OCEAN DRILLING PROGRAM

LEG 162 SCIENTIFIC PROSPECTUS

NORTH ATLANTIC ARCTIC GATEWAYS II

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ABSTRACT

Understanding the causes and consequences of global climatic and environmental change is an important challenge for humanity. The high northern latitude oceans are of great relevance to this task since 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 chemistry. Thus, any serious attempt to model and understand the Cenozoic variability of global climate must take into account climate processes occurring in this region.

Leg 162 represents the second in a two-leg program designed to investigate three major geographic locations (the northern gateway region, the Greenland-Norway transect, and the southern gateway region) with the aim of reconstructing 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/Daansgard-Oeschger Events) to millions of years. Leg 162 will provide sedimentary sequences containing records of biogenic fluxes ($CaCO_3$, opal, and organic carbon), lithologic fluxes, and geochemical records which will be used to document oceanic processes on millennial, Milankovitch, and tectonic time scales. In combination with the Leg 151 sites, these sites are arrayed as broad north-south and east-west transects to monitor spatial paleoclimatic variability. In addition, a vertical array of sites in the North Atlantic will monitor water mass variability at intermediate water depths. Lastly, deep drilling targets in the north should constrain the time of opening of the Fram Strait, and the inception of high northern latitude glaciation.

INTRODUCTION

The NAAG-DPG report (early 1991) constructed two legs of drilling in the North Atlantic-Arctic region. The first of these legs was completed in 1993 as Leg 151. Remaining high priority objectives, not addressed during Leg 151 are the timing and nature of the opening of the Northern

Gateway (Fram Strait) and the history of glaciation on Svalbard/Barents Sea and on Greenland. These will be addressed by specific drilling targets during Leg 162 (Fig. 1).

In addition, the recognition that sub-Milankovitch climate signals such as those recently documented in the Greenland ice cores, can be recovered in North Atlantic and Nordic seas sediments is currently an exciting new area of paleoceanography (Fig. 2; Bond et al., 1993). NAAG-II will provide an opportunity to recover high-resolution sedimentary sections allowing us to study the long term evolution of millennial-scale climate variability in the North Atlantic. In particular, we will be able to evaluate the amplitude and frequency of millennial-scale variability during intervals warmer than today. The combination of earlier objectives outlined in the NAAG-DPG report with new objectives on high resolution paleoclimatology will guide drilling on Leg 162.

OCEANOGRAPHIC SETTING

The Nordic Seas, including the Norwegian and Iceland seas, the Greenland Sea, and the Arctic Ocean, form a series of interconnected basins containing a total volume of roughly 10 x 10^6 km^3, excluding the Amerasian Basin of the Arctic Ocean. This is about 0.7% of the volume of the world ocean with the Eurasian Basin of the Arctic Ocean making up nearly 60% of this volume. Despite the small volume of these areas, they nevertheless act as a primary source of a large portion of deep, ventilated waters in the world ocean. The idea that deep waters are formed in the Norwegian-Greenland seas (Helland-Hansen and Nansen, 1909), and that some of this newly formed water flows into the deep Atlantic across saddles on the Greenland-Scotland Ridge (Fig. 3; see Warren, 1981; Mantyla and Reid, 1983, for reviews), was suggested a long time ago. Previous notions about the Arctic Ocean indicated that it has been a passive recipient of ventilated water from the south. In recent years, however, it has been demonstrated that the Arctic Ocean itself is an important contributor of deep waters which flow southward through the Fram Strait, and, after mixing with deep waters formed in the Greenland/Iceland seas, pass farther on into the world ocean (Aagaard, 1981; Aagaard et al., 1985). The processes leading to the formation of dense deep waters in the Arctic Ocean are thought to involve either intense cooling of Atlantic waters on the Barents Sea Shelf (Swift et al., 1983), or an increase in salinity through salt release during sea-ice formation on the large Arctic shelves (Aagaard et al., 1985). Smethie et al. (1988) suggest that both processes are in operation.

The chief components of the surface water systems of the Nordic Seas involve the influx of warm and relatively high-salinity waters via the North Atlantic Current, which continues its northward flow as the Norwegian Current, and outflow via the cold and low-salinity East Greenland Current. The Norwegian Current is sufficiently cooled to allow deep water formation within the cyclonic gyre of the Greenland Sea. Another branch of this current continues along the western margin of Svalbard as the West Spitsbergen Current, before entering the Arctic Ocean. Within the Arctic this relatively warm water mass mixes with low-salinity surface waters, sinks and flows as an intermediate water mass counterclockwise before being exported out of the Arctic via the Fram Strait along the Greenland Margin. The surface outflow from the Arctic Ocean sweeps the east margin of Greenland before entering the Irminger Sea of the North Atlantic via the Denmark Strait.

Aagaard et al. (1985) concluded that nearly 50% of the water volume in the Nordic Seas, including the Amerasian Basin, is potentially in communication with the world ocean. The Nordic Seas might hence be characterized as the "lungs" of the present world ocean, implying that it is of fundamental importance to derive a detailed understanding of the timing and history of deep and shallow water exchange between the Nordic Seas and the remainder of the world ocean. The unique topographic constraints provided by a single deep, narrow passageway to the north (the Fram Strait), and a major submarine ridge system to the south (Greenland-Scotland Ridge) make it pertinent to address the question of the Cenozoic paleoceanography of the Nordic Seas as a gateway problem.

SCIENTIFIC OBJECTIVES

The underlying rationale for this leg is the importance of the Arctic and subarctic regions to the global climate and ocean systems. This is a region where much of the world's deep waters are formed with associated large regional releases in sensible and latent heat. Likewise, major amplification of climate changes can occur in this region due to snow and ice albedo feedbacks. In addition, the Arctic and Nordic Seas may play a key *active* role in long-term evolution of global climate via linkages such as the effects of gateway openings on deep circulation, ocean alkalinity, and atmospheric CO_2. Linkages between deep-ocean circulation and atmospheric CO_2 have already been proposed for late Pleistocene changes at glacial-interglacial time scales (e.g. Boyle, 1988; Broecker and Peng, 1989; Broecker et al., 1985). To address these fundamental long-term problems, the results of Leg 162 and its sister Leg 151 will fill large gaps of time over which we have no oceanic record of climate change at high northern latitudes. Our drilling strategy will focus on the three general scientific objectives discussed below.

Cenozoic Climate Evolution of the Arctic and Nordic Seas Region

The gateways in the north (Fram Strait) and south (Greenland-Scotland Ridge) are among the most important submarine topographic constrictions to global oceanic circulation. The opening of the Fram Strait and subsidence of the Greenland-Scotland Ridge below critical levels are necessary conditions for deep water exchange between the Nordic Seas and Atlantic Ocean. The history of these gateways is thus a key component in understanding the long-term evolution of both Northern Hemisphere climate and global thermohaline circulation.

The Fram Strait, with a present critical sill depth of 2600 m, represents the only deep connection between the Arctic Ocean and the global ocean. The initiation of this connection may have taken place as early as Anomaly 13 time, close to the Eocene/Oligocene boundary (Crane et al., 1982; Eldholm et al., 1987a; see also reviews by Vogt, 1986a, b). The tectonic history of the Fram Strait area, however, is characterized by complex and, at present, vaguely understood processes, which might include stretching of the Svalbard continental crust and hotspot activity. When taking into account the strongly oblique opening of the Fram Strait and the nearness to surrounding land areas (Greenland and Svalbard), it seems possible that a truly deep Arctic Ocean/Greenland-Norwegian Sea connection became established considerably later than Anomaly 13 time, perhaps as late as Anomaly 6 time.

Likewise, few oceanic gateways can compete with the Greenland-Scotland Ridge in having such a profound influence on the present world hydrography (Bott et al., 1983; Wright, 1991). Overflow from northern sources occurs in the Faeroe-Shetland Channel, across the Iceland-Faeroe Ridge and in the Denmark Strait. Tracer studies indicate that the overflow waters originate from waters shallower than 1000-1200 m, probably to a large extent formed by deep convection in the Iceland

Sea (Peterson and Rooth, 1976; Warren, 1981; Aagaard et al., 1985). Reconstructions of the subsidence history of the ridge system suggest that its eastern parts sank beneath sea level probably sometime during middle Eocene times, and during early to middle Miocene times in the Denmark Strait area. The distribution of shallow water benthic foraminifers, however, indicates that the Nordic Seas were effectively isolated from any "deep" Atlantic influence until middle Miocene times (Berggren and Schnitker, 1983; Thiede, 1983; Thiede and Eldholm, 1983). The overflows have both influenced the Atlantic and global deep water masses through their contribution to North Atlantic Deep Water (NADW) production and to the formation of North Atlantic sedimentary records. Basic questions as to why and when NADW production was initiated, and how and why the chemical and physical signature of this major water mass has varied, remain to a large degree unanswered (Wright, 1991). Quite obviously the physical and chemical characterization of surface and deep waters through time, in the main source regions and directly south of the ridge, will greatly improve the understanding of world ocean hydrography, global energy budgets, and North Atlantic patterns of sedimentation and erosion.

This drilling prospectus focuses on two key objectives not addressed in drilling prior to NAAG I and II: (1) constraining the tectonic history of opening of these barriers, primarily by drilling to obtain basement ages; and (2) defining the subsequent history of surface and deep water exchange across these barriers, based on both proxy water-mass indicators and on current-sculpted features on the seafloor. Sites where the long-term evolution of these gateways will be studied include NAMD-1, EGM-4, SVAL-1B, and YERM-1.

We will also use these sites to address the Neogene history of glaciers and ice sheets around the Nordic Seas. Results from ODP Leg 104 trace the glacial history of the Fennoscandian Ice Sheet back to 2.57 Ma (Jansen and Sjøholm, 1991). Sporadic earlier occurrences of minor quantities of ice-rafted debris in various North Atlantic drill sites, including Legs 151 and 152, indicate a still-earlier onset of glaciation around the Nordic Seas. However, both the location of the earlier ice sheets and the kind of glaciation remain uncertain. Were there mountain glaciers that reached the sea, or small continental ice sheets? Were they located on Greenland, on Svalbard, or over the Barents Sea (Fig. 4)? What is the history of glaciation in these various regions? It is thus a primary drilling objective to obtain sediments from sites adjoining each of these regions to assess their glacial histories individually. Specific objectives are:

- To record and date the onset, and improve the general understanding of glaciations in the European high Arctic (YERM-1, SVAL-1B).

- To record and date the initiation and important phases in the glacial history of the Greenland Ice Sheet (EGM-4).

- To record and date important phases in the glacial history of the Svalbard-Barents Sea Ice Sheet, such as initiation of glaciations over the continental shelves, and the submergence of the Barents Sea platform and probable transition from a terrestrial to a marine based Barents Sea Ice Sheet (SVAL-1B).

- To investigate the nature of glacial continental margin sedimentary processes, with special emphasis on the processes of late Cenozoic uplift and erosion of the Svalbard-Barents Sea platform, and to calculate rates of glacial erosion and sediment fluxes in this type of environment (EGM-4, SVAL-1B, YERM-1).

- To investigate the nature of pre-glacial sediments, both in the deep sea, and on the outer shelf (ODP Site 907, SVAL-1B, YERM-1, EGM-4).

The Neogene evolution of sea ice cover in this region will also be examined. The present Arctic climate is strongly influenced by its sea ice cover, which greatly increases the regional albedo and reduces heat and gas exchange with the atmosphere. Very little is known about how this ice cover first developed and subsequently varied. It has been proposed that the Arctic Ocean has been permanently ice covered since the late Miocene (Clark, 1982). Other studies conclude that this event happened in the Matuyama or at the Brunhes/Matuyama boundary (Herman and Hopkins, 1980; Carter et al., 1986; Repenning et al., 1987). *JOIDES Resolution* drilling along the present ice margins will provide better constraints on the history of sea-ice extent just north of a key Arctic gateway and southward into the Nordic Seas.

Finally, the long term history of surface, intermediate, and deep water chemistry and the exchange of these water masses across the northern and southern gateways will be an important scientific objective. Associated objectives are understanding the long-term history of biogenic fluxes in the region, in particular the bathymetric variability of the CCD and lysocline and the spatial and temporal history of silica preservation. Drilling on the Yermak Plateau (YERM-1) is designed for studying the Arctic intermediate water environments during and after the opening phase of the Northern gateway which enabled water mass exchange between the Arctic and the North Atlantic. Drilling in the North Atlantic (NAMD-1) will obtain late Cenozoic sections for the documentation of North Atlantic water mass circulation at times when no North Atlantic Deep Water (NADW) is thought to exist, and document the transition to the modern type of ocean circulation.

Role of High Northern Latitudes in Orbital Forcing of Global Climate

Much of the natural variability in the Earth's environment on time scales less than a million years originates in the geometry of the Earth-Sun orbital system. It is likely that the sensitivity of the Earth's climate to orbital forcing increased during the late Cenozoic because of the increased extent of snow and ice, with particularly high sensitivity in the last million years. Obtaining records that document the development of these climatically sensitive latitudes is critical for elucidating how, why, and when enhanced sensitivity evolved and for improving our understanding of the mechanisms by which orbital insolation variations have forced Cenozoic climatic change (e.g., Imbrie et al., 1992, 1993).

The northern North Atlantic is an important source region for deep-ocean ventilation. North Atlantic Deep Water is composed of water masses forming in the Norwegian-Greenland Seas, the Irminger Sea south of Iceland, and the Labrador Sea. Surface water salinities are high in these areas, and thus winter time cooling increases surface densities to an extent that deep convection occurs (Fig. 3). Because of their rapid formation and short residence times, these deep waters are rich in O_2 but poor in CO_2 and nutrients. The deep water which spills over the Greenland-Scotland Ridge mixes with warmer North Atlantic waters to form southward-flowing NADW. North Atlantic Deep Water helps to oxygenate the deep ocean and transfers heat and salt to the Antarctic. Glacial/interglacial changes in deep-water formation in the Nordic Seas are implicated as the key driving force in conceptual models of atmospheric CO_2 variations and global climate change (Imbrie et al., 1992). Unfortunately, the lack of high quality records from the highest northern latitudes has precluded comprehensive evaluation of hypotheses such as that described by Imbrie et al. (1992).

ODP drilling in the Nordic Seas will improve our understanding of deep-water evolution north of the Southern Gateway by providing spatial and vertical transects that constrain the development of physical/chemical gradients in deep water and their response on Milankovitch time scales. Drilling south of the gateway will provide sorely needed shallow and intermediate water depth end members for Atlantic-scale studies of thermohaline circulation. We will reconstruct water mass behavior in the North Atlantic on glacial-interglacial time scales of the Plio/Pleistocene with special emphasis on the formation of Glacial North Atlantic Intermediate Water (GNAIW) and the links to surface water conditions.

Millennial Scale Climate Variability in High Northern Latitudes

Sites on the North Atlantic sediment drifts (FENI-1, GARDAR-1, and BJORN-1) will address several questions relating to climatic variability on a range of time scales. As a result of recent investigations on high sedimentation rate marine cores, it is evident that rapid oscillations such as those observed in temperature and dustiness in Greenland ice cores (Dansgaard/ Oeschger events) also exist in the marine record (Fig. 2). They can be seen as changes in surface fauna (sea surface temperature), carbonate, color, and deep ocean chemistry. The transitions between cold epochs and warm epochs in ice cores are abrupt: ~6°C warmings occurred in as little as 50 years and fourfold drops in dust content in as little as 20 years. Broecker (1994) reviews possible causes for these oscillations and the linkages between deep sea sedimentation and ice core records. One possibility is that millennial scale climate variations in ice cores are related to the strength of the thermohaline "conveyor belt." In addition to examining this hypothesis, we will use the long, high sedimentation rate cores to determine whether these oscillations characterized the marine record during earlier, warmer climatic regimes of the past 3 million years.

Also found in the marine record are events with longer characteristic repeat times (~10,000 years), which are related to surges of the eastern Laurentian ice sheet (Bond et al., 1993; Broecker, 1994). Determining the geographic distribution of these Heinrich events, their long-term character, and the timing of their first occurrence is a main objective of drilling at FENI, GARDAR, and BJORN. For instance, are they restricted to the "100kyr world" of the Brunhes characterized by the largest continental ice sheets? By studying sedimentation patterns, surface water properties, and deep-water variability on suborbital time scales and relating these observations to ice cores, we hope to better understand the forcing and dynamics of decadal to millennial climate variability in the North Atlantic-Arctic region.

LEG 151 PRELIMINARY RESULTS

During the Arctic summer of 1993, *JOIDES Resolution,* accompanied by the Finnish icebreaker *Fennica,* recovered the first scientific drill cores from the eastern Arctic Ocean, including material which records the long history of glacial climate in the Arctic and evidence for massive ice caps on the Arctic Ocean margin during certain glaciations (Myhre, Thiede, Firth, et al., 1995).

During ODP Leg 151, drilling operations recovered over 3 km of core, which ranges in age from middle Eocene to Quaternary. Site 907 on the Iceland Plateau recovered a middle Miocene to Quaternary sequence overlying basement basalts with calcareous microfossils only in the upper Pliocene to Quaternary, but with a middle to upper Miocene biosiliceous-rich interval indicating high-productivity conditions. Site 908 in the Fram Strait documents a late Oligocene age for the biosiliceous-rich pre-rifted strata on the Hovgård Ridge microcontinent. Nearby Site 909 penetrated 1061.8 m into the Fram Strait basin, which acts as the corridor for deep-water flow between the Arctic Ocean and Norwegian-Greenland Sea, and recovered an upper Oligocene?/lower Miocene to Quaternary sequence high in organic matter and hydrocarbons but virtually devoid of calcareous and siliceous microfossils. Sites 910, 911, and 912 on the Yermak Plateau consist of Pliocene to Quaternary glacio-marine sediments with abundant dropstones and high organic carbon content. Site 913 on the East Greenland Margin drilled a thick section of Pliocene to Quaternary glacio-marine sediments with abundant dropstones, overlying a middle Eocene to lower Oligocene and middle Miocene sequence of clays and silty clays. A biosiliceous-rich interval occurs in the upper Eocene to lower Oligocene.

The oldest sediments recovered, middle Eocene at Site 913, contain the highest abundance of terrigenous organic matter recovered during Leg 151 and indicate the close proximity of a continental source during this initial phase of seafloor spreading in the Greenland Basin. Episodes of laminated sediment deposition suggest a lack of infaunal activity and bioturbation during the middle Eocene. The dissolved-silica level is extremely low, suggesting an absence of biosiliceous deposition and hence indicates a restricted basin or basins receiving nutrient-depleted surface water over shallow sills, well above the mid-water nutrient maxima common in modern oceans. During this time, Fram Strait remained closed to deep-water flow. Productivity increased throughout the middle Eocene, and Site 913 remained below the CCD.

At Site 913, there was a renewed influx of terrigenous organic carbon in the late Eocene, coinciding with the first appearance of preserved biogenic silica. Upsection the preservation and abundance of siliceous microfossils increases. The siliceous intervals were formed during times of high productivity, resulting in high sedimentation rates and high abundance of marine organic carbon. Nevertheless, ventilation of the deep waters was poor, resulting in lamination and probably causing the accumulation of CO_2 in deep water, which dissolved carbonate.

The late Oligocene to earliest Miocene interval from Site 908 on the Hovgård Ridge suggests moderately well-mixed oceanic conditions in the Norwegian-Greenland Sea. Laminated-sediment intervals continued until about the middle/late Miocene boundary (Sites 907, 909, and 913) and provide evidence for restricted circulation in the early Miocene Greenland-Norwegian Sea. Leg 151 did not find evidence for deep-water flow from the Arctic or modern type deep-water production in the Nordic Seas before this time.

The late Miocene time interval is represented only at two sites. Site 909 is characterized by a paucity of microfossils, while Site 907 is rich in siliceous microfossils which appeared prior to the middle/late Miocene boundary but disappeared by about 7 Ma when true Norwegian-Greenland Sea deep water may have begun to form. The disappearance of anoxic indicators close to the middle late Miocene boundary at Site 909 marks the start of deep mixing in the Greenland Basin, while the presence of siliceous production on the Iceland Plateau shows that the southern part of the Nordic Seas still had net upward transfers of nutrients from deeper waters to the surface, unlike modern conditions.

