# OCEAN DRILLING PROGRAM

# LEG 170 PRELIMINARY REPORT

# COSTA RICA ACCRETIONARY WEDGE

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This Scientific Prospectus is based on pre-cruise JOIDES panel discussions and scientific input from the designated Co-Chief Scientists on behalf of the drilling proponents. The operational plans within reflect JOIDES Planning Committee and thematic panel priorities. During the course of the cruise, actual site operations may indicate to the Co-Chief Scientists and the Operations Manager that it would be scientifically or operationally advantageous to amend the plan detailed in this prospectus. It should be understood that any proposed changes to the plan presented here are contingent upon approval of the Director of the Ocean Drilling Program in consultation with the Science and Operations Committees (successors to the Planning Committee) and the Pollution Prevention and Safety Panel.

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# SCIENTIFIC REPORT

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**ABSTRACT**

Leg 170 investigated mass and fluid flux through a subduction complex unencumbered by fluctuations of turbidite deposition in the trench axis. The strategy was to drill a complete reference site through the sediments and into the basement in the trench (CR-1, Site 1039), a site in the lower, deformed wedge through the décollement and into basement (CR-2, Site 1040), and a site higher up on the continental slope to determine the composition and age of material making up a high-amplitude, high-velocity reflector at about 500 m beneath a sedimentary slope apron (CR-3, Site 1041). Additional sites CR-6 (Site 1043) and CR-7 (Site 1042) were defined on board and drilled based on operational developments and scientific needs. Material drilled beneath the continental slope could then be examined for any signs of offscraped oceanic crust material by comparison with the reference section. Further objectives included an understanding of the cause of regionally very low heat flow through the Cocos Plate and continental slope, and the nature of gas hydrate known to occur within the slope sediments.

Site 1039 provided an excellent reference site, recovering a complete, 378-m thick sedimentary section that bottomed in gabbroic sills, as well as a complete section of high-quality logging-while-drilling (LWD) data. Geochemical data at this site showed evidence of a seawater source deep in the section, implying flow of water through seafloor conduits (faults?) into the upper part of the crust and possibly explaining the low heat flow.

Sites 1040 and 1043 were drilled through the lowermost slope, penetrating the décollement at 371 mbsf and 151 mbsf, respectively, and recovering the underthrust sedimentary section to total depths of 661 mbsf and 282 mbsf, respectively. Site 1040 also bottomed in gabbroic sills. At Site 1043, LWD logging was successful through the entire sediment section (total depth of 482 mbsf), whereas at Site 1040 the LWD tools did not penetrate the décollement. The deformed sedimentary wedge above the décollement showed hardly any resemblance with the reference site, suggesting little or no frontal accretion. In addition, the underthrust sections at the two sites showed little if any loss of material relative to the reference site, based on lithology, biostratigraphy and magnetostratigraphy, geochemistry, and physical properties. The underthrust sections did, however, show significant

volume change during subduction, with reductions in some lithologic units approaching two-thirds of the original volume. Detailed comparisons between the underthrust and reference sections are possible because of excellent LWD logs and detailed lithologic and physical properties measurements on cores.

Sites 1041 and 1042 were drilled farther upslope, through the sedimentary apron to total depths of 424 mbsf and 391 mbsf, respectively. LWD was successful at Site 1042 to a depth of 298 mbsf. Lithological, physical, and geochemical character of the apron material drilled at these sites shows close correspondence with the deformed wedge material at Sites 1040 and 1043. It is likely that the deformed wedge is composed largely of material from the sedimentary apron and very little from accreted trench sediment. Site 1041 yielded abundant gas hydrate, including several frozen sections where gas-hydrate cement was filling the pore space in volcanic ash layers. Site 1042 penetrated the high-velocity zone beneath the apron at a depth of about 300 mbsf, retrieving a middle Miocene breccia consisting of angular fragments of sandstone, basalt, red chert, and cumulate gabbro, cemented with calcite. These rocks were not derived by accretion from the Cocos Plate, but they closely resemble rocks exposed in coastal Costa Rica. It seems most likely that the high-velocity prism beneath the apron represents an extension of the rocks found onshore, and therefore, the amount of accretion is quite limited. Further analysis of benthic foraminifers post-cruise may clarify the vertical motion of the margin, with implications for either underplating or tectonic erosion.

Fluid conduits were in evidence at each of the four sites through the continental slope, based on geochemistry and LWD logs. Within the slope apron at Sites 1041 and 1042, localized minima of Cl and salinity, silica, and K lie in narrow zones, implying fluid flow from sources less saline than seawater. Such sources could be either deeper zones of clay dehydration or meteoric water. Some deep sources are needed, however, to explain local buildup of propane and butane, requiring formation temperatures approaching 100˚C. The lower wedge Sites 1040 and 1043 each showed a major conduit within the wedge, and each showed that the décollement represents a significant fluid conduit as well. Fluid conduits are also supported by extremely low-density spikes in LWD logs over depth intervals of a few meters, within the wedge as well as along and just above the décollement zone.

## INTRODUCTION

There is a scarcity of accurate mass-balance estimates at convergent margins due to (1) the complexity of both the sedimentary and structural processes at these margins, (2) the poor structural imaging of the deeper parts of forearc regions, and (3) the need for reliable age estimates that generally require drilling. To establish the mechanisms of accretion and underplating, tectonic erosion, and deformation and dewatering, essential observations must include (1) the rate (positive and negative) of prism growth as a function of incoming sediment volume and type; (2) the partitioning of frontal offscraping, underplating, internal prism deformation, and subduction erosion; and (3) the effects of fluids. Excellent control is required of material mass-balance and residence time in the prism, in addition to detailed structural geometry of the complex interior regions of forearcs. Such control and imaging is not well established in any convergent margin, despite expending a great amount of effort to understand these margins. The convergent margin off Costa Rica (Fig. 1) satisfies all the requirements necessary to determine accurate mass-balance and flow estimates, except for knowledge of the age and residence time of the prism material. The trench is devoid of turbidites here and the convergence rate is known. Recently acquired 2D and 3D seismic reflection data across the margin provide excellent control of the internal structure of the forearc, and they define boundaries between the accretionary prism and the overlying slope cover, as well as between the prism and the subducting plate. These data show that the slope cover extends to within 3-5 km of the trench, so it protects the accreted mass from erosion and conserves its volume. Consequently, the growth rate of this prism can be calculated accurately when the emplacement age of the accreted material is determined by drilling through the basal slope cover and top of the prism.

Five sites were drilled during Leg 170. The major objective of Site 1039 was to serve as a reference site for drilling in the Costa Rica subduction complex. Site 1039 was chosen for its location in the trench axis and away from fault scarps (Figs. 1-4). Thus, any turbidites entering the trench would be expected to be found at Site 1039. The site was located on seismic Line CR-20, acquired on the *R/V Fred Moore* in 1987. Two major units were identified from the seismic data. An upper unit of about 180 m was thought to consist of hemipelagic sediment, whereas the lower layer was thought to be pelagic carbonate ooze, based on earlier drilling off Central America. Seismic data indicated that the strata at Site 1039 decrease in thickness beneath Proposed Site CR-2, so it is important to understand the properties of the sediment section prior to its subduction. In addition, Site 1039 provides a geochemical reference for comparison with that of the active volcanic arc, including chemical tracers such as $Be^{-10}$ and Ba. In addition to standard coring and core analyses, we used logging-while-drilling (LWD) logs to obtain high-resolution porosity and density measurements.

Site 1040 was located 1.6-km landward of the toe-of-slope off the Nicoya Peninsula, Costa Rica. The objective of this site was to pass through the sedimentary wedge near the toe, the décollement, and the underthrust sedimentary section beneath the décollement. Specific objectives included determining (1) the nature and age of the wedge material; (2) the physical properties of the wedge and underthrust section; (3) the chemistry of pore waters within the wedge, décollement, and underthrust section; and (4) the implications for the balance of mass and fluids between the trench sequence and the underthrust and wedge sequence. The specific location of Site 1040 was chosen because in the seismic records the wedge appeared to be entirely sedimentary, the underthrust section was traceable from the reference section and appeared to be thinned, and the basement was also accessible to the drill. In addition, the décollement reflector was clearly of reversed polarity, indicating an inversion of seismic impedance, possibly the result of elevated pore-fluid pressure. Furthermore, surface studies in this area measured very low heat flow, and we hoped to learn the cause of this anomaly as well to obtain a better definition of the problem with depth. LWD was a high priority for Site 1040, as it was for Site 1039. Comparison of LWD data from Site 1040 and Site 1039 could provide us with a record of density and porosity of unprecedented detail between a reference site and an underthrust sedimentary section.

Site 1041 is located on the midslope of the Costa Rica margin, about 12 km up from the toe-of-slope off the Nicoya Peninsula. The margin here consists of a prism section underlying much of the slope, and a sedimentary apron of 500-600 m thickness that overlies the prism. A major uncertainty exists as to whether the high-amplitude reflection underlying the slope apron off Costa Rica represents ophiolitic rocks of the onshore Nicoya peninsula, or sediment accreted by underplating of the underthrust Cocos Plate stratigraphy. The prime objective of this site was to determine the nature and composition of the prism material underlying the slope apron. Additional objectives included (1) determining the fluid-flow regime of the midslope; (2) comparing the apron material with that of the lower wedge above the décollement drilled at Site 1040; and (3) penetrating through an out-of-sequence fault zone, marked by a well-developed reflection at about 1.4 s (two-way traveltime) beneath the seafloor. Using velocities obtained from Shipley et al. (1992), we estimated that the reflector depth was ~1200 mbsf. New seismic velocities from McIntosh and co-workers (unpubl. data), indicated this reflector more likely lies at a depth of 1500 to 1600 mbsf. We were unable to sample the prism beneath the apron at this site because of difficult hole conditions. For this reason, we obtained permission to drill Site 1042 where the prism reflector occurs at an estimated depth of ~300 mbsf, i.e., 200 m shallower than at Site 1041 (Fig. 5). Site 1042 had the same objectives as Site 1041.

Site 1043 was designed to test whether or not offscraping is temporally and spatially intermittent. At Site 1040, rotary core barrel (RCB) drilling disturbance essentially destroyed much of the primary structural fabric above the décollement. Site 1040 showed much less offscraping (~1%) than expected based on seismic reflection data (~10%). At Site 1043, we anticipated less drilling disturbance using extended core barrel (XCB) coring because the décollement is much shallower (approximately 150 mbsf) than at Site 1040 (371 mbsf). The rate of change of thickness of the underthrust hemipelagic sequence (Units U1 and U2) appeared to be highest at Site 1043. This rate of change may correspond to a high rate of dewatering of the underthrust section as well. The hemipelagic section shows evidence of anomalous dips at Site 1040, suggesting deformation of this section beneath the décollement. Site 1043 was also designed to test whether deformation of the underthrust hemipelagic sediments develops soon after subduction. LWD was a high priority and comparison of LWD data from Sites 1043 and 1039 has provided us with an unprecedented, detailed record of density and porosity between a reference site and an underthrust sedimentary section.

# RESULTS

## SITE 1039

We successfully obtained a complete and undeformed stratigraphic section of the incoming sediments on the Cocos Plate at Site 1039, which will be used for comparison with sites on the Costa Rica margin. Three sedimentary units and one intrusive unit were recognized at Site 1039 (Fig. 6). Unit U1 consists of dark olive green diatomaceous ooze with ash layers. Subunit U1A (Holocene to Pleistocene, 0-5 mbsf) is distinguished by abundant graded sand layers interpreted as turbidites, and grades downward into Subunit U1B (Pleistocene, 5-84 mbsf), in which graded sand layers are sparse to absent. Below a sharp contact at a thick gray ash layer, Unit U2 is distinguished by a sharp decrease in biogenic sediment. Subunit U2A (early Pleistocene to late Pliocene, 84-133 mbsf) consists of dark olive-green silty clay, and grades downward into Subunit U2B (late to early Pliocene, 134-152 mbsf). Subunit U2B is a dark olive-green silty clay interbedded with light olive-green calcareous clay; ash layers are common throughout Unit U2.

Unit U3 records a dramatic increase in biogenic sedimentation, changing sharply from the nearly barren clays of Unit U2 to calcareous and siliceous oozes. Subunit U3A (early Pliocene to late Miocene, 152-180 mbsf) is ivory-colored siliceous nannofossil ooze interbedded with calcareous clay; ash layers are sparse. Subunit U3B (late to middle Miocene, 180-280 mbsf) consists of ivory to light green and mottled siliceous nannofossil ooze with minor ash layers. Subunit U3B grades downward into Subunit U3C (middle Miocene, 280 to 378 mbsf in Hole B and 363 to 445 mbsf in Hole C), and consists of a mottled ivory-colored calcareous ooze, interbedded in the lower part with siliceous ooze and matrix-supported breccia of calcareous ooze clasts. Preliminary shipboard X-ray fluorescence (XRF) results show that the basal oozes of Subunit U3C are metalliferous, being enriched in nickel, copper, and zinc.

Unit U4 was encountered at depths of 378-381 mbsf in Hole 1039B and 423-445 mbsf in Hole 1039C. It consists of fine- to medium-grained glassy pyroxene gabbro with plagioclase glomerocrysts. Multiple chill zones were recovered within the 22 m of gabbro. The reason for the difference in the depth to the top of the intrusion in Holes 1039B and C is not yet known.

A complete or nearly complete late Pleistocene through early middle Miocene (approximately 16.4 Ma) section cored at Site 1039 is recognized in the combined calcareous nannofossil, diatom, and planktonic foraminifer record. An age-depth model calculated from the combined last and/or first occurrence datums of index microfossils yields average rates of about 46 m/m.y. (0-120 mbsf) for the Pleistocene in the upper part of the section, 6 m/m.y. for the upper Miocene and Pliocene interval (120-200 mbsf), and 47 m/my for the middle Miocene interval (200-448 mbsf). Calcareous nannofossil, diatom, and planktonic foraminifer biostratigraphic zones are easily resolved in the intervals of higher interval/age rates. However, in the upper Miocene and Pliocene section, a few of the late Miocene and Pliocene zones apparently cannot be resolved due to low rates and widely spaced (9.6 m) sampling intervals. All microfossils generally exhibit good preservation and sufficient abundances for reliable biostratigraphic analysis. The distribution of diatoms with depth shows clear relationships with the boundaries between Units 1 and 2 and Units 2 and 3.

Demagnetization of natural remanence in both split cores and discrete samples was successful in defining portions of magnetostratigraphy at Site 1039. The uppermost sequence (0-132 mbsf) has reversals ranging in age from the Blake (0.105 Ma) and Jamaica (0.200 Ma) events to the termination of Chron C2An.3n (3.33 Ma). The lower sequence of well-defined reversals (302-387 mbsf) spans Chrons C5Ar.1n (12.678 Ma) to C5Cn.2n (16.488 Ma). A large interval of predominantly normal polarity, coinciding with a zone of increased intensity of remanence (120-180 mbsf) occurs within sediment ranging in age from 3.5 to 8.2 Ma. Calculated depth-age rates are 105 m/m.y. for Subunit U1A, and 30 m/m.y. for the interval 11 to 133 mbsf. Within Unit U3, rates decrease from 20 m/m.y. (305-370 mbsf) to 5 m/m.y. (370-380 mbsf) downhole.

The geochemical objectives at Site 1039, similar to those for lithostratigraphy and biostratigraphy, were to obtain a reference section for the distribution of chemical components in the incoming sedimentary section. Here again our objectives were met. Concentrations of methane were low throughout Site 1039. Only in the interval between 25 and 110 mbsf did methane contents exceed the background concentration of 4-8 ppm. In this sequence, slightly enhanced methane concentrations ranging from 11 to 110 ppm were detected. The strongly reducing conditions needed for bacterial methane generation evidently never were achieved in the sediments at Site 1039, and sulfate concentrations remain high throughout the recovered sedimentary sequence.

The carbonate content varies from 0.5 to 87.8% $CaCO_3$, assuming that all of the carbonates are present as pure calcite. Low $CaCO_3$ concentrations (0.3 to 4.6%) are found in the upper part of the sediment column (Unit U1). At depths between 113 and 152 mbsf, alternating high and low carbonate contents were measured (Unit U2). Below this zone, $CaCO_3$ increases rapidly (up to 87.8%) and remains high throughout the whole sequence of Unit U3.

Organic carbon contents range from 0.1% to 1.89%. The highest concentrations occur in the turbidite sequence, suggesting a downslope transport of sediments enriched in organic compounds. The pelagic, calcareous sediments are characterized by low total organic carbon (TOC) concentrations ranging from 0.1% to 0.6%. Sulfur concentrations-depth profile parallels that of organic carbon contents. Only the hemipelagic sediments contain significant amounts of sulfur, whereas in the sequence dominated by carbonates no sulfur was detected.

In the organic-matter-rich hemipelagic lithologic Unit U1, with TOC content of 0.6-1.9 wt%, and also Unit U2 with 0.4-0.6 wt% TOC, bacterially mediated organic matter diagenesis, dissolution of diatoms, and volcanic ash alteration reactions control the chemistry of the pore waters. These reactions affect the physical, magnetic, and chemical properties of the sediments via carbonate, sulfide(s), and probably magnetite precipitation, as well as ion exchange reactions between ammonia, K, and Na in the clay minerals. In the pelagic calcareous Unit U3, where the TOC content is mostly <0.3% and where dissolved sulfate concentration is close to that of seawater, the chemical signatures of the pore waters are controlled by volcanic ash alteration, diatom dissolution, and to a lesser extent carbonate recrystallization. Dissolved silica concentrations are at equilibrium with amorphous silica (opal A) solubility, and Ca concentrations are twice as high as in seawater. The concentration-depth profiles of Ca, Mg, Si, and Cl faithfully reflect the lithologic units and even the subunits at this site. In the lowermost variegated, somewhat metalliferous sedimentary Subunit U3C, diffusion of dissolved metals, such as Mn, influence the sediment color and its distribution. Except for a fluid conduit at 95-130 mbsf, the pore-water chemical-depth profiles do not support vertical or horizontal fluid advection within the sediment section. In the basal section, however, the pore-water concentration profiles of Cl, K, Ca, Mg, and Si indicate seawater flow in the upper oceanic basement. This hydrologic regime may be responsible for the unusually low heat flow at this site.

Physical properties objectives included obtaining complete distributions of in-situ density and porosity, magnetic susceptibility, thermal conductivity, and changes in original lithology, consolidation state, and diagenesis in the sedimentary section. These objectives were met with abundant core and downhole measurements at Site 1039. Lithostratigraphic units are mapped with the color spectrometer, mainly because of the drastic differences in color between the diatomaceous ooze and the nannofossil ooze, as well as the ash-rich layers. Magnetic susceptibility also mapped the transitions from hemipelagic to pelagic carbonate intervals, as well as intervals with abundant ash. Porosities are high and show a general decrease downsection from about 75% at the seafloor to 65-70% at the base of Unit U3. A marked drop in porosity and increase in bulk density and thermal conductivity occur at about 180 mbsf, marking the region where the sediments become dominated by calcareous oozes. *P*-wave velocities are exceptionally low, attaining maximum values of 1650 m/s at 350 mbsf.

In situ density and porosity measurements were collected by the Compensated Density Neutron tool (CDN) as part of the LWD downhole assembly. Downhole measurements correlate closely with core measurements, although downhole densities are a little higher than the core-based values, particularly for carbonate Subunit U3B below 200 mbsf. Major features occur at slightly greater depths (a few meters) on the downhole profiles than on the core-based profiles. This effect may be caused by a small angle deviation of Hole 1039D relative to Hole 1039B. Below 395 mbsf, exceptionally high density values (up to 2.8 g/cm$^3$) are consistent with the gabbro intrusions in this interval.

Porosities calculated directly from the downhole neutron log fluctuate widely throughout the logged interval. The filtered neutron porosity profile correlates well with porosity measurements on core specimens. The large decrease in porosity at 185-195 mbsf corresponds with a marked increase in downhole bulk density at 188 mbsf. Cyclical changes in porosity occur over the interval 195-285 mbsf, with rapid downward decreases between more gradual downward increases.

In situ resistivity measurements were collected using the Compensated Dual Resistivity tool (CDR) of the LWD assembly in Hole 1039D. The deep and shallow resistivity logs show very similar trends and amplitudes, indicating excellent hole conditions. Computed formation factors based on constant pore-water salinity of 0.035 range from 1.7 to 3 and show the same trends as the resistivity variations. Resistivity trends largely mimic the bulk-density log. They vary between 0.6 to 0.8 ohm-m over the sedimentary interval. The gabbro intrusion at 395-398 mbsf shows exceptionally high resistivities (up to 20 ohm-m).

In situ natural gamma-ray measurements were collected by CDR, and the photoelectric effect (PEF) was measured by CDN in Hole 1039D. The profile of the total spectral gamma ray shows a similar trend to the magnetic susceptibility profile from cores throughout the section. Uranium yields a distinctive decrease at 127 mbsf. Most of the strong peaks of the gamma-ray profile can be correlated to ash layers. The PEF profile shows a similar trend to that of carbonate and colorimetry. Between 138-188 mbsf, PEF increases from 2 to 4, which coincides with the increasing content of carbonate in lithologic Unit U3A. In the intervals between 210 and 227 mbsf and 267 and 292 mbsf, PEF decreases to values as low as 1.5, which is best explained by an increased abundance of biogenic opal.

To better understand the anomalously low heat flows reported from this region, one drilling objective was to determine heat-flow measurements though the sedimentary section. Our efforts were successful. Temperature measurements at Site 1039, using the Adara and Davis-Villinger Temperature Probe (DVTP) tools, reveal a geothermal gradient of 9.8 K/km. Measured thermal conductivity of 0.85 W/(m*K) gives a heat flow of 8.4 $mW/m^2$, which is very close to values obtained from surface heat-flow measurements. This very low heat flow suggests that processes act to refrigerate the uppermost igneous crust in this location.

In summary, all lithostratigraphic and biostratigraphic, as well as all geochemical and physical properties objectives were reached in the sedimentary section of Site 1039. We were not completely successful with the basement section because the basal units were gabbroic intrusive rocks, which did not represent true basement. A seismic reflection model of the intrusives suggests a thickness of about 70 m. We concluded that, while useful, finding extrusive basalt did not justify the potential time expenditure at this site. Lack of a 50-m hole into true basement limited our ability to understand the recycling of deeper crustal rocks. An additional goal of obtaining an unequivocal maximum age of the downgoing crust was not achieved for the same reasons. Future drilling in this area should plan to obtain 100-200 m of oceanic basement for geochemical recycling studies.

## SITE 1040

Lithostratigraphic and biostratigraphy objectives included determining the nature and age of the wedge material, the relationship of underthrust units to those of reference Site 1039, and the implications for the balance of mass and fluids between the trench sequence and the underthrust and wedge sequence. Another important objective was to determine the structural fabric of both the deformed wedge and the underthrust sediments. We were successful for the most part in achieving these objectives by drilling through the décollement and the entire underthrust sedimentary sequence and into gabbro intrusions very similar to those in Site 1039. Because LWD operations were only partially successful at this site, we did not obtain a full in situ physical properties data set for correlations with Site 1039.

