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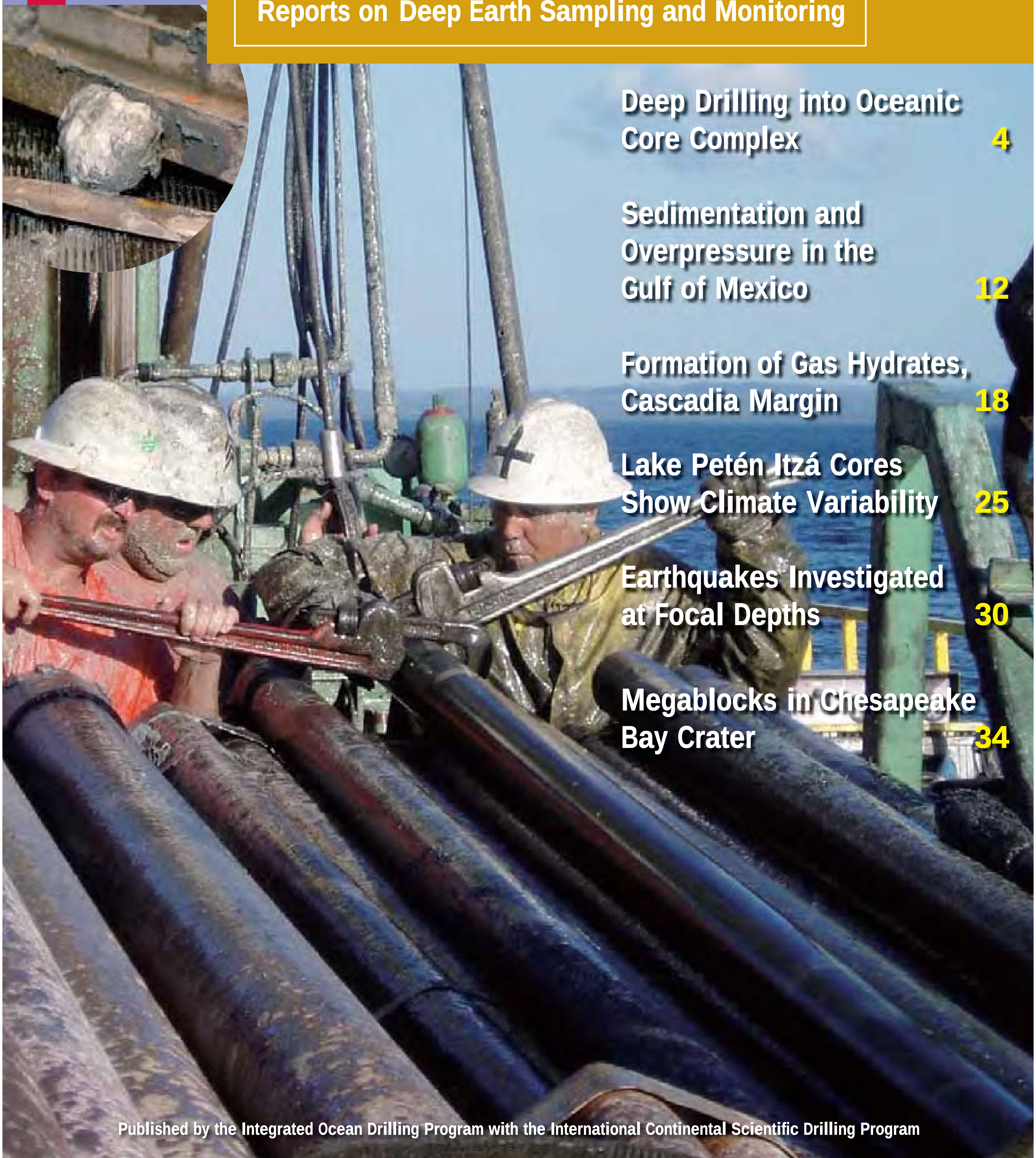
Scientific Drilling

Reports on Deep Earth Sampling and Monitoring



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Editorial Preface

Dear Reader:

We appreciate that many of you have commented favorably on the first two issues of Scientific Drilling. Respondents have frequently expressed delight, and often surprise, at learning about the remarkable breadth and scope of scientific projects that employ drilling as a means of studying the Earth and its environments. This third issue of the journal is no exception, spanning topics from extraterrestrial impact events over gas hydrates to fluid flow in both shallow and deep crustal settings. In addition, we are pleased to introduce in this issue yet another international scientific drilling program—ANDRILL. This Antarctic drilling program will recover sediment cores from beneath the ice shelf, tracking the history of Antarctic ice-sheet variation and evolution back in time to well before the date of the oldest preserved ice in Antarctica.

