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Scientific Drilling

Reports on Deep Earth Sampling and Monitoring

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Editorial Preface

Dear Reader:

This second issue of *Scientific Drilling* covers a truly diverse and global array of drilling experiments conducted on land, in lakes, and in the sea. Two missions in particular exhibit a remarkable overlap of fundamental scientific goals, despite targeting two very different natural settings on opposite sides of the Pacific Ocean. In 2005, the International Continental Scientific Drilling Project (ICDP) drilled through the San Andreas Fault at a depth of 3 km below the surface (p. 32), and, in 2007, the Integrated Ocean Drilling Program (IODP) will begin drilling even deeper into a part of the subduction zone east of Japan that has generated several devastating earthquakes in historical time (p. 23). These two projects will push the limits of scientific drilling technology well beyond those of traditional coring and sampling to include instruments that will monitor seismic activity and the changing physical, chemical, and fluid conditions directly within the boreholes. Such ambitious scientific drilling experiments, spanning decades and involving hundreds of scientists, should bring us closer to understanding the mechanisms of large earthquakes.

We also wish to highlight the exciting new research frontier of the deep biosphere, as emphasized in the IODP Initial Science Plan and during the recent ICDP science conference (p. 43). In addition to sampling routinely for microbiology during drilling, the IODP last year specifically investigated the possible links between microbial activity and the formation of cold-water carbonate mounds (p. 11). The ICDP has begun to examine subsurface microbiology as part of the Chesapeake Bay Impact Structure Deep Drilling Project (p. 60), and a workshop report (p. 56) concerns conditions for early life. Furthermore, a drilling and sampling strategy for the exploration of the deep biosphere is the focus of a major international workshop to be held later this year (p. 58), and manifests the importance of this new research challenge in future scientific drilling.

Finally, we welcome your contributions to Scientific Drilling as well as your suggestions on how we may better serve your needs. You may contact us at: journal@iodp-mi-sapporo.org.

We wish you pleasant reading,

Hans Christian Larsen
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Front Cover: Drilling operations at the ICDP site of the San Andreas Fault Observatory at Depth Project (SAFOD), California, U.S.A. Photo by Lothar Wohlgemuth, ICDP, GFZ Potsdam.

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IODP is an international marine research drilling program dedicated to advancing scientific understanding of the Earth by monitoring and sampling subsea-floor environments. Through multiple drilling platforms, IODP scientists explore the program's principal themes: the deep biosphere, environmental change, and solid earth cycles.

ICDP is a multi-national program designed to promote and coordinate continental drilling projects with a variety of scientific targets at drilling sites of global significance.

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The next issue of *Scientific Drilling* will be distributed in:
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IODP Expeditions 303 and 306 Monitor Miocene-Quaternary Climate in the North Atlantic

by James E.T. Channell, Tokiyuki Sato, Toshiya Kanamatsu, Rüdiger Stein, Mitchell Malone, Carlos Alvarez-Zarikian, and the IODP Expeditions 303 and 306 Scientists

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Introduction

The IODP Expeditions 303 and 306 drilling sites were chosen for two reasons: (1) to capture Miocene-Quaternary millennial-scale climate variability in sensitive regions at the mouth of the Labrador Sea and in the North Atlantic ice-rafted debris (IRD) belt (Ruddiman et al., 1977), and (2) to provide the sedimentary and paleomagnetic attributes, including adequate sedimentation rates, for constructing high-resolution isotopic and magnetic stratigraphies.

High accumulation rates, reaching 20 cm ky^{-1}, permit the study of millennial-scale variations in climate and in the Earth's magnetic field over the past several million years, when the amplitude and frequency of climate variability changed substantially. Shipboard logging and scanning data (magnetic susceptibility and remanence, density, natural gamma radiation, digital images and color reflectance) and post-expedition x-ray fluorescence (XRF) scanning data have revealed that the sediment cores recovered on Expeditions 303 and 306 contain detailed histories of millennial-scale climate and geomagnetic field variability throughout the late Miocene to Quaternary epochs. The climate proxies will be integrated with paleomagnetic data to place the records of millennial-scale climate change into a high resolution stratigraphy based on oxygen isotope and relative paleomagnetic intensity (RPI). The paleomagnetic record of polarity reversals, excursions and RPI in these cores is central to the construction of the stratigraphic template and will provide detailed documentation of geomagnetic field behavior.

Background and Goals

The discovery of climatic oscillations in the Greenland ice cores, the so-called “Dansgaard-Oeschger” (D-O) events, demonstrated that large temperature changes had occurred over Greenland during the last glaciation (Johnsen et al., 1992; Dansgaard et al., 1993; Grootes et al., 1993). The abruptness of these events was impressive, occurring on timescales as short as decades to centuries. Broecker et al. (1992) proposed that layers of IRD-containing detrital carbonate (termed “Heinrich events” after Heinrich, 1988) in North Atlantic sediments were derived from massive discharges of ice from the Hudson Straits region. Over the past fifteen years, this hypothesis spawned numerous studies on IRD in the North Atlantic Ocean (for reviews, see Andrews, 1998, 2000; Hemming, 2004). Most significant were those by Bond and colleagues who linked Heinrich events and other IRD events from North Atlantic sediment cores with temperature oscillations in Greenland (Bond et al., 1992, 1993; McManus et al., 1994; Bond and Lotti, 1995). Higher frequency variations were found to be superimposed upon these signals. These variations were apparent in IRD components such as hematite-stained grains and Icelandic glass and have ~1500 yr pacing (Bond and Lotti, 1995; Bond et al., 1999b, 2001).

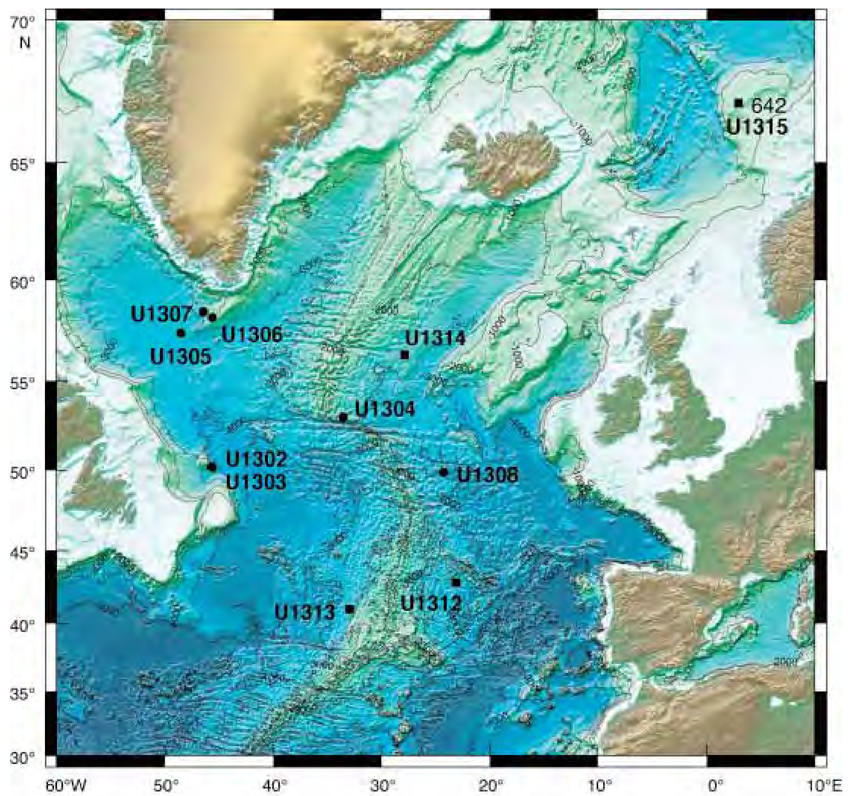

Figure 1. Location of sites occupied during IODP Expedition 303 (Sites U1302–U1308, September–November 2004), and Expedition 306 (Sites U1312–U1315, March–April 2005).

Millennial-scale climate variability has been well documented for the last glacial cycle, most notably in ice cores from Greenland that extend back 123 ky (North Greenland Ice Core project members, 2004). Studies of deep-sea sequences indicate that high-frequency climate variability was also prevalent prior to this period (Oppo et al., 1998; Raymo et al., 1998; McManus et al., 1999; Hiscott et al., 2001; de Abreu et al., 2003; Martrat et al., 2004), but such studies have been limited by the availability of long cores with high sedimentation rates. During IODP Expeditions 303 and 306, we recovered cores from multiple locations in the North Atlantic (Fig. 1) that are well suited for examining suborbital climate variability beyond the last glacial–interglacial climate cycle.

The results of this drilling will address significant climate- and geomagnetic-related questions such as the following.

1. When did Heinrich events first appear in the sedimentary record of the North Atlantic?
2. Was millennial-scale climate variability fundamentally different in magnitude or pacing before the mid-Pleistocene transition from 41-ky to 100-ky glacial cycles?
3. How have horizontal and vertical gradients in surface- and deep-water mass properties changed on both orbital and millennial time scales?
4. Is the 1500-yr pacing documented for the last climate cycle a stable feature of the North Atlantic throughout the Pleistocene?
5. Can the promise of RPI as documented during the last glacial cycle be extended and linked to marine isotope stages to provide a viable means of global correlation?
6. Can offsets in benthic $\delta^{18}O$ records, due to local deep-water $\delta^{18}O$ and temperature (e.g. Skinner and Shackleton, 2005), be resolved using RPI as a stratigraphic tool?
7. How can lithologic contamination in RPI records be minimized, and can periodicities in those records be attributed to geomagnetic behavior?
8. What was the morphology of the geomagnetic field during reversals, excursions and brief subchrons?
9. As geomagnetic field intensity is a control on cosmogenic nuclide production, does the correlation of North Atlantic climate or IRD cycles to cosmogenic isotope flux (Bond et al., 2001) imply a link between climate and geomagnetic field strength, or between climate and solar activity?

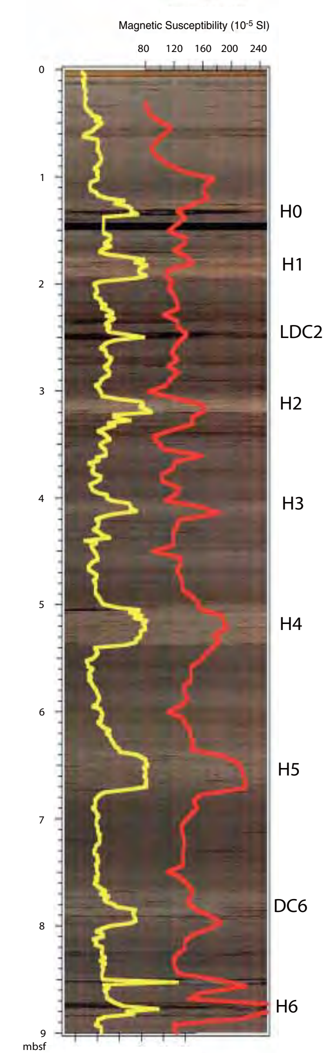

Figure 2. Detrital layers at Hole U1303B, in the uppermost 9 mbsf. Enhanced digital image scan overlain by susceptibility (red, right) and gamma ray attenuation density (yellow, left). Detrital layer nomenclature from Stoner et al. (2000) for Core MD95-2024 taken nearby.

Sedimentary Sections Recovered During IODP Expeditions 303 and 306

The primary objectives of IODP Expeditions 303 and 306 (Fig. 1) were to recover cores that would yield complete and continuous records of millennial-scale environmental variability (i.e., ice sheet–ocean interactions, deep circulation changes and sea-surface conditions), and also be suitable for the development of high-resolution magnetic and isotope stratigraphies. Many of these study sites have been instrumental in developing marine records of suborbital climate variability for the last climate cycle (e.g., Orphan Knoll, Eirik and Gardar Drifts, and DSDP Sites 607, 608, and 609). Emphasis was placed on the recovery of complete, undisturbed, composite sections from multiple advanced piston corer (APC) holes. Shipboard data and post-cruise XRF scanning of the recovered cores appear to document millennial-scale variability that extends through the last several million years.

At each site, drilling was terminated at the limit of the APC. The extended core barrel (XCB) was not used because the increase in drilling disturbance associated with the XCB, particularly in the upper part of the XCB section, is not conducive to high-resolution studies, and because previous DSDP or ODP drilling legs have sampled the deeper stratigraphic section at all locations other than the Gardar Drift sites.

Sites U1302 and U1303 are located close to Orphan Knoll on the Labrador Rise (Fig. 1), where proximal records of Laurentide ice-sheet (LIS) instability are manifest in detrital layer stratigraphy. Piston cores collected at or near Sites U1302 and U1303 (HU91-045-094P, MD95-2024, MD95-2025, MD99-2237) preserve a detailed stratigraphic record of LIS instability through detrital carbonate-rich and -poor layers (Hillaire-Marcel et al., 1994; Stoner et al., 1996, 1998; 2000; Hillaire-Marcel and Bilodeau, 2000; Hiscott et al., 2001). Isotopic data from planktic foraminifers indicate that these detrital layers are associated with large depletions in $\partial^{18}O$ that likely reflect significant meltwater incursions. Sites U1302 and U1303 record these detrital layers (e.g., see Fig. 2) and provide an opportunity to document LIS instability and its intercalibration with oxygen isotopes and RPI, to the base of the recovered section, or approximately marine isotopic stage (MIS) 17 (Fig. 3). Mean sedimentation rates for the upper 105 m at Sites U1302 and U1303 are estimated to be ~15 cm ky^{-1}.

Site U1304 is located at the southern tip of the Gardar Drift and the northern end of the central Atlantic IRD belt, near the Gibbs Fracture Zone (Fig. 1). It provides a more distal record of LIS instability compared to Sites U1302 and U1303, and it lies in sufficiently deep water (3065 m) to document lower North Atlantic Deep Water (NADW) variability. Site U1304 also complements ODP Site 983, which was drilled at an intermediate water depth (1983 m) on the northern Gardar Drift. The sediments at Site U1304 comprise interbedded diatom and nannofossil oozes with clay and silty clay. The lithologies are generally interbedded on centimeter to decimeter scales. Diatom assemblages are dominated by needle-shaped species of the *Thalassiothrix–Lioloma* complex. The diatom-rich sedimentary section extends to the uppermost Pliocene at 258 mcd (Fig. 3). Mean sedimentation rates of 17.8 cm ky^{-1} are estimated for the last 0.78 Ma, and 12.2 cm ky^{-1} for the interval from 0.78 to 1.77 Ma. The episodic occurrence of diatom-rich strata implies that the site has been located near the sub-arctic convergence related to the confluence of the Labrador and North Atlantic Currents (see Boden and Backman, 1996). The good preservation of benthic and planktic foraminifers, the excellent magnetic properties apparent from shipboard data and the construction of a complete composite section from four holes indicate that the environmental record can be placed into a reliable and precise age model.

Sites U1305, U1306 and U1307 were drilled on the Eirik Drift (Fig. 1). Site U1305 was the designated deep-water site in 3459 m water depth at the western extremity of the Eirik Drift, and Site U1306 was the primary shallow-water site in 2273 m water depth, located 191 km northeast of Site U1305. These two sites were chosen by maximizing the thickness of the Quaternary sedimentary section in the multichannel seismic (MCS) network obtained over the Eirik Drift during Cruise KN166-14 of the R/V *Knorr* in 2002, whereas Site 1307 is located where the Quaternary sedimentary section appears to be thinned relative to its thickness at Site U1306, providing APC access to the underlying Pliocene section. Conventional piston cores have shown that the sedimentation history on the Eirik Drift during the last glacial cycle was strongly affected by the Western Boundary Undercurrent (WBUC) that sweeps along east Greenland and into the Labrador Sea (Hillaire-Marcel et al., 1994; Stoner et al., 1998). Data from two such piston cores (HU90-013-013 and HU90-013-012) from contrasting water depths suggested that Site U1305 should display relatively expanded interglacials and relatively condensed glacial intervals, and that Site 1306 should show the the converse. The base of the section at both sites lies within or just below the Olduvai Subchronozone at ~300 mcd (Fig. 3), and the mean sedimentation rates were 17–18 cm ky^{-1}. Sites U1305 and U1306 will provide complementary high-resolution records of the history of the WBUC detrital layer stratigraphy signifying

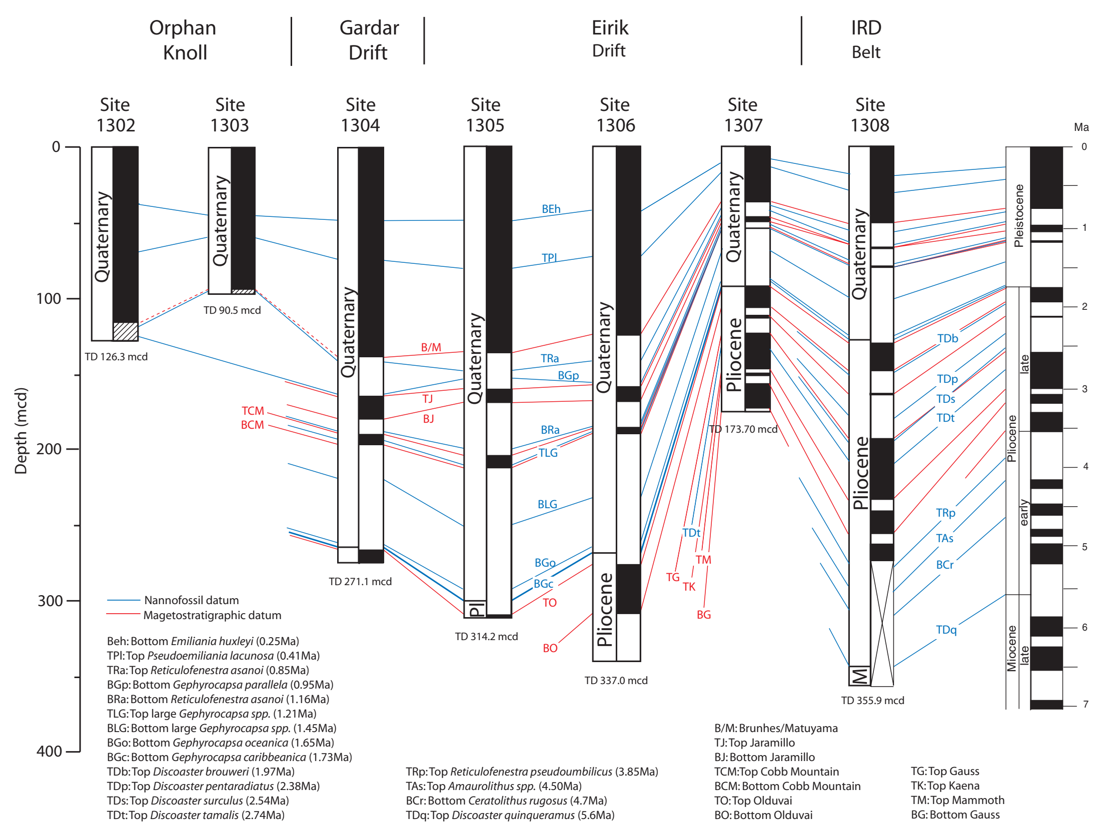

Figure 3. Schematic stratigraphy at the seven sites drilled during Expedition 303. The geomagnetic polarity timescale is shown on the right. The normal and reverse polarity zones indicated in black and white, respectively, are based on shipboard measurements after AF demagnetization in the 10–15 mT peak field range. Hatched intervals indicate uncertain polarity in the debris flow of Sites 1302 and 1303. Blue tie lines indicate nannofossil data and correlations. Red tie-lines indicate magnetostratigraphic correlations. Reference polarity timescale in right-side column from Cande and Kent (1992, 1995).

instability of the surrounding ice sheets, and the attributes for well-constrained age models using stable isotopes, biostratigraphy and RPI. Two holes were drilled at Site U1307 reaching a maximum depth of 162 mcd in the uppermost Gilbert Chronozone (~3.6 Ma) (Fig. 3). The mean sedimentation rate for the recovered section was 4.9 cm ky^{-1}. Interval sedimentation rates between polarity reversals ranged from 2.7 to 7.6 cm ky^{-1}. Poor weather and excessive ship heave curtailed drilling at this site, and the two holes were insufficient to generate a complete composite section. The site did, however, establish the feasibility of recovering the Pliocene sedimentary section on the Eirik Drift using the APC. The site extends the environmental record back to ~3.6 Ma and will provide invaluable age control throughout the MCS network established on the Eirik Drift by the KN166-14 cruise. The cores recovered at Site U1307 thus will enhance our understanding of the sedimentary architecture of the Eirik Drift.

Site U1308 represents a reoccupation of DSDP Site 609, which has played a prominent role in some of the most important developments in millennial-scale climate research during the past fifteen years. IRD layers containing detrital carbonate (Heinrich events) were recognized at this site (Bond et al., 1992); they also correlated to the Greenland ice-core record (e.g., Bond et al., 1993). The 1500-yr cycle in petrologic characteristics such as hematite-stained grains and Icelandic glass has also been recognized at this site (Bond et al., 1999b). Most of the recent work on DSDP Site 609 sediments has focused on the last glacial cycle, partly because of uncertainties in the continuity of the section at greater depth. Site U1308 has improved upon Site 609 in that a complete composite section was obtained to 247 mcd, with its base within the Gauss Chronozone at ~3.1 Ma (Fig. 3). Sedimentation rates averaged 7.9 cm ky^{-1} over the entire period.

Site U1312 represents a reoccupation of DSDP Site 608 (Fig. 1). The main objective was to obtain continuous records of surface- and deep-water characteristics and their interactions with proxies for ice-sheet instability during Neogene-Quaternary times. In this context, an important target at this site was the recovery of a complete, undisturbed, upper Miocene section by APC. The Holocene to upper Miocene sedimentary sequence at Site U1312 consists of varying mixtures of biogenic and detrital components, primarily nannofossils, foraminifers and clay minerals. Near 3.5 Ma, the progressive but oscillatory deterioration of the Northern Hemisphere climate, which gradually led to the onset of major continental ice sheets at about 2.7 Ma, is reflected in the increase in detrital sediment input, followed by climate-controlled, short-term variability in detrital input in the late-Pliocene to Pleistocene. Average sedimentation rates were low (1–2 cm ky^{-1}) during the late Miocene, the late Pliocene,

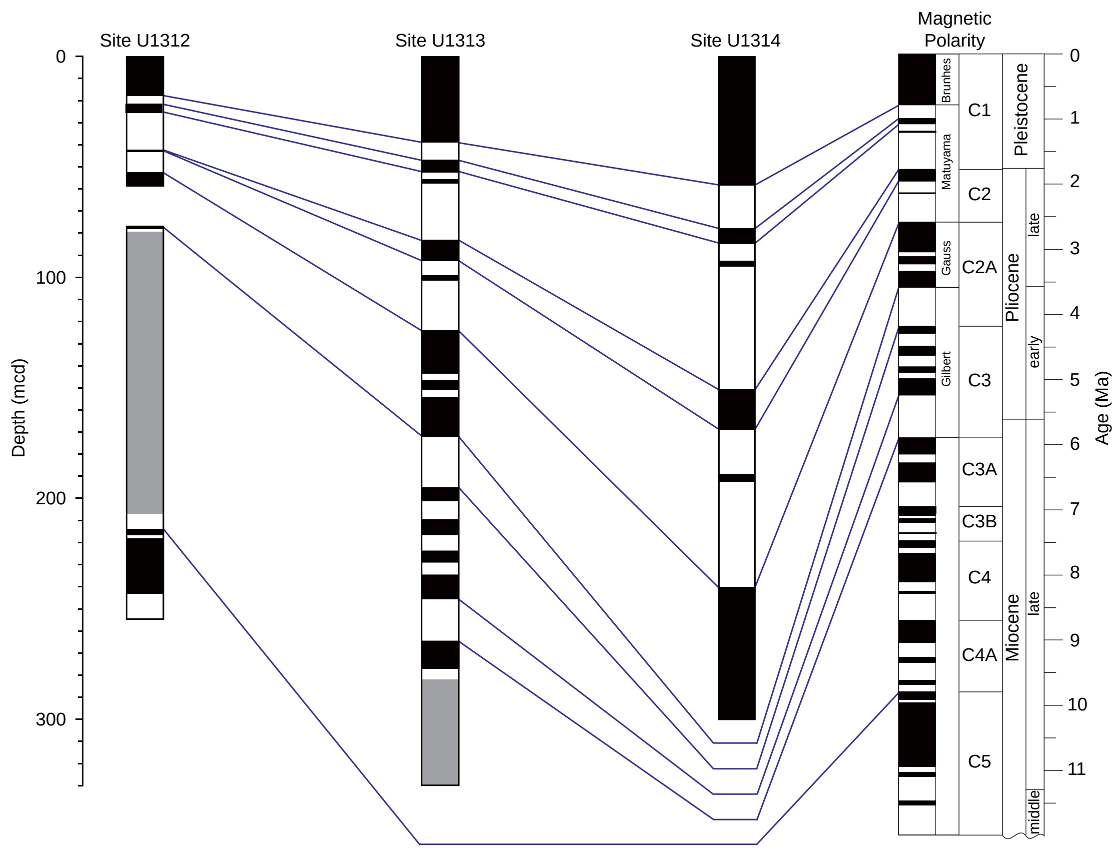

Figure 4. Expedition 306 schematic magnetostratigraphy. The paleomagnetic polarity interpretations (black = normal polarity, white = reversed polarity, gray = undetermined polarity) were obtained on the basis of shipboard inclination data acquired after 20 mT AF demagnetization. Continuous blue lines = principal magnetostratigraphic tie points used to establish the age models. Reference polarity timescale in right-side column from Cande and Kent (1992, 1995).

and the Pleistocene, but higher in the early Pliocene (3–8 cm ky^{-1}). The sedimentary sequence of Site U1312 representing approximately the last 11 My (Fig. 4) will allow the study of short- and long-term climate variability and ocean–atmosphere interactions under very different boundary conditions, such as the closure and re-opening of Atlantic–Mediterranean connections at the end of the Miocene (6–5 Ma), the closing of the Isthmus of Panama (4.5–3 Ma), and the onset of major Northern Hemisphere glaciation near 2.7 Ma.

Site U1313 represents a reoccupation of DSDP Site 607 (Fig. 1). Site 607 has been very important for generating a late Pliocene to Pleistocene stable isotope stratigraphy and for interpreting it in terms of ice-sheet variability and changes in NADW circulation. At the site of Core VM 30-97, located close to DSDP Site 607, Heinrich events are marked by the distinctive detrital carbonate signature, and planktonic foraminifer-derived sea-surface temperatures warmed markedly during the Heinrich events and during the Last Glacial Maximum, in distinct contrast to the climate records from the sub-polar North Atlantic (Bond et al., 1999a). The Holocene to latest Miocene sediment at Site U1313 (Fig. 4) consists primarily of nannofossil ooze with varying amounts of foraminifers and clay- to gravel-sized terrigenous components. The detrital components become much more important and variable in the upper Pliocene–Pleistocene interval of the sequence, probably reflecting Northern Hemisphere ice-sheet instability. Bio- and magneto-stratigraphy indicate nearly constant sedimentation rates of ~4.1–4.5 cm ky^{-1} throughout the Pliocene–Pleistocene time interval, whereas in the late Messinian sedimentation rates were approximately 13–14 cm ky^{-1}. The correlation of downhole logging data with core data should allow the mapping of the spliced core record to actual depth, resulting in more accurate sedimentation rate calculations and more detailed age–depth models. Site U1313 provides a unique and complete Pliocene–Pleistocene sedimentary section (Fig. 4) that will allow an optimal reconstruction of the phasing of the temperature records and its relationship to ice-sheet instability and changes in deep-water circulation since approximately 5 Ma. In addition, sedimentation rates of 13–14 cm ky^{-1} will allow a high-resolution study of paleoenvironmental change during the late Messinian.

Site U1314 was drilled on the southern Gardar Drift (Fig. 1) at a water depth of approximately 2800 m. The complete upper Pliocene to Holocene sedimentary sequence recovered at this site (Fig. 4) consists of an alternation of predominantly nannofossil oozes enriched in biogenic and terrigenous components, and terrigenous silty clay with a varying proportion of calcareous and siliceous organisms. This alternation is also reflected in the varying carbonate content between ~5% and 70%. Sand- and gravel-sized sediment, common at Site U1314 from 0 to 240 mbsf, provides direct evidence of ice rafting and documents the influence of Plio-Pleistocene glaciations in this region. Site U1314 yields abundant moderately to well-preserved assemblages of calcareous and siliceous microfossils throughout the section and an excellent paleomagnetic record of the Brunhes, Matuyama and the upper part of the Gauss Chrons. Several brief geomagnetic excursions are present in the paleomagnetic record. Sedimentation rates based on microfossil data and polarity reversals indicate decreasing rates from approximately 11–11.5 cm ky^{-1} during the late Pliocene, to ~7.0–7.5 cm ky^{-1} during the Pleistocene. Due to its proximity to the IRD belt and within the NADW, the complete upper Pliocene to Holocene sequence at Site U1314 (Fig. 4) will establish a high-resolution paleoenvironmental record of sea-surface and bottom-water characteristics and a detrital (Heinrich-type) stratigraphy for the past ~2.7 Ma.

Site U1315 is located on the Vøring Plateau close to ODP Site 642 (Fig. 1). At this site, a borehole observatory for long-term measurements of bottom-water temperatures was installed in a newly drilled 180-m-deep hole (see progress report p. 28). The hole was sealed from the overlying ocean after two pressure cases and a thermistor string were installed. This configuration allows high-precision temperature measurements as a function of both depth and time. The sub-bottom temperature perturbations should allow reconstruction of the temperature record of bottom water during at least the last 100 years, far beyond the directly measured temperature records available up to now.

Summary

Long-term records of millennial-scale variability from North Atlantic proxies of surface temperature, ice-sheet dynamics and thermohaline circulation provide valuable constraints on the nature of atmosphere–ice–ocean interactions that are responsible for abrupt climate change (e.g., Alley et al., 1999). The overall post-cruise objectives of IODP Expeditions 303 and 306 are to resolve the climate records from the high-sedimentation-rate sedimentary sections that have been recovered, and to generate a stratigraphic framework based on biostratigraphy, oxygen isotope data and magnetic stratigraphy, including RPI data. The integrated stratigraphy will allow the climate record, such as the detrital layer stratigraphy indicative of ice-sheet instability, to be placed in a suitable framework for correlating North Atlantic climate records to one another and to high-resolution records elsewhere. The power of shipboard whole-core logging data (susceptibility, natural gamma, digital image, reflectance, and density) and shore-based scanning data (e.g. XRF) means that the basic climate-related lithologic variability (e.g. detrital layers) can be recognized throughout the late Miocene-Quaternary. The key is placing this detrital record and other climate proxies (e.g. stable isotopic data for deep- and surface-water mass temperature and chemistry, faunal and floral overturn, etc.) into a precise stratigraphic framework. This stratigraphic framework is essential for meeting the objectives of Expeditions 303 and 306, and for studying millennial-scale climate change on long timescales.