The deformed sedimentary wedge overlies the same three sedimentary units and one basement unit drilled at Site 1039 (Fig. 7). The deformed wedge unit (Unit P1) consists of a subunit (P1A, 0-74.8 mbsf) of olive green silty clay with debris flows and silty sands, overlying a lower subunit (P1B, 74.8-371.2 mbsf) of olive green silty clay with intervals of silt to very fine sand. The age of the deformed wedge unit is uncertain. Below Unit P1, Unit U1A (late Pleistocene, 371.2-384.8 mbsf) is a clayey diatomite with silty sand interbeds, and Unit U1B (Pleistocene, 384.4-422.6 mbsf) is clayey diatomite with ash layers. Unit U2A (Pleistocene to late Pliocene, 422.6-472.47 mbsf) is silty claystone with ash layers, and Unit U2B (Pliocene, 472.47-479.7) is silty claystone with calcareous clay and ash layers. Unit 3A (early Pliocene to late Miocene, 479.7-497.8 mbsf) is a siliceous nannofossil chalk and clay, whereas Unit U3B (late to middle Miocene, 497.8-653.53) is siliceous nannofossil chalk. Unit U3C is siliceous nannofossil chalk with calcareous diatomite interbeds. Finally, Unit U4 (post 15.6 Ma, 653.53-661.47 mbsf) is a pyroxene gabbro intrusion.

Deformational structures were observed in the first core at Site 1040. Fissility to incipient scaly fabric were observed from the top of the prism discontinuously throughout Unit P1 (0-371 mbsf). Deformation bands and distributed fractures are common in the upper 20 mbsf and discontinuous throughout Unit P1. Many of these may be drilling-induced, particularly all stratal disruptions. Both brittle and plastic deformation structures are common from the surface to 370 mbsf. Plastic deformation is associated with soft, sticky clay and severe drilling disturbance. Therefore, original plastic deformation cannot be identified although it may have existed within these clay-rich intervals. From 340-350 mbsf, we find that fracture networks, stratal disruption, veins, and incipient scaly clay structures are common. Locally, a very intense fracture fabric is formed. From 350-360 mbsf, brittle deformation gives way to plastic deformation in sticky clays. Throughout Unit P1, cores are highly disrupted by drilling, with evidence of both flow-in and intensive torque transfer to the cores. Paleomagnetic studies indicate that the more plastic intervals have cork-screwed tens of times.

Below 371 mbsf, the intense fissility, fracture networks, and stratal disruption disappear, and evidence for torque transfer to the cores decreases markedly. Burrows, a primary sedimentary structure, are common. Mud-filled veins are present. Steep bedding dips are measured in the interval 420 to 484 mbsf. At 460 mbsf, microfaulting is more abundant in the cores, and fluid escape breccias were noted. Minor faults occur through the cores to the base of the section. Microfaults are mostly reverse in the interval 430-500 mbsf, and show mostly normal displacement in the interval 610-650 mbsf. Incipient stylolitization is present in the lowest 10 m of the sediment section, developed largely subhorizontally, and rare boudinage structures are present. The lower 150 m of the section show consistent bedding dips of up to 20°. This attitude can be explained by a measured hole deviation of up to 18°.

The distribution of ages vs. depth at Site 1040 for Units U1, U2, and U3 is similar to that of Site 1039. The major difference between the two sites is the difference in thickness of the corresponding units. Units 1 and 2 at Site 1040 are approximately 67% of the thickness of the units in Site 1039, whereas Unit 3 at Site 1040 is about 80% of that in Site 1039. These differences correspond well with measured differences in porosity and bulk density between the two sites. Although some of the same fossil zones are present at both sites, a number are different, probably due in part to the 10-m spacing of core-catcher samples for shipboard analysis. Post-cruise work should shed more light on these differences. Within the deformed sedimentary wedge (0-330 mbsf), numerous normal and reversed polarity intervals were found. Lack of good biostratigraphic control and the high probability of thrust faults within this interval have so far prevented a unique assignment of our reversal stratigraphy to any specific portion of the magnetic polarity time scale. The reversed-polarity results at 5 mbsf in Hole 1040B do suggest, however, that these near-surface sediments are at least 0.78 Ma in age. Beneath the décollement (371-655 mbsf), a good magnetostratigraphic record was obtained from the underthrust sediments. In particular, the Jamaica event (0.2 Ma) has been located at 383.7 mbsf, and a complete set of reversals ranging in age from 2.14 Ma (C2r.1n) to 6.935 Ma (C3Bn) occurs between 458 and 482 mbsf in Hole 1040C. Preliminary age vs. depth estimates for the underthrust section at Site 1040 from biostratigraphy and magnetostratigraphy are, respectively, 41 and 72 m/m.y. for the Pleistocene, and 6 and 5.8 m/m.y. for the Pliocene to upper Miocene. Biostratigraphic data for the middle Miocene indicates a sedimentation rate of 32 m/m.y. The oldest sediment at Site 1040 was 15.6 Ma, younger than the 16.4 Ma age found at Hole 1039C.

A primary objective for Site 1040 was to determine the chemistry of pore waters within the wedge, décollement, and underthrust section to compare Site 1040 chemistry with that of Site 1039 and to gain a fuller understanding of the nature of fluid and heat flow near the toe of the subduction zone. We were successful in meeting these fluid chemistry objectives, obtaining accurate chemical depth profiles even from intervals with severe drilling disturbance.

Pore-water geochemistry at Site 1040 shows significant decreases in salinity in the upper 371 m. Chloride concentrations decrease rapidly in the upper 40 mbsf from 550 mM to about 512 mM, and salinity decreases from 34.5 to ~30 in the upper 40 m. Chloride and salinity both decreased further to ~500 mM and 28, respectively, by 80-100 mbsf. In addition, both properties show large minima at 200 mbsf and a moderate one at 300 mbsf, implying that both flow through fractures and a presence of gas hydrate at 200 mbsf, which suggests a fluid conduit. Both properties also show minimum concentrations in the décollement zone, at 360 mbsf, and both return to normal seawater values at 371 mbsf, just beneath the décollement, and maintain these values to 653 mbsf. Calcium and magnesium also show similar effects. Magnesium decreased from 50 mM at the surface to about 20 mM at 100 mbsf. It also shows minima at 200 mbsf, 300 mbsf, and in the décollement zone, then increases to 41 mM at 390 mbsf. Just below the décollement, magnesium increases to a small maximum concentration of 47 mM at 382 mbsf. Calcium displays a curve that is reversed to magnesium, with maxima at 200 and 360 mbsf, and a small maximum at 280 mbsf. The distributions of ammonium, phosphate, silica, potassium, sulfate, and alkalinity all show sharp boundaries and major changes across the décollement.

The distribution of methane gas also changes significantly at the décollement. Methane increases from a few ppm in the upper few meters to 8996 ppm at 28.5 mbsf. From 28.5 to 374 mbsf, concentrations increase to values between 4818 and 116,561 ppm. Below the base of the décollement, methane values decrease sharply, and from 460 to 653 mbsf the values are again a few ppm. Propane is very low at Site 1040, but shows a peak of 24 ppm between 191 and 203.6 mbsf, and a peak of 19 ppm between 348.2 and 357.8 mbsf. These two intervals coincide with anomalies in fluid composition of the pore waters, suggesting a significant input in allochthonous thermogenic gas. Below 374 mbsf, only small amounts of propane were detected throughout the underthrust section. The distribution of calcium carbonate in the underthrust section shows the same distinct patterns as reported for Site 1039.

The primary objectives for studying the physical properties of the wedge and underthrust section included determining what changes occurred to the accreted or underthrust material. Physical properties at Site 1040 show significant changes compared to equivalent units at Site 1039. Seismic velocity measurements at Site 1040 average about 1700 m/s from 371 to 496 mbsf. From 496 to ~560 mbsf, seismic velocity averages 1660 m/s, and increases steadily from 1660 m/s at 560 mbsf to 1760 m/s at 653 mbsf. Porosity varies from 50% at 150 mbsf to 40% at 371 mbsf. At this depth (the décollement) porosity increases rapidly to about 60% and stays at this value to a depth of 650 mbsf. Bulk density at Site 1040 increases from about 1660 to 1720 kg/m$^3$, from 150 mbsf to 371 mbsf. Density drops to 1430 kg/m$^3$ between the décollement at 372 mbsf and a depth of 430 mbsf. Thermal conductivity shows considerable scatter, but measurements indicate an average value of 0.9 W/(m*K) from 0 to 490 mbsf. Magnetic susceptibility is a primary property for cross-hole correlation because its natural variations are not significantly affected by core disturbance. It displays some peaks in the upper 20 m, then stays very low to 270 mbsf. From 270 to 496 mbsf, magnetic susceptibility is relatively high and varied, and from 496 to 650 mbsf it is essentially zero, increasing only slightly in the lower 30 m and showing a single peak at 653 mbsf due to the presence of the gabbro sill.

Temperature measurements downhole show an extremely low gradient of 8.3°C/km from the surface to 200 mbsf, followed by 5.3°C/km from 200 to 350 mbsf, returning to 8.4°C/km at 350-475 mbsf. The corresponding heat flows calculated for these intervals are 7.5, 4.8, and 8.9 mW/m$^2$.

In situ density, porosity, resistivity, and gamma-ray measurements were collected with the CDN and CDR tools as part of the LWD downhole measurement program. Two logging runs were made using different drill bits in an unsuccessful attempt to penetrate through the décollement. The total logged intervals at Holes 1040D and 1040E are from the seafloor to 325 mbsf and 307 mbsf, respectively.

Downhole density and porosity measurements correlate roughly with the core specimen measurements, and resistivity generally follows the pattern of density. Although the profiles from Holes 1040D and 1040E generally show the same trend in density and porosity, they show different log responses in several intervals. Bulk-density profiles gradually increase with depth, but display a number of segments with rapid downward decreases between more gradual downward increases. Most of the density values range between 1.7 and 2.0 g/cm$^3$. Significant decreases in density occur at 84 mbsf (1.55 g/cm$^3$), 237 mbsf (1.68 g/cm$^3$), and 310 mbsf (1.60 g/cm$^3$) in Hole 1040D, and 168 mbsf (1.70 g/cm$^3$) and 269 mbsf (1.72 g/cm$^3$) in Hole 1040E. Porosities calculated directly from the neutron log fluctuate widely throughout the logged interval. The filtered neutron porosity profile indicates porosities from 65% to 50%, decreasing gradually with depth. The porosity profiles show a reverse trend to that of the density profile, but several low density intervals indicate low neutron porosities.

In the interval 0-200 mbsf, the resistivity values gradually increase from 1 to 2.5 ohm-m in Hole 1040D, whereas in Hole 1040E the values show greater fluctuation. In Hole 1040D, the interval 200-277 mbsf is characterized by relatively high resistivity values up to 3.2 ohm-m. In Hole 1040E, high resistivity is identified between 210 and 242 mbsf. A resistivity maximum at 114 mbsf corresponds to a density maximum. However, resistivity maxima at 168, 238, and 270 mbsf are correlated to minima in density.

In summary, we were highly successful in meeting our primary objectives in determining the geochemistry, physical properties, lithoastratigraphy and biostratigraphy. We had only partial success at this site in carrying out LWD because of the inability of the tool to penetrate beneath a presumably overpressured zone.

## SITE 1041

The lithostratigraphic objectives at Site 1041 were to determine the stratigraphy of the sedimentary apron, the composition and properties of gas hydrate, and the composition of the prism material directly beneath the apron. We succeeded in determining the stratigraphy of the upper 395 m of the apron and sampled gas hydrate in a number of places down the hole. Because of deteriorating hole conditions, we did not reach our target depth of 550 mbsf, thus, missing the objective of the prism composition.

One lithologic unit is defined at Site 1041 (Fig. 8). Only the first two cores were recovered by advanced hydraulic piston core (APC). Below 14.30 mbsf (Core 170-1041A-2H) the cores are generally of poor quality, with incomplete recovery, extensive biscuiting due to drilling disturbance, and entire sections of rubble that are probably upper-hole infall. Beginning with Core 170-1041A-12X and extending to the bottom of Hole 1041C, the cores are extensively fractured. In Core 170-1041A-15X through 1041B-20R, many original textures and structures were destroyed by gas-hydrate dissociation.

Apron Unit A1 consists mainly of Pleistocene (?) to late Miocene clay(stone) and silt(stone), with minor sandstone, limestone, and volcanic ash. These lithologies are dominated by terrigenous rather than biogenic material. Unit A1 is divided into two subunits, with Subunit A1B consisting of coarser-grained material (siltstones and sandstones) than the claystone-dominated Subunit A1A. Gas hydrate was recovered between 116 and 184 mbsf. Although evidence of submarine mass wasting and slumping was observed near the base of the hole, we found little evidence of tectonic deformation in the cores except for microfaults, fissility, and changes in bedding dips. Biostratigraphic markers are not abundant enough to indicate age reversals, which would have resulted from major internal faults, and age determinations are complicated by reworked middle Miocene taxa that increase near the base of the hole. However, the increase in microfaults and changes in bedding dip between 180 and 200 mbsf, and an abrupt change in bedding orientation at 275 mbsf, suggest at least two minor faults within the section.

Distributions of age vs. depth at Site 1041 are not as clear as those at the previous two sites because of poorer preservation and significant reworking. The general trend of age vs. depth rates, based largely on diatoms, suggests 55 m/m.y. in the upper 240 mbsf and 93 m/m.y. below this depth. Rates based on nannofossils are slightly higher at 62 m/m.y. above 240 mbsf. The magnetostratigraphy of this site can be divided into two zones, an upper zone (0-160 mbsf) of apparently remagnetized, entirely normal polarity, and a zone with both normal and reversed polarity (160 mbsf-TD). Using biostratigraphic markers, polarity intervals ranging from the onset of C3n.2n (4.62 Ma) at 174 mbsf to the termination of C4n.2n (7.43 Ma) at 369.5 mbsf were identified. Age-depth relationships are 38 m/m.y. for the interval 174-222 mbsf and 99 m/m.y. for the interval 222-396 mbsf. Thermal demagnetization of multicomponent isothermal remanent magnetizations (mIRM) was performed on selected samples and indicated the presence of Fe-sulfides and magnetite.

The main geochemical scientific objectives for Site 1041 were to characterize the fluid stratigraphy and flow distribution within the slope-apron sediments, as well as in the rocks or prism sediments beneath the high amplitude reflection at its base, and to determine the origin(s) of the fluid(s). Finally, we sought to establish the occurrence and geochemistry of the gas hydrate to deduce its mode of formation and origin. We succeeded in establishing a fluid stratigraphy in the upper 395 mbsf of the slope apron and we established the occurrence and geochemistry of the gas hydrate. Our data have implications for the nature of the rocks beneath the apron, but we did not sample those rocks directly at Site 1041.

Below the very thin sulfate reduction zone at about 15 mbsf, methane concentrations are high throughout the section drilled. Gas hydrate is concentrated between about 100 and 280 mbsf, the zone of highest TOC wt%. Its primary mode of occurrence is disseminated, as indicated by the almost constant salinity in this depth interval, with thin sheets of gas hydrate filling microfractures. The gas hydrate analyzed within this interval also contains small amounts of the higher hydrocarbons ethane ($C_2$) and propane ($C_3$). Below ~280 mbsf, just beneath the lithologic transition from Unit A1A to A1B, the concentrations of volatile hydrocarbons, especially of propane, are highest and then decrease below the interval. Across this boundary, the concentration-depth profiles of several inorganic chemical components, particularly Cl, Ca, Si, and phosphate, and of Na/Cl and Mg/Ca ratios, show sharp transitions to lower or higher values, suggesting a two-tier hydrologic system having different fluid sources.

The section drilled from 1.5 to 395 mbsf has Cl concentrations and salinities lower than seawater, and they decrease steadily to the depth of the main gas-hydrate zone (120-280 mbsf). From 280 to 340 mbsf, the concentrations are rather constant. Below ~340 mbsf, they have slightly higher values. The source of the fluid with low Cl and high Ca concentration in the lower apron sediments is located at >3-4 km depth. Clay mineral dehydration reactions are the most likely fluid-rock reactions responsible for freshening this fluid at the source region. The source of the low-Cl fluid in the upper apron sediments is less clear. Gas-hydrate dissociation alone would not result, for example, in Na/Cl ratios higher than seawater, whereas the in situ temperatures are too low for hydrous mineral dehydration reactions. Testing for the possibility of meteoric water influence requires shore-based analyses. Carbonate formation of both calcite and dolomite is pervasive throughout the apron sediments. Although the total inorganic carbonate content is not high, it ranges between 0.5 and 6.3 wt%.

The apron sediments show increasing compaction through the section, with porosity decreasing from nearly 75% at the seabed to less than 45% at 330 mbsf. *P*-wave velocities increase monotonically over the same interval, from 1540 m/s to over 2000 m/s at the greater depths, reflecting increasing consolidation and cementation. The widespread occurrence of (melted) gas hydrate does not significantly affect the physical properties measured on core samples, but clathrates filling pores and fractures are expected to have major influence on velocities and resistivities in situ.

In summary, some of our objectives at Site 1041, including determination of lithostratigraphy and geochemistry of the apron and sampling the distribution of gas hydrate with depth, were met. We fell short of our total depth objective, the high-amplitude prism reflector, because of drilling problems and, therefore, targeted an additional Site CR-7 (Site 1042) to meet that objective.

## SITE 1042

We succeeded in reaching and coring the high-amplitude reflection marking the top of the prism. Spot coring every 50 m showed a sedimentary section similar to the deeper parts of Site 1041, although more careful study will be necessary to make any detailed comparisons. We subdivided the sedimentary section into two subunits on the basis of lithological and age differences; Subunits 1A and 1B (Fig. 9). Subunit 1A (48.7-240.1 mbsf) consists mostly of silty claystone including ubiquitous volcanic glass with common to trace amounts of microfossils. Subunit 1A is late Pleistocene to middle Miocene in age on the basis of planktonic foraminifers. Subunit 1B (201.7-240.1 mbsf) is composed dominantly of silty claystone and limestone with matrix supported breccia. Thin layers of glauconitic sandstone were also recognized. The late to middle Miocene age of Subunit 1B was determined from common to well-preserved foraminifers with few to trace amounts of nannofossils and diatoms.

At 316 mbsf, we cored a carbonate-cemented breccia, consisting of angular to subangular sandstone clasts and other clasts that have not yet been analyzed. Between 350 and 360 mbsf we recovered breccia composed of fragments of red chert, doleritic basalt, and altered mafic rock. These rocks are similar to outcrops described onshore. The carbonate-cemented breccia has a density and sound velocity of about 2 g/cm$^3$ and 4.6 km/s, respectively, sufficient to explain both the high-amplitude reflection at the top of the prism and the velocities obtained from ocean-bottom seismometer (OBS) and ocean-bottom hydrophones (OBH) refraction data. Preliminary age determination on the breccia is middle Miocene. Beneath the breccia is a scaly clay of late Miocene age, interpreted to represent a fault zone.

Objectives of the geochemistry program at Site 1042 were similar to those at Site 1041. Additional chemistry at Site 1042 was needed to tie in these observations with those at other sites. In this light, the work was a success. Because coring was done only every 50 m until 200 mbsf, all the pore-fluid samples analyzed were from beneath the sulfate reduction zone; therefore, methane concentrations have high values even in the shallowest sample analyzed at ~50 mbsf. The section drilled lies within the stability field of methane hydrate, and mild gas escape was observed in the few sediment samples obtained from ~100 to 230 mbsf. This effect is most likely responsible for at least some of the Cl freshening also encountered at this site. An abrupt increase in the content of $C_1$ through $C_3$ and traces of higher hydrocarbons through $C_6$ were observed between 150 and 200 mbsf, where a major fault was intersected, suggesting that they formed at >100˚C. A change in the pore-fluid chemistry occurs at ~100 mbsf; below 100 mbsf and crossing a major fault to about 230 mbsf, the chemistry is roughly constant with characteristics similar to those observed at Site 1041 beneath the fluid conduit at 280-300 mbsf, and at Site 1040 beneath the conduit at about 180 mbsf. Characteristics include elevated Ca concentration and both Cl concentration and Na/Cl ratios that are lower than seawater.

Downhole logging acquired resistivity and gamma-ray logs with the CDR tool. A major break in resistivity occurs in the interval between 67 and 74 mbsf. This change in resistivity roughly coincides with the location of a normal fault in the seismic reflection records. A large increase in resistivity occurs at 145 mbsf, and below that resistivity values increase gradually with depth. A number of small peaks could represent gas hydrate.

In summary, even though this site was spot-cored for the first 200 mbsf, it was highly successful in contributing to the major objective of determining the physical nature of the top of the prism. Together with Site 1041, the combined sites through the apron have provided a nearly complete picture of mid-slope geology. These sites have clarified the environment and character of the gas hydrate, the pathways of fluid flow, and the sources of the fluids moving through the apron and prism. Physical properties data from cores and from LWD have also contributed in important ways to this knowledge. The primary goal of drilling through the apron, that of understanding the nature of the prism material below, has been met. Thus, Sites 1041/1042 have been fully successful.

## SITE 1043

Lithologic objectives included description of the complete section through the wedge, décollement, and underthrust units, and determination of whether material was missing at the top of the underthrust section. One lithologic unit was defined above the underthrust section at Site 1043, Unit T1 (Fig. 10). Below the décollement, U1B through U3A of the Cocos Plate reference section were recognized. Unit T1 (Holocene? to early Pliocene; 0-150.57 mbsf) consists mainly of thick intervals of clay and silty clay interbedded with relatively thin intervals of matrix-supported breccia. The breccias consist of firm lumps of claystone, siltstone, and ooze embedded in a clayey to sandy matrix. Thin layers and small pods of volcanic ash, and minor interbeds of silt and sand, appear throughout Unit T1. Minor clasts of Pliocene and Miocene limestone and calcareous ooze suggest that older calcareous units contributed debris to the unit. Units U1B, U2, and U3A at Site 1043 are similar to the units defined at the reference site, Site 1039. Three structural domains were defined at Site 1043. Domain I (0-141.3) is the less-deformed part of the wedge toe, and coincides with all but the lowermost part of Unit T1. Domain II (141.3-150.57 mbsf) is the more intensely deformed décollement zone at the base of Unit T1, and Domain III represents the underthrust section of Units U1B-U3A, which are only slightly deformed.

Within the Site 1043 wedge sediments, reversals in age-depth distribution can be used to define the occurrence of thrust faults. A foraminifer marker with an age of 1.77 Ma, the C2n onset at 125 mbsf, and the occurrence of a diatom marker with an age less than 0.62 Ma below that interval, indicate that an age inversion occurs between 125 and 130 mbsf, arguing strongly for the existence of a thrust fault. Another possible age-depth inversion defined by nannofossil and foraminifer datums and the Brunhes/Matuyama (B/M) magnetic polarity boundary matches an interval of low bulk density and high porosity at 25-30 mbsf in the LWD logs of Hole 1043B. Below the décollement, age-depth relationships can be calculated using a combination of biostratigraphic and paleomagnetic information. In Unit U1 (150-194 mbsf), age-depth rates range from 52 to 40 m/m.y., within Unit U2 (194-263 mbsf) the rate is 15 m/m.y., and within Unit U3 (263 mbsf to total depth [TD]) the rate is less than 12 m/m.y. Comparing the depth of the B/M boundary at this site (180 mbsf, 30 m below the décollement) with the depth of this polarity transition at Site 1039 (59 mbsf) indicates that the portion of lithostratigraphic Unit U1 above the B/M boundary has been thinned approximately 30 m by some combination of faulting and compaction at this site.

