OCEAN DRILLING PROGRAM

LEG 175 SCIENTIFIC PROSPECTUS

BENGUELA CURRENT

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This Scientific Prospectus is based on pre-cruise JOIDES panel discussions and scientific input from the designated Co-Chief Scientists on behalf of the drilling proponents. 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 Manager 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 Science and Operations Committees (successors to the Planning Committee) and the Pollution Prevention and Safety Panel.

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ABSTRACT

During Leg 175, we propose to drill between eight and ten advanced hydraulic piston and extended core barrel core sites off the western coast of Africa (Angola and Namibia) to reconstruct the late Neogene history of the Benguela Current and the associated upwelling regime between 5°S and 32°S. The Angola/Namibia system contains one of the great upwelling regions of the world. Like the systems off Peru and California, which were studied during recent Ocean Drilling Program legs, it is characterized by organic-rich sediments that contain an excellent record of productivity history, which can be read on a very fine scale. In addition, this environment provides an excellent setting for natural experiments in diagenesis.

The individual transects reflect a compromise between geographic coverage, accessibility, and time constraints. We aim to study specific "end-member" environments, which collectively comprise one of the most active areas of ocean productivity. One of the major goals is to reconstruct the evolution of the Benguela Current system and its relationship with the onset of glacial cycles in the northern hemisphere. Most of the proposed sites are expected to have high sedimentation rates, offering an opportunity to develop detailed paleoceanographic records, and all proposed sites will extend and refine the partial record of the paleoceanographic and paleoclimatic changes for the late Neogene that was provided by Deep Sea Drilling Project Sites 362 and 532. Sediments will be largely diatomaceous and carbonate-rich clays with variable, and occasionally very high organic carbon contents.

INTRODUCTION

The ocean's role in climatic change through heat transport and control of carbon dioxide is increasingly being recognized. This new awareness, and the urgency that must be accorded the attempt to understand the mechanisms of climatic change, have led to the initiation of large integrated efforts in physical and chemical oceanography. Likewise, the potential of the oceanic record for understanding climatic change has received increased attention in recent years (CLIMAP, 1976; COSOD II, 1987). The Angola/Namibia high-productivity system needs to be studied because of its importance in the global ocean-carbon cycle, and to provide for comparison with the Peru system and the California system. Only by comparing these systems with each other shall we be able to learn which elements of a system are peculiar, and which have general validity through time and on a global scale. To further these goals, Leg 175 will drill at least eight APC/XCB sites off the southwestern coast of Africa (Fig. 1) to study the paleoenvironment of the Benguela Current and Angola/Namibia upwelling system, with emphasis on the late Neogene.

Eastern boundary upwelling is strongly involved in modulation of the carbon cycle and therefore, in control of the partial pressure of carbon dioxide (pCO_2) ("biological pumping", Berger and Keir, 1984; Sundquist and Broecker, 1985; Boyle and Keigwin, 1987; Sarnthein et al., 1988, Berger et al., 1989). It is now generally thought that such pumping is a crucial factor for the explanation of short-term fluctuations in atmospheric CO_2 , of the type seen in ice cores (Barnola et al., 1987). Along these lines of argument, there is a good correlation between productivity indices in the eastern equatorial Pacific and the ice-core record of pCO_2 (Fig. 2). Likewise, there is good correlation between the ice-core record and estimates of CO_2 pressure in surface water (Fig. 3).

On a longer time scale, Vincent and Berger (1985) have postulated that depositional pumping by coastal upwelling is responsible for changing the general level of atmospheric pCO_2. They propose a climatic preconditioning by upwelling-induced carbon extraction from the ocean-atmosphere system for the beginning of the modern ice-cap dominated world. Their argument is based on the observation that carbon isotopes in deep-sea benthics become ^{13}C enriched just when organic-rich phosphatic sediments begin to accumulate around the Pacific margins (Fig. 4). In this view, eastern boundary upwelling, and therefore upwelling off Angola and Namibia, has global implications for the long-term history of the carbon cycle and climate and for the evolution of life and biogeography on land and in the sea.

To be able to predict the effects of changes in productivity on the CO_2 content of the atmosphere, the interrelationships between ocean circulation, nutrient transport, and the sedimentation of organic compounds and carbonate must be established for each of the important productivity regions. Until now, there is no information on Neogene upwelling fluctuations off Angola and Namibia, a region that is probably of considerable importance for the global carbon cycle.

The most important period for understanding the workings of the present system is the time since the Miocene. Within this period, we see the evolution of the present planetary orography, the buildup of ice-caps on both poles, the development of modern wind and upwelling regimes, and the stepwise increase in North Atlantic Deep Water (NADW) production, which dominates the style of deep circulation in the ocean. The present system is characterized by a strong 100,000-yr climatic cycle, beginning 700,000 years ago (Berger et al., 1996). High-amplitude fluctuations associated with buildup and decay of northern ice sheets began around 2.8 million years ago (Shackleton et al., 1984; Hodell and Venz, 1992) (Fig. 5).

BACKGROUND

The Angola/Namibia system is one of five or six great upwelling regions in the world. It extends over a considerable portion of the western margin of South Africa, with productivity values of 180 g°C/m^{2}yr, and greater (black areas in Fig. 6). It is characterized by organic-rich sediments, containing an excellent record of productivity history, which, in turn, is closely tied to the regional dynamics of circulation, mixing, and upwelling, as seen in the oxygenation of thermocline waters (Fig. 7). In addition, this environment provides an excellent setting for "natural experiments" in diagenesis, especially concerning the genesis of economically important resources (e.g., petroleum and phosphate).

Upwelling off southwest Africa is at present centered on the inner shelf and at the shelf edge. The Benguela Current flows roughly parallel to the coast and within ~180 km of it south of 25°S, and then turns to the west over the Walvis Ridge between 23° and 20°S (Fig. 8). At about 20°S, warm, tropical-water masses from the north meet the cold Benguela Current water. Eddies of cold, upwelled water contain radiolarian and diatom skeletons, which are transported from the upwelling area to the northern part of the Walvis Ridge, where they have been sampled at Deep Sea Drilling Project (DSDP) Sites 532 (Hay, Sibuet, et al., 1984) and 362 (Bolli, Ryan, et al., 1978).

According to previous studies, during the last glacial maximum (LGM) eddies formed farther north and the Benguela Current flowed parallel to the coast and over the Walvis Ridge to reach the Angola Basin, finally bearing to the west at about 17°S. Sediments deposited at Site 532 during the LGM apparently confirm the absence of upwelling eddies by containing zero to very few opal skeletons (Hay, Sibuet, et al., 1984; Diester-Haass, 1985). Upwelling may have continued to occur on the African shelf, but the Benguela Current then did not transport that upwelling signal to the Walvis Ridge. However, from the distribution of foraminiferal assemblages at Site 532, it appears that the northeastern Walvis Ridge was in fact characterized by intensified upwelling and a westward expansion of coastal upwelling cells at glacial periods during the last 500,000 yr (Oberhänsli, 1991). The issue of contrasting models of glacial/interglacial upwelling dynamics in this region is unresolved. It hinges on the question of why opaline fossils show contrary abundance variations, with respect to the productivity record from other proxy indicators.

The results from Sites 362 and 532 can be used to reconstruct, tentatively, the evolution of the Benguela Current during the past 10 m.y. This evolution is characterized, on the whole, by increasing rates of accumulation of organic carbon. In addition, there are indications from changing correlations between percent carbonate, percent C_{org}, and diatom abundance that the dynamics of the system undergo stepwise modification. In this connection, as well, a distinct opal maximum in the early Quaternary is of great interest (Fig. 9). The nature of this transition is not clear; perhaps it is a response to the migration of the polar front to its modern position.

The evolution of the climate of the northern hemisphere, and particularly that of northern Europe, is linked to the exchange of heat between the South Atlantic and the North Atlantic Oceans (Fig. 10). This energy transport, operating over large distances, is involved in the formation and magnitude of polar ice caps. In today's world, a net heat transfer from the South Atlantic to the North Atlantic exists in currents above the thermocline (Fig. 11). A part of the heat contribution from the South Atlantic is believed to originate from the Indian Ocean via the Agulhas Current. The Benguela Current is a connection between the waters north of the polar front in the South Atlantic and the Equatorial Currents of the Atlantic. Northward and southward shifts of the Southern Ocean polar front constrict or expand, respectively, the interchange of heat from the Indian Ocean to the South Atlantic (McIntyre et al., 1989). This interchange presumably has a drastic impact on the heat budget of the Benguela Current and, consequently, that of the entire Atlantic Ocean. Such variations in heat transfers should appear as changes in the course and intensity of currents and productivity regimes and should be recorded in the sediments accumulating along the southwest African margin.

An important element of the heat transfer dynamics is the deep-circulation pattern. Traditionally, the focus in reconstructing this pattern has been on the properties and boundaries of NADW-related water masses, as seen in the $\delta^{13}C$ of benthic foraminifers. The emphasis has been on glacial-to-interglacial contrast (Fig. 12). This contrast shows that NADW production was greatly reduced during glacial periods (as also reflected in the pattern of carbonate preservation). More recent studies have added much detail to this story (summarized in Bickert and Wefer, 1996) (Fig. 13). It appears that the strength of the NADW is reflected in the differences between eastern and western basins and in gradients within the eastern basin. Information on associated changes at depths above the NADW has been sparse. It must be assumed that the strength of the nutrient maximum underlying the Benguela upwelling regions (Fig. 14) is somehow coupled to the evolution of NADW, which in turn influences dynamics of intermediate water-mass formation to the south. At this point, we do not know how the different cycles are related, so little or nothing can be said about causal relationships.

Paleoceanographic interpretations regarding the history of the Benguela Current are derived mainly from a single location off southwest Africa (Site 532) and must be considered preliminary. Given the indications that the axis and the intensity of the Benguela Current have changed over the past 15 m.y. and that productivity has fluctuated with glacial/interglacial cycles, confirmation and refinement of these ideas is needed. Although DSDP Legs 40, 74, and 75 occupied sites in the Cape and Angola Basins and on the Walvis Ridge, these sites are situated too far offshore to provide the needed information. The Benguela Current and its associated upwelling are not recorded well in the sediments at these sites. Even Sites 362 and 532 on the Walvis Ridge are too far offshore to contain a direct record of upwelling. They receive an indirect record of near-coastal upwelling from material transported to their location by the Benguela Current. Furthermore, modern coring technology (advanced hydraulic piston corer [APC], extended core barrel [XCB]) allows for high-resolution studies by avoiding much of the drilling disturbance present in the Leg 40 cores. Such high-resolution work is crucial if the dynamics of upwelling are to be captured back to the Miocene on a scale of glacial/interglacial cycles. Information from an array of sites situated in the southern and central Cape Basin, on the Walvis Ridge, and in the southern Angola Basin would allow the construction of a coherent picture.

SCIENTIFIC OBJECTIVES

The results from DSDP Sites 362 and 532 suggest that there has been a general northward migration of the Benguela Current upwelling system during the last 14 m.y. Because the shape of the South Atlantic has not changed appreciably during this time, the changes in the upwelling system must reflect large-scale, perhaps global, changes in ocean circulation. Leg 175 will focus primarily on the paleoceanographic and paleoclimatic aspects of the area. However, there is interest in investigating samples from the upwelling area off Angola and Namibia with regard to early diagenetic processes taking place in this unique environment. Possible work includes study of the formation of dolomite (Baker and Kastner, 1981; Kulm et al., 1984), phosphorite (Calvert and Price, 1983), and chert (see articles in Garrison et al., 1984). We also hope to examine the organic-matter type and distribution as a function of time and climatic cycles. Important questions that are being addressed during Leg 175 include the following:

- Determine the history of the Benguela Current for the late Neogene. Of special interest is the changing response to orbital forcing, as seen in spectral amplitudes and phase relationships (e.g., McIntyre et al., 1989; Schneider, 1991; Berger and Wefer, 1996; Jansen et al., 1996; Schneider et al., 1996; Wefer et al., 1996).

- Study the history of productivity of the upwelling off Angola and Namibia and the influence of the Zaire River, extending available information about the late Quaternary (Bremner, 1983; Jansen et al., 1996) to earlier periods. The history of opal deposition off the Zaire River is of interest (Schneider, 1991), as well as the origin of cycles of carbonate, organic matter-deposition, and diatoms, in each region.

- Determine what kind of oceanographic changes occur simultaneously in the Atlantic Ocean (Agulhas Current, polar front position, equatorial current, Argentine Current) with the shifting of the Benguela Current. Results from Ocean Drilling Program (ODP) Legs 108 and 114 can help define the past equatorial and polar boundaries of the Benguela Current. The final aim is to reconstruct the late Neogene paleocirculation pattern of the South Atlantic Ocean to evaluate implications for the glacial/interglacial heat balance through time between the South and North Atlantic. Of special interest is the identification of changes in modes of circulation, as seen in changes in correlations between proxy variables, as a function of time.

- Determine if changes in the surface-current and upwelling patterns of the Benguela Current cause, or are related to, changes in climates of western South Africa. For example, is the origin of the Namib desert related to the initiation of upwelling off southwest Africa? Sites close to the continent probably contain enough information (clay minerals, grain size of terrigenous material, pollen, phytoliths, and fresh water diatoms) to allow reconstruction of continental climatic changes and to determine whether these changes are synchronous with oceanographic changes (i.e., the establishment of upwelling off southwest Africa).

- Examine the effect of sea-level changes, if any, on sedimentation below the Benguela Current. Published eustatic sea-level curves (Haq et al., 1987) will be useful for this purpose.

- Study early diagenetic processes in environments with very high organic carbon and opal contents, which will offer an interesting contrast to the studies undertaken during Leg 112, off Peru (Suess, von Huene, et al., 1990). The upwelling sediments off the Peruvian active margin are deposited in forearc basins in a disturbed tectonic setting, whereas off Angola/Namibia sedimentation occurs on a steadily sinking passive margin with quite stable conditions. Therefore, we expect a more continuous and longer record in comparison to the sites drilled off Peru, although the sedimentation rate might not be quite as high.

DRILLING STRATEGY

Leg 175 will drill at least eight sites as part of a latitudinal transect between 5°S and 32°S. Time permitting, ten or eleven sites will be attempted. Proposed sites are located in the Lower Congo Basin (LCB), Mid-Angola Basin (MAB), Southern Angola Basin (SAB), Walvis Basin (WB), Northern Cape Basin (NCB), Mid-Cape Basin (MCB), and Southern Cape Basin (SCB). To recover a complete stratigraphic sequence, we anticipate coring two or three holes with the APC at each site.

PROPOSED SITES

1. Lower Congo Basin (LCB)

Two LCB sites will sample a complex environment dominated by riverine input, seasonal coastal upwelling, and incursions from the southern equatorial counter current (Fig. 8). Whereas these two sites represent the same depositional environment, they are located at varying distances from the shelf break, in different water depths, and at different positions with respect to the river plume and

Congo Canyon. Seismic lines and proposed drill sites are shown in Figure 15. Maximum penetration is 200 m, for Sites LCB-1 and LCB-4. Time permitting, Site LCB-3A will be attempted to 200 m, with double APC coring.

2. Mid-Angola Basin (MAB)

The MAB sites, off the bight of Angola near 12°S, were chosen to provide information on "most nearly normal" margin sedimentation, being influenced neither by riverine input, nor by sustained year-round upwelling. Upwelling is greatly influenced by variations in the Angola Thermal Dome. It is seasonal, and productivity is relatively weak compared to that of adjacent regions (Schneider, 1991). This setting allows maximum expression of a pelagic signal in the regional high-productivity record. Proposed drill sites are located on seismic Line GeoB 93-015 (Fig. 16), because the southerly profile Line GeoB 93-017 is significantly influenced by slumping of shelf sediments and turbidity currents. Of the various sites proposed originally, the two shallow sites were determined to be feasible for drilling: Site MAB-1 for a maximum of 200 m, and Site MAB-2 for 120 m.

3. Southern Angola Basin (SAB)

The Southern Angola Basin sites are positioned to sample the northern end of the Angola/Namibia upwelling region. The transect should nicely complement previous results obtained from Walvis Ridge. This transect is important not only for the history of the Benguela Current and coastal upwelling migration, but also for its contribution to the climatic history of southern Africa. The Kunene River, reaching the coast at ~17°S, is at the climatological barrier between an illite zone in arid areas to the south and a kaolinite zone from tropical weathering areas to the north (Bornhold, 1973). The proposed sites are situated on a climatic boundary, and should sensitively reflect changes in the position of continental climatic zones. Suitable drill sites were identified from seismic lines in water depths between 2200 and 3000 m. The bathymetric survey confirmed the complex nature of the depositional environment. Although the survey was not sufficient to analyze all structures in detail, it is clear from the combined HYDROSWEEP and PARASOUND echosounder data set that few potential drill sites may be found in the area. Seismic Line GeoB 93-030 lies across proposed Site SAB-2 (Fig. 17). Stratigraphic data from two gravity cores (GeoB

1023-5, 17°09.4'5, 11°00.7'E, water depth 1918 m; GeoB 1024-2, 17°09.8'E, water depth 2799 m) show high Pleistocene sedimentation rates (10-50 cm/1000 yr) (Wefer et al., 1988; Schneider et al., 1992). We will attempt to drill to 600 m at Site SAB-2. Time permitting, Site SAB-1 will be drilled for double APC coring.

4. Walvis Basin (WB)

Sites WB-B and WB-C, together with DSDP Sites 532 and 362 at water depths of 1331 m and 1325 m, form a transect that is central to the reconstruction of the history of the Benguela Current (Fig. 18). The DSDP sites are seaward of the upwelling center, but contain an upwelling signal that was transported to this location by the Benguela Current and its filaments. At the other end of the transect, proposed Site WB-B will give a better record of the upwelling itself. Cores spanning the late Quaternary from nearby areas show a sedimentation rate of 4-7 cm/1000 yr (Schulz et al., 1992). We will attempt to drill to 600 m at Site WB-B. Time permitting, Sites WB-C and/or WB-A will be drilled for double APC coring.

