# OCEAN DRILLING PROGRAM

# LEG 172 PRELIMINARY REPORT

# NORTHWEST ATLANTIC SEDIMENT DRIFTS


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## ABSTRACT

Ocean Drilling Program Leg 172 drilled 11 sites in the westernmost North Atlantic Ocean: two on the Carolina Slope (Sites 1054 and 1055), seven on the Blake-Bahama Outer Ridge (Sites 1056 to 1062), one on the Bermuda Rise (Site 1063), and one on the Sohm Abyssal Plain (Site 1064). More than 5700 m of sediments were cored that range in age from the early Pliocene to the Holocene. The westernmost North Atlantic Ocean is presently the location of an important exchange of heat, salt, and water with other ocean basins and the location of huge sediment accumulations (sediment drifts) related to deep- and intermediate-water oceanic circulation. Sediment drifts are characterized by high accumulation rates, and have recently proven to be excellent recorders of past climate variability on orbital to centennial time scales. The 11 sites cored during Leg 172 succeeded in recovering complete and expanded sequences of slope and drift sediments well suited for high-resolution paleoceanographic studies, particularly for the past 1 m.y. The cored locations span a wide range of water depths (from 1306 m at Site 1054 on the Carolina Slope to 4786 m at Site 1062 on the Bahama Outer Ridge), "sampling" virtually all the various components of the North Atlantic Deep Water. Shore-based studies of stable isotope, chemical, and sedimentological paleotracers should allow a detailed three dimensional reconstruction of circulation changes related to climatic evolution and variability since the inception of Northern Hemisphere Glaciation. Shipboard results show striking evidence of orbital-scale climatic changes, but millennial and perhaps centennial scale changes should be resolvable at some sites. Sedimentation patterns are surprisingly uniform in the Carolina Slope and Blake-Bahama Outer Ridge region. Every location has an upper unit characterized by cyclic alternation between nannofossil-rich and clay-rich beds, the base of which appears at most sites to be about 0.8 m.y. old. Hence, this lithologic change seems to reflect the dramatic onset of the 100-k.y. glacial/interglacial cycles of the middle and late Pleistocene and attests to the strong influence of climate on sedimentation and circulation patterns. Below this upper lithologic unit, clayey sedimentation prevails. The stratigraphy at Bermuda Rise Site 1063 is largely similar to that detected in the Blake-Bahama Outer Ridge and Carolina Slope region, thus suggesting basinwide sedimentation patterns.

Primary age control was provided by calcareous planktonic biostratigraphy, integrated at most sites with magnetostratigraphy. Paleontologists noted that some planktonic foraminifer datums do not seem to be applicable in the western North Atlantic region. The expanded sections recovered will, however, offer the opportunity of an accurate calibration of late Pliocene to late Pleistocene calcareous plankton horizons and an evaluation of their inter-regional synchroneity. Furthermore, at all sites, except the shallow-water Site 1054, it has been possible to establish a highly resolved age model for the past 0.9 m.y. based on magnetic susceptibility, which correlates well with the standard marine oxygen isotope scale. This age model surprisingly suggests no major change in the sediment accumulation rates between glacial and interglacial cycles.

Most sites contain a detailed record of the behavior of the Earth's magnetic field, providing unprecedented documentation of secular variation (e.g., excursions) during the Brunhes Chron and the Matuyama-Brunhes transition. Finally, shipboard geochemical analyses have documented the regional extension of gas hydrate and the important role of organic and inorganic diagenesis in the sediment-drift environment.

## INTRODUCTION

The Blake-Bahama Outer Ridge (BBOR) and Carolina Slope (CS) form the western boundary for deep- and surface-water circulation in the subtropical North Atlantic. Between the northward-flowing surface waters of the Gulf Stream and the net southerly flow of intermediate and deep waters, most of the climatically important exchanges of heat, salt, and water with other ocean basins occur in the westernmost North Atlantic. At the deepest levels of the western North Atlantic, Antarctic Bottom Water (AABW) flows northward and blends with several other water masses in the deep recirculating gyres to form North Atlantic Deep Water (NADW) (Fig. 1). The western intensification and flow of these waters erode the continental margin in some locations and preferentially deposit sediments, known as sediment drifts, at other locations.

The main focus of Ocean Drilling Program (ODP) Leg 172 was recovery of a sequence of high-deposition rate sediment cores from sediment drifts in the western North Atlantic to document rapid changes in climate and ocean circulation during middle Pliocene to Pleistocene time (Figs. 2, 3). Because it is difficult to understand the ocean-climate system from the study of single core locations, Leg 172 was planned as a depth transect. For example, paleochemical results from Bermuda Rise (BR) cores illustrate changes in deep ocean circulation from only one water depth (4500 m), because the northeast BR is a plateau. Proxy data for deep-ocean nutrient content at that location show large changes with time, but we cannot distinguish between latitudinal changes in the mixing zone between southern- and northern-source waters and changes due to vertical migration of a benthic front. Groups of sites must be located across a range of depths to study the ocean in three dimensions.

Leg 172 cored 11 sites: two on the CS (Sites 1054 and 1055), six on the BBOR (Sites 1056 to 1062), one on the BR (Site 1063), and one on the Sohm Abyssal Plain (Site 1063; Figs. 2, 3; Site Summary Table in Operations Report). The main purpose of Leg 172 was to provide a latest Neogene depth transect to document changes in depth distribution of water masses (Fig. 4). The geographic range of sites may also help distinguish between latitudinal changes in the mixing zone between southern and northern source waters and changes due to vertical migration of a benthic front, especially when considered in the context of other recent ODP legs such as 154 and 162. Sites 1054 and 1055 monitor the shallowest components of NADW, which originate in and near the Labrador Sea and which can be traced using chlorofluorocarbons (CFCs) (Pickart and Smethie, 1993). This water mass is expected to wax and wane on glacial/interglacial and millennial time scales, out of phase with production of Lower NADW (LNADW) (Boyle and Keigwin, 1987; Oppo and Lehman, 1993). Reconstructions of glacial North Atlantic hydrography show that the hinge point between better ventilated waters at intermediate depth and more poorly ventilated deep waters occurs at about 2000 m. This boundary is bracketed by Sites 1055 and 1056, which are positioned to detect changes in its depth. Likewise, Site 1057 is located at the interface between Upper (U) and LNADW. Sites 1058, 1059, and 1060, which lie within the core of LNADW, should be insensitive to all but the largest changes in benthic fronts between AABW, LNADW, and UNADW. Lastly, our deepest Sites 1061-1064 are situated to record more subtle changes in the AABW/LNADW front.

Complementing these paleoceanographic/paleoclimatic objectives, it was hoped that the Leg 172 sediments would reveal a high-resolution history of magnetic field behavior and a history of biotic change. Indeed, the paleomagnetic record reveal detailed geomagnetic field changes, including many excursions that were present in multiple holes and at multiple sites, as well as transitional field directions at the Brunhes/Matuyama polarity reversal that could be correlated at sites over 1000 km apart (Fig. 5).

In addition, sedimentary microstructures at Leg 172 sites reflect the combination of both downslope and along-slope depositional processes. Mud-wave dynamics have been a long-standing interest of ODP, but have not been successfully studied by ODP until this leg. Mud-wave migration can be measured by determining the ratio of sediment thickness deposited on each wave flank during a time interval or between two correlated layers, from which a model-dependent flow speed can be estimated (Flood, 1988). Leg 172 successfully cored across a single mud wave, mapping the variations in sedimentation rates that occurred as it migrated eastward. Our pre-drilling seismic survey also revealed with great clarity structures within the mud wave, which will be combined with the coring results to give a detailed dynamic history of this mud wave (Fig. 6).

The world's best-known marine gas hydrate occurrence is located within the operating area of Leg 172 on the Blake Ridge and Carolina Rise. Gas hydrate, present on continental margins world-wide (e.g., Shipley et al., 1979; Kvenvolden, 1988), is important because it may (1) affect the Earth's climate through the storage and release of methane, a greenhouse gas (e.g., Nisbet, 1989; Paull et al., 1991); (2) cause sediment slumping on continental margins (e.g., Carpenter, 1981; Popenoe et al., 1993; Paull et al., 1996); and (3) influence the diagenesis of continental rise sediments (e.g., Lancelot and Ewing, 1972; Matsumoto, 1983; Borowski et al., 1996a, b). Gas hydrate occurrence is usually inferred from the appearance of a bottom-simulating reflector (BSR) on seismic reflection profiles (Tucholke et al., 1977). However, geochemical concentrations and isotopic profiles are potentially more sensitive indicators of underlying gas hydrate than established seismic detection methods (Borowski et al., 1996a). On Leg 172, seismic data collected showed a probable BSR under all the sites drilled along the Blake-Bahama Outer Ridge. Moreover, the pore-water samples taken from cores give chloride concentrations that strongly suggest the presence of underlying gas hydrate. These data are critical to improve estimates of the size of the gas hydrate reservoir in the Blake Ridge area (and elsewhere), and to understand the geochemical processes involved in the development of extensive gas hydrate fields.

## RESULTS

### Shallow Water Sites of the Carolina Slope

Sites 1054 and 1055 are located on the Carolina Slope and form the shallow end members of the paleoceanographic depth transect of cores extending down the Blake Outer Ridge and over to the Bahama Outer Ridge (Figs. 2-4). Site 1054, at a water depth of 1281 m, is about 2 km above the headwall scarp of the Cape Fear Slide, one of the largest and best documented continental margin slide features in the world (Dillon et al., 1982). Site 1055 is on the lower Carolina Slope at a water depth of 1798 m, and it is 24 km south of Site 1054.

The Carolina Slope and Rise region is well known for its abundant gas hydrate (Paull, Matsumoto, Wallace, et al., 1996). Seismic data show at least 1000 m of sediment accumulation with a prominent BSR, which occurs at the base of the gas hydrate stability zone.

Presently, the environment overlying the Carolina Slope is influenced by the Gulf Stream and by the shallowest waters of the Deep Western Boundary Current (DWBC), which are thought to originate in the southern Labrador Sea (Pickart and Smethie, 1993). During glacial times, when production rate of the lower component of NADW decreased and the upper component increased (Boyle and Keigwin, 1987; Oppo and Fairbanks, 1987; Lehman and Keigwin, 1992), Sites 1054 and 1055 were probably influenced by glacial North Atlantic Intermediate Water. The presence of high-latitude clay mineralogies and red sediments of Nova Scotian origin on the Carolina Slope could be advective tracers for the flow of intermediate-depth waters (Heezen et al., 1966; Hathaway, 1972).

Drilling objectives at Sites 1054 and 1055 were to (1) monitor the shallowest reaches of UNADW in Pleistocene time; (2) provide high-resolution sections for paleomagnetic study; and (3) provide sections for studying geochemical processes related to gas hydrate formation and dissociation. In addition, the sedimentary record recovered at Site 1055, together with that at Sites 1054 and 1056, may prove useful for testing models of continental slope sedimentation during glacial lowering of sea level.

*Site 1054*

The sedimentary succession recovered from the three holes drilled at Site 1054 consists of a well dated 200-m-thick interval of latest middle Pliocene (Piacenzian) to Holocene nannofossil ooze and silty clay, with variable proportions of biogenic and siliciclastic components. Biogenic carbonate and opal are present throughout the succession. Three lithologic units were recognized (Fig. 3). Unit I (0-19 meters below seafloor [mbsf], Holocene to middle Pleistocene) consists of clayey and silty mixed sediments and is defined largely on the basis of relatively abundant carbonates (up to 67%) and higher amplitude oscillations in color reflectance than the underlying units. Unit II (19 to 119 mbsf; middle Pleistocene to early Pleistocene) consists of interbedded mixed sediment and silty foraminifer sand with decreased presence of carbonate and color variations. Unit III (119 to 200 mbsf; early Pleistocene to the latest middle Pliocene) consists of mixed sediment with increased clay content. There is evidence of downslope transport with as many as 20 thin carbonate turbidites and debris-flow deposits observed at Hole 1054A, but their thickness and occurrence among Site 1054 holes suggests spatial variability.

The succession contains abundant and well preserved calcareous nannofossils and planktonic and benthic foraminifers. Diatoms are common to abundant and exhibit moderate to good preservation. Pteropods are well represented and become abundant in several discrete layers. Siliceous flagellates (including silicoflagellates and ebridians) and radiolaria range from trace to common occurrences with good to moderate preservation. The abundance of diatoms suggests that conditions of high productivity might have characterized the area of Site 1054 in the past 2.5 m.y. Reworking and displacement of shallow-water forms is surprisingly low, in spite of the sedimentological evidence of downslope transport and current activity.

Paleomagnetic results indicate that the Brunhes Epoch (0-0.78 Ma) is possibly located at 26 mbsf in Hole 1054A, with the Jaramillo event (0.99-1.07 Ma) between 27 and 31.5 mbsf. Below 75 mbsf in Hole 1054A, the magnetization signature is weak and difficult to interpret owing to drilling overprints.

Sedimentation rates were 46 m/m.y. in the past 0.5 m.y., 15 m/m.y. between 0.5 and 1.0 Ma, 120 m/m.y. between 1.0 and 2.0 Ma, and 75 m/m.y. between 2.0 Ma and the bottom of the succession at 2.5 Ma. Low sedimentation rates between 0.5 and 1.0 Ma are associated with an interval where there is evidence of removal and redeposition of sediments by bottom currents.

Calcium carbonate contents fluctuate between 30% and 67% with an average value of 46.5%, gradually decreasing with increasing sediment depth. The carbonate cycles probably reflect glacial/interglacial fluctuations. Total organic carbon (TOC) content varies between 0.7% and 1.84% with an average value of 1.2%. Organic C/N ratios between 5 and 10 are indicative of predominantly marine organic material. Results of Rock-Eval analysis indicate that organic matter is thermally immature with respect to petroleum generation.

Pore-water profiles from Site 1054 are typical of sediments in which sulfate reduction and methanogenesis occur. Sulfate concentrations decrease from seawater values at the top of the hole to values less than 1 mM at 48 mbsf. The onset of the methanogenic zone occurs at 48 mbsf, coincident with the level of zero pore-water sulfate. The boundary between sulfate reduction and methanogenesis is very sharp, presumably because utilization of methane by sulfate-reducing bacteria prevents significant diffusive penetration of methane into the overlying sulfate reduction zone. The high $C_1/C_2$ ratios and the absence of major contribution of higher molecular weight hydrocarbons suggest that the source for methane is most likely in situ bacterial methanogenesis resulting from decomposition of organic matter in the sediments. Although Site 1054 is located in a well-characterized gas-hydrate area, gradients of chloride are absent, suggesting that gas hydrate was not recovered in cores from Site 1054.

*Site 1055*

The sedimentary succession recovered from the five holes at Site 1055 is a 130-m-thick interval of early Pleistocene to Holocene nannofossil ooze and silty clay with variable proportions of biogenic and siliciclastic components. Biogenic carbonate and opal are present throughout the succession. Two lithologic units were recovered(Fig. 3). Unit I (0 to 80 mbsf; Holocene to early Pleistocene) is composed of interbedded layers of nannofossil ooze, nannofossil ooze with silt, clayey nannofossil ooze, silty clay, silty clay with foraminifers, clay with silt, and clay. The occurrence of pteropods in several silty clay layers and the presence of dolomitized clay concretions in Section 1055D-6H-1 are noteworthy. Unit II (80 to 128 mbsf; early Pleistocene) is composed of predominantly massive, structureless, and homogeneous dark greenish gray clay with siliceous, calcite-cemented burrow fills. Although nannofossils are present throughout Unit II, the nannofossil-rich layers found above are completely absent.

Fauna and flora at Site 1055 are rich and diverse. Calcareous nannofossils and planktonic foraminifers are abundant and well preserved, whereas benthic foraminifers are rare to few but well preserved. Diatoms are less abundant than at Site 1054 and exhibit moderate to good preservation. Paleomagnetic results indicate that the upper 100 m of Hole 1055B lie within the Brunhes Chron, although below this level the magnetization is weak and difficult to interpret owing to drilling overprints.

Sedimentation rates, based on six calcareous nannofossil and planktonic foraminifer events, increased with decreasing age from 30 m/m.y. for the interval from 1.0 to 1.3 Ma, to 79 m/m.y. in the interval 1 Ma to 0.5 Ma, and to 120 m/m.y. for the past 0.5 m.y. Multisensor track (MST) investigations document that recovery was complete over the entire sequence (0-129 mbsf) with good overlap across core breaks.

Calcium carbonate content fluctuates between 34% and 67%, with an average value of 48%, and gradually decreases downhole. The carbonate cycles probably reflect glacial/interglacial fluctuations. TOC varies between 0.3% and 2.10%. Organic C/N ratios lie mainly between 5 and 35, with an average value of 6, and are indicative of predominantly marine organic material.

Results of Rock-Eval analysis indicate that organic matter is thermally immature with respect to petroleum generation.

Pore-water profiles from Site 1055 are typical of sediments in which sulfate reduction and methanogenesis occur. Sulfate concentrations decrease from the seawater value at the top of the core to values less than 1 mM at 25 mbsf. The shallower and thinner sulfate reduction zone at Site 1055 compared to Site 1054 is probably due to the labile nature of the sedimentary organic matter at Site 1055. The onset of the methanogenic zone occurs at 25 mbsf, coincident with the sulfate consumption. High $C_1/C_2$ ratios and the absence of major contribution of higher molecular weight hydrocarbons suggest that the source for methane is most likely in situ bacterial methanogenesis resulting from decomposition of organic matter in the sediments. Although Site 1055 is located in a well-characterized gas-hydrate area, gradients of chloride are absent, suggesting that no gas hydrate was recovered.

**Intermediate Water Sites on the Blake Outer Ridge**

Sites 1056-1059 are located at intermediate water depths (2177 to 2997 m) along the crest of the BBOR (Fig. 2), at locations ideal for monitoring Pleistocene to late Pliocene changes in production and flow of NADW. All four sites were cored within the advanced hydraulic piston corer (APC) at least three times to ensure complete recovery of the stratigraphic section, a prerequisite for high-resolution paleoenvironmental studies. Site 1056 lies within the core of UNADW, Sites 1058 and 1059 are in the core of LNADW, and Site 1057 straddles the boundary between those two water masses (Fig. 4). It is expected that during glacial and stadial climate episodes paleoproxy data from Sites 1058 and 1059 will show increased nutrient content (reduced flow of LNADW), whereas shallower sites will show nutrient depletion (increased flow of UNADW).