Geochemistry objectives included determining the pathways and potential sources of pore fluids through the deformed wedge, décollement, and underthrust section. Two regions showed narrow zones of very low density on the LWD logs. One was 74-77 mbsf and the other was in the décollement zone (148-157 mbsf). Each of these depths is associated with major anomalies in Cl, Si, K, $PO_4$, and salinity. These anomalies are zones of relative freshening of the pore waters. The source of the fresher water could be from dehydration of clay minerals or input from meteoric water. Gas hydrate effects could influence some of the anomalies but cannot explain the entire effect. Post-cruise analyses will be required to distinguish these alternatives. Sulfate decreases rapidly with depth in the upper 15-20 mbsf, beneath which it is completely reduced through the décollement. Immediately beneath the décollement, sulfate jumps to relatively high levels and continues to approach the value of seawater with depth in the hole. Alkalinity behaves opposite to that of sulfate, increasing rapidly in the top 15 mbsf, staying high until the décollement, then jumping to lower values below the décollement and gradually decreasing with depth in the underthrust section. Alkalinity approaches seawater values at 270 mbsf. Our geochemistry objectives have been well satisfied at Site 1043.

Physical properties measurements, including downhole observations, were central to the objectives of Site 1043. Significant changes in thickness and reduction in density were noted between correlative units at Sites 1039 and 1040. Site 1043 is located at a position intermediate in terms of potential dewatering. Bulk density and porosity in the wedge section here show a complex pattern, including a number of intervals where the consolidation state decreases somewhat with depth. Some of these may be related to increased fracturing, which affects the downhole logs more than core measurements. The most prominent negative excursion of bulk density down to 1.1 $g/cm^3$ from the baseline (1.8 $g/cm^3$) occurs in the interval 72-75 mbsf, which is correlated to the interval characterized by a geochemical anomaly. A broad negative excursion down to 1.3 $g/cm^3$ occurs in the interval 88-107 mbsf. All negative excursions in the upper 150 mbsf are correlated with the relatively large stand-off of up to 7.5 cm indicated by the differential caliper log. At the décollement zone itself, there is a steep gradient in physical properties, possibly indicating some shear-enhanced compaction in addition to the dewatering of the underthrust section produced by the weight of the prism. The trends through the underthrust section match those in the reference section (Site 1039), but density, *P*-wave velocity, and resistivity are higher, whereas porosity is somewhat lower. A distinct increase in density occurs at 285 mbsf, which coincides with the top of nannofossil ooze in Hole 1039B. It is apparent that only the upper part of the underthrust section (150-190 mbsf) has dewatered significantly, and there is an interval below this (190-250 mbsf) where the physical properties suggest a modest reversal in the consolidation state.

In summary, drilling at Site 1043 attained all of our objectives. We both cored and logged complete sections through the décollement, acquiring excellent quality core and data. Geochemistry, as it has all through the leg, provided detailed signals of the fluid behavior with depth, and the fluid pathways required by the geochemistry coincide with zones of very low density seen with the logs and with the structural geology of the cores.

## SUMMARY

The objectives of Leg 170 were to determine the sediment, chemical, and fluid mass balances within the subduction complex and the larger subduction system (including the volcanic arc). Origins and pathways of fluids through the subduction system were of primary importance, as was the recently discovered enigma of anomalously low heat flow. The approach included building on a major database of seismic reflection and refraction data, heat flow, submersible diving observations, seismicity, and onland geological investigations to place the leg results in a broader and more tightly constrained framework.

Primary drilling sites proposed to address these objectives included (1) a reference site in the Middle America Trench to determine the entire incoming sedimentary section and to learn something of the underlying basaltic crust; (2) a site through the lower slope wedge, to determine the age and origin of the wedge material and to compare that and the underthrust section with the results of drilling at the reference site; and (3) the final drilling objective included a site in the mid-slope region, to core through the slope apron and into the prism material below. The latter site would determine whether the material of the sub-apron prism was accreted from the subducting Cocos Plate or older material related to the Costa Rican onshore geology.

Site 1039 was drilled through the trench floor as a reference site, and a continuous set of cores was acquired through the sedimentary section and bottomed in 22 m of intrusive gabbro. The reference section was not deformed in any way, providing a true reference for this program. Drilling recovered about 5 m of terrigenous turbidites, overlying a thick sequence of diatom ooze with ash. Silty clay with ash underlies the diatom ooze, and this sequence rests on calcareous clay and siliceous nannofossil ooze. A few tens of meters of calcareous ooze and breccia overlies the igneous gabbro intrusives. The sedimentary section is just under 400 m thick. The sequence is sufficiently distinctive that most of it should be recognizable if present within the continental margin. Geochemistry of pore waters show gradients of Ca, K, and Si approaching those of seawater in the lowermost few tens of meters in this section, implying a source of seawater at the base of, or beneath, the sedimentary section. Relatively rapid communication between the seawater and the oceanic crust could provide a clear explanation for the very low values of heat flow determined by surface data and by downhole measurements on Leg 170.

Site 1040 was cored through the deformed sedimentary wedge, the décollement, and the underthrust sedimentary section beneath the décollement. Major discoveries were made in this site. First, the material making up the deformed sedimentary wedge does not resemble that of the incoming strata in Site 1039. If anything, these sediments more closely resemble those of the slope apron, cored at Site 1041 (discussed below). Secondly, the underthrust section beneath the décollement appears to be nearly intact. Only the top few meters of the turbidites seen at Site 1039 are missing, but this difference could be explained by winnowing of bottom currents, because a 3.5 kHz seismic record taken between the two sites shows the upper 5-8 m of sediment pinching out toward the trench axis. Third, the underthrust section at Site 1040 is reduced in thickness relative to that at Site 1039. The upper 180 m at Site 1039 are reduced to approximately 67% of original thickness at Site 1040 and the lower 200 m are reduced to about 80% of original. These are approximate numbers and ~~the~~ variations occur within these intervals. In addition, relatively steep dips noted in the cores from the highest 100 m of the underthrust section at Site 1040 could result in some thickening of that section over what it would be without the dips. Quantitative determinations of these differences must be carried out post-cruise. Finally, the geochemistry has documented two major fluid conduits. One is at a depth of about 170 mbsf within the deformed wedge and the second is associated with the décollement.

Two problems occurred during the drilling of Site 1040. First, many of the cores in the lower part of the deformed wedge underwent extreme torsion due to RCB coring of a ductile clay. The induced deformation made it extremely difficult to discern natural deformation fabrics in these cores. A second problem was that the LWD logging was not able to pass through the décollement, in spite of two efforts with different drill bits to carry it out. For these reasons, we developed a shipboard proposal to drill an additional site (Site 1043) through the wedge, décollement, and underthrust section at a location just 400 m landward of the toe of the margin. At Site 1043, the depth to the décollement is about 150 mbsf, making it significantly more accessible to both XCB coring and LWD.

Site 1043 penetrated the deformed wedge, décollement, and hemipelagic section. Coring stopped just above the contact with the nannofossil ooze. A complete set of LWD logs was acquired at this site. We obtained a less disturbed cored section above and through the décollement than at Site 1040, and the geochemistry data is of high quality at both sites. The LWD logs showed fine detail in the physical properties downhole, including several thin (1-2 m), low-density layers within the décollement zone that are very likely faults. Another fault zone ~80 m above the décollement is clearly marked as a low density zone in the logs, and both of these faulted regions are associated with chemical anomalies requiring fluid conduits. First examination of the combined dataset suggests that as much as 10 m may be missing from the top of the incoming section relative to that at Site 1039. A careful post-cruise comparison of Sites 1039, 1043, and 1040 will be necessary to determine how much material is removed from the lower plate during subduction. Very preliminary analyses of the LWD logs suggest that roughly 9 m of the section cored at Site 1039 may be missing from Site 1043 beneath the décollement. Whether all or only part of this 9 m has been accreted to the upper plate remains to be determined.

Site 1041 was designed to answer questions about the nature of the sediment apron and the composition of the upper part of the prism. We made two attempts to drill through the apron but did not succeed in getting much below 400 mbsf (high-amplitude top-of-prism reflection was at about 550 m there). Nonetheless, we succeeded in acquiring an excellent section through the apron, including a number of samples of gas hydrate. The apron is largely composed of silty clay with rare nannofossils and microfossils, very different from the pelagic oozes resting on the Cocos Plate at Site 1039. The inability to penetrate through to the prism reflector prompted adding yet another site originating on the ship. Site 1042 was located 7-km landward of the toe-of-slope at the seaward edge of what is still clearly the high-amplitude, top-of-prism reflection. At Site 1042, the reflecting surface lies at a depth of 310-320 mbsf. We spot-cored to 200 m but were unable to reach the reflecting surface on the first try. We then drilled to the surface with a larger diameter bit, then reentered the hole with the RCB bit. We cored successfully to 390 mbsf, initially penetrating the high-amplitude reflecting surface at 316 mbsf. The material was a carbonate-cemented breccia containing sandstone clasts, basalts, chert fragments, and cummulate gabbro or ultramafic rock. Many of the fragments were angular, suggesting little abrasion during deposition. The breccia matrix and some of the sandstone clasts were dated as middle Miocene. These breccias and their clasts resemble rocks known to occur onshore in Costa Rica, and the measured seismic velocity and density of the breccia can explain the seismic velocities and reflectivity measured for that surface. We feel reasonably confident that we penetrated the prism surface.

Finding material with affinities to onshore Costa Rica but not with the incoming Cocos Plate makes it very likely that much of the incoming sediment on the Cocos Plate bypasses the toe region of the continental margin. Seismic data show evidence of some underplating beneath the prism, but the rate of underplating is unknown at present. Paleodepth determinations on Deep Sea Drilling Project (DSDP) Leg 84 (Site 565) show evidence of uplift of the middle to lower slope region. Onland exposures attest to coastal uplift during the Pleistocene. Post-cruise science will address the question of how much underplating is possible. Nonetheless, much (from 90% to 99%) of the incoming sediment is bypassing the toe region through underthrusting.

## REFERENCE

Shipley, T.H., McIntosh, K.D., Silver, E.A., Dean, D., and Stoffa, P., 1992. Three dimensional seismic imaging of the Costa Rica Accretionary Prism: Structural diversity in a small volume of the lower slope. *J. Geophys. Res.*, 97:4439-4459.

## FIGURE CAPTIONS

**Figure 1.** Location of 2D and 3D seismic profiles from 1987 cruise of *Fred Moore*. Inset shows map of Central America, Cocos Plate, and Caribbean Plate. Nicoya Peninsula is located just below the "C" in Costa Rica on the inset drawing. The stippled rectangle shows the location of the 3D seismic grid. The longer lines are 2D profiles.

**Figure 2.** Bathymetric map of the Middle America Trench and lower continental slope region off the Nicoya peninsula, Costa Rica. Dotted lines show the locations of 2D seismic Line CR-20, on which Sites 1039, 1040, and 1043 are positioned, and 3D lines and cross lines locating Sites 1041 and 1042. Bathymetry is from Hydrosweep data, shown with permission of R. von Huene and GEOMAR. Contour interval is 20 m.

**Figure 3.** 2D seismic reflection Profile CR-20, showing the locations of Sites 1039, 1043, 1040, and 1041 (geometrically projected). Note the high-amplitude reflection at the base of the sedimentary apron beneath Site 1041 (geometrically projected). Vertical scale is in two-way traveltime.

**Figure 4**. Depth migrated seismic Line CR-20, located in Fig. 2. Positions of Sites 1039, 1043, and 1040 are shown.

**Figure 5.** 3D seismic reflection Line CR3D-48, which crosses Site 1042. Profile is taken from depth-migrated 3D grid and is located near the southeast corner of the grid. Small escarpments on the seafloor are interpreted as the outcrop of normal faults that effect the uppermost ~100 m. At greater depth, the prism appears to be cut by thrust faults.

**Figure 6.** Graphical representation and summary plots of shipboard core and downhole measurements. LWD = logging while drilling, MST = multisensor track, SGR = spectral gamma ray (total counts), and CGR = computed gamma ray (total counts minus contribution of uranium). Gabbro contact was located ~40 m deeper in Hole C than in Hole B; it remains uncertain whether

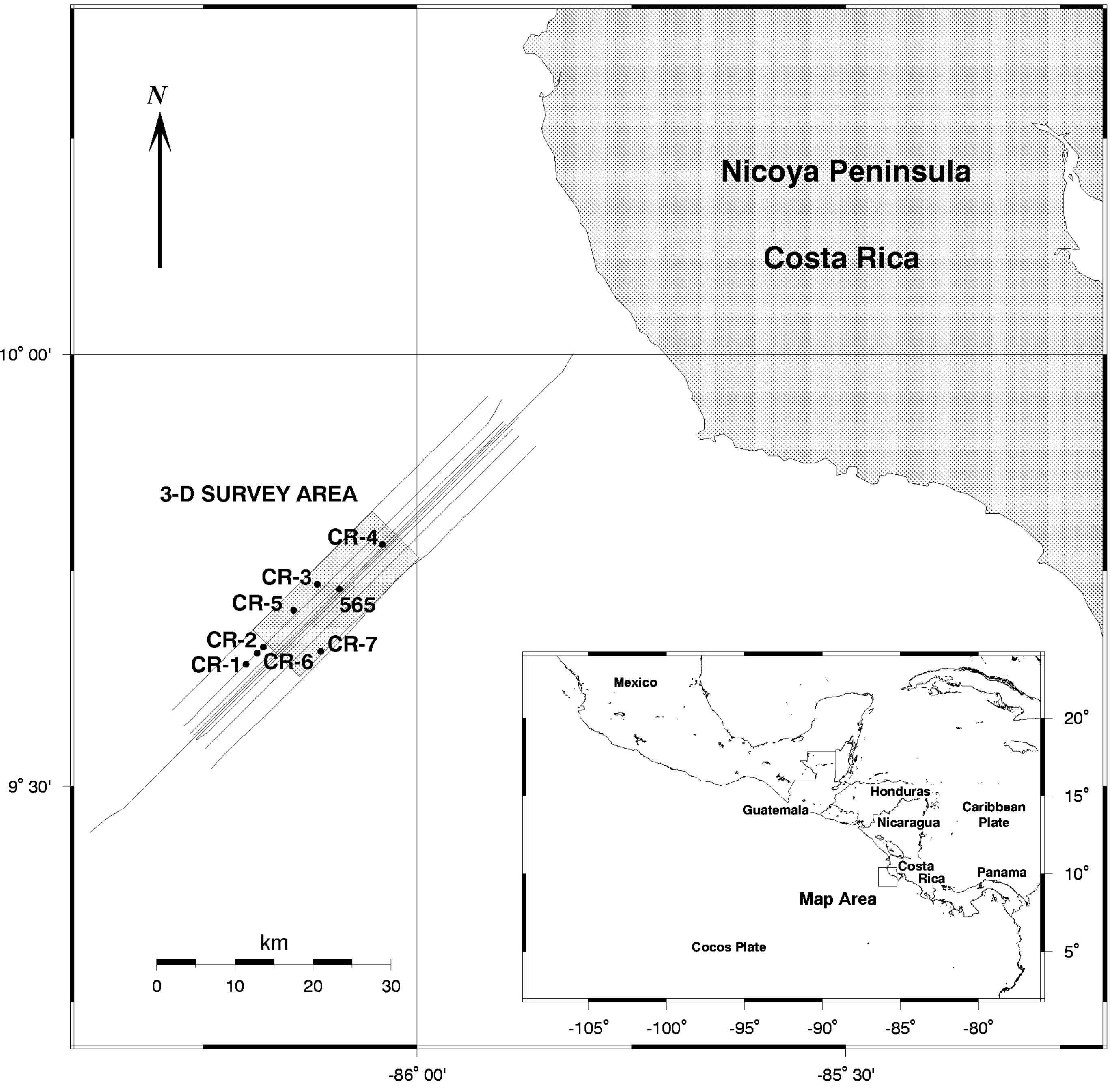
this is caused by a depth datum problem or by a local geological feature (fault; discontinuous gabbro layer). Difference of gabbro depth between Holes B and D (~15 m) can be attributed to measured deviation of Hole D from vertical.

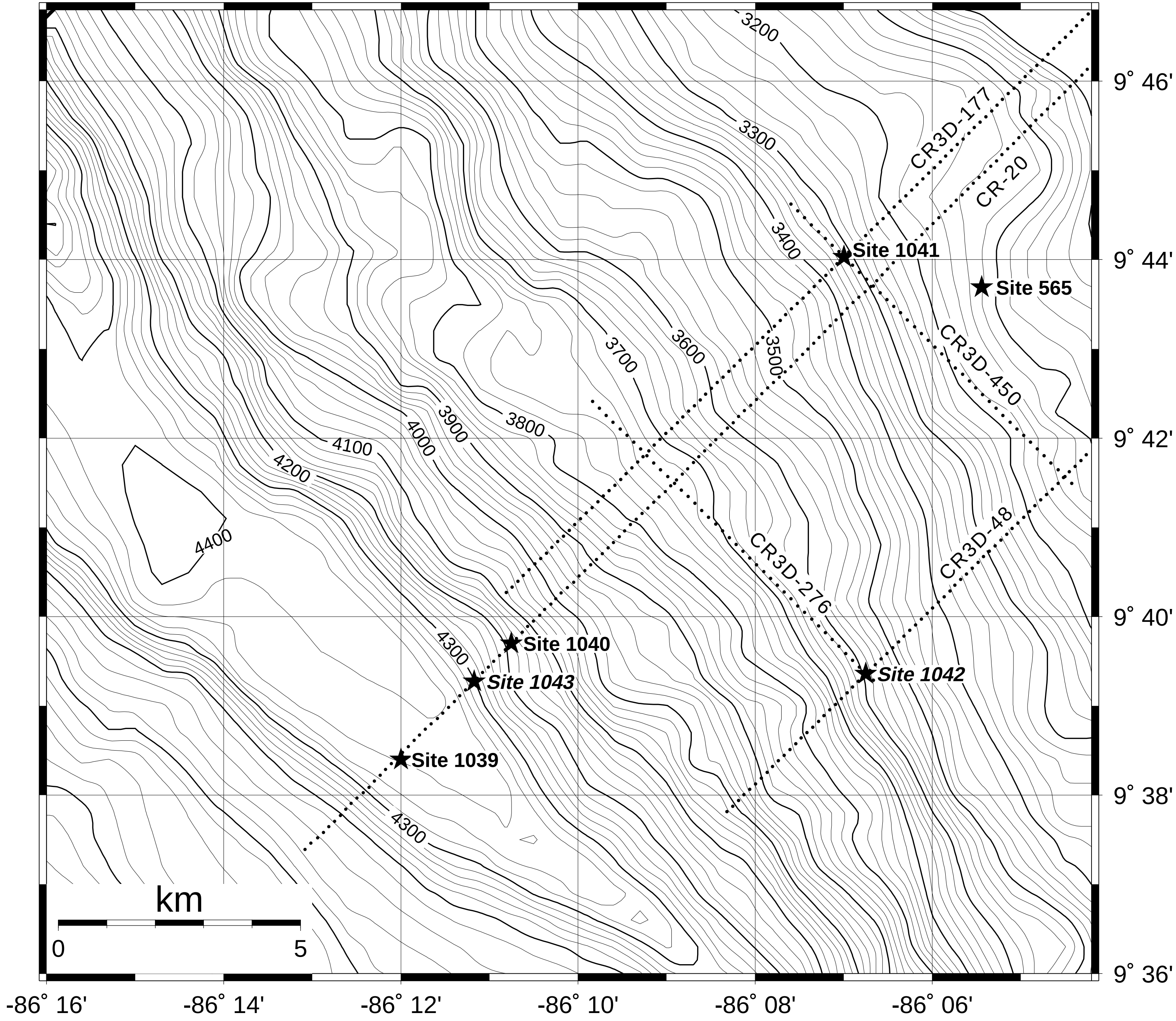
**Figure 7.** Graphical representation and summary plots of shipboard core and downhole measurements. LWD = logging while drilling and SGR = spectral gamma ray (total counts).

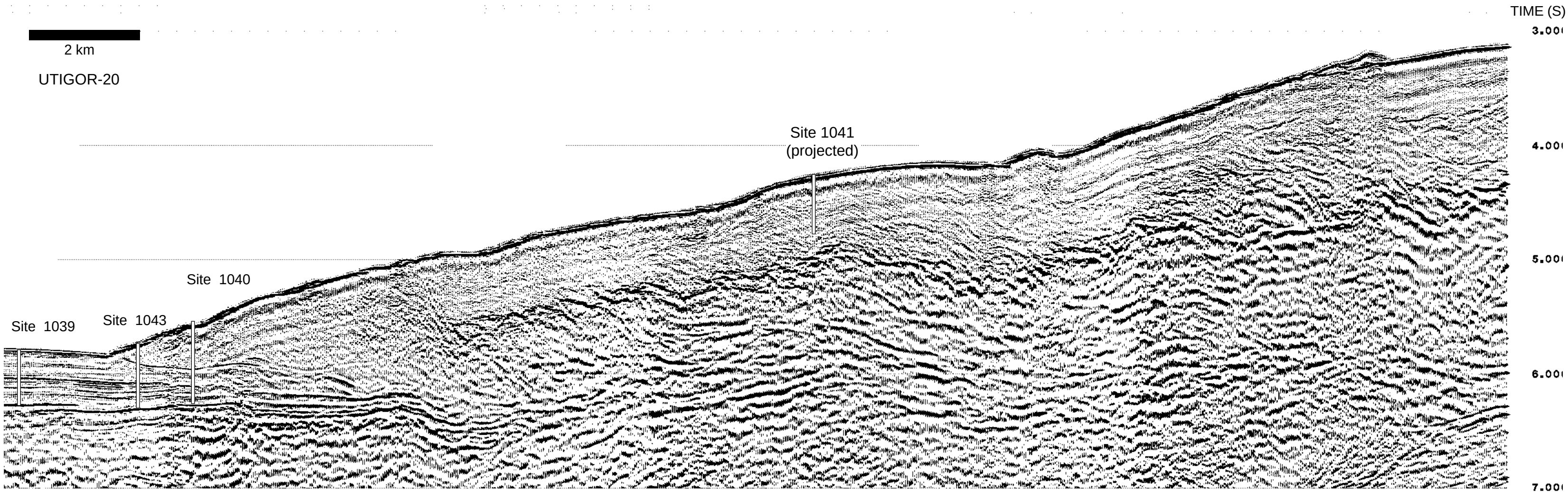
**Figure 8.** Graphical representation and summary plots of shipboard core and downhole measurements.