5. Northern Cape Basin (NCB)

The NCB site will help document the northward migration of the Benguela Current system from the Miocene to the Quaternary, as well as the shoreward/seaward migration of the upwelling center. This site will also provide a record of maximum productivity in the system. Previous work in this area (for a summary see Dingle et al., 1987) has documented anaerobic, in part varved, sedimentation in the upper margin regions. Phosphatic deposits also are abundant (Calvert and Price, 1983). Seismic lines and the proposed drill site are shown in Figure 19.

The results of Emery et al. (1975) and Austin and Uchupi (1982) show a thick hemipelagic wedge sitting on "rifted continental crust." Slumps would not seem to pose a major problem, although hiatuses are anticipated. Noteworthy is the confirmation of a thick sequence below the shelf region. A close tie-in between pelagic and terrigenous sedimentation is expected to be present within the slope record. During the SONNE Cruise SO-86, vertical profiles were shot over multichannel seismic (MCS) Line AM-1, which were collected by the University of Texas to obtain detailed data for the planned site. A first stratigraphy on an 11-m-long core taken in the high-production upwelling area off Namibia (GeoB 1711-4, 23°18.9'S, 12°22.6'E) from a depth of 1967 m indicated a sedimentation rate of 11 cm/1000 yr (Schulz et al., 1992). We will attempt to drill to 600 m at Site NCB-2B.

6. Mid- and Southern Cape Basin (MCB, SCB)

These sites are located in the southernmost area of the Cape Basin (Figs. 1, 20, 21). The sedimentary records will help in exploring the early history of the Benguela Current in the southern Cape Basin and in detecting possible Agulhas Current influences. The sites are located close to the continent to detect upwelling signals and signals from continental climates (pollen, clay minerals, and coarser terrigenous matter), as well as sea-level changes. South of the proposed transect, the margin becomes too steeply sloped to support undisturbed sediments. Site MCB-A is located along GeoB/AWI Line 96-009 (Fig. 20), Site SCB-1 is located along MSC Line AM-54, collected by the University of Texas and along profile GeoB/AWI 96-003 (Fig. 21). A sedimentation rate of about 5 cm/1000 yr was determined (Schulz et al. 1992) for an 11-m-long core collected from near the same water depth (GeoB 1719-7, 28°55.6'S, 14°10.7'E, water depth 1010 m), but ~150 miles to the north. Time permitting, Site MCB-A will be drilled for double APC coring, on the way to SCB. Site SCB-1 will be attempted to a depth of 600 m.

Site SCB-1, as the last site, could be deepened if time is available at the end of the leg. If it appears that time is indeed available, permission to deepen this hole beyond the 400 m now allowed should be sought promptly, to take account of recommendations by the Ocean History Panel (OHP). Alternatively, second priority sites (SCB-A, SCB-B, SCB-C) will be drilled for APC coring.

SAMPLING STRATEGY

General

Most of the core material to be recovered during Leg 175 will be retrieved by APC, generally by triple coring for the first priority sites and by double coring for any secondary priority sites drilled. One half of the first hole at each site will be the permanent archive half. Micropaleontology and sedimentology sampling will be done after a composite sampling splice is constructed from the two or more holes drilled at that site. High-resolution sampling is anticipated for most sites (5 cm interval), with 10 to 20 cm^3 needed for each sample, depending on the abundance of fossils (especially benthic foraminifers). Sampling schedules will be worked out between the parties involved to optimize stratigraphic coverage and to minimize overlap. Geochemical sampling, which calls for larger volumes, will be done on material from the third hole if it interferes with micropaleontology and sedimentology sampling. Also, whole-round samples will be available for pore-water studies from the third copy, as long as a sample's position is not crucial to filling gaps in the continuous stratigraphic record. If there is a need for a rapid decision on the location of a whole-round sample, but information is insufficient to place critical intervals for continuous stratigraphy, whole-round sections that would result in gaps greater than 15 cm will be avoided. Such sections should be separated by at least 1 m. Sampling for microbiological studies also will follow this strategy. Sampling for physical properties should be done so as not to interfere with stratigraphically sensitive sampling sequences, and to take advantage of available continuous nondestructive measurements. U-channel sampling for high-resolution paleomagnetic and rock-magnetic studies will be carried out along the composite sampling splice (temporary archive), where appropriate.

Ultra-high Resolution Sites

There is a possibility that varves will be encountered in some sites, notably in Walvis Basin. Detailed sampling will be necessary to achieve objectives in such sections. The sampling allocation committee ([SAC], consisting of the Co-chiefs, Staff Scientist, and Curator's representative) will determine details of the sampling pattern in these cases.

Sampling Time Table

Detailed sampling of cores from a given site will proceed after a composite stratigraphy is constructed from cores from the two or more holes drilled at the site. The splice will be constructed, and the stratigraphic information will be distributed to the scientific party in advance of post-cruise sampling to facilitate planning and scientific collaboration. Requests to sample on board, for pilot studies or for projects requiring lower stratigraphic resolution, will be considered by the SAC.

General Sampling Procedure

Investigators should avoid sampling the center of core halves. Sample plugs should be taken as close to the edges of a core half as is feasible, given the purpose of sampling. Samples may also be taken with the "scoop" tool, which inherently takes samples from the edges of the core half. Large samples taken with the "cookie-cutter" tool, for example for lamina-scale studies, should be shared among interested scientific party members.

Archives

The permanent archive will be the ODP-defined "minimum permanent archive." Once the working half of a section is depleted, the temporary archives for that section will be accessible for sampling. Wherever possible, one quarter of such temporary archives should be preserved by sampling off-center to one side.

Special Core Handling

Large numbers of samples for organic geochemistry analysis may be taken and may need to be frozen.

LOGGING STRATEGY

A total of four sites will be logged during Leg 175 (Sites SAB-2, WB-B, NCB-2B, and SCB-1). Possibly one other site will be logged at the end of the leg, if time is available (e.g., SCB-A). Variations in biogenic carbonate, opal, and detrital deposition associated with climatic, oceanographic, and eustatic changes will be reflected in terms of corresponding changes in physical and geochemical properties. Coring may be discontinuous over deeper intervals because of gas expansion or XCB-coring disturbance. Consequently, downhole log data present an excellent resource for developing a quantitative paleoclimatic and paleoceanographic time series.

Special software for core-core and core-log data integration (CLIP) will be used during Leg 175 to etablish composite sedimentary sections vs. depth.

Only holes deeper than 250 m will be logged with a combination of geophysical sensors: Triple-combo tool, the Formation MicroScanner (FMS) associated with the sonic tools, and the geological high-sensitivity magnetic tool (GHMT). The Triple-combo provides measurements of gamma ray, porosity, density, and electrical resistivity, which will be used to describe the lithology, sedimentary fabric, degree of lithification, and fluid composition. The FMS tool string produces high-resolution electrical resistivity images of the borehole wall that can be used to study the structure of bedding, diagenetic features, hiatus, and cyclicity recorded by sediments. The sonic tool coupled to the FMS can be useful to establish synthetic seismograms. By combining acoustic velocity with density evaluations and then convolving them with appropriate wavelet techniques, we can accurately calibrate the seismic lines. The GHMT provides continuous measurements of magnetic susceptibility and the vertical component of the total magnetic field. This latter measurement provides a magnetic reversal stratigraphy, if the magnetization of the sediments is sufficiently strong.

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FIGURE CAPTIONS

Figure 1. Overview map showing general areas of planned sites (black rectangles).

Figure 2. Carbon dioxide concentrations in the Vostok ice core from Antarctica (Barnola et al., 1987; Jouzel et al., 1993; solid triangles), compared with a productivity-related carbon isotope signal from the eastern tropical Pacific (difference between the $\delta^{13}C$ values of planktonic and benthic foraminifera; Shackleton et al., 1983; heavy line), show that ocean productivity and atmospheric CO_2 tend to vary together. Time scale of Barnola et al. is adjusted to the one of Shackleton et al. by correlation of the deuterium signal in the ice with the oxygen isotope signal in the sediment (from Berger et al., 1996).

Figure 3. Comparison of ice-core CO_2 record of Barnola et al. (1987) with surface water pCO_2 estimates for Core GeoB 1016-3, using conversion for $\delta^{13}C$ of organic matter to CO_2 pressure as proposed by Popp et al. (1989) and Rau et al. (1991). Time scale of Vostok ice core adjusted for best fit. (From Müller et al., 1994).

Figure 4. Relationship between $\delta^{18}O$ record and $\delta^{13}C$ record of benthic foraminifers, DSDP Site 216, tropical Indian Ocean. It suggests that extraction of organic carbon in upwelling regions during Monterey time eventually resulted in cooling because of downdraw of atmospheric pCO_2 (after Vincent and Berger, 1985).

Figure 5. The cooling step observed between 2.5 and 3 Ma (as seen in the shift to more positive values of $\delta^{18}O$) marks a change toward greater instability of climate, as seen in increased fluctuations of $\delta^{18}O$ values of planktonic foraminifers (*Neogloboquadrina pachyderma*, *Globigerina bulloides*) and benthic foraminifers (*Cibicides* spp.) sampled near the boundary between the South Atlantic and Southern oceans. From Hodell and Venz (1992).

Figure 6. Angola/Namibia upwelling system off southern Africa, as seen in productivity distributions. Modified from Berger (1989). Numbers are the primary production in g°C/m^2yr; black areas have primary production values greater than 180 g°C/m^2yr.

Figure 7. Conceptual model showing areas where low-oxygen water is formed in the Southeast Atlantic and the inferred movement of this water (dashed arrows; from Chapman and Shannon, 1987).

Figure 8. Schematic representation of the large-scale, upper-level geostrophic currents and fronts in the South Atlantic Ocean. After Peterson and Stramma (1991) with minor additions from several other compilations.

Figure 9. Depositional cycles in biogenous sediments on Walvis Ridge, in the Benguela System. Note overall trend in diatom abundance, with maximum in early Quaternary (after Dean and Gardner [1985] and Hay and Brock [1992]).

Figure 10. Meridional heat transport in the Indian and Atlantic Oceans (from Woods, 1981, modified). Note the major transfer of heat from the Indian Ocean to the Atlantic, which can be modulated through time by changing the position of the subantarctic frontal system.

Figure 11. Estimates for annual heat transports for the present world ocean (heavy solid line with thin lines showing the approximate error bounds) and for the Atlantic (present conditions and last glacial maximum, as labeled). From Berger and Wefer (1996a), after Miller and Russell (1989), modified. Note the anomalous pattern for the present South Atlantic and the more symmetric pattern for glacial conditions.

Figure 12. Deep-water patterns and flow in the South Atlantic during the present (a, b) and the last glacial maximum (c). **(a)** Present salinity distributions; from Sverdrup et al. (1942), according to G. Wüst. **(b)** Distribution of $\delta^{13}C$ values in dissolved inorganic carbon; from Kroopnick (1980). **(c)** Distribution of $\delta^{13}C$ values in dissolved inorganic carbon, 20 k.y. ago, inferred from $\delta^{13}C$ values in benthic foraminifers of that age; source: Berger and Wefer (1996a), after Duplessy et al. (1988) and Sarnthein et al. (1994).

Figure 13. Plot of carbon isotope records, measured on the benthic foraminifer taxon *C. wuellerstorfi*, as a function of time. From Bickert and Wefer (1996). Numbers are core labels, in the GeoB collections.

Figure 14. Zonal section of nitrate concentrations at 11°20'S. From Siedler et al. (1996).

Figure 15. Seismic lines and proposed drill sites in the Lower Congo Basin (LCB).

Figure 16. Seismic lines and proposed drill sites in the Mid-Angola Basin (MAB).

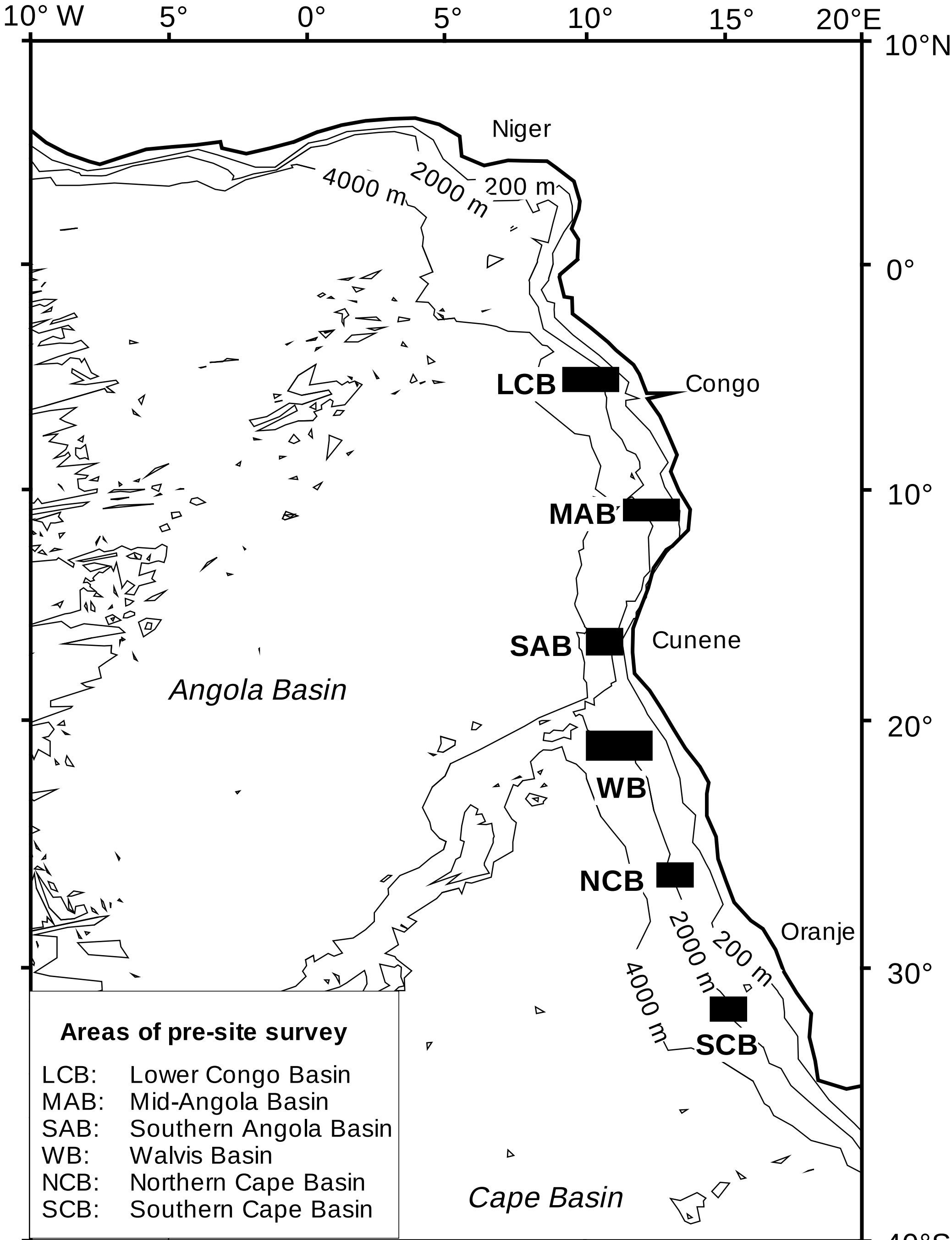
Figure 17. Seismic lines and proposed drill Site SAB-2 in the Southern Angola Basin (SAB).

Figure 18. Seismic lines and proposed drill sites in the Walvis Basin (WB).

Figure 19. Seismic lines and proposed drill Site NCB-2B in the Northern Cape Basin (NCB).

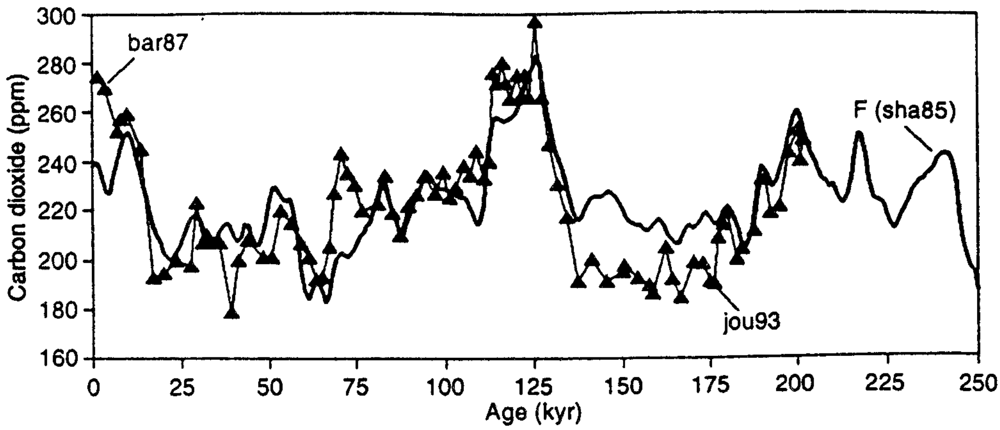
Figure 20. Seismic lines and proposed drill Site MCB-A in the Mid-Cape Basin (MCB).

Figure 21. Seismic lines and proposed drill Site SCB-1 in the Southern Cape Basin (SCB).