At all sites, the Pliocene and Quaternary interval is marked by evidence of ice. Significant quantities of dropstones appear near the late Miocene/Pliocene boundary and show a marked increase in abundance at about 2.75 Ma. Pliocene and Quaternary sediments on the Yermak Plateau at the southern edge of the Arctic Ocean are extremely thick, deposited either by the melting of sediment-laden pack ice transported to the region by Arctic surface circulation or by ice melted from a massive Barents Sea ice sheet or an ice cap centered on Svalbard. The former scenario seems more likely, because the melting ice edge now supports high productivity, which could cause the observed high levels of marine organic carbon deposition. The summer edge of Arctic pack ice would then have been near the Yermak Plateau for most of the Plio-Pleistocene interval.

Lastly, Site 910 was marked by a highly overconsolidated interval, beginning at about 25 m depth in the sediment column. No such interval was found at the deeper water Site 912 (south) or Site 911 (north). At Site 912, sedimentary evidence of an ice sheet was recorded for the same time interval. The consolidated interval was traced along the Yermak Plateau with seismic reflection profiles. This consolidation possibly indicates that an ice lobe of the Barents Ice Sheet reached well out to sea in the late Pleistocene and was grounded on the top of the Yermak Plateau. These event(s) may have occurred prior to the last glacial maximum at 18 kyr. Evidence for the extension of the Barents Ice Sheet westward will provide important constraints for Pleistocene ice models.

STUDY AREAS

Northern Gateway: the Yermak Plateau and Svalbard Margin

The Yermak Plateau is a topographic marginal high due north of Svalbard. In the prospectus of Leg 151 Sites YERM-1, -2A, -3, -4 and -5 were proposed. Drilled were YERM-2A (Site 912, maximum total penetration 209 mbsf), YERM-3 (Site 911, maximum total penetration 506 mbsf) and YERM-4 (Site 910, maximum total penetration 507 mbsf). Sea ice continually drove the ship off site, and at no location was the late Neogene glacial package penetrated. The plan for Leg 162 is to drill YERM-1A or, in the event that this site is inaccessible due to ice cover, to drill alternate sites -1B, -1C or -1D, or a deepening of Site 912 (YERM-2A) from 200 to 550 m.

Site YERM-1 is located on the eastern flank of the Plateau and is a deep target site. This site has been proposed to document the subsidence history of the Yermak Plateau and its control on the water-mass exchange through the Arctic gateway, and to determine the age and nature of basement. Furthermore, it will provide records of surface and deep-water communication between the Arctic and the Norwegian Sea and the ice rifted debris (IRD)-sedimentation history of the Arctic. Lastly, with this site we hope to date the inception of glacial climate in the Arctic proper.

YERM-1A is our prime target since it is here that basement is most accessible. However, due to potential sea ice problems, a number of alternate sites which will address the same objectives are included in our drilling prospectus (YERM-1B, -1C, -1D). In the event that none of the YERM-1 sites are accessible, site YERM-2A could serve as a less desirable alternate site for YERM-1. YERM-2A is located deeper than site YERM-1 on the southwest slope of the plateau. The thick sediment pile at this site prevents drilling to basement. This means that while we would be able to date the inception of glacial sedimentation in the region and look at the long-term history of North Atlantic surface water exchange with the Arctic, we would not be able to document the subsidence history of the Yermak Plateau.

We also expect to drill one site (SVAL-1B) on the Svalbard margin to examine the onset of glaciation in the European Arctic and establish the history of the Barents Ice Shelf, including dating the transition from a terrestrial to marine based ice sheet. Svalbard is also believed to be the likely location for the initiation of Pliocene glaciation in the European Arctic. This site will also address questions related to glacial fan development and will serve as an eastern counterpoint to EGM-4 located on the East Greenland Margin.

Nordic Seas Transect

Sites on the Iceland Plateau and on the East Greenland Margin are designated to be parts of an east-west transect across the Nordic Seas from the present temperate waters in the east to the polar waters off Greenland in the west. The aim of the transect is to trace the evolution of environmental gradients across this region in the late Cenozoic. The sites drilled on the Vøring Plateau on Leg 104 form the eastern end member of the transect, the Iceland Plateau sites form the central element, and site EGM-4 on the East Greenland Margin forms the western end member of the transect.

ICEP-1 is located on top of the Iceland Plateau and is an open-ocean site isolated from continental marine influence on IRD records. This is also the location of Leg 151 Site 907 which, because of a medical evacuation, had only a single hole drilled. Leg 162 plans to redrill this site to retrieve a complete section. This site is included to (1) monitor the history of oceanic and climatic fronts moving east and west across the Iceland Plateau, (2) derive an open-ocean record of IRD and carbonate, and (3) determine the history of northern-source deep water formation. While the first hole did not have abundant carbonate, an excellent record of siliceous microfossils extended back to the middle Miocene, and physical property time series from this hole record obvious Milankovitch scale cyclicity. Given that this site is likely to become a type section for the region, it was decided to drill two more offset holes (APC to 200 m).

Site ICEP-3, located farther to the east, is a low priority alternate site chosen to study oceanic response to different stages in the opening of the Greenland-Scotland Gateway. This site could also provide a record of pelagic IRD input well away from the ice sheets, thereby avoiding strong continental influence. The more eastern location would also improve chances for recovering a carbonate biogenic record.

The sites on the East Greenland Margin proposed in the NAAG-DPG report are located on a north-south transect paralleling the path of the East Greenland Current (EGC). In order to document the history of EGC and of deep-water flow out of the Arctic downstream from Fram Strait, EGM-2 (Site 913) was drilled during Leg 151. Drilling encountered difficulties when coring the uppermost 400 m of sediment. Between 20 and 430 m, core recovery was almost zero. In addition, the lack of carbonate at this site precluded many of the planned paleo-circulation studies. Because of this we do not intend to drill EGM-3 during Leg 162. However, we do plan on drilling EGM-4 situated on the lower slope of the trough-mouth fan at Scoresbysund. Piston cores recovered from this region indicate that this area is protected from the eroding deep water currents encountered farther north at EGM-2 (Site 913). Likewise, the presence of carbonate in this region will allow paleochemical studies of the surface and deep waters of the Greenland Sea and allow studies of the evolution of the East Greenland Current. EGM-4 is also intended for high-resolution studies of the late Neogene history of IRD input from and evolution of the Greenland Ice Sheet and will serve as the Greenland counterpart to SVAL-1B.

Southern Gateway

The major objectives of these sites are related to Plio-Pleistocene water mass evolution and the role of thermohaline circulation in controlling the exchange of carbon between the ocean and atmosphere. In particular, these sites will address the character, causes, and consequences of

Milankovitch and millennial scale climate variability with the goal of correlation to the ice core records for the Quaternary. We will also examine the question of when high frequency millennial to century scale climate variations started to occur and whether warmer periods in the past were characterized by such high frequency instabilities. The Greenland ice core records of interglacial stage 5e suggest that ice sheets are not necessarily a prerequisite for rapid oscillations in ocean-atmosphere circulation (although these records may be biased by ice deformation). The recovery of long, high sedimentation rate sedimentary sequences in the North Atlantic should establish whether this type of climate "instability" was present during the early Pleistocene or prior to major Northern Hemisphere glaciation.

Two of the proposed sites are located on the Feni Drift in the eastern Atlantic, perfectly situated to record the large north-south swings in surface water conditions (the polar front) which occur during glacial-interglacial, and potentially millennial, climate cycles. These sites, at 2157 m water depth, will also monitor Wyville-Thomson Ridge Overflow Waters as well as southern source deep water during times of minimal overflow. Here we expect to recover an approximately 100-m record of the Brunhes Chron (FENI-1) at sedimentation rates of between 11 and 20 cm/kyr. At FENI-2, located at the same depth but slightly to the southeast, we expect to recover a 225 m late Pliocene to Pleistocene record of sedimentation, also at greater than 10 cm/kyr. These sites will be used to study mid-depth nutrient variability, deep water circulation, and surface-deep water links on both Milankovitch and millennial time scales.

BJORN-1 is located 10° farther west on the Bjorn-Gardar Drift on the eastern flank of the Reykjanes Ridge at a shallower water depth of 1653 m. Sedimentation rates at this site are lower (~10 cm/kyr) although still high by open ocean pelagic standards. Here we hope to get continuous APC records extending to the Pliocene as well as an XCB record to the Miocene. In addition to extending farther back in time, this site will also allow us to assess east-west gradients in surface water conditions as well as monitor Norwegian-Greenland Sea overflows farther to the west. A nearby alternate site, GARDAR-1 (1977 m), is located at the depth of Glacial North Atlantic Intermediate Water during the last glaciation. Piston core results suggest that sedimentation rates as high as 13 cm/kyr would be found here, again providing an unprecedented record of both glacial-interglacial and millennial scale variations in thermohaline circulation, surface water temperatures, and ice-rafting history.

The last southern gateway site, NAMD-1 (1150 m water depth), is a re-occupation of DSDP Site 116. Information from this site, located on the top of the Rockall Plateau, will help reconstruct the water mass behavior in the North Atlantic on glacial-interglacial time scales of the Plio/Pleistocene with special emphasis on the formation of Glacial North Atlantic Intermediate Water (GNAIW). In addition, we will be able to document the water mass structure in the North Atlantic during the late middle Miocene when the Iceland-Faeroe Ridge subsided to depths that allowed deep water exchange between the Nordic Seas and the North Atlantic.

Site 116 seems to be well suited for the proposed program in that a discontinuously drilled carbonate record back to the Oligocene has been recovered at this location. Its position on a structural high protects this site from turbidites, and its shallow depth greatly diminishes the risk of carbonate dissolution due to vertical fluctuations of the carbonate compensation depth. Furthermore, this site is in the flow path of the Iceland-Faeroe Ridge overflow waters which comprise a major constituent of NADW, and is in the area of potential glacial North Atlantic Intermediate Water formation.

SHIPBOARD SCIENCE AND DRILLING PLAN

Drilling Strategy

Most of the NAAG objectives require drilling rapidly deposited (>50 m/m.y.) sequences, with triple APC coring to refusal. This approach will permit the retrieval of continuous sections for high resolution analysis of the higher frequency (orbital- and millennial-scale) variations of the climate system. At the same time, it also provides sequences spanning millions of years, over which time the average climate state has evolved toward generally colder conditions and over which the spectral character of orbital-scale variations has changed dramatically. Composite sections representing continuous sedimentation records will be developed at each site during coring operations. These composites will be based on continuous data obtained by the multisensor track, logging, and spectral reflectance. Triple APC cores are necessary to allow normal ODP sampling density guidelines to be exceeded for ultrahigh resolution paleoceanographic studies. In addition, triple coring will ensure that U-channel magnetic studies as well as geotechnical measurements on whole round samples can be done without sacrificing record continuity . If deemed necessary it may also be possible to preserve the cores from the third hole for X-ray imaging before sampling.

The drilling schedule (Tables 1 and 2) outlines a 56-day leg with operations at eight sites (Figs. 5-18). We will begin drilling on the sediment drifts south of Iceland (FENI-1 and -2), moving to the Rockall Plateau (NAMD-1). At NAMD-1 we currently plan to XCB to 500 m. If the recovered sediment looks continuous and undisturbed, a second XCB hole will be considered. If any time is gained by an early ship departure, and/or at operations on FENI-1 and -2, we plan to double XCB the B hole as well as the C hole in hopes of generating continuous composite sequences through the Miocene. We will then move to BJORN-1, Site 907 (ICEP-1), and EGM-4, before moving to SVAL-1B. Time permitting, a third dedicated geotechnical hole will be drilled at Site 907 (APC to 220 m). At SVAL-1B a decision will be made as to whether sea ice conditions will permit drilling at the Yermak Plateau sites. We will need to have 8 days of ice free conditions in the YERM area to complete operations. Ice conditions will be monitored weekly by satellite from the start of the leg and the monitoring frequency will increase if an ice window appears imminent. We will not transit to the drilling sites unless they are likely to be ice free for the duration of time needed to complete operations. If YERM-1 (A through D) are ice-covered or near the ice margin, we will move to YERM-2. If YERM-2 is also inaccessible we will transit to secondary site objectives ICEP-3 and GARDAR-1 (Figs. 19-25).

Downhole Temperature Measurements

We may elect to establish one or two in-situ temperature profiles across the upper 200 m sediment section to examine effects of upper ocean temperature changes during the Holocene on the geothermal gradient. We would use the APC temperature tool until APC refusal or critical overpull in some of the sites south of Iceland. This instrument is located within the cavity of the APC coring shoe and does not require a separate tool lowering.

Logging Strategy

The standard three tool strings, Quad-Combination, Geochemical, and the Formation Microscanner, have been selected for Leg 162 holes drilled over 400 m. In holes less than 400 m, logging may occur where it assists in meeting the scientific objectives of the site.

Some of the benefits to be gained by logging during Leg 162 are direct core-log depth merging (to ensure that composite depths can be scaled back to true vertical depth), use of the spectral gamma ray (NGT) tool data for basic clay typing (mineralogy tied to changing climate), use of the geochemical logging tool for estimating bulk mineralogy, and integration of the Formation MicroScanner images (FMS) with the spherically focused log (SFL) data to resolve fine-scale (orbital) bedding cycles. The tools are described briefly below; more information on the tools exists in the Lamont Loggers Manual.

Quad-Combination Tool String. This will be first logging tool string to be run in the hole, measuring formation velocity, resistivity, density, and natural gamma-ray activity in a single logging pass. Sonic velocity data are combined with density measurements to calculate an impedance log and generate synthetic seismograms which can be used to tie the seismic information directly to the logs and core data. The density and resistivity logs are valuable for lithologic information of the hole. This tool string also provides continuous physical property measurements of density and porosity at half foot (0.1524 m) intervals, or at one inch (.025 m) and two inch (.05 m) measurements of density and porosity respectively when logged in the "high resolution" logging mode.

Geochemical Tool String. The geochemical tool string measures relative concentrations of Si, Ca, Fe, S, H, and Cl and wet weight percentages of K, U, Th, and Al on the ship. Shore-based processing produces dry weight percentages of these major rock forming elements along with Gd and Ti. These elemental logs infer lithology of the hole, and a shore-based log analysis program at Lamont will be used for matrix inversion. Continuous chemical measurements from this tool will exist every 0.1524 m.

Formation MicroScanner. The FMS provides oriented, two-dimensional, high resolution images of the variations in microresistivity around the borehole wall. The string also includes a general purpose inclinometer tool (GPIT) which allows for the orientation of the microresistivity measurements from accelerometry measurements and from the declination and inclination components of the Earth's magnetic field vector. The FMS can be used for the following applications: correlation of coring and logging depth, orientation of cores and location of the cored sections when recovery is less than 100%, mapping of sedimentary structures and interpretation of depositional environments. On this leg, it is planned that the FMS be merged with the shallow resistivity in order to create a high resolution log of the resistivity of the hole. From this high resolution log, porosity and density can be calculated, which will show fine scale lithologic changes.

REFERENCES

Aagaard, K., 1981. On the deep circulation in the Arctic ocean. Deep-Sea Res., 15:281-296.

Aagaard, K., Swift, J.H., and Carmack, E.C., 1985. Thermohaline circulation in the Arctic Mediterranean Seas. J. Geophys. Res. C3, 90:4833-4846.

Berger, W.H., and Jansen, E., 1994. Mid-Pleistocene Climate Shift: The Nansen Connection. In Johannessen, O.M., et al.(Eds.), The Role of the Polar Oceans in Shaping the Global Environment: Geophysical Monographs.

Berggren W.A., and Schnitker, D., 1983. Cenozoic marine environments in the North Atlantic and Norwegian-Greenland Sea. In Bott, M.H.P., et al. (Eds.), Structure and Development of the Greenland-Scotland Ridge. NATO Conf. Ser. IV: New York (Plenum Press), 495-548.

Bond, G., Heinrich, H., Broecker, W., Labeyrie, L., McManus, J., Andrews, J., et al., 1992. Evidence for massive discharges of icebergs into the North Atlantic Ocean during the last glacial. Nature, 360: 245-249.

Bond, G., Broecker, W., Johnsen, S., McManus, J., Labeyrie, L., Jouzel, J., and Bonani, G., 1993. Correlations between climate records from the North Atlantic sediments and Greenland ice. Nature. 365:143-147.

Bott, M.H.P., Saxov, S., Talwani, M., and Thiede, J., (Eds.), 1983. In Bott, M.H.P., et al. (Eds.), Structure and Development of the Greenland-Scotland Ridge. NATO Conf. Ser. IV: New York (Plenum Press), 1-685.

Boyle, E.A., 1988. Vertical ocean nutrient fractionation and glacial/interglacial CO_2 cycles. Nature, 331:55-56.

Broecker, W.S., 1994. Massive iceberg discharges as triggers for global climate change. Nature, 372:4221-424.

Broecker, W.S., Peng T.-H., 1989. The cause of the glacial to interglacial atmospheric CO_2 change: a polar alkalinity hypothesis. Global Biogeochem. Cycles, 3:215-239.

Broecker, W.S., Peteet, D.M., and Rind, D., 1985. Does the ocean-atmosphere system have more than one stable mode of operation? Nature, 315:21-26.

Carter, L.D., Brigham-Grette, J., Marinkovich, L., Pease, V.L., and Hillhouse, J.W., 1986. Late Cenozoic Arctic Ocean sea-ice and terrestrial paleoclimate. Geology, 14:675-678.

Clark, D.L., 1982. Origin, nature and world climate effect of Arctic Ocean ice-cover. Nature , 300:321-325.

Crane, K., Eldholm, O., Myhre, A.M., and Sundvor, E., 1982. Thermal implications for the evolution of the Spitsbergen transform fault. Tectonophysics, 89:1-32.

Eldholm, O., Faleide, J.I., and Myhre, A.M., 1987a. Continent-ocean transition at the western Barents Sea/Svalbard continental margin. Geology, 15:1118-1122.

Eldholm, O., Thiede, J., Taylor, E., et al., 1987b. Proc. ODP, Init. Repts., 104: College Station, TX (Ocean Drilling Program).

Helland-Hansen, B., and Nansen, F., 1909. The Norwegian Sea: Its physical oceanography based upon the Norwegian researches 1900-1904. Rep. Norw. Fish. Mar. Invest., 2:1-390.

Herman, Y., and Hopkins, D.M., 1980. Arctic Ocean climate in late Cenozoic times. Science, 209:557-562.

Imbrie, J., Boyle, E.A., Clemens, S.C., Duffy, A., Howard, W.R., Kukla, G., Kutzbach, J., Martinson, D.G., McIntyre, A., Mix, A.C., Molfino, B., Morley, J.J., Peterson, L.C., Pisias, N.G., Prell, W.L., Raymo, M.E., Shackleton, N.J., and Toggweiler, J.R., 1993. On the structure and origin of major glaciation cycles. 2. The 100,000-year cycle. Paleoceanography, 8:699-736.

Imbrie, J., Boyle, E.A., Clemens, S.C., Duffy, A., Howard, W.R., Kukla, G., Kutzbach, J., Martinson, D.G., McIntyre, A., Mix, A.C., Molfino, B., Morley, J.J., Peterson, L.C., Pisias, N.G., Prell, W.L., Raymo, M.E., Shackleton, N.J., and Toggweiler, J.R., 1992. On the structure and origin of major glaciation cycles. 1. Linear responses to Milankovitch forcing. Paleoceanography, 7:701-738.

Jansen, E., and Sjøholm, J., 1991. Reconstruction of glaciation over the past 6 million years from ice-borne deposits in the Norwegian Sea. *Nature* , 349:600-604.

Mantyla, A.W., and Reid, J.L., 1983. On the abyssal circulation of the world ocean. Deep-Sea Res., 30:805-833.

Myhre, A.M., Thiede, J., Firth, J.V., et al., 1995. Proc. ODP, Init. Repts., 152: College Station, TX (Ocean Drilling Program).

Peterson, W.H., and Rooth, C.G.H., 1976. Formation and exchange of deep water in the Greenland and Norwegian seas. Deep-Sea Res., 23:273-283.

Repenning, C.A., Brouwers, E.M., Carter, L.D., Marincovitch, L., Jr., and Ager, T.A., 1987. The Beringian ancestry of *Phenacomys* (Rodentia: Cricetidae) and the beginning of the modern Arctic Ocean borderland biota. U.S. Geol. Survey Bull., 1687:1-28.

