OCEAN DRILLING PROGRAM

LEG 162 PRELIMINARY REPORT

NORTH ATLANTIC ARCTIC GATEWAYS II

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ABSTRACT

Leg 162 is the second of two legs designed to investigate what role three major northern geographical areas (the Northern Gateway region, the Greenland-Norway sea, and the Southern Gateway region) have played in regulating the global climate system. To accomplish this goal the biogenic fluxes ($CaCO_3$, opal, and organic carbon), lithologic fluxes, and geochemical records contained in the cores were, and will continue to be, analyzed in order to reconstruct the temporal and spatial variability of the oceanic heat budget, the history of intermediate and deep water formation, and the history of glaciation on the surrounding land masses on millennial, Milankovitch, and tectonic time scales. In addition, because of the very high sedimentation rates (10-20 cm/k.y.) at some of the drilled sites, we will be able to analyze the sediments on century (Dansgaard-Oeschger events). Perhaps more importantly, these paleoceanographic reconstructions will span millions of years instead of the 100,000-year time spans typical of piston cores. Before generating time scales for these sedimentary sequences, composite records were constructed at each site based on continuous data obtained by the multisensor track (including magnetic susceptibility, natural gamma radiation, and gamma-ray attenuation, or GRAPE, which measures bulk density), as well as on color spectral reflectance measurements. The sites are arrayed, in combination with the Leg 151 sites, as broad north-south and east-west transects to examine the evolution of vertical and horizontal gradients in water-mass properties over time and to date the inception of high northern latitude glaciation.

The drilling schedule included 56 days at sea with coring operations at nine sites (Sites 907, 980, 981, 982, 983, 984, 985, 986, 987). We began on the sediment drifts south of Iceland, eventually moving northward to the Svalbard Margin, Fram Strait, and the East Greenland Margin as sea ice retreated through the month of August. Overall, we recovered 6730.74 m of core, setting a new record for recovery during a single leg, and made over 1 million shipboard measurements.

INTRODUCTION

Understanding the causes and consequences of global climatic and environmental change is an important challenge for society. The northern polar oceans are of great relevance to this task, because they directly influence the global environment through the formation of permanent and seasonal ice-cover, transfer of sensible and latent heat to the atmosphere, and by deep-water formation and deep-ocean ventilation which control or influence both oceanic and atmospheric carbon content. Thus, any serious attempt to model and understand the Cenozoic variability of global climate must take into account the climatic processes occurring in this region.

Leg 162 represents the second in a two-leg program designed to investigate three geographic locations in the high northern latitudes (the Northern Gateway region, the Greenland-Norway transect, and the Southern Gateway region; Fig. 1). Our goal is to reconstruct the temporal and spatial variability of the oceanic heat budget, the history of intermediate- and deep-water formation, and the history of glaciation on the surrounding land masses. Ultimately, we want to understand the role played by the high northern latitude seas in the global climate system on time scales ranging from decades (Heinrich/Dansgaard-Oeschger events) to millions of years.

Overall, the choice of sites for Leg 162 was guided by two primary scientific objectives. First, we wanted to recover sequences with sedimentation rates high enough to delineate millennial-scale variability in lithologic, biologic, and geochemical characteristics. This goal was attained by recovering sedimentary sequences at five sites located on sediment drifts in the North Atlantic (Fig. 2) and on rapidly accumulating continental slope regions in the Nordic seas. Both of these areas have average accumulation rates greater than 10 cm/k.y. Continuous sediment recovery was documented over millions of years at almost all the sites, and clear evidence was found for variability of sediment physical properties on millennial time scales over many different time periods (Fig. 3). In addition, the drift sites (980, 981, 983, and 984) open a new window of exploration in the pelagic realm of the deep sea, and will allow us, for the first time, to study the evolution of millennial-scale climate variability in the North Atlantic over millions of years. In particular, we will be able to evaluate the amplitude and frequency of millennial-scale variability during the mid-Pliocene, a time period warmer than today.

The second objective of Leg 162 was to recover sequences in a spatial array suitable for examining the evolution of vertical and horizontal gradients in water-mass properties. The North Atlantic sites form a depth transect in the northeastern basins spanning the depth interval of glacial intermediate water-mass formation (specific depths of sites: Site 982 — 1150 m, Site 984 — 1660 m, Site 983 — 1995 m, Site 980 — 2180 m, and Site 981 — 2184 m). Likewise, two of the sites (983 and 984) are located just south of waters spilling over the Iceland-Faeroe Ridge while the other sites (981 and 982) are just south of the Wyville-Thompson Ridge Overflow (Figs. 4, 5). These sites will allow us to examine the history of North Atlantic thermohaline circulation both on millennial and Milankovitch time scales. In addition, the sediment records of two sites, 981 at 2157 m and 982 at 1150 m, extend back to the upper Miocene and lower middle Miocene, respectively. These long sediment sequences will allow us to examine how North Atlantic thermohaline circulation responded to tectonic changes in the sill depth of the Greenland-Scotland Ridge, as well as other tectonic (e.g., the Isthmus of Panama) and climatic events (e.g., middle Miocene glaciation of Antarctica) that may have influenced the physical oceanography in the source areas of bottom-water formation.

The sites in the North Atlantic also form a northwest-southeast surface-water transect (Fig. 2), which crosses the major area of polar front movement on glacial-interglacial (G-I) cycles. Thus, we should be able to compare east-west gradients in surface-water temperature and iceberg trajectories on suborbital time scales, and further improve our understanding of the dynamics of Heinrich events and the even shorter duration Dansgaard-Oeschger events (e.g., Broecker, 1994; Bond and Lotti, 1995).

Likewise in the Nordic sea Sites 987, 907, and 985 complete an east-west transect originally begun with Leg 104 Sites 642, 643, and 644 (Fig. 6). With these sites we will be able to reconstruct the history of the strong climatic gradients in the Nordic seas caused by warm-water inflow ("the Nordic heat pump") in the east. This warm inflow is compensated by outflow of cold, polar waters in the west and cold deep-water outflow across the bottom of the Southern Gateway ridge.

Lastly, with the addition of Site 986 on the Svalbard Margin and Site 987 on the Greenland Margin, the Nordic sea sites are situated to determine the long-term initiation and growth history of the three major regional ice sheets: the Barents Sea Ice Sheet, the Scandinavian Ice Sheet, and the Greenland Ice Sheet.

CORING STRATEGY

Our strategy at most sites was to core three holes to refusal using the Advanced Hydraulic Piston Corer (APC) followed by the Extended Core Barrel (XCB). On the deepest holes the Rotary Core Barrel (RCB) was used. This approach allowed the retrieval of continuous sedimentary records without gaps due to core breaks or drilling disturbance. At every site, interhole comparison of magnetic susceptibility, GRAPE bulk density, natural gamma radiation, and spectral reflectance data permitted the development of continuous composite sequences. Furthermore, as these data were collected and compared in real time, we were able to adjust the coring strategy at each hole to provide maximum recovery of intervals that fell at core breaks in the first or second holes.

Triple APC coring was also necessary to exceed normal ODP sampling density guidelines, and thus to permit ultra-high-resolution paleoceanographic studies. At some sites, a 5-cm sample interval will give a temporal resolution of about 300 years. Likewise, triple APC coring provides enough material to generate continuous U-channel sequences with which to study century- to millennial-scale variability in the intensity of the Earth's geomagnetic field, as well as other magnetic properties of the sediments.

We began coring on the Feni Drift (FD in Fig. 5), located on the southeast flank of the Rockall Plateau, at Sites 980 and 981. We gained time at this site despite APC recovery that was significantly deeper than projected in the prospectus. Using this extra time in addition to time gained by an early departure from Leith, we chose also to deepen the next site by about 100 m more than was called for in the prospectus. As a result, Site 982 on the Rockall Plateau was drilled by APC and XCB to refusal at a depth of ~610 mbsf. Departing Site 982, still with significant time savings, we steamed to a second priority, alternate site that was on our cruise track: Site 983 on the Gardar Drift (Fig. 4). We spent about two days recovering three APC holes to approximately 250 mbsf. After coring Site 983, we moved to the nearby Bjorn Drift (Site 984) where we completed our proposed drilling objectives.

After moving north of Iceland, we cored two additional APC holes at Site 907 (907B and 907C) visited previously on Leg 151 (Hole 907A). Following Site 907, we would have proceeded to EGM-4, but for heavy ice cover in that region. As we needed to remain near Iceland to wait for resupplies (i.e., core liners), we elected to drill our second alternate Iceland Plateau site (Site 985). As soon as possible, we proceeded north to Site 986 on the Svalbard Margin. As we were finishing operations at this site, it was apparent that the proposed sites on the Yermak Plateau (including contingency sites) were well within the area of sea ice and hence could not be cored. We thus proceeded to our last target on the East Greenland Margin, Site 987 (EGM-4).

Four holes cored deeper than 400 m were logged on Leg 162, Sites 982, 984, 986 and 987. We typically chose to run the Formation MicroScanner (FMS), the Geological High-Sensitivity Magnetic Tool (GHMT-A), and the Geochemical Logging Tool (GLT) after the Quad Combo. These tools were run in order to measure in situ properties characteristic of the lithology such as bedding structures, downhole magnetic susceptibility, and major element abundances, as well as magnetic polarity sequence. The downhole logs are particularly useful in intervals where shipboard measurements were not possible due to a lack of recovery or coring disturbance, and proved to be extremely interesting when combined with discrete physical properties, pore-water chemistry measurements (e.g., see "Site 982" section of "Results" this report), and seismic stratigraphy. With these data we have also been able to develop synthetic seismograms in order to link more directly the cored sequences to the seismic sequences of the region, an objective that was particularly important on the Svalbard and East Greenland Margins. Likewise, the logging data will allow us to scale the recovered and typically expanded sedimentary sections back to their true subsurface depths.

RESULTS

Overview

Clearly one of the most exciting results of this leg is the mere fact that so many continuous sequences with high sedimentation rates were recovered from areas where major components of the climate system can be monitored (Fig. 7). In addition, a complete magnetostratigraphic record from the interval of the Northern Hemisphere Ice Ages was obtained at nearly every site (Fig. 7). Sedimentation rates for four of the five North Atlantic drift sites are shown in Fig. 8. Almost all of these sites have upper Pleistocene sedimentation rates greater than 10 cm/k.y., and Site 984 has upper Pliocene sedimentation rates in excess of 15 cm/k.y. It is clear from many of the records collected (e.g., Fig. 3) that detailed sampling will allow us to investigate changes in surface- and deep-water chemistry and sediment lithology on the time scale of hundreds to thousands of years.

The drift sites are interesting for two reasons. First, these sequences will provide information about the chemistry of water masses in these regions through time by isotopic and trace element analyses. Second, we will also be able to infer paleocurrent velocities through sedimentological analyses. Such investigations will allow us to test the response of thermohaline circulation to climate changes on many time scales and in many different climate regimes.

At all the sites, high-resolution continuous measurements of key lithologic parameters were made, such as magnetic susceptibility and spectral reflectance (Fig. 9). Such data allowed development of composite sequences and continuous time series of all parameters with no significant gaps in the triple APC sections. Ground-truthing the cause of variation in these nonintrusively measured parameters will be a high priority for initial shore-based studies. For instance, it appears that spectral reflectance may be a good indicator of carbonate percentage in the sedimentary sections (Fig. 10).

In order to understand the transformation of the Earth's climate system into an ice age world during the Neogene, it is important to identify where and why ice sheets started to form. Data on the inception, variability, and dynamics of these ice masses needs to be assessed for each ice sheet individually in order to understand which areas are the most sensitive to early ice sheet growth. For example, when did glaciation shift from mountain and fjord style glaciation to full fledged ice sheets, and when did marine-based ice sheets begin to extend to the outer continental shelf? To obtain this information, we cored Sites 986 and 987 close to the Svalbard and East Greenland margins, respectively. These last two sites of Leg 162 were planned in order to core continental margin sediments proximal to major Northern Hemisphere ice sheets; namely, the Barents/Svalbard Ice Sheet in the European Arctic and the Greenland Ice Sheet. With these sequences we will be able to document and date the main phases of glaciation of the respective ice sheets as well as ground-truth the seismic network used to map the main glacial sequences on the margins. The successful coring of deep holes at both locations was a major achievement of the leg. Shipboard analyses document very different evolutionary histories of the two ice sheets, and provide new insight into similarities in the dynamics of glacial deposition between the two sites. At Site 987, glacial deposits exist throughout the sediment section, suggesting continuous glaciation on Greenland since the late Miocene, with major ice sheet expansion and deposition in the early and late Pliocene. The Barents/Svalbard Ice Sheet history appears to be much younger, probably starting in the late Pliocene with major expansion to the shelf break occurring in the Pleistocene.

Finally, at almost every site an interesting discovery was made from the pore-water profiles (Fig. 11). A downhole decrease in interstitial sulfate was observed at all sites. This decrease appears to be related to sedimentation rate; that is, greater and more rapid depletions of dissolved sulfate are observed at faster rates of deposition (Fig. 11A). This decrease may occur because fluxes of organic matter may be greater at higher sedimentation rates or because rapidly deposited sediments may restrict diffusive communication with overlying seawater to relatively shallow depths within the sediment. Besides the reduction of organic matter, the other important process which controls pore-water geochemistry is the alteration of basement rock as well as volcanic material within the sediment column. The degree of depletion in the Mg^{2+} profiles at these sites reflects the age and nature of the basement and the proximity of the site to a volcanic source (Fig. 11B). Sites 980, 981, and 982 exhibit the smallest Mg^{2+} depletions, reflecting the influence of a rifted continental block (i.e., Rockall Plateau) and the great distance from a volcanic source. The remaining sites are all located on oceanic basement and many receive significant inputs of volcanogenic sediment from Iceland. High heat flow at Sites 907 (121°C/km) and 986 (152°C/km) may also contribute to the extent of Mg^{2+} depletion by accelerating reaction rates between interstitial waters and basement (and/or sedimentary volcanic material).

Several of the most unexpected geochemical results are reflected in the dissolved chloride profiles (Fig. 11C). Dissolved chloride usually behaves conservatively in sediment pore waters, but three of the Leg 162 sites display downhole depletions in chloride concentrations (985, 986, and 987), four show little to no change (907B, 980, 981, and 983), and two sites record downhole increases in chloride (982, 984). Several processes were considered to explain such anomalous chloride behavior: (1) decomposition of methane hydrates (e.g., <400 mbsf at Sites 982 and 985); (2) hydration (Site 982) or dehydration (e.g., >400 mbsf in Site 982) of clay minerals; and (3) variable paleosalinity of the ocean (Sites 982 and 985). Additional shore-based work is necessary to test these hypotheses put forth to explain the enigmatic chloride anomalies at Leg 162 sites.

Sites 980/981

Sites 980 and 981 are located on the Feni Drift, east of the Rockall Bank, in the northeast Atlantic. The drift was deposited along the northwestern flank of Rockall Trough under the influence of geostrophic currents formed by Norwegian Sea overflow waters flowing across the Iceland-Scotland Ridge and deeper waters originating from the south (including Antarctic Bottom Water). The excess deposition of fine-grained sediment on the Feni Drift produced expanded sediment sections (>10 cm/k.y.) that are ideally suited for high-resolution paleoceanographic studies.

These sections consist of rapidly accumulated nannofossil ooze with variable amounts of clay and clayey nannofossil mixed sediments. The main component of lithologic variability occurs on decimeter to meter scales throughout the sections, in the form of cyclic changes in color that are mainly related to relative changes in the proportions of biogenic carbonate, detrital clay, and silt. The upper unit (Unit I), recovered at Site 980 (0 to 114 mbsf) and Site 981 (0 to 160 mbsf), includes the upper Pliocene to Holocene, and is characterized by alternating dark and light gray clays and oozes. The lower unit (Unit II), 160 to 320 mbsf at Site 981, encompasses the lower to upper Pliocene and consists of a more homogenous nannofossil ooze with subtle color changes. Carbonate content is higher and less variable than in Unit I (80%-90% vs. 20%-80%). Proceeding downhole, the boundary between the two units is marked by a sharp decrease in magnetic susceptibility and natural gamma radiation, and a sharp increase in carbonate content and spectral reflectance.

All cores recovered were measured with the multisensor track (MST). Correlation of natural gamma radiation, gamma-ray attenuation, and magnetic susceptibility records confirms that we have recovered a complete stratigraphic sequence at Site 980 and 981 to a depth of 250 meters composite depth (mcd), which is about 230 mbsf, or approximately 3.4 Ma. The MST records are easily correlated between the holes as well as between the two sites. However, at Site 981 small coring gaps may exist below 230 mbsf. Low-amplitude MST signals prevented unambiguous correlation between holes over this interval.

Age control is derived from paleomagnetic datums down to the Matuyama/Gauss boundary (where the magnetic signal deteriorates), and from nannofossil and foraminifer biostratigraphy. Site 980 extends to about 1.2 Ma whereas Site 981 extends beyond 5 Ma. At Site 980, estimated sedimentation rates (in the composite section) are ~135 m/m.y. in the Brunhes section, decreasing to about 70 m/m.y. in the Matuyama section. Based on color variations, it would appear that interglacial sedimentation rates are significantly higher than glacial rates. At Site 981, sedimentation rates average ~55 m/m.y. in the Pleistocene and ~70 m/m.y. in the Pliocene, although there may be an interval with a rate as high as 125 m/m.y. between ~2.4 and 3.0 Ma.

The highest resolution shipboard analyses are from the MST and spectral reflectance data, and both appear to exhibit millennial-scale oscillations. In all intervals, these proxies correlate extremely well with each other, as well as with shipboard measurements of carbonate percentage. The onset of major Northern Hemisphere glaciation (and ice-rafted debris [IRD] input) and the transition from 41-k.y. climate variability to 100-k.y. variability are obvious in these records. As the amplitude of the MST signals (including susceptibility) decreased significantly below 2.5 Ma, we looked to the spectral reflectance record for evidence of sub-Milankovitch-scale lithologic variability in the preglacial Pliocene. Given the 8-cm (or approximately 1000 yr.) resolution of the measurements, there appears to be a precessional signal (1-2 m cycle) and a 5-10-k.y. cycle (~50 cm cycle) within this interval.

The extremely high sedimentation rates and strong magnetic signal at Site 980 will permit high-resolution studies of paleomagnetic transitions, as well as secular variation in the intensity of the magnetic field. Likewise, these two sites, ~4 km apart, provide a natural laboratory for investigating the effects of sedimentation rate on pore-water chemistry and organic matter preservation. In particular, sulfate reduction appears to be more prevalent in the upper sections of Site 980 vs. 981, with Site 980 displaying approximately 25% higher accumulation rates. Major ion and stable isotopic studies on pore-water samples collected on the ship will be completed on shore.

Site 982

Site 982 (NAMD-1), the site with the shallowest water depth (1145 m), will allow documentation of the evolution of intermediate waters of the North Atlantic during the Neogene. This record will help reconstruct water-mass behavior in the North Atlantic on glacial-interglacial time scales of the Pliocene/Pleistocene, as well as during the middle to late Miocene interval when the Iceland-Scotland Ridge subsided to depths that allowed deep water exchange between the Nordic seas and the North Atlantic. This site should also enable reconstruction of the intermediate water-mass structure of the North Atlantic during the latest Miocene Messinian events. In addition, the recovery of a lower middle Miocene section should document North Atlantic water-mass circulation at times when no North Atlantic Deep Water (NADW) was thought to exist.