10° W
5°
0°
5°
10°
15°
20°E
10°N
0°
10°
20°
30°
40°S
Niger
4000 m
2000 m
200 m
LCB
Congo
MAB
SAB
Cunene
Angola Basin
WB
NCB
2000 m
200 m
Oranje
4000 m
SCB
Cape Basin
Areas of pre-site survey
LCB: Lower Congo Basin
MAB: Mid-Angola Basin
SAB: Southern Angola Basin
WB: Walvis Basin
NCB: Northern Cape Basin
SCB: Southern Cape Basin

Figure 1



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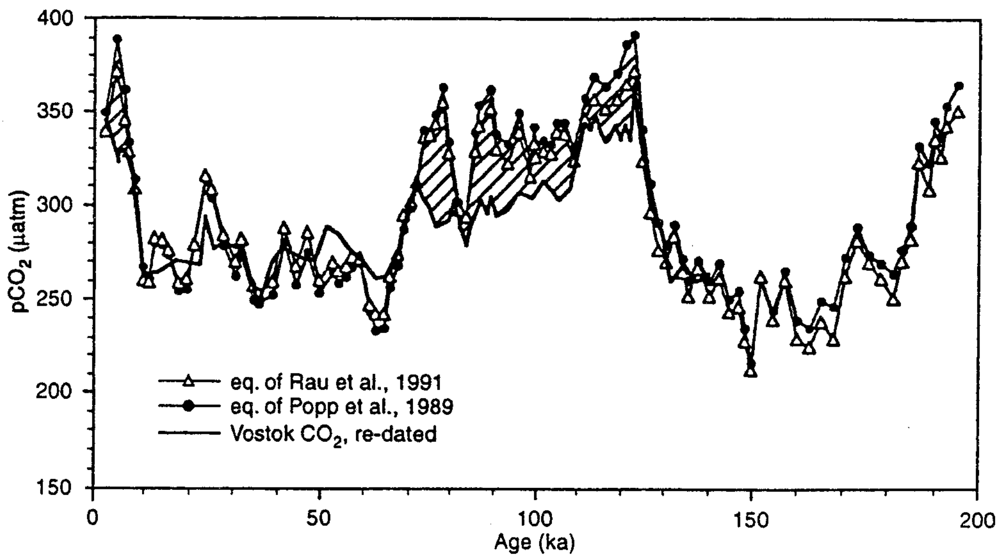


Figure 3

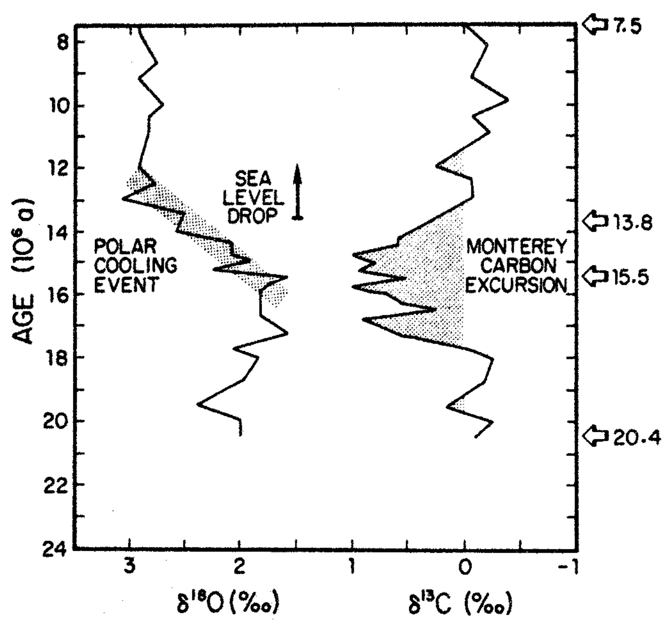
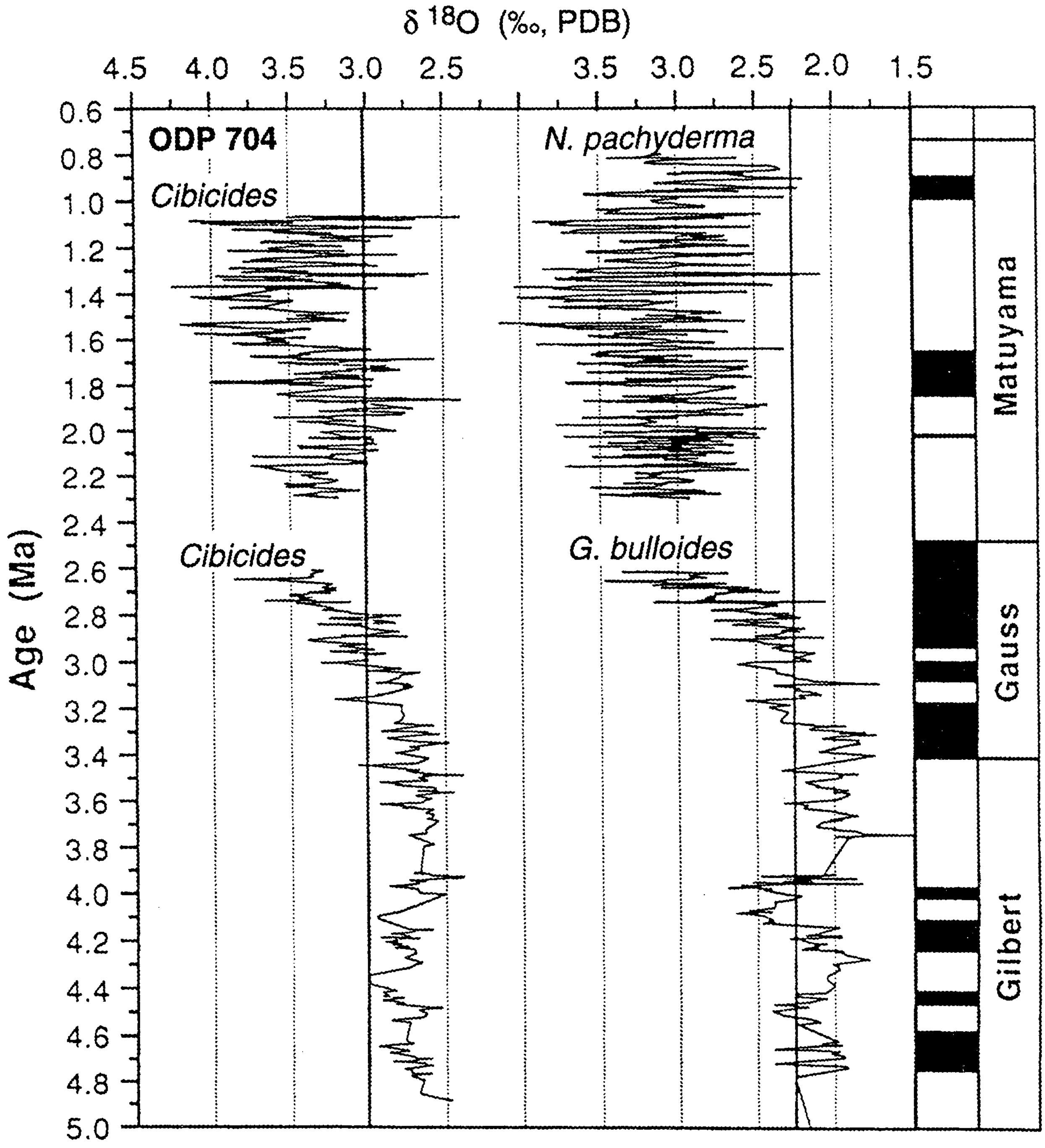


Figure 4



δ 18O (‰, PDB)
4.5 4.0 3.5 3.0 2.5
3.5 3.0 2.5 2.0 1.5
Age (Ma)
0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0 4.2 4.4 4.6 4.8 5.0
ODP 704
Cibicides
N. pachyderma
Cibicides
G. bulloides
Matuyama
Gauss
Gilbert

Figure 5

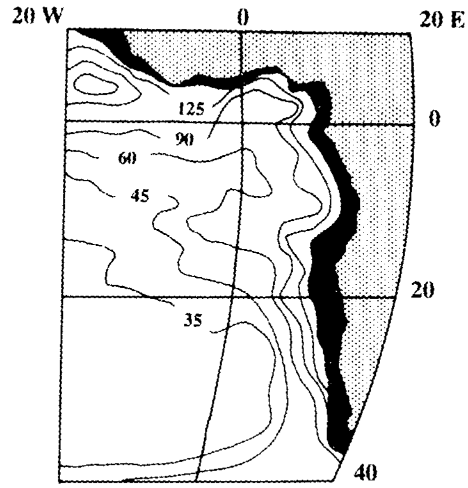


Figure 6

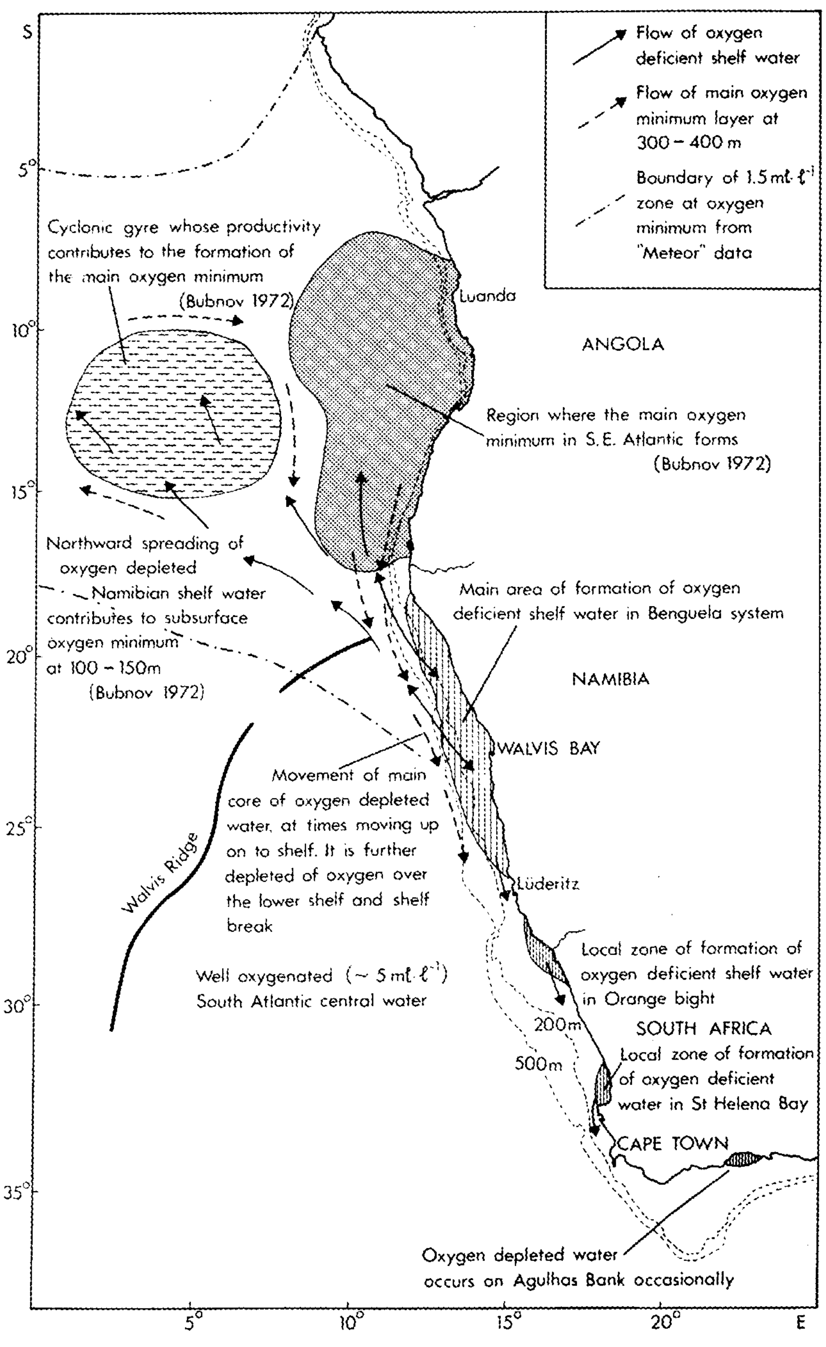


Figure 7

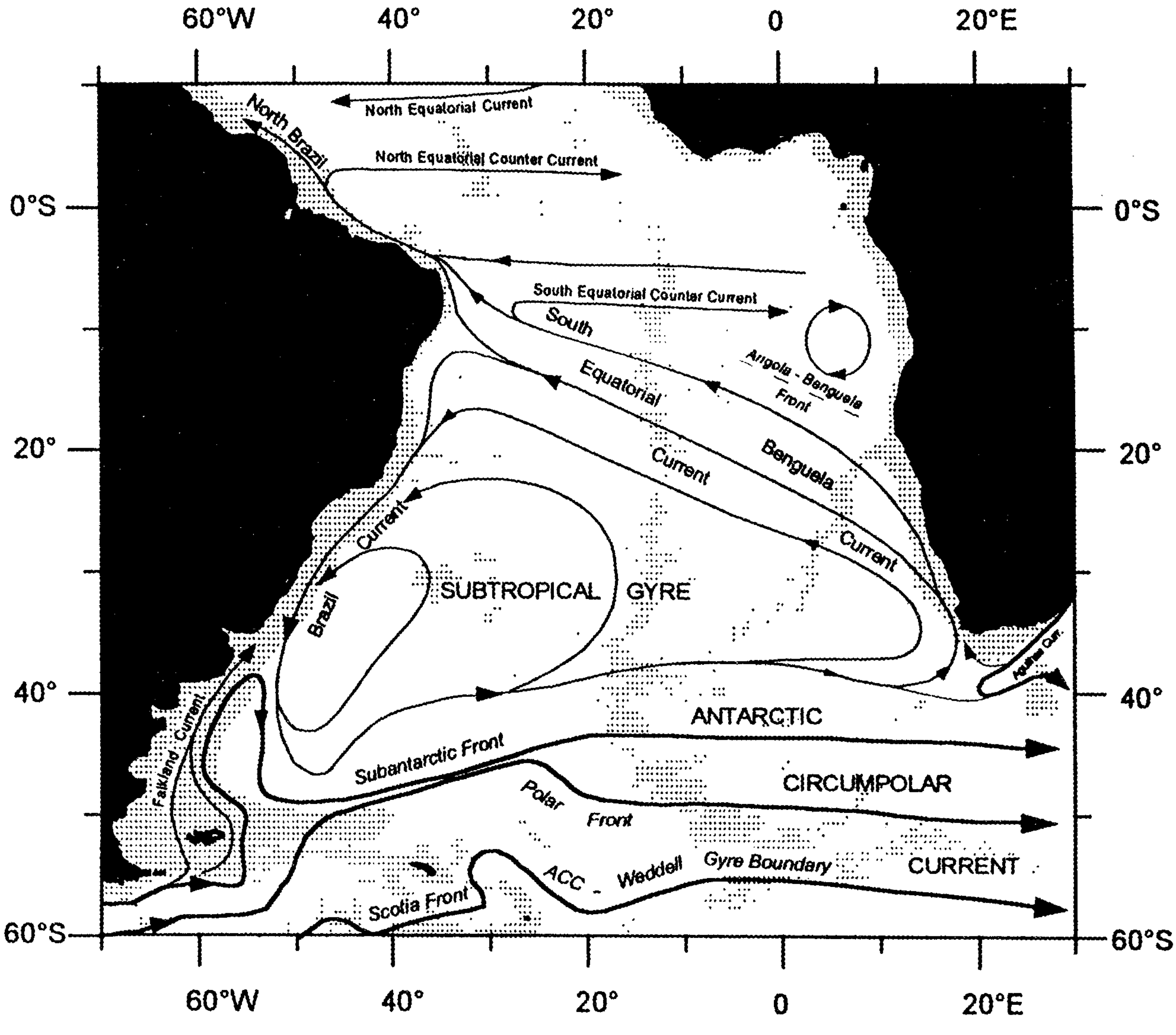

60°W
40°
20°
0
20°E
0°S
20°
40°
60°S
North Equatorial Current
North Brazil
North Equatorial Counter Current
South Equatorial Counter Current
South
Equatorial
Current
Angola - Benguela
Front
Benguela
Current
Brazil
Current
SUBTROPICAL GYRE
Agulhas Curr.
ANTARCTIC
CIRCUMPOLAR
CURRENT
Falkland Current
Subantarctic Front
Polar
Front
ACC - Weddell Gyre Boundary
Scotia Front