Smethie, W.M., Chipman, D.W., Swift, J.H., and Kolterman, K.P., 1988. Chlorofluoromethanes in the Arctic Mediterranean Sea: Evidence for formation of bottom water in the Eurasian Basin and deep-water exchange through Fram Strait. Deep-Sea Res., 35:347-370.

Swift, J.H., Takahashi, T., and Livingston, H.D., 1983. The contribution of the Greenland and Barents Seas to the deep water of the Arctic Ocean. J. Geophys. Res., 88:5981-5986.

Thiede, J., 1983. Outstanding geological problems of the Greenland-Scotland Ridge: An introduction. In Bott, M.H.P., et al. (Eds.), Structure and Development of the Greenland-Scotland Ridge. NATO Conf. Ser. IV: New York (Plenum Press), 313-318.

Thiede, J., and Eldholm, O., 1983. Speculations about the paleo-depth of the Greenland-Scotland Ridge during Late Mesozoic and Cenozoic times. In Bott, M.H.P., et al. (Eds.), Structure and Development of the Greenland-Scotland Ridge. NATO Conf. Ser. IV: New York (Plenum Press), 445-456.

Vogt, P.R., 1986a. Seafloor topography, sediments, and paleoenvironments. In Hurdle, B.G. (Ed.), The Nordic Seas: New York (Springer Verlag), 237-412.

Vogt, P.R., 1986b. Geophysical and geochemical signatures and plate tectonics. In Hurdle, B.G. (Ed.), The Nordic Seas: New York (Springer Verlag), 413-662.

Warren, B.A., 1981. Deep circulation of the world ocean. In Warren, B.A. and Wunsch, C. (Eds.), Evolution of Physical Oceanography: Cambridge, Mass. (MIT Press), 6-41.

Wright, J.D., 1991, Evolution of modern deepwater circulation: evidence from the late Miocene Southern Ocean. Paleoceanography, 6:275-90.

TABLE 1 - PRIMARY SITE TIME ESTIMATES

Proposed Site	Position	Water Depth (m)	Penetration (mbsf)	Drilling Operations (days)	Downhole Measurements (type)	Downhole Measurements (days)	Transit Time (days)
Transit - Leith to FENI-1							2.8
FENI-1	55°30.0'N 14°42.4'W	2157	110	1.7	None	0	
Transit - FENI-1 to FENI-2							0.1
FENNI-2	55°28.2'N 14°40.0'W	2157	225	2.6	None	0	
Transit - FENI-2 to NAMD-1							0.5
NAMD-1	57°30.8'N 15°52.5'W	1150	500	3.6	Standard	1.1	
Transit - NAMD-1 to BJORN-1							1.4
BJORN-1	61°25.17'N 24°06.33'W	1653	500	4.6	Standard	1.2	
Transit - BJORN-1 to Site 907							2.6
Site 907	69°14.988'N 12°44.894'W	1800.8	220	1.8	None	0	
Transit - Site 907 to EGM-4							0.6
EGM-4	70°30.0'N 18°20.0'W	1670	800	6.1	Standard	1.1	

Proposed Site	Position	Water Depth (m)	Penetration (mbsf)	Drilling Operations (days)	Downhole Measurements (type)	Downhole Measurements (days)	Transit Time (days)
Transit - EGM-4 to SVAL-1B							2.4
SVAL-1B	77°22.80'N 09°06.17'E	2120	900	8.2	Standard	1.2	
Transit - SVAL-1B to YERM-1A							0.9
YERM-1A	81°06.0'N 07°00.0'E	900	730	5.8	Standard	1.2	
Transit - YERM-1A to Reykjavik							4.5
Total				34.4		5.8	15.8
Total days at sea = 56							

TABLE 2 - ALTERNATE SITE TIME ESTIMATES

Alternate Site	Position	Water Depth (m)	Penetration (mbsf)	Drilling Operations (days)	Downhole Measurements (type)	Downhole Measurements (days)
YERM-1B	80°54.9'N 07°13.10'E	960	1000	8.7	Standard	1.5
YERM-1C	80°44.67'N 07°53.2'E	960	900	7.5	Standard	1.5
YERM-1D	80°41.20'N 07°59.0'E	930	1000	7.5	Standard	1.5
Site 912	79°57.552'N 05°27.360'E	1038.6	550	3.8	Standard	1.2
ICEP-3	66°56.0'N 06°27.0'W	2807	500	4.3	Standard	1.3
GARDAR-1	60°24.21'N 23°38.45'W	1977	300	3.9	None	0

FIGURES

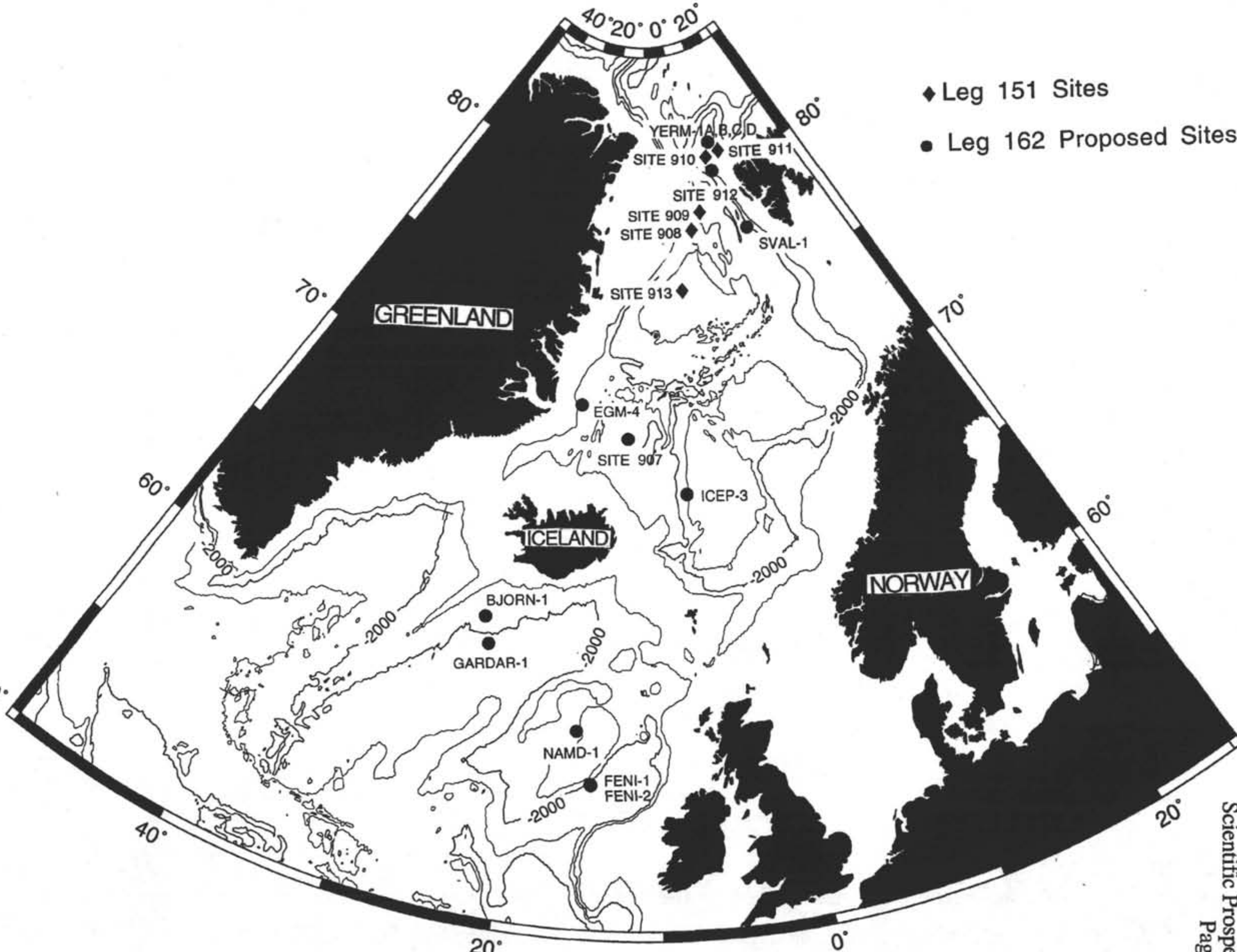
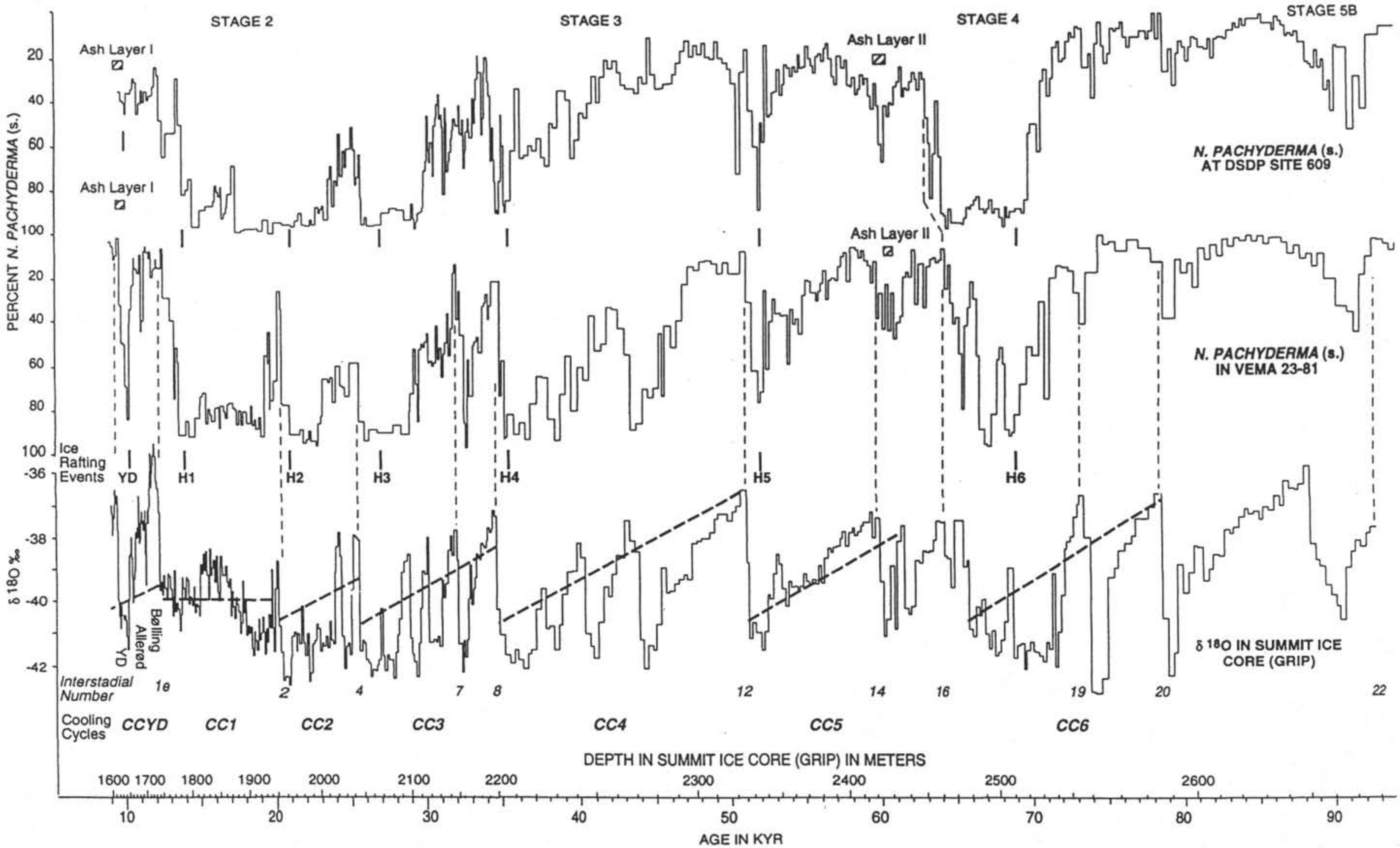

♦ Leg 151 Sites
● Leg 162 Proposed Sites
GREENLAND
ICELAND
NORWAY
YERM-1A,B,C,D
SITE 911
SITE 910
SITE 912
SITE 909
SITE 908
SVAL-1
SITE 913
EGM-4
SITE 907
ICEP-3
BJORN-1
GARDAR-1
NAMD-1
FENI-1
FENI-2
2000
40° 20° 0° 20°
80°
70°
60°
50°
40°
20°
0°

Figure 1



STAGE 2
STAGE 3
STAGE 4
STAGE 5B
Ash Layer I
Ash Layer II
PERCENT N. PACHYDERMA (s.)
N. PACHYDERMA (s.) AT DSDP SITE 609
N. PACHYDERMA (s.) IN VEMA 23-81
Ice Rafting Events
YD
H1
H2
H3
H4
H5
H6
δ 18O ‰
Bølling Allerød
YD
δ 18O IN SUMMIT ICE CORE (GRIP)
Interstadial Number
1e
2
4
7
8
12
14
16
19
20
22
Cooling Cycles
CCYD
CC1
CC2
CC3
CC4
CC5
CC6
DEPTH IN SUMMIT ICE CORE (GRIP) IN METERS
AGE IN KYR

Figure 2

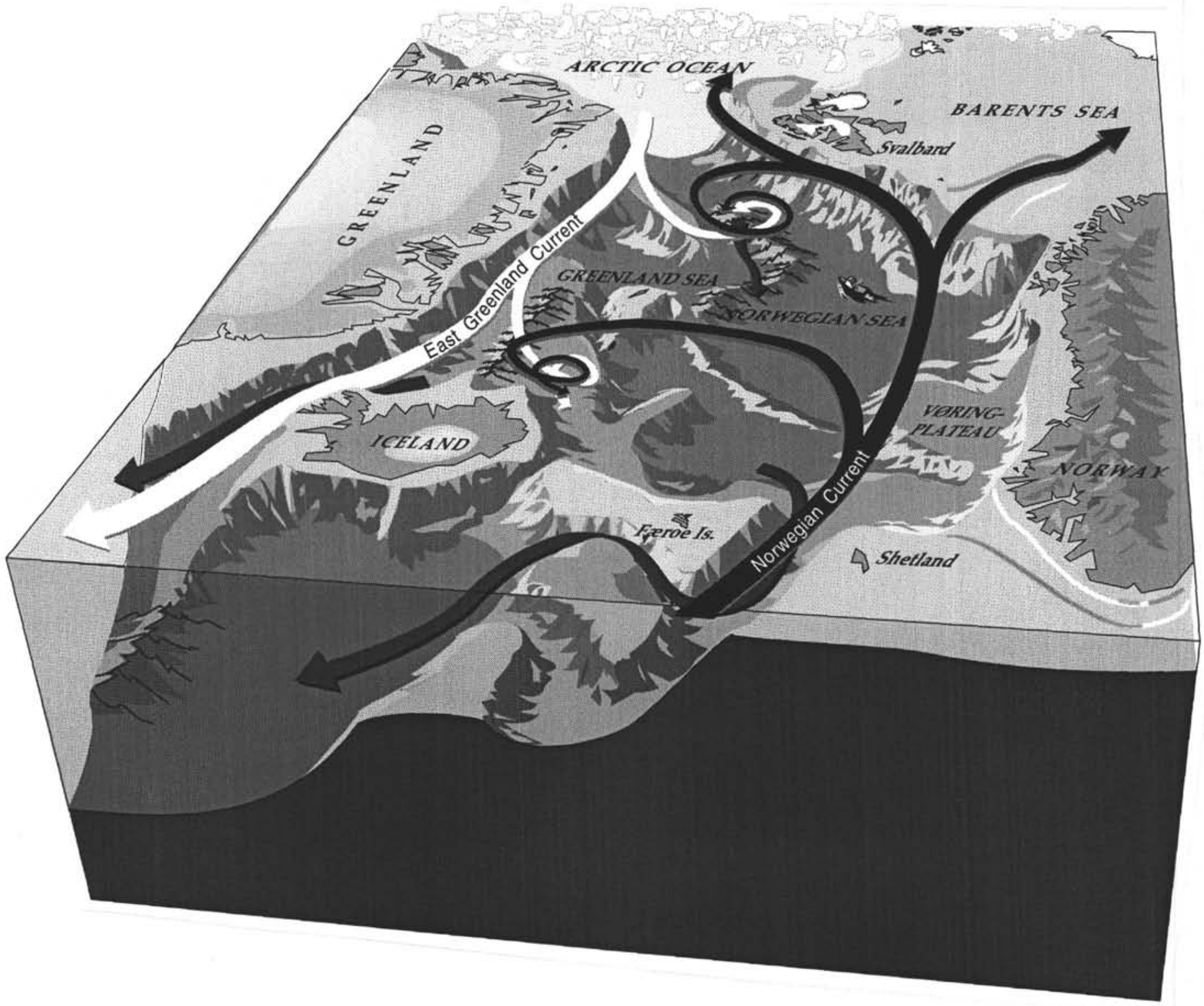

ARCTIC OCEAN
BARENTS SEA
Svalbard
GREENLAND
East Greenland Current
GREENLAND SEA
NORWEGIAN SEA
VØRING-
PLATEAU
ICELAND
NORWAY
Færoe Is.
Norwegian Current
Shetland

