JOIDES Journal

Volume 29, No. 1
Spring 2003

Joint Oceanographic Institutions
for Deep Earth Sampling

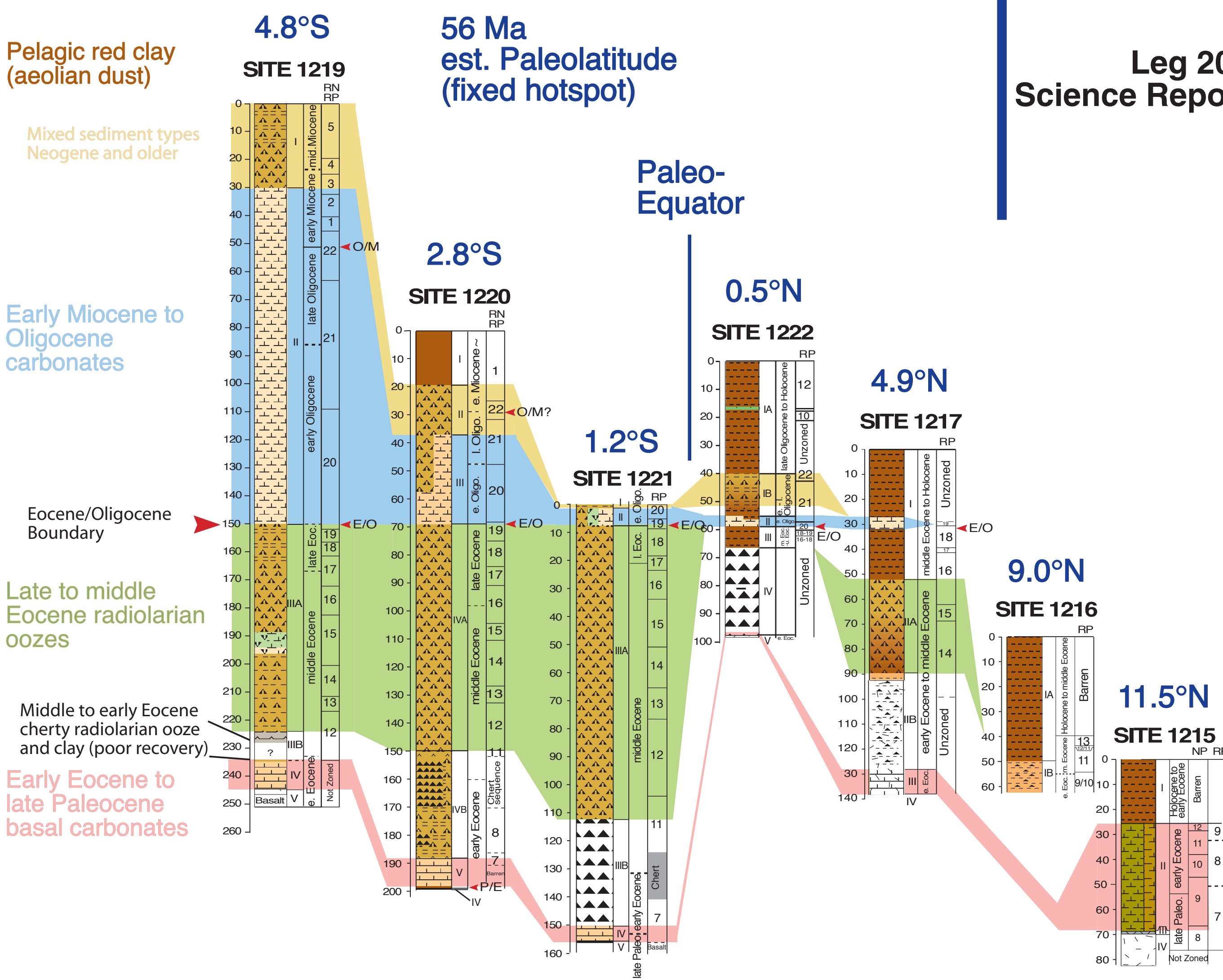
In this issue:

Leg 197 Science Report

Leg 201 Science Report

Leg 202 Science Report

ODP Leg 199 Investigates the "Greenhouse" Eocene in the Tropical Pacific Ocean



Plus:

SCICOM Consensus Statement of Appreciation for the Ocean Drilling Program Delivered at the Final ODP SCICOM Meeting, March 17-20, 2003, Austin, Texas

ODP/DSDP Legacy Holes: A Review of Borehole Installations

In this issue from pages 2-5:

ODP Leg 197: A Paleomagnetic Test for Motion of the Hawaiian Hotspot

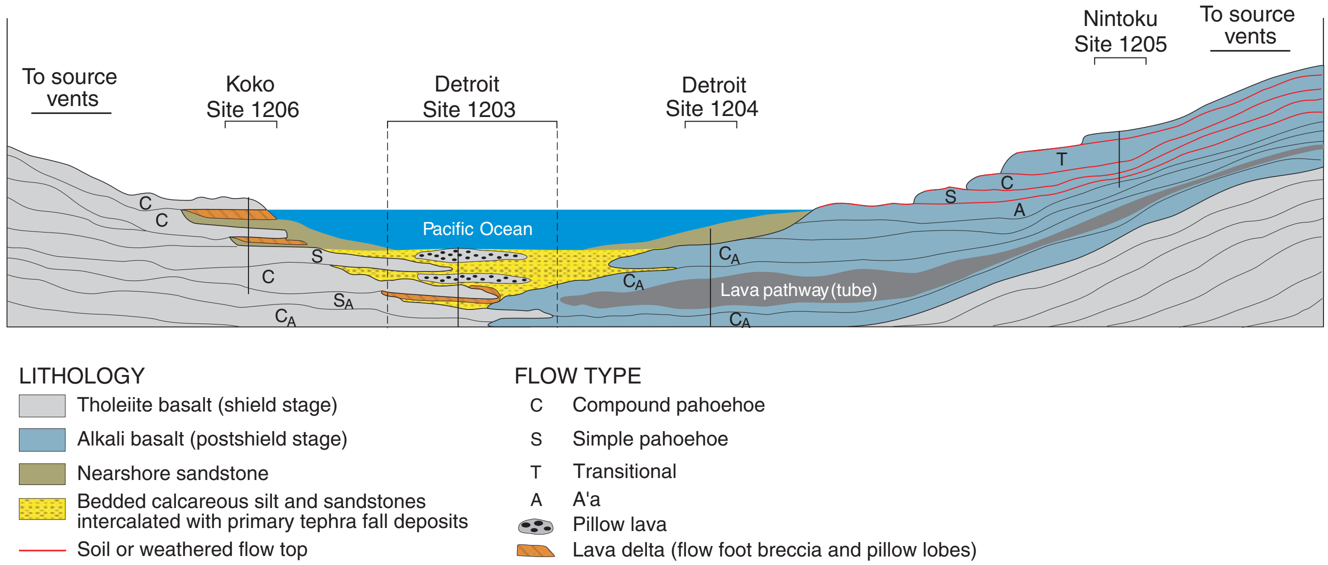


Figure 3. *Schematic drawing (not to scale) showing the inferred volcanic environments for the volcanic sections drilled at Detroit (Sites 1203 and 1204), Nintoku (Site 1205) and Koko (Site 1206) Seamounts during Leg 197. The Detroit lava flows at Site 1204 and the lower part of the Site 1203 section were subaerially erupted (although shown as a submerged sequence following post-eruption subsidence). The lava flows and associated tephra fall deposits in the upper part of the Site 1203 section were emplaced into a low energy shallow marine environment. The Site 1205 lavas were entirely subaerial, as indicated by numerous soil horizons between flows. The 1206 section at Koko consists of lava flows that have flowed from land into water in a nearshore environment. Subscript "A" indicates subaerial lava emplacement.*

In this issue from pages 6-10:

ODP Leg 199 Investigates the "Greenhouse" Eocene in the Tropical Pacific Ocean

Figure 4. *Paleocene-Eocene boundary sections from ODP Leg 199 (Nomura et al., 2002).*

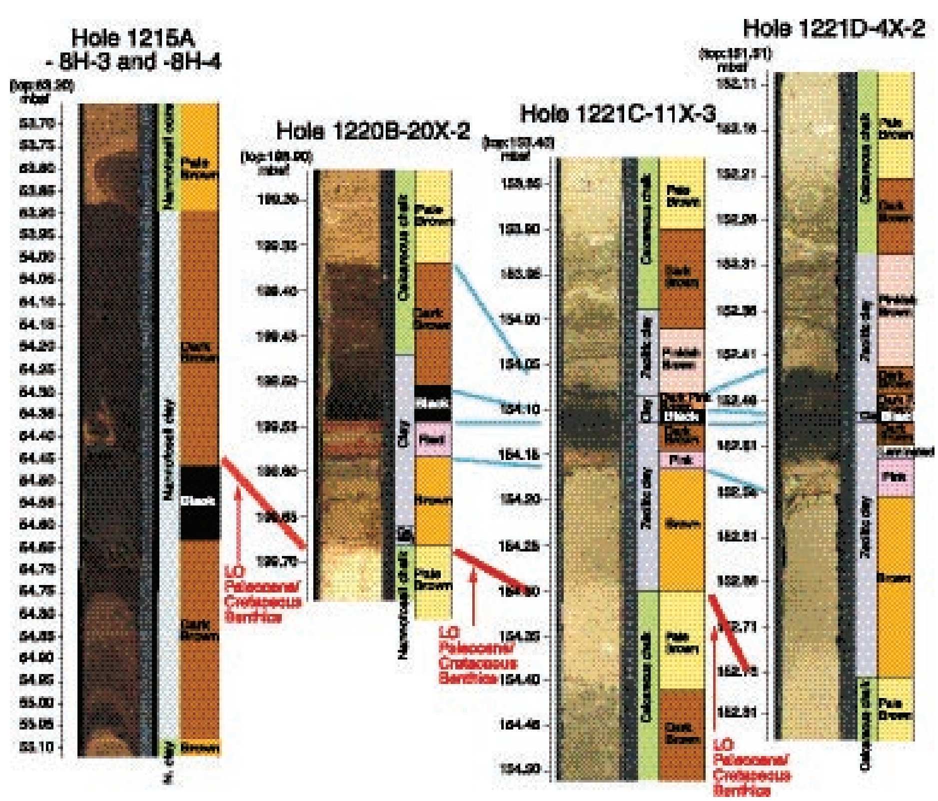


Figure Caption for the Front Cover Illustration:

Figure 2. *Lithologic summary at Leg 199 drillsites. The common reference level is the earliest Oligocene appearance of $CaCO_3$.*

JOIDES Journal

TABLE OF CONTENTS

Volume 29, No. 1
Spring 2003

In this issue:

SCIENCE - Leg Reports

ODP Leg 197: A Paleomagnetic Test for Motion of the Hawaiian Hotspot 2
ODP Leg 199 Investigates the "Greenhouse" Eocene in the Tropical Pacific Ocean 6
ODP Leg 201 Explores Microbial Life in Deeply Buried Marine Sediments off Peru 11
ODP Leg 202: Southeast Pacific Oceanographic Transects 16

SCIENCE/ TECHNOLOGY - Special Report

ODP/DSDP Legacy Holes: A Review of Reentry Holes, CORKs and other Borehole Installations 21

PLANNING - Panel Report

Consensus Statement of Appreciation for the Ocean Drilling Program: Final ODP SCICOM Meeting, March 17-20, 2003, Austin, Texas 27

Leg	Destination	Port (Origin)	Dates[1]	Total days[2] (Port/Sea)	Co-Chief Scientists	TAMU contact
208	Walvis Ridge	Rio de Janeiro	8 March - 9 May '03	62 (5/57)	D. Kroon J. Zachos	P. Blum
209	MAR Peridotite	Rio de Janeiro	9 May - 10 July '03	62 (5/57)	P. Kelemen E. Kikawa	J. Miller
210	Newfoundland Margin	Bermuda	10 July - 9 September '03	61 (5/56)	J.-C. Sibuet B. Tucholke	A. Klaus
	Transit	St. John's	9 September - 21 September '03	12 (1/11)	N/A	N/A
	Demobilization[3]	Galveston	21 September - 30 September '03	9 (9/0)	N/A	N/A

13 April 2003

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

[1] Start date reflects the first full day in port, and is the date of the ODP and ODL cross-over meetings. The *JOIDES Resolution* is expected to arrive late the preceeding day. Port call dates have been included in the dates that are listed.

[2] Although 5-day port calls are generally scheduled, the ship sails when ready.
[3] Demobilization assumes a 7-day (+2 day port call) period tentatively scheduled for Galveston.

SCIENCE
Leg Reports

ODP

ODP Leg 197: A Paleomagnetic Test for Motion of the Hawaiian Hotspot

Robert Duncan [1], John Tarduno [2], David Scholl [3], and the Leg 197 Scientific Party

INTRODUCTION

Many of our ideas of where mantle plumes originate, how they interact with the convecting mantle, and how plates moved in the past rest on interpretations of the Hawaiian-Emperor hotspot track. This lineament is known for its monotonically increasing age progression of volcanoes, and for the prominent bend that marks a change in orientation from the westward-trending Hawaiian Islands to the northward-trending Emperor Seamounts (Fig. 1). The bend, dated at approximately 43 Ma, is often cited as the clearest physical manifestation of a change in plate motion in a fixed hotspot reference frame (Morgan, 1971). However, attempts to reconcile fixed Atlantic and Pacific basin hotspots have failed to predict the bend (Molnar and Stock, 1987).

Norton (1995) suggested that the Hawaiian-Emperor bend records the time when the moving hotspot became fixed in the mantle after moving southward and creating the Emperor seamount chain. Other workers feel the absence of relative motion changes in the North Pacific at the time of the bend is reason enough to question the immobility of hotspots. New modeling efforts, utilizing a viscosity structure based on geoid constraints, mantle flow fields consistent with tomographic data, and plate motion histories, also predict motion of hotspot groups (Steinberger and O'Connell, 1998).

