OCEAN DRILLING PROGRAM

LEG 172 SCIENTIFIC PROSPECTUS
NW ATLANTIC SEDIMENT DRIFTS

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October 1996

Scientific Prospectus No. 72

First Printing 1996

Distribution

Electronic copies of this publication may be obtained from the ODP Publications Home Page on the World Wide Web at http://www-odp.tamu.edu/publications.

D I S C L A I M E R

This publication was prepared by the Ocean Drilling Program, Texas A&M University, as an account of work performed under the international Ocean Drilling Program, which is managed by Joint Oceanographic Institutions, Inc., under contract with the National Science Foundation. Funding for the program is provided by the following agencies:

Canada/Australia/Korea Consortium for the Ocean Drilling Program
Deutsche Forschungsgemeinschaft (Federal Republic of Germany)
Institut Français de Recherche pour l'Exploitation de la Mer (France)
Ocean Research Institute of the University of Tokyo (Japan)
National Science Foundation (United States)
Natural Environment Research Council (United Kingdom)
European Science Foundation Consortium for the Ocean Drilling Program (Belgium, Denmark, Finland, Iceland, Italy, The Netherlands, Norway, Spain, Sweden, Switzerland, and Turkey)

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

ABSTRACT

The Blake-Bahama Outer Ridge (BBOR) and Carolina Slope (CS) form the western boundary for deep- and surface-water circulation in the North Atlantic. Between the northward-flowing surface waters of the Gulf Stream and the net southerly flow of intermediate and deep waters, most of the climatically important exchanges of heat, salt, and water with other ocean basins occur in the westernmost North Atlantic. Ocean Drilling Program Leg 172 is designed to monitor changes in these water masses and their fluxes through the late Pliocene and Quaternary.

Virtually all water transported by the Gulf Stream to sites of convection in the northern North Atlantic comes from the western subtropical North Atlantic. The Carolina Slope (~1-2 km depth) underlies the axis of the Gulf Stream, as well as the shallowest component of Labrador Sea water. At depths greater than ~2 to ~4 km, the Blake Outer Ridge monitors changes in North Atlantic Deep Water (NADW), and the Bahama Outer Ridge (~4 to 5 km depth) extends coverage from the deepest components of NADW to Antarctic Bottom Water (AABW). On geological time scales it is known that during cold epochs the North Atlantic switches from today’s circulation mode of deep nutrient-depleted water mass production (i.e., NADW) to production of a less dense nutrient-depleted water mass at intermediate depths. A shallow component of Labrador Sea water was identified recently, which interacts with the Gulf Stream and probably controls the distribution of sediment on the Carolina Slope. This water mass may be the modern equivalent of glacial NADW. According to the "Great Ocean Conveyor" paradigm, knowledge of the history of these surface, intermediate, and deep-water masses is essential to understanding the world ocean’s role in climate change.

Drilling on Leg 172 will provide paleoenvironmental records for late Neogene hemipelagic sediments that are deposited at accelerated rates on western North Atlantic sediment drifts on the BBOR and CS. These two areas may represent the only sediment drift locations in the world’s oceans where it is possible to conduct high-resolution paleoclimate studies through a 3500-m-range of water depths. Data obtained from the gyre-center, which will be sampled at the Bermuda Rise (BR) site at a depth of ~4.5 km, will be compared with data from sites located at deep, high-deposition-rate locations on the BBOR and CS to document late Neogene

oceanographic changes in the western North Atlantic for millennial, as well as Milankovitch times scales over the entire deep and intermediate water column. In addition to geochemical and micropaleontological studies of climate change, the hemipelagic composition and high deposition rates of BBOR, CS, and BR sites will enable high resolution studies of magnetic reversals and excursions and studies of current-controlled sedimentation.

INTRODUCTION

Sediment drifts are widespread in the North Atlantic basin and reflect both the abundant sources of sediment and the focusing of the sediments by deep currents (Lonsdale, 1982; McCave and Tucholke, 1986). There is at least one sediment drift associated with every water mass in the North Atlantic, suggesting a potential for tracing the individual components of North Atlantic Deep Water (NADW) on geological time scales using geochemical and sedimentological techniques (Keigwin and Jones, 1989; Mienert et al., 1994).

Leg 172 will core 11 sites: seven primary and one alternate on the Blake-Bahama Outer Ridge (BBOR), two on the Carolina Slope (CS), and one on the Bermuda Rise (BR) (Figs. 1, 2, Table 1). The main purpose of Leg 172 is to provide a latest Neogene depth transect for documenting changes in depth distribution of water masses (Fig. 3). The geographic range of sites may also help distinguish between latitudinal changes in the mixing zone between southern and northern source waters and changes due to vertical migration of a benthic front, especially when considered in the context of other recent Ocean Drilling Program (ODP) legs such as 154 and 162. A North Atlantic depth transect at the BBOR is especially important, because this feature forms a western boundary for deep currents (Stommel, 1958), which follow depth contours (Heezen et al., 1966). Above ~4000 m depth, these waters mostly have a northern source, whereas, at greater depths there is a greater proportion of recirculated southern-source water (Hogg, 1983). The latest scheme depicting the role of deep recirculating gyres in mixing northern and southern source waters (after Schmitz and McCartney, 1993) is shown in Figure 4. BBOR coring is essential to document and understand first-order changes in the ocean-climate system such as glacial-interglacial variability in the production and flow of North Atlantic water masses and changes in terrigenous, authigenic, and biogenic fluxes. In addition, coring on sediment drifts with high deposition rates is especially important in order to understand North Atlantic climate on millennial and even centennial time scales.

BACKGROUND

Paleoceanography and Paleoclimatology

One of the most intensively studied sediment drifts in the North Atlantic lies on the northeast BR, where the overlying deep water is the most turbid in the basin (Biscaye and Eittreim, 1977) due to advection of clays and silts by the deep Gulf Stream return flow (Laine and Hollister, 1981; see also Hogg, 1983; Schmitz and McCartney, 1993). The ultimate source of this terrigenous sediment is probably eastern Canada, although Laine et al. (1994) document local erosion on the eastern scarp of the BR and redeposition on the BR plateau. During glaciation, deposition rates were as high as 200 cm/k.y. on the BR (Fig. 5). Geochemical studies of cores from the BR have revealed the coupling of the ocean, the atmosphere, and ice sheets on the submillennial scale (Fig. 5). For example, deep ocean circulation at the depth of the BR (~4500 m) responded to the Younger Dryas cooling episode (Boyle and Keigwin, 1987), as well as to earlier oscillations in the climate system (Keigwin et al., 1991; Keigwin and Jones, 1994). Unfortunately, the price for high resolution studies is a short temporal record, even in a core 28 m long such as KNR 31 GPC-5 (Fig. 6, Table 2). Recent coring by the International Marine Global Change Study (IMAGES) program on the *Marion Dufresne* has produced a 53-m core extending into isotope Stage 6 near Site BR-1. Thus, it is important to core a much longer interval on the BR using the Advanced Hydraulic Piston Corer (APC) in order to document more than just one glacial/interglacial cycle.

In the BBOR/CS region at the western boundary of the Sargasso Sea, available evidence indicates patterns of climate change similar to those on the BR. The most heavily studied core from the BBOR region, KNR 31 GPC-9, was taken in 1973 from the northwest flank of the Bahama Outer Ridge at a depth of 4758 m (GPC-9 is located near Site BBOR-1 in Fig. 2, Table 2). Initial stratigraphy of that core was discussed by Flood (1978), followed by unpublished benthic foraminiferal (Lohmann, unpublished) and stable isotope studies (Curry and Lohmann, 1983). Keigwin and Jones (1989) documented the planktonic, stable isotope stratigraphy and presented accelerator mass spectrometer (AMS) radiocarbon results. Using AMS and $\partial^{18}O$ stratigraphy (Fig. 5), they plotted percent-carbonate results at 4-cm spacing from the upper 2200 cm of GPC-9 vs. age (Fig. 6). It is apparent that many of the same millennial-scale climate oscillations are present on both the BBOR and the BR. These oscillations are thought to be a useful proxy for deep-ocean circulation changes (Keigwin et al., 1994; Keigwin and Jones,1994). Grain size results on the Blake Outer Ridge are consistent with nutrient proxy results as monitors of deglaciation changes in deep-ocean circulation, indicating there were important glacial/interglacial changes in the intensity and position of the Deep Western Boundary Current (DWBC) on the Blake Outer Ridge (Haskell, 1991; Haskell et al., 1991). Two pairs of Leg 172 sites from identical water depths, but very different sedimentary regimes, will document directly the effects of current-controlled sedimentation.

Large vertical gradients can be expected in the Tertiary and Quaternary oceans. Using benthic foraminiferal chemistry, the BBOR region will monitor southern source waters entering the North Atlantic basin as well as northern source deep and intermediate waters exported in the depth range of 2000 to 4800 m. We also can expect to monitor important basin-wide changes in the position of the lysocline, which may be additionally influenced at this location by the position of the Deep Western Boundary current (Balsam, 1982).

Mud Wave Dynamics

Recent studies of mud-wave dynamics suggest that mud waves migrate because there are cross-wave changes in bed shear stress (Flood, 1988; Blumsack and Weatherly, 1989). In the case of fine-grained cohesive sediment, accumulation rate decreases as shear stress increases (McCave and Swift, 1976), thus, less sediment accumulates on the wave flank with the higher flow speed. In the case of a lee-wave flow pattern, flows on the upcurrent, upslope wave flank are weaker than those on the downcurrent wave flank, leading to upslope and upcurrent wave migration. Enhanced wave migration is expected at higher flow speeds because currents on the downcurrent flank approach the critical shear stress for deposition before those on the upcurrent flank (Flood, 1988).

Wave migration can be measured by determining the ratio of sediment thickness deposited on each wave flank during a time interval or between two correlated layers, and a model-dependent flow speed can be estimated (Flood, 1988). This approach was used with success in the Argentine Basin where a mud wave appears to have become inactive during the last 20-30 k.y. (Manley and Flood, 1992). Although our present understanding suggests that only two core sites are required to make this comparison (one on each wave flank), this needs to be explicitly tested by sampling at least four places across the wave profile (crest, trough, and each flank) in order to choose the best locations for future ODP cores. Independent evidence of changes in flow speed will supplement interpretations of circulation change made on the basis of ocean paleochemistry.

Wave migration on sediment drifts has been a long-standing interest of the ODP, but it has not yet been successfully studied. As the Sedimentary and Geochemical Processes Panel (SGPP) White Paper (JOIDES Journal, 1990) states:

> "The history of thermohaline bottom current processes is preserved in sediment drifts and sediment waves molded under relatively steady currents. Drilling transects will test sedimentation models for sediment structure and bottom current depositional processes and use these models to determine past variations in the bottom flow regime of the ocean."

Waveforms observed at Deep Sea Drilling Project (DSDP) Sites 610 and 611 were found to be surprisingly stable, migrating on the million-year time scale (Kidd and Hill, 1987). However, that study sampled wave crests and troughs, not wave flanks. Evidence from the Bahama Outer Ridge (Flood, 1978) and the Argentine Basin (Manley and Flood, 1992), as well as wave models suggest that the largest difference in sedimentation rates is to be expected on the flanks. The Bahama Outer Ridge wave field (Fig. 7) is mapped with much greater precision than those on Gardar and Feni Drifts and carbonate content in small free-fall cores indicates that sedimentation rates did indeed change between upstream and downstream wave flanks during the latest Quaternary (Flood, 1978).

Gas Hydrate and Pore-Water Geochemistry

The world's best-known marine gas hydrate occurrence is located within the operating area of Leg 172 on the Blake Ridge and Carolina Rise. Three DSDP-ODP legs in the Blake Ridge area (Fig. 8) have recovered gas hydrate and/or found pore-water signatures indicating its presence: DSDP Leg 11 (Sites 102, 103, and 104; Hollister, Ewing, et al., 1972), DSDP Leg 76 (Site 533; Sheridan, Gradstein, et al., 1983), and ODP Leg 164 (Paull, Matsumoto, Wallace, et al., in press). Gas hydrate, present on continental margins world-wide (e.g., Shipley et. al., 1979; Kvenvolden, 1988), is important because it may (1) affect the Earth's climate through storage and release of methane, a greenhouse gas (e.g., Nisbet, 1989; Paull et. al., 1991); (2) cause sediment slumping on continental margins (e.g., Carpenter, 1981; Popenoe et al., 1993; Paull et al., 1996); and (3) influence the diagenesis of continental rise sediments (e.g., Lancelot and Ewing, 1972; Matsumoto, 1983; Borowski et al., 1996a, b).

The presence of gas hydrate in the BBOR/CS region is of particular concern to Leg 172 for two reasons. First, both DSDP Leg 76 and ODP Leg 164 found that gas charging and sediment diagenesis associated with gas hydrate prevented successful operation of the APC at sub-bottom depths greater than ~150 m. Second, although the acoustic signature of gas hydrate is not present in the BBOR region at water depths >4 km, Leg 164 scientists found that the absence of the acoustic signature (the bottom-simulating reflector [BSR], below) does not mean the absence of hydrate. Thus, hydrate may compromise the Leg 172 objective of coring a high-resolution Pliocene section deep on the Blake Outer Ridge.

Gas hydrate occurrence is usually inferred from the appearance of a bottom-simulating reflector on seismic reflection profiles (Tucholke et al., 1977). However, geochemical concentration and isotopic profiles are potentially more sensitive indicators of underlying gas hydrate than established seismic detection methods (Borowski et al., 1996a). For example, Site 994 (Leg 164) displays no BSR but possesses the following pore-water anomalies that strongly suggest the presence of underlying gas hydrate (Paull, Matsumoto, Wallace, et al., in press): (1) chloride concentration decreases with depth, probably reflecting dissociation of gas hydrate at the base of the stability zone and upward migration of fresher fluids (Hesse and Harrison, 1981; Ussler and Paull, 1995); (2) the sulfate concentration profile decreases linearly, suggesting an upward methane flux from gas hydrates below (Borowski et al., 1996a); and (3) extreme depletion of ^{13}C occurs within the interstitial methane and CO_2 pools at shallow depths (Borowski et al., 1996b).

ODP Leg 172 will drill holes both inside and outside of the mapped distribution of BSRs of the Blake Ridge hydrate field (Fig. 8). The leg, thus, provides an opportunity to: (1) assess the lateral distribution of gas hydrate and its related geochemical signatures within the continental rise; and (2) assess the linkage of various geochemical patterns to diagenetic processes which may be directly or indirectly caused by gas hydrate. These data are critical to improve estimates of the size of the gas hydrate reservoir in the Blake Ridge area (and elsewhere), and to understand the geochemical processes involved in the development of extensive gas hydrate fields.

SCIENTIFIC OBJECTIVES

The major objectives of Leg 172 are to obtain a detailed history of late Neogene paleoceanography and paleoclimate in the North Atlantic by investigating: 1) millennial scale oscillations of stable isotopes (C and O), faunal and floral abundance, percent carbonate and other lithologic components, and trace metals in drift deposits; 2) the nature of cyclicity of these oscillations; and 3) how these cycles are related to the history of Northern Hemisphere glaciations during the late Neogene.

In addition, this proposal seeks to investigate:

- sediment wave migration and drift sedimentation processes,
- detailed variations of the Earth's magnetic field (secular variations and reversals),
- geotechnical/acoustic properties of deep-sea sediments, and

- geochemical signals associated with the formation, dissociation, and distribution of gas hydrate.