Figure 3

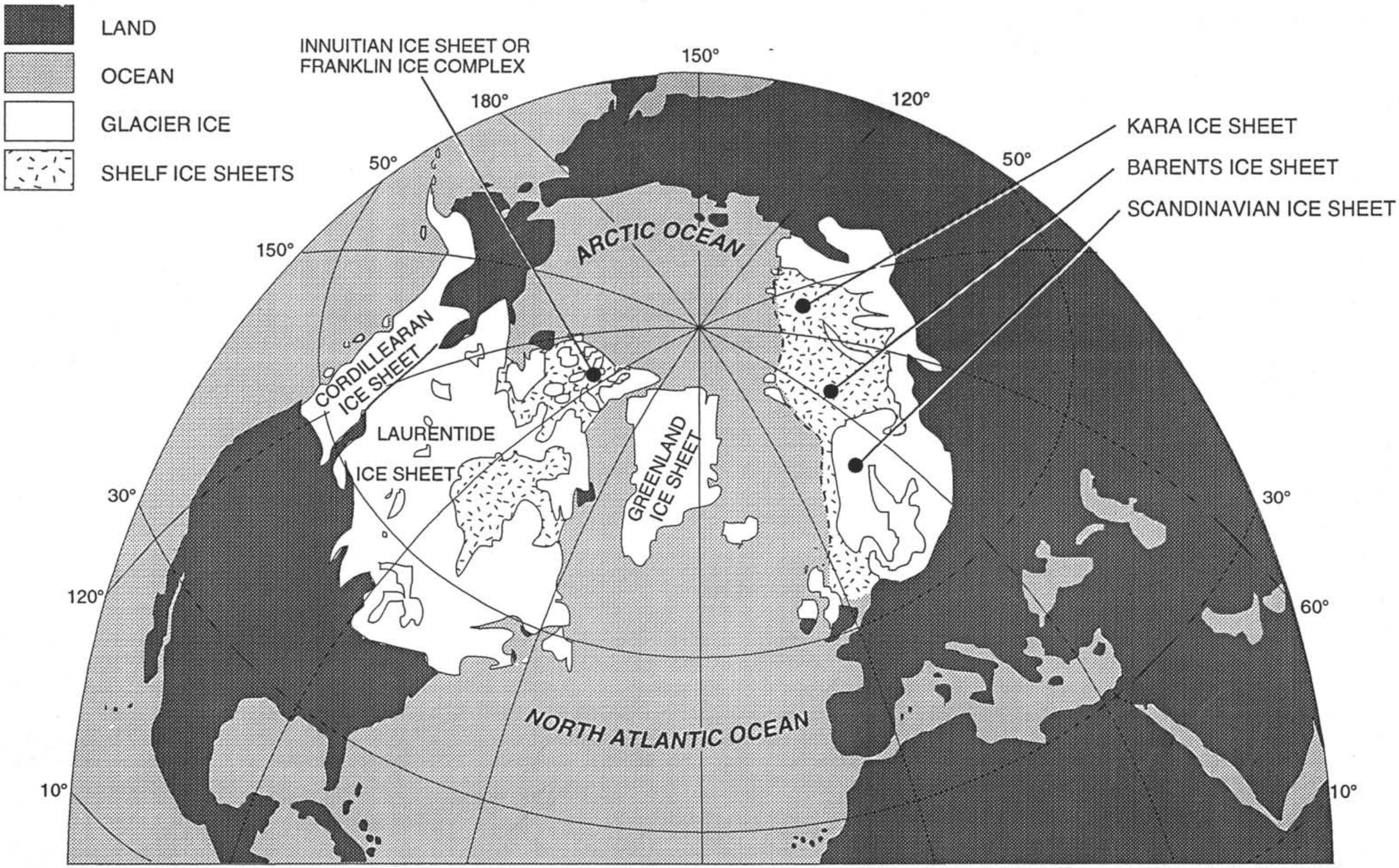
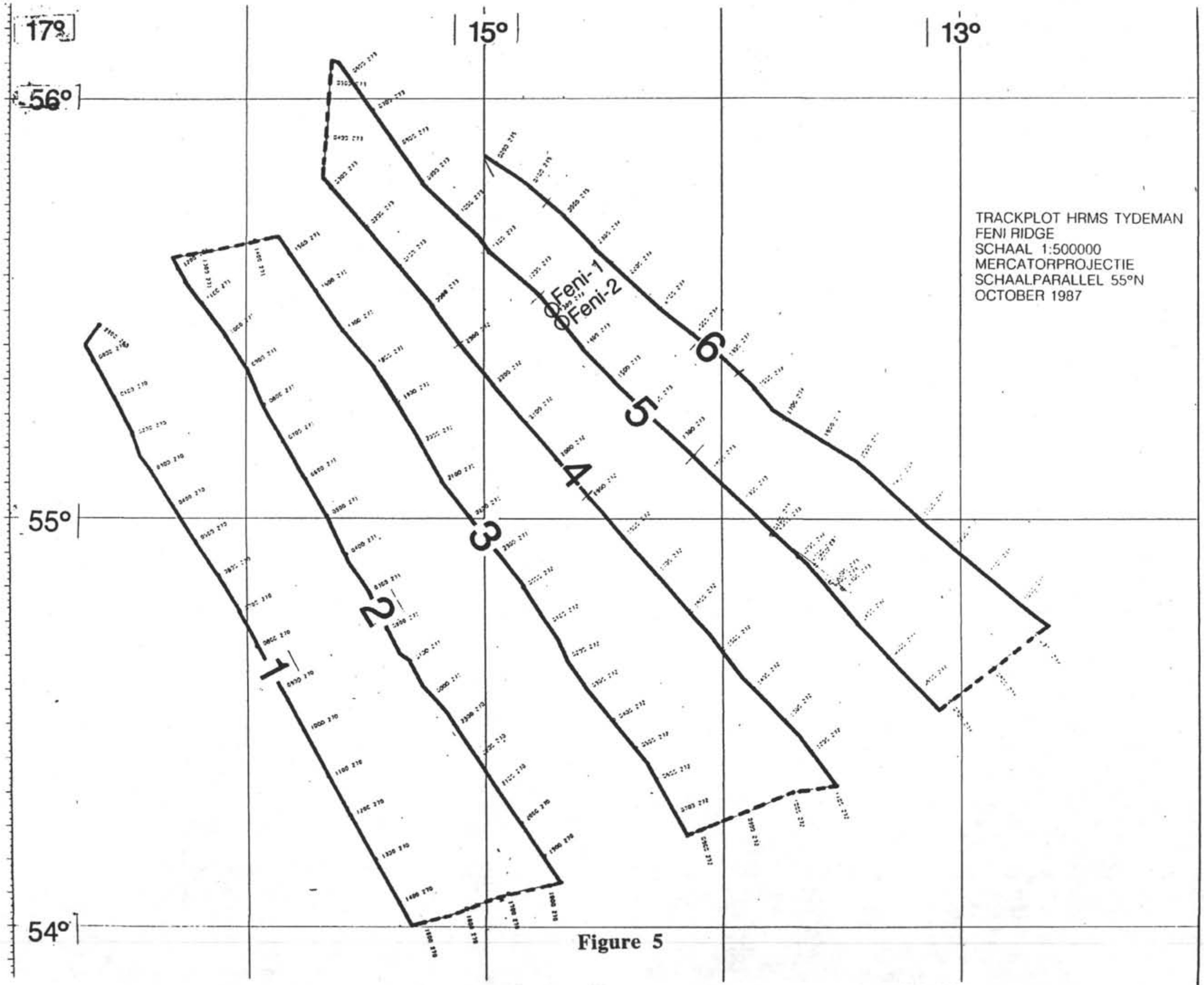

LAND
OCEAN
GLACIER ICE
SHELF ICE SHEETS
INNUITIAN ICE SHEET OR
FRANKLIN ICE COMPLEX
150°
180°
120°
KARA ICE SHEET
BARENTS ICE SHEET
SCANDINAVIAN ICE SHEET
50°
50°
150°
ARCTIC OCEAN
CORDILLEARAN
ICE SHEET
LAURENTIDE
ICE SHEET
GREENLAND
ICE SHEET
30°
30°
120°
60°
NORTH ATLANTIC OCEAN
10°
10°

Figure 4



17°
15°
13°
56°
55°
54°
1
2
3
4
5
6
Feni-1
Feni-2
TRACKPLOT HRMS TYDEMAN
FENI RIDGE
SCHAAL 1:500000
MERCATORPROJECTIE
SCHAALPARALLEL 55°N
OCTOBER 1987

Figure 5

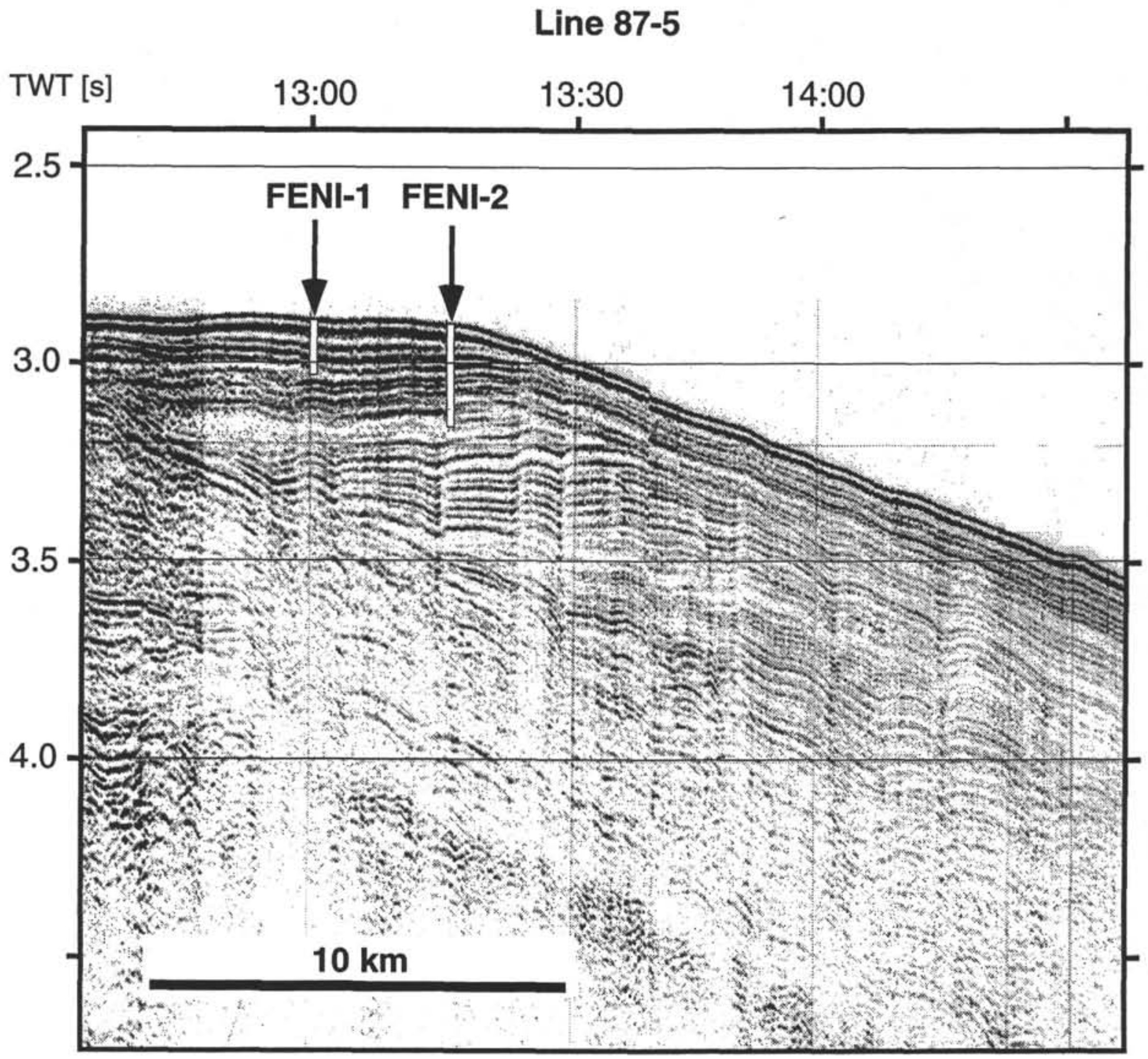


Figure 6

Site: FENI-1
Priority: 1
Position: 55°30.0´N, 14°42.4´W
Water Depth: 2157 m
Sediment Thickness:
Total Penetration: 110 mbsf
Seismic Coverage: Tydeman 87 Line 5 - 13.00 hr

Objectives: Located on the Feni Drift, this site will recover an approximately 100-m record of the Brunhes Chron at sedimentation rates of better than 100 cm/kyr. This site will be used to study mid-depth nutrient variability (1900 m), deep water circulation, and the surface-deep water links on both Milankovitch and millenial time scales.

Drilling Program: Hole A: APC -> 110 m; Hole B: APC -> 110 m; Hole C: APC -> 110 m.

Logging: No logging.

Nature of Rock Anticipated: Pelagic to hemipelagic muds with ice rafted detritus.

Site: FENI-2

Priority: 1

Position: 55°28.2´N, 14°40.0´W

Water Depth: 2157 m

Sediment Thickness:

Total Penetration: 225 mbsf

Seismic Coverage: Tydeman 87 Line 5 - 13.18 hr.

Objectives: This site is at the same depth as FENI-1 and should recover a late Pliocene to Pleistocene record of sediments, also at greater than 10 cm/kyr. This site is essentially an extension of FENI-1 at a nearby location on the drift and would address many similar scientific objectives.

Drilling Program: Hole A: APC -> 225 m; Hole B: APC -> 225 m; Hole C: APC -> 225 m.

Logging: No logging.

Nature of Rock Anticipated: Pelagic to hemipelagic muds with ice rafted detritus.

Geological Survey of Denmark

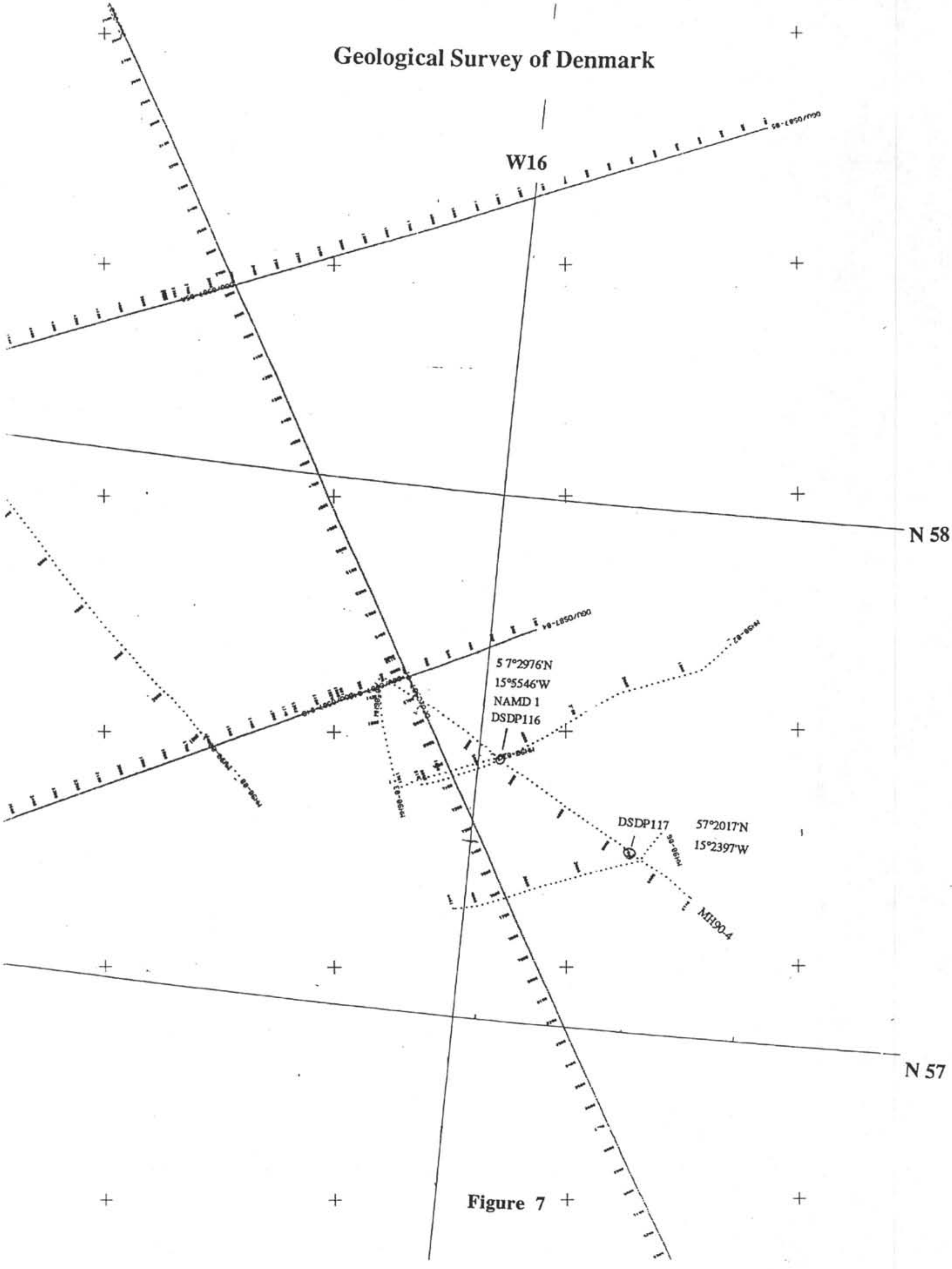


Figure 7

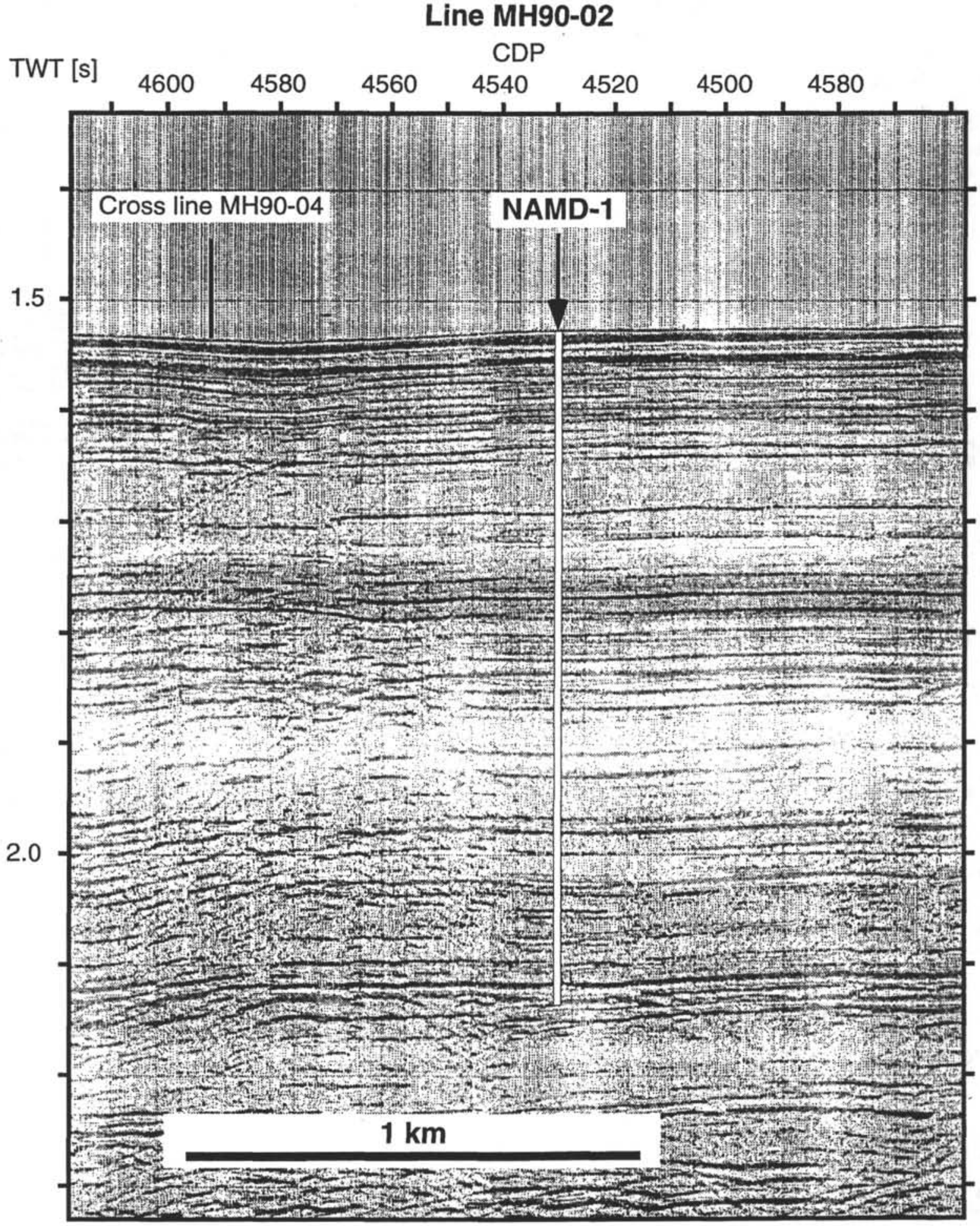

Line MH90-02
CDP
TWT [s]
4600
4580
4560
4540
4520
4500
4580
Cross line MH90-04
NAMD-1
1.5
2.0
1 km

Figure 8

Site: NAMD-1
Priority: 1
Position: 57°30.8´N , 15°52.5´W
Water Depth: 1150 m
Sediment Thickness: ca. 820 m
Total Penetration: 500 mbsf
Seismic Coverage: MH 90-2 (SP 4530)

Objectives: This site will help reconstruct the water mass behavior in the North Atlantic on glacial-interglacial time scales of the Plio/Pleistocene with special emphasis on the formation of Glacial North Atlantic Intermediate Water (GNAIW). In addition, we will be able to document the water mass structure in the North Atlantic during the late middle Miocene when the Iceland-Faeroe Ridge subsided to depths that finally allowed deep water exchange between the Nordic Seas and the North Atlantic to evolve. The recovery of a pre-middle Miocene section should document North Atlantic water mass circulation at times when no NADW existed; obtaining Oligocene sediment sections will allow studies of how the high-latitude North Atlantic responded to early intervals of apparent Antarctic glaciation as implied by the existence of glacially derived sediments in the Southern Ocean area.

Drilling Program: Hole A: APC -> 200 m; Hole B: APC -> 200 m, XCB -> 500 m, log; Hole C: APC -> 200 m.

Logging: Standard logging.

Nature Of Rock Anticipated: Pelagic to hemipelagic muds with ice rafted detritus.

