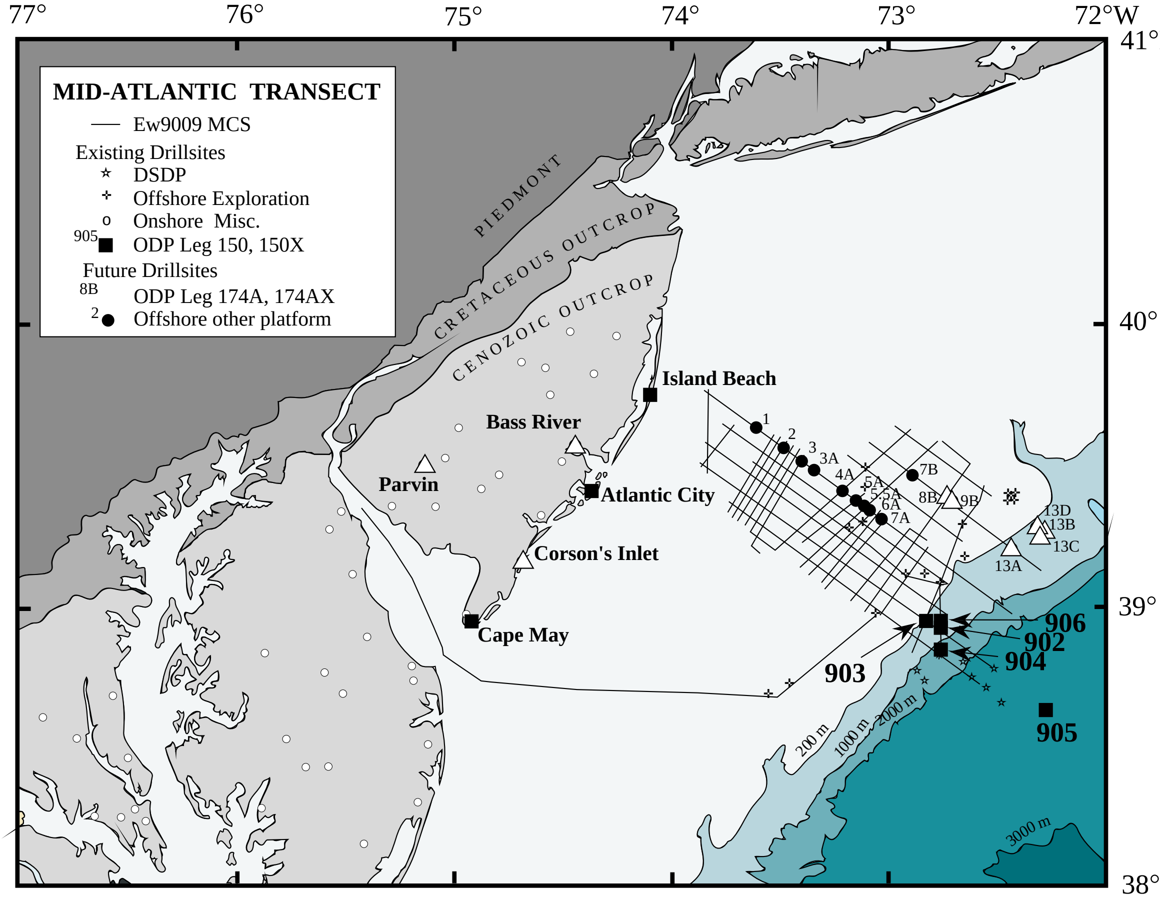

Figure 2. Seismic and borehole data contributing to the New Jersey Sea Level Transect. ODP Legs 150/150X drilled on the slope and coastal plain, respectively, and dated major Oligocene-Recent "Icehouse" sequence boundaries, and correlated them to glacioeustatic falls. Legs 174A/174AX will continue this offshore/onshore pairing at sites MAT-8B and -9B to determine the amplitude of sea-level changes in the middle Miocene. Sites MAT-1 through -7 have been selected to complete the transect and evaluate similar facies and glacioeustatic amplitudes of older Icehouse sequence boundaries; because of shallow water depths (<75 m) these will have to be drilled with a platform other than the JOIDES Resolution.

Bahamas; more will be done off south Australia during Leg 182. All these locations addressed sea-level questions in carbonate environments. This article reports on work along the New Jersey margin during Legs 150/150X and soon to continue on 174A/174AX (J. Austin and N. Christie-Blick, Co-Chief Scientists; Fig. 2), in a setting where the sedimentary record is exclusively siliciclastic. Carbonate and siliciclastic facies respond differently to sea-level fluctuations, and for a full understanding of the effects of sea-level change, records from both types of settings are required.

A grid of high-quality seismic data was collected on the New Jersey margin aboard the R/V *Ewing* in 1990 to prepare for ODP drilling. This grid included long dip lines that for the first time made it possible to map "Icehouse" sequence boundaries from the inner shelf to the slope. In 1995, the *Ewing* data were augmented by higher-resolution profiles collected aboard the R/V *Oceanus*. These latter are of such high quality that they make it possible to examine the New Jersey stratal record for evidence of sea-level changes on a much shorter time scale (at the orbitally-forced frequencies of 10^4-10^5 years) than previously thought possible (10^6 years).

ODP Leg 150 (Mountain, Miller, Blum, *et al.*, 1994) drilled four locations on the slope (Sites 902-904 and 906) at water depths between 445 and 1250 m (Fig. 2). These sites documented the age and facies of sediments associated with a total of 22 lower Eocene to mid-Pleistocene reflecting surfaces traced to sequence boundaries beneath the shelf and tentatively interpreted to register times of sea-level lowering (Fig. 1). Integrated bio-, magneto-, and strontium isotopic stratigraphy provided temporal resolution that in most cases was better than 10^6 years. Several major surfaces matched the age of rapid $\delta^{18}O$ increases derived from deep-sea records; these increases result from global ice buildup and eustatic lowerings (Fig. 3). In almost all instances, sequence boundaries sampled on the slope during Leg 150 were associated with little or no temporal hiatus; many were expressed by a slight coarsening of sediment that had been transported to the slope during sea-level lowstands. Others were marked by underlying intervals of intensified cementation that may have been the result of lengthy periods of reduced slope sedimentation when deposition centered on the adjacent shelf, presumably at times of sea-level highstand.

Complementing Leg 150 offshore drilling, we launched an onshore drilling program with support from the ODP, NSF, USGS, and State of New

Jersey Geological Survey (Miller *et al.*, 1994). The primary objectives of these Leg 150X onshore boreholes were to date Late Cretaceous to Cenozoic sequences and evaluate facies architecture in this updip setting. Four holes close to the modern shoreline have thus far been cored and logged; more are planned (Fig. 2.) As in the offshore slope sites, Oligocene to middle Miocene sequence boundaries correlate with prominent δ^{18}O increases, consistent with the hypothesis that these surfaces developed during global lowerings of sea level (Fig. 3). The ages of these sequence boundaries also compare well with timing of "global" boundaries interpreted by Haq *et al.* (1987) on the basis of proprietary seismic and well-log data plus outcrop interpretations. Facies successions in the Paleocene through middle Miocene of these onshore wells are typically a transgressive shell bed or glauconite sand at the base of each sequence followed by quartz sand at the top (upper part of the highstand systems tract). Thus, onshore drilling has provided important data for regional profiles, although all of the boreholes are landward of the Oligocene-Miocene clinoforms imaged in seismic reflection data beneath the shelf.

The shelf sites remain as the most important locations for estimating amplitudes of sea-level change during the "Icehouse" interval. Only sites paired to either side of clinoform "roll-overs" (Fig. 1) can hope to provide accurate estimates of water depths at the time of deposition, and as our seismic surveys correlated to Leg 150 on the slope have shown, these positions for Icehouse strata are spread across the shelf in steadily prograding packages. The stratal geometries observed in Icehouse sediments of the New Jersey shelf are common in sedimentary basins of all ages, and have spawned several depositional models that strive to explain the spatial and temporal distribution of facies ("systems tracts") and their bounding unconformities. A major contribution by ODP drilling on the New Jersey shelf that will begin with Leg 174A, or on any shelf with similar sequence geometry, will be to evaluate these various models.

Implementing this global ocean-drilling strategy has been long in coming, and remains incomplete. Several shortfalls need to be addressed in the science planning and in the technological developments required to achieve global sea level history objectives.

(1) ODP drilling for sea-level objectives has thus far focused on Icehouse sequences dating from the last 35 Ma. However, the geologic record from earlier times shows stratal patterns that are indistinguishable from those of the Icehouse; to understand their significance, and to understand fully the Earth's response to global sea-level change, it is necessary that we investigate times when there were no known ice buildups.

(2) The response of the underlying crust to changing loads of water and sediment, controlled by the age and character of that crust and by local processes, can be very large compared to the magnitude of sea level changes and is different for every margin. Consequently, it is crucial that identical intervals of sea-level change be examined in sedimentary packages from margins of widely contrasting tectonic histories so that we can untangle the true eustatic signal that is woven into the observed sedimentary architecture.

