OCEAN DRILLING PROGRAM

LEG 171A PRELIMINARY REPORT

BARBADOS ACCRETIONARY PRISM LOGGING WHILE DRILLING:

FAULTING, FLUID FLOW, AND SEISMIC IMAGING OF THE NORTHERN
BARBADOS SUBDUCTION ZONE

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Figure 2A

ABSTRACT

In less than 12 days of operations during Leg 171A, logging while drilling (LWD) acquired over 2959 m of density, resistivity, gamma-ray, photoelectric effect, and neutron porosity logs at five sites in and adjacent to the Barbados accretionary prism. All of the sites are located within a 3-D seismic reflection survey area, and three of these sites are reoccupations of previously cored holes. The stratigraphy of the other two LWD sites correlates to reflectors determined from the 3-D seismic survey.

Penetrating the sedimentary sequence seaward of the subduction zone, reference Sites 1044 and 1048 show that the proto-décollement occurs in a lower Miocene radiolarian mudstone unit of unusually low density. Beneath the accretionary prism, this radiolarian mudstone unit is synonymous with the décollement zone at every cored site, indicating that special properties of the mudstone foster detachment along this surface. Logs at Sites 1045, 1046, and 1047 that penetrated the accretionary prism show various stages of consolidation in the décollement zone. The initial low density of the radiolarian mudstone indicates high fluid pressure and low strength that trigger and localize décollement formation.

As underthrusting proceeds, burial and shear strain lead to consolidation of the décollement zone, erasing the original low-density signature. At Site 1045, however, a local area of arrested consolidation of the décollement zone shows a strong negative polarity seismic reflection. Logs there indicate that the negative polarity reflection is a sharply defined low-density interval in the consolidating low-density radiolarian mudstone. The thickness of the underconsolidated interval causes constructive interference or "tuning" of the incident seismic waveform producing the strong negative polarity reflection.

The degree of consolidation along the décollement zone does not vary systematically with distance of underthrusting; perhaps local features such as faults in the overlying prism may be important in controlling fluid escape from, and therefore, consolidation of the décollement zone. At greater depths than we drilled, the décollement zone displays extensive areas of negative polarity

reflections, indicating either large regions of arrested consolidation or other processes that dilate the fault zone.

Comparison of the density profiles between sites penetrating the incoming sedimentary sequence and equivalent strata thrust beneath the accretionary prism quantifies the magnitude of consolidation due to loading by the prism. In the underthrust strata, a turbidite sequence of higher porosity and permeability than adjacent deposits apparently transports some of this fluid seaward and produces the anomalously high thermal gradient at Site 672 (Leg 171A, LWD Site 1044).

The high quality of the LWD data coupled with information from the boreholes and seismic data calibrate the logs for recognition of geologic features. Thrust faults are evident as repeated log signatures, often as density inversions. Fluid conduits documented by the pore-water chemistry in the cores can be recognized in the logs as low-density intervals. Known sediment compositions allow inversion of log signatures to specify sediment types in uncored areas.

INTRODUCTION

As fluids influence fault behavior, Leg 171A focused on the role of fluids in deformation along the subduction megathrust between the North American and Caribbean Plates (Fig. 1). Faulting and deformation in accretionary prisms change the physical properties that produce fluid, alter rheologic properties, control fluid flow, and affect seismic velocities and reflection characteristics. Physical properties, specifically porosity, permeability, density, and sonic velocity, change through consolidation and chemical diagenesis. These alterations are both distributed, due to the loss of fluids in response to accumulating stresses (Bray and Karig, 1986; Bangs et al., 1990), and localized along faults, in response to overpressuring, fluid migration, mineral precipitation, lithologic juxtaposition, or fault collapse (Shipley et al., 1994; Tobin et al., 1994; Bangs et al., 1996). Modifications of physical properties associated with consolidation, fluid overpressuring, and faulting directly affect seismic reflections; therefore, seismic data provide a direct method to remotely sense the changes in physical properties that are coupled to deformation.

Physical property evolution in sedimentary sequences, including accretionary prisms, cannot be comprehensively evaluated with recovered cores and must be studied in situ. Elastic rebound and microcracking of coherent sedimentary samples degrade laboratory physical property measurements. Fault gouge and other incoherent lithologies are either not recovered or cannot be measured after recovery. Transient properties (e.g., excess pore pressures) must be measured in situ (Fisher et al., 1996; Screaton et al., in press). Logging while drilling (LWD) is the best available tool for measuring physical properties of the typically underconsolidated prism sediments; LWD results can be used as input to time transient models of prism evolution.

Large strains at subduction zones accelerate the rate of change in the physical properties of sedimentary sequences that are accumulating and deforming there. Accretionary prisms allow us to study these changes because deformational features are shallowly buried and shallowly dipping, and therefore can be cored and imaged seismically. Studies of fault geology, sedimentary consolidation, and seismic imaging at subduction zones aid in understanding hydrocarbon migration, groundwater flow, and seismicity in other less active sedimentary environments. Logging while drilling was conducted in a transect across the toe of the northern Barbados accretionary prism to better understand the interrelationships of deformation, fluid flow, seismic imaging, and changes in physical properties (Figs. 2-4).

Tectonic Setting of the Northern Barbados Accretionary Prism

The northern Barbados accretionary prism is the leading edge of the Caribbean Plate that is being underthrust by Atlantic Ocean floor at rates estimated between 20 and 40 km/m.y. (Dorel, 1981; Jordan, 1975; Sykes et al., 1982; DeMets et al., 1990). On the west, the Lesser Antilles defines the volcanic arc, whereas east of the arc the island of Barbados is an outcrop of the forearc accretionary prism. Frontal structures south of the Tiburon Rise include long wavelength folds, widely spaced ramping thrust faults, and extensive décollement reflections (e.g., Bangs and Westbrook, 1991; Westbrook and Smith, 1983). North of the Tiburon Rise, trench sediment thickness is much thinner, and prism thrusts are more closely spaced (Biju-Duval et al., 1982; Westbrook et al., 1984). North of the Tiburon Rise, the Barbados accretionary prism reaches at least 10 km thick and 120 km wide in addition to a 50-km-wide forearc basin to the west (Bangs et al., 1990; Westbrook et al., 1988). Thus, the accretionary prism forms a wide low-taper wedge (Figs. 2-4).

Deep Sea Drilling Project (DSDP) Leg 78A and Ocean Drilling Program (ODP) Legs 110, 156, and 171A all focused on the northern flank of the Tiburon Rise. Here the décollement is relatively shallow, and the dominantly hemipelagic/pelagic sedimentary section offers good drilling conditions and good biostratigraphic resolution. In this area, previous drilling documented numerous biostratigraphically defined faults of mostly thrust displacement (Brown and Behrmann, 1990). The décollement zone becomes better defined in a landward direction and is a shear zone up to 40 m thick at Sites 671/948 (Mascle, Moore, Taylor, et al., 1988; Shipley, Ogawa, Blum, et al., 1995). Anomalies in pore-water chemistry (Gieskes et al., 1990; Kastner, in press) and temperature (Fisher and Hounslow, 1990) indicate focused fluid flow along fault zones and in sand layers. Models simulating this fluid expulsion from the prism suggest that the flow is transient (Bekins et al., 1995). The faults are characterized by suprahydrostatic, and locally near lithostatic, fluid pressures (Brückmann et al., in press; Labaume and Kastner, in press; Screaton et al., in press; Zwart et al., in press).

A 3-D seismic reflection survey (Figs. 1-4; Shipley et al., 1994; Moore et al., 1995b) has greatly improved the interpretation of drilling results from the northern Barbados accretionary prism. In addition to better defining the stratigraphy and structure, the seismic survey also has outlined patches of positive and negative seismic polarity on the décollement (Figs. 2B, 3). These polarity signatures may signify differing fluid regimes and stress states along the décollement zone (Shipley et al., 1994; Bangs et al., 1996; Tobin and Moore, in press; Shipley et al., in press). Determining the physical properties that define these polarity signatures was a major goal of Leg 171A.

Logging While Drilling

LWD is the most effective tool for measurement of physical properties in poorly consolidated sediments where standard wireline systems previously acquired either no data or poor quality data. LWD provides measurements from the seafloor to the bottom of the deepest level of bottom-hole assembly penetration. It acquires a continuous log of physical properties directly above the drill bit where hole conditions are optimal for logging, and it measures properties of the formation minutes after cutting the hole, thereby closely approximating in situ conditions.

Objectives of the Logging Program

1. Overall Prism Consolidation. Porosity distribution is the foundation for a variety of studies of the large-scale, long-term fluid budget of accretionary prisms. We can use logs to determine a continuous record of density and porosity as a function of depth as was done at Sites 947 and 948 during Leg 156. Between-site variation in the porosity-depth relationship provides an estimate of the amount of fluid expulsion (and therefore volumetric strain). Unfortunately in accretionary prisms, these measurements of volume change are usually impossible with standard logs, as they frequently fail due to the typically unstable hole conditions. Even under ideal conditions wireline logs do not obtain data from the top 60-120 m (because the drill pipe extends below the seafloor) nor the bottom 60-120 m of the hole (because of fill). The shallowest 100 m is of particular interest in volumetric studies because this is where porosity reduction is the greatest. Only LWD can obtain reliable porosity logs from the entire depth range, including the critical top 100 m.

   The overall fluid budget of the northern Barbados prism requires modeling to evaluate the fluid loss and geochemical budgets (e.g., Bekins et al., 1995). Observations of prism consolidation critically constrain these models. This series of LWD holes plus existing penetrations and seismic reflection results provide the essential data.

2. Correlation of Physical Properties of Faults with Displacement and Fluid Flow. There are several key questions that we wish to answer. Do faults collapse and strain harden with displacement (e.g., Karig, 1986)? Does active fluid flow retard this process and are collapsed faults inactive with respect to fluid flow (e.g., Brown et al., 1994)? Are hydrofractures as observed in the Barbados décollement common elsewhere? Can faults act as hydrologic conduits with variable and transient properties, as required by the models of Bekins et al. (1995)?

The Leg 171A LWD transect across the Barbadian décollement addresses these questions. Information from cores and seismic reflection data locates faults. Once the faults are positively identified, LWD can measure their physical properties, which can then be correlated to variations in displacement and fluid activity.

3. Consolidation State of Sediments in and Around Faults. At Site 948, high quality density measurements demonstrated underconsolidation around faults, indicating the faults had recently loaded subjacent sediments. Consolidation state can also be interpreted in terms of effective stress and fluid pressure. Clearly the consolidation varies around faults and needs to be defined to develop a tectono-hydrologic model of the fluid expulsion system.

4. Physical Characteristics of Negative Polarity Seismic Reflections From Fault Zones. Seismic reflections are created by changes in physical properties that can be measured in boreholes. In principle the seismic data provide a proxy for changes in physical properties on a tens of meters scale. Models reproduce the polarity and shape of seismic waveforms from the décollement zone beneath accretionary prisms (Bangs and Westbrook, 1991; Moore and Shipley, 1993). Accordingly, negative polarity reflections are interpreted as either due to overthrusting of higher over lower impedance sediment (Shipley et al., 1990) or due to the reduction of fault zone impedance through dilation (Bangs and Westbrook, 1991; Shipley et al., 1994; Bangs et al., 1996). The modeling, however, is incomplete without documenting the in situ physical properties across fault zones in areas with high quality 3-D seismic data.

The Barbados décollement zone has been logged at only one locality (Shipboard Scientific Party, 1995). This LWD data is in an area of positive reflection polarity and shows impedance increases that reproduce the positive polarity in synthetic seismograms (Shipboard Scientific Party, 1995). The LWD results also suggest thin (0.5-1.5 m) hydrofractures within this interval of positive impedance contrast in the décollement zone (Moore et al., 1995a). The hydrofractures apparently are too thin to be resolved seismically. A major question is whether negative polarities elsewhere in the Barbados décollement consist of thicker zones of hydrofractures.

Why Barbados?

The absence and/or failure of wireline logging operations means that hundreds of previously drilled DSDP and ODP holes provide scientifically exciting locales for LWD. Barbados is especially attractive for focussed LWD investigations because:

- Previous drilling at Barbados has provided high quality structural, pore-water chemistry, heat flow, and shipboard physical property studies. This information provides independent determination of fault locations, of fluid flow activity, and of correlative physical properties. A wealth of shipboard information and subsequent scientific results provide a rich framework to enhance log interpretation.

- The décollement zone occurs at depths that can be reached by drilling.

- Barbados is one of only two convergent margins with 3-D seismic reflection surveys. These extraordinary data sets vastly expand the opportunity for core-log-seismic integration and the consequent 3-D analysis of faulting, fluid flow, and consolidation.

- Finally, the northern Barbados Ridge is an end-member accretionary prism characterized by moderately thin pelagic and hemipelagic sediment, in contrast to, for example, the Cascadia accretionary prism, which is forming from a voluminous coarse terrigenous clastic influx.

Drilling Plan

LWD investigations of the northern Barbados prism build on existing LWD measurements at Site 948 (ODP Leg 156) that penetrated the décollement where it is of positive polarity (Fig. 2). Although LWD was conducted at Site 947 (ODP Leg 156), this locality was never cored nor reached the décollement because of the unstable hole conditions encountered during the LWD penetration. The Leg 171A sites (Figs. 2-4) begin with logging of the incoming sedimentary section at Site 1044, which was previously cored as Site 672 (ODP Leg 110). The remaining sites extend westward across the deformation front and sample various stages of development of the accretionary prism, décollement, and the reflections along the décollement.

RESULTS

SITE 1044

Site 1044 lies on the northern flank of the Tiburon Rise 6 km east of the Barbados accretionary prism frontal thrust at ODP Site 672 (Figs. 2-4). Site 672 was drilled as an undeformed reference locality to gauge changes in the sedimentary section caused by accretion or underthrusting observed at other DSDP and ODP sites to the west. Surprisingly, the structural and geochemical anomalies at the projected stratigraphic level of the décollement showed that the section at Site 672 is disturbed by the encroaching accretionary prism. LWD at Site 1044 and data from Site 672 provide valuable baseline information on the nature of the incoming sedimentary section and set new limits on possible extent of proto-décollement deformation.

Site 672 provides a wealth of information for correlation to the Site 1044 LWD data. Cores at DSDP Site 543, located 18 km north on the oceanic plate, constrain the nature of the lower Eocene to Cretaceous part of the section not penetrated at Site 672. The sedimentary section is about 650 m thick beneath Site 672 and overlies oceanic crust of probable Cretaceous age. The uppermost Pleistocene to lower Miocene hemipelagic unit extends to about 200 mbsf and is equivalent to the section incorporated into the accretionary prism. This upper 200 m section correlates to seismic Unit 1, which displays moderately continuous reflectors and is underlain by the proto-décollement. The proto-décollement shows no deformation at the resolution of the seismic data; sediments below this are underthrust. The underthrust upper Oligocene to middle Eocene units consist of alternating muddy and calcareous lithologies with terrigenous sandstone and siltstone interbeds. Lower middle Eocene to Cretaceous rocks are siliceous, calcareous, and clay-rich pelagic deposits overlying pillow basalt.

The principal questions addressed at Site 1044 are: (1) What is the log signature of the proto-décollement? Does this deformation zone include any indicators of hydrofractures, such as observed at Site 948? (2) What are the overall physical properties of the incoming section, especially porosity? Equivalents of this sequence are the sources of fluids being expulsed from the accretionary prism and underthrust sequence. (3) How do the observed physical properties determined from LWD account for the seismic reflection signature of this well-imaged incoming sedimentary section?

Site 1044 penetrated through 685 m of sediment to the basaltic basement of the North American Plate 6 km east of the frontal thrust of the northern Barbados accretionary prism. LWD acquired spectral gamma-ray, resistivity, density, caliper, photoelectric effect, and neutron porosity logs in this hole (Fig. 5). All logs are of good quality except for neutron porosity. The high quality log data results from the in-gauge hole immediately behind the bit that the LWD tools sense. Ninety-nine percent of the hole had differential caliper measurement of less than 1 in and 94% had less than 0.5 in. The density log mimics both the character and values of density measurements made from cores, further indicating log reliability.