The hypothesis of hotspot motion can be tested independently using paleomagnetic data, and

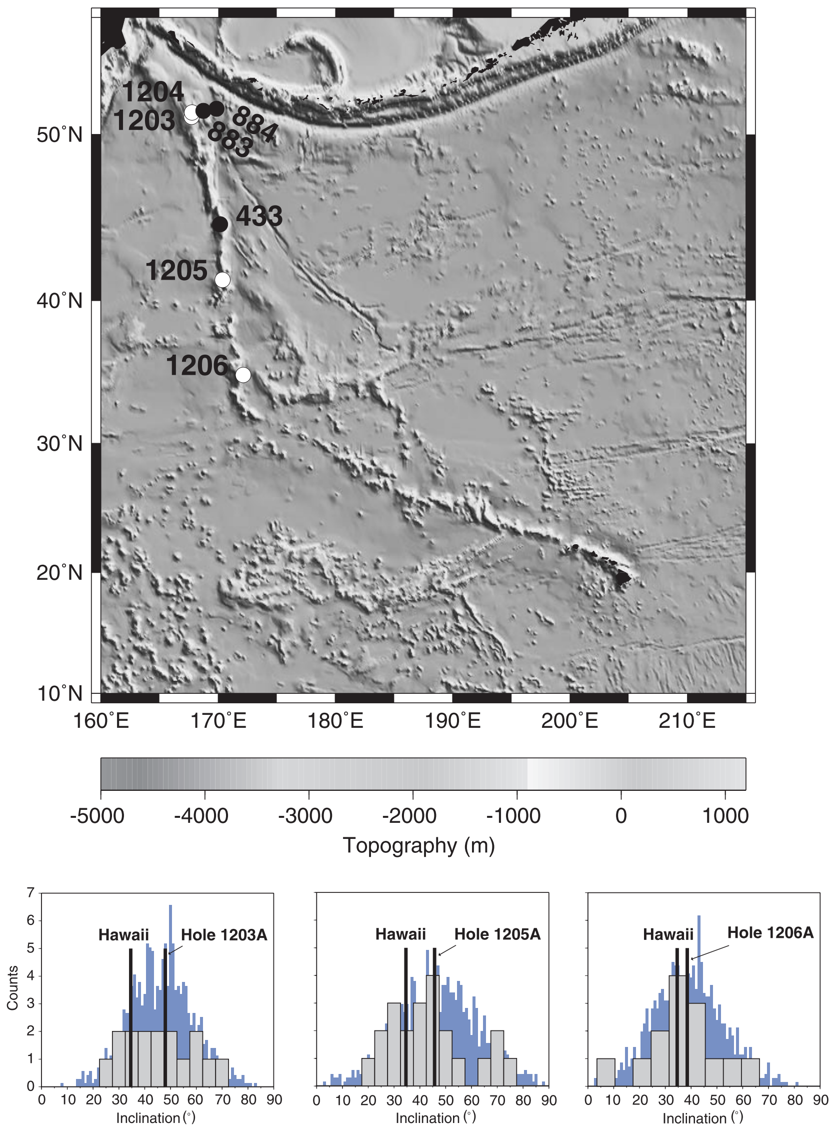


Figure 1. ***Top.*** *Location of Leg 197 sites (open circles) and previous DSDP and ODP sites on the Emperor Seamounts (solid dots). The Hawaiian Islands are at the lower right.* ***Bottom.*** *Preliminary paleolatitudes from basaltic lava flows from Detroit Seamount (Site 1203, 35.2°), Nintoku Seamount (Site 1205, 27.1°) and Koko Guyot (Site 1206, 21.7°) are based on characteristic inclinations derived from shipboard alternating field demagnetization. The darker columns in the foreground are measured inclinations, in 5° bins; in the background are synthetic Fisherian distributions generated from the same mean and precision parameter (k) as the measured data. All paleolatitudes are significantly north of Hawaii, and indicate a southward motion of the hotspot, relative to the geomagnetic pole, during construction of the Emperor Seamounts.*

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most directly by sampling volcanoes that comprise a given hotspot track and measuring the magnetic inclination preserved in well-dated lava flows. In the case of the Hawaiian hotspot, the paleolatitudes of extinct volcanoes comprising the Emperor chain should match the present day latitude of Hawaii if the hotspot has remained fixed with respect to the Earth's spin axis. Until recently, only a few deep sea boreholes had sufficient depth penetration to conduct direct paleomagnetic tests of hotspot mobility. The primary goal of Leg 197 was to obtain accurate and precise paleolatitude and age determinations at several volcanoes along the Emperor chain. The drilling plan was guided by results of analyses of cores recovered during previous drilling at ODP Site 884 (81 Ma) and DeepSEa Drilling Program (DSDP) Site 433 (65 Ma) that indicated significant southward hotspot motion at 3 to 5 cm/yr (Cottrell and Tarduno, 2003).

SCIENTIFIC OBJECTIVES

Drilling objectives at Detroit Seamount Sites 1203 and 1204 were to improve the precision of prior paleolatitude estimates obtained from Site 884 cores recovered during ODP Leg 145. An investigation of how discrepancies between paleomagnetic data and predictions based on fixed hotspot models may have occurred was conducted at the younger Nintoku Seamount (Site 1205) and Koko Guyot (Site 1206). Time-averaged paleomagnetic data from these seamounts, combined with data from Suiko Seamount (Kono, 1980), were and continue to be used in shorebased studies to test existing models and potentially develop new models for the generation of the Emperor seamount trend and the Hawaiian-Emperor bend.

Another Leg 197 objective was to investigate the mantle source and melting history of the Hawaiian hotspot, the most intensely examined hotspot track from a geochemical perspective. An observed range of distinct mantle compositions enables investigation of important issues such as geochemical evolution of the mantle, temporal and spatial scales of mantle convection, and lithosphere-mantle interactions. The Sr-isotope ratios of tholeiitic basalts, for example, show a systematic trend through time (Fig. 2). These ratios are approximately constant along the Hawaiian Ridge out to the 43 Ma bend, and then decrease steadily northwards along the Emperor seamounts to Detroit Seamount to a minimum value within the range for Pacific mid-ocean ridge basalts (Keller et al., 2000). This composition, confirmed with other isotopic and elemental ratios, is unprecedented in the Hawaiian hotspot-produced volcanism to the south, but is consistent with the interpretation from plate reconstructions that the hotspot was located close to a spreading ridge about 80 Ma. The seamount magmas, then, appear to be derived from a mixture of plume ("enriched") and predominantly aesthenosphere ("depleted") mantle sources.

In other locations where plumes are close to ridges (Galapagos Islands, Easter Island, Iceland), the isotopic compositions of hotspot products extend toward Mid-Ocean Ridge Basalt (MORB) values. One possible cause for this effect is that thinner ridge lithosphere would promote a longer melting columns in the plume, leading to greater degrees of partial melting and homogenation of geochemical heterogeneities (Regelous et al., 2003). The degree of geochemical variability at sites

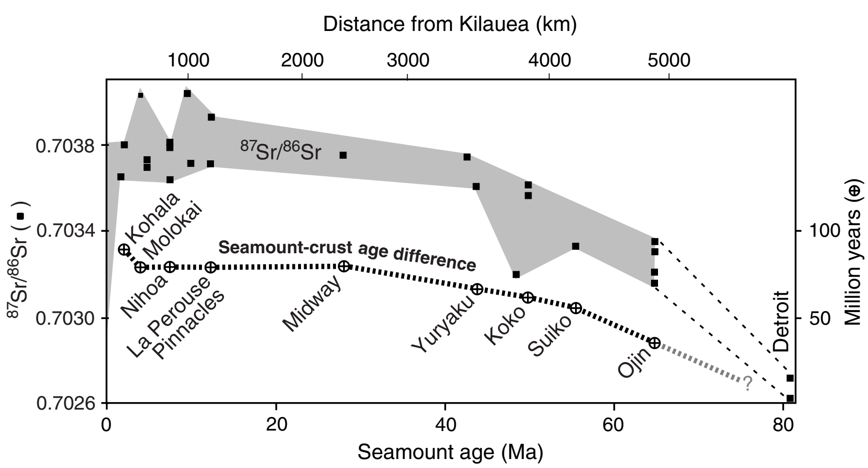

Figure 2. Compositional changes in magmas produced by the Hawaiian hotspot through time. The shaded field shows the range of published $^{87}Sr/^{86}Sr$ of tholeiitic basalts vs. age and distance along the Hawaiian-Emperor chain. Note that data from Detroit Seamount are significantly less radiogenic than at younger volcanoes. The circles connected by the thick dotted line show the trend in age difference between seamounts and the underlying ocean crust (from Keller et al., 2000).

within the Emperor seamounts was not established prior to Leg 197.

RESULTS AND IMPLICATIONS

A significant achievement of Leg 197 was the remarkable depth of borehole penetration into three seamounts. We set a new record for total basement penetration, to 1220 m, and had a core recovery rate of 52%.

Paleomagnetism and the Hotspot Test

Shipboard paleomagnetic and rock magnetic measurements provided a firm basis both for an initial assessment of the results of the Leg 197 paleolatitude experiment and for guiding the shorebased work that must be completed to finalize the hotspot test. The paleolatitudes suggested from our preliminary paleomagnetic analysis of basement cores recovered at Sites 1203 and 1204 (76 Ma), 1205 (56 Ma) and 1206 (49 Ma) clearly differ from the latitude of Hawaii (Fig. 1). The values are consistent with prior data from Suiko and Detroit Seamounts and the hypothesis that the Hawaiian hotspot moved southward from 81 to 43 Ma at rates of 30 to 50 mm/yr. These rates, which are within the range of typical velocities for lithospheric plates, force us to reconsider the cause of the Hawaiian-Emperor bend, rates of mantle convection, and Pacific plate reconstructions based on the fixed hotspot assumption.

Shorebased stepwise thermal demagnetization and rock magnetic analyses will allow us to achieve a confirmation of our preliminary paleolatitude values and may allow us to better constrain the uncertainty limits of each paleolatitude data set. Thermal demagnetization analysis of recovered soils and deeply weathered lava from flow tops recovered in Site 1205 and 1206 cores can potentially provide paleolatitude constraints based on a natural recording medium that averages significantly more time than a given lava flow. We recovered an outstanding collection of basement rocks that will be used to investigate inclination anomalies of geomagnetic origin. These anomalies, while much smaller than those associated with the debate over hotspot drift rates, are nevertheless important for understanding the geodynamo. The strength of the Late Cretaceous geomagnetic field will be assessed from paleointensity data. The results of shorebased thermal demagnetization analyses, combined with rock magnetic measurement data, will allow us to isolate and identify magnetic overprints. If properly understood, such overprints can be used to reorient cores and obtain paleodeclination information (Cottrell and Tarduno, 2003).

In addition to the use of magnetic overprints, we will use Formation MicroScanner (FMS), General Purpose Inclinometry Tool (GPIT) and Deutsche Montan Technologie Digital Color CoreScan (DMT) data to reorient basement cores. Veins and fractures were imaged in the recovered cores with the shipboard DMT system. Similar features were seen in the high-quality FMS images (which are automatically oriented with respect to north with the GPIT data) obtained from downhole logging at Detroit Seamount (Site 1203). Combining these data will produce true paleodeclinations needed to determine a Late Cretaceous paleomagnetic pole for the Pacific plate. Additional constraints on paleodeclination may become available through shorebased analyses of downhole data collected with the Goettingen borehole magnetometer. This was the first deployment of a magnetometer at an ODP site with a sensor to record tool rotation. Preliminary data analyses indicate the rotation history of the tool was successfully recorded.

Source and Melting History of the Hawaiian Hotspot

Observations of lava flow thickness, vesicularity, and crystallinity in the cores, together with analysis of volcaniclastic sediments, provided a picture of eruptions in subaerial to shallow water conditions at Detroit and Koko Seamounts, and waning subaerial activity at Nintoku Seamount (Fig. 3, inside front cover). Further study of all core material and integration with the downhole logging data, particularly FMS images from Site 1203, promise to reveal additional details about eruption rate, volume of flows, and distance from source.

A limited number of shipboard geochemical measurements indicate that we have captured the transition from Hawaiian tholeiitic shield stage to alkalic postshield stage at each of the volcanic complexes. The range of compositions at Detroit Seamount observed in samples recovered from Sites 1203, 1204, 883, and 884 spans most of the variability seen in the volcanoes of the island of Hawaii. Nintoku Seamount (Site 1205) basalts are dominantly alkalic but include tholeiitic compositions, while Koko Seamount (Site 1206) basalts are dominantly tholeiitic but include alkalic basalt compositions. We did not sample any material of the post-erosional stage of evolved compositions that occur at the end of Hawaiian island volcanic activity, except as cobbles in a conglomerate above basement at Site 1205.

We may have sampled different source compositions based on the variability of shipboard trace element ratios such as Ti/Zr. Shorebased studies of additional trace elements and isotopic compositions (Sr, Nd, Pb, Hf and He) are underway to evaluate and define these suspected source heterogeneities. Unaltered olivine, which will be separated for He-isotopic studies, was observed at all sites; fresh glass and melt inclusions in olivine and feldspar will be probed to discover parental melt compositions. Magma evolution will also be addressed through studies of zoned feldspars. Other shorebased studies are focused on opaque minerals that provide information about cooling rates of lava flows and subsequent alteration history, and on low temperature alteration via the composition of secondary minerals in multiple generations of vesicle and vein fillings.

Excellent material was recovered for age determinations; the timing and duration of volcanism will be estimated through ^{40}Ar-^{39}Ar incremental heating radiometric dating. Shore-based research will explore the evidence for prolonged volcanic activity suggested by soil horizons at Site 1205 and alternating shallow water volcaniclastic sediment with subaerial lava flows at Site 1206.

LEG 197 SCIENTIFIC PARTY

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SCIENCE Leg Reports

ODP

Leg 199 Investigates the "Greenhouse" Eocene in the Tropical Pacific Ocean

Mitchell Lyle [1], Paul Wilson [2], Thomas Janecek [3], and the Leg 199 Scientific Party

INTRODUCTION

The Eocene epoch from 55 to 33.7 Ma represents a 21-m.y. geologic interval of relatively stable but warm climate conditions very much different than those of the Pleistocene-Recent Earth. The warmest global temperatures in the Cenozoic occurred in the early Eocene (ca. 50 Ma), but conditions sufficiently warm to support *Metasequioa* forests at paleolatitudes of 80ºN occurred even in the middle Eocene, at roughly 40 to 45 Ma (Christie and MacMillan, 1991). The Eocene epoch is sandwiched between two unique boundary events. The base of the Eocene is now defined by a remarkable carbon isotope excursion that may represent a massive gas hydrate dissociation, methane release, and transient greenhouse warming (Dickens et al., 1995). Just above the Eocene-Oligocene boundary is an oxygen isotope event (Oi-1) that marks the beginning of the first permanent ice sheets on Antarctica (Miller et al., 1987). Understanding how the Eocene began, how warm climate conditions were maintained for 20 m.y., and how climate changed as Antarctica became glaciated are fundamental to understanding basic climate processes on Earth.