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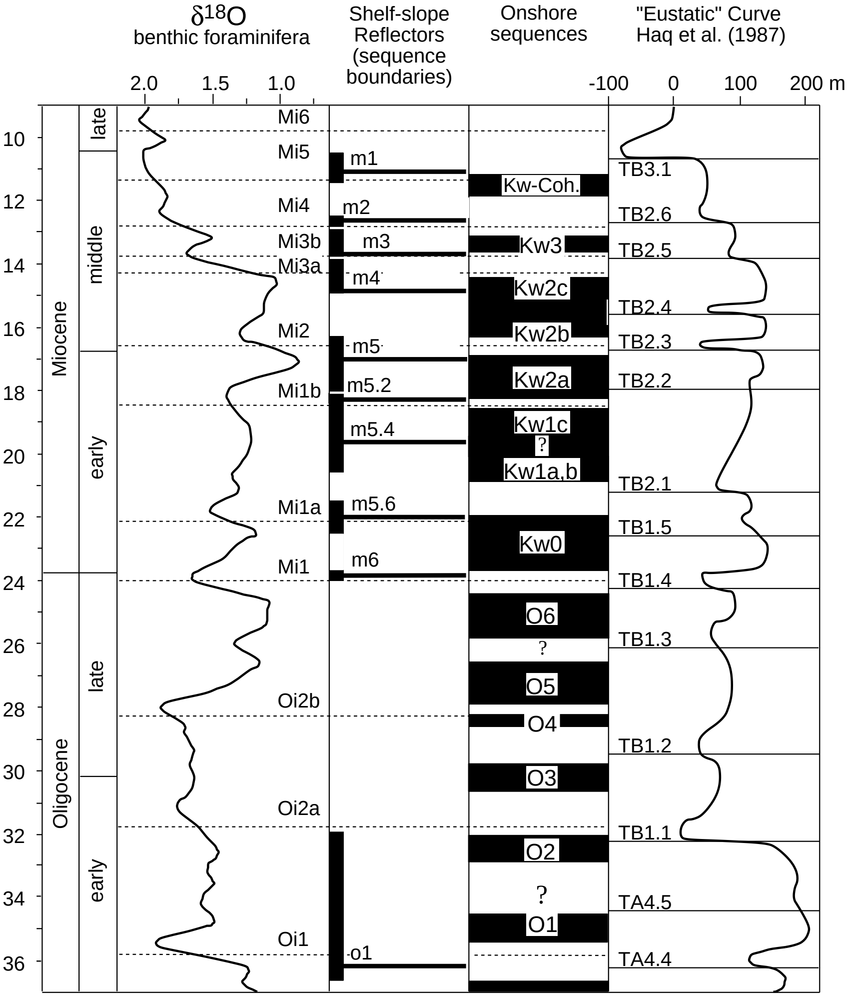

Figure 3. The timing of Oligocene to middle Miocene reflectors on the New Jersey slope vs. δ^{18}O, onshore sequences, and the inferred eustatic record of Haq et al. (1987). The δ^{18}O is a stacked record of Cibicidoides spp. *from several sites, smoothed to remove periods longer than ~1 m.y. Oi1 to Mi6 are δ^{8}O maxima; dashed lines mark inflections in the δ^{18}O records. o1 to m1 are reflectors dated on the New Jersey slope; horizontal lines mark best age estimates; vertical lines indicate uncertainties. Onshore sequences are shown in black; white areas in between are hiatuses. O1 to O6 are Oligocene and Kw0 to Kw-Coh. are Miocene onshore sequences; gray areas indicte uncertain ages. TA4.4 to TB3.1 are sequence boundaries of Haq et al. (1987), drawn at the inflection points of their inferred eustatic record. Time scale is that of Berggren et al. (1985). (From Miller et al., 1996a)*

Drilling Tectonic Windows into the Lower Crust and Upper Mantle: ODP Leg 153

by J.A. Karson, M. Cannat, J. Miller and ODP Leg 153 Shipboard Scientific Party

A major, long-term goal of the Ocean Drilling Program (ODP) is to investigate the composition and structure of deep crustal and upper mantle rocks of the oceanic lithosphere. As a shortcut, ODP drilling has exploited tectonic exposures of deep-level plutonic rocks, in an approach referred to as “offset drilling”. Leg 153 was the first attempt at offset drilling in slow-spreading (~30 mm/yr) oceanic crust of the Mid-Atlantic Ridge (MAR).

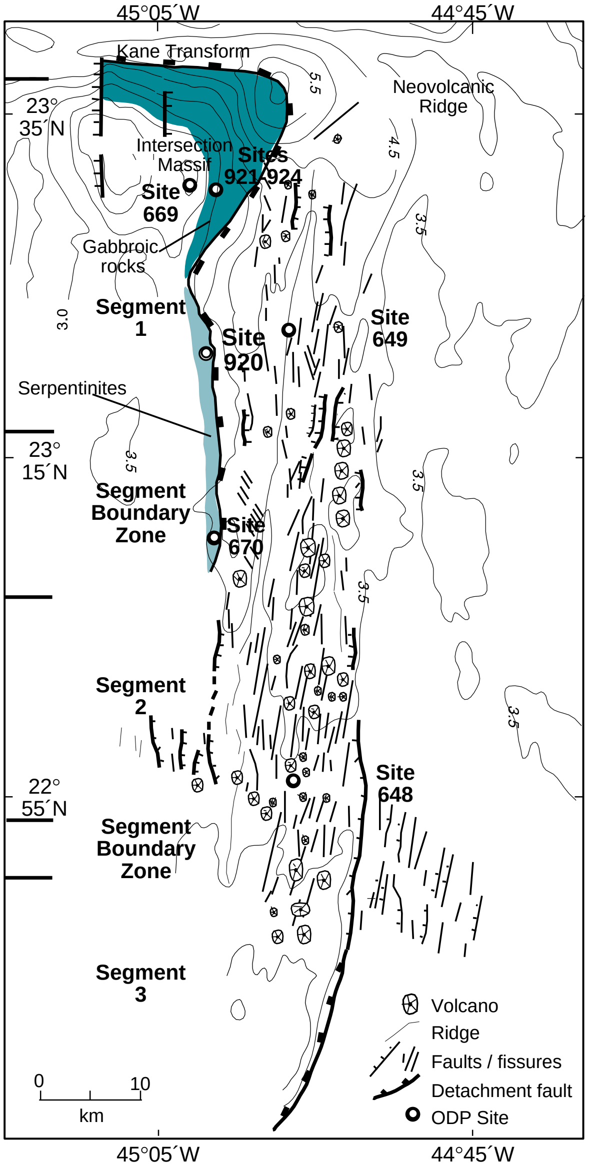

Figure 1. Generalized geological map of the MARK Area. Sites 920 and 921-924 are located 5 and 35 km south of the Kane Transform, respectively in extensive tectonic windows into lower crustal gabbroic rocks (dark blue) and serpentinized upper mantle peridotites (light blue).

Five drill sites were located on the western wall of the MARK Area (Figure 1) where previous submersible studies suggested that mafic and ultramafic plutonic rocks are exposed in the footwall of major detachment faults (Karson et al., 1987; Mével et al., 1991). Site 920 is located in an exposure of serpentinized upper mantle peridotites within a narrow belt of serpentinite outcrops extending for ~20 km along the edge of the rift valley. This area is interpreted as a dominantly serpentinite crust that has been stripped of its basaltic cap by major normal faults. Sites 921-924 are located to the north in middle to lower crustal gabbroic rocks where a detachment fault has unroofed a thick (few km) magmatic crustal assemblage.

Serpentinized Mantle Peridotites at Site 920

At Site 920, serpentinized peridotites were drilled at 2 holes about 40 m apart to depths of 126 m and 200 m, with recovery of 38% and 47%, respectively. The recovered material (144.5 m of core) is dominantly pyroxene-poor serpentinized harzburgite to dunite with pyroxene-rich (up to 35% orthopyroxene) layers a few meters to centimeters thick. Mineral chemistry of the primary phases indicate moderate partial melting of a depleted mantle source. Widely preserved relict coarse-grained porphyroclastic textures define a high-temperature foliation with a variable orientation. Also present are numerous elongate segregations of clinopyroxene and lesser spinel interpreted as the crystallization products of interstitial melt channels in the ultramafic rocks.

Intercalated with the serpentinites are minor intervals of mafic rocks with textures ranging from magmatic to mylonitic; they have granulite to amphibolite metamorphic assemblages. A few diabase dikes with chilled margins also cut the serpentinized harzburgites in both holes. Collectively the mafic rocks are compositionally similar to those drilled to the north (see below) and represent a wide range of magmatic differentiates.

The primary minerals in the ultramafic rocks are pervasively serpentinized or altered to amphibolite to greenschist facies assemblages. Multiple generations of serpentine veins are one of the most obvious features of the cores. Moderately to gently east-dipping anastomosing serpentine veins are nearly ubiquitous. Both the groundmass and vein serpentines have low oxygen isotope values indicating serpentinization at temperatures greater than 300°C.

Paleomagnetic studies document significant anisotropy of susceptibility and show that no post-serpentinization rotation has affected the massif or the dikes. Thus, despite a complex alteration and deformation history near the MAR axis, uplift and exhumation of the serpentinites appears to have been accomplished primarily by displacement on steeply dipping normal faults of the median valley wall.

Variably Deformed Gabbroic Plutons at Sites 921-924

Sites 921-924 are located in extensive exposures of gabbroic rocks, in a 2 km x 2 km area of the western wall of the MAR median valley. At these sites, a total of 120 m of gabbroic rocks was recovered from coring 447 m (26.8% recovery). The material recovered spans a wide range of igneous compositions, from relatively primitive troctolite and olivine gabbro to lesser volumes of leucogabbro to trondhjemite. The dominant rock types are gabbro and olivine gabbro. Primary magmatic layering defined by changes in grain size and modal mineralogy, is present on the scale of 1 cm up to a few meters. The attitude of this layering varies significantly within the cores, locally changing from subhorizontal to subvertical over a few decimeters. In some cores, cycles of relatively primitive to somewhat more evolved rock types may indicate recurrent evolutionary magmatic sequences on the scale of a few meters. The cycles may record, to varying degrees, a transition from crystallization of relatively primitive olivine gabbro, or troctolite to gabbro. Igneous textures are highly variable and heterogeneous, and several intervals of olivine gabbro display cumulus textures.

Many of the gabbroic rocks recovered contain essentially igneous textures. Weak foliations and/or lineations suggest magmatic deformation in some places. A remarkably wide range of crystal-plastic to cataclastic deformation fabrics are concentrated in shear zones. The shear zones are mostly moderately dipping and commonly have down-dip stretching lineations and normal-slip kinematic indicators, possibly correlating with fault surfaces mapped by submersible studies.

Alteration in the gabbroic rocks is typically not extensive, but pervasive greenschist facies alteration occurs in areas of concentrated fracturing or veining. Locally amphibolite and less common granulite facies assemblages also occur.

The most striking characteristic common to all the gabbroic rocks drilled during Leg 153 is the wide range of compositions and textures developed over length scales of a few centimeters to a few tens of meters. This variability may result from closed-system fractionation in relatively small plutons with sharp temperature gradients that produce a complex interplay between magmatism and deformation. Although clear contacts between different rock types were only rarely recovered, variations in geochemical trends, deformation, metamorphism, and magnetic characteristics indicate that in nearly all the holes, multiple distinct plutonic bodies were penetrated. In addition, the cores have complex remanent magnetizations, including components of both normal and reversed polarity, suggesting the possibility of intimately mixed intervals of different polarities.