Site 982 recovered a continuous, carbonate-rich sequence of sediments extending to the lower Miocene, and triple APC coring down to 235 mbsf has provided a complete composite section of approximately the last 7 Ma. Extended Core Barrel coring from 235 to 615 mbsf in Hole 982B provided good documentation of the 7-19 Ma interval. Recovery decreased below 480 mbsf where silicified layers started to appear.

The sediments have an average calcium carbonate content of about 86%, and are predominantly composed of nannofossil ooze with variable amounts of clay, clayey nannofossil mixed sediments, and clays with variable amounts of nannofossils and silt. A distinct boundary, occurring at approximately 57.4 mbsf, divides the sequence into two units. This boundary marks the initiation of major Northern Hemisphere glaciation in the late Pliocene, and is characterized by a sharp downcore decrease in siliciclastic sediments and magnetic susceptibility, as well as by pronounced downcore increases in calcium carbonate content and spectral reflectance. The sediments in Unit I are dominated by variable amounts of calcareous nannofossils, clay, and, to a lesser extent, silt and foraminifers. These variations are responsible for the considerable color contrast observed between the oozes and clays within the unit, particularly when compared with Unit II. These compositional changes form distinct high-amplitude cyclic variations which occur on a 0.5- to 3-m scale, and are mainly related to relative changes in the proportions of biogenic carbonate, detrital clay minerals, and, to a lesser extent, detrital silt. All dropstones observed in Site 982 sediments occur in Unit I.

Unit II sediments are dominated by biogenic carbonate, primarily nannofossil ooze, with only minor amounts of clay, and, to an even lesser extent, biogenic silica. The mean carbonate content of Unit II, 90.8%, is considerably higher than that of Unit I. The unit is characterized by very light gray, light gray, and very light greenish-gray nannofossil ooze. The 195.5 to 480.0 mbsf interval is Miocene in age and very homogenous with the sediments approaching a chalk-like hardness downcore. Several distinct ash layers were identified in the unit, and the lower part of the unit contains chert-like silicified layers.

Age control for the sequence is primarily based on magnetostratigraphy, and on calcareous nannofossil and foraminiferal biozonation. The magnetic signal is too weak to provide reliable polarity sequences below the Matuyama/Gauss boundary (2.6 Ma) and calcareous fossils provide the primary age control below this boundary. The bottom of the drilled sequence is about 19 Ma, and no major breaks in sedimentation are indicated by shipboard analyses. Sedimentation rates average about 25 m/m.y. for the mid-Pliocene through Pleistocene. Below this level sedimentation rates increase to about 32 m/m.y.

A sharp horizon was identified within Unit II at 268 mbsf consisting of a poorly recovered silicified foraminiferal sand cobble. This horizon, in sediments 7-8 Ma, marks the upper regional seismic reflector of the Rockall Basin (Reflector R1). Downhole logs indicate that the silicified material is a 4-m-thick sequence which we tentatively interpret as a turbidite. This silicified layer apparently formed a barrier that dampened or disabled pore-water diffusion, as indicated by distinct differences in pore-water profiles above and below the layer. This apparent lack of diffusion may open possibilities for studying differences in ocean chemistry (especially salinity) before and after the Messinian salinity crisis.

Site 983

Site 983 (GARDAR-1) is located on the Gardar Drift at a water depth of approximately 1995 m on the eastern flank of the Reykjanes Ridge. This is the approximate mid-depth of Glacial North Atlantic Intermediate Water (GNAIW) during the last glaciation. Obtaining a long-term history of this water mass is one of the primary scientific objectives of this site. In conjunction with Sites 980, 981, and 982 to the east, this site will also be used to assess east-west gradients in surface-water conditions as well as to monitor Norwegian-Greenland Sea overflows across the Greenland-Scotland Ridge. In particular, Site 983 lies on the northwest margin of the Iceland Basin directly downstream of overflows from the Iceland-Faroe Ridge. The high sedimentation rates expected (and found) here will provide an unprecedented record of both glacial-interglacial and millennial-scale variations in thermohaline circulation, surface-water temperatures, and ice-rafting history during the late Pliocene and Pleistocene.

Site 983 recovered a continuous sequence of sediments ranging in age from upper Pliocene to Holocene (2.0 to 0 Ma). Sedimentation rates, determined using magnetic polarity reversals and biostratigraphic datums, range from 10 cm/k.y. in the upper Pleistocene, up to 17 cm/k.y. in the upper Pliocene section. MST data allowed the construction of a continuous composite section for this site and preliminary studies aboard ship indicate strong variance throughout the section in a number of parameters on both Milankovitch and sub-Milankovitch time scales.

The sediments at Site 983 are predominantly composed of rapidly accumulated fine-grained terrigenous particles with minor amounts of biocarbonate and biosilica. While discrete ash layers are rare, pale to dark brown glass (tachylite) commonly occurs as a constituent of the silt- and sand-sized fractions. Authigenic iron sulfides, primarily in the form of disseminated pyrite, are also typically present. The dominant lithologies include silty clay, clay, clayey nannofossil mixed sediment, and clay with variable amounts of nannofossils and silt. Nannofossil oozes with variable amounts of clay and sponge spicules also occur. Lithologic variation on decimeter- to meter-scales characterizes the sediment at this site, and is due to changes in the abundance of silt and biogenic materials relative to clay content.

No major lithologic boundaries occur within the 260 m of sediment recovered at this site; therefore, only one lithostratigraphic unit is recognized. Subtle but distinct boundaries that delimit three subunits occur at depths of 120 mbsf and 180 mbsf. The shallower boundary is recognized primarily in the spectral reflectance signal. It is characterized by a downcore decrease in the amplitude of the higher frequency (decimeter- to meter-scale) reflectance signal and an absence of the lower frequency reflectance signal (>10 m-scale). The deeper boundary is recognized in visual examination of split cores and smear slides, and is characterized by a downcore absence of layers in which biocarbonate is predominant. All dropstones, which are never common, occur above this deeper horizon. There is no evidence of significant sediment disturbance, winnowing, or erosion at Site 983, although bioturbation is ubiquitous throughout the cores.

Calcium carbonate contents fluctuate between 0.7% and 43.3% (with an average value of 16.8%), and gradually decrease with increasing sediment depth. As at Sites 980, 981, and 982, the carbonate cycles of Hole 983A probably reflect glacial-interglacial fluctuations. Calcareous nannofossils are the dominant fossil group at this site and are generally abundant and well-preserved. All the standard Quaternary nannofossil zones were recognized. Planktonic foraminifers are generally common to abundant and well-preserved throughout the uppermost Pliocene to Holocene sequence, although rare barren intervals are observed. Benthic foraminifers are present at most of the levels examined and preservation is good throughout. Diatoms at Site 983 were common to abundant and exhibit moderate to good preservation. Due to the possible influence of the East Greenland Current, warmer-water species were rare, whereas many cooler-water indicators were more common. Siliceous flagellates (including silicoflagellates, ebridians, and actiniscidians) range from trace to common in abundance with good to moderate preservation.

Pore-water profiles from Site 983 are typical of sediments in which sulfate reduction and methanogenesis are occurring. Sulfate concentrations decrease from seawater values at the top of the core to zero at about 100 mbsf. Below 120 mbsf, methane begins to increase from 0 parts per million volume (ppmv), reaching a maximum of 9000 ppmv near the base of the hole. The boundary between sulfate reduction and methanogenesis is very sharp at 120 mbsf, presumably because utilization of methane by sulfate-reducing bacteria prevents significant diffusive penetration of methane into the sulfate reduction zone above. The sharp sulfate/methane boundary at 120 mbsf also corresponds with lithostratigraphic subunit boundary IA/IB and with seismic Reflector R2. Ethane and propane values occur in detectable amounts below 165 mbsf; however, the high C_1/C_2 ratios suggest that the source for methane is most likely in situ bacterial methanogenesis resulting from decomposition of organic matter in the sediments.

Site 984

Site 984 (BJORN-1) is located on the Bjorn Drift at a water depth of approximately 1660 m on the eastern flank of the Reykjanes Ridge. This is within the core of Glacial North Atlantic Intermediate Water (GNAIW) during the last glaciation. Obtaining a long-term history of this water mass was one of the primary scientific objectives of this site and, in conjunction with Sites 980, 981, and 982 to the east and Site 983 to the south, this site will be used to assess east-west gradients in surface-water conditions, as well as to monitor Norwegian-Greenland Sea overflows across the Greenland-Scotland Ridge. The high sedimentation rates expected (and found) here will provide us with an unprecedented record of both glacial-interglacial and millennial-scale variations in thermohaline circulation, surface-water temperatures, and ice-rafting history during the Pliocene and Pleistocene.

A continuous sequence of sediments ranging in age from lower upper Pliocene to Holocene (3.0 to 0 Ma) was recovered at Site 984. Calcareous nannofossils are the dominant fossil group at this site. However, all fossil groups exhibit variable abundance and preservation, possibly correlated to glacial-interglacial events. Sedimentation rates were determined using magnetostratigraphy combined with the biostratigraphic datums, and indicate accumulation rates of ~10-13 cm/k.y. MST data allowed construction of a continuous composite section down to about 270 mbsf. Preliminary studies done aboard ship indicate strong variance in a number of parameters on both Milankovitch and sub-Milankovitch time scales.

Sediments at Site 984, predominantly composed of rapidly accumulated fine-grained terrigenous particles, are very similar to those at Site 983. Discrete ash layers occur throughout the upper sediment column, and pale to dark brown glass commonly occurs as a constituent of the silt- and sand-sized fractions. Authigenic iron sulfides, primarily in the form of disseminated pyrite, are also commonly present in minor amounts. The dominant lithologies include silty clay, clay, clayey nannofossil mixed sediment, and clay with variable amounts of nannofossils and silt. Nannofossil oozes with variable amounts of clay and sponge spicules also occur. As at Site 983, lithologic variation on a decimeter- to meter-scale characterizes the sediment at this site, and is due to changes in the abundance of silt and biogenic materials relative to clay content.

Only one lithostratigraphic unit is defined at Site 984, with a subdivision into four subunits, IA to ID. Changes in the spectral reflectance, the character of the magnetic susceptibility signal, and the occurrence or abundance of minor lithologies interbedded within the dominant clays and silty clays, define subunit boundaries at 120, 165, and 279 mbsf. While the sediments recovered at Sites 983 and 984 share many similarities, there are notable differences. One difference is the more common occurrence of dropstones at Site 984 possibly due to iceberg trajectories and/or increased melting in this region. Another difference between the two sites is the pronounced abundance of discrete ash layers in Subunits IA and IB at Site 984. This may be due to the proximity of Site 984 to Iceland, an obvious source of ash falls from discrete eruptions.

Calcium carbonate contents in Hole 984B range from 0.4% and 32.2% with an average value of 8.0%. $CaCO_3$ gradually decreases downhole and fluctuates, having a lower amplitude with increasing depth. As at Site 983, the carbonate cycles of Hole 984B most likely reflect glacial-interglacial fluctuations.

Calcareous nannofossils are generally abundant and well preserved in the upper 200 m at this site, with both the abundance and preservation deteriorating lower in the section. All the standard Quaternary nannofossil zones are recognized. Similar to the nannofossils, planktonic and benthic foraminifers are generally well-preserved and common throughout the upper Pliocene to Holocene at Site 984, but become progressively scarcer below 200 m. Diatoms vary in preservation and abundance while siliceous flagellates display scattered occurrences downsection in Holes 984A and 984B. The abundance of these microfossils ranges from trace to common with good to poor preservation.

Site 907

The primary objective of drilling operations at Site 907 was to recover an undisturbed pelagic sedimentary sequence with carbonate and IRD records. Shore-based studies of the one hole cored by Leg 151 at Site 907 in 1993 provided a reliable stable isotope record of the last 1 Ma, and a record of IRD back to more than 7 Ma. Given that a detailed paleoclimatic record can be extracted from these sediments, we wanted to return to this site and finish the planned triple coring to provide a complete and undisturbed high-latitude section for much of the Neogene. Thus, the site was reoccupied by Leg 162 and two additional holes were cored (Holes 907B and 907C).

High resolution shipboard multisensor track (MST) data allowed us to combine the MST records from Legs 151 and 162 to generate a spliced composite section. We were thus able to fill in recovery gaps over core breaks in Hole 907A and will now be able to complete Leg 151 for the high-resolution paleoclimate studies begun on Leg 151.

The scarcity of biogenic material in certain intervals reduces the possibility of biostratigraphic age control. However, a relatively clean magnetic polarity sequence enables correlation with confidence to the geomagnetic polarity time scale back to the upper Miocene, and with somewhat less confidence further back to approximately 16 Ma. Two short hiatuses, or condensed intervals, are indicated in the middle to upper Miocene section. Sedimentation rates averaged 15-25 m/m.y. over the last 3 Ma, 5-15 m/m.y. in the 3-14 Ma interval, and 25-30 m/m.y. in the 14-16 Ma interval.

The sediments at Site 907 are dominantly composed of silty clay, clay with silt, and clayey mixed sediment with varying amounts of biogenic material. The biogenic component, which includes calcareous nannofossils, foraminifers, diatoms, and/or spicules, is highly variable with increasing depth. The bulk calcium carbonate content at this site displays high amplitude variations from near 0% to greater than 50% within the upper 100 mbsf depth. Below this level the sediments are carbonate-free for the most part. Dropstones greater than 1 cm in size are present above 62.9 mbsf. Ash layers and ash pods are abundant throughout Site 907 sediments. Four distinct lithostratigraphic units are defined with unit boundaries at 16, 63, and 196 mbsf.

Lithostratigraphic Unit I (0 to 15.6 mbsf; Holocene to middle Pleistocene) is primarily defined by the presence of relatively abundant calcareous microfossils, and high amplitude fluctuations in spectral reflectance. The sediment consists predominantly of alternating layers of clayey nannofossil mixed sediment with silty clay and clay with silt. Quartz, feldspar, and inorganic calcite are the most common terrigenous silt-sized particles (although the calcite could possibly be authigenic). The pervasive colors of this unit are olive brown and olive gray, broken only by thin darker volcanic ash layers.

Unit II (15.6 to 63.1 mbsf; middle Pleistocene to Pliocene) is characterized by the absence of biogenic sediment. The dominant lithologies include silty clay, clay with silt and ash, and clay. The sediments are predominantly composed of clay, quartz, feldspar, mica, and accessory minerals. Unit II, as well as Unit I, contains higher amounts of quartz, feldspar, and mica than deeper intervals. Dark greenish gray, dark gray, and greenish gray-colored sediments are pervasive, although minor gray to black volcanic ash layers occur intermittently. Terrigenous components such as quartz and feldspar are relatively invariant across the boundary of Units I and II, in contrast to the downsection disappearance of biogenic material.

Unit III (63.1 to 196.1 mbsf; Pliocene to middle Miocene) is defined by the reoccurrence of biogenic sediment, in this case, biogenic silica throughout the unit with minor calcareous materials occurring within the uppermost section. The primary lithologies of Unit III are dark greenish gray to very dark greenish gray silty clay, clay with silt, clay, and clay with diatoms. With the exception of a small interval containing more than 55% nannofossils, Unit III is characterized by minor repeated occurrences of biogenic material, which increase downcore from less than 5% at the upper boundary, to 5%-20% (primarily siliceous materials) in the lower portion of the unit.

The major lithologies in Unit IV (196.1 to 214.9 mbsf; middle Miocene) are dark greenish gray to greenish gray silty clay, clay with silt, and clay. No biogenic sediment is found in the unit except for trace amounts of siliceous microfossils within the upper portion. The coarse fraction of Unit IV is similar to Unit III, except that it contains slightly smaller amounts of quartz and larger amounts of sulfides.

Biogenic material occurs sporadically and intermittently throughout the sequence. In Unit I it includes both calcareous and siliceous material, but in Unit III it consists solely of siliceous material. The alternating biogenic-bearing and nonbiogenic sediments may reflect climatically driven changes over a long time scale. Shorter-term changes of oceanographic conditions are superimposed on this long-term variation, as indicated by the variable abundance of biogenic components occurring within Units I and III. The boundary between Units II and III probably reflects the onset of increased glaciation during the Pliocene. At this level, quartz and feldspar increase markedly upsection, the first dropstones occur, and changes in the suite of clay minerals occur as indicated by changes in natural gamma-ray emissions.

The geochemistry of the sedimentary sequence is characterized by processes typical of sulfate reduction, and processes reflecting alteration of volcanic ash within the sediments and basement basalts below. Organic carbon values are generally low, but are highest in the intervals with the most siliceous microfossils. Most geochemical parameters correlate well with Leg 151 results except those involved in reduction of organic matter. Leg 151 sulfate values from Hole 907A are substantially higher than those of Holes 907B and 907C in certain intervals. Whether this reflects lateral discontinuity or analytical differences remains to be determined.

Site 985

Site 985 (ICEP-3) is located on a gentle slope of the Iceland Plateau, at a water depth of 2799 m, and is part of the paleoenvironmental transect with Sites 907 and 987. The site was a second-priority site for Leg 162, and was cored due to operational constraints which required our staying in the vicinity of Iceland. With the recovered sequences we intend to (1) monitor the history of oceanic and climatic fronts moving east and west across the Norwegian Sea, (2) derive an open-ocean record of IRD and carbonate accumulation, and (3) document the history of formation of northern-source deep waters.

The sediments recovered at Site 985 are predominantly fine-grained siliciclastics. The dominant lithologies include silty clays, clays with silt, and clays. Biocarbonates are restricted to the upper parts of the sedimentary sequence. Clays and silty clays containing biosilica are encountered only between 240 and 290 mbsf. Disseminated volcanic ash, ash pods, and ash layers occur throughout the sedimentary sequence, whereas dropstones are confined to the upper sedimentary sequence (0-70 mbsf). The sequence was dated down to the latest Miocene by means of magnetic polarity records. Below the upper Miocene it became difficult to correlate to the geomagnetic polarity time scale; therefore, the underlying sequence has poor age constraints. Siliceous microfossils and arenaceous benthic foraminifers indicate that the cored sequence ends in the upper Oligocene.

Multisensor track (MST) investigations document that a complete section has been recovered over the upper 131 mbsf (Holocene to latest Miocene) with good overlap across core breaks. Within the last 7 m.y., sedimentation rates are highest in the last 3 m.y. (20-30 m/m.y.), and drop to 10-15 m/m.y. in the middle and early Pliocene. Somewhat higher sedimentation rates (about 20 m/m.y.) are documented for the latest Miocene.

Five lithostratigraphic units were recovered. Unit I (0-17.2 mbsf; Holocene to upper Pleistocene) is defined largely on the basis of relatively abundant biocarbonates (up to 30%) and higher color spectral reflectance than underlying units. The sediments are composed of interbedded layers of gray clayey nannofossil ooze with foraminifers; dark gray nannofossil clay with silt; dark gray silty clay with nannofossils; brown and dark grayish brown clay with silt; and very dark gray to dark grayish brown silty clays. The cyclic, interbedded nature of the sediments testifies to their glacial-interglacial origin.

Unit II (17.2 to 99.2 mbsf; upper Pleistocene to lower Pliocene) is defined, in part, by the diminished presence of biocarbonate which occurs as a variable sedimentary component, averaging 6.9 ± 10.1%. The unit is composed largely of silty clay, clay with silt, and clay. X-ray diffraction (XRD) and smear slide analyses both demonstrate an increase in quartz, plagioclase, and pyroxene within Unit II relative to the underlying sediments. Both reflectance values and natural gamma counts decrease noticeably at the boundary with the underlying unit. Both Unit I and II contain dropstones, in contrast to the underlying units.