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IODP Expedition 307 Drills Cold-Water Coral Mound Along the Irish Continental Margin

by Timothy G. Ferdelman, Akihiro Kano, Trevor Williams, and the IODP Expedition 307 Scientists

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Introduction

Over the past decade, oceanographic and geophysical surveys along the slope of the Porcupine Seabight off the southwestern continental margin of Ireland have identified upwards of a thousand enigmatic mound-like structures (Figs. 1 and 2). The mounds of the Porcupine Seabight rise from the seafloor in water depths of 600–900 m and form impressive conical bodies several kilometers wide and up to 200 m high. Although a few mounds such as Thérèse Mound and Galway Mound are covered by a thriving thicket of cold-water corals, most mound tops and flanks are covered by dead coral rubble or are entirely buried by sediment (De Mol et al., 2002; Fig. 2, Beyer et al., 2003). *Lophelia pertusa* (Fig. 3) and *Madrepora oculata* are the most prominent cold-water corals growing without photosynthetic symbionts. The widespread discovery of large and numerous coral-bearing banks and the association of these corals with the mounds have generated significant interest as to the composition, origin and development of these mound structures.

Challenger Mound, in the Belgica mound province, has an elongated shape oriented along a north-northeast to south-southwest axis and is partially buried under Pleistocene drift sediments. In high-resolution seismic profiles the mounds appear to root on an erosion surface (van Rooij et al., 2003). During IODP Expedition 307 the Challenger Mound in the Porcupine Seabight was drilled with the goal of unveiling the origin and depositional processes within these intriguing sedimentary structures. Challenger Mound, unlike its near neighbors the Thérèse and Galway mounds, has little to no live coral coverage and, therefore, was chosen as the main target for drilling activities, so that no living ecosystem would be disturbed.

External vs. Internal Control on Mound Development

Two theories have been forwarded to explain the initiation and growth of these impressive structures: (1) oceanographic and paleoenvironmental conditions control mound initiation and growth (external control), and (2) hydrocarbon seepage initiates microbial-induced carbonate formation and indirectly fuels coral growth (internal control) (Hovland et al., 1998; Henriet et al., 2001). The oceanographic or environmental hypothesis states that the two most important conditions for stimulating mound development are (1) strong, nutrient-rich currents that provide suspended food to the filter-feeding corals, sweep the polyps clean of detritus and inhibit sediment burial, and (2) a stable substrate for settlement of coral larvae (Frederiksen et al., 1992). Strong bottom currents in the Belgica mound province, resulting from internal tidal wave effects at the boundary between Mediterranean Outflow Water and East North Atlantic Water, provide the suspended nutrients for filter-feeding cold-water corals.

The hydrocarbon seepage hypothesis was first proposed by Hovland et al. (1998), who suggested that hydrocarbon seepage may promote favorable development conditions for deep-sea corals. Elevated dissolved inorganic carbon concentrations derived from the microbially mediated oxidation of light hydrocarbons—in particular methane—are conducive to skeletal accretion and for submarine lithification. Based

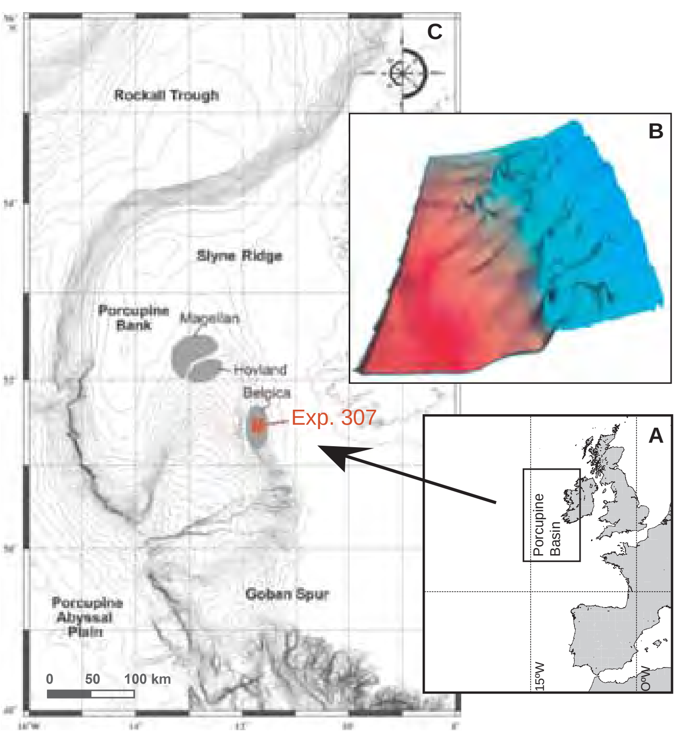

Figure 1. Location of Porcupine Seabight and IODP Expedition 307 operations area.

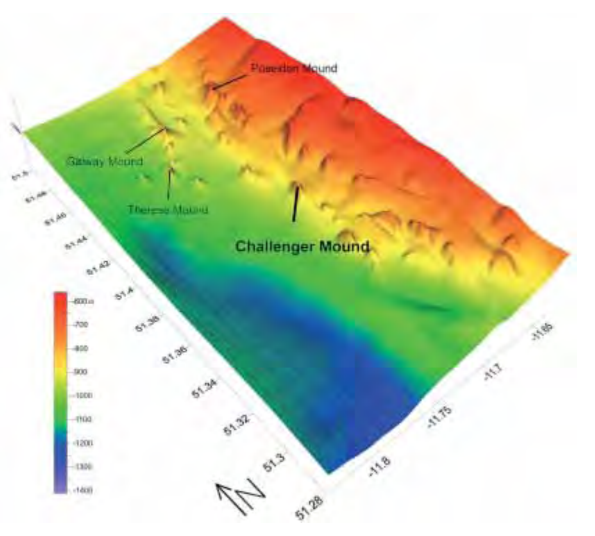

Figure 2. Multibeam bathymetry of Belgic mound province on eastern slope of Porcupine Seabight (after Beyer et al., 2003).

on seismic profiling, Henriet et al. (2002) suggested a four-stage developmental model applicable to Challenger Mound. The initial stage may have related to fluid venting and authigenic carbonate precipitation, which provided a hardground for corals to colonize. In the second stage, the settling of corals on the hardground in connection with microbially induced carbonate precipitation catalyzed mound growth. Further growth of corals developed a carbonate mound in the third stage. Pelagic ooze and current-transported siliciclastic sediments were trapped in the framework of branching corals. In the final stage, Challenger Mound was buried asymmetrically by drift sediments.

Challenger Mound is one of thousands of mound structures in the Porcupine Seabight and the first to be scientifically cored deeper than 12 m, so drilling this structure was true exploration. Did it contain corals deeper within the mound and to the base? Is it a carbonate mud mound composed of microbial automicrite similar to structures that occur ubiquitously in Paleozoic-Mesozoic strata worldwide? On what type of surface did the mound root? To answer these and other questions, we successfully drilled three sites in an off-mound–mound–upper-slope transect (Fig. 4), within just twelve days of science operations onboard the *JOIDES Resolution*. The sites were chosen (1) to constrain the stratigraphic framework of the slope and mound system, (2) to identify and correlate regional erosional surfaces identified in seismics and (3) to investigate the hypothesized presence of hydrocarbons as the energy source for mound nucleation and sustained growth in a microbe-dominated environment.

Drilling and Sampling Challenges

IODP Expedition 307 faced a number of new and interesting operational and scientific challenges. The lead time from scheduling the expedition to sailing was extremely short (less than five months). The expedition was planned for only ten days of science operations with a short transit from Dublin, Ireland to the drilling sites. Fortunately, the weather was fair and two extra days were gained from a shortened port call in Dublin harbor. In these twelve days it was possible to complete the project and recover nearly 1400 meters of sediment from eleven holes at three sites. This included a five-hole transect at site 1317 across the western flank of Challenger Mound itself, logging on all sites, and a vertical seismic profile taken within the mound.

The expedition employed an integrated sedimentological, geochemical, and microbiological approach. Each specialty group was aware of the value of their analyses to the other groups and the connections between parameters such as microbial action, interstitial water chemistry and diagenetic alteration of the sediments. As much as 1.5-m core sections were assigned for microbiological sampling and forwarded to the temporary cold lab established in the ship's hold for sampling of DNA, lipids, cell enumeration and whole-round cores for experimental work. All cores, including a number of sections assigned to microbiology, were run through the fast-track magnetic susceptibility meter without problems.

Expedition 307 faced the technical challenge of how to split and curate coral-bearing sediment. Conventional methods of core-splitting, using both wire-cutter and saw, resulted in fragmenting the coral, with coral pieces being dragged down the split core surface and degrading the sediment structure. In the core laboratory, a new technique was developed for splitting coral-bearing cores in an unlithified matrix. All core sections from Hole U1317C were split by saw only after being frozen to −50°C for 48 hours. Apart from some centimeter-long freeze-cracks on the split core face, the coral structure was beautifully preserved, and it was unanimously agreed that this method produced the best results (Fig. 5). Holes U1317A and U1317D were split using the conventional saw, so that the sedimentologists could describe at least one full stratigraphic section. Holes U1317B and U1317E remained unopened onboard and awaited freeze-splitting at College Station, Texas, U.S.A. Additionally, selected coral-bearing cores were sent to Erlangen, Germany, for high-resolution computer-tomography scanning. A two-week description and sampling party in October 2005 at the Bremen Core Repository (Germany), concluded the initial science activities of IODP Expedition 307.

Figure 3. Micro-image of Lophelia pertusa.

Challenger Mound is a Coral Bearing Build-up

Drilling at Site U1317 revealed that the Challenger Mound does indeed rest on a sharp erosional surface (Fig. 6) corresponding to the one identified in seismic profiles (Fig. 4). This surface cuts across the lower lying Miocene-Pliocene siliciclastic sequence (seismic unit P1). Sediments below this erosional surface consist of glauconitic and silty sandstone drift deposits of Miocene age. The Miocene strata end abruptly in the firm ground that underlies the Pleistocene mound sequence. Initial magnetostratigraphic and biostratigraphic results suggest that the hiatus between the two sequences spans at least 1.65 million years. While the mound appears to be Pleistocene in age, the mound flanks are draped by comparably younger Pleistocene (< 0.26 Ma) silty clay deposits that contain frequent dropstones.

The Challenger Mound itself is dominated by unlithified coral-bearing *(Lophelia pertusa)* floatstone and rudstone. The muddy matrix of the sediment consists largely of terrigenous clay and calcareous nannofossils, including reworked Cretaceous species. The micritic carbonate component of the mound consists almost completely of coccolithophorids. The mound sequence shows pronounced recurring cycles on a scale of one to several meters. The cycles exhibit distinct changes in carbonate content and generally consist of floatstone overlain by rudstone interbedded with wackestone. The cycles found in the mound succession are possibly associated with the Pleistocene glacial–interglacial cycles; however, preliminary investigation of foraminifera assemblages shows rare occurrences of cold-water species and suggests that the mound sequence might have formed main-ly during interglacial periods.

Figure 4 shows the first interpretation of the lithostratigraphy and age model superimposed on the seismic interpretation. Based on this schematic overview, the mound initiated on the erosion surface that separates seismic units P1 and P2 from unit P3. The timing of this erosional episode is still unclear based on initial shipboard data, but it tentatively correlates to an early Pliocene erosional episode in the nearby Rockall Basin (DeMol et al., 2002; Van Rooij et al., 2003). Calcareous nannofossil biostratigraphy indicates that deposition of the 150-m thick coral-bearing mound section started after 1.95 Ma and ended before 0.46 Ma. Upper Pleistocene to recent sediments have onlapped and already buried the older Pleistocene mound strata. At present, neither the internal mound structure nor the processes of mound formation and accretion are well understood. Evidence from Site U1316, located 700 m to the southwest of Challenger Mound, indicates down-slope coral transport (Fig. 7). Relating mound and off-mound successions will be important for answering questions on the growth mechanics, accretion and shedding processes (i.e., vertical and lateral growth vs. verified growth and down-slope shedding). It will also be important to investigate the horizontally contiguous extent of coral growth phases and strata. These questions will be the focus of close examination of the various physical and lithostratigraphic data collected during Expedition 307.

No Role for Hydrocarbon Seepage in the Challenger Mound?

Significant hydrocarbon seepage is not evident from the lithostratigraphy or from the initial geochemical and microbiological results. Only low to moderate concentrations of methane or ethane (< 2 mM) were measured in the mound or

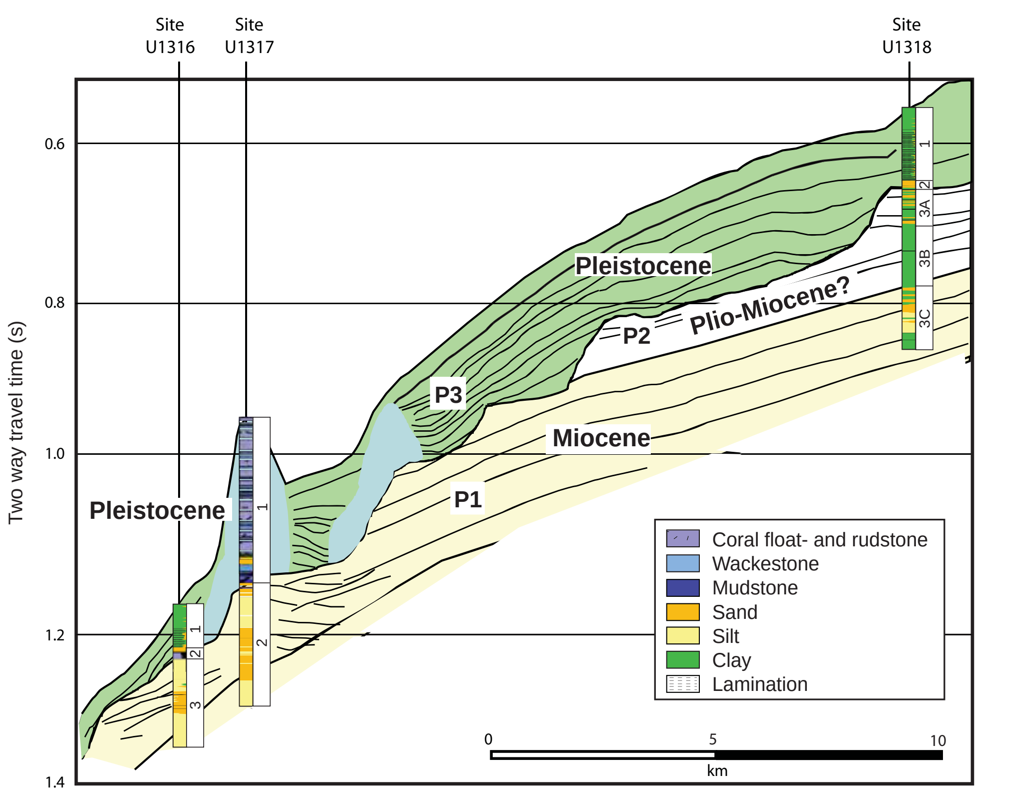

Figure 4. Lithostratigraphy of three drilling sites projected on seismic profile of Challenger Mound along a north-northwest to south-southeast transect. Biostratigraphic dates for the 150-m thick mound sequence (blue) suggest that mound growth initiated 1.95 Ma and ended before 0.46 Ma. Note that more recent, siliciclastic Pleistocene sediments have onlapped and slowly buried the older Pleistocene mound strata.

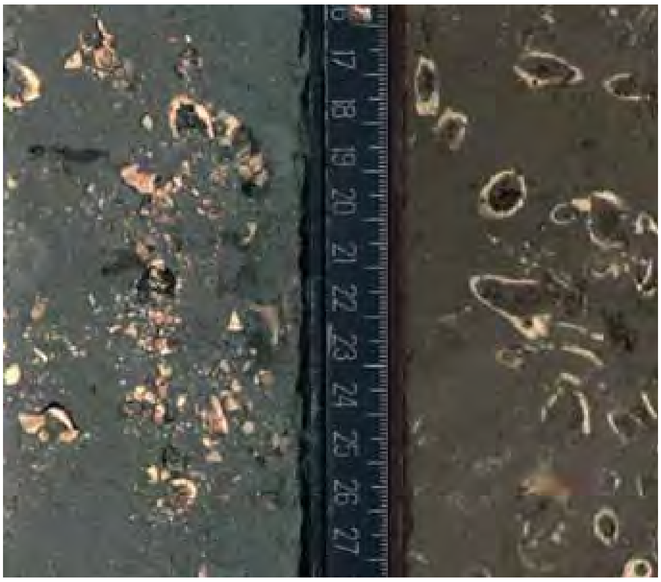

Figure 5. Comparison of cores split with traditional (left) versus freezing and sawing (right) methods.

in the sub-basal mound sediments. At Site U1317 on the Challenger Mound, the methane to sulfate transition was detected in the underlying Miocene silt and sandstones. Although the mound has a sharply defined base, no basal carbonate hardgrounds were observed to suggest microbially induced carbonate precipitation. However, this latter finding awaits confirmation through stable isotope, biomarker and microbiological analyses. Although hydrocarbon seepage may occur in certain mound structures elsewhere in the world (e.g., the Pen Duick structures off the coast off Morocco), our current interpretation of Expedition 307 data suggests that hydrocarbon seepage is not a necessary condition for the development of a coral mound and very likely not for the Belgica mound province in general.

The Microbial Imprint

Challenger Mound might not be a suitable modern analog for understanding the Phanerozoic mounds of microbial origin; however, fascinating aspects of deep microbial activity at all sites were evident already in the shipboard interstitial-water chemistry and prokaryote distributions. For instance, the subtle intertwining of carbonate-mineral-controlled diagenesis and microbially mediated organic matter decay represents one of the highlights of the geochemical and microbiological investigations on the mound site. Methane, sulfate and alkalinity profiles, as shown in Figure 8, reflect zones of microbially mediated organic decay. Below 150 mbsf, within the zone of sulfate reduction coupled with anaerobic oxidation of methane, increasing dissolved Ca^{2+} levels and decreasing dissolved Mg^{2+} levels suggest that dolomite is forming within Miocene sediments below the mound base. Surprisingly, there were significantly more prokaryotic cells in these much deeper and older Miocene sediments than would be expected from their age and depth. They are also present in comparable or greater numbers in the overlying Pliocene–Pleistocene sequences.

Within the mound itself, the curved profiles for sulfate and alkalinity between 0 and 50 mbsf indicate decay of organic matter and consumption of the sulfate mediated by sulfate-reducing bacteria. In addition, an increase in dissolved Sr^{2+} indicates that aragonite dissolution is releasing strontium into the interstitial water. Over the same depth interval, dissolved Mg^{2+} also shows a loss, as evidenced in the decreased Mg concentration (Fig. 8), thus suggesting that dolomite or some other Ca-Mg carbonate mineral (e.g., low-Mg calcite or calcian dolomite) is precipitating and removing Mg from solution. Decomposition of organic matter by sulfate reduction may be driving this process by producing CO_2, which enhances aragonite dissolution, and increasing the overall dissolved inorganic carbon concentration. Iterestingly we detected no dissolved hydrogen sulfide that should accumulate in the interstitial water as a product of sulfate reduction. It is very likely that the sulfide reacts with ferric-iron-containing minerals in the siliciclastic fraction and precipitates as iron sulfide minerals, particularly pyrite (FeS_2). Overall, sulfate reduction coupled with pyrite formation would drive re-precipitation of carbonates as described in the following equation.

$$3SO_4^{2-} + 6CH_2O + 2FeOOH + Ca^{2+} + 2Mg^{2+} + CaCO_3$$
$$\Rightarrow$$
$$FeS_2 + FeS + 4Ca_{0.5}Mg_{0.5}CO_3 + 3CO_2 + 7H_2O$$

Lower sulfate, Ca^{2+} and Mg^{2+}, along with higher alkalinity and Sr^{2+} concentrations, in Hole U1317E suggest that microbially mediated organic matter decay and carbonate mineral

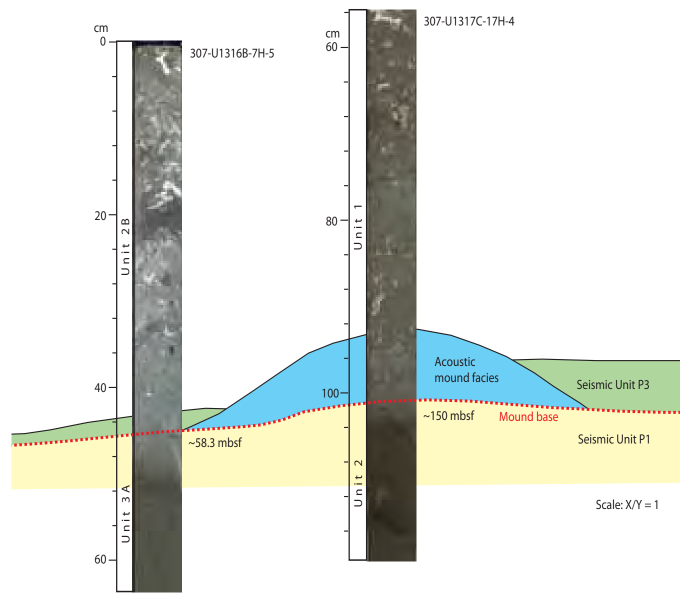

Figure 6. Comparison of mound base core photographs from Sites U1316 and U1317 with schematic representation of the mound.

diagenesis are more intense at the mound top (Fig. 8), where sediments remain *in situ* relative to the mound flanks (Holes U1317A–U1317D which are characterized by downslope-transported sediments). The mound facies suggests that there are dark zones of good coral preservation and little lithification alternating with light colored zones of very poor carbonate preservation. It remains to be seen if microbial or oceanographic factors govern the geochemistry and subsequent carbonate dissolution, re-precipitation and lithification. These answers will provide the basis for understanding how the mound structure is maintained. These interstitial-water chemistry results already provide some insight into the lithification processes and suggest hypotheses for further testing onshore.

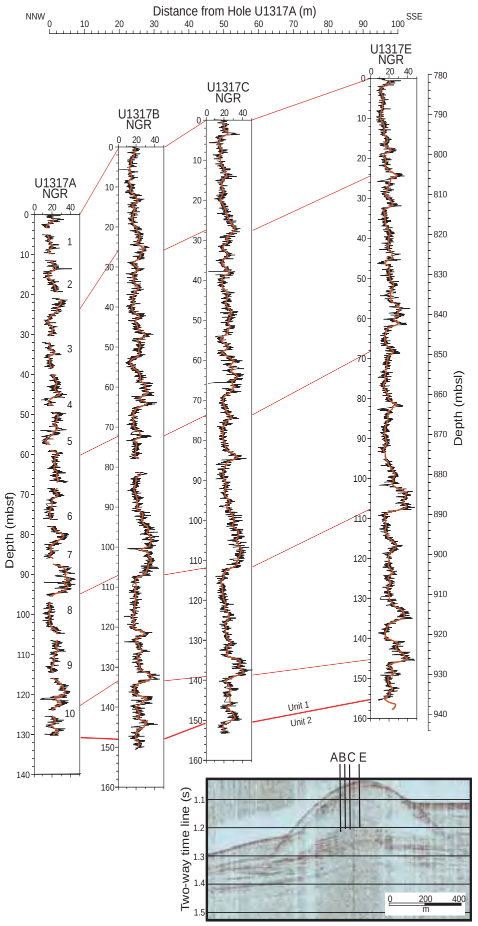

Figure 7. Transect of holes at Site U1317 on the seaward side of Challenger Mound. The natural gamma distributions show the variations in strata that will be used to form a stratigraphic framework for interpreting mound growth. The track data are arranged to reflect the variations in water column depth at each hole.

Forthcoming Research and Implications

Results from IODP Expedition 307 demonstrate that unlithified sediments form high and steep-flanked conical structures in a shelf margin setting. One intriguing question is how such structures are stabilized on the seafloor. The presence or absence of a coral framework may be a key to understanding not only the sediment-stabilizing process but also the rapid accretion. Further research will address this and other issues by high-resolution x-ray computer-tomography (CT) scanning of the whole-round core sections from selected horizons. Furthermore, cold-water coral mounds may serve as high-resolution environmental recorders. Based on observations of sediment composition, color and coral preservation, the mound sequence appears to record glacial–interglacial climate changes. Because cold-water corals are sensitive to conditions such as water temperature, nutrient conditions, and current strength, their mineralogy, assemblage, and geochemistry will provide ideal proxy records for studying these changes over time. Cold-water corals grow at rates of up to 25 mm yr^{-1}, or fast enough to apply the same methods of coral paleoclimatology used for tropical and subtropical reef-forming corals. Analyses of stable isotopes and trace elements are expected to provide temperature and carbon circulation data with sub-annual resolution. Although coral reefs are commonly associated with shallow-water tropical to subtropical regions, cold-water coral bioherms are known from the geological record. Well-known examples include the coral mound communities of the Danian in the chalks at Fakse in Denmark (Bernecker and Wiedrich, 2005) and the Pleistocene St. Paul's Bay Limestone on the island of Rhodes (Titschack and Freiwald, 2005). We are confident that IODP Expedition 307 will pro-

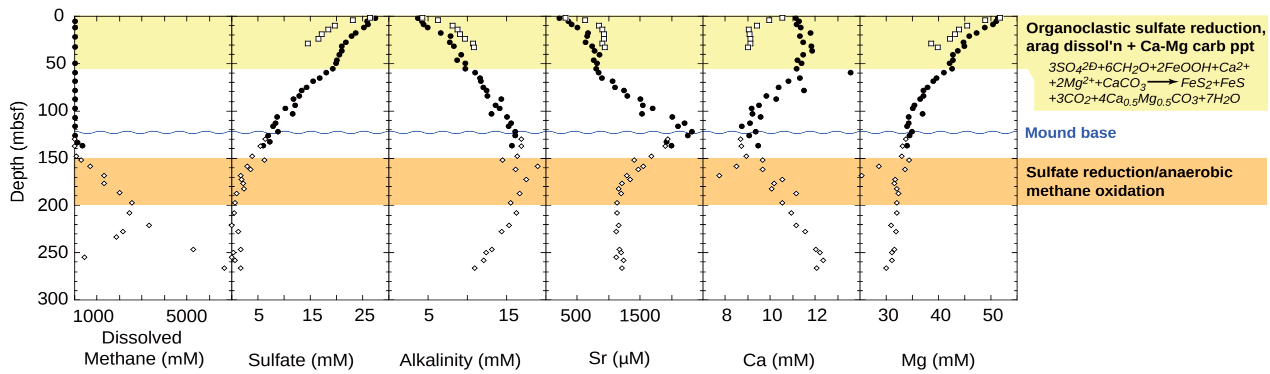

Figure 8. Geochemical profiles of interstitial water collected from Site U1317 (Challenger Mound). The yellow bar shows the zone of sulfate reduction and carbonate diagenesis in the coral-bearing upper meters of mound sediment. An equation linking organic matter decay, pyrite formation, and carbonate diagenesis is also shown. Sulfate reduction associated with anaerobic oxidation of methane, as shown by the orange bar, occurs below the mound base.

vide insight into the establishment and sustainability of coral-bearing mounds and build-ups in a predominately siliciclastic slope environment, and into the interpretation of these morphologies and facies in seismic profiles and the geological record.

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IODP Expedition 307 never could have sailed without the vision, dedication and enthusiasm of Professor Jean-Pierre Henriet, the lead proponent and driving force behind the scientific effort to drill these enigmatic structures. Jean-Pierre was unable to sail with us but was responsible for much of the pre-expedition preparations and was an indispensable source of advice and insight during and after the expedition. We sincerely thank Eibhlyn Doyle at the Geological Survey of Ireland (GSI) for all of her help and the GSI for graciously hosting our pre-expedition workshop. The success of IODP Expedition 307 lies largely with the extraordinary "can-do" attitude of the *JOIDES Resolution* IODP staff, the sterling performance of the Transocean crew, and the assistance of the Gulf Coast and Bremen Core Repositories.

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Fig. 1: 3-D map from Beyer et al., 2003.
Fig. 2: Photo by E. Van der Meersche ©MINERAL COLOR VZW
Fig. 3: Mound Seismic from DeMol et al., 2002.

The 2005 Lake Malawi Scientific Drilling Project

by Christopher A. Scholz, Andrew S. Cohen, Thomas C. Johnson,
John W. King, and Kathryn Moran

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Introduction

Lake Malawi, located in the southern part of the East African Rift Valley, is one of the world's largest, deepest (700 m) and oldest (>7 Ma) lakes and is renowned for its biodiversity, especially its unique ecosystem including hundreds of species of fish and invertebrates found nowhere else on Earth. Geologists and paleolimnologists have sought for several decades to establish a high-resolution East African geologic and climatic history through scientific drilling of the East African Rift Valley lakes. The Lake Malawi Scientific Drilling Project reached this goal by acquiring more than 623 m of core at two sites—one high-resolution site and one deep site extending back to 1.5 Ma. A total of seven holes, including one hole in 600 m water depth that reached a subbottom depth of 380 m, were cored with an average recovery of 92%. The high-resolution site was triple-cored and extends back ~80 ky. The deep site was double cored in the upper part that covers the past ~200 ky and then single-cored to its target depth of 380 m (Figs. 1 and 2).

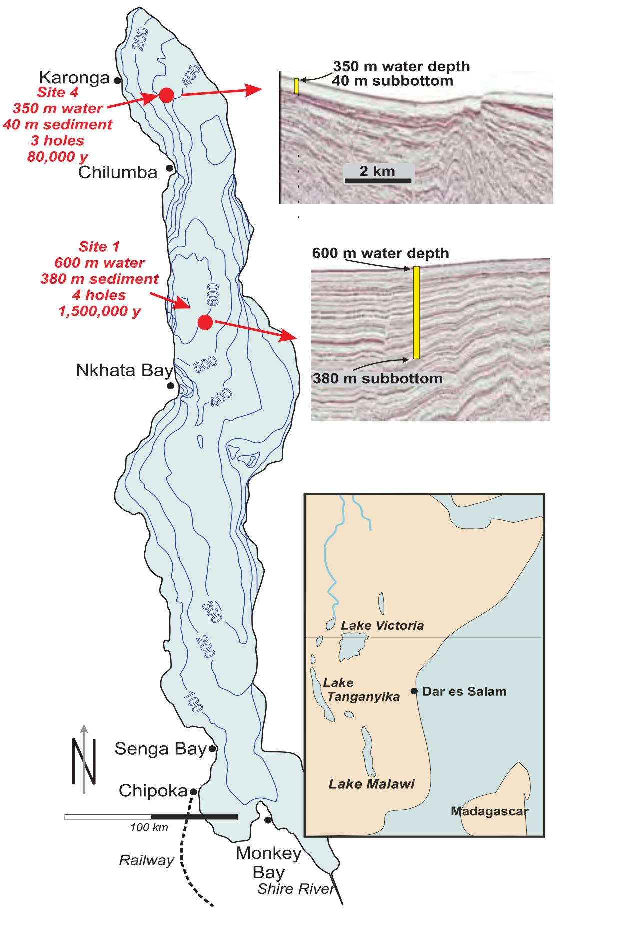

Figure 1. Bathymetry of the Lake Malawi Rift, with drill site locations and seismic profiles.

The Importance of the Continental Tropics in the Global Climate System

The climate of tropical East Africa shows strong seasonal variability in rainfall and wind regime. Seasonal variability in temperature is minor in comparison but still significant in its impact on lake circulation dynamics. East African rainfall is strongly influenced by the seasonal migration of the Intertropical Convergence Zone (ITCZ) across the equator. The passage of the ITCZ gives rise to heavy rains on the landscape. The moisture is derived from both the Atlantic and Indian Oceans in monsoonal circulation associated with summer heating of the continental interior. Regions located near the equator experience two rainy seasons per year—long rains from March to May, and short rains from October to November, while areas farther from the equator experience only the southernmost or northernmost extent of the ITCZ and a single rainy season in the year. Lake Malawi experiences the latter case, as the rainy season occurs during the hottest months of the austral summer, from December to February.