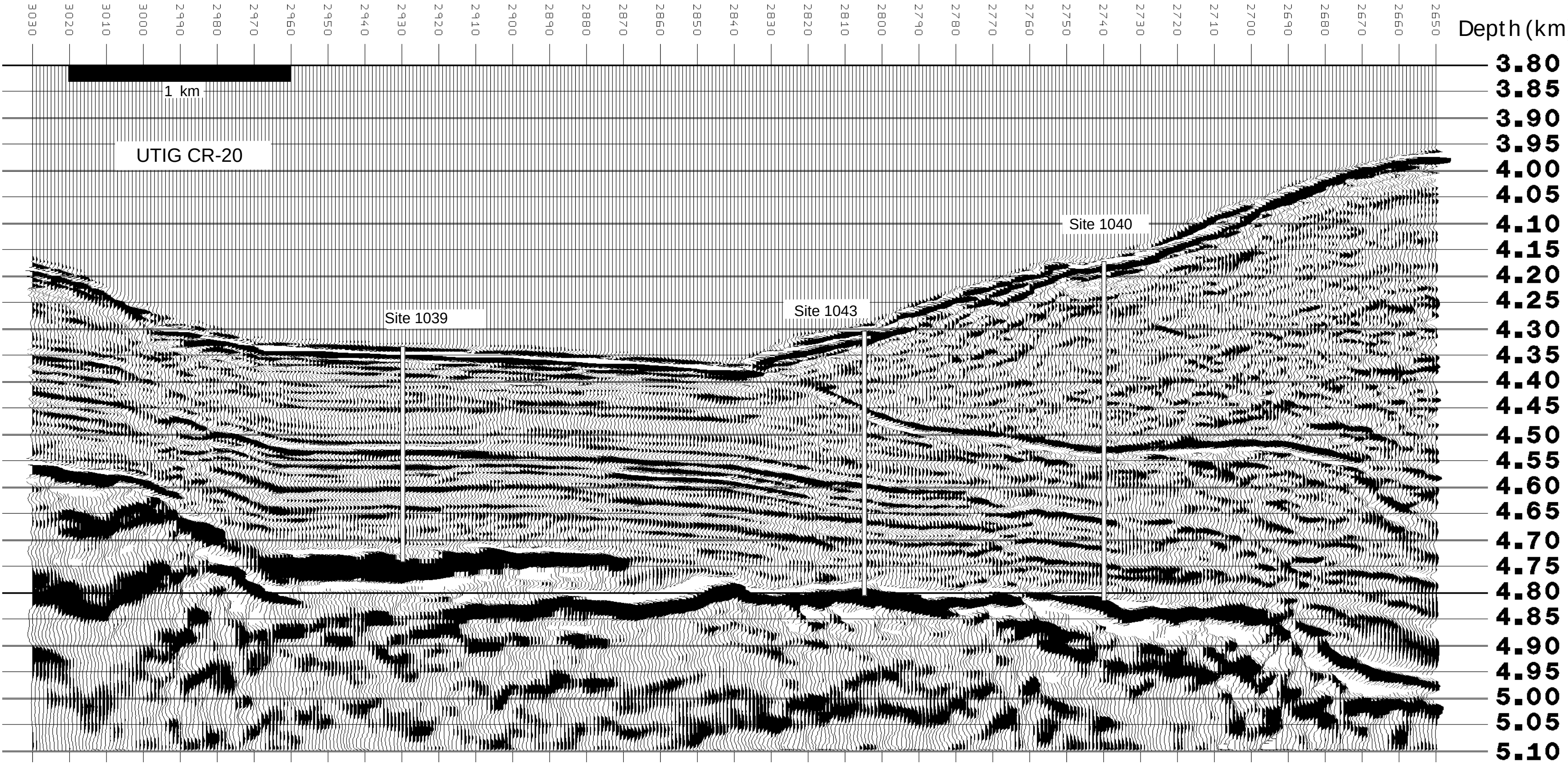
**Figure 9.** Graphical representation and summary plots of shipboard core and downhole measurements. LWD = logging while drilling, SGR = spectral gamma ray (total counts), and CGR = computed gamma ray (total counts minus contribution of uranium).

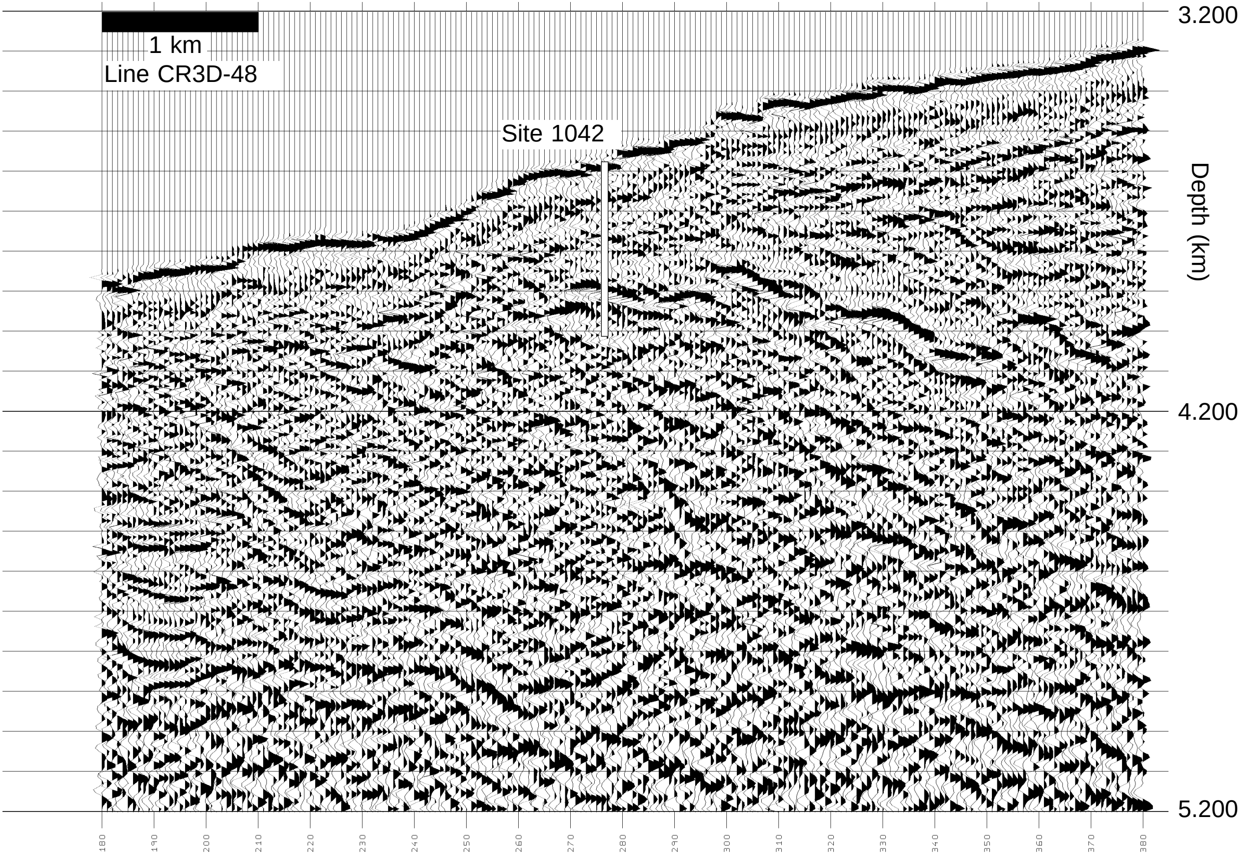
**Figure 10.** Graphical representation and summary plots of shipboard core and downhole measurements. LWD = logging while drilling, SGR = spectral gamma ray (total counts), and CGR = computed gamma ray (total counts minus contribution of uranium).


N
Nicoya Peninsula
Costa Rica
10° 00'
9° 30'
-86° 00'
-85° 30'
3-D SURVEY AREA
CR-4
CR-3
CR-5
565
CR-2
CR-7
CR-1
CR-6
km
0
10
20
30
Mexico
Honduras
Guatemala
Nicaragua
Caribbean Plate
Costa Rica
Panama
Map Area
Cocos Plate
20°
15°
10°
5°
-105°
-100°
-95°
-90°
-85°
-80°

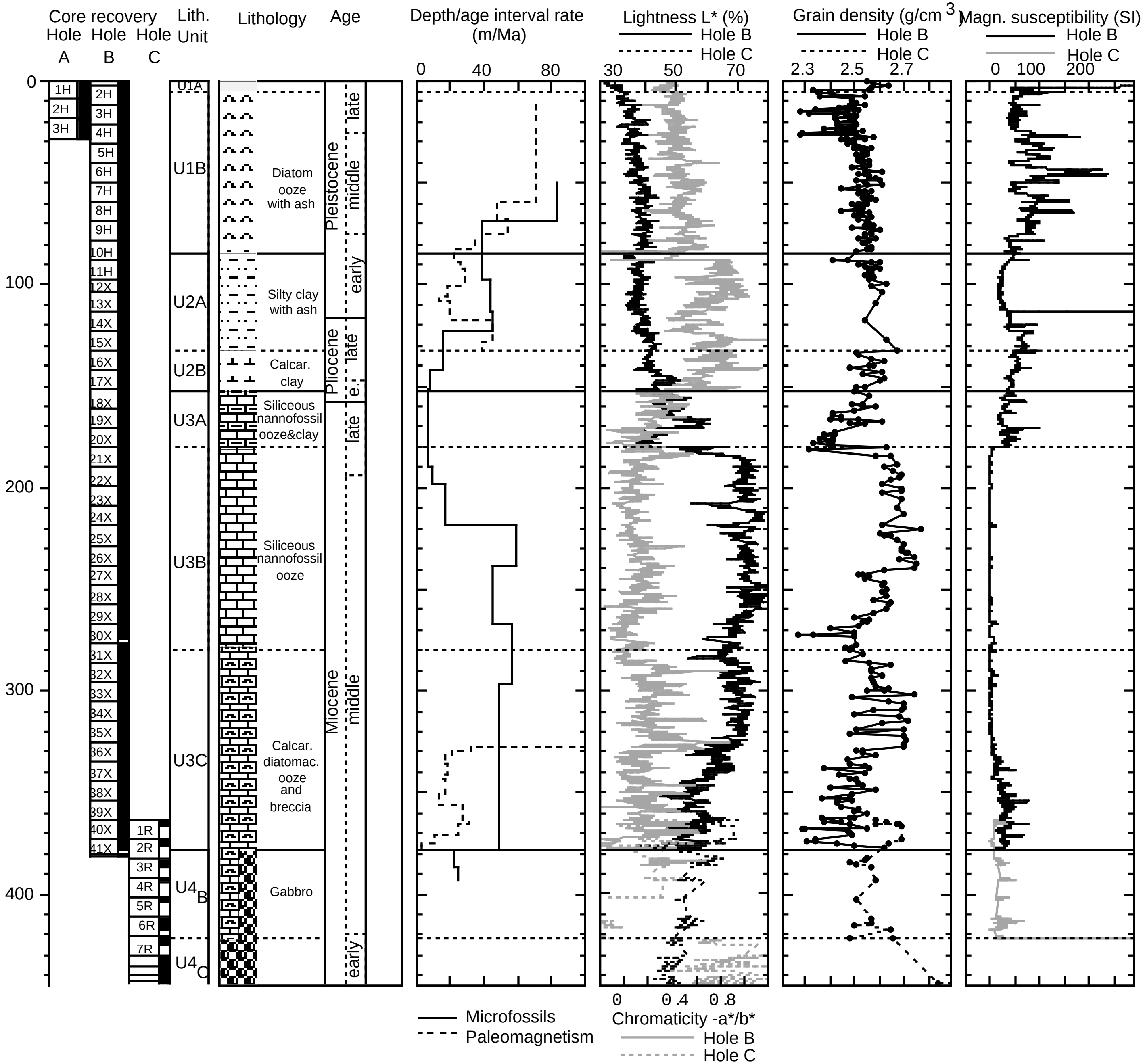

3200
3300
3400
3500
3600
3700
3800
3900
4000
4100
4200
4300
4400
4300
CR3D-177
CR-20
CR3D-450
CR3D-276
CR3D-48
Site 1041
Site 565
Site 1040
Site 1043
Site 1042
Site 1039
km
0
5
9° 46'
9° 44'
9° 42'
9° 40'
9° 38'
9° 36'
-86° 16'
-86° 14'
-86° 12'
-86° 10'
-86° 08'
-86° 06'


2 km
UTIGOR-20
TIME (S)
3.00
4.00
5.00
6.00
7.00
Site 1041
(projected)
Site 1040
Site 1039
Site 1043


UTIG CR-20
1 km
Depth (km)
Site 1039
Site 1043
Site 1040
3030
3020
3010
3000
2990
2980
2970
2960
2950
2940
2930
2920
2910
2900
2890
2880
2870
2860
2850
2840
2830
2820
2810
2800
2790
2780
2770
2760
2750
2740
2730
2720
2710
2700
2690
2680
2670
2660
2650
3.80
3.85
3.90
3.95
4.00
4.05
4.10
4.15
4.20
4.25
4.30
4.35
4.40
4.45
4.50
4.55
4.60
4.65
4.70
4.75
4.80
4.85
4.90
4.95
5.00
5.05
5.10



1 km
Line CR3D-48
Site 1042
3.200
4.200
5.200
Depth (km)
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380



Core recovery
Hole A
Hole B
Hole C
Lith. Unit
Lithology
Age
Depth/age interval rate (m/Ma)
Lightness L* (%)
Hole B
Hole C
Grain density (g/cm 3)
Hole B
Hole C
Magn. susceptibility (SI)
Hole B
Hole C
U1A
U1B
U2A
U2B
U3A
U3B
U3C
U4B
U4C
Diatom ooze with ash
Silty clay with ash
Calcar. clay
Siliceous nannofossil ooze&clay
Siliceous nannofossil ooze
Calcar. diatomac. ooze and breccia
Gabbro
Pleistocene
Pliocene
Miocene
late
middle
early
e.
Microfossils
Paleomagnetism
Chromaticity -a*/b*
Hole B
Hole C


Figure 6A

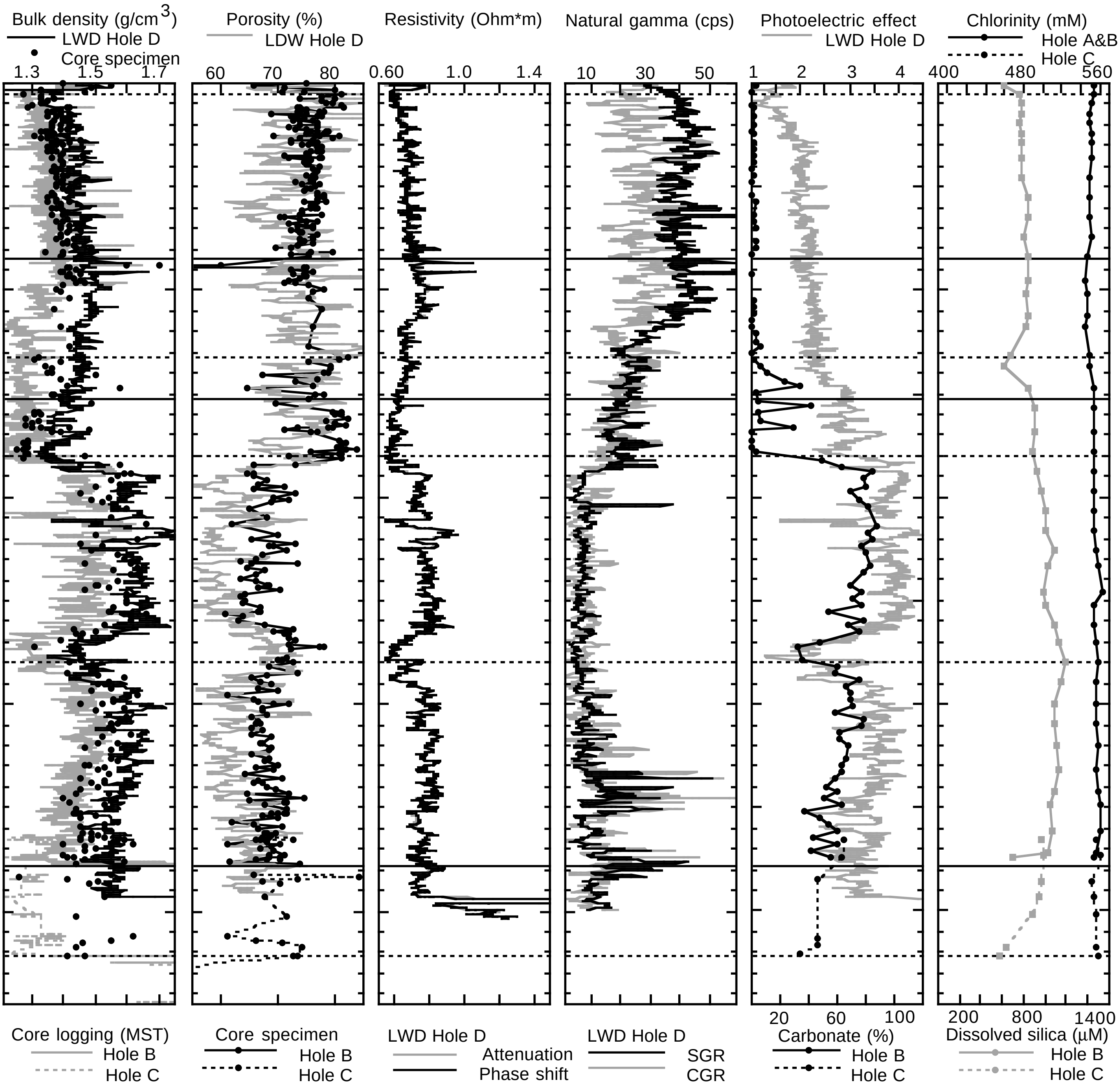
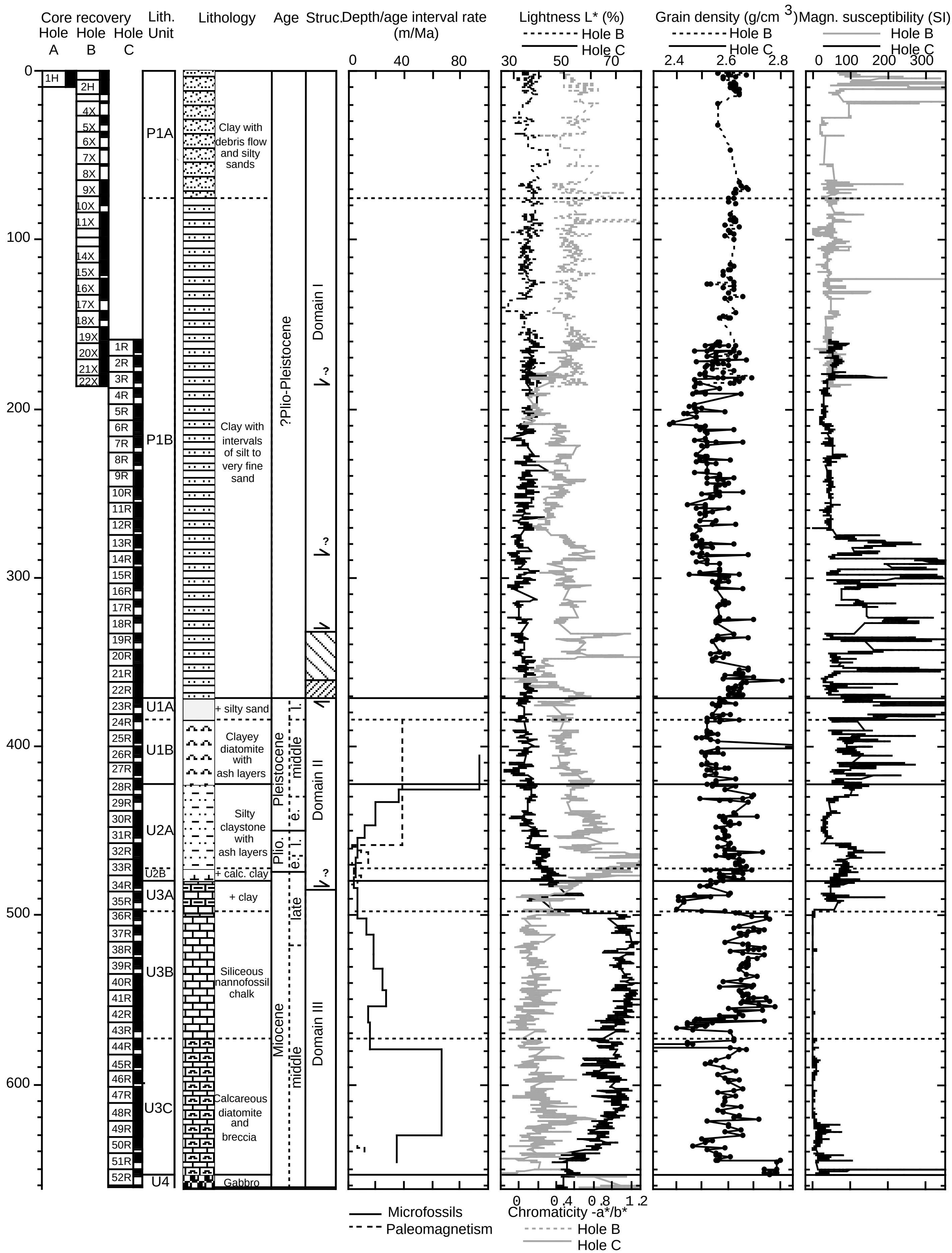
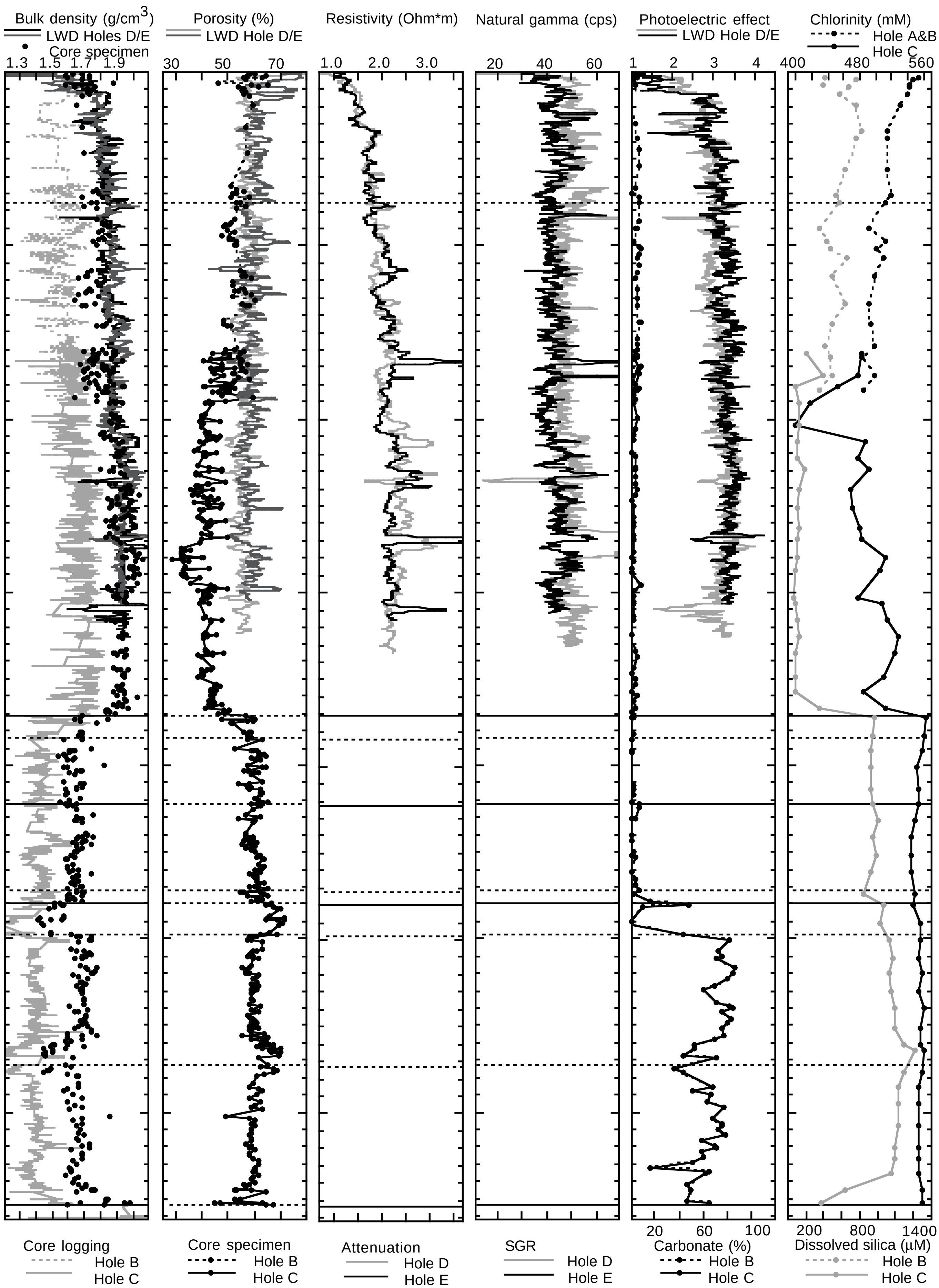