Fine-Scale and Large-Scale Heterogeneity in Oceanic Lithosphere

Despite the limited depths of penetration, drilling on Leg 153 has substantially improved the understanding of the processes that create and modify the lower crust and upper mantle at slow-spreading ridges. This study documents that significant heterogeneity in both gabbroic and ultramafic rocks is present on scales of less than a centimeter to several kilometers. This variability is likely to be a reflection of the complex interplay between tectonic extension, magmatism, and hydrothermal metamorphism that occurs along many parts of slow-spreading ridges.

The array of holes drilled into the gabbroic massif reveals a bewildering level of compositional and textural heterogeneity, inconsistent with crystallization of these gabbros in a long-lived sub-axial magma chamber. Instead, this heterogeneity suggests that the gabbros crystallized in a collage of small plutons that intruded one other as well as proximal upper mantle rocks during tectonic extension. A similar interpretation was proposed for gabbros drilled at Site 735 in the SW Indian Ocean, suggesting that this process is typical of crustal accretion at slow-spreading ridges.

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Detection of *in situ* Physical Properties using Logging-While-Drilling

by Dave Goldberg

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Over the last 5-10 years, new technology has been developed to measure *in situ* properties in oil industry holes where conventional logging with a flexible wireline is not feasible. This innovative technology is called “logging-while-drilling” (LWD; Fig. 1) and uses sensors placed just above the drill bit to measure porosity, resistivity, and density (referred to as a “triple combo”), and natural gamma radiation (e.g. Allen et al., 1989; Bonner et al., 1992; Murphy, 1993). Consequently, data are recorded 4-30 minutes after the drill bit cuts through the formation and ephemeral *in situ* physical properties can be measured with precision. In many industry and ODP environments, LWD is the only type of open hole logging possible. More detailed descriptions of LWD and wireline tools can be found via the URL site http://www.ldeo.columbia.edu/BRG.

LWD has several advantages over conventional wireline logging. The primary advantage is that data can be acquired continuously with depth even in unstable holes. *In situ* physical properties can be measured over the entire drilled interval, particularly in the critical shallow section where wireline logging is compromised by the need to leave the drillpipe 80-100 m below the seafloor and at the bottom of the hole which is often filled by sloughed material from the borehole walls. LWD measurements also do not require interruption during drilling as occurs during normal coring operations, hence, the chances of borehole wall collapse are reduced and unstable intervals can be logged more easily. Another advantage of LWD is that transient physical properties such as porosity can be measured before *in situ* conditions deteriorate.

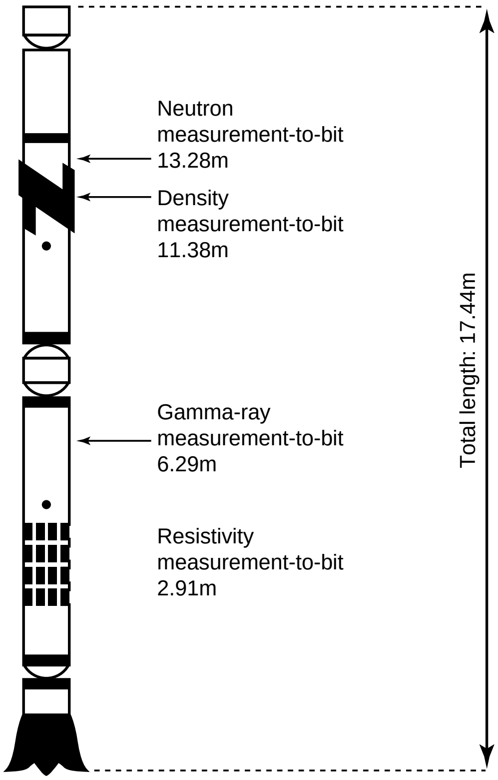


Figure 1. Schematic diagram of LWD tools located immediately above the drill bit that enable measurements within minutes after the hole is made (after Shipley, et al., 1995).

LWD data were recorded on the Barbados accretionary prism during ODP Leg 156 and produced a new understanding of this active tectonic regime, its physical properties, and the migration of pore fluids. These data were used to address critical questions such as the physical properties at the plate boundary fault, its role as a conduit for fluid movement, and the deformation of sediment accreted in the prism (Shipley et al., 1995). Porosity computed from the LWD density and resistivity logs were used to identify zones of high porosity and low resistivity within the fault zone, which are too thin (0.5-1.5 m) to be resolved seismically. Moore et al. (1995) suggest that these zones may be tectonically significant because the pore pressure inferred from the porosity surpasses 90% of the overburden pressure, which leads to dilation and fracturing in the formation. The ability to acquire and resolve *in situ* data in such environments is critical because physical properties change immediately after the hole is drilled.

Previous wireline logging results on another accretionary prism off the Cascadia margin (MacKay et al., 1994) provide an excellent opportunity to compare wireline records with continuous LWD profiles as a function of depth. Two LWD porosity logs (calculated with density and resistivity measurements) from Barbados compared with a conventional wireline porosity log from the Cascadia accretionary prism illustrates the advantage of LWD in these notoriously difficult drilling environments (Figure 2). In the Cascadia example, the wireline log shows a gap in a zone of high water content associated with faulting, and the measurements of porosity from both laboratory core tests and the wireline log are sparse and less representative of the porosity structure in the upper 150 m of the hole. The porosity profiles from Barbados, in contrast, cover the entire depth range including the top 100 meters and correspond well with the laboratory data. When calibrated, LWD profiles and core data can be used jointly to compute pore pressure and effective stress versus depth (e.g. Moore et al, 1995; Saito and Goldberg, 1997).

It is clear that “triple combo” logs using LWD can identify the porous structure within accretionary prisms and that these measurements are more robust than standard wireline techniques. However, differences in measurement technologies must be considered when directly comparing results from wireline and LWD tools (e.g. Evans, 1991). The resolution of LWD sensors is similar to that of wireline logging tools (approx. 15-30 cm), but depends on rotation and drilling rates. With adequate drilling rates, LWD porosity measurements have a vertical resolution of about 30 cm; resistivity, density, and gamma-ray measurements have resolution of 15 cm or less. The reliability and comparison of LWD to wireline logs has been under considerable study by industry groups for typical oil and gas drilling environments (Brami *et al.*, 1996). Both core and wireline log measurements should be acquired in ODP environments, which often differ substantially from those in industry, to enable comparisons and the evaluation of LWD measurement reliability on a leg-by-leg basis.

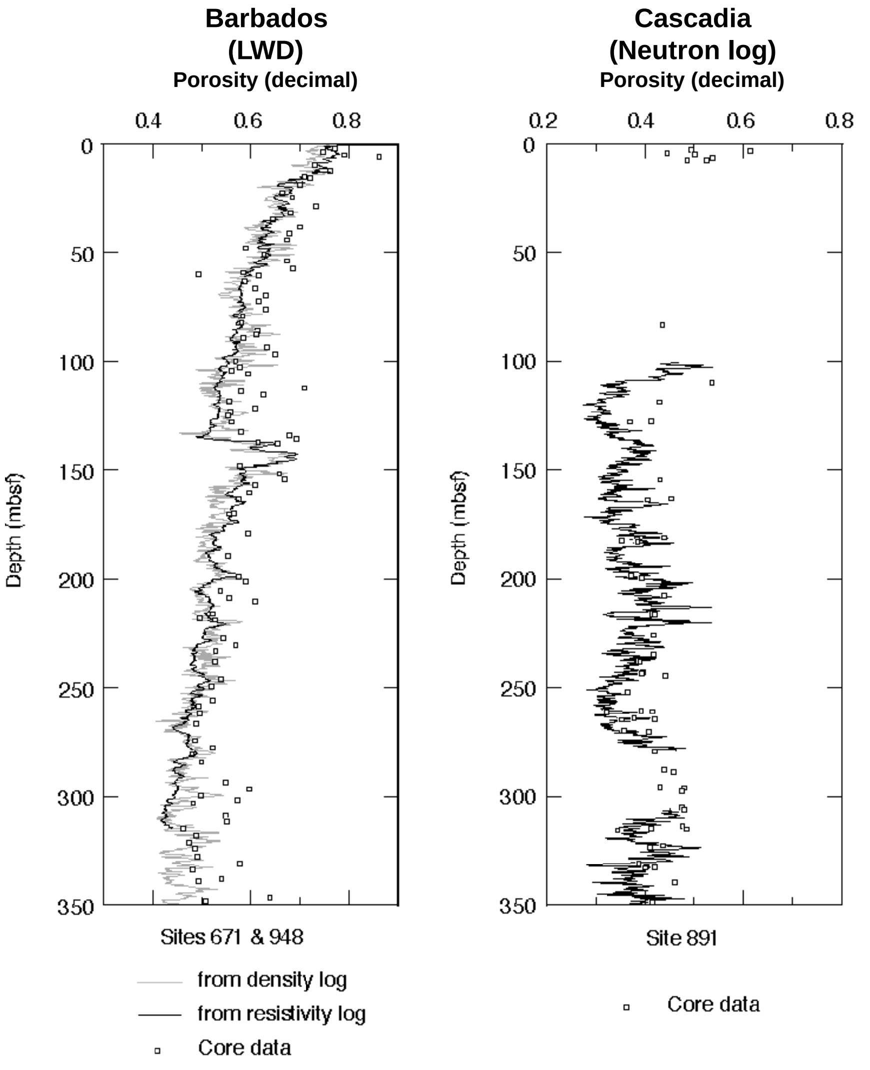
So far this year, LWD data have been acquired during two ODP legs and another is scheduled this summer. Five holes were logged using the LWD "triple combo" on the Costa Rica accretionary prism (Leg 170), one of which penetrated the décollement fault zone. Wireline logs were acquired over a short interval in one other hole, allowing a comparison with the LWD data. A return to the Barbados accretionary prism (Leg 171A) successfully recorded LWD "triple combo" data across the décollement fault zone at a total of five additional sites, generating ODP's most comprehensive data set across an oceanic plate boundary. Leg 174A on the New Jersey continental shelf/slope will use LWD through potentially unstable prograding sand/clay sequences at two sites and compare the results with wireline logs at least at one. Determining *in situ* properties using LWD during Leg 174A will quantify shallow sequence boundaries, thought to result from rapid sea level fluctuations, and estimate profiles in the shallow sea floor.