To understand paleoclimate on a global scale, it is essential to understand the history of tropical climatic change, and especially variations from the modern climatology described above. Ocean sediment cores from offshore North Africa

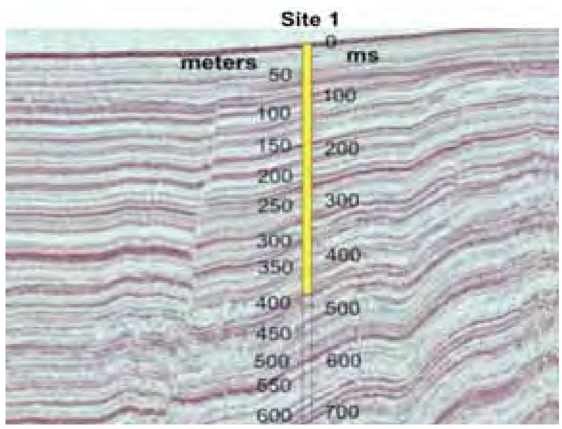

Figure 2. Airgun seismic profile with penetration at Site 1.

Figure 3. The *Viphya* drilling barge in central Lake Malawi.

have shown that African climate responds to insolation change on orbital (Milankovitch) timescales. The timing, controls and behavior of this vast tropical region, however, have been interpreted primarily from data from Ocean Drilling Program cores that integrate the signal from nearly half the continent (deMenocal, 1995; Clemens et al., 1996). The new drill cores from Lake Malawi sample an important region of the southern hemisphere continental tropics not previously sampled at a decadal to century scale beyond ~25 ka.

The key science questions addressed by the Lake Malawi drilling include the following.

- What is the direction, magnitude, and timing of effective moisture, wind and temperature change of this southern tropical setting, on a millennial scale, during the past two glacial–interglacial cycles?
- Do the observed shifts coincide in a consistent manner with sea-surface temperature (SST) variability in the tropical oceans, or with the North Atlantic thermohaline circulation?
- What is the lake level history of Malawi, and how does it compare with the methane record of the polar ice cores, which is interpreted to be a globally averaged measure of tropical moisture on the continents?
- Does the observed evidence for abrupt climate change in Lake Malawi and other parts of East Africa coincide with known events from other regions on Earth, e.g., Heinrich or Dansgaard-Oeschger events? What are the direction, duration and magnitude of these changes?
- What was the tropical climate behavior during earlier periods of global warmth (e.g., Marine Isotopic Stage 5e, or alternatively MIS 11), and how abruptly did these periods begin and end?
- Did the climate of this site in the southern tropics respond only to changes in low-latitude precessional insolation (23–19 ky) or also to high-latitude, ice-volume (100 ky and 41 ky) forcing in the last part of the Pleistocene?
- How did Pleistocene climate change impact early modern human evolution and population dynamics?
- How do the controls of climate impact species evolution and ecosystem change in large, ancient lakes?

Logistical and Engineering Challenges of Drilling in Interior Africa

Lake Malawi is 560 km long, 40 km wide, and situated ~400 km from the Indian Ocean. No navigable waterways connect this vast lake to the ocean; however, the Lake Malawi Scientific Drilling Project took advantage of an existing fuel barge Viphya (Fig. 3) operated by Malawi Lake Services as the drilling platform. Under the direction of the University of Rhode Island, the project's general contractor, various engineering components were procured in Europe, North America and South Africa and shipped to the local shipyard in Monkey Bay in southern Lake Malawi. During the second half of 2004, Lengeek Vessel Engineering of Halifax supervised significant modifications of the barge, including the installation of a moon pool, containerized living quarters and a dynamic positioning system. Initial underway trials were conducted in December 2004, and the Seacore C-100 drilling rig was installed in February 2005. Drilling tools run by Drilling, Observation and Sampling of the Earth's Continental Crust Inc. (DOSECC), were used in the project. They included a hydraulic piston corer and extended nose sampler that were fitted with a custom bottom-hole assembly.

Drilling commenced in late February 2005, after extensive testing and modification of equipment. Operations involved a team of twenty-six persons aboard the drilling barge, including nine drillers and a team of thirty persons onshore and on support boats as logistical support staff (Fig. 4). The onshore team also undertook an extensive outreach effort, visiting many Malawian secondary schools and government offices and informing them of the project.

Various technological difficulties that arose right from the start were ultimately overcome by a resourceful team of

Figure 4. The drilling project team.

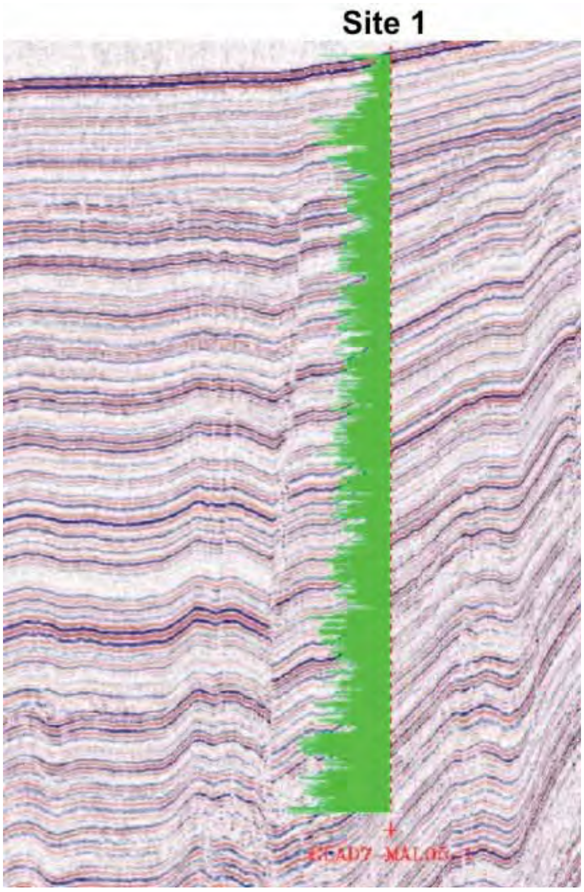

Figure 5. Seismic profile from Site 1 with GRAPE density curve.

engineers and technicians, and routine drilling operations finally began on 9 March 2005. Drilling then commenced for ten days at the deep site, located at a water depth of approximately 600 m in the central basin of Lake Malawi.

Preliminary Results

Whole-core measurements of recovered samples were made using the International Continental Scientific Drilling Program (ICDP) GEOTEK logging system, based at the science station in Chilumba, Malawi. Core data were comlemented through gamma-ray downhole logging by the operational support group of the ICDP (Fig. 5). Initial core description efforts are underway at the National Lacustrine Core Repository (LacCore) based in Minneapolis, Minn., U.S.A. Initial inspection of the cores reveals the presence of laminated and homogenous diatomaceous mud, cemented siltstone, volcanic ash horizons and fine-grained, well-sorted sands at the base of holes at both sites. Preliminary results indicate that lake levels fell and rose hundreds of meters on numerous occasions over the time interval represented by the recovered cores. Geochronological analyses are underway utilizing paleomagnetic data and a variety of radiometric dating methods. Preliminary results suggest that the deep site in the central basin is about 1.5 million years old at its base and that the holes in the north basin bottom out in shoreface sand deposits are about 80,000 years old. Whole-core measurements on physical properties show pronounced 100-ky cyclicity extending over the length of the longest record, suggesting that the level of Lake Malawi has fluctuated dramatically over the past million years.

Acknowledgements

We thank the people and government of Malawi for permission to conduct this research, and in particular the Geological Survey of Malawi for local assistance and participation. Numerous individuals from key contractors worked tirelessly to complete the program. We thank the U.S. National Science Foundation (NSF) Earth System History and Paleoclimate Programs, and the ICDP for financial support. As part of the project, funding from both agencies was used to acquire a portable dynamic positioning (DP) system for use by drilling projects that demand alternative platform technologies.

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Related Web Links

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Lake Qinghai Scientific Drilling Project

by An Zhisheng, Ai Li, Song Yougui, and Steven M. Colman,

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Lake Qinghai in the People's Republic of China covers 4400 km^2 on the northeastern margin of the Tibetan Plateau ,at an elevation of 3194 m (Fig. 1). The lake is extremely sensitive to changes in climate because it lies in a critical transitional zone between the humid climate region controlled by the East Asian monsoon and the dry inland region affected by westerly winds. Three major atmospheric circulation systems affect its climate: (i) the winter monsoon, induced by Siberian high pressure and associated high-latitude ice cover, (ii) tropical moisture from low latitudes, carried by the East Asian summer monsoon, and (iii) climatic changes in the North Atlantic region, the effects of which are inferred to be transmitted via the westerlies. A study of drill cores from the lake and the surrounding area is critical for understanding the climatic, ecological, and tectonic evolution of the area, including the development of the East Asian monsoon system and its relationship to major global atmospheric circulation.

Lake Qinghai occupies a closed tectonic depression, or piggy-back basin, on the upper plate of a major, active thrust fault. The basin is bound to the north by the Qilian Mountains, which constitute the northeastern margin of the Tibetan Plateau. The lake basin thus is intimately related to the active tectonics of the Tibetan Plateau. Seismic-reflection data show that the lake sediments are tectonically deformed in some parts of the basin and largely undeformed in other parts, where they should record at least the timing of regional tectonism. The seismic surveys indicate that the shallow lake is underlain by northern and southern sub-basins and that the southern sub-basin contains a continuous stratigraphic sequence of unconsolidated sediments more than 700 m thick.

At an international workshop in Xining, China in October 2003, the Qinghai Drilling Project was planned to obtain a series of cores from at least four different sites, penetrating 200–700 m into the lake sediment and possibly reaching Pliocene or older strata. Other sites with shallower penetrations of 5–50 m were planned to target specific high-resolution climatic intervals in the Holocene and last several glacial cycles. The overall scientific objectives of the project are listed below.

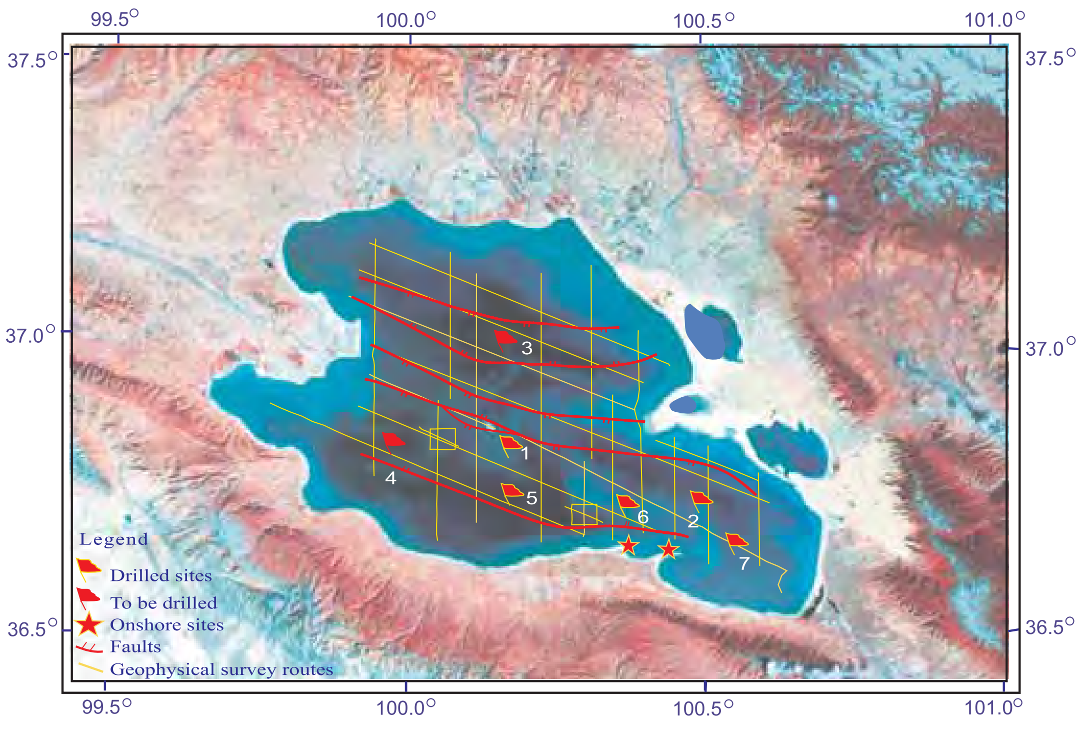

Figure 1. Satellite photo of Lake Qinghai with sketch map of drilling sites and major tectonic features.

Figure 2. The GLAD800 drilling system towed away from the dock site for first coring.

- To obtain an improved understanding of the late Cenozoic environmental history of the Lake Qinghai region and the development of the East Asian monsoon climate
- To understand the Late Cenozoic tectonic evolution of the Lake Qinghai basin and the growth of the northeastern margin of the Tibetan Plateau and its effects on regional climate
- To correlate Lake Qinghai environmental records with other regional and global paleoclimatic records to obtain a better understanding of the connection between regional climatic change, the development of the East Asian monsoon system, prevailing westerlies, and, ultimately, the evolution of global climate

After several weeks of delay caused by poor weather and a regional outbreak of bird flu, drilling operations began in late July 2005 and continued to early September. The drilling was conducted from a barge with the Global Lake Drilling 800 m (GLAD800) coring system (Fig. 2), the modular ICDP drilling platform and drilling system operated by the Consortium for Drilling, Observation and Sampling of the Earth's Continental Crust (DOSECC). DOSECC's coring operations were supported by the Qinghai Geology Survey and scientists from the Xi'an Institute of Earth Environment of the Chinese Academy of Sciences (IEECAS, Fig. 3). The sediment cores were described initially onboard by observing through the plastic core liners and examining core-catcher samples. The maximum 1.5-m-long core segments were scanned for petrophysical properties with a GEOTEK instrument at a shore base that was occupied throughout the drilling operations.

In total, 324 core runs for 548 m of drilling acquired 323 m of core at an average recovery rate of 59% (Table 1). The upper few tens of meters of sediment were mainly gray clay and silty clay. Core recovery was excellent in this upper part of the lake bed, and these cores will serve for the planned high-resolution study of climatic changes extending through much of the last glaciation. The sediment below the clay-rich upper section was mainly rather fine-grained, unconsolidated sand with only a few clayey layers. The character of

Figure 3. ICDP´s optical core scanning system in use at the shore base.

these sandy units plus the persistent rough wind and wave conditions experienced during the drilling operation greatly hindered the recovery of good cores. The principal investigators thus decided to postpone the proposed 700-m drilling for a future campaign and to focus on obtaining high-quality, overlapping cores of the upper 30–50 m of relatively fine-grained sediment at several sites (Fig. 1). Hole 2C penetrated the deepest (114.9 m), and the cores from this site may provide paleoenvironmental information through the late Pleistocene.

Concurrently with offshore drilling, an onshore site was drilled successfully on Erlang Jian on the southeastern shore of the lake (Fig. 1) using Chinese equipment (Fig. 4). The drill rig was deployed to its maximum drillstring capacity, allowing coring down to 1108.9 m, with an average recovery of more than 90% (Table 1, Fig. 5). Comparison to field exposures suggests that the lowermost sediment recovered has a maximum age of late Miocene. The onshore drilling was conducted by the Qinghai Geology Survey, in collaboration with the IEECAS. Encouraged by the initial success,

Figure 4. Yilang Jian land-based drill site on the shore of Lake Qinghai, China.

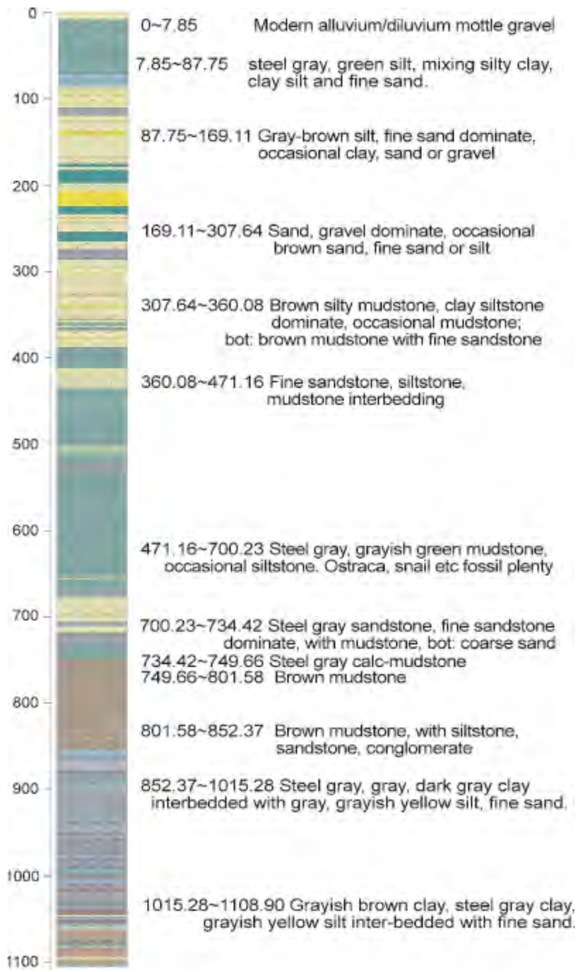

Figure 5. Lithology of the onshore core from Erlang Jian.

the team drilled a second borehole at Yilang Jian and retrieved another 628.5 m of core.

All drill cores were shipped in refrigerated trucks to the IEECAS in Xi'an, China for storage at 2–5°C. So far, about sixty scientists from China, Japan, Europe, and North America have expressed interest in participating in upcoming studies. The principal investigators Z. An, S.M. Colman, G. Haug, P. Molnar, and T. Kawai and the science team members are planning a science coordination and sampling meeting as soon as samples can be made available after opening and fully describing the cores.

Acknowledgements

About 500 scientists, engineers, and technicians from the People's Republic of China and abroad worked at and visited the drilling sites, mainly from the Chinese Academy of Sciences, the Ministry of Science and Technology of China, the National Science Foundation of China, the China Meteorological Association, the ICDP, and several universities and research organizations, as well as local governments. China Central Television and other TV stations and newspapers gave enthusiastic attention to this scientific research. They are all thanked for their contributions.

Table 1: Drill holes, core recovery, and statistics of coring.

Hole	Drilled m	Cored m	Recovery
Offshore cores			
2A	18.8	18.2	97 %
2B	3.0	2.9	98 %
2C	114.9	76.8	67 %
2F	25.2	23.5	93 %
1A	93.0	39.7	43 %
1F	20.2	19.3	95 %
1G	20.4	17.6	86 %
5A	26.7	14.0	53 %
5B	36.6	16.9	46 %
6A	50.6	23.4	46 %
6C	27.6	17.5	63 %
7A	51.4	24.1	47 %
7B	59.4	29.3	49 %
Total	547.9	323.3	Average 59 %
Onshore cores			
1	1108.9		>90 %
2	628.5		>90 %

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Related Web Link

http://qinghai.icdp-online.org

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Figure 2 by Ronald Conze (ICDP).
All other figures courtesy of the Lake Qinghai Drilling Project.

NanTroSEIZE: The IODP Nankai Trough Seismogenic Zone Experiment

by Harold J. Tobin and Masa Kinoshita

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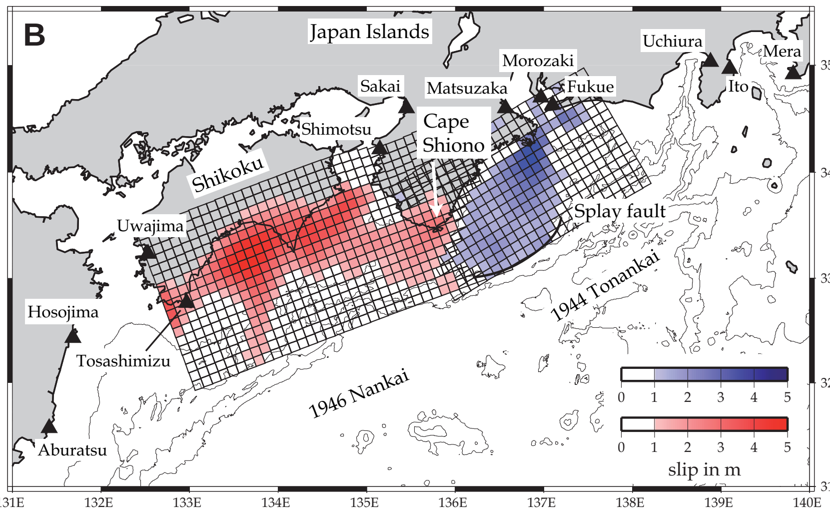
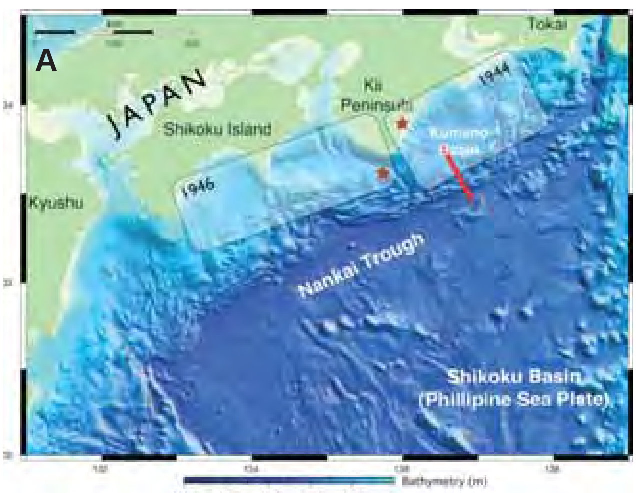
Introduction: The Seismogenic Zone Initiative

The IODP Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) will, for the first time ever, attempt to drill into, sample, and instrument the seismogenic portion of a plate-boundary fault or megathrust within a subduction zone. Access to the interior of active faults where *in situ* processes can be monitored and fresh fault zone materials can be sampled is of fundamental importance to the understanding of earthquake mechanics. As the December 2004 Sumatra earthquake and Indian Ocean tsunami so tragically demonstrated, large subduction earthquakes represent one of the greatest natural hazards on the planet. Accordingly, drilling into and instrumenting an active interplate seismogenic zone is a very high priority in the IODP Initial Science Plan (2001). Through a decade-long series of national and international workshops, a consensus emerged that the Nankai Trough is an ideal place to attempt drilling and monitoring of the seismogenic plate interface. The first phase of NanTroSEIZE drilling operations has now been scheduled for the late summer of 2007. It involves parallel deployment of both the new U.S. Scientific Ocean Drilling Vessel (SODV, this volume) and the riser drilling vessel *Chikyu*.

The fundamental goal of the NanTroSEIZE science plan (http://ees.nmt.edu/nantroseize) is the creation of a distributed observatory spanning the up-dip limit of seismogenic and tsunamigenic behavior at a location where great





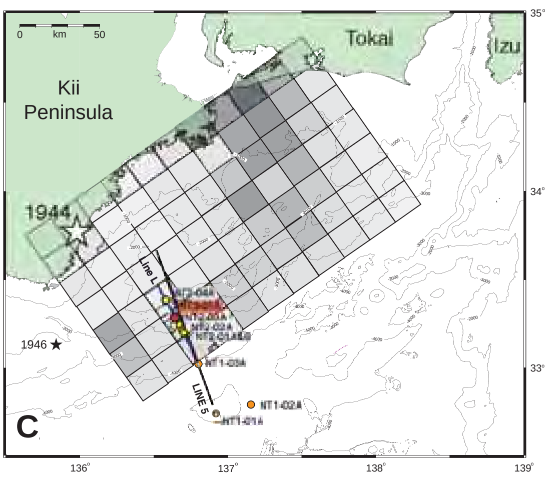


Figure 1-A. The Nankai Trough region of southwestern Japan is the locus of subduction of the Philippine Sea plate beneath Honshu and Shikoku islands. Shaded boxes are the generalized slip areas of the last two great subduction earthquakes (stars represent epicentral locations for earthquake nucleation). Red line is location of seismic reflection section of Figure 2.
Figures 1-B and C. Coseismic slip (B) and tsunami source (C) inversions of the 1944 Tonankai earthquake by Ichinose et al., (2003) and Baba and Cumming (2005), respectively. Both show that the coseismic displacement had a large component of shallow slip (seismic asperity) up-dip of the nucleation region. The NanTroSEIZE drilling transect targets this apparent asperity region. The shallow high-slip zone corresponds to the location of the mega-splay fault (see fig. 2), suggesting that it may have been the locus of coseismic slip.

subduction earthquakes occur, thus allowing us to observe the hydrogeologic behavior of subduction megathrusts and the aseismic to seismic transition of the megathrust system. This will involve drilling of key elements of the active plate boundary system at several locations off the Kii Peninsula of Japan, from the shallow onset of the plate interface to depths where earthquakes occur (Figs. 1 and 2). At this location, the plate interface and active mega-splay faults implicated in causing tsunami are accessible to drilling within the region of coseismic rupture in the 1944 Tonankai (magnitude 8.1) great earthquake. The most ambitious objective is to access and instrument the Nankai plate interface within the seismogenic zone. The science plan entails sampling and long-term instrumentation of (a) the inputs to the subduction conveyor belt, (b) faults that splay from the plate interface to the surface and that may accommodate a major portion of coseismic and tsunamigenic slip and (c) the main plate interface at a depth of up to 6 km.

NanTroSEIZE shares many of its goals with the San Andreas Fault Observatory at Depth (SAFOD, this volume) project. This burgeoning interest in active fault drilling is taking place in the context of rapidly growing research efforts on the mechanics and dynamics of faulting processes that integrate rock mechanics, seismology, geodesy, frictional physics and fluid-fault interactions. Despite recent advances, there is at present no unified theory of fault slip to account for earthquake nucleation and propagation, nor to explain the mechanisms of strain across the spectrum of observed deformation rates ranging from seconds to years. Consequently, the question of whether precursory signals exist for major earthquakes, even in theory, remains controversial. Progress on these topics is severely limited by a lack of information on ambient conditions and mechanical properties of active faults at depth. Extant rheological models for how faults behave depend on specific physical properties at the fault interface and in the surrounding rock volume. Coefficients of friction, permeability, pore-fluid pressure, state of stress and elastic stiffness are examples of such parameters that can best (or only) be measured through drilling and through geophysical sensing of the surrounding volume.

Why the Nankai Trough?

Subduction zones like the Nankai Trough (Fig. 1), on which great earthquakes (M≥8.0) occur, are especially favorable for study because the entire width (dip extent) of the seismogenic zone ruptures in each great event, so the future rupture area is perhaps more predictable than for smaller earthquakes. The Nankai Trough region is among the best-studied subduction zones in the world. It has a 1300-year historical record of recurring and typically tsunamigenic great earthquakes, including the 1944 Tonankai (M=8.1) and 1946 Nankaido (M=8.3) earthquakes. The rupture area and zone of tsunami generation for the 1944 event are now reasonably well understood (Fig. 1; Ichinose et al., 2003; Baba and Cummins, 2005). Land-based geodetic studies suggest that the plate boundary thrust here is strongly locked (Miyazaki and Heki, 2001). Similarly, the relatively low level of microseismicity near the up-dip limits of the 1940s earthquakes (Obana et al., 2004) implies significant interseismic strain accumulation on the megathrust; however, recent observations of very low frequency (VLF) earthquake event swarms apparently taking place within the accretionary prism in the drilling area (Obara and Ito, 2005) demonstrate that interseismic strain is not confined to slow elastic strain accumulation.

The Kumano Basin region (Fig. 1-A) has been chosen based on three criteria: 1) the up-dip end of the seismogenic zone must be definable based on slip in past great earthquakes, 2) seismic imaging must present clear drilling targets and 3) deep targets must be within the operational limits of riser drilling (i.e., maximum of 2500 m water depth and 7000 m sub-bottom penetration). In the Kumano Basin, the seismogenic zone lies ~6000-m beneath the seafloor (Nakanishi et al., 2002). Slip inversion studies suggest that only here did past coseismic rupture clearly extend shallow enough for drilling (Ichinose et al., 2003; Baba and Cummins, 2005), and an up-dip zone of large slip (asperity) has been identified and targeted (Fig. 1-B). Coseismic slip during events like the 1944 Tonankai earthquake likely occurred on the mega-splay fault rather than on the decollement beneath it, though slip on either plane is permissible given the available data. The mega-splay fault therefore is a primary drilling target equal in importance to the basal decollement zone.

Scientific Objectives

Conditions for stable versus unstable sliding—which define seismic versus aseismic behavior—have long been the subject of research and debate, as has the frictional strength of likely fault zone material. Fault zone composition, consolidation state, normal stress magnitude, pore-fluid pressure, and strain rate may affect the transition from aseismic to seismic slip (e.g., Saffer and Marone, 2003). NanTroSEIZE will sample fault rocks over a range of pressure and temperature (P-T) conditions across the aseismic–seismogenic transition, the composition of faults and fluids and associated pore pressure and state of stress and will address partitioning of strain spatially between the decollement and splay faults. Long-term borehole observations will test whether interseismic variations or detectable precursory phenomena exist prior to great subduction earthquakes.

Drilling Targets

We plan to drill at eight sites (Fig. 2): three target the incoming plate section and frontal thrust of the accretionary wedge, three target the mega-splay fault system at different depths, one will sample the mega-splay uplift history recorded in the forearc basin sediments, and one ultra-deep site targets the plate interface in the seismogenic zone.

Sampling of the sediments, fluids, and crustal rocks seaward of the deformation front will characterize the subducting plate before deformation. It has been hypothesized that sediment type (especially clay mineral content), fluid content, and basement relief on the incoming plate govern the mechanical state of the plate interface at depth and influence the formation of fault-zone asperities. Two sites (NT1-01 and NT1-07) are planned to sample the entire sedimentary section and up to 100 m of the basement, respectively on and off of a pre-existing basement high that controlled deposition of thick turbidites in the lower part of the stratigraphy. Long-term monitoring of pore pressure, seismicity, and other observations in these boreholes will define the hydrological and stress conditions and microseismic activity at the point where sediments enter the subduction zone.

Three drill sites targeting the mega-splay fault zone (NT2-01, NT2-02, and NT2-03) and one site targeting the frontal thrust (NT1-03) are designed to document the evolution of fault rock properties and the state of stress, fluid pressure, and strain at different P-T conditions. These sites will access faults from ~500 m to 3500 m depth below the seafloor. Sealed borehole observatories at some of these sites will monitor pore-fluid pressure, strain, seismicity, and other properties to document the physical state of the fault zone and its wall rock environment. Site NT2-03 will cross the seismically reflective mega-splay at a depth of 3000–3500 m, in a location where slip may have propagated in 1944.

After initial instrumentation at Site NT2-03 site, our attention will turn to the 5500–6000 m deep Site NT3-01. Drilling there will pass through both the mega-splay fault system and the basal detachment, bottoming in the oceanic crustal rocks of the subducting plate. Drilling of these deep objectives requires novel borehole engineering. Project scientists envision a multi-path approach to allow collection of both logs and cores from deep target zones, as well as implementation of a comprehensive monitoring system (Fig. 3), and we are working with the borehole engineers to determine how best to implement this ambitious plan.