Bulk density (g/cm3)
LWD Hole D
Core specimen
1.3
1.5
1.7
Porosity (%)
LDW Hole D
60
70
80
Resistivity (Ohm*m)
0.60
1.0
1.4
Natural gamma (cps)
10
30
50
Photoelectric effect
LWD Hole D
1
2
3
4
Chlorinity (mM)
Hole A&B
Hole C
400
480
560
Core logging (MST)
Hole B
Hole C
Core specimen
Hole B
Hole C
LWD Hole D
Attenuation
Phase shift
LWD Hole D
SGR
CGR
20
60
100
Carbonate (%)
Hole B
Hole C
200
800
1400
Dissolved silica (µM)
Hole B
Hole C

**Figure 6B**



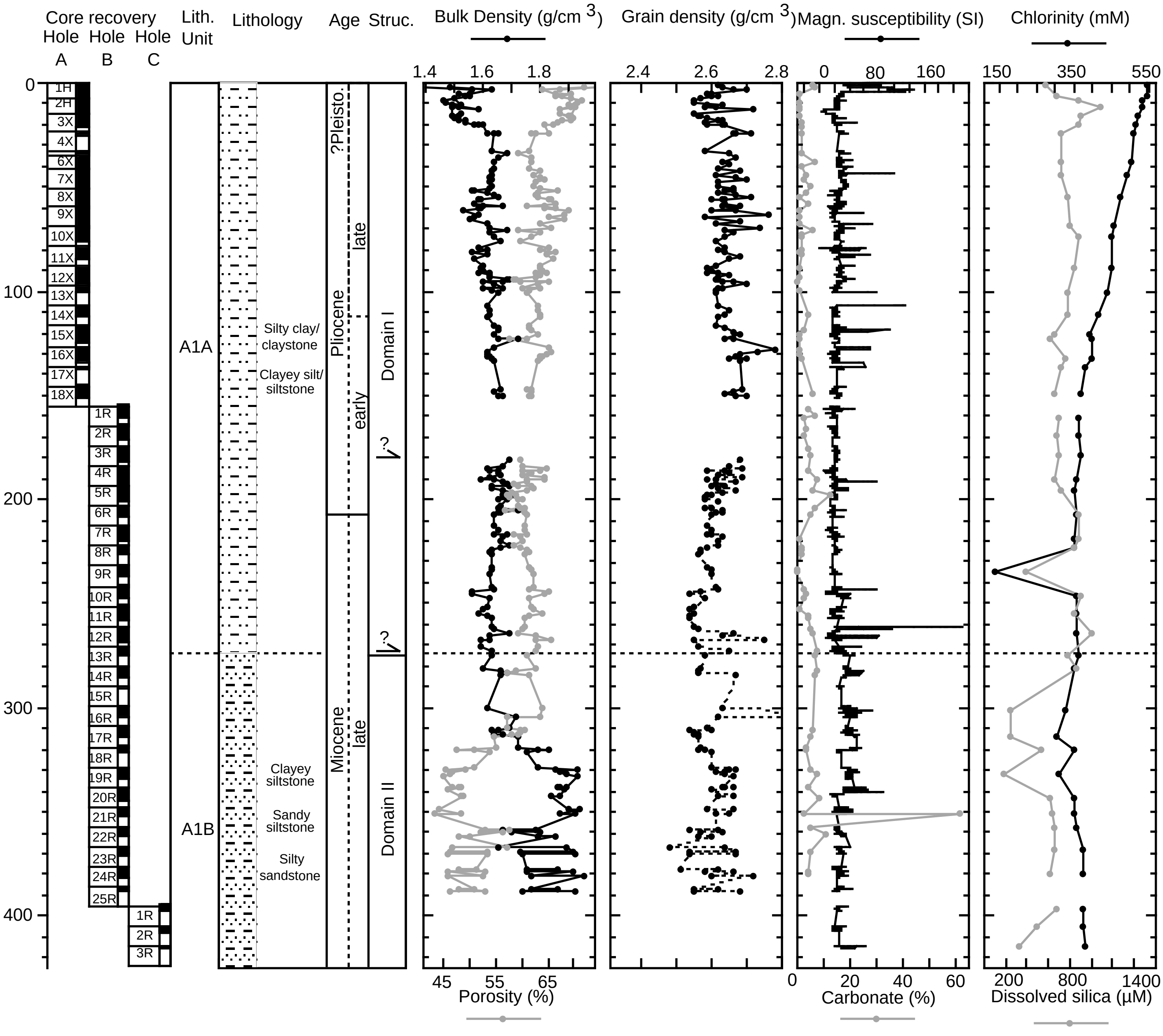
Core recovery
Hole A
Hole B
Hole C
Lith. Unit
Lithology
Age
Struc.
Depth/age interval rate (m/Ma)
Lightness L* (%)
Hole B
Hole C
Grain density (g/cm 3)
Hole B
Hole C
Magn. susceptibility (SI)
Hole B
Hole C
P1A
Clay with debris flow and silty sands
P1B
Clay with intervals of silt to very fine sand
?Plio-Pleistocene
Domain I
U1A
+ silty sand
U1B
Clayey diatomite with ash layers
U2A
Silty claystone with ash layers
U2B
+ calc. clay
U3A
+ clay
U3B
Siliceous nannofossil chalk
U3C
Calcareous diatomite and breccia
U4
Gabbro
Pleistocene
middle
Plio.
late
Miocene
middle
Domain II
Domain III
Chromaticity -a*/b*
Microfossils
Paleomagnetism
Hole B
Hole C


Figure 7A



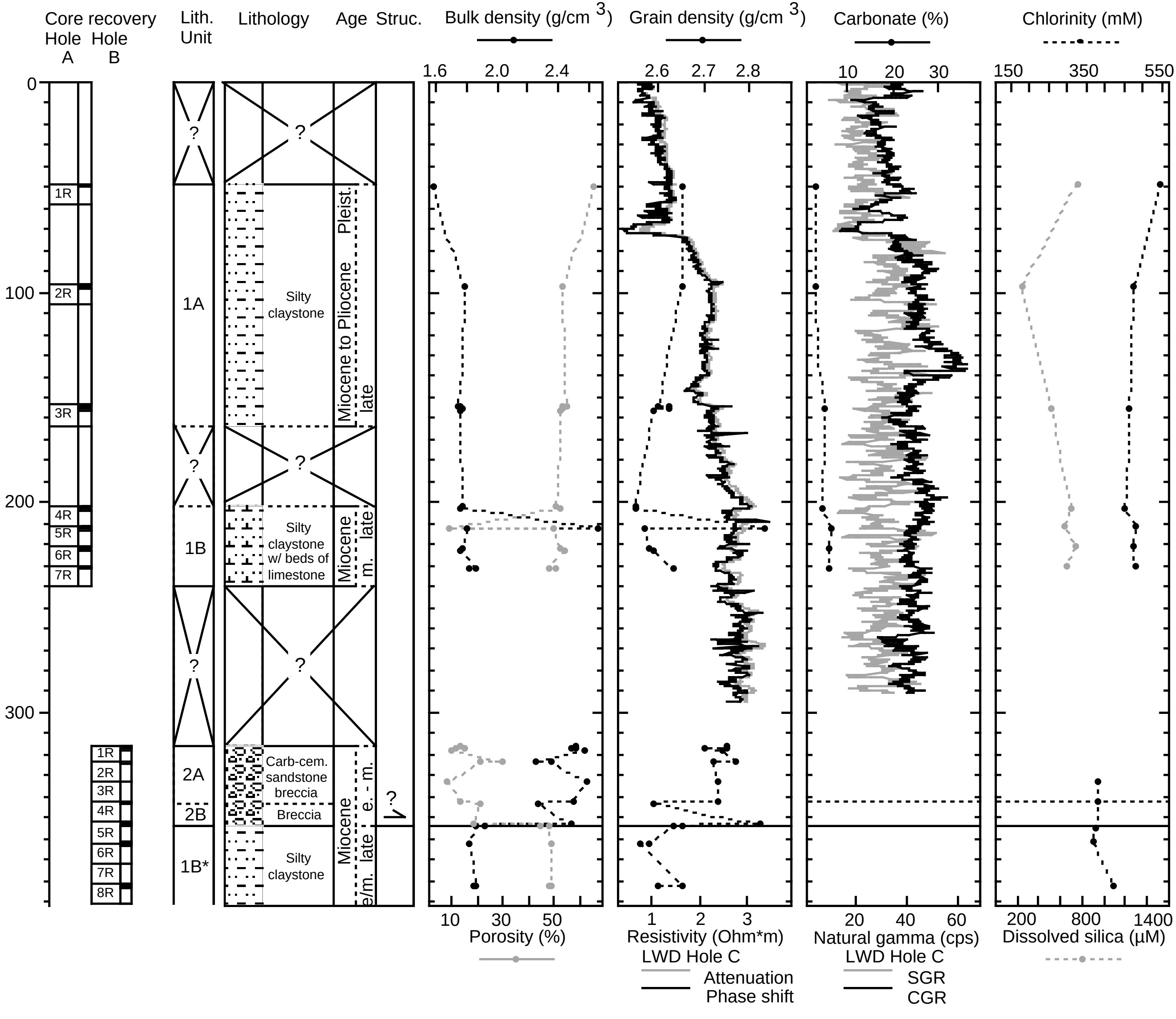
Bulk density (g/cm3)
LWD Holes D/E
Core specimen
1.3 1.5 1.7 1.9
Porosity (%)
LWD Hole D/E
30 50 70
Resistivity (Ohm*m)
1.0 2.0 3.0
Natural gamma (cps)
20 40 60
Photoelectric effect
LWD Hole D/E
1 2 3 4
Chlorinity (mM)
Hole A&B
Hole C
400 480 560
Core logging
Hole B
Hole C
Core specimen
Hole B
Hole C
Attenuation
Hole D
Hole E
SGR
Hole D
Hole E
20 60 100
Carbonate (%)
Hole B
Hole C
200 800 1400
Dissolved silica (μM)
Hole B
Hole C


**Figure 7B**



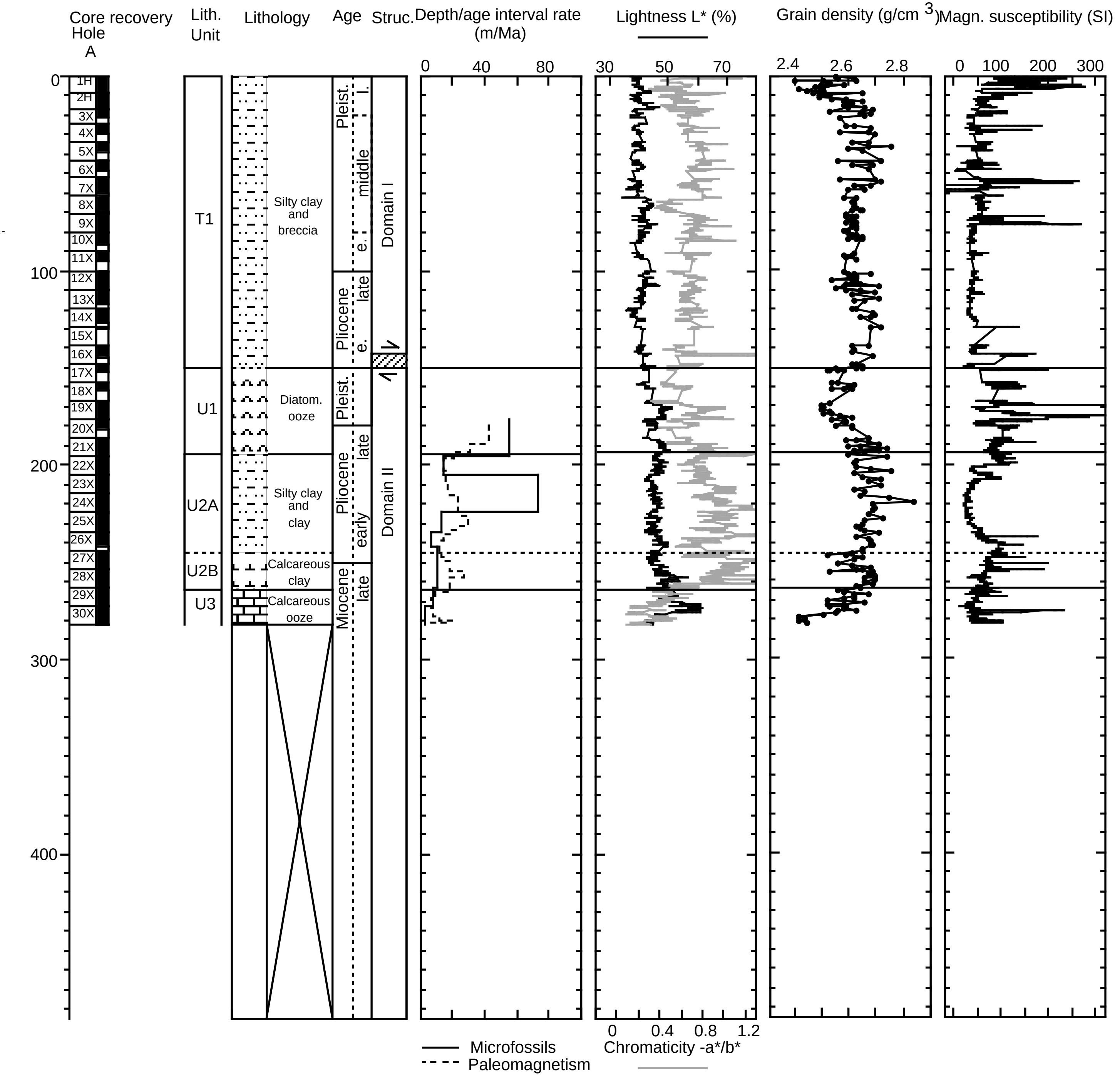
Core recovery
Hole A
Hole B
Hole C
Lith. Unit
Lithology
Age
Struc.
Bulk Density (g/cm 3)
Grain density (g/cm 3)
Magn. susceptibility (SI)
Chlorinity (mM)
A1A
A1B
Silty clay/ claystone
Clayey silt/ siltstone
Clayey siltstone
Sandy siltstone
Silty sandstone
?Pleisto.
Pliocene
late
early
Miocene
late
Domain I
Domain II
Porosity (%)
Carbonate (%)
Dissolved silica (µM)


Figure 8



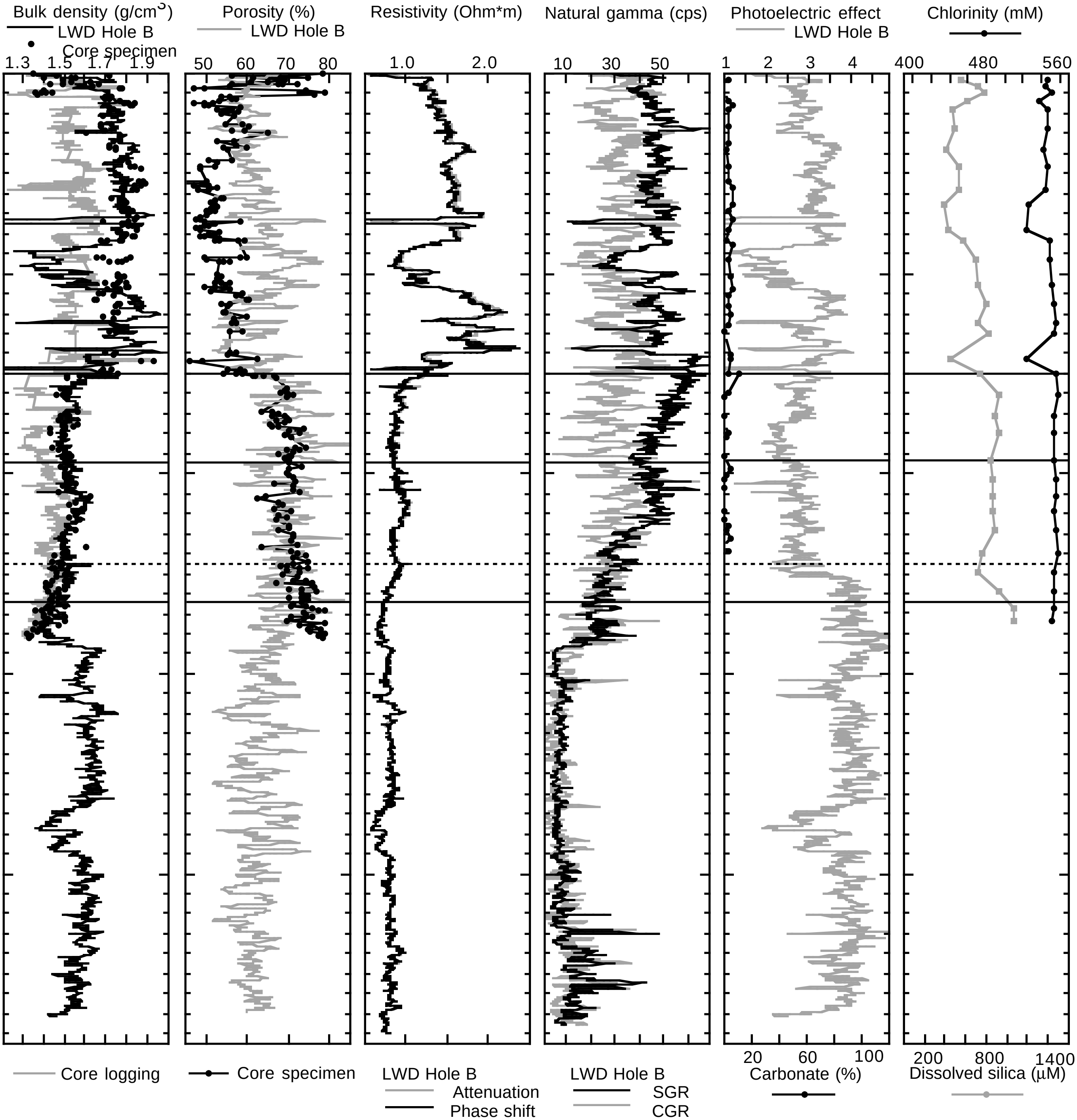
Core recovery
Hole A
Hole B
Lith. Unit
Lithology
Age
Struc.
Bulk density (g/cm 3)
Grain density (g/cm 3)
Carbonate (%)
Chlorinity (mM)
1.6 2.0 2.4
2.6 2.7 2.8
10 20 30
150 350 550
0
100
200
300
1R
2R
3R
4R
5R
6R
7R
8R
?
1A
1B
2A
2B
1B*
Silty claystone
Silty claystone w/ beds of limestone
Carb-cem. sandstone breccia
Breccia
Pleist.
Miocene to Pliocene late
Miocene late m.
Miocene e. - m. late e/m.
10 30 50
Porosity (%)
1 2 3
Resistivity (Ohm*m)
LWD Hole C
Attenuation
Phase shift
20 40 60
Natural gamma (cps)
LWD Hole C
SGR
CGR
200 800 1400
Dissolved silica (µM)


Figure 9



Core recovery Hole A
Lith. Unit
Lithology
Age
Struc.
Depth/age interval rate (m/Ma)
Lightness L* (%)
Grain density (g/cm 3)
Magn. susceptibility (SI)
T1
U1
U2A
U2B
U3
Silty clay and breccia
Diatom. ooze
Silty clay and clay
Calcareous clay
Calcareous ooze
Pleist.
Pliocene
Miocene
middle
late
early
Domain I
Domain II
Microfossils
Paleomagnetism
Chromaticity -a*/b*


Figure 10A



Bulk density (g/cm3)
LWD Hole B
Core specimen
1.3
1.5
1.7
1.9
Porosity (%)
LWD Hole B
50
60
70
80
Resistivity (Ohm*m)
1.0
2.0
Natural gamma (cps)
10
30
50
Photoelectric effect
LWD Hole B
1
2
3
4
Chlorinity (mM)
400
480
560
Core logging
Core specimen
LWD Hole B
Attenuation
Phase shift
LWD Hole B
SGR
CGR
20
60
100
Carbonate (%)
200
800
1400
Dissolved silica (μM)


**Figure 10B**

# OPERATIONS SYNOPSIS

The ODP Operations and Engineering personnel aboard *JOIDES Resolution* for Leg 170 were:

| | |
|---|---|
| Operations Manager: | Michael Storms |
| Schlumberger Engineer: | Steven Kittredge |

# SITE 1039
## (Proposed Site CR-1)

### Transit to Site 1039

The ship departed San Diego on 22 October at 1900 hr and set a southerly course to Proposed Sites CR-1 and CR-2. At 1200 hr on 26 October, medical evacuation of a roustabout took place by motor launch near Mazatlan, Mexico. An hour later the ship continued its site approach. Work begun or completed during the transit included general rig maintenance; installation of an air duct extension; standpipe pressure testing for Leg 174 hammer drill tests; installation of new top drive electrical umbilical; sandblasting, painting, and coating of helicopter pad; and changing the name identified on all ship's equipment in preparation for changing the official name of registry in Panama from SEDCO/BP 471 to *JOIDES Resolution*.