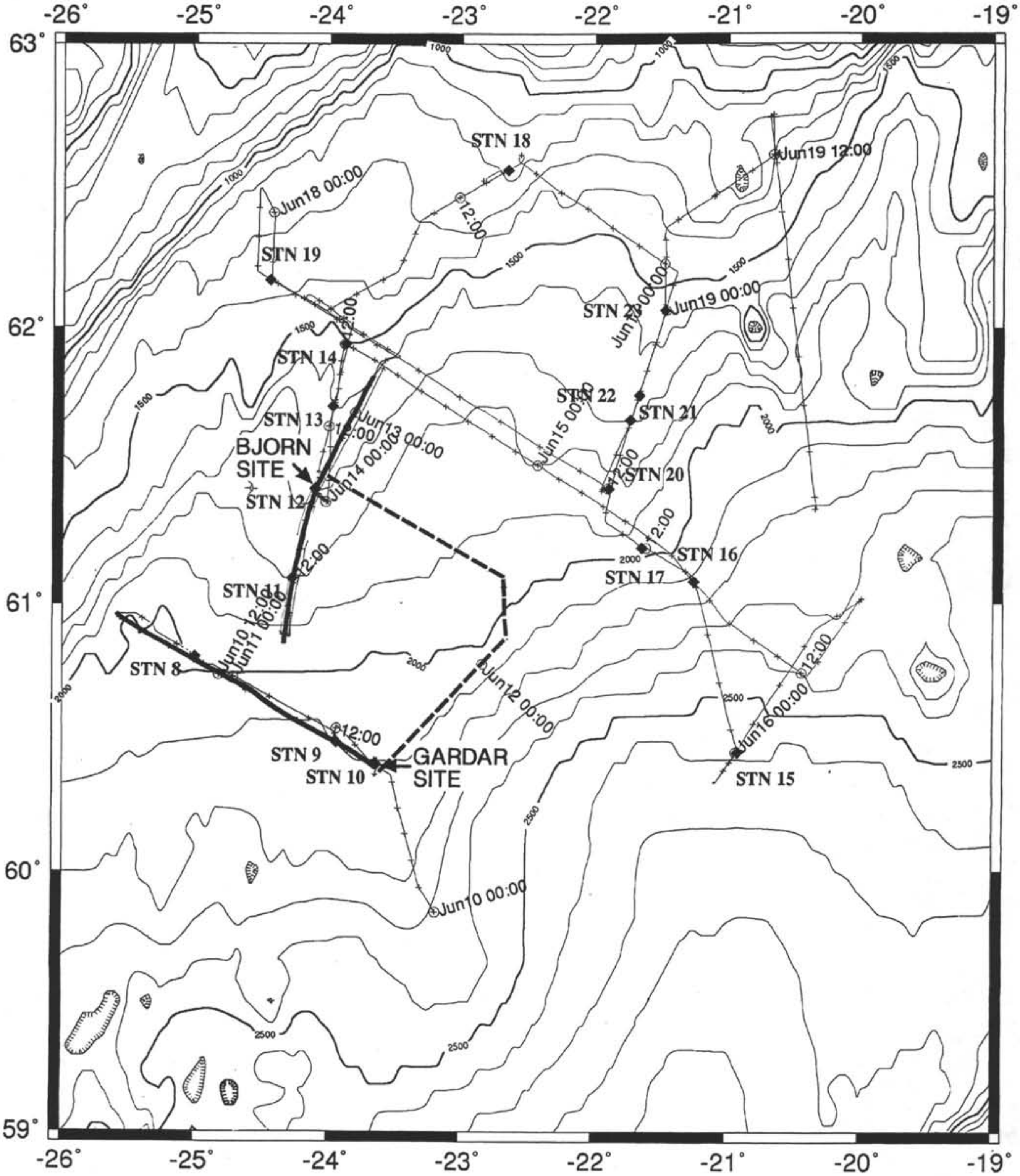

-26°
-25°
-24°
-23°
-22°
-21°
-20°
-19°
63°
62°
61°
60°
59°
STN 18
Jun19 12:00
Jun18 00:00
12:00
STN 19
STN 23
Jun19 00:00
STN 14
STN 22
STN 21
STN 13
Jun13 00:00
BJORN
SITE
Jun14 00:00
Jun15 00:00
STN 20
STN 12
STN 16
STN 17
STN 11
12:00
Jun10 12:00
Jun11 00:00
STN 8
Jun12 00:00
12:00
Jun16 00:00
STN 9
GARDAR
SITE
STN 10
STN 15
Jun10 00:00
1000
1500
2000
2500

Figure 9

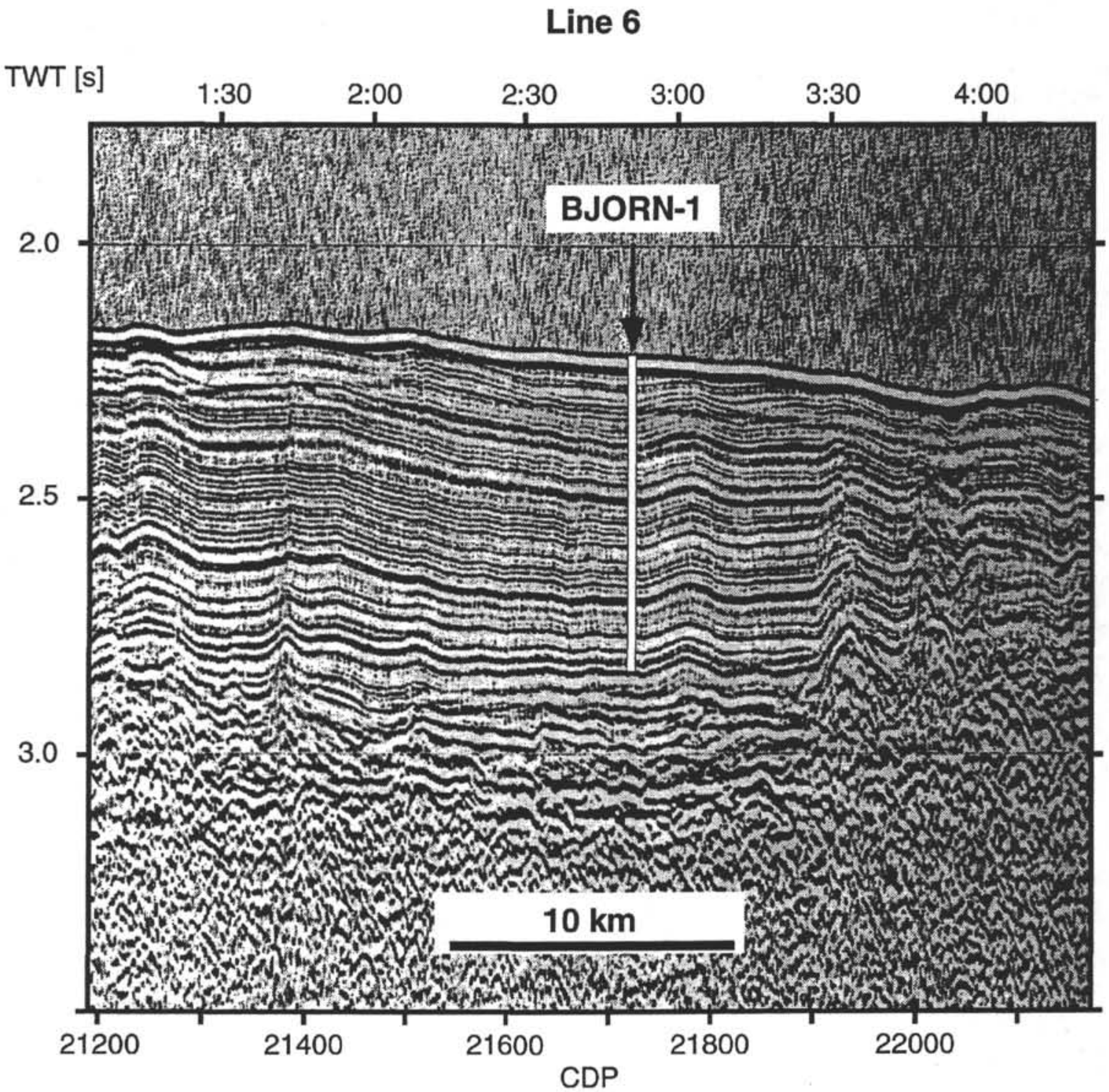

Line 6
TWT [s]
1:30
2:00
2:30
3:00
3:30
4:00
BJORN-1
2.0
2.5
3.0
10 km
21200
21400
21600
21800
22000
CDP

Figure 10

Site: BJORN-1
Priority: 1
Position: 61°25.17´N, 24°06.33´W
Water Depth: 1653 m
Sediment Thickness: >700 m
Total Penetration: 500 mbsf
Seismic Coverage: Ewing 9302 Line 6b @ 02.45 hr, CDP 21720 X-ing line 2 @ 02.00 hr.

Objectives: This site is in the same region as GARDAR-1 at a shallower depth. Sedimentation rates are lower (5-9 cm/kyr), although still high by open ocean pelagic standards. The attraction of this site is the ability to get a high resolution record of intermediate water circulation extending back to the Miocene.

Drilling Program: Hole A: APC -> 300 m; Hole B: APC -> 300 m, XCB -> 500 m, Hole C: APC -> 300 m.

Logging: Standard logging.

Nature of Rock Anticipated: Pelagic to hemipelagic muds with ice rafted detritus and ash layers.

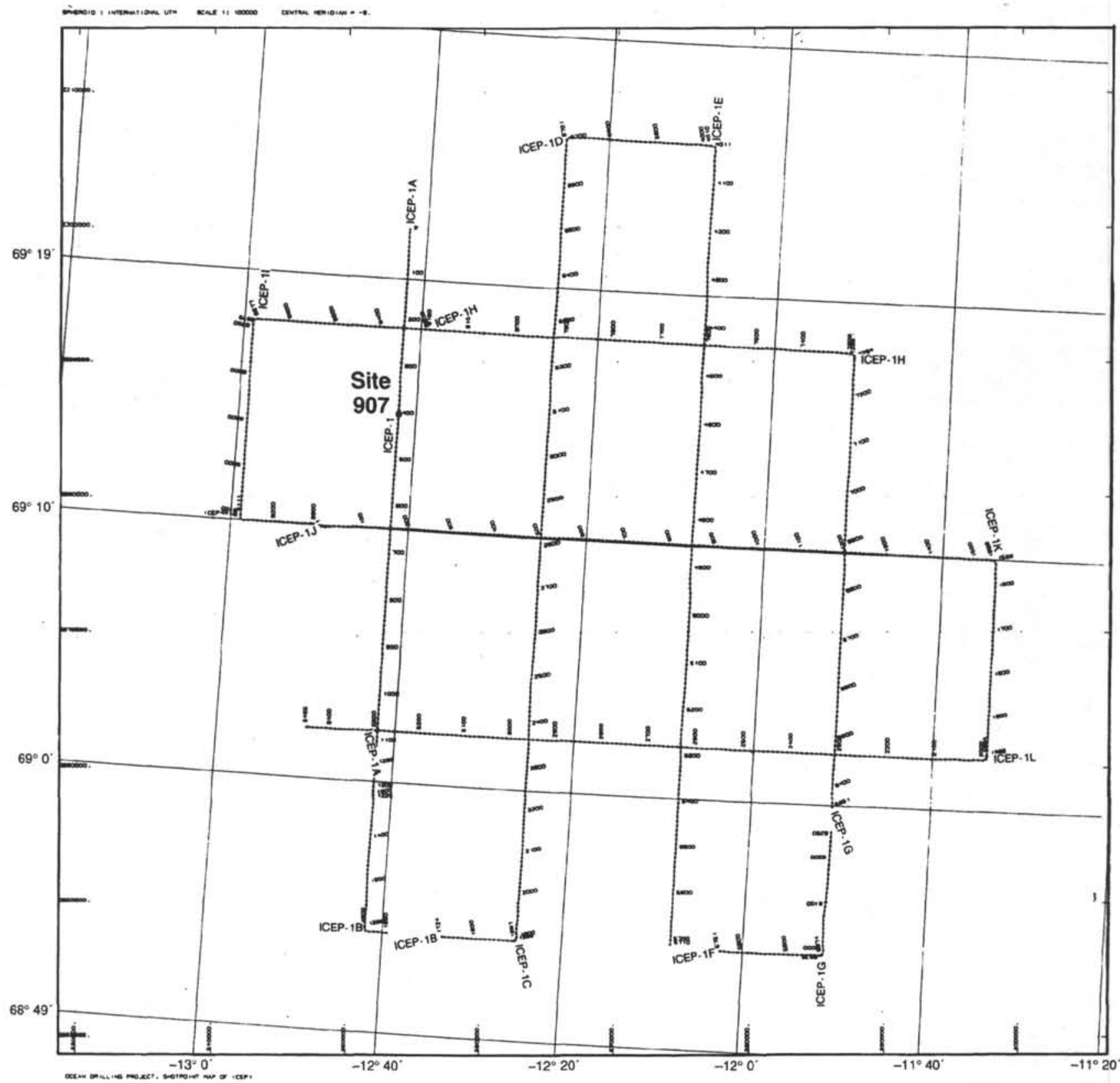

69° 19'
69° 10'
69° 0'
68° 49'
-13° 0'
-12° 40'
-12° 20'
-12° 0'
-11° 40'
-11° 20'
Site
907
ICEP-1
ICEP-1A
ICEP-1B
ICEP-1C
ICEP-1D
ICEP-1E
ICEP-1F
ICEP-1G
ICEP-1H
ICEP-1I
ICEP-1J
ICEP-1K
ICEP-1L

Figure 11

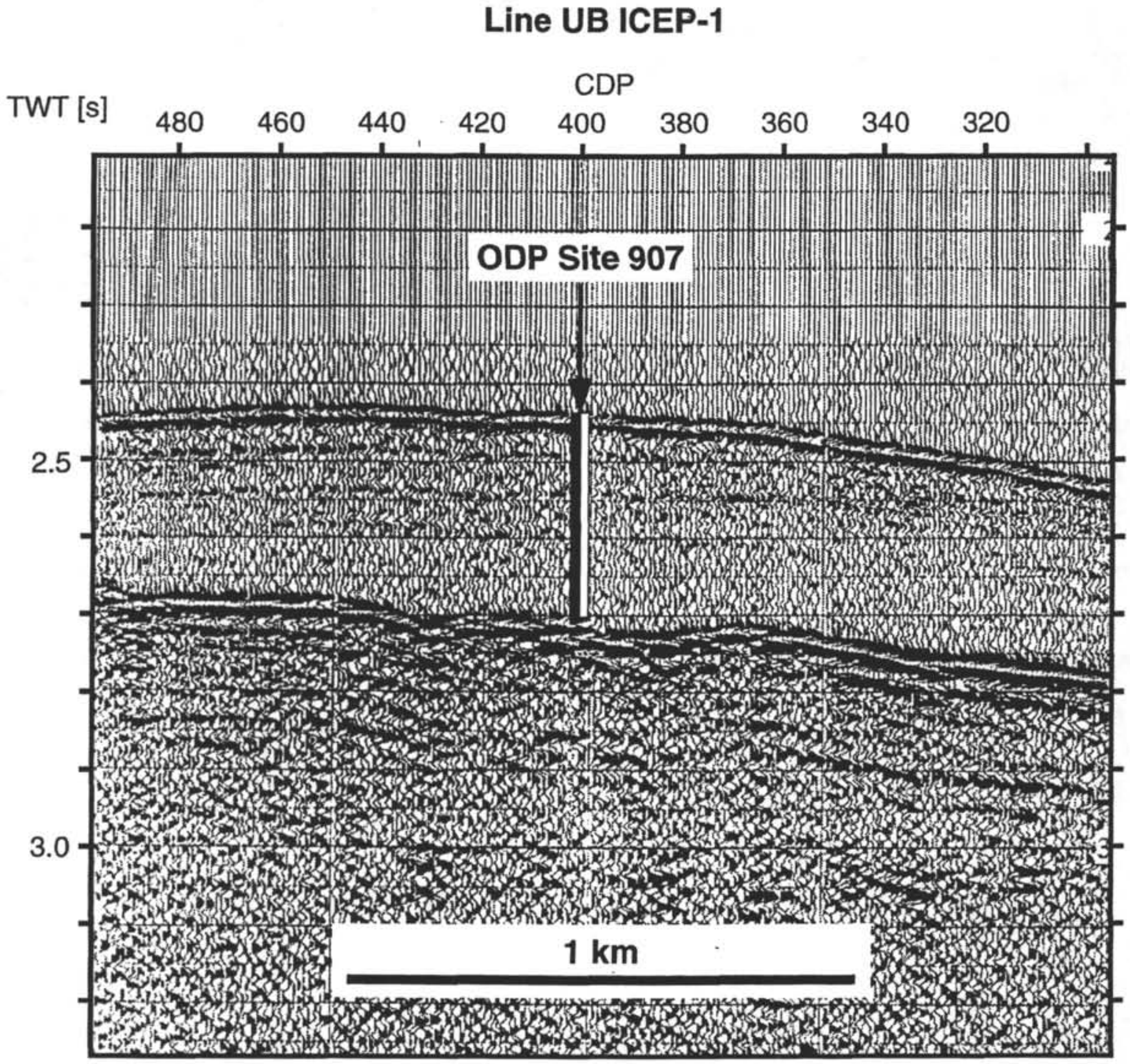

Line UB ICEP-1
CDP
TWT [s]
480
460
440
420
400
380
360
340
320
ODP Site 907
2.5
3.0
1 km

Figure 12

Site: ODP Site 907 (ICEP-1)
Priority: 1
Position: 69°14.988´N, 12°44.894´W
Water Depth: 1800.8 m
Sediment Thickness: 230 m
Total Penetration: 220 mbsf
Seismic Coverage: UB-ICEP-1-Segm.A (SP400)

Objectives: This site is proposed to (1) monitor the history of oceanic and climatic fronts moving east and west across the Iceland Plateau, (2) derive an open-ocean record of IRD and carbonate, and (3) determine the history of the formation of northern-source deep waters. While the first hole did not have abundant carbonate, an excellent record of siliceous microfossils extending back to the middle Miocene and physical property time series from this hole record impressive Milankovitch scale cyclicity. Given that this site is likely to become a type section for this region, additional offset holes were considered desirable. Site 907 is located on top of the plateau and is an open-ocean site isolated from continental marine influence on IRD records. It is planned to complete Site 907 with two more holes.

Drilling Program: (Hole A drilled on Leg 151); Hole B: APC -> 220 m; Hole C: APC -> 220 m.

Logging: No logging.

Nature of Rock Anticipated: Pelagic to hemipelagic muds with ice rafted detritus and ash layers.