The Blake Outer Ridge first becomes noticeable as a bulge in the continental slope at Site 1056; therefore, that site and those at greater depths should show progressively less influence of downslope sedimentary processes and greater influence of current-controlled sedimentation. Sites 1058 and 1059 provide a test location for the effects of current control. These two sites are only about 1 km apart, but seismic surveys indicate enhanced sediment accumulation in the upper part of Site 1059 relative to Site 1058. Because they underlie the same surface waters, any sedimentological and mass accumulation rate differences between them must be ascribed to the local effects of DWBC flow. Seismic data also show an approximately 1000-m-thick sediment sequence and a BSR, which is produced at the base of the gas hydrate stability zone.

The objectives of drilling at these sites were to (1) determine the history of circulation change in the western North Atlantic; (2) provide high-resolution sections for paleomagnetic study; (3) provide sections for studying geochemical processes related to gas hydrate formation and dissociation; and (4) monitor the extent of gas hydrate along the Blake-Bahama Outer Ridge.

*Site 1056*

The sedimentary succession recovered from the four holes at Site 1056 consists of a well dated ~155-m-thick interval of early Pleistocene to Holocene alternating clay and nannofossil ooze with variable amounts of foraminifers and diatoms (Fig. 3). Compared to the shallower water sites, Sites 1054 and 1055, there is much less evidence of downslope transport and current activity. The reworking of both planktonic foraminifers and calcareous nannofossils is surprisingly low. Stratigraphic correlation based on MST records from all holes suggest that we have recovered a complete stratigraphic sequence.

Two lithologic units were recognized (Fig. 3). Unit I (0 to 95 mbsf, Holocene to middle Pleistocene) is characterized by alternating clay and carbonate-rich nannofossil sediments. The unit is defined largely on the basis of relatively high carbonate content (up to 67%) and higher amplitude oscillations in color reflectance than the underlying unit. Distinct layers of red lutite, from 1 to 1.6 m thick, occur at 15, 64, and 90 mbsf in Hole 1056B. Unit II (95 to 155 mbsf; middle Pleistocene to early Pleistocene), is defined by predominant clayey lithologies with decreased carbonate content and color variability with respect to the overlying unit. Unit II has been subdivided into two subunits: Subunit IIA is a 5-m-thick convoluted clayey interval. Subunit IIB is fairly homogeneous, greenish to gray clayey lithologies (clay, silty clay, clayey silt, nannofossil clay, and, more rarely, nannofossil-clay mixed sediments). Nannofossil ooze layers, present in the overlying unit, are missing. Numerous thin silt layers occur at various levels suggesting winnowing by deep-water flow and/or deposition by turbidity currents. A 60-cm-thick biogenic sandy layer with a sharp lower contact occurs at 133 mbsf in Hole 1056B.

The succession contains abundant and well preserved calcareous nannofossils and common to few planktonic and benthic foraminifers with good to moderate preservation. Diatoms are few to common, and often fragmented. Seven calcareous nannofossil and planktonic foraminifer datum levels suggest sedimentation rates of 81-82 m/m.y. for the past 0.5 m.y. and 105-110 m/m.y. in the underlying interval. The oldest sediments recovered date to the early Pleistocene (between 1.25 and 1.58 Ma).

Magnetic susceptibility and magnetic intensities show cyclic variations that can be correlated with marine oxygen isotope stages for the past 600 k.y. (Fig. 7). Magnetic polarity assessment is difficult because of the effects of overprints, reduction diagenesis, and core disturbance due to gas expansion. The onset of the Brunhes Chron (0-0.78 Ma) is possibly located at 91 mbsf in Hole 1056D, with the top of the Jaramillo Subchron (0.99-1.07 Ma) at 111 mbsf.

Calcium carbonate contents fluctuate between 11% and 67%, gradually decreasing with increasing sediment depth. TOC contents vary between 0.1% and 1.14%, increasing downhole. C/N ratios of samples that contain more than 0.5% TOC average 5.5%, and are indicative of predominantly marine organic material. Results of Rock-Eval analysis indicate that organic matter is thermally immature with respect to petroleum generation.

Pore-water profiles from Site 1056 are typical of sediments in which sulfate reduction and methanogenesis occur. The sulfate reduction zone extends to only 16 mbsf, and carbonate precipitation probably occurs below that level. A chloride profile shows a trend of increasing concentration with depth. Anomalous excursions toward lower chloride values at discrete depths suggest the occurrence of gas hydrate, which could comprise as much as 5.5% of the sediment volume. The $C_1/C_2$ ratios and the absence of major contribution of higher molecular weight hydrocarbons indicate that the source for methane is most likely in situ bacterial methanogenesis resulting from decomposition of organic matter in the sediments.

Site 1056 provides an expanded succession ideally suited for high-resolution paleoceanographic studies on the climatic variability of the past 1.5 m.y. on both Milankovitch and millennial time scales. The alternations of nannofossil ooze and clay intervals are interpreted as switching of the climate system from interglacial to glacial times, respectively.The pattern of alternating lithologies in Unit I is likely to be a function of both changes in surface water productivity patterns and varying quality and quantity of terrigenous sediment input. On longer time scales, the transition from the 41-k.y. to the 100 k.y. climatic variability is obvious in the Site 1056 record, correlating with the transition from lithologic Unit II to Unit I.

*Site 1057*

The three holes at Site 1057 contain a well dated 136-m-thick interval of early Pleistocene to Holocene alternating nannofossil ooze and clay with variable amounts of foraminifers and diatoms. Compared to Site 1056, Site 1057 contains more silt layers in intervals inferred to be glacial epochs, and those intervals appear to be thicker. In contrast, the shallower site seems to have thicker interglacial episodes. Stratigraphic correlation based on MST records from all holes suggests that we have recovered a complete stratigraphic sequence.

Two lithologic units were recognized (Fig. 3). Unit I (0 to 80 mbsf; Holocene to middle Pleistocene) is characterized by alternating clay-dominated and carbonate-rich nannofossil sediments. The unit is defined largely on the basis of relatively high carbonate content (up to 64%) and higher amplitude oscillations in color reflectance than the underlying units. This unit correlates to Unit I at Site 1056. At Site 1057, however, the darker clay intervals are considerably thicker than the light nannofossil-rich layers, which is the opposite of what was observed at Site 1056, despite the short distance between the two sites. Unit II (78 to 138 mbsf; middle Pleistocene to early Pleistocene) was subdivided into two subunits: Subunit IIA (80 to 89 mbsf in Hole 1057A and from 78 to 85 mbsf in Hole 1057B) is contorted and deformed nannofossil clay and clay with nannofossils, without any lithologic contrast with the overlying and underlying units. Subunit IIB (85-90 to 137 mbsf) contains fairly homogeneous greenish to medium dark gray clayey lithologies (clay, nannofossil clay, clay with silt and nannofossils, and, more rarely, nannofossil-clay mixed sediments). The lack of nannofossil ooze layers, the lower carbonate content, and the low variability in color reflectance are the features that distinguish Unit IIB from Unit I. Silt layers occur at various levels suggesting winnowing by deep-water flow and/or deposition by turbidity currents.

Site 1057 contains abundant and well preserved calcareous nannofossils and common to few planktonic and benthic foraminifers with good to moderate preservation. Diatoms are few and often fragmented. Sedimentation rates were 70 m/m.y. in the past 0.5 m.y., and 125 m/m.y. between 0.5 and 1.25 Ma. Oldest sediments are early Pleistocene (between 0.96 and 1.25 Ma).

The magnetic polarity assessment is difficult because of the effects of overprints, reduction diagenesis, and core disturbance due to gas expansion. The onset of the Brunhes Chron (0-0.78 Ma) is tentatively located at 79 mbsf in Hole 1057A, with the Jaramillo Subchron (0.99-1.07 Ma) between 113 and 122 mbsf. These initial magnetic polarity data agree very well with biochronological results based on calcareous plankton. As at Sites 1055 and 1056, magnetic susceptibility and magnetic intensities show cyclic variations that correlate with marine oxygen isotopic stages (Fig. 6).

Calcium carbonate contents fluctuate between 11% and 64%, gradually decreasing with increasing sediment depth. TOC contents vary between 0.1% and 1.14%, increasing downhole. C/N ratios of samples containing more than 0.5% TOC average 9.0%, and are indicative of predominantly marine organic material. Results of Rock-Eval analysis indicate that organic matter is thermally immature with respect to petroleum generation.

As at Site 1056, pore-water profiles from Site 1057 are typical of sediments in which sulfate reduction and methanogenesis occur. The top of the sulfate reduction zone is close to the seafloor. The onset of the methanogenic zone occurs at 15-20 mbsf, coincident with the level of zero pore-water sulfate. The distributions of Ca and Mg concentrations suggest active Mg-enriched carbonate precipitation near the sulfate-methane interface and within the methanogenic zone. Chlorinity shows a trend toward lower values below 83 mbsf and suggests the occurrence of gas hydrate, which could occupy a maximum of 4.2% of the sediment volume. $C_1/C_2$ ratios and the absence of major contribution of higher molecular weight hydrocarbons suggest that the source for methane is most likely in situ bacterial methanogenesis resulting from decomposition of organic matter in the sediments.

Site 1057 provides an expanded succession ideally suited for high-resolution paleoceanographic studies of the climatic variability during the past 1.0 m.y. on both Milankovitch and millennial time scales. On longer time scales, the transition from the 41-k.y. to the 100-k.y.climatic variability is obvious in the Site 1057 record, correlating with the transition from lithologic Unit II to Unit I. The alternation of nannofossil ooze and clay intervals in Unit I is interpreted as switching of the climate system from interglacial to glacial times, respectively. The pattern of alternating lithologies is likely to be a function of both changes in surface-water productivity patterns and varying quality and quantity of terrigenous sediment input. No clear evidence is available at this stage for the former process, although the latter process is supported by the changes in sedimentation rates and sediment type between Sites 1056 and 1057. The smaller scale differences between sites during the same climatic interval (i.e., carbonate-rich interglacials or clay-dominated glacials) can be explained by shifts of the Western Boundary Undercurrent Current (WBUC) between different depths in response to climate forcing. For instance, the fluctuating position and/or intensity of UNADW can be envisaged as a likely cause for the differences in sedimentation rates in glacial and interglacial times between Sites 1056 and 1057.

*Sites 1058 and 1059*

Sites 1058 and 1059 consist predominantly of rapidly accumulated nannofossil ooze, clay with nannofossils, and clays with minor amount of silt. The main component of lithologic variability occurs on decimeter to meter scales throughout the section in the form of cyclic changes in color that are mainly related to relative changes in the proportions of biogenic carbonates, detrital clay, and silt. Stratigraphic correlation based on MST records from all holes suggests that we have recovered a complete stratigraphic sequence at both sites.

Two lithologic units were recognized at the location of Sites 1058 and 1059 (Fig. 3). Unit I (0 to

112 mbsf at Site 1058, and 0 to 98 mbsf total depth [TD] at Site 1059; Holocene to late and middle Pleistocene at Sites 1058 and 1059, respectively) is characterized by cyclically alternating light gray nannofossil ooze and dark greenish gray clay containing reddish-brown layers. The latter are more common in the upper part of the unit. The unit is defined largely on the basis of relatively high carbonate content (up to 53%) and higher-amplitude oscillations in color reflectance than the underlying unit. Bioturbation, pyrite, and pyrite nodules are common in the olive-gray nannofossil clay. Silt-sized biogenic layers are present at the top of light colored nannofossil ooze intervals and have sharp upper contacts at Site 1058. Unit II (recovered only at Site 1058, between 112 and 164 mbsf TD; early Pleistocene) is dominantly clay, clay with silt, and clay with nannofossils. It is characterized by a lower and less variable carbonate content (9%-26%). The red lutite layers are missing and pyrite nodules occur throughout the unit.

These sites contain abundant to common calcareous nannofossils, which are generally well preserved. Reworking of mainly Cretaceous and Paleogene forms is present in the expanded section at Site 1059. Planktonic foraminifers are common to few with good to moderate preservation. Benthic foraminifers are rare to few and are generally moderately well preserved. Diatoms are relatively common and well preserved in the middle part of the succession.

Age control is provided by integrated calcareous planktonic biostratigraphy and magneto-stratigraphy. At Site 1058, the oldest sediments extend to 1.24-1.58 Ma. Sedimentation rates average 95 m/m.y. in the past 0.5 m.y. and 110 m/m.y. in the underlying interval. At Site 1059, the oldest sediments date to 0.5 Ma and sedimentation rates average 120-140 m/m.y. over the past 0.5 m.y. Magnetic susceptibility and magnetic intensities show cyclic variations that evidently correlate with marine oxygen isotopic stages at least for the past 0.8 m.y. (Fig. 7). If correct, this correlation indicates that at Site 1059, late Pleistocene sedimentation rates may have been as high as 280 m/m.y.

Magnetic polarity assessment is difficult because of the effects of overprints, reduction diagenesis, and core disturbance due to gas expansion. The onset of the Brunhes Chron (0-0.78 Ma) is tentatively located between 89 and 99 mbsf in Hole 1058A, with the Jaramillo Subchron (0.99-

1.07 Ma) between 116 and 126 mbsf. At Site 1059, only normal polarity directions were observed from the entire interval cored, which correlates to the Brunhes Chron. An excellent agreement is observed between the pass-through measurements of the archive halves and the best-fit directions obtained from progressive alternating field (AF) demagnetization of the discrete samples.

Calcium carbonate contents fluctuate between 6.6% and 53% at Site 1058 and between 9% and 49% at Site 1059. TOC contents vary between 0.1% and 1.14% at Site 1058 and between 0.2% and 1.14% at Site 1059. C/N ratios of samples containing more than 0.5% TOC average 6.5% and 7.0% at Site 1058 and 1059, respectively, and are indicative of predominantly marine organic material. Results of Rock-Eval analysis indicate that organic matter is thermally immature with respect to petroleum generation.

Pore-water chemistry shows a very thin sulfate reduction zone at both Site 1058 (at 10 mbsf) and Site 1059 (at 15 mbsf). Carbonate precipitation probably occurs near the sulfate-methane interface and within the methanogenesis zone. At Site 1058, chlorinity gives equivocal indications concerning the presence of gas hydrate. Anomalous excursions towards lower chloride values at 94 and 139 mbsf indicate the possible occurrence of gas hydrate, which could comprise 1.5% of the sediment volume. At Site 1059, chlorinity decreases slightly downcore, indicating the presence of gas hydrate at depth. The cored interval (0-98.8 mbsf) does not show anomalous excursions towards fresher chloride values and should be free of gas hydrate. At both sites the $C_1/C_2$ ratios and the absence of higher molecular weight hydrocarbons suggest that the source for methane is most likely in situ bacterial methanogenesis resulting from decomposition of organic matter in the sediments.

Sites 1058 and 1059 provide expanded sections ideally suited for high-resolution paleoceanographic studies on the climatic variability of the past 1.0 m.y. on both Milankovitch and millennial time scale. As at Sites 1056 and 1057, the transition from the 41-k.y. to the 100-k.y.climatic variability is obvious at Sites 1058/1059 and correlates with the transition from lithologic Unit II to Unit I. The alternations of nannofossil ooze and clay intervals are interpreted as switching of the climate system from interglacial to glacial times, respectively. It is noteworthy that at Site 1058, the tops of the carbonate beds are persistently sharp and overlain by coarser sediments, suggesting stronger currents at the end of interglacial periods. This contrasts with Site 1059, where the base of the carbonate unit seems characterized by an abrupt transition and the top is gradual, indicating stronger currents at the beginning of the interglacials.

**Deep Water Sites on the Blake-Bahama Outer Ridge**

The three deepest sites on the Blake-Bahama Outer Ridge depth transect (Sites 1060-1062; Fig. 2) were occupied to recover a continuous sequence of sediments from near the interface (approximately 4000-m water depth) between present-day NADW and AABW (Fig. 4). Sites 1060 (3481 m) and 1061 (4037 m) are on the crest of the Blake Outer Ridge (Site 1060 is near the position of Deep Sea Drilling Project [DSDP] Site 102). Both sites were cored with the goal of obtaining a history of circulation changes near the boundary between AABW and NADW.

Site 1062 (4763 m) is located in a 37-m-high mud wave situated about 400 m downslope and west of the crest of the Bahama Outer Ridge. This location is near the position of Core KN31-GPC-9, which has provided an important climate and deep-circulation record of the late Pleistocene (Keigwin et al., 1994). Presently, Site 1062 is under the influence of the WBUC, which is composed of 15% AABW at this depth. Waters of the WBUC follow a convoluted path along the topographic contours of the eastern and western flanks of the Blake-Bahama Outer Ridge and flow northwards at Site 1062. This deep current activity has generated a mud wave field from 26°N to 30°N in the area surrounding the location of Site 1062. Previous studies and the site survey data indicate lateral and vertical stratigraphic variability in the architecture of the mud wave, resulting from a higher depositional rate in the east flank than in the west flank and from migration of the mud wave with time. This variability may be a response to changing climate and ocean circulation patterns on both orbital and millennial time scales. A transect of eight holes drilled across the mud wave at Site 1062 documents changes in paleocirculation.

Other objectives at these sites were to (1) provide high-resolution sections for paleomagnetic study; and (2) monitor the extent of gas hydrate along the Blake-Bahama Outer Ridge.

Sites 1060, 1061, and 1062 have similar lithologies, which we grouped into two units (Fig. 3). Unit I is defined by its cyclically alternating light gray nannofossil ooze and dark greenish gray clay containing reddish brown layers. Because of shallow penetration, this is the only unit recovered at Site 1060. Unit II is recognized by its reduced abundance of pelagic carbonates and dominance of clays and silts. At Site 1061, Unit II appears more homogeneous than Unit I, whereas on the mud wave (Site 1062) the lithology is more heterogeneous because of the presence of shallow-water carbonate turbidites. Because the mud-wave field is in the Bahama Basin, a depression adjacent to the Bahama Banks and Blake Escarpment, it is subject to more turbidite deposition than Sites 1060 and 1061. Unit III at these sites is composed of clayey mixed sediments.

All three sites contain excellent paleomagnetic records, especially for the Brunhes Chron. There are no other long, well-dated paleomagnetic records of directional field variability available anywhere in the world for the time interval from 0.2 to 0.8 m.y. Preliminary analysis of the paleomagnetic secular variation at each hole of Sites 1060, 1061, and 1062 indicates convincingly that eight excursions may be present in the Brunhes Chron. These sites provide the material necessary for detailed paleoclimatical and sedimentological studies.