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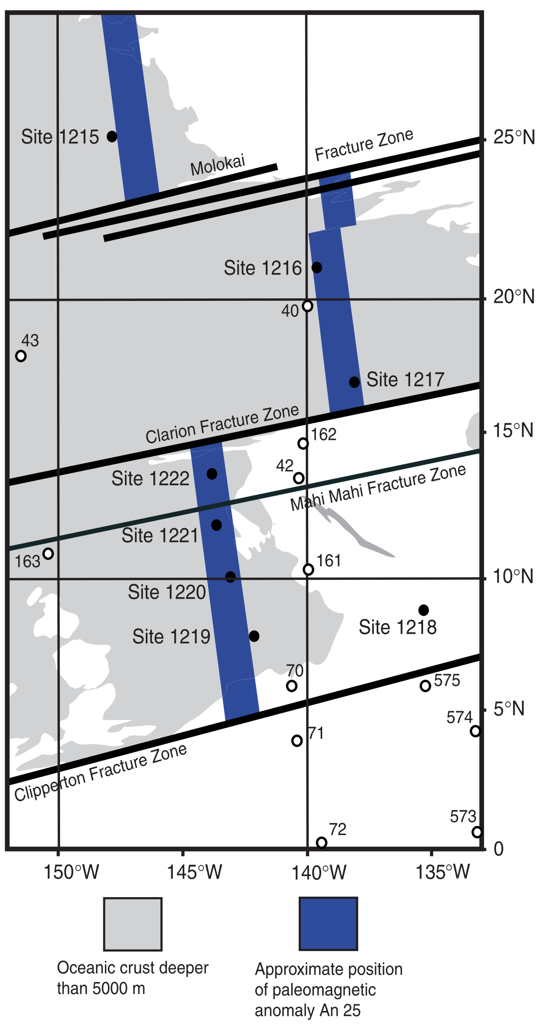

Figure 1*. Map of ODP Leg 199 and DSDP site locations in the central tropical Pacific.*

OBJECTIVES

Leg 199 was designed to explore the evolution of the Pacific equatorial current system as Earth moved from maximum Cenozoic warmth to initial Antarctic glaciations (Fig. 1). In the Neogene, tradewind-induced divergent upwelling along the equatorial region built a >500 m-thick mound of biogenic sediments. The limited information available for the Paleogene suggests that pre-Oligocene latitudinal patterns of sedimentation were significantly different than this narrowly focused Neogene arrangement (Moore et al., 2002). Pacific plate motion transported biogenic sediments of the Paleogene equatorial belt northward with time into a zone of extremely slow sediment (red clay) accumulation. These Paleogene sequences were never deeply buried and can be cored by the ODP's advanced piston core (APC) system. Because of the northward displacement of the Paleogene equatorial region almost no biogenic sediments younger than the early Miocene were found along the transect.

The principal scientific objectives of Leg 199 were (1) to define sedimentation, paleoproductivity, circulation, and wind patterns in the Eocene equatorial Pacific; (2) to study the Paleocene-Eocene and Eocene-Oligocene transitions; (3) to obtain continuous Oligocene and lower Miocene sequences to study the effects of glaciation in Antarctica upon equatorial Pacific circulation; and (4) to improve Paleogene chronostratigraphy and plate motion models so that fluxes of material can be better estimated and paleogeographic positions better known. Boreholes were drilled along a transect of 56 to 57 Ma crust in order to capture the Paleocene/Eocene (P/E), Eocene/Oligocene (E/O) and Oligocene/Miocene (O/M) boundaries. Twenty-one holes were drilled at seven sites (Sites 1215 through 1222; Fig. 1) along the transect extending from a paleolatitude at 56 Ma of ~11ºN to ~4ºS. Site 1218, located in 40 Ma crust, was drilled to collect a near-equatorial sediment sequence from the middle Eocene-late Eocene.

SCIENTIFIC ACCOMPLISHMENTS

A major success of Leg 199 was the recovery of continuous sedimentary records with uninterrupted sets of distinct Cenozoic geomagnetic polarity zones from ca. Chron 20r to Chron 5n (46 to 10 Ma). Shipboard sediment studies revealed fundamental differences in the Pacific equatorial circulation system, ocean chemistry, and plankton ecology during the Eocene compared to the Neogene. These results provide important insights into early Cenozoic oceanography and climate. Details of Leg 199 shipboard results can be found in Lyle et al. (2002).

Major Lithologies of the Paleogene Equatorial Pacific

The sediments of Leg 199 fall into five broad lithochronostratigraphic units (Fig. 2; inside front cover): (1) a surficial red clay (wind blown dust, clay and reworked radiolaria); (2) a nannofossil ooze/chalk unit whose base is just above the E/O boundary and whose top is of early Miocene age in the south (Sites 1218 and 1219) and Oligocene age in the central part of the transect (Sites 1217, 1220, 1221, and 1222); Oligocene-Miocene carbonates are nonexistent in the north (Sites 1215 and 1216); (3) a middle-upper Eocene radiolarian ooze and radiolarian clay present at all sites except northern Sites 1215 and 1216; (4) a lower middle-lower Eocene unit composed of cherts, clays, and radiolarian ooze that is present in varying thicknesses at all Leg 199 sites along the 56 Ma transect except one in the extreme north (Site 1215); and (5) a lower Eocene-upper Paleocene nannofossil ooze or chalk resting upon basalt basement.

Timescales, Rates and Stratigraphic Correlation

Stratigraphic intercalibration of the Paleogene was a major accomplishment of Leg 199. The continuous sediment record recovered from the Paleogene and early Miocene equatorial Pacific Ocean contained ubiquitous biogenic silica, a high-quality record of magnetic reversals, and an archive of biogenic carbonate for establishing an intercalibrated tropical Pacific Ocean reference section of siliceous and calcareous microfossil events, all tied directly to the geomagnetic reversal history. Periodic variations of lithological parameters, such as bulk density and magnetic susceptibility, will allow the calibration of these datum events to Earth's orbital variations, thus giving independent time constraints for the late middle Eocene to the early Miocene. Sedimentation rates averaged around 10 m/m.y., with higher rates during the early Oligocene and across the Oligocene-Miocene boundary, thus resolving lithological variations on an orbital time scale. We were able to correlate lithological characteristics between drillsites hundreds of kilometers apart. The large spatial scale of even relatively minor Paleogene paleoceanographic events is thus similar to spatial scales in the Neogene equatorial Pacific (Shackleton et al., 1995).

Biogenic Fluxes and Paleoproductivity

Paleoproductivity, based on calcium and silica mass accumulation rates (Fig. 3), was significantly different during the Eocene compared to modern conditions. The equatorial region exhibited modest biological productivity over a broad latitudinal span in the early Eocene. Productivity in the middle Eocene increased several fold but continued to have a latitudinal distribution, with significant biogenic sediments being deposited at >10°N paleolatitude. The late Eocene zone of biogenic deposition shrank to within ±3° of the equator. The Neogene is dominated by calcareous plankton (e.g. coccolithophoriods, foraminifera) and diatoms, but the Eocene assemblages consist primarily of radiolaria, siliceous skeleton-building heterotrophs that have never again achieved such dominance.

In contrast, Oligocene productivity and fluxes were narrowly focused at the paleo-equator, with high biogenic calcium carbonate accumulation and a much deeper calcium carbonate compensation depth (CCD). This shift appears to record a fundamental response to changing atmospheric and oceanic circulation patterns concomitant with a climate change from a warm early Eocene to cooler Oligocene, with a large ice cap on the South Pole.

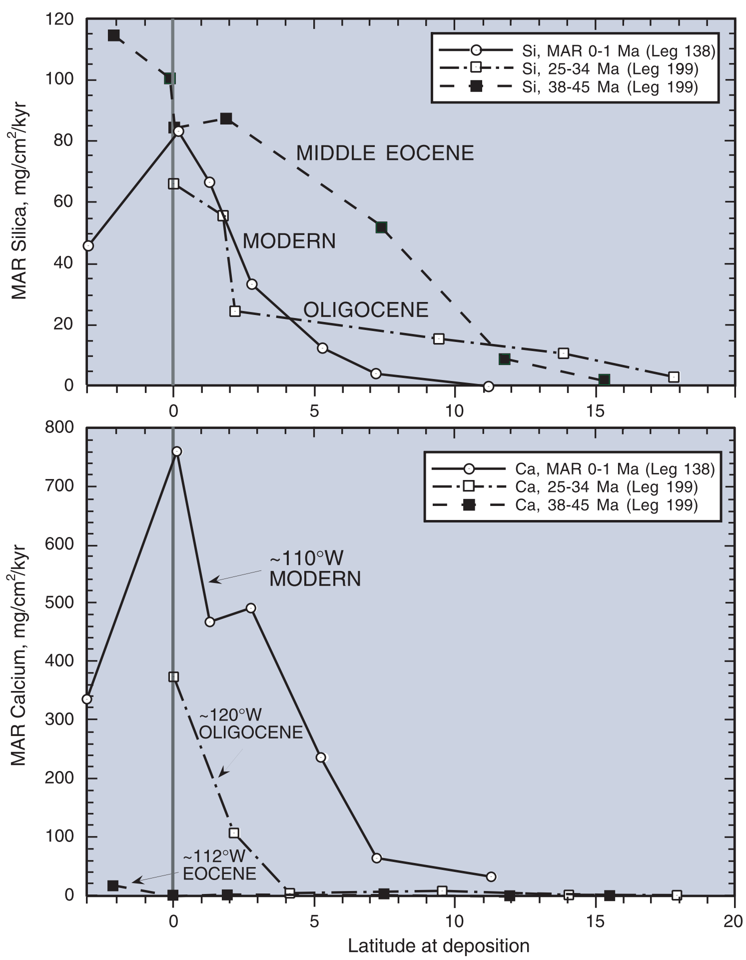

Figure 3. *Calcium and silica mass accumulation rates (MAR) profiles for the Pleistocene (0 to 1 Ma), Oligocene, and middle Eocene. Late Pleistocene data are from Farrell et al. (1995).*

Oligocene-Miocene

Complete and continuous Oligocene sequences extending through the upper Oligocene into the lower Miocene were recovered from Site 1218 and 1219 boreholes. These cores also display unambiguous magnetostratigraphy, and a series of biostratigraphic events in calcareous nannofossils, planktonic foraminifers, and radiolarians that afford direct correlation to previously drilled sites without magnetostratigraphy. Sedimentation rates in the Oligocene and through the O/M boundary average between 10 to 20 m/Myr before the disappearance of biogenic sediments near the end of the early Miocene. Sedimentation rates are sufficiently high to permit the development of a standard Pacific reference stable isotope stratigraphy and Mg/Ca data set that can be correlated at orbital resolution to records throughout the tropical and subtropical oceans. The excellent timescales for Site 1218 and 1219 will help to evaluate the rates of change in ice volume and deep ocean temperatures during the early years of Icehouse Earth.

Eocene/Oligocene boundary and Paleogene CCD shifts

The unique boundary events that define the beginning and end of the Eocene were recovered at multiple drillsites. Complete E/O boundary sections recovered in cores from Sites 1217, 1218, 1219, 1220, and 1221 with unprecedented magneto- and cyclostratigraphic age control. The sediments document an extremely rapid transition to the proto-modern sedimentation pattern of the Oligocene, associated with the Oi-1 glaciation of Antarctica. Elsewhere in the deep oceans this important paleoceanographic boundary is often characterized by condensed sequences containing poorly preserved microfossils or a hiatus.

The E/O transition is instantly recognizable in the equatorial Pacific by a sharp upsection shift from opal-rich (dark-colored) to carbonate-rich (light-colored) sediments. At Site 1218, the location of the shallowest Leg 199 boreholes, the shift occurs in two steps of about 40% $CaCO_3$ each. The pronounced deepening of the CCD indicated by the sudden appearance of carbonates just above the E/O (van Andel et al., 1975) raises the intriguing possibility that this pronounced deepening of the CCD is in some way related to the first widely accepted sustained glaciation in Antarctica (Oi-1). The sharp transition from carbonate-free to carbonate-bearing sediments, typically occurring over a 10- to 20-cm interval, implies that the changes in ocean chemistry that depressed the CCD occurred over only a few tens of thousands of years. A major and rapid global climate switch must have been crossed near the E/O boundary. Understanding this climate switch and how it is linked to tectonic reorganizations or to declines in atmospheric CO_2 (e.g., Exon et al., 2001; DeConto et al., 2003) will provide important new understanding of global climate.

Paleocene/Eocene Boundary

The Paleocene/Eocene (P/E) boundary is marked by a pronounced negative excursion in $\delta^{13}C$, transient global warming, and mass extinction of benthic foraminifers, implying rapid and significant alteration of deep ocean chemistry and habitats. We recovered P/E boundary sections in cores at Sites 1215, 1220 and 1221 (Fig. 4; inside front cover) from paleolatitudes of approximately 1ºS to 11ºN. The P/E boundary sediments recovered at Sites 1220 and 1221 display a lithologically remarkable and complicated stratigraphy composed of highly colored clay and chalk. Sediments change from Paleocene calcareous chalk to brown, pink, black, and dark brown beds just above the last Paleocene benthic foraminifers. The distinctive multicolored banding and layering of the P/E boundary can be correlated between Sites 1220 and 1221, 206 km apart. The boundary interval also contains abundant *Thoracosphaera* dynoflagellate cysts. Thoracosphaerid blooms, previously recorded at the Cretaceous/Paleogene mass extinction, are thought to represent opportunistic post-disaster taxa (Brinkhuis and Biffi, 1993).

LEG 199 SCIENTIFIC PARTY

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ODP Leg 201 Explores Microbial Life in Deeply Buried Marine Sediments off Peru

Steven D'Hondt [1], Bo Barker Jørgensen [2], D. Jay Miller [3], and the Leg 201 Scientific Party

INTRODUCTION

The principal objective of ODP Leg 201 was to document the nature, extent, and biogeochemical consequences of microbial activity and prokaryotic communities in different deeply buried marine sedimentary environments. Seven sites were located in open ocean sediments of the equatorial Pacific and the Peru Basin, ocean margin sediments of the Peru continental shelf, and hydrate-bearing deep water sediment of the Peru continental slope (Fig. 1). We drilled up to 420 m into oceanic sediments and the underlying basaltic crust in water depths as great as 5300 m and as shallow as 150 m. Sediment temperatures ranged from 1°C to 25°C and sediment ages from 0 to almost 40 m.y.

Three fundamental questions about the deeply buried biosphere were addressed during Leg 201. Are different sedimentary geochemical regimes characterized by completely different prokaryotic activities and communities, or merely by shifts among the dominant species and different levels of community activity? How does the transport of electron acceptors, electron donors, and, potentially, of prokaryotes through deep sediments affect sediment chemistry and community structure? To what extent do past oceanographic conditions affect prokaryotic communities now active in deep-sea sediments?

Leg 201 shipboard biogeochemical, geophysical, and sedimentological studies provided new understanding of the effects of interstitial water chemistry, sediment composition and structure, fluid flow, and past oceanographic conditions on metabolic diversity, prokaryotic activities, and the nature of metabolic competition in these subsurface environments (D'Hondt et al., 2003). These studies have improved our understanding of how deep subsurface biogeochemical processes affect both their local environments and the surface world. Other aspects of these questions, such as genetic assays of the prokaryotic communities and isotopic studies of biogeochemical fluxes, require extensive postcruise research.

SCIENTIFIC APPROACHES

The study of deep subsurface prokaryotes and their activity is a methodological and experimental challenge at the frontiers of modern life and Earth sciences. Leg 201 was the first deep-sea drilling expedition dedicated to the study of life deep beneath the seafloor.