Figure 8

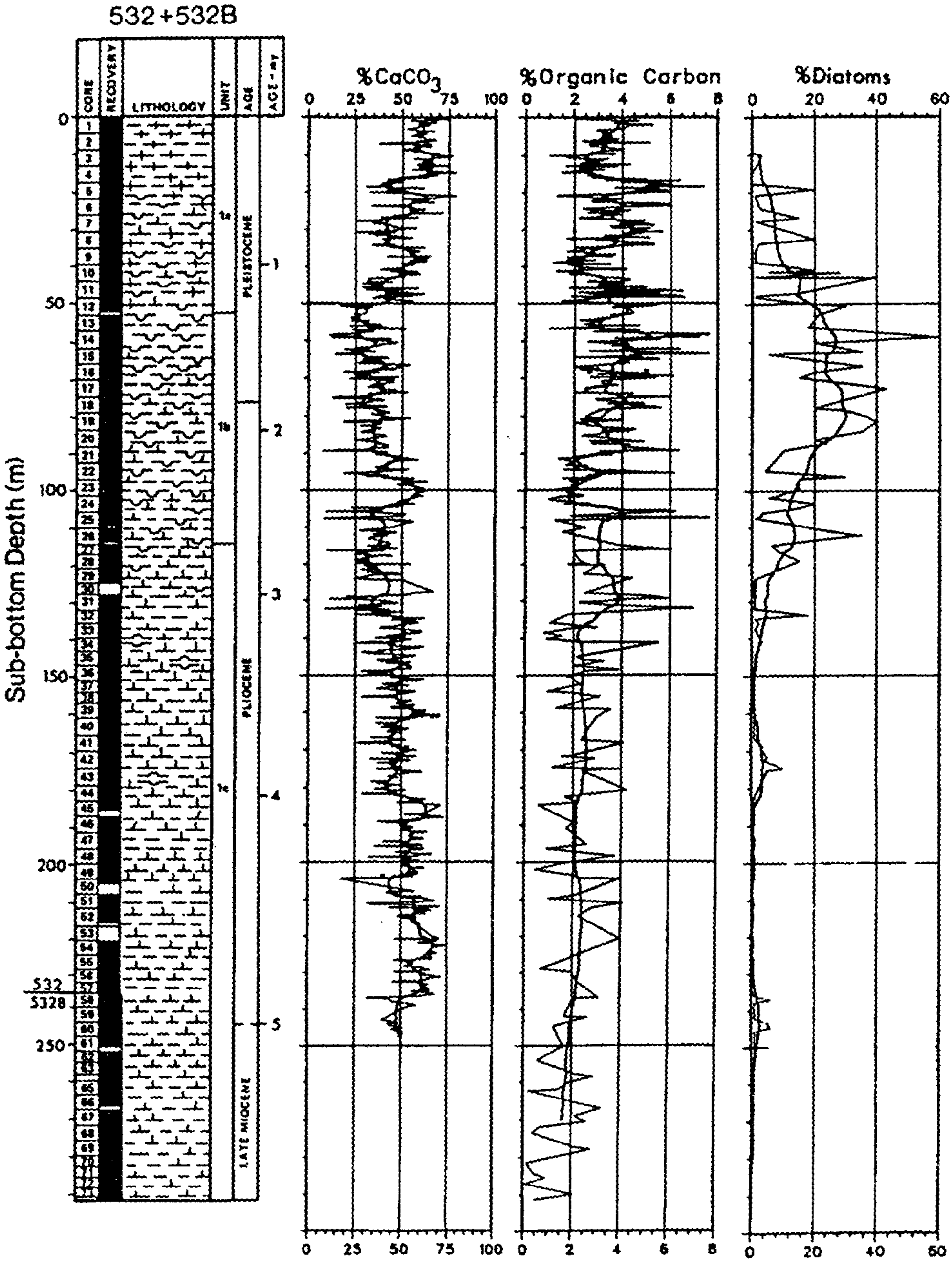

532+532B
CORE
RECOVERY
LITHOLOGY
UNIT
AGE
AGE - my
Sub-bottom Depth (m)
PLEISTOCENE
PLIOCENE
LATE MIOCENE
532
532B
%CaCO3
%Organic Carbon
%Diatoms

Figure 9

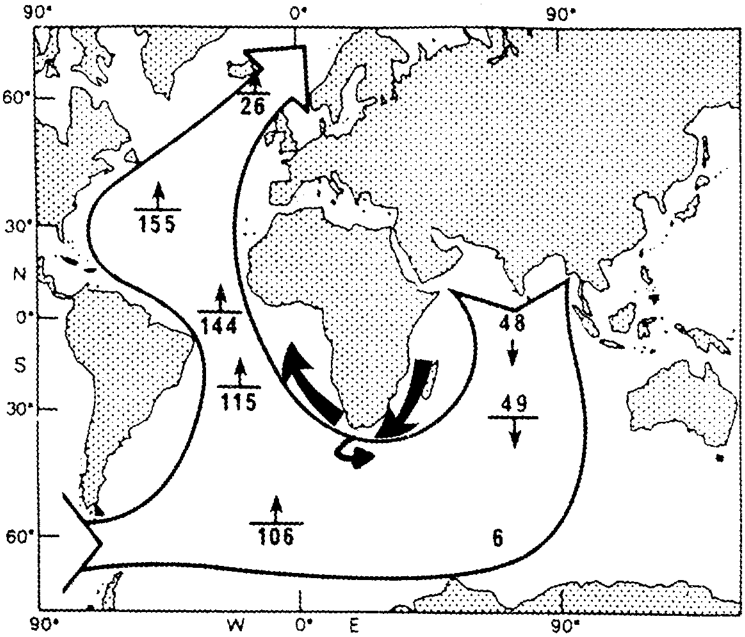


Figure 10

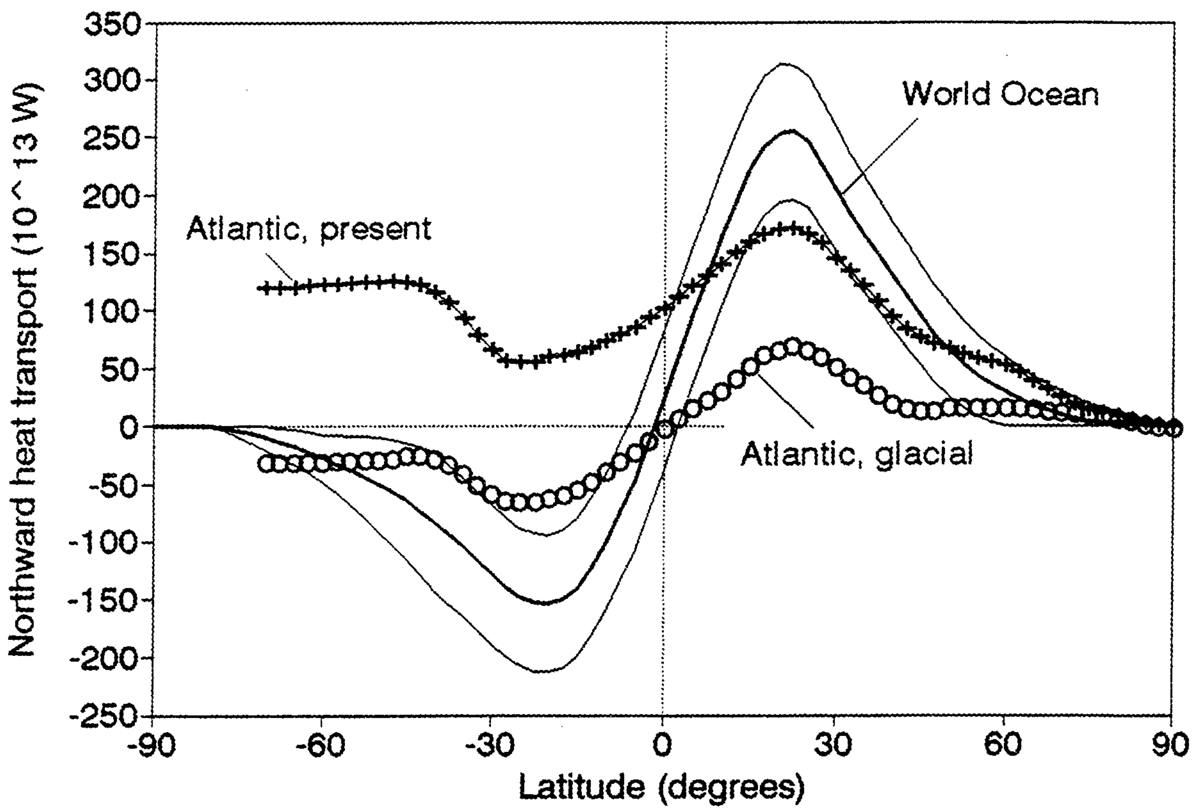


Figure 11

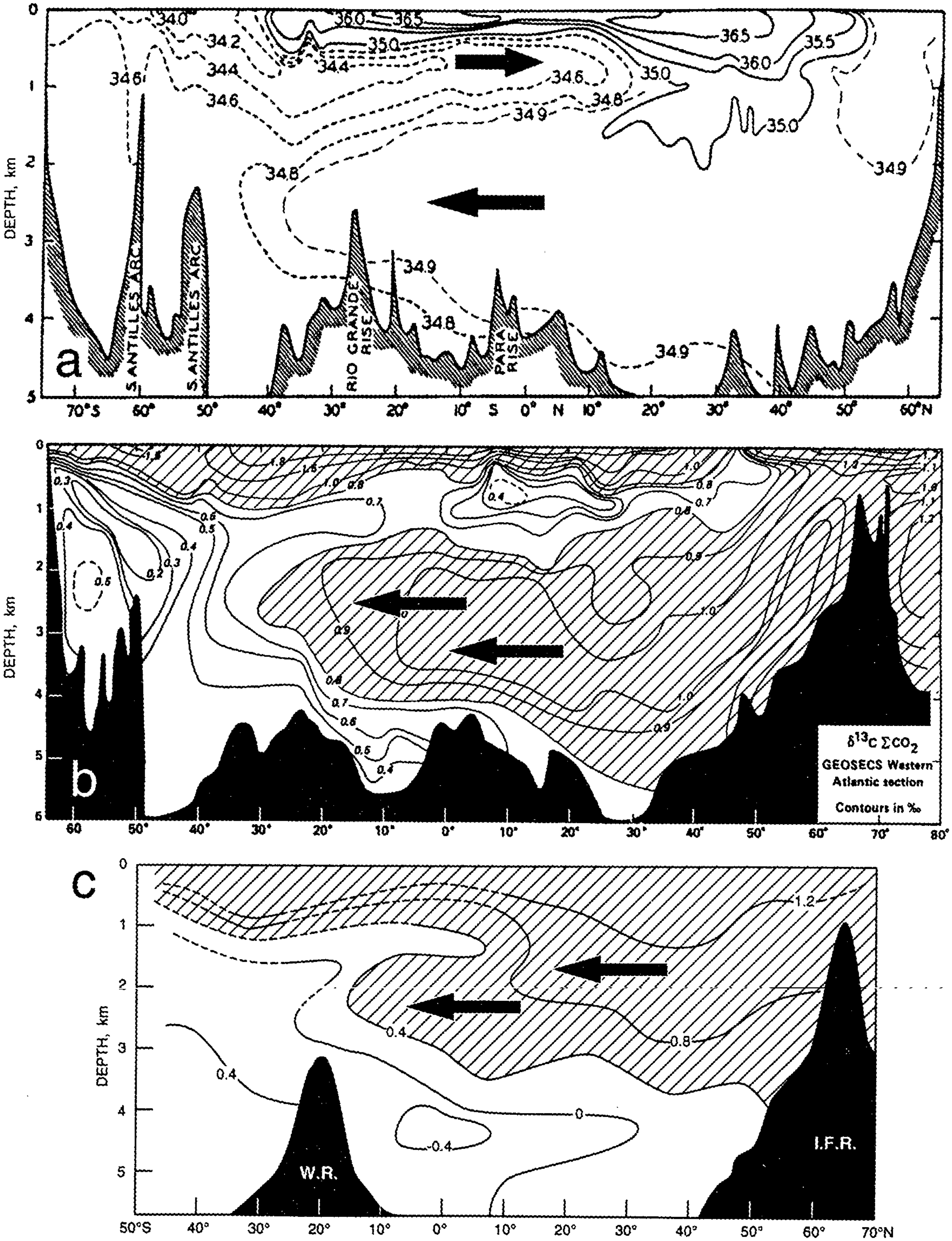
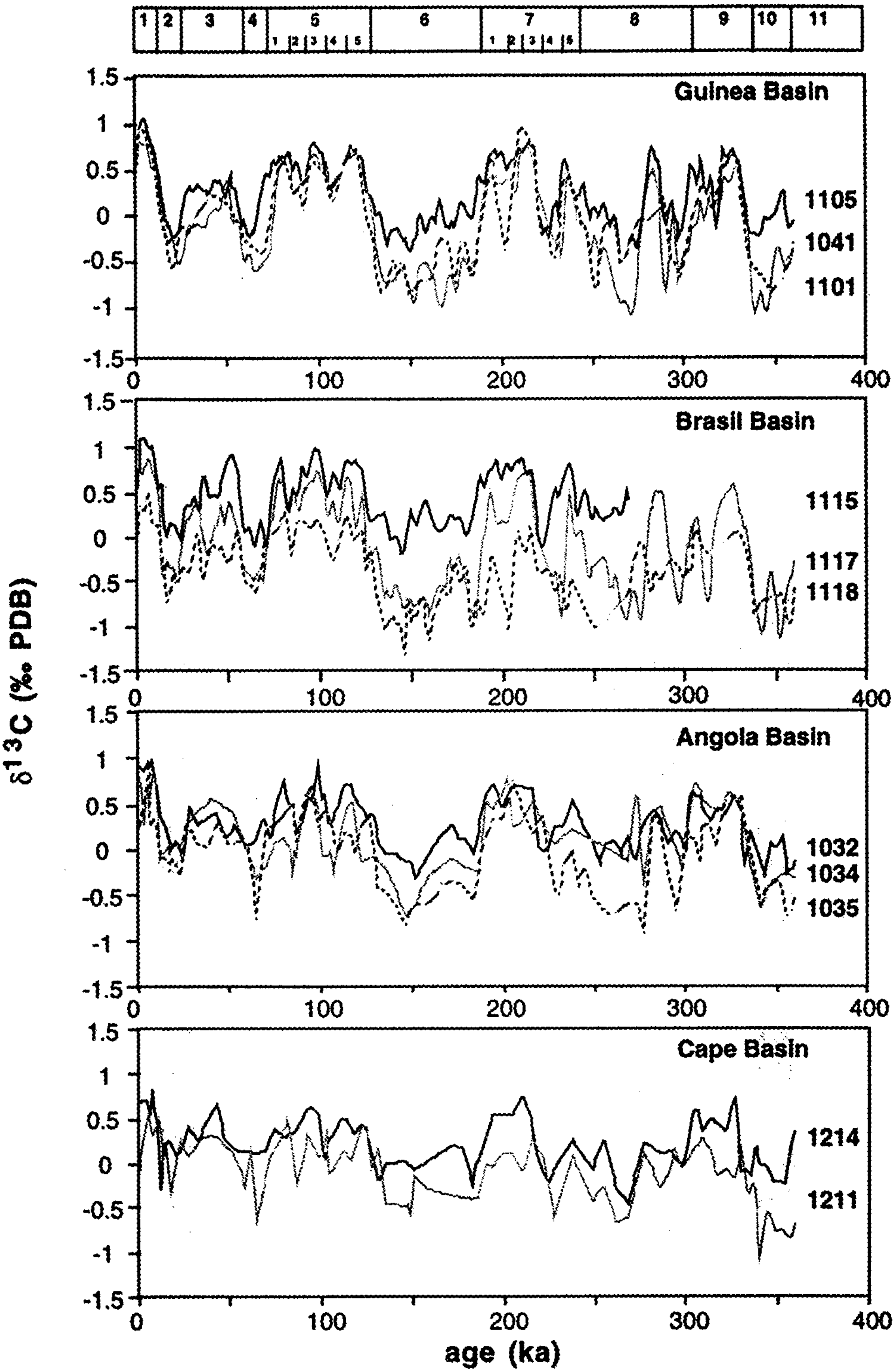

a
DEPTH, km
S ANTILLES ARC
S ANTILLES ARC
RIO GRANDE RISE
PARA RISE
70°S
60°
50°
40°
30°
20°
10°
S
0°
N
10°
20°
30°
40°
50°
60°N
b
DEPTH, km
δ13C ΣCO2
GEOSECS Western Atlantic section
Contours in ‰
c
DEPTH, km
W.R.
I.F.R.
50°S
40°
30°
20°
10°
0°
10°
20°
30°
40°
50°
60°
70°N

Figure 12



1
2
3
4
5
1 2 3 4 5
6
7
1 2 3 4 5
8
9
10
11
Guinea Basin
1105
1041
1101
Brasil Basin
1115
1117
1118
Angola Basin
1032
1034
1035
Cape Basin
1214
1211
$\delta^{13}C$ (‰ PDB)
age (ka)