Both traditional visual and multivariate statistical analyses of the logs define six log units, which account for the majority of the lithologic variations observed in the cores. This profile of log properties specifies the nature of the incoming sedimentary section and correlates well with Site 672 and 3-D seismic survey data. This core-log-seismic data suite provides an unparalleled reference for analysis of accretionary prism evolution to the west.

A decrease in density, resistivity, and gamma-ray logs from 169 to 189 mbsf defines log Unit 2, which correlates well with a structurally defined proto-décollement. Both logs and incompletely recovered cores recognize this low density unit, but logs better define its discrete boundaries and explicitly correlate it to a radiolarian mudstone interval at Site 672. A stratigraphically correlative mudstone interval always characterizes the décollement zone beneath the accretionary prism. Adjacent consolidation tests suggest high fluid pressures in this low density zone that would favor deformation there. The logs show no evidence in the proto-décollement for extreme fluid pressures, which might be seen as hydrofractures, and the geochemical evidence for fluid flow is equivocal here. The synthetic seismogram based on log results shows that this low density interval would have a reflection similar to that seen beneath much of the accretionary prism. Thus, incipient structures, physical properties, stratigraphic correlation, and seismic character all confirm that log Unit 2 is the proto-décollement.

Significant spikes in caliper, bulk density, resistivity and photoelectric effect plus a decrease in gamma-ray and an increase in resistivity values define log Unit 4 from 330 to 470 mbsf. This unit correlates with cyclically bedded sediments with high concentrations of sand and carbonate at Site 672. Anomalies in pore-fluid geochemistry suggest fluid flow in this unit. Lithologic properties derived from the logs indicate sand layers that could act as fluid conduits. A synthetic seismogram generated from the logs correlated through the 3-D seismic survey shows that this unit extends beneath the accretionary prism, where the fluids could be sourced.

SITE 1045

Site 1045, located 2.7 km west of the frontal thrust, was drilled through the décollement zone of the northern Barbados accretionary prism (Figs. 2-4). This is the first penetration of a high-amplitude negative polarity reflection of the Barbados décollement. This reflection might indicate high fluid pressures and perhaps physical dilation and hydrofractures. Drilling stopped 58 m below the top of the décollement zone because of hole instability but recorded a log profile through the bottom of this structure. At Site 1045, LWD acquired spectral gamma-ray, resistivity, density, caliper, photoelectric effect, and neutron porosity logs in this hole (Fig. 6). All logs are of excellent quality except neutron porosity. High quality is due to an in-gauge hole. Ninety-eight percent of the hole had differential caliper measurement of less than 1 in, below which density measurements are reliable.

Traditional visual and multivariate statistical analyses of the logs define eight log units. Because Site 1045 was never cored, we inferred lithology from log properties and seismic correlation. Carbonate-rich and clay-rich lithologies apparently dominate the accretionary prism, with a substantial clay-rich interval for about 100 m above the décollement zone. Correlation of the logs to the seismic reflection data identifies an interval of extremely low density between 425 and 438 mbsf as the décollement zone. Density and resistivity curves correlate positively, except below the décollement zone. These curves are inverted along two thrust faults that can be identified in the seismic reflection data and at several other depths in the logs where no structures are resolved seismically.

The density log places significant constraints on the hydrogeology of the accretionary prism, the décollement zone, and the underthrust sediments. A reversal of the consolidation trend in density occurs about 100 m above the top of the décollement zone. We believe that thrust imbrication of a low permeability clay-rich section has hindered consolidation. Extremely low densities down to 1.5 g/cm^3 characterize the décollement zone. Sharp changes in density (~0.2 g/cm^3) mark the top and bottom of the décollement zone. A comparison of the density profile through the proto-décollement at Site 1044 and the décollement at Site 1045 shows that density lows at Site 1045 are higher, thinner, and more sharply defined than the broader low in the Site 1044 density data. Therefore the density distribution in the décollement can be explained by compaction of the proto-décollement zone; dilation is not required. A synthetic seismogram based on the density log at Site 1045 reproduces the observed negative polarity reflection. Beneath the décollement zone, consolidation in the clay-rich upper part of the underthrust section is retarded, probably due to its low permeability and rapid loading by the overthrusting accretionary prism.

SITE 1046

Site 1046 was drilled through the décollement zone of the northern Barbados accretionary prism 1.9 km west of the frontal thrust and about 900 m east of Site 1045 (Figs. 2-4). Site 1046 is a re-occupation of Site 949, a site that was partially cored and instrumented with a Circulation

Obviation Retrofit Kit (CORK). The negative polarity reflection that characterizes the décollement beneath Site 1045 diminishes in strength during the lateral transition to Site 1046. At Site 1046, LWD acquired spectral gamma-ray, resistivity, density, caliper, photoelectric effect, and neutron porosity logs from the surface, through the décollement, and to the oceanic basement at 832 mbsf (Fig. 7). All logs are of excellent quality except neutron porosity.

Traditional visual and multivariate statistical analyses define eight log units. These log units subdivide into two sedimentary packages corresponding to the sections above and below the décollement zone. Sediments above the décollement are carbonate- and clay-rich calcareous claystone and noncalcareous claystone. Log Units 1-3a are dominated by the calcareous claystone. Falling resistivity in log Units 3a and 3b suggest a transition to a more clay-rich lithology above the décollement zone. A low-density interval in log Unit 4 and 5a correlates with the décollement zone. High gamma-ray and potassium values indicate significant terrigenous input in log Units 5b through 6b. The spiky resistivity response in log Unit 6 indicates cyclical sedimentation, probably turbidite deposition. The low resistivity and low gamma-ray values in log Unit 7 suggest pelagic sediment accumulation. Higher gamma-ray and resistivity values in log Unit 8 suggest correlation to the calcareous ferruginous unit cored at the base of Site 543.

Deformational features from cores and seismic data correlate well with log-inferred structural features. Inversions in the gamma-ray and density curves indicate thrust faults at 162, 225, 280, and 350 mbsf. Results from adjacent Site 949 confirm thrusting at 260, ~280, and 350 mbsf, but not at 162 mbsf because of discontinuous coring at that depth. Seismic data indicate a thrust fault at 282 mbsf that apparently correlates with the log-inferred thrust at 280 mbsf. The structurally defined décollement zone from the cores lies between 370 and 437 mbsf. A sharp drop in the density curve suggests that the top of the décollement zone is in log Unit 4 at 380 mbsf. The lower contact is indistinct but probably below 437 mbsf in a gradient of increasing density. Broad geochemical anomalies and a lack of thermal anomalies around the faults and décollement at Site 949 indicate fluid flow is not currently active along these structures. The synthetic seismogram reproduces the reflection at the thrust fault at ~280 m, but only weakly identifies the décollement.

The density log agrees well with all available core densities at Site 949, except those from the carbonate-rich zone at 300-322 mbsf. Comparisons of mean densities through the underthrust turbidite sequence at Site 1046 and an equivalent sequence at the reference Site 1044 suggest selective consolidation of this interval, assuming equivalent starting densities. Apparently fluids are being drained seaward through the high permeability turbidites. This hydrogeologic phenomenon also explains the high thermal gradient observed here at Site 949 and the reference Site 672.

Site 1047
(Leg 110, Site 676)

Site 1047 was drilled 1 km west of the deformation front through the décollement zone and more than 300 m into the underthrust section of the northern Barbados accretionary prism (Figs. 2-4). Site 1047 is a re-occupation of Site 676, which was cored to 310 m and documented processes associated with initiation of sediment offscraping. At Site 1047, LWD tools acquired spectral gamma-ray, resistivity, density, caliper, photoelectric effect, and neutron porosity logs from the seafloor through the décollement and to ~300 m below it into the underthrust section (Fig. 8). All logs are of excellent quality except neutron porosity.

Traditional visual and multivariate statistical analyses define six log units (Fig. 8). Log Unit 1 (0-158 mbsf) is characterized by increasing density with depth, a normal compaction trend, high resistivity, and high photoelectric effect. These log signatures are consistent with a carbonate-rich lithologic unit that occurs over the same depth interval at Site 676. Log Units 2, 3a, and 3b (158-276 mbsf) show a general decrease in resistivity, density, photoelectric effect, and gamma-ray values. These log responses reflect a downhole transition to an increasingly underconsolidated clay-rich unit above the décollement zone. An interval of very low density, low resistivity, and low gamma-ray values defines log Unit 3c (276-300 mbsf). This interval correlates to a lower Miocene radiolarian mudstone that includes mud-filled veins, a thrust fault, and a methane anomaly. This interval was interpreted as the incipient décollement zone at Site 676. An increase in differential caliper here and increased torque on the drill bit suggest that the muddy section was extruding into the drill hole, perhaps because of overpressuring. Log Units 4 (300-493 mbsf) and 5 (493-562 mbsf) exhibit a highly variable photoelectric effect and gamma-ray response, suggesting interbedded lithologies. Resistivity data in Unit 5 indicate sand interbeds that are probably correlative to the turbidite sequence cored at Sites 671 and 672. Log Unit 6 (562-619 mbsf) is characterized by decreasing photoelectric effect and density, and increasing and variable gamma-ray values. Log Unit 6 correlates with the early Eocene-aged noncalcareous claystones and siliceous claystones recovered at Sites 672 and 543.

Comparisons of the density curves from the reference Site 1044 and Site 1047 show selective consolidation in the décollement zone (log Unit 3) and the underthrust sandy turbidite section (log Unit 5). Presumably both intervals of localized consolidation are due to dewatering in response to localized deformation and loading due to underthrusting. A synthetic seismogram generated from the density log reproduces the negative polarity reflection from the décollement and the strong reflections from the underthrust turbidite sequence, but poorly matches reflections in the accretionary prism.

SITE 1048

Site 1048 was drilled 2.1 km east of the deformation front into the sedimentary section coming into the northern Barbados accretionary prism and is 3.8 km west-southwest of co-located Sites 1044 and 672 (Figs 2-4). At Site 1048, LWD acquired spectral gamma-ray, resistivity, density, caliper, photoelectric effect, and neutron porosity logs in a tectonically undisturbed oceanic section from the seafloor, through the proto-décollement, to a total depth of 324 mbsf (Fig. 9). All logs are of excellent quality except neutron porosity.

Traditional visual and multivariate statistical analyses define four log units whose lithology can be interpreted by correlation to Site 672. Log Unit 1 (0-105 mbsf) is characterized by increasing density, resistivity, and photoelectric effect with depth, and a normal compaction trend. These log signatures are consistent with a carbonate-rich lithologic unit that occurs from 0 to 123 mbsf at Site

672. Log Unit 2 (105-187 mbsf) shows a general decrease in resistivity, density, photoelectric effect, and gamma-ray values. Comparisons to Site 672 suggest that these log responses probably signify a downhole transition to an increasingly underconsolidated clay-rich unit. An interval of very low density, low resistivity, low photoelectric effect, and low gamma-ray values defines log Unit 3 (187-207 mbsf). This interval probably correlates to a lower Miocene radiolarian mudstone interpreted as the proto-décollement at Site 672. Log Unit 4 (207-324 mbsf) is characterized by increases in the density, gamma-ray, and photoelectric effect values. The highly variable (spikey) nature of the curves suggests interbedding of contrasting lithologies, and correlates with the muddy turbiditic unit beneath the décollement at Site 672.

Comparisons of the logs from the more seaward reference Site 1044 to Site 1048 show good correlation but a slightly thicker section at 1048. A synthetic seismogram generated from the density log reproduces well the shape and amplitude of the negative polarity reflection from the proto-décollement. The location of the proto-décollement occurs slightly higher in the upper reflective seismic unit than at Site 1044; thus, the basal surface of this seismic stratigraphic unit appears to be time transgressive. The most important result of Site 1048 is confirmation of the extremely low-density nature of the proto-décollement and the associated implications for localization of the detachment as the accretionary prism forms to the west.

CONCLUSIONS

The principal goal of Leg 171A was to acquire logging while drilling (LWD) data from the Barbados accretionary prism to obtain in situ physical properties in an area of extensive previous coring where previous wireline logging was unsuccessful. The principal scientific objectives were (1) evaluation of overall prism consolidation and velocity-porosity relationships, (2) correlation of physical properties of faults with displacement and fluid flow, (3) evaluation of the consolidation state of sediments in and around faults, and (4) determination of the origin of the negative polarity reflections in fault zones.

1. *Evaluation of overall prism consolidation and velocity-porosity relationships:* LWD data obtained at five sites during Leg 171A and two sites during Leg 156 provide an overview of prism consolidation. Two reference sections at Site 1044 and 1045 establish a baseline for evaluating consolidation of both the offscraped and underthrust sections up to 6 km east of the deformation front. Comparisons of the density curves from the reference sites enable calculation of underthrust sequence consolidation because of loading by the overlying accretionary prism at the LWD sites west of the deformation front. Velocity-porosity relationships could not be evaluated because of the absence of an LWD velocity tool that could measure sediments with such low velocities and the lack of time to conduct wireline velocity measurements.

2. *Correlation of physical properties of faults with displacement and fluid flow:* We found no correlation between consolidation and amount of underthrusting.

3. *Evaluation of the consolidation state of sediments in and around faults:* The localization of the décollement zone beneath the northern Barbados accretionary prism is controlled by the physical properties of the incoming sedimentary section, providing a classic example of the principle of sedimentary inheritance. A siliceous mudstone interval at reference Sites 1044 and 1048 (mean depth range = 178 to 198 mbsf) is characterized by a wet bulk density (mean = 1.47 g/cm^3) that is lower than the mudstones immediately above and below and comparable to the surface sediment. This lower Miocene low-density layer biostratigraphically correlates to the décollement zone at five ODP sites that penetrate through the accretionary prism.

   The low density of the radiolarian mudstone layer indicates underconsolidation and high fluid pressure, which facilitates décollement formation. Based on LWD data from boreholes penetrating the décollement beneath the accretionary prism, the low-density radiolarian mudstone layer consolidates, probably because of dewatering associated with shearing. Consolidation locally thins and more sharply defines the top and bottom of the low-density layer. Here negative and positive seismic reflections respectively from the top and bottom of the layer interfere or "tune," producing a strong negative polarity seismic reflection. Producing the strong negative polarity reflections by selective consolidation contrasts with previous interpretations that invoke dilation and hydrofracture to generate the reflections. Both interpretations are viable, but the data from 171A may be more simply interpreted as a consolidation response. Where consolidation has eliminated the low-density signature of the décollement zone, its seismic reflection becomes positive because of a preserved positive shift in density and impedance at the base of the radiolarian mudstone interval. Thus, the areas of negative polarity reflections of the décollement zone are intervals of arrested partial consolidation. This pattern of arrested consolidation bears no simple relationship to the prism geometry, distance of underthrusting, or underthrust sediment form.

4. *Determination of the origin of the negative polarity reflections in fault zones:* LWD data were obtained through a negative polarity reflection, thereby documenting the in situ physical properties that produce these distinctive reflections.

In summary, Leg 171A partially accomplished Objective 1 by determining prism consolidation. However, we did not establish velocity-porosity relationships of these sediments. We tested the prediction of Objective 2 and found no correlation between consolidation and the amount of underthrusting; but we were successful in determining the consolidation state of sediments around the décollement (Objective 3). We recorded logs through a negative polarity reflection, established that it is probably a residual fluid accumulation, and now have documented the physical property variations that produce these distinctive reflections (Objective 4).

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FIGURE CAPTIONS

Figure 1. Map of large-scale regional setting and inset map. Black rectangle locates area of 3-D seismic survey and previous drill sites. All drill sites except Site 543 are included in the area of 3-D seismic survey (Figs. 2A, B, 3, 4). Shaded region encompasses Barbados accretionary prism with forearc basin to west. Bathymetry is in meters.

Figure 2. **(A)** Bathymetric map and location of drill sites. **(B)** Peak seismic amplitude on décollement (after Shipley et al., 1994; Moore et al., 1995). Bold line on both A and B indicates location of seismic line in Figure 3. Bathymetry is derived from mapped seafloor reflection in migrated 3-D seismic records.