The ship arrived in the survey area at 0630 hr on 1 November 1996. The course was changed to allow a survey across both Sites 1040 (CR-2) and 1039. Vessel speed was reduced and the seismic gear was deployed 45 min before reaching the desired survey point. Both 200 $in^3$ and 80 $in^3$ water guns were deployed, however, a hose failed on the 80 $in^3$ gun 20 min into the survey. The technicians managed to repair the gun and get it back in the water before reaching Site 1039, but it was decided to continue using the 200 $in^3$ gun for consistency. Once the survey was completed, the ship returned to Site 1039 and prepared for drilling operations. A positioning beacon was dropped at 0930 hr on 1 November 1996, initiating operations at Site 1039.

### Hole 1039A

Due to the loss of the drill string at Leg 169, we used refurbished 5" drill pipe at Site 1038 and all new drill collars were picked up. In addition, a new seal bore drill collar for APC coring was picked up. All drill collars were rabbited and all reconditioned drill pipe was rabbited and strapped while running in the hole (RIH). When the drill collars were being made up, the iron roughneck developed a leak that necessitated using the rig tongs while it was repaired. One joint of reconditioned 5" drill pipe had to be set aside during the trip because the box tool joint was too short for make-up.

Hole 1039A was spudded at 0015 hr on 2 November 1996. The mudline core recovered 9.0 m, placing the drill pipe measured seafloor at 4362.5 m or 5.9 m above the corrected precision depth recorder (PDR) mudline depth of 4368.4 m. The plan was to only recover three piston cores from this hole. Coring was terminated after core 170-1039A-3H at a total depth of 28.0 mbsf. The drill string was pulled above the mudline and the vessel was immediately offset 10 m to the north in preparation for spudding Hole 1039B.

**Hole 1039B**

Hole 1039B was spudded at 0430 hr on 2 November. The first core recovered 2.02 m, established a seafloor depth of 4364.5 m or 3.9 m above the corrected PDR mudline for this site. APC coring continued with electronic core orientation (Tensor) beginning on Core 170-1039B-5H at a depth of 40.0 mbsf. Oriented APC coring was terminated with Core 170-1039B-11H at a depth of 97.0 mbsf after Cores 170-1039B-10H and 11H failed to fully stroke. A maximum overpull of 50 kips was experienced on Core 170-1039B-8H.

Coring continued using the XCB system to approximately 378 mbsf, where a drilling break was noted. The formation turned hard and drilling torque increased. Core 170-1039B-41X was pulled early after an 8.0 m advance. One meter of fill was detected on bottom prior to cutting Core 170-1039B-42X. The hole was advanced an additional 3.5 m to a total depth of 384.3 mbsf. Core 170-1039B-42X recovered gabbroic rock fragments.

Immediately after recovering the mudline core a Water Sampler Temperature and Pressure Probe (WSTP) was deployed with an Adara temperature measurement sub attached. The bit was positioned 10 m above the seafloor for taking a bottom-water sample and temperature reading. During recovery, the tool hung up at ~45 m above the seafloor. The tool came free after jarring it. It is assumed an errant APC shear pin stub wedged the barrel. The bottom-water sample had a salinity of 31.5, indicating surface-water contamination caused by the circulation used to pump the tools to bottom. Additional bottom-water deployments were done without circulation by running the wireline winch at slower speeds.

After taking three more piston cores, another WSTP fluid sample was taken after Core 170-1039B-4H at a depth of 30.5 mbsf. Apparently the wrong sub was installed for this run and the tool only sampled drill pipe circulating fluid. Another WSTP fluid sample was attempted after Core 170-1039B-7H at a depth of 59.0 mbsf. This time the tool hung up at ~1800 m below the ship during deployment. After 20 min of working the wireline jars, the overshot shear pin sheared and the barrel dropped to bottom. An attempt was made to collect data, but the temperature data indicated that the tool never penetrated the formation. It appears that the core line operator ran the tool in too fast, causing the barrel to float. When the line went slack on the XCB latch it allowed the latch dogs to come out enough to wedge the barrel. The WSTP system was not deployed for the remainder of the hole.

A total of 10 temperature measurements were taken, four with the Adara tool during APC coring and six with the DVTP during XCB coring. One Adara measurement was bad due to battery failure. One DVTP measurement was bad.

There were no significant hydrocarbon shows identified while drilling this hole. Methane ranged from 3 to 36 ppm and there was no ethane or propane identified with the exception of Core 170-1039B-10X at 84 mbsf where 110 ppm methane and 6 ppm ethane were recorded.

No mud sweeps were required during coring. Once coring had ceased, the hole was filled with 10.5 pound per gallon (lb/gal) mud and the drill string was tripped out of the hole. While pulling pipe, an overpull of 50 kips was taken at a depth of 4600 m. The drill string cleared the seafloor at 2400 hr, ending Hole 1039B.

**Operations at Site 1040 (CR-2)**

Before drilling deeper at Site 1039 using the RCB system, operations began at Site 1040 with the APC and XCB to save a pipe trip. See Site 1040 section for operations report.

**Hole 1039C**

The ship was moved 30 m south of Hole 1039A to spud Hole 1039C. An RCB bottom hole assembly (BHA) was made-up, and the RCB core barrel space-out was checked. The BHA was tripped in the hole and the top drive picked up placing the bit at a depth of 4313.0 m. The rig floor corrected PDR water-depth reading for this site was 4366.4 m. This was very close to the drill pipe measured depth of 4362.5 m for Hole 1039B. Due to the proximity of the two holes, the water depth for Hole 1039A was used for Hole 1039C.

After collecting a bottom-water fluid sample, a center bit was deployed, the pipe was tripped the remaining distance to bottom, and Hole 1039C was spudded at 0030 hr 9 November 1996. Drilling ahead with a center bit continued to a depth of 363.1 mbsf. A Sepiolite mud sweep was pumped at 344.0 mbsf to flush any remnant cuttings from the hole before RCB coring began with Core 170-1039C-1R. Coring continued through Core 170-1039C-7R where a gabbro intrusion was contacted at a drillers's depth of 4789.7 m (427.2 mbsf). This is ~46 m deeper than where gabbro was contacted at Hole 1039B. Coring continued through apparent sills and occasional thin (1.0 to 3.0 m thick) softer material, presumed to be sediments, with dramatically different drilling rates. However, no sediments were recovered from these intervals. Coring continued through Core 170-1039C-11R to a total depth of 4811.2 m (448.7 mbsf). Coring was terminated due to slow rate of penetration (0.5 to 1.0 m per hr) through the massive gabbroic units and an inability to recover the softer interlayered sediments.

No drilling mud was circulated during the coring operation. However, the hole was displaced with 10.5 lb/gal mud before pulling out. Overpulls of 20-30 kips were required while pulling out of the hole from 340.9 to 167.8 mbsf. The bit cleared the seafloor at 0115 hr, ending hole 1039C.

No temperature measurements were made in this hole and no WSTP fluid samples were taken except for a bottom-water sample collected prior to spudding the hole at approximately 50 m above the seabed. No significant hydrocarbon shows were identified while drilling this hole. Methane ranged from 3 to 4 ppm and neither ethane nor propane were identified.

**Operations at Site 1040 (CR-2)**

After completion of Hole 1039C, the ship returned to Site 1040 to drill the RCB Hole 1040C. During the transit back from Site 1039, the drill string was recovered and preparations for logging-while-drilling were made.

**Hole 1039D**

The ship was already positioned on the drilling location for Hole 1039D before the drill string and BHA were fully recovered aboard ship. Hole 1039D was to be spudded 50 m south of Hole 1039A.

Prior to making up the LWD tools the drill line was slipped and cut. It required 2.5 hr to make-up the LWD tools (CDR and CDN), load the nuclear sources, and make-up the cross-over sub between the Schlumberger Anadrill LWD drill collars and the modified connection on the ODP 8-1/4" drill collars. The remaining BHA was then made up and tripped to the seafloor with the drill string.

LWD Hole 1039D was spudded at 2330 hr on 18 November 1996. Drilling proceeded slowly at first until the BHA was fully buried. Overall, the rate of penetration (ROP) averaged 23.3 m/hr, which was very close to the maximum desired rate of 25 m/hr. A 3.5-m-thick hard layer was contacted at a depth of 395.0 mbsf. A reduced ROP of ~2.5 m/hr continued until breaking out at a depth of 398.5 mbsf. The original drilling rate resumed until severe torquing began approximately 5 m later. The bit became stuck on bottom during drilling, which required 40 kips overpull to free it. The driller immediately pumped a 30 bbls Sepiolite mud sweep and pulled above the hard layer. We reamed back through this area without incident until the bit was again on bottom, where torque increased dramatically and the bit became stuck on bottom again. The bit was freed with 40 kips overpull and the decision was made to terminate the LWD hole at a depth of 4769.5 m or 407.0 mbsf. The stabilizer on the LWD tool was suspected of causing the problem as it entered the hard layer. We felt that continued reaming of the area coupled with the use of generous mud sweeps would probably have corrected the problem. However, the co-chiefs felt that the main objectives were achieved, and the decision was made to pull out of the hole. The hole was subsequently filled with 10.5 lb/gal mud and the drill string was pulled clear of the seafloor by 0100 hr on 20 November 1996. The pipe trip continued to the surface where the nuclear sources were removed, and the LWD collars were laid out. The positioning beacon for this site was released/recovered and the bit cleared the rotary table at 0915 hr ending Hole 1039D and operations at Site 1039.

## SITE 1040
## (Proposed Site CR-2)

### Hole 1040A

After completion of Holes 1039A and B, the ship was moved to Site 1040 in dynamic positioning (DP) mode. The PDR reading of 4136.4 m water depth (corrected to the rig floor) was in error due to several diffracted side echos. After three water cores the drill string was lowered until a firm seafloor was identified ("felt") at a depth of 4191 m. The bit was positioned at a depth of 4188 m for Core 170-1040A-1H, but did not vent, indicating that the barrel did not fully stroke. In addition, 30 kips were required to extract the barrel from the seabed. When recovered, the barrel contained 9.58 m of material. Because a reliable mudline depth was not identified, it was decided that a new hole should be started.

### Hole 1040B

The bit was raised to a depth of 4185 m for spudding Hole 1040B. This time the barrel did fully stroke and only required 15 kips to extract. It recovered 5.51 m of core material establishing the mudline. Core 170-1040B-2H did not fully stroke but 8.5 m were recovered, and it was decided to attempt a third APC core. However, while attempting to drill out the rathole from Core 170-1040B-2H it became apparent that the hole could not be advanced without a core barrel in place. The APC barrel was recovered and an XCB core barrel was dropped at that point.

Coring with the XCB continued at a slow pace, because the drill collars making up the BHA were well above the seabed. Low bit weight and top drive rpm were used initially and each were increased as penetration advanced into the firm seabed. Even with the drill collars buried below the seabed the ROP was slow. Bit balling was suspected as the primary reason, because the material being cored was not hard enough to dictate such a slow ROP. Coring continued to Core 170-1040B-22X at 4379.2 mbrf when an XCB space sub failed leaving the XCB hard formation cutting shoe in the hole. The failure terminated coring in Hole 1040B at a total depth of 190.2 mbsf.

Head space methane levels varied from 44,529 to 53,995 ppm whereas ethane levels were 7 to 209 ppm. Propane varied from 0 to 6 ppm. Vacutainer data indicated over 100% methane in several cores. Core 170-1040B-16X was under high pressure when recovered, and core started being ejected out of the barrel at the rig floor immediately upon recovery. Standard precautions regarding safety were taken on the rig floor and core receiving platform.

A total of four DVTP measurements was taken beginning after Core 170-1040B-6X and continued on ~50 m intervals during XCB coring. The first DVTP measurement was bad.

Several mud sweeps were pumped in the lower 100 mbsf after fill (1.5 to 12.0 m) was identified between connections. Once coring ceased, the hole was filled with 10.5 lb/gal mud and the drill string was tripped out of the hole. While pulling pipe, an overpull of 30 kips was taken between 120.1 and 177.7 mbsf. The drill string cleared the seafloor at 0630 hr 8 November 1996.

**Operation at Site 1039 (CR-1)**

During the pipe trip, the vessel was offset 1.2 nmi back to Site 1039 to RCB drill Hole 1039C (see Site 1039 section). After completing Hole 1039C at 0115 hr on 11 November, the pipe was secured, placing the bit at 3988.1 m, for the DP transit back to Site 1040 to RCB spud Hole 1040C.

**Hole 1040C**

After spacing out the drill pipe to 4148.0 mbrf, the WSTP was deployed and a bottom-water sample was collected. The previously collected sample at this site was not good. A center bit assembly was then pumped downhole and the drill string was lowered to 4189.0 m. Hole 1040C was spudded at 0915 hr on 11 November 1996 and drilling continued to a depth of 4348.3 m

(159.3 mbsf) where RCB coring began. An overlap of approximately 30 m was desired with the previously drilled XCB hole at this site. Coring with the RCB began with Core 170-1040C-1R and continued until a hard layer near the décollement was contacted at the bottom of Core 170-1040C-19R at a depth of 342.2 mbsf. Cores 170-1040C-20R and part of 21R were considerably fractured and assumed to be in the décollement zone. Coring continued on from that point with the penetration rate continually increasing until it stabilized around 60-70 m/hr (8-9 minutes rotating time). The rapid ROP was attributed to coring through the underconsolidated sediments beneath the décollement. A gabbro sill was contacted in Core 170-1040C-52R at a depth of 657.0 mbsf and the last core recovered was 170-1040C-53R at a total depth of 665.0 mbsf.

Some drill string drag was identified while drilling Hole 1040C. The Tensor electronic multishot tool was deployed and drift measurements were taken while retrieving Core 170-1040C-43R. Measurements were taken on bottom at 4750 m (573.1 mbsf) and 100 m above bottom at 4650 m (473.1 mbsf). The hole angle was 18.5° and 17.5°, respectively. It is assumed that the hard seafloor, coupled with a noncentralized coring assembly, contributed to the build-up of angle. A complete drift survey was conducted while recovering Core 170-1040C-53R. The data indicated a dog leg at approximately 440 mbsf. Hole deviation continued to build from 8.25° at 40 mbsf to 18.5° at 440 mbsf and then declined to 14° at 640 mbsf.

A total of 350 bbls of Sepiolite drilling mud was circulated during the coring operation, including spotting mud around the drill collars during DVTP temperature measurements. A bottom-water temperature was taken with the Adara tool during the WSTP deployment and then a total of six DVTP measurements were taken. These began after Core 170-1040C-7R and continued in ~50 m intervals during RCB coring. The last DVTP measurement was taken after Core 170-1040C-32R, because it was deemed unwise to risk the drill string and hole by sitting on bottom without circulating.

Above the décollement (Cores 170-1040C-1R to 19R), head space methane levels varied from 4818 to 116,556 ppm, whereas ethane levels were 5 to 65 ppm. Propane varied from 3 to 24 ppm.

Vacutainer data indicated 50%-100% methane, whereas $C_2$ ranged from 226 to 1561 ppm and $C_3$ was 0 to 169 ppm. Heavier hydrocarbons like IC4 ranged from 0 to 26 ppm and IC5 was 0 to 9 ppm. There was geochemical evidence of hydrate in situ above the décollement, however, no hydrate was recovered in the cores. The hydrate stability zone for this site extended all the way to basement.

Below the décollement (Cores 170-1040C-20R to 51R), head space methane levels dropped from 12,724 to 4 ppm whereas ethane levels went from 15 to 0 ppm. Propane varied from 19 to 0 ppm, with nothing over 1 ppm after Core 170-1040C-21R. The only vacutainer data recovered below the décollement was for Core 170-1040C-21R. Methane indicated 98% while $C_2$ was 781 ppm and $C_3$ was 76 ppm. Heavier hydrocarbons like IC4 and IC5 registered 29 ppm and 1 ppm, respectively. After that there was not enough gas to warrant vacutainer analysis. There was no geochemical evidence of hydrate in situ below the décollement.

Because there was interest in getting wireline sonic and Formation MicroScanner (FMS) logs (not available through LWD), we decided that if the hole remained open another wiper trip would be made followed by two logging runs . A wiper trip was completed to 4278.0 m (89.0 mbsf) noting a maximum overpull and drag of 40 kips. The bit was released and the mechanical bit release (MBR) sleeve was reverse shifted to close off the dog ports. The hole was displaced with 220 bbls of Sepiolite mud and the open ended pipe was positioned for logging at 4292.8 m (103.8 mbsf).

The first suite of logs (sonic) was only able to advance to 129.2 m below the bit before being halted by a bridge or ledge in the hole. This interval was logged and the tools were recovered ending the wireline logging attempt. The open ended pipe was run to a depth of 4480.1 m (291.1 mbsf) where the drag reached 35 kips. The trip was halted at that point and the hole was displaced with 80 bbls of 10.5 lb/gal mud. The drill pipe was pulled out of the hole and cleared the seafloor at 0400 hr. The ship was then DP offset back to Site 1039 while the pipe trip continued to the surface. The MBR reached the rig floor at 1200 hr on 18 November 1996, ending Hole 1040C.

**Operations at Site 1039 (CR-1)**

The ship returned to Site 1039 to drill the LWD Hole 1039D, which was spudded at 2330 hr on 18 November 1996. An operational summary is given in the Site 1039 section. Hole 1039D was ended at 0915 on 20 November.

**Hole 1040D**

The LWD tools from the previous hole were removed from the rig floor and new ones with fresh batteries were madeup while the ship was moved in DP mode to Site 1040. Once the nuclear sources were loaded, the CDN and CDR tools were run to bottom. A Smith tricone F4 bit was run with 12/32" and 14/32" jets installed to allow coring of a limited amount of igneous rock. LWD Hole 1040D was spudded at 1830 hr 20 November 1996. Because of the very hard seafloor, very controlled drilling parameters were used. Weight-on-bit was limited to 2-4 kips and the rotary speed was 30-45 rpm. Penetration rate for the first 40 m was 7.9 m/hr. Drilling proceeded relatively well, although the penetration rate (average 14.6 m/hr) was hampered by continual bit balling and suspected balling around the LWD stabilizer. At a depth of 279.8 mbsf, pump pressure and torque increased and generous Sepiolite mud sweeps did little to correct the condition. Drilling continued to a depth of 308.7 mbsf while hole conditions continued to deteriorate. A wiper trip was made to 103.6 mbsf with overpulls of 20 kips and 300-500 psi back pressure prevalent to 214.0 mbsf. On the way back to bottom there were 10-15 kips of pipe drag in the hole. In all, a total of 10-1/2 hr of remedial work was attempted to stabilize the hole. Drilling resumed and the hole was deepened to a depth of 4526.5 m (337.5 mbsf). At each connection, we took care to double-ream the hole. Continued hole trouble eventually resulted in stuck pipe, which forced a halt to drilling operations at a total depth of 337.5 mbsf. An overpull of 50 kips coupled with 800 amps torque was required to free the drill string.

Suspected hole deviation and possible formation overpressure was suspected as the primary cause for failure to achieve the depth objective. After pulling pipe to a "safe" depth of 4475.0 m (286.0 mbsf), the Tensor electronic multishot was deployed for a drift survey of the hole. Because of poor hole conditions and the nuclear sources installed in the LWD tools, the lowest data point recorded was at 271.0 mbsf, which was 66.5 meters above hole TD. Drift data indicated that the hole was started at an angle of 7.6° from vertical and proceeded to straighten with depth. The angle was 2.9° at a depth of 271.0 mbsf. After completing the survey, the pipe stuck again. This time 25 kips overpull and 700 amps torque were required to free the string. The hole was displaced with 10.5 lb/gal mud and the drill string tripped back to the surface. Once the nuclear sources were removed from the LWD tools, the bit was pulled to the rig floor. The log data were transferred from the tools to a workstation computer for plotting and analysis. Subsequent analysis of the LWD log data by the logging engineer confirmed a probable overpressured zone in the hole extending from a depth of 281.0 mbsf to TD.

**Hole 1040E**

Hole 1040E was located 30 m north of Hole 1040D. We made another attempt to get LWD logs down to and across the décollement. The CDN and CDR tools were changed out for those with fresh batteries, and the same Smith FDGH tricone drag bit that was used successfully in Hole 1039D was run. We hoped that a faster penetration rate and a straighter hole would allow this hole to reach a deeper TD. Drilling in this hole proceeded at a much faster ROP with this more efficient drag-type bit. The first 221.9 m were drilled at an average ROP of 30.6 m/hr. Drilling continued without incident until a depth of around 280 mbsf. At that point hole problems similar to those encountered in Hole 1040D began. Pump pressure (400-500 psi back pressure) and drilling torque (400-500 amps) were higher and tight hole (20-30 kips) conditions were the rule rather than the exception. The hole was advanced to a depth of 4507.4 m (318.4 mbsf) when the drill string began sticking every time a connection was made and it was apparent that the hole could not be drilled much farther. The hole was terminated to avoid the potential loss of the expensive LWD tools. The drill string was raised to 247.9 mbsf and the hole was displaced with 10.5 lb/gal mud. The pipe was pulled clear of the seafloor at 1130 hr. The vessel immediately got underway in DP mode for Site 1041 while the LWD tools were removed from the rig floor and the APC/XCB BHA for the next site was made up.

## SITE 1041
## (Proposed Site CR-3)

### Hole 1041A

Site 1041 is located 6.2 nmi landward of Site 1040. Hole 1041A was spudded at 0430 hr on 25 November 1996. The first APC was shot from a depth of 3315.0 m and recovered 7.4 m of core establishing a mudline of 3317.2 m. APC Core 170-1041A-2H did not fully stroke and required 40 kips overpull to extract the core from the stiff sediment beneath the seafloor. An XCB core barrel was dropped and 2 hr were required to drill down to 14.3 mbsf. Because the drill string came clear of the seabed after Core 170-1041A-2H, the interval from 0 to 14.3 mbsf had to be re-drilled. The wash barrel that was in place was pulled because of the extended rotating time. XCB coring commenced with Core 170-1041A-3X and continued through Core 170-1041A-18X to a total depth of 155.1 mbsf. Coring was suspended there due to slow ROP (8.9 m/hr for last 2 cores), poor core quality (natural fractures in the clay/silt stone were highly disturbed by the drilling process), and steadily deteriorating hole conditions (fill, elevated pump pressure, and breakout torque after each connection). Gas-hydrate nodules were recovered from Cores 170-1041A-15X through 18X and fissility was observed in most cores.

The DVTP was deployed a total of three times at depths of 45.7 mbsf, 87.9 mbsf, and 126.4 mbsf. One run, at a depth of 78.2 m, recovered erroneous data. Hydrocarbon vacutainer analysis indicated that the hydrate-rich sediments had 0.8% to 1% methane.

Two 30 bbl Sepiolite mud sweeps were made in the hole at depths of 126.4 mbsf and 135.5 mbsf, respectively. The hole was displaced with 52 bbls of 10.5 lb/gal mud prior to retrieving the drill string. Once clear of the seafloor, 1.25 hr were taken to slip and cut the drilling line and the drill string was recovered back to the ship.