In addition to the primary fault zone targets, Site NT3-01 will pass through about 1000 m of the Kumano forearc basin section, including an apparent gas hydrate reflector, several thousand meters of the active accretionary wedge, and a zone of potential underplated rocks below the splay fault. Sites NT3-01 and NT2-04 together will document the history and growth of the Kumano forearc basin, which has formed as a response to slip on the mega-splay fault system, as well as processes of accretionary wedge growth. The basinal history will shed light on the evolution of this long-lived, mid-wedge fault that may be a primary feature of many subduction zone forearcs that produce great earthquakes (Wells et al., 2003).

Drilling will yield both geophysical logs and physical samples of the rocks, sediments, and fluids. Logging and borehole imaging will determine *in situ* physical properties and help define stress state (e.g., through borehole breakout and tensile fracture studies). Sampling the inputs and splay faults at several depths, and the plate interface at great depth, will provide key data on the evolution of fault zone composition, fabric development, and lithification state as a function of pressure, temperature, and cumulative slip. Finally, long-term monitoring through downhole instrumentation will yield time-series datasets after the drilling disturbance signals have subsided, possibly including the pre-seismic near term for a future great earthquake. Ideally, thermal signals, fluid pressure, geochemical tracers, tilt and volumetric strain, microseismicity, and time-varying seismic structure will be monitored.

Getting There: Plans for Implementation

The NanTroSEIZE project will span a number of years and many individual expeditions to achieve all of the proposed scientific objectives, with onboard and shore-based scientific

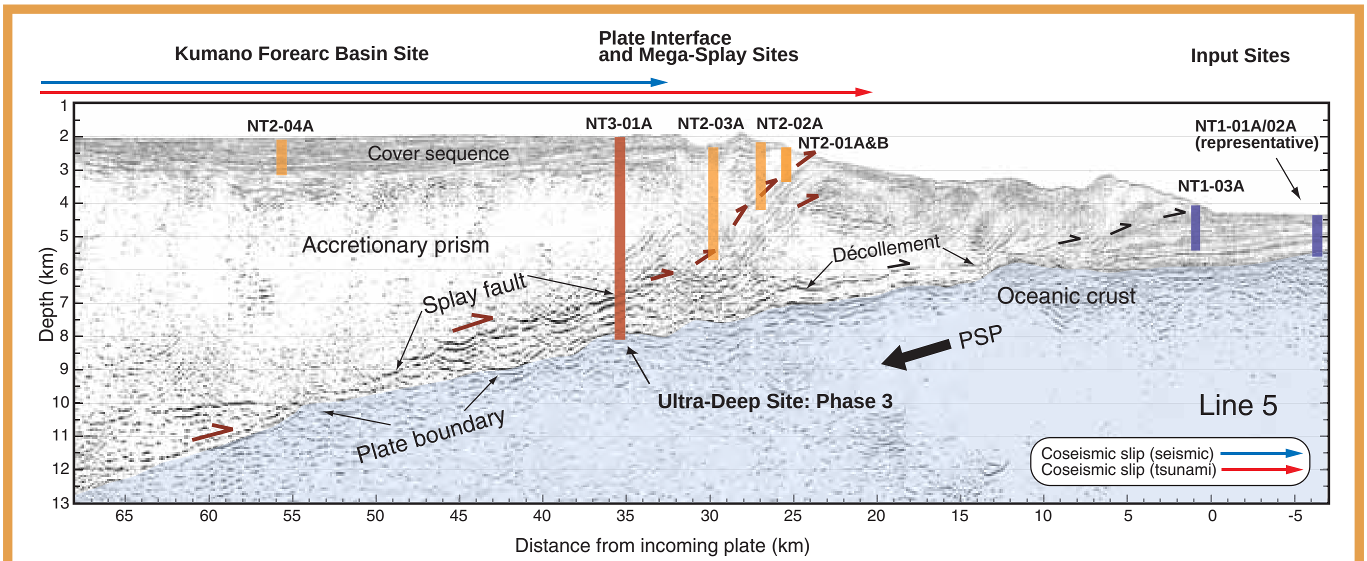


Figure 2. Pre-stack depth migrated seismic line of Park et al. (2002), with locations of planned drill sites.

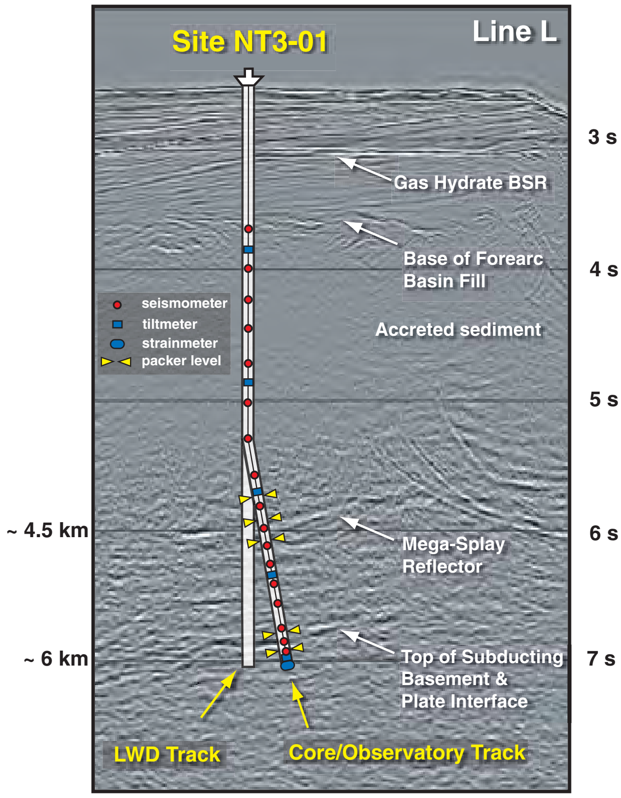


Figure 3. Conceptual drilling and long-term observatory plan for the deepest site, NT3-01. Drilling is planned to proceed with a mix of LWD and coring with casing to total depth, followed by sidetracking to core the prime fault targets and install monitoring instrumentation. Sensors shown here are positioned schematically. A number of sensor elements are not shown for clarity, including temperature arrays, and fluid pressure sensors. Packers isolate perforated zones for fluid communication to the formation above, below, and inside each of the 2 target fault zones. Depths are based on Line 5 in Fig. 2. The borehole deviation is shown conceptually and is not meant to represent true angle or scale.

teams matched to the goals of each sub-expedition. A project management team (PMT) with two co-chief project scientists (the authors), several additional lead scientists, representatives of the drillship operators, and IODP management has been formed and charged with coordinating all scientific and logistical planning.

Volumes of site-survey data have been collected in the drilling area over many years, including multiple generations of 2-D seismic reflection, wide-angle refraction, natural seismicity, heat flow, side-scan sonar and swath bathymetry, and submersible and ROV dive studies. In 2006, Japan and the United States will conduct a joint, 3-D seismic reflection survey over a 14 × 60 km area. The 3-D survey will be used to refine selection of drill sites and targets in the complex mega-splay fault region, to analyze physical properties of the subsurface through seismic attribute studies, to expand findings in the boreholes to wider areas, and to assess drilling safety.

Drilling activities are organized into four stages, each of which will include multiple individual expeditions. Stage 1 calls for drilling and sampling at six of the sites: (a) the incoming sediment of the Shikoku Basin and underlying oceanic crust (two sites), (b) the frontal thrust system at the toe of the accretionary wedge, (c) the mid-wedge mega-splay fault system, and (d) approximately 1000-m-deep pilot holes at the two sites planned for later deep penetrations of the seismogenic zone faults (two sites). Comprehensive coring and logging of the boreholes is planned, including extensive use of logging-while-drilling (LWD) technology to obtain high quality logs. One borehole observatory installation is planned for a pilot hole at Site NT3-01 to monitor pore-fluid pressure, strain, temperature, and seismicity above the plate boundary. This observatory deployment (Becker and Davis, 2005) will serve as a prototype and test-bed for technologies to be used in future deeper borehole observatories. The IODP currently plans to allocate approximately eight months of ship time, divided between the new U.S. SODV and the *Chikyu*, for NanTroSEIZE Stage 1 drilling to take place from September 2007 through January 2008.

Stage 2 will involve drilling the first of the two planned ultra-deep riser holes using the *Chikyu*, targeting the mega-splay fault zone at ~3000 m below the sea floor at Site NT2-03. Extensive coring, use of LWD, downhole experiments to measure pore pressure and seismic properties, and an initial, retrievable, long-term monitoring package are all planned for this site. Additional Stage 2 operations will include deepening and installing borehole observatory systems in several of the shallower boreholes from Stage 1. Stage 2 is likely to begin in mid- to late-2008 and extend into 2009.

Stage 3 is focused on 5500–6000-m-deep drilling into the seismogenic zone and across the plate interface into subducting crust at Site NT3-01. This unprecedented deep ocean borehole will be accomplished through a program of riser-based drilling and a carefully planned casing program. The results of pilot-hole operations, 3-D seismic data, and real-time LWD and MWD monitoring will guide the borehole design. Given the frontier nature of this drilling, it is uncertain how long it will take to complete the borehole, but it may well exceed a full year of drilling. Once drilling is complete, an initial monitoring system will be deployed in the borehole, components of which remain to be designed. We intend for this monitoring system to remain in place for a period of one to two years, while the "final" long-term monitoring package is readied.

Stage 4, will be concerned with installing the final long-term observatory systems into the two ultra-deep boreholes (Figure 3). This monitoring installation will be planned as much as possible for robust, long-duration deployment, such that data pertinent to the behavior and evolution of the plate interface fault system during a significant portion of the seismic cycle can be recorded. In Japan, a system is proposed to deploy a seafloor fiber-optic network for seismic monitoring and other applications in the Kumano Basin region. One exciting possibility is that the NanTroSEIZE boreholes ultimately could be connected to this network in Stage 4, allowing for real time access to the data. We envision that Stage 4 installations will be completed sometime in 2012 or 2013.

Opportunities for Scientific Participation

Detailed plans for how to organize the NanTroSEIZE scientific teams are still being worked out, but there is clearly a need for involving a large number and range of scientists. Shipboard and shore-based opportunities will exist across all stages for interested researchers. Besides the central fault-zone objectives, diverse geological environments will be sampled, including the deep interior of an actively developing accretionary wedge, gas hydrates, partially subducted oceanic crust, abyssal plain turbidite systems, and a major forearc basin sequence. Opportunities will be plentiful in sedimentology, structural geology, physical properties, geochemistry, rock magnetism, borehole geophysics, seismology, microbiology, hydrogeology, crustal deformation, and other disciplines.

The first call for applications to participate in the NanTroSEIZE effort will be forthcoming and widely advertised in 2006. Individual scientists from participating countries should apply according to normal IODP practice. Stage 1 operations in 2007–2008 alone will require the efforts of 50–100 scientists in this massive and challenging undertaking.

Acknowledgements

We are grateful to the dozens of scientists who helped develop the science plans through all the workshops and planning meetings, and especially to all twenty-four of our NanTroSEIZE co-proponents for their efforts in helping write the drilling proposals.

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Borehole Observatory Installations on IODP Expedition 306 Reconstruct Bottom-Water Temperature Changes in the Norwegian Sea

by Robert N. Harris and the IODP Expedition 306 Scientists

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Introduction

The ocean covers 70% of the Earth's surface, and because of its fluid motion and large thermal inertia, it plays a central role in redistributing heat about the globe and in shaping the Earth's climate. The northern North Atlantic is the primary deep ventilator of the world ocean, and it is now recognized that deep-water production is closely related to global climate (Broecker et al., 1985). Despite the importance of North Atlantic Deep Water to global and regional climate, there is a lack of long-term observations of temperature and salinity variations. Surface and near-surface measurements show natural variability on timescales of decades (Wunsch, 1992; Gammelsrød et al., 1992). The few deep oceanographic observations indicate that the thermohaline structure of the North Atlantic has changed over the past twenty to thirty years and that bottom-water temperatures (BWT) have varied significantly (Brewer et al., 1983; Roemmich and Wunsch, 1984; Antonov, 1993). We hypothesize that, assuming purely conductive heat transfer, temperature profiles obtained from beneath the seafloor can be used to reconstruct BWT histories at timescales of decades to a century. The conductive thermal regime of the oceanic crust and sediment reflects the superposition of two processes—the long-term, outward heat flow from the Earth's deep interior that changes on timescales of millions of years, and short-term perturbations to this regime resulting from changes in BWT at the seafloor. These thermophysical perturbations provide a straightforward measure of temperature, not a proxy. Changes in BWT diffuse slowly downward through marine sediment because of its low thermal diffusivity (~1 x 10^{-6} m^2 s^{-1}) such that excursions in BWT that occurred 100 years ago now appear as maximum temperature anomalies at a depth of 40 m. Resolution analysis indicates that a 100-year record of temperature change is potentially recoverable from high-precision temperature logs in boreholes 150 m deep, with the deeper part used to estimate the background thermal regime. If this hypothesis is correct, and given that seafloor sediments continuously incorporate changes in BWT, it is theoretically possible to reconstruct BWT histories anywhere in the ocean.

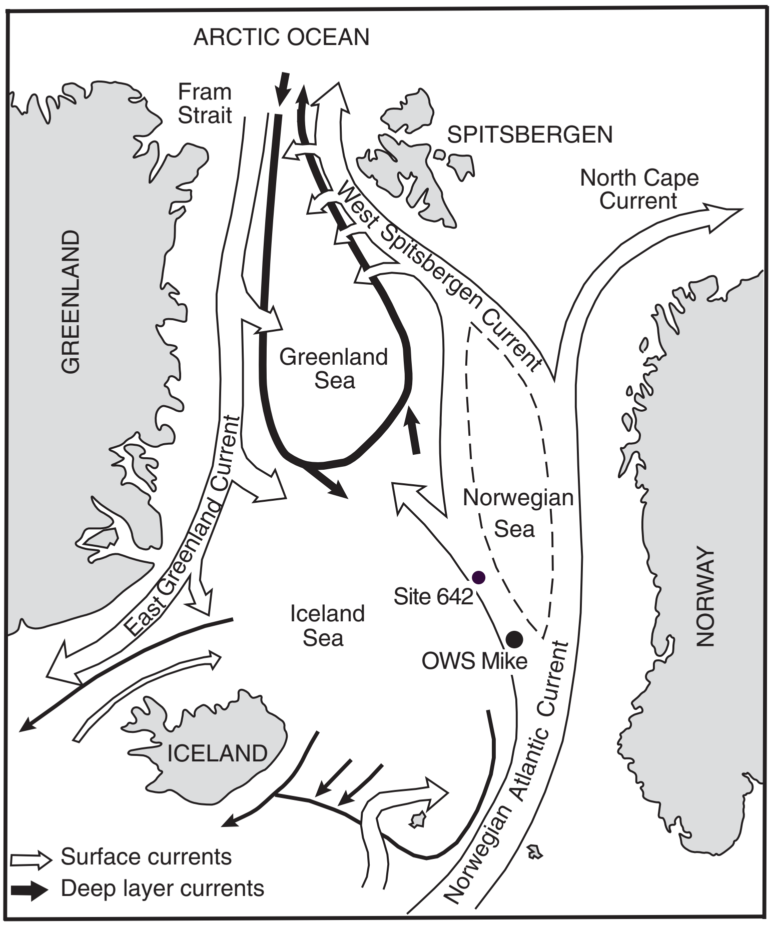

Figure 1. Location map of the Norwegian Sea and Vøring Plateau showing ODP Site 642 and Ocean Weather Ship Station "Mike" (modified from Gammelsrød et al., 1992).

The primary objectives of this experiment and borehole installation during IODP Expedition 306 are to document BWT variations, monitor their downward propagation beneath the seafloor over a five-year period, investigate the feasibility of reconstructing BWT variations over longer time periods, and establish whether observed BWT variations reflect long-term climate trends or random fluctuations expected in a complex fluid system.

Previous Work

Several studies have identified BWT variations from temperature profiles measured in sediments. In the Denmark Strait, for example, BWT has fluctuated on the order of 0.4°C (Lachenbruch and Marshall, 1968). Along the Reykjanes Ridge (Sclater and Crowe, 1979), temperature profiles are apparently linear between 7.5 mbsf and 12.5 mbsf (the base of the measurements), but show a sharp decrease (~0.4°C) in the upper 5 m, consistent with an annual BWT fluctuation. Other studies documenting BWT variations based on sediment temperature profiles include the Bay of Biscay (Foucher and Sibuet, 1980), Bermuda Rise (Galson and Von Herzen, 1981), the Canadian Beaufort Shelf (Taylor and Allen, 1987), the Gulf of Mexico (Cathles and Nunns, 1991) and the Scotia Sea (Barker and Lawver, 2000). Across the Norwegian margin at shallow water depths of 600–800 m, Vogt and Sundvor (1996) attributed curvature in thermal gradients to the upward movement of pore fluids, although they could not rule out BWT variations. Two studies of available oceanic BWT time series (Lachenbruch and Marshall, 1968; Cathles and Nunns, 1991) successfully modeled perturbations in temperature profiles in terms of deep water movements; however, the time span of the inferred results was limited by the length of the gravity-driven probe used to make the measurements.

Experimental Setting

The Norwegian Sea (Fig. 1) is an important source of Northern Hemisphere deep water (Kushnir, 1994; Weaver et al., 1999). While the upper few hundred meters of the Norwegian Sea are dominated by the warm, saline water of the Norwegian Atlantic current, the bottom water is a product of Greenland Sea Deep Water and Arctic Ocean Deep Water (Swift and Koltermann, 1988). These deep water masses are an important source of intermediate and deep water in the Northern Hemisphere and contribute significantly to North Atlantic Deep Water production; hence they ventilate the world ocean via global thermohaline circulation. ODP Site 642 lies at a water depth of approximately 1300 m on the Vøring Plateau in the Norwegian Sea (Fig. 1). This represents an ideal location to investigate the feasibility of reconstructing BWT from temperature profiles measured beneath the seafloor for three reasons: 1) the Norwegian Sea is in a climatically sensitive area, 2) existing data indicate that the sedimentary environment is suitable for this experiment, and 3) it is located near Ocean Weather Ship Station (OWS) “Mike,” which has operated continuously since 1948 providing the longest and most complete time series of monthly bottom-water temperature and salinity measurements from the deep ocean (Gammelsrød et al., 1992, Østerhus et al., 1996).

Temperature data from a depth of 1500 m at OWS Mike show a minimum of –0.89°C in 1983 increasing to a maximum of –0.80°C in 2000 (Østerhus et al., 1996), a difference of 90 mK over seventeen years. The recent warming of the Norwegian Sea deep water is tied to warming of Greenland Sea deep water and has been interpreted as a sign that deep-water production ceased in the Greenland Sea (Østerhus et al., 1996). These data will be used to check the efficacy of our

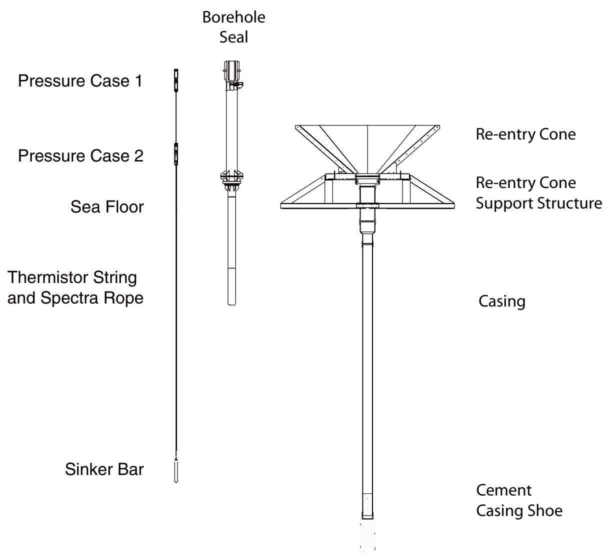

Figure 2. Experimental setup showing instrumentation, Circulation Obviation Retrofit Kit (CORK), re-entry cone, and casing.

measurement technique and analysis. Core recovery and quality at ODP Site 642 were high and revealed approximately 400 m of Neogene and Quaternary pelagic and hemipelagic sediment overlying volcanic basement (Eldholm et al., 1987). An important factor for assuring the success of this experiment is that the sedimentary thermal regime must be entirely conductive. Unfortunately, at the time of drilling Site 642, no temperature measurements were made. Candidate processes leading to advective heat flow include crustal hydrothermal circulation, pore-water advection, and fluid convection within the borehole itself. Hydrothermal processes are unlikely to disturb the shallow thermal regime because of the thick sedimentary cover and because Site 642 sits on a 55-Ma-old passive margin in an area of low background heat flow (~ 50 mW m^{-2}). The low permeability of marine muds encountered at this site (Eldholm et al., 1987) makes pore-water advection unlikely. Variations in major elements and isotope composition determined on interstitial fluid samples are consistent with diagenetic and alteration reactions and do not show evidence of an advective signal (Aagaard et al., 1989; Whiticar and Faber, 1989). To minimize the possibility of convection within the borehole, we minimized the hole diameter and filled it with low viscosity bentonite mud.

Experimental Design

We chose not to re-enter Hole 642E for installing the experiment during IODP Expedition 306 because this hole has remained open for approximately 20 years, and advective heat flow between the top of the hole and the ocean and convection within the hole would negatively impact the experiment. Additionally, Hole 642E penetrates basement, which could provide a conduit for fluid flow. Temperature

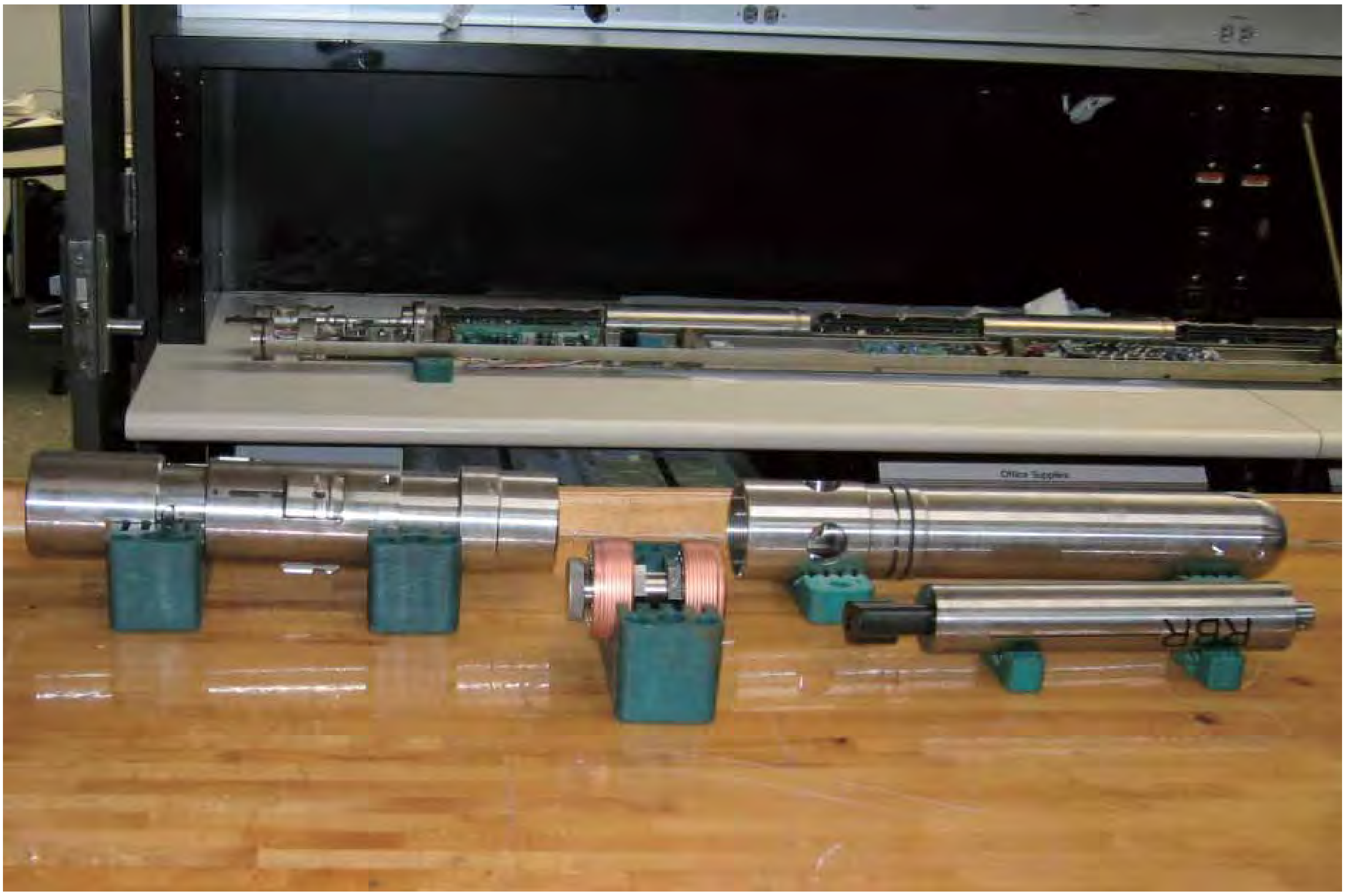

Figure 3. Assembling the data logger and thermistor string in the *JOIDES Resolution* Downhole Laboratory. The figure shows upper components of instrumentation. In the background (left) is the XN lock mandrel for latching the system into the CORK assembly. Foreground middle shows slip joint connecting the mandrel to battery pack housing. Foreground (right) shows pressure casing for bottom water temperature thermistor and back-up battery pack. Below this assembly is another housing containing batteries, data logger, and thermistor string.

logs made in Hole 642E during IODP Expedition 306 confirmed the upflow of water. Instead, we drilled a new hole at Site U1315, approximately 2 km south-southeast of Site 642, at a water depth of 1283 m. Hole U1315A was drilled to a depth of 179.07 mbsf and cased with 10-3/4 inch casing (Fig. 2). The base of the casing was cemented, and the casing string was displaced with bentonite mud. The thermistor string is connected to a data logger and external battery at the pressure case.

The Circulation Obviation Retrofit Kit (CORK) instrumentation in Hole U1315A consists of two pressure cases and a thermistor string (Fig. 3). Diffusion of the thermal wave through the subsurface is monitored with a 150-m armored thermistor string deployed in a cased and sealed borehole. Twenty-four thermistors increase in spacing downstring to account for the natural scale of thermal diffusion. The thermistors have a resolution of $<5 \times 10^{-5}$°C, are calibrated using the National Institute of Standards and Technology (NIST) traceable reference standards, and have a reported uncertainty of <0.2 mK. The top pressure case houses a salinity and temperature sensor that sits in the water column via an elevated re-entry cone and is designed to monitor the bottom water. Data are collected every hour, based on expected battery life and the five-year duration of the experiment.

Significance

Although variations in bottom-water temperature have been shown to be important in terms of climate change, and modern records show that these variations are significant over the last few decades, no data exist for documenting these variations over the past 100 years. This study is aimed at reconstructing BWT variations and, through comparisons with other geophysical and geochemical data, investigating ties between bottom-water formation and large-scale forcing of deep thermohaline circulation on a timescale of 10–100 years. A successful experiment offers the exciting possibility of establishing transects of such measurements across climatologically important gateways such as the Reykjanes Ridge and, more generally, reconstructing and monitoring BWT histories with confidence anywhere in the ocean.

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SAFOD Penetrates the San Andreas Fault

by Mark D. Zoback

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SAFOD, the San Andreas Fault Observatory at Depth (Fig. 1), completed an important milestone in July 2005 by drilling through the San Andreas Fault at seismogenic depth. SAFOD is one of three major components of EarthScope, a U.S. National Science Foundation (NSF) initiative being conducted in collaboration with the U.S. Geological Survey (USGS). The International Continental Scientific Drilling Program (ICDP) provides engineering and technical support for the project as well as online access to project data and information (http://www.icdp-online.de/sites/sanandreas/news/news1.html). In 2002, the ICDP, the NSF, and the USGS provided funding for a pilot hole project at the SAFOD site. Twenty scientific papers summarizing the results of the pilot hole project as well as pre-SAFOD site characterization studies were published in *Geophysical Research Letters* (Vol. 31, Nos. 12 and 15, 2004).

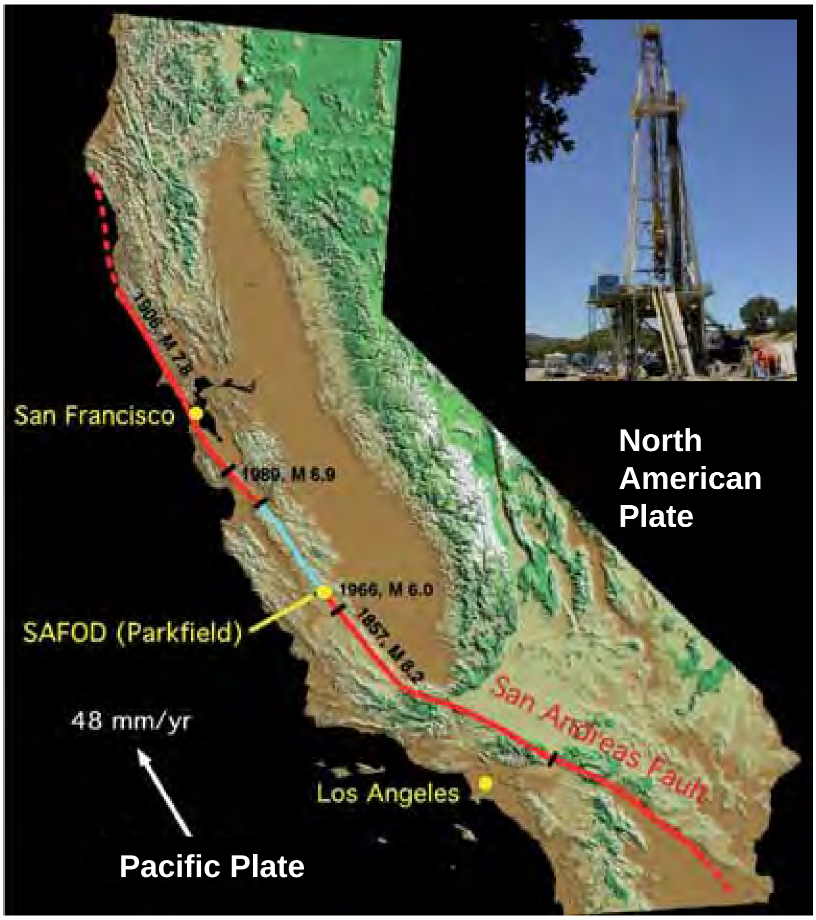

Figure 1. Location map of the SAFOD drilling site on the San Andreas Fault, with some major historical earthquakes marked. The inset shows the SAFOD drill site in June 2005.

EarthScope is designed to investigate the geological processes that shape the North American continent. The other Earth Scope components, USArray and the Plate Boundary Observatory, are large-scale research efforts focusing on deformation and properties of the Earth's crust in North America (www.earthscope.org).