Figure 13

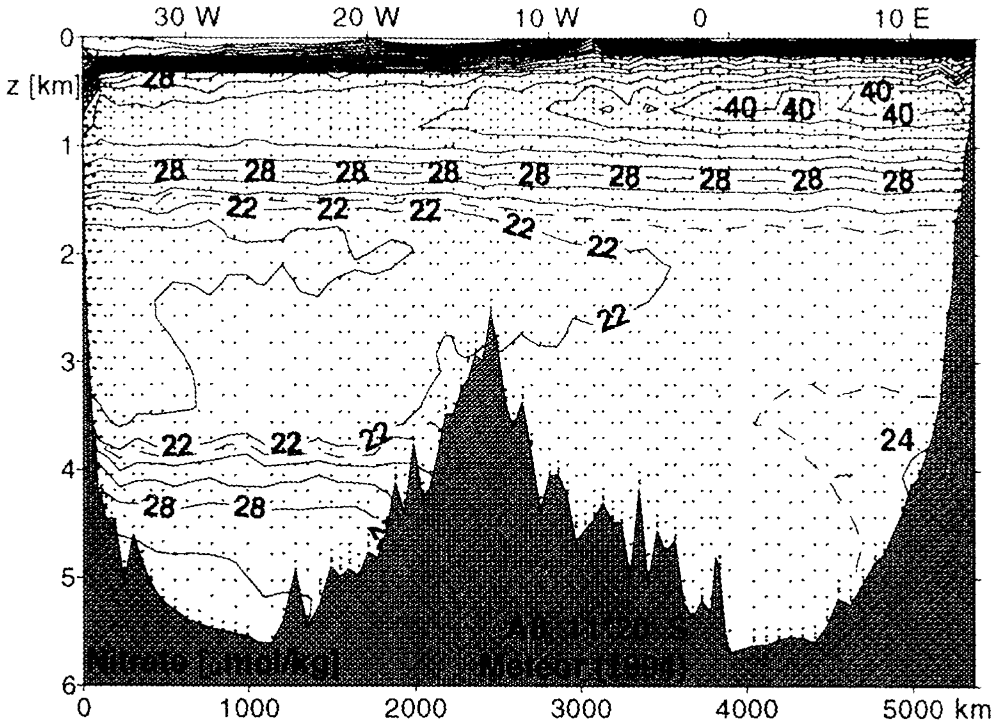

30 W
20 W
10 W
0
10 E
z [km]
0
1
2
3
4
5
6
28
22
40
24
0
1000
2000
3000
4000
5000 km

Figure 14

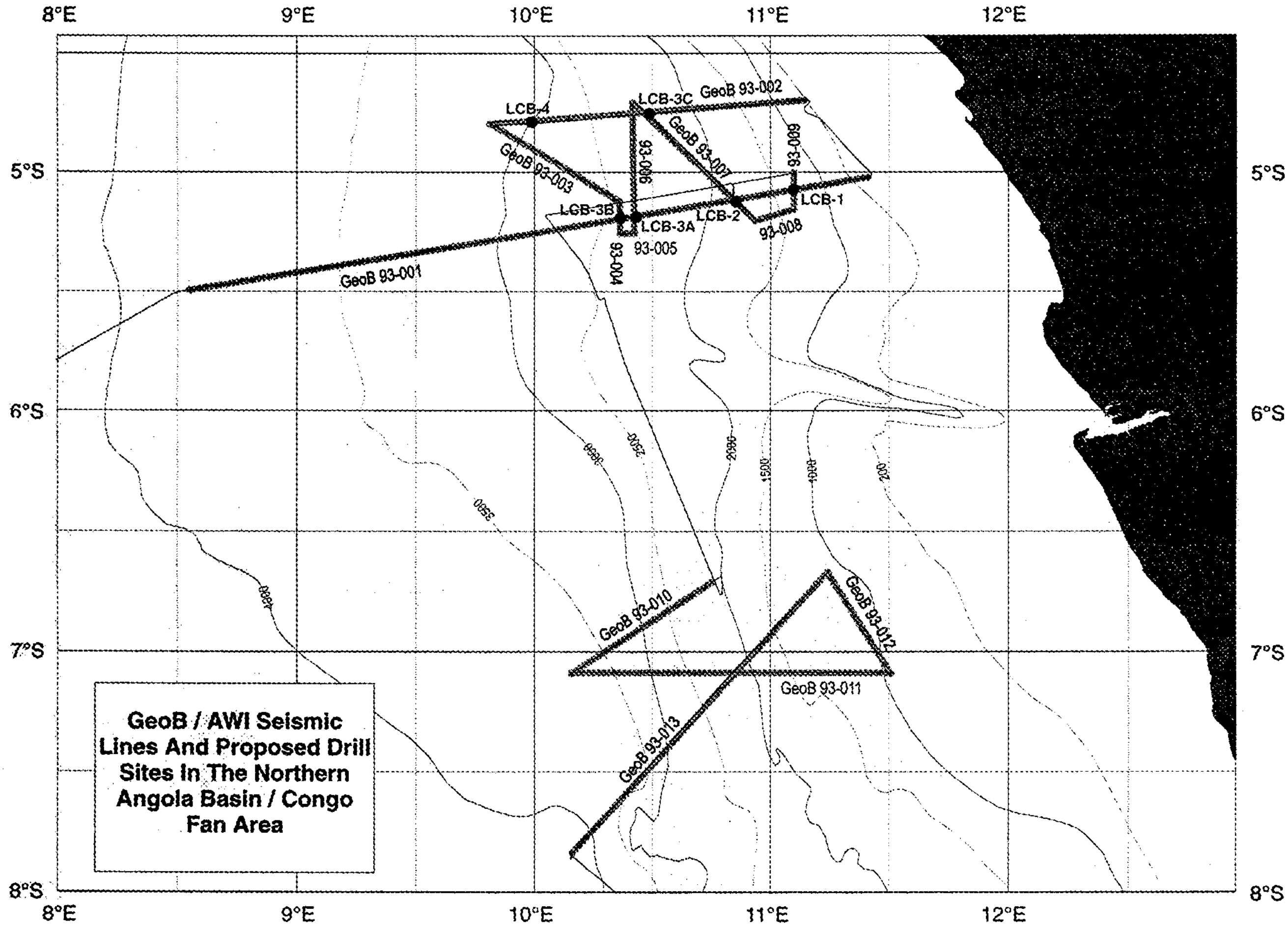
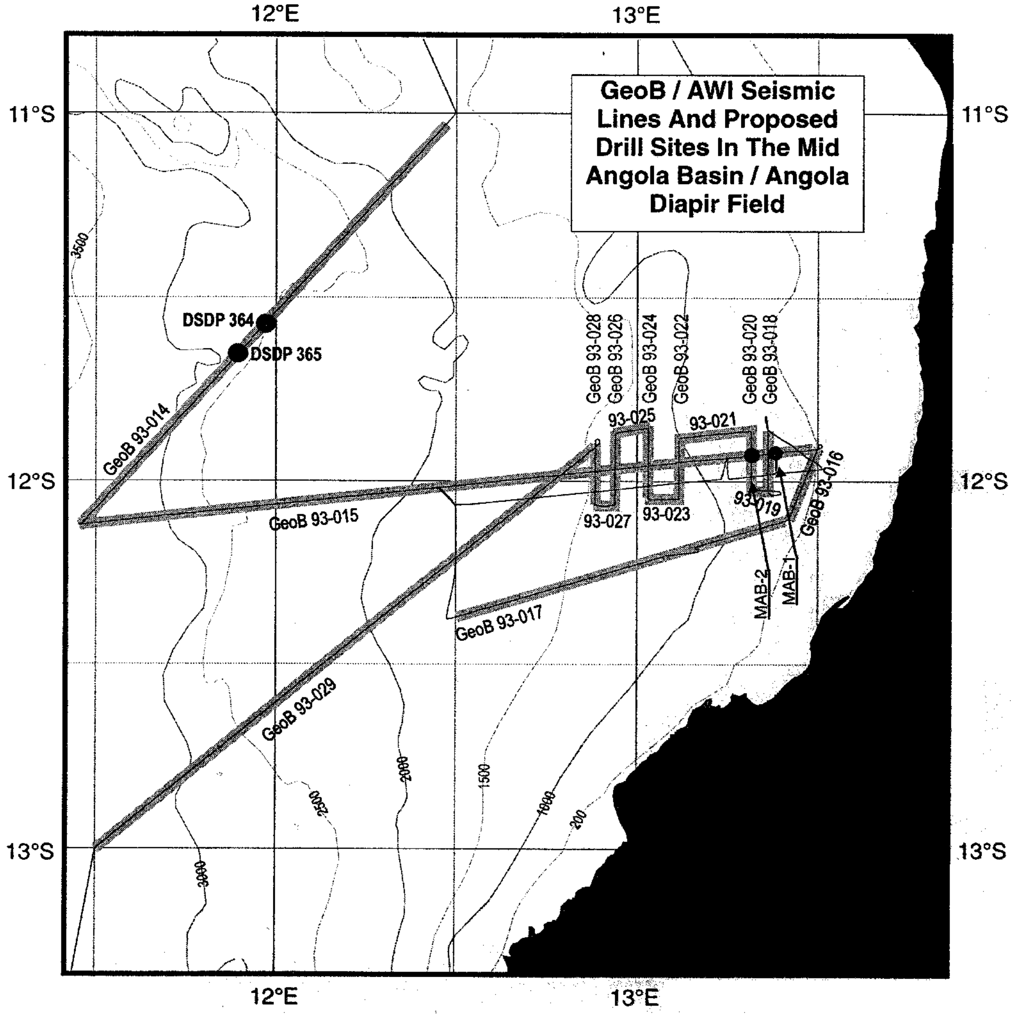

8°E
9°E
10°E
11°E
12°E
5°S
6°S
7°S
8°S
LCB-4
LCB-3C
GeoB 93-002
GeoB 93-007
93-006
93-009
GeoB 93-003
LCB-3B
LCB-3A
LCB-2
LCB-1
93-008
93-005
93-004
GeoB 93-001
GeoB 93-010
GeoB 93-012
GeoB 93-011
GeoB 93-013
GeoB / AWI Seismic Lines And Proposed Drill Sites In The Northern Angola Basin / Congo Fan Area

Figure 15



GeoB / AWI Seismic Lines And Proposed Drill Sites In The Mid Angola Basin / Angola Diapir Field
12°E
13°E
11°S
12°S
13°S
DSDP 364
DSDP 365
GeoB 93-014
GeoB 93-015
GeoB 93-017
GeoB 93-029
GeoB 93-016
GeoB 93-028
GeoB 93-026
GeoB 93-024
GeoB 93-022
GeoB 93-020
GeoB 93-018
93-025
93-021
93-027
93-023
93-019
MAB-2
MAB-1
3500
3000
2500
2000
1500
1000
200

Figure 16

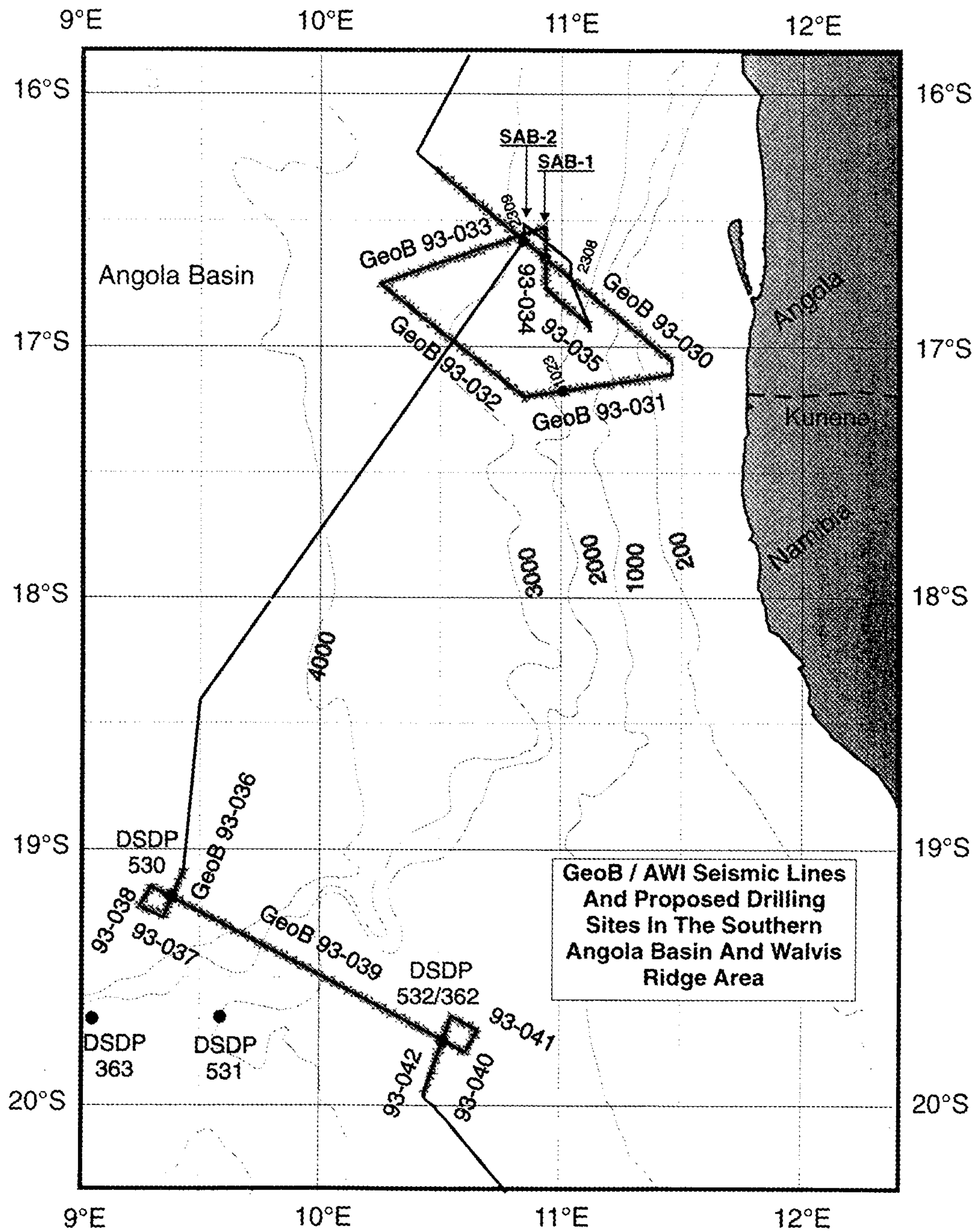
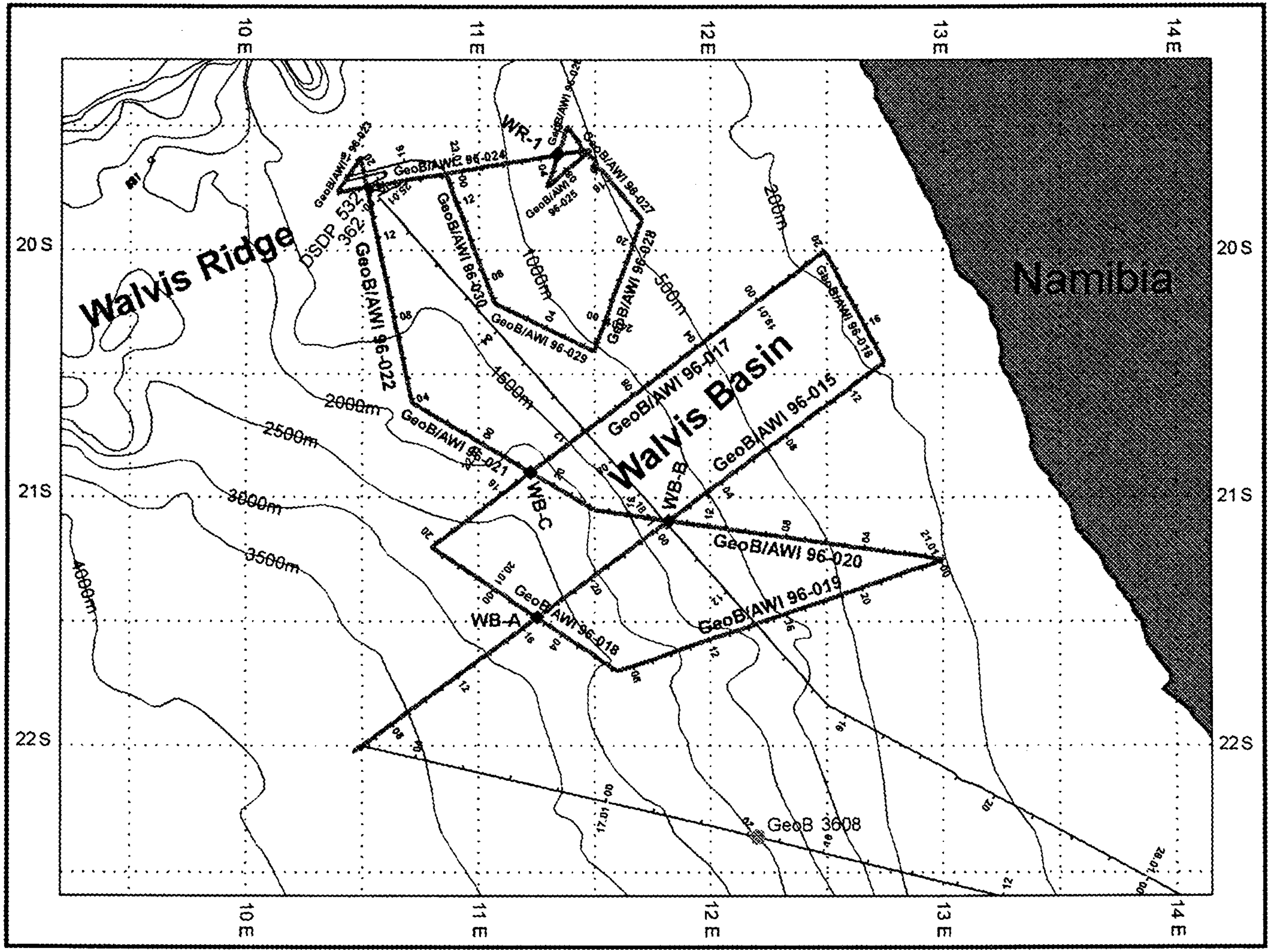
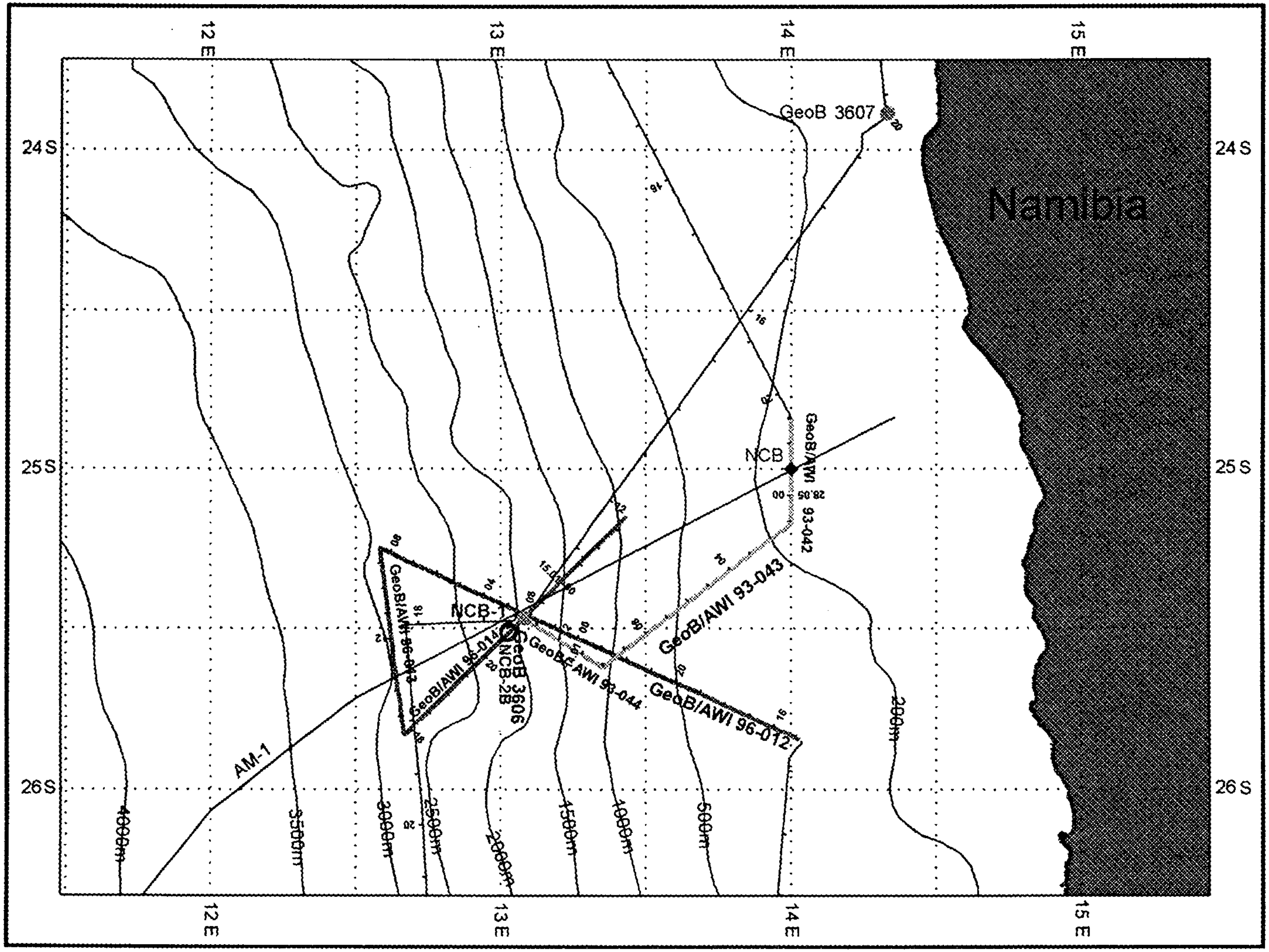