We editors are no less impressed than the readers by the diversity of scientific drilling and the technology applied, but also note that, despite differences in technology and organization, there is a remarkable coincidence, if not identity, of scientific themes addressed by the many projects. For example, in this issue we report on drilling supported studies of seismogenesis in deep South African mines, a project naturally complementing the ICDP drilling of the San Andreas Fault in California and the IODP Nankai Trough project off the shore of Japan. A most striking feature is how lake drilling in climatically sensitive areas complements the deep sea record of climatic change over geological time. This is important for underpinning predictive climatic models, not only by expanding the global array of observations, but also by providing direct evidence for the impact of climate changes on continental settings outside the polar regions. The most detailed history of climatic changes is contained within ice cores from the Arctic and Antarctic ice shields, and we intend to expand the scope of our journal by featuring reports on this topic in the International Polar Year 2007–2008.

We conclude that Scientific Drilling has proven that the whole can be greater than the sum of its parts, and we hope that this publication can prove to be a model for future collaborations in scientific planning, developments in drilling-related technology, and efficiency in the distribution of samples and data. Enjoy your reading!

Hans Ch. Larsen

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Front Cover: *Main:* Drilling operations at Lake Petén Itzá, Guatemala, (see article on page 25). Photograph by Mark Brenner, University of Florida, Gainesville, Fla.
Left inset: Gas hydrates found during IODP Expedition 311 (see article on page 18).

Scientific Drilling

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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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Contents

Science Reports

Progress Reports

Program Developments

Technical Developments

Workshop Reports

News and Views

Schedules

The Lake Petén Itzá Scientific Drilling Project

by David Hodell, Flavio Anselmetti, Mark Brenner, Daniel Ariztegui,
and the PISDP Scientific Party

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Introduction

Polar ice cores provide us with high-resolution records of past climate change at high latitudes on both glacial-to-interglacial and millennial timescales. Paleoclimatologists and climate modelers have focused increasingly on the tropics, however, as a potentially important driver of global climate change because of the region's role in controlling the Earth's energy budget and in regulating the water vapor content of the atmosphere. Tropical climate change is often expressed most strongly as variations in precipitation, and closed-basin lakes are sensitive recorders of the balance between precipitation and evaporation. Recent advances in floating platforms and drilling technology now offer the paleolimnological community the opportunity to obtain long sediment records from lowland tropical lakes, as illustrated by the recent successful drilling of Lakes Bosumtwi and Malawi in Africa (Koeberl et al., 2005; Scholz et al., 2006).

Tropical lakes suitable for paleoclimatic research were sought in Central America to complement the African lake drilling. Most lakes in the Neotropics are shallow, however, and these basins fell dry during the Late Glacial period because the climate in the region was more arid than today. The search for an appropriate lake to study succeeded in 1999 when a bathymetric survey of Lake Petén Itzá, northern Guatemala, revealed a maximum depth of 165 m, making it the deepest lake in the lowlands of Central America (Fig. 1). Although the lake was greatly reduced in volume during the Late Glacial period, the deep basin remained submerged and thus contains a continuous history of lacustrine sediment deposition. A subsequent seismic survey of Lake Petén Itzá in 2002 showed a thick sediment package overlying basement, with several subbasins containing up to 100 m of sediment (Anselmetti et al., 2006).

Site Location

Lake Petén Itzá is located at ~16°55' N, 89°50' W in the Department of Petén, northern Guatemala, and has a surface area of 100 km^2 (Fig. 1). Maximum water depth is 165 m, and the surface elevation is only 110 m above sea level. This means the deepest basin is a cryptodepression that extends to ~55 m below present sea level. The lake is located in a climatically sensitive region where rainfall is highly seasonal