*Site 1060*

This site contains various combinations of Holocene and Pleistocene nannofossil ooze, clay and silt, with clay and clay with nannofossils being dominant. Bedding generally ranges from 0.2 to 2 m in thickness. Most lithological changes are gradual, although pronounced transitions can take place within a decimeter. One characteristic of this site is the degree of variability in the lithology, which is evident in the records of color reflectance and carbonate content of the sediment. Sediment color usually ranges from dark greenish gray in the clay, to light greenish gray in the sediments with more biogenic carbonate. In some intervals the clay and clay with nannofossil lithologies have a brownish gray to pale brown color or a reddish tinge. Calcite dominates the carbonate mineralogy and appears primarily in the form of calcareous nannofossils which can make up a significant proportion of the clay-size fraction in carbonate-rich sediments. Carbonate values range from 7%-44%.

Three calcareous nannofossil and planktonic foraminifer events suggest sedimentation rates of 240 m/m.y. The oldest sediments recovered are middle to early Pleistocene (between 0.46 and 0.96 Ma) in age.

Magnetic susceptibility and magnetic intensities show cyclic variations that appear to correlate with carbonate fluctuations and marine oxygen isotope stages (Fig. 7). Paleomagnetic studies indicate that the site is almost all Brunhes normal polarity with the Brunhes/Matuyama reversal occurring near the base of Hole 1060A. Reproducible records of magnetic field secular variation during the Brunhes Chron are present in Site 1060 cores.

Pore-water chemistry shows a very thin (13 m) sulfate reduction zone. Both calcium and magnesium decrease sharply with depth in the zone of sulfate reduction. In the zone of methanogenesis, alkalinity and magnesium decrease downhole, whereas calcium and strontium increase, suggesting dolomitization of carbonates. Methane is biogenic, based on methane:ethane ratios. No gas hydrate was directly observed, but chloride profiles freshen slightly with depth indicating that gas hydrate may underlie Site 1060.

*Site 1061*

At this site, the interval from 0 to 183 mbsf was cored several times and appears to provided a complete composite sequence down to the latest early Pleistocene. XCB coring at Hole 1061A from 152 to 350 mbsf recovered a sedimentary interval that spans 0.8 to 3.2 Ma. In addition to high-resolution Pleistocene objectives, Site 1061 was intended to provide a high-resolution record of climate and ocean changes associated with the onset of Northern Hemisphere glaciation (2.8 Ma) for comparison to other Atlantic records from ODP Legs 154 and 162. Although we XCB cored through the interval, sediment biscuiting, incomplete core recovery, and low sedimentation rates in the Pliocene lowered the value of Site 1061 as a middle Pliocene reference section.

Sediments at this location are predominantly composed of carbonate-rich and carbonate-poor units that alternate on a scale ranging from ~20 cm to ~10 m. The sediments range from nannofossil ooze in the most calcareous units (carbonate content of 20%-55%) to clay in the least calcareous units (carbonate content of 2%-15%). A few thin laminations were noted, presumably deposited by currents. Colors range from dark greenish gray to shades of orange and reddish brown. Three sedimentary units were distinguished on the basis of the bed thicknesses, carbonate content, and color. Additional information that helped to distinguish sedimentary units came from downhole logs.

Unit I (0-170 mbsf; Holocene to middle Pleistocene) is defined by cyclically alternating carbonate-rich (20%-55% $CaCO_3$) and carbonate-poor intervals (4%-15% $CaCO_3$). Sediments in carbonate-rich intervals range from nannofossil ooze to nanofossil clay. In carbonate-poor intervals, sediments are clay, clay with silt, or clay with nannofossils. Colors range from light greenish gray to dark greenish gray alternating with reddish brown and reddish green intervals. This unit is well resolved on the downhole logs, with clear cyclic variations in gamma ray, bulk density, velocity, and resistivity. Unit II (170 to 260 mbsf; early Pleistocene) consists of alternating carbonate-rich and carbonate-poor intervals and is defined, in part, by the diminished carbonate contents (range 5%-20%), which are distinctly lower than in Unit I. Unit II sediments are nannofossil clay and clay with silt. Colors show limited variations from light to dark greenish gray. On downhole logs the unit has more constant gamma-ray counts and lower bulk density, resistivity, and uranium contents with respect to Unit I. A 40-cm-thick, multicolored lithified interval occurs at the top of Core 172-1061A-23X (215 mbsf), and marks the top of a gradual downhole increase in carbonate from 10% to 20%. Unit III (260-360 mbsf; early Pleistocene to middle Pliocene) is defined by alternating intervals of higher and lower carbonate with a somewhat higher carbonate content (2%-35%) than Unit II. The sediments are predominantly composed of nannofossil clay, clay with nannofossil, clay with silt, and clay. Colors include greenish gray (light and dark) and reddish brown, and there are numerous purple and green (diagenetic?) layers. Cores 1061A35X and 36X have distinctly less pyrite and perhaps lower carbonate (2%-20%) than the above sediments, and may represent a distinct subunit. Logs of this unit show increasing gamma-ray counts with an additional increase below ~315 mbsf and higher resistivity that decreases abruptly below 325 mbsf.

Eighteen calcareous planktonic biohorizons suggest that sedimentation rates were 227-228 m/m.y. during the past 0.5 m.y., 144 m/m.y. between 0.5 and 1.6 Ma, 87 m/m.y. between 1.6 and 2.0 Ma, 52 m/m.y. between 2.0 and 2.5 Ma, and 31 m/m.y. between 2.5 Ma and the bottom of the succession at 3.2-3.3 Ma.

Magnetic susceptibility and magnetic intensities show cyclic variations that evidently correlate with carbonate percentage fluctuations and marine oxygen isotopic stages (Fig. 7). Site 1061 has mixed magnetic polarity, with Hole 1061A ending in the Gauss normal chron. The Brunhes/Matuyama reversal occurs at 149 mbsf in Holes 1061A, C, and D, and appears to be a promising candidate for a high-resolution record of a polarity transition. Several excursions within the Brunhes Chron are reproducible among the holes.

As in previous Blake Ridge sites, pore-water chemistry shows a very thin sulfate reduction zone of about 13 m. Calcium and magnesium distribution indicate carbonate precipitation near the sulfate-methane interface and within the methanogenic zone. Methane is biogenic based on methane:ethane ratios. No gas hydrate was directly observed, but chloride profiles freshen with depth, indicating gas hydrate may underlie Site 1061.

Downhole measurements were made from 350 to 77 mbsf in Hole 1061A, using two tool strings: the Triple-combo (resistivity, density, porosity, and natural gamma ray) and Formation MicroScanner (FMS)-Sonic (resistivity imager and sonic velocity) tools. The logs are generally of good quality. The borehole diameter was mostly around 12 to 13 in, with numerous thin wash-outs up to 16 in. Resistivity, total natural gamma, and bulk density all show marked cyclicity down to 160 mbsf, i.e., during the past 0.8 m.y. This cyclicity is not evident between 160 and 260 mbsf and variations are more modest. Below 260 mbsf (2.5 Ma), bulk density, resistivity, and natural gamma all step up to higher values. The FMS resistivity images show a curious decimeter-scale banding in this lower section.

*Site 1062*

At Site 1062, we drilled eight holes on either flank and in the crest of the mud wave (Fig. 6). Holes 1062A, B, C, and D are on the east side of the mud wave, Holes 1062E and F are on the west side, and Holes 1062G and H are near the crest. Hole 1062B was cored by XCB from 2.6 to 4.0 Ma, and Hole 1062E was cored by XCB from 2.7 to 3.0 Ma. The holes located on the far west and far east sides of the mud wave are 1050 m apart. A total of 1000 m of sediments was cored with recovery in excess of 100%.

Three lithologic units were recognized (Fig. 3). Unit I (0 to 79 mbsf on the east flank, and 0 to 61 mbsf on the west flank; Holocene to middle Pleistocene) is composed of cyclically alternating dark gray to reddish brown clay layers (typically 5- to 10-m thick) and light olive gray nannofossil-clay mixed sediment layers (typically only 1.5-m thick). The transitions from carbonate-rich layers to clay layers are abrupt, whereas, those from clay-rich to carbonate-rich sediment are gradual. An entire sedimentary cycle typically occupies 10 to 20 m, and more than five of these cycles are contained in Unit I. Four distinctly reddish layers are also present that can be correlated to the red lutite layers observed at other shallower Leg 172 sites. Unit II (77.0 to 167 mbsf on the east flank and 61 to 117 mbsf on the west flank; middle Pleistocene to late Pliocene) is predominantly composed of interbedded clay and clay with nannofossils. Contacts are gradual and moderately to heavily bioturbated. The average thicknesses of clay layers and nannofossil-rich layers are 2 m and 1 m, respectively. Unit II also contains well-sorted foraminiferal or carbonate silt and sand layers, generally 7- to 12-cm thick, which are interpreted as carbonate turbidites. The source area of the turbidites was most probably the Bahama Banks. Unit III (167 to 239 mbsf on the east flank and 117 to 209 mbsf on the west flank; middle to early Pliocene) is dominantly dark greenish gray clay with nannofossils interbedded with clay, clay with silt, and nannofossil clay. Thin carbonate-rich layers are present. There is an increase of silt-sized lithologies with respect to the overlying units.

Calcareous nannofossils are the dominant microfossils at Site 1062. However, their abundance and preservation vary with depth and between holes. Samples with abundant and well-preserved nannoflora assemblages alternate with samples with a few partially dissolved specimens and those barren of nannofossils. Reworking is often strong, which makes recognizing the horizons around the Pliocene/Pleistocene boundary difficult at Site 1062. At Hole 1062E, the interval between 100 and 120 mbsf is apparently disturbed, as all the biostratigraphic markers appear displaced uphole relative to the ages indicated by magnetostratigraphy. Even though planktonic foraminifer abundance and preservation is highly variable, it is better than at Site 1061 which is 725 m shallower. Benthic foraminifers are rare to very rare, and moderately to poorly preserved.

Magnetic susceptibility and magnetic intensities show cyclic variations that correlate with oxygen isotope Stages 1 to 22 in all holes at Site 1062 (Fig. 7). Magnetic polarity stratigraphy is well defined down to the base of the Jaramillo Subchron. In the underlying interval, the presence of the turbidite layers makes the paleomagnetic record more difficult to interpret. The base of the Brunhes Chron is at 92-95 mbsf at Holes 1062A, B, and C on the eastern flank, whereas at Hole 1062E on the western flank, it is at 71.5 mbsf. The Jaramillo Chron is between 108.4 and 112.4 mbsf at Hole 1062B (eastern flank of the mud wave), but it is between 79 and 86 mbsf in Hole 1062E (western flank). Paleomagnetic directional changes, which likely reflect paleomagnetic secular variation, are observed within the Brunhes Chron on a variety of length scales from 10 cm to 10 m in all holes. When checked carefully in selected intervals, these correlate between holes as well as with directional changes observed at Sites 1060 and 1061.

Age control provided by calcareous planktonic biostratigraphy and magnetostratigraphy indicates that the sedimentation rates at Site 1062 were generally very high and that the successions recovered are well suited for paleoceanographic reconstruction at the orbital and millennial time scales. In addition, it indicates, in accordance with the evidence of the seismic images of the investigated mud wave, varying sedimentation rates in the east and west flanks. Specifically, in the east flank (Holes 1062A and B) sedimentation rates were 110 m/m.y. during the past 1 m.y., 32 m/m.y. between 1.0 and 2.5 Ma, and 73 m/m.y. between 2.5 and 2.86 Ma. In the west flank (Hole 1062 E), sedimentation rates were 82 m/m.y. during the past 1 m.y., 27 m/m.y. between 1.0 and 2.5 Ma, and 109 m/m.y. between 2.5 and 2.86 Ma

The interface between the sulfate and methanogenic zone is at 70 mbsf, deeper by 50 m than at the Blake Outer Ridge sites. The sulfate profile displays a distinct concave down profile suggesting that sulfate is predominantly consumed by microbially-mediated reactions with sedimentary organic matter. This, however, contrasts with the high methane levels in the lower part of the sulfate reduction zone and with the presence of a BSR in the area. Although gas hydrate was not directly observed, the chlorinity decreases with depth, indicating its presence above the BSR.

**Deep Water Sites on the Bermuda Rise and Sohm Abyssal Plain**

The sediment drift which comprises the northeast Bermuda Rise is one of the highest resolution archives of paleoclimate and paleo-ocean information known from the open sea. Sedimentation rates as high as 200 m/m.y. are the result of clay and silt advection by deep recirculating gyres, the strength of which is linked to surface ocean and atmospheric conditions. Because much of the clay and silt is derived from eastern Canada, studies of the Bermuda Rise have the potential to link the marine, terrestrial, and atmospheric components of the climate system. Prior to Site 1063, the longest continuous core from the Bermuda Rise was 53 m, terminating in sediments of glacial Stage 6. Accordingly, one of the most important Leg 172 objectives was to recover a complete sequence of sediments back through the origin of Northern Hemisphere glaciation. Such sediments should document any changes in lithology associated with the first glaciation of eastern Canada, which might also account for the base of the acoustically stratified sediments (at 0.3 s two-way traveltime [twt]). In addition, they should document any important changes in deep-ocean circulation patterns associated with that event. Finally, Bermuda Rise sediments should be useful for high-resolution studies of changes in Earth’s magnetic field.

When it was clear that we had the extra time, we requested permission to drill a hole on the Sohm Abyssal Plain near the northeast Bermuda Rise. Site 1064 was chosen because it was near some conventional piston cores taken by CSS *Hudson*, and it appeared to be ideally situated to fulfill two paleoceanographic objectives. One objective of this site was to study the distal turbidites on the abyssal plain to determine the link between their Canadian source and the fine-grained sink on the Bermuda Rise. A second objective of Site 1064 was to provide a pore-water record of $\delta^{18}O$ from a deep water location unaffected by climatically controlled changes in the flux of NADW. It was assumed that an abyssal plain site at this latitude would have been continuously bathed by AABW during the past 20 k.y. If this proved to be correct, then the change in $\delta^{18}O$ from modern bottom water to glacial-aged pore water at Site 1064 would reflect mostly the secular change in oxygen isotope composition of the ocean.

*Site 1063*

Site 1063 is located on the northeast Bermuda Rise, in the northern Sargasso Sea, at a water depth of 4584 m (Fig. 2). This location is close to the interface between AABW and NADW, marked by bottom water temperatures of ~2°C. Four holes were cored with total recovery in excess of 100%. The interval 0-201.4 mbsf was triple APC cored and appears to provide a complete composite sequence down to the early Pleistocene. A fourth APC penetrated to 173 mbsf. Double XCB coring extended the site to the early Pliocene with penetration to 418.4 mbsf at Hole 1063A and 342 mbsf at Hole 1063B.

The base of acoustically stratified sediments appears to be late Pliocene to early Pleistocene in age, but the most reflective sediment was deposited beginning ~1 m.y. ago (Fig. 8). These reflectors seem to correlate with late Pleistocene climate change from 40 k.y. to 100 k.y. variability. In spite of the "biscuiting" in the cores drilled with the XCB, good sedimentary structures could still be observed. Overall, an excellent and continuous sedimentary succession highly suitable for paleoceanographic studies was recovered at Site 1063.

The sediments reflect the rapid deposition of clays and silts by deep recirculating gyres in the western North Atlantic. Only one lithostratigraphic unit (Fig. 3) is recognized at Site 1063, characterized by 70%-100% clays alternating with nannofossil-bearing intervals (commonly 15% to 30% but occasionally exceeding 60%). The persistence of one sedimentary unit for more than 3 m.y. suggests that sediment focussing by deep currents at this site has been the dominant depositional process during the late Neogene. In addition to the clays and nannofossils, two other accessory components are silt and biogenic silica. The presence of 15% to 30% biogenic silica (mostly diatoms) within clays and silty clays marks Subunit IA (0-135 mbsf). Within the last glacial maximum, at 4-11 mbsf, a region of black diagenetic mottles containing troilite and hydrotroilite is correlatable with Sites 1061 and 1062 on the Blake-Bahama Outer Ridge. As in the upper sections of other Leg 172 sites, Bermuda Rise sediments contain distinct red lutite beds that are thought to reflect increased advection of fine-grained sediment from the Nova Scotia region during cold climates. Subunit IB also contains these red lutites, and their last appearance at 270 mbsf defines its lower boundary. Between 270 and 420 mbsf, Subunit IC consists of dark greenish gray, homogeneous clays interbedded with light greenish gray carbonate-rich intervals. Erosional events, common at several of the Blake-Bahama Outer Ridge sites, are virtually absent here, with the exception of a thin (10 cm), laminated deposit at 101 mbsf.

Calcareous nannofossils are the dominant microfossils, and they are generally well preserved except for some intervals where they are dissolved. Eleven nannofossil horizons were constrained for the past 3.3 m.y. Foraminifer assemblages are generally dissolved, but despite poor preservation, eight foraminifer horizons were identified. Where diatoms are most common, the sediment has the unusual association of high sonic velocity and low bulk density. It is thought that this stems in part from a structural framework provided by the diatoms and other siliceous microfossils. The diatoms seem to be most prevalent in cold climatic episodes, probably reflecting some combination of higher surface-water productivity and better preservation.

Paleomagnetic results from Site 1063 are exceptional, providing an excellent record of geomagnetic secular variation, geomagnetic excursions, transitional field directions during reversals (Fig. 5), and a detailed magnetostratigraphy down to the Gauss Chron (Fig. 9). In Hole 1063A, the Brunhes/Matuyama reversal boundary (0.78 Ma) is located at 138.5 mbsf, the top and bottom of the Jaramillo (0.99 and 1.07 Ma, respectively) are located at 175.0 and 187.3 mbsf, respectively, and the top of the Gauss (2.581 Ma) is at 347.7 mbsf. Also, clearly identified are the Cobb Mountain Subchron, Olduvai Chron, and the Reunion I and II Subchrons.

There is excellent agreement between the 19 calcareous planktonic biohorizons recognized and the magnetic polarity reversal stratigraphy. The integrated biomagnetostratigraphy indicates a sedimentation rate of 200 m/m.y. from 0 to 0.5 Ma, 140-170 m/m.y. between 0.5 and 1.1 Ma, 100-110 m/m.y. between 1.1 and 2.5 Ma, and 75 m/m.y. in the underlying interval.

The sulfate/methane boundary occurs at 38 mbsf. Methane concentrations below the interface were sufficient to cause significant sediment expansion in the recovered cores. Downhole profiles of interstitial-water calcium, magnesium, and strontium indicate dissolution of biogenic carbonates and probable dolomitization in the zone of methanogenesis. Manganese concentrations (up to 37 mM) in the top of the sulfate reduction zone are higher than at the other sites, which is probably due to the relative proximity of Site 1063 to volcanic sources. Interstitial water profiles indicate decreasing amounts of biogenic silica in the sediment column below 250 mbsf. Chloride concentrations decrease downhole, showing an overall freshening of 3% relative to seawater.