DRILLING STRATEGY

The goals of Leg 172 can best be achieved by advanced hydraulic piston coring/extended core barrel coring(APC/XCB) one site on the Bermuda Rise, coring sites at many depths on the BBOR (seven primary sites and one secondary site), and coring two sites on the CS. The CS and BBOR sites will form the first such ODP transect in the North Atlantic. The original drilling plan called for APC coring at all the sites and only coring with the XCB if it was necessary to achieve 300-m depth penetration on the BR. At the annual Planning Committee (PCOM) meeting in December 1995, PCOM considered this proposal in the light of results from the Leg 162 North Atlantic-Arctic Gateways II and decided that ODP's long-term planning for climate and ocean circulation studies would be best served by extending the penetration of some of the sites in the transect.
Although we have extended the penetration of some sites (below), it is difficult to predict how successful Leg 172 will be in recovering high deposition rate Pliocene sediment. Judging from the experience on Leg 164, APC coring in the presence of sediments containing gas hydrate will not be successful below ~150 m. According to shipboard scientists, gas from the sediment charged the tool, which interfered with operation of the piston corer. It should also be noted that hydraulic piston coring was abandoned at about the same depth at Site 533, several hundred meters deeper on the seaward flank of the Blake Outer Ridge. The presence of gas also contributed to poor recovery of XCB cores on Leg 164 (Fig. 9), as well as to sediment disturbance.

There are a few important constraints on the overall drilling plan. First, for efficiency, sites must be occupied in the BBOR/CS region from shallow to deep water depths (Table 1). Second, of 56 days overall, 15 are allotted to transit, and 1.1 to seismic and 3.5 kHz surveys. About 2.2 days have been budgeted for logging, which will help provide continuous stratigraphic coverage where coring may be incomplete and in situ measurements of the sediments including gas hydrate. This leaves about 37.7 days for drilling and coring operations (Table 1). Third, it is hoped that gas hydrate will be less of a problem with increasing water depth, so we have chosen Site BBOR-4B on the Blake Outer Ridge for deep penetration. If the rate of sedimentation is significantly overestimated from the site survey cores, and if some combination of APC and XCB coring is successful to 350 mbsf, then that site could provide a high resolution record of the late Pliocene.

SEISMIC PROFILING

Owing to the poor seismic coverage of the proposed sites by the site survey package for Leg 172, the ODP Site Survey Panel and Planning Committee have requested that intersecting single-channel seismic lines be collected over each site by the *JOIDES Resolution*, which will then be tied to existing seismic lines.

LOGGING PLAN

Logging is planned at Holes BBOR-4B and BR-1 (each ~350 m in depth). The primary objectives of Leg 172 will depend on good core recovery of material for stable isotope measurements, as well as other paleoclimate proxies. Downhole logging can help achieve the primary goals of this proposal by ensuring that full stratigraphic coverage is achieved through the integration of core and log measurements.Where core recovery is incomplete or core disturbance is high, usually in XCB cored sections, downhole logs will provide continuously sampled physical properties that can serve as proxies for paleoclimatic indicators.

Geophysical logs (sonic, porosity, density, natural gamma, resistivity, and Formation MicroScanner [FMS]) will characterize the sediment. Resistivity, FMS, and sonic logs can provide in situ data on the gas hydrate present in the sediments. FMS images can provide very high resolution (2.5 mm) characterization of sedimentary structures, which are particularly difficult to obtain in XCB cores. In addition, these images show grain-size changes that aid in interpreting sedimentary processes in drift deposits, help orient XCB cores for magnetic studies, and provide a record of resistivity (although not in absolute values) for cyclicity studies. The planned dedicated logging holes are likely to provide a stable borehole and, thus, good quality logs.

SPECIAL SAMPLING PROCEDURES

Shipboard geochemical investigations and post-cruise sampling for paleoceanography will require the following modifications to normal ODP procedures:

1) *Drilling a separate hole of about 50 m length (~5 cores via APC) dedicated to geochemical and paleoceanographic investigations at several sites*. This replication in coring will result in complete and meaningful geochemical sampling without compromising the paleoceanographic objectives of the leg. High-resolution geochemical sampling is necessary in order to adequately document concentration profiles of key interstitial chemical species (see #2 below). Highest-priority sites for geochemical sampling are Sites CS-2, BBOR-5, and BR-1.

2) *Increasing interstitial water sampling of the geochemical holes to 1.5 m intervals (each section cut, 6 samples per full core).* High-resolution sampling will establish meaningful chloride and sulfate profiles, which are necessary to test their response to the presence or absence of underlying gas hydrate. For example, we expect that linear sulfate profiles will occur over the shallower portions of the Blake Ridge, and that this linearity will give way to convex-upward profiles down-ridge as the influence of gas hydrate wanes. These data are important to monitor in developing the best coring strategy. Sediment "squeeze-cakes" will still be available for biostratigraphy and paleoceanographic purposes, and microfossils are not affected by the squeezing.

3) Using a Reeburgh-style, rather than Manheim-style, squeezer for pore-water sampling. Unfortunately, Manheim squeezers allow gas to escape. Pore waters (and gases) will also be collected in syringes from the Reeburgh squeezers so no other modifications to ODP procedures are needed. This will allow collection of methane gas samples directly from sediment that is analyzed for interstitial waters. (The Reeburgh squeezers will be supplied by Leg 172 geochemist Walter S. Borowski.)

4) Sampling interstitial waters at an interval of one sample per core in one hole at each site. One, 5- to 10-cm-thick, whole-round-section will be required from the bottom of the third hole at each site, depending on water content. This will enable construction of detailed chloride profiles (and other profiles, e.g., NH_4^+, alkalinity, $\partial^{13}C_{\Sigma CO_2}$) to fully evaluate the influence of underlying gas hydrate.

5) Exceed ODP sample volume restrictions. Leg 172 objectives (as outlined above) differ from conventional high-resolution paleoceanography legs because the major goals are not to generate detailed time series of data, but rather to synthesize time-stratigraphic intervals from all sites in a depth transect. Thus, for the leg to succeed we must have comparable data from all sites in the transect. Because of very low abundance of benthic foraminifers (<<1/g) at some sites in intervals such as glacial maxima, it may be impossible to adequately define millennial scale variability in climate without frequent or continuous sampling, or without large volume sampling. Thus, in some holes it may be necessary to completely sample away critical intervals of core and in most situations high-resolution investigations will require individual scientists to sample 100 cm^3 per meter of core. Such heavy sampling for studies that use foraminifers will occur outside dedicated intervals only if required to meet the primary leg objectives.

6) *U-channel samples may be taken in the working half of some dedicated and non-dedicated intervals to facilitate high-resolution measurements of magnetic properties.* Magnetic studies of U-channels are nondestructive, with the exception that the magnetic remanence will likely be partially or totally removed. In cases where U-channels are

necessary in nondedicated intervals, other samples within these intervals will come from the U-channel following magnetic measurements. In these cases, magnetic laboratory analysis will be completed as rapidly as possible so that the U-channels can be returned to the repository for subsampling, which will be conducted by the repository staff.

PROPOSED SITES

Sites are discussed in the order they will be drilled.

CS-2 and CS-3B

These proposed sites will begin the depth transect in the BBOR/CS region by providing high-resolution sections from water depths of ~1800 m and ~1300 m, respectively. Site CS-3B is presently in the shallowest waters of the Deep Western Boundary Current, which are thought to originate in the southern Labrador Sea. During glacial times the CS sites probably monitor glacial North Atlantic Intermediate Water. CS sites have much higher deposition rates than nearby sites on the Blake Outer Ridge; a pair of accelerator ^{14}C dates from a site survey core close to Site CS-3B indicates zero years at the core top and 4500 yrs at 300 cm for a rate of 670 m/m.y. Together with BBOR-8C, these sites will test models of continental margin sedimentation during glacial lowering of sea level (see Paull et al., 1996). From the pore-water geochemical perspective, Site CS-2 is the first priority site for having a dedicated fourth hole as deep as 50 mbsf. Data from site survey cores show low foraminiferal abundances, giving added importance to quadruple coring at this site.

BBOR-8C

This site is located at a water depth (~2164 m) where the Blake Outer Ridge first becomes noticeable as a bulge on the continental slope. Presently that location lies within the core of upper NADW, close to the hinge between nutrient-enriched deeper waters and nutrient-depleted intermediate waters in hydrographic reconstructions of the last glaciation. By correlation to nearby ODP Site 996, Site BBOR-8C might extend back to 2.6 Ma if it is cored to 150 m.

BBOR-7A

This Blake Outer Ridge site was chosen for its high sedimentation rate and its modern day location between the upper and lower limbs of the NADW (Fig. 3). Site BBOR-7A will be triple APC cored to at least 100 m.

BBOR-6 and BBOR-9

Like the deeper mud wave field (Site BBOR-1/-1B), this pair of sites reveals striking physical evidence of current-controlled sedimentation. At present, the plan calls for three APC cores to at least 100 m at Site BBOR-6 where the boundary current at ~3000 m water depth has expanded the section, and three comparison APC holes cored to at least 150 m at Site BBOR-9, a location with a *relatively* lower sedimentation-rate, that is about a mile away. For reference, the site survey piston core at "lower-resolution" Site BBOR-9 has a higher rate of sedimentation than well-known “high-resolution” DSDP Site 609 in the northern North Atlantic. The Site BBOR-6 and -9 pair will allow us to directly observe the history of boundary current movement by comparing sedimentation rates for short-time intervals. Such a comparison might reveal, for example, that the boundary current is only active at this location during interglacial time. Sediment flux studies at these sites will test some fundamental assumptions in sediment drift paleoceanography. If the only difference between the two groups of holes is the lateral flux of sediment brought by the boundary current, and if the foraminifers are not subject to traction transport, then the foraminiferal fluxes should be identical regardless of sedimentation rate. More cores might be taken to greater depth at Site BBOR-9 in order to recover a longer temporal sequence.

BBOR-5

This site will be triple APC cored to at least 150 m, projected to an age of ~1.5 Ma. It is located very close to the position of DSDP Site 102 (3430 m), a high sedimentation rate location in the heart of the lower NADW. Unless the benthic front migrates by more than 500 m, this site will always be bathed by lower NADW (Fig. 3). From Site 102 we know that the sedimentation rates are nearly constant, with the ~3 Ma level at 350 m (based on the last appearance [LA] of

Sphaeroidinellopsis and *G. altispira*). Significant gas expansion was noted at Site 102 beginning at ~100 m, but carbonate diagenesis similar to that which interfered in part with APC operations on Leg 164 was not noted. A fourth shallow (~50 m) hole at this site would be valuable in documenting the shallowest depth-of-no-sulfate on the Blake Outer Ridge. This peculiar occurrence implies a very high upward flux of methane at this site.

BBOR-3

This second priority site on the tip of the Blake Outer Ridge at ~4250 m water depth is not currently part of the drilling plan. Sediments there might be free of gas hydrate, and clearance has been granted to core as deep as 350 m, if the situation permits. This location has the highest late Quaternary sedimentation rate of the entire BBOR region (~339 m/m.y.). It should make a useful complement to the BR site far to the northeast in the Sargasso Sea.

BBOR-4B

At ~4 km water depth, proposed Site BBOR-4B lies close to the boundary between AABW and lower NADW in the western North Atlantic (Fig. 3). This position makes it sensitive to changes in the balance between these two water masses, and its record will complement that of Site BR-1 at ~4.5 km. No BSR is evident in the seismic data, so it is hoped that triple APC penetration will be greater than 150 m and that XCB cores will have complete recovery and little disturbance. If time permits, double or triple XCB coring to 350 m will be attempted. If XCB recovery is high, the cores should contain Pliocene sediments that record a high sedimentation rate. This record could then be compared with the cores from Legs 154 and 162, which are located to the south and north, respectively, of this study.

BBOR-1 and BBOR-1B

This site is in the well-known deep mud-wave field just northwest of the Bahama Outer Ridge (~4700 m). The waters there are composed of ~20% AABW (Fig. 3) that has mixed with the southward-flowing NADW and follows the bathymetric contours. The deposition rates are very high and foraminiferal abundance is very low, which we know from the site survey and other cores. For example, during the latest Quaternary a typical wave accumulated at an average of 262 m/m.y. and benthic foraminifers are frequently absent during glacial and stadial climates. At this site we plan to core six holes to at least 100 m. The minimum plan is for three holes on the high-depositional-rate east flank (Site BBOR-1), and two on the lower-rate western flank (Site BBOR-1B). These sites will be the deepest high-resolution paleoceanography sites in the North Atlantic (and perhaps the deepest anywhere), and will be useful for monitoring the evolution of the blend of NADW and AABW in the North Atlantic, for studying magnetic reversals in high resolution and for directly measuring paleocurrent speed through ratios of sedimentation rates on either flank of the wave. As these holes are the last to be cored in the CS/BBOR region and may be less affected by gas hydrate than sites in shallower water, this site may be cored as deep as 350 mbsf if problems are experienced at shallower sites. Other possible sites in this sedimentary environment include a wave crest site (Site BBOR-1C) and another east-flank site on a nearby mud wave (Site BBOR-1A). One of the two holes on the low-deposition-rate flank will be available for pore-water sampling once per section in the upper few tens of meters.

BR-1

This is the last site to be cored by Leg 172, on the way to port in Lisbon, Portugal. The location is very well surveyed, and the facies should be the same as those cored by DSDP Site 9 (Hays, et al., 1972). Goals for that site were to date the bottom of the prominent acoustic reflectors at ~300 mbsf and to date sediment overlying basalt as a test of seafloor spreading. Neither objective was achieved because of spot coring, core catcher failure, and generally unfossiliferous sediments at great depth. It is expected that the onset of Northern Hemisphere glaciation led to increased terrigenous flux which may account for the acoustically stratified facies. Site BR-1 will be triple cored to not less than 350 m. If time is available, a fourth hole will be cored at this site for pore-water studies and to ensure enough sample for high-resolution studies.