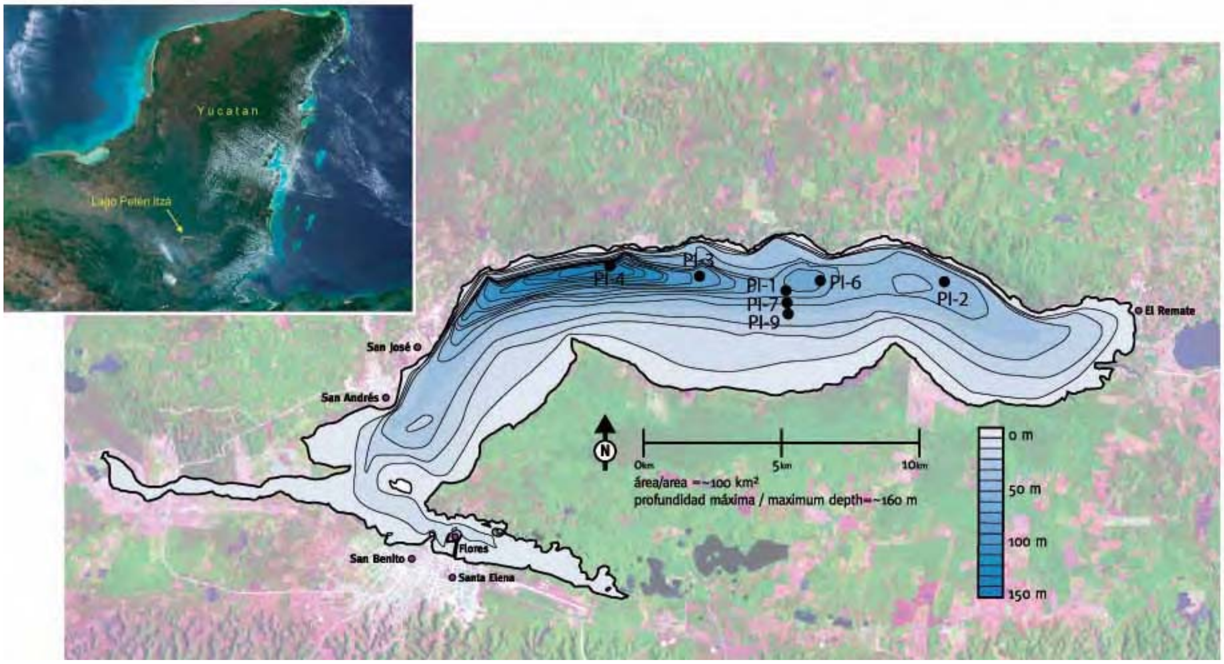

Figure 1. Inset satellite image shows location of Lake Petén Itzá on Yucatan Peninsula. Bathymetric map shows location of drilling sites .

Table 1: Location of drilling sites, water depth, penetration, and core recovery at Lake Petén Itzá

Site	Latitude	Longitude	Water Depth(m)	Penetration Depth (meters below lake floor)					Average Recovery
				Hole A	Hole B	Hole C	Hole D	Hole E	
PI-1	16° 59.9706' N	89° 47.7396' W	65	94.5	90.3	82.5			89.3
PI-2	16° 59.9712' N	89° 44.685' W	54	66.5	41.2	82.4	42.0	68.5	86.3
PI-3	17° 0.2016' N	89° 49.24' W	100	96.9	95.3	90.0			92.9
PI-4	17° 0.3342' N	89° 50.772' W	150	67.4	46.1	25.4			86.7
PI-6	17° 0.0162' N	89° 47.0868' W	71	75.9	66.4	66.8			94.9
PI-7	16° 59.7234' N	89° 47.6844' W	46	133.2	122.8	63.8			92.1
PI-9	16° 59.436' N	89° 47.646' W	30	16.4					91.8

and related to the seasonal migration of the Intertropical Convergence Zone (ITCZ). The lake water today has a high pH (~8.0) and a low total ionic concentration (12.22 meq·l^{-1}) dominated by calcium, magnesium, sulfate, and bicarbonate, and it is saturated for calcium carbonate. During the Late Glacial period, the lake volume was reduced by 87%, and the water was saturated for gypsum (Hillesheim et al., 2005).

The Petén Lake District has been a region of paleoenvironmental study for over thirty years, with most investigations focused on Holocene paleoecologic reconstruction, especially the impact of the Maya civilization on the lowland tropical environment. Previous studies showed that the region underwent profound climatic and environmental change from the arid Late Glacial period to the moist early Holocene, but the climate history on millennial or shorter time scales is not known for the last glacial period, and no paleoclimatic data exist beyond ~36 ka.