Unit III (99.2 to 155.2 mbsf; lower Pliocene to upper Miocene) is characterized by the occurrence of clay with silt, and the absence of biogenic sediments. Isolated spikes of inorganic carbonate are superimposed on a carbonate-free background. XRD analysis of the bulk sediments reveals that plagioclase, quartz, and pyroxene are present to a lesser extent than in Units I and II.

Unit IV (155.2 to 465 mbsf; upper Miocene to upper Oligocene [?]) comprises the bulk of the sedimentary sequence at Site 985. These sediments are distinguished from those of Unit III and V by the transition from silty clay and clay with silt to lithologies in which indurated clays are dominant. Other characteristics of this lithofacies include very low magnetic susceptibility values and the absence of biocarbonates. Yellowish brown carbonate concretions are observed in Unit IV, some of which are composed of fluorapatite, and may be similar in composition to yellowish orange layers found at shallower depths. Unit IV can be subdivided into three distinct subunits. Subunit IVA (155.2 - 241.5 mbsf) is distinguished from the underlying sediments by higher magnetic susceptibility and natural gamma radiation values, and by the absence of biosilica. Two carbonate-rich layers in Subunit IVA may act as barriers to the diffusion of interstitial waters. XRD analysis of the upper layer indicates that it is composed of poorly crystallized carbonate. These layers yield high-velocity measurements and bracket sediments with interstitial waters that have anomalously low chloride, sodium, and salinity content; and unusually high proportions of long-chain hydrocarbon gases relative to methane. Reduced diversity of arenaceous benthic foraminifers also characterize this interval. The cause for these anomalies are not known. Subunit IVB (241.5 - 289.6 mbsf) is defined by the presence of biosilica. Subunit IVC (289.6 - 465 mbsf) is distinguished from Subunit IVB by the absence of biosilica and by a gradual increase in natural gamma radiation counts.

Unit V (465 to 578.9 mbsf; lower Miocene [?] to upper Oligocene [?]) is comprised of indurated dark greenish gray to very dark greenish gray clay; olive gray to dark greenish gray silty clay; and very dark greenish gray clay with glauconite and glauconitic clay. These sediments are distinguished from the overlying sediments by a sharp increase in magnetic susceptibility.

Site 986

Site 986 (SVAL-1B) was drilled on the Svalbard Margin to examine the onset of glaciation in the European Arctic and establish the history of the Svalbard-Barents Ice Sheet, including a probable transition from a terrestrial to marine-based ice sheet in the Barents Sea. Four holes were cored with a maximum penetration of 964.6 mbsf. The sequence penetrated all the main regional seismic reflectors (R1-R7) of the Svalbard-Barents Sea margin with good ties to the reflectors and main seismic sequences from core physical property measurements and wireline logging. These data will allow us to document the main phases of glacial erosion and deposition on the margin. The sediments recovered are predominantly fine- to coarse-grained siliciclastics with varying amounts of gravel. Dropstones (>1.0 cm in size) are abundant in most cores of the upper sedimentary sequence (0-561.8 mbsf). Sedimentary rocks are common throughout this sequence, whereas igneous and/or metamorphic rock fragments are more common in the interval from 380 to 550 mbsf. Over 500 dropstones greater than 1.0 cm in size are present from 2.58 mbsf to 845.3 mbsf.

High methane content in the rapidly deposited sediments and high dropstone content lead to variable recovery. However, all main seismic units are documented by recovery, and important additional information from wireline logging of the upper 500 m of the sequence enables a comprehensive description of the formations, consisting of 4 lithostratigraphic units.

Unit I (0 to 98.0 mbsf, Holocene to upper Pleistocene) is primarily defined by the presence of relatively common calcareous nannofossils. The lower boundary of this unit is marked by a decrease in the silt content. The sediments of Unit I are predominantly dark gray to very dark greenish gray silty clay and clay with silt, with interbedded layers of more nannofossil-rich sediments. Numerous dropstones, some as large as 7.9 cm, were identified throughout this unit.

Unit II (98.0 to 561.8 mbsf; lower Pleistocene to upper Pleistocene) comprises the bulk of the sedimentary sequence at Site 986. The unit is composed exclusively of dark to very dark greenish gray and dark to very dark gray silty clay and clay with silt. The most significant change is the increase in the amount of dropstones. Up to 30 dropstones per core, some as large as 16.5 cm, were found throughout this unit. Numerous well-defined millimeter- to decimeter-scale sandy to silty layers characterize the sediments of the uppermost part of this unit. Reworked shell fragments commonly appear in the uppermost 230 mbsf. In addition, wireline logging results show an increased number of larger than 10 m-thick intervals of increased resistivity within the interval from 235 to 550 mbsf. These are interpreted as debris-flow deposits.

Unit III (561.8 to 820.3 mbsf; middle to upper Pliocene [?]) is primarily characterized by relatively high sand content and the absence of dropstones. The primary lithologies of Unit III are very dark gray to very dark greenish gray silty clay with sand, clayey silt with sand, silty clay, and sandy silty clay. Unit III is characterized by the reoccurrence of biogenic calcareous sediment, which is present throughout the unit.

Unit IV (820.3 to 964.6 mbsf; Pliocene[?]) comprises the deepest sediments recovered at this site (Hole 986D). The transition from Unit III to Unit IV is marked by a gradual decrease in sand-sized grains and in the amount of silt- to sand-sized terrigeneous components.

Although age constraints are relatively uncertain throughout the sedimentary sequence, sedimentation rates at Site 986 appear to have remained between 160 to 360 m/m.y. from the Pliocene to Holocene. Foraminifer and calcareous nannofossil evidence indicate an age between 3.6 and 2.4 Ma for the sequence below 700 mbsf, whereas a dominant reversed magnetization in the lower sequence may indicate an even younger age. The shipboard results suggest that the fan buildup on the Svalbard Margin happened in the Pliocene-Pleistocene due to glacial erosion/deposition. A major shift in glacial style and ice sheet size took place in the Quaternary, and is characterized by the onset of excessive debris-flow sedimentation, which probably originated from ice sheets grounded at the shelf break. Debris flows are more conspicuous and thicker during the initial phase of this development than those flows during the later stages.

Methanogenesis occurs as shallow as 20 mbsf at Site 986 due to the high sedimentation rates. High methane content prevails throughout the section with higher mass hydrocarbons becoming more abundant with burial depth. A low salinity level at about 50 mbsf indicates that methane clathrates may be decomposing, whereas a strong reduction in chlorine content and salinity below 400 mbsf may be attributed to dewatering of clays due to high heat flow. Downhole temperature measurements and shipboard thermal conductivity measurements document higher heat flux at the site than previously anticipated.

Site 987

Five holes were cored at Site 987. Maximum penetration was 859.4 mbsf, which is estimated to be within a few meters of the oceanic basement. All major seismic sequence boundaries were penetrated, and there was overall good recovery. Despite gas expansion problems in the upper few hundred meters of the section, offsets between holes could be determined for approximately the upper 180 mbsf, and a continuous spliced section was produced for the upper 100 mbsf (approximately the last 1 Ma). Paleomagnetic data provided time control, which enabled detailed documentation of the glacial history of the Greenland Ice Sheet back to the late Miocene. Biostratigraphic age information is scarce due to the predominance of intervals lacking microfossils. The recovered sediments are mostly fine- to coarse-grained siliciclastics. Evidence of glacial depositional environments prevails throughout the recovered section. Five lithostratigraphic units were defined.

Unit I (0 to 305.6 mbsf; Pleistocene to upper Pliocene) is characterized by low magnetic susceptibility. The lower boundary of this unit is clearly marked by a sharp increase in magnetic susceptibility, an increase in the sand-sized content, and a decrease in the clay-sized content. Sediments containing up to 35% carbonate occur in inorganic calcite-rich bands, but the average for the unit is only 4.9%. The sediments of Unit I are predominantly silty clays interbedded with silt, and silt with sand and clay. Thick sandy turbidites with sharp erosional lower contacts and graded upper contacts are common. Turbidites are thicker and more common toward the top of the unit. Dropstones were identified throughout this unit.

Unit II (305.6 to 369.2 mbsf; upper Pliocene) is primarily defined by the presence of numerous isolated clasts >1.0 cm and of randomly oriented gravel. The top of Unit II is marked by a sharp increase in magnetic susceptibility and sand-sized fraction, as well as a decrease in the clay-sized content. Sediments of Unit II are predominantly silty clay with sand, silty clay with sand and gravel, sand-silt-clay, and clayey silt with sand and gravel. Carbonate content is very low, but some inorganic calcite layers occur at the base of the unit. The numerous clasts (up to 91 clasts in Core 162-987E-40X) are interpreted to be components of debris-flow deposits rather than dropstones, and the dominant rock type of these clasts is crystalline.

Unit III (369.2 to 575.5 mbsf; upper Pliocene to lower Pliocene) is defined by a sharp downcore decrease in magnetic susceptibility and in sand-sized particles. The lower boundary is marked by a strong downcore increase in magnetic susceptibility and in sand-sized content, and by a decrease in natural gamma radiation and clay-sized fraction. This unit contains few clasts larger than 1.0 cm; those that are found are mainly sedimentary and igneous rock fragments and are interpreted to be dropstones. Distorted and dipping beds, as well as laminations, occur in various intervals in the unit.

Unit IV (575.5 to 657.6 mbsf; lower Pliocene) is defined by the downcore increase in magnetic susceptibility and in sand-sized content, and by a decrease in natural gamma radiation and in clay-sized content. The lower boundary of this unit is marked by a decrease in magnetic susceptibility and sand-sized content. Like Unit II, this unit is mainly composed of silty clay with sand, silty clay with sand and gravel, silty clay with gravel, and silty clay. Various igneous, metamorphic, and sedimentary clasts are present.

Unit V (657.6 to 859.4 mbsf; Miocene to lower Pliocene) is defined by low magnetic susceptibility and by a reduced number of gravel clasts. The sediments of Unit V are composed of silty clay interbedded with clayey silt, clay with silt, and sand and clayey silt with sand. A few graded sandy turbidites are present, and sediments are highly indurated. Fine-scale structures, including flaser bedding, dipping beds, wavy laminae, convoluted structures, and folding interpreted to be slumps occur throughout the unit.

Turbiditic downslope sediment transport seems to be an important sedimentary process during the Pleistocene and late Pliocene at this location. Units II (upper Pliocene) and IV (lower Pliocene) are very similar, and appear to have originated from gravity-driven debris flows. Units III (lower to upper Pliocene) and V (lower Pliocene to upper Miocene) appear to have a higher component of hemipelagic, deposition with less downslope sediment transport than in Units I, II and IV.

The high deposition rates at this site are reflected by the change from sulfate reduction to methanogenesis at shallow burial depth (30 mbsf). Methane content as high as 68000 ppm was observed at 74 mbsf, and it decreased somewhat downsection. No evidence for gas hydrates was found, and natural gas profiles reflect normal biogenic processes. The organic matter content is variable, primarily reflecting marine organic matter with low C/N ratios.

Both the seismic stratigraphy, lithostratigraphy, sediment physical properties, and wireline logging results at Site 987 reflect variations in the frequency and amount of gravity-driven sediment transport from the East Greenland Shelf, which is in accord with the site being located on the northeastern flank of the Scoresby Sund glacial fan. Intervals of more frequent debris flows form the most distinct seismic reflectors. Results of the shipboard paleomagnetic studies indicate a late Miocene age for the lowermost cored sediments immediately above basement. A main result of coring at Site 987, based on the paleomagnetic data, is that new and younger ages than previously proposed can be assigned to the main buildup of the Scoresby Sund Fan. The main phase of fan construction took place in the late Pliocene to Pleistocene. Although glacial marine deposition and downslope transport is characteristic of most of the drilled sequence, two phases, one in the early Pliocene and another in the late Pliocene, are the most noticeable intervals of thick debris-flow deposition, presumably from an ice margin at the paleo shelf break.

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FIGURES

Figure 1. Bathymetric map (in meters) of sites cored during Leg 162, which departed Edinburgh, Scotland, on 8 July and returned to Reykjavik, Iceland, on 3 September, 1995. Sites 980-984 form a depth transect and a surface-water transect from warm to cool areas of the North Atlantic. Sites 907, 985, and 987, together with previous ODP sites, form a transect from temperate areas off Norway to the polar waters off Greenland. Site 986 is positioned off the location of the Svalbard/Barents Sea Ice Sheet in the European Arctic, and Site 987 off the Greenland Ice Sheet.

Figure 2. Bathymetry (in meters) of the "Southern Gateway" region of the northeast Atlantic showing major physiographic features. Norwegian Sea Overflow Water (NSOW) originates in the Nordic seas, and in this region spills across the Greenland-Scotland Ridge as Wyville-Thompson Ridge Overflow Water (WTRO) or Iceland Sea Overflow Water (ISOW). RR=Reykjanes Ridge.

Figure 3. Example of millennial- and suborbital-scale variability on top of longer orbital periods of 40 k.y. in the magnetic susceptibility of sediments from Site 983. The susceptibility signal reflects changes in mineral input to the site which varies with the state of climate. This interval is from about 1.9 Ma. Depth is based on a composite scale obtained from correlating results from the Site 983 holes.

Figure 4. Detailed topographic view of the Gardar and Bjorn Drift region showing locations of Sites 983 and 984.

Figure 5. View of the Rockall Trough and Rockall Plateau showing location of Sites 980, 981, and 982. Flow from northeast is over the Wyville-Thompson Ridge. Land in southeast corner is Ireland. Physiographic features: RB = Rockall Bank, FD = Feni Drift, RT = Rockall Trough, FI = Faeroe Islands, HRB = Hattan-Rockall Basin, HB = Hattan Bank.

Figure 6. Bathymetry (in meters) of Nordic seas transect.

Figure 7A. Summary of lithologies and paleomagnetic stratigraphy recovered at North Atlantic sites on Leg 162.

Figure 7B. Summary of lithologies and paleomagnetic stratigraphy of Nordic sea sites.

Figure 8A. Age-depth plots for North Atlantic Drift Sites 980, 981, 983, and 984.

Figure 8B. Age vs. sedimentation rates for North Atlantic Drift Sites 980, 981, 983, and 984.

Figure 9. Summary of lithologies recovered at Gardar Drift Site 983 showing correlative percentages of spectral reflectance, magnetic susceptibility, and natural gamma radiation data.

Figure 10. Percentage of carbonate from discrete samples plotted against the nearest spectral reflectance measurement (in the blue 450-500 nm range).

Figure 11. Pore-water profiles from Leg 162 sites illustrating downhole changes in (A) sulfate, (B) magnesium, and (C) chloride.

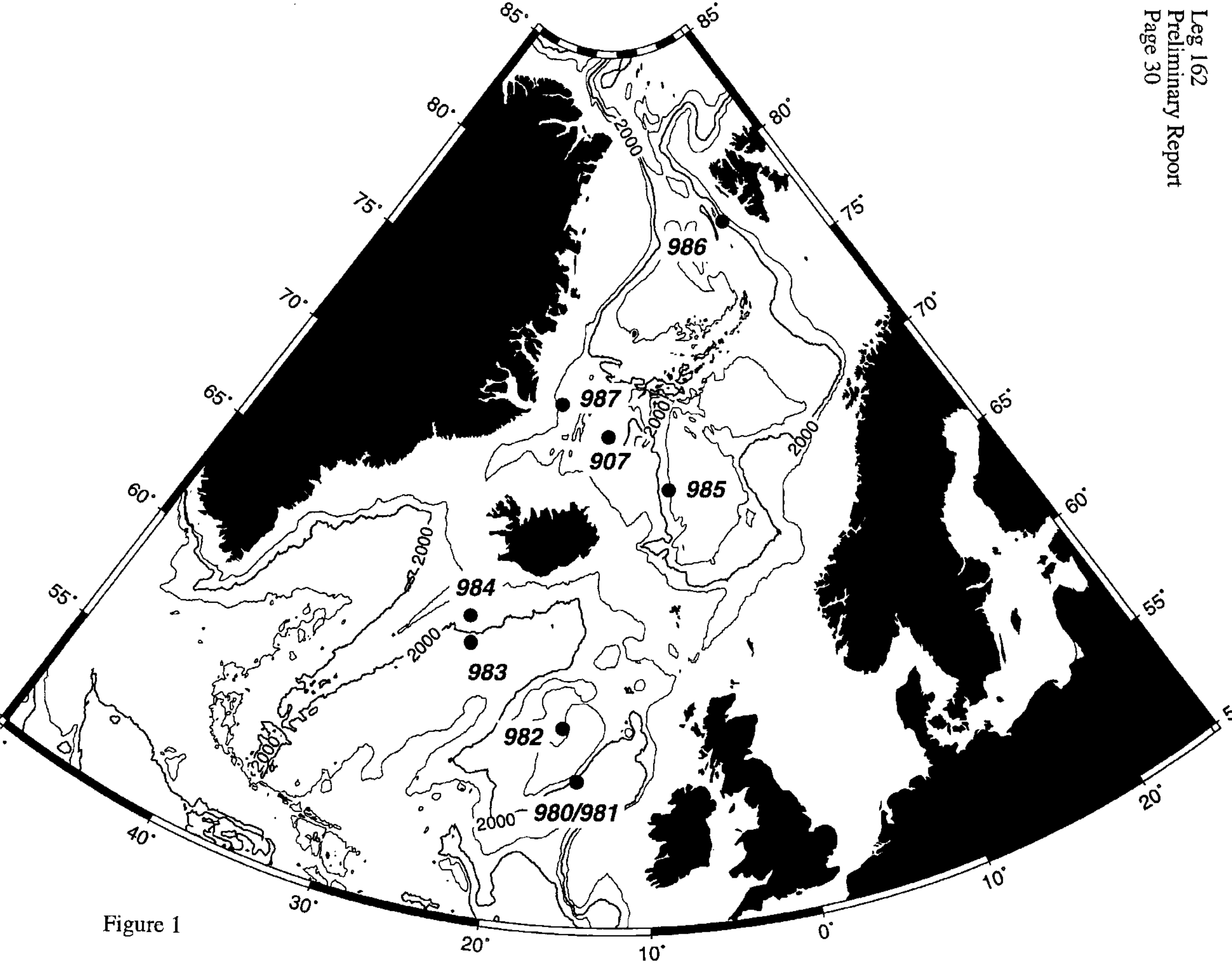

85°
80°
75°
70°
65°
60°
55°
50°
40°
30°
20°
10°
0°
2000
986
987
907
985
984
983
982
980/981