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Table 1. Site Time Estimates

Site Name	Water Depth	PPSP† OK (m)	Plan A APC	Plan A XCB	Plan A time (d)	Transit Time (days)	Seismic Surveying (d)	Logging time (d)	Pene-tration	Bottom Age (Ma)	Basis for Bottom Age
Transit from Charleston, N.C.						0.7					
CS-3B	1292	200	3 to 150 m 1 to 50 m		2 0.2		0.1 (3 hrs)		100	0.15	Site survey GGC's*
Transit						0.1					
CS-2	1790	200	3 to 125 m 1 to 50 m		1.6 0.2		0.1 (3 hrs)		100	0.45	Site survey GGC's
Transit						0.1					
BBOR-8C	2164	200	3 to 150 m 1 to 50 m		2.7 0.3		0.1 (3 hrs)		100	2.4	Correlation to ODP 996 (paleo./mag.)
Transit						0.1					
BBOR-7A	2585	200	3 to 100 m		1.7		0.1 (3 hrs)		100	1.7	Correlation to ODP 994
Transit						0.2					
BBOR-9	2975	350	3 to 150 m		2.2		0.1 (3 hrs)		150	2.60	Site survey GGC-39 correlation to ODP 994, 995, 997 (paleo./mag.)
Transit						0					
BBOR-6	2975	350	3 to 100 m		1.9		0.1 (3 hrs)		100	0.68	Correlation to ODP 994, 995, 997 (paleo./mag.)
Transit						0.3					
BBOR-5	3430	350	3 to 150 m 1 to 50 m		2.9 0.3		0.1 (3 hrs)		150	~1.5 Ma	Based on DSDP 102
Transit						0.2					
BBOR-4B	3975	350	3 to 200 m	1 to 350 m	5.3		0.1 (3 hrs)	1.1	300	0.8	Estimate based on extra-polation from PC
Transit						0.4					
BBOR-1	4715	350	3 to 200 m 1 to 125 m		4.7 0.6		0.1 (3 hrs)		100	>1 Ma	Sed rates in GPC¥-9 and site survey PC's
BBOR-1B	4725	350	2 to 100 m		2		0.1 (3 hrs)		100		
Transit						3.6					
BR-1	4450	350	3 to 200 m 1 to 100 m	3 to 350 m	8.5 0.6		0.1 (3 hrs)	1.1	350	2-4 Ma	Est. based on acoustic stratigraphy; DSDP 9 suggests middle Pliocene
Transit to Lisbon						9.3					
Total					37.7	15.0	1.1	2.2			**Total Time=56 days**

*GGC=Giant Gravity Core

¥GPC=Giant Piston Core

†PPSP=Pollution Prevention Safety Panel

Table 2. ODP Leg 172 site plan with age estimates based on site survey cores

Site Name	Lattitude, Longitude	Water Depth	Physio-graphy	Seismic Lines	Cores	Penetration (m)	Sed. Rate (m/m.y.)	Age pick	Bottom Age (Ma)
BBOR-1	28°14.780´N, 74°24.418´W	4715	East flank	V2114,	KNR140-JPC17	200	231	Stage 4	0.87
BBOR-1A	28°14.7´N, 74°26.4´W	4760	East flank	KNR31,	KNR31-GPC9	100	262	Stage 4	0.77
BBOR-1B	28°14.769´N, 74°25.056´W	4725	West flank	KNR140	KNR140-JPC16	100	175	Stage 4	1.14
BBOR-1C	28°14.750´N, 74°24.622´W	4705	Wave crest		KNR140-GGC21	125	?		
BBOR-3	29°04.476´N, 72°53.899´W	4250	Tip of Blake	V2807,	KNR140-JPC12	200	339	Stage 4	0.59
BBOR-3A	29°04.00´N, 72°54.20´W	4250	Outer Ridge	KNR140					
BBOR-3B	29°03.00´N, 72°55.00´W	4250						stage 5/4	0.65
BBOR-4	30°01.075´N, 73°36.216´W	3975	Saddle on	C2102,	KNR140-JPC27		300	Stage 4	1-2 Ma
BBOR-4A	29°58.5´N, 73°35.0´W	3975	Blake Outer	KNR140					
BBOR-4B	29°58.5´N, 73°36.0´W	3975	Ridge			at least350	282	Stage 5/4	0.53
BBOR-5	30°44.017´N, 74°27.995´W	3430	Blake	V2807, C2102,	KNR140-JPC8	150	254	Stage 4	0.59
BBOR-5A	30°43.0´N, 74°27.0´W		Outer Ridge	KNR140, DSDP 102				(based on 102)	1.5Ma
BBOR-6	31°40.47´N, 75°25.13´W	2975	High rate	CH1292line 16,	KNR140-GGC39	100	220	d18-O	0.68
BBOR-6B	31°38.75´N, 75°25.70´W		on Blake	KNR140					
BBOR-9	31°41.415´N, 75°25.807´W	2975	Low rate	CH1292-16,	KNR140-JPC37	150	170	d18-O	0.88
BBOR-9A	31°43.2´N, 75°21.8´W		on Blake	KNR140					
BBOR-7	32°04.961´N, 76°09.963´W	2540	Blake Outer	Farnella 17, 18;	KNR140-JPC44		115	Stage 4	0.87
BBOR-7A	32°01.00´N, 76°04.00´W	2585	Ridge	KNR140	KNR140-JPC3	100			
BBOR-8B	32°29.0´N, 76°20.5´W	2164	Blake Outer	Fay 25, line 3					
BBOR-8	32°30.105´N; 76°17.627´W	2155	Ridge &	Farnella 16,	KNR140-GGC66		139	Magneto-	0.72
BBOR-8A	32°30.105´N, 76°19.5´W		Carolina	KNR140				stratigraphy (ms)	
BBOR-8C	32°29.1´N, 76°19.8´W	2164	Slope			150			
BR-1	33°41.2´N, 57°36.9´W	4450	Bermuda	KNR31,	GPC-5, HU89-PC8,	350	392	Stage 4 (GPC-5)	0.77
			Rise	IFP line BER1;	EN120, GGC1/2				
BR-1A	33°41.0´N, 57°38.2´W	4469	Plateau	HU89	HU89-PC10		344	5e (MD core)	0.87
CS-2	32°47.041´N; 76°17.178´W	1790	Carolina	CH0692-41;	KNR140-GGC51	125	222	ms,	0.45
CS-2A	32°45.158´N, 76°14.180´W	1900	Slope	Farn. 8,16;	KNR140-GGC50		167	d18-O	0.6
			intermed.	CH9115-8,9;					
			depth	CH0790; KNR140					
CS-3B	33.00°N; 76°17´W	1292	Shallow			125			
CS-3	32°58.626´N, 76°18.970´W	1205	Carolina	Farn. 7; CH0692-43;	KNR140-GGC59		670	14C	0.15
CS-3A	32°57.783´N, 76°17.803´W	1323	Slope	KNR140	KNR140-GGC57				

Note: bold type marks primary coring sites

FIGURE CAPTIONS

Figure 1. Map of the western North Atlantic Ocean showing the location of Leg 172 sites on the northeast Bermuda Rise (Site BR-1), the Carolina Slope (CS), and Blake-Bahama Outer Ridge (BBOR). Note that alternate sites are not shown.

Figure 2. Map showing the location of the Carolina Slope and Blake-Bahama Outer Ridge sites. These sites form a depth transect in water depths from ~1200 to 4800 m. Sites BBOR-6 and BBOR-9 (~2 km apart) span an abrupt change in terrigenous sediment flux, and Site BBOR-1 and -1B will sample across a mud wave. Note: primary sites are shown in addition to the secondary Site BBOR-3.

Figure 3. Position of BBOR and CS Leg 172 sites with respect to water masses in the western subtropical North Atlantic. Water depths are indicated every 500 m along the temperature/salinity (T/S) plot. Sites were chosen so at least one lies within each modern water mass and one lies at the boundary between water masses. This depth distribution of sites is required to monitor the most likely changes in water masses and their boundaries through the late Neogene. U = upper. L = lower. KNORR 140/2 Hydro Sta. 1 refers to the site survey cruise and station number that were used to collect the data.

Figure 4. Schematic of circulation patterns in the deep western North Atlantic (updated from Schmitz and McCartney, 1993 by M.S. McCartney, pers. comm. to L. Keigwin, 1995). The thin lines represent streamlines of two recirculating gyres with approximate transport in Sverdrups (1 Sv = 10^6 $m^3 s^{-1}$). Thick lines represent generalized flow direction of AABW and NADW, which contribute to the Deep Western Boundary Current (DWBC). The stippled pattern marks the region marked by high surface eddy kinetic energy (EKE), deep EKE, and deep suspended sediment. Note that in this scheme the southern recirculating gyre, over the Bermuda Rise, is the mixing zone for northern and southern origin waters, and that true "NADW" is formed in that mixing zone.

Figure 5. Age-depth relationship for Bermuda Rise Site BR-1 (core GPC-5, open circles) and for Bahama Outer Ridge site BBOR-1A (core GPC-9, solid circles). Solid line without data points is the calendar year age model for GPC-5 (Keigwin and Jones, 1994). AMS = accelerator mass spectrometer.

Figure 6. Percent-carbonate data for two Leg 172 sites (Core KNR31-GPC-5 for the Bermuda Rise and Core KNR31-GPC-9 for the Bahama Outer Ridge), plotted on the age model (solid line) of Fig. 5. The millennial-scale stadial/interstadial carbonate variability is thought to correlate with similar oscillations in ice core records of climate, and has been linked to variable production of NADW (Keigwin and Jones, 1994).

Figure 7. Map of mud-wave field on northwestern flank of Bahama Outer Ridge, based on Scripps deep tow with 4-kHz profiler, sidescan sonar, etc. (Flood, 1978). Note location of core GPC-9 in southwest corner. Sites BBOR-1 and -1B (asterisk) will be on the flanks of the mud wave just to the east of the GPC-9 location.

Figure 8. Map showing the outline of the Blake Outer Ridge gas hydrate field (stippled) for comparison with prospective Leg 172 core sites (Fig. 2). Gas hydrate is typically detected by the presence of a bottom-simulating reflector (BSR) on seismic reflection profiles. The gas hydrate outline is based on mapping the presence of BSRs (from Dillon and Paull, 1983; modified after Paull, Matsumoto, Wallace et al., in press).

Figure 9. Percent-core-recovery at ODP Hole 994C on the Blake Outer Ridge near Sites BBOR-6 and -9. This pattern is typical of other Leg 164 sites. Note the sudden drop in APC recovery at ~160 mbsf, and the generally poor recovery using the XCB. Difficult coring conditions are attributed to the presence of gas and to gas-related sediment diagenesis (carbonate nodules, drilling biscuits).

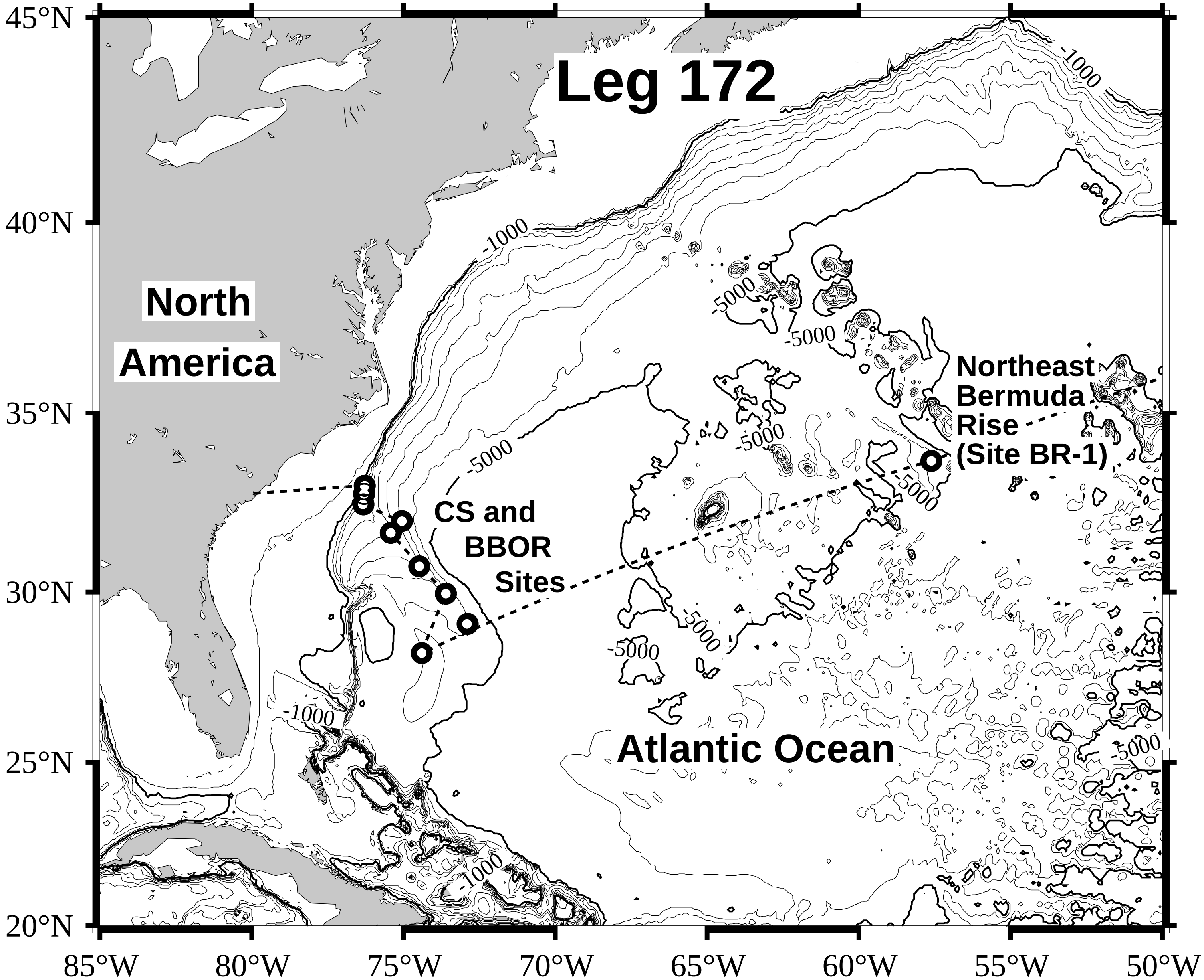

Leg 172
North America
Atlantic Ocean
CS and BBOR Sites
Northeast Bermuda Rise (Site BR-1)
-1000
-5000
45°N
40°N
35°N
30°N
25°N
20°N
85°W
80°W
75°W
70°W
65°W
60°W
55°W
50°W

Figure 1

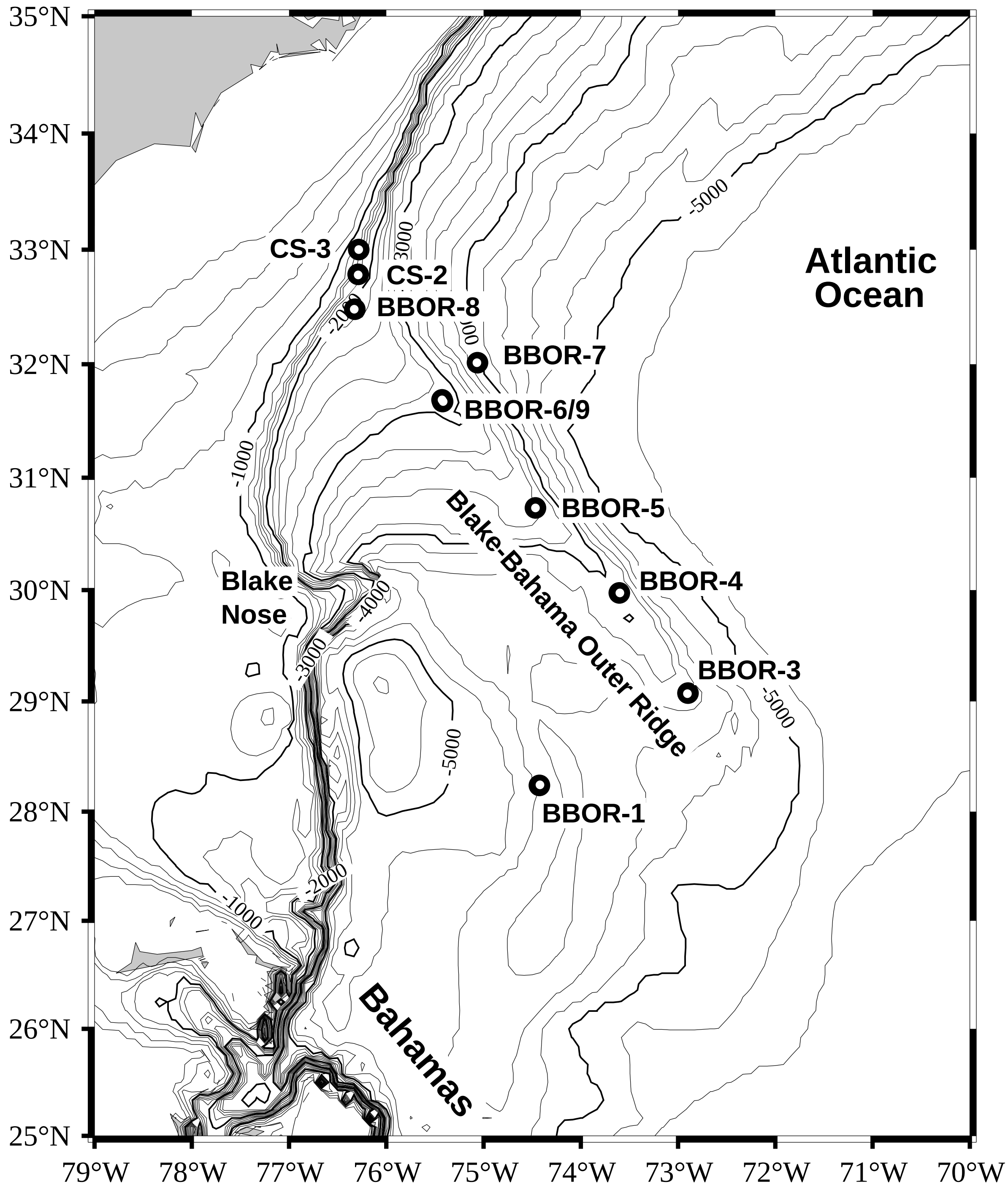

35°N
34°N
33°N
32°N
31°N
30°N
29°N
28°N
27°N
26°N
25°N
79°W
78°W
77°W
76°W
75°W
74°W
73°W
72°W
71°W
70°W
Atlantic Ocean
CS-3
CS-2
BBOR-8
BBOR-7
BBOR-6/9
BBOR-5
BBOR-4
BBOR-3
BBOR-1
Blake Nose
Blake-Bahama Outer Ridge
Bahamas
-1000
-2000
3000
-4000
-5000