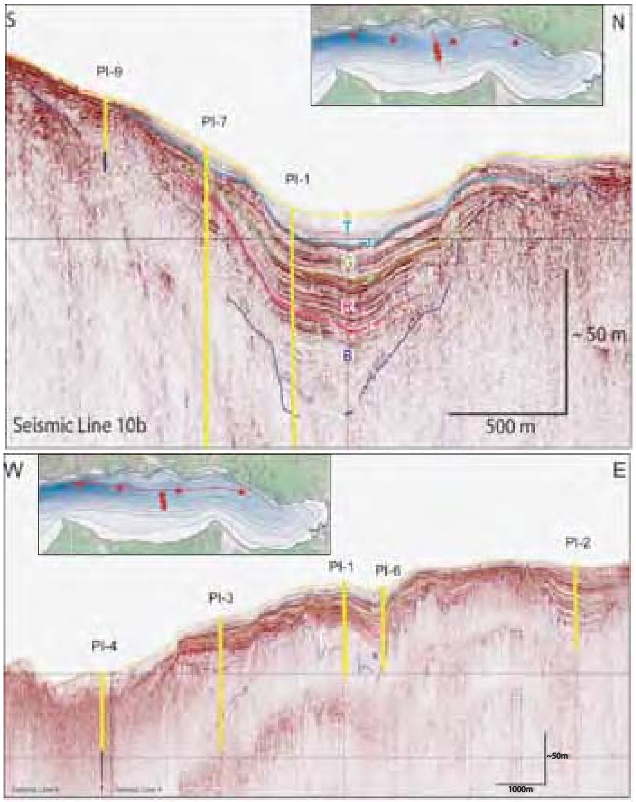

Figure 2. Top: Airgun seismic profile line 10b oriented N-S with drilling penetration depths of Sites PI-9, PI-7, and PI-1. Bottom: Airgun seismic profiles 8 and 9 oriented E-W with drilling penetration depths of Sites PI-2, PI-6, PI-1, PI-3, and PI-4 (Site PI-1 projected). Inset lake maps shows position of seismic lines.

Objectives and Operations

The primary purpose of the Lake Petén Itzá Scientific Drilling Project (PISDP) was to recover complete lacustrine sediment sequences to study the following:

- the paleoclimatic history of the northern lowland Neotropics on decadal to millennial timescales, emphasizing marine-terrestrial linkages (e.g., correlation to Cariaco Basin, Greenland ice cores, etc.)
- the paleoecology and biogeography of the tropical lowland forest, such as the response of vegetation to disturbance by fire, climate change, and humans
- the subsurface biogeochemistry, including integrated studies of microbiology, porewater geochemistry, and mineral authigenesis and diagenesis

Drilling operations were conducted in February–March 2006 by Drilling, Observation and Sampling of the Earth's Continental Crust (DOSECC), Inc., using the Global Lake Drilling platform, GLAD 800 (Fig. 2). All primary sites (PI-1, PI-2, PI-3, PI-4, PI-7, and PI-9) and one alternate site (PI-6) were drilled with an average core recovery of 93.4% (Table 1). A total of 1327 m of sediment was recovered, and the deepest site (PI-7) reached 133 m below the lake floor. Multiple holes were drilled at most sites, and cores were logged in the field for density, p-wave velocity, and magnetic susceptibility using a GEOTEK core logger provided by the International Continental Scientific Drilling Program (ICDP). Complete stratigraphic recovery was verified in nearly real time using Splicer, a software program developed by the Ocean Drilling Program that permits alignment of features among holes using core logging data. Downhole logging was conducted by the ICDP Operational Support Group (OSG) at five sites using their slimhole logging tools. Samples from at least one hole from most of the primary sites were squeezed for porewater geochemical analysis, and ephemeral properties such as alkalinity and pH were measured on site. Smear-slides were prepared from core-catcher samples to describe lithologic changes at each site. Cores were stored onsite in a refrigerated container that was shipped to the National Lacustrine Core Repository (LacCore) at the University of Minnesota (U.S.A.), where initial core descriptions are under way. All data collected on the drilling platform and in the field laboratories were entered into the ICDP Drilling Information System (DIS), uploaded with daily reports and photos to the servers at the GeoForschungsZentrum, Potsdam, Germany, and made available online (http://peten-itza.icdp-online.org).