All shipboard analyses and downhole studies were closely integrated to maximize the scientific utility of Leg 201 results. Physical

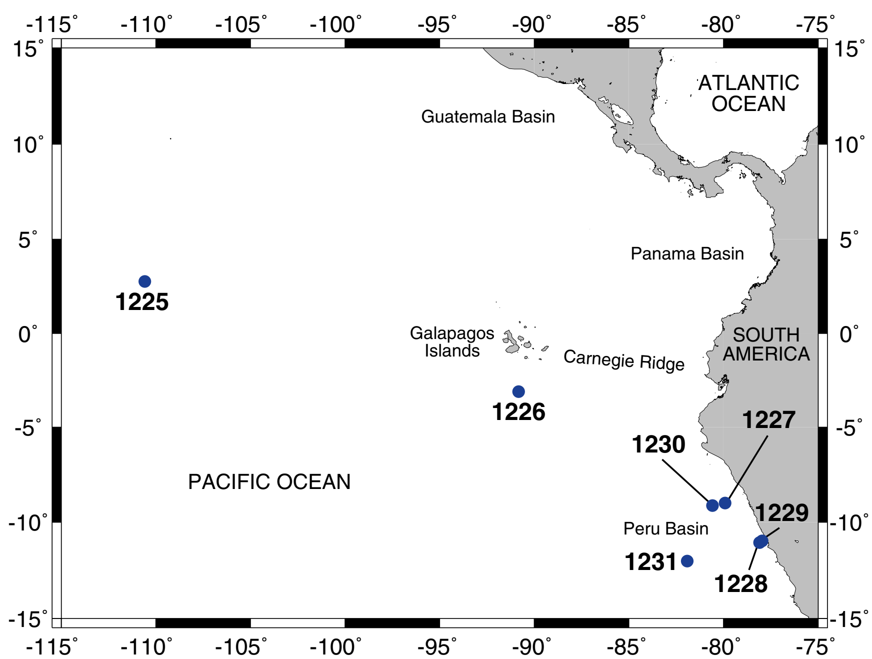

Figure 1. Location map of seven ODP Leg 201 drillsites off Peru.

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properties, sedimentology, and downhole studies provided detailed evidence of the environmental factors that influence subseafloor microbial life and are, in turn, influenced by it. Biogeochemical studies provided comprehensive records of net microbial activities and their consequences. Microbiological studies provided a strong basis for comprehensive records of subseafloor prokaryotic communities. Whenever possible, a full range of environmental, geochemical and biological analyses were conducted on the same sediment samples or samples immediately adjacent to each other.

PRINCIPAL RESULTS

Subseafloor Microbial Communities and Activities in Different Sedimentary Environments

Direct cell counts showed that prokaryotic cell concentrations are generally much higher in sediments buried on the continental shelf of Peru than in sediments of the open Pacific Ocean (Fig. 2A). The open Pacific sites contained some of the lowest average cell concentrations ever observed in deep-sea sediments. In contrast, some sediments recovered on the Peru shelf contained the highest concentrations of prokaryotes ever observed beneath the seafloor. At the Peru shelf sites, the concentration of sedimentary prokaryotes was highest in a narrowly focused zone of anaerobic methanotrophy tens of m beneath the seafloor.

Interstitial water studies of Leg 201 sediment cores showed that net subseafloor microbial activity, as measured, for example, by concentrations of dissolved inorganic carbon (DIC = HCO_3- + CO_3^{-2} + CO_2) and ammonium, also is much higher at ocean margin sites than at open ocean sites (Fig. 2B). DIC and ammonium are generic products of microbial activity, regardless of the principal electron-accepting pathway. Consequently, the interstitial concentrations of these dissolved chemicals at Leg 201 sites suggest that net respiration of organic carbon to CO_2 and net mineralization of organic nitrogen to ammonium is much higher

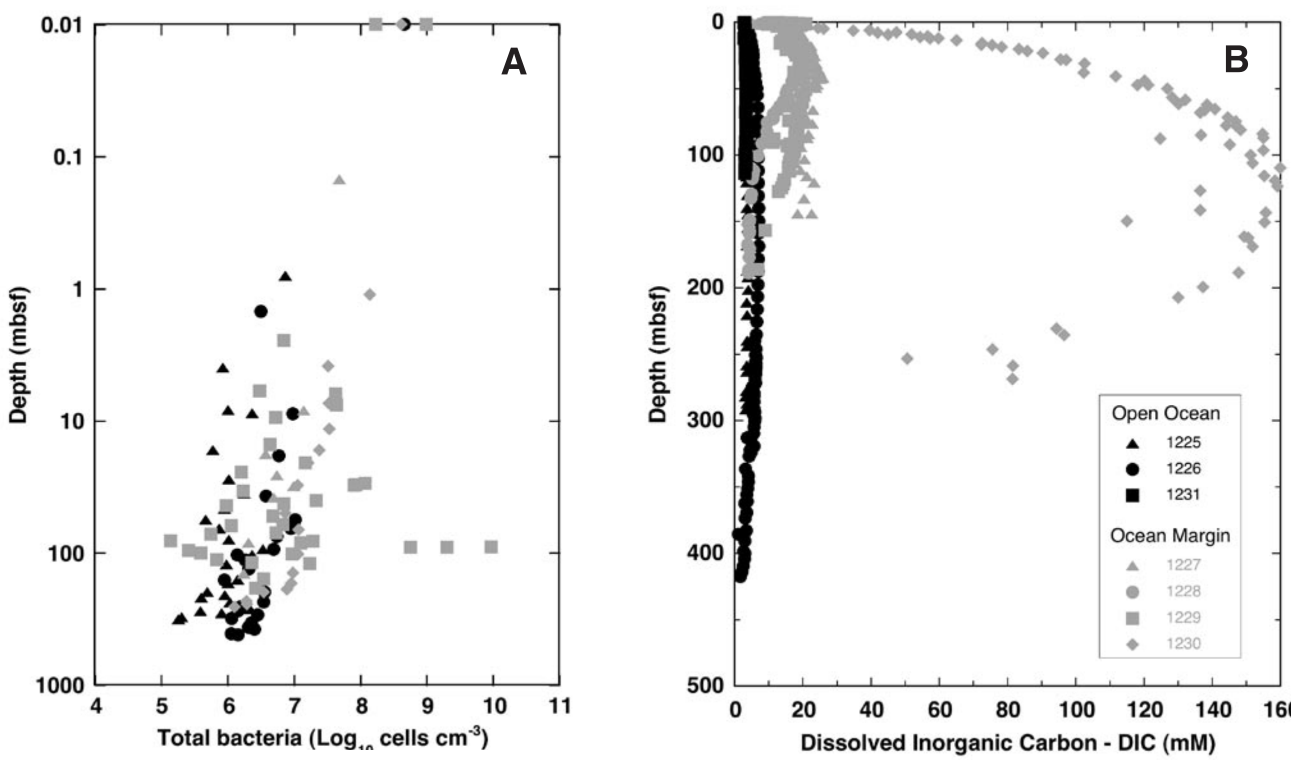

*Figure 2. **A.** Estimates of cell concentrations in Leg 201 sediment samples. Legend given in Fig. 2B. **B.** Dissolved inorganic carbon (DIC) concentration profiles for Leg 201 sediment samples. In both figures the gray symbols represent open ocean sites, black symbols represent Peru Shelf sites, and gray diamonds represent the hydrate-bearing Peru Trench Site.*

in subseafloor sediments of the ocean margin than in subseafloor sediments of the open ocean. Peak DIC and ammonium concentrations, like cell concentrations, increase from open ocean sites to ocean margin sites (Fig. 2B). This similarity suggests that subsurface cell concentrations are related to net subsurface microbial activity.

Profiles of dissolved chemicals in interstitial waters also document the subseafloor occurrence of specific microbial processes. Despite the large apparent differences between net microbial activities of the ocean margin sites and those of the open ocean sites, all of the microbial processes that we inferred to occur in subsurface ocean margin sediments also appear to occur in subseafloor open ocean sediments. These processes include sulfate reduction, iron reduction, manganese reduction, and methanogenesis, as well as the production and destruction of formate, acetate and hydrogen. Unexpectedly, Leg 201 studies also showed that both ethane and propane are biologically created and destroyed in parallel with methane at both open ocean and ocean margin sites.

Influences of Subseafloor Flow and Brines on Microbial Activities and Sediment Chemistry Deep in the Sediment Column

Classic models of microbial activity in marine sediments assume that the oxidants (electron acceptors) used to support respiration by sedimentary prokaryotes are introduced to the sediment through the sediment/water interface. Sulfate is the most common electron acceptor in marine sediments. Oxygen and nitrate are the electron acceptors that yield the highest free energies. Sulfate, dissolved oxygen, and nitrate are all introduced to the subseafloor realm by diffusion from the overlying ocean (Jørgensen, 2000). Studies at open ocean Leg 201 Sites 1225 and 1231 showed that nitrate and traces of oxygen also enter at least some deep sea sediments by diffusing or advecting upward from waters flowing through the underlying basaltic crust. In this manner, electron acceptors with high free energy yields enter deep in open ocean sediment columns. Conversely, downward diffusion from the sediment into the water flowing through the basement strips away products of microbial activity, such as methane, ammonium, and DIC. In both processes, chemical exchange between the sediment column and the underlying basement mirrors diffusive exchange across the sediment/ocean interface. The discovery that nitrate and dissolved oxygen enter the sediment column from the formation waters of the underlying basalt implies that, at least in some areas, microbial activity within the basalt is insufficient to strip even the scarcest preferentially utilized electron acceptors from the water that flows through it.

At the Peru shelf sites, chemical species diffuse upward from underlying Miocene brine. For example, dissolved sulfate at Site 1229 diffuses upward into methane-rich Pleistocene sediment. Downhole profiles of dissolved sulfate, methane, acetate, and barium show that chemical distributions at the lower (brine-controlled) sulfate/methane interface mirror those of the overlying “normal” sulfate/methane interface. Cell counts and the pronounced inflections in chemical profiles demonstrate that the subseafloor prokaryotic cell populations and activity are focused at the lower sulfate/methane interface. Perhaps the most striking feature of this interface is its thousand-fold increase in cell concentrations relative to the sediments that lie immediately above and below it (Fig. 2A). The observed cell concentrations at this interface are an order of magnitude higher than the concentrations observed at the seafloor.

Interplay Between Microbial Activities, Ocean History, and Sedimentary Properties

Sedimentary properties and, by inference, past oceanographic conditions at all sedimentary environments sampled during Leg 201 affect the current rates and sediment depths of several principal microbial activities, including manganese reduction, iron reduction, and sulfate reduction. This result was most broadly demonstrated by the general correspondence between each site’s geographic location (open ocean, equatorial upwelling, or coastal upwelling) and its current cell concentrations and concentrations of metabolic products (e.g., DIC and methane). Stratigraphic relationships between interstitial water chemistry, lithology, and physical properties at individual sites also were observed.

Leg 201 studies indicated that the relationship between microbial activities and sediment properties is dialectic; each affects the other. This relationship is most clearly expressed in chemical profiles for cores from ocean margin sites, where microbial activity is highest and where the precipitation and dissolution of a number of minerals, including pyrite, barite, dolomite, and apatite, are catalyzed by microbial activities.

Structure of Subseafloor Microbial Communities

A broad range of microbiological studies was initiated during Leg 201 to study the diversity and population size of subsurface prokaryotic communities and to analyze the pathways and rates of their metabolic activities. Many of these studies did not yield immediate results, partly because deep subsurface prokaryotes are expected to grow slowly and partly because the research requires special analytical equipment available only in shorebased laboratories.

A very large number of microbial cultivation experiments were initiated during Leg 201 to isolate and identify a broad spectrum of microorganisms with respect to energy metabolism (general heterotrophs; fermenters; autotrophic and heterotrophic sulfate reducers, methanogens, and acetogens; iron and manganese reducers; anaerobic ammonium and methane oxidizers), temperature adaptation (psychrophiles, mesophiles, and thermophiles), and/or different pH, salinity, pressure requirements, and survival strategies (e.g., spore formers). Some cultivation experiments focused on syntrophic consortia and others screened for different substrate concentration requirements, served as starting material for isolation of specific prokaryotes, and served to detect minimal growth.

The genetic diversity and geographic continuity of subseafloor prokaryotic populations are being addressed by postcruise research that largely relies on the recently developed approach of analyzing nucleic acids from entire communities in natural samples. Consequently, an extensive Leg 201 sampling scheme was developed for such postcruise analyses.

An important goal of Leg 201 was to identify and quantify dominant microbial processes in the deep subsurface. Experiments using radioactive or stable isotope tracers were conducted on the *JOIDES Resolution* to identify gross rates of specific microbial processes such as sulfate reduction, methanogenesis, acetogenesis, anaerobic methane oxidation, acetate and hydrogen turnover, and prokaryotic growth using thymidine and leucine incorporation. Although specific activities are generally limited to a subset of the prokaryotic community, they typically serve a crucial role in the flow of energy and material through the entire community. Most of these experiments were terminated by the end of the cruise, and specific activities are now being measured in shorebased laboratories. The results of these experiments will be compared to net rates obtained by modeling of interstitial water chemical gradients.

Total cell numbers of prokaryotes were determined during Leg 201 by direct microscopy of fluorescently stained cells, a standard approach on many ODP legs in the past decade. Such studies do not distinguish between different kinds of prokaryotes or between active and inactive cells. Consequently, counts of defined groups of prokaryotes (e.g., Archaea and Bacteria) are now underway using fluorescence *in situ* hybridization to specifically stain active cells that share genetic sequence information.

Contamination Tests

The study of deep subsurface prokaryotic communities is highly dependent on rigorous contamination control. Consequently, the refinement of routine methods for testing and avoiding potential contamination was an important part of the microbiological work initiated during Leg 201 (House et al., 2003). We relied on a chemical tracer (perfluorocarbon) to monitor sample contamination by drill water, and on fluorescent beads to evaluate the extent to which contaminating prokaryotes may have penetrated into a sample. Our experiments showed that core centers are much less contaminated than core peripheries, and that advanced hydraulic piston corer (APC) cores are generally much less contaminated than extended core barrel (XCB) cores. In both core types, potential contamination was highly irregular from sample to sample. We recommend that contamination tests in future experiments be conducted specifically on the same sample used for a microbiological experiment to assess that sample's contamination potential.

Samples specifically used for isolations and viable bacterial counts during Leg 201 were generally proven by our contaminant tracing tests to have very low or undetectable contamination. Rigorous contamination controls and aseptic sampling techniques will ensure that deep subsurface samples can routinely be obtained without the introduction of microorganisms from the surface environment.

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ODP Leg 202: Southeast Pacific Paleoceanographic Transects

Ralf Tiedemann [1], Alan Mix [2], Peter Blum [3], and the Leg 202 Scientific Party

INTRODUCTION AND OBJECTIVES

Leg 202 set out to examine the oceanic, climatic, and biogeochemical systems in the southeast Pacific Ocean on time scales including tectonic (>10^6 yr), orbital (10^4 to 10^6 yr), and centennial to millennial (10^2 to 10^4 yr). A total of 7081 m of sediment were recovered from boreholes at 11 sites that span latitudes from 41°S to 8°N and water depths from 490 m to 4070 m (Fig. 1, inside back cover). Shipboard use of a new rapid-scanning core logger (up to five times faster than the familiar ODP Multi-Scanner Track) helped to optimize drilling strategy, and made time for extensive Advanced Piston Coring (APC) overdrilling that improved total recovery, including some of the longest APC-cored intervals in ODP history (six boreholes cored to >250 m, with some spanning ages 0 Ma to 32 Ma). Other innovations include the use of a nonmagnetic core barrel that significantly improved paleomagnetic stratigraphies. The combination of detailed magnetics and biostratigraphies biostratigraphies based on all major fossil groups provided a unified chronologic framework at sites that range from cool transitional to warm tropical settings.