### Hole 1041B

While the RCB BHA was being made up the vessel was offset 30 m to the east. The drill string was tripped to the seafloor and Hole 1041B was spudded at 1600 hr 27 November 1996. With a center bit in place, the bit was advanced to a depth of 155.0 mbsf. No overlap was desired between Holes A and B coring intervals as the objective of the hole was to advance to the high-amplitude reflector at about 500 mbsf as fast as possible. The drilled interval took a total of 6.75 hr and an average ROP of 37.5 m/hr was achieved. RCB coring began at that depth and continued through Core 170-1041B-25R to a total depth of 395.6 mbsf. A distinct difference in formation was identified in Core 170-1041B-15R at an approximate depth of 290 mbsf. More fill was identified between connections and higher torque was required after picking up the pipe from the dual elevator stool. Once rotation and circulation was established, however, the drilling parameters remained normal and stable. Hole conditions got progressively better during the subsequent 12 hr of coring.

After cutting Core 170-1041B-25R, the driller used a sweep of Sepiolite drilling mud to flush the hole. At this point the pipe became stuck ~12 m off bottom. Various combinations of circulation pressure, torque, and overpull were used to work the pipe free. The pipe was worked with up to 950 amps (28,000 ft-lbs) of torque, 40 kips downward drag, and 100 kips overpull, all with 500 psi back pressure. After 1 hr, the pipe came free using 200 kips of overpull. No torque was in the string at the time. With the top drive still in the string, the pipe was pulled to a depth of 3565.4 mbrf (248.3 mbsf) where all back pressure was lost and drilling parameters again became normal. At that point the hole was displaced with 74 bbls of 10.5 lb/gal mud and the drill string was pulled to clear the mudline.

During the course of drilling and coring in this hole, eight 30 bbls Sepiolite mud sweeps were pumped at depths of 203.1 mbsf, 241.6 mbsf, 270.5 mbsf, 289.9 mbsf, 309.2 mbsf, 338.0 mbsf, 366.8 mbsf, and 395.6 mbsf. The DVTP was deployed twice. The first run was made after Core 170-1041B-2R at a depth of 174.2 mbsf and did not obtain good data. A second run was made after Core 170-1041B-3R at a depth of 183.8 mbsf.

As in Hole 1041A, gas hydrate was dispersed throughout the recovered core material beginning with Core 170-1041B-1R and continuing through Core 170-1041B-25R. As the formation became more indurated and the porosity decreased, the hydrate was less plentiful but still present to some extent primarily within naturally occurring fractures. Hydrocarbon vacutainer analysis indicated that the hydrate-rich sediments had 0.7% to 1% methane. Ethane values ranged from 1214 ppm to a low of 274 ppm. Propane values ranged from 4 to 29 ppm. Only two cores registered higher hydrocarbons. Cores 170-1041B-9R and 170-1041B-11R identified 1 ppm IC4.

**Hole 1041C**

The ship was offset 100 m southeast of Hole 1041B and Hole 1041C was spudded with a center bit in place. Drilling advanced to a depth of 395.0 mbsf in 21.0 hr achieving a penetration rate of 28.0 m/hr. It became apparent even during the course of the drilled interval that the hole was deteriorating. The pump strokes required to displace mud sweeps continually increased above the calculated amount, indicating the hole was enlarging with time. RCB coring advanced the hole from 395.0 mbsf to a depth of 423.8 mbsf (Core 170-1041C-3R). Before Core 170-1041C-3R could be recovered the drill string again became stuck. A total of 30 min was taken to work the pipe with torque of 900 amps, 40 kips drag, 100 kips overpull, and 200-400 psi back pressure. The pipe was eventually pulled free with 225 kips of overpull. The drill string was pulled to a depth of 363.8 mbsf and the hole was displaced with 115 bbls of 10.5 lb/gal mud. The drill string was pulled clear of the seafloor ending Hole 1041C. The total depth of the hole (423.8 mbsf) was short of the desired scientific objective estimated at ~550 mbsf. Because hole deterioration continued to present a major drilling problem, an alternate site, Site CR-7, was chosen as the next location. The geologic environment was expected to be the same as that drilled at Site 1041, but the depth of the target reflector was estimated to be located at a shallower depth of 325 mbsf.

During the course of drilling and coring this hole, Sepiolite mud sweeps were pumped at depths of 280.2 mbsf (40 bbls), 309.1 mbsf (30 bbls), 337.9 mbsf (30 bbls), and 366.8 mbsf (30 bbls). There were no temperature measurements or water samples recovered from this hole.

Hydrocarbon vacutainer analysis indicated that the sediments recovered from the three cores had 71,080-10,474 ppm methane. Ethane values ranged from 83 ppm to a low of 21 ppm in Core 170-1041C-3R. Propane values ranged from 1-5 ppm. No higher hydrocarbons were present.

# SITE 1042
# (Proposed Site CR-7)

**Hole 1042A**

The ship proceeded in DP mode from Site 1041 to Site 1042. The move was made in 5-3/4 hr and a positioning beacon was deployed at 2030 hr 1 December 1996. The pipe was tripped to a depth of 3529.0 m where the WSTP/Adara tools were deployed for a bottom water sample and temperature measurement. After recovering the WSTP assembly, a center bit was dropped and the pipe was lowered slowly while "feeling" for bottom. The corrected PDR depth of 3529.0 m was thought to be inaccurate because of the seafloor geometry. Seismic survey data corrected to the rig floor indicated the seafloor should be at ~3589.4 m. Bottom was tagged with the drill pipe at 3605.0 m and this depth was used as the official seafloor depth.

Drilling proceeded to a depth of 48.7 mbsf where the center bit was recovered and an RCB core barrel was dropped. Permission was received to allow spot coring of this hole in 50-m increments to a depth of ~200 mbsf. RCB cores were recovered from depths of 48.7 to 57.8 mbsf (170-1042A-1R), 96.1 to 105.7 mbsf (170-1042A-2R), and 153.7 to 163.3 mbsf (170-1042A-3R). Core recovery was poor as is often the case during spot coring operations. An RCB center bit assembly was used for the drilled intervals between cores. DVTP temperature measurements were attempted after Cores 170-1042A-1R and 170-1042A-2R, but the data was bad.

Continuous RCB coring began with Core 170-1042A-4R at a depth of 201.8 mbsf and continued through Core 170-1042A-7R to a depth of 3845.1 (240.1 mbsf). Cores 170-1042A-6R and 7R were cut with 300-400 amps of torque and 300-400 psi, which was the beginning of hole problems that were never corrected. A total of 12 hr was spent conducting remedial work on the hole. Wiper trips, hole sweeps with Sepiolite and Quick Sweep material, and washing/reaming were all tried to no avail. Stalling torque, persistent back pressure, and a general inability to clean the hole eventually led to abandonment of further drilling/coring attempts at 2245 hr on 3 December 1996. A total depth of 240.1 mbsf was achieved, which was short of the desired 325 mbsf objective. The cause of the hole trouble was thought to be an inability to properly clean

cuttings out of the hole (lost circulation), aggravated by formation overpressure, and a high angle fault zone at ~180 mbsf.
The hole was displaced with 70 bbls of 10.5 lb/gal mud and the drill string was pulled clear of the seafloor. Sepiolite mud sweeps of 30 bbls each were pumped at depths of 201.8 mbsf, 211.3 mbsf, and 220.9 mbsf. In addition, a 50 bbls Quick Sweep pill was pumped at a depth of 229.0 mbsf. Although the material was extremely viscous when pumped, it seemed to have little benefit over the standard Sepiolite sweeps. A pump pressure increase of 100-150 psi was all that was noted as the material came out of the bit and into the annulus of the hole.

Some higher order hydrocarbons were identified in this hole but not in large quantities. The numbers dropped off rapidly after drilling through the fault zone source. Hydrocarbon vacutainer analysis for Cores 170-1042A-3R and 4R above or within the fault identified 837,897 and 723,706 ppm methane, 829 and 792 ppm ethane, and 172 and 292 ppm propane, respectively. Higher hydrocarbons included IC4 = 40 and 79 ppm, NC4 = 5 and 4 ppm, and IC5 = 12 and 6 ppm. Only in Core 170-1042A-4R were NC5 (1 ppm) and IC6 (4 ppm) measured. Data from Cores 170-1042A-5R through 7R (no data on 170-1042A-6R), which are located below the fault zone, identified 238,342 and 70,307 ppm methane, 302 and 112 ppm ethane, and 122 and 28 propane respectively. Higher hydrocarbons included IC4 = 47 and 11 ppm, NC4 = 2 and 1 ppm, and IC5 = 3 and 7 ppm, and NC5 = 0.5 and 1 ppm.

**Hole 1042B**

Because we failed again to reach the high-priority target in Hole 1042A, a more radical solution was devised. We thought at least part of the drilling complications in the hole might be the result of inadequate annular clearance between the hole wall (nominal 9-7/8" diameter) and the drill collars/BHA (8-1/4" outside diameter). In fact, from a depth-achieved perspective one of the most successful holes of the leg was a hole drilled with the XCB drill bit, which drills a larger diameter (11-7/16") hole. We decided to make one last attempt to reach a minimum depth of 325 mbsf by drilling a 12-1/4" tricone drill bit hole before reentering for coring.

The ship was offset 50 m to the southeast while the BHA was made up. The assembly was tripped to the seafloor and Hole 1042B was spudded at 1615 hr 4 December 1996. The mudline was estimated at 3592.5 m, which was somewhat higher than at Hole 1042A. The 12-1/4" tricone bit rapidly drilled to a depth of 316.0 mbsf at an average ROP of 34.5 m/hr. There were no problems spudding with the drilling jars and correspondingly longer BHA (1 extra stand of drill collars). There were no hole problems experienced during the drilling. With the bit on bottom at 316.0 mbsf all parameters were normal. There was no evidence of overpressure and drilling torque was smooth and constant at 100 amps.

A wiper trip identified tight hole from 3830.0 m (237.5 mbsf) to 3797.0 m (204.5 mbsf). A drilling torque of 500 amps and overpulls of 30 kips were initially seen but were reduced to normal after working the pipe through the affected area. Sepiolite mud sweeps of 30 bbls each were circulated at depths of 90.6, 119.5, 148.2, 177.1, 205.9, and 316.0 mbsf while drilling the 12-1/4" hole. After the wiper trip, the hole was displaced with 180 bbls of Sepiolite drilling fluid and the pipe was tripped back to within 100 m of the surface. The hole was again tight through 204.5 to 237.5 mbsf with the same 500 amps of torque and 30 kips of overpull required.

A free fall funnel (FFF) was made up and deployed, and it was followed by the subsea TV camera (VIT frame). The bit was observed with the TV as it was pulled clear of the FFF and seafloor at 1530 hr 5 December. The drill string was tripped back to the surface while recovering the subsea TV. Then the drill string was tripped back to the seafloor with an RCB BHA and the drilling line was slipped and cut before attempting reentry. The search for the FFF and subsequent vessel maneuvering took 2 hr. The pipe was RIH without picking up the top drive until encountering an obstruction at 151.5 mbsf. Drag was 10-15 kips so the pipe was pulled back to a depth of 128.0 mbsf and the top drive was picked up at that point. The subsequent trip required heavy reaming all the way to bottom. Initially there were two circulating pumps online at 75 strokes per minute (spm) each. Eventually this was cut back to a single pump at 75 spm to reduce the back pressure and hydraulic pump effect resulting from the very tight formation. The rate of progress increased, torque was reduced, and hole problems declined with the use of a single circulating pump.

Once on bottom, RCB coring commenced and continued to a depth of 90.7 mbsf through alternating green mudstone and brecciated sandstone cemented with carbonates. A second wireline run was required to recover Core 170-1042B-4R when the overshot shear pin failed. Core 170-1042B-7R was recovered with an empty liner, so the chisel type bit deplugger was deployed. After recovering the deplugger, a 30 bbls Sepiolite mud sweep was pumped. Pump pressures increased by 400 psi when the pill came out of the bit. This was accompanied by elevated torque as well. Hole conditions remained acceptable for the cutting of Core 170-1042B-8R. However, the consensus of opinion was to stop coring at that point before hole conditions deteriorated. Core recovery was a poor 11.9% for the eight cores recovered, because coring parameters had to be set to optimize hole stability.

The hole was displaced with 85 bbls of 10.5 lb/gal mud, the top drive was set back, and the pipe was recovered back to the surface. The bit cleared the seafloor at 1845 hr 7 December 1996 and the ship began DP offsetting to Site 1043 while the pipe trip continued. No water samples or formation temperature measurements were taken in this hole and no significant hydrocarbons were detected.

**Operations at Site 1043 (CR-6)**

Before completing operations at Site 1042 with LWD, Site 1043 was cored and logged (see Site 1043 section). The vessel then returned to Site 1042.

**Hole 1042C**

Logging-while-drilling at Hole 1042C was the last hole operation of Leg 170. As before, the jars were pressure tested (low = 500 psi and high = 3,000 psi) prior to making up the LWD BHA and tricone drill bit. This time the Compensated Density Neutron tool was left out of the BHA. Based on the previously cored holes, we thought that the potential for penetrating below the target reflector at this site was higher if we did not use the stabilizer associated with the CDN tool. The CDR tool was made up as part of a standard BHA including the McCullough mechanical drilling jars. As before, it was considered safe to run the jars because the firm bottom was likely to be drillable in a short period of time using the tricone bit. In addition, the sea state remained calm. The drill string was tripped to the seafloor filling the pipe every 30 stands.

Hole 1042C was spudded at 1345 hr 13 December 1996. Drilling continued at a target rate of 35 m/hr until 1515 hr 13 December 1996 when the driller was advised by Anadrill/LDEO that they wished to reduce the ROP back to 25 m/hr. At a depth of 35.0 mbsf the target ROP was decreased accordingly. Drilling continued without incident to a depth of 257 mbsf where pump pressure was elevated by 150 psi and some drill string torque was noted. The hole was swept with 30 bbls of Sepiolite mud and the drilling parameters returned to normal. Drilling continued to a total depth of 297.6 mbsf. A steady increase in drilling torque coupled with persistent high pump pressure was noted. Another 30 bbl sweep with Sepiolite mud did not improve the hole condition. Since drilling was within 2.5 hr of being halted because of time constraints, we decided to halt further LWD operations at that point. The hole was displaced with 48 bbls of 10.5 lb/gal mud. The drill string was then pulled clear of the mudline and the drilling line was slipped and cut for the last time. The bit reached the rig floor at 2030 hr 14 December 1996. The rig floor was secured, thrusters raised, and the vessel got underway for Balboa, Panama at 2200 hr 14 December 1996, ending Hole 1042C.

## SITE 1043
## (Proposed Site CR-6)

### Hole 1043A

Hole 1043A was spudded at 1545 hr on 8 December with the bit at 4322.5 mbrf. Core 170-1043A-1H recovered 8.01 m of sediment. APC Core 170-1043A-2H failed to bleed off pressure, indicating incomplete stroke in the firm seafloor material. XCB coring began with core 3X and continued through Core 170-1043A-18X at a depth of 167.1 mbsf. A small amount of fill and slightly elevated pump pressure was identified at 157.5 mbsf, after Core 170-1043A-17X. A single 30 bbl sweep of Sepiolite drilling mud cleaned up the hole and no further problems were encountered. A rapid increase in ROP occurred while cutting Core 170-1043A-18X, which only took five minutes to cut. Although the formation softened, the material remained quite stiff. The APC barrel was deployed for Core 170-1043A-19H (167.1 to 176.6 mbsf) in an attempt to get an undisturbed core sample. The barrel did achieve full stroke and recovered 9.83 m of high quality core. Because the sediment was even more highly compacted than on the previous core, and it was deemed unwise to advance the hole below the décollement with the core liner in the pipe, coring was resumed with the XCB system. Coring continued with the XCB to a total depth of 282.3 mbsf. Coring was abandoned at this point to allow time for two final LWD holes at Sites 1043 and 1042. The hole was displaced with 75 bbls of 10.5 lb/gal mud. As the pipe was tripped, the vessel was offset 50 m to the southeast for spudding Hole 1043B. The bit arrived at the rig floor by 0545 hr 11 December 1996, ending Hole 1043A.

A single temperature measurement with the DVTP was attempted after Core 170-1043A-4X at 33.4 mbsf. However, the data was bad (formation too hard). Subsequent temperature measurements were canceled.

Evidence of the presence of hydrate nodules was seen beginning with Core 170-1043A-6X. Hydrocarbon levels were highly variable and dropped significantly below the top of the underthrust zone as identified in Core 170-1043A-17X at ~150 mbsf. Methane values measured by headspace analysis ranged from 81 to 237,615 ppm above the décollement and ranged from 6 to 165 ppm below it. Ethane values ranged from 2 to 48 ppm above the décollement and nothing below Core 170-1043A-18X (167.1 mbsf). Propane measured 0-6 ppm and no higher hydrocarbons were identified.

**Hole 1043B**

Hole 1043B was to be the first of two back-to-back LWD holes. The jars were pressure tested (low 500 psi and high 3000 psi) prior to making up the LWD BHA with a tricone drill bit. The CDR and CDN LWD tools were made up as part of a standard BHA including the McCullough mechanical drilling jars. The drill string was tripped to the seafloor, filling the pipe every 40 stands. Hole 1043B was spudded at 1645 hr 11 December 1996. Drilling continued at a target rate of 25 m/hr until 0430 hr 12 December 1996 when the driller was advised by Anadrill/LDEO that 35 m/hr was acceptable. At a depth of 196.0 mbsf, the target ROP was increased accordingly. Drilling continued without incident to a total depth of 4803.3 m (482.3 mbsf), when a drastic reduction in

ROP as well as an increase in torque indicated that the target reflector had been reached. Basement for the site was projected at ~490.0 ±10 mbsf. It was assumed that the hole stopped on basement or indurated sediments directly overlying basement.

No problems were experienced penetrating the décollement and only a single 30 bbls Sepiolite mud sweep was required during the drilling. The pill was circulated at a depth of 453.4 mbsf where a slight increase in pump pressure was recognized by the driller. The hole was displaced with 140 bbls of 10.5 lb/gal mud before being abandoned. The vessel was then offset back to Site 1042. The bit cleared the rotary table at 0345 hr 13 December 1996, thereby ending Hole 1043B.

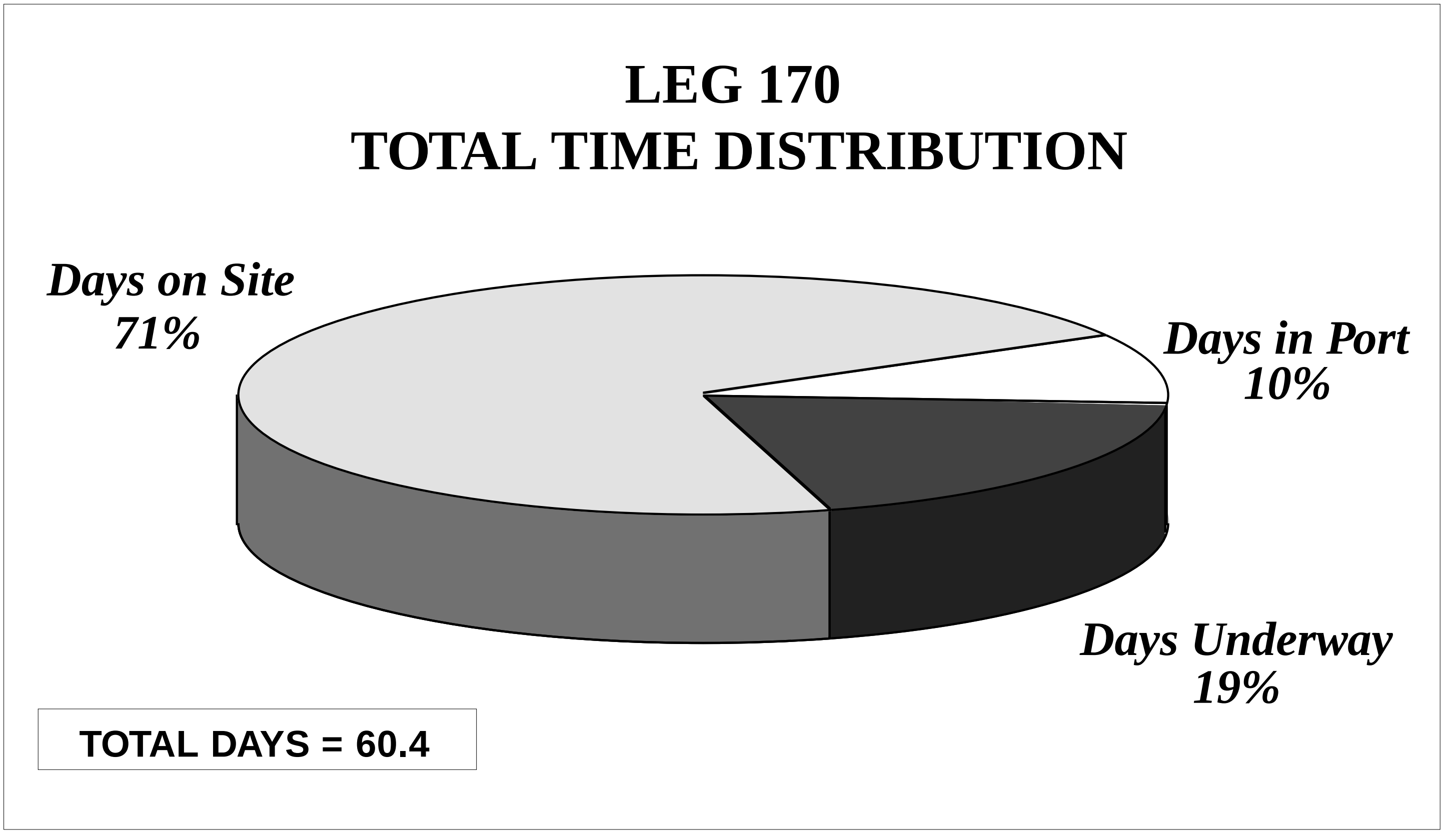
# LEG 170 CHRONOLOGY

| | | | |
|---|---|---|---|
| Nov 1-2 | 1039A | APC | |
| Nov 2-5 | 1039B | APC/XCB | |
| ********Transit******* | | | |
| Nov 5 | 1040A | APC | |
| Nov 5-8 | 1040B | APC/XCB | |
| ********Transit******* | | | |
| Nov 8-11 | 1039C | RCB | |
| ********Transit******* | | | |
| Nov 11-18 | 1040C | RCB | |
| ********Transit******* | | | |
| Nov 18-20 | 1039D | LWD | Day 30 Site 1039 completed |
| ********Transit******* | | | |
| Nov 20-23 | 1040D | LWD | |
| Nov 23-24 | 1040E | LWD | Day 34 Site 1040 completed |
| ********Transit******* | | | |
| Nov 24-27 | 1041A | APC/XCB | |
| Nov 27-30 | 1041B | RCB | |
| Nov 30-01 | 1041C | RCB | Day 41 Site 1041 completed |
| ********Transit******* | | | |
| Dec 1-4 | 1042A | RCB | |
| Dec 4-8 | 1042B | RCB | |
| ********Transit******* | | | |
| Dec 8-11 | 1043A | APC/XCB | |
| Dec 11-13 | 1043B | LWD | Day 53 Site 1043 completed |
| ********Transit******* | | | |
| Dec 13-14 | 1042C | LWD | Day 54 Site 1042 completed |