9°E
10°E
11°E
12°E
16°S
17°S
18°S
19°S
20°S
SAB-2
SAB-1
Angola Basin
GeoB 93-033
GeoB 93-030
GeoB 93-032
GeoB 93-031
93-034
93-035
2308
Angola
Kunene
Namibia
3000
2000
1000
200
4000
DSDP
530
GeoB 93-036
93-038
93-037
GeoB 93-039
DSDP
532/362
93-041
93-042
93-040
DSDP
363
DSDP
531
GeoB / AWI Seismic Lines And Proposed Drilling Sites In The Southern Angola Basin And Walvis Ridge Area

Figure 17



10 E
11 E
12 E
13 E
14 E
20 S
21 S
22 S
Walvis Ridge
Namibia
Walvis Basin
DSDP 532
362
WR-1
WB-A
WB-B
WB-C
GeoB/AWI 96-022
GeoB/AWI 96-024
GeoB/AWI 96-027
GeoB/AWI 96-028
GeoB/AWI 96-029
GeoB/AWI 96-030
GeoB/AWI 96-017
GeoB/AWI 96-015
GeoB/AWI 96-018
GeoB/AWI 96-019
GeoB/AWI 96-020
GeoB/AWI 96-021
GeoB 3608
200m
500m
1000m
1500m
2000m
2500m
3000m
3500m
4000m

Figure 18



12 E
13 E
14 E
15 E
24 S
25 S
26 S
Namibia
GeoB 3607
NCB
GeoB/AWI 93-042
GeoB/AWI 93-043
NCB-1
GeoB 3606
NCB-2B
GeoB/AWI 93-044
GeoB/AWI 96-012
GeoB/AWI 96-013
GeoB/AWI 96-014
AM-1
4000m
3500m
3000m
2500m
2000m
1500m
1000m
500m
200m

Figure 19

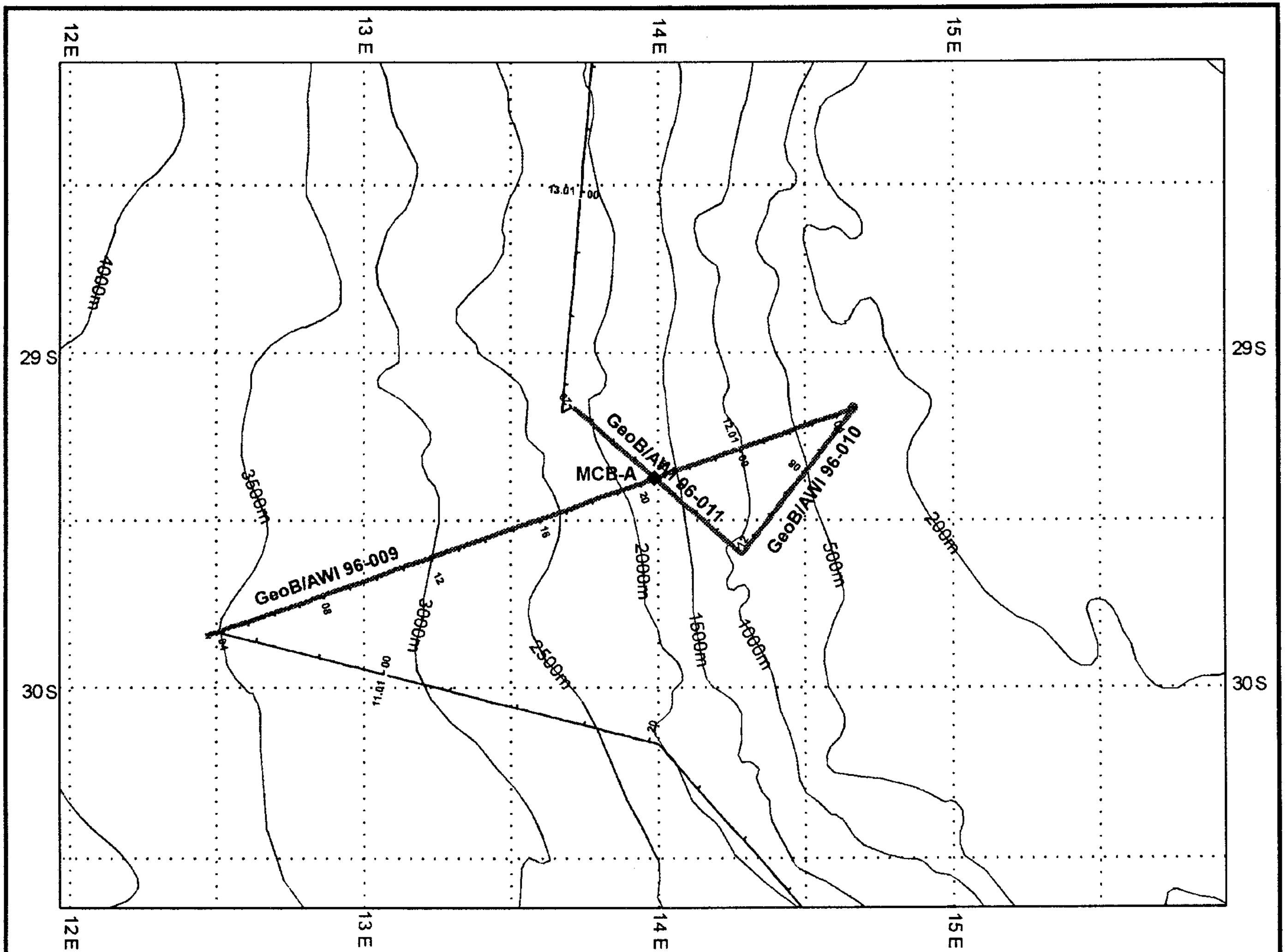

12 E
13 E
14 E
15 E
29 S
30 S
4000m
3500m
3000m
2500m
2000m
1500m
1000m
500m
200m
GeoB/AWI 96-009
GeoB/AWI 96-010
GeoB/AWI 96-011
MCB-A
13.01
12.01
11.01

Figure 20

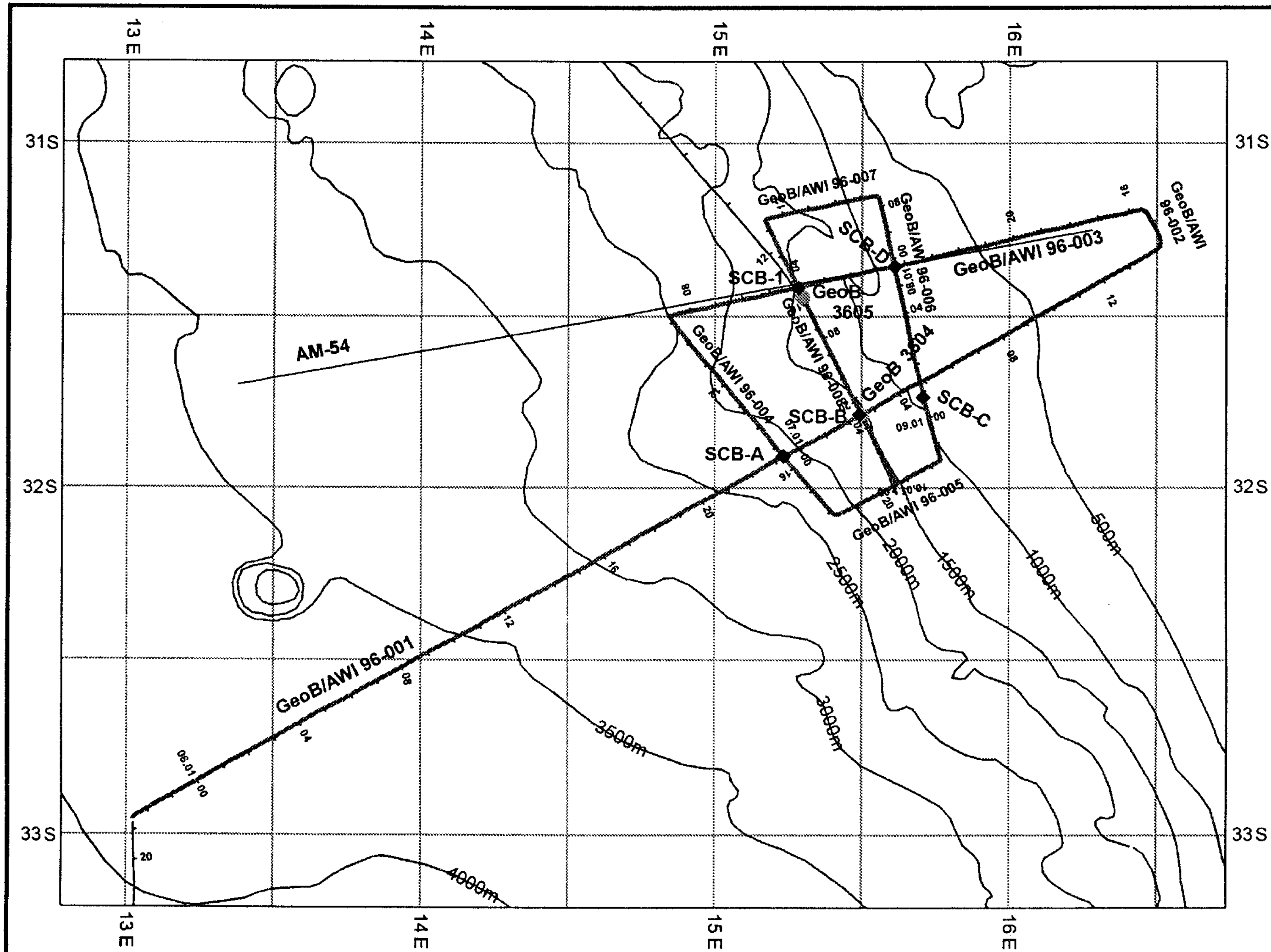

13 E
14 E
15 E
16 E
31S
32S
33S
GeoB/AWI 96-007
GeoB/AWI 96-006
GeoB/AWI 96-002
GeoB/AWI 96-003
SCB-D
SCB-1
GeoB 3605
GeoB 3604
AM-54
GeoB/AWI 96-004
GeoB/AWI 96-008
SCB-B
SCB-C
SCB-A
GeoB/AWI 96-005
GeoB/AWI 96-001
500m
1000m
1500m
2000m
2500m
3000m
3500m
4000m

Figure 21

TABLE 1. PRIMARY SITE TIME ESTIMATES

Site	Latitude Longitude	Water Depth (m)	Penetration (mbsf)	Drilling Operations (days)	Logging (days)	Transit Time (days)
Transit Las Palmas to LCB-1						12.4
LCB-1	5°04.1'S 11°06.1'E	1408	200	2.8	0.0	
Transit from LCB-1 to LCB-4						0.3
LCB-4	4°47.1'S 10°04.5'E	3000	200	3.8	0.0	
Transit from LCB-4 to MAB-1						1.9
MAB-1	11°55.2'S 13°24.0'E	432	200	1.9	0.0	
Transit from MAB-1 to MAB-2						0.1
MAB-2	11°55.8'S 13°02.3'E	722	120	1.5	0.0	
Transit from MAB-2 to SAB-2						1.2
SAB-2	16°33.7'S 10°49.3'E	2843	600	7.0	0.7	
Transit from SAB-2 to WB-B						1.1
WB-B	21°05.6'S 11°49.2'E	1290	600	5.1	0.7	
Transit from WB-B to NCB-2B						1.1
NCB-2B	25°30.8'S 13°01.7'E	2004	600	6.1	0.7	
Transit from NCB-2B to SCB-1						1.1
SCB-1	31°25.0'S 15°17.0'E	1350	600	5.2	0.7	
Transit from SCB-1 to Cape Town						0.9
Total				**33.4**	**2.8**	**20.1**

Total Days at Sea = 55.9 (Available Time = 56.0)

TABLE 2. ALTERNATE SITE TIME ESTIMATES

Site	Latitude Longitude	Water Depth (m)	Penetration (mbsf)	Drilling Operations (days)	Logging (days)
LCB-2	5°6.6'S 10°51.1'E	1811	200	3.2	0.0
LCB-3A	5°10.8'S 10°26.2'E	2392	200	3.5	0.0
LCB-3B	5°11.4'S 10°22.3'E	2500	200	3.5	0.0
LCB-3C	4°45.0'S 10°29.3'E	2435	200	3.5	0.0
SAB-1	16°39.6'S 10°57.0'E	2588	600	6.6	0.7
WR-1A	19°37.0'S 11°20.4'E	763	600	8.1	0.7
WB-A	21°29.0'S 11°15.1'E	2707	600	7.0	0.7
WB-C	20°53.9'S 11°13.4'E	2201	600	6.1	0.7
MCB-A	29°22.5'S 13°59.4'E	1726	600	5.7	0.7
SCB-A	31°54.4'S 15°14.1'E	2234	600	6.2	0.7
SCB-B	31°47.1'S 15°30.0'E	1507	600	5.5	0.7
SCB-C	31°41.4'S 15°41.9'E	887	600	4.7	0.7
SCB-D	31°21.3'S 15°36.5'E	778	600	4.6	0.1
Total				**68.2**	**5.7**

Orientation & T measurement times have been incorporated into drilling operations

Site: LCB-1

Priority: 1
Position: 5°04.1'S, 11°06.1'E
Water Depth: 1408 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 200 mbsf
Seismic Coverage: High-resolution multichannel seismic (MCS) survey, seismic Line GeoB 93-001 and 93-009

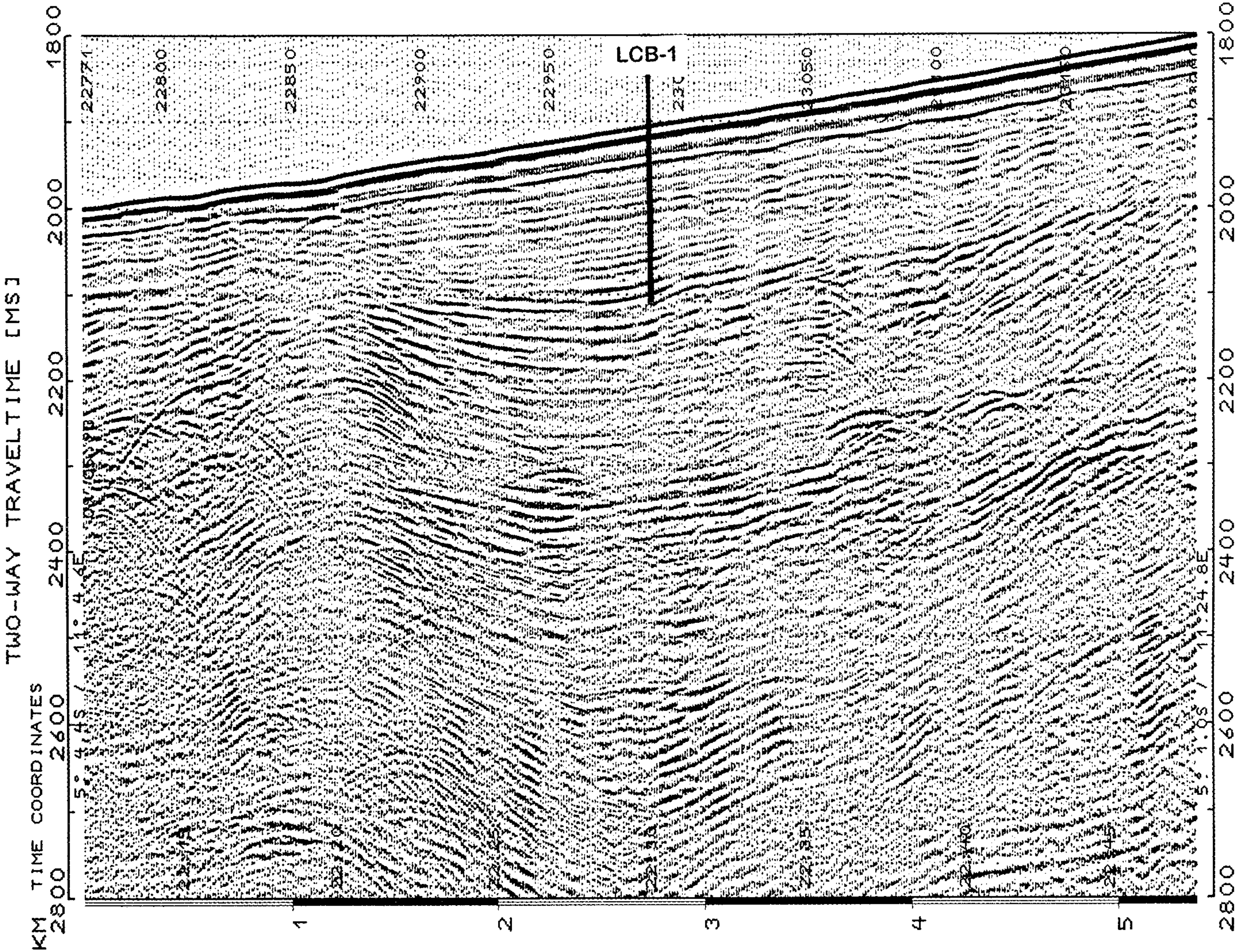
Objectives: The objectives of LCB-1 are to determine the:

1. variability of riverine input (Congo), and
2. history of opal, carbonate, and organic-matter deposition off Zaire (Congo).