Drilling addressed hypotheses on (1) the evolution of the South Pacific in response to major tectonic and climatic events, such as the opening of the Drake Passage, uplift of the Andes Mountains, closure of the Panama Isthmus, and major expansion of polar ice sheets in both hemispheres; (2) linkage between climate changes in the high latitudes and the equatorial Pacific related to rhythmic changes in Earth's orbit and the relationship of such changes to known glacial events of the Northern Hemisphere; and (3) regional changes in climate, biota, and ocean chemistry on scales of centuries to millennia and their timing in view of the temporal offset pattern of polar warming and cooling between both hemispheres.

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RESULTS

Pore Waters and Biogeochemical Constraints

Geochemical data revealed the role of organic matter oxidation on interstitial water chemistry and sediment diagenesis, and constrained the interpretation of climate and biogeochemical changes from sedimentary records. Sites characterized by complete sulfate reduction (Sites 1232 to 1235, 1239, and 1242) were influenced more heavily by authigenic carbonate remineralization. Sites with little or no sulfate reduction (Sites 1236, 1237, and 1241) had very little remineralization and thus offer opportunities for development of exceptionally long paleoceanographic records. Chloride decreases in interstitial waters of cores recovered from Sites 1233 and 1235 on the Chile margin gave clear evidence of methane hydrates, while active fluid flow in the underlying basement was revealed at Site 1240.

Crash and Bloom: Tectonics and Environmental Change

The sedimentary imprint of the gradual plate tectonic drift of sites relative to the continental margin is clear. Superimposed on these long-term trends are substantial temporal variations in the environments that modify the supply of terrigenous material and drive production and preservation of biogenic sediments. An interval of low carbonate accumulation from 11 to 9 Ma has been referred to in the equatorial Pacific as a carbonate crash event of poor preservation related to changing deep sea circulation (Lyle et al., 1995). We traced this event for the first time into shallow paleowater depths of <2000 m at equatorial Site 1241 and <1000 m at subtropical Site 1236. Because carbonates are well preserved at these depths, we concluded that low carbonate production contributed to the crash event.

A stepwise increase in hematite contents (Site 1236) and terrigenous dust flux (Site 1237) 8 to 9 Ma ago may reflect a critical threshold in the history of Andean uplift. The high Andes create a low-latitude rain shadow that maintains the Atacama Desert, one of the driest places on Earth, as a dust source. Andean topography also steers winds along the eastern boundary that drive coastal upwelling and productivity (Fig. 2A, B, C). More than 200 volcaniclastic horizons were deposited during the last ~9 m.y. at Site 1237, perhaps recording the onset of intense volcanism that accompanied tectonic uplift. Peaks in ash layer frequency occurred at ~8 to 6 Ma and during the last 3 m.y. match the inferred timing of Andean uplift recorded in sediments off the Amazon River in the Atlantic Ocean (Harris and Mix, 2002). An interval of anomalously high carbonate accumulation rates, with an essentially synchronous onset near 7 to 8 Ma at Sites 1236 to 1239 and 1241, and at other equatorial Pacific sites visited during Legs 130 and 138, is thought to represent a widespread Miocene interval of high production referred to as a biogenic bloom (Farrell et al., 1995). Our finding of this bloom event at all water depths confirms production as the cause. Furthermore, discovery of the event in the southeast Pacific proves that the event was not uniquely associated with equatorial upwelling, as some previous hypotheses suggested. Instead, the bloom may be linked to substantial changes in the eastern boundary current system or regional nutrient budgets, perhaps in response to Andean uplift.

The termination of the Miocene bloom event occurred near 5 Ma at equatorial sites at great water depths, such as Leg 138 Sites 849 and 850 (water depths of 3839 m and 3786

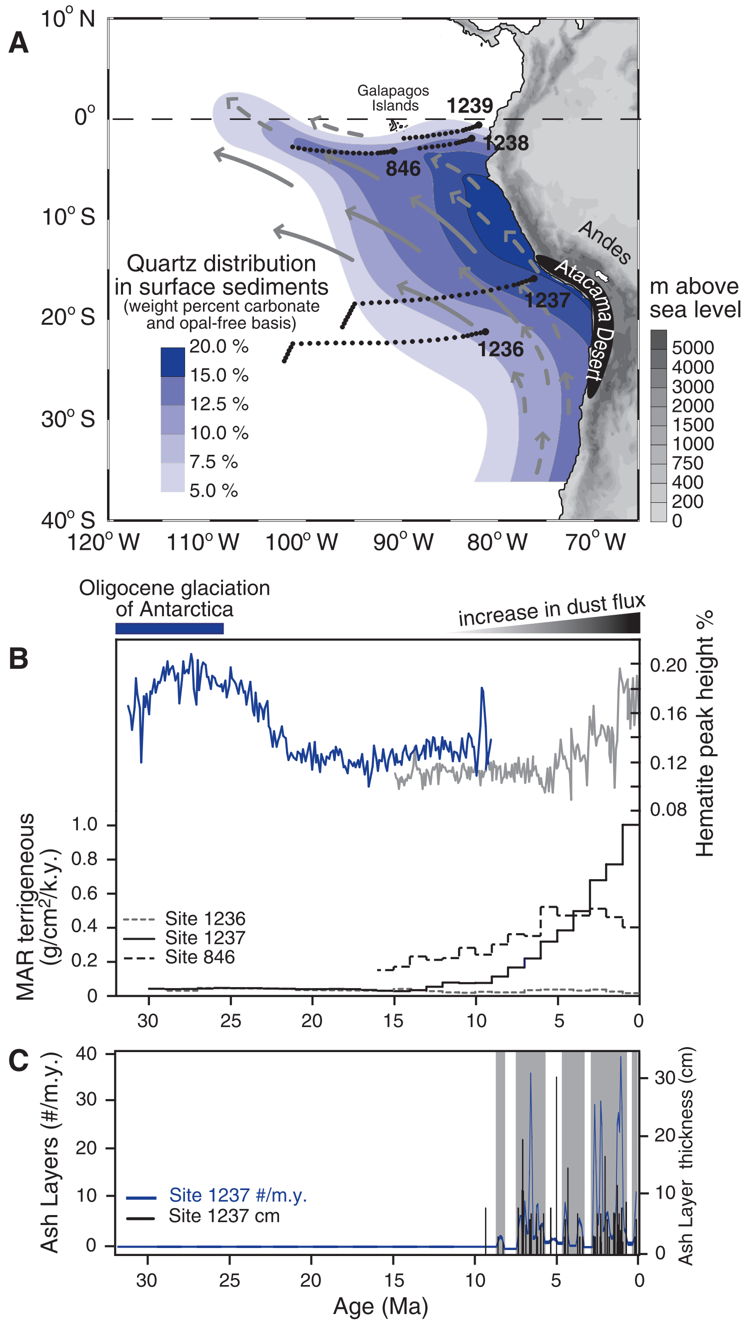

Figure 2. ***A.*** *Quartz distribution in surface sediments of the subtropical southeast Pacific, expressed as weight percentage (carbonate- and opal-free basis; Molina-Cruz, 1977). Gray arrows indicate trade winds. Sites 1236, 1237, 1238, and 1239 (Leg 202), and Site 846 (Leg 138) are shown with their plate tectonic backtracks at 1 m.y. intervals.* ***B.*** *Siliciclastic accumulation rates and hematite peak height at Sites 1236 (gray line) and 1237 (blue line). Accumulation rates of siliciclastics were estimated at 1 m.y. intervals as the product of (100% - wt% $CaCO_3$ - wt% organic matter - wt% biogenic opal), sedimentation rate, and dry bulk density. The hematite peak height is derived from color reflectance spectra (550 nm peak above background) and serves as a rough proxy for changing concentrations of hematite.* ***C.*** *Ash frequency at Site 1237 (#/m.y., blue line), calculated as the first derivative of the cumulative number of ash layers vs. age. Vertical bars indicate the age and thickness (cm) of individual ash layers.*

m, respectively). At shallow water sites on Carnegie Ridge, the bloom continues to 3 Ma at Site 1238 (2204 m depth) and 2 Ma at Site 1239 (1414 m depth). Such diachroneity associated with water depth points to decreasing carbonate preservation through Pliocene time, perhaps in response to gradual shoaling and final closure of the Panama Isthmus and the development of the modern global "conveyor belt" deep circulation that maintains corrosive waters in the deep Pacific (Haug and Tiedemann, 1998).

Orbital-scale Cyclicity Before and During the Ice Ages

Lithologic changes at meter and decimeter scales are likely related to orbitally induced changes in precession and obliquity (Fig. 3). If so, these cycles provide a basis for developing orbitally tuned age models and for assessing the role of the South Pacific in a chain of climate mechanisms associated with the ice ages.

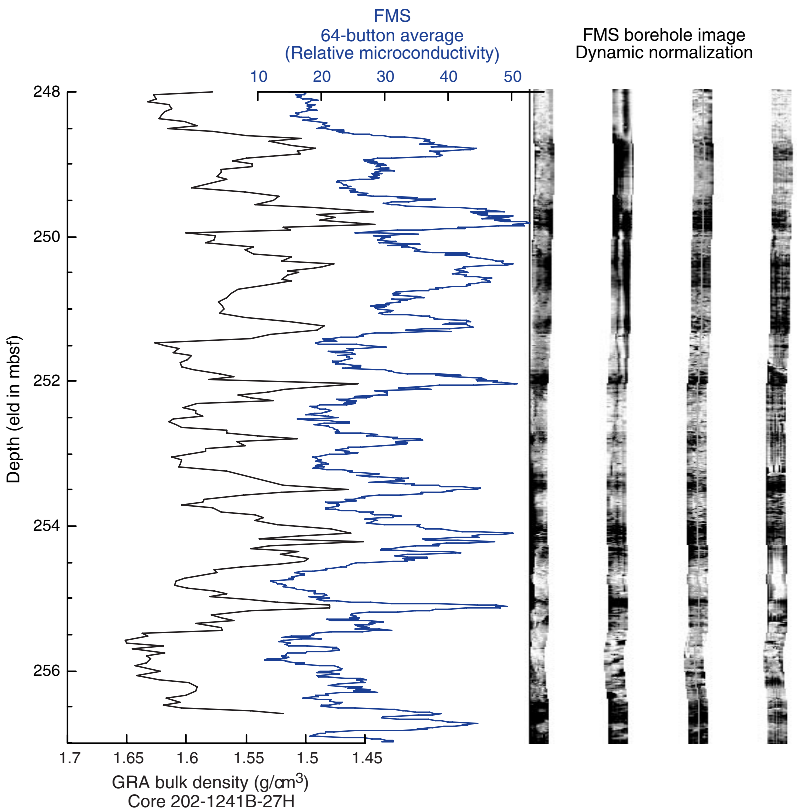

Figure 3. Pervasive meter-scale rhythmic variations were observed in borehole resistivity and core density logs at Sites 1238, 1239, and 1241. The data shown here are in the late Miocene interval. Such variability is associated with fluctuations in fractions of carbonate and biogenic opal in the sediments. The Formation MicroScanner (FMS) borehole image for Hole 1241B is shown in the blue curve to the right of the 64-button average (5-point smoothing). The similarity of the smoothed FMS and the lower-resolution gamma ray attenuation (GRA) bulk density record (black curve) in cores from Hole 1241B suggests that borehole logs will provide a relatively continuous proxy record of lithologic variability. eld=equivalent logging depth in meters below seafloor (mbsf). Rhythmic oscillations observed in shipboard stratigraphic analyses are likely associated with orbital precession and have a wavelength of 19 to 23 k.y.

An apparent ~400-k.y. cycle of lithologic change is found at several sites, especially prior to 1 Ma. This cycle is probably associated with low-latitude climate oscillations driven by orbital precession, which can induce such long-period variations based on responses to shorter-period orbital changes (Crowley et al., 1992). With refined post-cruise timescales, we will examine the evolution of such climate cycles with both 400-k.y. and 100-k.y. periods, to explore the possibility that climate oscillations of tropical origin provide a forcing template that eventually leads to large Pleistocene oscillations of polar ice sheets (Mix et al., 1995).

Abrupt Magnetic and Climate Changes

Sites 1233 to 1235, along the continental margin of Chile, between latitudes 41°S and 36°S and at water depths of 490 m to 1115 m, have exceptionally high sediment accumulation rates of up to 160 cm/k.y. Such high rates reflect rapid erosion of the southern Andes under heavy continental rainfall and glaciation. Rapid changes in biogenic and terrigenous sediment components (Fig. 4), extend a record of abrupt climate changes within Holocene time (Lamy et al., 2002) through the last glacial-to-interglacial cycle. A rich array of biogenic, mineralogic, and geochemical tracers at these sites offer the potential to reconstruct regional climate variations down to the scale of centuries and perhaps even decades.

Rapidly accumulating sediments also yielded a highly refined record of paleomagnetic variations. The Laschamp magnetic excursion at ~41 ka is particularly pronounced (e.g., covering an interval of ~2 m at Site 1233), and offers the potential for fundamental advances in understanding the dynamics of Earth's magnetic field. These extraordinary paleomagnetic records provide opportunities for high-resolution regional and global correlation of marine and terrestrial records using paleomagnetic secular variation and paleointensity variation (Stoner et al., 2002). This stratigraphic synchronization strategy will help to establish the relative phasing and origin of millennial-scale climate changes in the Southern and Northern Hemispheres.

In the tropics, rapid climate change and oceanographic changes on the scale of centuries and millennia are recorded at Site 1240 in the Panama Basin and at Site 1242 on Cocos Ridge. Both sites provide a complete stratigraphic sequence of the last ~2.6 m.y. with sedimentation rates in the range of 5 to 17 cm/k.y. Relatively high sedimentation rates of 5 to 10 cm/k.y. also characterize the early Pliocene to late Miocene intervals of Sites 1238 and 1239 at Carnegie Ridge. Natural gamma spectra revealed major variations in uranium content of the sediment, a likely diagenetic imprint of suboxia at the sea floor driven by varying organic carbon rain. Persistent decimeter- to meter-scale variability in bulk density and magnetic susceptibility here are mainly related to changes in the relative supplies of carbonate, biosiliceous, and siliciclastic material associated millennial-scale changes in tropical productivity driven by upwelling.

These sites will help address questions on the role of the tropics in large scale climate change, including the possibility that long-term ocean-atmosphere changes analogous to El Niño-Southern Oscillation events of the modern world may help to trigger global climate changes (Cane and Clement, 1999). Leg 202 data also may answer whether freshwater transport from the Atlantic to Pacific Basins, via winds that cross the Panama Isthmus, modify the global thermohaline circulation through control of basin-scale salinity (Rahmstorf, 1995).