Figure 2

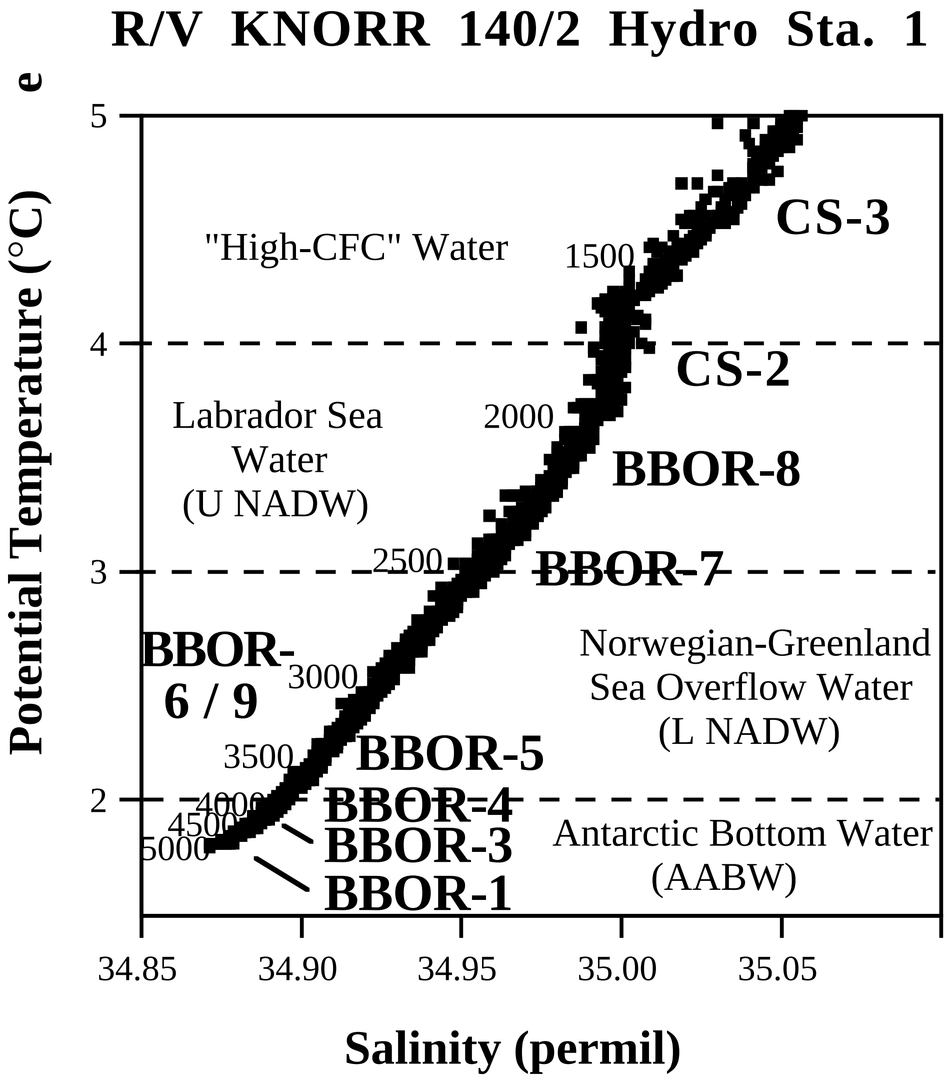

R/V KNORR 140/2 Hydro Sta. 1
Potential Temperature (°C)
e
5
4
3
2
"High-CFC" Water
1500
CS-3
CS-2
Labrador Sea
Water
(U NADW)
2000
BBOR-8
2500
BBOR-7
BBOR-
6 / 9
3000
Norwegian-Greenland
Sea Overflow Water
(L NADW)
3500
BBOR-5
4000
BBOR-4
4500
5000
BBOR-3
BBOR-1
Antarctic Bottom Water
(AABW)
34.85
34.90
34.95
35.00
35.05
Salinity (permil)

Figure 3

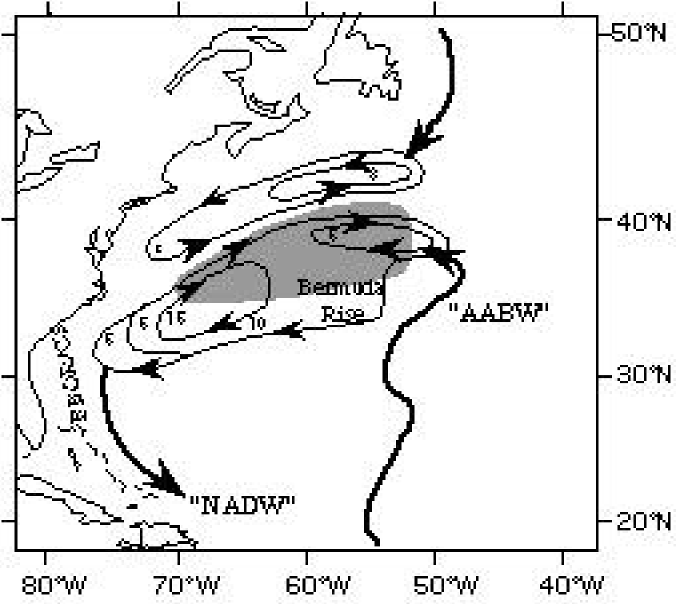
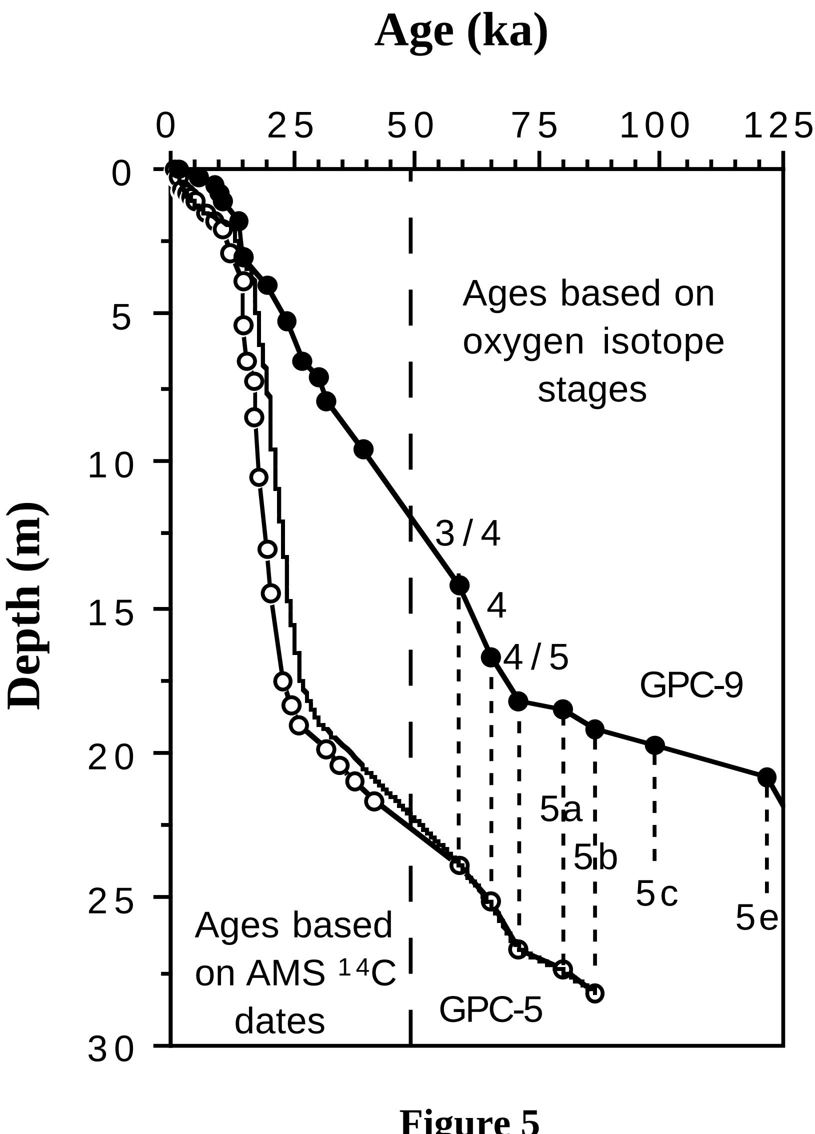
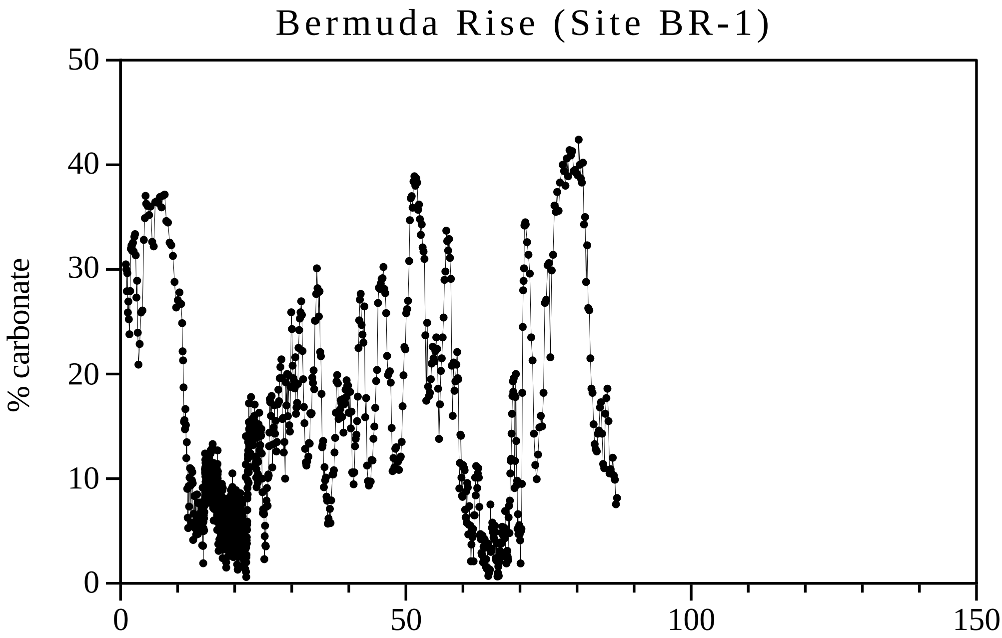


Figure 4



Age (ka)
0
25
50
75
100
125
Depth (m)
0
5
10
15
20
25
30
Ages based on oxygen isotope stages
3/4
4
4/5
GPC-9
5a
5b
5c
5e
Ages based on on AMS 14C dates
GPC-5

Figure 5


Bermuda Rise (Site BR-1)
% carbonate
0
10
20
30
40
50
0
50
100
150

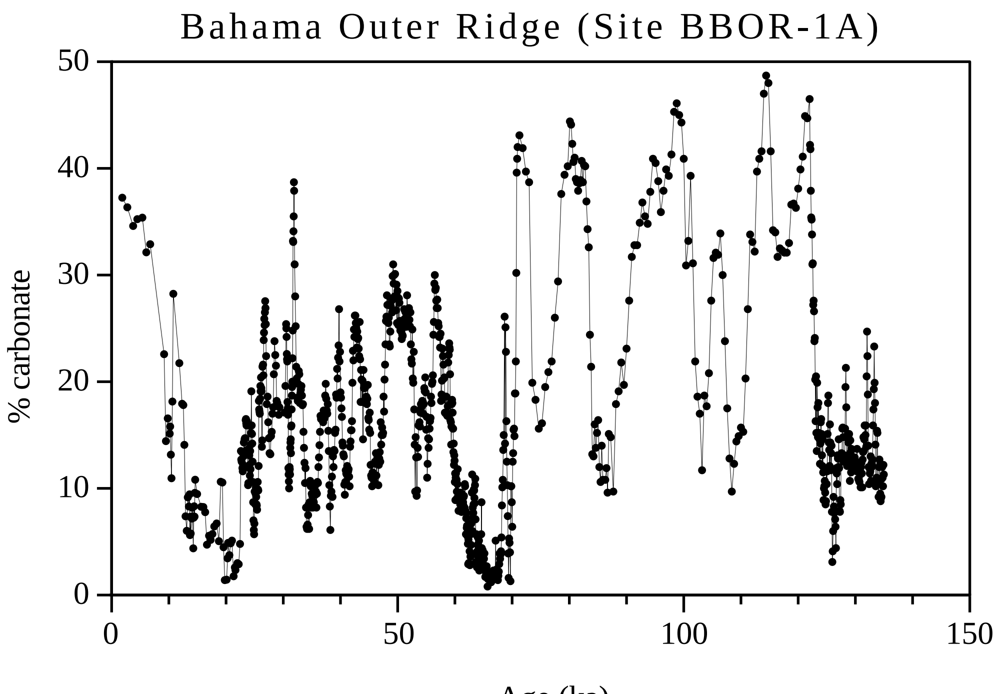

Bahama Outer Ridge (Site BBOR-1A)
% carbonate
0
10
20
30
40
50
0
50
100
150
Age (ka)