Figure 1

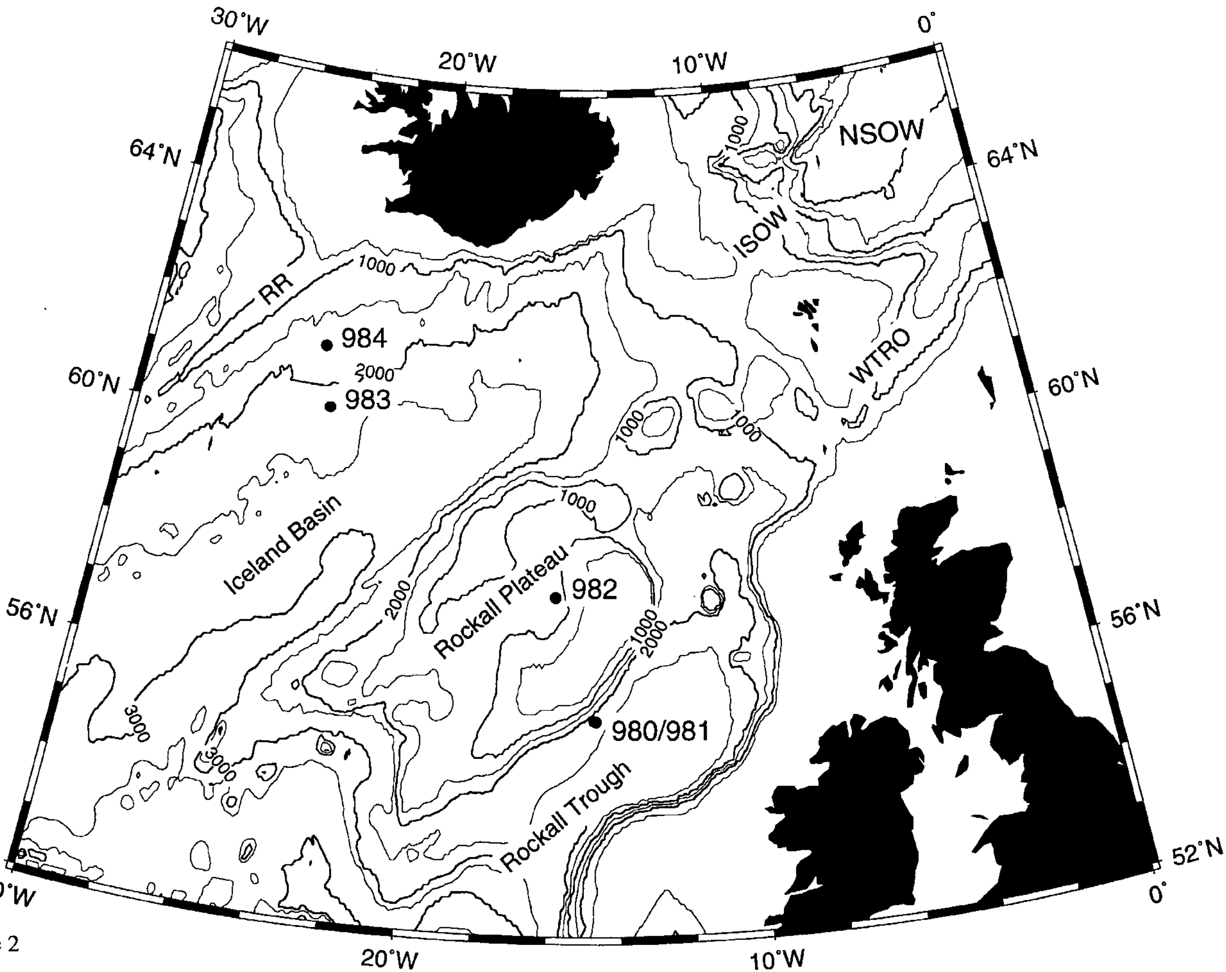
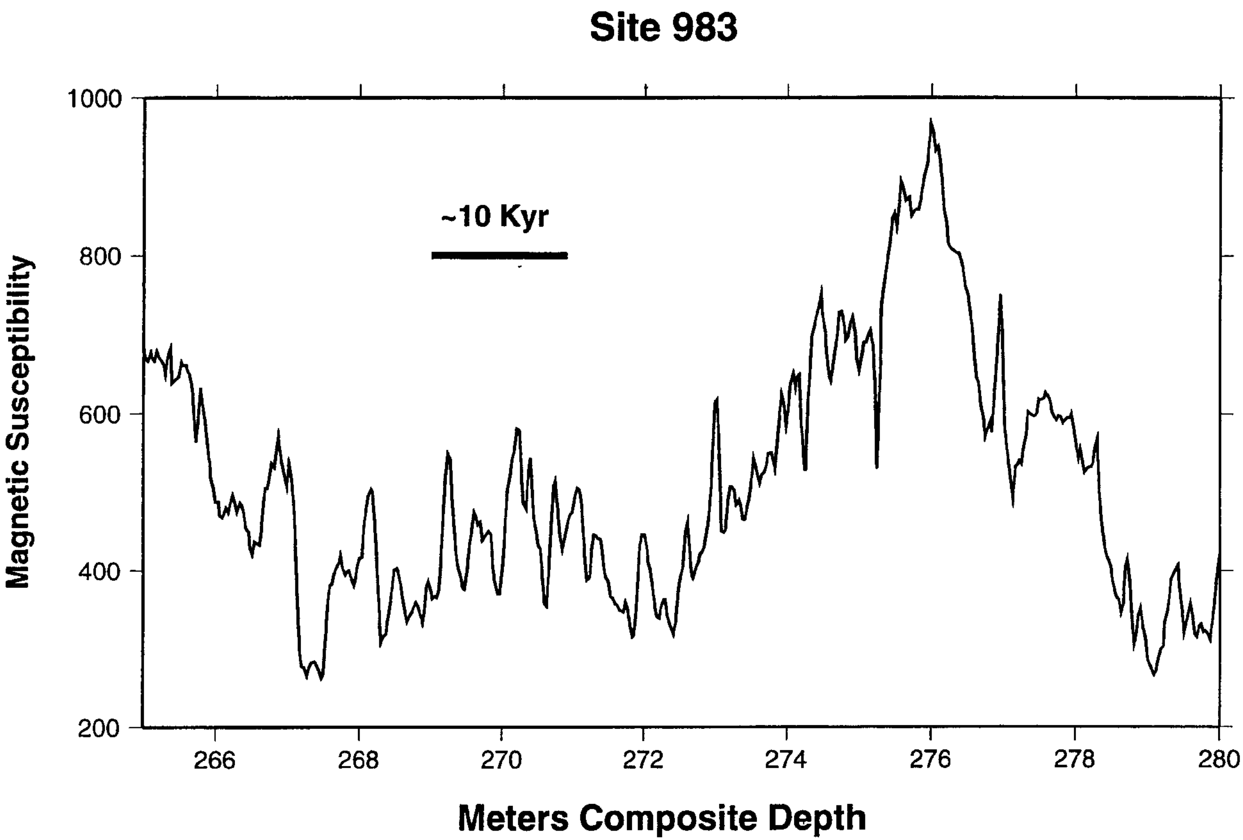
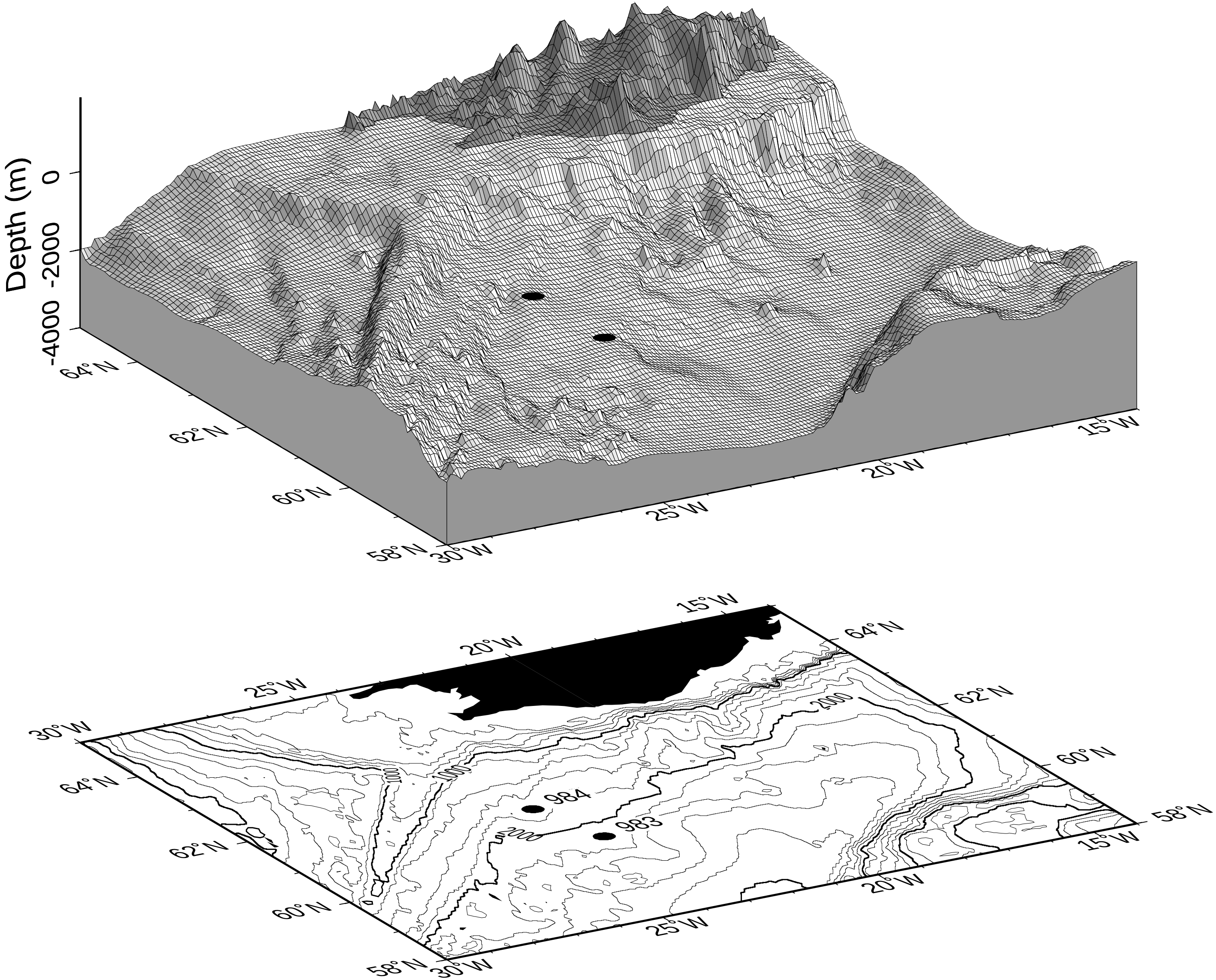

30°W
0°
20°W
10°W
NSOW
1000
64°N
64°N
ISOW
1000
RR
984
WTRO
2000
60°N
60°N
983
1000
1000
1000
Iceland Basin
982
Rockall Plateau
2000
56°N
56°N
1000
2000
3000
980/981
3000
Rockall Trough
Rockall Trough
52°N
52°N
30°W
0°
20°W
10°W

Figure 2



Site 983
~10 Kyr
Magnetic Susceptibility
1000
800
600
400
200
266
268
270
272
274
276
278
280
Meters Composite Depth

Figure 3


Depth (m)
0
-2000
-4000
64° N
62° N
60° N
58° N
30° W
25° W
20° W
15° W
1000
2000
984
983

ROCKALL PLATEAU BATHYMETRY

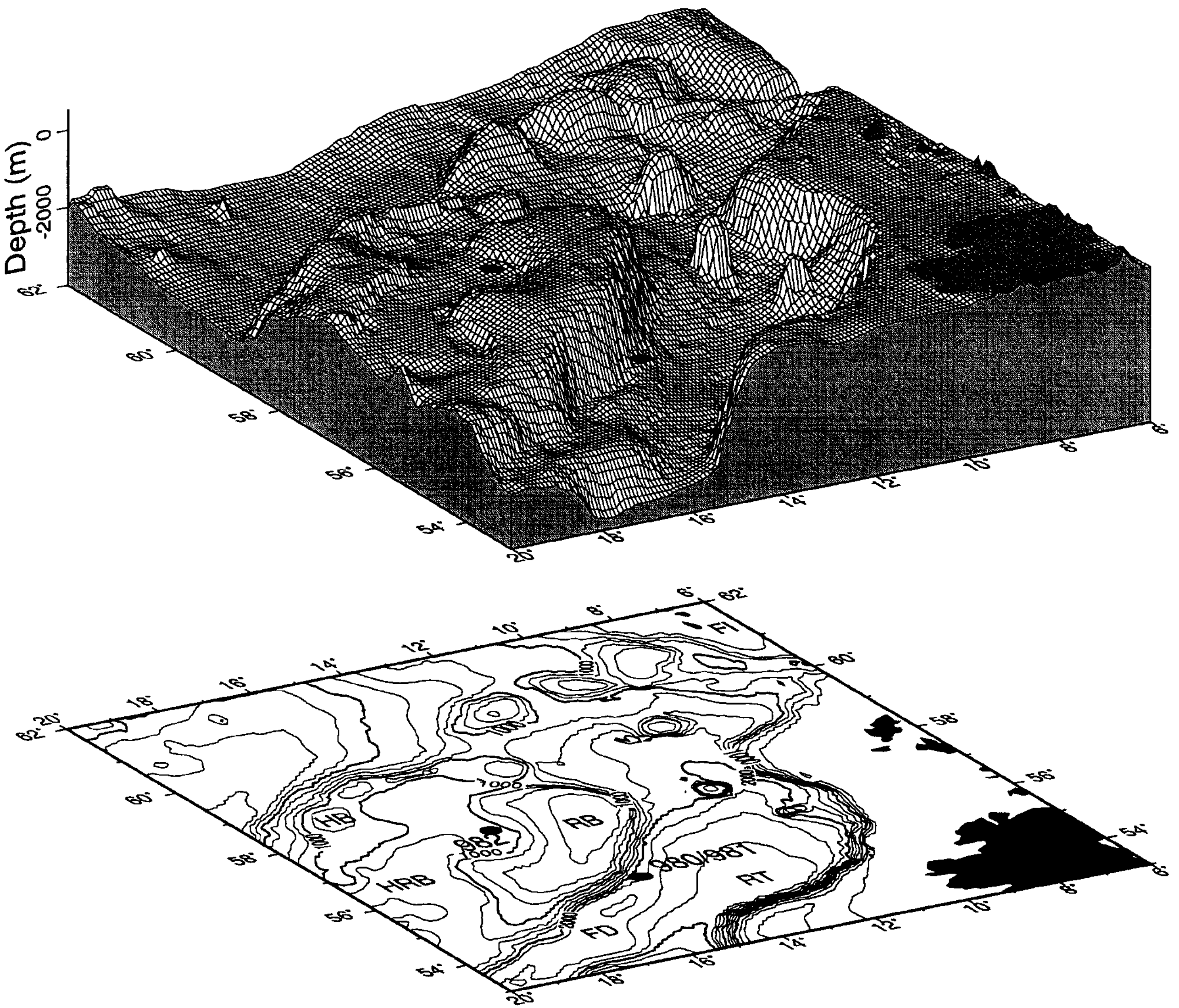
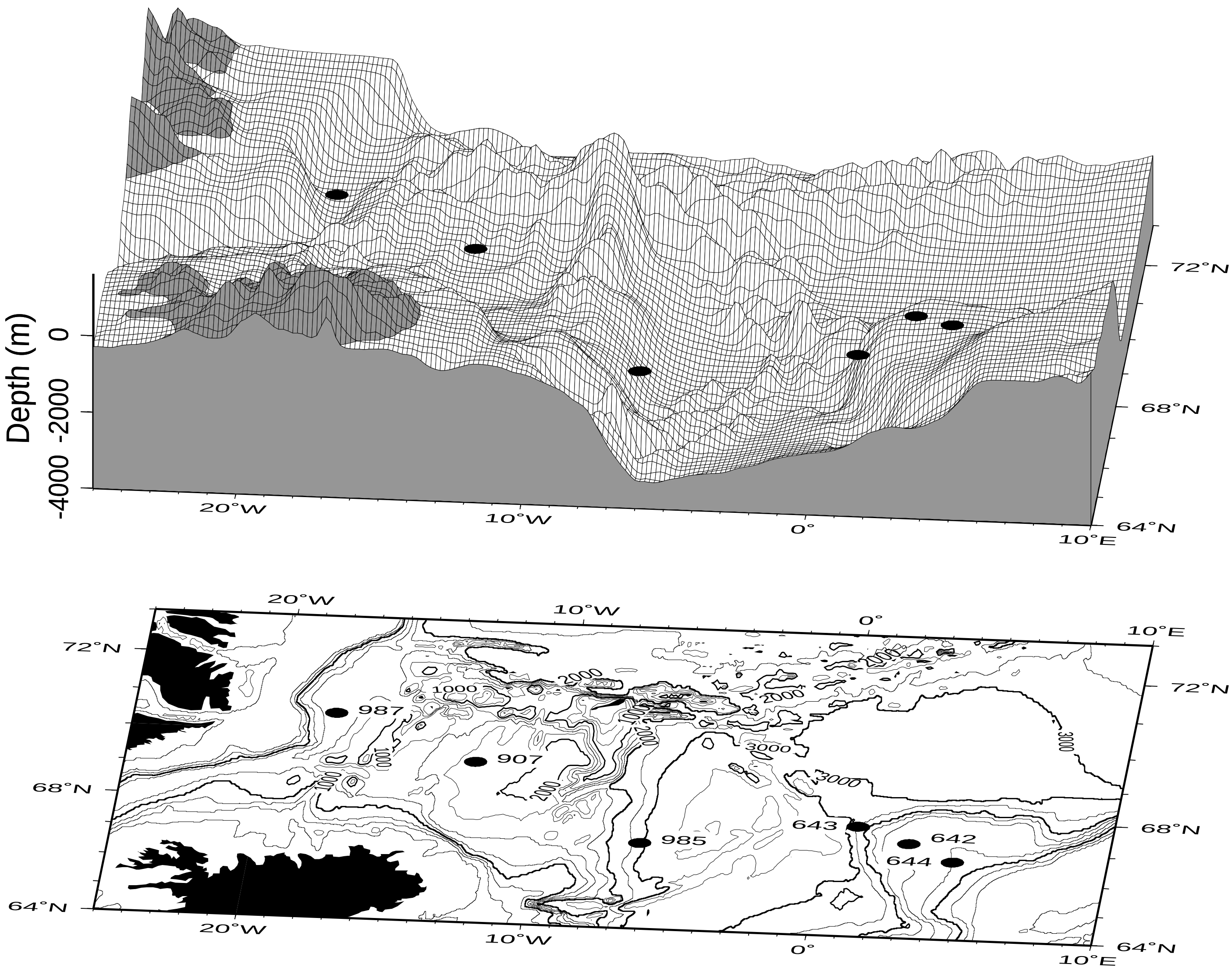


Figure 5



Depth (m)
0
-2000
-4000
20°W
10°W
0°
10°E
64°N
68°N
72°N
987
907
985
643
642
644
1000
2000
3000