Preliminary Results

Two shallow sites (PI-9 and PI-7) were drilled in 30 m and 46 m water depth to a maximum depth below the lake floor of 16.4 m and 133.2 m, respectively (Table 1). The great thickness of sediment at PI-7 was surprising, as basement was thought to lie much shallower, at ~47 m (Fig. 2). The shallow sites were not expected to yield long, continuous lacustrine records because relatively short (<6 m) piston cores at these water depths contain paleosols, indicating subaerial exposure during the Late Glacial period (Hillesheim et al., 2005). Shallow-water facies consist primarily of carbonate-rich sediment with abundant shell material, gypsum sand, and indurated gypsum crusts. Deep-water facies consist of diatom-rich, gray to brown clay that was deposited during lake highstands.

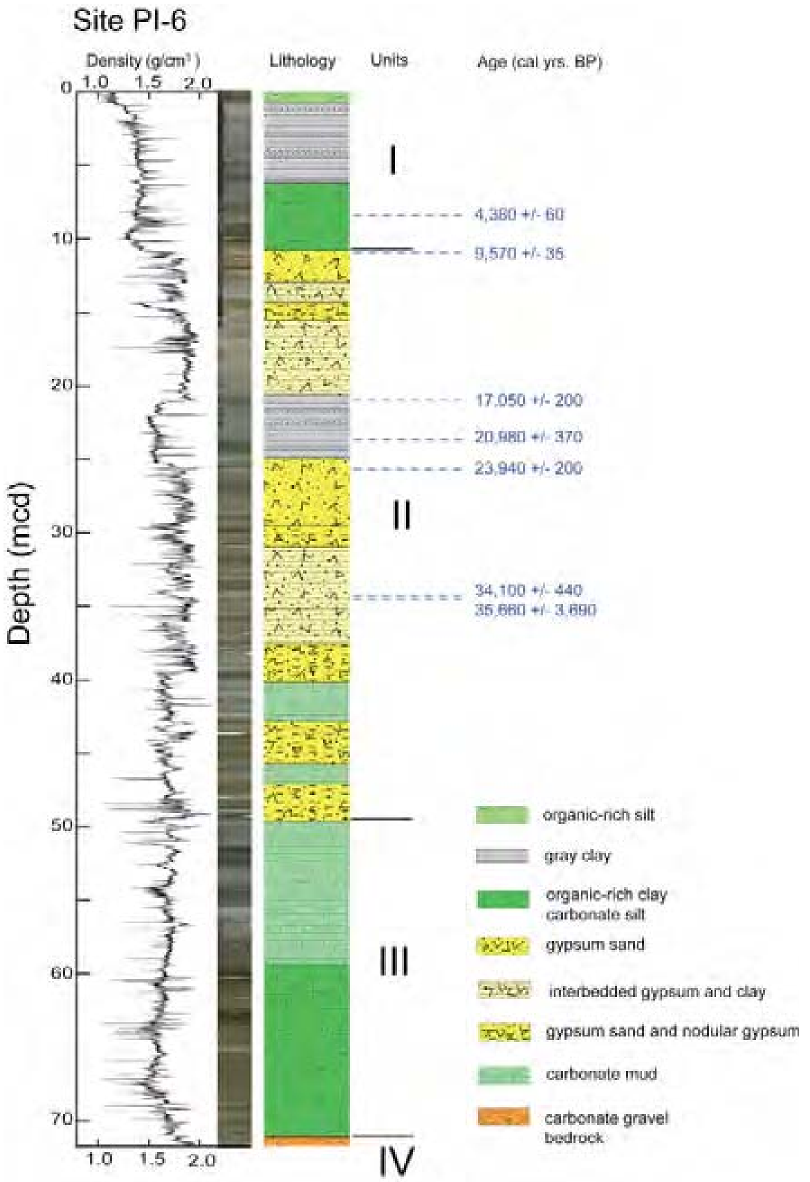

Figure 3. Density, core images, and lithostratigraphy for composite section of Site PI-6. Positions of calibrated radiocarbon dates on terrestrial organic matter are indicated.

Continuous lacustrine deposition was expected for the intermediate (PI-1, PI-2, and PI-6) and deep-water sites (PI-3 and PI-4), with lowstands represented by shallow-water facies (e.g., gypsum sand), especially at the sites of intermediate water depth. Intermediate Site PI-2 is located in the eastern basin that was separated from the central basin during times of greatly reduced lake level (Fig. 1), thereby providing an opportunity to study a semi-independent basin during lowstands. At the deepest sites (PI-3 and PI-4), we were concerned about potential downslope transport, and, indeed, clear evidence of slumping (tilted beds) and sediment disturbance was observed in parts of the section at both sites.