At the surface, the SAFOD drilling site is located 1.8 km southwest of the nearly vertical San Andreas Fault such that the inclined borehole passes through the entire fault zone at seismogenic depths (see Fig. 2). Phase 1 of the project was conducted during the summer of 2004 and involved rotary drilling to 2.5-km vertical depth and to within 700 m of the San Andreas Fault. Phase 2 was conducted during the summer of 2005 and involved rotary drilling through the San Andreas Fault Zone while collecting nearly continuous cuttings, gas samples, and appreciable geophysical logging data, including logging-while-drilling (LWD) data within the San Andreas Fault. Three spot cores were obtained at casing set points during Phases 1 and 2. Rock and fluid samples recovered from the fault zone and country rock are being studied in the laboratory to determine their composition, deformation mechanisms, frictional behavior, and physical properties.

Drilling, sampling, and downhole measurements directly within the San Andreas Fault Zone will substantially advance our understanding of the processes controlling faulting and earthquake generation by providing direct observation on the composition, physical state, and mechanical behavior of a major active fault zone at the depths where earthquakes occur. It will now be possible to measure these processes directly and answer basic questions about earthquake nucleation (including whether some earthquakes are predictable) and rupture propagation. By directly evaluating the roles of fluid pressure, rock friction, chemical reactions, stress, and other parameters during the earthquake process, opportunities will arise to

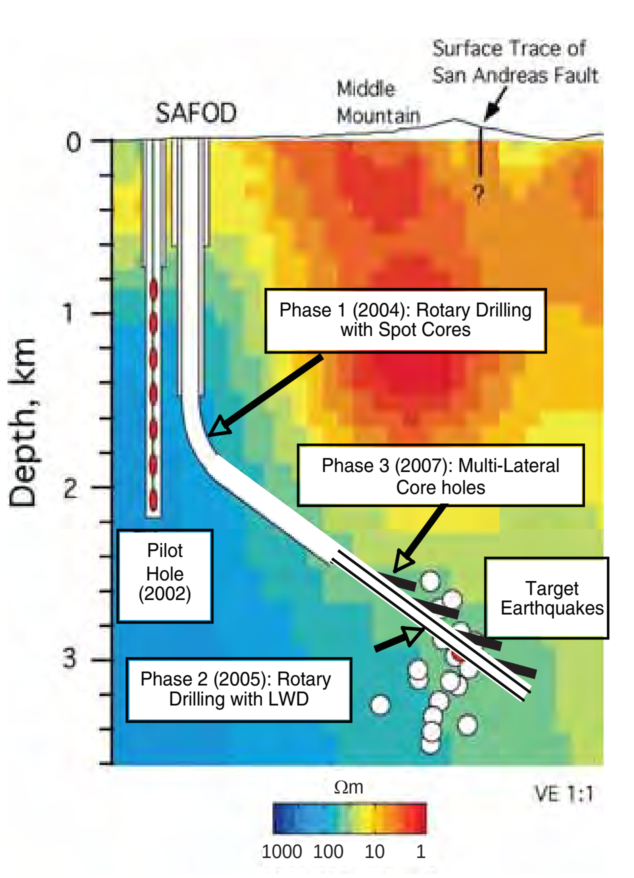

Figure 2. Schematic of SAFOD drilling program superimposed on electrical resistivity structure (after Unsworth and Bedrosian, 2004). The exact locations of the four multi-lateral core holes to be drilled in 2007 will be determined from analysis of data obtained during Phases 1 and 2.

simulate earthquakes in the laboratory and on the computer using representative fault-zone properties and physical conditions.

After considering a number of possible locations along the 1,287-km-long San Andreas Fault, SAFOD scientists agreed upon a unique segment near Parkfield, California, about halfway between Los Angeles and San Francisco (Fig. 1). Parkfield is the most extensively instrumented fault section in the world because of magnitude 6.0 earthquakes that occur in the area every two or three decades, including one on 28 August 2005. SAFOD aims to intersect the fault at 3-km depth in the vicinity of repeating magnitude 2.0 micro-earthquakes. The locations of microearthquakes and ongoing fault creep detected through repeat measurements of casing shear will be used to select intervals from which to obtain continuous core using sidetracks to the main SAFOD borehole in the summer of 2007, during Phase 3 of the project. This will permit scientists to compare the mineralogy, physical properties, and deformational behavior of fault rocks that fail primarily through creep against those that fail during earthquakes.

Construction of the multi-component SAFOD observatory is well underway, with a three-component seismometer and tiltmeter operating at ~1-km depth in the pilot hole and a fiber-optic laser strainmeter cemented into place behind the casing in the main hole. A number of surface-to-borehole seismic experiments have been performed to characterize seismic velocities and structures at depth, including deployment of an 80-level, 240-component seismic array in SAFOD in the spring of 2005.

With knowledge of P- and S-wave velocities from the borehole geophysical logs in conjunction with downhole recordings of the SAFOD target earthquake, it appears that the seismically active trace of the fault lies approximately 500 m southwest of the surface trace, near several candidate zones of particularly anomalous geophysical properties. Following the installation of the casing in the hole in September 2005, observations of casing deformation have apparently pinpointed the exact location of the active fault trace, although this remains to be confirmed by locating microearthquakes using downhole seismic instrumentation located directly within the fault zone.

Scientific results from the Phase 1 and Phase 2 drilling were presented in special sessions at the Fall 2005 American Geophysical Union Meeting in San Francisco. For more information, see the EarthScope Web site (www.earthscope.org), or contact one of the principal investigators Mark Zoback (zoback@pangea.stanford.edu), Stephen Hickman (hickman@usgs.gov) and William Ellsworth (ellsworth@usgs.gov). Anyone interested in accessing SAFOD data or samples should contact SAFOD data manager Charles Weiland (cweiland@stanford.edu).

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http://safod.icdp-online.org
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New Developments in Long-Term Downhole Monitoring Arrays

by Bernhard Prevedel and Jochem Kück

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Introduction

The long-term observation of active geological processes is a major research goal in an increasing number of scientific drilling projects. An extended monitoring phase within a potentially hostile environment (e.g., temperature, pressure, salinity) requires new long-lasting and robust instrumentation currently unavailable from either industry or academia. Extended exposure of instrument packages to extreme conditions will typically cause seals to weaken and fail, electronic parts to break under permanent load, and sensors to degrade or develop strong drift. In the framework of scientific exploration, there are currently several major research projects targeting fault zone drilling and *in situ* measurements to monitor physical and chemical conditions before, during, and after seismic events. Planning has now begun for tool development, testing, and continuous long-term monitoring for the San Andreas Fault Zone Observatory at Depth, SAFOD (Parkfield, Calif., U.S.A.; See article on page 32.).

Figure 1. Distributed Temperature Profiling (DTS) fiber-optic cable installation for permanent temperature surveys behind the casing at Mallik Gas Hydrate drilling site in Canada. Fiber-optic cables are attached to the outside of the casing wall by special cable clamps to prevent cable damage while running into the hole.Special cable outlet connectors at the well head ensure safe data retrieval from the cemented borehole annulus to the surface.

State of Technology

The prime technical objectives of a permanent monitoring array concern the reliability of components over time under borehole conditions, the repeatability of measurements and reproducibility of results, and the redundancy of the system in case of failure. In contrast to recent technological advances in drilling and logging techniques and imaging software tools, very little has been achieved in permanent borehole monitoring. In the hydrocarbon industry, even after the advent of horizontal drilling, long-term and reliable double-hole measurements were slow to emerge. Attempts to image geological structures by means of instrumented casings and smart wells never passed the experimental stage. Repeated 3-D seismic surveys (4-D seismics) therefore remain the only and remote means to monitor subsurface dynamics, though the answers only provide indirect information at best.

Monitoring a deep scientific borehole traditionally has been restricted to measuring only a few parameters, such as pressure and temperature, possibly taking fluid samples, and recording seismicity via analog cable. The limited bandwidth and vulnerability of tools for those measurements can be overcome by using sensors made of fiber-optic cables (See on-site installation, Fig. 1.). Initially, distributed temperature measurements were made over the entire length of the borehole via one single fiber-optic cable. The next step was to measure pressure at discrete points with special grated fiber elements integrated in the cable. The latest fiber-optic application is the optical geophone based on the measurement of fiber strain acceleration.

Fiber-optic temperature surveys as part of long-tem monitoring have been obtained in several projects supported by the International Continental Scientific Drilling Program (ICDP) including the Hawaii Scientific Drilling Project and the Mallik Gas Hydrate Research Well (Fig. 1). In addition, strain measurements were recorded during the Gulf of Corinth and SAFOD projects.

Table 1: A selection of commercially available sensor systems for the Type-1 permanent downhole monitoring installations.

Type-1	Noisefloor	dyn. Range	Sample rate	max. Temp	Telemetry
3c-Geophone (4.5 Hz - 2 kHz)	10^{-5} V•cm^{-1}•s^{-1}	100 dB	-	180°C	analog, electr.
3c-Accelerometer (1 Hz - 800 Hz)	10^{-6} g•Hz^{-1}	130 dB	> 0,25 ms	175°C	optical
Temperature Profiling	10^{-2} K	100 dB	-	175°C	optical
Pressure	10^{-7} bar	130 dB	> 0,25 ms	175°C	optical
Strain Gauges	10^{-6} ΔV/V	120 dB	-	175°C	electr., optical
Tiltmeter	10^{-4} rad	75 dB	> 2 Hz	175°C	optical

Table 2: A selection of commercially available sensor systems for the Type-2 permanent downhole monitoring installations.

Type-2	Noisefloor	dyn. Range	Sample rate	max. Temp	Telemetry
3c-Geophone (15 Hz - 2 kHz)	10^{-6} V•cm^{-1}•s^{-1}	120 dB	> 0,25 ms	150°C	optical
3c-Accelerometer (DC - 1 kHz)	10^{-6} g•Hz^{-1}	120 dB	> 0,25 ms	125°C	digital, optical
Temperature Pressure Gauge	10^{-4}	130 dB	< 10 Hz	200°C	digital, electr.
Strainmeter	10^{-9} ΔV/V	180 dB	> 1 Hz	65°C	digital, electr.
Tiltmeter	10^{-8} rad	120 dB	> 1 Hz	125°C	digital, electr.

New Developments for Fault Zone Arrays

High-precision permanent monitoring arrays and sensors are currently being developed to address the extremely harsh operating conditions and highest measurement requirements in fault-zone drilling projects. *In situ* stress and strain, as well as fluid activity in deforming zones, are major scientific goals of both ICDP-funded projects such as the SAFOD or the Taiwan Chelungpu Fault Drilling Project as well as in scientific ocean drilling. The typical downhole monitoring design requirements for such projects can be categorized into two modular end-member designs for different temporal and spatial scales. Type-1 is a permanently and irretrievably installed cable consisting of passive, unpowered sensors attached to the outside wall of a lower casing and cemented in place. Such monitoring systems are typically based on fiber-optic cables but may also comprise analog electric and mechanical devices or hydraulic actuators with communication lines to the surface (Fig. 2). Currently, however, the excellent long-term stability of such systems will have to be compromised with limitations in measurement resolution, dynamic range, and sensor stability. Table 1 shows the sensors for Type-1 designs that are commercially available today.

Type-2 are high-end measuring devices typically designed for several years of data acquisition and for recovery from the borehole for maintenance and sensor upgrade as well as recalibration. They are semi-permanently installed inside the last casing or inside the open hole section by cable, coiled tubing, or pipe conveyance from the surface. The array is actively powered from the surface at all times. Densely sampled data (4 kHz at 24-bit resolution) are transmitted digitally via copper or fiber-optic cable to the surface. Repeated repositioning of the array in the borehole is also possible for optimized resolution (Fig. 2). A selection of commercially available sensor systems for the Type-2 permanent downhole monitoring installations is compiled in Table 2.

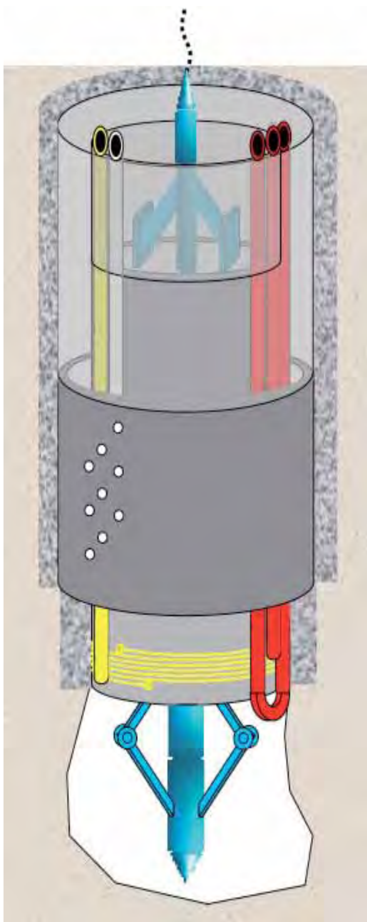

Figure 2. Sketch of showcase instrument array for a lower open-hole section. Two casings (partly drawn transparent) are cemented in place to achieve best possible coupling to the borehole wall. The inner casing is permanently instrumented on the outside with Type-1 fiber-optic (red) and electric (yellow) cables as well as fluid (white) pressure hoses to the surface. Inside is a cable- or pipe-deployed monitoring array (blue) for permanent high-resolution observations as per Type-2 (e.g. tilt- and strain-meters, pressure and temperature gauges, electro-kinetic tools, or seismometers). The measurement cable or pipe is retrievable for instrument check, repairs, and replacements; it can be repositioned at a different depth in the borehole. Perforations on the outer casing are for chemical fluid monitoring and for collecting samples.

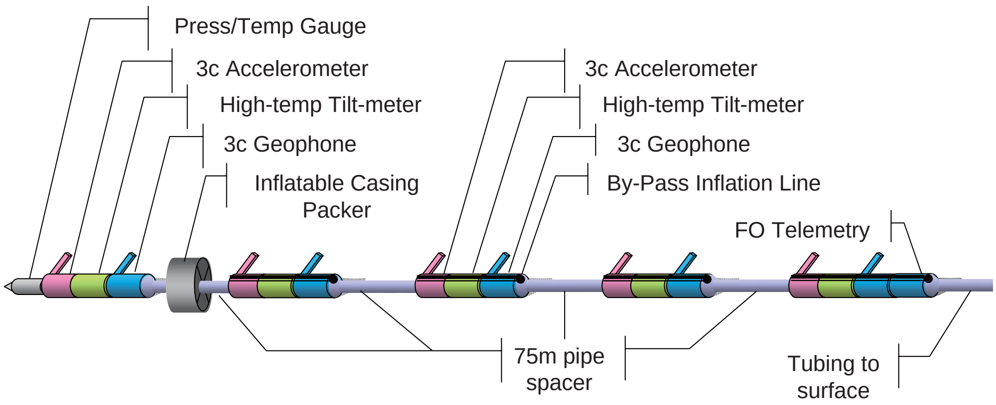

Figure 3. Permanent Array for the SAFOD Main Hole with five stations and a 7-inch casing packer to isolate the pressure monitoring within the bottom section from that of the main hole.

A High Resolution Permanent Array for SAFOD Main Well

The SAFOD comprises a pilot hole drilled in 2002 and a main borehole drilled in 2004–2005 (see p. 32). The latter was drilled vertically to almost 2 km and deviated to 58° with classic oilfield directional drilling techniques. It penetrated the trace of the San Andreas Fault at about 3 km depth during the summer 2005 drilling campaign. The current monitoring installation in the main borehole comprises a fiber-optic cable for temperature and strain measurement (cemented outside the 9-5/8-inch casing) as well as a wireline deployed tool string with three-component geophones, accelerometers, and tilt-meters (inside the lower 7-inch casing portion). The latter tool is a prototype designed primarily to monitor magnitude 2 (M2) seismic events within a few hundred meters of the borehole during a twelve-month period.

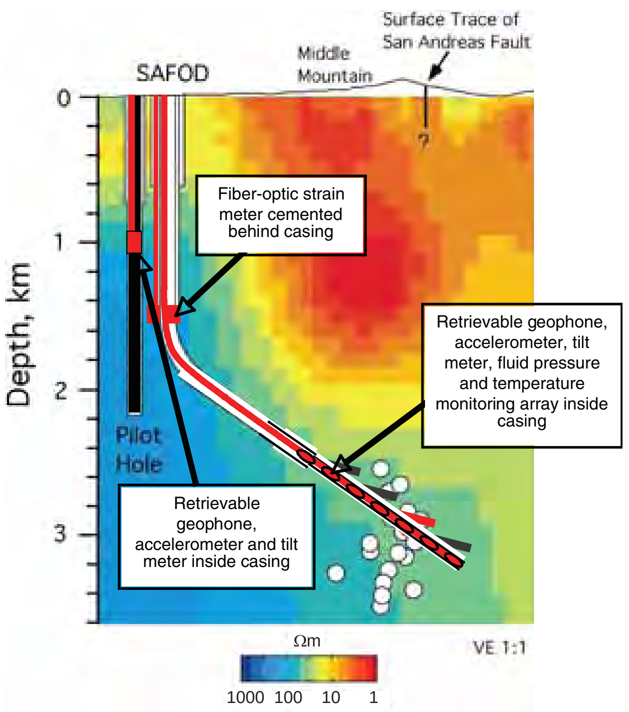

Figure 4. Scheme of SAFOD observatory. Seismic and tilt instrumentation is being deployed in the pilot hole. A fiber optics strain meter is installed behind the casing in the vertical section of the main hole. An array of seismometers, accelerometers and tiltmeters are being developed for deployment in the main hole.

During the planned Phase-3 drilling from June to August 2007, a series of four continuously cored sidetrack holes will intersect the actively deforming traces of the San Andreas Fault near the existing main borehole. After completing the sidetrack coring program in 2007, a permanent Type-2 instrumentation array will be installed for a monitoring period of fifteen years (Fig. 4). It will consist of five stations, each equipped with a three-component geophone, a three-component accelerometer, and tilt-meters, spaced by 75-m-long, electrically wired, rigid pipes. The bottom station of the array will also include pressure and temperature gauges. This part of the array will be positioned in one of the sidetrack holes and will be sealed off from the rest of the hole with a casing packer above the sidetrack point. To maintain roll-angle orientation, the entire array will be installed by pipe conveyance with cable and packer inflation lines leading to the surface. Borehole clamping arms will be pointing to the upper side of the hole to ensure optimum coupling to the borehole wall at each station. The development, construction, and testing of the retrievable monitoring array (as shown in Fig. 3) will be completed by August 2007, and the string will be installed in September 2007.

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Figure Credit

Fig.1: Jan Henninges, GFZ Potsdam.

Non-Destructive X-Ray Fluorescence (XRF) Core-Imaging Scanner, TATSCAN-F2

by Tatsuhiko Sakamoto, Kazushi Kuroki, Toshikatsu Sugawara, Kan Aoike, Koichi Iijima, and Saiko Sugisaki

Introduction

During the Deep Sea Drilling Project (DSDP) and the Ocean Drilling Program (ODP), continuous non-destructive measurements such as magnetic susceptibility, gamma-ray density, and P-wave velocity of whole-round and split cores were of great importance for paleoceanographic, structural, and sedimentological studies. The data sets have been used to determine coring strategy, inter-hole correlation, and core-logging integration, and to record the physical condition of the core before discrete sampling. These data series also allow spectral analyses and correlations to orbitally calibrated timescales. Non-destructive measurements hold great potential in the multi-platform Integrated Ocean Drilling Program (IODP) and its associated laboratories at the IODP core repositories.

The recent global warming enigma requires Earth scientists to predict future environmental conditions of the warming Earth and evaluate the effects of these climatic changes; however, capturing records of past climate and global change from deep-sea or lake cores at a resolution of decadal to centennial timescales requires non-destructive measurements on a millimeter or micrometer scale. “TATSCAN” is a code name for recently developed instruments for non-destructive sediment scanning and imaging on such a scale. Two types of non-destructive x-ray fluorescence (XRF) scanners, TATSCAN-F1 and TATSCAN-F2, have been constructed. They provide two-dimensional elemental imaging of the surface of soft sediment and hardrock cores. This article describes the system and the capabilities of the TATSCAN-F2 that has been installed on the Japanese drilling vessel *Chikyu* and in the IODP Kochi Core Repository (KCR).

Figure 1. Photograph of the non-destructive XRF scanner, TATSCAN-F2.

Instrument Specifications

The TATSCAN-F2 is designed to allow rapid elemental imaging and scanning through energy-dispersive-type XRF (EDXRF) spectroscopy (Fig. 1). It can measure the elemental fluorescence intensity of the surface of split cores, thin sections, or polished hand specimens, up to 150 cm long and 15 cm wide, and it employs a new x-ray generator with a rhodium (Rh) target that can generate x-rays with a five-times higher intensity compared to standard EDXRF instruments used up to now, thus reducing the time needed for individual measurements. The time for a single measurement can be set to 100 seconds and still yield enough data to quantify elements within a 1-cm-long core increment, resulting in a scanning time of 250 minutes for a standard length core section. The sample chamber is filled with air, so it can be used for processing wet, dry, or powdered samples. The measurement device is automatically laser guided to a 1-mm distance between the measurement spot and the sample surface. To minimize x-ray absorption by the vapor in the surrounding air, a He-filled apparatus is installed around the measurement window, including the x-ray generator and the detector. This allows for quantifying of light elements well enough to detect subtle sedimentary cycles or episodic event layers.

The TATSCAN-F2 can measure in diameters of 0.8 mm or 7 mm, and with the generator and the detector positioned at a 45° angle to the sample surface, the incident field of x-rays on the sample surface has an ellipsoidal shape, yielding practical measurement diameters of 1.13 mm and 9.9 mm, respectively. The scanning resolution is flexible and controlled by the operating software, with minimum scanning resolution of approximately 1 mm. Possible options include spot measurements, line scanning and two-dimensional map imaging. Table 1 lists the quantitative accuracy of the TATSCAN-F2, achieved with discrete tablets of pressed-powder standard samples.

The TATSCAN-F1 is designed to achieve very high-resolution measurements of two-dimensional elemental distributions. It uses measurement diameters of 40, 100, 400, and 1900 µm and a scanning resolution of 10 µm. It therefore provides the same level of analytical precision as normal EDXDF. As the scan of a whole section in high resolution requires significant time, the core is first scanned with the faster TATSCAN-F2. The results of this initial scan help to

Table 1. Analytical accuracy* of the major elements of the TATSCAN-F2.

	Range of contents	Measurement diameter 7 mm
Na_2O	2.52–4.75 wt%	0.48%
MgO	0.05–35.01 wt%	0.24%
Al_2O_3	5.56–18.94 wt%	0.14%
SiO_2	0.21–98.46 wt%	0.23%
P_2O_5	0.02–0.70 wt%	0.05%
S	0.00–1.35 wt%	0.01%
K_2O	0.00–4.34 wt%	0.04%
CaO	0.05–98.55 wt%	0.29%
TiO_2	0.00–1.61 wt%	0.02%
MnO	0.00–0.30 wt%	0.01%
Fe_2O_3	0.04–18.61 wt%	0.22%

* For the accuracy test, repeated measurements of 11 standard samples produced by the Geological Survey of Japan have been used. Range of the contents represents the range of the standard sample for each element. The accuracy (absolute error) for a 7-mm measurement diameter is calculated as the standard deviation of the measurement versus the average of repeated measured values.

target specific intervals for subsequent high-resolution measurements with the TATSCAN-F1. The TATSCAN-F1 is currently installed only in the Institute for Research on Earth Evolution (IFREE) at the Japan Agency for Marine Earth-Science and Technology (JAMSTEC).

Critical Conditions for Non-Destructive Measurements

The quality of the measurements with the non-destructive XRF scanner depends strongly on the sample condition. The measurements are affected by the x-ray attenuation (i.e., attenuation coefficient of the bulk sample, atmospheric density, and distance between sample surface and detector). Three particularly critical factors for XRF scanning are the distance between the sample surface and the detector, the smoothness and flatness of the sample surface, and the preservation conditions of the water content. In our experience, a difference of 1 mm from spectroscopic setting point results in 10% attenuation for the x-ray of Si in the atmosphere of air; this represents a 2% measurement error for quantifying Si. Another difficulty arises from the fact that a difference in water content within a core section or among successive cores may yield different results for a specific element. This may happen even if the recovered core is carefully split for XRF scanning, because the x-rays are attenuated by water on the surface of the wet core. It is therefore very important to keep the core material under the same conditions after coring and splitting. To allow better comparison of data, the elemental ratio of the result for wet sediment cores is usually used.

Another significant issue concerns x-ray attenuation by the plastic-wrap cover used to protect the core. Commercial plastic wraps using polyethylene, polypropylene, or polyester cause problems because of high x-ray absorption rates, especially for the light elements. For scans with the TATSCAN-F2 a very thin prolene film that has a high x-ray transmission rate is used to cover the wet core.

Application Examples

About 13 m of Cretaceous sedimentary rock cores, including the layers with Ocean Anoxic Event (OAE) Ia (Goguel) from southeastern France, were scanned with the TATSCAN-F2 (Fig. 2). All split cores were carefully split and polished. Organic-rich, dark-colored intervals of the Goguel event were intercalated in the continuous alternating sequence of marlstone and limestone. The major element variations of the cores were obtained by continuous, non-destructive, TATSCAN-F2 measurements using a 1-cm scan diameter and a 5-mm scanning interval. $CaCO_3$ and Al_2O_3 contents correspond distinctly to the sedimentary cycle of the marlstone–limestone alternation, represented by a gray image and color reflectance; increasing spikes of total Fe_2O_3 at about 9.5 m core length below the Goguel event and at about 7 m core length in the lower part of the Goguel correspond distinctly to sporadic pyrite nodules. In this case, the TATSCAN-F2 measurement successfully detected the sedimentary cycles of $CaCO_3$ and episodic events of pyrite accumulation.

Soft, wet sediment core MR99-K03-PC1 from the Chukchi Sea in the Arctic Ocean was scanned by the TATSCAN-F2 (Fig. 3). Samples wrapped in prolene were scanned using a 1-cm scanning diameter and a 5-mm scanning interval. Color-shaded intervals represent relatively bioturbated, reddish-colored, silty clay layers with a high concentration of dropstones and a high Ca/Al ratio corresponding to interglacial seasonal change in sea-ice conditions.

An artificial conglomerate core has been scanned as two-dimensional elemental images (Fig. 4). The core was made by filling a core liner with

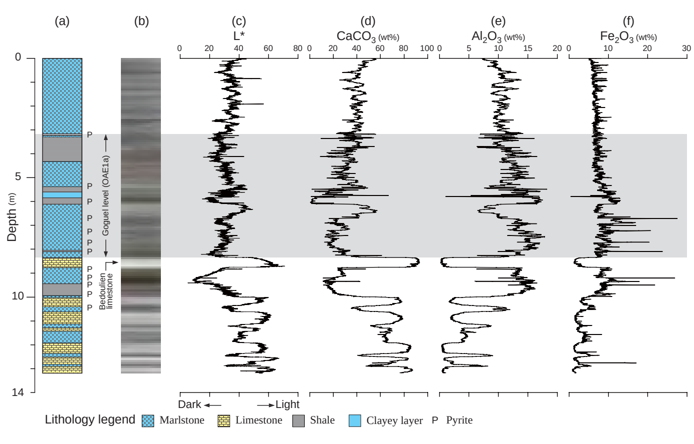


Figure 2. Example TATSCAN-F2 scan of a Cretaceous sedimentary rock core drilled at a land-section in SE France including the Ocean Anoxic Event (OAE) Ia (Goguel) stage. (a) Graphic representation of geological column. Gray-shaded interval represents OAE-Ia (Goguel) interval. (b) Gray-scale photo image of the core. Dark-colored intervals correspond with organic-rich intervals. (c) Lightness of color reflectance (L*). The contents of $CaCO_3$ (d), Al_2O_3 (e), and Fe_2O_3 (f) measured by the TATSCAN-F2 present as oxides. Gray band is the horizon of Goguel level.

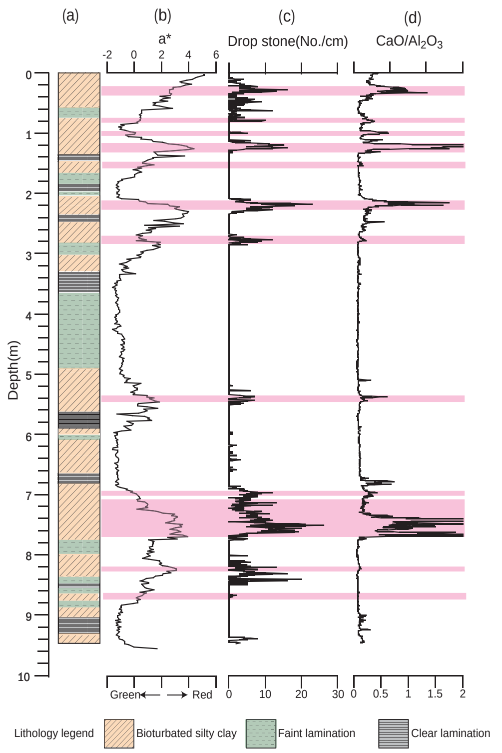
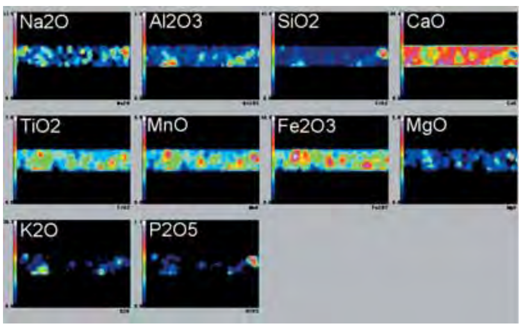


Figure 3. Example for the TATSCAN-F2 measurement for wet soft sediment core, MR99-K03-PC1 from the Chukchi Sea, Arctic Ocean. (a) Graphic representation of geological column. (b) The color index of a* of color reflectance. (c) Numbers of dropstone (>2 mm in diameter) counted on soft x-ray image of the core. (d) Elemental ratio of Ca/Al analyzed by the TATSCAN-F2. Color-shaded intervals represent relatively bioturbated reddish-color silty clay layers with a high concentration of dropstones and a high Ca/Al ratio, corresponding to the interglacial seasonal change in sea-ice conditions.

Figure 4. Example of core images using the TATSCAN-F2 with an artificial conglomerate core. The plastic core liner was filled with concrete and gravel-sized rocks and then split. It was scanned with a 7-mm diameter with 1cm-cube intervals. (a) Split core placed in the TATSCAN-F2. (b) 2-dimensional elemental imaging of major elements analyzed by the TATSCAN-F2. The colors represent concentrations in wt%. The color bar on the left side of each image corresponds to the content image, brighter colors representing a higher concentration. Range of the content is given for each element. Na2O (0.0–17.5 wt%), Al2O3 (0.0–1.5 wt%), SiO2 (0.0–47.0 wt%), CaO (0.0–68.4 wt%), TiO2 (0.0–7.0 wt%), MnO (0.0–8.9 wt%), Fe2O3 (0.0–58.0 wt%), MgO (0.0–5.0 wt%), K2O (0.0–20.3 wt%), P2O5 (0.0–1.1 wt%).

(a)

(b)



concrete and gravel-sized rocks. Gravel can be easily recognized by the brighter color (high content) in each elemental image of Al_2O_3, TiO_2, MnO, and Fe_2O_3 with a $CaCO_3$ matrix.