*Site 1064*

Site 1064 is one sedimentary unit consisting of alternating brown and red clays with exceptionally sharp contacts. The brown clays are probably distal turbidites because of the occurrence of thin basal laminae and scoured contacts. Reddish clays may be turbiditic as well, although there is no evidence of basal scour. The relationship between clays at this site and those on the Bermuda Rise is unclear, because the three APC cores at Site 1064 were insufficient to establish a reliable biostratigraphy.

## CONCLUSIONS

Leg 172 succeeded in recovering complete and expanded sequences of slope and drift sediments that are well suited for high-resolution paleoceanographic studies, particularly those concentrating on the past 1 m.y. of Earth's history. The cored locations span a wide range of water depths, from 1306 m at Site 1054 on the Carolina Slope to the 4786 m at Site 1062 on the Bahama Outer Ridge, and sample virtually all the various components of the North Atlantic Deep Water. Besides providing the raw material for shore-based studies that will address the long-range leg objectives (as given in the Leg 172 Scientific Prospectus and outlined below in italics), Leg 172 accomplished many of the objectives through shipboard studies. These results are described briefly below.

1. *Obtain a detailed history of late Neogene paleoceanography and paleoclimate in the North Atlantic by investigating: (a) millennial scale oscillations of stable isotopes (C and O), faunal and*

*floral abundance, percent carbonate and other lithologic components, and trace metals in drift deposits; (b) the nature of cyclicity of these oscillations; and (c) how these cycles are related to the history of Northern Hemisphere glaciations during the late Neogene.*

Through coring multiple holes at each site along the Blake-Bahama Outer Ridge and at the Bermuda Rise, we obtained thick, complete Pleistocene sedimentary sequences. Shore-based studies of stable isotope, chemical, and sedimentological paleotracers from these sequences should allow a detailed three dimensional reconstruction of circulation changes related to climatic evolution and variability since the inception of Northern Hemisphere Glaciation. Shipboard results show striking evidence of orbital-scale climatic changes, but millennial and perhaps centennial scale changes should be resolvable at some sites. Sedimentation patterns are surprisingly uniform in the Carolina Slope and Blake-Bahama Outer Ridge region. Every location has an upper unit characterized by cyclic alternation between nannofossil-rich and clay-rich beds, the base of which appears at most sites to be about 0.8 m.y. old. Hence, this lithologic change seems to reflect the dramatic onset of the 100-k.y. glacial/interglacial cycles of the middle and late Pleistocene and attests to the strong influence of climate on sedimentation and circulation patterns. The expanded sections recovered will offer the opportunity of an accurate calibration of late Pliocene to late Pleistocene calcareous plankton horizons and an evaluation of their interregional synchroneity. Furthermore, at all sites, except the shallow-water Site 1054, it has been possible to establish a highly resolved age model for the past 0.9 m.y. based on magnetic susceptibility, which correlates well with the standard marine oxygen isotope scale. This age model surprisingly suggests no major change in the sediment accumulation rates between glacial and interglacial cycles.

2. *Investigate sediment wave migration and drift sedimentation processes.*

Mud-wave dynamics have been a long-standing interest of ODP, but had not been successfully studied by ODP until this leg. On Leg 172, we cored a transect of eight holes across a single mud wave. The coring results revealed variations in the sedimentation rates on opposite flanks of the mud wave, indicating a net eastward migratration of the mud wave. Our pre-drilling seismic survey also revealed, with great clarity, structures within the mud wave, which will be combined with the coring results to give a detailed dynamical history of this mud wave and to document THE changes in paleocirculation that have occurred during the late Pliocene and Pleistocene.

3. *Investigate the detailed variations of the Earth's magnetic field (secular variations and reversals).*

Most sites proved to be excellent magnetic recorders, and given the high sedimentation rates, they will yield some of the most detailed records of the behavior of the Earth’s magnetic field obtained to date. Highlights from shipboard analyses include exceptional magnetostratigraphic records that agree well with biostratigraphic constraints, transitional field behavior at the Brunhes-Matuyama reversal that can be correlated at sites over 1600 km apart, and excursions and secular variation events that can be correlated between multiple holes and sites, and that were documented in measurements on discrete samples as well as split cores. Shore-based studies at higher resolution will further refine the paleomagnetic direction and paleointensity record, which will then be used to test and constrain models that attempt to explain how the geomagnetic field is generated and maintained.

4. *Investigate geotechnical/acoustic properties of deep-sea sediments.*

Physical properties showed variations that appear to reflect both the 41-k.y. cycles of the early Pleistocene and the onset of the 100-k.y. glacial/interglacial cycles of the middle and late Pleistocene. The orbitally driven variations in acoustic properties were so dominant that they were even visible in seismic records collected during the cruise, an observation that could prove to be very significant for seismic stratigraphy studies in the region.

5. *Investigate geochemical signals associated with the formation, dissociation, and distribution of gas hydrate.*

On Leg 172, seismic data collected showed a probable bottom simulating reflector under all the sites drilled along the Blake-Bahama Outer Ridge. Moreover, the pore-water samples taken from cores give chloride concentrations that strongly suggest the presence of underlying gas hydrate. These data are critical to improve estimates of the size of the gas hydrate reservoir in the Blake Outer Ridge area (and elsewhere), and to understand the geochemical processes involved in the development of extensive gas hydrate fields.

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## FIGURE CAPTIONS

**Figure 1.** Schematic of circulation patterns in the deep western North Atlantic (updated from Schmitz and McCartney [1993] by M.S. McCartney, pers. comm. to L. Keigwin, 1995). The thin lines represent streamlines of two recirculating gyres with approximate transport in Sverdrups (1 Sv = 106 $m^3$/s). Thick lines represent generalized flow direction of AABW and NADW, which contribute to the Deep Western Boundary Current (DWBC). The stippled pattern marks the region marked by high surface eddy kinetic energy (EKE), deep EKE, and deep suspended sediment. Note that in this scheme the southern recirculating gyre, over the Bermuda Rise, is the mixing zone for northern and southern origin waters and that true "NADW" is formed in that mixing zone.

**Figure 2.** Map of the western North Atlantic Ocean showing the location of Leg 172 sites on the Carolina Slope (Sites 1054 and 1055), Blake-Bahama Outer Ridge (Sites 1056-1062), northeast Bermuda Rise (Site 1063), and the Sohm Abyssal Plain (Site 1064).

**Figure 3.** Schematic columnar logs and biomagnetostratigraphic correlations between Sites 1054 through 1063.

**Figure 4**. Position of Leg 172 sites with respect to water masses in the western subtropical North Atlantic. Water depths are indicated every 500 m along the temperature/salinity (T/S) plot. Sites were chosen so at least one lies within each modern water mass and one lies at the boundary between water masses. This depth distribution of sites is required to monitor the most likely changes in water masses and their boundaries through the late Neogene. U = upper; L = lower. KNORR 140/2 Hydro Sta. 1 refers to the site survey cruise and station number that were used to collect the data.

**Fig. 5.** Comparison of inclination changes of the paleomagnetic field are shown for the Brunhes-Matuyama polarity transition at Sites 1060 and 1063.

**Fig. 6.** Seismic image of mud waves at Site 1062, with sedimentation rate variation vs. depth plotted to the right. The position of the biostratigraphic datums shown in the sedimentation rate are plotted as hollow boxes on the seismic profile. Note how the relative distance between the seafloor and the positions of the datums change from one side of the mud wave to the other, reflecting sedimentation rate variations.

**Figure 7.** Susceptibility correlation between sites and with the marine oxygen isotopic record.

**Figure 8.** Seismic record collected by the *JOIDES Resolution* that shows the high amplitude (100-k.y. cycles?) overlying lower amplitude and more closely spaced reflectors of pre-mid-Pleistocene (40-k.y. cycles?).

**Figure 9.** Magnetostratigraphy of Site 1063.

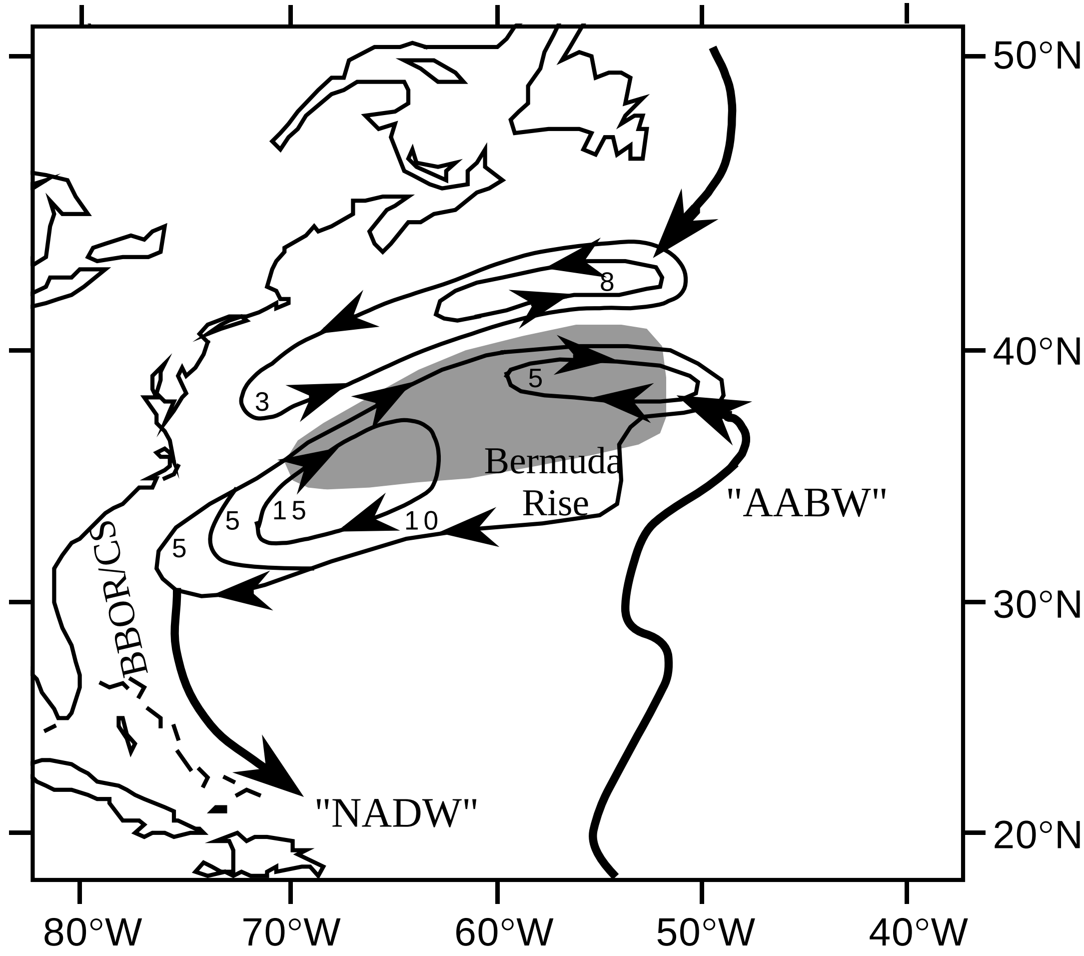

50°N
40°N
30°N
20°N
80°W
70°W
60°W
50°W
40°W
8
3
5
5
15
10
5
5
Bermuda Rise
"AABW"
BBOR/CS
"NADW"

**Figure 1**

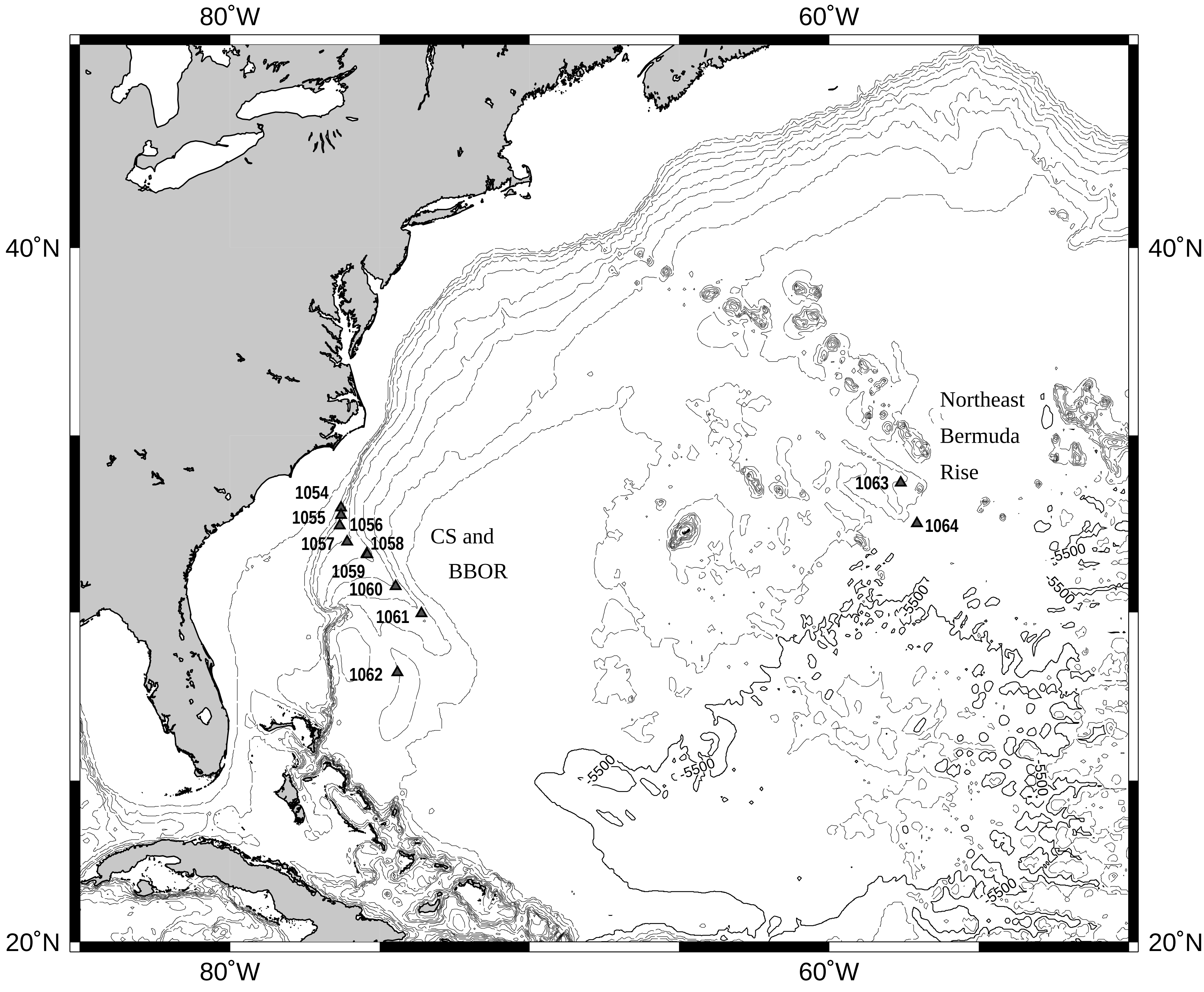

80°W
60°W
40°N
20°N
Northeast
Bermuda
Rise
CS and
BBOR
1054
1055
1056
1057
1058
1059
1060
1061
1062
1063
1064
-5500

Figure 2

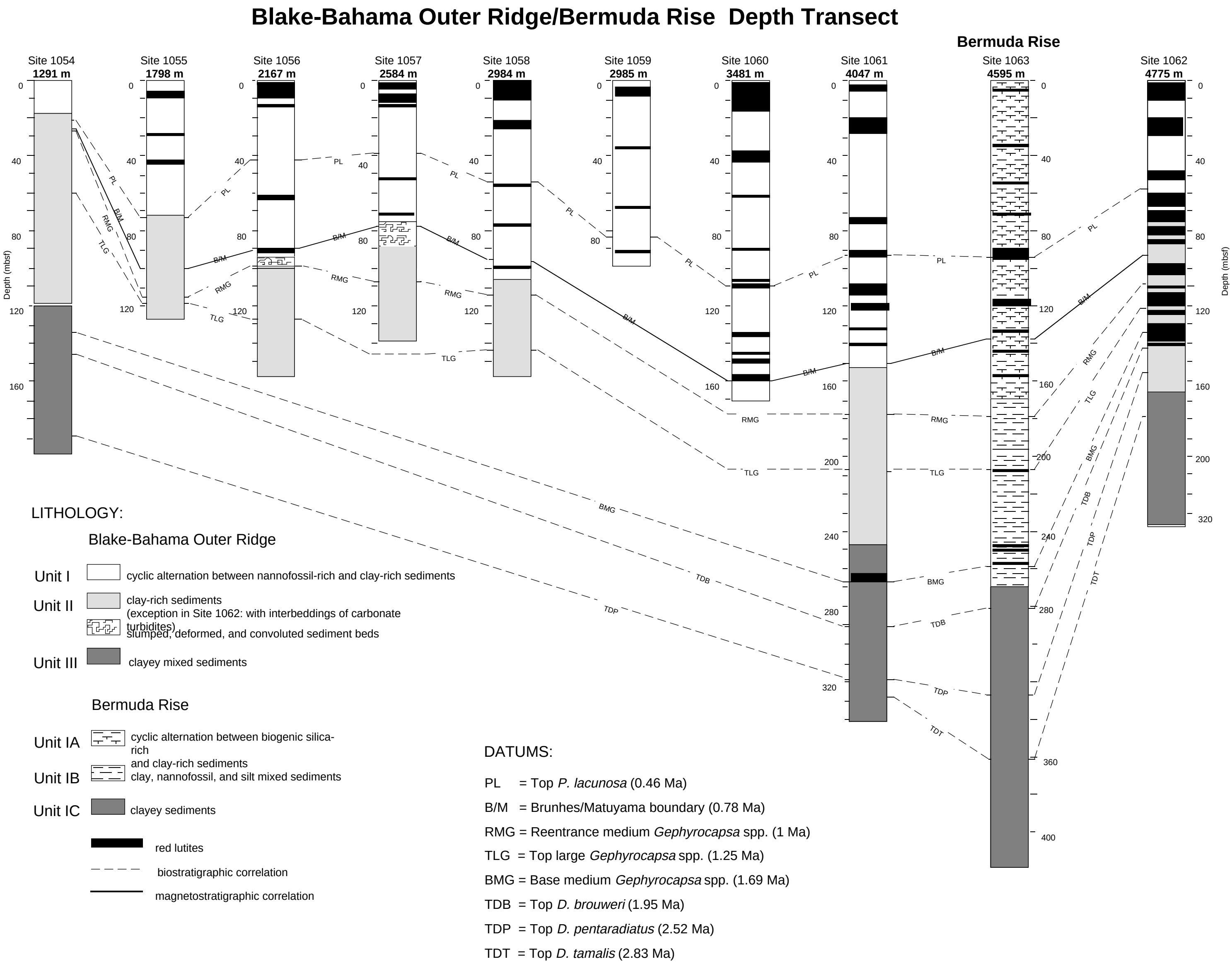

Blake-Bahama Outer Ridge/Bermuda Rise Depth Transect
Bermuda Rise
Site 1054 1291 m
Site 1055 1798 m
Site 1056 2167 m
Site 1057 2584 m
Site 1058 2984 m
Site 1059 2985 m
Site 1060 3481 m
Site 1061 4047 m
Site 1063 4595 m
Site 1062 4775 m
Depth (mbsf)
LITHOLOGY:
Blake-Bahama Outer Ridge
Unit I cyclic alternation between nannofossil-rich and clay-rich sediments
Unit II clay-rich sediments (exception in Site 1062: with interbeddings of carbonate turbidites)
slumped, deformed, and convoluted sediment beds
Unit III clayey mixed sediments
Bermuda Rise
Unit IA cyclic alternation between biogenic silica-rich and clay-rich sediments
Unit IB clay, nannofossil, and silt mixed sediments
Unit IC clayey sediments
red lutites
biostratigraphic correlation
magnetostratigraphic correlation
DATUMS:
PL = Top P. lacunosa (0.46 Ma)
B/M = Brunhes/Matuyama boundary (0.78 Ma)
RMG = Reentrance medium Gephyrocapsa spp. (1 Ma)
TLG = Top large Gephyrocapsa spp. (1.25 Ma)
BMG = Base medium Gephyrocapsa spp. (1.69 Ma)
TDB = Top D. brouweri (1.95 Ma)
TDP = Top D. pentaradiatus (2.52 Ma)
TDT = Top D. tamalis (2.83 Ma)