Figure 6

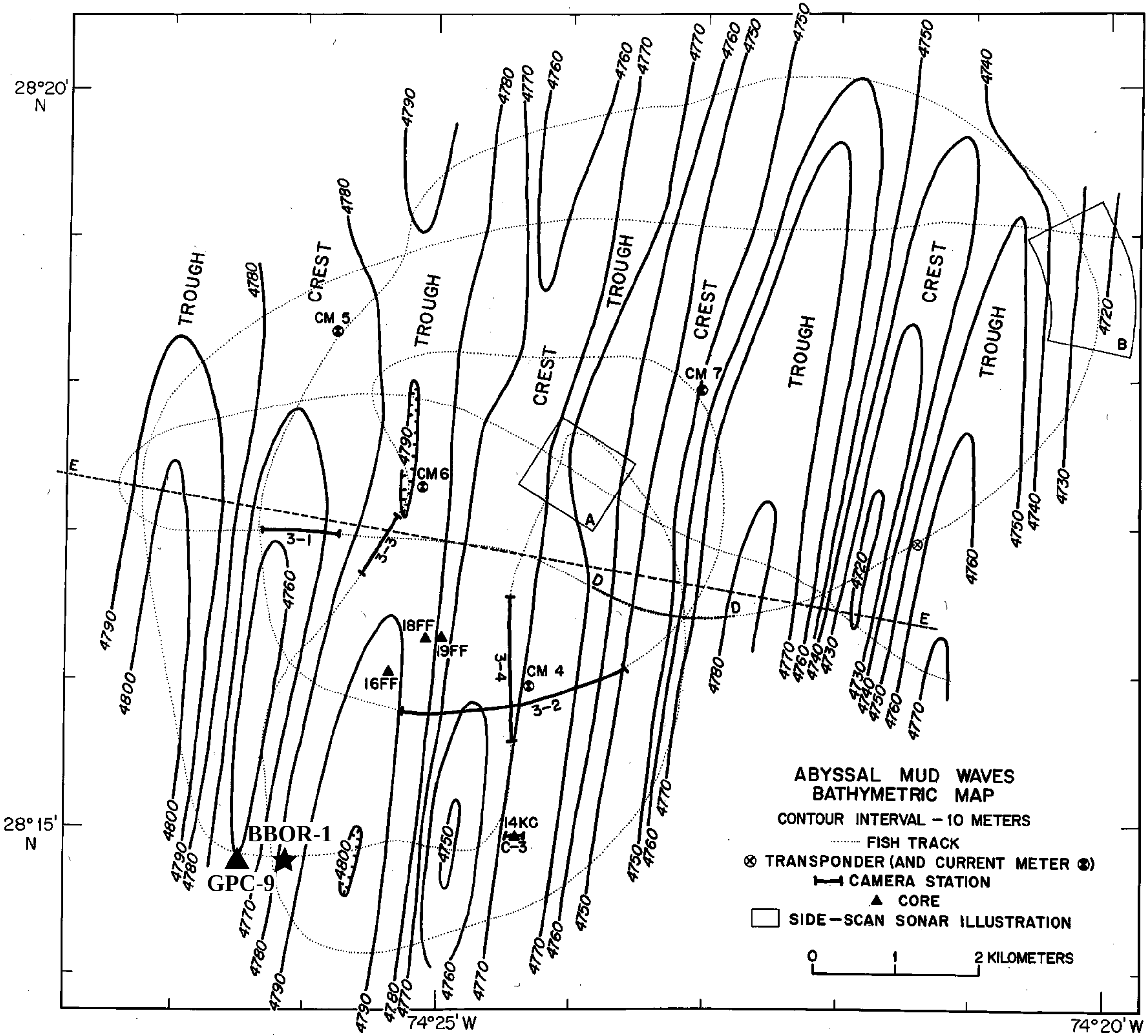
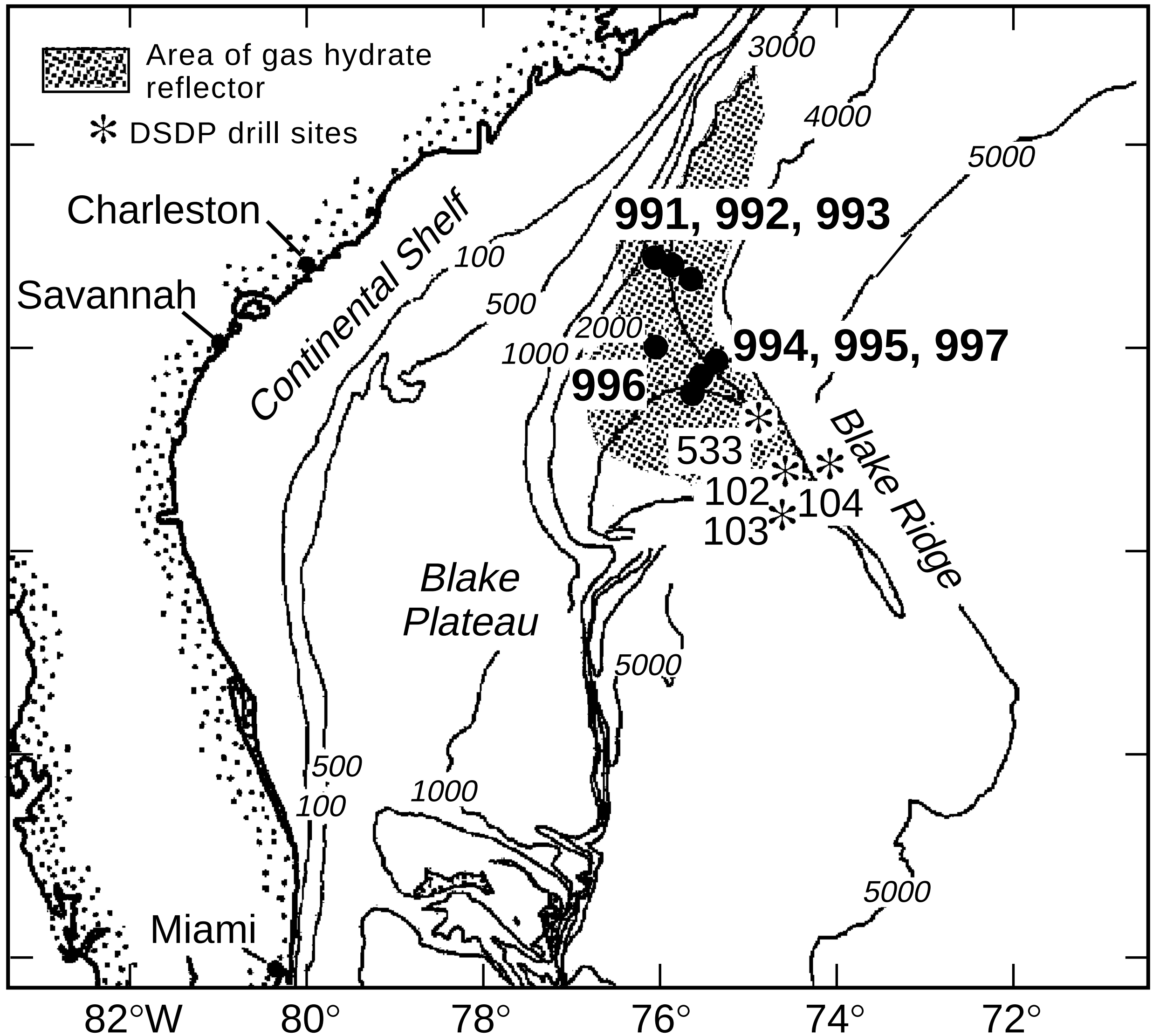

ABYSSAL MUD WAVES
BATHYMETRIC MAP
CONTOUR INTERVAL – 10 METERS
FISH TRACK
TRANSPONDER (AND CURRENT METER)
CAMERA STATION
CORE
SIDE–SCAN SONAR ILLUSTRATION
0 1 2 KILOMETERS
28°20' N
28°15' N
74°25' W
74°20' W
TROUGH
CREST
CM 5
CM 6
CM 7
CM 4
BBOR-1
GPC-9
16FF
18FF
19FF
14KC
C-3
3-1
3-2
3-3
3-4

Figure 7



Area of gas hydrate reflector
DSDP drill sites
34° N
32°
30°
28°
26°
82°W
80°
78°
76°
74°
72°
Charleston
Savannah
Miami
Continental Shelf
Blake Plateau
Blake Ridge
991, 992, 993
994, 995, 997
996
533
102
103
104
100
500
1000
2000
3000
4000
5000

Figure 8

ODP 994C
Blake Outer Ridge ~2800m

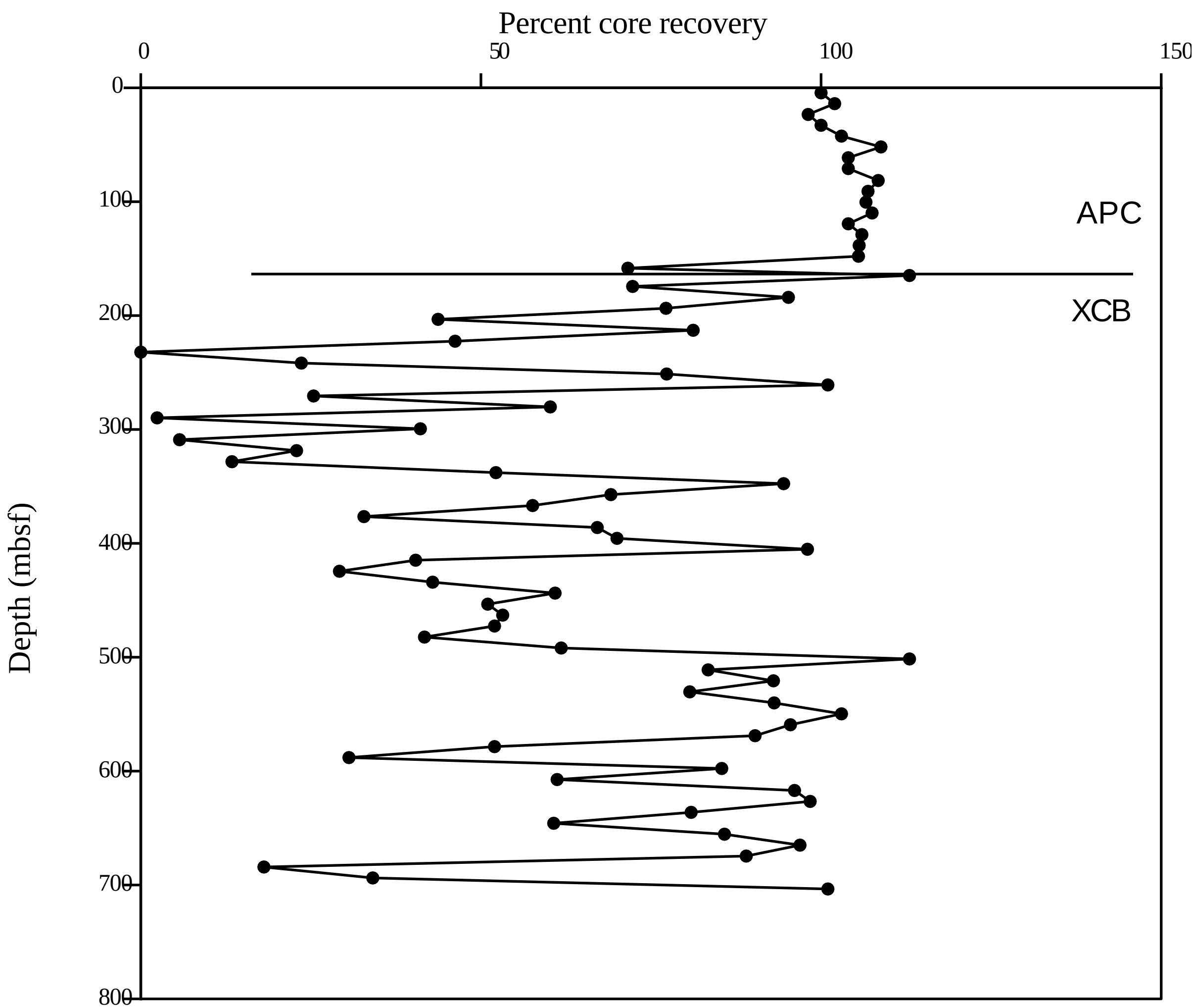


Figure 9

Site: BBOR-1

Priority: 1
Position: 28°14.780'N, 74°24.418'W (BBOR-1)
28°14.769'N, 74°25.056'W (BBOR-1B)
28°14.750'N, 74°24.622'W (BBOR-1C)
Water Depth: 4715 m (BBOR-1), 4725 m (BBOR-1B), 4705 m (BBOR-1C)
Sediment Thickness: 1000 m
Approved Maximum Penetration: 350 mbsf
Seismic Coverage: Single channel seismic Vema 2114; Vema 2401; 3.5 KHz seismic KNR 31 and 140

Objectives: The objectives of BBOR-1 and BBOR-1B are to determine the:

1. History of circulation change in the deep western North Atlantic; the deep end member of the depth transect

2. Processes of mud wave migration and to develop proxy for deep current speed

3. High-resolution history of paleomagnetic change

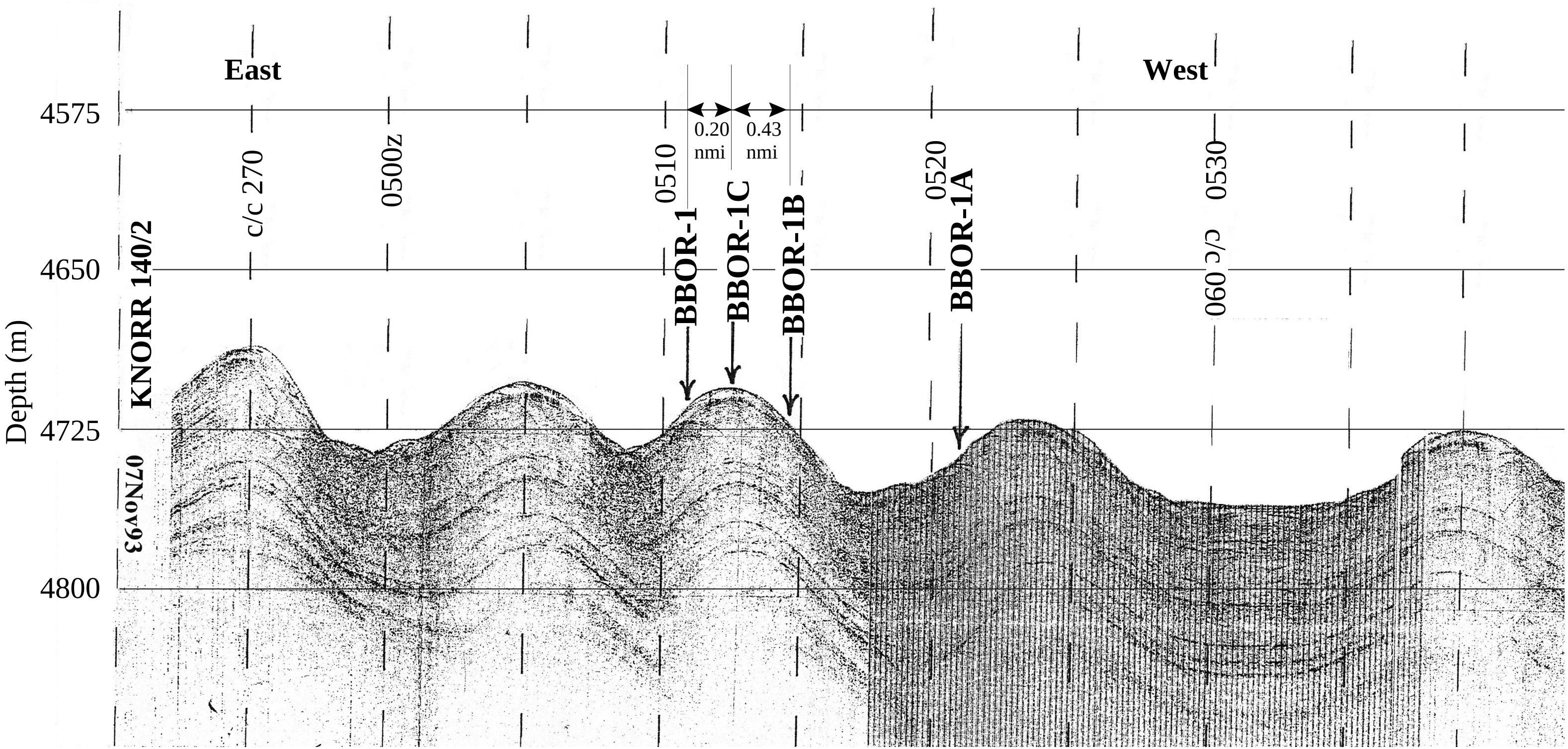
4. Extent of gas hydrate effects at deep end of depth transect

Drilling Program:
The following are to be considered three locations at a single site. If the beacon is dropped on the wave crest (BBOR-1C), then BBOR-1 and BBOR-1B can be offset to the east and west, respectively.