Figure 3. Cross section from seismic depth section extending from west of Site 1045 to Site 1044. Solid lines below level of décollement and proto-décollement show approximate limits of underthrust terrigenous sequence.

Figure 4. **(A)** Shaded relief image of the seafloor within the 3-D seismic survey area. The seismic horizon was interpreted along the zero crossing between the first negative and first positive seafloor reflections on a grid of roughly every 10th line and every 50th common midpoint. Between interpreted lines, the horizon was mapped using the Landmark™ Zone Autopicker algorithm, which extends horizon interpretations throughout the data set by following the specified trace characteristics. The resultant horizon contains a value for every line and common midpoint of the 3-D survey (bin spacing is 25 m x 15 m respectively). Illumination is from the southeast, and gray scale shades are histogram equalized. Overall bathymetry is increasing to the east, but small scale bathymetric variations reveal at least three distinct structural regions. Within the first region, between common midpoints 480 and 920, a series of south-southwest-trending lineations are visible downstepping to the north-northwest. The second region, from common midpoint 920 to 1386, encompasses south-southeast-trending lineations related to thrusting in the toe of the prism. East of common midpoint 1386, within the third structural region, bathymetric changes are subdued but a series of south-southwest-trending

lineations is visible. These downstep to the north-northwest and are related to the topography of the underlying oceanic crust. **(B)** 200% zoom of the area between common midpoints 153 and 986 showing locations of Leg 110 sites. **(C)** 200% zoom of the area between common midpoints 986 and 1781 showing the locations of sites drilled during Legs 110, 156, and 171A.

Figure 5 (A, B). Summary of LWD data from Site 1044 compared to core data from Site 672. Shaded bar across diagram shows the proto-décollement zone.

Figure 6 (A, B). Summary of LWD data from Site 1045. Décollement zone (log Unit 7) in this region is characterized by a high-amplitude negative polarity seismic reflection.

Figure 7 (A, B). Summary of LWD data from Site 1046 compared to core data from Holes 959B and 949C. Shaded bars across diagram show fault zones identified in cores.

Figure 8 (A, B). Summary of LWD data from Site 1047 and core data from Site 676. Log units for Hole 1047A can be compared to lithologic units of Site 676. Shaded bars across diagram show fault zones as identified in core and décollement zone as inferred from interval of low density (log Unit 3c).

Figure 9 (A, B). Summary of LWD data from Site 1048 compared to core data from Site 672 and the Site 1044 density curve. Log units for Site 1048 can be compared to the lithologic units of Site 672. Shaded bars across diagram show proto-décollement zone as inferred from low-density log Unit 3.

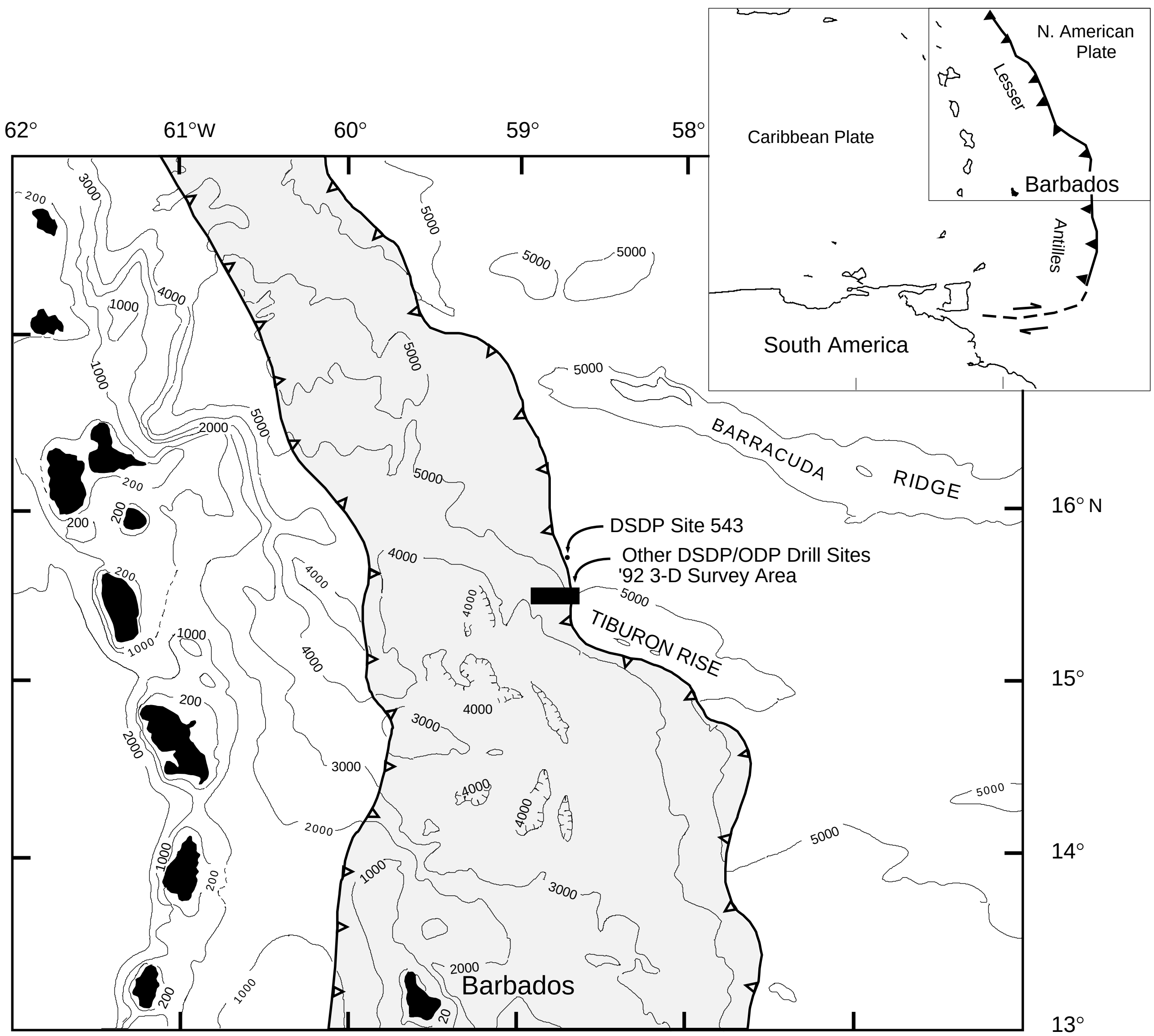

62°
61°W
60°
59°
58°
16° N
15°
14°
13°
N. American Plate
Caribbean Plate
Lesser
Antilles
Barbados
South America
BARRACUDA RIDGE
TIBURON RISE
DSDP Site 543
Other DSDP/ODP Drill Sites
'92 3-D Survey Area
Barbados

Figure 1

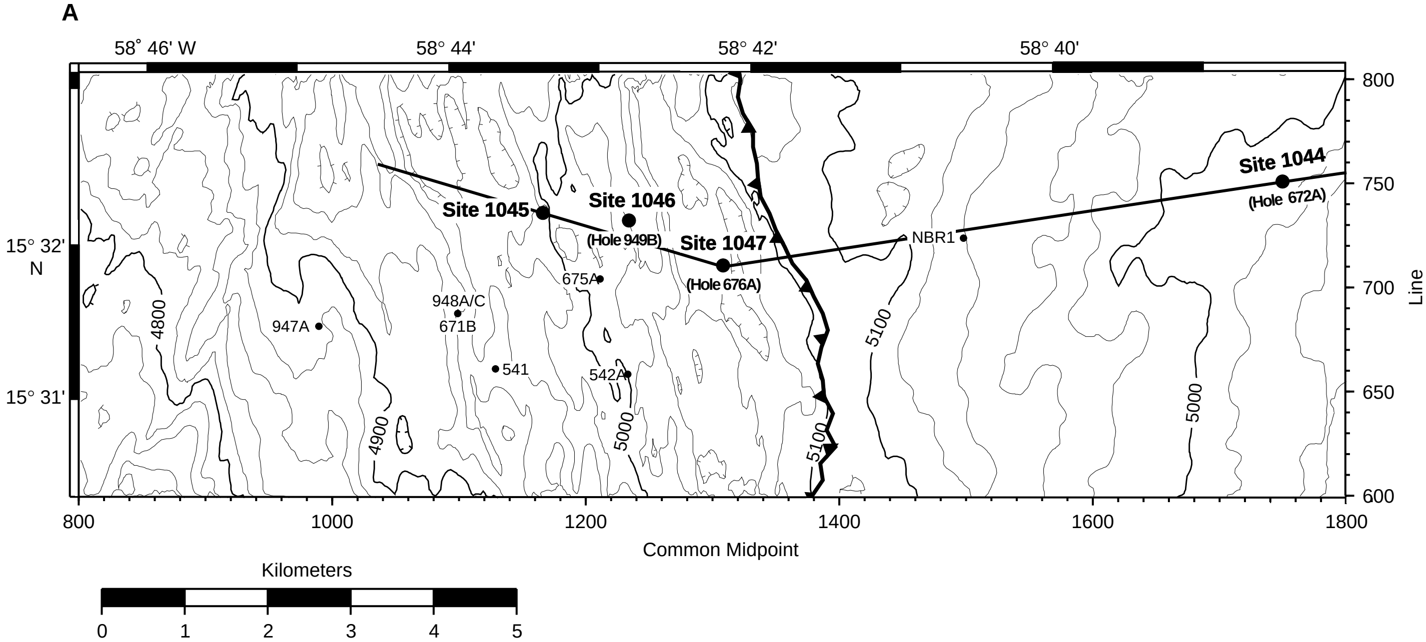

A
58° 46' W
58° 44'
58° 42'
58° 40'
15° 32' N
15° 31'
Site 1044
(Hole 672A)
Site 1045
Site 1046
(Hole 949B)
Site 1047
(Hole 676A)
NBR1
675A
948A/C
671B
947A
541
542A
4800
4900
5000
5100
800
750
700
650
600
Line
800
1000
1200
1400
1600
1800
Common Midpoint
Kilometers
0
1
2
3
4
5

Figure 2A

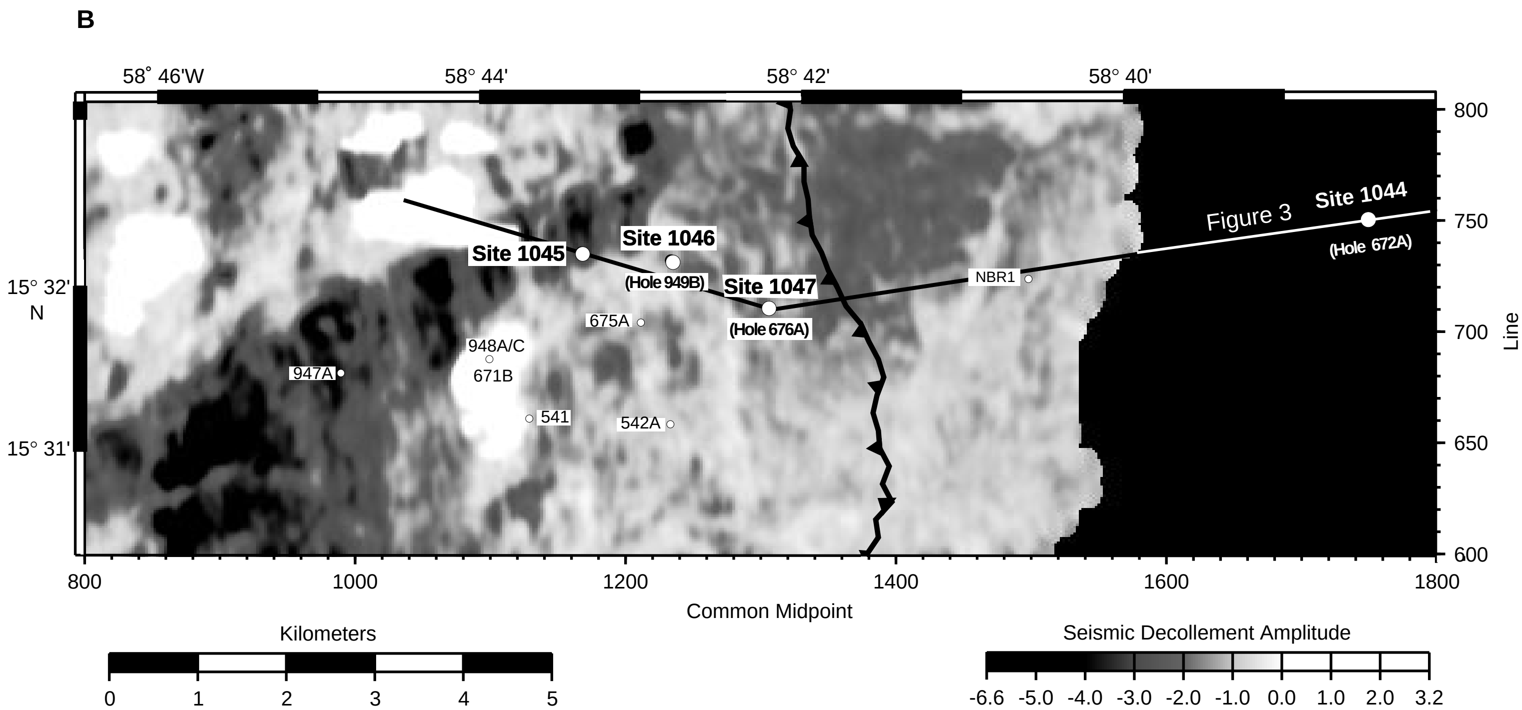

B
58° 46'W
58° 44'
58° 42'
58° 40'
15° 32' N
15° 31'
Site 1045
Site 1046
(Hole 949B)
Site 1047
(Hole 676A)
Site 1044
(Hole 672A)
Figure 3
NBR1
675A
948A/C
671B
947A
541
542A
800
1000
1200
1400
1600
1800
Common Midpoint
Line
800
750
700
650
600
Kilometers
0
1
2
3
4
5
Seismic Decollement Amplitude
-6.6
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.2

Figure 2B

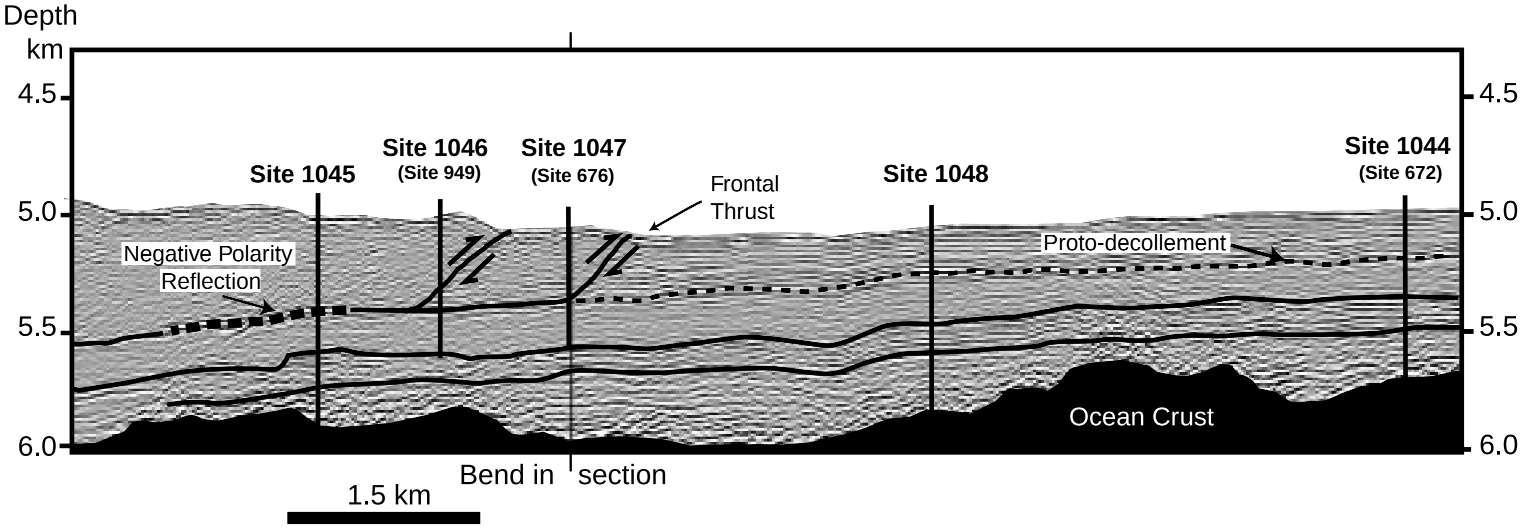

Depth
km
4.5
5.0
5.5
6.0
4.5
5.0
5.5
6.0
Site 1045
Site 1046
(Site 949)
Site 1047
(Site 676)
Frontal
Thrust
Site 1048
Site 1044
(Site 672)
Negative Polarity
Reflection
Proto-decollement
Ocean Crust
Bend in
section
1.5 km