Drilling Program: APC Holes A, B, C to 200 m or to refusal

Logging and Downhole: None

Nature of Rock Anticipated: Hemipelagic calcareous silty mud.


LCB-1
TWO-WAY TRAVELTIME [MS]
1800
2000
2200
2400
2600
2800
KM
1
2
3
4
5
TIME COORDINATES

Site LCB-1

Site: LCB-2

Priority: 2
Position: 5°6.6'S, 10°51.1'E
Water Depth: 1832 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 200 m
Seismic Coverage: High-resolution MCS, seismic Line GeoB 93-001 and -007

Objectives: The objectives of LCB-2 are to determine the:

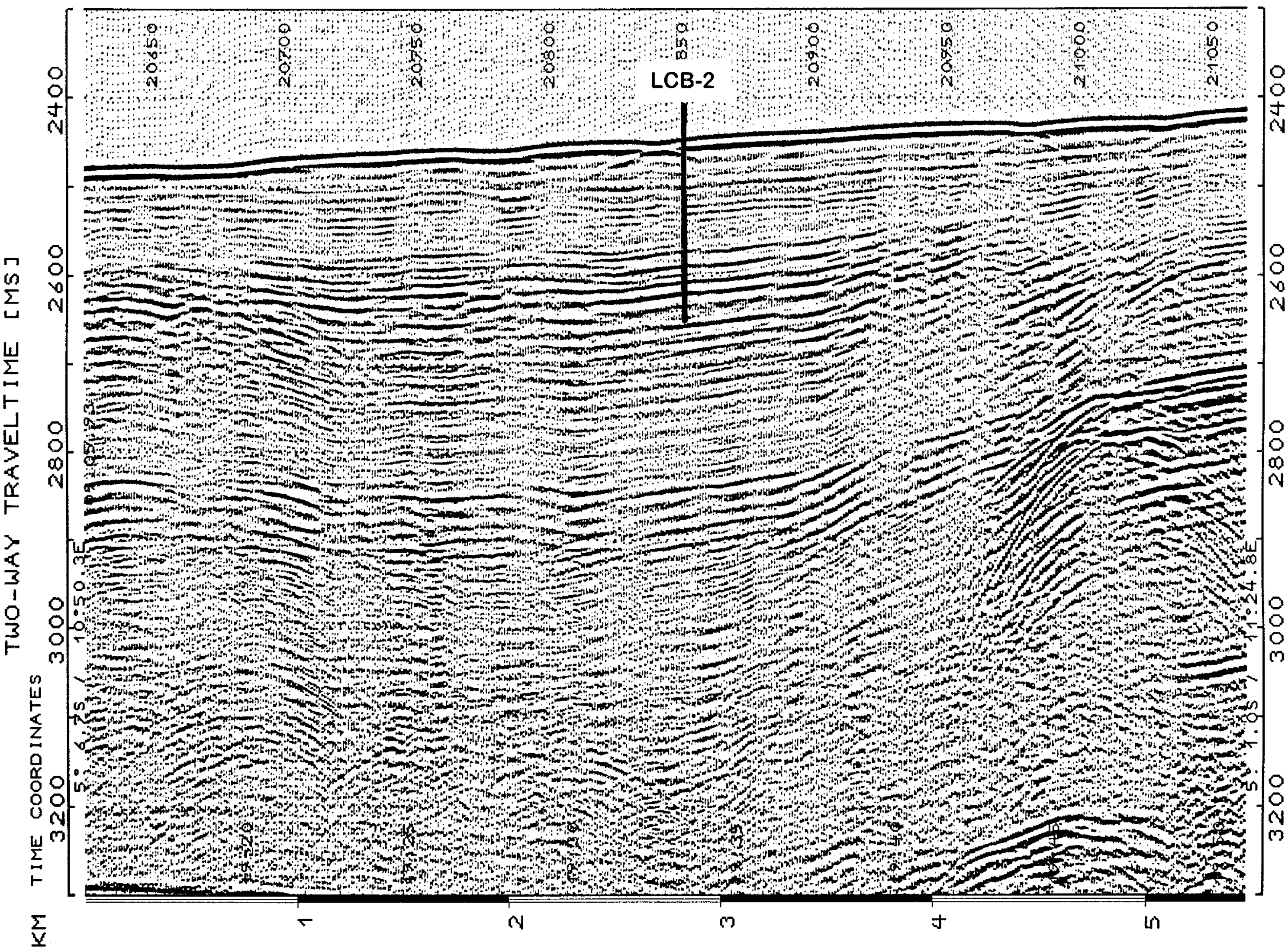
1. variability of riverine input (Congo), and
2. history of opal, carbonate, and organic-matter deposition off Zaire (Congo).

Drilling Program: APC Holes A, B, C to 200 m or to refusal

Logging and Downhole*: None

Nature of Rock Anticipated: Hemipelagic calcareous silty mud.

***Note:** It is anticipated that this site may not be drilled, or only drilled for APC, depending on time available. In the event that there is less than 250 m penetration, no logging or other downhole measurements will be attempted.



LCB-2
TWO-WAY TRAVELTIME [MS]
TIME COORDINATES
2400
2600
2800
3000
3200
KM
1
2
3
4
5

Site LCB-2

Site: LCB-3A

Priority: 2
Position: 5°10.8'S, 10°26.2'E
Water Depth: 2392 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 200 m
Seismic Coverage: High-resolution MCS survey, seismic Lines GeoB 93-001 and -006

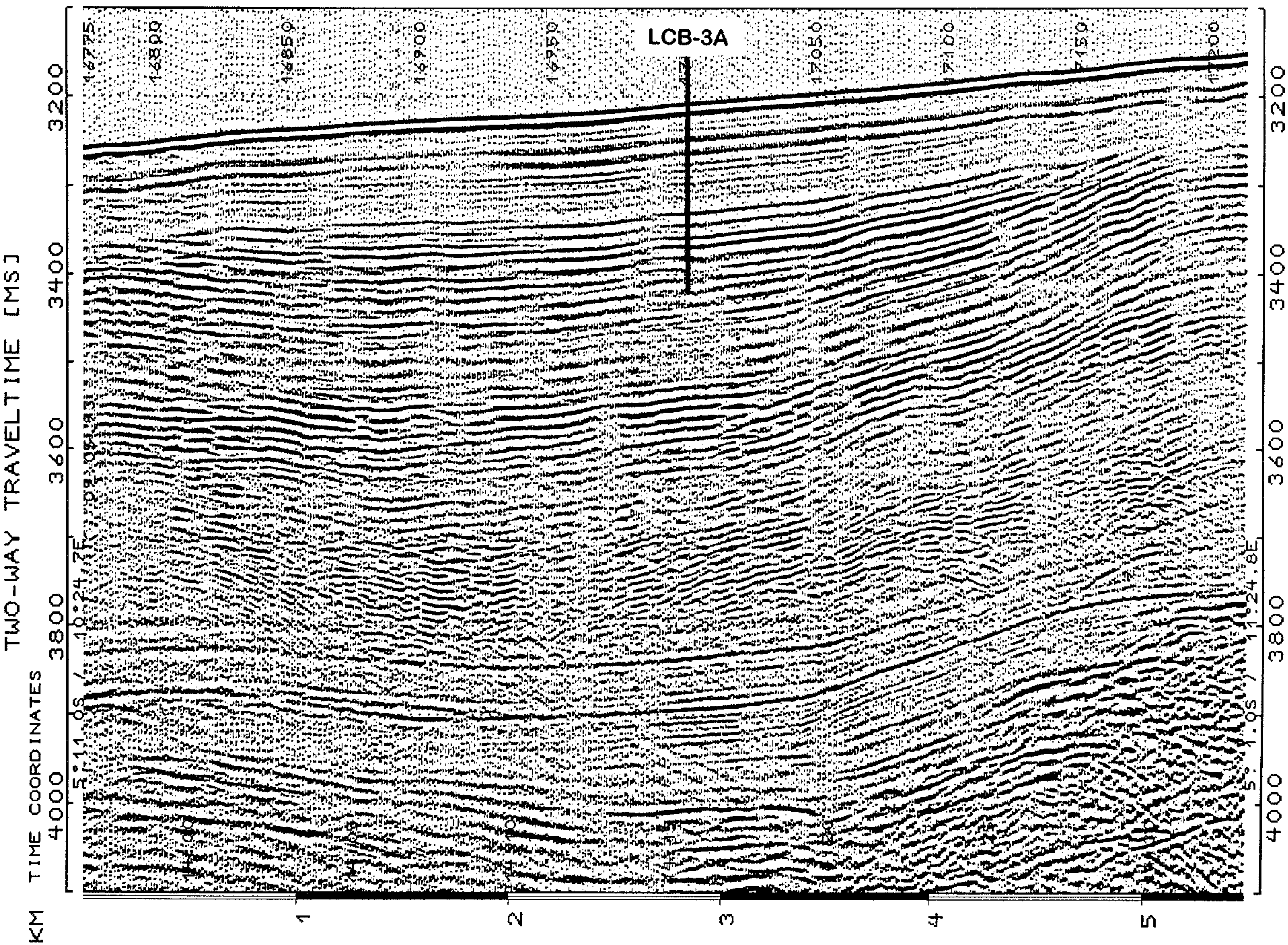
Objectives: The objectives of LCB-3A are to determine the:

1. variability of riverine input (Congo), and
2. history of opal, carbonate, and organic matter deposition off Zaire (Congo).

Drilling Program: APC core Holes A, B, C to 200 m or to refusal

Logging and Downhole: None

Nature of Rock Anticipated: Hemipelagic calcareous silty mud



Site LCB-3A

Site: LCB-3B

Priority: 2
Position: 5°11.4'S, 10°22.0'E
Water Depth: 2506 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 200 m
Seismic Coverage: High-resolution MCS, seismic Lines GeoB 93-001 and -004

Objectives: The objectives of LCB-3B are to determine:

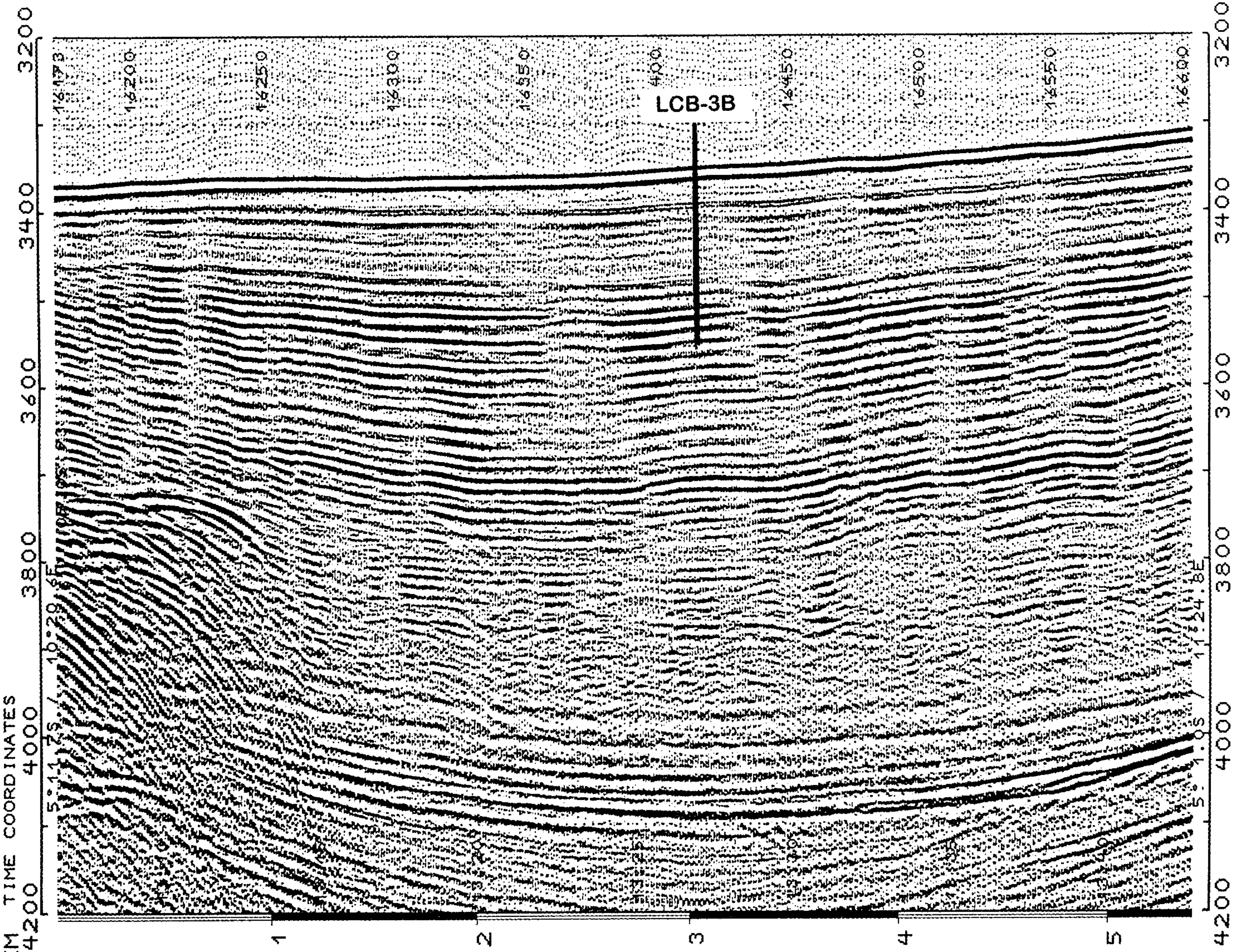
1. the variability of riverine input (Congo), and
2. the history of opal, carbonate, and organic-matter deposition off Zaire (Congo).

Drilling Program: APC Holes A, B, C to 200 m or to refusal

Logging and Downhole*: None

Nature of Rock Anticipated: Hemipelagic calcareous silty mud.

***Note:** It is anticipated that this site may not be drilled, or only drilled for APC, depending on time available. In the event that there is less than 250 m penetration, no logging or other downhole measurements will be attempted.