OUTLOOK

Leg 202 has opened a new window into understanding global climate change by providing high-quality sediment sequences from a previously unsampled region of the Southeast Pacific. As with most ODP legs that focus on paleoceanographic objectives, rigorous hypothesis tests await detailed shorebased studies. Isotopic, geochemical, magnetic, faunal, and floral studies will refine stratigraphies and chronologies. With these high-resolution data, detailed reconstructions will lead to better understanding of variations in production and preservation of biogenic sediments, as well as climatic and tectonic influences on continental

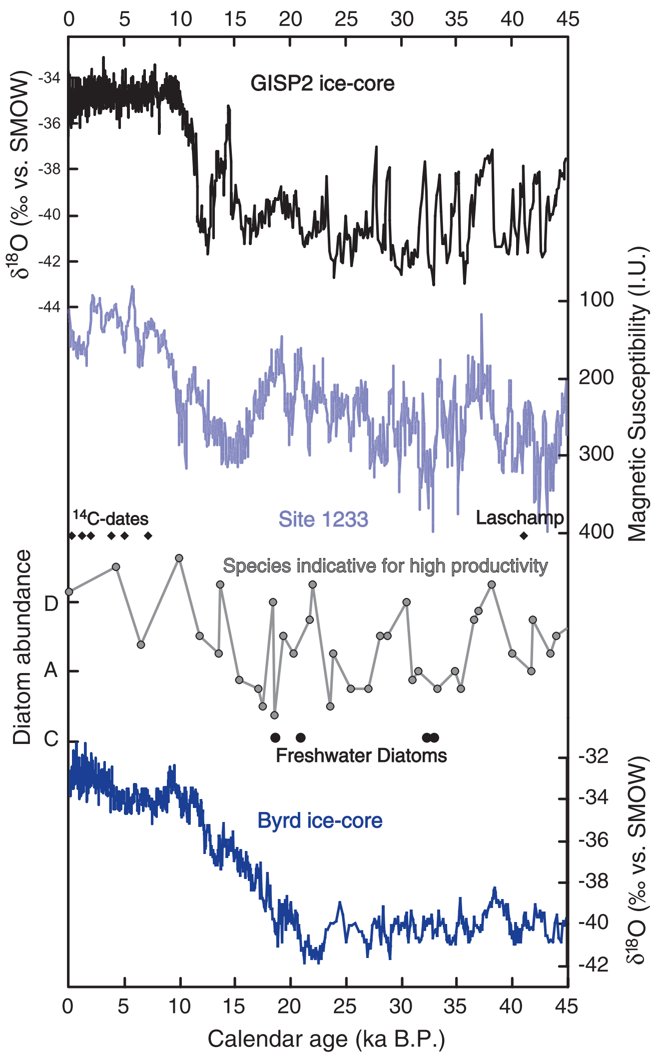

Figure 4. Millennial-scale variability at Site 1233. Magnetic susceptibility and diatom abundance plotted on a preliminary age scale for the interval 0 to 45 ka. The age scale is based on Holocene age control points derived from a correlation of the magnetic susceptibility records between Site 1233 and AMS-^{14}C dated core GeoB 3313-1 (Lamy et al., 2002) and the location of the Laschamp Event. All ages are calendar years before present (B.P.) and are linearly interpolated between the dates, resulting in substantial uncertainty between 9 and 40 ka. General character of variability at Site 1233 is similar to isotopic variability in the GISP2 ice core in Greenland and the Byrd ice core in Antarctica. Both ice core records are plotted on the GISP2 time scale (Blunier and Brook, 2001). SMOW=oxygen isotopic composition of standard mean ocean water.

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erosion and explosive volcanism. Detailed studies of organic matter and its nitrogen and carbon isotopic character, along with biotic tracers of productive upwelling systems, will yield insights into nutrient cycling in the region. Analysis of subsurface water masses using isotopic, geochemical, and faunal analyses will constrain the role of the South Pacific in the circuit of water masses that influences global climate and biogeochemistry.

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SCIENCE/ TECHNOLOGY Special Report

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ODP/DSDP Legacy Holes: A Review of Reentry Holes, CORKs and other Borehole Observatory Installations

Henny Gröschel, JOIDES Office

INTRODUCTION

Since 1991, long-term borehole observatories in four basic configurations have been installed in a number of ODP legacy holes, and several reentry holes have been drilled specifically for future observatory deployments. This article provides a brief summary of these installations, described in more detail by Graber et al. (2002). Figure 1 (inside back cover) shows the locations of ODP and Deep Sea Drillling Project (DSDP) reentry holes with observatories installed or planned for the near future.

Table 1 summarizes geographic and technical data for these hydrogeological and seismic observatory sites; Table 2 provides similar data for all other DSDP/ODP reentry holes to date.

REENTRY CONE AND CASING

The Reentry Cone and Casing (RECC) system is the foundation for ODP/DSDP legacy holes (Fig. 2A, C). The latest version of the RECC supports installation of up to four nested casing strings that case off unstable shallower formations to achieve deeper objectives. Earlier

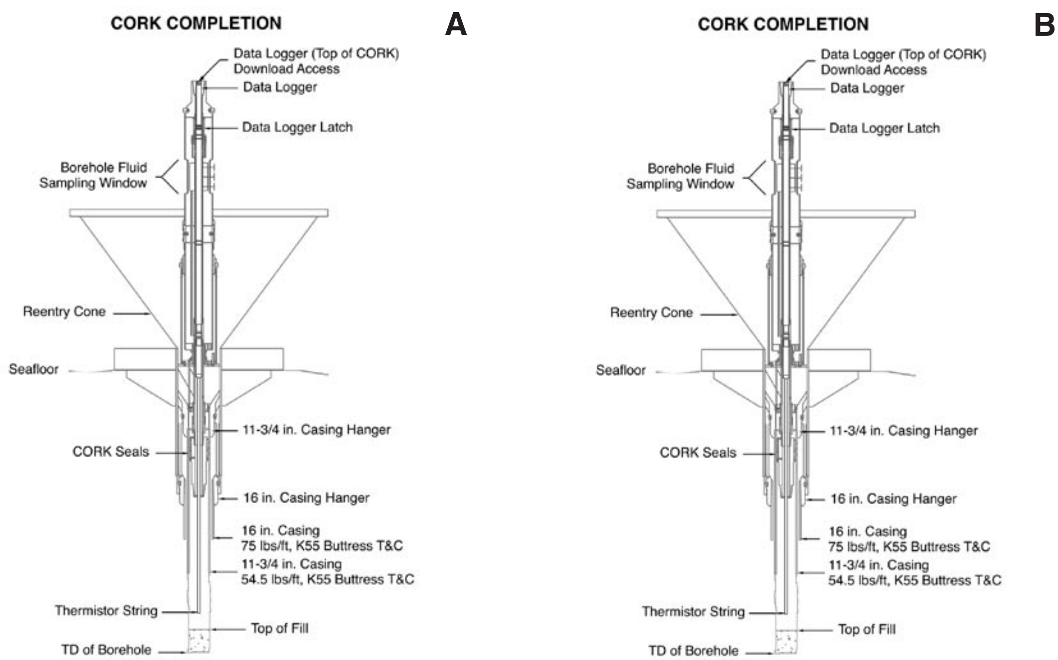


Figure 2. A. *Schematic diagram of the Reentry Cone and Casing (RECC) system that is the foundation for ODP/DSDP legacy holes (after Graber et al., 2002). The RECC allows for additional drilling to deepen or log a borehole, or to deploy an observatory for long-term downhole measurements and sampling.* **B.** *Schematic diagram of a Circulation Obviation Retrofit Kit (CORK) installed in an older borehole reentry cone with 16 in and 11-3/4 in casing set in the hole (after Graber et al., 2002). The CORK seals the 11-3/4 in casing, and isolates the formation to allow long-term borehole pressure and temperature measurements. Data logger and fluid sampling ports extend above the top of the reentry funnel.* **C.** *CORK installed in Hole 395A on the west flank of the Mid-Atlantic Ridge during ODP Leg 174B in 1997. The Hole 395A RECC was set after initial drilling during DSDP Hole 45 in 1975. Still from video acquired during a 2001 DSV* Alvin *dive courtesy of WHOI.*

SCIENCE/ TECHNOLOGY Special Report

ODP

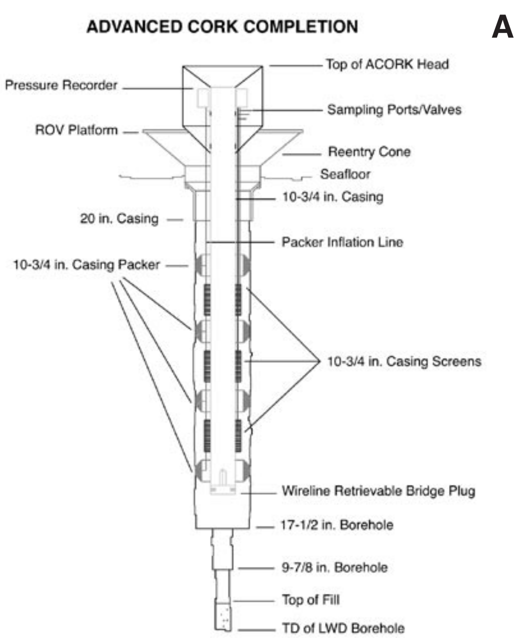
versions allowed for fewer casing strings of slightly different diameters. The deeper strings are cemented in place to prevent circulation of fluids outside the casing. The system allows reentering the hole for deepening and logging on multiple legs, or to install a borehole observatory. The four types of borehole observatories installed by ODP in such reentry holes are the Circulation Obviation Retrofit Kit (CORK), the Advanced CORK (ACORK), a borehole instrument hanger (BIH) for a seismometer package, and a BIH for an osmosampler also known as CORK-II. Each system normally includes a landing platform at the top of the reentry cone to support revisits by manned and unmanned submersibles for data retrieval and instrument servicing.

CORK HYDROGEOLOGICAL OBSERVATORY

The Circulation Obviation Retrofit Kit (CORK; Fig. 2B, C) was designed for long-term *in situ* monitoring of temperature and pressure as well as borehole fluid sampling through tubing and valves (Davis et al., 1992). The CORK seals the top of the 10-3/4 in or 11-3/4 in casing in an ODP or DSDP reentry cone to prevent circulation between the open hole and ocean bottom water. It allows thermal and pressure characterization of subseafloor hydrology over the open formation interval in a variety of settings. Optional third-party sensors or samplers can be installed in addition to the basic sensor package of pressure gauges and thermistor string.

ACORK BOREHOLE OBSERVATORY

The Advanced CORK (ACORK; Fig. 3A, B) is a completely new design that employs external casing packers to isolate multiple zones behind casing for hydrogeological studies of several zones of interest in a single hole (Shipboard Scientific Party, 2002). Pressures and fluids in these zones can be sampled through screened sections on the outside of the casing. The screened sections are connected by a hydraulic umbilical that incorporates multiple tubings to pressure gauges and sampling ports on the ACORK head that extends above the reentry cone. After the ACORK head and casing string are installed, the hole may be drilled or cored deeper just as through normal casing.



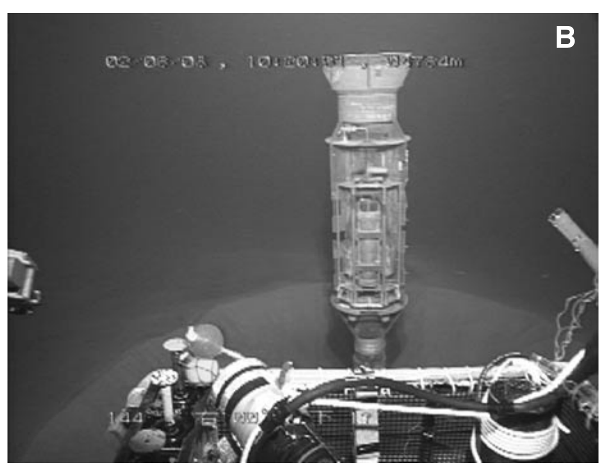


Figure 3. A. *Schematic diagram of an Advanced CORK (ACORK) installed in a borehole reentry cone that has 20 in and 10-3/4 in casing set in the hole (after Graber et al. 2002). Downhole external 10-3/4 in casing packers seal off zones of open hole between external screened sampling sections and below the casing. Screened sections are connected by hydraulic sampling tubing to valves and ports in the ACORK head that sits above the reentry cone and submersible platform; the head contains hydraulic and pressure sampling devices and provides access for downloading data.* **B.** *ACORK installed at Hole 1173B in the Nankai Trough off Japan during ODP Leg 196 in 2001. The reentry cone was set at the end of initial drilling during ODP Leg 190 in 2000. The basket of the ROV* Kaiko *is visible in front of the ACORK head in this image taken during a 2002 data collection dive (Video still courtesy of JAMSTEC).*

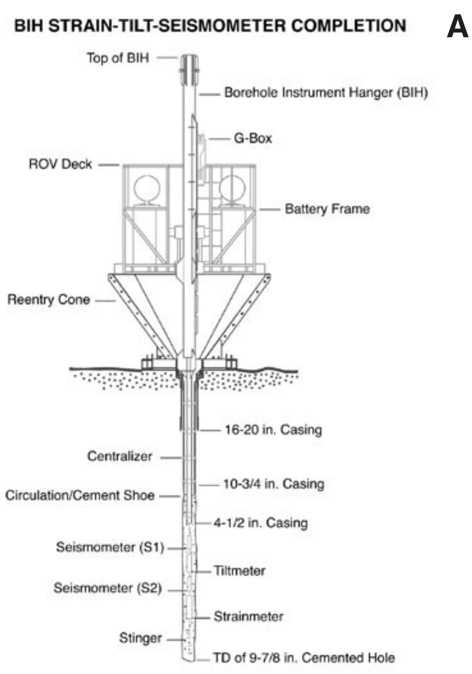
The bottom of the ACORK casing is then sealed with a bridge plug to isolate the deepest zone, and an additional sensor package can be installed inside the casing.

BOREHOLE INSTRUMENT HANGER (STRAIN-TILT-SEISMOMETER)

The ODP Borehole Instrument Hanger (BIH) was developed to provide structural support for scientific instrumentation that needs to be emplaced deep within a hole. The support is provided by 4-1/2 in casing hung within a normal reentry hole. The BIH was first used to deploy a pair of broadband seismometers, a tiltmeter, and a strainmeter deep within a hole (Fig. 4A) where they were cemented in place for *in situ* monitoring of tectonic processes (Shipboard Scientific Party, 2000). The 4-1/2 in casing provides the support for the cabling between these instruments and data loggers and battery packs on the wellhead (Fig. 4B). The multiple-access expandable gateway package, or G-Box, combines the digital data from the seismometers into one serial data stream and also distributes power downhole. The downhole instruments are activated when a submersible revisits the hole for the first time after installation.