Figure 3

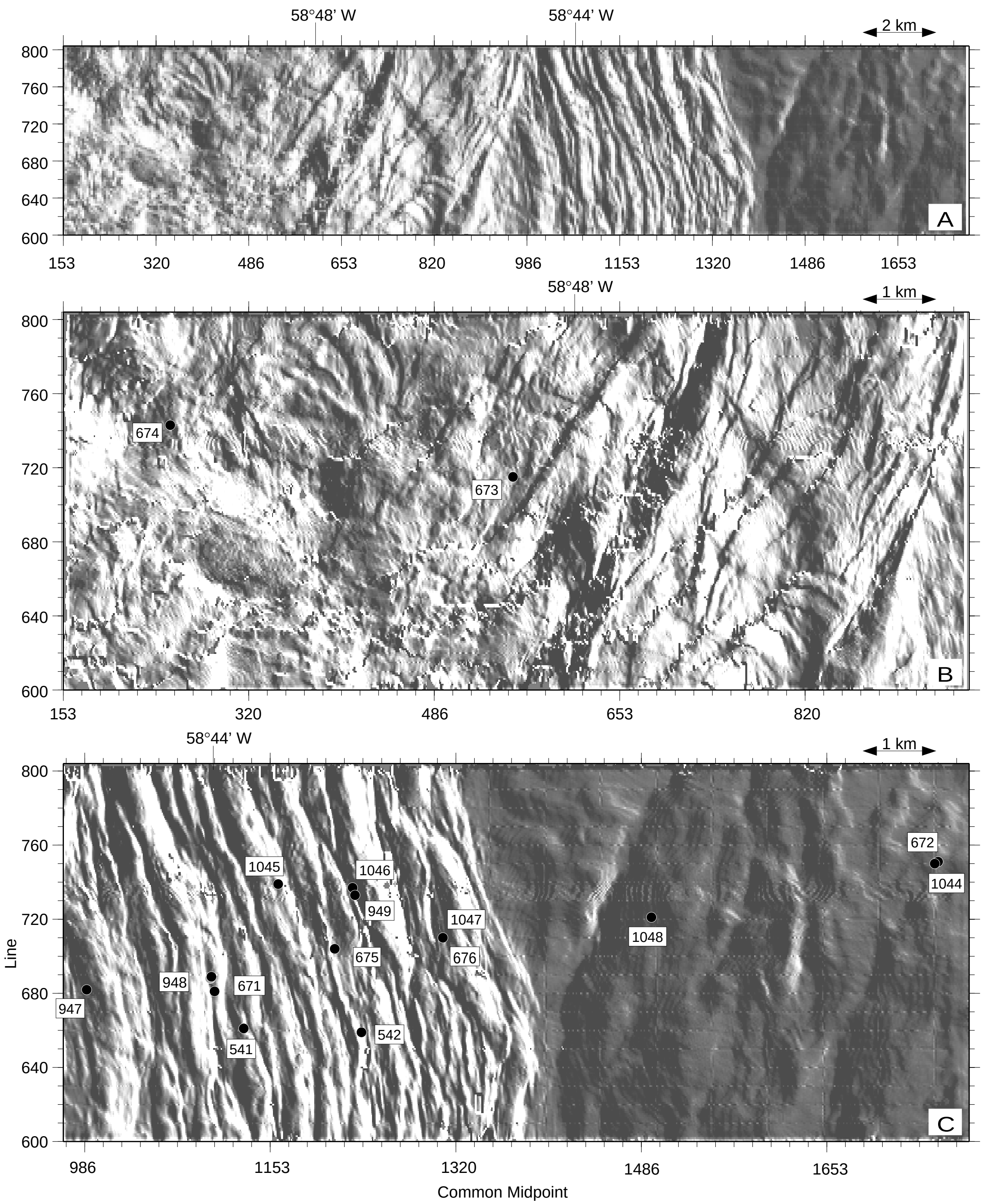

58°48' W
58°44' W
2 km
800
760
720
680
640
600
A
153
320
486
653
820
986
1153
1320
1486
1653
58°48' W
1 km
674
673
B
58°44' W
1 km
Line
1045
1046
949
1047
675
676
948
671
947
541
542
1048
672
1044
C
Common Midpoint

Figure 4

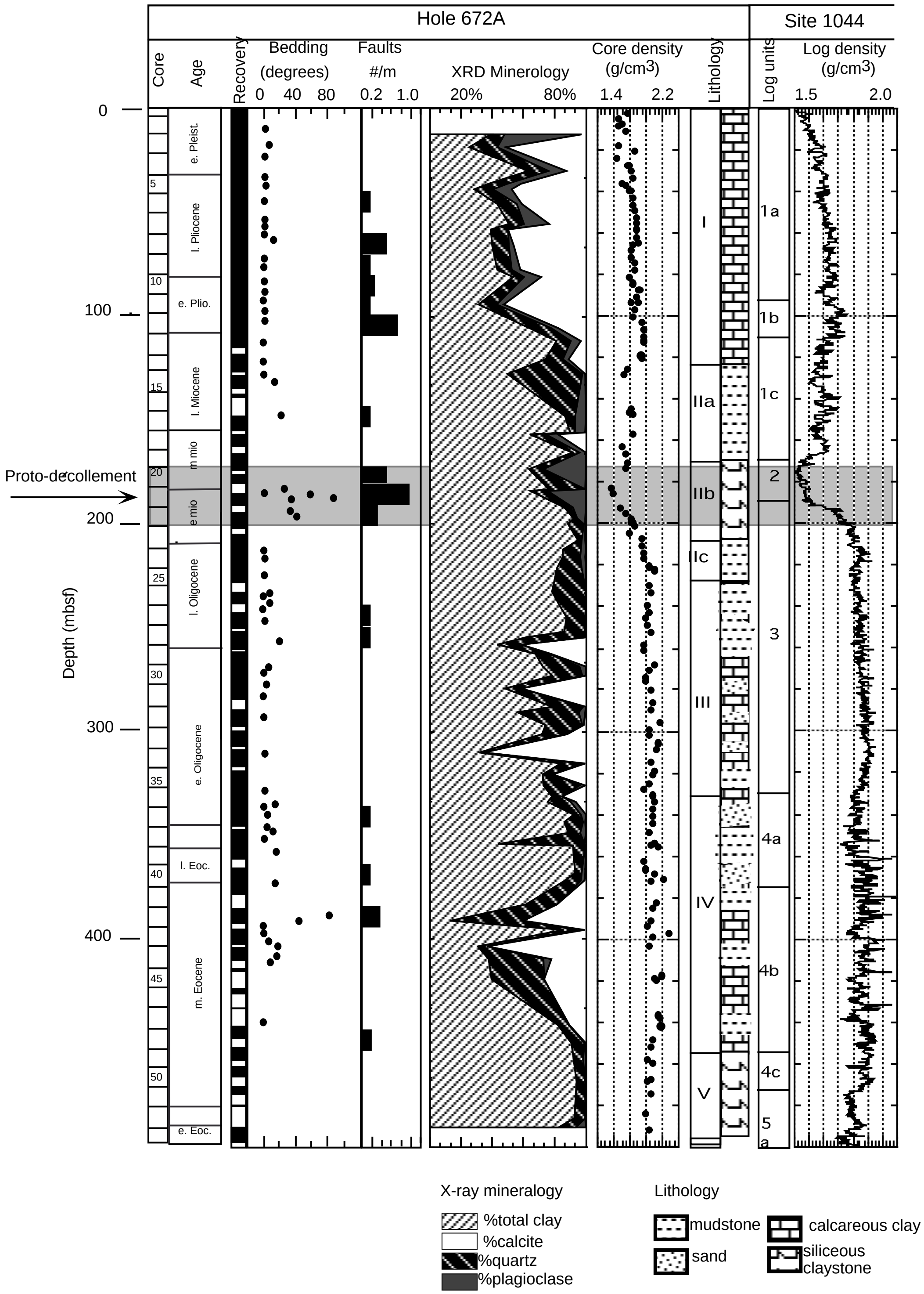

Hole 672A
Site 1044
Core
Age
Recovery
Bedding (degrees)
0 40 80
Faults #/m
0.2 1.0
XRD Minerology
20% 80%
Core density (g/cm3)
1.4 2.2
Lithology
Log units
Log density (g/cm3)
1.5 2.0
Depth (mbsf)
0
100
200
300
400
Proto-décollement
e. Pleist.
l. Pliocene
e. Plio.
l. Miocene
m mio
e mio
l. Oligocene
e. Oligocene
l. Eoc.
m. Eocene
e. Eoc.
I
IIa
IIb
IIc
III
IV
V
1a
1b
1c
2
3
4a
4b
4c
5a
X-ray mineralogy
%total clay
%calcite
%quartz
%plagioclase
Lithology
mudstone
sand
calcareous clay
siliceous claystone

Figure 5A

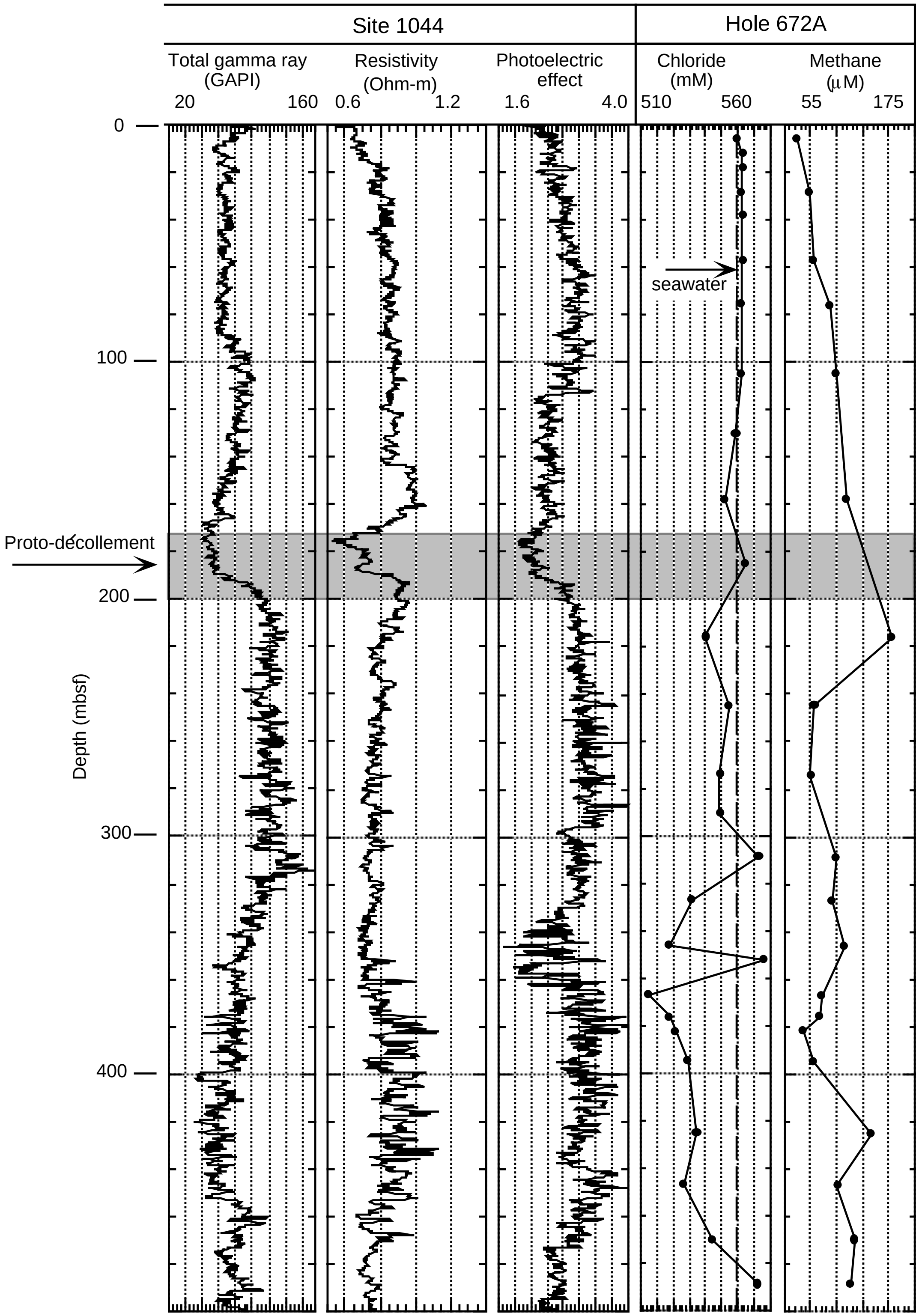

Site 1044
Hole 672A
Total gamma ray (GAPI)
20
160
Resistivity (Ohm-m)
0.6
1.2
Photoelectric effect
1.6
4.0
Chloride (mM)
510
560
Methane (µM)
55
175
0
100
200
300
400
Depth (mbsf)
Proto-décollement
seawater

Figure 5B

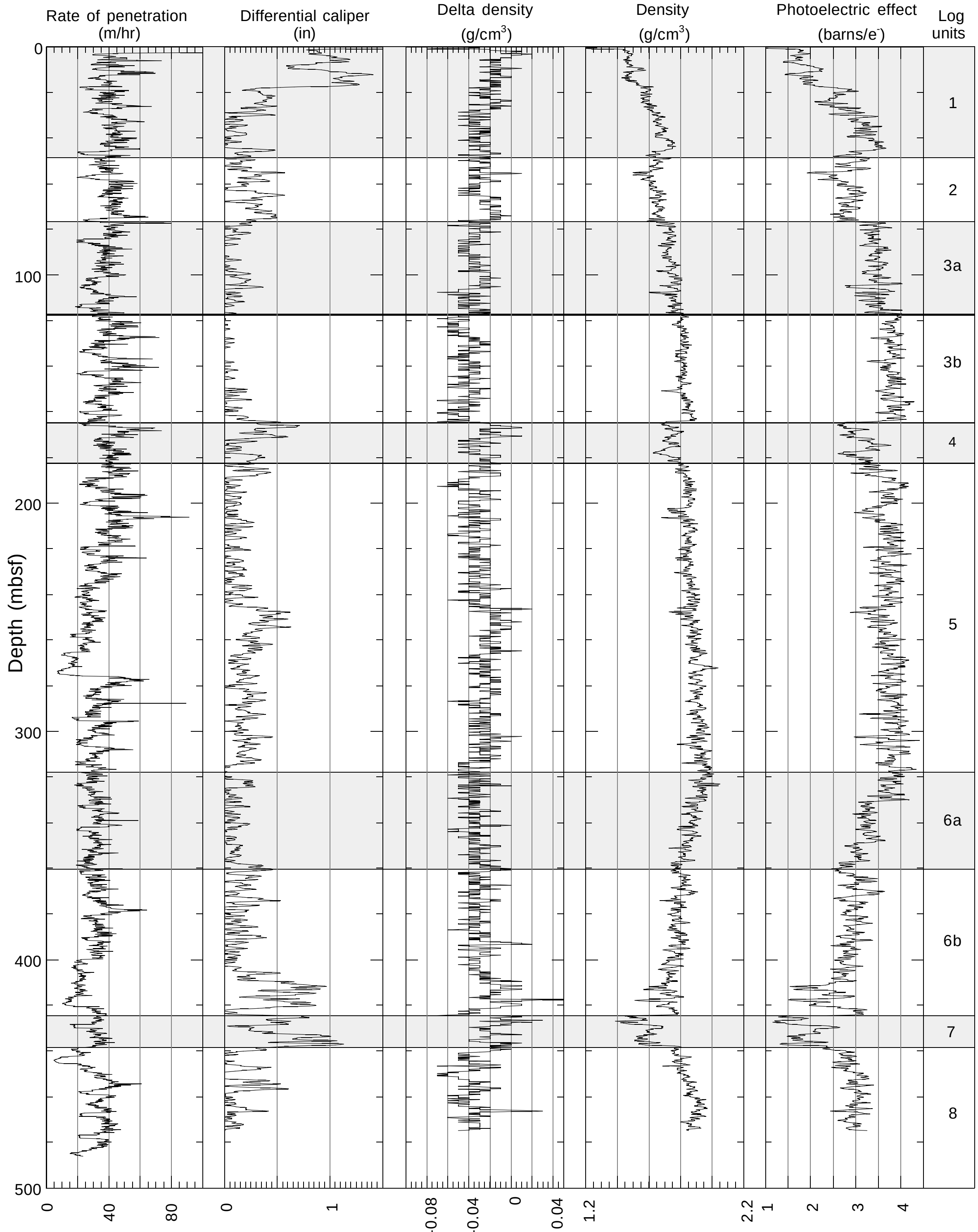

Rate of penetration
(m/hr)
Differential caliper
(in)
Delta density
(g/cm3)
Density
(g/cm3)
Photoelectric effect
(barns/e-)
Log
units
Depth (mbsf)
0
100
200
300
400
500
1
2
3a
3b
4
5
6a
6b
7
8
0
40
80
0
1
-0.08
-0.04
0
0.04
1.2
2.2
1
2
3
4