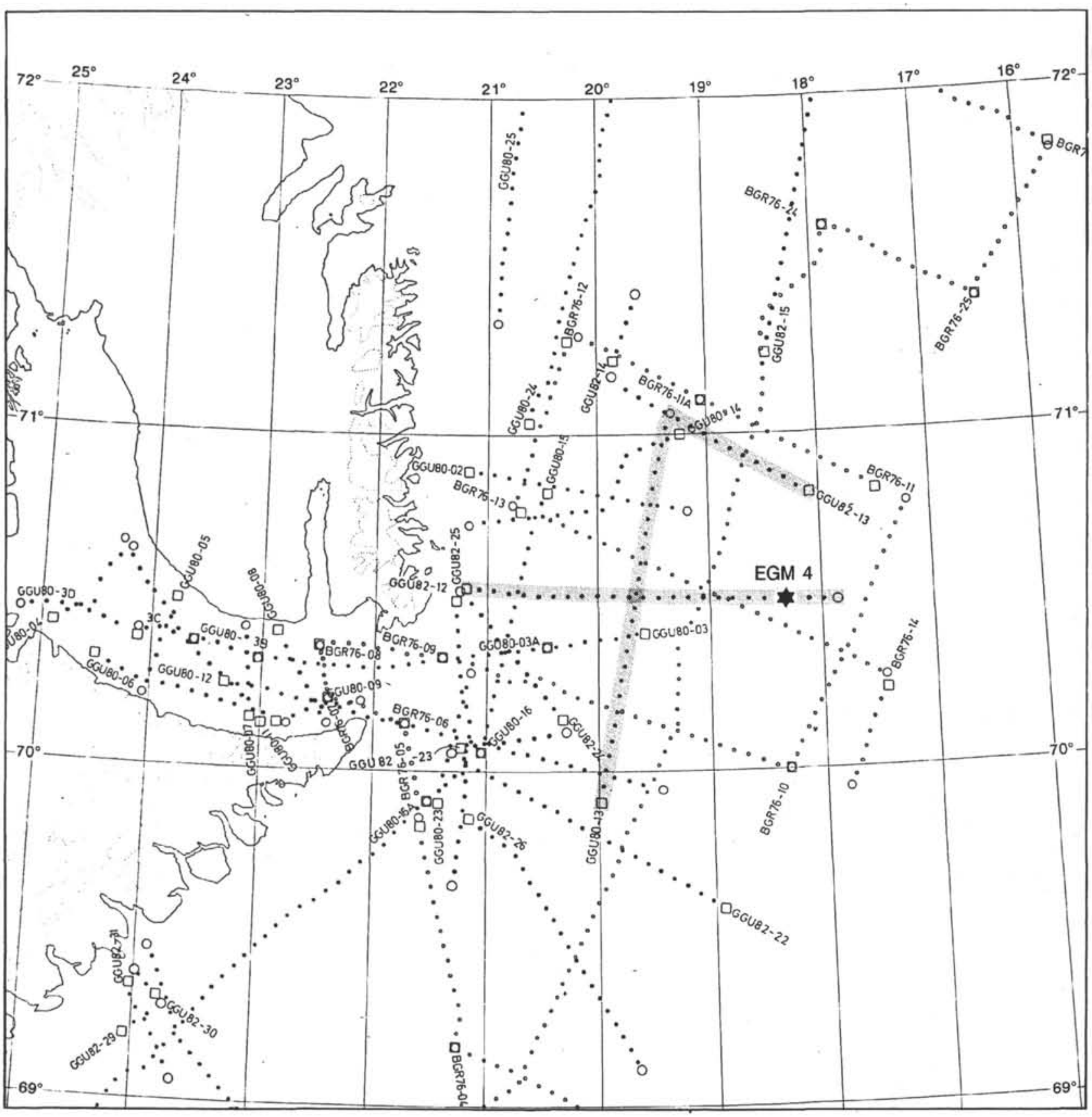


Figure 13

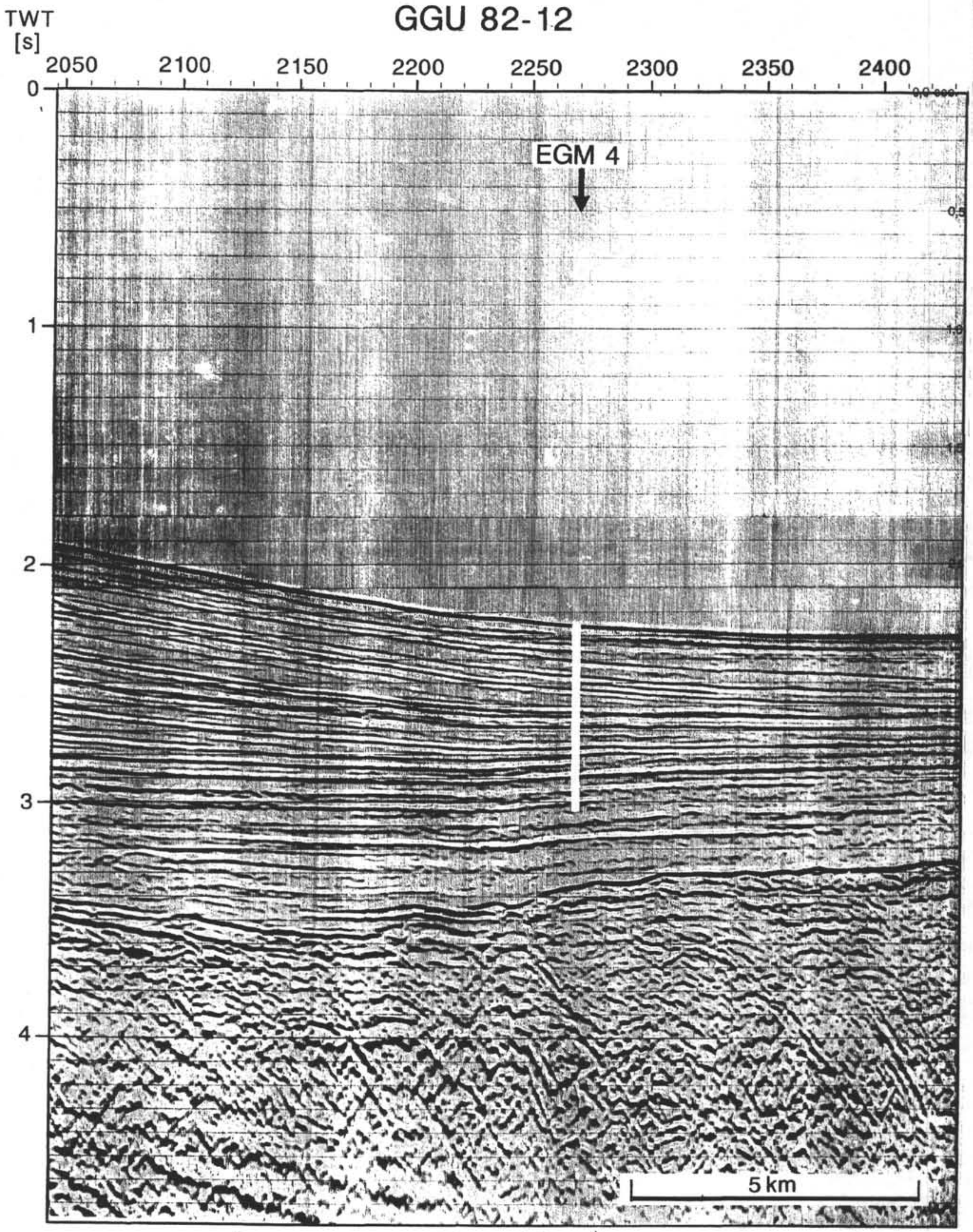

GGU 82-12
TWT
[s]
2050
2100
2150
2200
2250
2300
2350
2400
0
1
2
3
4
EGM 4
5 km

Figure 14

Site: EGM-4

Priority: 1

Position: 70°30.0'N, 18°20.0'W

Water Depth: 1670 m

Sediment Thickness: 1000 m

Total Penetration: 800 mbsf

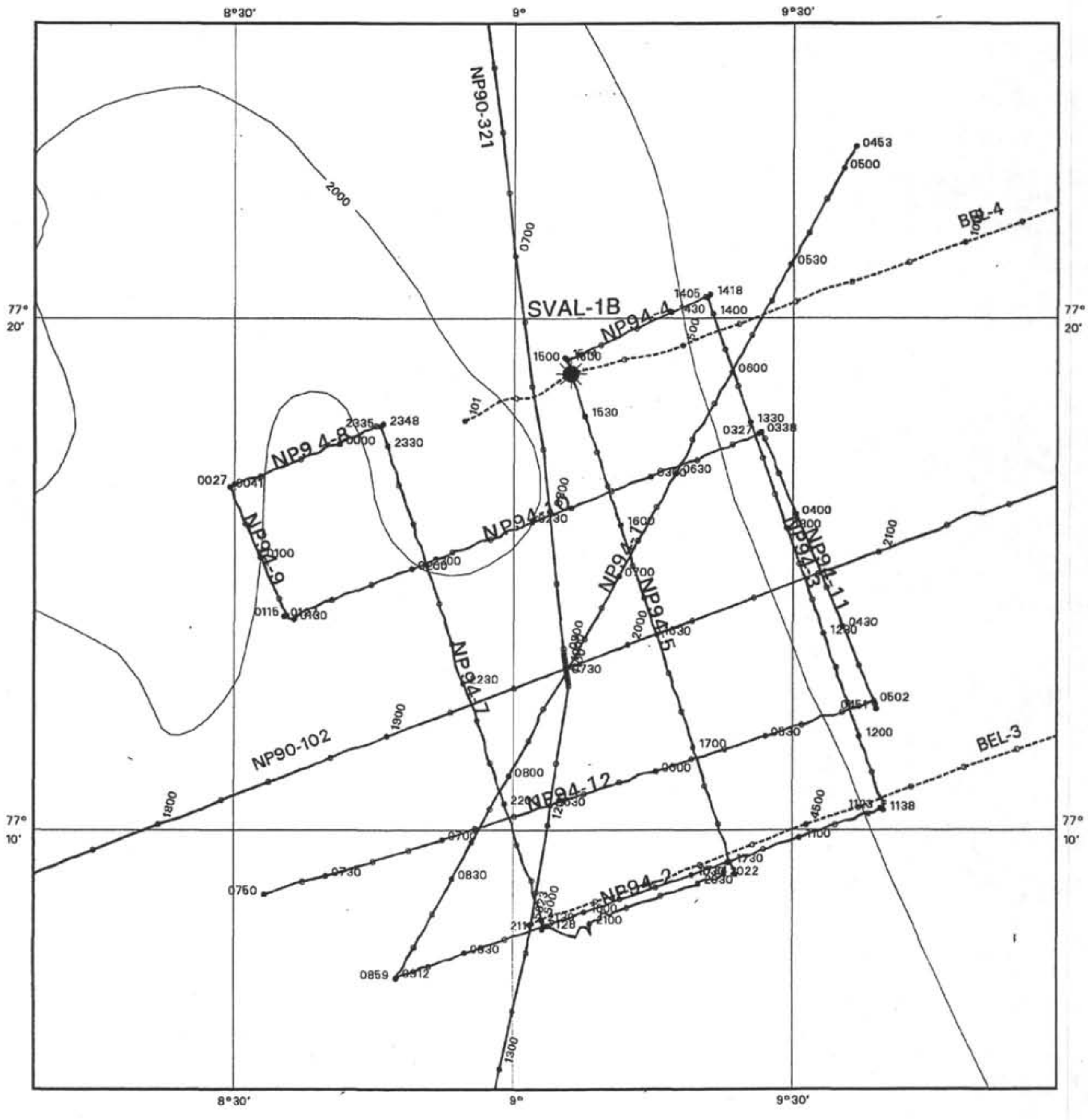
Seismic Coverage: GGU-18-12, SP 2270

Objectives: Site EGM-4 is situated on the lower slope of the trough mouth fan at Scoresby sund. It is intended for high-resolution studies of the late Neogene history of IRD input and evolution of the Greenland Ice Sheet and will serve as the Greenland counterpart to SVAL-1B. It is also located where intermediate and deep waters from the Greenland Sea flow toward Denmark Strait.

Drilling Program: Hole A: APC ->200 m; Hole B: APC -> 200 m, XCB -> 500 m; Hole C: Drill to 500 m, RCB to 800 m, log.

Logging: Standard logging.

Nature of Rock Anticipated: Hemipelagic muds with ice rafted detritus and ash layers.



Map scale 1:250 000 | SCS Lines w/hours
Mercator Projection | MCS Lines w/shotpoints
At 78°N | Drilling site

Figure 15

LINE BEL-4

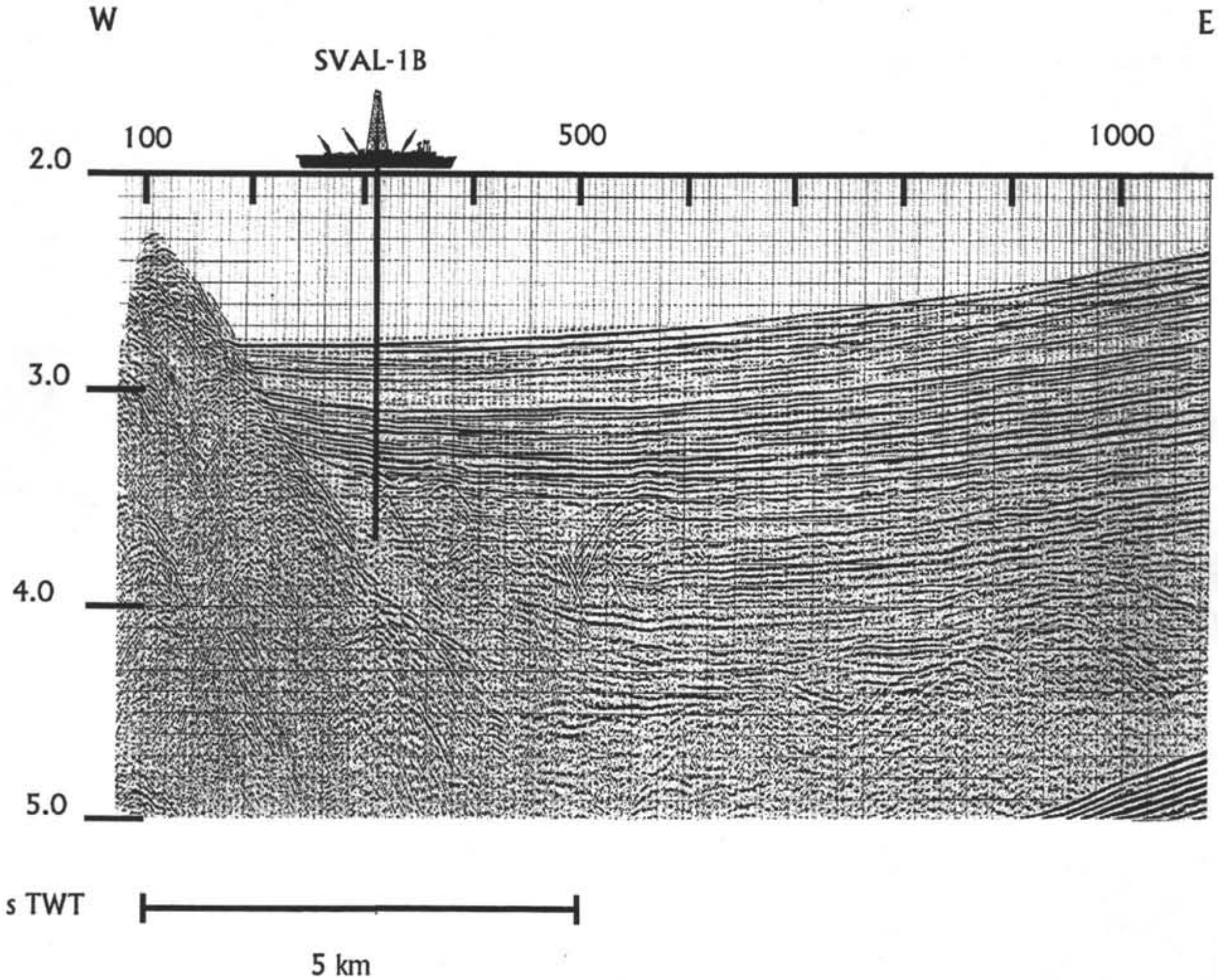


Figure 16A

LINE NP94-5

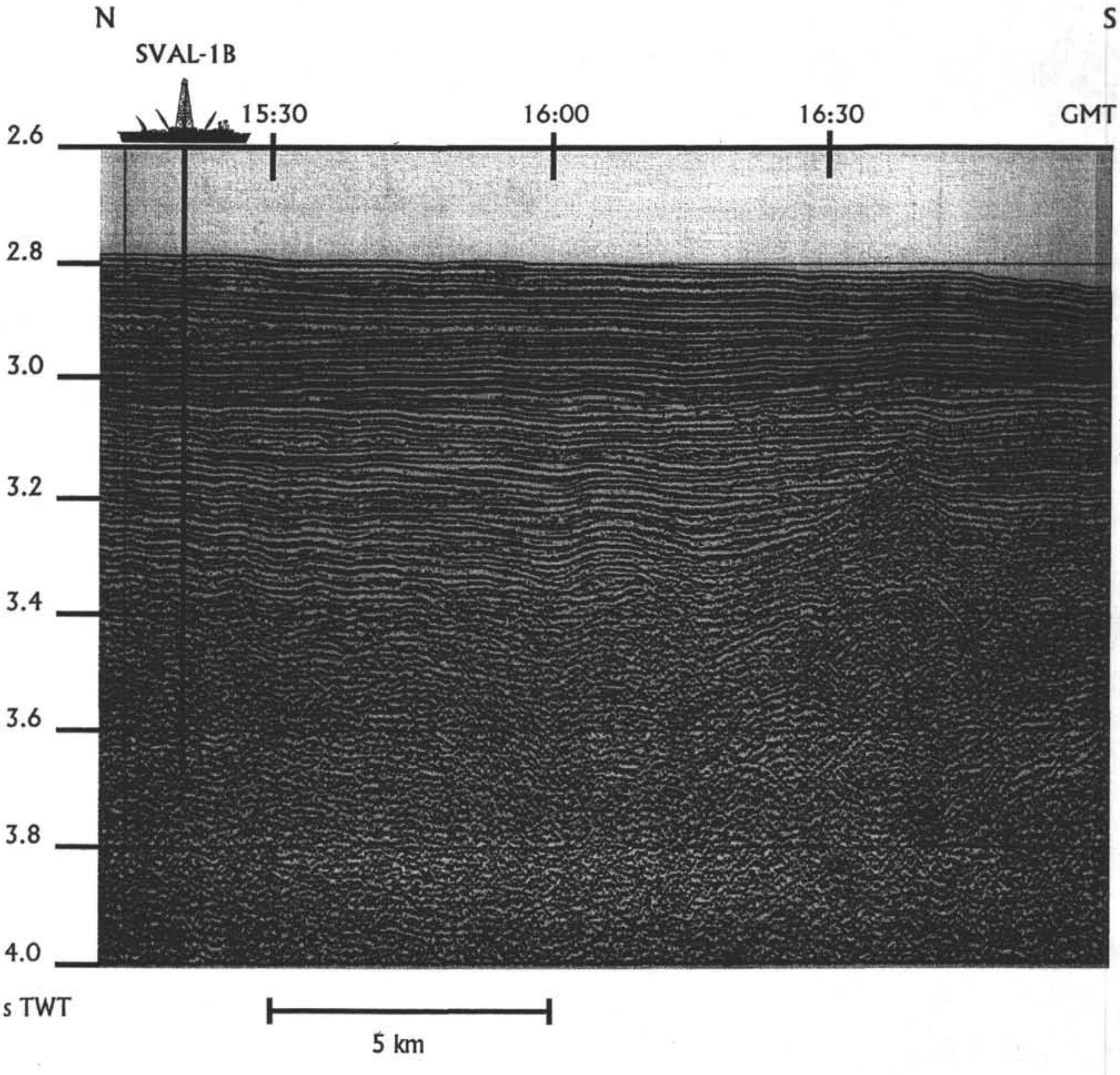


Figure 16B

Site: SVAL-1B
Priority: 1
Position: 77°22.80'N, 09°06.17'E
Water Depth: 2120 m
Sediment Thickness: 1200 m
Total Penetration: 900 mbsf
Seismic Coverage: Mobil Search BEL 4, SP 305; NP 94-5, GMT 15.18 (x-ing)

Objectives: This site is to be drilled on the Svalbard margin to examine the onset of glaciation in the European Arctic and establish the history of the Barents Ice Shelf, including dating the transition from a terrestrial to marine based ice sheet. Svalbard is believed to be the likely location for the initiation of Pliocene glaciation in the European Arctic. This site will also address questions related to glacial fan development and will serve as a counterpoint to EGM-4.

Drilling Program: Hole A: APC -> 200 m, 21 cores, or to refusal; Hole B: APC -> 200 m, XCB -> 500 m; Hole C: Drill 500 m, RCB -> 900 m, log.

Logging: Standard logging.

Nature of Rock Anticipated: Hemipelagic muds with ice rafted detritus.