**Figure 3**

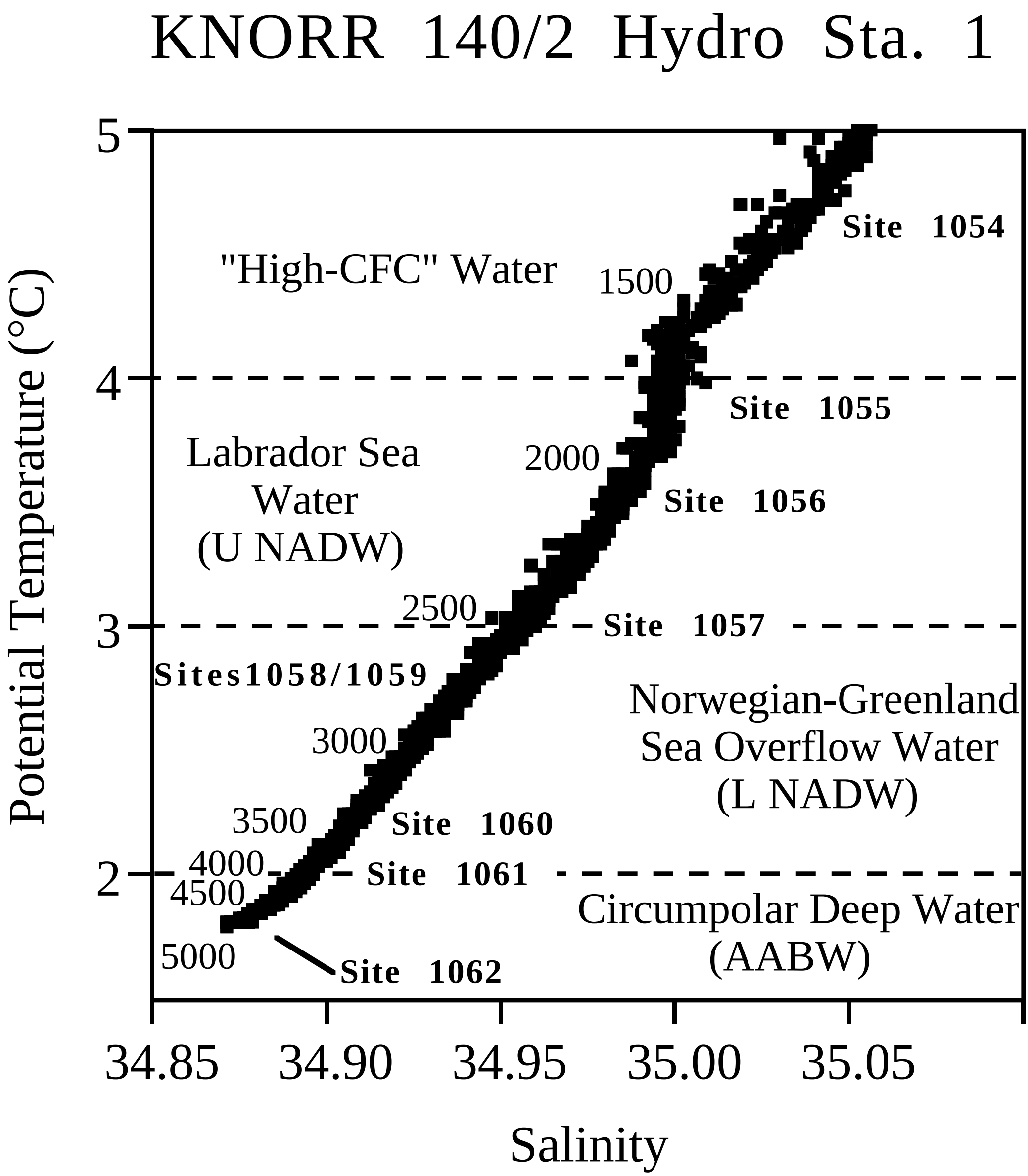

KNORR 140/2 Hydro Sta. 1
Potential Temperature (°C)
5
4
3
2
34.85
34.90
34.95
35.00
35.05
Salinity
"High-CFC" Water
Labrador Sea Water (U NADW)
Norwegian-Greenland Sea Overflow Water (L NADW)
Circumpolar Deep Water (AABW)
1500
2000
2500
3000
3500
4000
4500
5000
Site 1054
Site 1055
Site 1056
Site 1057
Sites1058/1059
Site 1060
Site 1061
Site 1062

**Figure 4**

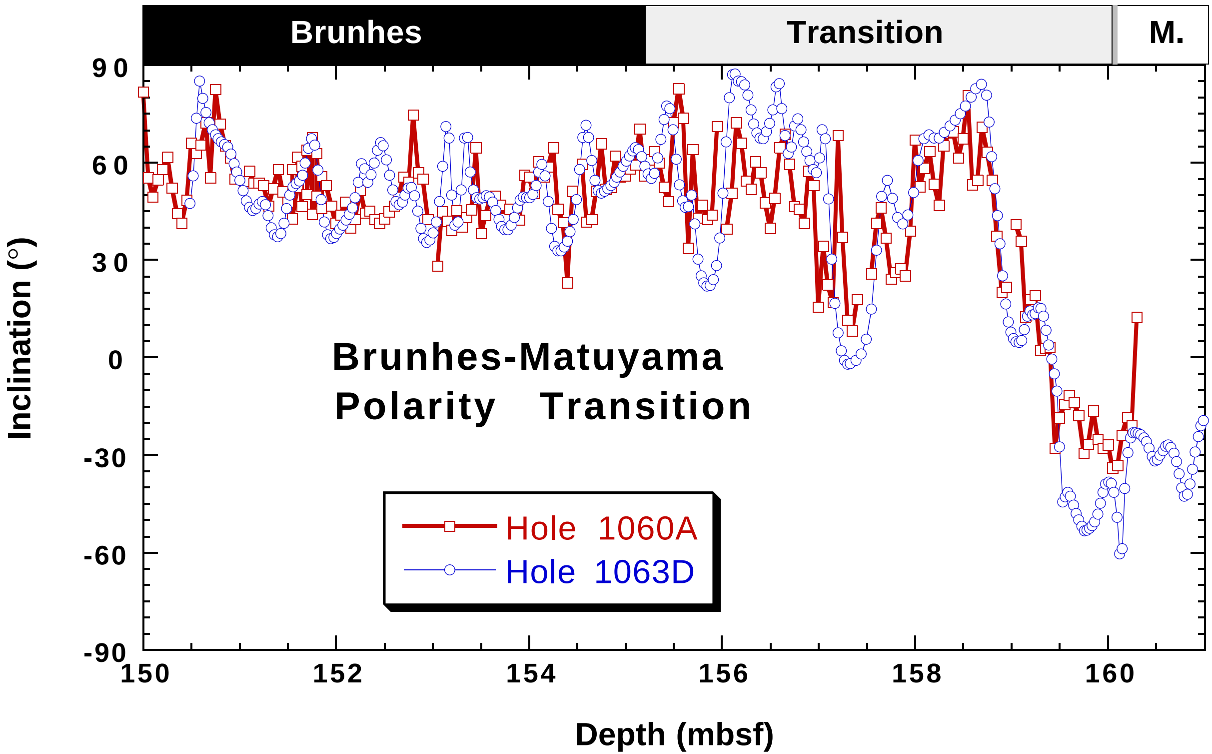

Brunhes
Transition
M.
Brunhes-Matuyama
Polarity Transition
Hole 1060A
Hole 1063D
Inclination (°)
Depth (mbsf)
90
60
30
0
-30
-60
-90
150
152
154
156
158
160

**Figure 5**

# Leg 172 Mud Wave Study

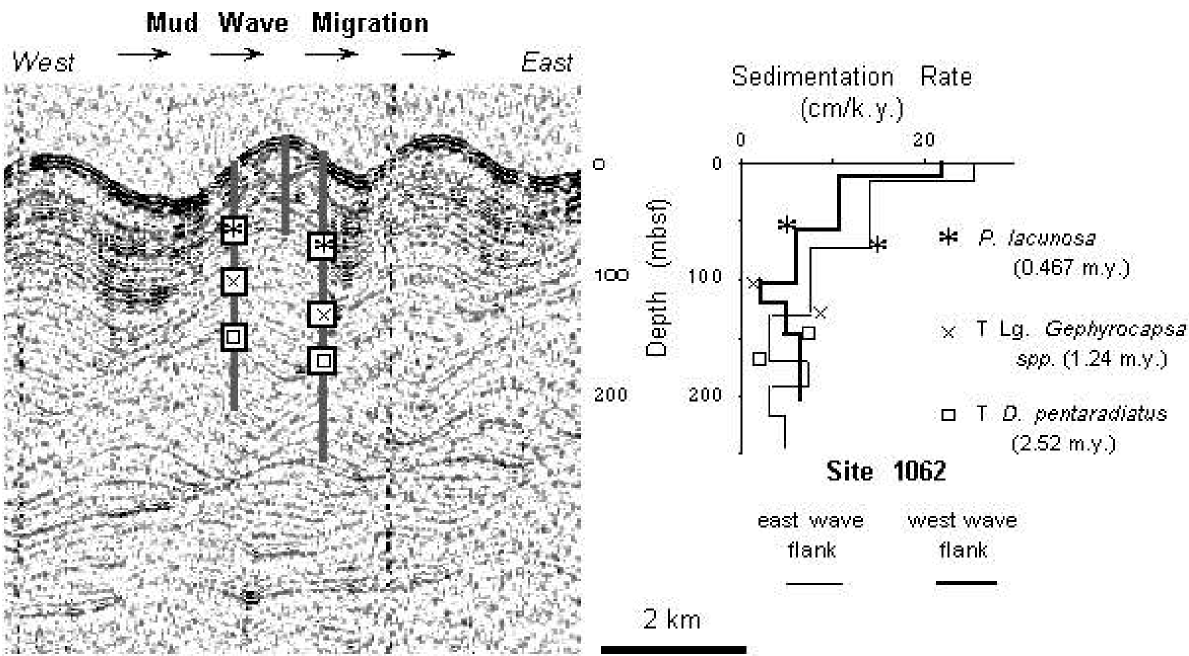
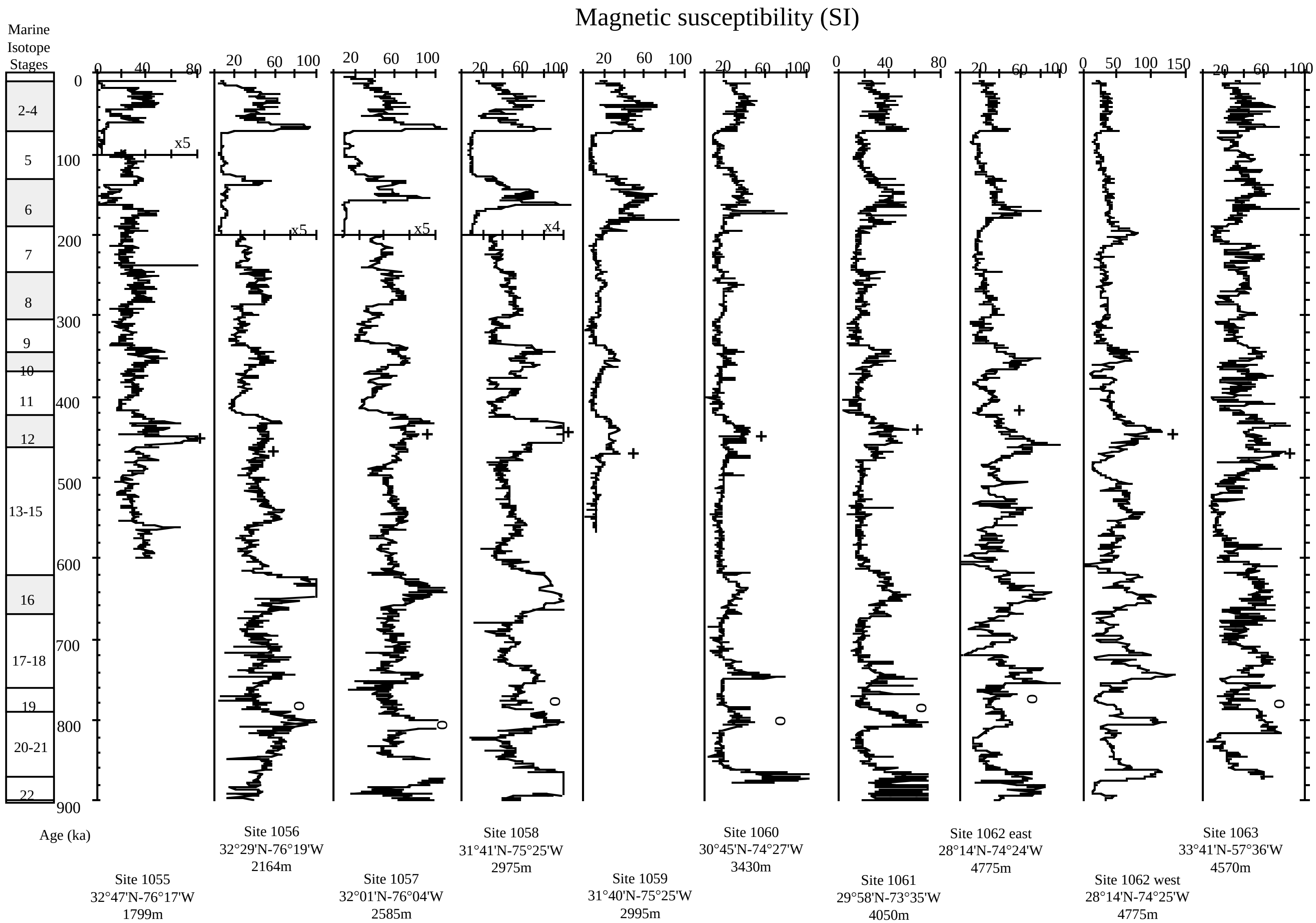