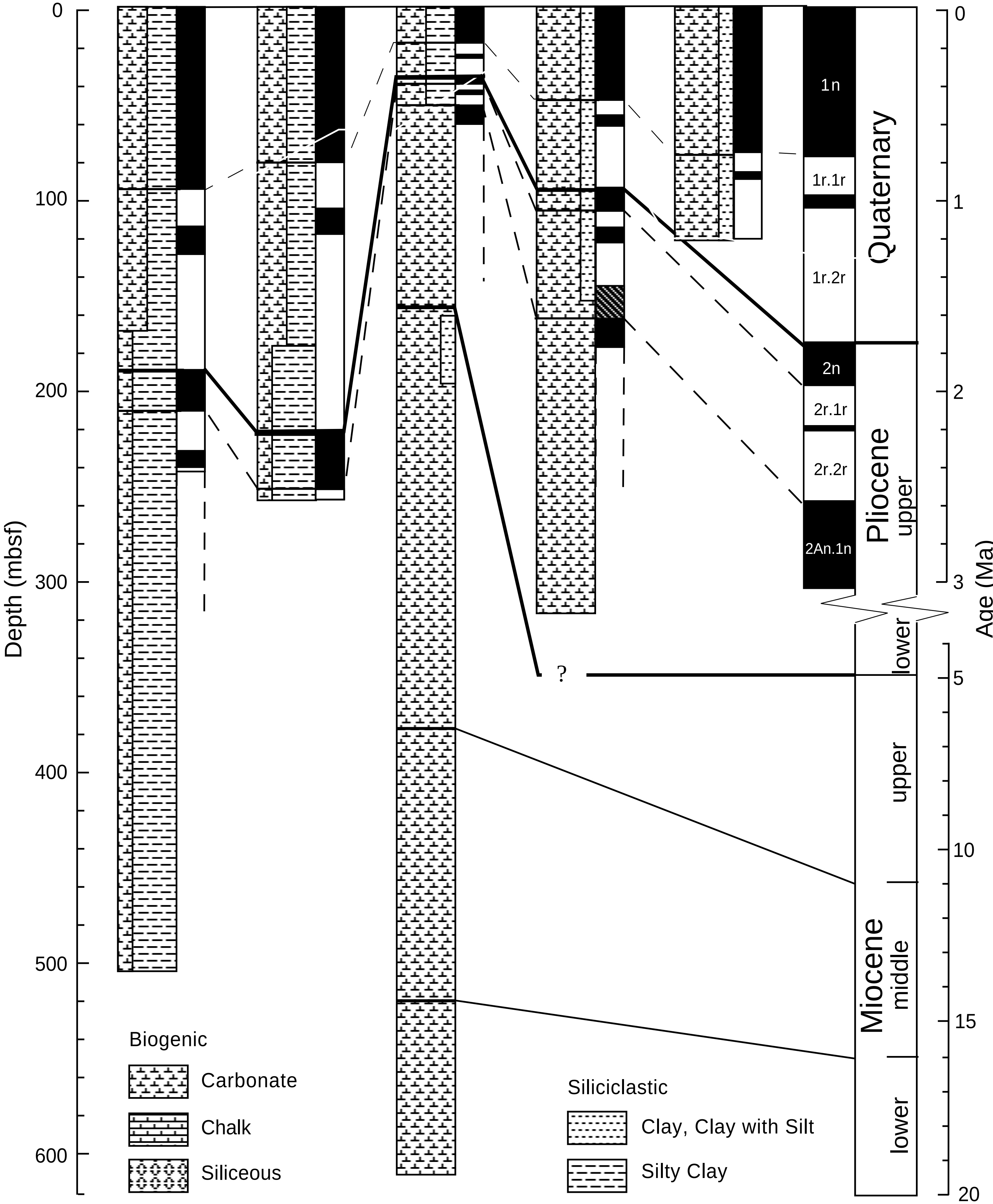
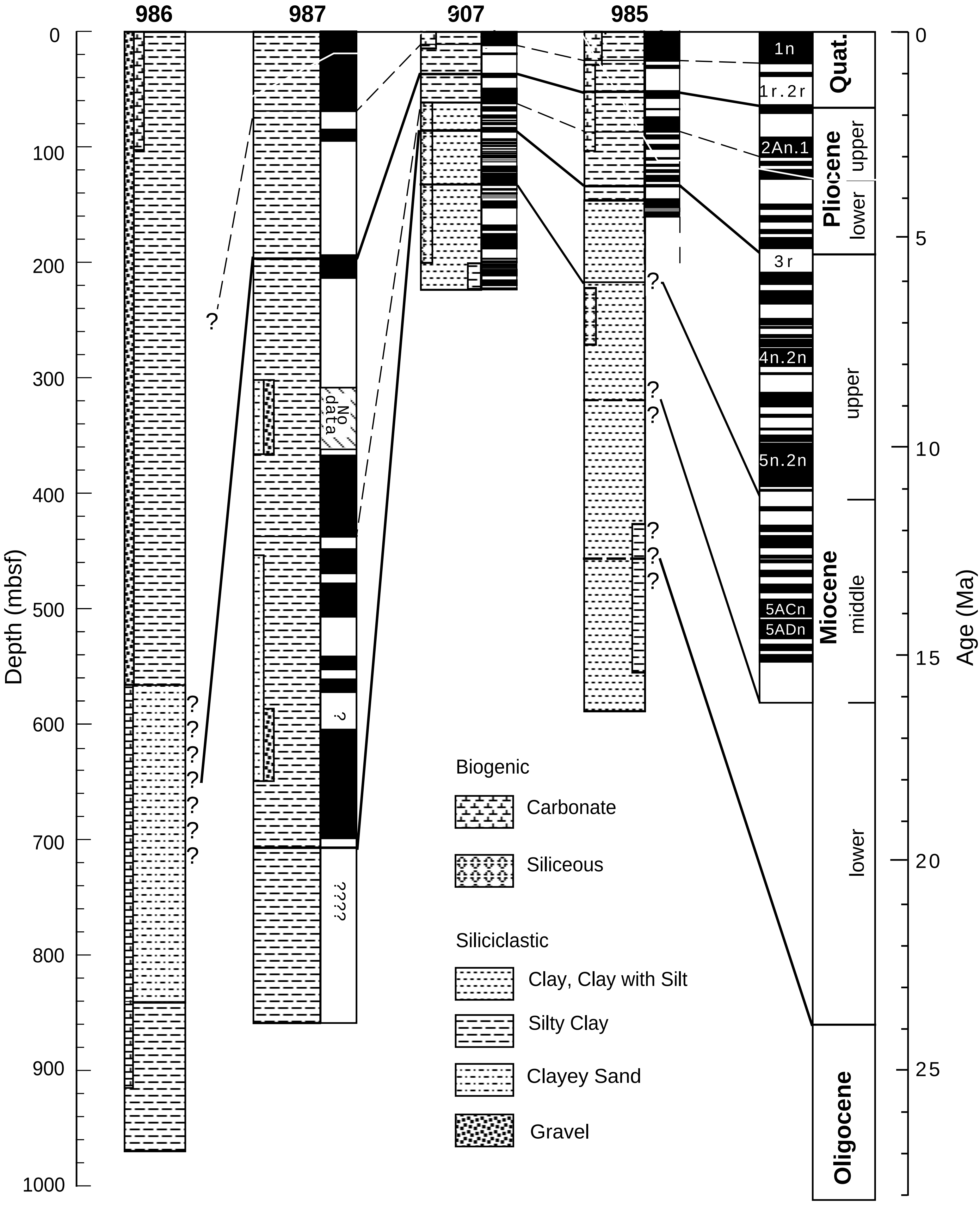

Depth (mbsf)
0
100
200
300
400
500
600
Age (Ma)
0
1
2
3
5
10
15
20
1n
1r.1r
1r.2r
2n
2r.1r
2r.2r
2An.1n
Quaternary
Pliocene
upper
lower
Miocene
upper
middle
lower
?
Biogenic
Carbonate
Chalk
Siliceous
Siliciclastic
Clay, Clay with Silt
Silty Clay

Figure 7A



986
987
907
985
Depth (mbsf)
0
100
200
300
400
500
600
700
800
900
1000
No data
1n
1r.2r
2An.1
3r
4n.2n
5n.2n
5ACn
5ADn
Quat.
Pliocene
upper
lower
Miocene
upper
middle
lower
Oligocene
Age (Ma)
0
5
10
15
20
25
Biogenic
Carbonate
Siliceous
Siliciclastic
Clay, Clay with Silt
Silty Clay
Clayey Sand
Gravel

Figure 7B

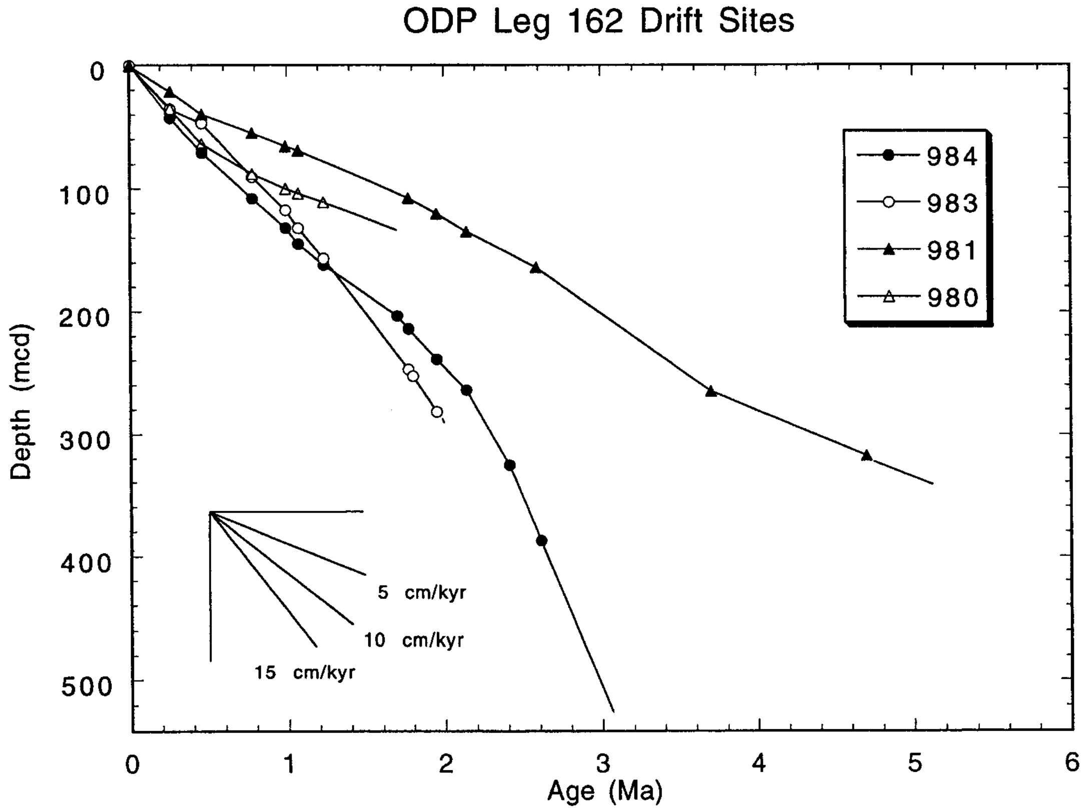
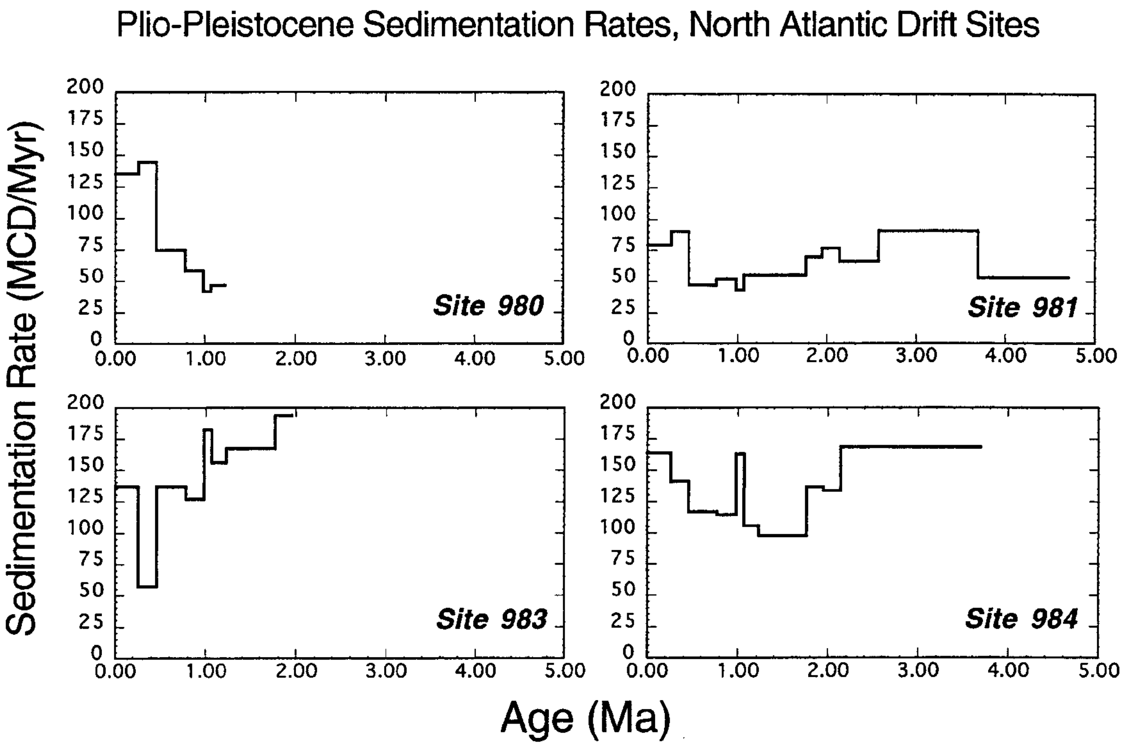

ODP Leg 162 Drift Sites
Depth (mcd)
Age (Ma)
0
100
200
300
400
500
0
1
2
3
4
5
6
984
983
981
980
5 cm/kyr
10 cm/kyr
15 cm/kyr

Figure 8A

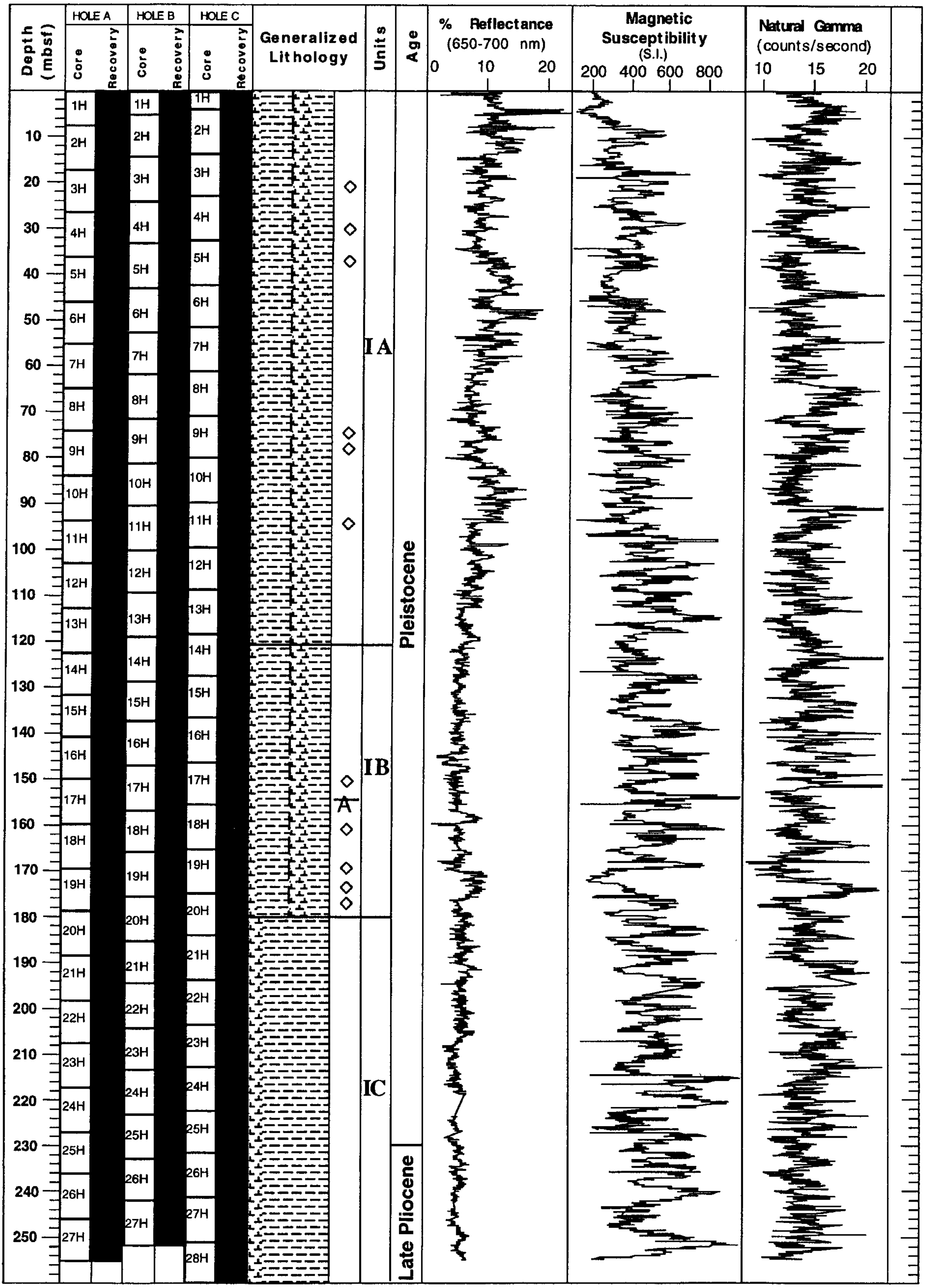


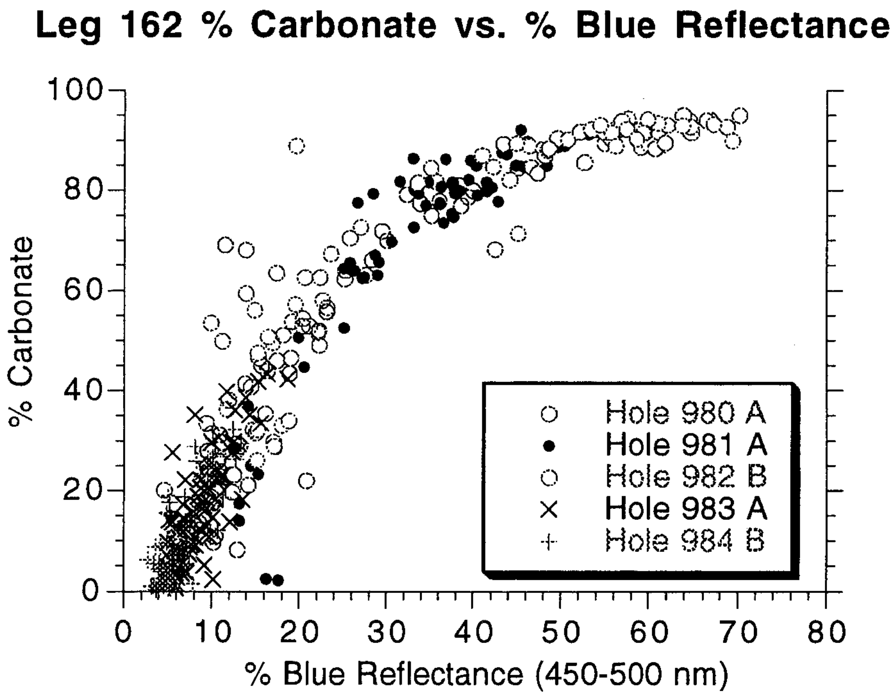
Plio-Pleistocene Sedimentation Rates, North Atlantic Drift Sites
Sedimentation Rate (MCD/Myr)
Age (Ma)
Site 980
Site 981
Site 983
Site 984
0
25
50
75
100
125
150
175
200
0.00
1.00
2.00
3.00
4.00
5.00