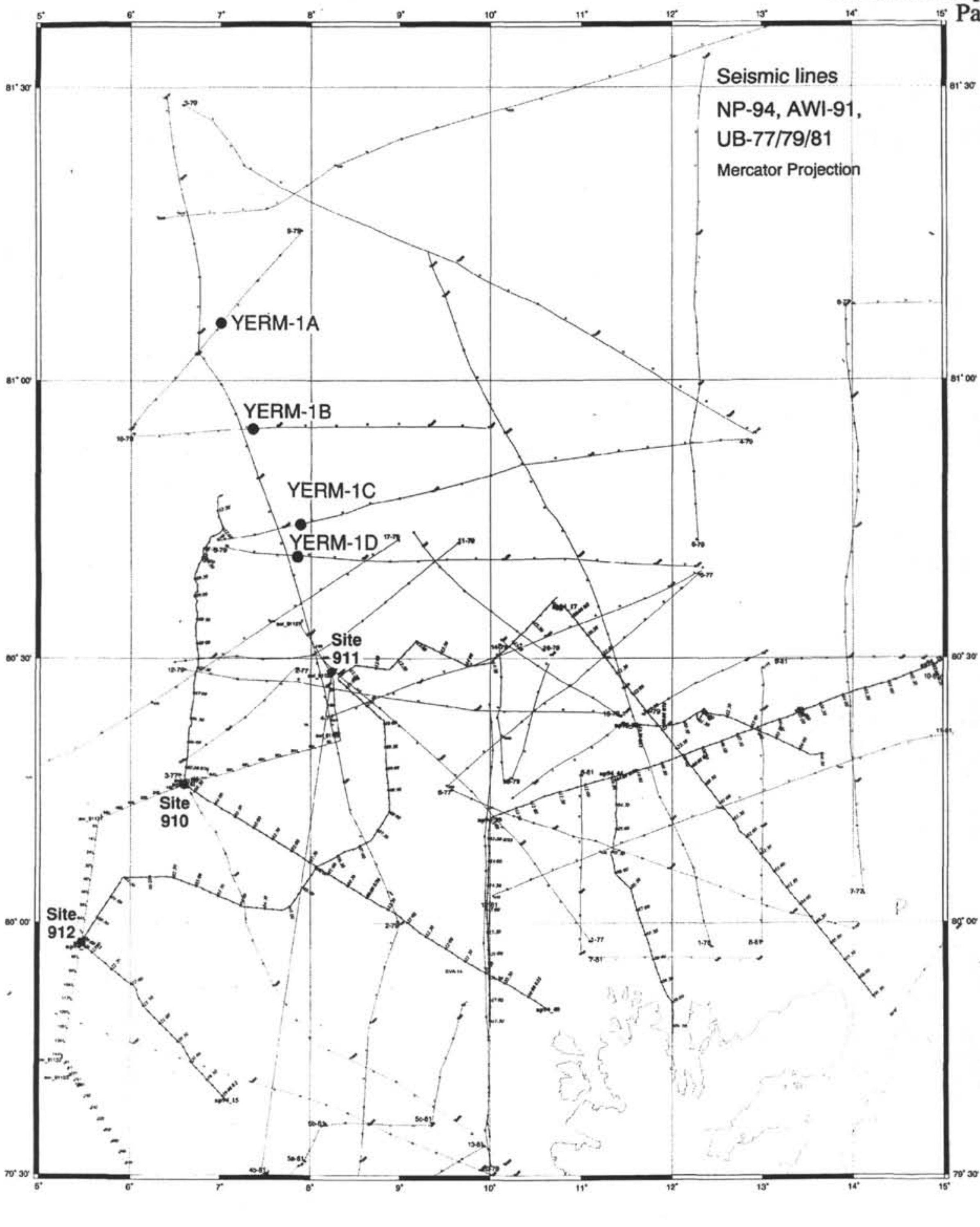

Seismic lines
NP-94, AWI-91,
UB-77/79/81
Mercator Projection
YERM-1A
YERM-1B
YERM-1C
YERM-1D
Site 911
Site 910
Site 912

Figure 17

LINE BU79-9

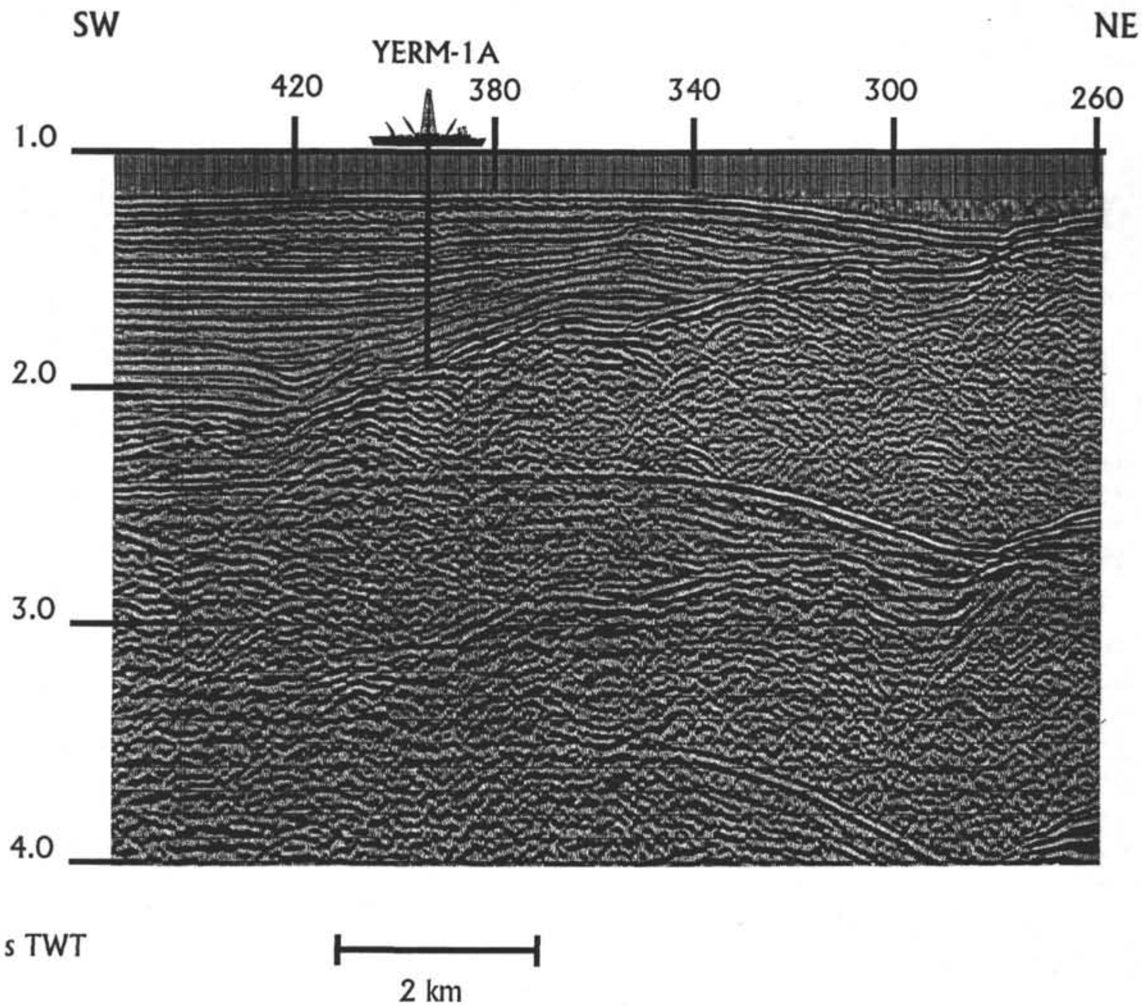


Figure 18

Site: YERM-1A
Priority: 1
Position: 81°06.0′N, 07°00.0′E
Water Depth: 900 m
Sediment Thickness: 680 m, penetration 730 m
Total Penetration: 730 mbsf
Seismic Coverage: BU 79-9 (SP 390), BU 79-2 (x-ing)

Objectives: This site has been proposed to document the subsidence history of the Yermak Plateau and its control on the water-mass exchange through the Arctic gateway, and to determine the age and nature of basement. Furthermore, it will provide records of surface and deep-water communication between the Arctic and the Norwegian Sea and the IRD-sedimentation history of the Arctic. This site is important for monitoring the inception of glacial climate in the Arctic proper. YERM-1A is the prime target. Due to expected sea ice problems, a number of alternate sites which will address the same objectives are included (YERM -1B, -C, -D).

Drilling Program: A-hole: APC -> 200 m, XCB to 500 m; B-hole: wash to 500 m, RCB to 730 m, log; C-hole: APC to 50 m dedicated for geotechnical measurements.

Logging: Standard logging.

LINE BU10-79

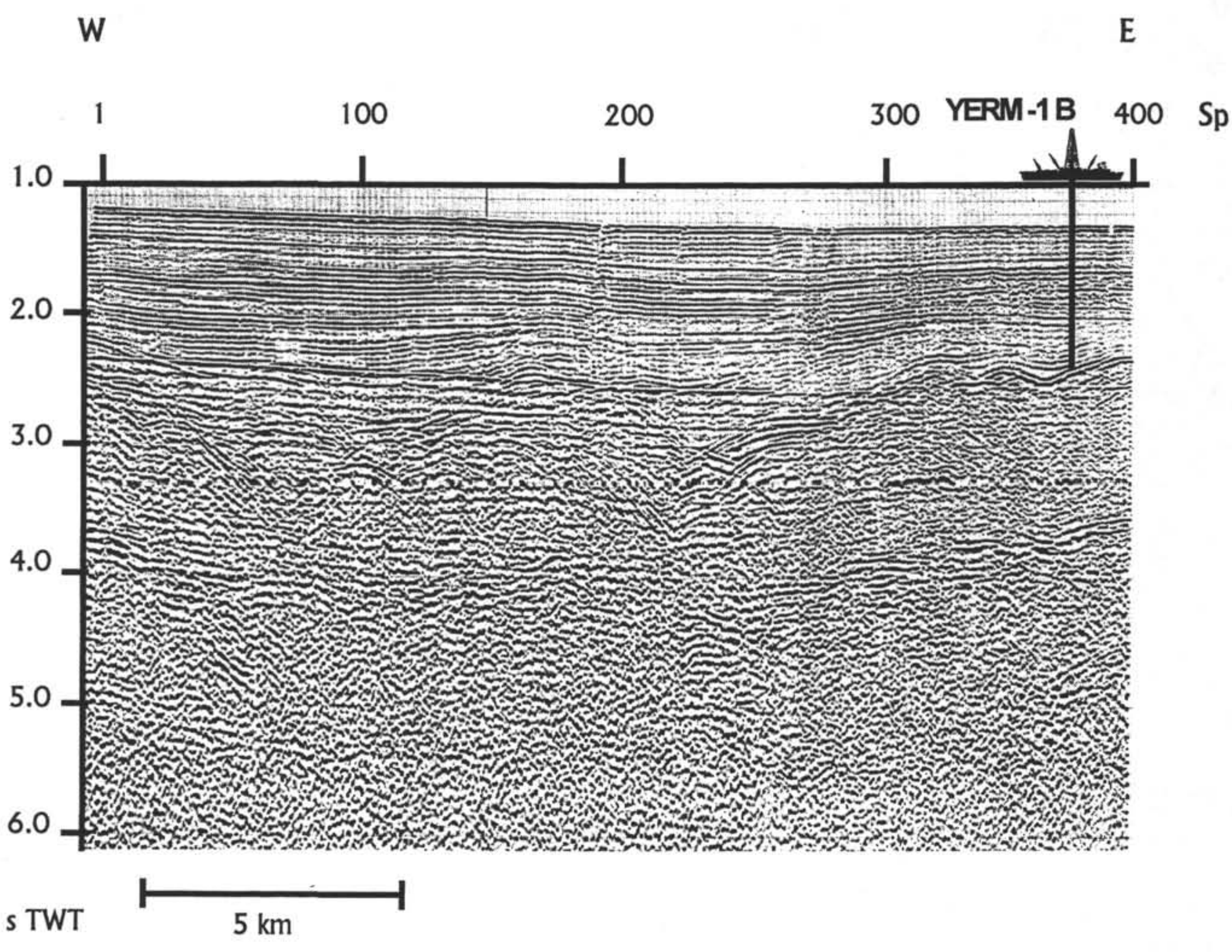


Figure 19

Site: YERM-1B
Priority: 2
Position: 80°54.9'N, 07°13.10'E
Water Depth: 960 m
Sediment Thickness: 1000 m
Total Penetration: 950 mbsf
Seismic Coverage: BU 10-79, sp 360, BU 2-79 x-ing immediately to the west, sp 1650

Objectives: This site has been proposed to document the subsidence history of the Yermak Plateau and its control on the water-mass exchange through the Arctic gateway, and to determine the age and nature of basement. Furthermore, it will provide records of surface and deep-water communication between the Arctic and the Norwegian Sea and the IRD-sedimentation history of the Arctic. This site is important for monitoring the inception of glacial climate in the Arctic proper. YERM-1A is the prime target. YERM-1B functions as an alternate in case of inaccessibility due to sea ice problems.

Drilling Program: A-hole: APC -> 200 m; B-hole: APC -> 200 m, XCB to 500 m; C-hole: Drill to 500 m, RCB to basement. Tag basement, log.

Logging: Standard logging.

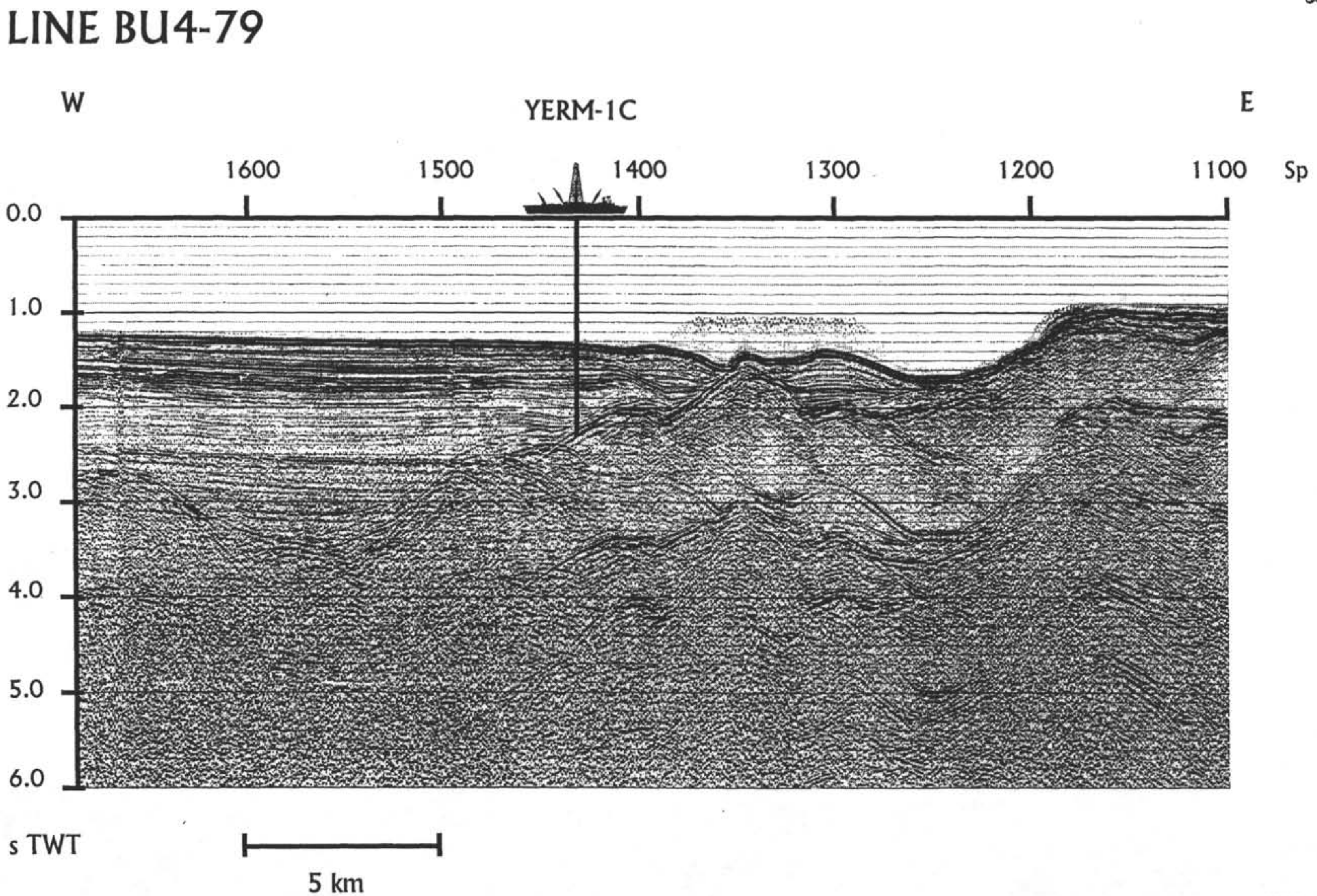

LINE BU4-79
W
YERM-1C
E
1600
1500
1400
1300
1200
1100
Sp
0.0
1.0
2.0
3.0
4.0
5.0
6.0
s TWT
5 km

Figure 20

Site: YERM-1C
Priority: 2
Position: 80°44.67'N, 07°53.2'E
Water Depth: 960 m
Sediment Thickness: 900 m
Total Penetration: 900 mbsf
Seismic Coverage: BU 4-79, sp 1435, BU 2-79 x-ing 3 n.miles to the west, sp 1350

Objectives: This site has been proposed to document the subsidence history of the Yermak Plateau and its control on the water-mass exchange through the Arctic gateway, and to determine the age and nature of basement. Furthermore, it will provide records of surface and deep-water communication between the Arctic and the Norwegian Sea and the IRD-sedimentation history of the Arctic. This site is important for monitoring the inception of glacial climate in the Arctic proper. YERM-1A is the prime target. YERM-1C functions as an alternate in case of inaccessibility due to sea ice problems.

Drilling Program: A-hole: APC -> 200 m; B-hole: APC -> 200 m, XCB to 500 m; C-hole: Drill to 500 m, RCB to basement. Tag basement, log.

Logging: Standard logging.

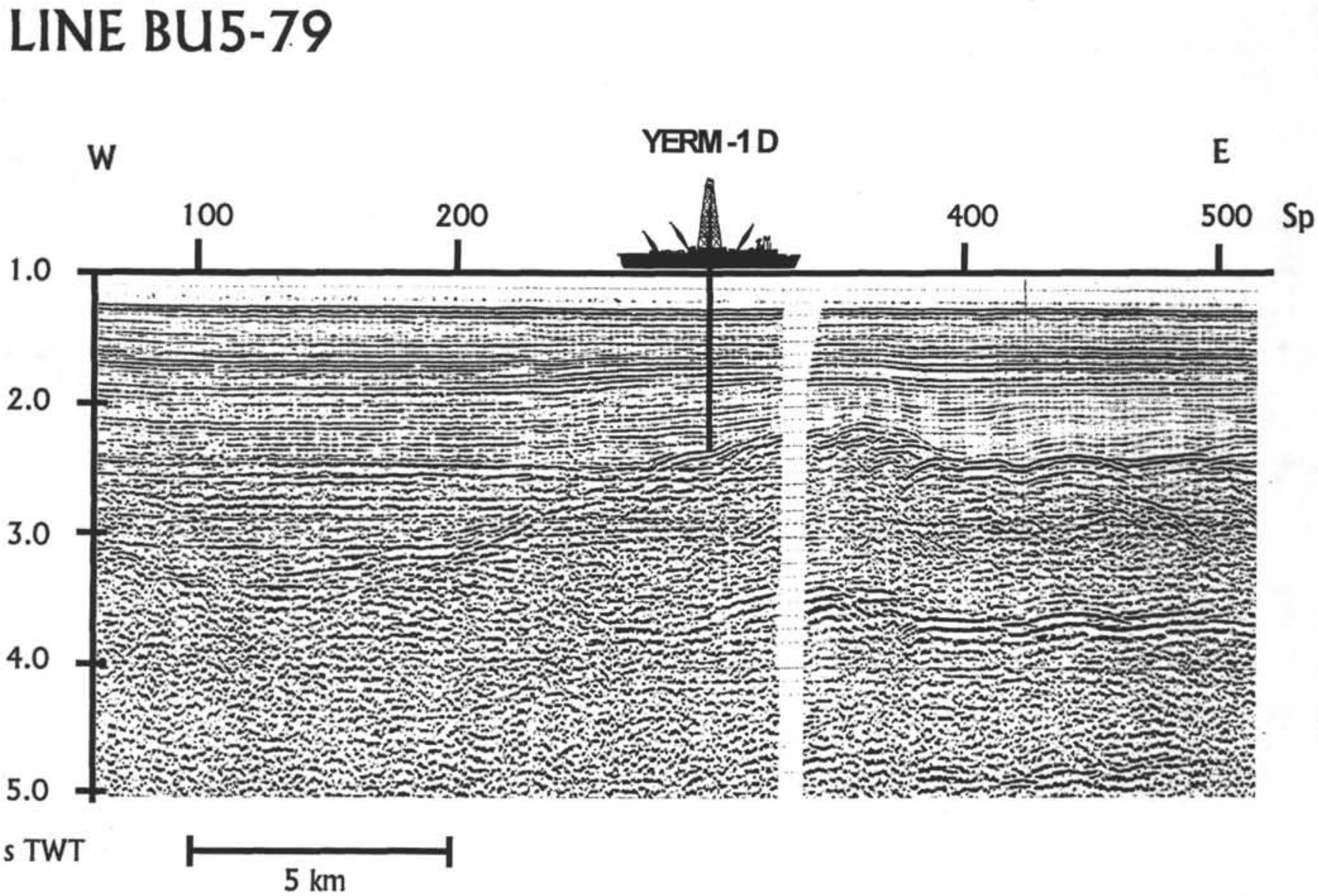


Figure 21

Site: YERM-1D
Priority: 2
Position: 80°41.20′N, 07°59.0′E
Water Depth: 930 m
Sediment Thickness: 1000 m
Total Penetration: 1000 mbsf
Seismic Coverage: BU 5-79, sp 300, BU 2-79 x-ing 4 n.miles to the west, sp 1270

Objectives: This site has been proposed to document the subsidence history of the Yermak Plateau and its control on the water-mass exchange through the Arctic gateway, and to determine the age and nature of basement. Furthermore, it will provide records of surface and deep-water communication between the Arctic and the Norwegian Sea and the IRD-sedimentation history of the Arctic. This site is important for monitoring the inception of glacial climate in the Arctic proper. YERM-1A is the prime target. YERM-1D functions as an alternate in case of inaccessibility due to sea ice problems.