Future LWD Measurements and Applications

Penetrating young crustal sections and hydrothermal environments have proven to be a difficult task throughout the history of ocean drilling. Hole instability while coring has been a major cause of low recovery (often 20-30%) and poor logging success in the recent past. New LWD tools measuring resistivity-at-the-bit (e.g. RAB™) and sonic-while-drilling (e.g. ISONIC™) may be critical in such environments which characteristically recover only limited lithological and structural information. The RAB tool records oriented electrical images with 5-cm resolution using sensors that scan a full 360 degrees around the drill bit, as well as natural gamma ray, bit inclination, and drill string information (Lovell et al., 1995). These images resemble wireline resistivity imaging data (e.g. FMS™) tool with somewhat poorer resolution, but unlike the FMS, borehole wall coverage is complete and the data are recorded before borehole conditions deteriorate (Figure 3). The structural fabric and formation anisotropy are important parameters in shallow crustal environments, as are fractures and bedding in competent sedimentary sequences. In both of these environments, poor core recovery and low-quality logs may no longer limit interpretations of the subsurface lithostratigraphy and the orientation of structures and anisotropy.

Sonic-while-drilling presents unique challenges. LWD sonic tools must be strong enough to withstand drilling stresses, yet must sufficiently attenuate noise generated by the drill bit to distinguish formation signals. LWD sonic tools can measure formation velocities reliably above 2,000 m/s (e.g. Aron et al., 1994), which limits their application in marine sediments to depths greater than about 500 m. The potential for improving

Figure 2. Porosity logs through accretionary prisms in ODP Hole 948A (Barbados) and 889C (Cascadia) recorded using LWD and wireline logging tools, respectively. The LWD logs indicate continuous porosity profiles derived from density and resistivity measurements from the seafloor to 350 m depth. The wireline logs are limited to depths greater than 80-100 m below the seafloor and are of lesser quality due to poor borehole conditions after drilling. Measurements of porosity from laboratory core tests are shown from both holes for comparison.



shallow seismic-log correlation, detection of natural fractures, and estimation of shallow mechanical properties are clear applications of sonic LWD. Neither resistivity imaging, nor sonic-while-drilling measurements, have yet been used in ODP environments.

LWD may be used with little additional time to address scientific questions in new ways. Simply employing a new strategy that uses LWD to drill closely spaced holes could produce three-dimensional maps of the *in situ* properties where coring multiple holes would be too time consuming. Using such a strategy, the five holes drilled during Leg 171A logged nearly 3,000 m depth in less than 12 operating days. With a full leg 'pogo-stick' drilling program, ~10-20 km of logs could be acquired over an array of shallow-penetration (100-500 m) LWD holes, providing dense spatial characterization of an area. Alternatively, using LWD in conjunction with a riser, drilling in horizontal and highly deviated holes, something that has routinely been accomplished for industry drilling objectives , would be possible for scientific ocean drilling. Directional drilling using a riser will require LWD with real-time data monitoring for the control of drilling parameters. Such experiments may reveal unique information in close lateral proximity to a structure, such as along a fault zone or around a mineral deposit.

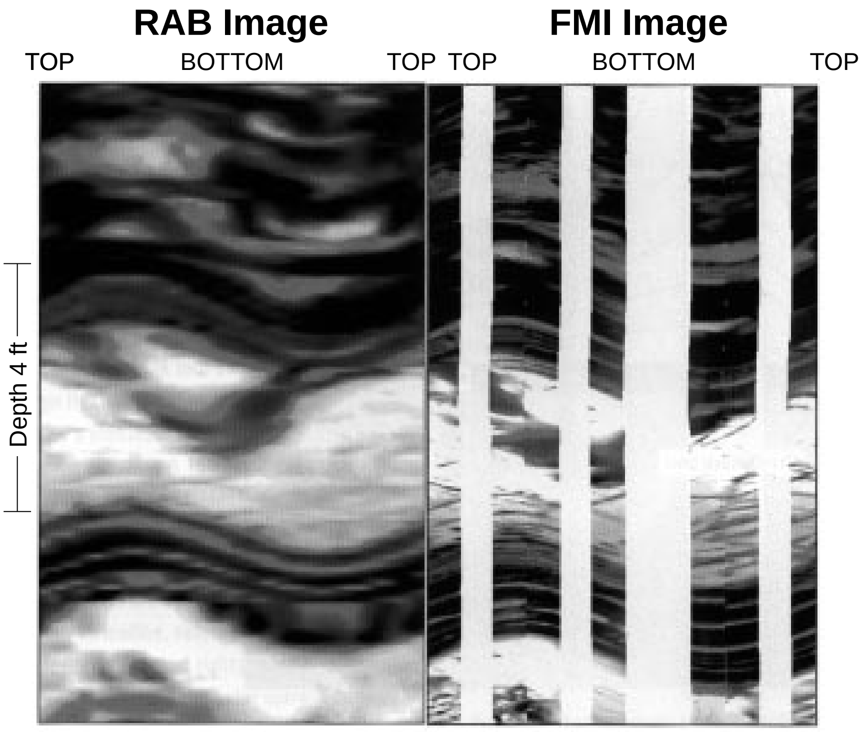


Figure 3. Comparison of LWD resistivity-at-bit RAB™ tool (left) and wireline electrical imaging FMI™ tool (right) of dense fracturing in consolidated sediments (after Lovell et al., 1995). Both images of the interior of the borehole wall are oriented to top and bottom of a deviated hole. Although the LWD tool has inferior bed resolution (by a factor of 30), it offers the advantage of data coverage around the entire circumference of the borehole and measurements within minutes after the hole is made.

Conclusions

LWD technology can now measure *in situ* properties like porosity across fault zones, in accretionary prisms, and in unconsolidated shallow sequences. This technology will become increasingly important as ODP attempts to drill in more challenging environments and core recovery becomes more difficult, such as in ultra-deep and deviated holes, when real-time hydrocarbon monitoring is required, or when coring time constraints limit the spatial distribution of holes drilled. The acquisition of downhole data are most representative of *in situ* conditions and most valid as a proxy for geologic interpretation when they are made immediately after drilling. Using LWD, it will be possible to observe high-resolution formation properties and transient variations in new, unexplored environments will be possible to observe.

™RAB, ISONIC, FMS , and FMI are marks of Schlumberger

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Technological Innovations for ODP: The Hard Rock Coring System (HRCS) and the Hard Rock Re-Entry System (HRRS)

by C. A. Buddy Bollfrass, P.E., Michael W. Friedrichs, G. Leon Holloway, P.E., Thomas L. Pettigrew, P.E., Mark Robinson

Buddy Bollfrass, P.E., Team Leader, ODP Development, Engineering, Michael W. Friedrichs, Engineering Advisor, G. Leon Holloway, P.E., Senior Development Engineer, Thomas L. Pettigrew, P.E., Engineering Advisor; Mark Robinson, Senior Development Technician, all at ODP– Texas A&M University.

Achievement of a large number of the scientific objectives within the ODP Long Range Plan requires improved core recovery, the ability to drill in young, fractured oceanic crust and the alternating sequences of very different lithologies, and the initiation of drilling and re-entering holes on sloping, hard-rock surfaces. The Development Engineering Team at ODP–TAMU is addressing these issues through two challenging technological developments programs. The first of these is to develop a Hard Rock Coring System (HRCS)–an initiative that began several years ago and was known to many as the Diamond Coring System (DCS) development–which is now taking an exciting new direction. The second innovative program is the development of a Hard-Rock Re-entry System (HRRS) that has been referred to in the past as the Hammer Drill-in Systems (HDS), but that consists of considerably more than a hydraulic hammer.

The Hard Rock Coring System (HRCS)

The Hard Rock Coring System (HRCS) is intended to provide a stable platform on the *JOIDES Resolution* from which to employ high speed diamond bits to improve coring in hard rock. A key requirement for high-speed diamond drilling is the ability to maintain a uniform weight-on-bit (WOB) under sea conditions that cause significant ship heave. Diamond bits are considerably less tolerant of impact than the roller cone bits now in use, that are designed to withstand bouncing against hard rock. For example, the desirable WOB variation for diamond drilling is 250 Kg compared with 3000 Kg for roller core bits. A second requirement for diamond drilling coring is rotational speeds that are currently limited by the capacity of the *JOIDES Resolution*. Thus, higher speed requirements for diamond bits can be met by downhole motors. Both of these problems must be managed if high-speed diamond drilling is to be implemented from the *JOIDES Resolution*.

Heave Compensation on the *JOIDES Resolution*

The *JOIDES Resolution*'s existing passive Heave Compensator is used to reduce the effect of ship heave on drilling and coring tools, as well to provide soft landings for Hard Rock Guide Bases or CORKS. This passive Heave Compensator is a large shock absorber, or pneumatic spring, that translates the increase in string weight due to ship heave into air compression. Its capacity for compensating ship heave is related to responsiveness (seal friction and compression rate) and mechanical limits (length of stroke). Seal friction creates a threshold (lower limit) operational value, where very small sea swells (heave forces) cannot overcome the compensator seal friction, and therefore, lift and drop the drill string a small amount. This variation of drill collar WOB is only an inconvenience for roller-cone bits, but the consequence for diamond bits is potential damage from bumping the bottom of the hole.

The normal operating mode of the existing Heave Compensator is the range of sea swells where heave forces exceed the threshold friction and can be mostly compensated by air compression. The consequence of partial compensation is drill string stretch and relaxation due to ship momentum. Additionally, when the heave period is less than the compensator response to ship momentum, the compensator cannot react to the shorter period and additional motion is transmitted to the drill string.

The maximum operating condition (upper limit) of the Heave Compensator occurs when ship heave exceeds the compensator stroke limit (about 6 meters). Sea swell greater than this would also have to be added directly to the drill string motion. However, personnel safety would normally limit sea floor activities to about 3 meters stroke for 5-6 meter seas.

In summary, the existing Heave Compensator imposes a threshold movement (stretches the drill string) for low sea states, absorbs up to 4 meters of heave for normal operational sea states and is inadequate for high sea states, with total heave greater than 6 meters. Nevertheless, without the shock protection provided by the passive Heave Compensator for rotary drilling or landing bits, CORKS and Hard Rock Bases, current operations in sea swells would be quite limited.