Figure 6A

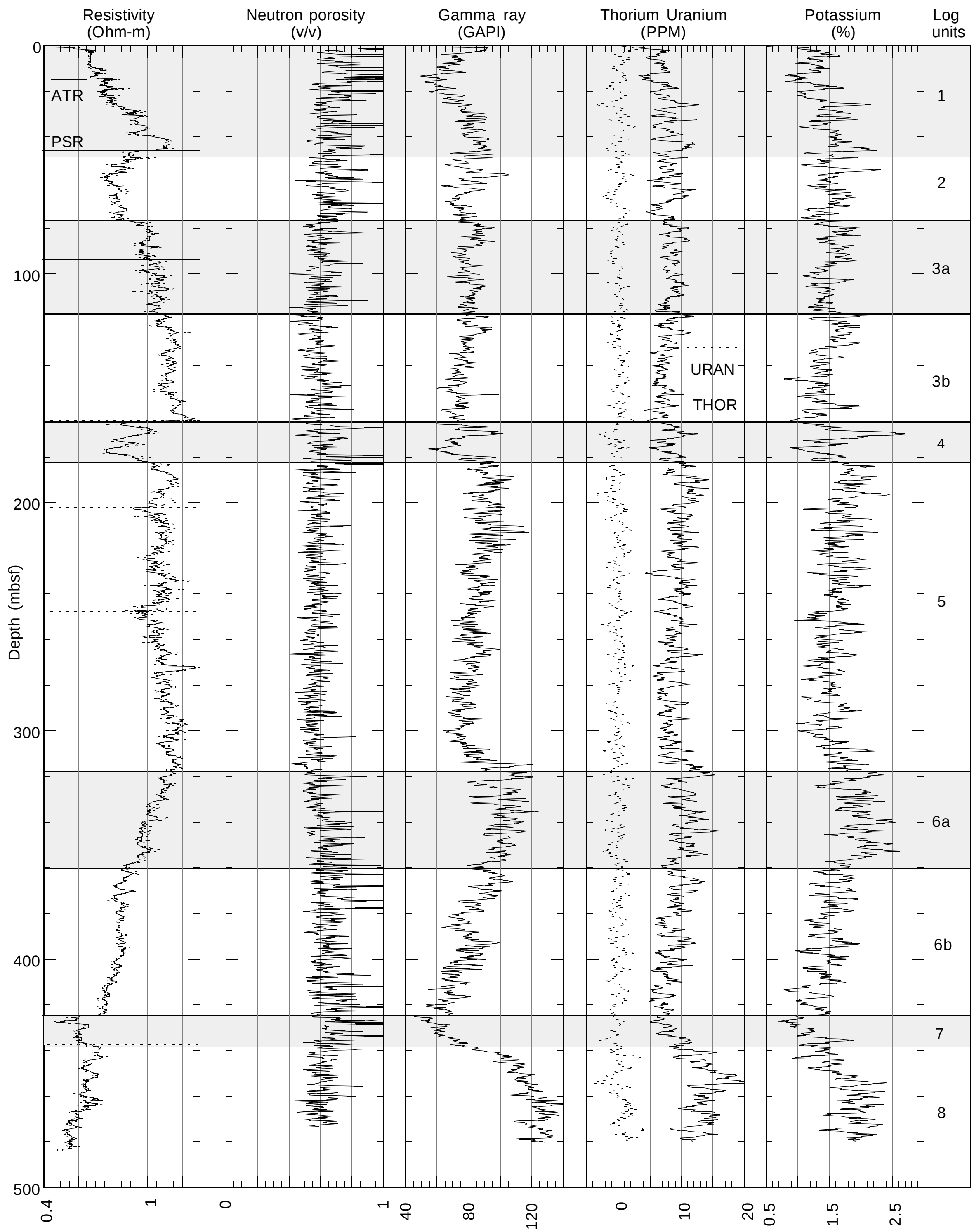

Resistivity
(Ohm-m)
Neutron porosity
(v/v)
Gamma ray
(GAPI)
Thorium Uranium
(PPM)
Potassium
(%)
Log
units
Depth (mbsf)
ATR
PSR
URAN
THOR
1
2
3a
3b
4
5
6a
6b
7
8
0
100
200
300
400
500
0.4
1
0
1
40
80
120
0
10
20
0.5
1.5
2.5

Figure 6B

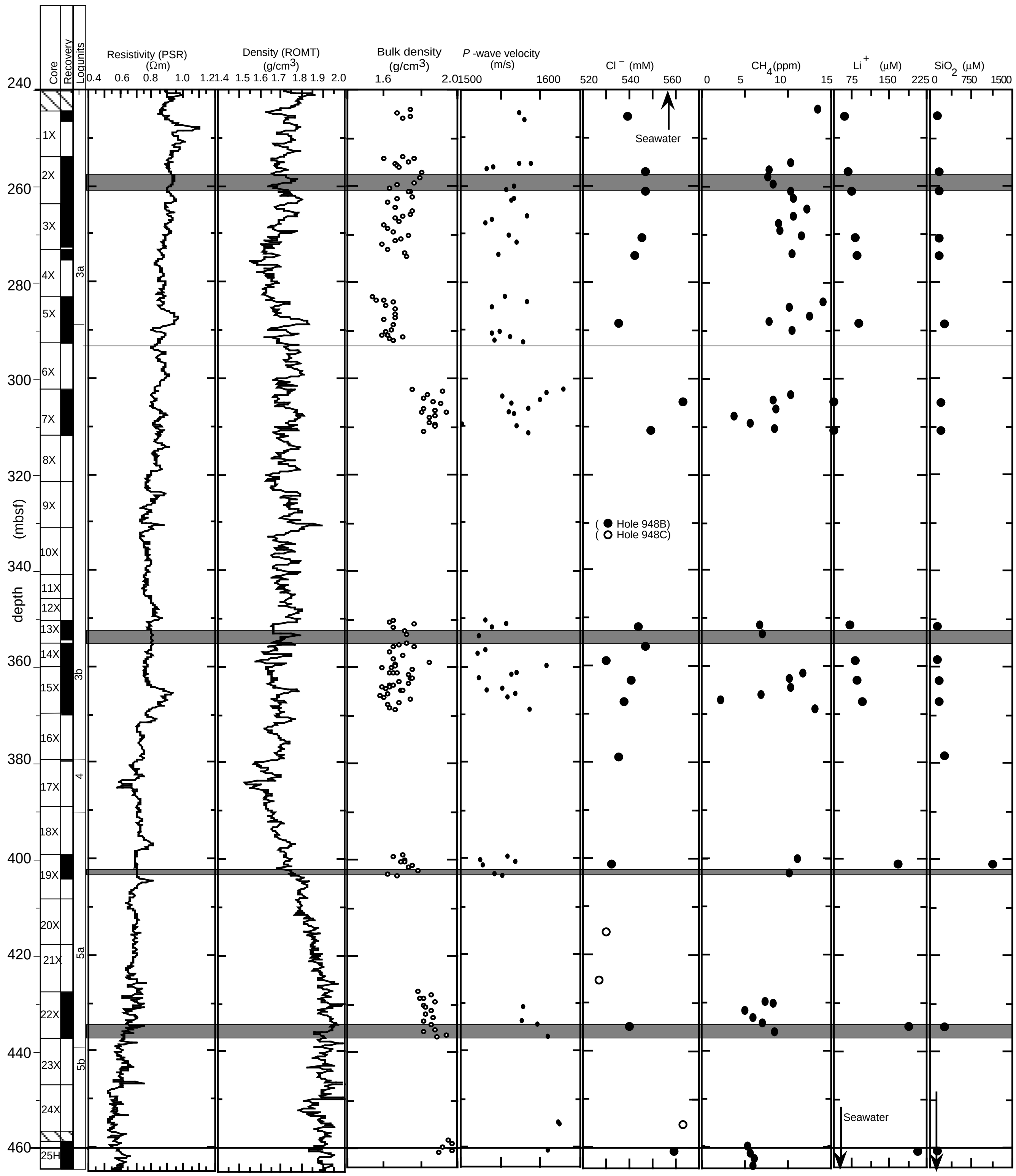

Core
Recovery
Log units
Resistivity (PSR) (Ωm)
Density (ROMT) (g/cm3)
Bulk density (g/cm3)
P -wave velocity (m/s)
Cl− (mM)
CH4(ppm)
Li+ (µM)
SiO2 (µM)
depth (mbsf)
Seawater
Hole 948B
Hole 948C
3a
3b
4
5a
5b
1X
2X
3X
4X
5X
6X
7X
8X
9X
10X
11X
12X
13X
14X
15X
16X
17X
18X
19X
20X
21X
22X
23X
24X
25H

Figure 7A

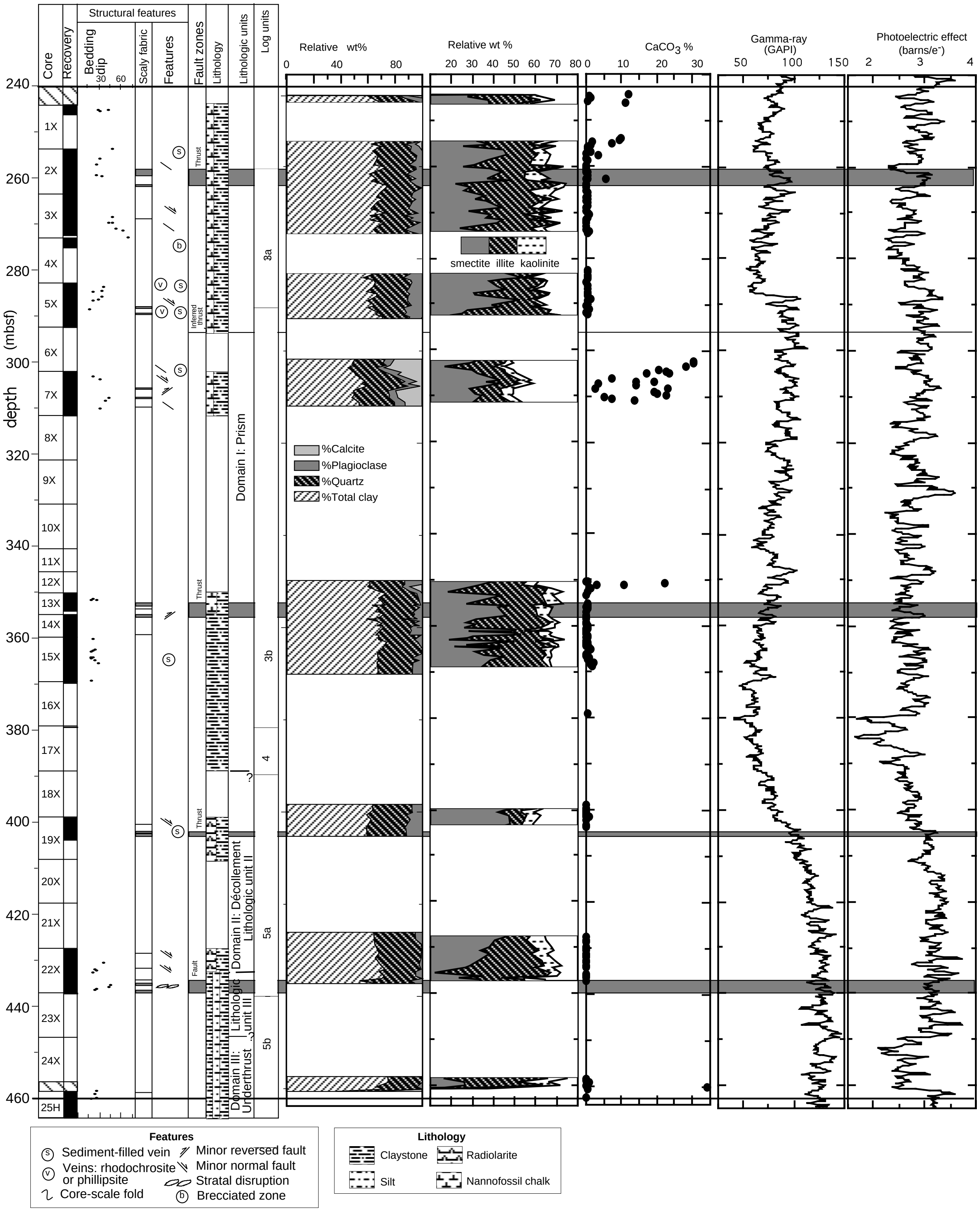

Structural features
Core
Recovery
Bedding dip
30 60
Scaly fabric
Features
Fault zones
Lithology
Lithologic units
Log units
Relative wt%
0 40 80
Relative wt %
20 30 40 50 60 70 80
smectite illite kaolinite
CaCO3 %
0 10 20 30
Gamma-ray (GAPI)
50 100 150
Photoelectric effect (barns/e-)
2 3 4
depth (mbsf)
240
260
280
300
320
340
360
380
400
420
440
460
1X
2X
3X
4X
5X
6X
7X
8X
9X
10X
11X
12X
13X
14X
15X
16X
17X
18X
19X
20X
21X
22X
23X
24X
25H
Thrust
Inferred thrust
Fault
Domain I: Prism
Domain II: Décollement
Lithologic unit II
Lithologic unit III
Domain III: Underthrust
3a
3b
4
5a
5b
%Calcite
%Plagioclase
%Quartz
%Total clay
Features
Sediment-filled vein
Veins: rhodochrosite or phillipsite
Core-scale fold
Minor reversed fault
Minor normal fault
Stratal disruption
Brecciated zone
Lithology
Claystone
Radiolarite
Silt
Nannofossil chalk