Advantages and Limitations of Non-Destructive Measurements

The TATSCAN shows its strengths at rapid and automated measurements with <1 % quantitative error. It performs very well in detecting sedimentary cycles or events without destroying sedimentary structures and structural features, or where discrete measurements cannot be done quickly or efficiently. The data precision, however, depends strongly on a high standard of sample preparation, in particular concerning a smooth, flat surface and preservation of initial water content. We strongly recommend that users learn the advantages and limitations of non-destructive XRF scanning and the necessarily careful assessment of the data quality and sample conditions before using this technique. It might be necessary to combine discrete measurements with non-destructive scanning measurements to fully evaluate the usefulness of scan-data for scientific research.

For more information about the TATSCAN-F1 or -F2, technical information, or scanning inquiries, please contact Tatsuhiko Sakamoto (tats-ron@jamstec.go.jp).

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Figs 2 and 4: Data produced by Koichi Iijima and Tatsuhiko Sakamoto.
Fig 3: Data produced by Saiko Sugisaki and Tatsuhiko Sakamoto.

The Fully Electronic IODP Site Survey Data Bank

by Barry W. Eakins, Stephen P. Miller, John Helly, Barry Zelt, and the SSDB Staff

Introduction

The next generation all-digital Site Survey Data Bank (SSDB) opened for service on 15 August 2005 as an online resource for proponents, panel members, and worldwide operations of the Integrated Ocean Drilling Program (IODP). The SSDB functions primarily as a digital home for data objects contributed in support of IODP drilling proposals and expeditions. Overarching goals include easy submission of digital data, support of panelists reviewing data in support of drilling proposals, and providing a secure and accessible archive of information that evolves throughout the lifecycle of proposals and the program. To ensure a close tie between the data, data bank users, and the program, IODP Management International (IODP-MI) provides a dedicated science coordinator to support proponents, members of the IODP Science Advisory Structure, and the implementing organizations in their site-survey data needs.

The new Web-accessible data bank will have an integrated user management system that provides secure data storage and easy access for uploading and reviewing. The main viewing portal into the data bank enables discovery of all data objects displayed over a basemap of global topography (Fig. 1). Within this Java application, users may search for objects by data type, proposal number, or other user-specified criteria. The data bank currently supports twenty-six data types (see Table 1), and this number may increase as necessary. The IODP currently has 107 active proposals for drilling at sites around the globe, involving nearly 1000 proponents from more than forty countries. Of these proposals, sixty-four currently have digital objects residing within the SSDB.

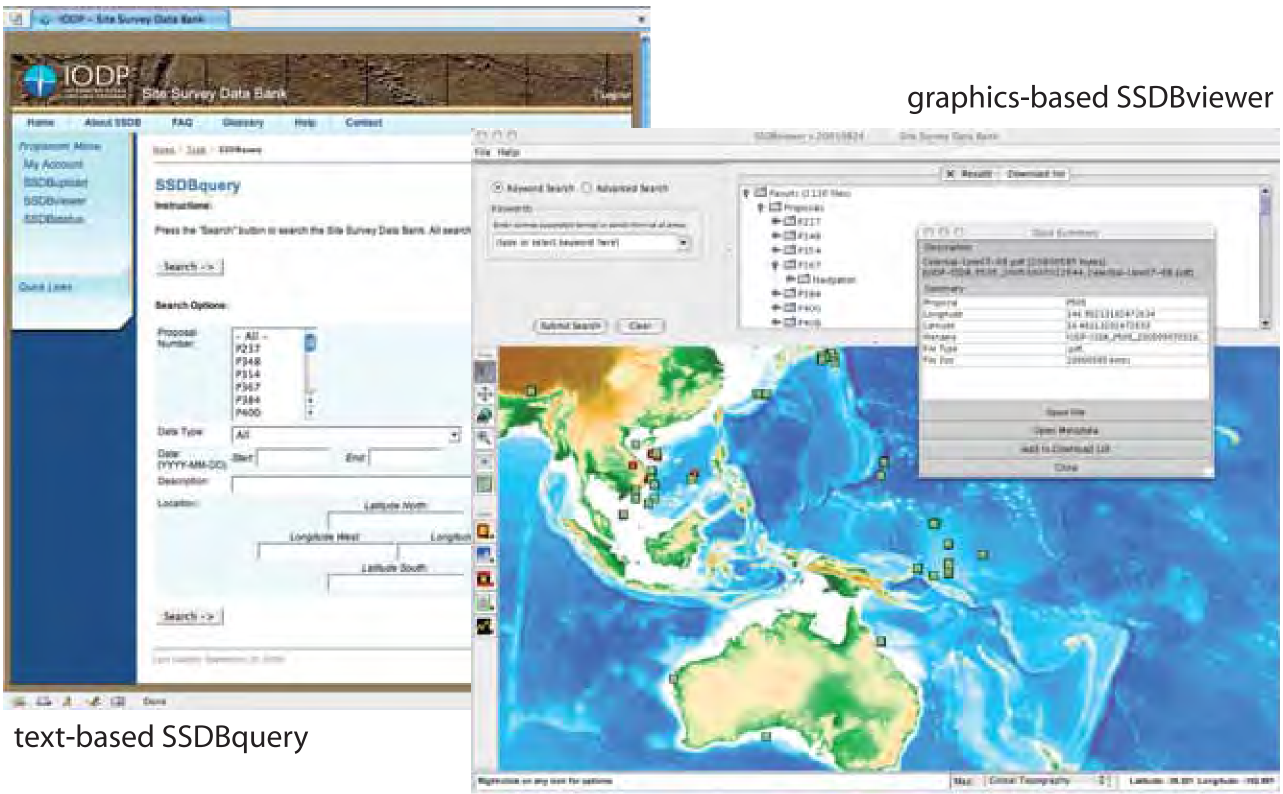

Figure 1. During 2005 a total of 64 proposals have become available online in the SSDB Digital Library, including 3136 spatially referenced digital objects. Data may be discovered by searching for specific data types, proposal number, geographic coordinates, keyword, and other criteria, using either SSDBquery (left image) or SSDBviewer (right image). With SSDBviewer, users may pan around or zoom in on the displayed icons which meet their search criteria, and then open a 'Data Summary' panel. From this panel they may then choose to open the file and display its contents on screen, view associated metadata, or download the file pair to a computer.

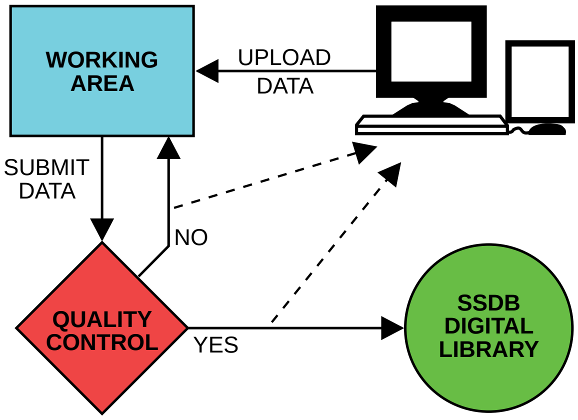

Figure 2. Schematic of data flow into the SSDB Digital Library. A proponent uploads digital data files from their computer into the 'working area' on the SSDB site, providing appropriate metadata. In the working area, they may review and modify the metadata before submitting the data files and associated metadata to the SSDB for quality control checking (QC). If the file pairs are acceptable, they are entered into the Digital Library. If errors are discovered during the QC process, the submissions are moved back into the working area, where the proponent can make needed changes. In both cases, e-mail notification (dashed line) is sent to the proponent informing them of the QC result.

Serving the Needs of Proponents

New users must complete an online registration form when first visiting the SSDB Web site (http://ssdb.iodp.org). An IODP-MI science coordinator will subsequently authorize an account and grant appropriate access. Once authorized, proponents may begin the process of submitting digital data objects over the Web using an upload tool that guides them through the submission process. This includes selecting an appropriate proposal number and data type, entering data-specific supporting information (metadata), selecting digital files to upload from the proponent's computer, reviewing of the entered metadata, and uploading to a temporary working area.

All data files submitted to the SSDB must meet specific requirements before acceptance into the Digital Library, the online SSDB data resource. These include geographic coordinates for georeferencing and visual display, and supporting metadata describing the object and its importance, allowing discovery using the viewer and query tools. Objects may be given a 'point' coordinate such as logging data from prior drilling sites, beginning and ending 'line' coordinates such as seismic lines, or a 'bounding box' suitable for maps. Data objects may be associated with one or more proposed drilling sites and may be flagged as proprietary, ensuring access only by authorized panelists, reviewers and members of the IODP implementing organizations.

Proponents also may use a status tool to manage their submissions once the data objects have been uploaded to the working area. Following submittal, the data objects and associated metadata pass through quality control (QC) performed by SSDB staff to ensure that georeferencing is appropriate, that metadata are satisfactory, and that the data file can be viewed with the necessary viewer before entering the Digital Library. The status tool can be used to track progress through the QC process, though proponents will also receive e-mail alerts stating success or failure of the QC check. Figure 2 conceptualizes this process. In addition, the viewer and query tools can be used to discover other data objects in a region of interest.

Serving the Needs of Panelists

The SSDB serves the needs of panel members and reviewers in evaluating proposals, which is why it is so critical for proponents to supply the requested metadata when uploading data. The digital data bank's most significant role in this regard is its search capability, using either the graphically driven viewer tool or the text-based query tool (Fig. 1). These tools permit discovery of data objects related to specific proposals, through user-specified search criteria, with the aim of finding the data most relevant to answering a panelist's questions. These criteria include searching by data type, site name, special keywords, or date of submission to the SSDB—to find, for example, all proposal-related data submitted since the last panel meeting. Users may view data objects either directly over the Web or after downloading to their computer. By having the digital data bank as an online resource, panelists can review proposal data prior to gathering for panel meetings as well as for browsing the data bank during review sessions.

One important aspect of the online digital SSDB is its ability to display seismic profiling data (SEG-Y format) over the Internet (Fig. 3). The advantage of a Web-driven visual

Table 1. Data types supported within the SSDB

Backscatter
Bathymetry
Documents
Electromagnetics
Environmental Conditions
Fluid Flux
Geology
Gravity
Heatflow
Location Maps
Logging
Magnetics
Navigation
Permits
Sample Data
Seafloor Photography
Seismic Data:
Single-channel Reflection
Multi-channel Reflection
3-D Reflection
Sub-bottom Profiler
Refraction
Velocity Models
Ocean Bottom Seismometer
Seismicity
Visualization
Water Column

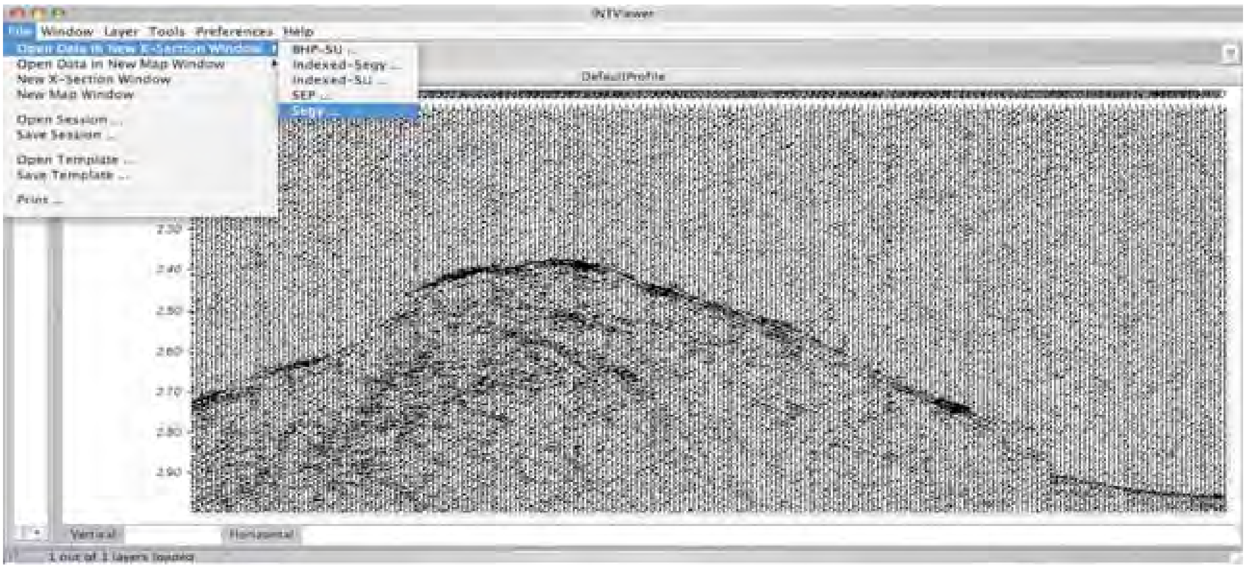

Figure 3. The SSDB utilizes the Java application INTViewer for displaying digital seismic profiles (SEG-Y format) which reside within the Digital Library. Data are displayed as an image onto the user's computer screen, permitting evaluation of the data, as well as printing. INTViewer has several ways of displaying the seismic traces (deflection, positive color fill, etc.), and gain can be applied to enhance weaker signals. It can also display specific sections of a SEG-Y file, for example, by limiting the traces and time range displayed.

display, rather than file download, is that issues of connection speed and local storage space are largely circumvented, though users may still download the SEG-Y data if desired.

The Future …

Now that the SSDB has entered the Internet Age, what does the future hold? Certainly, there will be continuing improvements, including 3-D seismic capabilities, expanding search criteria, and improved administrative tools. The capabilities now also exist for integrating with other online data resources, which will allow discovery of potentially relevant data that reside outside the SSDB. For example, the information architecture of the SSDB is derived from the SIOExplorer Project, which has placed 647 Scripps Institution of Oceanography (SIO) cruises online (http://SIOExplorer.ucsd.edu), including 323 multibeam cruises. This effort is currently being extended in collaboration with the Woods Hole Oceanographic Institution (WHOI) to include WHOI cruises, *Alvin* dives, and ROV (remotely operated vehicle) operations. In the future, IODP proponents should be able to conduct joint searches over the holdings of the SIO and the WHOI, as well as the SSDB, as they prepare site-survey data contributions. The IODP Site Survey Panel is also developing online guides to help proponents determine what data types are necessary for their proposal to be approved. Data held within the SSDB have already been used in support of at-sea drilling operations, a function that will expand dramatically when IODP Phase II drilling operations start in 2007.

Acknowledgements

The SSDB has been developed by a team of researchers and computer scientists at the Scripps Institution of Oceanography and the San Diego Supercomputer Center, University of California, San Diego (UCSD), under contract with, and guidance from, IODP Management International, supported by NSF OCE 0432224.

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and the SSDB staff Dru Clark, Goldamer Thach, Don Sutton and John Weatherford.

Related Web Links

http://ssdb.iodp.org
http://www.iodp.org
http://www.int.com
http://SIOExplorer.ucsd.edu

Conference on Continental Scientific Drilling: Defining Future Goals

by Ulrich Harms

A recent conference to discuss achievements and to guide future priorities in continental scientific drilling received overwhelming support by the scientific community. The meeting brought together a broad spectrum of researchers in the solid earth sciences through a common necessity for drilling as a tool to obtain otherwise inaccessible samples and critically needed data on active processes (Fig. 1).

More than 200 participants from twenty-four countries and from a very large variety of disciplines attended the meeting. The first day served to provide an overview and review of the past ten years of research conducted within the framework of the International Continental Scientific Drilling Program (ICDP). The second day of the meeting was used to develop visions for the future, to prioritize scientific questions, and to identify potential key locations. For this purpose, the conference split into eight breakout groups: climate dynamics and global environments, impact structures, geobiosphere and early life, volcanic systems and thermal regimes, hotspot volcanoes and large igneous provinces, active faulting and earthquake processes, convergent plate boundaries and collision zones, and natural resources. Results of the thematic working groups were presented on the third day in a plenary discussion to define the overarching goals and synergies.


Figure 1. Participants of the ICDP conference.

The working group on climate dynamics and global environments identified two grand challenges—to understand rapid changes during the late Quaternary at an unprecedented temporal resolution, and to gain a physical understanding of the reconstructed climate change by quantifying environmental change. For a mechanistic understanding of critical thresholds in the climate system, it is necessary to concentrate on natural experiments in the geological past that contain critical variations such as in greenhouse gas forcing. Laminated and high sedimentation-rate lake sediment sequences are instrumental for closing huge gaps in the knowledge of the impact of climate change on continental biota and ultimately the human environment. Specific research goals include a) understanding the variability of and the interplay among large-scale ocean–atmosphere oscillations, b) investigating the continental response of climate variability at centennial-to-millennial timescales, c) understanding potential shifts in climate zones of interannual to decadal climate variability during abrupt climate change, d) quantifying how interglacial modes of climate variability at centennial to millennial timescales modulate climate variations, and e) understanding the varying duration and amplitude of interglacial episodes during the late Quaternary. A full realization of such climate research goals requires the integration of terrestrial and marine archives and the application of improved analytical tools.

The formation of impact craters has changed the Earth dramatically through geological time and has been a key factor in the development of life on our planet. It is beyond any doubt that the study of impact craters on Earth is an absolute prerequisite for understanding some of the most fundamental problems of earth and planetary sciences, such as the variation of the morphology and structure of craters as a function of their size and of planetary gravity; the origin and evolution of early primitive life; the origin, constitution, and evolution of the Archean crust of the Earth; and the discontinuities in the evolution of later complex life (Phanerozoic mass extinctions). Also, a major topic of impact research is the effect on the global environment and possible relations to mass extinctions. At present, the Chicxulub impact structure, with an age close to the Cretaceous-Tertiary (K/T) boundary, is the only one for which a relation with a major mass extinction was established (at least with respect to the timing). To explore and demonstrate the potentially important role of a meteorite impact on biotic extinctions and subsequent evolution, it is important to find other examples of meteorite impacts that are related to mass extinctions. Scientific drilling should continue to focus on impact craters that are inherently world-class structures (e.g., Chicxulub), those that address world-class scientific issues, and those that are best addressed by available technology.

The still unexplored deep biosphere of Earth plays a fundamental role in global biogeochemical cycles over both short and longer timescales. Estimates that the mass of the deep biosphere could be equal to that of the surface biosphere have been made by extrapolating from data collected from a very limited number of boreholes in marine and terrestrial environments. The lower depth limit of the biosphere has not been reached in any borehole studies that have included a microbiological component, and the factors that control the abundance and activities of microbes at depth and the lower depth limit of life are still poorly understood. While the Integrated Ocean Drilling Program (IODP) is now systematically probing the marine regions of the deep biosphere, the terrestrial deep biosphere is receiving somewhat less attention. This is where the continental drilling program must play the leading role. Another important target for future scientific drilling is to address the hallmark features of the Archean–Palaeoproterozoic transition when aerobic life began to shed light on the early biogeochemical evolution of the Earth.

The future exploration of volcanic systems and thermal regimes was discussed within three main topics. One fundamental scientific issue is that the origin and growth of the continents is governed by volcanic systems developing silicic plutons resisting subduction. Despite mankind's presence on the continents, however, the formation of oceanic crust is currently far better understood than that of continental crust. An issue of high societal relevance is the investigation of hazards caused by volcanic eruptions. Drilling provides a means to improve substantially our predictive capabilities about the onset, style, and cessation of eruptions, either at specific sites such as in the Tokyo area near Mount Fuji and the Naples area near Campi Flegrei and Vesuvius, or in general through improved understanding of relevant processes. The third issue discussed centered on the largely untapped renewable energy resource provided by continental thermal regimes, whose exploration and exploitation needs to be addressed using drilling as a tool.

In the last decade, continental scientific drilling allowed for unprecedented access to and novel observations in actively deforming zones. Although important knowledge thus has been gained on the strength of the upper crust and the global-scale tectonic stress fields, several long-standing fundamental questions on faulting processes are still not satisfactorily answered. Basic issues exist concerning the minimum stresses causing slip on a fault; the factors determining seismic, aseismic or weak behavior of fault zones; the controls of nucleation, propagation, arrest, and recurrence of earthquake rupture; and the role and origin of fluids in fault processes. The concepts and objectives for future drilling will be guided by contributions from three main sources: a) the cumulative experience from drilling active faults, such as the San Andreas Fault Observatory at Depth (SAFOD) or the IODP NanTroSEIZE project, revealing the capabilities and limitations of direct probing of faulting for the future, b) current geodynamic investigations, such as EarthScope, that generate new ideas and avenues for drilling linked to complementary field research, and c) an envisioned increase in the collaboration with industry and government agencies in the near future to the benefit of all sides.

Hot spot volcanoes and large iIgneous provinces (LIPs) originate most probably at the base of the mantle and therefore provide unique information about the deep Earth. Drilling through the horizontally layered flows and strata of such volcanoes allows for the collection of sample suites—

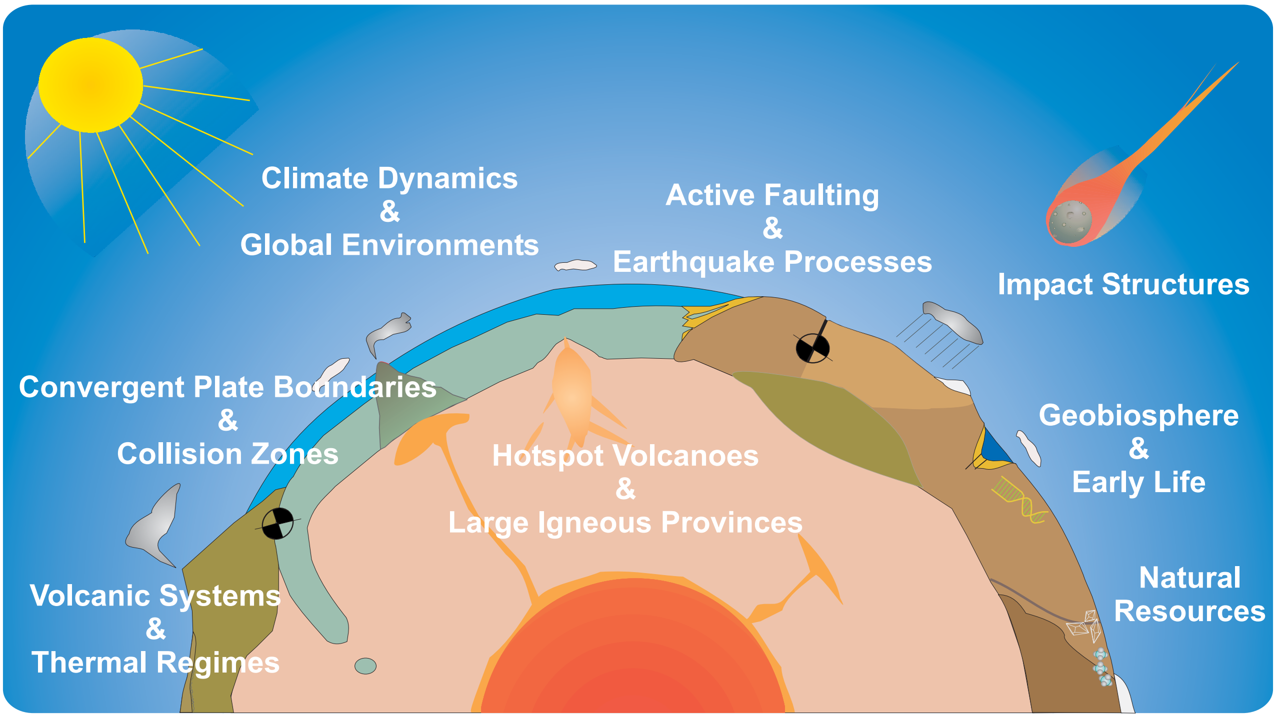

Figure 2. Sketch representing the major scientific themes of the ICDP.

from youngest to oldest—recording volcano build-up, plume structure, and melt extraction processes. The resulting geochemical and petrological datasets are critical for developing and testing a new generation of mantle magmatism models, and they provide input for new models of hotspot volcano growth and lithosphere deformation. Drilling also provides detailed tests of the relationship between LIPs and other global events as well as unique information on aquifers, temperature distributions, chemical alteration, and biological activity in the deep subsurface. Possible future targets for drilling that were discussed included oceanic island, the continental Snake River Plain to study plume lithosphere interaction, and the Kerguelen region and flood basalt provinces on land.

The majority of human population and industry is concentrated in the continental areas bordering convergent and collisional plate boundaries, where major natural disasters such as earthquakes, tsunamis, and volcanic eruptions threaten human life and economy. A strong need therefore exists for scientific and economic efforts to elucidate and understand the processes responsible for such geohazards as well as for mitigation strategies. Scientific drilling will play a vital role in such studies and is an integral part of this effort. The ICDP drilling in convergent and collisional plate margins faces unprecedented challenges regarding drilling technology, drilling depth, and requirements for long-term monitoring of Earth processes in downhole observatories. A comprehensive initiative to drill the continental crust bordering plate boundaries encompasses a wide range of topics: a) dynamics of active subduction and collision zones, with focus on the seismogenic zone at the plate interface, and the distribution of deformation and seismicity, b) the role of mantle plumes in orogeny, c) supra-subduction magmatism in arc systems, d) the geological manifestation of deep subduction and exhumation of the lithosphere, and e) aspects relating to the birth and growth of continental crust through the history of the Earth.

The natural resources working group recommended that this area should be recognized as a unique theme for scientific drilling within its broad scope because of the ever-growing societal relevance of environmentally sustainable natural resources. Limited funds for scientific drilling should not be used in ways that subsidize or compete with drilling that is more properly the domain of industrial and government entities concerned with the development of natural resources. Drilling projects involving the natural resources topic should strive to focus on leading-edge scientific questions of broad global significance and not on economic issues such as exploration or resource assessment. The ICDP should encourage novel drilling-related research with overarching research questions that are not routinely addressed by industry and with a potential for positive contributions to environmental problems.

At the same time as these thematic sessions, a workshop on drilling technology was held to highlight and summarize the existing and necessary technological needs of continental drilling. A second workshop on education and outreach addressed the use of scientific drilling results for training courses for graduate students and for undergraduate teaching, as well as for outreach to the general public.

Regarding the realization of the key scientific questions, all participants in their closing remarks expressed the need for internationally coordinated and community-steered continental scientific drilling in the future. Close cooperation with the IODP will play a major role, as the main scientific goals of the ICDP and the IODP overlap to a very high degree. Outstanding examples with a critical need of a joint approach are marine–continental transects across seismogenic zones as well as the integrated investigation of marine and continental climate archives.

The conveners of the thematic sessions have compiled the working results in a white paper, that will serve in the future as a Science Plan for the forthcoming activities of the ICDP. The white paper replaces the “Scientific Rationale for an International Continental Scientific Drilling Program” that served as a guideline for the ICDP from the start of supported activities in 1998. More information on the conference and the resulting white paper can be found at http://www.icdp-online.org.

The Conference on Continental Drilling was held at the GeoForschungsZentrum in Potsdam, Germany under the title “Continental Scientific Drilling 2005–A Decade of Progress and Challenges for the Future” from 30 March to 1 April 2005.

Acknowledgements

This conference was financially supported by the ICDP. It is gratefully acknowledged that the participants contributed enthusiastically to the success of the conference, that the Conference Chairman Mark Zoback (Stanford University, U.S.A.) prepared and moderated the meeting inspiringly, as well as that the following conveners volunteered to oversee the thematic sessions and to prepare the white paper: Jan Behrmann, Julie Brigham-Grette, Scott Dallimore, Don DePaolo, John Eichelberger, Wilfred Elders, Gerald Haug, Brian Horsfield, Hisao Ito, Tom Kieft, Christian Köberl, Bernd Milkereit, Ze’ev Reches, Kozo Uto, Dominique Weis, and Jingsui Yang.

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Related Web Link

http://www.icdp-online.org/news/future.html

New U.S. Drillship to Join IODP in 2007

by Kelly Kryc

After twenty years of service to the Ocean Drilling Program (1985–2003) and the Integrated Ocean Drilling Program (2003–present), the *JOIDES Resolution* is slated to receive an 'extreme makeover' transforming the ship into a state-of-the-art scientific ocean drilling vessel (SODV). The SODV is the U.S. contribution to the IODP and will be dedicated to advancing our understanding of the Earth by monitoring and sampling the ocean floor.

As IODP's riserless platform, the U.S. SODV will provide a mobile, robust, and versatile ship that can operate in all the world's oceans. During the coming year, the drillship will undergo a dramatic conversion that will make it virtually unrecognizable to drilling veterans. The U.S. SODV also will be renamed to reflect its new role in the IODP fleet.

The $115 million ship conversion is funded by the U.S. National Science Foundation (NSF) over three years and is managed by the JOI Alliance (Joint Oceanographic Institutions, Texas A&M University, and Lamont-Doherty Earth Observatory of Columbia University). The JOI Alliance and NSF are committed to providing an enhanced drillship to exceed community expectations and to provide IODP with a platform capable of meeting 21st-century scientific drilling goals.

To exceed community expectations is the highest priority for the JOI Alliance. For the past six years, the community has provided guidance and advice through workshops, planning meetings, and committees to define the requirements of the riserless platform. In 1999, the Conference on Multiple Platform Exploration of the Ocean (COMPLEX) produced a report identifying requirements for riserless ocean drilling, sampling, downhole-logging, *in situ* measurements, and necessary laboratory facility improvements to achieve specific scientific results.

Building on the COMPLEX vision, the U.S. Science Advisory Committee created the Conceptual Design Committee (CDC) to formulate design characteristics of a single, riserless drillship configured to address the widest range of drilling objectives. The CDC report describes the performance specifications of a riserless ship targeted to nine scientific themes: observatories, rifting processes, convergent margins, large igneous provinces, oceanic crust, hydrothermal systems and massive sulfide deposits, deep ocean sediments, passive margin stratigraphy, and carbonate reefs, atolls, or banks (See Web link at the end of this article).

The CDC report also specified an idealized range of platform capabilities for the riserless drillship, including the ability to drill in a range of water depths (shallow and deep), a total drillstring length of 11,000 meters; continuous coring and sampling with high recovery in a wide range of lithologies, the ability to operate globally (including high latitudes) in a wide range of sea states with a sizeable scientific party, and a potentially larger diameter core barrel to allow for state-of-the-art downhole-logging tools.

At the NSF's request, more than 100 scientists from ten countries responded to a questionnaire about the CDC report. Responses were compiled into a report that, together with the CDC report, has created the 'gold standard' reference used by the JOI Alliance.

The JOI Alliance continues to work to provide the IODP with a riserless drillship that will push the frontiers of scien-

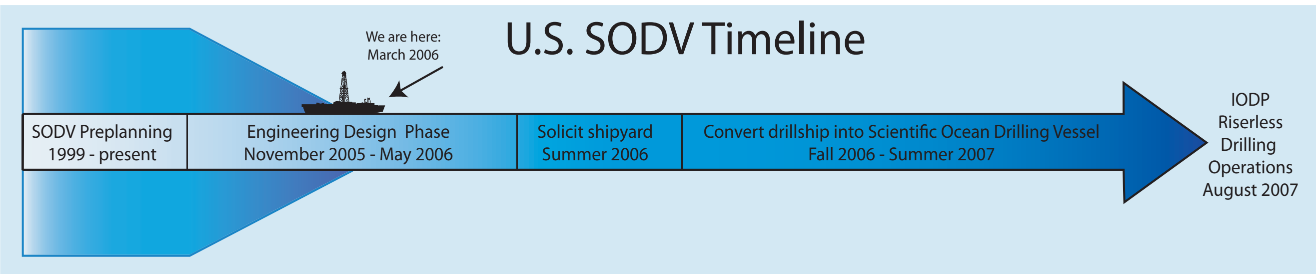

Figure 1: Anticipated timeline for the U.S. SODV conversion and IODP operations.

tific ocean drilling. Efforts accelerated in 2004 when the JOI Alliance hired key personnel to lead the conversion. A contract was awarded in December 2005 to Ocean Drilling Limited to convert the *JOIDES Resolution*.