**Figure 6**




+ top of *P. lacunosa*
o Brunhes-Matuyama boundary

**FIgure 7**

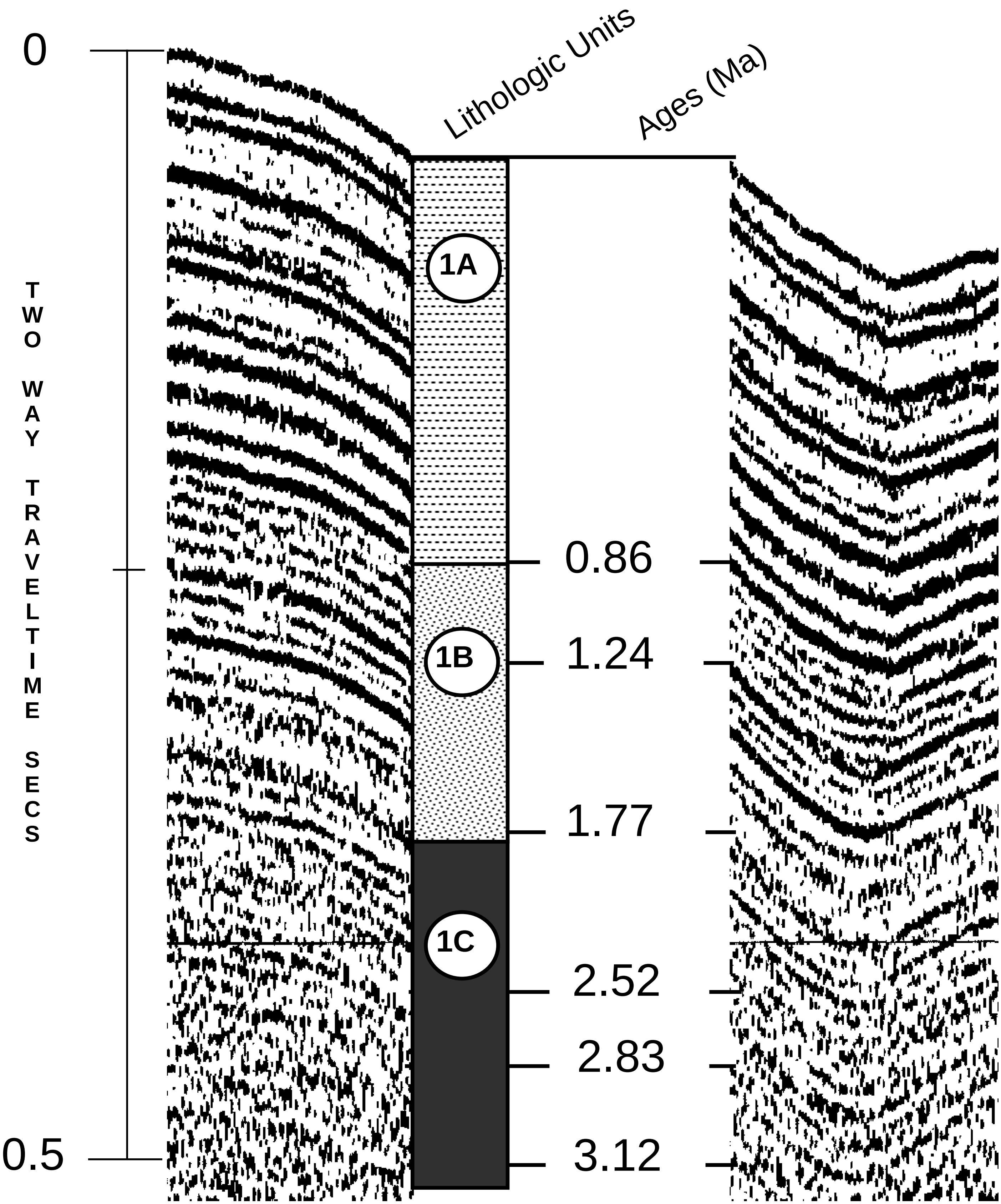

0
TWO WAY TRAVEL TIME SECS
0.5
Lithologic Units
Ages (Ma)
1A
1B
1C
0.86
1.24
1.77
2.52
2.83
3.12

**Figure 8**

# 1063A Paleomagnetics

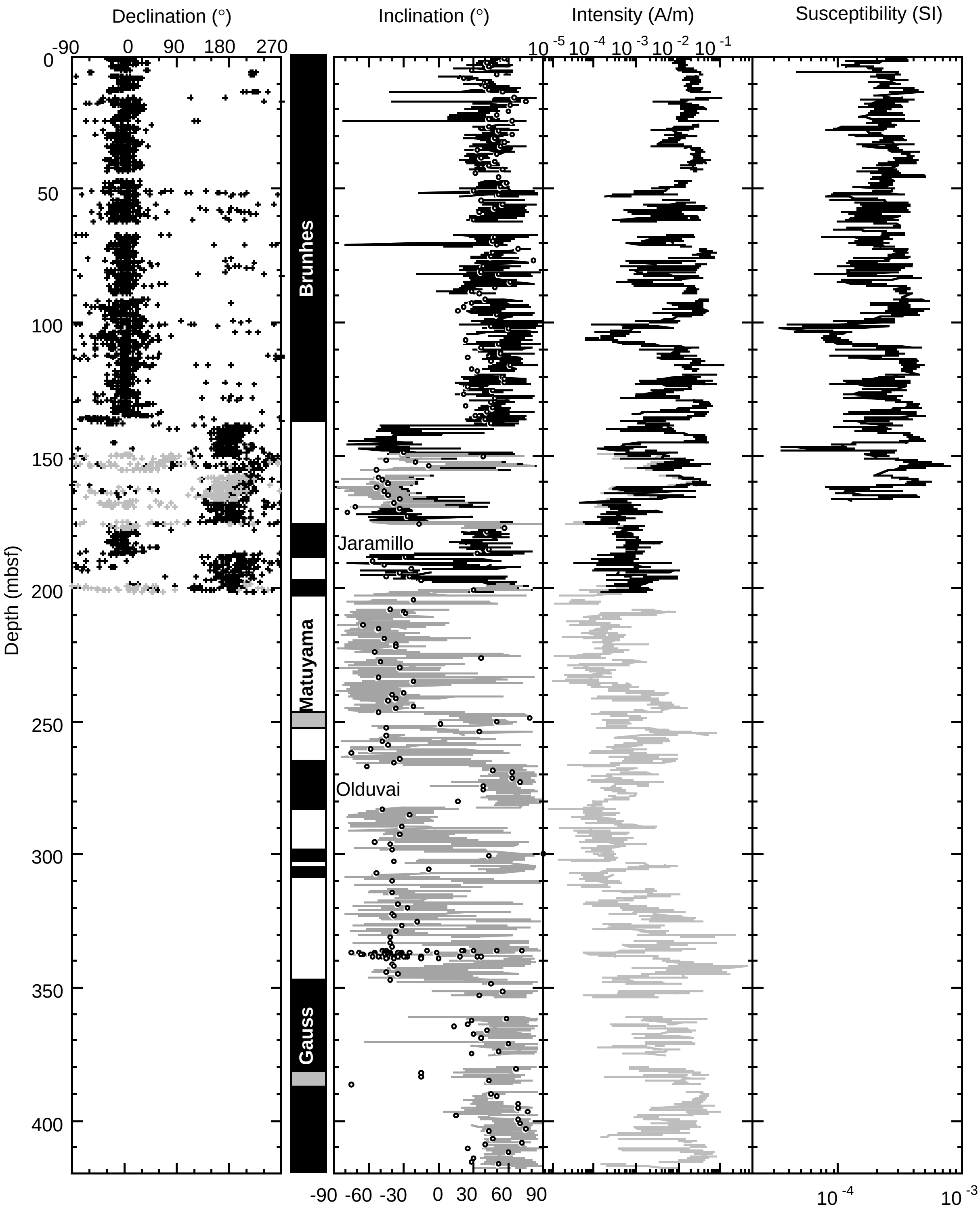



**Figure 9**

# OPERATIONS REPORT

The drilling and engineering personnel aboard *JOIDES Resolution* for Leg 172 were:

| | |
|---|---|
| Operations Manager | Ron Grout |
| Schlumberger Engineer | Steve Kittredge |

## TRANSIT FROM CHARLESTON TO SITE 1054

The *JOIDES Resolution* (*JR*) departed Charleston, South Carolina at 1900 hr (local time) on 18 February 1997. At 0700 hr on 19 February, the ship was slowed to deploy and test new seismic gear, which included a generator injector (GI) air gun, on loan from Seismic Systems Incorporated, and two new multichannel seismic streamers produced by Innovative Transducers Incorporated. By 1200 hr, we began a 46-km-long seismic survey over the first two drill sites—Sites 1054 and 1055. Very good seismic images were obtained using a combination of the GI gun source and the Teledyne single-channel oil-filled streamers, the latter of which are due to be replaced by the new multichannel streamers. Unfortunately, the first of the two multichannel streamers failed when deployed. The total transit to Site 1054, including the seismic survey, was 156 nmi, which was traveled at an average speed of 9.9 knots (kt).

## SITE 1054
## (Proposed Site CS-3B)

Drilling operations commenced at 1817 hr on 19 February at Site 1054 using the advanced hydraulic piston corer (APC) coring system and, for the lower part of Hole 1054A, the extended core barrel (XCB) system. Cores 172-1054A-3H through 10H and 12H, 1054B-4H through 12H, and 1054C-3H through 13H were oriented with the Tensor tool.

At Hole 1054A, the APC system reached 84.8 mbsf (Core 1054A-10H) with its usual high recovery (91%-108%), but failed to penetrate on the next try. One XCB core was taken from 84.8

to 93.5 mbsf and penetrated a small hard claystone zone, which was underlain by ooze. Piston coring was resumed on the next core and advanced with a full stroke to 103.0 mbsf. When an attempt with another piston core failed to advance due to indurated sediments, the remainder of the hole was cored with the XCB.

After the vessel was offset ~30 m south of the initial hole, Hole 1054B was spudded at a depth of 1304.8 mbrf. APC coring advanced to refusal, which was 103.2 mbsf. The vessel was offset another 30 m south and Hole 1054C was cored to 101.0 mbsf. By 1700 hr on 21 February, the drilling equipment was secured and the vessel was underway on a 14-nmi transit to the next site.

## SITE 1055
## (Proposed Site CS-2)

Coring operations started at Site 1055 at 0025 hr on 22 February. All holes were APC cored with recovery ranging from 98% to 118%. Cores 1055B-3H through 14H, 1055C-3H through 14H, and 1055B-3H through 14H were oriented with the Tensor tool.

The first core barrel in Hole 1055A contained 9.82 m of sediment, and therefore did not give a reliable indication of the mudline depth. Thus, Hole 1055B was spudded ~15 m to the west, and the mudline was obtained in the first core. A seafloor depth of 1809.0 mbrf was estimated from this core.

The vessel was offset ~30 m north of Hole 1055B, and Hole 1055C was spudded at a mudline depth calculated as 1809.0 mbrf. Hole 1055D was spudded ~30 m north of Hole 1055C at a mudline depth calculated as 1809.9 mbrf. The final two cores were collected at Hole 1055E, which is ~40 m north of Hole 1055D, in order to have multiple copies of the glacial-to-interglacial transition recorded by the near surface sediments at this site. The *JR* was on its way to Site 1056 by 1145 hr on 23 February.

## SITE 1056
## (Proposed Site BBOR-8C)

At 1300 hr (local time) on 23 February 1997, the *JR* slowed to deploy the seismic gear for a survey over Sites 1056 and 1057. A north-south survey line was collected over Site 1056 at 6 kt followed by a west-to-east crossing line. The survey gear was left in as the ship followed a southeast course toward Site 1057 at 8 kt. The *JR* again slowed to 6 kt as it crossed over Site 1057, first on a northwest-to-southeast course and then again on an east-to-west crossing line. The total survey length was 85 km. The multichannel streamer failed again during this survey, but was later fixed by changing the polarity of its pin configuration.

Because the water depth was ~400 m deeper at Site 1056 than the previous site, additional joints of pipe were used, which included the reconditioned drill pipe loaded in Charleston. This reconditioned pipe was first measured and "rabbited" (a process in which a small piece of bar or tubing of known diameter is passed through the drill pipe to ensure that it is free of obstructions or diameter restrictions).

At 0340 hr on 24 February, the initial attempt at a mudline core in Hole 1056A was obtained, but the core barrel was full and the seafloor depth could not be determined with any accuracy. Hole 1056B was then started ~7 m northeast of Hole 1056A and 6 m shallower. A mudline core was retrieved, and the seafloor depth at this hole was estimated at 2177.9 mbrf, which was 5.5 m shallower than the depth estimated by the Precision Depth Recorder (PDR).

The ship was offset after Holes 1056B and 1056C, with Hole 1056C located ~25 m northwest of Hole 1056B and Hole 1056D ~30 m northwest of Hole 1056C. The total core recovered at the site was 480.5 m with 108.8% recovery. The large recovery probably results from gas expansion. By 1945 hr on 25 February, the drilling equipment was secured and the vessel was underway on a southeasterly heading to the next site.

## SITE 1057
## (Proposed Site BBOR-7A)

Coring operations at Site 1057 began at 2246 hr on 25 February after a 31-nmi transit from Site 1056. All holes were APC cored with recovery ranging from 100% to 115%. Starting with the third core in each hole, all cores downhole were oriented with the Tensor tool.

The seafloor depth was established at 2595.0 m at Hole 1057A, which was 6 m deeper than the PDR measurement. Hole 1057B is ~35 m south of Hole 1057A, and Hole 1057C is another ~33 m south of Hole 1057B. Relative to the drill string position for Hole 1057A, the drill string was raised 3 m higher for Hole 1057B and only then lowered 2 m for Hole 1057C. During operations on Hole 1057B, a chartered tuna boat, *The Winds of Fortune*, came alongside at 1345 hr on 26 February and disembarked two crew members, who joined us for the remainder of the cruise. By 1515 hr on 27 February, the vessel was underway to the next location.

## SITE 1058
## (Proposed Site BBOR-9)

The 30-nmi transit to Site 1058 was traveled at an average speed of 12 kt. At 1745 hr, the vessel slowed as the seismic gear was deployed about 8 nmi before Site 1058. The survey proceeded over Sites 1058 and 1059 along a southeasterly course. The vessel came about and performed a northeast to southwest crossing over Site 1059 and then a southwest to northeast crossing over Site 1058. During the 24-km-long survey, data was collected simultaneously with a single-channel and a six-channel streamer. Accurate survey and drilling positions were obtained owing to the availability of differential global positioning system (GPS).

At 2045 hr on 27 February, the seismic equipment was retrieved and the vessel returned to Site 1058, and coring operations began at 2109 hr on 27 February. All holes were APC cored with recovery ranging from 98% to 114%. Starting with the third core in each hole, all cores downhole were oriented with the Tensor tool.

The seafloor depth was established at 2996.0 mbrf in Hole 1058A, which was 4 m shallower than the PDR measurement. Hole 1058B is ~24 m south of Hole 1058A, and Hole 1058C is another ~30 m south and ~5 m west of Hole 1058B. The starting drill string position was vertically offset 3 m shallower for Hole 1058B than Hole 1058A and then another 3 m shallower for Hole 1058C.

On the evening of 28 February, we received sad news of a death in the family of an ODP crew member. After assessing all options, including queries to the local military installations in North and South Carolina, looking into the availability and suitability of local transport (air and boat), and exploring the possibility of using a vessel of opportunity, it was decided to interrupt operations in order to divert the vessel to Charleston for a humanitarian evacuation. At 0515 hr on 2 March, operations ceased at Site 1058 and we proceeded to Charleston.

At 0354 hr on 3 March, the *JR* arrived at the Charleston pilot station where it rendezvoused with the tug *Robert B. Turecaro*. Bill Stevens disembarked the vessel at 0414 hr and by 0418 hr the vessel was underway to Site 1059. The total round trip distance for this unscheduled transit was 447 nmi and consumed 41.2 hr.

## SITE 1059
## (Proposed Site BBOR-6)

Coring operations at Site 1059 began at 2307 hr on 3 March. All holes were APC cored with recovery ranging from 91% to 109%. Starting with the third core in each hole, all cores downhole were oriented with the Tensor tool.

The seafloor depth was established at 2996.7 mbrf in Hole 1059A. Hole 1059B is ~28 m southwest of Hole 1059A, and Hole 1059C is another ~30 m southwest of Hole 1059B. The starting drill string position was vertically offset 3 m shallower for Hole 1059B than Hole 1059A and then another 2 m shallower for Hole 1059C. By 1424 hr on 5 March, the vessel was underway to Site 1060.

## SITE 1060
## (Proposed Site BBOR-5, Revised to 5B)

The 68-nmi transit to Site 1060 was accomplished at a very rapid average speed of 13.3 kt. At 2000 hr, the ship was slowed to deploy seismic equipment. The ensuing seismic survey consisted of a north-to-south line over Site 1060 and a crossing west-to-east line. During this survey, the seismic record from the chart recorder displayed several bright patches (areas with no reflectors) and horizontal reflectors that were slightly upturned on either side of the bright patches. One of these patches occurred at the intended drill site. Because the bright patches could be produced by hydrate accumulations, the presence of which would adversely affect core recovery, permission was requested and obtained to move the site 1.7 nmi north of BBOR-5. For pre-drilling purposes, this new site was designated BBOR-5B.

Drilling operations at Site 1060 began at 2253 hr on 5 March. All holes were APC cored with recovery ranging from 84% to 108%, with a site average of 104%. The Tensor tool was used to orient Cores 1060A-3H through 11H, but sustained water damage and no data were retrieved. Thus, no cores were oriented at this site.

The seafloor depth was established at 3481.2 mbsl in Hole 1060A, which was 8.4 m shallower than the PDR depth. APC coring advanced without incident to a total depth of 170.0 mbsf. Hole 1060B is ~22 m southwest of Hole 1060A, and Hole 1060C is another ~32 m southwest of Hole 1060B. The starting drill string position was 3 m lower for Hole 1060B than Hole 1060A, and then another 3 m lower for Hole 1060C. By 0400 hr on 8 March, drilling operations were completed at Site 1060 and the vessel was underway to Site 1061.

# SITE 1061
## (Proposed Site BBOR-4B)

The 63-nmi transit to the survey area of Site 1061 was accomplished at an average speed of 11.6 kt. At 0930 hr on 8 March, the vessel slowed to deploy the seismic equipment. The ensuing seismic survey consisted of a north-to-south line over Site 1061 and a crossing west-to-east line.

At 1325 hr on 8 March, a beacon was deployed at the new site, and at 1153 hr on 9 March, a second beacon was dropped as a backup. Five holes were drilled at Site 1061 with core recovery exceeding 100% at all holes except 1061A.

From the first APC core at Hole 1061A, the seafloor depth was estimated as 4046.6 mbsl, which was 8.9 m shallower than the PDR (3.5 kHz) depth. Later, after examining the upper cores from other holes at this site and the downhole logging measurements, we confirmed that Core 1061A-1H did not capture the mudline. The top of the core was instead ~11 m below the mudline, thus indicating the PDR depth was probably off by ~20 m.

APC coring advanced in Hole 1061A without incident to 152.0 mbsf, which was considered to be APC refusal. Cores 1061A-3H through 8H and 10H through 16H were oriented, although no other cores were oriented at this site because there was only one operational Tensor orientation tool. Coring resumed with the XCB and advanced to a total depth of 350.3 mbsf by 1630 hr on 10 March.

In preparation for logging, the hole was flushed with a 30-bbl sepiolite (drill mud) sweep and the drill string was pulled back to 308 mbsf and then up to 68 mbsf, with a maximum drag of 20 kips. When the drill string was run back to the bottom of the hole, it contacted only 2 m of soft fill. The hole was cleaned with 162 bbl of 8.9 ppg sepiolite mud. The drill string was pulled up and the bit positioned at the logging depth of 93 mbsf.

By 2330 hr on 10 March, the Schlumberger equipment was prepared and the first logging tool

(Triple-combo Suite-DITE [digital dual induction tool], HLDT [slim-hole lithodensity logging tool], APS [accelerator porosity sonde], HNGS [hostile environment natural gamma-ray sonde]) was run in the drill pipe. The logging tool went almost to bottom with no apparent problems and the hole was successfully logged from 348 to 77 mbsf, and then from 350 to 262 mbsf on a second pass. The final log consisted of two passes with the Formation MicroScanner (FMS), SDTC (sonic digital logging tool), and NGTC (natural-gamma spectrometry tool) combination, which was run in the hole from 338 to 73 mbsf. The diameter of the hole was found to vary from 28 to 38 cm (11 to 15 in) and the angle of the hole was less than 2° from vertical. The quality of the logging data were considered to be very good.

At 1606 hr on 11 March, Hole 1061B was spudded 36 m north of Hole 1061A, and the drill string was positioned 3 m higher. The first APC core recovered a full barrel, and so the hole was abandoned. The bit was picked up to 4044.5 mbrf and Hole 1061C was spudded ~4 m to the south of Hole 1061B. Based upon the mudline recovery, the seafloor depth was established at 4036.9 mbsl. APC coring advanced to an APC refusal depth of 166.8 mbsf.

Hole 1061D was spudded ~32 m north of Hole 1061C, and the bit was positioned 3 m higher than at Hole 1061C. The seafloor depth was estimated at 4038.4 mbsl. APC coring advanced to 162.7 mbsf, which was just below the APC refusal depth of Hole 1061C. The hole was then deepened with the XCB to a total depth of 180.0 mbsf.