Figure 7B

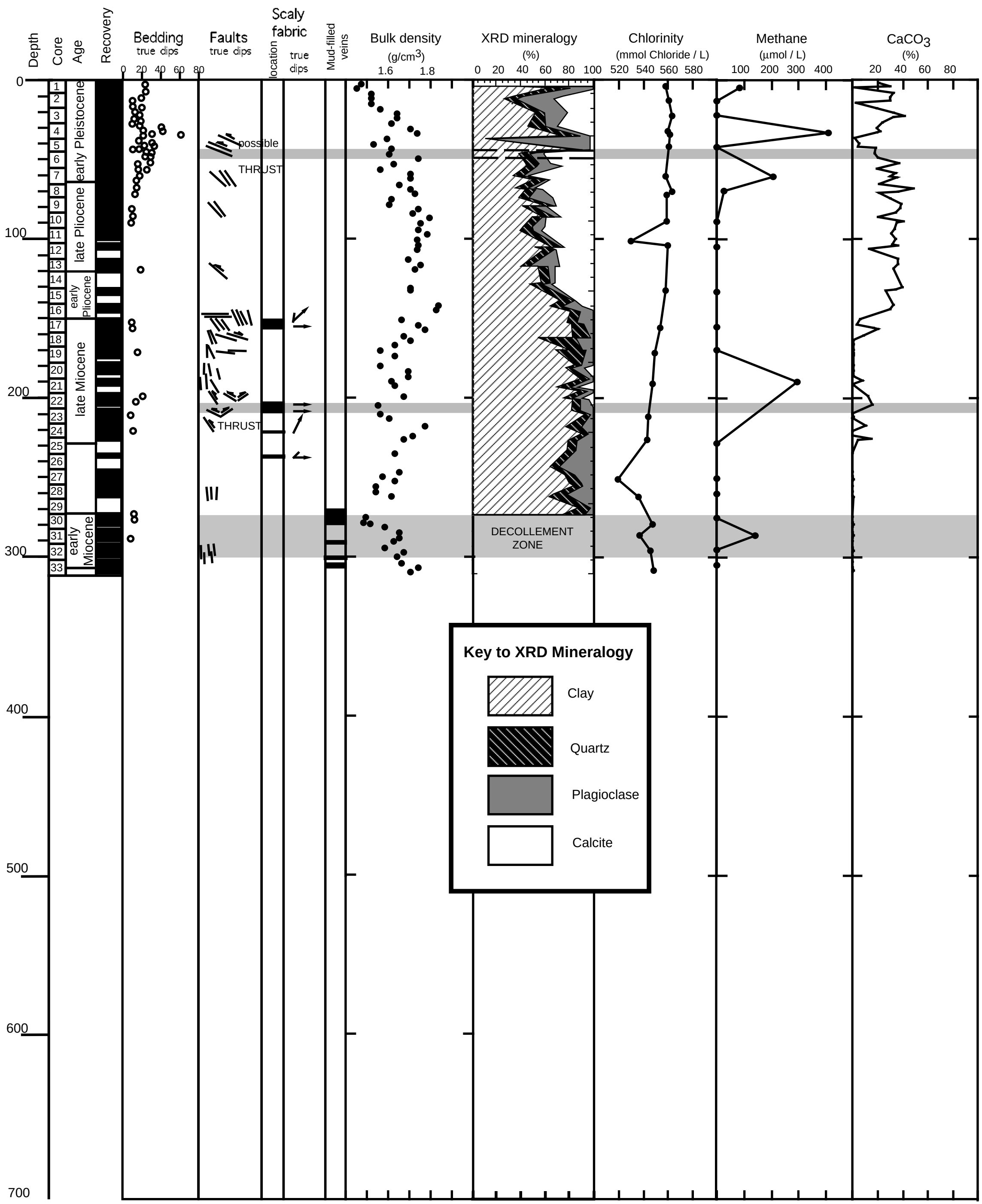

Depth
Core
Age
Recovery
Bedding
true dips
Faults
true dips
Scaly fabric
location
true dips
Mud-filled veins
Bulk density
(g/cm3)
XRD mineralogy
(%)
Chlorinity
(mmol Chloride / L)
Methane
(µmol / L)
CaCO3
(%)
early Pleistocene
late Pliocene
early Pliocene
late Miocene
early Miocene
possible
THRUST
THRUST
DECOLLEMENT
ZONE
Key to XRD Mineralogy
Clay
Quartz
Plagioclase
Calcite

Figure 8A

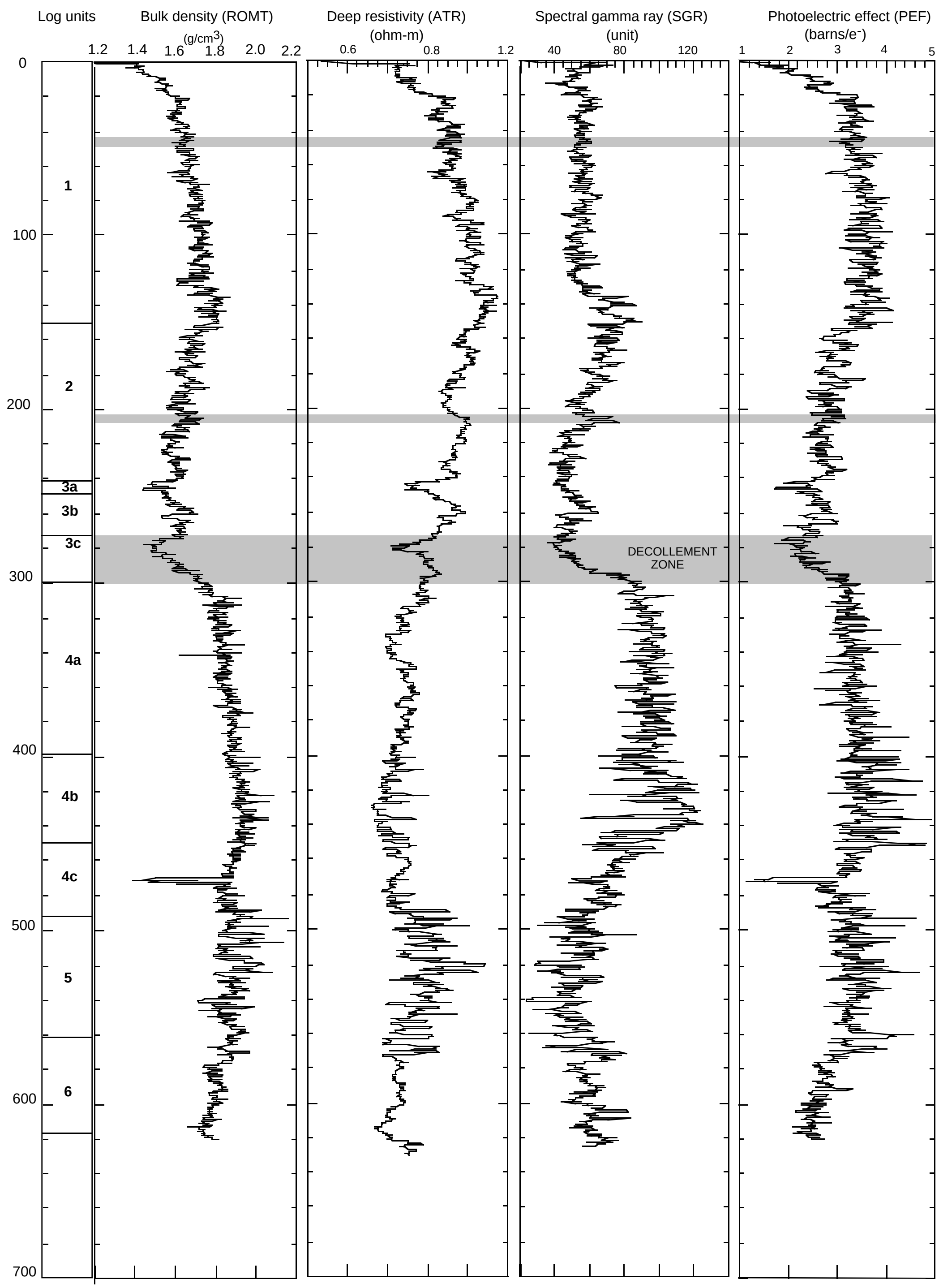

Log units
Bulk density (ROMT)
(g/cm3)
1.2
1.4
1.6
1.8
2.0
2.2
Deep resistivity (ATR)
(ohm-m)
0.6
0.8
1.2
Spectral gamma ray (SGR)
(unit)
40
80
120
Photoelectric effect (PEF)
(barns/e-)
1
2
3
4
5
0
100
200
300
400
500
600
700
1
2
3a
3b
3c
4a
4b
4c
5
6
DECOLLEMENT
ZONE

Figure 8B

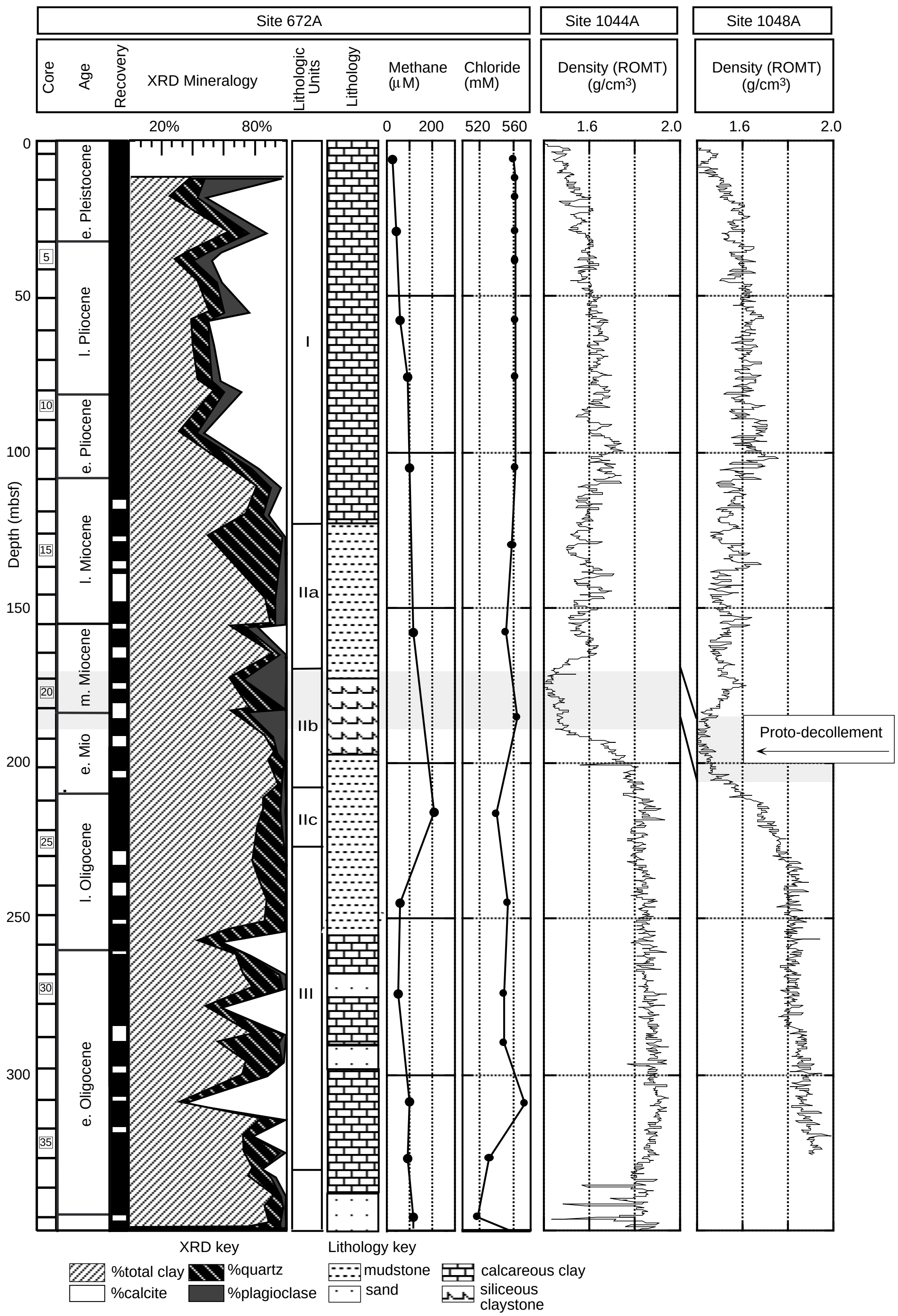

Site 672A
Site 1044A
Site 1048A
Core
Age
Recovery
XRD Mineralogy
Lithologic Units
Lithology
Methane (µM)
Chloride (mM)
Density (ROMT) (g/cm³)
Density (ROMT) (g/cm³)
20%
80%
0
200
520
560
1.6
2.0
1.6
2.0
Depth (mbsf)
0
50
100
150
200
250
300
5
10
15
20
25
30
35
e. Pleistocene
l. Pliocene
e. Pliocene
l. Miocene
m. Miocene
e. Mio
l. Oligocene
e. Oligocene
I
IIa
IIb
IIc
III
Proto-decollement
XRD key
%total clay
%quartz
%calcite
%plagioclase
Lithology key
mudstone
sand
calcareous clay
siliceous claystone

Figure 9A

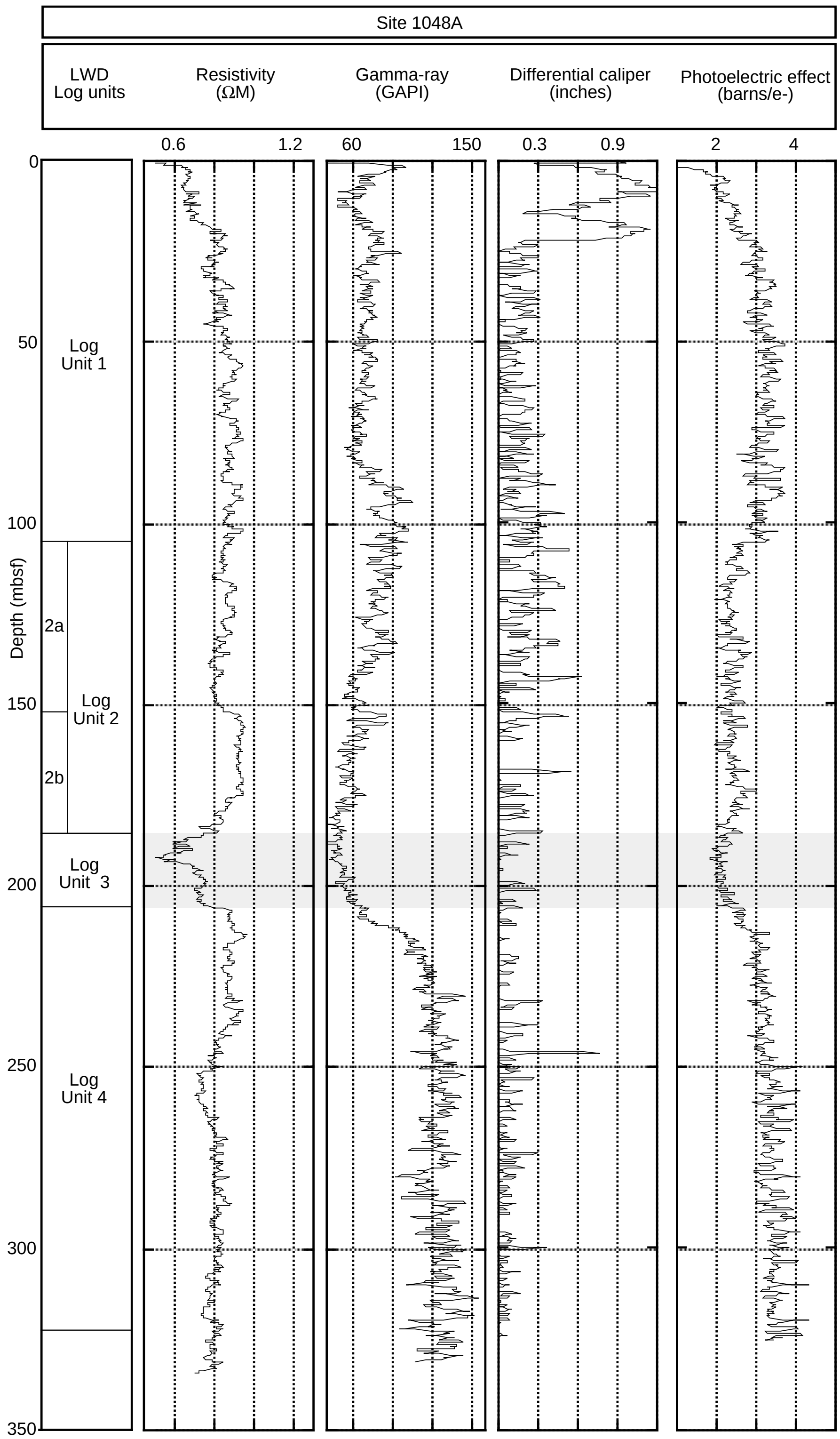

Site 1048A
LWD
Log units
Resistivity
(ΩM)
Gamma-ray
(GAPI)
Differential caliper
(inches)
Photoelectric effect
(barns/e-)
0.6
1.2
60
150
0.3
0.9
2
4
0
50
100
150
200
250
300
350
Depth (mbsf)
Log
Unit 1
2a
2b
Log
Unit 2
Log
Unit 3
Log
Unit 4

Figure 9B

OPERATIONS SYNOPSIS

The ODP Drilling Services Department personnel aboard *JOIDES Resolution* for Leg 171A were:

Operations Manager:	Scott McGrath
ODP Engineer:	Mark Robinson
Schlumberger Engineer:	Jonathan Kreb
Anadrill Engineer:	Thomas Horton
Anadrill Engineer:	Peter Ireland

BALBOA TO SITE 1044A

The last line was cast off from Pier 18 at Balboa, Panama, at 0300 hr 20 December and the vessel commenced its sea voyage through the Panama Canal. Due to heavy traffic, the vessel waited at anchor for 13 hrs in Gatum Lake until clearance was received to pass through the Gatum Locks. After exiting the Panama Canal, moderate seas (8-12 ft) and winds (25-30 kt) held the vessel speed to under 8 kt for two days. Improved weather and sea states allowed for better progress toward the end of the transit to Proposed Site NBR-11A. The vessel arrived at Site NBR-11A at 2100 hr on 26 December after a transit of 1371 nmi with an average speed of 9.1 kt.