BBOR-1:	triple APC to 200 m.
BBOR-1B:	double APC to 100 m
BBOR-1C:	if time permits, APC third hole on wave crest to 125 m

Logging and Downhole: None anticipated

Nature Of Rock Anticipated: Foraminifer-bearing silty clay and nannofossil marl



Proposed Site BBOR-1

Site: BBOR-3

Priority: 2
Position: 29°4.476'N, 72°53.899'W
Water Depth: 4250 m
Sediment Thickness: 1000 m
Approved Maximum Penetration: 350 m
Seismic Coverage: V2807 single channel seismic, KNR140 3.5kHz

Objectives: The objectives of BBOR-3 are to determine the:

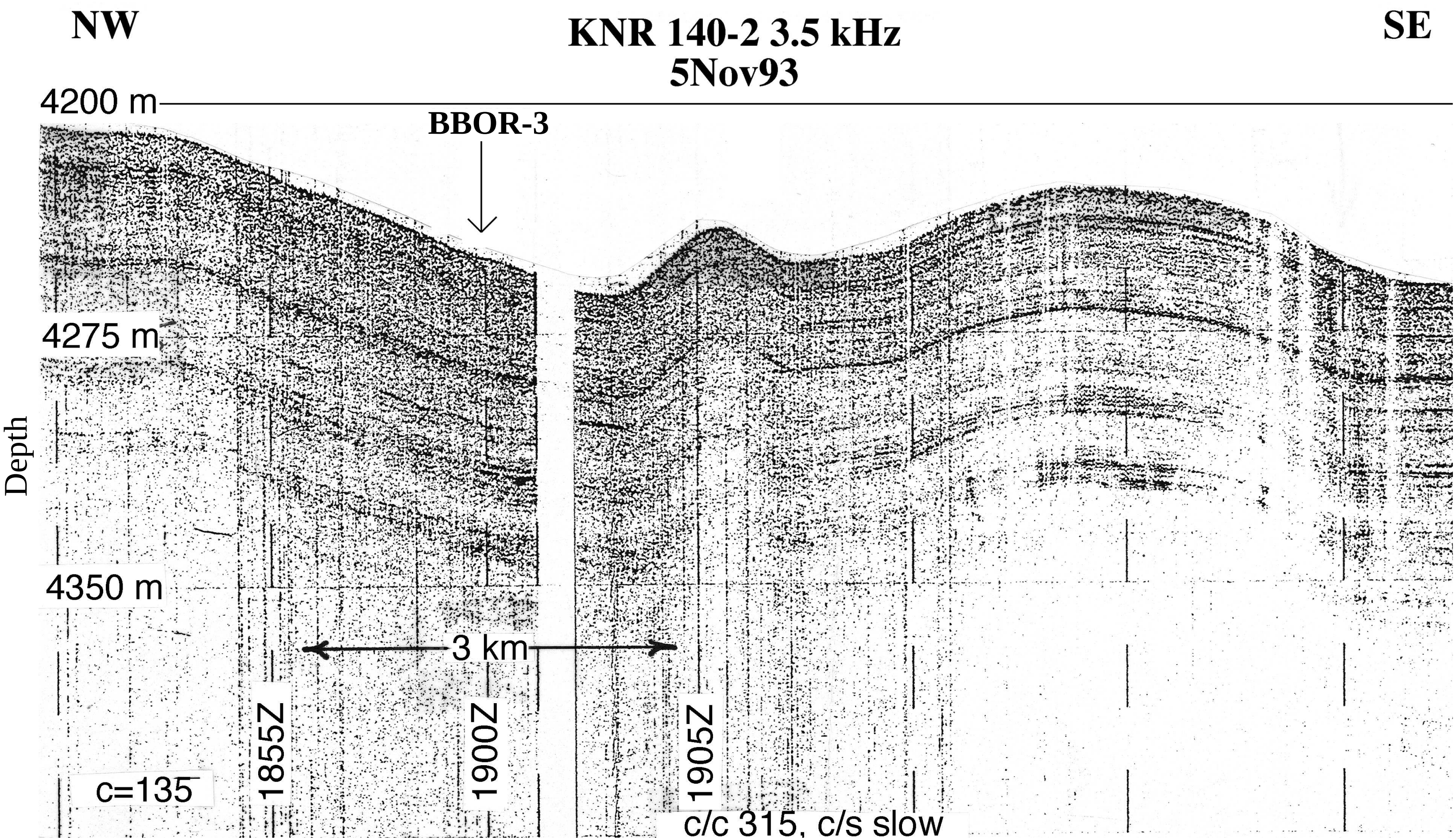
1. History of circulation change in the deep western North Atlantic near the boundary between AABW and NADW

2. High-resolution history of paleomagnetic change

Drilling Program:
Triple APC/XCB to <350 m

Logging and Downhole: None anticipated

Nature of Rock Anticipated: Foraminifer-bearing silty clay and nannofossil marl



Proposed Site BBOR-3

Site: BBOR-4B

Priority: 1
Position: 29°58.5'N, 73°36.0'W
Water Depth: 3975 m
Sediment Thickness: 1000 m
Approved Maximum Penetration: 350 m
Seismic Coverage: Conrad 2102 (LDGO line 87), conrad 1601, Conrad 2012, KNR 140 3.5kHz

Objectives: The objectives of BBOR-4B are to:

1. Determine the history of circulation change in the deep western North Atlantic near the boundary between AABW and NADW.

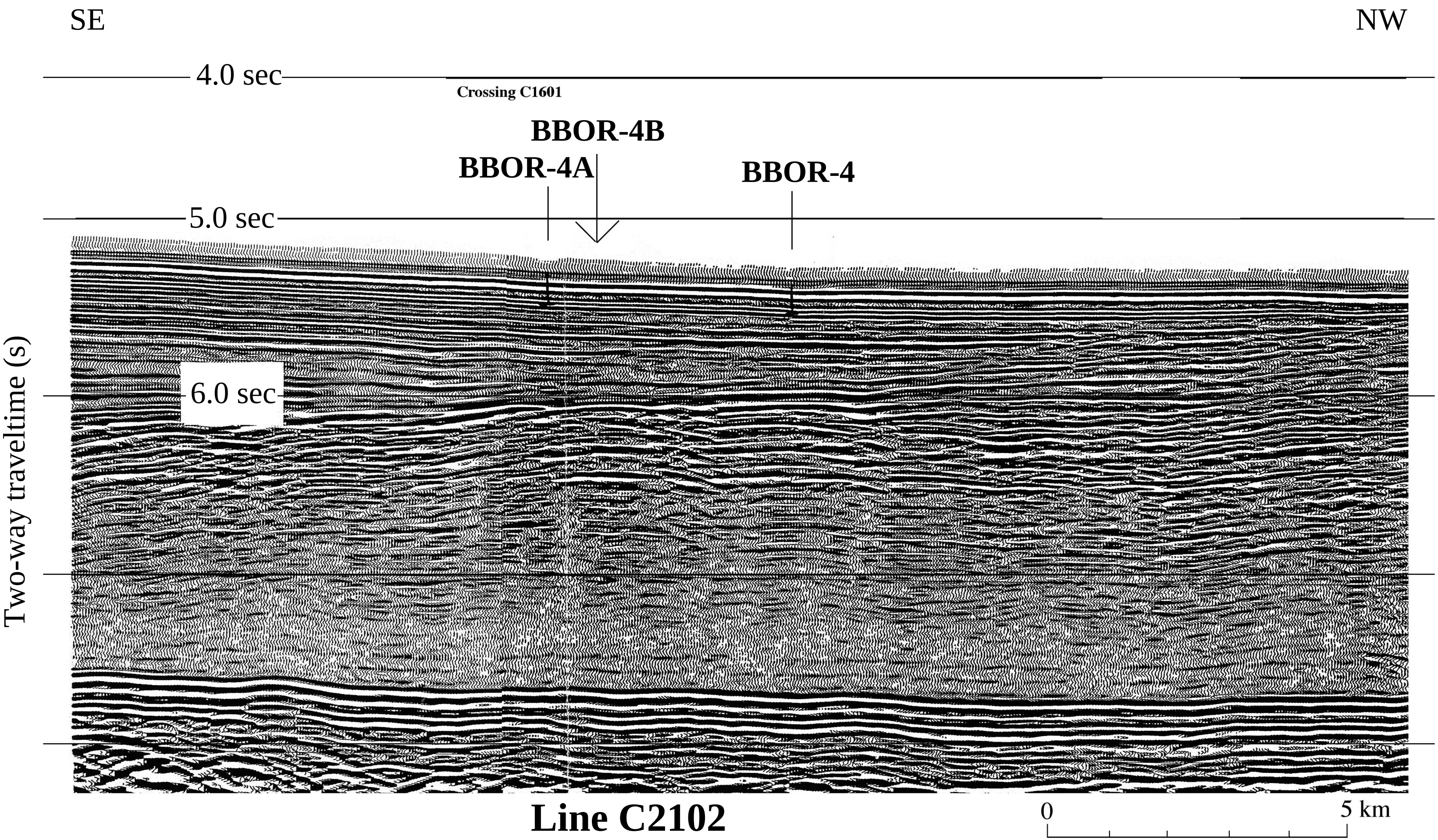
2. Provide reference section for Pliocene circulation change associated with onset of northern hemisphere glaciation

3. Determine a high-resolution history of paleomagnetic change

Drilling program:
Triple APC to 200 m, extending one hole to 350 m by XCB coring if recovery and degree of disturbance are satisfactory. If time permits, double or triple XCB coring to 350 m will be attempted.

Logging and Downhole: FMS-sonic and Triple combo, possibly in a dedicated logging hole, if time permits.

Nature of Rock Anticipated: Foraminifer-bearing silty clay and nannofossil marl



Proposed Site BBOR-4B

Site: BBOR-5

Priority: 1
Position: 30°44.017'N, 74°27.995'W
Water Depth: 3430 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 350 m
Seismic Coverage: V2807, C2102, DSDP 102, KNR140 3.5kHz

Objectives: The objectives of BBOR-5 are to:

1. Determine the history of circulation change in the deep western North Atlantic deep within Lower NADW.

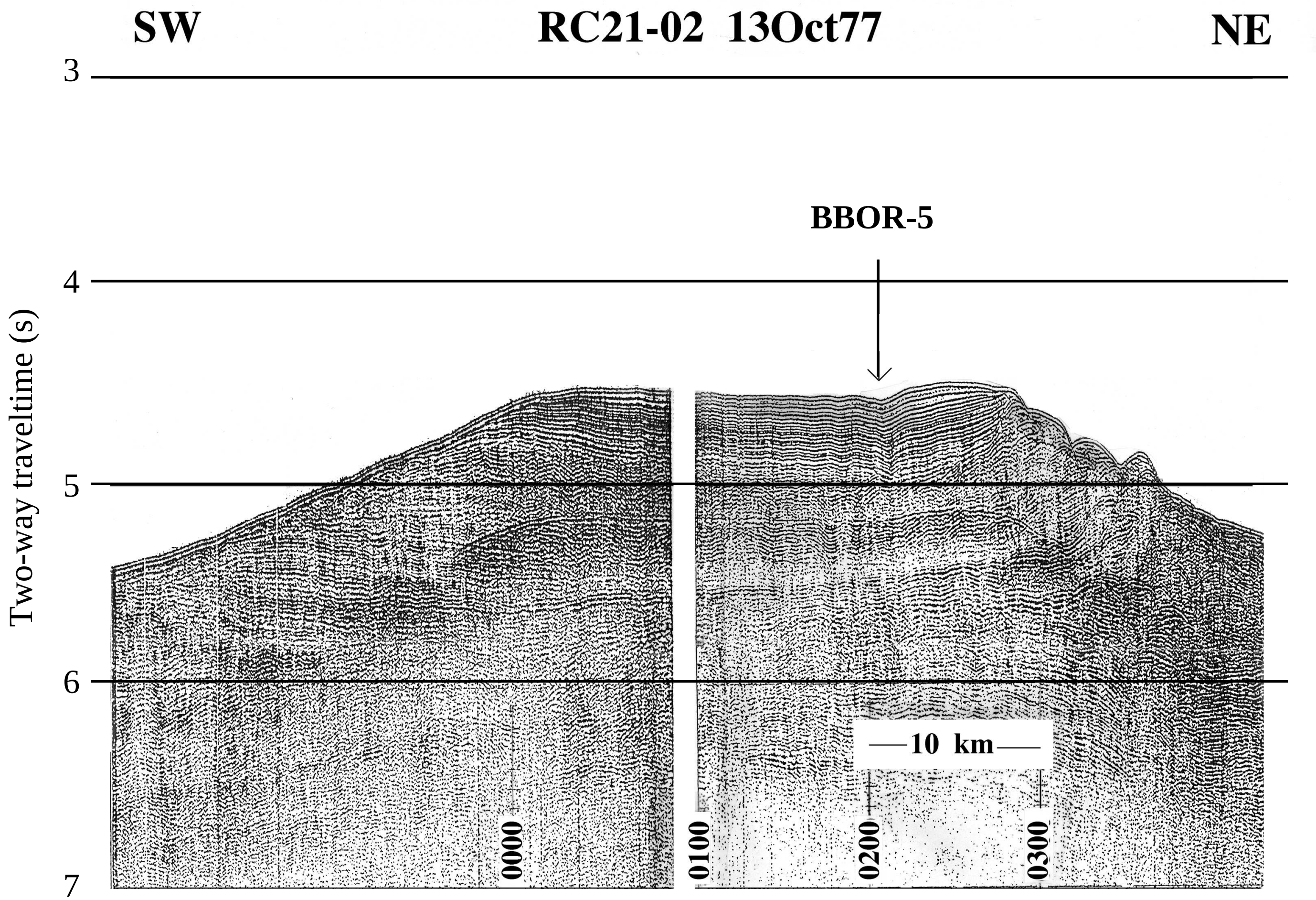
2. High-resolution history of paleomagnetic change

3. Provide a section for studying geochemical processes related to gas hydrate formation and dissociation

Drilling Program:
Triple APC to 150 m; short (50 mbsf) fourth hole desirable for pore-water geochemistry and high-resolution paleoceanography

Logging and Downhole: None anticipated

Nature of Rock Anticipated: Foraminifer-bearing silty clay and nannofossil marl



Proposed Site BBOR-5

Site: BBOR-6

Priority: 1
Position: 31°40.47'N, 75°25.13'W
Water Depth: 2975 m
Sediment Thickness: 1000 m
Approved Maximum Penetration: 350 m
Seismic Coverage: CH1292 line 16 SCS, Fay 19 minisparker and SCS, V2807 SCS, KNR 140 3.5kHz

Objectives: The objectives of BBOR-6 are to:

1. Determine the history of circulation change in the deep western North Atlantic in the core of Lower NADW.

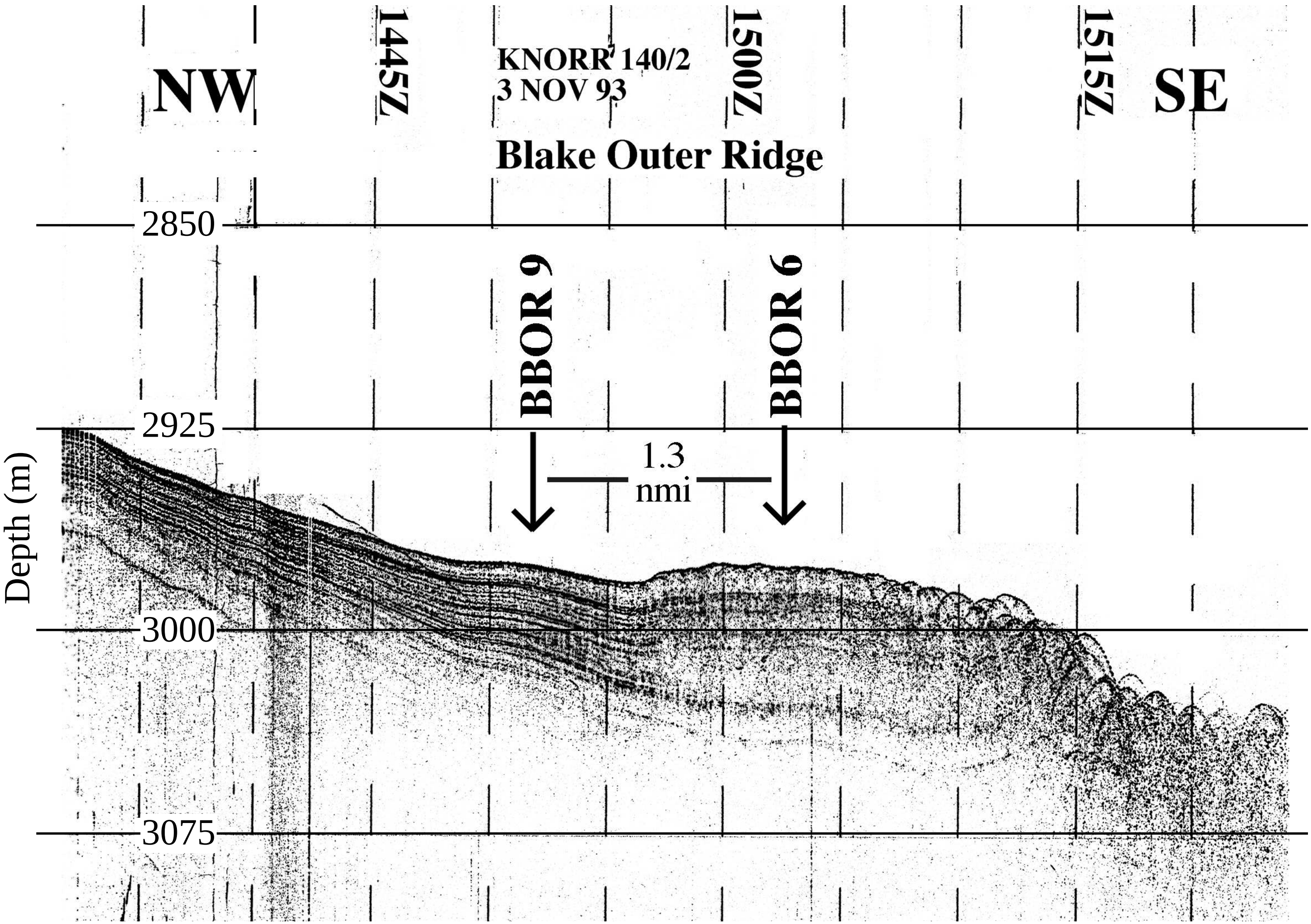
2. Test hypotheses about current-controlled sedimentation and sediment rain rates (combined with BBOR-9)

3. High-resolution history of paleomagnetic change

Drilling Program:
BBOR-6 and -9 are companion sites. BBOR-6 will be triple cored with APC to 100 mbsf

Logging and Downhole: None anticipated

Nature of Rock Anticipated: Foraminifer-bearing silty clay and nannofossil marl, cores may be gassy



Proposed Site BBOR-6/-9

Site: BBOR-7A

Priority: 1
Position: 32°01.00'N, 76°04.00'W
Water Depth: 2585 m
Sediment Thickness: 1000 m
Approved Maximum Penetration: 200 m
Seismic Coverage: V2807, Farnella 87-1 line 18, KNR 140 3.5kHz

Objectives: The objectives of BBOR-7A are to:

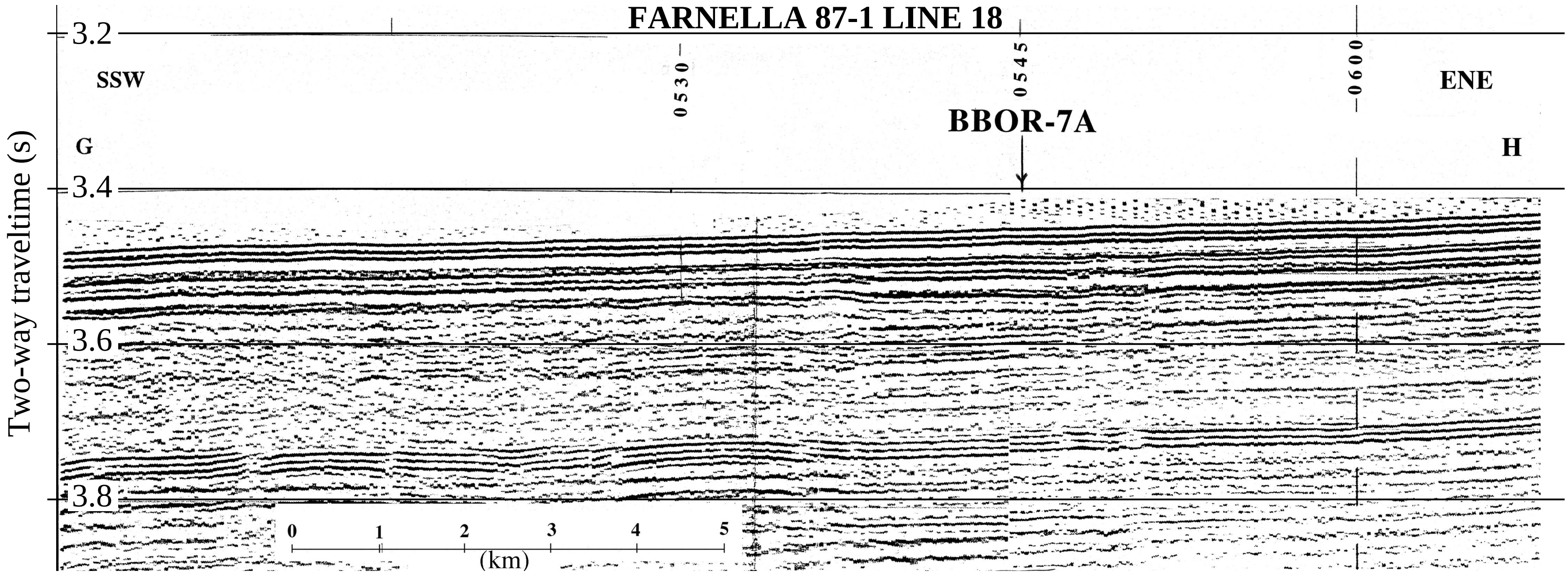
1. Determine the history of circulation change in the deep western North Atlantic near the boundary between Lower and Upper NADW.

2. Determine a high-resolution history of paleomagnetic change

Drilling Program:
Triple APC to 100 m

Logging and Downhole: None anticipated

Nature of Rock Anticipated: Foraminifer-bearing silty clay and nannofossil marl



Proposed Site BBOR-7A

Site: BBOR-8C

Priority: 1
Position: 32°29.1'N, 76°19.8'W
Water Depth: 2164 m
Sediment Thickness: 1000 m
Approved Maximum Penetration: 200 m
Seismic Coverage: Fay 25 line 3, Farnella 87-1 line 16, KNR 140 3.5kHz

Objectives: The objectives of BBOR-8C are to:

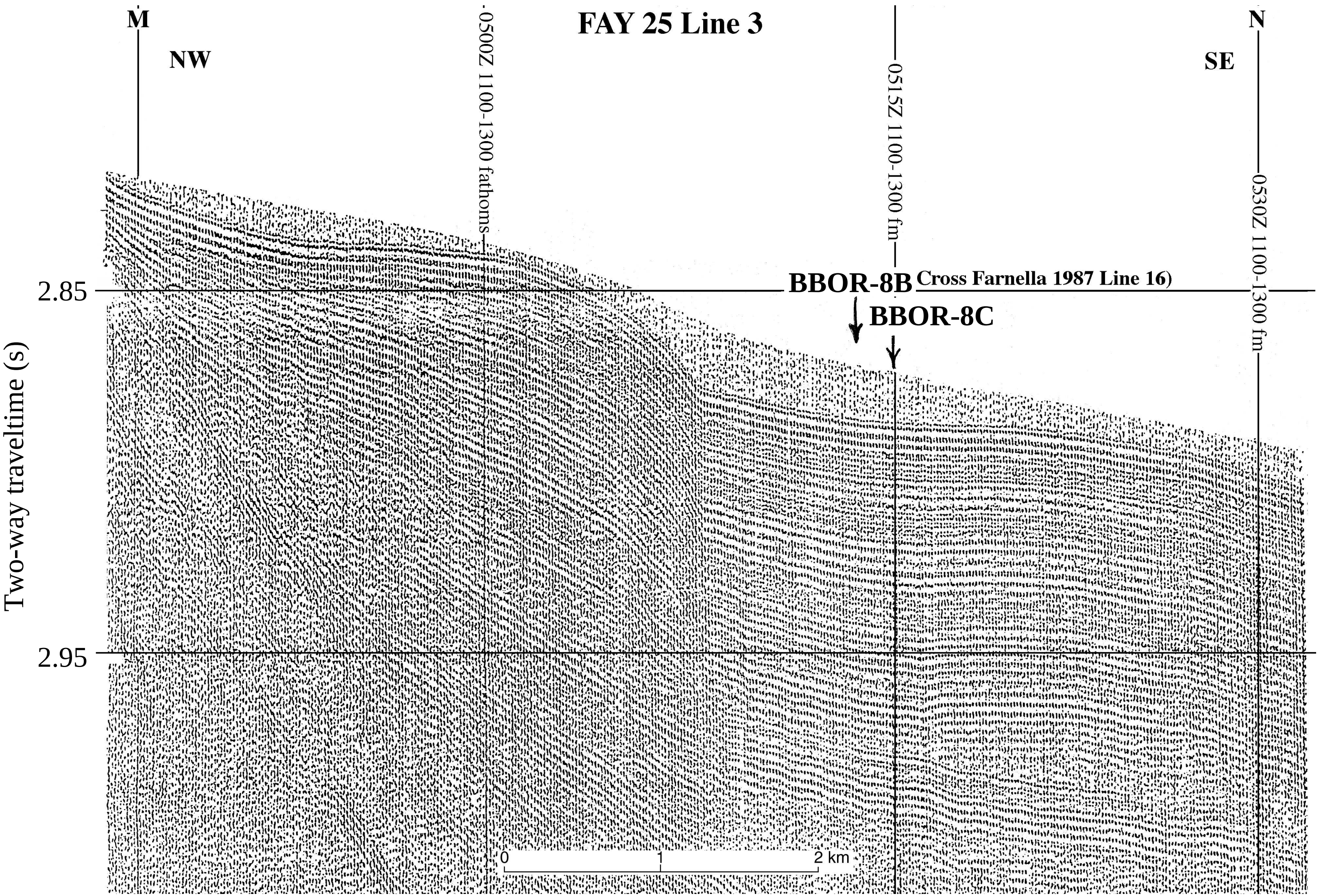
1. Determine the history of circulation change in the deep western North Atlantic within the core of Upper NADW.

2. Determine a high-resolution history of paleomagnetic change

Drilling Program:
Triple APC to 150 m and single APC to 50 m

Logging and Downhole: None anticipated

Nature of Rock Anticipated: Foraminifer-nannofossil ooze



Proposed Site BBOR-8C

Site: BBOR-9

Priority: 1
Position: 31°41.415'N, 75°25.807'W
Water Depth: 2975 m
Sediment Thickness: 1000 m
Approved Maximum Penetration: 350 m
Seismic Coverage: CH1292 line 16 SCS, Fay 19 minisparker and SCS, V2807 SCS, KNR 140 3.5kHz

Objectives: The objectives of BBOR-9 are to:

1. Determine the history of circulation change in the deep western North Atlantic in the core of Lower NADW.

2. Test hypotheses about current-controlled sedimentation and sediment rain rates (combined with BBOR-6)

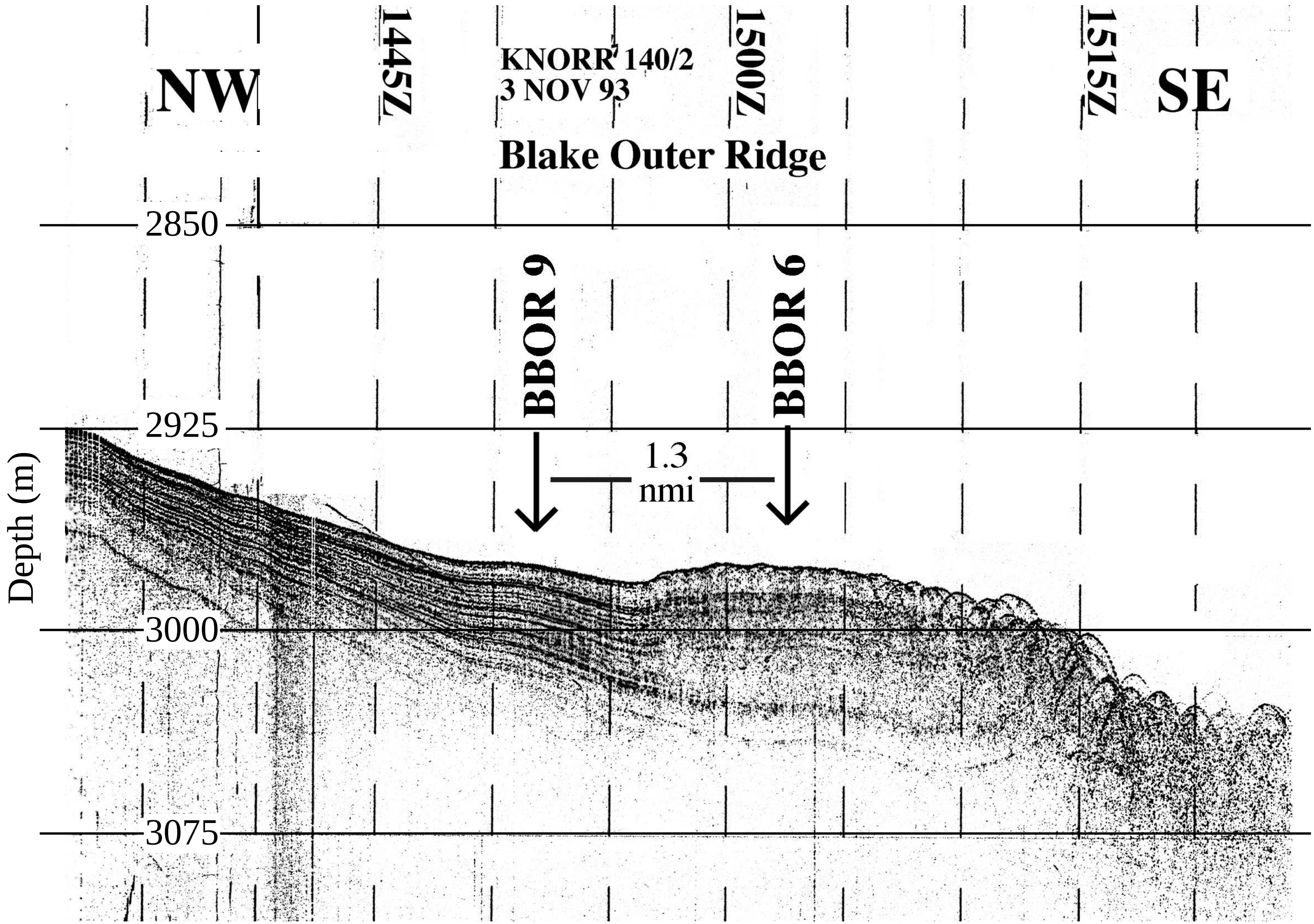
3. Determine a high-resolution history of paleomagnetic change