The lithostratigraphy is similar for the intermediate- and deep-water sites, and four lithostratigraphic units are defined on the basis of preliminary core-catcher descriptions and the split cores of Site PI-6. The boundaries between Units I, II, III and IV also correspond to changes in the character of the bulk-density curve and to changes in the seismic profiles (Figs. 3 and 4). Uppermost Unit I, coinciding with seismic sequence T (Fig. 2), consists primarily of gray clay with abundant charcoal, and this unit has been recovered previously from the basin in numerous Kullenberg piston cores (Hillesheim et al., 2005). Unit I spans the entire Holocene, but the bulk of the clay was deposited in a relatively short period between ~3000 and 1000 yrs BP as a consequence of soil erosion brought about by deforestation of the watershed for Maya agriculture. Unit II coincides approximately with seismic sequences G and R (Fig. 2) and consists of interbedded dense gypsum sand, clay, and carbonate mud that were deposited during the latest Pleistocene. The boundary

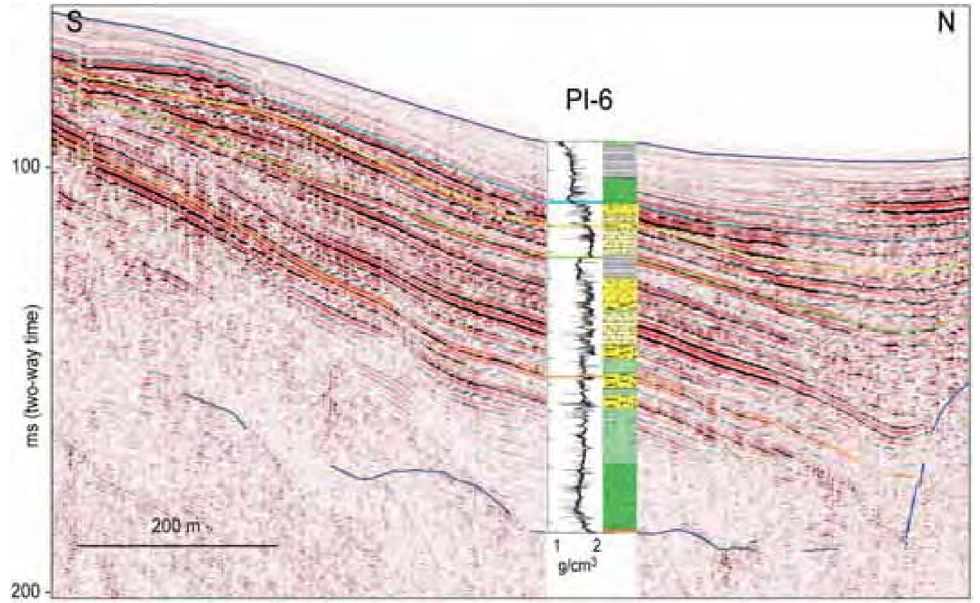

Figure 4. Composite record of MSCL-bulk density and lithology superimposed on seismic data for Site PI-6. Color code of lithologic section is indicated in Figure 3.

between Units II and I coincides with the Pleistocene/Holocene boundary and reflects a transition from an arid climate during the Late Glacial period to a moist climate during the early Holocene (Hillesheim et al., 2005). The boundary corresponds to a sharp change in sediment density (Figs. 5 and 6).

High-frequency variations in bulk density occur throughout lithologic Unit II and can be correlated among sites in the deep basin (Fig. 5). These density changes reflect alternating beds of gypsum and clay-rich sediment, which represent lake-level lowstands (gypsum) and highstands (clay). Initial radiocarbon dates suggest an average sedimentation rate for the upper 35 mcd of about 1 m per thousand years. Unit III occurs below the gypsiferous deposits and correlates roughly to seismic sequence B (Fig. 2). It consists of a thick sequence of organic-rich carbonate clay and silt that is rich in diatoms and carbonate microfossils. The age of Unit III is not yet known, but radiocarbon and U/Th measurements are under way to date these deposits. At the bottom of the holes, Unit IV consists of gravels and angular pieces of indurated carbonate rock that likely represent bedrock.