HOLE 1044A
(Site 672; Proposed Site NBR-11A)

Logging while drilling (LWD) Hole 1044A was located at global positioning system (GPS) coordinates 15°32.3965'N and 58°38.4793'W. This location is at a range of 35 m and a bearing of 259° from ODP Site 672. The location of Hole 1044A was based on 3-D seismic reflection survey, dGPS navigation data, and the final site position for Site 672 (Leg 110), which was produced by averaging transit satellite fixes. *JOIDES Resolution* GPS navigation data were automatically corrected to the moonpool using the ship's heading (gyro compass) and the known offset of the GPS antenna from the moonpool. Upon arrival at the desired drill site GPS coordinates, a beacon was deployed. After the beacon had settled to the seafloor and while we were tripping pipe to the seafloor, the ship was stabilized over the beacon using the ship’s dynamic positioning system. The GPS data collected during the pipe trip to the seafloor were averaged, and we offset from the beacon location prior to spudding the hole to ensure we were in the desired location with respect to the 3-D seismic data. After we spudded into the seafloor, GPS data collected while we were drilling were averaged over approximately a 48-hr period to calculate the final site position.

The LWD bottom-hole assembly (BHA) consisted of a used 9-7/8 in Smith FDGH (3x14) bit, LWD Bit Sub, LWD Compensated Dual Resistivity (CDR) tool, double pin LWD crossover, LWD Compensated Density Neutron (CDN) tool, LWD crossover sub, 8 each 8-1/4 in drill collars, crossover, Bowen down jars, Bowen up jars, crossover, 2 each 8-1/4 in drill collars, Tapered Drill Collar (TDC), and 6 joints of 5-1/2 in drill pipe.

Hole 1044A was spudded at 1400 hr 27 December 1996. Drilling was initiated at 25 m/hr at a water depth of 4991.4 mbrf based on the precision depth recorder (PDR) reading. It was not possible to determine the mudline with the drill pipe in the soft hemipelagic sediments. Therefore, the PDR reading of 4991.4 mbrf was used for the water depth and the actual water depth will be corrected after analyzing the LWD data. Drilling continued at 25 m/hr down to 5291 mbrf (300 mbsf) where a precautionary wiper trip was made. The proto-décollement was estimated at 200 mbsf and the wiper trip was made from 300 mbsf back to 160 mbsf to allow the top of the BHA to clear the seafloor and also ream the hole in the location of the décollement. No drag or hole problems were encountered during the wiper trip. A 30-bbl sweep of sepiolite mud was used to clean out 9 m of fill that had accumulated at the bottom of the hole and drilling resumed at 25 m/hr. The rate of penetration was increased to 35 m/hr at 5379 mbrf (388 mbsf) to finish the hole more quickly. The drilling rate slowed down dramatically to 4 m/hr at a depth of 5663 mbrf, indicating we had reached basement. Hole 1044A was terminated at 5666 mbrf (675 mbsf) having successfully achieved the depth objective.

The drill string was raised to 5126 m (135 mbsf) and the hole was displaced with 45 bbl of heavy (10.5 lb/gal) mud. The LWD tools were raised to the drill floor where the nuclear sources were removed and the LWD collars were laid out. The beacon was recovered and the bit cleared the rotary table at 0200 hr 30 December ending Hole 1044A.

SITE 1045
(Proposed Site NBR-8A)

The vessel was offset in dynamic positioning mode at a speed of 2 nmi/hr from Hole 1044A to Site 1045 while retrieving the BHA and downloading the LWD data from Hole 1044A. The distance between NBR-8A and NBR-9A is ~1 km, and one beacon was dropped between these sites and used for operations at both sites. LWD Hole 1045A was located at GPS coordinates 15°32.2407'N and 58°43.4222'W. After changing out the LWD tools, the same BHA from Hole 1044A was assembled with a new Smith 9-7/8 in FDGH (3x14) bit. Hole 1045A was spudded at 1445 hr 30 December 1996. Drilling was initiated at a water depth of 4980.4 mbrf based on the PDR reading. As at all the LWD sites, it was not possible to determine the mudline with the drill pipe in the soft sediments. Therefore, the PDR reading of 4980.4 mbrf was used for the initial water depth. The final water depth was established at 4982 mbrf (4971 mbsl) based on the analysis of the LWD data.

We attempted to drill at 35 m/hr down to 5416 mbrf (434 mbsf) where high pump pressure and torque were encountered. The décollement zone was estimated at 424 mbsf and considerable back reaming and hole conditioning were required to advance the drill string beyond this point. The drill string was pulled up to 5371 mbrf (389 mbsf) and a 30-bbl sepiolite mud sweep was pumped. The hole was then reamed back down from 5371 to 5416 mbrf (389 to 434 mbsf). Drilling continued down to 5468 mbrf (486 mbsf) where the hole packed off and high pump pressures and torque were encountered. Rotation was required to pull the drill string back up the hole and 30,000 lb of overpull was encountered.

A request was made to ODP/TAMU for permission to deepen Site NBR-9A by 250 m from 600 to 850 mbsf to achieve the deeper depth objectives below the décollement (underthrust section), which we suspected could not be achieved at Hole 1045A. Permission was granted from ODP/TAMU for an additional 250 m (±25 m) penetration or first contact with basement at Site

NBR-9A. Because the total time on the LWD tool batteries was approaching 48 hr and they can provide power for a maximum of ~100 hr, the decision was made to abandon Hole 1045A and offset in DP mode over to Site NBR-9A. The remaining time would allow Hole 1046A to be drilled without having to trip the drill string which would result in a time savings of approximately 20 hr. The drill string was pulled out of the hole, and the seafloor was cleared at 1945 hr 31 December ending Hole 1045A. The drill string was pulled an additional 50 m above the seafloor, and the vessel was offset in DP mode over to Site NBR-9A.

SITE 1046
(Site 949; Proposed Site NBR-9A)

After pulling out of Hole 1045A, the drill string was raised to 50 m above the seafloor and the vessel was offset in DP mode over to Site NBR-9A. Hole 1046A was spudded at 2200 hr 31 December 1996 at 15°32.1912'N and 58°42.8583'W. This location is approximately 50 m south of the Site 949C reentry cone and CORK. Drilling was initiated at a water depth of 5021.4 mbrf based on the PDR reading. The final water depth was established at 5028 mbrf (5017 mbsl) based on the analysis of the LWD data.

The décollement zone for NBR-9A was estimated at 424 mbsf. We attempted to drill at 35 m/hr down to 5487 m (459 mbsf) where high torque and pump pressures were encountered. The drill string was pulled back to 362 mbsf with a maximum drag of 50,000 lb. The hole was washed and reamed for 3 hr in the zone from 362 to 459 mbsf. All drilling parameters returned to normal and drilling resumed at 459 mbsf. No further difficulties were experienced, and the hole was drilled at about 35 m/hr to a total depth of 5860 m (832 mbsf) where basement was encountered and the drilling rate slowed to 6 m/hr. Hole 1046A was terminated at 5860 mbrf (832 mbsf) having successfully achieved the depth objective. Average LWD drilling parameters during Hole 1046A were 0-15 K weight on bit (WOB), 40-55 rpm, 300-550 psi, 100-200 Amps torque, and 35 m/hr rate of penetration (ROP).

The drill string was raised to 400 mbsf, and the hole was displaced with 130 bbl of heavy (11.0

lb/gal) mud. The trip continued to the surface where the nuclear sources were removed, the LWD data were retrieved, and the LWD collars were laid out. The bit cleared the rotary table at 1530 hr 03 January ending Hole 1046A.

SITE 1047
(ODP Site 676; Proposed Site NBR-10A)

After the drill string was pulled clear of the seafloor following Hole 1046A, the vessel was offset in DP mode over to Site NBR-10A, and a positioning beacon was deployed. During the move to Site NBR-10A, the LWD tools were changed out. A request was made to ODP/TAMU to deepen the penetration at NBR-10A from the approved 500 to 650 mbsf. The deeper penetration was intended to obtain LWD data from the turbidite sequence in the underthrust section at a location between the reference Site 1044 and Site 1046 farther to the west in the accretionary prism. This request was approved by ODP/TAMU.

Hole 1047A was spudded at 0115 hr 04 January 1997 at GPS coordinates 15°31.8344'N and 58°42.1909'W. This location is approximately 27 m south of ODP Site 676 (Leg 110). Drilling was initiated at 35 m/hr at a water depth of 5070 mbrf based on the drill pipe depth from Site 676. The final water depth was established at 5067 mbrf (5056 mbsl) based on the analysis of the LWD data.

Drilling continued at 35 m/hr down to 5353 m (286 mbsf) where high pump pressure and high torque were encountered due to penetration of the décollement zone. The zone from 283 to 350 mbsf required considerable back reaming and hole conditioning in order to alleviate elevated pump pressures and torque values. Sepiolite mud sweeps (20 to 30 bbl) were used to condition the hole during four different wiper trips through the décollement. After drilling deep enough to get the top of the BHA below the décollement, the pump pressures and torque returned to normal. Drilling continued without problems at a rate of penetration of 35 m/hr down to 5700 mbrf (633 mbsf) at which point we expended the time allotted for drilling this hole. The drill string was pulled clear of the seafloor at 2115 hr 05 January ending Hole 1047A.

SITE 1048
(Proposed Site NBR-1A)

The drill string was pulled two stands above the seafloor and the vessel was offset in DP mode at a speed of 2 kt/hr from Hole 1047A to NBR-1A. LWD Hole 1048A was located at GPS coordinates 15°32.0284'N and 58°40.5800'W. Hole 1048A was spudded at 0100 hr 06 January 1997. Drilling was initiated at 35 m/hr at a water depth of 5060 mbrf based on the PDR reading. The final water depth was established at 5064 mbrf (5053 mbsl) based on the analysis of the LWD data.

Drilling continued at 35 m/hr down to 5401 m (337 mbsf) with no problems. Time allocated for the leg's drilling operations expired, and the drill string was pulled out of the hole. The bit cleared the seafloor at 1830 hr 06 January. During the pipe trip the beacon was released and recovered. The vessel was offset in DP mode back to Site 1047 where the beacon from 1047A was released and recovered. The trip continued until all the pipe reached the surface, then the nuclear sources were removed, the LWD data from Holes 1047A and 1048A were downloaded, and the LWD collars were laid out. The bit cleared the rotary table at 0300 hr 07 January ending Hole 1048A.

The drill collars were laid out and secured for transit. The vessel continued offsetting in DP mode to Site 1046, where the beacon used at Sites 1046 and 1045 was released but failed to surface. The thrusters and hydrophones were raised, and the vessel was under way to Bridgetown, Barbados, at 1000 hr 07 January.

TRANSIT TO BRIDGETOWN, BARBADOS

The transit to Bridgetown, Barbados, was completed in mild weather and calm seas. Arrival at the anchor buoy just outside of the Bridgetown harbor was timed to coincide with the scheduled time of 0600 hr 08 January 1997. Leg 171A officially ended with the first line ashore at 0700 hr 08 January 1997.

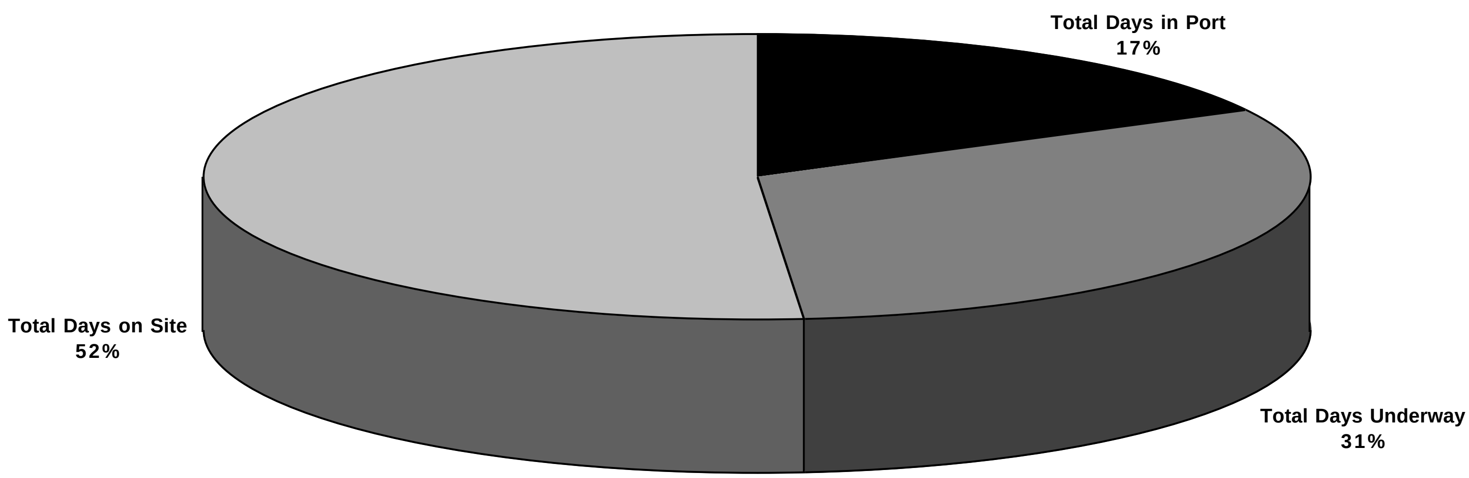
OCEAN DRILLING PROGRAM
OPERATIONS RESUME
LEG 171A

Total Days (17 December 1996 to 08 January 1997)	**22.2916667**
Total Days in Port	**3.75**
Total Days Underway	**6.875**
Total Days on Site	**11.25**

	days
Drilling	**7.18**
Other	**0.59**
Tripping Time	**3.63**
Stuck pipe/Hole Trouble	**0.27**
Logging/Downhole Science	**0.00**
Mechanical Repair Time (Contractor)	**0.00**
Reentry Time	**0.00**
W.O.W.	**0.00**
Coring	**0.00**

Total Distance Traveled (nautical miles)	**1533**
Average Speed Transit (knots):	**9.7**
Number of Sites	**5**
Number of Holes	**5**
Number of Cores Attempted	**0**
Total Interval Cored (m)	**0**
Total Core Recovery (m)	**0**
% Core Recovery	**0**
Total Interval Drilled (m)	**2973**
Total Penetration	**2973**
Maximum Penetration (m)	**832**
Minimum Penetration (m)	**337**
Maximum Water Depth (m from drilling datum)	**5067**
Minimum Water Depth (m from drilling datum)	**4982**