Diamond Coring System Platform

Coring in several hundred meters of water has been conducted from geotechnical vessels over the years with a secondary platform that is suspended in the derrick and senses heave related to a taut wire fixed to the sea floor. ODP built a secondary platform and tested it on Legs 124E (1989), 132 (1990) and 142 (1992). Its purpose was to adapt mining coring technology to obtain hard rock cores with recovery near 100%. This entailed provision for a high speed top drive for diamond bits, drilling inside the drill string (small riser) to provide structural stability for the small coring string and provision for active heave compensation from this platform to maintain uniform WOB.

Active heave compensation is the adaptation of computer technology to ship movement sensors in order to hydraulically move the active heave compensator in cycle with ship heave, rather than to allow the passive heave compensator to react to heave forces. The significant difference is that the system is responsive enough to reduce ship heave to some small threshold amount due to systemic friction. The negative aspect is that coring tools at the sea floor are affected by the activity below the ship, as well as ship heave. This includes drill string reaction to dynamic positioning, ocean currents, heave friction, WOB drill-off end hole friction.

New Development Direction

Three recent advances have now altered the direction of development of a secondary platform for diamond coring. The first has been the recent (since 1990) successful application of active controllers to large heave compensators for low string weight (coring) and shallow water depth (<700 meters). This "activation" modification would now be more cost effective to apply to the *JOIDES Resolution* than completing (testing and installing) the secondary platform with its attendant logistics (17 truck loads) and the great amount of ship time required to rig-up and rig down.The second advance was the recognition that significant variables exist below the ship that require additional controls, irrespective of heave compensation on the ship. This means that the prudent course for the present is to "activate" the existing heave compensator aboard the *JOIDES Resolution* to remove at least 90% of ship heave, and then to resolve the remaining variables with "smart" tools at the sea floor. The third advance has been the creation of "smart" tools, that can be adapted to isolate the bottom-hole-assembly (BHA) from the remaining ship heave and drill string dynamics and to provide the necessary drilling operations at the sea floor. Such tools should require far less logistical support or operational time aboard ship than would a secondary platform.

Hence, ODP is now planning to activate the existing Heave Compensator onboard the *JOIDES Resolution* instead of developing a Secondary Platform Compensator. Mike Fredrichs is planning on making these changes during the Capetown port call in mid October 1997. The improved compensator responsiveness should improve **all** drilling, landing and coring activities—not just diamond coring.

At the Halifax port call in July 1997, the compensator cylinder will be evaluated by Mark Robinson and the existing heave compensator rod and piston seals will be replaced with more current fluorocarbon materials. This will greatly reduce seal break-away friction which will lower the threshold heave value, allowing the existing heave compensator to be more responsive to lower sea swells and with lower hanging loads, i.e., improved core recovery and quality.

The effect of variables such as drillstring reaction to heave friction, ship dynamic positioning or ocean currents, as well as WOB drill-off and hole friction as on scientific coring tools, will also have to be addressed. Sea floor solutions may involve the adaptation of an Isolation Sub and "Smart" Tools, such as a WOB Sub and Vertical Thruster to provide downward force-on-bit (FOB), much like the existing Motor Driven Core Barrel (MDCB) tool. The MCB utilizes a high speed motor to achieve diamond coring speeds. The effectiveness of such tools depends on the capability of minimizing the effects of ship heave in order to be able to focus the efforts on the drilling tools. With structural stability available at the sea floor, the possible use of existing diamond coring tools should be revisited.

Hard Rock Re-Entry System (HRRS)

The Hard Rock Re-entry System consists of a unique set of drilling tools that are designed to create a re-entry hole in a sloping, hard rock sea floor. Tom Pettigrew and G. Leon Holloway are collaborating to develop a hard rock drill-in casing re-entry system, designed around a water hammer and compatible with ODP's casing program, that will:

- spud-in on bare, sloped hard rock,
- drill into rock with an improved rate of penetration,
- carry casing into the hole along with the drilling tools, and
- achieve a setting depth adequate to structurally support re-entry.

Since the heart of the system is a hydraulic hammer, actuated by sea water, this project has been referred to in the past as the Hammer Drill-In System (HDS). However, much more innovation is required by this system than by a drill hammer. The other components being developed are retractable and eccentric bits, a hydraulically actuated casing running tool, a casing hanger latch system, latch type free-fall re-entry cone, and a hardened casing shoe.

Continued on page 23

A Message from the Chair—

This is the first JOIDES Journal produced from the JOIDES Office in Woods Hole. It has been completely redesigned to consist of articles on ODP-related scientific research and technological developments; contributions of articles or suggestions of topics you would like to hear about are always welcome. We have retained an extensive Planning Section that will continue to provide news from ODP and the JOIDES Advisory Structure, and announcements and updates from all ODP-partner countries and consortia. This new JOIDES Journal will be issued twice a year, with an Annual JOIDES ODP Panel Directory accompanying the Fall issue. If you have any comments about the new format, or any suggestions as to how to make it more useful to the ODP community, we would like to hear from you.

As many of you are aware, this is a time of important changes for the Ocean Drilling Program. The Long Range Plan published a year ago identified a range of scientific problems for the next five years and beyond that are broadly focused under two major themes: Dynamics of Earth's Environment and Dynamics of Earth's Interior. In order to better align the flow of scientific and operational advice within the program to the goals of the Long Range Plan, the JOIDES Planning Committee has developed a plan of reorganization for the JOIDES Advisory Structure. At its February 1997 meeting, the Executive Committee gave final approval to the new structure that is discussed in the Planning section. As I write this, the national ODP committees are in the process of nominating members to panels that will convene for the first time in the next few months.

In response to community input, there will also be some changes to the proposal submission and evaluation process. EXCOM has approved a change in the ODP proposal deadline, which will be 15 March and 15 September of each year. Hence, the next deadline will be 15 September 1997. New guidelines for proposal preparation and submission are being developed that will better facilitate the nurturing of exciting scientific ideas, and will eventually lead to a new evaluation process for fully-developed drilling proposals. We hope to have the new guidelines approved by EXCOM in June 1997 to come into effect for the 15 September deadline. Hence, if you are considering submitting a new or revised proposal at that time, check with our web site, or the JOIDES Office for new requirements.

During the fall of 1996, JOI organized a workshop to revise ODP's Sampling and Curation Policy to provide the greater flexibility in sampling of ODP cores that will be needed to achieve new scientific objectives (e.g., very high-resolution studies of climate change). The new policy has now been approved, and ODP-TAMU will begin implementation for upcoming legs.

All of these changes mean that the current Guide to the Ocean Drilling Program is outdated. We plan to publish a new version in the summer, when the changes have been approved and new policies are in effect.

The next few months will be challenging for us all as we attempt to implement these changes. We will do our best to make the transition as smooth as possible, and ensure we have an efficient, fair, and effective advisory and evaluation process in place. However, throughout this reorganization, it is important to keep in mind that the science conducted by the Ocean Drilling Program is ultimately driven by the quality of proposals submitted by members of the geoscience community. We can accomplish these scientific goals of the ODP Long Range Plan, and hopefully move beyond them, with your continued input and support.

Susan E. Humphris

Susan Humphris, the head of the JOIDES Office in Woods Hole and Chair of the new JOIDES SCICOM, has had a long association with deep sea drilling. She sailed on two of the first legs which attempted to drill into "zero-age" crust at an oceanic spreading center (DSDP Leg 54 to the East Pacific Rise and Galapagos Spreading Center in 1977, and ODP Leg 106 to the Mid-Atlantic Ridge MARK area in 1985), and was Co-Chief Scientist on ODP Leg 158 which successfully drilled the TAG hydrothermal mound. She also served on the Lithosphere Panel from 1988 to 1993, and as its Chair between 1990 and 1993. Susan has published extensively on the alteration history of oceanic basalts, volcanic processes on slow spreading ridges, and the distribution and mineralogy of sulfides from both the TAG and Lucky Strike hydrothermal areas on the Mid-Atlantic Ridge. She is also a widely respected marine educator and lecturer, and the former Dean of the Sea Education Association in Woods Hole. When not at sea, or flying off to attend yet another ODP meeting, Susan can be found at home with her husband Pat tending their chickens and vegetable garden.

An Overview of the New JOIDES Science Advisory Structure

by Maria Mutti

Providing scientific and technological advice to a program as complex as the Ocean Drilling Program, while satisfying the diverse scientific communities as well as the funding agencies of the ODP partners, is a challenging task. The ODP Mid-Term Review Committee in late 1995 recognized that the structure that had evolved to provide this advice had been “outstandingly successful” in maintaining a proposal-driven program while delivering high-quality science. However, with the development of the ODP Long Range Plan, with an emphasis on new directions for ocean drilling, reorganization of the advisory structure to be better aligned with the themes and scientific objectives of the ODP Long Range Plan was recommended.

The process of redesigning the JOIDES Advisory Structure began in early 1996 through the efforts of the Planning Committee and the JOIDES Office (which was then in Cardiff, UK). Taking advice from all the panels and committees within the structure, a simplified JOIDES Advisory Structure was developed that closely reflects the goals of the Long Range Plan but maintains the emphasis on a proposal-driven program. After several iterations and refinements of the new committee and panel structure, their mandates, and terms of reference over the course of a year, the new JOIDES Science Advisory Structure was formally approved at the most recent EXCOM meeting, which took place February 10-12 in Washington DC.

This article is intended to give a brief overview of the new structure and the mandates of the different committees and panels. One important change is that membership for JOIDES Panels and Committees will now be determined by the ODP committee for each member country/consortium, rather than by direct recommendations from the JOIDES Panels and Committees. Although this has been the case for most non-US members in the past, the US Science Advisory Committee (USSAC) will be playing more of a role in the US in determining JOIDES Panel membership. Another important change is a stronger emphasis on collaboration with other international geoscience programs. More information about the new structure is now available under the JOIDES Office web page (http://www.whoi.edu/joides), and a new Guides to the Ocean Drilling Program will be issued later this year.