**OCEAN DRILLING PROGRAM**
**OPERATIONS RESUME**
**LEG 170**

| | | |
|---|---|---|
| Total Days (16 October 96 to 17 December 96) | | 60.4 |
| Total Days in Port | | 5.9 |
| Total Days Underway | | 11.6 |
| Total Days on Site | | 42.9 |
| | days | |
| Stuck Pipe/Downhole Trouble | 1.5 | |
| Tripping | 11.1 | |
| Other | 1.5 | |
| Drilling | 8.4 | |
| Coring | 18.5 | |
| ODP Breakdown | 0.0 | |
| Logging/Downhole Science | 2.4 | |
| Fishing & Remedial | 0.0 | |
| Development Engineering | 0.0 | |
| Repair Time (Contractor) | 0.0 | |
| Reentry | 0.1 | |
| W.O.W. | 0.0 | |
| Casing and Cementing | 0.0 | |

| | |
|---|---|
| Total Distance Traveled (nautical miles) | 2991.0 |
| Average Speed Transit (knots): | 10.9 |
| Number of Sites | 5 |
| Number of Holes | 17 |
| Number of Reentries | 1 |
| Number of Cores Attempted | 223.0 |
| Total Interval Cored (m) | 2051.6 |
| Total Core Recovery (m) | 1464.5 |
| % Core Recovery | 0.7 |
| Total Interval Drilled (m) | 3404.6 |
| Total Penetration | 5456.2 |
| Maximum Penetration (m) | 665.9 |
| Minimum Penetration | 9.5 |
| Maximum Water Depth (m from drilling datum) | 4364.5 |
| Minimum Water Depth (m from drilling datum) | 3317.1 |
| Average Water Depth | 3986.8 |


LEG 170
TOTAL TIME DISTRIBUTION
Days on Site
71%
Days in Port
10%
Days Underway
19%
TOTAL DAYS = 60.4

# OCEAN DRILLING PROGRAM
# SITE SUMMARY
# LEG 170

| HOLE | LATITUDE | LONGITUDE | SEA FLOOR (mbrf) | NUMBER OF CORES | INTERVAL CORED (meters) | CORE RECOVERED (meters) | PERCENT RECOVERED (percent) | DRILLED (meters) | TOTAL PENETRATION | TIME ON HOLE (hours) | TIME ON HOLE (days) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1039A | 09 38.397 N | 86 12.006 W | 4362.5 | 3 | 28.0 | 28.91 | 103.3% | 0.0 | 28.0 | 18.00 | 0.75 |
| 1039B | 09 38.405 N | 86 12.003 W | 4364.5 | 42 | 384.3 | 382.46 | 99.5% | 0.0 | 384.3 | 68.50 | 2.85 |
| 1039C | 09 38.383 N | 86 12.002 W | 4362.5 | 11 | 85.6 | 37.65 | 44.0% | 363.1 | 448.7 | 59.25 | 2.47 |
| 1039D | 09 38.374 N | 86 12.004 W | 4362.5 | 0 | 0.0 | 0.00 | 0.0% | 407.0 | 407.0 | 45.25 | 1.89 |
| | SITE 1039 (CR-1) TOTALS: | | | 56 | 497.9 | 449.02 | 90.2% | 770.1 | 1268.0 | 191.00 | 7.96 |
| 1040A | 09 39.707 N | 86 10.746 W | 4188.0 | 1 | 9.5 | 9.58 | 100.8% | 0.0 | 9.5 | 12.00 | 0.50 |
| 1040B | 09 39.707 N | 86 10.746 W | 4189.0 | 22 | 190.2 | 127.92 | 67.3% | 0.0 | 190.2 | 70.25 | 2.93 |
| 1040C | 09 39.697 N | 86 10.735 W | 4189.0 | 53 | 505.7 | 377.28 | 74.6% | 159.3 | 665.0 | 178.75 | 7.45 |
| 1040D | 09 39.719 N | 86 10.758 W | 4189.0 | 0 | 0.0 | 0.00 | 0.0% | 337.5 | 337.5 | 66.00 | 2.75 |
| 1040E | 09 39.731 N | 86 10.755 W | 4189.0 | 0 | 0.0 | 0.00 | 0.0% | 318.4 | 318.4 | 41.00 | 1.71 |
| | SITE 1040 (CR-2) TOTALS: | | | 76 | 705.4 | 514.78 | 73.0% | 815.2 | 1520.6 | 368.00 | 15.33 |
| 1041A | 09 44.027 N | 86 06.995 W | 3317.1 | 18 | 155.1 | 114.32 | 73.7% | 0.0 | 155.1 | 61.00 | 2.54 |
| 1041B | 09 44.025 N | 86 06.981 W | 3317.1 | 25 | 240.6 | 133.18 | 55.4% | 155.0 | 395.6 | 66.50 | 2.77 |
| 1041C | 09 43.989 N | 86 06.945 W | 3317.1 | 3 | 28.8 | 6.85 | 23.8% | 395.0 | 423.8 | 34.00 | 1.42 |
| | SITE 1041 (CR-3) TOTALS: | | | 46 | 424.5 | 254.35 | 59.9% | 550.0 | 974.5 | 161.50 | 6.73 |
| 1042A | 09 39.352 N | 86 06.760 W | 3605.0 | 7 | 66.7 | 12.85 | 19.3% | 173.4 | 240.1 | 54.75 | 2.28 |
| 1042B | 09 39.334 N | 86 06.739 W | 3592.5 | 8 | 74.8 | 8.89 | 11.9% | 316.0 | 390.8 | 92.75 | 3.87 |
| 1042C | 09 39.315 N | 86 06.722 W | 3585.0 | 0 | 0.0 | 0.00 | 0.0% | 297.6 | 297.6 | 42.25 | 1.76 |
| | SITE 1042 (CR-7) TOTALS: | | | 15 | 141.5 | 21.74 | 15.4% | 787.0 | 928.5 | 189.75 | 7.91 |
| 1043A | 09 39.273 N | 86 11.160 W | 4324.0 | 30 | 282.3 | 224.60 | 79.6% | 0.0 | 282.3 | 73.75 | 3.07 |
| 1043B | 09 39.259 N | 86 11.143 W | 4321.0 | 0 | 0.0 | 0.00 | 0.0% | 482.3 | 482.3 | 46.00 | 1.92 |
| | SITE 1043 (CR-6) TOTALS: | | | 30 | 282.3 | 224.60 | 79.6% | 482.3 | 764.6 | 119.75 | 4.99 |
| | LEG 170 TOTALS: | | | 223 | 2051.6 | 1464.49 | 71.4% | 3404.6 | 5456.2 | 1030.00 | 42.92 |

# TECHNICAL REPORT

The ODP Technical and Logistics personnel aboard *JOIDES Resolution* for Leg 170 were:

| | |
|---|---|
| Tim Bronk | Marine Lab Specialist (Chemistry) |
| Roy Davis | Marine Lab Specialist (Photographer) |
| Sandy Dillard | Marine Lab Specialist (Storekeeper) |
| Brad Julson | Laboratory Officer |
| Margaret Hastedt | Assistant Lab Officer (Paleomagnetics) |
| Jeff Sauls | Marine Computer Specialist (System Manager) |
| Kuro Kuroki | Assistant Lab Officer |
| Mont Lawyer | Marine Lab Specialist (Underway Geophysics) |
| Jaque Ledbetter | Marine Lab Specialist (X-Ray) |
| Erik Moortgat | Marine Lab Specialist (Physical Properties) |
| Erinn McCarty | Marine Lab Specialist (Curator) |
| John Eastlund | Marine Computer Specialist (System Manager) |
| Chris Nugent | Marine Lab Specialist (Downhole Tools) |
| Anne Pimmel | Marine Lab Specialist (Chemistry) |
| Jo Ribbens | Marine Lab Specialist (Yeoperson) |
| Bill Stevens | Marine Electronics Specialist |
| Mark Watson | Marine Electronics Specialist |

## PORT CALL ACTIVITIES - SAN DIEGO

The ship arrived in San Diego the evening of 16 October 1996. The ship stopped in Los Angeles for refueling before San Diego. The ODP crew arrived the next morning, boarded the ship, and crossed over with the offgoing crew. A "Stuck Pipe School" was held in San Diego before the port call for some of the ODL/SEDCO and ODL personnel. San Diego was a very busy port call. The offgoing cores, air freight, and surface freight were unloaded before more than 18 truckloads of supplies, casing, Anadrill equipment, sepiolite, cement, and barite could be loaded onto the ship. The JANUS Steering Committee met with Tracor during the port call to discuss the progress of the JANUS database. The pacing item for the port call was the installation of the new radar system on the bridge to replace the unit damaged during Leg 163. Chemical waste was unloaded to a UCSD hazardous waste disposal group. The Pelagos navigation program, WinFrog, was upgraded. The new version is 32 bit but requires a dongle on the master computer to work.

There were many groups from high schools and universities throughout San Diego that received tours of the ship. ODP and BRG borrowed a UNOLS fleet Inmarsat B, high-speed marine communication system that was installed and will be tested to look at the feasibility of purchasing one in the future. These can send digital data faster and cheaper. We refilled our Liquid nitrogen dewars in anticipation of clathrate recovery during the leg. A new air plenum was built, which will raise the air intake for the lab stack and quarters above the Bridge deck in a move to reduce obnoxious fumes from $H_2S$ or painting and increase air circulation. There was a GFE property Inventory of the ship during the port call. The ship departed from San Diego about 1900 Tuesday, 22 October 1996

## GENERAL LEG INFORMATION

The ship sailed 22 October for an eight day transit to the first site off the Nicoya Peninsula, Costa Rica. Off the coast of Mexico, one of the crewmen developed health problems and was evacuated onto a launch from Mazatlan.

The ship arrived at the first Site 1030 (CR-1) on 1 November 1996. The ship drilled 17 holes at five sites. On 10 November the name of the ship was officially changed to the *D/V JOIDES Resolution*. Letters were changed on the bow and stern and the life rings and survival suits. The hold overhead crane was removed during the leg to create more room to store supplies and make it easier to work in the storage spaces. At the end of the cruise, there was a two-day transit to Panama.

**UnderWay Activities**

Navigation, bathymetry, and seismic data were collected during Leg 170. The site locations were well surveyed with 3D geophysics from previous expeditions. All beacons were dropped on predetermined coordinates. A short seismic survey was done during the approach to the first site. Hole positions were determined by averaging GPS fixes taken at one-minute intervals over a period of many hours for each hole. Because the sites were so close together, the ship was moved in DP mode from site-to-site during the entire leg.

## LAB ACTIVITIES

Because of the water depth, the nature of the material being cored, and logging while drilling, the amount of core recovery was generally low. In addition, drilling through décollements and in accretionary prisms has historically been difficult. Hole problems were also encountered during this leg.

Technical support in the Chemistry, Physical Properties, X-ray, and Downhole Labs played key roles in supporting the leg’s scientific objectives. Work in the chemistry lab was especially challenging because of the large number of interstitial water (IW) samples collected.

This was the last full leg of testing JANUS, the ODP database, before official implementation on 171B. A Tracor representative did not sail during the leg, but there was a full Tracor crew at the San Diego port call to install the latest build and demonstrate the system to the Steering Committee evaluators. The crew entered real data into the available JANUS applications for the entire cruise while double entry was still done to the old system. This was done in an effort to debug the program. Weekly test results were sent to Tracor.

**Chemistry Lab**

Due to the interest in gaining an understanding of the fluid-flow patterns in the Costa Rica margin accretionary wedge, a major effort was devoted to detailed pore-water analysis. A large number of IW's were squeezed (>3% of the total recovery for the leg).

Interstitial water shipboard analysis on Leg 170 included refractometric analysis for salinity; titrations for pH, alkalinity, chloride, calcium, and magnesium; ion chromatography for sulfate, potassium, sodium, calcium, and magnesium; and colorimetric analyses for silica, phosphate, and ammonium. Atomic absorption spectrophotometry was used to quantify concentrations of potassium in pore waters.

Solid core samples were analyzed for inorganic and total carbon (using the coulometer and the carbon, nitrogen, and sulfur [CNS] elemental analyzer ). Based on their organic carbon content, some samples were selected and analyzed with the Rock-Eval. The system was used to determine $S_1$, $S_2$, and $S_3$.

Gas Chromatograph #3 (GC3) and National Gas Analysis (NGA) were used during this leg to provide real-time monitoring of the volatile hydrocarbons. A new version of Chemstation was installed. The initial testing of the chemistry input to the JANUS database began on this leg. Difficulties were noted and described and sent to the beach for modification in the new version due for Leg 171.

**Computer Service**

The technical staff entered real data into the available JANUS applications for the entire cruise, while double entry was still done on the old system. Double entry is time consuming, but necessary during this interim period. Weekly test results were sent to Tracor. This is the last time to test the JANUS applications before they go on line during Leg 171.

A Marisat-B system was borrowed from the UNOLS fleet to test high-speed data transmission, especially for logging data. Unfortunately we were not able to do much testing. Hopefully it will be used more on the next leg. This will ultimately be used to send e-mail to ODP.

The Novell/cc:Mail setup was enhanced with more hardware, software patches, system tuning, and reconfiguration. PC and Macintosh workstation software was upgraded and tuned, and standard installation sets created. The Appleshare server was retired and the files moved to Novell volumes. More memory was added to Grosbeck and Grubby so print queues, backups, and other utilities could work better together. GEOREF, the geology reference utility, was moved to a PC so more users could login. Another SCSI controller was added to Grosbeck, so tape drives and hard drives would be separated for better performance. Print queues were cleaned up. The cc:Mail post office was enlarged.

**Core Lab**

During the initial transit, new wooden book cases were built for the DSDP/ODP *Initial Results* and *Scientific Results* stored in the rear of the core lab. These beautiful wood book cases dramatically increased the storage area for books in the Core Lab. A half-core Multisensor system was bought from Geotek and left set up in the lab. This system has a line scan camera, a Cesium source for density measurements, and a "point" susceptibility meter. This system was not used very much during this leg and was packed up to be sent back to ODP for extensive modification. A new core box on the catwalk was built as a prototype using PVC for the top. The catwalk hatch has a new locking-type mechanism when it is raised. This will make it easier to lock the hatch in place and eliminate the search for bolts. The last of the "new" style core boxes were used up, and we are back to our original style.

**Curation**

The primary objective of Leg 170 was to gain a better understanding of fluid-flow patterns and structural deformation associated with the Costa Rica margin accretionary wedge. Most of the sample requests received for this leg focused on detailed pore-water analyses, consolidation and trivial testing, microstructural analyses, and geochemical/geotechnical analyses of gas hydrate and its associated host sediments. Detailed paleoceanographic studies focused on the one pelagic reference site, Site 1039, drilled at the start of the leg.

Great emphasis was placed on pore-water analysis and consolidation/triaxial testing to determine fluid flow/dewatering characteristics of the accretionary prism. Since most of the sediments recovered were obviously consolidated, large volume whole rounds were required to obtain enough water for shipboard analyses. Sample volume was determined by Information Handling Panel (IHP) policy as mandated by Patty Fryer:  no more than 10% of the core was to be taken for IW, and any whole round greater than 25 cm required co-chief approval. Structural geologists were also present on the catwalk to ensure that critical intervals were not squeezed into oblivion. Catwalk sampling went very smoothly and the amount of sediment taken for squeezing as related to the total recovery is a little over 3%.

The scientists and technicians tried out the JANUS sample application for the first time. Although double entry was necessary in the JANUS sample application and the old MUDLOG, everyone agreed that the new sampling program will be much easier to use and decrease mistakes.

**Downhole Lab**

In situ temperature measurements were taken repeatedly to measure the anomalously low heat-flow values that may suggest widespread refrigeration of the crust by vigorous fluid flow at depth. Most of the temperature measurements were with the new Davis-Villinger Temperature Probe. Water samples were also taken both above the seafloor and in the sediment.

**Electronic Service**

The lab equipment acted satisfactorily for the most part during the leg. The two lower NGR detectors on the multisensor (MST) track were corroded due to water leaking on them. One detector was dead, but the other could be tuned. New detectors are on order. The library Xerox copier’s document belt ripped. This is temporarily working and spares are on order. The centrifuges in the Paleo lab also required a lot of maintenance.

**Fantail**

During the initial seismic survey, the 80" water gun was deployed but suffered a blown air line just before the start of the line. The 200" water gun was deployed and used for the entire survey. The six-channel digital streamer and the single-channel analog streamer were both used for the survey to compare the two systems. The six-channel streamer developed a cracked depth transducer and was shipped back to shore for replacement.

**METS**

The Marine Emergency Technical Squad (METS) volunteers continue to train with ODL on a limited basis. We report to each drill, but unless we are the initial response team to the area, we standby on the catwalk.

**Microscopes**

The microscopes were used heavily in the core lab. The photographer was busy instructing and maintaining the microscopes. An inventory was done on all the microscopes.

**Paleomagnetics Lab**

Paleomagnetics lab activities for Leg 170 included further testing/evaluation of the new Labview cryomagnetometer software and the new count buffer chips that arrived at port call. The usual suite of pass-through measurements were made and interesting results were obtained from high-resolution runs. The new cryomagnetometer impressed everyone with its ability to run many discrete samples in very short order. Other equipment in the lab (spinner, K-bridge, etc.) was not used.

Special Projects:

- Installed new count buffer chips from 2G. The new buffers go to at least 200,000 counts, and Bill Goodman thought they might go to 64 million. He’ll check with his programmer. No detectable decrease in the slew rate was noticed, although 2G thinks there is about a 15% reduction.
- Demonstrated Bill Mills’ Labview cryomagnetometer software to Bill Goodman of 2G during

the San Diego port call. Apparently they plan to use our software in all their new cryomagnetometers as a replacement for the inadequate in-house program supplied to us on Leg 168.

- The "magic numbers" for the SQUID response curves were determined in port call to be 6.071, 6.208, and 9.923 for XYZ respectively. A calibration "wand" was provided by Lisa Tauxe of Scripps Institute of Oceanography as a cross-calibration test between her 2G cryomagnetometer and our new one. Good results were obtained with the new response numbers.

**Photography Lab**

The photo lab ran smoothly during the leg. There were no problems associated with equipment for the core photos, color transparencies, or close ups.

**Physical Properties Lab**

This lab was heavily used by four scientists. A new Moisture and Density (MAD) program was used for the Index Properties. This program was designed to collect the weight of the sample from the balance; collect the reading from the pycnometer, and download the results to the JANUS database. There were problems with the program and the scientists preferred using Excel spreadsheets.

Data from the MST was downloaded to the JANUS database. This is still in the testing phases, and there were many problems associated with this. The National Gamma Radiation (NGR) detector experienced problems due to water dripping onto two of the sensors and corroding them. The system was cleaned and new sensors ordered. The new TK04 thermal conductivity system was used for the half space measurements, but the scientists finished the leg using the old Woods Hole System for the full space measurements. Vane, shear, and resistivity measurements were also collected.

**Thin Section Lab**

This lab was not heavily used. Twenty-seven thin sections were produced. Most of them were basalts with some sediment requests and a pyrite. Some of the instruments needed a lot of maintenance.

**UnderWay Geophysics Lab**

Navigation, bathymetry, and seismic data were collected during Leg 170. The site locations were well surveyed with 3D geophysics from previous expeditions. All beacons were dropped on predetermined coordinates. A short seismic survey was done during the approach to the first site. Hole positions were determined by averaging GPS fixes taken for each hole at one-minute intervals over a period of many hours. A new version of the navigation program, WinFrog, was installed during the port call. Additional memory was also added to the primary WinFrog PC.

**X-ray Lab**

During Leg 170, 213 samples were analyzed by X-ray diffraction. Most of the samples submitted were a split of the "trimmings" from IW samples. This procedure conserved sample material, and significantly improved the turnaround time for X-ray diffraction (XRD) analyses, because the sample was taken almost immediately after the core was recovered. Results of the XRD analyses were often available to the scientists within 24 hr.

The X-ray fluorescence (XRF) was used extensively this cruise to analyze samples from a wide range of lithologies. A total of 94 samples for major element analysis and 118 samples for trace element analysis were submitted. Sample lithologies include basalt, glass, and siliciclastic and carbonate sediment. The sediment samples were generally splits of IW squeezecakes, or samples of ash layers taken from the core.

The XRF performed flawlessly throughout the cruise, producing a large dataset of accurate and precise results. Basalt sample beads for major element analysis were made with the new flux (Flux VII) using the NT-2100 bead sampler throughout the cruise, and the bead sampler was used to make all the sample beads at the last few sites. High quality beads can now be safely produced without the requirement of having a technician present. This results in a significant time savings for the technician and will increase lab productivity. A new ashing furnace was installed to replace the old "original equipment" ashing furnace.

**Miscellaneous**

Many long-line fishing lines drifted towards the ship and had to be cut. The ship's new water maker produces water at 130°. Because of the warm surface water (89°F), it was difficult cooling the water low enough to send to the hotels and labs. We also had problems with pressure and flow of drill water to the core lab. New drain lines with plastic lining will be installed under the labs during the port call.

# LAB STATISTICS: LEG 170

| | |
|---|---|
| **General Statistics:** | |
| Sites | 5 |
| Holes | 17 |
| Cored Interval (m) | 2051.6 |
| Core Recovered (m) | 1464.49 |
| Percent Recovered | 71.4% |
| Total Penetration (m) | 5525.7 |
| Days on Site | 43.38 |
| Number of Cores | 223 |
| Number of Samples | 16,243 |
| Whole Rounds | 301 |
| Boxes of Core | 21 |
| **Samples Analyzed**: | |
| Inorganic Carbon ($CaCO_3$) | 268 |
| Total Carbon (NCHS) | 250 |
| Water Chemistry (the suite includes pH, Alkalinity, Sulfate Calcium, Magnesium, Chlorinity, Potassium, Silica, Salinity) | 215 |
| Pyrolysis Evaluation (Rock Eval and GHM) | 63 |
| Gas Samples | 229 |
| Extraction | 0 |
| Thin Sections | 27 |
| XRF | 207 |
| XRD | 265 |
| MST Runs | 5,020 |
| Cryomagnetometer Runs | 733 |
| Cubes | 214 |
| Oriented Cores | 8 |
| Physical Properties Velocity | 1,025 |
| Thermal Conductivity | 597 |
| Index Properties. | 1,744 |
| Resistivity | 527 |
| Shear Strength | 306 |
| MST | 1073 |
| **UnderWay Geophysics:** | |
| Bathymetry (NM) | 2,961 |
| Seismic Survey (NM) | 12 |
| XBT's launched | 30 |
| **DownHole Tools:** | |
| WSTP | 8 |
| Adara | 3 |
| DVTP | 25 |
| **Additional:** | |
| Close-up Photos | 150 |
| Whole Core Photographs | 193 |
| Color Transparencies | 193 |
| Black and White Prints | 2452 |