LEG 171A
TOTAL TIME DISTRIBUTION



Total days of leg = 19.0

OCEAN DRILLING PROGRAM
SITE SUMMARY
LEG 171A

HOLE	LATITUDE	LONGITUDE	WATER DEPTH (mbrf)	NUMBER OF CORES	INTERVAL CORED (meters)	CORE RECOVERED (meters)	PERCENT RECOVERED (percent)	LWD/ DRILLED (meters)	TOTAL PENETRATION (meters)	TIME ON HOLE (hours)	TIME ON SITE (days)
1044A	15 32.3924N	58 38.4766W	4983.0	0	0.0	0.00	0.0%	685.0	685.0	77.00	3.2
		1044 SITE TOTALS:		**0**	**0.0**	**0.00**	**0.0%**	**685.0**	**685.0**	**77.00**	**3.2**
1045A	15 32.2407N	58 43.4222W	4982.0	0	0.0	0.00	0.0%	486.0	486.0	41.75	1.7
		1045 SITE TOTALS:		**0**	**0.0**	**0.00**	**0.0%**	**486.0**	**486.0**	**41.75**	**1.7**
1046A	15 32.1912N	58 42.8583W	5028.0	0	0.0	0.00	0.0%	832.0	832.0	67.75	2.8
		1046 SITE TOTALS:		**0**	**0.0**	**0.00**	**0.0%**	**832.0**	**832.0**	**67.75**	**2.8**
1047A	15 31.8344N	58 42.1909W	5067.0	0	0.0	0	0.0%	633.0	633.0	53.75	2.2
		1047 SITE TOTALS:		**0**	**0.0**	**0.00**	**0.0%**	**633.0**	**633.0**	**53.75**	**2.2**
1048A	15 32.0284N	58 40.5800W	5064.0	0	0.0	0	0.0%	337.0	337.0	29.75	1.2
		1048 SITE TOTALS:		**0**	**0.0**	**0.00**	**0.0%**	**337.0**	**337.0**	**29.75**	**1.2**
		LEG 171A TOTALS:		**0**	**0**	**0**	**0.0%**	**2973**	**2973**	**270**	**11.25**

TECHNICAL REPORT

The ODP Science Services technical personnel aboard *JOIDES Resolution* for Leg 171A were:

Burney Hamlin	Laboratory Officer
John Dyke	Marine Lab Specialist (Storekeeper/Shipping)
Dennis Graham	Marine Lab Specialist (Underway Geophysics)
Gus Gustafson	Marine Lab Specialist (Downhole Tools)
Michiko Hitchcox	Marine Lab Specialist (Yeoperson)
Lorraine Southey	Marine Lab Specialist (Curator)
Terry Klepac	Marine Computer Specialist
Matt Mefferd	Marine Computer Specialist
Bill Stevens	Marine Electronic Specialist

From a technical staffing perspective, Legs 171A and B were considered to be one leg; therefore, the laboratory activities are combined into one technical report. Laboratory statistics were separated and so only 171A statistics are included at the end of this report.

GENERAL LEG INFORMATION

Port Call Activities - Panama

A smaller technical staff supported Leg 171A; they arrived in Panama City, Panama, on 17 December 1996. To explain the re-organization that had taken place ashore while the ship was at sea, the Director of Science Operations at ODP and the Interim Manager of Science Services went to the Balboa dock facilities early to deliver an explanation to the ODP specialists on board. ODP Alternate Sea Pay Plan (ASPP) personnel for Leg 171 arrived at the ship by taxi to listen to the presentation. The remainder of the specialists arrived by bus about 10 a.m. Individuals then met with the Interim Manager of Science Services and the Director to ask questions and to review the job information forms (JIF), which describe the individuals' jobs. Crossover between the two technical teams commenced and continued until early afternoon when a bus took the offgoing crew to the hotel. Freight that was expected to arrive in the afternoon did not show up. The Sedco Christmas party was held in the evening and all enjoyed themselves.

During the 18th and 19th, freight moved off and on the ship in a normal manner. The shore shipping office staff, the staff scientist, and the operations manager helped the technical staff move the core boxes off the ship.

The ship sailed at 0200 on 20 December to begin passage through the canal. There was a 12-hr delay at the north locks to the Caribbean due to lock maintenance. Sailing with us were two Tracor representatives who installed the final software and made hardware changes for the implementation of the JANUS database. Also on board were two Anadrill Engineers to support the logging while drilling (LWD) program, an ODP engineer to review our inventory database for eventual merging with their Foxpro system, and a programmer to assist with a UNIX installation on our underway seismic system.

The time we saved by making an early departure from Panama City was lost waiting for canal passage and sailing into the heavy trade winds on the way to our drilling sites off Barbados.

Under way from Panama

Navigation tapes were initiated entering the Caribbean from the Panama Canal. No watches were stood until 25 December. This time was used to demonstrate the lab procedures to the programming specialist who assisted in the Solaris operation system 2.5 upgrade of the SUN computers and who works for the Information Services' database group on shore.

On Christmas Day the ship responded to a distress call and came along side a Venezuelan fishing boat dead in the water. We relieved a Greek ship that had been there two days. Three hours later the USCG cutter *Nantucket* arrived from San Juan to control the situation.

The *JOIDES Resolution* arrived at the Leg 171A drilling area on the evening of 26 December, and a beacon was dropped at the preselected site. While the drill pipe was being tripped, Global

Positioning System (GPS) positions were collected and averaged to ensure the best offset from the beacon for the drill site before spud in. This LWD site was terminated in basement and the pipe tripped. After the logging records were processed, the final seafloor depth could be posted. The remainder of the Leg 171A sites proceeded in the same manner. The LWD tools were used to drill five sites/holes into the accretionary prism off Barbados. No cores or samples were taken. Drilling objectives were terminated at 0000 hr on 7 January and the ship was under way at 1000 hr for Barbados.

LAB ACTIVITIES

Chemistry Lab

There was little gas and low organic carbon associated with the majority of the cores recovered during Leg 171B. Hydrocarbons were monitored at each site as there were safety concerns for this region. Gas values entered into the JANUS data were retrieved easily to monitor trends. Few problems were associated with the equipment, though new Gas Chromatograph (GC) Chemstation software was found to be incompatible with the valve switcher. A new version of the software is expected to work as anticipated. There was also a problem with a Coulometer application in LabView that will require more work. Replacement parts and valves for the Atomic Absorption's (AA) exterior acetylene manifold were ordered for port call service. Other maintenance in the lab was routine.

Computer Services

Many related tasks were performed with the implementation of the JANUS database on this leg. There were hardware upgrades, an OS upgrade, the initialization of the database, user training for the scientists and specialists, bugs to fix, user resistance to overcome, etc. Full user support was available from Tracor’s Paul Albright and Glen Corser for the JANUS applications, and they continued working on the Business Objects Users software queries throughout the leg. The deployment of JANUS on Leg 171 was a success; it is basically up and functioning as intended. There were problems mirroring data across the hard drives and implementing DecSafe, an application that switches computers if a processor fails. Those shortcomings will soon be addressed.

The latest version of AppleCORE was used successfully by the scientists to prepare barrel sheets. It was found to be flexible and allowed an almost unlimited amount of information to be entered. A VIDEO program was sent out to replace the old corelog video display. It was modified to some degree to change sort orders, precision, and to add scrolling. On several occasions at the end of the leg the maximum number of users on the Grosbeck/USERVOL server was reached. A license change is planned. There were several problems with cc:mail, aggravated by the holidays at TAMU. Bulletin boards failed to propagate for one period of time. There was a crash of the system shortly after leaving Barbados when new addresses were being added. The last short run of the FDDI fiber optics cable was run. These will be terminated with the rest of the system cables during the Charleston port call.

Core Lab

During Leg 171A's LWD effort, SUN workstations were set up in the aft end of the core lab to support the scientists reviewing the data collected. Working in the area during daylight hours was difficult as the entire deck above was being chipped, scaled, and then repainted. Some people used hearing protection, whereas others elected to work later hours.

There were few problems accommodating the recovered sediments studied on Leg 171B. Drilling breaks and logging activities provided time for the special requirements that support K/T boundary cutting and sampling efforts.

As this was the first leg for a fully implemented JANUS database, double entry into S1032 corelog was made as a backup. During the last sites, maintaining the core entry white board was dropped as most of the drilling information is now available on the workstations that were logged onto JANUS. The white board is still handy for planning and scheduling Adara deployments, special sampling, and paleontological ages.

Curation

Core recovery was quite high from the relatively shallow-water sites during this five-week effort, but chert and harder layers encountered precluded achieving some of the higher estimates. Rotary coring and the logging program provided the time necessary for the lab to catch up and conduct sample parties.

Several critical boundaries, including the K/T boundary, were recovered, and many cutting and sampling suggestions and ideas were evaluated. Some special tools, now stored in a K/T kit, were used. Thin aluminum oxide cutting disks were tried on the rock saw with marginal success. They were too fragile for much regular use and they ablated material off onto the core that could not easily be cleaned off. A series of cores with organic-rich layers was recovered and handled in a special manner. They were placed in foil bags and purged with nitrogen to preserve them. They will be held until a sample plan is worked out. Some cores contained colorful laminated zones and were selected to join the K/T boundary cores as a part of an exhibit supporting port call Public Relation efforts. All of these sections will be shipped to the Bremen Core Repository for future work and storage. A second curatorial person was a fine complement to the staff, allowing full-time help and oversight in the lab and catwalk.

Magnetics Lab

This was the first heavy recovery leg for the new cryogenic magnetometer; both the hardware and the software preformed satisfactorily. There were a few problems to puzzle over, but the extra sensitivity was appreciated. Core sections contaminated with metal bits possibly contributed to some unexplained flux jumps and slow recovery of stability after the chill water was off for two hours. While the data was modified by JANUS to add depths, the raw data files were stored on DATA1 file server.

The Tensor orientation tools were used regularly. The data retrieval program was modified to run on a Pentium laptop. One of the tools is being returned with a damaged battery contact and intermittent problems.

Microscope/Photography Labs

The microscopes were set up to meet individual preferences, and time was spent finding special equipment and supplies to fill requests. Occasionally, we were asked to change lenses or readjust the optics or illumination and replace bulbs. Notes were taken for a port call microscope service call so problems can be directly addressed and also for some instruction on aligning one new model microscope.

Close-up photographs of some of the critical boundaries were taken before and after the surfaces were scraped clean. Duplicate slides of the K/T boundary were taken so each of the scientists could have one, thereby reducing the number of times the boundary would be handled. Macrophotographs of some ammonite fossils were taken. No microphotographs were requested. There were no problems with the lab equipment.

Paleontology Lab

The facilities were fully utilized with seven paleontologists sharing the space. Once all requests were satisfied during the initial setup, no problems were reported. A situation attributed to gray water fumes was reported in the aft end of the microscope lab. Better termination of an old drain line seemed to fix the problem. The chemists responded to most of the consumable requests during the leg.

Physical Properties

The physical properties scientists were familiar with the instruments and had few problems. Those making thermal conductivity measurements found less scatter in the values with the newer TKO4, so it was preferred over the WHOI multiprobe device. The users found that core flow was not affected using the TKO4's single needle probe. Sets of Adara downhole temperature measurements were collected at two drill sites.

Storekeeping

The storekeeper travelled early to Panama to meet the ship's agent, to familiarize himself with the area, and to help locate the arriving equipment. Hotel reservations were verified, and outgoing travel arrangements verified. The port call in Panama went well once shipments started, and everything was received in good order.

During Leg 171A, time was spent with the engineer who joined the staff to study migrating the MATMAN S1032 database into an interim Foxpro database (the software the engineering group is accustomed to using). It had been discussed that the storekeeper would become involved with the engineering inventories, but there was no involvement this leg.

There was time to make a physical count of several of the storage areas, with Hold Stores (HS) getting the most attention. On-hand numbers were adjusted and orders made accordingly. Two pieces of laboratory equipment, the HP FAXATRON X-radiograph and the Spectrex PC-2000 particle analyzer, were included in the shipment to ODP. Core boxes will be sent to the Bremen Core Repository with trans-shipped supplies from the Gulf Coast Repository.

Underway/Fantail

The opportunity of sailing on the LWD part of Leg 171 afforded time for a JANUS mandated conversion of operating systems on the underway SUN workstations to Solaris 2.5. A UNIX specialist sailed to help with the hardware and software updates and to rewrite the applications as necessary for them to run under the new operating system. There was also the opportunity to write a new SiteFix program for the SUNs and for the underway geophysical specialist to be introduced to nuances of the seismic processing applications. A new a2d trigger was designed and built to replace the external SUN trigger, which did not work with the new version of a2d software.

Both the port and starboard seismic bundles were refurbished and signal leads replaced. The Teledyne single-channel streamer was used during the last leg and was reported to be noisy. A bad leak was located and repaired temporarily, the streamer connectors were cleaned, and the streamers were filled with oil. One magnetometer sensor was leaking fluid and the other sensor was noisy so both sensors were serviced. A selector switch was added to a front panel in the lab that will allow easier comparisons between the two sensors.

X-Ray Lab

The lab was used sparingly during Leg 171B with one scientist making the most use of it and the XRD to identify clay minerals in 45 samples. A few sediment samples were analyzed with the XRF. Some old or seldom-run XRF standards were re-analyzed for comparison with the original numbers. A routine PM service call was scheduled for Charleston. Most time and effort was given supporting core recovery and the core lab routine.

MISCELLANEOUS

Electronics Support

Legs 171A and B were supported by one electronic technician each. Although there were few problems with lab equipment on the A part of the leg, both of the Xerox copiers were cleaned and serviced to reduce jamming and improve copy quality. Signal leads and connectors on the fantail were checked and replaced as necessary.

Problems with the lab equipment during the B part were mostly in the first few days of the cruise as various instruments were turned on for the first time in awhile. Six successful heat flow Adara measurements were taken. It was necessary to put in some off-shift hours supporting one of the Adara deployments and the Minolta color scanner. Assistance was given removing TOTCO components that will be used as spares and testing Lamont’s borrowed Marisat B installation.

Special Projects

A replacement piece of gym exercise equipment was received in Panama and assembled on the transit. There was much discussion on where the monolithic Promaxima assembly should be located. Users were very pleased with the smoothness, range of challenge, and varieties of exercise it offered.

Around a continual shuffle of alligator boxes of core liner, the core lab roof was completely chipped, primed, and painted. Scalloping was noted on thinning roofplates, to 2-3 in in from the edges. The rails around the deck were replaced; the 4 in drain lines were replaced and moved.

A rain gauge sponsored and built by Grant Petty from Purdue University was brought aboard in Barbados for trial use. Scientist Jim Ogg assumed responsibility for the device. Actual rain values (ground truths) were to be compared with estimates derived from satellite images and used to refine the algorithms for area rainfall. Some good data were collected and some changes were suggested for a more rugged version. The instrument and software were returned at Charleston. Perhaps it will be deployed on another leg.

Safety

No METS participants sailed on the first half of the leg. Most of the usual participants on the second half of the leg were on night shifts and excused.

Air Quality /environmental survey forms from Texas A&M University Health and Safety were available to the scientists and specialists for those who wished to participate. Sedco/Catermar did not participate. An abbreviated CO_2 survey of 10 areas in the ship house and labs was made for background information.

Problems

Water leaks from the hold access hatch below the catwalk persisted despite attention from the deck people on two occasions. Captain Oonk added the hatch to the drydock work list where a better design might be implemented. On one instance the Captain had the area mopped while the area was being used to prepare the off-going shipment.

Although there were plans to install the new plastic-lined chemical pipes under the lab stack, it was not done this leg.

Leg 171A Laboratory Statistics

General

Sites:	5
Holes:	5
Meters of Penetration:	2973
Meters Cored:	0
Meters Recovered:	0
Time on Site (days):	11.25
Number of Cores :	0
Number of Samples, Total	0

Underway Geophysics (est.)

Total Transit Nautical Miles:	1533
Bathymetry:	test
Magnetics:	test
XBT's Used:	21