New JOIDES Science Advisory Structure

JOIDES provides scientific direction for ODP through an advisory structure of panels and committees (Figure 1). The primary governing body of the JOIDES organization is, and will continue to be, the Executive Committee (EXCOM), which consists of representatives of organizations that are partners in the Ocean Drilling Program. A Science Committee (SCICOM) replaces the previous Planning Committee (PCOM) as head of the new JOIDES Science Advisory Structure. However, the mandate of SCICOM is now more narrowly focused on the long-term science planning activities necessary to meet, and go beyond, the goals of the ODP Long Range Plan. In this capacity, SCICOM will prioritize scientific and technological objectives, based on input and advice from the rest of the Advisory Structure, in order to optimize the scientific returns from ODP drilling. In addition, it will take a more proactive role in soliciting drilling proposals to address the scientific themes and initiatives of the ODP Long Range Plan. A subcommittee of SCICOM, the Operations Subcommittee (OPCOM), will deal with

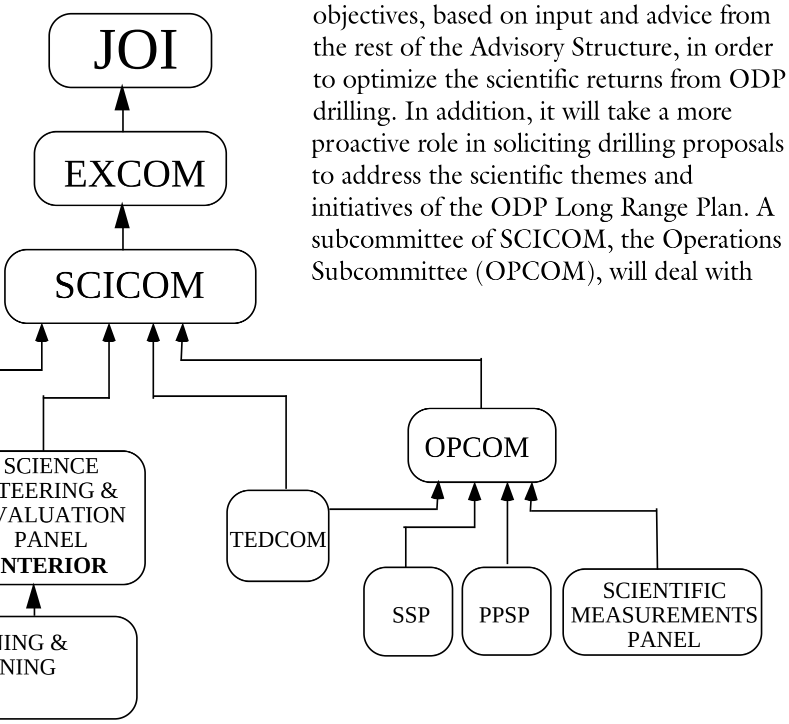


Figure 1. The new JOIDES Scientific Advisory Structure.

many of the logistical and technological implementation issues that previously occupied much of PCOM's time. For the first year, OPCOM will be chaired by the SCICOM Chair and will consist of two other SCICOM members, plus three other members from the international marine geoscience community. OPCOM's responsibilities will include determining drilling schedules (for SCICOM approval) based on the SCICOM ranking of proposals, and advising SCICOM on short-term logistical and technological implementations of highly ranked scientific programs, as well as longer term technological requirements for implementing the ODP Long Range Plan.

SCICOM will receive advice on drilling proposals from two Science Steering and Evaluation Panels (SSEPs) — the Dynamics of Earth's Environment SSEP and the Dynamics of Earth's Interior SSEP — which replace the previous thematic panels. They will provide SCICOM with evaluations of high priority drilling proposals, as well as advice on longer-term thematic development. In order to allow evaluation of interdisciplinary proposals, the SSEP's meetings will be scheduled to overlap by at least one day for joint deliberations. A new aspect of the proposal review process will be the inclusion of external evaluations solicited from members of the geoscience community. External evaluation of ODP proposals has been introduced to broaden the participation of the community in the program, and to ensure that ODP drilling focuses on high priority problems with the potential to yield exciting results and contribute to fundamental advances in understanding earth's history and/or earth's processes. The external evaluation process is still under preparation, but will include changes to the proposal submission process; these will be made available as soon as they are approved.

Program Planning Groups (PPGs) and Detailed Planning Groups (DPGs) are small focused groups that may be created by SCICOM. PPGs will be formed when there is a need to develop drilling programs of technological strategies to achieve the goals of the ODP Long Range plan. They can be appointed for up to three years. DPGs are short-lived groups that may meet only once or twice for more intensive study of certain aspects of planning. For example, as in the previous Advisory Structure, a DPG may be asked to create a viable drilling plan from a series of drilling proposals for a specific scientific objective.

JOIDES Service Panels include the Site Survey Panel (SSP), the Pollution, Prevention and Safety Panel (PPSP), and the new Scientific Measurements Panel (SciMP). The latter replaces the Shipboard and Downhole Measurements Panels, and the Information Handling Panel, and will provide information and advice on the handling of ODP data, samples and information, and on methods and techniques of all ODP measurements, including shipboard and downhole measurements, and experiments. The Service Panels are not directly involved with selection of drilling targets or definition of cruise objectives. The Service Panels will report to OPCOM, although recommendations involving major fiscal decisions or major programmatic changes will be channeled through OPCOM to SCICOM.

The Technology and Engineering Development Committee (TEDCOM) will continue to be charged with recommending the proper drilling tools and techniques to meet the objectives of ODP Long Range Plan, and monitoring the progress of their development.

The new JOIDES Science Advisory Structure will be fully in place by November 1997, after a period of transition that is already underway. The schedule of meetings for this year (See the JOIDES Web site) reflects the timing required to implement the transition, and to ensure that information can be passed from the different panels in a timely manner. This transition towards the new Advisory Structure will be difficult, but its smooth and efficient implementation is in the interest of the entire ODP community.◆

Technological Innovations (Continued from page 20)

The Drill-In Casing concept was tested by ODP and the hammer manufacturer in Australia in mid-1996. In quarry tests, a small hammer was used to drill-in 7" casing. A larger hammer has now been produced and is currently undergoing performance testing by the manufacturer. ODP plans to test this hammer with a 14-3/4" bit to drill-in 13-3/8" casing in early 1997 in order to evaluate a more typical environment prior to sea trials of these systems on Leg 179 in April 1998.

Innovation

Both the Hard Rock Coring System and the Hard Rock Re-Entry System are broad development programs that will each provide incremental advances in our ability to improve core recovery and quality, to diamond core in deep oceans, and to initiate drilling on sloping, hard rock and provide a re-entry hole therein.

These are important and challenging projects that are crucial to technological innovation within the Ocean Drilling Program, and to the accomplishment of the scientific goals of the Long Range Plan.◆

The ODP Science Plan
Legs 176 to 181 (FY 1998) & Legs 182 to 183 (FY 1999)

by Kathy Ellins

The ODP Science Plan for Legs 176 to 183 was developed by the JOIDES Planning Committee (PCOM) in December of 1996 and comprises a series of legs that address important scientific objectives in the ODP Long Range Plan (Table 1). The schedule takes the *JOIDES Resolution* from the Indian Ocean (Leg 176) through the Atlantic sector of the Southern Ocean (Leg 177) to the Pacific margin of the Antarctic Peninsula (Leg 178). From there, the *JOIDES Resolution* will sail eastwards (Leg 179) to the south western Pacific for three Legs around Australia and New Zealand (Legs 180, 182, and 181), and then back to the Indian Ocean (Leg 183) (Figure 1).

Leg 176 will deepen **ODP Hole 735B**, located on a wave cut terrace east of the Atlantis II transform fault in the Indian Ocean. The goal of Leg 176 is drill to a nominal depth of 2 km sub-basement to directly determine the nature of the magmatic, metamorphic, tectonic and hydrothermal processes in the lower ocean crust at a slow spreading ocean ridge. While it is hypothesized that deepening Hole 735B may reach the petrologic Moho, the recovery of a truly representative section of plutonic crust, will, by itself, be a major breakthrough in understanding the geologic processes occurring beneath ocean ridges.

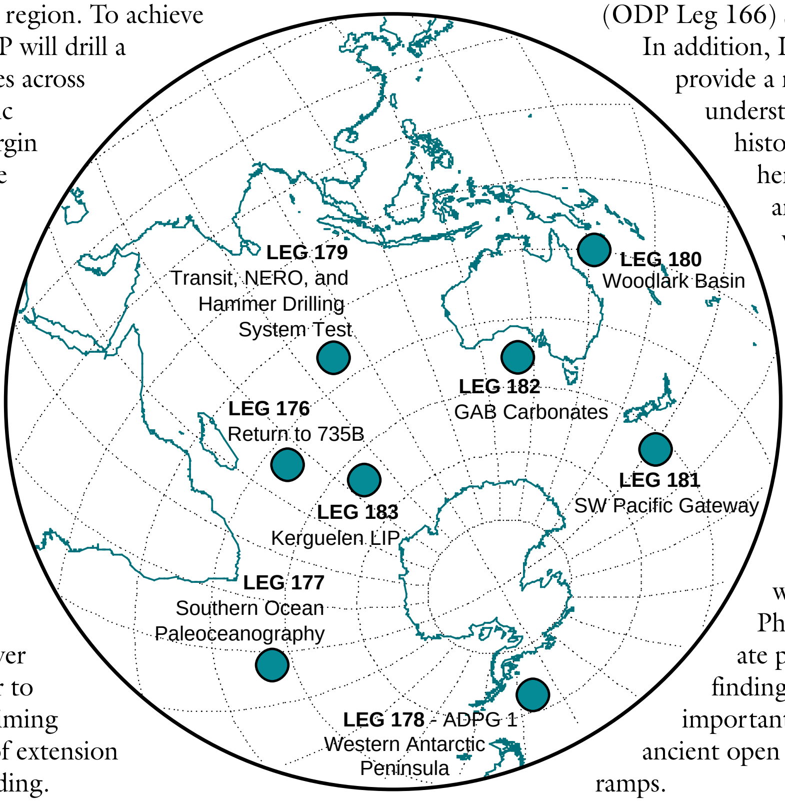
The primary goal of **Leg 177, Southern Ocean Paleocanography,** is to recover a latitudinal and depth transect across the Antarctic Circumpolar Current to document the paleoceanographic and climatic history of the southern high latitudes in the Atlantic sector of the Southern Ocean. This period was marked by major changes in Southern Hemisphere paleogeography, including the gradual isolation of the Antarctic continent and the opening of the Drake Passage. A second major objective of Leg 177 is to obtain expanded sections of late Neogene sediments in order to resolve the timing of Southern Hemisphere climatic events relative to those previously documented in ice cores and sediment records from the Northern Hemisphere. Leg 177 will contribute significantly to understanding the Earth's climatic system by permitting paleoclimatic and paleoceanographic studies on both the long (Cenozoic) and short (orbital and sub-orbital) time scales of the history of the Southern Ocean, a key component of Earth's climate system.