Figure 8B

Figure 9

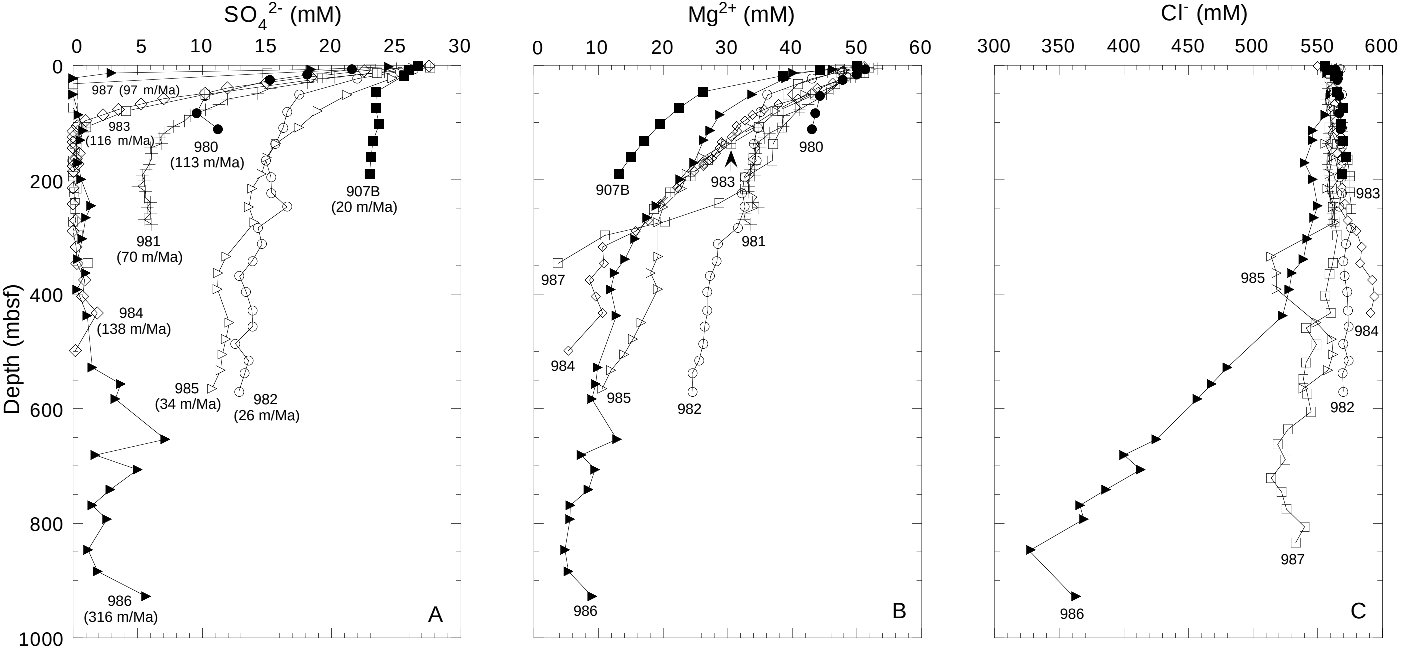
Leg 162 Site 983





Leg 162 % Carbonate vs. % Blue Reflectance
% Carbonate
% Blue Reflectance (450-500 nm)
0
20
40
60
80
100
0
10
20
30
40
50
60
70
80
Hole 980 A
Hole 981 A
Hole 982 B
Hole 983 A
Hole 984 B

Figure 10



SO4 2- (mM)
Mg2+ (mM)
Cl- (mM)
Depth (mbsf)
0
5
10
15
20
25
30
0
10
20
30
40
50
60
300
350
400
450
500
550
600
0
200
400
600
800
1000
987 (97 m/Ma)
983
(116 m/Ma)
980
(113 m/Ma)
981
(70 m/Ma)
907B
(20 m/Ma)
984
(138 m/Ma)
985
(34 m/Ma)
982
(26 m/Ma)
986
(316 m/Ma)
A
907B
983
980
981
987
984
985
982
986
B
983
985
984
982
987
986
C

OPERATIONS SYNOPSIS

The ODP Operations and Engineering personnel aboard JOIDES Resolution for Leg 162 were:

Operations Superintendent:	Michael Storms
Schlumberger Engineer:	Steven Kittredge

OPERATIONS SYNOPSIS

Sites 980 and 981

The operational plan for Sites 980 and 981 (FENI-1 and FENI-2) called for coring to approximately 110 mbsf and 225 mbsf, respectively, for three APC holes at each site. The vessel left Leith the evening of 7 July. At midnight on 9 July the ship slowed down to 6.0 kt. The seismic gear was deployed and tested for 1.5 hr, and approximately 6 hr were spent surveying these first two coring sites near the crest of the Feni sediment drift. Based on the survey results, we located Site 980 (FENI-1) about 0.5 nm south of the originally proposed site in order to better target an expanded upper seismic sequence (Pleistocene). Site 981 (FENI-2) was located about 0.5 nautical miles (nmi) northeast of the original site in the Leg 162 Prospectus and targeted an expanded lower seismic section (Pliocene). After the site survey was completed, the ship returned to Site 980 and dropped the beacon at 0846 hours on 10 July 95.

A standard APC/XCB bottom-hole assembly (BHA) was used for all holes at Sites 980 and 981, including a nonmagnetic drill collar. At both sites, subsequent holes (B and C) were offset 15 m to the north. The mudline was established for each hole. The APC firing depth was offset by a few meters for subsequent holes to establish continuous sediment sections.

Coring at Site 980 proceeded smoothly, with only one minor incident. The first APC shot at Hole 980B from 2179 mbrf, which was 3 m higher than for Hole 980A, recovered a full core that was discarded. The pipe was raised to 2174 mbrf, or a full 8 m higher than where Hole 980A was spudded from, and recovered 4.17 m of core. Target depth was reached in each hole. Core orientation was conducted using the Tensor tool on Cores 980B-3H through 13H, and Cores 980C-4H through 14H. Operations at Site 980 were terminated when the beacon was recovered at 2300 hrs on 11 July.

Site 981 (FENI-2) is approximately 2 nmi southeast of Site 980, so the vessel was maneuvered in DP mode to the global positioning system (GPS) coordinates defined by the site survey. This took about 2.4 hr. The drill string was pulled to a depth of 2059.1 m or approximately 120 m above the seafloor during this transit. At 0120 hrs on 12 July the positioning beacon was dropped. Coring proceeded without incident with two minor exceptions. First, an incomplete stroke occurring on Core 981A-32H unseated the oil saver when the APC barrel was rigged for Core 981A-34H, at which point the sinker bars were laid out and operations were switched to the forward coring line. Second, coring was suspended in Hole 981A when a maximum overpull of 50,000 pounds occurred on Core 981A-34H. Scientific target depth was reached in all holes.

Core orientation was conducted using the Tensor tool on Cores 981A-3H through 34H and Cores 981C-4H through 14H. In addition, 15 temperature measurements were made using the ADARA tool. Eleven consecutive temperature measurements were made on Cores 981C-4H through 14H, and additional measurements were made on Cores 981C-16H, 18H, 20H, and 22H. Core 981C-22H required washover of 5.0 m and an overpull of 100,000 lb prior to retrieval. Temperature measurements were suspended at that point. Occupation of Site 981 ended when the vessel was secured for transit and got underway at 0315 hr on 15 July 1995.

Site 982

The operational plan for Site 982 (NAMD-1) called for three APC holes to approximately 200 mbsf, and one XCB hole to 500 mbsf. Standard Quad-combo and FMS logging were to be conducted in the deep hole, with the added possibility of running the magnetic susceptibility tool.

At 1506 hr on 15 July the ship slowed down to 6.0 kt and the seismic gear was deployed for a 9 nmi (about 1.5 hr) predrilling survey of Site 982 (NAMD-1). Based on the survey we chose Site 982 to be about 300 m to the northeast of the proposed NAMD-1 site in order to avoid small-scale faulting observed in the seismic records. By 1815 hr on 15 July, the seismic profiling gear had been recovered, the vessel had returned to the drilling location based on GPS coordinates, and the positioning beacon had been deployed initiating Site 982 and Hole 982A.

A standard APC/XCB BHA was used for all holes at Site 982, including a nonmagnetic drill collar. Subsequent holes (982B and C) were offset 15 m to the north, while Hole 982D was offset 5 m to the north. The mudline was established for each hole except Hole 982D. The APC firing depth was offset by a few meters for subsequent holes in order to establish continuous sediment sections, except for Hole 982D.

Coring at Hole 982A proceeded without incident until Core 982A-27H would not come free with 100,000 lb of overpull. The previous Core 982A-26H required 40,000 lb of overpull. Both cores had full stroke indications. The washover technique was used, but was limited to 4.0 m due to drilling kelly limitations. After several heave cycles and limited jarring attempts, the driller continued to apply increasing tension to the coring assembly. During an upheave the overpull reached 150,000 lb and the barrel apparently came free. Upon recovery it was found that the pin thread on the upper inner core barrel had parted, leaving the lower 15-ft inner barrel, liner seal sub, and core shoe in the hole. Advance by recovery was used to determine the final hole depth, and the hole was terminated at that point. Hole 982A reached the scientific target for triple coring, and Hole 982B was deepened instead of this hole.

Coring at Hole 982B was without incident until Core 982B-26H. This core penetrated to a depth of 243.0 mbsf, just one core above the point where the high overpull and subsequent inner barrel connection failure occurred. Although Core 26H only required 25,000 lb of overpull to extract it from the formation, it was considered prudent to switch to XCB coring at that point. Coring was suspended at a depth of 614.9 mbsf when the scientific target was reached. The last four XCB cores, from 576.4 to 614.9 mbsf, were characterized by low recovery that averaged between 2% to 8%.

Upon completion of coring operations at Hole 982B, two annular-hole volumes of seawater were circulated. A wiper trip identified no overpull or drag. Only 1.5 m of fill was found at total depth (TD), which was readily circulated out. The pipe was pulled to a logging depth of 82.6 mbsf. No drilling mud was required during the drilling operation, and the hole was considered to be in excellent condition. Two successful logging runs were made. The first run, using the Quad combo suite of tools, was deployed to within 1.9 m of bottom. The second run, using the FMS, reached to within 4.9 m of bottom. After completing the logging operations, the upgraded LDEO/BRG wireline heave compensator control system was tested. After the final suite of tools was recovered and the logging sheaves were rigged down, the drill pipe was tripped above mudline, clearing the seafloor and ending Hole 982B.

Coring at Hole 982C proceeded without incident until the scientific target for the hole had been reached. Core orientation on this hole using the Tensor tool was conducted on Cores 982C-3H through 7H.

The vessel was offset 5 m north in preparation for spudding Hole 982D. This hole was to be a single APC core across an area not recovered completely in the previous three holes. The same water depth as Hole 982C was used as a reference point for drilling to 20 mbsf. APC Core 1H was then taken, recovering 9.76 m. The positioning beacon was recovered and the vessel was secured for transit. We were underway at 2112 hr on 19 July 1995.

Site 983

Site 983 (GARDAR-1) was a high-priority contingency site which was drilled because the leg was ahead of schedule by nearly 2 days. The operational plan called for three piston-cored holes to approximately 300 m below the sea bed. Because time was short, we decided to core three shallower holes rather than two deeper holes.

Head winds limited the vessel's speed while en route to Site 983. Prior to slowing down for presite seismic profiling, the vessel averaged a mere 8.3 kt. At 0742 hr on 21 July 1995 the ship slowed down to 6.0 kt, and the seismic gear was deployed for a limited pre-site survey of the site. By 1158 hr on 21 July the seismic profiling gear was recovered, the vessel returned to the drilling location, based on GPS coordinates, and the positioning beacon was deployed, initiating Hole 983A.

A standard APC/XCB BHA was used for all holes at Site 983, including a nonmagnetic drill collar. Subsequent holes (983B and C) were offset 15 m to the north. The mudline was established for each hole. The APC firing depth was offset by a few meters for subsequent holes in order to establish continuous sediment sections.

Coring proceeded without incident at all three holes until scientific target depth was reached. The following cores were oriented with the Tensor tool: 983A-3H through 27H; 983B-3H through 27H; and 983C-3H though 27H. The drill pipe was tripped above mudline, clearing the seafloor, and the positioning beacon was released and subsequently recovered at 2225 hr on 23 July 95. The vessel was secured for transit and we were underway at 0200 hr on 24 July 95.

Site 984

The operational plan for proposed site BJORN-1 called for 3 piston-cored holes to approximately 300 m below the sea bed, with one hole deepened to approximately 500 mbsf using the XCB coring system. Core orientation was desired on at least two of the holes along with the possibility of ADARA temperature measurements on one hole. All four logging strings were deployed on the deepest hole.

After a brief 57 nmi transit to Site 984 (BJORN-1), the vessel slowed to survey speed (6.0 kt) at 0636 hr on 24 July, and the seismic profiling gear was deployed for a short seismic site survey. By 1020 hr on 24 July 95 the seismic profiling gear was recovered, the vessel returned to the drilling location based on GPS coordinates, and the positioning beacon was deployed, initiating Hole 984A.

A standard APC/XCB BHA was used for all holes at Site 984, including a nonmagnetic drill collar. Subsequent holes (984B and C) were offset 15 m to the north. The mudline was established for each hole. The APC firing depth was offset by a few meters for subsequent holes in order to establish continuous sediment sections.

Routine piston coring at Hole 984A proceeded until the core barrel for Core 984-20H jammed inside the drill pipe while running in the hole. The barrel was stuck at approximately 1605 m depth. After several limited attempts to free the barrel the overshot shear pin was sheared, and the sinker bar string with the Tensor core orientation hardware was recovered. The orientation gear was removed and the sinker bar string was run in for another, more vigorous, but unsuccessful attempt at jarring the barrel free. The decision was made to abandon the hole, and the drill pipe cleared the seafloor at 0246 hr on 25 July 95, ending Hole 984A. Upon recovery the barrel was found to be jammed by a shear pin stub.

At Hole 984B, APC coring proceeded without incident until Core 984A-31H required 100,000 lb overpull and drillover to recover. Extended Core Barrel (XCB) coring was initiated with Core 984B-32X and continued with remarkable recovery (100%) until Core 984B-48X. Beginning at a depth of 446.1 mbsf, five straight zero-recovery cores were taken. All attempts to recover the formation proved futile. The final Core 984B-53X reached scientific target depth and recovered 6.6 m of core that appeared to be similar to, but perhaps slightly more friable than, the formation recovered earlier with good success. No satisfactory explanation of the recovery problem was found.

Upon completion of coring operations at Hole 984B, two annular-hole volumes of seawater were circulated, and a wiper trip with the drill string was made to 1759.0 m (100.0 mbsf). No overpull or drag was identified during the wiper trip and no fill identified on bottom. The go-devil for locking open the LFV was pumped downhole, and the pipe was pulled to a logging depth of 102.2 mbsf. The hole was considered to be in excellent condition, and therefore it was unnecessary to displace it with mud for logging. Four successful logging runs (Quad combo, FMS, GHMT, and geochemical tool) were made and all tool strings reached to within 3.7 m, or less, of bottom.

At Hole 984C, APC coring proceeded until the scientific target was reached. Severe liner collapse problems were encountered on the final two cores. The barrel for Core 984C-30H was actually removed from the pipe with several feet of liner (with core) dangling below the shoe. The liner collapsed and stretched resulting in a significantly reduced outer diameter.

Because Hole 984A was terminated prematurely, it was decided to once again offset the vessel 15 m north and spud Hole 984D. After establishing mudline with Core 984D-1H, the hole was deepened by drilling ahead an additional 157.8 m. Continuous APC coring then commenced at a depth of 166.2 mbsf and continued until the scientific target for the hole had been reached. Coring was terminated slightly higher than on Hole 984C to avoid a repeat of the severe liner collapse problems encountered on the final two cores of that hole.

ADARA temperature measurements were taken continuously on Cores 984B-3H through 13H and Cores 984B-15H, 17H, and 19H. The bottom-water temperature was measured with the ADARA tool before taking Core 984D-1H. The following cores were oriented with the Tensor tool: Cores 984A-3H through 19H and Cores 984B-3H through 19H.

The positioning beacon was released and subsequently recovered at 1420 hr on 29 July 95. The vessel was secured for transit and got underway for Site 907 (ICEP-1) at 1742 hr on 29 July 95.

Site 907

The vessel covered the 625 nmi transit from Site 984 to Site 907 (ICEP-1) at an average speed of 11.9 kt At 2249 hr, the vessel slowed to survey speed (6.0 kt) and a short PDR acoustic profile was recorded across the site. The ship then returned to the site coordinates using the GPS.

Site 907 was cored initially on Leg 151. The first Hole 907A was contacted and penetrated into a basalt sill at approximately 220 mbsf, and ADARA temperature measurements were taken during the piston coring operation. The Leg 162 drilling plan was to core two additional APC holes in order to construct a complete sediment section and provide additional sampling material. Because there was no interest in recovering the igneous contact, it was planned that both holes would be terminated slightly above the total depth of Hole 907A.

At 0304 hr on 1 August 1995 the positioning beacon was deployed, initiating Hole 907B. A site location error of 3 min (1.5 nmi) to the east was discovered in the Leg 162 prospectus when the PDR showed nearly 100 m more water depth than at Hole 907A. The beacon was released and subsequently recovered, and the vessel was offset in dynamic positioning (DP) mode to the correct site coordinates while the pipe was being tripped.

A standard APC/XCB BHA was used for all holes at Site 907, including a nonmagnetic drill collar. Hole 907B was offset 15 m to the north of Hole 907A, and Hole 907C was offset the same distance north of Hole 907B. The mudline was established for each hole. The APC firing depth was offset by a few meters for subsequent holes to establish continuous sediment sections.

Routine piston coring proceeded without incident at Holes 907B and 907C until the scientific target depths were reached. All cores, beginning with Cores 907B-3H and 907C-3H, were oriented using the Tensor tool. The positioning beacon was released and subsequently recovered at 1138 hr on 2 August, and the vessel was secured for transit and started underway for Site 985.

Site 985

According to the plan in the Leg 162 Prospectus, the next site should have been EGM-4 on the East Greenland Margin. The ice data available to the shipboard party during the coring of Hole 907C showed that the EGM-4 drill site was positioned on the edge of the 20% ice concentration line. Just hours before getting underway, an updated special sensor microwave imager (SSMI) report was obtained which placed the EGM-4 drill site 20 nmi "outside" the 20% ice concentration line. Based on this promising report, and with a plan to survey alternate sites up to 10 nmi east of the proposed EGM-4 site, the vessel departed for EGM-4 at 1445 hr on 2 August 1995. Less than 1 hr after getting underway, a faxed "interpreted" synthetic aperture radar (SAR) image with data from 2 August 1995 was received which indicated that the EGM-4 drill site was 15 nmi "inside" what was referred to as "closed ice." In addition to being more recent, the SAR data is considered more accurate then the more general SSMI information. This new information made the EGM-4, as well as its alternate sites EGM-4a-d, essentially undrillable at that time.

In the normal course of events, we would have then proceeded to our next first-priority site, SVAL-1. However, we had to remain near Iceland to wait for resupplies of some critical items. The ship had only enough core liners onboard to complete a limited amount of coring (about 700 m) and was running very low on acetone. A resupply was scheduled to take place via rendezvous with the supply boat M/V *Strakur* prior to departure for the northern drill sites. Hence, the decision was made to steam towards ICEP-3, a second-priority alternate site. While underway, the computer file containing the SAR photo was picked up from the ODP directory, and the interpreted information received earlier regarding EGM-4 ice conditions was confirmed.

The drilling plan for ICEP-3 (Site 985) was to core a single APC/XCB hole as deep as possible in the time before the resupply ship arrived. The Pollution Prevention and Safety Panel (PPSP) had approved drilling to a depth of 500 mbsf, but the co-chiefs felt that any major scientific rewards would most likely be attained at deeper depths. As a result, they asked for and received permission to extend the depth of Hole 985A to 650 mbsf, time permitting. No core orientation or temperature measurements were to be taken at this site.