To prepare for the conversion, experts were mobilized to design and outfit the SODV. Their efforts resulted in the SODV Briefing Book, which presents a vision for the U.S. riserless platform (http://www.joialliance.org/MREFC/briefing_book). The briefing book synthesizes numerous recommendations received from the community into a comprehensive document that describes the capabilities and enhancements proposed for the drillship, including onboard scientific capabilities, drilling and coring technology, and habitability enhancements. The briefing book was released to the community in January 2005, with an online questionnaire to solicit feedback on the conceptual design characteristics of the ship.

In addition to the briefing book, the JOI Alliance developed a comprehensive SODV Advisory Structure of experts in science, drilling, information technology, lab design, and naval architecture. Twenty external advisors were selected to represent the community during the conversion (www.joialliance.org/MREFC/committees).

What exactly can science party members expect for $115 million and several years of planning? The science capabilities proposed for the U.S. SODV will certainly turn heads. At a minimum, there will be a fifty percent increase in lab space compared with the *JOIDES Resolution*. The increased square footage will ensure better core flow through the laboratories and a greater variety of scientific instruments. Some enhancements may include x-ray fluorescence scanning, x-ray computed tomography scanning, a U-channel cryogenic magnetometer, an inductively coupled plasma mass spectrometer, a particle size analyzer, and multiple parallel sensor tracks to expedite core flow.

Improved core flow through the laboratories is important because the U.S. SODV will have the potential to collect more cores with better recovery than ever before due to a new and enhanced drilling instrumentation system, a sub-sea camera system with improved handling, and a new drillstring with upgraded drilling tools. Proposed changes to the hull and machinery will produce faster transit speeds and a greater cruising range, which translate into more drilling time on station.

Gone are the days of cozy four-person staterooms and eight-person bathrooms that made the ODP experience so memorable. Instead, the converted drillship will have no more than two people to a stateroom and no more than four people sharing a bathroom. There also will be nine additional berths for scientists. Noise and vibration throughout the drillship will be significantly diminished compared to the ODP days. Better recreational facilities, a new mess area, and increased office and conference spaces will also improve the onboard habitability.

The timeline for the ship conversion is short. During summer 2006, a shipyard will be selected, and the conversion will take place between the third quarter of 2006 and the second quarter of 2007. Finally, in August 2007, the U.S. SODV will begin drilling operations for IODP.

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Related Web Link

http://www.joialliance.org/MREFC/

Figure Credit

Porthole photo by Robert Burger, JOI.
Drillbit photograph courtesy of the Ocean Drilling Program.

Data Management in the IODP

by Bernard Miville, Emanuel Soeding, and Hans Christian Larsen

The Challenge

The Integrated Ocean Drilling Program (IODP) is challenged to develop a program-wide, state-of-the-art data management concept enabling the receipt and handling of scientific data from three different IODP drilling platforms, legacy data from the Ocean Drilling Program (ODP) and the Deep Sea Drilling Project (DSDP), and post-drilling scientific data published in the open literature. Data collected from boreholes and cores include various types of measurements, images and downhole logging data and ranges in nature from microbiology and micropaleontology to geochemistry and physical properties. The data underpin research spanning from fundamental geodynamics and solid Earth cycles over biological evolution, the deep biosphere, paleoclimatology, and hydrosphere–lithosphere interaction. A proper data management system for the future must present these highly diverse data in a transparent way through a single user-interface and provide links to related data bases (Fig. 1). Accomplishing these goals will be a major step forward not only in ocean drilling, but ultimately also in the broader field of Earth sciences. To be successful it requires strong coordination and involvement of the IODP science and drilling operators and eventually strong integration with related initiatives in the broader community.

The IODP Management International (IODP-MI) is charged with providing the overarching IODP data portal and integrating all data provided by the different platform operators and eventually by individual researchers. The IODP-MI is also taking a lead in establishing a Web-based system for scientific drilling proposals and an all-digital data bank for pre-drilling site-survey data. In all of these efforts, actual programming work is outsourced as much as possible to interested partners in the community or via commercial vendors identified through a process of competitive bidding.

Scientific Earth Drilling Information Service—SEDIS

The key to providing easy and seamless top-down data community access from a web of distributed operator databases is defining program-wide standards in data and metadata collection. The Scientific Earth Drilling Information Service (SEDIS) data management system that the IODP-MI is pursuing builds on such metadata and will provide a unique entry point to locate all IODP and legacy data. The ISO 19115 metadata standard has been chosen in anticipation of its widespread future use.

SEDIS will be developed in close cooperation with the IODP operators and other Earth science initiatives, and will

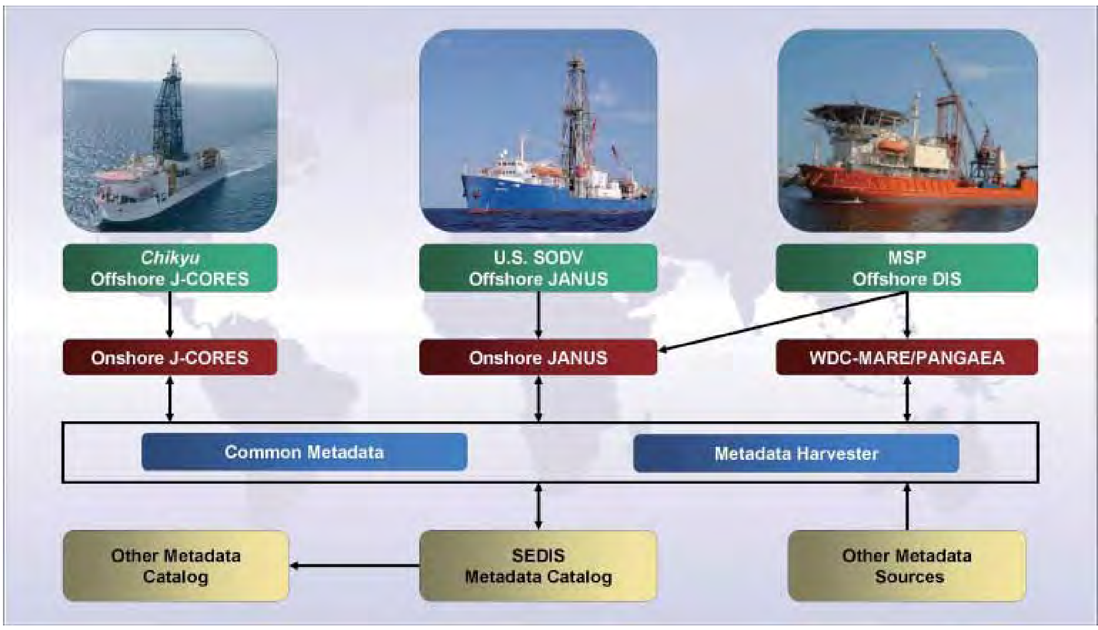

Figure 1: IODP data and metadata flow for SEDIS.

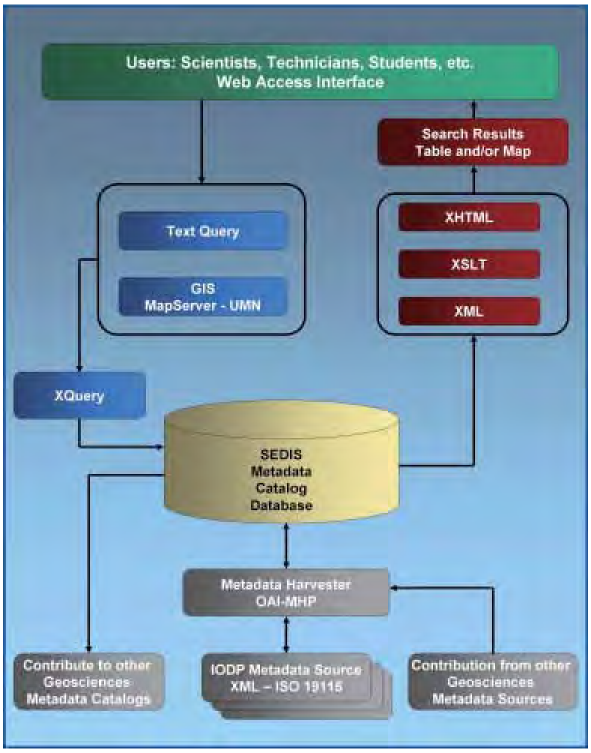

Figure 2: SEDIS structure planned for Phase I.

be aimed at the broadest possible interoperability of both data and related data manipulation and visualization tools. International standards and open-source components will be used whenever possible. The development of SEDIS will take place in three phases during 2006–2008. Phase I will concentrate on creating a searchable catalog of all IODP and ODP drilling and logging data stored in the primary databases maintained by the IODP operators. A competitive request for proposals is planned for the second quarter of 2006, and implementation will happen in early 2007.

SEDIS Phase I will allow the user to discover, via database search queries and geographic information system (GIS) techniques, what type of measurements are available for specific drill sites and holes. It will also provide links to the data itself, independently of acquisition, storage location or archival status (Fig. 1). This concept allows the data to be stored in distributed systems while offering centralized access. The use of internationally recognized metadata standards will also allow other geoscience portals to harvest IODP metadata and make it more easily visible and available to researchers outside the IODP community.

SEDIS Phase II is intended to closely tie together the program data, program publications and post-drilling data from core samples, the boreholes, and any related experiments. SEDIS will not store publications but will have the capability to do searches based on keywords and Digital Object Identifiers (DOI) for the required information within the underlying program databases. Most IODP post-drilling research will be published in the open peer-reviewed literature, and the system will also need to access as broadly as possible all program data associated with such publications.

In SEDIS Phase III, advanced tools enabling users to search, extract, and combine data as well as to integrate advanced data visualization and mapping tools are to be developed. Implementation likely will involve other organizations and projects that have developed certain specialized applications (e.g. CHRONOS, CoreWall, Stratigraphy.net and others). The goal is to enable the user to extract any part or combination of data from any drilling expedition, and to provide methods to process these data with online viewing, mapping, and manipulation tools from a single entry point. Figure 2 provides an overview of the SEDIS structure.

Core Samples, Drilling Proposals and Data in Support of Drilling,

There are three IODP core repositories: Bremen (Germany), College Station (Texas, U.S.A.) and Kochi (Japan). To facilitate core sampling and tracking sample history and sample availability, an IODP Sample Materials Curation System (SMCS) is targeted for implementation during 2007. The SMCS will provide single Web-based access for sample requests and sample management. Sample requests will be submitted through the SMCS frontend to the appropriate curator and recorded in the SMCS database for user and curator reference. It is to be developed in close collaboration with the drilling and IODP core repository operators. Information about physical samples in the SMCS will eventually be linked to sections within the expedition publications and the metadata in the SEDIS via DOI, interlinking all the information.

In 2005 a new proposal database for IODP drilling proposals and a new fully electronic Site Survey DataBank (SSDB) were initiated. Both projects move proposal and data submission to an all-digital stage, making it easier to upload, access, and manage proposal information and site-survey data. The proposal database is still under development and is expected to be online by mid-2006. The SSDB is in operation, but new functionality is still being added (see article on page 40 in this journal).

Authors

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Related Web Links

http://sedis.iodp.org
http://www.iodp.org/data-management/

Recent Advances in Research on Terrestrial and Marine Sequences From the Mid-Cretaceous Oceanic Anoxic Events (OAEs)

by Reishi Takashima, Pitambar Gautam, and Hiroshi Nishi

The Cretaceous period was a time of greenhouse climates characterized by sea-surface temperatures of at least 15°C warmer than today. During the climax of Cretaceous warming, anoxic conditions in the oceans expanded globally, resulting in accumulations of organic-rich sediments (so-called black shales). These events, called Oceanic Anoxic Events (OAEs), occurred at least eight times during the Cretaceous period (Fig. 1). Three important aspects make the study of OAEs so interesting: (a) the OAEs acted as a global thermostat because carbon to a large extent was sequestered in the sediments (black shales) instead of adding to the CO_2 content of the atmosphere, (b) the expansion of anoxic conditions in the oceans caused mass extinctions of marine biota, and (c) most hydrocarbon source rocks from the Cretaceous formed under anoxic oceanic environments.

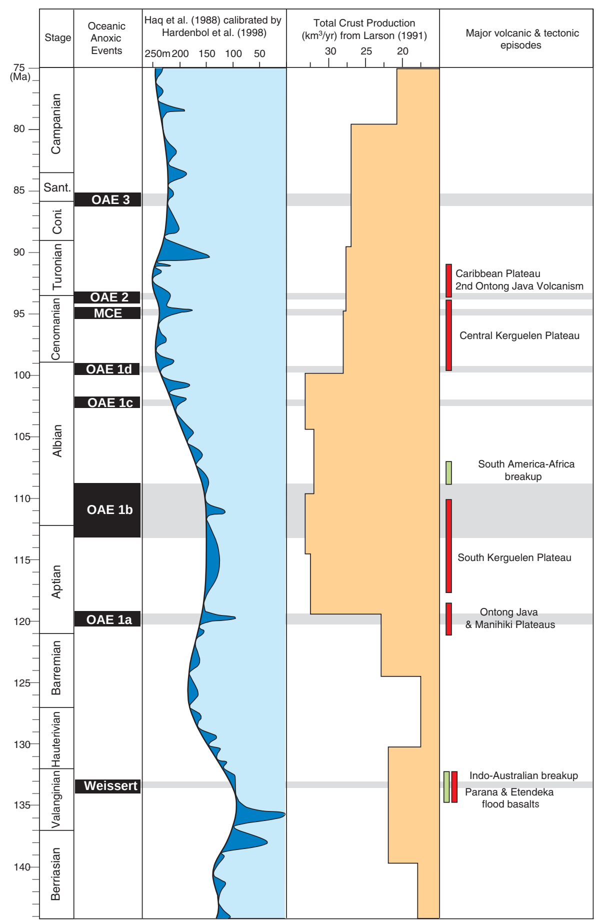

Figure 1. OAE horizons, sea level changes and production rate of the oceanic crust.

The discovery of the Cretaceous OAEs (Schlanger and Jenkyns, 1976) was an important achievement of the Deep Sea Drilling Project (DSDP), and understanding Cretaceous OAEs is one of the major scientific objectives of the extreme climate initiative outlined in the Integrated Ocean Drilling Program (IODP) Initial Science Plan. To support this initiative a symposium entitled "Recent Advances in Research on Terrestrial and Marine Sequences from the mid-Cretaceous Oceanic Anoxic Events (OAEs)" was held at Hokkaido University, Sapporo, Japan during 21–23 September 2005. The symposium was hosted by the 21st Century Center of Excellence (COE) Program for the Neo-Science of Natural History, and was organized by Hisatake Okada (COE program leader) and Hiroshi Nishi. Thirteen talks were given, eight by invited speakers, and eight posters dealt with land and marine OAE sections shown in Figure 2. Discussion of land sections concentrated on two types of regions: (a) those with black shale, such as Umbria-Marche Basin, Western Interior, Northwest German Basin and Vocontian Basin; and (b) those devoid of black shale, such as the Anglo-Paris Basin, Yezo Basin and Great Valley Basin. For regions of the first type, the group discussed results of high-resolution studies on a millimeter to centimeter scale of microfossils and organic and inorganic geochemical analyses. It was demonstrated that the black shales in continental interiors and on the continental margins were deposited during marine transgressions, with individual laminae corresponding to the increased runoff from the land areas. For regions of the second type, attention was paid to the integrated analysis of macro- and microfossil and carbon isotope stratigraphies for identification of the precise horizons of OAE levels. Although fully anoxic environments apparently did not develop in these basins, clear evidence of remarkable faunal turnover, involving various taxa, was shown at the OAE levels. Studies of the marine sections dealt with core data mainly from Blake Nose (ODP Leg 171B) and the Demerara Rise (ODP Leg 207). Both sections have yielded extremely well-preserved calcareous fossils suitable for isotopic geochemical analysis. Oxygen and carbon isotope data on planktic and benthic foraminifers revealed the development of two types of water-column structures during OAEs. The first type, represented by collapse of the vertical structure of the water column caused by abrupt deep-water warming, is recognized in OAE2 and OAE1d. Such OAEs are characterized by increased primary production, drowning of carbonate platforms and worldwide deposition of black shale. The second type corresponds to intensified water-column

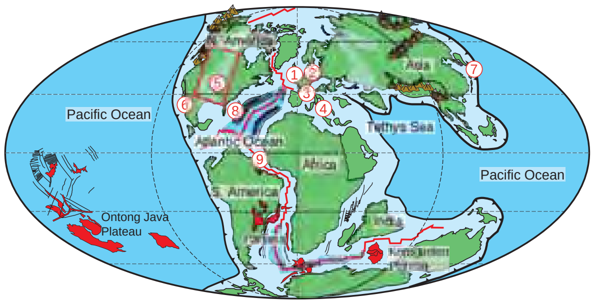

Figure 2. Study areas (presenters) considered during the OAE Sapporo Symposium.
1. Anglo-Paris Basin (A.S. Gale), 2. NW-German Basin (J. Mutterlose), 3. Vocontian Basin (R. Takashima; K. Nagai et al.; K. Okano et al.), 4. Italy (J. Kuroda et al.), 5. Western Interior (M. Leckie et al., B. Sageman et al.), 6. Great Valley (A. Fernando et al., T. Tomosugi et al.), 7. Yezo Basin (H. Ando; K. Kurihara & F. Kawabe), 8. Blake Nose (B. Huber et al., J. Erbacher et al.), and, 9. Demerara Rise (J. Erbacher et al., A. Bornemann & R.D. Norris; P.A. Meyers & J.–G. Yum; A. Forster et al.)

stratification triggered by an increase in the surface water temperature or a decrease in salinity (e.g., Pacquier level of OAE1b).

One question related to OAEs focuses on identifying the factors responsible for the increased runoff observed in the land sections and the warming of surface and deep water observed in marine sections. The emplacements of large igneous provinces (LIPs) are thought to be the most plausible trigger because they occurred contemporaneously with each OAE (Larson, 1991); however, the emplacement positions of LIPs, their depths of eruption, the amount of magma production, and the composition of the magma were highly variable. Moreover, there still are no adequate data that allow scientists to deduce the relationship between the formation of LIPs and development of the anoxic water column in the ocean.

During the concluding session of the symposium, the activities of the IODP and the Japan Drilling Earth Science Consortium (J-DESC) were introduced, and potential IODP drilling sites directed at Cretaceous OAE research were discussed. To understand how the OAEs occurred requires

Figure 3. Outcrop of the OAE2 horizon in the Yezo Group, Hokkaido.

knowledge of the thermal structure of the ocean during those greenhouse periods. As reliable ocean temperature data for pre-Aptian times and high-latitude regions are still inadequate, these aspects need due consideration in the future. The Falkland Plateau was recommended as the most appropriate target for a future IODP drilling campaign.

The symposium ended with an one-day field trip to the OAE2 section in Hokkaido (Fig. 3). This section bears evidence of a prominent positive excursion in the $\delta^{13}C$ of organic matter, weakened bioturbation, and occurrence of abundant pyrite, although typical black shale is absent.

Further information about the talks and future directions can be obtained from the links mentioned below.

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Related Web Links

http://nature.sci.hokudai.ac.jp/index_e.html

http://nature.sci.hokudai.ac.jp/symposium/050921/OAE-Sapporo-abstracts.pdf

Core–Log–Seismic Integration—New Scientific and Technological Challenges

by Philippe Gaillot, Hideki Masago, Moe Kyaw Thu, and Hisao Ito

Introduction

"Core-Log-Seismic Integration: New Scientific and Technological Challenges," a technical workshop addressing critical issues in scientific drilling and coring was held in Tokyo, Japan on 3–4 October 2005. The workshop was organized by the Center for Deep Earth Exploration – Japan Agency for Marine-Earth Science and Technology (CDEX-JAMSTEC) and the Japan Drilling Earth-Science Consortium (J-DESC) following an initiative discussed during the February 2005 IODP Scientific Measurements Panel (SciMP) meeting.

One aim of this workshop was to promote discussions between scientists who use core, log, and seismic data to address academic or industrial problems and those who are developing new databases, data handling procedures, and visualization technologies. Goals of the workshop included reviewing and exploring extant methods for processing and analyzing core, log, and seismic data, with significance placed upon problem solving using a variety of methodologies and approaches to core-log-seismic integration. Forty scientists from Asia, North America, and Europe attended the meeting. The topics discussed included (1) the different approaches to core-log and core-log-seismic integration concerning theoretical aspects such as scaling problems, modeling, or petrophysics or technologies such as engineering or IT, (2) the possibilities for testing these methods using individual case studies including marine, coastal, and continental environments, and most important, (3) comparison and exchange of methods and views between researchers working in related or complementary fields. The workshop program, proceedings, and most of the presentations can be accessed at http://www.jamstec.go.jp/chikyu/jp/news/nw_050712.html. The major items from the discussions are summarized as follows.

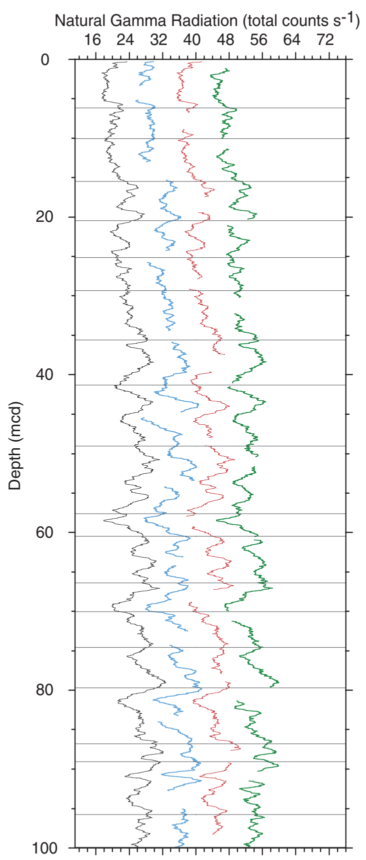

Figure 1. Example of spliced stratigraphic section: Natural gamma radiation data from ODP Site 1146 (black) was compiled by splicing the individual core logs (blue, red, green, Wang et al., 2000).

Information Exchange

Core-log-seismic integration methodology and practice lie intrinsically at the interface between multiple scientific and technical fields of inquiry, thus requiring a major effort (1) to promote better documentation of methods, assumptions, tools, resolution, and limitations inherent in each newly acquired data set and (2) to address better the problems associated with parallel measurements acquired at different scales or resolution, often using different equipment or tools, or relying on different principles and assumptions. A clear example of potential problems associated with these kinds of overlaps is the measurement of porosity. Porosity can be measured or derived from discrete samples (moisture and density measurement vs. Hg or BET porosities), neutron-porosity logs, density logs, resistivity logs or analysis of downhole imagery, and all reported in any database as porosity, in the same units; however, these measurements of porosity can have vastly different values depending on methodology, even within the same core interval. It was proposed that a working group including industry should address a discipline-wide descriptive terminology for standard measurement techniques and results.

Depth Issues

A critical issue in core-log integration is the question of standardizing depth positioning and depth accuracy of collected data sets. This issue generated extensive discussion and debate among the workshop participants, who clearly identified the need for standard definitions and processing procedures to generate depth scales for the geological and geophysical aspects of drilling, coring, and logging.

Geological measurements, including cores, cuttings, and gas or mud logging operations, must be calibrated accurately and efficiently. Specifically, the conversion of incident time (for mud logging, cuttings, and gas logging data) and the conversion of curation depth (for cores and samples) must be undertaken to derive accurate and internally consistent depth values (Fig. 1).

Geophysical measurements, including wire-line logging, logging-while-drilling, vertical-seismic-profiling (VSP), seismic-while-drilling, and regional 2-D and 3-D seismic surveying, must be converted from either rig-floor depth or seismic two-way traveltime into the final depth reference frame (Fig. 2). The role of VSP in seismic calibration of depth scales was widely emphasized and led to discussions of four issues:

1. The receiver technology (i.e. frequency range)
2. The nature of the source (e.g., borehole, seafloor, sea-level, air gun, vibration, explosion)
3. The coupling between formation and seismic tool in complex environments
4. The role of offset VSPs and multi-component tools in investigation of S-waves and acoustic/seismic anisotropy

These discussions gave rise to a series of complementary proposals for depth-processing procedures dependent on data type and quality that will be reported separately.

New Technology: Initiatives and Needs

In addition to the depth issue, presentations and discussions of new technological developments and challenges focused on data acquisition in extreme environments and integration of a wide array of new data types and formats. Examples of such developments included intensive feasibility testing of logging-while-coring systems potentially equipped with geophones (for check-shot surveys while coring) and development of new downhole probes for microbiological and geochemical investigations of the deep biosphere.

Additional discussion with respect to core-log-seismic integration focused on the problem of *in situ* conditions versus laboratory core or sample measurements. Challenges arose regarding the differences between, for example, acoustic properties like P- and S-wave velocities, Q-factor values, or anisotropy determined from sample or core measurement as opposed to downhole *in situ* seismic velocity or attenuation values.

Depending on scientific objectives, recommendations were devised for a review of available equipment and expertise (specifications vs. needs) and adoption of an optimal strategy (selection of samples, on-site vs. delayed investigations).

Proposal for a Natural Laboratory

A proposal was made to dedicate one or several well-characterized test site(s) encompassing a wide variety of geological settings for educational and methodological uses. At such a site(s), experiments, methods, and tools could be calibrated and tested, providing references for further study and a basis for continued progress. Also, a competence network for consultation, feedback, advice, and interaction was put in place.

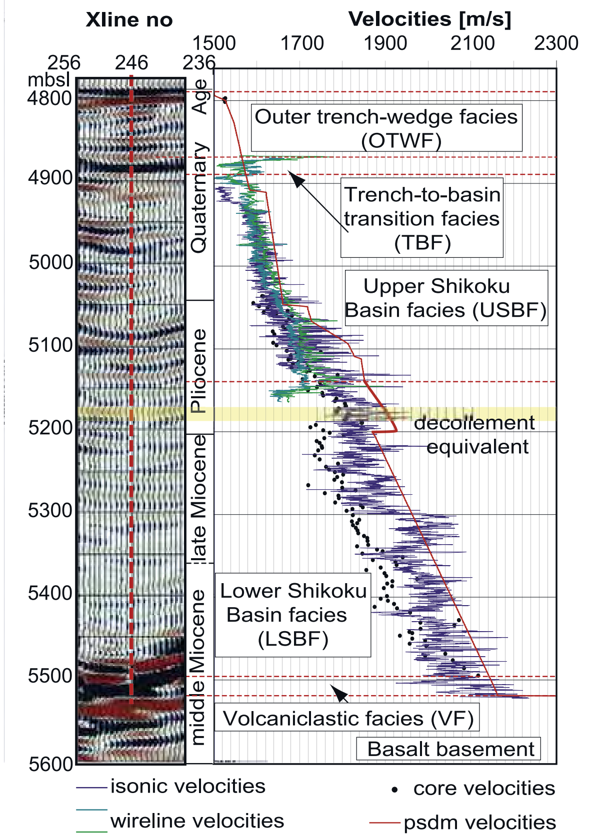

Figure 2. Prestack Depth Migration PSDM depth section across ODP Site 1173 (left); comparison of velocities obtained from PSDM with velocities from cores and logs at Site 1173 (right, from Pisani et al., 2005).

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Related Web Links

http://www.jamstec.go.jp/chikyu/jp/news/CLSI/program.html

http://www.jamstec.go.jp/chikyu/jp/news/nw_050712.html

3-D Seismic Reflection Imaging Workshop 2005—Opportunities for IODP Site Survey Collaboration

by Gregory F. Moore and John C. Mutter

The capability of the U.S. academic marine geoscience fleet will be significantly improved with the addition of the research vessel *Marcus G. Langseth* in 2006 (Fig. 1). The *Langseth,* which until recently was collecting commercial quality 3-D seismic data for WesternGeco as the *Western Legend,* will provide seismic acquisition capabilities well beyond those currently available to U.S. scientists by allowing the systematic collection of high-quality, 3-D seismic data in a wide variety of environments around the globe. To date, a small number of 3-D seismic data acquisition cruises have been run in the U.S. academic community using single streamer vessels acquiring 3-D grids by multiple closely spaced lines. This method of acquiring 3-D data is very inefficient, and limitations such as minimal streamer navigation cause data quality to be less than desirable. The *Langseth* will make it possible for the academic community to acquire 3-D seismic data in a time-efficient and cost-effective manner and of comparable quality to industry exploration.

In the commercial sector the introduction of 3-D seismic acquisition is credited as one of the advances in technology that produced the three most significant increments in oil field discovery rate in the last fifty years. Best practices for 3-D seismic data acquisition are now well understood and available in extensive literature, and processing software for 3-D data is now readily available and very stable. Moreover, there is much experience in the exploration industry on the processing and analysis of 3-D data sets. With the acquisition of the *Langseth,* the academic sector is poised to take advantage of these developments and gain a similar major advance in scientific discoveries. At the same time, because of the very limited experience in our community with the 3-D approach, many scientists are not fully apprised of the range of new problems that become accessible to study.

Figure 1. Model of the *Marcus G. Langseth* is a 235 ft, 2578 gross ton research vessel which is owned by the National Science Foundation and operated by Lamont-Doherty Earth Observatory of Columbia University. The *Langseth* replaces the *Maurice Ewing,* which has just ended a distinguished career (picture from http://www.ldeo.columbia.edu/res/fac/oma/langseth/).

Against this background, a group of ninety-one scientists from around the world gathered at the Lamont-Doherty Earth Observatory (LDEO) on 8–10 September 2005 to discuss 3-D Seismic Reflection Imaging. The workshop, funded by the U.S. National Science Foundation (U.S. NSF), emphasized the great breadth of the new and emerging areas of scientific inquiry that can be uniquely tackled using 3-D imaging, including high-resolution approaches, and the participants discussed possible 4-D applications as well. The questions that were explored included those fundamental to mid-ocean ridge studies, continental margins, and Integrated Ocean Drilling Program (IODP) objectives.

A series of presentations by academic and petroleum industry speakers focused on how successes in the petroleum industry might be used as models for academic research. Numerous examples of 3-D images similar to those shown in Fig, 2 were presented to show the level of detail that can be achieved for defining the morphology and evolution of slope, channel, and deep-water sedimentary environments, as well as structurally complex regions (Posamentier, 2003, 2004). State-of-the-art seismic interpretation software was used to demonstrate how quickly and accurately horizons and faults can be interpreted from 3-D seismic cubes. Other industry speakers illustrated the recent advances in 4-D surveys and improvements in marine acquisition that allow better deghosting of source signatures.

Several academic speakers discussed lessons learned from academic 3-D seismic programs in accretionary prisms and spreading centers, and they introduced the use of seismic reflection data in the relatively new field of seismic oceanography (Holbrook et al., 2003). Because academic surveys have recently encountered challenges in obtaining clearances and permits, a summary was presented to make everyone aware of their requirements, lead times required to obtain permits, and other issues. A joint presentation focused on new results relating to seismic sources and their effects on marine mammals. In addition, recommendations and requirements for 3-D site surveys for the IODP were discussed.