One unexpected finding was the common occurrence of elemental sulfur nodules at several sites (Fig.6). These nodules form post-depositionally as they cut across bedding and tend to occur at the transitions from gypsum to clay facies. We speculate that abundant sulfate, both in the water column and at depth in the sediment, promotes sulfate reduction and production of H_2S. In the absence of abundant Fe, the H_2S may then be oxidized to elemental S. An integrated program of subsurface microbiology and pore-water geochemistry is planned to study this process.

Downhole logging with slimline tools was conducted at five sites (PI-1, PI-2, PI3, PI-4, and PI-7) both through the drill pipe and in the open borehole where conditions permitted. Natural and spectral gamma radiation tools were run through the cased hole at all sites. Similar natural gamma radiation measurements are being made on whole cores, and these measurements will permit core-log integration and construction of another depth scale (i.e., equivalent logging depth) that will correct for stretching or compression of the cores. Comparison of core and borehole logging data with seismic profiles will enable correlation of seismic reflections to lithologic changes and development of a seismic sequence stratigraphy for the entire lake basin.

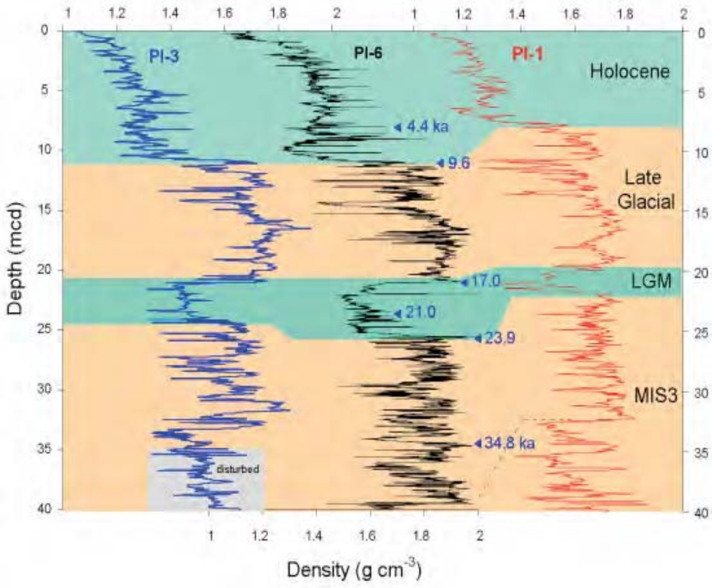

Figure 5. Correlation of composite density records for upper 40 m of Sites PI-3 (water depth =100 m), PI-6 (water depth = 71 m), and PI-1 (water depth =65 m) from Lake Petén Itzá's central basin. Calibrated radiocarbon dates on terrestrial organic matter are indicated from Site PI-6. LGM = Last Glacial Maximum; MIS3 = Marine Isotope Stage 3

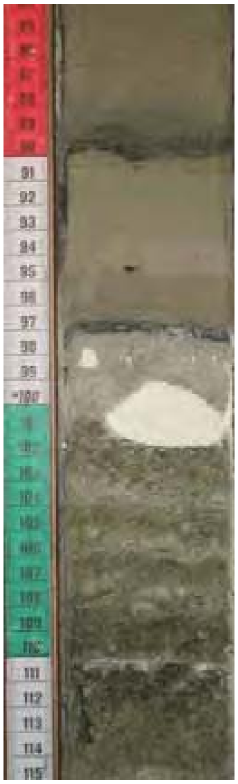

Figure 6. Sulfur nodule from ~99 to 101 cm in Core 6A-4H-2 near Pleistocene-Holocene boundary. Nodule formed near interface between underlying gypsum sand (Unit II) below and overlying clay (Unit I).

Summary

The Petén Itzá Scientific Drilling Project achieved all of its field objectives and recovered 1327 m of high-quality core at seven sites. Preliminary results with respect to sediment lithology, density, magnetic susceptibility, and downhole natural gamma logs display a high degree of climate-related variability that can, in some cases, be correlated among sites. The overall post-drilling objective will be to place this variability in a firm chronologic framework and decipher the history of the northern Neotropic hydrologic cycle, its relation to changes in the position of the Atlantic ITCZ, and linkages to climate variability in the region (e.g., Cariaco Basin) and elsewhere (e.g., high-latitude North Atlantic).

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