After completing the presite survey, the vessel returned to the coring location based on GPS coordinates. The positioning beacon was deployed at 1358 hr on 3 August 1995, initiating Hole 985A.

A standard APC/XCB BHA was used for all holes at Site 985, including a non-magnetic drill collar. The mudline was established for each hole. The APC firing depth was offset by a few meters for Hole 985B relative to Hole 985A in order to establish a continuous sediment section over the double-cored interval. Position, depths, and coring totals for each hole are summarized at the top of this chapter.

Routine piston coring at Hole 985A proceeded until Cores 985-14H through 17H failed to bleedoff pressure, indicating incomplete stroke. Extended Core Barrel (XCB) coring was initiated with Core 985A-18X and continued with excellent recovery. Coring was temporarily halted when the methane/ethane ratio dropped from 100,000+ in Core 985-36X to 6 in Core 985-37X; gas concentrations were very small. In addition to the abrupt reduction in gas ratio, trace amounts of higher hydrocarbons up through IC6 were detected. At that time cutting of Core 985A-40X was just completed and coring operations were halted until additional analyses could be evaluated. The hydrocarbon trends returned to normal in Cores 985A-38X and 39X, and the results from Core 985A-40X were completely back to normal. Throughout the coring cycle there were no changes in formation properties or coring parameters. Coring resumed and continued without incident through Core 985A-62X when the scientific target was reached.

Upon completion of coring operations a wiper trip was made in preparation for wireline logging. Overpull of 30,000 to 50,000 lb was experienced, and 9 m of fill were identified on bottom. The hole was again circulated with two annular-hole volumes of seawater while the go-devil was pumped downhole. The pipe was then pulled to a logging depth of 90.1 mbsf with 10,000 to 20,000 lb of drag. Wireline logging was not successful in this hole. The first logging run, which ran the Quad combo, was only able to get to 23 m below the bit, and all efforts to exceed that point failed. After a consultation with the co-chief scientists and the loggers, it was decided that any further logging attempts on Hole 985A be abandoned.

The vessel was offset 15 m north for spudding Hole 985B. APC coring proceeded without incident until the last remaining core liner was used on Core 985B-14H. Fortunately, the supply boat was expected within a few hours.

While waiting for the supply boat, the drilling line was cut and slipped prior to tripping the drill string back to the vessel. During the trip, the supply boat M/V *Strakur* arrived (1715 hr). After several unsuccessful attempts to come alongside due to "thruster wash" the captain decided to release the beacon, retract the hydrophones, and turn the vessel to give the supply boat more of a lee to come alongside. During the process the drill ship was allowed to drift with the current. The beacon was recovered at 1820 hr, and at 1845 hr the M/V Strakur was alongside, discharging her cargo.

The core liners, acetone, mail, and other requested supplies were taken aboard. Shipboard mail and a small airfreight package were discharged to the supply boat along with a Borehole Research Group logging trainee who had elected to leave his field of study and requested to return to shore. At 1915 hr on 7 August, the *Strakur* departed for a small harbor just north of Reykjavik.

The pipe trip continued throughout the loading/unloading process, and at 2115 hr that same day the vessel was secured and underway for Site 986 (SVAL-1).

Site 986

The vessel covered the 685 nmi to Site 986 (SVAL-1) at an average speed of 11.9 kt and encountered no difficulties while underway. At 0642 hr on 10 August 1995 the vessel slowed to survey speed (5.3 kt) and a seismic survey was carried out near the drill site. The main purpose of the survey was to offset slightly from the proposed drill site (SVAL-1) to avoid drilling through the entire thickness of a major debris flow identified in the pre-cruise data. Once the survey was completed, the ship returned to the site coordinates using GPS data.

The operational plan for this site called for two APC holes drilled to refusal or to approximately 200 mbsf. One hole was to be deepened to XCB refusal, which was estimated to occur at about 500 mbsf. The third hole was to be cored just short of the XCB hole TD and then continuously

RCB cored to a depth of 900 mbsf. This hole would not penetrate basement, but drill through the entire glacial sediment package, which was the major site objective.

Core orientation was not taken due to the high latitude of the site. A minimum number of ADARA temperature measurements were taken in the upper (APC) portion of the hole in order to establish a temperature gradient for the site. A full suite of logging tools was to be deployed on the deepest site, although intermediate logging of the XCB hole was to be considered if the hole TD reached an adequate depth.

The positioning beacon was deployed at 1208 hr on 10 August, initiating Hole 986A. A standard APC/XCB BHA was madeup, but the nonmagnetic drill collar was not required at this site. Hole 986A was spudded, and routine piston coring continued through Core 986A-14H, at which point the core pressure failed to bleed off, indicating incomplete stroke. Since APC refusal occurred at such a shallow depth it was decided to continue coring operations with the XCB system to approximately 200 mbsf, if recovery and core quality remained acceptable. XCB coring was initiated with Core 986A-15X. Coring continued with excellent recovery, averaging 81%, except for two cores with zero and 0.75 m recovery. Coring was halted after Core 986A-24X when the scientific target was reached.

Methane was encountered beginning with Core 986A-2H and continued through Core 24X at 206.0 mbsf. Headspace data for the hole indicated methane (C1) concentrations ranging from 955 to 57852 ppm, and ethane (C2) concentrations ranging from 2 to 65 ppm. Propane (C3) was detected beginning with Core 12H and ranged from 1 to 7 ppm. The methane/ethane ratios varied from 356-11570. Higher molecular weight hydrocarbons were not detected.

Hole 986B was spudded 15 m south of Hole 986A. We suspected that the first core barrel impacted a dropstone, which would have affected the total recovery. In addition, if this were true the mudline established from this core would be erroneous, and this was not desirable on a hole with a projected deep penetration. It was therefore decided that a new hole should be spudded.

The spudding of Hole 986C took place at the same location as Hole 986B (no vessel offset), and the bit was positioned at the same level (2061.0 m) prior to spudding. Routine piston coring continued until Cores 986C-6H through 8H failed to bleed off pressure, indicating incomplete stroke. Three successful ADARA temperature measurements were taken on Cores 986C-3H, 5H, and 7H, and these data indicated a high temperature gradient of 152°C/km.

XCB coring was initiated with Core 986C-9X and continued until coring was halted after Core 986C-44X, when a core barrel became stuck inside the drill pipe. After several attempts at jarring the barrel loose, it came free. After recovering the core barrel, we found that the XCB cutting shoe thread connection had over-torqued, leading to a swollen box and subsequent mechanical failure. Continued coring with the XCB system was deemed unwise and would risk losing the opportunity to log the existing hole; therefore, coring operations were suspended.

Small quantities of hydrocarbons were present throughout the core until TD with Core 986C-44H at 408.0 mbsf. Headspace data for the hole indicated methane (C1) ranged from 3334 to 49887 ppm, and ethane (C2) from 10 to 117 ppm. Propane (C3) ranged from 0 to 16 ppm. The methane/ethane ratios varied from 256 to 1672. Higher molecular weight hydrocarbons were not detected.

As done on the previous holes, two annular-hole volumes of seawater were circulated. A wiper trip with the drill string was then made to 2150.4 m (87.4 mbsf). No overpull was experienced during the wiper trip, but 30,000 lb of drag was noted at 2304 m during the trip back to bottom. In addition, 15 m of fill were identified on bottom. The go-devil for locking open the LFV was pumped downhole while another two hole volumes of fluid were pumped. The pipe was then pulled to a logging depth of 102.6 mbsf. Drilling mud was not required during the drilling operation, and the hole was considered to be in excellent condition; therefore, the hole was not displaced with mud for the logging run. Three logging runs were successfully made on this hole. The Quad combo, FMS, and GHMT/NGTC tool strings were deployed to within 21.0, 36.0, and 41.0 m, respectively, of the bottom of the hole. After the final suite of tools was recovered, the logging sheaves were rigged down, the bit was run to bottom, and the hole was filled with heavy mud.

The vessel then moved 50 m to the south in DP mode in preparation to core Hole 986D. This was the first hole on Leg 162 where the Rotary Core Barrel (RCB) coring system was used, which required a change in the bottom-hole assembly and the type of rotary core bit used. The new BHA was tripped back to bottom and Hole 986D was spudded at 0137 hr on 15 August. Because several hundred meters of the upper formation were to be drilled rather than cored, the seafloor depth from Hole 986C, 2063.0 m, was used. This was more accurate than the depth that would have been obtained by the driller "feeling" for bottom with the RCB drilling assembly.

Drilling ahead continued with a center bit in place to a depth of 2450.8 m or 387.8 mbsf. The center bit was recovered via wireline. Hole deviation measurements were taken on bottom and at 100 m increments on the way out of the hole. A hole deviation of approximately 3.6° was determined based on these measurements.

Continuous RCB coring commenced with Core 986-1R. Core recovery was highly variable, ranging from 0% to an excellent 100%. Beginning with Core 986D-22R a string of five straight empty core barrels was retrieved through an apparent coarse-grained sandy debris-flow zone, but flows of this nature were not unexpected in this geological environment. Core 986D-27R recovered a mere 0.33 m and then core recovery improved significantly. With the exception of two zero-recovery cores all remaining cores recovered between 11% and 102%. Small quantities of hydrocarbons were present throughout the coring of the hole, just as in the other holes cored at this site. Headspace data were monitored closely throughout the coring process.

Coring was terminated after Core 986D-60R, which reached a depth of 3027.6 m (964.6 mbsf). The termination depth was in excess of the original scientific target depth of 900 mbsf, but did not reach the desired 1000 mbsf. Coring was halted due to several low-recovery cores and to the bit plugging, which occurred on three successive core barrels. In addition, primarily because of the bit plugging problems, the rate of forward progress decreased substantially. The bit deplugger was deployed several times during the coring process when we suspected dropstones were plugging the bit throat. One final run with the bit deplugger was made after recovering Core 986D-60R, and pump pressures were once again restored to normal.

Upon completion of the coring program, the hole was swept with two mud sweeps of 60 barrels each. A wiper trip with the drill string was then made to 2163.0 m (100.0 mbsf). While running back in the hole, a hard bridge (45,000 lb of bit weight) was tagged at a depth of 2557.0 m (494.0 mbsf). The top drive was picked up and a center bit was dropped at that point. The hole continued to cause problems from that point on and required a total of 6.5 hr of reaming to get back to the original hole TD. Several additional gel mud sweeps were pumped during the reaming operation.

After again sweeping the hole with two gel mud pills, the center bit was recovered, and two additional wireline runs were made to release the bit and reverse shift the mechanical bit release (MBR) sleeve back down again. Because of the difficulty experienced in reaching bottom with the top drive and a working drill bit, it was considered unlikely that the feat could be duplicated upon completion of logging with open-ended pipe. Therefore, the hole was displaced with heavy mud to avoid the need to get back to bottom and to enhance the chances of the logging program succeeding in the quickly deteriorating hole.

After filling the hole with mud, the pipe was tripped to a logging depth of 2385.7 m (322.7 mbsf). A maximum of 15,000 lb of overpull was experienced throughout the trip. The logging equipment was rigged and the first run, with the Quad combo suite of tools, was deployed to a depth of 2468.0 m (405.0 mbsf). This was only 82.3 m below the open-ended pipe. The logging tools were removed and the pipe was lowered to a depth of 2501.1 m (438.1 mbsf). A second run with the Quad combo tools reached a depth of 2514 m and was eventually worked to a depth of 2550 m (487.0 mbsf) or 48.9 m below open-ended pipe. Further logging attempts were thought to be futile, and subsequent logging was abandoned. The tools were recovered, the logging sheaves rigged down, and the pipe tripped back to the surface. The beacon was recovered while a BHA inspection took place, and the ship departed the site at 2100 hr on 20 August 95.

Site 987

While underway to Site 987 (EGM-4), we received conflicting ice map data regarding the outer edge of the ice margin. The most recent SSMI data indicated that the ice edge was well to the west of the proposed EGM-4 site. Later, advanced very-high-resolution radiometer (AVHRR) and SAR data showed the site to be 10 nmi within closed ice. As a result, the first survey waypoint was selected well to the east along the 70°30.0' latitude. At 2400 hr on 22 August 1995 the vessel slowed to survey speed (5.4 kt). In dense fog a seismic profile toward the ice margin in the west was begun. Repeated freezing of the water guns hampered the survey and eventually all water guns were inoperative. The profile extended all the way to 18°9.89'W. This data allowed a tie with an existing pre-cruise survey line that crossed the proposed EGM-4 site. The location of the ice margin was estimated to be approximately 10 nmi farther to the west, or roughly at the coordinates

TABLE 1
LEG 162 HOLE SUMMARIES

HOLE	LATITUDE	LONGITUDE	SEA FLOOR DEPTH (mbrf)	TOTAL PIPE DEPTH (mbrf)	TOTAL NO. CORES	TOTAL INTERVAL CORED (meters)	TOTAL CORE RECOVERED (meters)	AVERAGE PERCENT RECOVERED (percent)	TOTAL INTERVAL DRILLED (meters)	SUB-BOTTOM DEPTH (mbsf)	TOTAL TIME ON HOLE (hours)	TOTAL TIME ON HOLE (days)
980A	55 29.087 N	14 42.134 W	2182.1	2296.0	12	113.9	117.62	103.3%	0.0	113.9	17.00	0.71
980B	55 29.094 N	14 42.137 W	2179.3	2297.5	13	118.2	122.48	103.6%	0.0	118.2	11.25	0.47
980C	55 29.103 N	14 42.128 W	2178.9	2300.5	14	121.6	126.61	104.1%	0.0	121.6	9.00	0.38
FENI-1 SITE TOTALS:					**39**	**353.7**	**366.71**	**103.7%**	**0.0**	**353.7**	**37.25**	**1.55**
981A	55 28.631 N	14 39.052 W	2184.0	2504.0	34	320.0	327.51	102.3%	0.0	320.0	33.00	1.38
981B	55 28.642 N	14 39.049 W	2184.1	2405.0	24	220.9	227.29	102.9%	0.0	220.9	16.00	0.67
981C	55 28.646 N	14 39.045 W	2182.8	2464.0	30	281.2	293.81	104.5%	0.0	281.2	28.25	1.18
FENI-2 SITE TOTALS:					**88**	**822.1**	**848.61**	**103.2%**	**0.0**	**822.1**	**77.25**	**3.22**
982A	57 30.992 N	15 52.001 W	1146.3	1395.0	27	248.7	253.23	101.8%	0.0	248.7	17.75	0.74
982B	57 31.002 N	15 51.993 W	1145.0	1759.9	65	614.9	488.50	79.4%	0.0	614.9	62.50	2.60
982C	57 31.009 N	15 51.992 W	1144.7	1395.5	27	250.8	256.49	102.3%	0.0	250.8	13.75	0.57
982D	57 31.009 N	15 51.992 W	1144.7	1174.2	1	9.5	9.78	102.9%	20.0	29.5	5.00	0.21
NAMD-1 SITE TOTALS:					**120**	**1123.9**	**1008.00**	**89.7%**	**20.0**	**1143.9**	**99.00**	**4.13**
983A	60 24.200 N	23 38.437 W	1994.1	2248.5	27	254.4	264.42	103.9%	0.0	254.4	21.50	0.90
983B	60 24.210 N	23 38.437 W	1993.8	2245.5	27	251.7	261.83	104.0%	0.0	251.7	17.75	0.74
983C	60 24.218 N	23 38.443 W	1996.1	2256.5	28	260.4	271.75	104.4%	0.0	260.4	22.75	0.95
GARDAR-1 SITE TOTALS:					**82**	**766.5**	**798.00**	**104.1%**	**0.0**	**766.5**	**62.00**	**2.58**
984A	61 25.507 N	24 4.939 W	1660.4	1836.5	19	176.1	180.16	102.3%	0.0	176.1	16.50	0.69
984B	61 25.517 N	24 4.949 W	1659.0	2162.7	53	503.7	458.26	91.0%	0.0	503.7	77.50	3.23
984C	61 25.524 N	24 4.951 W	1659.7	1950.1	31	290.4	296.00	101.9%	0.0	290.4	17.50	0.73
984D	61 25.528 N	24 4.957 W	1659.1	1929.8	12	112.9	115.22	102.1%	157.8	270.7	15.25	0.64
BJORN-1 SITE TOTALS:					**115**	**1083.1**	**1049.64**	**96.9%**	**157.8**	**1240.9**	**126.75**	**5.28**
907B	69 14.989 N	12 41.898 W	1812.8	2024.5	23	211.7	219.56	103.7%	0.0	211.7	19.50	0.81
907C	69 14.998 N	12 41.900 W	1812.4	2027.5	23	215.1	220.23	102.4%	0.0	215.1	19.50	0.81
ICEP-1 SITE TOTALS:					**46**	**426.8**	**439.79**	**103.0%**	**0.0**	**426.8**	**39.00**	**1.63**

TABLE 1
LEG 162 HOLE SUMMARIES

HOLE	LATITUDE	LONGITUDE	SEA FLOOR DEPTH (mbrf)	TOTAL PIPE DEPTH (mbrf)	TOTAL NO. CORES	TOTAL INTERVAL CORED (meters)	TOTAL CORE RECOVERED (meters)	AVERAGE PERCENT RECOVERED (percent)	TOTAL INTERVAL DRILLED (meters)	SUB-BOTTOM DEPTH (mbsf)	TOTAL TIME ON HOLE (hours)	TOTAL TIME ON HOLE (days)
985A	66 56.490 N	6 27.012 W	2797.8	3385.7	62	587.9	553.42	94.1%	0.0	587.9	86.25	3.59
985B	66 56.498 N	6 27.001 W	2799.1	2926.0	14	126.9	129.44	102.0%	0.0	126.9	17.00	0.71
ICEP-3 SITE TOTALS:					**76**	**714.8**	**682.86**	**95.5%**	**0.0**	**714.8**	**103.25**	**4.30**
986A	77 20.438 N	9 4.661 E	2062.9	2268.9	24	206.0	181.30	88.0%	0.0	206.0	24.25	1.01
986B	77 20.431 N	9 4.664 E	2064.5	2080.0	2	15.5	15.10	97.4%	0.0	15.5	2.00	0.08
986C	77 20.431 N	9 4.664 E	2063.0	2471.0	44	408.0	229.78	56.3%	0.0	408.0	72.50	3.02
986D	77 20.408 N	9 4.654 E	2063.0	3027.6	60	576.8	241.56	41.9%	387.8	964.6	150.00	6.25
SVAL-1B SITE TOTALS:					**130**	**1206.3**	**667.74**	**55.4%**	**387.8**	**1594.1**	**248.75**	**10.36**
987A	70 29.796 N	17 56.243 W	1683.0	1882.3	22	199.3	173.01	86.8%	0.0	199.3	23.00	0.96
987B	70 29.798 N	17 56.216 W	1683.3	1782.5	11	99.2	74.18	74.8%	0.0	99.2	10.50	0.44
987C	70 29.787 N	17 56.188 W	1681.9	1725.5	5	43.6	44.91	103.0%	0.0	43.6	3.00	0.13
987D	70 29.798 N	17 56.178 W	1684.2	2057.2	42	373.0	268.46	72.0%	0.0	373.0	49.00	2.04
987E	70 29.787 N	17 56.188 W	1684.2	2543.6	52	496.1	308.83	62.3%	363.3	859.4	133.50	5.56
EGM-4B SITE TOTALS:					**132**	**1211.2**	**869.39**	**71.8%**	**363.3**	**1574.5**	**219.00**	**9.13**
LEG 162 GRAND TOTALS:					**828**	**7708.40**	**6730.74**	**87.3%**	**928.90**	**8637.30**	**1012.25**	**42.18**

of the original EGM-4 drill site. The vessel used GPS coordinates to return to a previously approved alternate site, EGM-4B, located on the site survey line. Unfortunately, a cross line could not be shot over site EGM-4b due to the gun failures.