Leg 178 to the margin of the **Western Antarctic Peninsula** is the first in a series of proposed ODP Antarctic drilling legs to study the timing, extent, and variability of the Antarctic ice sheet in order to better understand its effect on global sea level, and its influence on the surrounding ocean. Drilling will recover a direct record of Antarctic Cenozoic glacial history by sampling sediments that have been transported at the base of grounded ice sheets to the Antarctic continental margin, and deposited on the shelf and slope as progradational wedges and on the continental rise in drifts. A single site within the Palmer Deep, a small depression on the western side of the Antarctic Peninsula, will also be drilled to obtain a high resolution Holocene record of paleoproductivity which can be compared with the results of ODP drilling in Saanich Inlet, the Cariaco Basin, and the Santa Barbara Basin. Leg 178 holds the promise of significantly advancing our understanding of the vital role of the Antarctic ice sheet in global climate dynamics by providing an unprecedented high-resolution record of Antarctic continental climate over the past 6-10 Ma.

During the long transit **(Leg 179)** from the Western Antarctic Peninsula to the Woodlark Basin, ODP will drill a borehole into basement on the Ninety East Ridge in the Indian Ocean to provide a site for the installation of a broadband ocean seismometer and instrument package for the International Ocean Network (ION) program. The **Ninety East Ridge Observatory (NERO)** will fill a gap in the Global Seismic Network and permit study of the dynamics of the Indian Plate. Drilling plans entail the reoccupation of either ODP Leg 121 Site 756 or Site 757 and penetration of basement to 100 m to allow the subsequent installation of the instrument package by submersible. Setting the stage for **NERO** underscores ODP's commitment to provide boreholes for conducting long-term experiments.

The **Hammer Drill-In Casing System**, currently under development, will be tested on **Leg 179** at a site yet to be determined. This system uses a 14 $^{3}/_{4}$ inch bit to establish holes on the seafloor in terrain that is difficult to penetrate with current ODP drilling technology. Initial land testing carried out in Australia and Iceland in 1996 have yielded promising results. Additional land tests of the Hammer Drill-In Casing System are planned for 1997.

The role of low-angle normal faulting in continental break-up is a fundamental unanswered question relating to the physical processes and mechanics of lithospheric extension. **Leg 180** drilling will address the nature of low-angle faulting, continental break-up, and the evolution of conjugate rifted margins in the western **Woodlark Basin**, where lateral variation from active continental rifting to seafloor spreading occurs within a small region. To achieve this goal, ODP will drill a transect of sites across the asymmetric conjugate margin to characterize the *in situ* properties of the active low-angle fault zone in the region of continental separation, and to determine the vertical motion history of the upper and lower plates in order to estimate the timing and amount of extension prior to spreading.



Leg 181 is another in the series of ODP Legs to examine the Global Conveyor Belt Model of ocean circulation in key "gateway" areas. An essential feature of the Global Conveyor Belt Model is the circulation of cold, deep Antarctic Bottom Water (AABW), which is believed to be particularly important in controlling Earth's climate. Today, forty percent of AABW enters the world ocean through the **Southwest Pacific Gateway** as a thermohaline-driven Deep Western Boundary Current (DWBC). Leg 181 will drill on the eastern New Zealand Plateau to reconstruct the stratigraphy, paleohydrography and dynamics of the DWBC and related water masses since the early Miocene when plate movements created the first deep-water oceanic gaps south of Australia and South America. This program will provide important information fundamental to understanding world oceanic and climatic histories, and yield the sedimentary sequences needed to address other high-priority problems in Southern Ocean Neogene palaeohydrography, sedimentology, paleoclimatology and micropaleontology.

Leg 182 will drill an array of holes across the **Cenozoic carbonate shelf in the Great Australian Bight** to determine how this platform, the largest cool-water carbonate shelf on Earth today, evolved throughout the past 65 Ma. in response to oceanographic and biotic change, and to document global sea level fluctuations. The results of Leg 182 will complement the findings of the New Jersey (ODP Legs 150 and 174A) and Bahamas (ODP Leg 166) sea level transects. In addition, Leg 182 drilling will provide a more detailed understanding of the history of southern hemisphere climates and global deep water circulation patterns throughout the Cenozoic evolution of the Southern Ocean. Finally, because of architectural and compositional similarities of the Great Australian Bight carbonates with many older Phanerozoic carbonate platforms, the findings of leg 182 will be important for modeling ancient open platforms and ramps.

Leg 183 represents the first leg in a proposed two-leg program to investigate the origin, growth, compositional variation, and subsidence history of the Large Igneous Province (LIP) formed by the **Kerguelen Plateau and Broken Ridge** in the southeastern Indian Ocean. A suite of holes of approximately 200 m basement penetration will be drilled into the plateau and an offset drilling program carried out in the vicinity of major fault scarps. The chief goals of this drilling strategy are to determine the length of time required to form the Broken Ridge-Kerguelen Plateau System and to establish the volume of magmatic products as a function of time, to examine the mechanism of plateau growth, to understand the role of the Kerguelen Plume, and to document the vertical tectonic history of the plateau. The study of LIPs is a high priority in the ODP LRP because they represent the products of the largest volcanic events in Earth history and are indicative of major episodic transfers of heat and mass from the mantle to the lithosphere. Evidence suggests that the intense episodic nature of formation of LIPs resulted in the rapid release of large quantities of volatiles, such as CO_2, which may have had an impact on past climate. ◆

See JOIDES Resolution Operations Schedule on page 26.

Table 1: FY 1998 *JOIDES Resolution* Operations Schedule

Leg	Program	Cruise Dates	Scientific Objectives	Relevance to ODP's Long Range Plan	Links to Initiatives
176	Hole 735B	15 Oct. – 10 Dec. 1997	To deepen Hole 735B in order to determine the nature of the magmatic, metamorphic, tectonic and hydrothermal processes in the lower ocean crust.	• LRP initiative III, "Exploring the Deep Structure of Continental Margins and Oceanic Crust"	ICDP, MARGINS
177	Southern Ocean Paleoceanography	15 Dec. 1997 to 9 Feb. 1998	To reconstruct the paleoceanographic and climatic history of the southern high latitudes.	• LRP Initiative I, "Understanding Natural Climate Variability and the Causes of Rapid Climate Change" • "Understanding Earth's Changing Climate"	ANTOSTRAT IMAGES, MARGINS, NAD
178	Antarctic DPG 1 (Western Antarctic Peninsula)	14 Feb. to 11 April	To advance knowledge of the role of the Antarctic ice sheet in global climate dynamics over the past 6-10 Ma.	• Initiative I, "Understanding Natural Climate Variability and the Causes of Rapid Climate Change" • "Causes and Effects of Sea-Level Change"	ANTOSTRAT IMAGES, MARGINS, NAD Cape Roberts Project
179	NERO Hammer Drilling Test	16 April to 30 May	1) To provide a site for the installation of a broadband ocean seismometer and instrument package for ION; 2) To test the Hammer Drilling System.	• Initiative II, "In Situ Monitoring of Geological Processes"	ION, BOREHOLE SEIZE
180	Woodlark Basin	4 June to 30 July	To investigate the role of low-angle normal faulting in continental breakup, and the nature of the continent-ocean transition.	• LRP Initiative III, "Exploring the Deep Structure of Continental Margins and Oceanic Crust" • "Investigating Deformation of the LIthosphere and Earthquake Processes"	MARGINS IMAGES
181	SW Pacific Gateway	4 Aug. to 29 Sept.	To reconstruct the stratigraphy, paleo-hydrography and dynamics of the DWBC and related water masses since the early Miocene	• Initiative I, "Understanding Natural Climate Variability and the Causes of Rapid Climate Change" • "Understanding Earth's Changing Climate	IMAGES, NAD ANTOSTRAT MARGINS, ICDP
182	Cenozoic Carbonates of the Great Australian Bight	4 Oct. to 29 Nov.	To document the evolution of a large, high-to mid-latitude cool water shelf carbonate platform throughout the past 65 Ma. in response to oceanographic and biotic change.	• "Causes and Effects of Sea Level Change" • "Sediments, Fluids, and Bacteria as Agents of Change" • "Understanding Earth's Changing Climate"	
183	Kerguelen LIP	4 Dec. 1998 to 2 Feb. 1999	To investigate the origin, growth, compositional variation, and subsidence history of the LIP formed by the Kerguelen Plateau and Broken Ridge	• Initiative II, "In Situ Monitoring of Geological Processes" • "Exploring the Transfer of Heat and Material to and from Earth's Interior"	LIPs IAVCEI, InterRIDGE

Janus in January

by Kate Moran

Kate Moran is at the Geological Survey of Canada Atlantic, Dartmouth.

Janus, the new ODP computer database system, was successfully deployed this January on Leg 171B. In addition to drilling and core/sample information, the system now captures paleontological, MST (multi-sensor track), physical property, chemistry and X-ray data directly into the Oracle relational database.The Janus system enables data acquisition and retrieval through both manual and instrumented interfaces which significantly reduces errors, data collection time, and entry of redundant data. Other features include:

- a bar code system for sample stickers;
- use of the computer system at novice and expert levels so that it may be customized for personal preferences;
- a consistent and user-friendly connection to the system through a graphical user interface; and
- database output that can easily be imported into commercial software packages such as Excel and Kaleidagraph.The science party on Leg 171B were able to access and share much data using developmental software to "query" the database and receive the desired information in a useful format.