Hole 1061E was spudded ~44 m north and 6 m west of Hole 1061D, with the bit positioned at 4047.0 mbrf, about 2.5 m deeper than at Hole 1061C. The hole consisted of only two piston cores, which were cored to insure that a complete record of the Holocene and upper Pleistocene section was recovered.The drill string was pulled out of the hole and cleared the seafloor at 1100 hr on 13 March. By 1845 hr on 13 March, drilling operations were completed and the vessel was underway to Site 1062.

## SITE 1062
## (Proposed Sites BBOR-1, -1B, and -1C)

The 61-nmi transit to the survey area of Site 1062 was accomplished at an average speed of 11.3 kt. At 0600 hr on 14 March, the vessel slowed as the GI air gun and seismic streamers were deployed. The vessel then steered a westerly course as a seismic survey was conducted over BBOR-1, BBOR-1C, BBOR-1B, and then BBOR-1A. The vessel came about and performed crossing profiles: first, a southwest-to-northeast seismic profile across BBOR-1A, then a northeast-to-southwest profile over BBOR-1B, and finally a south-southeast to north-northeast profile over BBOR-1.

Site 1062 includes eight holes drilled into a single mud wave. Holes 1061A, B, C, and D are on the east side of the mud wave, Holes 1061E and F are on the west side, and Holes 1061G and H are near the crest. The far west and far east holes are 1050 m apart. To properly position the vessel over the holes on both the east and west sides, two beacons were required. Normal practice would be to refer to the holes on either side of the mud wave as two different sites, since two different beacons were used. Because the holes comprise a transect across a single mud wave, we instead requested that they all be referred to as a single site, which was approved. The total core recovery for the site was greater than 100% with 1000 m of core recovered.

Drilling operations began at Hole 1062A (BBOR-1) at 1045 hr on 14 March. The drill string was run to 4743.0 mbrf, while additional stands of 5.5-in drill pipe were measured and rabbited. The bit was lowered to 4758.0 mbrf, which was 20 m shallower than the PDR. The first attempt at an APC mudline recovered only water, though a second attempt from 4767.5 mbrf successfully established the seafloor depth at 4763.3 mbsl (4774.8 mbrf). APC coring advanced to refusal at 180.7 mbsf. During coring at this hole in the early morning of 15 March, ship motion became severe enough (2 to 3 m of heave and 2 to 3 degree rolls, combined with 520 kips of string weight) that knobby joints (heavy-wall drilling joints) were used rather than drill pipe joints after recovering Cores 1062A-8H, 9H, and 10H. The weather had calmed by mid-morning and the knobby joints were removed and replaced with drill pipe joints. Adara temperature tool heat flow measurements were conducted at 30.7 (Core 1062A-4H), 59.2 (7H), 87.7 (10H), 116.2 (13H), and 144.7 (16H) mbsf. Cores 1062A-4H through 9H and 10H through 16H were oriented.

Hole 1062B was spudded 13 m north of Hole 1062A and with an initial bit position 9.5 m deeper. APC coring advanced to APC refusal depth (156.7 mbsf), after which coring continued with the XCB. No cores were oriented in this hole.

While attempting to retrieve the core barrel after cutting Core 1062B-27X (239.0 to 248.6 mbsf), it was discovered that the XCB shaft, the core barrel, the core, and miscellaneous hardware were missing. Since this hardware was left at the bottom of the hole, further progress to the depth objective of 250 mbsf was not possible.

Hole 1062C was spudded 12 m north and 7 m east of Hole 1062B at 0740 hr with the bit positioned at 4772.0 mbrf. The seafloor depth was estimated at 4772.1 mbrf based upon recovery of 9.39 m. APC coring advanced to a total depth of 132.9 mbsf by 2145 hr on 17 March. Cores 1062C-8H through 14H were oriented.

Hole 1062D was spudded 6 m north of Hole 1062C, and the bit was positioned at 4768.0 mbrf. The recovery of 5.81 m established the seafloor depth at 4771.7 mbrf. After the core barrel was recovered, a downhole water sampler, temperature, pressure (WSTP) probe was run down the pipe to a level just above the seafloor and a water sample was obtained. APC coring resumed and advanced to a total depth of 81.8 mbsf. No cores were oriented in this hole.

To prepare for the offset for Hole 1062E (BBOR-1B), the end of the drill pipe was placed at 4656 mbrf. The beacon was remotely commanded into standby mode to preserve battery life, and then the vessel was slowly offset west. At 1109 hr on 18 March, a second beacon was deployed on the GPS coordinates of BBOR-1B. The bit was positioned at 4772.0 mbrf, ~10 m shallower than the new PDR depth of 4782.4 mbrf. The first attempt at a mudline resulted in a water core and so the bit was lowered to 4780.0 mbrf, where Hole 1062E was spudded. Hole 1062E is 1044 m west and 62 m south of Hole 1062D. APC coring advanced to the refusal depth of 136.8 mbsf (Core

1062E-16H). Coring resumed with the XCB and advanced to the target depth of 208.8 mbsf by 1600 hr on 19 March. APC Cores 1062E-4H through 10H and 12H through 16H were oriented.

Hole 1062F was spudded 11 m north and 16 m west of Hole 1062E and the bit was positioned at 4783.0 mbrf. APC coring advanced to a total depth of 83.1 mbsf by 0230 hr on 20 March. No cores were oriented in this hole.

The end of the drill pipe was positioned at 4670.0 mbrf and the vessel was offset 725 m to Hole 1062G (BBOR-1C). As the drill pipe was being picked up, the second beacon deployed on this site was recovered. The first beacon was commanded out of standby mode as the vessel settled over the coordinates of BBOR-1C. Hole 1062G is 724 m east and 30 m south of Hole 1062F and is 330 m west and 50 m south of Hole 1062A. Hole 1062G was spudded with the APC bit at 4759.0 mbrf, which was 8.4 m shallower than the new PDR reading of 4767.4 m. This time, however, a full core barrel was obtained and so the hole was abandoned.

The bit was picked up to 4754.0 mbrf, where Hole 1062H was spudded 3 m southeast of Hole 1062G at 0902 hr on 20 March. The recovery of 6.5 m of core established seafloor depth at 4745.3 mbsl (4757.0 mbrf). APC coring advanced to a total depth of 63.5 m (Core 1062H-7H) by 1615 hr on 20 March. Cores 1062H-3H through 7H were oriented. By 0145 hr on 21 March, all drilling equipment had been secured and the vessel got underway to the Bermuda Rise.

## SITE 1063
## (Proposed Site BR-1)

After leaving Site 1062, we had a 943-nmi transit at an average speed of 11.6 kt to the Sohm Abyssal Plain, where we conducted a short seismic survey over a potential supplemental site (SAP-1). At 1130 hr, the *JOIDES Resolution* slowed to deploy seismic equipment. The ensuing seismic survey consisted of a west-to-east line that passed about 1 km south of the SAP-1 site, a broad turn to the south, and then a crossing line which traversed from south-southeast to north-

northwest across the original line and over SAP-1. This survey covered 28 nmi and was conducted at an average speed of 6.4 kt.

We then proceeded to the Site 1063 survey area, and prior to coring, conducted a 13 nmi seismic survey. This survey began with a south-southeast to north-northwest profile over Site 1063, followed by a crossing west to east line. The survey was conducted at an average speed of 4.5 kt.

Coring began in Hole 1063A at 1035 hr on 25 March. Following the first core, a near-bottom water sample was obtained with the WSTP for isotopic studies. APC coring advanced to 201.4 mbsf, which was considered APC refusal. Cores 1063-3 through 9H, 11H through 17H, and 20H through 22H were oriented, with gaps in orientation occurring during the interval in which data were being downloaded from the only operational Tensor tool. Hole 1063A was deepened with the XCB to 418.4 mbsf, which was 68 m deeper than originally planned.

In preparation for logging, Hole 1063A was flushed with a 30-bbl sepiolite sweep and the drill string pulled back to 377.5 mbsf. The drill string was pulled up to 99.1 mbsf with a maximum drag of 20 kips observed and then run to bottom where it contacted 16 m of soft fill. After a go-devil (a tool that free-falls down the drill pipe) was dropped to insure opening of the lockable float valve, the hole was swept with 50 bbl of sepiolite mud. The hole was then displaced with 190 bbl of 8.9 ppg sepiolite mud. Finally, the drill bit was positioned at the logging depth of 105.0 mbsf.

By 0700 hr on 28 March, the Schlumberger equipment was rigged up. Logs were collected in the interval from 416.8 to 105 mbsf using the Triple-combo (DITE, HLDT, APS, HNGS) and the FMS (FMS and SDTC) logging tools.

Hole 1063B was spudded 29 m south of Hole 1063A, and the bit was positioned approximately 2 m deeper than at Hole 1063A. The seafloor depth was established at 4594.7 mbsf based upon 7.83 m recovery in the first core. Cores 16H through 18H and 23H were not fully stroked, but due to the interest in high-quality cores for magnetic studies, piston coring was advanced by the core recovered to a depth of 213.8 mbsf. Hole 1063B was then deepened with the XCB to a total depth of 351.6 mbsf. Cores 3H through 9H, 11H through 17H, and 19H through 21H were oriented with the Tensor tool. The Adara temperature tool heat flow shoe was deployed at 55.3 (Core 6H), 74.3 (8H), 93.3 (10H), 112.3 (12H), and 140.8 mbsf (15H).

Hole 1063C was spudded 14 m south and 7 m west of Hole 1063B, and APC coring reached a total depth of 212.7 mbsf using advance by recovery. Cores 3H through 10H, 15H through 21H, and 23H through 24H were oriented.

Hole 1063D was spudded 17 m south and 6 m west of Hole 1063C, with the bit positioned 2 m higher than 1063A. APC coring advanced to 163.8 mbsf (Core 18H) without incident, although, while coring, the seas began to get rough with 5-6 m swells and up to 4 m ship heave. While attempting to recover Core 1063D-19H (163.8 to 173.1 mbsf), the wireline parted, leaving the sinker bar assembly, Tensor tool, pressure case assembly, and the inner core barrel with Core 19H in it in the hole. This hardware and the core were later retrieved. The wireline failure was attributed to the poor weather conditions, which continued to deteriorate. Winds were gusting to 52 kt as a massive cold front passed over the location during the early morning on 2 April. Coring operations were halted while we waited for conditions to improve. At 1700 hr on 3 April, there was a momentary lull in the storm, which allowed the vessel to retract hydrophones and thrusters and come about. With time running out for Leg 172 and the storm showing little signs of abating, we decided to transit to Site 1064 (SAP-1). By 1730 hr, the vessel was underway to the last site, leaving behind two positioning beacons, which we were unable to recover owing to weather and sea conditions.

## SITE 1064

The 73-nmi transit to the last site of the leg was accomplished at an average speed of 11.0 kt. The vessel’s track from Site 1063 took the storm on the starboard quarter, which was responsible for the very good transit speed.

A beacon was deployed at 0032 hr on 4 April. Shortly after deployment, the signal was lost and a back-up beacon was prepared and launched at 0114 hr. The back-up beacon started to behave erratically and a third beacon had to be deployed later in the day. As the vessel positioned over the beacon, the bottom hole assembly (BHA) received the routine end-of-leg magnetic particle inspection while drill pipe was being run into the hole.

Hole 1064A was spudded with the APC at 2310 hr on 4 April after the first two attempts resulted in water cores (APC cores that were shot into water above the seafloor). The seafloor depth was established at 5580.0 mbsf, but Core 1H had 101% recovery, which indicated that the mudline was probably not recovered. The previous water core, however, was shot from a bit position 6 m above the bit position for Core 1H. The end of the core catcher from the water core had a little mud on it, which indicated that we should have recovered about 6 m of sediment in Core 1H, rather than the 9.6 m recovered. The larger-than-expected recovery might be attributed to variation in the inclination of the drill pipe, ship heave, dynamic stretching of the more than 5.5 km of drill pipe, or some combination. Indeed, the weight on bit varied by as much as 50,000 lbs and the seas were still rough. The exact amount by which we missed the mudline is uncertain, but seems unlikely to exceed ~10 m because of the two previous attempts at 6 and 13 m above the drilling-estimated mudline. Seismic information indicates a possible 10 m of missing section, whereas extrapolation of chloride concentrations from pore-water samples indicates as much as 19 m are missing. In addition, the WSTP was deployed 10 m above the inferred seafloor following the mudline core, in an attempt to obtain a near-bottom water sample for isotopic studies. The WSTP sample was heavily contaminated with mud indicating that it had contacted the seafloor.

APC coring resumed and advanced to 28.5 mbsf. After recovering the third APC core (28.5 mbsf), the driller heard an unusual noise emanating from the drawworks, which upon investigation revealed a major failure of the forward drawworks traction motor. This failure left the drawworks with limited capability, ended coring at Site 1064, and ended Leg 172 approximately one day early. The drill string was raised slowly to the surface and the ship was underway toward Lisbon by 2215 hr on 5 April.

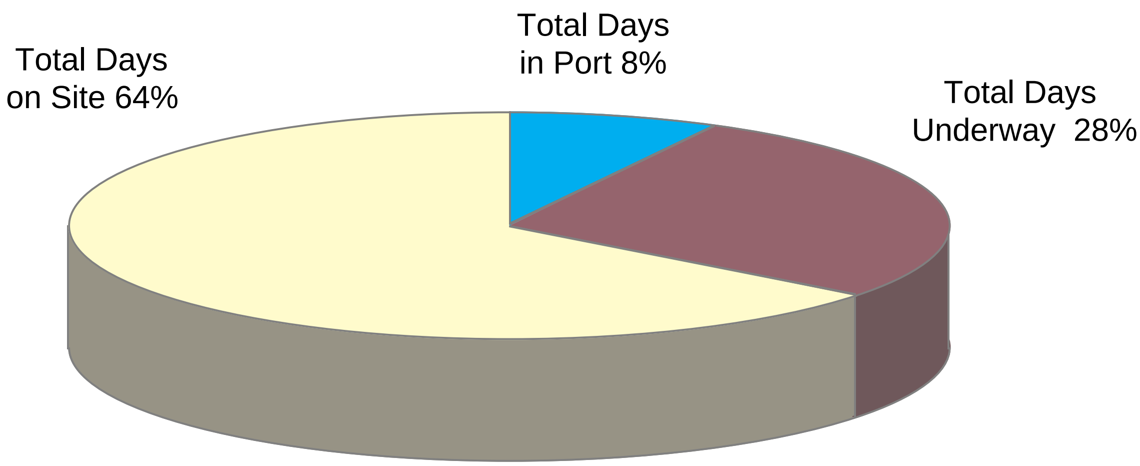
# OCEAN DRILLING PROGRAM
# OPERATIONS RESUME
# LEG 172

| | |
|---|---|
| Total Days (14 February 1997 to 16 April 1997) | 59.81 |
| Total Days in Port | 4.49 |
| Total Days Underway | 15.90 |
| Total Days on Site | 36.82 |

| | days |
|---|---|
| Drilling | 0.00 |
| Other | 1.04 |
| Tripping Time | 7.93 |
| Stuck pipe/Hole Troubl e | 0.30 |
| Logging/Downhole Science | 1.95 |
| Mechanical Repair Time (Contractor) | 1.14 |
| Reentry Time | 0.00 |
| W.O.W. | 0.75 |
| Coring | 24.86 |

| | |
|---|---|
| Total Distance Traveled (nautical miles) | 4405.0 |
| Average Speed Transit (knots): | 11.0 |
| Number of Sites | 11.0 |
| Number of Holes | 42.0 |
| Number of Cores Attempted | 623.0 |
| Total Interval Cored (m) | 5688.8 |
| Total Core Recovery (m) | 5765.3 |
| % Core Recovery | 101.34 |
| Total Interval Drilled (m) | 9.6 |
| Total Penetration | 5698.4 |
| Maximum Penetration (m) | 418.4 |
| Minimum Penetration (m) | 9.5 |
| Maximum Water Depth (m from drilling datum) | 5580.0 |
| Minimum Water Depth(m from drilling datum) | 1302.5 |