The operational plan for this site was similar to that for Site 986 (SVAL-1B). It called for two piston-cored holes drilled to refusal or approximately 200 m below the sea bed. One hole was to be deepened to XCB refusal, which was estimated to occur at about 500 mbsf. A third hole was to be drilled down just short of the XCB hole TD, and then continuously RCB-cored to a depth of 800 mbsf. This hole would terminate shy of basement, but penetrate the glacial sediment package which was the major site objective. A minimum number of downhole temperature measurements were to be taken in the upper (APC) portion of the hole in order to establish a temperature gradient. A full suite of logging tools was to be deployed on the deepest site. Iceberg warning and hole abandonment procedures were put in effect. In addition, the Danish Greenland Command was advised of the vessel's arrival onsite and its anticipated departure from the area.

The positioning beacon was deployed at 0920 hr on 23 August 95 initiating Hole 987A. Routine piston coring continued through Core 987A-10H. No core was recovered from Core 987A-3H, because the core-catcher flapper stuck open, allowing the entire core to slip out of the liner. Since APC refusal occurred at such a shallow depth, coring operations were continued with the XCB-system. XCB coring continued with excellent recovery until coring was halted after Core 987A-22X, when the scientific target for the hole was reached. Methane was encountered ranging from 7 to 67760 ppm and ethane from 0 to 7 ppm. Propane was detected beginning with Core 987A-13H and ranged from 0 to 1 ppm. Higher molecular weight hydrocarbons were not detected.

After offsetting the vessel 15 m east, a bottom-water temperature was taken with the APC temperature tool before spudding Hole 987B. APC coring continued through Core 987B-11H when the scientific target depth for the hole was reached. Core recovery was lost for Cores 987B-3H through 5H, again because of the core-catcher flapper sticking open. Four successful downhole temperature measurements were taken on Cores 987B-4H, 6H, 8H, and 10H, yielding a temperature gradient of 96°C/km.

Because of the lost core interval on the first two holes, a third APC hole, Hole 987C, was drilled through the problem zone. This time the core-catcher flapper was supplemented with a dog-type core catcher as well. Running dual core catchers worked successfully, and coring was suspended once the target for the hole was reached.

The ship was again offset 15 m east. Routine piston coring continued without incident at Hole 987D through Core 987D-11H. XCB coring was initiated with Core 987D-12X. The hard formation XCB cutting shoe was severely damaged on Core 987D-21X, apparently due to coring through a large dropstone. No core was recovered through an apparent mass-flow deposit from Cores 987D-21X through 23X. Normal coring parameters were regained on Core 987D-24X. Coring was ultimately discontinued due to a steadily deteriorating rate of penetration (ROP) and core recovery. In addition, the cores became increasingly more disturbed and many core "biscuits" were noticed. Cores 987D-24X through 42X contained methane from 3162 to 21087 ppm and ethane from 2 to14 ppm. Propane ranged from 0 to 3 ppm. Higher molecular weight hydrocarbons were not detected.

The first indications of encroaching sea ice were identified on the radar during the coring of Hole 987D. The floe was picked up at a range of approximately 6.3 nmi from the drill site. It was moving toward the site at approximately 0.25 kt; however, the closest point of approach was 5.5 miles, so the ice never posed a danger to drilling operations. So the drill pipe was tripped back to the drill floor to change the bit/BHA to one used for RCB coring in preparation for Hole 987E. During the pipe trip, the vessel was offset 50 m to the east. Several hundred meters of the upper formation were to be drilled rather than cored; therefore, the seafloor depth from Hole 987D was used as a reference. This is more accurate than "feeling" for bottom with the RCB drilling assembly. Drilling ahead continued to a depth of 2047.5 mbrf (363.3 mbsf). The center bit was then recovered via wireline, and continuous RCB coring commenced. Coring was terminated after Core 987E-52R at 859.4 mbsf. This depth was in excess of the original scientific target depth of 800 mbsf; however, permission was obtained earlier to advance to 900 mbsf. Coring had to be abandoned only a few tens of meters short of the elusive basement so the logging program would not be compromised. Maximum methane and ethane identified were 70,787 ppm at a depth of 792.9 m, and ethane was 62 ppm at a depth of 739.0 m.

During the following wiper trip, a tight spot was identified at 408.8 mbsf that required 30,000 lb of overpull. Then, while running back in the hole, a hard spot was tagged with 30,000 lb of bit weight at 409.8 mbsf. At that point, the top drive was picked up; however, advancement still could not be achieved so a center bit was dropped. Washing/reaming with the top drive continued from that point until the original TD for the hole was reached. An additional 60-barrel mud sweep was pumped during the reaming process. Twenty-two meters of fill were found on the bottom of the hole. Prior to recovering the center bit, the hole was swept a final time with 50 barrels of gel mud. Two additional wireline runs were then made to release the bit and reverse shift the MBR sleeve. The pipe was placed at a logging depth of only 2122.7 m (438.5 mbsf), because there was little confidence that the tools would be able to traverse the bad spot in the hole that was identified during the wiper trip. The logging equipment was rigged, and the first run, with the Quad combo suite of tools, was deployed to a depth of 2165.0 m (480.8 mbsf). This was only 42.3 m below the open-ended pipe, so the logging tools were removed and the pipe was lowered to a depth of 2180.5 m (496.3 mbsf). The second run with the Quad combo tools reached a depth of 2184.0 m (499.8 mbsf), which was only 3.5 m below the open-ended pipe. Further logging attempts in the lower part of the hole were considered futile. The tools were recovered, the logging sheaves were again partially rigged down, and the pipe was pulled to a depth of 1776.1 m (91.9 mbsf). A third run in the upper portion of the hole with the Quad combo suite of logging tools reached a depth of 2170.0 m (485.8 mbsf) or 394.0 m below open-ended pipe. This logging run was successfully completed at 1935 hr on 31 August 95.

The next logging run with the GHMT tool reached a depth of 2164.0 m (479.8 mbsf) or 387.9 m below open-ended pipe. This logging run was successfully completed at 2320 hr on 31 August 95. The final logging attempt with the FMS reached a depth of 2092.0 m (407.8 mbsf) or 315.9 m below open-ended pipe. During this final run, another set of data points documenting the performance of the new wireline compensator control system was collected for the Lamont-Doherty Earth Observatory, Borehole Research Group (LDEO/BRG). The tools were subsequently recovered on deck at 0400 hr and the logging equipment was rigged down.

The drill pipe knobbies were then laid out and the drill string was pulled clear of the seafloor at 0536 hr. The beacon was released and recovered during the subsequent pipe trip. The BHA components were broken down, cleaned, and stowed for transit. Thrusters and hydrophones were pulled and the remaining rig floor equipment was secured for the 1.7 day (455 nmi) transit to Reykjavik, Iceland. As the vessel got underway in moderate snow flurries at half speed, scattered bergy bits and a few isolated growlers, likely discharged from Scoresby Sund, littered the area. The ice margin was clearly visible to the west as the vessel sailed on a southerly course toward Iceland.

TECHNICAL REPORT

The ODP Technical and Logistics personnel aboard JOIDES Resolution for Leg 162 were:

Brad Julson	Lab Officer
Randy Ball	Marine Lab Specialist (Photographer)
Tim Bronk	Marine Lab Specialist (X-Ray)
Andy Deady	Marine Lab Specialist (Downhole Tools, Thin Section)
Sandy Dillard	Marine Lab Specialist (Storekeeper)
Margaret Hastedt	Assistant Lab Officer (Paleomagnetics)
Terry Klepac	Marine Computer Specialist
Helga Kleiven	Marine Lab Specialist
Kuro Kuroki	Assistant Lab Officer
Mont Lawyer	Marine Lab Specialist (Underway Geophysics)
Jaque Ledbetter	Marine Lab Specialist (X-Ray)
Eddy Lee	Marine Lab Specialist
Greg Lovelace	Marine Lab Specialist (Physical Properties)
Erinn McCarty	Marine Lab Specialist (Curator)
Matt Mefferd	Marine Computer Specialist
Anne Pimmel	Marine Lab Specialist (Chemistry)
Jo Ribbens	Marine Lab Specialist (Yeoman)
Bill Stevens	Marine Electronics Specialist
Mark Watson	Marine Electronics Specialist

TECHNICAL REPORT

Port Call Activities: Edinburgh

The ship arrived two days early, on the evening of 2 July. This was the first time in many years that the ship had a port call in the United Kingdom, and it was a very busy port call. Crew change was on 4 July. There was an off-site EXCOM meeting during the port call, and the EXCOM members later toured the ship. For one day, the general public was invited to tour the ship, and over 800 people visited.

The Lamont Borehole Research Group rebuilt the wireline heave compensator during the port call. At the same time, a new Zeiss Axiophot was installed by Emil Meylan. He also serviced the microscopes and conducted a training session on the new microscope. In addition, the liquid helium in the cryomagnetometer was refilled.

Operations

The ship left Edinburgh on the evening of 7 July for a 2.5-day transit. The first site was FENI-1 in the sediment drifts south of Iceland. Leg 162 was divided into two parts based on the site's position relative to Iceland. We had good weather and good core recovery throughout the leg. In fact, we recovered over 5 km of core in the first month. Due to this incredible recovery, we ran low on supplies by the middle of the leg, so a rendezvous was set up with M/V *Strakur* from Reykjavik, which brought out core liners and acetone. One of the Lamont loggers returned to shore via the vessel. The plan for the leg was to core the southern sites first and the northern sites last in the hope that the northern sites would become ice free. Unfortunately, this did not happen, so the Svalbard sites at 77° N were the farthest sites we were able to core. On the way back, we were able to core the EGM site, because the ice had receded off the eastern coast of Greenland.

Underway Lab Activities

Routine underway activities commenced soon after we left Edinburgh. Bathymetric data were collected between sites during the transits, and seismic data were collected as we approached the sites. The seismic information was collected at 6 kt using a single 80-in.^{3} water gun. A new magnetometer, a Geometrics 886, was installed during the first part of the leg. Two new sensors were installed and the magnetometer was connected to the PC running the navigation software, WinFrog. A new version of WinFrog had been installed during the port call, and that fixed some of the bugs experienced in the previous versions. After fine-tuning the signal, the navigation program recorded and wrote the magnetics data to a navigation file every 3 seconds. Unfortunately, we were not able to graph the magnetics on the screen.

We had problems with the guns icing up off the coast of Greenland on our last seismic survey. The water temperature was recorded at 1°C.

Physical Properties Lab

The physical properties lab was used heavily this leg. The stratigraphic correlator set up a station in the lab. The multisensor track (MST) was crucial to this leg in that it provided near-continuous records for hole-to-hole correlation. This equipment allowed the scientists to construct complete stratigraphic sequence cycles, which are the result of paleoceanographic changes. The magnetic susceptibility was the most useful sensor for this. The MST was set on the highest sensitivity level, which meant the slowest speed. A 7-section core took 70-80 minutes to run. There were over 4000 runs on the MST during this leg.

We had equipment problems with the thermal conductivity boxes. The needles were recalibrated many times before the values returned to their original setting. The new thermal conductivity unit was brought out to be tested as a possible replacement for the aging instruments. Unfortunately, it also experienced many problems, and will be sent back for further development.

Core Lab

This was an extremely busy leg in the core lab. Because of the shallow water depths and the high core recovery, the lab could not process the core as rapidly as it was recovered. Consequently, many cores were stored until they could be processed in the lab, and the core lab racks quickly filled. The use of the MST, color reflectance spectrophotometer, and the cryomagnetometer all contributed to this slow movement of cores through the lab. In order to insure proper labeling, new cores were first brought into the lab to be scribed and entered into CoreLog before being moved back outside on the outside core rack. When room was available inside the lab, the cores were shifted back into the core lab, which meant a lot of rehandling. When both racks were full, cores were not cut into sections immediately, but were laid down on the catwalk. When the pace slowed and a place became available in the racks, the core was cut into sections. At one point, there were 40 cores lying on the catwalk with 75 cores waiting to be processed. The cores received on the catwalk were two holes ahead of what was being processed in the core lab. At one point 31 cores were recovered in one 12-hour shift.

This was a high-latitude leg that required installing tarps over the catwalk to reduce the cold, Arctic winds. A water line was plumbed from under the sink in the core lab out to the catwalk so hot water could be used to rinse the catwalk. One nice thing about the northern sites was that everyone was on the day shift. The sun never set below the horizon for weeks at time.

Paleomagnetics Lab

The cryomagnetometer was heavily used this leg. Over 800 cores were run through the instrument at 25- or 30-mT levels, which required a liquid helium refill during the port call. There was an air plug in the fill port, so the rest of the liquid helium in the cryomagnetometer was boiled off in order to melt the plug. The original 100 L of liquid helium was used to cool down the cryomagnetometer. Fortunately, another 100 L was obtained to refill it. A low field was trapped the next day. All in all, with the large amount of core processed through the cryomagnetometer, there were only a few problems associated with the chain and the occasional jams in the dewar.

Chemistry Lab

The chemistry lab was used primarily for water, carbon/carbonate, and gas analyses. Both natural gas chromatographs were used throughout the leg for real-time analysis of hydrocarbons. Only at the Svalbard site did we encounter large amounts of higher molecular weight hydrocarbons. Methane was present at many of the sites. The methods used for the gas analysis were further optimized to reduce the time required for analysis.

Pore water was squeezed from sediment samples and analyzed throughout the leg. The Dionex ion chromatograph ran well, but there were a number of problems with the atomic absorption instrument. Due to the cold environment, acetylene flows were reduced, so the pressures were adjusted to compensate. An air regulator and an ignitor relay were all worked on.

Sediment samples were routinely analyzed on the Coulometer for carbonate content and on the Elemental Analyzer for organic carbon content. A few samples were also analyzed on the Rock-Eval.

X-ray Lab

Many clay sediment samples were analyzed on the XRD. Although no XRF analyses were requested during the leg, a number of major element standard beads and trace pellets were analyzed as unknowns to evaluate the stability of the Leg 161 calibration in preparation for Leg 163. In addition, a new cookbook was developed for the new bead sampler. This was translated from Japanese and edited into a very usable form.

Computers

ccMail was officially adopted by ODP this leg. All personal and official e-mail to and from the ship went through ccMail. This includes scientists, technicians, and Schlumberger employees. As with all new products, there were initial problems, but as personnel became familiar with the program, the problems diminished. Because of the extremely high latitude at some sites, the angle to the communication satellite was actually beneath the horizon. Consequently, it was difficult and expensive to send communications.

Ice maps played an important role in deciding our operations schedule, so we used a Norwegian company, NERSC, to send us maps over the satellite, or to ODP where they were FAXed or FTPed to the ship.

About midway through the leg, a COMPUSERVE science bulletin board was hosted by *US News & World Report* for two weeks. Questions from subscribers were sent to the ship and posted on the bulletin board. Cruise participants answered the questions and sent the replies back to the COMPUSERVE forum. Most of the questions were about global warming.

Eight new Pentium PCs were received and installed in the labs. These replaced older 386s and are part of our computer upgrade program. A 1.2-GIG disk was installed on the Novell server. A preliminary pre-Alpha copy of the upcoming JANUS database for Curation, CoreLog, and Operations was installed on three PCs to get user opinions. This information will be used for further development.

Curation

As expected on a record-breaking core recovery, paleoenvironmental leg, core sampling was heavy. Half the intensive sampling was deferred to a post-leg sampling party in Bremen, but still over 26,000 samples were taken on the ship. Many people are interested in high-resolution isotope analysis.

Close to 1000 boxes of core were recovered, and these not only filled both the Hold and Lower Tween refrigerators, but the excess core boxes were stored on the gym floor. This is only possible in the high latitudes where the temperature in the gym is colder than the temperature in the refrigerators.

Large amounts of methane were encountered at a couple of sites, so there were the associated gassy, expanding core problems. The gas and the cold temperatures also resulted in broken, shattered, and split liners. There were also many whole-round sections taken for post-cruise geotechnical testing.

Downhole Measurements Lab

Heat flow was determined at four sites using the ADARA downhole temperature probe, which fits into the coring shoe of the advanced piston core (APC) barrel. Four of these runs were dedicated bottom-water measurements. Instead of assuming the temperature of the sediment/water interface, the temperatures from the bottom water runs were extrapolated out to equilibrium to produce bottom-water temperatures. This is analogous to what is done when the ADARA tool is used in the sediments. One of the tools shorted out when the foil strip connecting two of the boards became frayed and came into contact with the inside of the coring shoe. This will be shipped back for repair.

Paleontology/Microscope Lab

There was a service call and a training session by Emil Meylan during the port call, and a new Zeiss Axiophot was installed. The Axiophot features a high-intensity arc lamp for fluorescence illumination. Fluorescence was not needed on this leg so the power supply was disconnected to prevent mishandling. The microscope will also be equipped for use in measuring reflectance on those legs which do not need it for fluorescence. The microscope parts were inventoried at the end of the leg.

The paleontology lab was used continuously by the five paleontologists, and over 2000 samples were examined. The paleontological 4D database, FossiList, was used by only one scientist this leg. She had used it at ODP headquarters before coming out and was familiar with it. The others felt it was too inconvenient to enter data directly into the database. They preferred to use the paper forms.

Photo Lab

Over 5000 black and white prints were produced in the photo lab. There were few problems with the photography equipment.

Miscellaneous

Five members of the technical staff practiced with the SEDCO emergency technical squad. Practice emergencies were held weekly.

The XEROX copiers were especially troublesome this leg. The ETs spent many hr troubleshooting and repairing problems. We are looking forward to the installation of new copiers scheduled for the end of next leg.

SEDCO thoroughly cleaned and painted the emergency backup battery lockers and put these batteries back on line. If time permits we will test the backup batteries to see how long they will last when they are put online.

LABORATORY STATISTICS: LEG 162

General Statistics:

Sites	9
Holes	30
Cored Interval (M)	7708.40
Core Recovered (M)	**6730.74**
Avg. Percent Recovered	87.30
Total Penetration (M)	8677.30
Time on Site (Days):	42.18
Number of Cores:	828
Number of Samples	26,727

232.83 m of core/day

Number of Samples Analyzed:

Chemistry Laboratory	
Inorganic Carbon ($CaCO_3$)	868
Total Carbon (NCHS)	690
Water Chemistry (the suite includes pH, Alkalinity, Sulfate, Calcium, Magnesium, Chlorinity, Potassium, Silica, Salinity)	208
Pyrolysis Evaluation (Rock-Eval and GHM)	47
Gas Samples	370
Extractions	0
X-Ray Laboratory	
XRF:	0
XRD:	500
Magnetics Laboratory	
Cryomagnetometer Runs:	4035
Cubes	9
Oriented Cores	233

Physical Properties Laboratory		
	Physical Properties Velocity	165
	Velocity:	2098
	Thermal Conductivity	496
	Index Properties	3032
	Resistivity:	0
	Shear Strength:	1802
	MST Runs	5020

Thin Sections	61
Underway Geophysics:	
Bathymetry (nmi):	3913
Magnetics (nmi):	2001
Seismic Survey (nmi):	199
XBTs launched	22
Downhole Tools:	
WSTP	0
ADARA	41
Additional:	
Close-up Photos:	628
Whole Core Photographs:	4140
Rolls of Microphotographs	1
Color Transparencies	828
Black and White Prints	5026