Major goals of this workshop were to inform academic marine scientists of the capabilities of the *Langseth* and to educate them on how to design 3-D surveys on it. Presentations by LDEO marine office personnel and a half-day seismic acquisition clinic achieved these goals by presenting details of the Langseth's acquisition capabilities and how they can be used to acquire fully imaged 3-D data volumes.

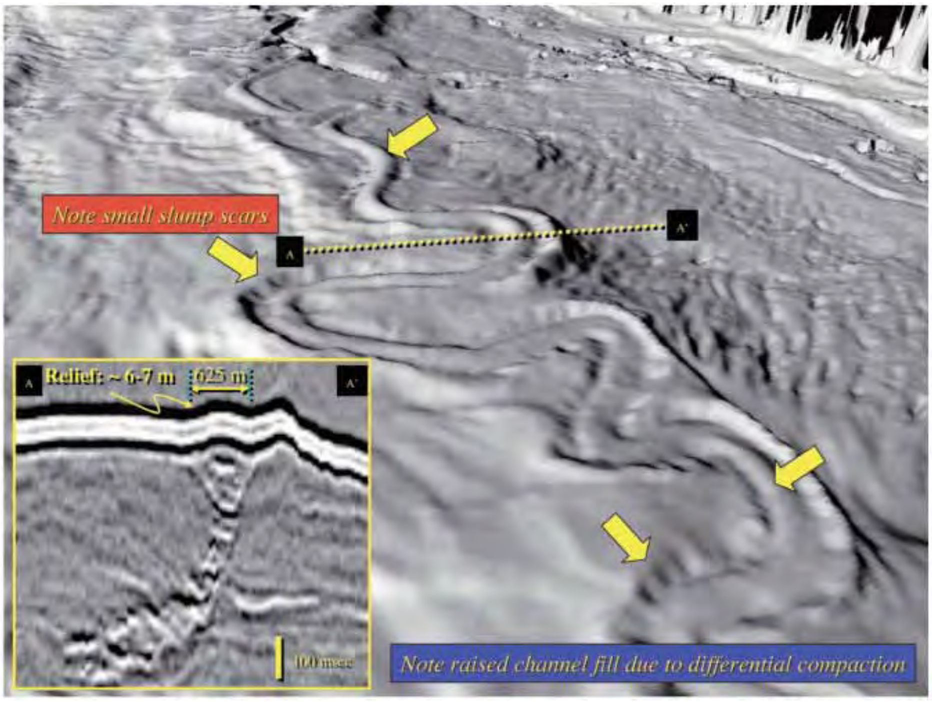

Figure 2. Illuminated and perspective views of the surface acquired by 3-D seismic imaging. The elevated aspect of the channel thalweg with its associated levees becomes quite apparent. The inset depicts a cross-section through the channel showing that the thalweg is associated with high reflection amplitude, indicative of a higher acoustic impedance relative to the surrounding mud and therefore suggesting the presence of sand. After Posamentier (2003) and Posamentier (2004).

A concluding half-day panel discussion focused on new opportunities for 3-D seismic acquisition and ways to make the broader academic community aware of our new capability to acquire 3-D seismic data. Many workshop attendees felt that a new paradigm for 3-D acquisition and interpretation is necessary to ensure the long-term success and growth of the field. The workshop agenda, including a list of participants is online at: http://www.ldeo.columbia.edu/events/workshops/3Dseismic/.

As a follow-up to discussions at the workshop, we would like to point out the opportunities for diversifying funding sources and expanding the community through international cooperation. Specifically, the IODP has already seen an increased need for 3-D seismic surveys in support of riser drilling on the new Japanese drilling vessel *Chikyu*. A large commercial 3-D seismic program has been jointly funded between the U.S. NSF and the Japanese ship operator, the Center for Deep Earth Exploration (CDEX) of the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). To date, only a single riser drilling proposal has been recommended for scheduling, but many more are either being considered now or will be considered in the future. Each riser hole will likely require 3-D data, and several planned riserless programs will also benefit from 3-D surveys. CDEX hopes to continue jointly funding these 3-D programs. This should be seen as an excellent opportunity for international scientific collaboration.

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Related Web Links

http://www.ldeo.columbia.edu/events/workshops/3Dseismic/index.html

http://www.ldeo.columbia.edu/res/fac/oma/langseth/

ICDP Workshop on the Emerging Modern Aerobic Earth System

by Victor A. Melezhik and Aivo Lepland

An ICDP workshop on “Archaean-Palaeoproterozoic Transition: Emerging Modern Aerobic Earth System,” was held in Trondheim, Norway on 25–29 September 2005. The Geological Survey of Norway (NGU) organized and supported the workshop with funding from the ICDP.

The concept of studying a critical interval in Earth’s history when the biosphere and geosphere experienced global scale changes was discussed during the 2004 Nordic Academy for Advanced Studies field course held in north-western Russia. An international group of scientists deliberated in the field and decided to propose a scientific drilling project to analyze the best preserved rock record of the hallmark events that typify the Archaean–Palaeoproterozoic (2500–1900 Ma) transition. Subsequent field studies identified potential drilling sites and specific target intervals and objectives, and focused discussions during the ICDP workshop on issues associated with preparing a full drilling proposal on the Russian side of the Fennoscandian Shield.

Figure 1. Simplified geological map of eastern Scandinavia showing position of planned drillholes (proposed Sites 1–13, in red).

Twenty-eight researchers from nine countries took part in the meeting, including representatives of the ICDP panels and the Federal Agency on Management of Natural Resources of the Russian Federation (ROSNEDRA). The Russian part of the Fennoscandian Shield was selected as a principle area for scientific drilling (Fig. 1) because it is characterized by exceptionally well preserved 2500–1900 Ma-old rocks compared to other regions in Australia, South Africa, and North America where rocks of similar age occur. Of the twelve global events that define worldwide environmental upheavals in the Archaean–Palaeoproterozoic transition (Fig. 2), nine are best developed in Russian Fennoscandia (shown in red), one is equally present in all four continents (shown in green), one is poorly developed (shown in blue) in Fennoscandia, and only one, a 2500-Ma banded iron formation event (shown in white), is missing in the Fennoscandian Shield. The workshop participants agreed that research of this key stage in Earth system evolution would focus on three main objectives: (i) to establish a well-characterized, well-dated, well-archived section for the period 2500–1900 Ma; (ii) to document the changes in the biosphere and the geosphere associated with the rise in atmospheric oxygen; and (iii) to develop a self-consistent model to explain the genesis and timing of the establishment of the modern aerobic Earth system. Workshop participants of breakout sessions made up six groups concerned with logistics and on-site geologists, depositional frameworks and basin analysis, stable isotopes, radiogenic isotopes, biosignatures, and palaeomagnetic studies. Each group investigated a series of designated biogeochemical events and processes. The questions of what, why, and where to drill were discussed dynamically throughout the entire workshop. The discussions also addressed how to define the knowns and unknowns of the various events and processes, including mantle evolution, major perturbations in the global carbon, phosphorus, and sulfur cycles, seawater evolution, the Great Oxidation Event, chemical biomarkers, recycling of organic matter, the oldest significant petroleum generation known, the earliest glaciations and their drivers, and palaeolatitudes and palaeomagnetic field reversals.

To obtain the best non-weathered and non-contaminated material recording the major global changes in the terrestrial biosphere and geosphere during this time interval, the workshop participants discussed and selected thirteen drilling sites (4000 m in total) in three geographically distinct regions (Fig. 1). Drilling operations will be performed simul-

Figure 2. Major Early Palaeoproterozoic events (see explanation in text).

taneously in these areas by hiring local drilling crews. Multiple funding sources including Worldwide Universities Network, national and international funding agencies, and Norwegian and British oil-based companies were discussed. The NGU, Scottish Universities Environmental Research Centre, and Westfälische Wilhelms-Universität will contribute substantial financial support for establishing detailed archived (logged and photographed) and analyzed (thin sections, major and trace elements, $\partial^{13}C_{carb}$, $\partial^{18}O_{carb}$, $\partial^{34}S_{sulphide}$) drillcore sections to be housed at the NGU drillcore storage facility.

Discussions took place about links with NASA astrobiology groups, relevant active International Geoscience Program (IGCP) and ICDP projects as well as outreach to the general public and education via Web sites and popular newspaper articles. The potential for applied aspects of the research program were recognized; issues included obtaining data useful to the petroleum industry (oil migration distance, chemical and isotopic transformation between *in situ*, migrated, and spilled petroleum that occurred as early as 2000 Ma ago) and to nanotechnology (occurrence, abundance, and distribution of natural fullerenes in Karelian shungites, a metamorphic bitumen rock).

The creative mood of the workshop resulted in a new project acronym FAR–DEEP, which stands for: Fennoscandian Arctic Russia – Drilling Early Earth Project. The participants were encouraged to move ahead and were further promised support by the ROSNEDRA representative. The project core group is now set to prepare a full drilling project proposal for submittal to the ICDP in 2006.

Authors

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Related Web Link

http://far-deep.icdp-online.org

Upcoming Workshops

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ICDP Workshop Potrok Aike Lake Sediment Archive Drilling Project (PASADO)

16–19 March 2006, Río Gallegos, southern Patagonia (Argentina)
More information at http://www.salsa.uni-bremen.de

An international research group is planning the research initiative "Potrok Aike Lake Sediment Archive Drilling Project" (PASADO) within the framework of ICDP. The intended project will address several key issues related to the evolution of maar craters, quantitative climatic and environmental reconstruction, fire history, tephra and dust deposition and palaeosecular variation of the Earth's magnetic field for the last several glacial to interglacial cycles. Moreover, dust and tephra records will provide links to marine sediment archives and ice cores. Obtained reconstructions of climate variability will be compared to climate simulations from global circulation models (GCM) to detect signals of climatic forcing.

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ICDP Workshop Scientific Drilling of the Snake River Plain

18–21 May 2006, Twin Falls, Idaho, U.S.A.
More information at http://www.usu.edu/geo/hotspot/

The Snake River Plain represents a world-class example of active mantle plume volcanism in an intra-continental setting. Because it is young and tectonically undisturbed, the complete record of volcanic activity can be sampled only by drilling. The preliminary scientific plan is to core a series of 4-6 drill holes along the axis of the eastern and western Snake River Plain in order to study the geochemical and stratigraphic variations in plume-related volcanism in space and time.
Interested parties should submit the application form available from the Web site to John Shervais at shervais@cc.usu.edu.

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ICDP Workshop Lake Van Drilling Project - PaleoVan

6–9 June 2006, Van, Turkey
More information at http://www.paleontology.uni-bonn.de/

Lake Van in Turkey is an excellent paleoclimatic archive comprising long high-resolution annually laminated sediment records covering several glacial-interglacial cycles. The lake is situated on the high plateau of eastern Anatolia. It is the fourth largest of all terminal lakes in the world and contains highly alkaline water.
Specific goals of the proposed PaleoVan project are to reconstruct the following: (1) Paleoclimate development in a sensitive semiarid region based on transfer functions (pollen, stable isotopes) and modeling; (2) Climatic variability in space and time based on teleconnection with other high-resolution records such as ice cores and marine sequences; (3) Dynamics of lake level fluctuations and hydrogeological development; (4) Formation and age of Lake Van; (5) History of volcanism and volcanic activities based on tephrostratigraphy; (6) Variations of the geomagnetic field; (7) Tectonic, paleoseismic and earthquake activities; (8) Interactions between man and environment since prehistoric time.
Registration: All participants are requested to register through the registration form from the Web site to Thomas Litt (t.litt@uni-bonn.de). The registration deadline is 31 March.

InterMARGINS

InterMargins Workshop on Climate-Tectonic Drilling in Southeast Asia

5–7 June 2006, Kochi, Japan
More information at http://www.abdn.ac.uk/%7ewpg008/RedRiverWorkshop.html

Interactions between the solid earth and the global climate system are a frontier area for ocean and Earth science research and have been highlighted as a focus area for the IODP. Of all the possible links between these earth systems, the proposed associations between the elevation of the Tibetan Plateau and the strength of the Asian monsoon are some of the most dramatic and controversial.

The workshop will explore the potential of using the Red River system as a means to understanding climate-tectonic interactions in Cenozoic Asia. The Red River is situated on the southeastern part of the Tibetan Plateau and is believed to have once been a much larger system that was reduced through time as drainage capture transferred the original headwaters to other major rivers in Asia. Since then, its drainage system has been influenced by the Asian Monsoon that is considered to be linked to Tibetan surface uplift. If these capture events can be dated, then these can be used to constrain the elusive uplift of Tibet.

For more information about the workshop, visit the Web site and contact the conveners.

Four IODP Workshops Announced for Summer/Fall 2006

More information on all IODP workshops can be found at http://www.iodp.org/workshops/

IODP-ICDP Workshop on Fault Zone Drilling: Developing a Global Perspective

23–26 May 2006, Miyazaki, Japan

Application deadline: 21 February 2006

The IODP and the ICDP announce a joint Workshop on Fault Zone Drilling to address the science and technology of drilling, sampling, testing and long-term borehole monitoring of active faults. The objective of this workshop is to bring together the active team members of all fault-zone drilling projects for an open and detailed exchange of results, ideas, and experiences, fostering cooperation and synergy in the interpretation of findings, experiment design and technology development. Participants will be invited by the steering committee, with preference given to applicants from IODP and ICDP member countries. Some invitations will be reserved for advanced level students and early career scientists.

IODP Workshop on Continental Breakup and Sedimentary Basin Formation

Tentative time and location: August–September 2006, Europe

Goals of this workshop are to formulate the key questions regarding the processes of continental rifting through the initiation of normal seafloor spreading; to compile a summary of the potential role for ocean drilling in addressing each key problem; and to come up with a global list of likely areas to be considered for drilling by IODP in the next decade to address these key problems. The studies should include assessments of what data exist and what data would be needed to make consideration for IODP drilling viable, as well as how and when these data might be acquired. The workshop should also address the following concerns: what combination of IODP drilling platforms (non-riser vessel, riser vessel operating with riser, riser vessel operating without riser, or special purpose platforms) are likely to be needed, and what general drilling strategies should be employed to address key problems.

Mission to the MOHO—Formation and Evolution of Oceanic Lithosphere

Tentative time and location: 6–9 or 10–13 September 2006, Portland, Oregon, U.S.A.

The goal of drilling a complete section through the oceanic crust and into the upper mantle has been reiterated throughout the history of ocean drilling and is embedded in the IODP Initial Science Plan as the "21st Century Mohole" initiative. Inherent in this goal is the tripartite need for a clearly defined scientific strategy, for parallel development of essential operational experience, and for phased development of the essential improved technologies, all of which are essential for the initiative to be fully realized.

This workshop will outline the scientific framework for a Mission to the Moho that will guide IODP's 21st Century Mohole initiative for a decade or more. The emphasis of the workshop is on the "Road to the Moho"—the scientific and engineering objectives and activities, beginning immediately and with available technology, that will lead us to the ultimate goal of a single deep "Mohole".

Please refer to the IODP web site for the latest information on how to register and attend.

IODP/JOI Workshop on Exploring the Deep Biosphere with the IODP

Tentative time and location: late September / early October 2006, Vancouver, Canada

IODP considers the deep biosphere as a special focus area of the program. To encourage research and to stimulate the generation of drilling proposals, a workshop on this subject will be organized in collaboration with the Joint Oceanographic Institutions (JOI). If interested, please monitor the IODP Web site for further announcements and registration procedures on this workshop.

ICDP Workshop on the Magma-Hydrothermal Connection at Mutnovski Volcano

September 2006, Petropavlovsk-Kamchatsky, Russia

More information at http://kamchatka.icdp-online.org

Mutnovski volcano in Kamchatka, Russia and related nearby 700°C hot fumaroles provide an ideal geometry for exploring the magma-hydrothermal connection by drilling. A 62-MWe power plant taps a productive hydrothermal zone that strikes towards the vent of the Mutnovski volcano, 8 km away. Geochemical data support the view that the hydrothermal fluids are derived from the environment of Mutnovski's hot conduit. The workshop will include participants from a variety of disciplines, who will develop the rationale and scientific basis for a formal drilling proposal, site selection criteria, formation of a science team and outline of a proposal for submission to the ICDP and national funding agencies.

Interested researchers are invited to submit a brief summary of their field of research, describing their intended contribution to John Eichelberger at eich@gi.alaska.edu.

InterRidge Polar Ridges Meeting and Workshop

20–22 September 2006, Sestri Levante, Italy

More information at http://www.interridge.org/SCIENCE/IRmeetings/2006PolarRidges.html

The mid-ocean ridges in the polar regions have become increasingly interesting as targets for scientific research during the recent years because of their key role in the formation of mid-ocean ridge basaltic melts, the breakup of continents, the evolution of life on Earth, ocean circulation and climate. To promote these initiatives, InterRidge has organized a workshop to exchange recent results of polar ridge research across disciplines, to formulate first-order questions and to produce a blueprint for the future of Arctic Ridge research. The workshop should also identify the resources and technology needed to conduct the exploration, and may lead to the formation of interdisciplinary projects.

The pre-registration deadline is 1 March 2006. Please visit the InterRidge workshop Web site for the latest information.

SHALDRIL II Sailing With New Sampling Tools

SHALDRIL II, the second leg of a drilling program from the RV/IB *Nathaniel B. Palmer* in the Weddell Sea, Antarctica, will take place from 28 February to 5 April, 2006, and will have several new sampling tools available. The first SHALDRIL cruise in 2005 (see *Scientific Drilling* Number 1, 2005), was a shakedown cruise to test the new drilling rig designed and operated by Seacore Ltd. The soft sediment sampling was very successful. Penetrating the stiff tills that overlie much of the continental shelf in the region proved to be difficult. Thus, new sampling options are developed for this second cruise and new tools were purchased from Drilling, Observation and Sampling of the Earth's Continental Crust Inc. (DOSECC). Five of the six proposed drill sites for the upcoming season are expected to have stiff diamicton overlying the lithified Tertiary section that is of interest to this leg. The sixth target is a 100-m thick section of very pebbly, highly compacted diamicton.

In general, two methods have been devised for coring during this leg. These include coring tools being advanced with a common bottom hole assembly (BHA). This BHA also allows a piggybacked diamond coring system (PBCH) to be used when a more competent formation is encountered. The PBCH is provided by Seacore Ltd. If advancement cannot be made with this BHA, then a more robust BHA with a roller cone bit and center bit is deployed. The center bit must be removed before diamond coring can begin. Details of these coring tools are given below.

The first option surrounds a suite of DOSECC tools that were designed to work within a common BHA. These tools were designed to operate with a drill bit with an internal diameter (ID) of 3.345 inches. However, for SHALDRIL, the bit throat was modified to accommodate a larger 3.85 inch ID. The larger throat will allow the PBCH to be deployed through the common BHA bit should high speed diamond coring be required. Since time on site is limited when drilling in drifting ice, it is important to have multiple tools fitting the same BHA in order to reduce tripping times to change the BHA.

Two coring assemblies and one non-coring tool were developed for this suite of tools to be operated in a common BHA. These include an extended-nose spring-loaded corer and another DOSECC assembly known as the alien corer. The extended nose corer is typically used for sediments after push or piston sampling is exhausted. The alien corer is similar to the extended nose corer but is designed to sample harder material. Due to the larger throat size in the primary BHA bit, it has the same core size as the extended nose corer. Both the extended nose option and the alien have secondary bits that rotate in tandem with the outer BHA bit.

The drill rig on the Nathanial B. Palmer during Shaldrill I in 2005 (by A. Frazer).

As noted above, the first option allows up to three sampling systems to be deployed through the same string. Should rock be encountered at a very shallow depth where the common BHA bit cannot be advanced easily then an altogether different approach can be deployed. This hardware, which was originally developed at ODP and slightly modified for SHALDRIL, uses a robust roller cone bit and a one cone center bit latched into its throat. The center bit is removable via wireline once the BHA has been drilled to depth to allow a clear passage for the PBCH to be initiated. See http://shaldril.rice.edu for updates during the cruise.

Andrill Starts Drilling McMurdo Ice Shelf in 2006

After several years of planning, the follow-up projects to the Cape Roberts Project are underway and scheduled. They will start in October to November 2006 with the McMurdo Ice Shelf Project (MIS). The drilling of the Southern McMurdo Sound (SMS) will follow in October to November 2007. Both projects have been scheduled by Andrill in 2004, and staffing for participation has been completed in 2005.

The key aim of the MIS Project is to determine past ice shelf responses to climate forcing, including variability at a range of timescales. To achieve this aim, one drillhole will sample a 1200-meter-thick body of Plio-Pleistocene glacimarine, terrigenous, volcanic and biogenic sediment that has accumulated in the Windless Bight region of a flexural moat basin surrounding Ross Island in approximately 900 m water depth.

The key aim of the SMS Project is to establish a robust history of Neogene Antarctic ice sheet variation and climate evolution that can be integrated into continental and global records toward a better understanding of Antarctica's role in the past, present and future global system. To achieve this aim, two drillholes (~500 m and ~700 m) will sample a sequence of strata identified on seismic lines and inferred to represent a middle Miocene to upper

Miocene sequence of seismic units that expand basinward. The two drillholes will recover a composite thickness of >1000 m of strata that lie stratigraphically above the lower Miocene section recovered at the top of the nearby Cenozoic Investigations in the Western Ross Sea (CIROS)-1 drillcore, and above the 1400-m composite section recovered by the Cape Roberts Project (CRP) (~34 to 17 Ma).

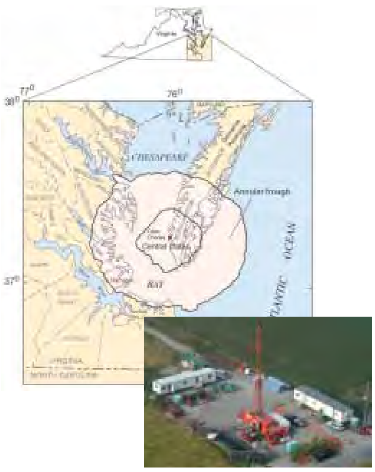
The drilling rig was successfully tested in Canterbury New Zealand in October 2005. The new rig is now headed to Antarctica, shipping out of Lyttleton Harbour in New Zealand. It will be offloaded in McMurdo Station and prepared for drilling in October 2006.

See http://www.andrill.org for the latest information about this project.

Chesapeake Bay Impact Structure Successfully Drilled

The Chesapeake Bay Impact Structure Deep Drilling Project started drilling in the late Eocene Chesapeake Bay crater in September 2005. The goal was to drill a deep hole through the post-impact sediments that cover the crater, through the complete section of impactites, and into the crater floor. The drill site was located at Eyreville near Cape Charles in Northampton County, Virginia, U.S.A., approximately midway between the collapsed central uplift and the crater margin.

Coring began at a depth of 125 m within upper Miocene sediments on 15 September and proceeded at a rapid pace through most of September. The



Location of the Chesapeake Drillsite.

The Chesapeake Drillsite at night.

base of the post-impact sediments was penetrated on 22 September, after coring the upper Miocene through upper Eocene shelf sediments continuously with an excellent (>96%) recovery. Subsequently the coring of the underlying Exmore breccia began. The upper part of the Exmore consists of clasts that represent all pre-impact sedimentary units "floating" in an unsorted muddy sand matrix. The lower part consists of very large blocks of Cretaceous sands and clays. The project faced several drilling obstacles, when rods got stuck and mud circulation was lost in the clay-dominated Exmore sections. This required extensive re-drilling and greatly slowed progress during the first half of October. The drilling was delayed again, when the drill bit encountered an unexpected, 275-m thick block of granite below the Exmore on 26 October. The granite proved to be underlain by a section of suevite, lithic breccia, and blocks of various crystalline rocks. Drilling was continuing in the impactite section at a depth of 1.6 km on 23 November 2005. Coring continued until 4 December reaching a total depth of 1766.3 m.

The project also included a geophysical logging program, collecting natural gamma ray and temperature logs. Core sampling will take place in the second half of March 2006 at the United States Geological Survey National Center in Reston, Virginia., U.S.A. In addition a microbiology group collected samples for DNA analysis, enumeration and culturing for numerous research groups at different institutions. For the International Continental Scientific Drilling Program (ICDP) the Chesapeake Bay drilling is a microbiology pilot project to learn about the needs for subsurface microbiology studies on drill sites. In particular a rigorous sampling protocol is developed, that can reduce potential contamination during sample collection in the dusty on-site conditions.

The project is financially and operationally supported by the ICDP and the U.S. Geological Survey. Drilling, Observation and Sampling of the Earth's Continental Crust Inc. (DOSECC) is serving as the general contractor, and Major Drilling America, Inc. is the contract driller. For more information about the Chesapeake Bay Impact Structure Deep Drilling Project visit http://chesapeake.icdp-online.org.

NELSAM Continues Work in Tautona Mine (RSA)

One major obstacle in earthquake investigations is the lack of direct and near-field observations that are essential for the validation of models and concepts. The Natural Earthquake Laboratory in South African Mines (NELSAM) project significantly reduces this limitation by investigating seismogenic processes at focal depths of earthquakes. This can be achieved drilling in deep gold mines of South Africa, which extend down to 3.6 km below the surface. During October to December 2005 the NELSAM project continued to drill in the Tautona mine in South Africa. After successfully completing the first borehole DAFAULT1, which was drilled at angle of 19° downward across the Pretorius fault to the planned depth of 60 m, it was continuously cored and cased with steel casing. The drilling of DAFAULT2 has been done in December 2005 as well. DAFAULT2 is collinear with DAFAULT1. Together they will host a 120-m displacement meter. Drilling continues with further monitoring holes. In addition 3-component accelerometer systems

NELSAM scientists in the gold mine. From left: Onno Oncken (Germany), Vincent Heesakkers (U.S.A.), Masao Nakatani (Japan), Georg Dresen (Germany), Aleksander Milev (S. Africa), George Kgori (S. Africa), Shaun Murphy (S. Africa), Jonas Machake (S. Africa), Ze'ev Reches (U.S.A.), Joerg Erzinger (Germany)

were installed in two sites. Three additional sites were drilled to 10 m, and accelerometers will be installed in early 2006.

More information about the NELSAM project is available from http://earthquakes.ou.edu/ and http://witwaters.icdp-online.org.

ESSAC Office Moves to Cardiff, U.K.

After two years in Amsterdam, the European consortium for ocean research drilling (ECORD) science support and advisory committee (ESSAC) office has moved to Cardiff, U.K on 1 October 2005. The office is headed by Chris MacLeod, the new ESSAC Chair, and Julian Pearce, who is the acting Chair for an initial period. Federica Lenci from Italy is the new Science Coordinator, maintaining the international flavor of the office. Gilbert Camoin, from CEREGE in Aix en Provence, has been nominated and appointed as the new Vice-Chair. One of the challenges of the new office is to extend outreach to more ECORD scientists as well as to scientists from the new EU member states. Another challenge will be to manage and coordinate the new ESF Programs in an efficient manner to maximize the participation and scientific impact of European scientists in the Program. As a first step the ESSAC Web site has been redesigned and improved to help meet these challenges. Take a look at http://www.essac.ecord.org.

New IODP Sample, Data and Obligation Policy in Place

The new Sample, Data and Obligations Policy for the Integrated Ocean Drilling Program's (IODP) came into effect November 1st 2005. This policy defines user groups of IODP samples and data, moratorium periods for samples and data following the IODP expedition by which they were acquired, rules for publication of results during moratorium periods for researchers involved in the actual IODP expedition and more. The policy also defines the obligations that individuals obtaining samples and data incur. For researchers this is an obligation to publish the results of their research in a peer-reviewed journal publishing in English. In addition, the policy define the roles of certain bodies, list members with contact details. These are the curatorial advisory board, which acts as an appeals board in case of conflicts between the sample requester and the core curator, the editorial review board, which organizes and reviews expedition publications and monitors fulfillment of obligations for an expedition, and the sample allocation committee, which provides the sampling strategy for each drilling project.

The IODP Sample, Data and Obligations Policy might seem to be an administrative monster to many scientists, but traffic rules are complex when written down. The IODP obligations policy serves a number of purposes including the following: (1) provide broad community access to samples and data while providing reasonable protection of expedition participants first right of investigating material; (2) define publication rules during moratorium to ensure fair treatment of all expedition participants; (3) maximize research done, but also ensure sufficient legacy core for the archives; and (4) provide core for display in museums and for teaching. The policy can be accessed online from the IODP Web site at http://www.iodp.org/program-policies/. An old policy for ODP samples obtained before 1 November 2005 can be found in the same place. The new policy applies to all IODP samples regardless of sampling data and to all DSDP and ODP samples sampled after 1 November 2005.

Schedules

IODP – Expedition Schedule http://www.iodp.org/expeditions/

	ESO Operations	Platform	Dates	Port of Origin
1	313 - New Jersey Shallow Shelf	MSP	Summer 2006	TBN
	USIO Operations	**Platform**	**Dates**	**Port of Origin**
2	Equatorial Pacific	U.S. SODV	1 Aug. '07- 1 Oct. '07	Honolulu, U.S.A.
3	NanTroSEIZE	U.S. SODV	1 Oct. '07- 1 Dec. '07	Honolulu, U.S.A.
3	NanTroSEIZE	U.S. SODV	1 Dec. '07- 31 Jan. '08	Yokohama, Japan
	TBN	U.S. SODV	31 Jan.'08 -TBD	TBN
4	Juan de Fuca Hydrogeology	U.S. SODV	TBD	TBN
	TBN	U.S. SODV	TBD	TBN
5	Canterbury	U.S. SODV	TBD	TBN
6	Wilkes Land	U.S. SODV	TBD	TBN
	CDEX Operations	**Platform**	**Dates**	**Port of Origin**
3	NanTroSEIZE	*Chikyu*	1 Sep.'07 - TBD	
3	NanTroSEIZE	*Chikyu*	TBD	
3	NanTroSEIZE	*Chikyu*	TBD - 31 Dec. '07	
	Maintenance	*Chikyu*	1 Jan. '08 - 31 Apr. '08	
3	NanTroSEIZE	*Chikyu*	1 May '08 - TBD (~215 days)	

SODV = Scientific Ocean Drilling Vessel   TBN = to be named
MSP = Mission Specific Platform   TBD = to be determined
All dates are approximate. Schedule is subject to approval by NSF/MEXT.

ICDP – Project Schedule http://www.icdp-online.org/project/project.html

	ICDP Projects	Drilling Dates	Location
1	San Andreas Fault Zone Observatory at Depth	June '02 - Oct. '07 **	Parkfield, Calif., U.S.A.
2	Hawaii Scientific Drilling Project	Oct. '04 - Dec '06	Hilo, Hawaii, U.S.A.
3	Drilling Active Faults in South African Mines	Jan. '05 - June '06 *	Witwatersrand, South Africa
4	Chesapeake Bay Deep Drilling Project	Aug. '05 - Dec. '05	Chesapeake Bay, Va., U.S.A.
5	Lake Peten-Itza Drilling Project	Jan. '06 - Mar. '06	Lake Peten-Itza, Guatemala
6	Lake El'gygytgyn Drilling Project	sched. for '06 - '07	Lake El'gygytgyn, Russia
7	Iceland Deep Drilling Project	sched. for '06 - '10	Reykjanes, Iceland

* Subsequent Borehole Monitoring
** Subsequent Borehole Monitoring until 2020