Drilling Program: A-hole: APC -> 200 m; B-hole: APC -> 200 m, XCB to 500 m; C-hole: Drill to 500 m, RCB to basement. Tag basement, log.

Logging: Standard logging.

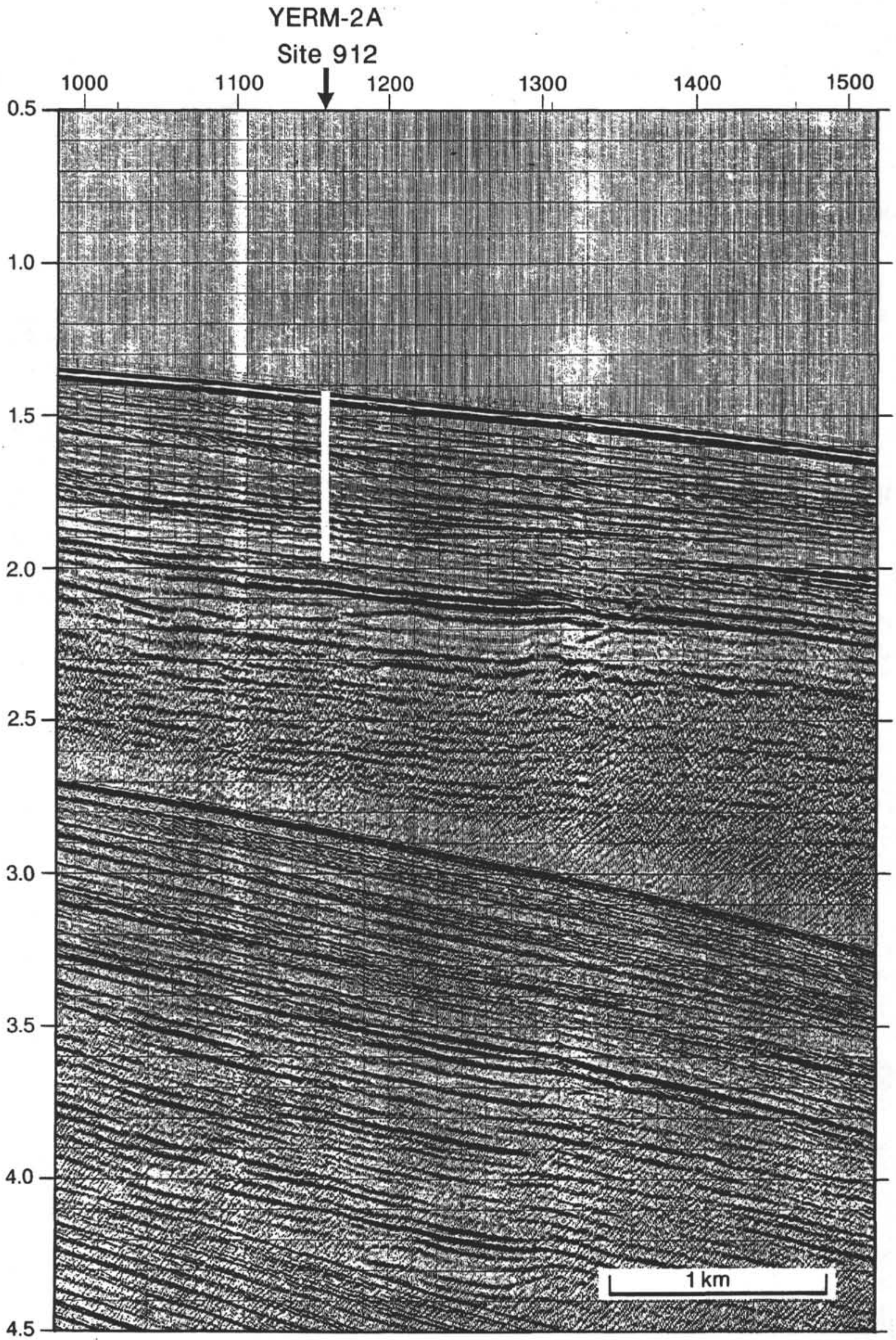

YERM-2A
Site 912
1000
1100
1200
1300
1400
1500
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
1 km

Figure 22

Site: 912 (YERM-2A)
Priority: 2
Position: 79°57.552'N, 05°27.360'E
Water Depth: 1038.6 m
Sediment Thickness: 1300 m
Total Penetration: 550 mbsf
Seismic Coverage: AWI 91131 (SP 800)

Objectives: Site YERM-2A might, in part, serve as an alternate site for YERM-1. YERM-2A is located deeper than site YERM-1 on the southwest slope of the plateau. It will, however, not be drilled to basement. Besides being an alternate site for YERM-1, this site is designed to study the Neogene glacial history of the Arctic, the history of North Atlantic surface water influx to the Arctic, and to be an intermediate member of a bathymetric transect. Basement is considered to be oceanic crust.

Drilling Program: APC -> 200 m, XCB to 500 m, log.

Logging: Standard logging.

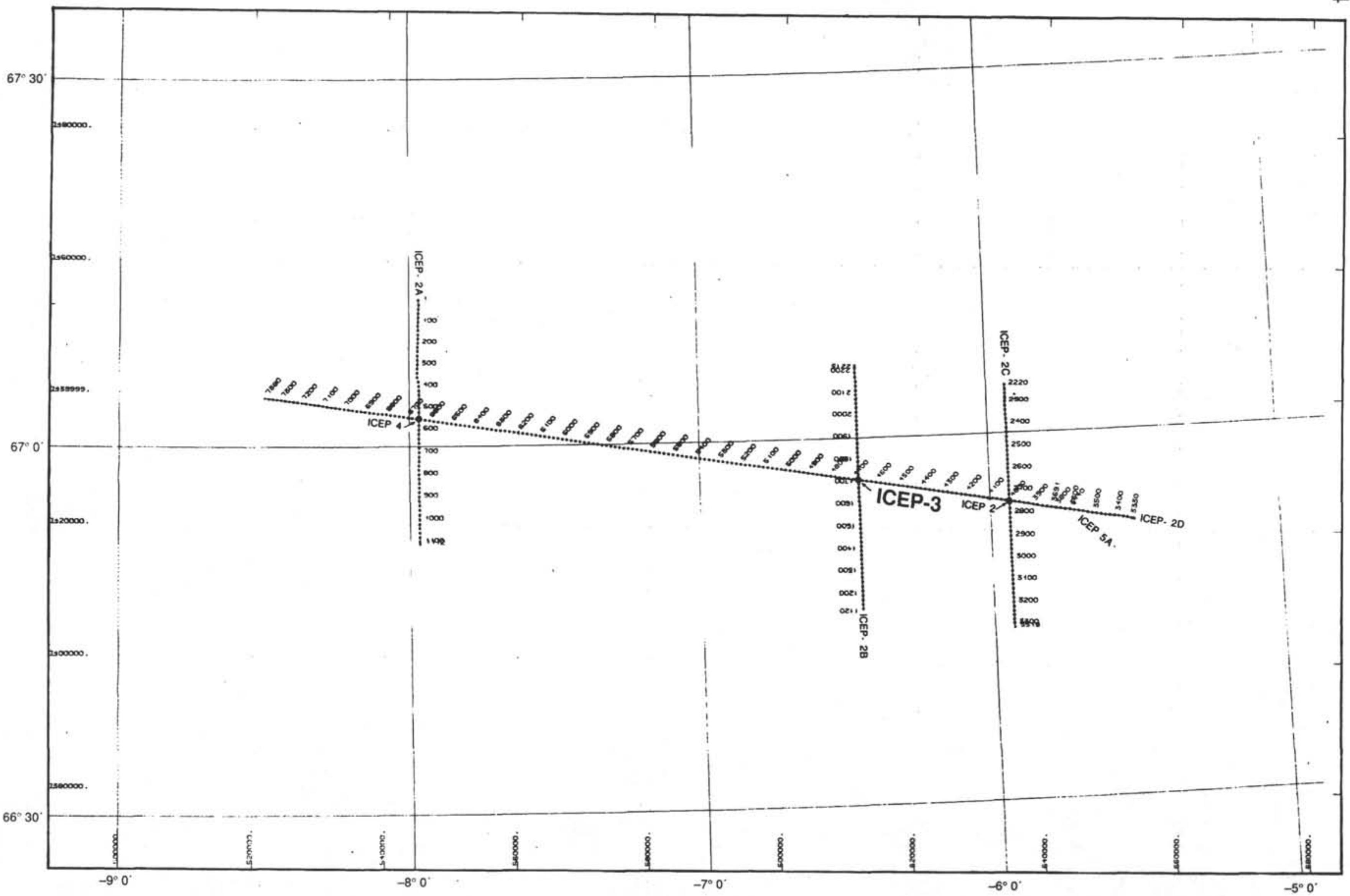

67° 30'
67° 0'
66° 30'
-9° 0'
-8° 0'
-7° 0'
-6° 0'
-5° 0'
ICEP- 2A
ICEP 4
ICEP- 2B
ICEP-3
ICEP- 2C
ICEP 2
ICEP- 2D
ICEP 5A

Figure 23

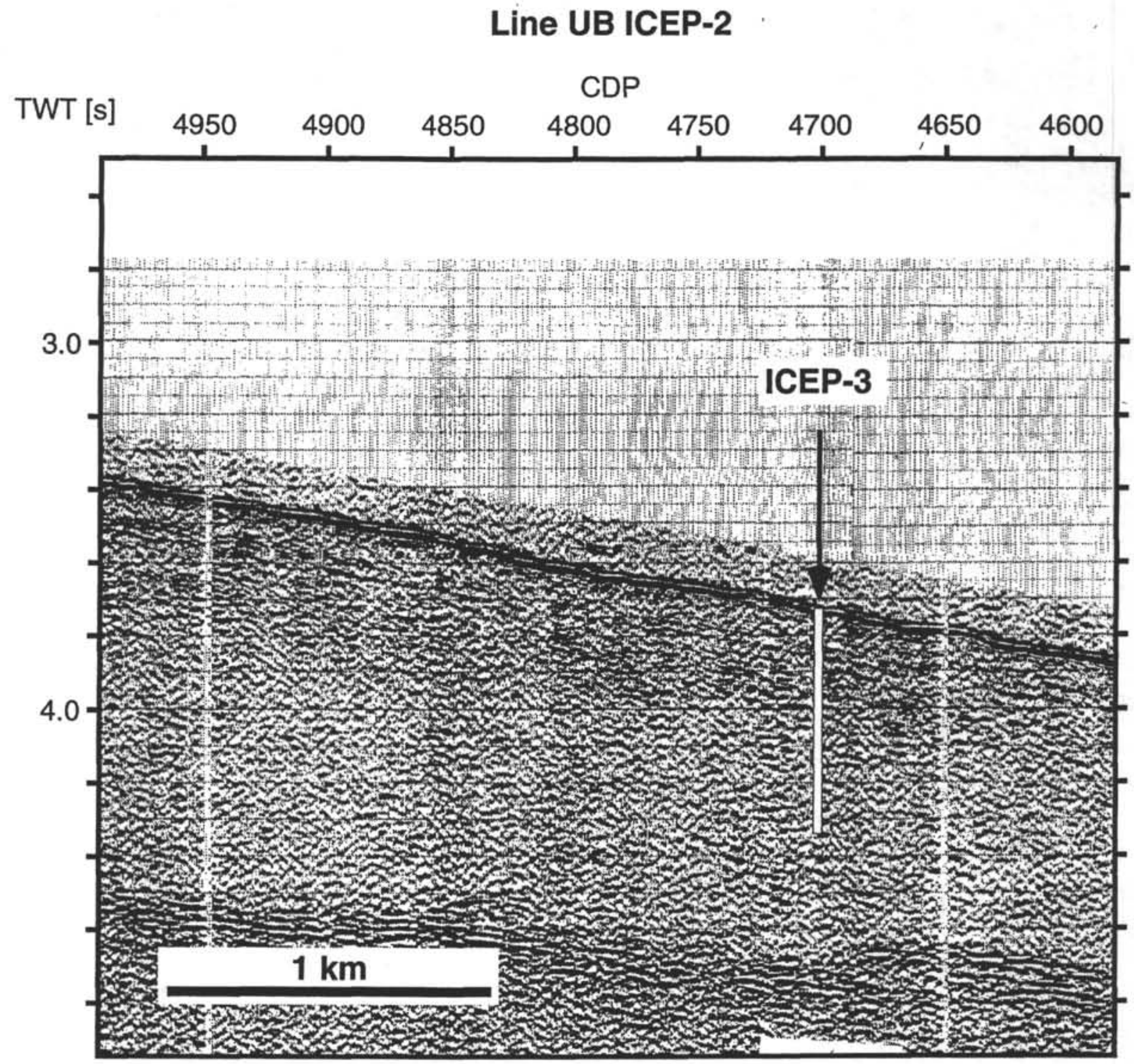

Line UB ICEP-2
CDP
TWT [s]
4950
4900
4850
4800
4750
4700
4650
4600
3.0
4.0
ICEP-3
1 km

Figure 24

Site: ICEP-3

Priority: 2

Position: 66°56.0′N, 06°27.0′W

Water Depth: 2807 m

Sediment Thickness: 800 m

Total Penetration: 500 mbsf

Seismic Coverage: UB-ICEP-2-Segm. D (SP 4700), Segm. B X-ing.

Objectives: This site will enable a study of oceanic response to different stages of the opening of the Greenland-Scotland Gateway north of the ridge. It will also provide a record of pelagic IRD input well away from the ice sheets, thereby avoiding strong continental influence. This, combined with a location farther east than Site 907, will improve chances for recovering a carbonate biogenic record.

Drilling Program: Hole A: APC -> 200 m; Hole B: APC -> 200 m, XCB 500 m, log.

Logging: Standard logging.

Nature of Rock Anticiapted: Pelagic to hemipelagic muds with ice rafted detritus and ash layers.

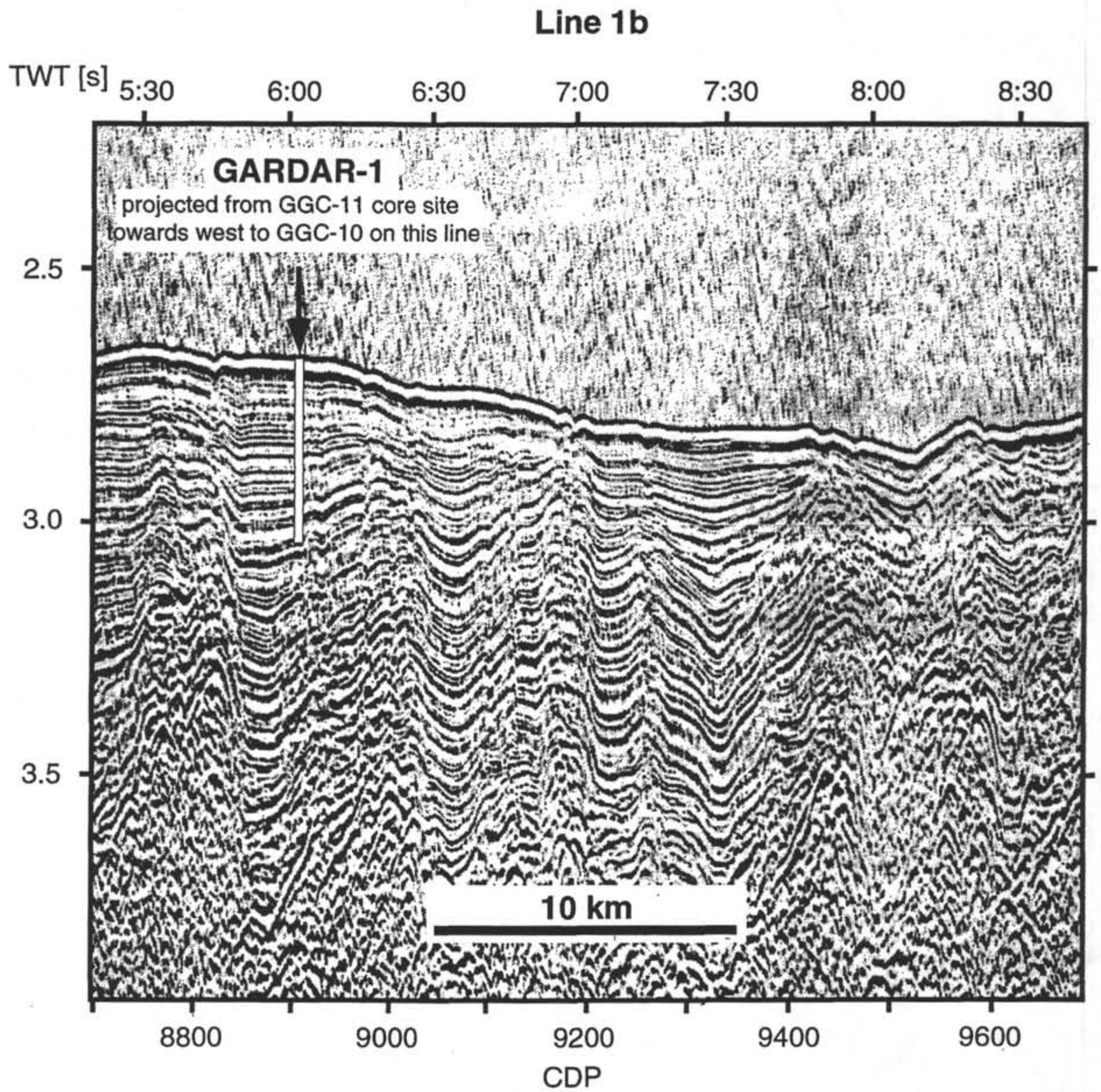

Line 1b
TWT [s]
5:30
6:00
6:30
7:00
7:30
8:00
8:30
GARDAR-1
projected from GGC-11 core site
towards west to GGC-10 on this line
2.5
3.0
3.5
10 km
8800
9000
9200
9400
9600
CDP

Figure 25

Site: GARDAR-1
Priority: 2
Position: 60°24.21´N, 23°38.45´W
Water Depth: 1977 m
Sediment Thickness: ca. 300 m
Total Penetration: 300 mbsf
Seismic Coverage: Ewing 9302 Line 1b @ 06.00 hr, CDP 8900 Line 2 x-ing at 1800 hr.

Objectives: This site is located on the Gardar Drift in 1980 m water depth on the eastern flank of the Reykjanes Ridge. It is located at the depth of Glacial North Atlantic Intermediate Water during the last glaciation. Site survey results suggest that sedimentation rates as high as 20 cm/kyr will be found here, providing an unprecedented record of both glacial-interglacial and millenial scale variations in thermohaline circulation, surface water temperatures, ice-rafting history, etc.

Drilling Program: Hole A: APC -> 300 m; Hole B: APC -> 300 m; Hole C: APC -> 300 m.

Logging: No logging.

Nature of Rock Anticipated: Pelagic to hemipelagic muds with ice rafted detritus and ash layers.

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