LEG 172
TOTAL TIME DISTRIBUTION




Total days of leg = 59.8

# OCEAN DRILLING PROGRAM
# SITE SUMMARY
# LEG 172

| HOLE | LATITUDE | LONGITUDE | WATER DEPTH (mbrf) | NUMBER OF CORES | INTERVAL CORED (meters) | CORE RECOVERED (meters) | PERCENT RECOVERED (percent) | DRILLED (meters) | TOTAL PENETRATION (meters) | TIME ON HOLE (hours) | TIME ON SITE (days) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1054A | 33 0.0001' N | 76 16.9996' W | 1302.5 | 22 | 200.00 | 182.55 | 91.3% | 0.0 | 200.00 | 25.97 | 1.1 |
| 1054B | 32 59.9850' N | 76 16.9999' W | 1304.8 | 12 | 103.20 | 106.29 | 103.0% | 0.0 | 103.20 | 8.67 | 0.4 |
| 1054C | 32 59.9676' N | 76 16.9995' W | 1305.9 | 13 | 101.90 | 104.55 | 102.6% | 0.0 | 101.90 | 11.98 | 0.5 |
| | | **1054 SITE TOTALS:** | | **47** | **405.10** | **393.39** | **97.1%** | **0.0** | **405.10** | **46.62** | **1.9** |
| 1055A | 32 47.0418' N | 76 17.1703' W | 1810.0 | 1 | 9.50 | 9.82 | 103.4% | 0.0 | 9.50 | 5.88 | 0.2 |
| 1055B | 32 47.0406' N | 76 17.1790' W | 1809.0 | 14 | 128.00 | 137.99 | 107.8% | 0.0 | 128.00 | 9.00 | 0.4 |
| 1055C | 32 47.0562' N | 76 17.1798' W | 1809.0 | 14 | 120.80 | 126.10 | 104.4% | 0.0 | 120.80 | 10.17 | 0.4 |
| 1055D | 32 47.0711' N | 76 17.1792' W | 1809.9 | 14 | 129.10 | 136.99 | 106.1% | 0.0 | 129.10 | 10.17 | 0.4 |
| 1055E | 32 47.0925' N | 76 17.1799' W | 1809.0 | 2 | 18.00 | 18.48 | 102.7% | 0.0 | 18.00 | 5.67 | 0.2 |
| | | **1055 SITE TOTALS:** | | **45** | **405.40** | **429.38** | **105.9%** | **0.0** | **405.40** | **40.88** | **1.7** |
| 1056A | 32 29.0995' N | 76 19.8025' W | 2178.0 | 1 | 9.50 | 9.98 | 105.1% | 0.0 | 9.50 | 5.52 | 0.2 |
| 1056B | 32 29.1018' N | 76 19.7988' W | 2177.9 | 17 | 155.60 | 171.81 | 110.4% | 0.0 | 155.60 | 12.75 | 0.5 |
| 1056C | 32 29.1105' N | 76 19.8113' W | 2178.2 | 17 | 154.80 | 166.25 | 107.4% | 0.0 | 154.80 | 12.58 | 0.5 |
| 1056D | 32 29.1215' N | 76 19.8253' W | 2177.7 | 13 | 121.80 | 132.46 | 108.8% | 0.0 | 121.80 | 14.75 | 0.6 |
| | | **1056 SITE TOTALS:** | | **48** | **441.70** | **480.50** | **108.8%** | **0.0** | **441.70** | **45.60** | **1.9** |
| 1057A | 32 1.7507' N | 76 4.7527' W | 2595.0 | 14 | 131.00 | 141.67 | 108.1% | 0.0 | 131.00 | 16.20 | 0.7 |
| 1057B | 32 1.7317' N | 76 4.7538' W | 2595.8 | 15 | 136.70 | 145.08 | 106.1% | 0.0 | 136.70 | 12.95 | 0.5 |
| 1057C | 32 1.7141' N | 76 4.7546' W | 2594.5 | 8 | 73.50 | 77.46 | 105.4% | 0.0 | 73.50 | 11.33 | 0.5 |
| | | **1057 SITE TOTALS:** | | **37** | **341.20** | **364.21** | **106.7%** | **0.0** | **341.20** | **40.48** | **1.7** |
| 1058A | 31 41.4153' N | 75 25.8049' W | 2996.0 | 16 | 152.00 | 164.56 | 108.3% | 0.0 | 152.00 | 19.83 | 0.8 |
| 1058B | 31 41.4022' N | 75 25.8038' W | 2995.5 | 17 | 158.00 | 166.00 | 105.1% | 0.0 | 158.00 | 13.93 | 0.6 |
| 1058C | 31 41.3861' N | 75 25.8014' W | 2996.0 | 18 | 164.00 | 173.81 | 106.0% | 0.0 | 164.00 | 22.33 | 0.9 |
| | | **1058 SITE TOTALS:** | | **51** | **474.00** | **504.37** | **106.4%** | **0.0** | **474.00** | **56.10** | **2.3** |
| 1059A | 31 40.4610' N | 75 25.1270' W | 2996.7 | 11 | 98.80 | 105.49 | 106.8% | 0.0 | 98.80 | 15.63 | 0.7 |
| 1059B | 31 40.4528' N | 75 25.1121' W | 2996.8 | 10 | 92.20 | 95.91 | 104.0% | 0.0 | 92.20 | 9.42 | 0.4 |
| 1059C | 31 40.4421' N | 75 25.0983' W | 2996.0 | 10 | 95.00 | 100.54 | 105.8% | 0.0 | 95.00 | 14.23 | 0.6 |
| | | **1059 SITE TOTALS:** | | **31** | **286.00** | **301.94** | **105.6%** | **0.0** | **286.00** | **39.28** | **1.6** |
| 1060A | 30 45.5971' N | 74 27.9897' W | 3492.5 | 18 | 170.10 | 177.74 | 104.5% | 0.0 | 170.10 | 23.12 | 1.0 |
| 1060B | 30 45.5849' N | 74 27.9887' W | 3492.1 | 14 | 129.90 | 134.23 | 103.3% | 0.0 | 129.90 | 11.42 | 0.5 |
| 1060C | 30 45.5682' N | 74 27.9896' W | 3492.5 | 14 | 126.50 | 130.78 | 103.4% | 0.0 | 126.50 | 18.58 | 0.8 |
| | | **1060 SITE TOTALS:** | | **46** | **426.50** | **442.75** | **103.8%** | **0.0** | **426.50** | **53.12** | **2.2** |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1061A | 29 58.4976' N | 73 35.9929' W | 4058.0 | 37 | 350.30 | 298.20 | 85.1% | 0.0 | 350.30 | 72.00 | 3.0 |
| 1061B | 29 58.5172' N | 73 35.9914' W | 4055.0 | 1 | 9.50 | 9.82 | 103.4% | 0.0 | 9.50 | 2.68 | 0.1 |
| 1061C | 29 58.5154' N | 73 35.9923' W | 4048.2 | 18 | 166.80 | 174.61 | 104.7% | 0.0 | 166.80 | 18.70 | 0.8 |
| 1061D | 29 58.5326' N | 73 35.9900' W | 4049.8 | 22 | 180.00 | 194.95 | 108.3% | 0.0 | 180.00 | 21.8 | 0.9 |
| 1061E | 29 58.5563' N | 73 35.9933' W | 4047.1 | 2 | 18.90 | 19.53 | 103.3% | 0.0 | 18.90 | 10.08 | 0.4 |
| | | **1061 SITE TOTALS:** | | **80** | **725.50** | **697.11** | **96.1%** | **0.0** | **725.50** | **125.28** | **5.2** |
| 1062A | 28 14.7819' N | 74 24.4192' W | 4774.8 | 20 | 180.70 | 181.24 | 100.3% | 0.0 | 180.70 | 37.00 | 1.5 |
| 1062B | 28 14.7888' N | 74 24.4204' W | 4774.5 | 26 | 239.00 | 239.08 | 100.0% | 9.6 | 248.60 | 30.67 | 1.3 |
| 1062C | 28 14.7954' N | 74 24.4163' W | 4772.1 | 14 | 132.90 | 134.56 | 101.2% | 0.0 | 132.90 | 16.17 | 0.7 |
| 1062D | 28 14.7998' N | 74 24.4157' W | 4771.7 | 9 | 81.80 | 82.66 | 101.1% | 0.0 | 81.80 | 11.58 | 0.5 |
| 1062E | 28 14.7653' N | 74 25.0552' W | 4785.7 | 23 | 208.80 | 203.72 | 97.6% | 0.0 | 208.80 | 31.05 | 1.3 |
| 1062F | 28 14.7710' N | 74 25.0651' W | 4785.4 | 9 | 83.10 | 83.77 | 100.8% | 0.0 | 83.10 | 9.78 | 0.4 |
| 1062G | 28 14.7548' N | 74 24.6218' W | 4759.2 | 1 | 9.30 | 9.27 | 99.7% | 0.0 | 9.30 | 4.80 | 0.2 |
| 1062H | 28 14.7537' N | 74 24.6204' W | 4757.0 | 7 | 63.50 | 65.29 | 102.8% | 0.0 | 63.50 | 17.95 | 0.7 |
| | | **1062 SITE TOTALS:** | | **109** | **999.10** | **999.59** | **100.0%** | **9.6** | **1008.70** | **159.00** | **6.6** |
| 1063A | 33 41.2043' N | 57 36.8979' W | 4595.2 | 45 | 418.40 | 400.34 | 95.7% | 0.0 | 418.40 | 94.18 | 3.9 |
| 1063B | 33 41.1885' N | 57 36.8982' W | 4594.7 | 38 | 351.60 | 341.95 | 97.3% | 0.0 | 351.60 | 50.67 | 2.1 |
| 1063C | 33 41.1808' N | 57 36.9028' W | 4596.0 | 24 | 212.70 | 204.39 | 96.1% | 0.0 | 212.70 | 28.17 | 1.2 |
| 1063D | 33 41.1717' N | 57 36.9067' W | 4596.2 | 19 | 173.10 | 176.54 | 102.0% | 0.0 | 173.10 | 59.17 | 2.5 |
| | | **1063 SITE TOTALS:** | | **126** | **1155.80** | **1123.22** | **97.2%** | **0.0** | **1155.80** | **232.18** | **9.7** |
| 1064A | 32 32.7199' N | 57 4.5876' W | 5580.0 | 3 | 28.50 | 28.83 | 101.2% | 0.0 | 28.50 | 45.02 | 1.9 |
| | | **1064 SITE TOTALS:** | | 3 | 28.50 | 28.83 | 101.2% | 0.0 | 28.50 | 45.02 | 1.9 |
| | | **LEG 172 TOTALS:** | | **623** | **5688.80** | **5765.29** | **101.3%** | **9.60** | **5698.40** | **883.57** | **36.8** |

# TECHNICAL REPORT

The ODP technical personnel aboard *JOIDES Resolution* for Leg 172 were:

| | |
|---|---|
| Bill Mills | Laboratory Officer |
| Jerry Bode | Marine Lab. Specialist (Curator) |
| Tim Bronk | Marine Lab Specialist (Chemistry) |
| Roy Davis | Marine Lab Specialist (Photographer) |
| Sandy Dillard | Marine Lab Specialist (Storekeeper) |
| David Fackler | JANUS Software Development Specialist |
| Cesar Flores | Marine Electronics Specialist (System Manager) |
| Margaret Hastedt | Assistant Lab Officer (Paleomagnetics) |
| Kuro Kuroki | Assistant Lab Officer (Fantail) |
| 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) |
| Gil Munoz | JANUS Software Development Specialist |
| 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 |
| Barry Weber | Marine Computer Specialist (System Manager) |
| John Weisbruch | Marine Lab Specialist |

## GENERAL LEG INFORMATION

The *Joides Resolution* docked in Charleston, S.C., on 14 February 1997, ending Leg 171. On the same morning the Leg 172 crew arrived and began crossover activities. On 18 February, we cast off lines and were underway to our first site with a crew of 122 (49 in the science party). In the first week of the cruise, we returned to Charleston so that Bill Stevens could return home for humanitarian reasons. A week later Monty Lawyer and a SEDCO welder were sent to the ship via a shrimp boat out of Charleston. Drilling operations were completed late in the evening on 5 April. After a nine-day transit, the *Joides Resolution* arrived in Lisbon at 0800 on 16 April ending Leg 172 operations.

### Portcall Activities Overview

Logistic activities began as soon as the *Joides Resolution* cleared U.S. Customs. In addition to our normal logistic activities, daily public relation tours were conducted for VIPs and the general public. Other portcall activities included:

Fison XRF service call
Microscope service
IMARSAT-B service call and training
JANUS steering committee meeting
JANUS database and application training
Radiation safety inspection and training by TAMU Radiation Safety Office
Fiber optic network cable terminations installed

## LAB ACTIVITIES

Processing 5688 m of core and implementing the new JANUS database and application kept everyone quite busy. Nevertheless, good coordination between the scientists and technical staff, and minimal equipment failures allowed the cores to be processed and analyzed efficiently. The focus of analyses involved the sediment, magnetics, physical properties, paleontology, and chemistry labs. There was only minor downhole and thin section work this leg.

The JANUS database and upload application were fully implemented for the first time during Leg 172. Although there are still numerous problems that must be fixed, overall it was a success and well accepted by the science party.

**Transit Activities**

Navigational data were collected on all transits using global positioning system (GPS). Differential GPS was available for the Blake-Bahama Outer Ridge and Carolina Slope sites but was lost for the Bermuda Rise sites and the transit to Lisbon. Bathymetric data was collected on all transits except for the last seven days of the transit to Lisbon. Magnetic data was collected only on the Lisbon transit.

All sites were located by seismic survey using a Generator-Injector (GI) water gun and our single channel streamer. The multichannel streamers were tested on all surveys but due to technical problems in the amplifier, only one survey collected any usable data.

**Chemistry Lab**

High-resolution interstitial water (IW) sampling, consisting of one IW sample per section for the first 60 m, then one per core for the remainder of the hole, resulted in more than 400 analyses. Interstitial water shipboard analysis included refractometric analysis for salinity; titration for phm, alkalinity, and chloride; 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 Fe, Mn, and Sr in pore waters.

**Computer Service**

The JANUS database was fully implemented this leg and the old 1032S database and associated programs were not used. Two programmers from the ODP Information Service Group sailed to provide additional support to the science party, fix problems with JANUS, and develop application data query tools for the JANUS database.

JANUS was well received by the scientists on the ship. Yet, there is still a great deal of fine-tuning needed in the areas of server performance, upload, and data query applications. Regardless of the problems that remain with JANUS, its use on Leg 172 should be considered a success.

The latest version of Applecore, version 0.7.5b, was received in port. It has a few bugs that need to be repaired and the users turned in quite a list of suggested improvements.

*Programs revised during Leg 172:*

- MAD: Moisture and Density - program was modified to further address JANUS data upload problems.
- Coulometer: Hybrid weighing/instrumentation program that allows the chemists to weigh samples, run them through the coulometer, and upload them to JANUS.
- RAP: Report Activation Program - gives the general user a menu driven interface to our Business Objects reports.
- JRS: JANUS Repository Sampling - Underwent work to enable corelog cross checking. Designed to be used exclusively by Curators and System Managers to complement the JANUS Sample screens as a troubleshooting/repair tool.
- JANUS Web: Web interface to our Oracle database to give the scientists another way to obtain all types of leg sample information.
- Curation: Many of the Business Object reports were reworked so they represent what the curators wanted.

*Programs written during Leg 172:*

- C1_C2: LabVIEW program designed to replace OPSGAS.
- HRLABELS: LabVIEW program designed to print miniature labels for hard rock legs.
- MSTV: LabVIEW program designed to display MST information in a graphical format in near real time for the sedimentologists.
- Tensor Tool: Neuron Data interface to the JANUS database designed to upload and change

tensor data.

- IMP_CARB: Associated with the Coulometer program. It downloads the sample information from the database so that a barcode scanner is not required at that instrument.
- IMP_MAD: Associated with the MAD program. It is a tool for reconstructing the MAD sample database. It downloads all the sample information and the beaker numbers from the moisture density tables in JANUS.

*New equipment installed:*

- Five 200MHZ PCs, Digital Equipment 200i.
- One HP 5M+ laser printer
- One HP 1600CM color printer
- 12 Sony monitors

**Core Lab**

High recovery and full implementation of the JANUS database and applications provided many challenges for the science and technical staff. The biggest nuisance was expanding gassy cores and split liners. The technical staff developed a new method for handling core expansion by cutting each section short (130 or 140 cm) and letting cores expand into capped liner patch. Splitting liners plagued the staff throughout the leg. No reason could be found for the problem and it is assumed that either the liners where made with inferior materials or that they deteriorated due to long term storage.

**Curation**

Sampling volume was light at each site resulting only in 18,384 samples being taken for 5688 meters of recovery. Most requests were deferred or partially deferred to the post-cruise sampling party. Only one hole from each site was sampled for "routine" shipboard analyses and investigator samples with a few exceptions. Preliminary isotope sampling took place at Hole 1062C; Cores 1 through 8 were sampled at 20-cm resolution for the various isotopic stage requests. All other preliminary isotopic sampling was conducted as pilot studies and at a much lower sampling resolution.

**Downhole Measurements Lab**

The APC/Adara temperature tool cutting shoe was used 10 times to measure in situ formation temperatures with a 90.0% success rate. The Water Sampling Temperature Probe (WSTP) pore-water sampler was used three times to collect seafloor water samples for carbon isotope studies.

**Electronic Service**

The lab equipment operated satisfactorily during the leg. As always, the first two weeks were spent addressing minor problems that were discovered during start-up operation. A great deal of time was spent trouble shooting the 6-channel streamer installation in the Underway Geophysics lab. Both tensor tools operated erratically, though the electronics technician maintained one functioning tool by using parts from the other one.

**Paleomagnetics Lab**

New cryogenic magnetometer control software and the DTECH demagnetizer were tested and evaluated. 2G Enterprise's new version of the Long Core controlling software for the cryogenic magnetometer was given to ODP, and during the leg it was modified to comply with ODP's hardware configuration and file handling requirements. The new DTECH demagnetizer can demagnetize five or six samples at a time and has an auto-shutoff feature if the software detects any problems with the coil. It will probably see little service since the cryogenic magnetometer is much more automated and easier to use when doing large numbers of samples.

**Physical Properties Lab**

The MST was heavily used this leg and was the primary correlation tool. Halfway through the leg we discovered that the gamma-ray attenuation porosity estimator (GRAPE) had been miscalibrated. Because of the data table design in JANUS, we were able to correct the calibration constants and reapply them to the raw data. Other than that, the MST ran without any major problems.

Two new natural gamma-ray (NGR) sensors were brought on-board in Charleston and were installed. The index properties station now has a label scanner to input sample IDs. Magnetic susceptibility, GRAPE, *P*-wave velocity, and natural gamma-ray data from the MST can be graphically displayed using the new LabVIEW program called MSTV. The scientists can choose a site/hole to look at and can visually get a sense of the characteristics of the cores to determine where to do their sampling.

**X-ray Lab**

The X-ray diffraction (XRD) performed flawlessly throughout the cruise, requiring no repairs or adjustments and performing 235 analyses. The scientists used a new version of MacDiff to interpret the XRD data. This version includes several new features that significantly enhance the usefulness of the program. No samples were submitted for X-ray fluorescence (XRF) analysis.

**Microscopes**

The microscopes were serviced at the Charleston portcall.

**Underway Geophysics Lab & Fantail**

The Site Survey Panel requirement for surveying all sites kept us busier than usual. All surveys were conducted using the GI air gun loaned for testing from Seismic System Incorporated. The GI gun worked flawlessly and produced excellent records. Unfortunately, our testing of the six channel streamer was not so successful because of problems (still unresolved) with amplifier/filter electronics in the lab.

# LEG 172 LABORATORY STATISTICS

## General

| | |
|---|---|
| Sites: | 10 |
| Holes: | 42 |
| Meters drilled (meters): | 9.6 |
| Meters cored (meters): | 5688.8 |
| Meters recovered (meters): | 5765.29 |
| Number of General Samples | 18383 |

## Lab Analyses

| | |
|---|---|
| **Whole Core Multi-Sensor Track** | |
| GRAPE (sections) | 4047 |
| Natural Gamma Radiation (sections) | 1861 |
| *P*-Wave (sections) | 997 |
| Magnetic Susceptibility (sections) | 4047 |
| **Physical Properties Lab:** | |
| PVS#1 Velocity (samples) | 569 |
| PVS#2 Velocity | 945 |
| PVS#3 Velocity | 30 |
| Vane Shear | 908 |
| Penetrometer | 1341 |
| Resistivity | 2750 |
| Moisture-Density | 2655 |
| Thermoconductivity | 1720 |
| **X-ray Lab:** | |
| X-ray Fluorescence | 0 |
| X-ray Diffraction | 235 |
| **Thin Section Lab:** | |
| Thin sections | 3 |
| **Chemistry Lab:** | |
| Carbonates | 682 |
| Gas | 390 |
| Interstitial water | 342 |
| **Downhole Measurements Lab:** | |
| Adara in situ temperature measurements | 10 |
| WSTP water samples | 3 |
| **Underway geophysics:** | |
| Total transit (nautical miles) | 4405 |
| Bathymetry | 3500 |
| Magnetics | 1500 |
| Seismic | 191 |