Visual description of the cores is now being accomplished with a software package called Applecore. This was first used on Leg 169 in its "off the shelf" mode, but was customized for ODP conventions for Leg 171B. This package is still under development, and additional modifications were incorporated into the version used on Leg 172. Applecore forms the basis of a new unified core description system for Janus. In the near future, Applecore will be modified to incorporate structural and hard rock data. The target for completion of these modifications is Leg 176 when Hole 735B will be deepened.

A software package named Paleo now links paleontological data captured directly to the Janus database. Data are entered as paleontological species are identified and species abundances determined. The data can be easily edited at any time so that scientists can be flexible with data entry. Reports are generated by direct queries to the database using the customized paleo software. For example, marker species, age, depth, and depth range can be downloaded from Janus into spreadsheets for interpretation of hole and site age models.

MST data, including GRAPE, P-wave velocity, magnetic susceptibility and natural gamma, were uploaded to Janus and made available to the shipboard party from any computer station. During Leg 171B, reporting software was written to download MST data into Splicer, the custom software used for construction of composite stratigraphic sections at multiple-hole sites. During the Leg 172 portcall, this reporting utility was improved in order to simplify access to Janus from Splicer.

Discrete physical property measurements have seen vast improvements over the past year with upgrades to the Labview interfaces for this diverse mix of instruments. With the new Janus database, the text files generated from these instruments are now uploaded using a simple windows environment. Given the diversity of measurements made in this lab, utilities will be developed for the physical properties specialists to upload and overwrite any data set.

Providing consistent and unified software systems for the chemistry lab has been a challenge during Janus development. Janus interfaces for chemistry are modeled after spreadsheets commonly used in this lab. The interfaces for interstitial waters, gas, and carbonate were completed and successfully tested during Leg 171B. Sample ID's are scanned into the system using a hand-held bar code scanner. The coulometer has recently been interfaced to a Labview application that automatically captures these data into spreadsheet form, reducing tedious data entry. The chemistry software systems will be completed during Leg 172 with the addition of wet rock chemistry and XRD data input and reporting utilities.

Drilling data are now captured to Janus. The drillers used Janus in real-time to track these operations and have suggested some improvements to their Janus data reports that will further assist them.

The highest priority for the next stage of Janus development is visual core description for hard rock and structures. Other developments will include the data capture for paleomagnetics, color reflectance, thermal conductivity and the routine downhole tools.◆

Editor's Note: Kate Moran is Chair of JOI's Janus Steering Committee.

OD-21 - Ocean Drilling in the 21st Century

by Hans Christian Larsen and Ikuo Kushiro

The current Ocean Drilling Program is scheduled to end in 2003, after 35 years and several programs of scientific ocean drilling. Thus, all earth scientists must consider the possibility that this exceptional program may not exist beyond 2003. The function of scientific ocean drilling is not a given, but something the geoscience community must constantly develop and justify. However, planning for the next era of ocean drilling that will build on the Program's remarkable scientific achievements to date is already well underway. New scientific problems, as well as some outstanding, but as yet unattained, scientific objectives have been defined for drilling post-2003 and are presented in the ODP Long Range Plan. Several of the future scientific goals can be achieved with current drilling and logging technology. However, the demands for drilling time, the specialization and the technical requirements of many future drilling experiments will require a new level of drilling capacity and and new capabilities; these must be planned for now, if we are to be ready to continue and develop scientific ocean drilling in the 21st century.

"Ocean Drilling in the 21st Century" (OD-21), the program proposed by JAMSTEC (Japan Marine Science and Technology Center), is welcomed by the international scientific community organized in JOIDES. It envisions scientific ocean drilling that will be further advanced through the construction of a large, deep drilling vessel with riser capabilities that will focus on scientific objectives beyond the current capability of the present ODP and its drilling vessel *JOIDES Resolution*. This initiative provides realistic hope for two, globally operating ships offering complementary drilling capabilities — as envisioned for post-2003 in the ODP Long Range Plan. OD-21 will form part of an integrated, international program of scientific ocean drilling beyond 2003 that will have a scientific advisory structure and a proposal process similar to the present JOIDES structure.

The OD-21 drill ship is expected to be constructed by the year 2003, and will be able to deploy as much as 11 km of drill string and to support large casing programs. It is also planned that it will carry a riser system that allows circulation of density-controlled muds into the borehole and back to the ship. These features will enable deep drilling, drilling through difficult and unstable formations, or a combination hereof. However, direct application of current industrial type risers to deep sea drilling (4000 m+) as required by the scientific community involves extremely large and heavy systems. Hence, construction of a riser system for deep sea drilling is a major engineering challenge that might involve completely new designs and/or materials.

In October, 1996, an International Workshop on Riser Technology was held in Yokohama, Japan jointly organized by JAMSTEC, the Ocean Research Institute of the University of Tokyo (ORI), and the JOIDES Technology and Engineering Development Committee. Representatives from the international science community presented a suite of highly challenging model holes in order to illustrate the types of environments in which deep drilling and use of a mud circulation system is envisaged. Engineers presented tentative thoughts on small diameter systems, riserless systems, etc. which could be developed to meet the scientific and environmental requirements, and demonstrated strong industry interest in pursuing alternative approaches to riser drilling in deep water.

The Workshop also emphasized the need for close linkages between science planning beyond 2003, and the specifications of the new OD-21

APPLY NOW!

CONCORD: CONference on Cooperative Ocean Riser Drilling

22-24 July 1997

National Olympics Memorial Youth Center, Tokyo, Japan

Expressions of interest should be sent by **30 May 1997** to one of the two Co-Chairs: Hans Christian Larsen, Director, Danish Lithosphere Centre, Oester Voldgade 10, 1350 Copenhagen K, Denmark (concord@dlc.ku.dk) or Ikuo Kushiro, Director, Institute for Study of the Earth's Interior, Okayama University, Japan (kushiro@misasa.okayama-u.ac.jp).

Please, provide brief statement of research interest and Working Group preference, fax and phone number when you register at concord@dlc.ku.dk

Additional information regarding the meeting can be found at the Web site: http://www.dlc.ku.dk.

drilling vessel and its drilling system. To do this, an important international meeting will be convened in order to identify the science that will be targeted for the OD-21 vessel, to manifest the international nature of OD-21, and to lay out the specifications that will need careful consideration during the initial planning phase (1998-1999). This meeting, CONCORD (CONference on Cooperative Ocean Riser Drilling), is to be held in Tokyo, Japan on July 22-24, 1997. Planned Working Groups for the meeting are:

- Climate and sea-level change
- Architecture of the oceanic lithosphere
- Continental rifting and LIPs
- Subduction and earthquake processes
- Drilling and tool technology developments
- Borehole and seafloor observatories.

It is critical for the continued development of ocean drilling to secure funding for this important project. The construction phase is budgeted at US$500 million. In order to get funding from the Japanese government for the planning and construction phase, and hence, for the OD-21 program to become reality, the international earth science community must demonstrate its strong support for continued ocean drilling and, in particular, for a vessel capable of deep penetration and hole stabilization. The CONCORD meeting provides that opportunity and the conference report will be part of the final proposal to be submitted by JAMSTEC and ORI later in 1997 to the Japanese government. We hope that you will demonstrate your support by applying for participation in the CONCORD meeting!◆

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Mitch Lyle, Co-Chief Scientist, Boise State University, Idaho; Itaru Koizumi , Co-Chief Scientist, Hokkaido University, Japan; Carl Richter, Staff Scientist, Ocean Drilling Program; Richard J. Behl, Per Boden, Jean-Pierre Caulet, Margaret L. Delaney, Peter deMenocal , Marc Desmet, Eliana Fornaciari, Akira Hayashida, Franz Heider, Julie Hood, Steven A. Hovan, Thomas R. Janecek, Aleksandra G. Janik, James Kennett, David Lund, Maria L. Machain Castillo, Toshiaki Maruyama, Russell Merrill, David J. Mossman, Jennifer Pike, A. Christina Ravelo, Gloria A. Rozo Vera, Rainer Stax, Ryuji Tada, Jürgen Thurow, Masanobu Yamamoto.

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Cause and Effect continued from page 13

(3) Until Leg 174A is successfully completed, no continental shelves will have been continuously cored because of concern for drilling without adequate safety and platform stability technology aboard the *JOIDES Resolution*. We stress that despite this obstacle, samples from this setting are absolutely essential because they provide the spectrum of sediment types that best record the effects and the magnitudes of past sea-level changes.

(4) The shelf sites in carbonate platforms and atolls are generally intensively lithified and it is difficult to recover continuos records necessary to unravel sea level records. Good core recovery in carbonate rocks is a technological challenge that must be overcome before these valuable records can be properly used.

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Leg 169 continued from page 5

Escanaba Trough suggests that the thickness of massive sulfide is little different from the amount exposed above the seafloor (5-15m). The absence of a well-developed, veined feeder zone indicates pervasive diffuse venting of hot fluid over a short period of time rather than long-lived, focused high temperature discharge, as was the case at Bent Hill.

A hydrothermal component in the pore fluids from Escanaba Trough indicates that hydrothermal fluid flow was relatively recent. Both low and high salinity fluids are present indicating phase separation, followed by segregation of most of the low salinity fluids in an unconsolidated sand unit in the interval from 70-120 mbsf. Concentrations of alkalis and other elements indicate that the hydrothermal fluids have interacted extensively with sediment, even though most of the recovered sediment is not extensively altered. Organic matter maturation confirms that the sediments have seen at least a brief pulse of high temperature that locally resulted in generation of minor amounts of hydrothermal petroleum.

Documentation of the contrast between the recurrent, highly focused, long-lived hydrothermal activity that formed large massive sulfide deposits at ODP Mound and Bent Hill and the high temperature, pervasive diffuse flow system that resulted in extensive surface mineralization in Escanaba Trough provides important insight into the ore forming process. Discovery of the unexpected high grade copper replacement mineralization (Deep Copper Zone) below the vein controlled feeder zone mineralization may provide new exploration targets for the minerals industry. While this leg was focused on the genesis of metallic mineral deposits, the Leg had considerable success in unraveling the tectonic and sedimentary history of these sediment cover spreading centers. Post cruise research promises to add greatly to our understanding of these systems. The success of Leg 169 is related in large part to the detailed planning and hard work of the group at ODP/TAMU, especially the engineering group, and is yet another example of how the scientific accomplishments of the Ocean Drilling Program are directly relevant to societally important problems such as natural resource availability.

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