BOREHOLE INSTRUMENT HANGER (OSMOSAMPLER) OR CORK-II

The BIH was subsequently adapted to include a downhole packer on the 4-1/2 in casing in addition to a seal inside casing at seafloor level (Fig. 5A), providing a dual zone hydrogeological observatory capability within a standard reentry hole (Jannasch et al., in press). The CORK-II design provides for pressure monitoring of both isolated zones via tubing run up outside the the 4-1/2 in casing to gauges and data loggers in the CORK-II head (Fig. 5B) that resembles the ACORK head (Fig. 3B). It also provides for the deployment of two long-term osmosamplers through the 4-1/2 in casing to sample fluids within the isolated zones. The osmosamplers can be recovered and replaced using a submersible without disturbing the rest of the installation.



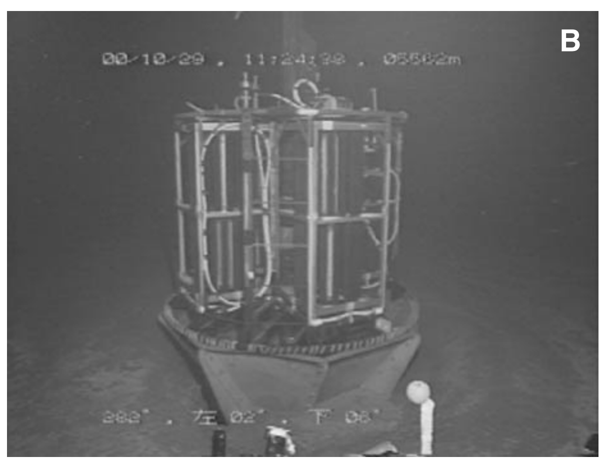


Figure 4. A. *Schematic diagram of a Borehole Instrument Hanger (BIH) strainmeter-tiltmeter-seismometer borehole installation deployed during Leg 186 to monitor subseafloor seismic activity (after Graber et al. 2002). The BIH is installed in a borehole reentry cone with nested 16 in to 20 in casing above 10-3/4 in casing; the 4-1/2 in casing supporting the downhole instruments hangs on the BIH. Two three-component digital broadband seismometers, housed in separate pressure vessels, are cemented into contact with bare rock near the bottom of the hole, and are connected by umbilicals to battery, recording, and data retrieval packages located at the seafloor above the reentry cone in a frame at also serves as a aubmersible platform.* **B.** *A BIH head assembly extending above the reentry cone in a seismometer-only deployment in Hole 1179E in the Northwest Pacific during ODP Leg 191 in 2000 (Shipboard Scientific Party, 2001). The seismometers were activated later in 2000 during a visit by ROV* Kaiko *(Video still courtesy of K. Suyehiro and JAMSTEC).*

SCIENCE/ TECHNOLOGY Special Report

ODP

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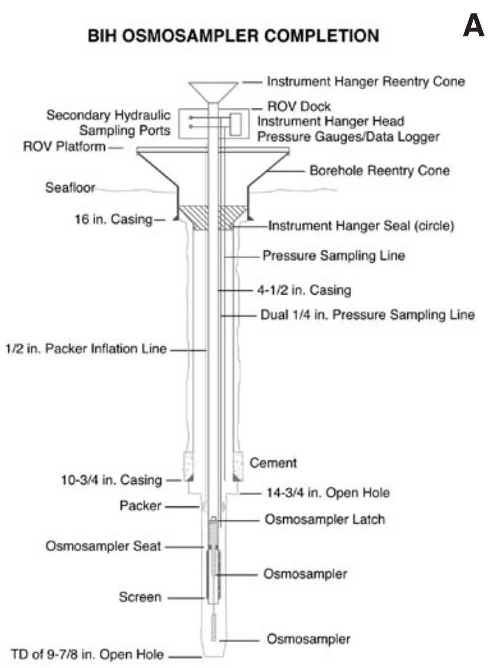

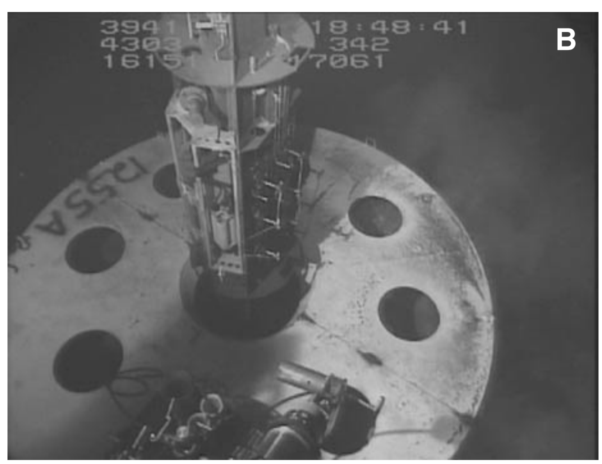

Figure 5. A. *Schematic diagram of a Borehole Instrument Hanger (BIH) osmosampler installation, also known as a CORK-II, used to monitor subsurface fluid circulation, pressure, and temperature (Graber et al., 2002; Jannasch et al., in press). The BIH is installed in a borehole reentry cone that has 16 in and 10-3/4 in casing set in the hole. A single packer is used to seal off zones of open hole below the casing; a formation fluid sampling screen is mounted on the outside of the casing. The removable osmosampler package is latched in below the packer so that one of the samplers extends into open hole. Head design and sampling and data port locations are similar to the ACORK.* **B.** *Head assembly of the CORK-II above the landing platform installed in Hole 1255A in the Costa Rica Trench during ODP Leg 205 in 2002 (Jannasch et al., in press). The observatory was visited by DSV* Alvin *later in 2002 for sampling; note the underwater mateable connector visible at the forward end of* Alvin*'s basket in the foreground of the image (Video still courtesy of WHOI).*

SCIENCE/ TECHNOLOGY Special Report

ODP

Table 1. *Geographic and technical data for DSDP and ODP boreholes with long-term borehole observatories. Notes: mbsl=meters below sea level, mbsf=meters below sea floor, CORK=Circulation Obviation Retrofit Kit, ACORK=Advanced CORK, OSN=Ocean Seismic Network, ION=International Ocean Network, NERO=Ninetyeast Ridge Observatory, H2O=Hawaii-2 Observatory.*

LEG NO.	HOLE	LOCATION	LATITUDE	LONGITUDE	WATER DEPTH (mbsl)	TOTAL DEPTH (mbsf)	BASEMENT PENETRATION (m)	CASING (m)	REMARKS
45	395A	Mid-Atlantic Ridge, W flank	22°45' W	46°0' W	4475	664	572	62/112	Fill and junk below 600 mbsf; CORK 1997
46	396B	Mid-Atlantic Ridge, E flank	22°59' W	43°31' W	4465	406	254	120/163	Wireline reentry: FARE 1988, SISMOBS seismometer tests 1992
69	504B	Costa Rica Rift, S flank	1°14' N	83°44' W	3464	2111	1836	90/276	Deepest DSDP/ODP hole; junk below 2000 mbsf; wireline CORK 2001
131/196	808I	Nankai Trough	32°22' N	134°57' E	4675	1058	0	157/934	ACORK 2001; top 37 m on seafloor but fully functioning; 3rd deepest ODP casing
136	843B	SW of Oahu	19°21' N	159°06' W	4407	313	79	30/244	OSN Pilot Experiment, 1998; now open
139	857D	Middle Valley	48°27' N	128°43' W	2421	936	456	48/573	CORK 1991; new CORK 1996; "basement" = sill/sediment sequence
139	858G	Middle Valley	48°27' N	128°43' W	2415	433	175	25/271	CORK 1991; new CORK 1996
146	889C	Vancouver margin	48°42' N	126°52' W	1315	385	0	52/260	CORK and 5-1/2" liner, 1992
146A	892B	Oregon margin	44°41' N	126°07' W	674	178	0	21/105	CORK and 5-1/2" liner 1992; logger removed 1995; hydrate experiment 1998
148	896A	Costa Rica Rift, S flank	1°13' N	83°43' W	3448	469	297	86/191	Wireline CORK 2001
156	948D	Barbados prism	15°32' N	58°44' W	4938	538	0	43/476/535	CORK 1994; logger and string removed 1995
156	949C	Barbados prism	15°32 'N	58°43' W	5005	468	0	46/398/466	CORK and bridge plug, 1994
168	1024C	Juan de Fuca Ridge, E flank	47°55' N	128°45' W	2612	174	22	39/166	CORK 1996; sensors recovered 1999; new logger 2000
168	1025C	Juan de Fuca Ridge, E flank	47°53' N	128°39' W	2606	147	46	40/102	CORK 1996; logger replaced 2000
168	1026B	Juan de Fuca Ridge, E flank	47°46' N	127°46' W	2658	295	48	38/249	CORK 1996; biosphere experiment 1997; sensors removed 1999
168	1027C	Juan de Fuca Ridge, E flank	47°45' N	127°44' W	2656	632	57	38/578	CORK 1996; sensors recovered 1999; new logger 1999
179	1107A	90°E Ridge	17°01' S	88°11' E	1648	494	123	49/413	ION NERO site; seismometer planned 2004/2005
186	1150D	Japan Trench	39°11' N	143°20' E	2681	1140	0	55/534/1035	W Pacific ION seismometer/strain observatory 1999: 2nd deepest ODP casing
186	1151B	Japan Trench	39°11' N	143°20' E	2182	1113	0	76/1068	W Pacific ION seismometer/strain observatory 1999; deepest ODP casing
190/196	1173B	Nankai Trough	32°15' N	135°01' E	4791	751	20	121/728	ACORK 2001; 5th deepest ODP casing; broken-off pipe above bridge plug
191	1179E	NW Pacific	41°05' N	159°58' E	5565	399	28	64/393	NW Pacific ION seismic observatory 2000
195	1200C	Mariana forearc	13°47' N	146°00' E	2932	266	0	24/108/203	CORK 2001
195	1201E	Philippine Sea	19°18' N	135°06' E	5710	580	0	39/527	W Pacific ION seismic observatory 2001
200	1224D	E Pacific	27°53' N	141°59' W	4967	65	37	26/58	H2O ION site, seismometer planned 2003
203	1243A	Eastern Equatorial Pacific	5°18' N	110°05' W	3871	224	103	48/212	E Pacific ION, seismometer to be planned 2003/2004/2005?
205	1253A	Costa Rica Trench	9°39' N	86°11' W	4376	600	171 (2 sills)	44/413	CORK-II 2002
205	1254B	Costa Rica Trench	9°40' N	86°11' W	4176	278	0	20/199	CORK-II 4-1/2" casing broke off and junked hole
205	1255A	Costa Rica Trench	9°29' N	86°11'W	4312	157	0	20/118	CORK-II 2002

Table 2. *Geographic and technical data for non-observatory DSDP and ODP boreholes fitted with reentry cones. Notes: mbsl=meters below sea level, mbsf=meters below sea floor, *=site operations not referenced by either DSDP Leg 11 or 12, TAG=Trans-Atlantic Geotraverse, BHA=Bottom Hole Assembly, HRGB=Hard Rock Guide Base, DCB=Diamond Core Barrel, HRRS=Hard-Rock Reentry System, ADCB=Advanced Diamond Core Barrel.*

LEG NO.	HOLE	LOCATION	LATITUDE	LONGITUDE	WATER DEPTH (mbsl)	TOTAL DEPTH (mbsf)	BASEMENT PENETRATION (m)	CASING (m)	REMARKS
?	110*	off New Jersey	37°59' N	71°47' W	3026	66	0	48/-	First test of reentry system; 10-3/4" casing
15	146	Caribbean Sea	15°07' N	69°23' W	3949	762	24	50/-	Lacks second casing string
34	319A	East Pacific Rise, E flank	13°01' N	101°31' W	4286	157	59	66/-	Lacks second casing string; bad hole conditions in basement
34	320B	Peru Basin	9°00' S	83°32' W	4487	184	29	65/-	Lacks second casing string; bad hole conditions in basement
37	333A	Mid-Atlantic Ridge, W flank	36°50' N	33°40' W	1670	529	311	70/-	Lost BHA at 488 mbsf; DIANAUT reentry 1990
47	398D	Galicia Bank	40°58' N	10°43' W	3890	1740	0	80/-	Hole filled with sediments
50	415A	off Morocco	31°02' N	11°40' W	2810	1080	0	68/311	Bad hole conditions, filled with cavings/mud
50	416A	off Morocco	32°50' N	10°48' W	4193	1624	0	40/-	Lacks second casing string; bad hole conditions
51	417D	S Bermuda Rise	25°07' N	68°03' W	5479	709	366	25/-	Cone plugged with mud; lost BHA in deepest 100m
52	418A	S Bermuda Rise	25°02' N	68°03' W	5509	868	544	71/-	Cone plugged with mud
55	433C	Suiko Seamount	44°47' N	170°01' E	1862	551	388	40/-	Lacks second casing string
58	442B	Shikoku Basin	28°59' N	136°03' E	4644	455	165	57/-	Lacks second casing string; bad hole conditions
61	462A	Nauru Basin	7°15' N	165°02' E	5176	1069	452	75/-	Lacks second casing string; "basement" = sill/sediment sequence
69	504A	Costa Rica Rift	1°14' N	83°44' W	3458	277	12	90/-	Lacks second casing string; abandoned when 14" bit cones lost
76	534A	E of Blake Escarpment	28°21' N	75°23' W	4966	1667	32	86/533	Wireline reentry: LFASE, 1989; DIANAUT, 1990
91	595B	SW Pacific	23°49' S	165°32' W	5620	124	54	34/74	Ngendei experiment, 1983; stinger left in hole
92	597C	East Pacific Rise, W flank	18°48' S	129°46' W	4147	143	91	40/-	Lacks second casing string; good hole in fastest-spread crust
103	638C	Galicia margin	42°09' N	12°12' W	4661	547	0	40/-	Lacks second casing string
104	642E	Norwegian margin	67°13' N	2°56' E	1277	1229	917	51/372	Top of cone at seafloor; "basement" = sill/sediment sequence
105	645E	Baffin Bay	70°27' N	64°39' W	2006	846	0	21/-	Lacks second casing string; sediment bridges in open hole
106	648B	Mid-Atlantic Ridge axis	22°55' N	44°57' W	3326	50	50	9/27	HRGB
118	735B	Atlantis Fracture Zone	32°43' S	57°16' E	720	1508	1508	none	HRGB; lost BHA below 600 mbsf
123	765D	Argo Abyssal Plain	15°59' S	117°34' E	5714	1195	267	91/933	4th longest DSDP/ODP casing
126	794D	Japan Sea	40°11' N	138°14' E	2807	734	192	58/560	Broadband seismometer experiment 1989; still in hole
129	801C	W Pacific Jurassic	18°39' N	156°22' E	5674	936	477	51/481	Oldest sampled oceanic crust. Leg 185:7.4 m DCB coring to TD with 7-1/4" dia.
130	807C	Ontong Java Plateau	3°36' N	156°37' E	2806	1528	148	58/350	Two bit cones lost in hole
131	808D	Nankai Trough	32°21' N	134°57' E	4673	780	0	21/?	741 m 11-3/4" casing lost on deployment, partly on seafloor
131	808E	Nankai Trough	32°21' N	134°57' E	4673	1200	0	21/521	bad hole conditions below casing; ONDO experiment lost in hole
132	809F	Sumisu Rift	31°04' N	139°53' E	1803	79	79	none	Mini-HRGB; slim hole cored with DCS
142	864A	East Pacific Rise axis	9°31' N	104°15' W	2571	15	15	none	HRGB
142	864B	East Pacific Rise axis	9°31' N	104°15' W	2572	7	7	none	HRGB
142	864C	East Pacific Rise axis	9°31' N	104°15' W	2572	7	7	none	HRGB
149	899B	Iberia Abyssal Plain	40°46' N	12°16' W	5291	563	192	50/217	Bit released at 539 mbsf
158	957E	TAG active mound	26°08' N	44°50' W	3635	126	126	28/-	13-3/8" casing; lost BHA below 14 mbsf
158	957L	TAG active mound	26°08' N	44°50' W	3700	67	67	20/-	16" casing; collapsed formation in open hole
165	999B	Colombia Basin	12°45' N	78°44' W	2828	1066	0	62/534	16" casing
186	1150C	Japan Trench	39°11' N	143°20' E	2681	1050	0	58/527/205	Unusable site - 205 m 10-3/4" casing lost at bottom of hole
192	1185B	Ontong Java Plateau	00°21' S	161°40' E	3899	435	125	28/-	Lacks second casing string; only 16" casing set in full-sized cone
193	1188F	E Manus Basin	03°44' S	151°40' E	1642	387	0	0.4/57/190	Freefall deployed cone with HRRS cone; ADCB cored with 7-1/4" dia.
206	1256D	Guatemala Basin	06°44' N	91°56' W	3635	752	502	95/269/?	20"/16" casing so far