Drilling Program:
BBOR-6 and -9 are companion sites. BBOR-9 will be triple APC cored to 150 m

Logging and Downhole: None anticipated

Nature of Rock Anticipated: Foraminifer-bearing silty clay and nannofossil marl

See figure for Proposed Site BBOR-6



Proposed Site BBOR-6/-9

Site: BR-1

Priority: 1
Position: 33°41.2'N, 57°36.9'W
Water Depth: 4450 m
Sediment Thickness: 1000 m
Approved Maximum Penetration: 350 m
Seismic Coverage: IFP line BER1, HU89, KNR 31

Objectives: The objectives of BR-1 are to:

1. Monitor the balance of northern and southern source deep waters over the Bermuda Rise through the past several m.y., and to monitor climate changes in surface waters of the northern Sargasso Sea

2. Provide a high-resolution section for paleomagnetic study

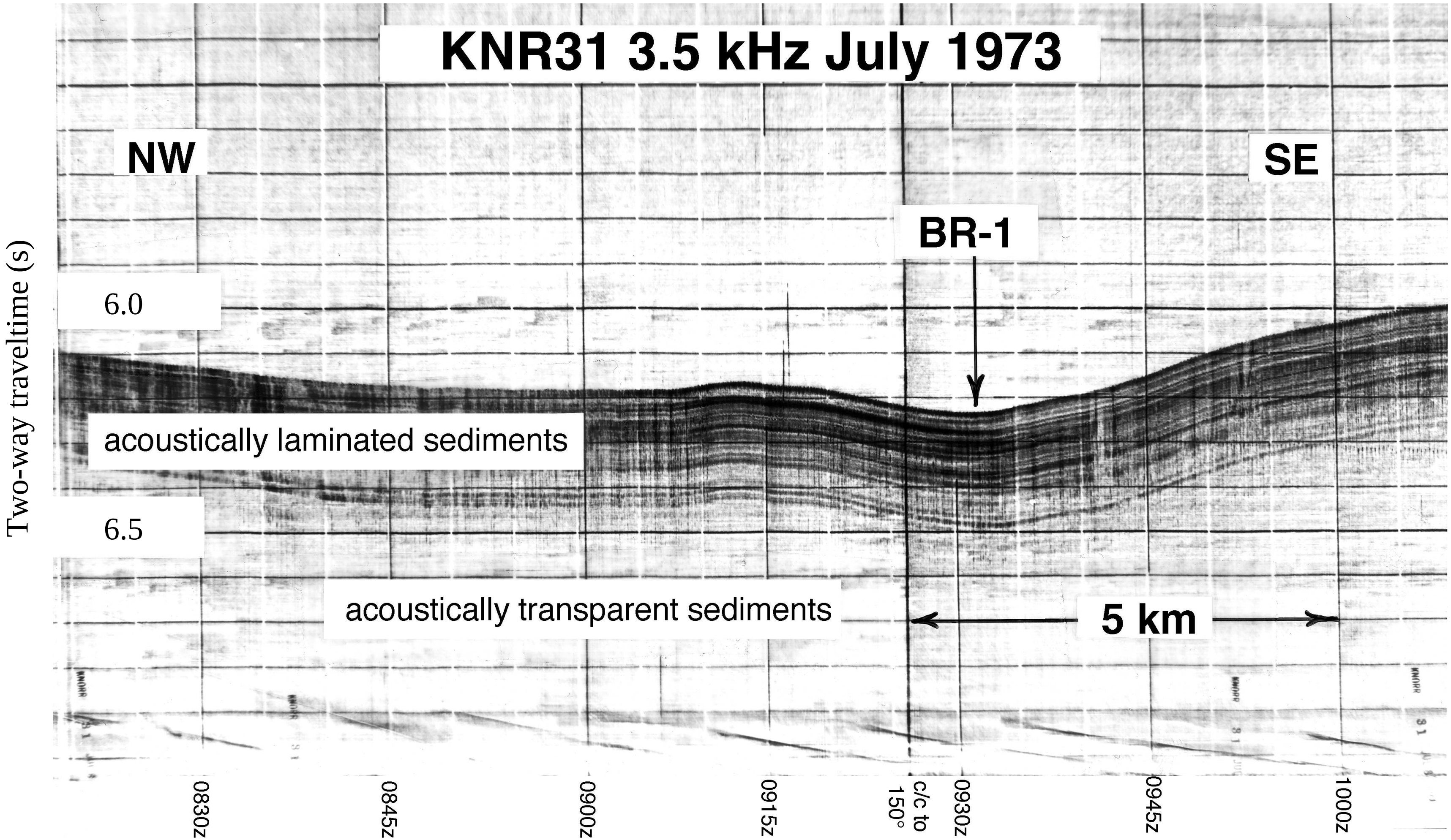
3. Date and identify nature of acoustic transition at ~300 ms

4. Provide a geochemical reference section for pore-water study in a hemipelagic setting that probably has no gas hydrates

Drilling Program:
Triple APC/XCB to 350 m, single APC to 100 m for pore-water geochemistry and high-resolution paleoceanography

Logging and Downhole: FMS-sonic and Triple combo, possibly in a dedicated logging hole if time permits.

Nature of Rock Anticipated: Foraminifer-bearing silty clay and nannofossil marl



Proposed Site BR-1

Site: CS-2

Priority: 1
Position: 32°47.041'N, 76°17.178'W
Water Depth: 1790 m
Sediment Thickness: 1000 m
Approved Maximum Penetration: 200 m
Seismic Coverage: CH6-92 line 41, CH07-90, Farnella 87 line 8, KNR 140 3.5kHz

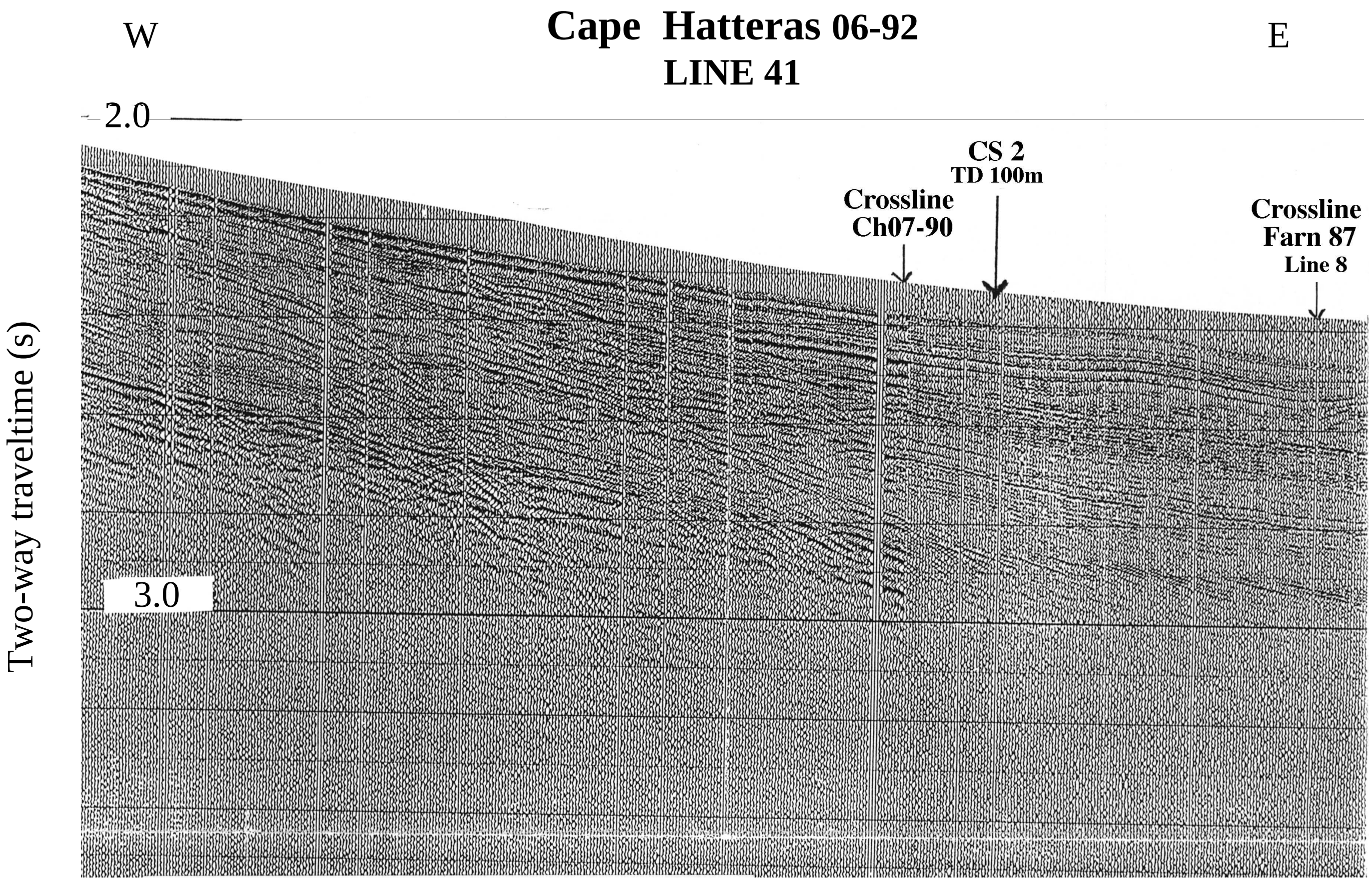
Objectives: The objectives of CS-2 are to:

1. Monitor the core of upper NADW in Pleistocene time
2. Test models of continental slope sedimentation
3. Provide a high-resolution section for paleomagnetic study
4. Provide a section for studying geochemical processes related to gas hydrate formation and dissociation

Drilling Program:
Triple APC to 125 m; fourth APC to ~50 m for pore-water geochemistry and high-resolution paleoceanography

Logging and Downhole: None anticipated

Nature of Rock Anticipated: Marly silt



Proposed Site CS-2

Site: CS-3B

Priority: 1
Position: 33°00'N, 76°17'W
Water Depth: 1292 m
Sediment Thickness: 1000 m
Approved Maximum Penetration: 200 m
Seismic Coverage: CH06-92 line 43, Farnella 87 line 7, KNR 140 3.5kHz

Objectives: The objectives of CS-3B are to:

1. Monitor the shallowest reaches of Upper NADW in Pleistocene time

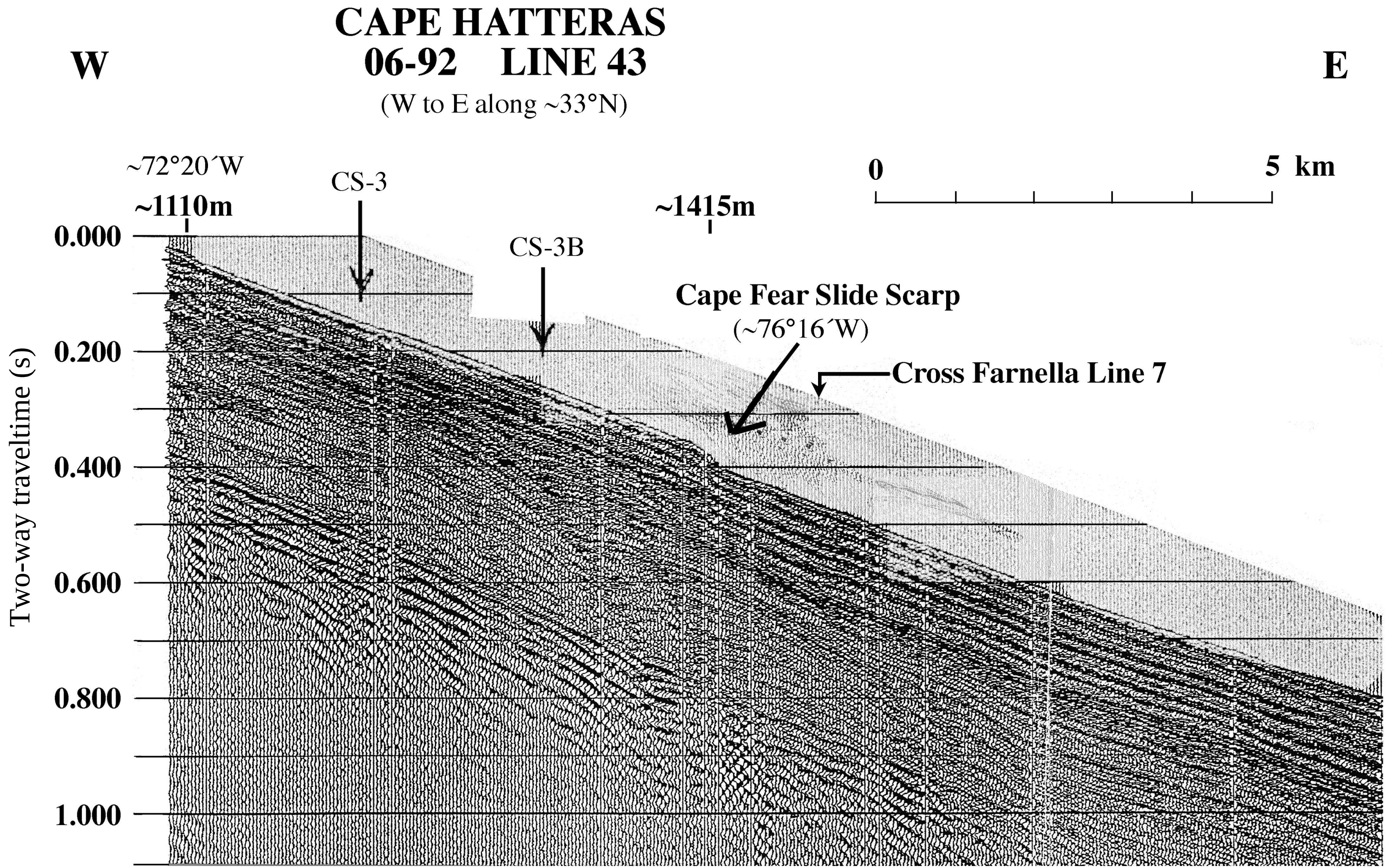
2. Test models of continental slope sedimentation

3. Provide a high-resolution section for paleomagnetic study

Drilling Program:
Triple APC to 125 m, single APC to 50 m

Logging and Downhole: None anticipated

Nature of Rock Anticipated: Calcareous ooze



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