SCICOM Consensus Statement of Appreciation for the Ocean Drilling Program Delivered at the Final ODP SCICOM Meeting, March 17-20, 2003, Austin, Texas

Jamie Austin [1], Sherman Bloomer [2], Larry Mayer [3], and Dave Rea [4]

The Ocean Drilling Program, its predecessor the Deep Sea Drilling Project, and its successor the Integrated Ocean Drilling Program, stand as probably the finest examples in science of how nations can cooperate to achieve a greater good than any could achieve alone. Since the first hole was drilled in January of 1985, the Ocean Drilling Program has been supported by the governments of over twenty nations. The Program has seen the end of the Cold War, the waxing and waning of geopolitical strife in all corners of the world, and innumerable changes of administrations. Through it all, the Program has continued to put a ship to sea six times a year with a contingent of scientists, students, crew, and staff who left politics and national identity on the beach. By the time the last hole is drilled in September of 2003, the Program will have drilled over 1700 holes, recovered over 215 km of core, and sailed over 2700 scientists from more than 40 nations.

The Ocean Drilling Program has provided scientific advances in solid Earth science, oceanography, paleoclimatology, and numerous other disciplines. The work of the Program has provided fundamentally new understandings of modern Earth processes and has provided the baseline against which much of geology interprets the past. The Program is recognized for the high quality of the science that it has produced over the past 18 years. That science has only been possible because of the efforts of a very large number of people. SCICOM (Fig. 1) wishes to acknowledge the efforts of those people and to thank them on behalf of the entire Earth science community.

The quality of the science that has been done owes much to the people who have written proposals, both those that have gone on to be drilled and those that have not. The exchange of ideas, the fertilization of one idea by another and the constant push of new ideas, approaches, and techniques have kept the Program vital. The greatest thanks need to go to the proponents who provided the raw material for the scientific ideas that guided the drilling.

Those myriad ideas for good science through drilling would never have come to fruition without the considerable efforts of the members of the scientific community who staffed the scientific advisory structure of the Program. The advisory panels reviewed ideas, nurtured them, questioned them, improved them, assembled site survey data for them, reviewed their safety and ultimately championed them for one of the very few available legs aboard D/V *JOIDES Resolution*. The advisory panels, in turn, only worked because there were people willing to give significant time and energy to leading and serving on those panels. SCICOM offers our heartfelt thanks to all of the hundreds of panelists and panel chairs who have staffed (in alphabetical order) ARP, BCOM, CEPAC, DBRP, DMP, EDRC, ESSEP, EXCOM, IHP, IOP, IPSC, ISSEP, LITHP, OHP, OPCOM, PANCH, PCOM, PPSP, TECP, TEDCOM, SCICOM, SCIMP, SGPP, SOHP, SMP, SOP, SSP, WPAC, DPGs, PPGs, WGs and PECs over the years. You all know who you are.

The best ideas in the world would not have done us any good unless someone managed the money, staffed the ship, arranged the travel, ordered the pipe, collected and sampled the core, built the instruments, curated the core, cooked the food, edited the publications, did the laundry, managed the computer network and on and on and on. The Program has been very fortunate to have had contractors,

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operators, and partners who were professional in all senses of the word. SCICOM expresses our deep appreciation, on behalf of present and past participants in the Program, to all of the staff and the leadership (past and present) of the Joint Oceanographic Institutions, Inc. office; the Ocean Drilling Program at Texas A&M University; the Borehole Research Group at Lamont-Doherty, Leicester, Montpellier, Aachen, and Tokyo; the Site Survey Data Bank at Lamont-Doherty Earth Observatory; the core repositories at College Station, Scripps, Lamont-Doherty, and Bremen; and the ship, drilling, and catering crews of the *SEDCO/BP 471*. We thank Texas A&M University in particular for the commitment the university made to the program at its inception and the facilities they have provided at College Station that have served so many scientists so well.

We recognize that none of this would have happened without money. While the money comes ultimately from governments, we all know that our governments are actually, in the end, run by people. SCICOM wishes to express our thanks to those people who have worked so hard over the years to secure funding for the program and to the agencies represented on the ODP Council that have provided that funding, including United States National Science Foundation; Natural Sciences and Engineering Research Council and Natural Resources Canada; the Australian Department of Primary Industries and Energy; National Taiwan University; the Korean Institute for Geology, Mining, and Minerals; the European Science Foundation representing Belgium, Denmark, Finland, Greece (1986-1995), Iceland, Ireland (since 1999), Italy, the Netherlands, Norway, Portugal (since 1998), Spain, Sweden, Switzerland, and Turkey (1986-1998); the Federal Republic of Germany's Deutsche Forschungsgemeinschaft; Institut Francais de Recherche pour l'Exploitation de la Mer and Institute National des Sciences de l'Univers-Centre National de la Recherche Scientifique; Japan's Ocean Research Institute, the University of Tokyo and Ministry of Education, Culture, Sports, Science and Technology; the Marine High-Technology Bureau of the State Science and Technology Commission of the People's Republic of China; the Natural Environment Research Council of the United Kingdom; and, in 1991-1992, the Institute of Lithosphere of the Soviet Union.

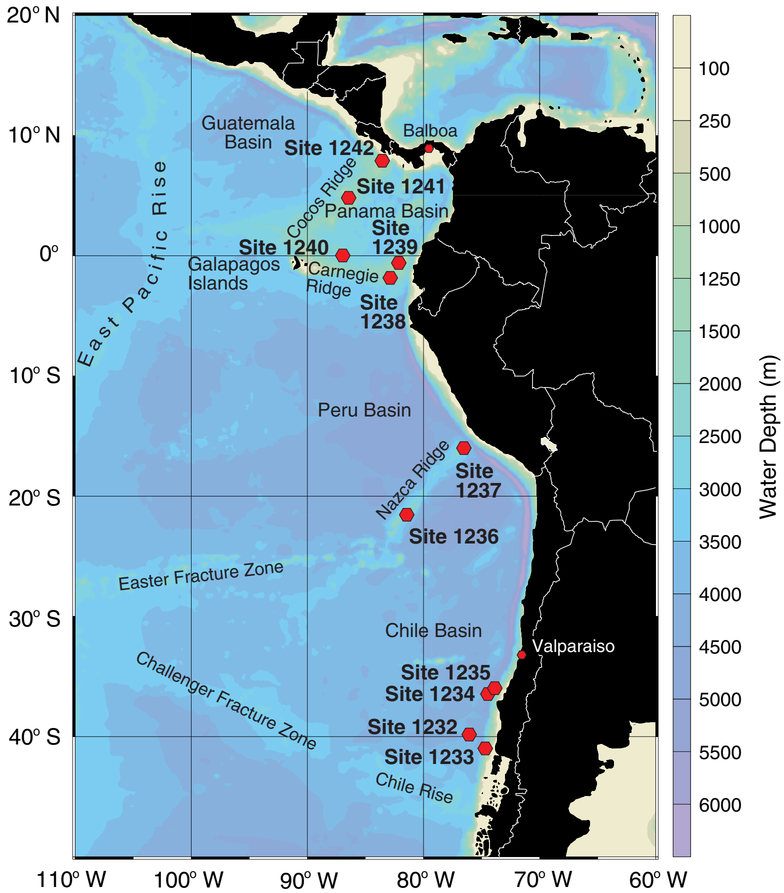
Finally, SCICOM wishes to thank those individuals, from many nations, who have worked so hard to see that there is a successor to the Ocean Drilling Program. We wish our colleagues in the Integrated Ocean Drilling Program planning structure, and the next generation of marine scientists, the same good fortune we have had to participate in one of the great endeavors of modern science and to experience the joy of discovery afforded by the ability to sample and monitor the ocean floor.

***Figure 1.** Members of the ODP SCICOM panel at its final meeting in Austin, Texas from March 17-20, 2003. Attendees are identified from Row 1 (bottom) to Row 6 (top). **Row 1**: T. Sakamoto, K. Kato, M. Ito, T. Moore, H. Kinoshita, N. Eguchi, U. Harms, and T. Ishii. **Row 2**: M. Yamakawa, F. Rack, J. Austin, S. D'Hondt, J. Allan. **Row 3**: B. Ildefonse, Y. Yamada, K. Gillis, B. Katz, D. Oppo, K. Becker, and Y. Tatsumi. **Row 4**: P. Stoffa, R. Murray, W. Sager, P. Dauphin, and H. Mikada. **Row 5**: A. Droxler, H. Doust, E. Urquhart (hidden), C. MacLeod, S. Gulick, and L. Mayer (hidden), **Row 6**: S. Bloomer, J. Reuss (hidden), S. Bohlen, A. Fisher, T. Byrne, P. Herzig, G. Camoin, J. Menter, W. Prell, J. Schuffert, and Z. Zhou.*

In this issue from pages 16-20:

ODP Leg 202: Southeast Pacific Paleoceanographic Transects

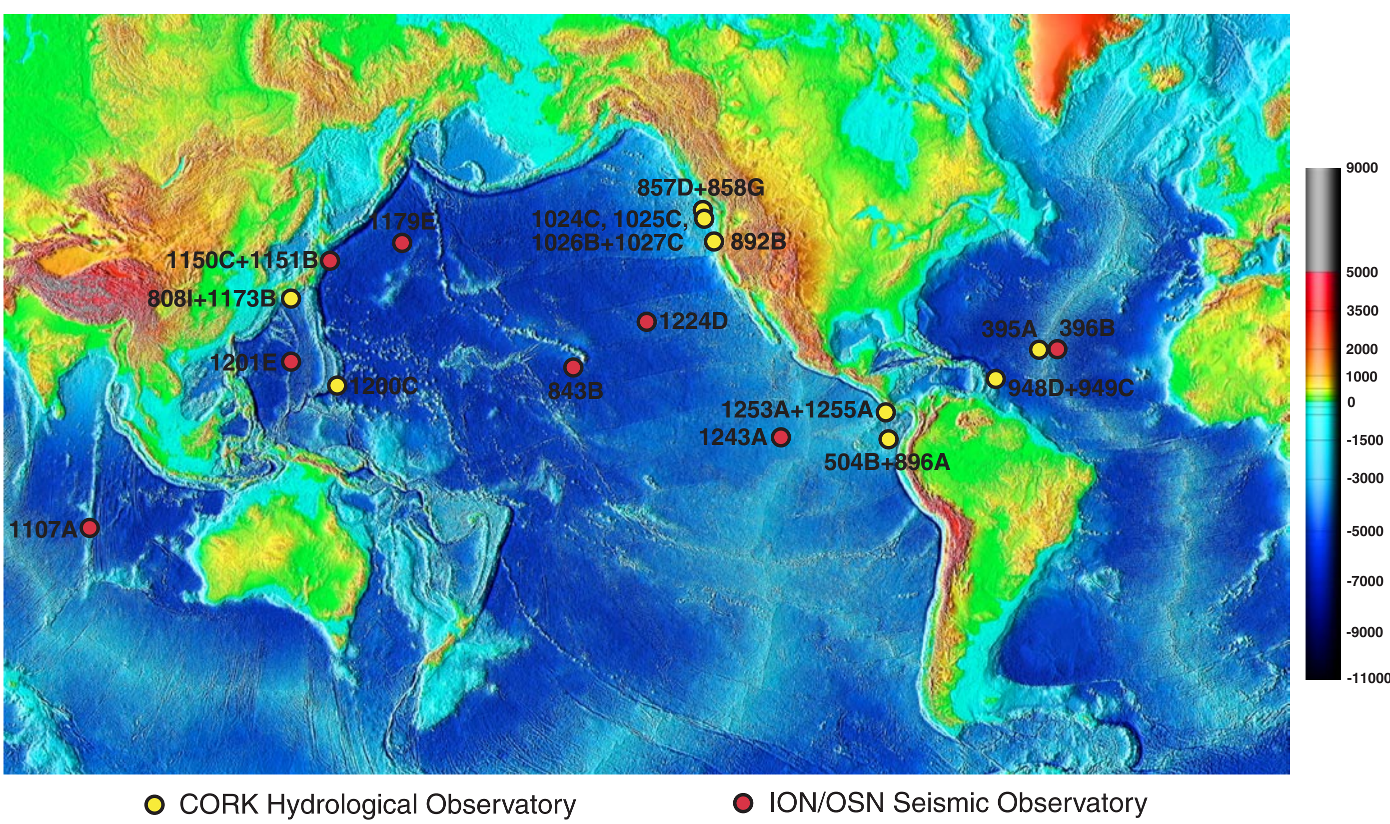
Figure 1. *Leg 202 drill sites span a broad latitudinal range from southern Chile to Central America. Site 1232 is in the Chile Basin; Sites 1233 to1235 are on the Chile margin; Sites 1236 and 1237 are on Nazca Ridge; Sites 1238 and 1239 are on Carnegie Ridge; Site 1240 is in the Panama Basin; and Sites 1241 and 1242 are on Cocos Ridge. Bathymetry based on ETOPO-5 (http://www.ngdc.noaa.gov/mgg/global/seltopo.html).*



In this issue from pages 21-26:

ODP/DSDP Legacy Holes: A Review of Reentry Holes, CORKs and Other Borehole Installations

Figure 1. *ODP borehole observatories installed in ODP/DSDP reentry holes. Mercator projection of digital bathymetry and topography data from National Geophysical Data Center (2000).*



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