LCB-3B
TWO-WAY TRAVELTIME [MS]
TIME COORDINATES
KM
3200
3400
3600
3800
4000
4200
1
2
3
4
5

Site LCB-3B

Site: LCB-3C

Priority: 2
Position: 4°45.0'S, 10°29.3'E
Water Depth: 2430 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 200 m
Seismic Coverage: High-resolution MCS, seismic Lines GeoB 93-002 and -007

Objectives: The objectives of LCB-3C are to determine:

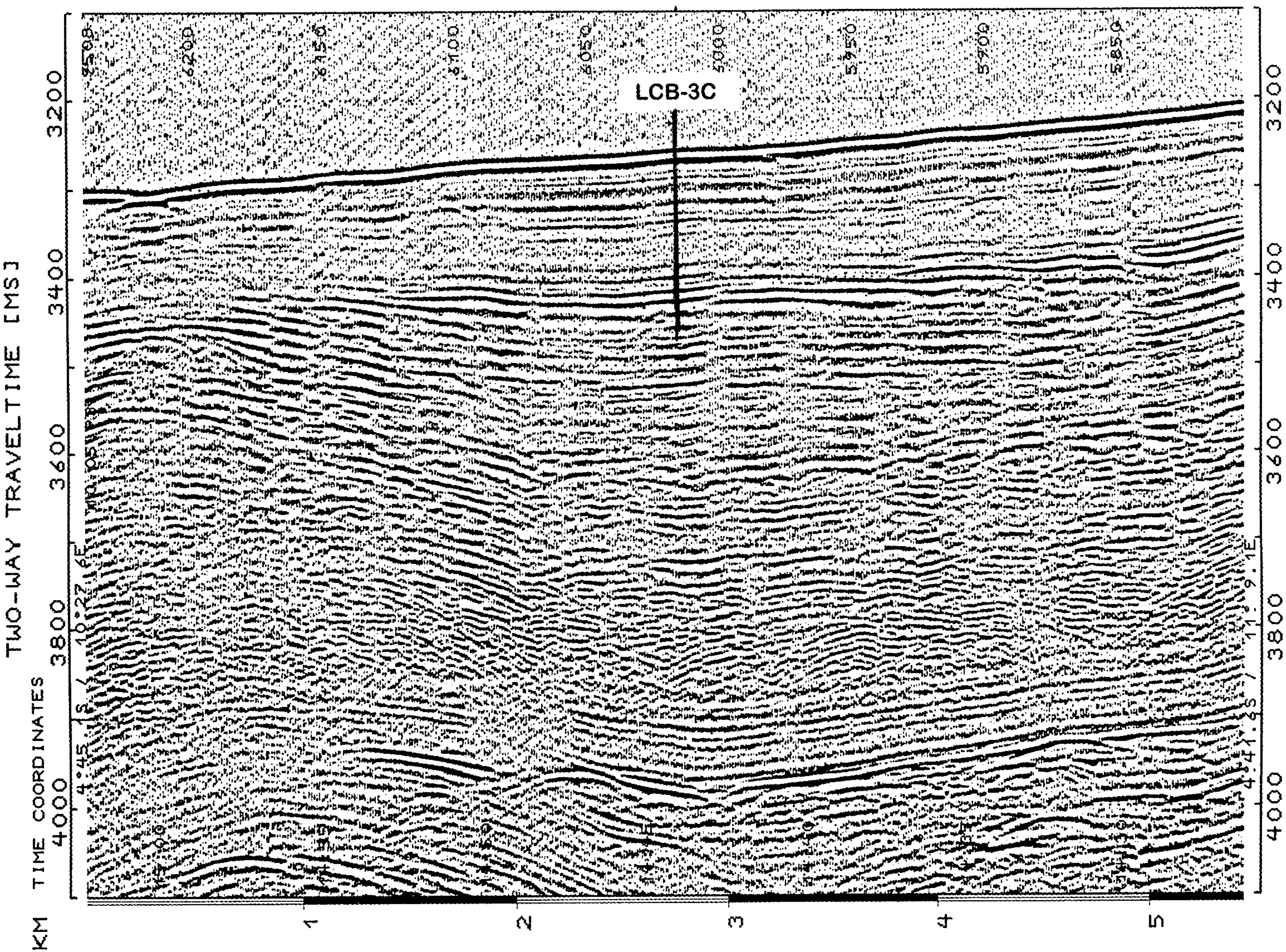
1. the variability of riverine input (Congo), and
2. history of opal, carbonate, and organic matter deposition off Zaire (Congo).

Drilling Program: APC Holes A, B, C to 200 m or to refusal

Logging and Downhole*: None

Nature of Rock Anticipated: Hemipelagic calcareous silty mud.

***Note:** It is anticipated that this site may not be drilled, or only drilled for APC, depending on time available. In the event that there is less than 250 m penetration, no logging or other downhole measurements will be attempted.


LCB-3C
TWO-WAY TRAVELTIME [MS]
TIME COORDINATES
3200
3400
3600
3800
4000
KM
1
2
3
4
5

Site LCB-3C

Site: LCB-4

Priority: 1
Position: 4°47.1'S, 10°04.5'E
Water Depth: 3000 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 200 m
Seismic Coverage: High-resolution MCS survey, seismic Line GeoB 93-002

Objectives: The objectives of LCB-4 are to:

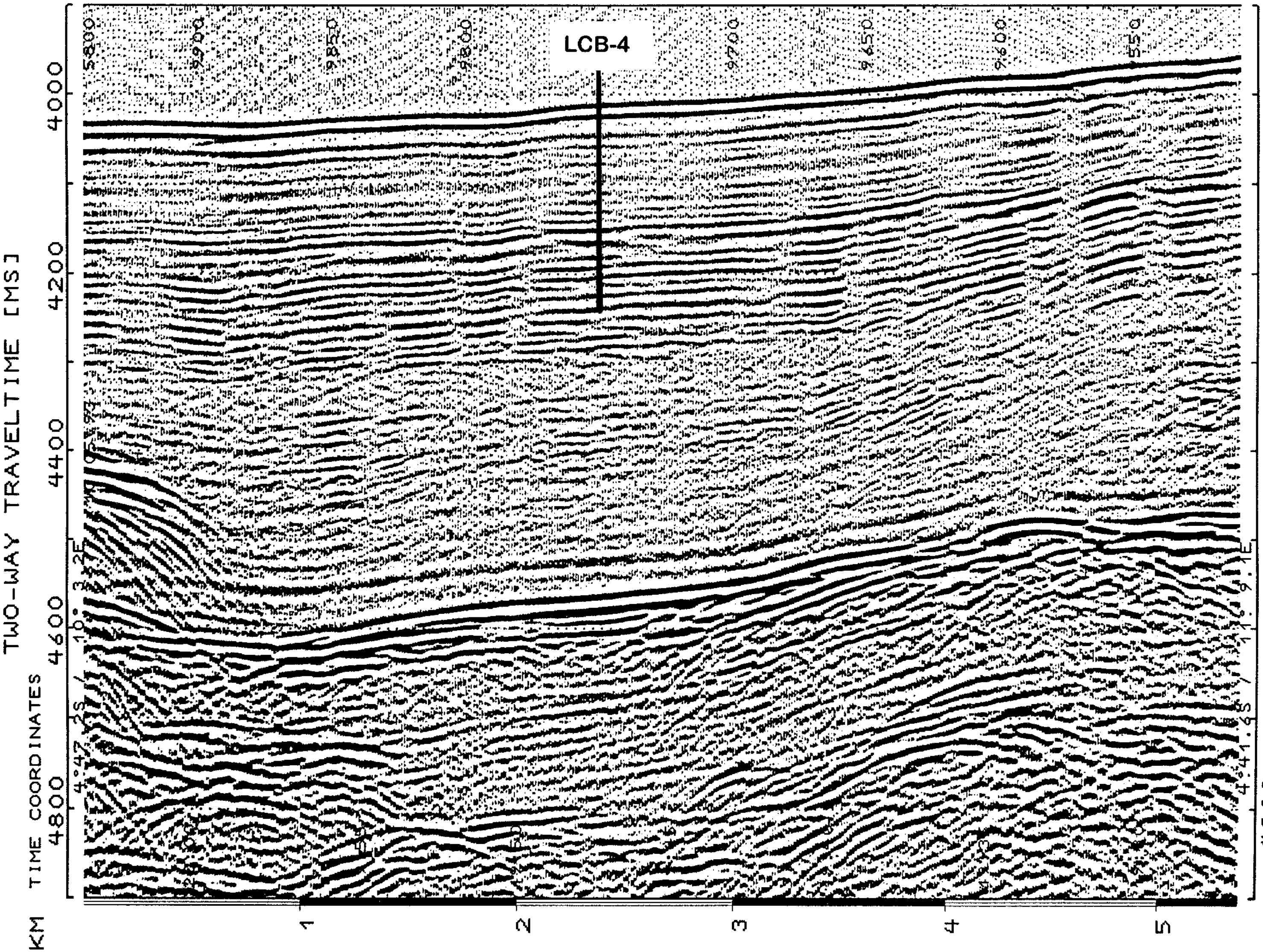
1. determine the variability of riverine input (Congo), and

2. determine the history of opal, carbonate, and organic-matter deposition off Zaire (Congo).

Drilling Program: APC core Holes A, B, C to 200 m or to refusal

Logging and Downhole: None

Nature of Rock Anticipated: Hemipelagic calcareous silty mud.


LCB-4
TWO-WAY TRAVELTIME [MS]
TIME COORDINATES
4000
4200
4400
4600
4800
KM
1
2
3
4
5

Site LCB-4

Site: MAB-1

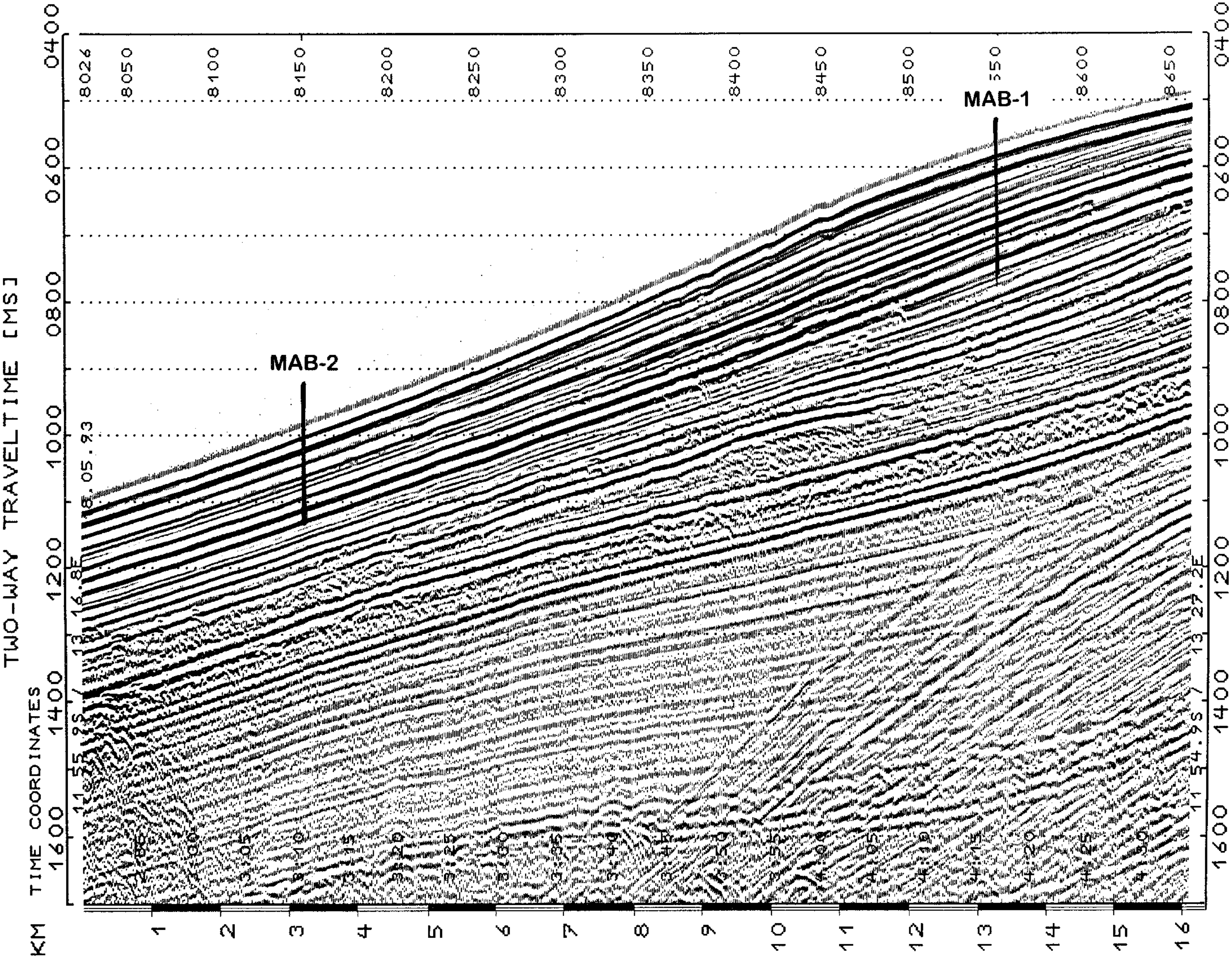
Priority: 1
Position: 11°55.2'S, 13°24.0'E
Water Depth: 432 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 200 mbsf
Seismic Coverage: High-resolution MCS survey, seismic Lines GeoB 93-015 and -018

Objectives: The objectives of MAB 1 are to determine the history of "nearly normal" sedimentation, being influenced neither by riverine input nor by sustained year-round upwelling.

Drilling Program: APC core Holes A, B, C to 200 m or to refusal

Logging and Downhole: None

Nature Of Rock Anticipated: Hemipelagic calcareous silty mud.



Sites MAB-1 and MAB-2

Site: MAB-2

Priority: 1
Position: 11°55.8'S, 13°02.3'E
Water Depth: 722 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 120 m
Seismic Coverage*: High-resolution MCS survey, seismic Lines GeoB 93-015 and -020

Objectives: The objectives of MAB-2 are to determine the history of "nearly normal" sedimentation, being influenced neither by riverine input nor by sustained year-round upwelling.

Drilling Program: APC core Holes A, B, C to 120 m or to refusal

Logging and Downhole: None

Nature of Rock Anticipated: Hemipelagic calcareous silty mud.

* See seisimic line for Site MAB-1

Site: SAB-1

Priority: 2
Position: 16°39.6'S, 10°57.0'E
Water Depth: 2588 m
Sediment Thickness: > 1000 m
Approved Maximum Penetration: 600 m
Seismic Coverage: High-resolution MCS survey, seismic Lines GeoB 93-030 and -034

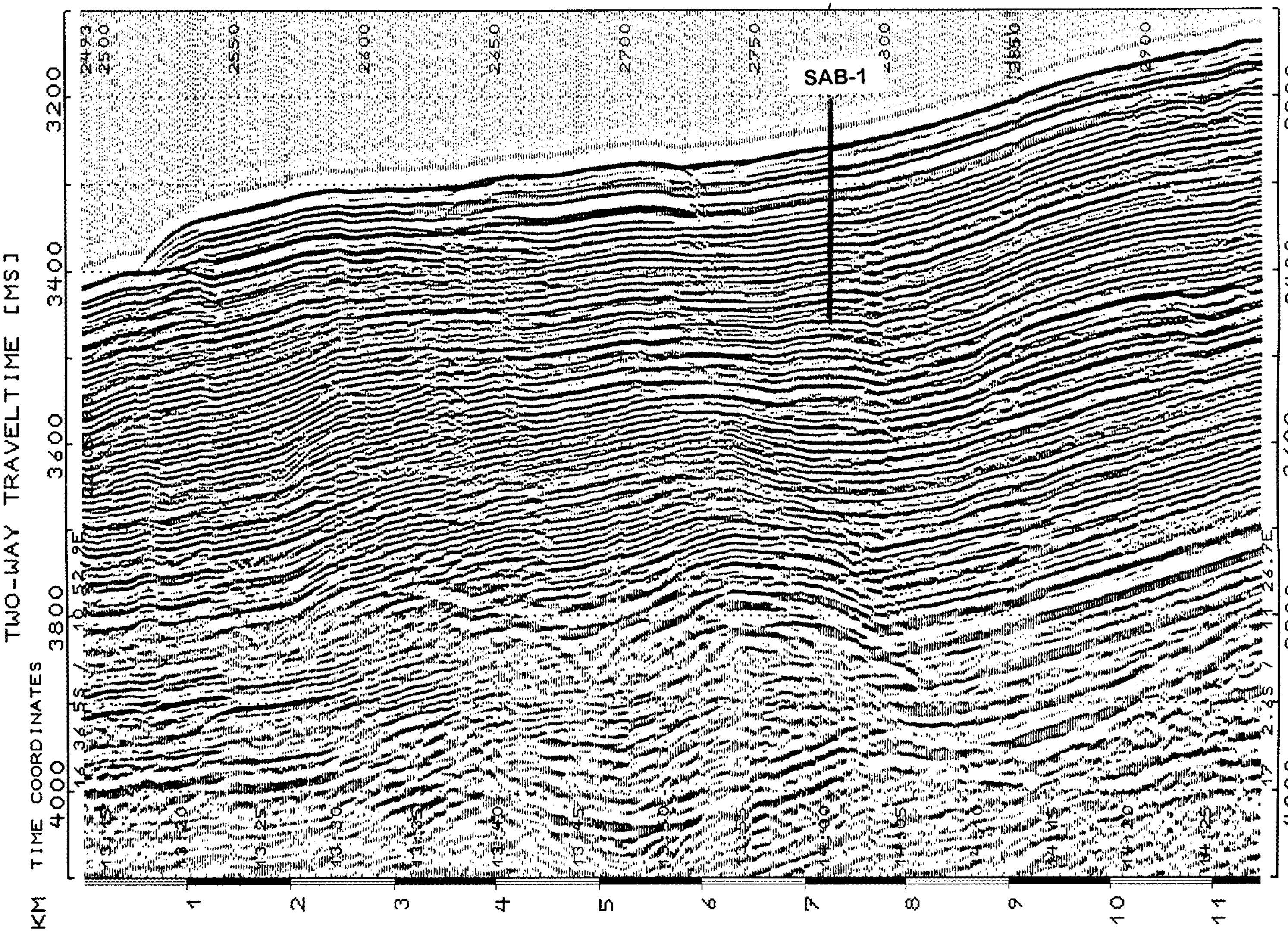
Objectives: The objective of SAB-1 is to determine the history of the northern end of Angola/Namibia coastal upwelling and that of the climate of southern Africa, as reflected in terrigenous sediments.

Drilling Program:
Hole A: APC/XCB to 600 m
Holes B and C: APC to refusal

Logging and Downhole*: Triple-combo, GHMT, FMS

Nature of Rock Anticipated: Hemipelagic calcareous silty mud.

***Note:** It is anticipated that this site may not be drilled, or only drilled for APC, depending on time available. In the event that there is less than 250 m penetration, no logging or other downhole measurements will be attempted.


SAB-1
TWO-WAY TRAVELTIME [MS]
TIME COORDINATES
KM
3200
3400
3600
3800
4000
2500
2550
2600
2650
2700
2750
2800
2850
2900
1
2
3
4
5
6
7
8
9
10
11

Site SAB-1

Site: SAB-2

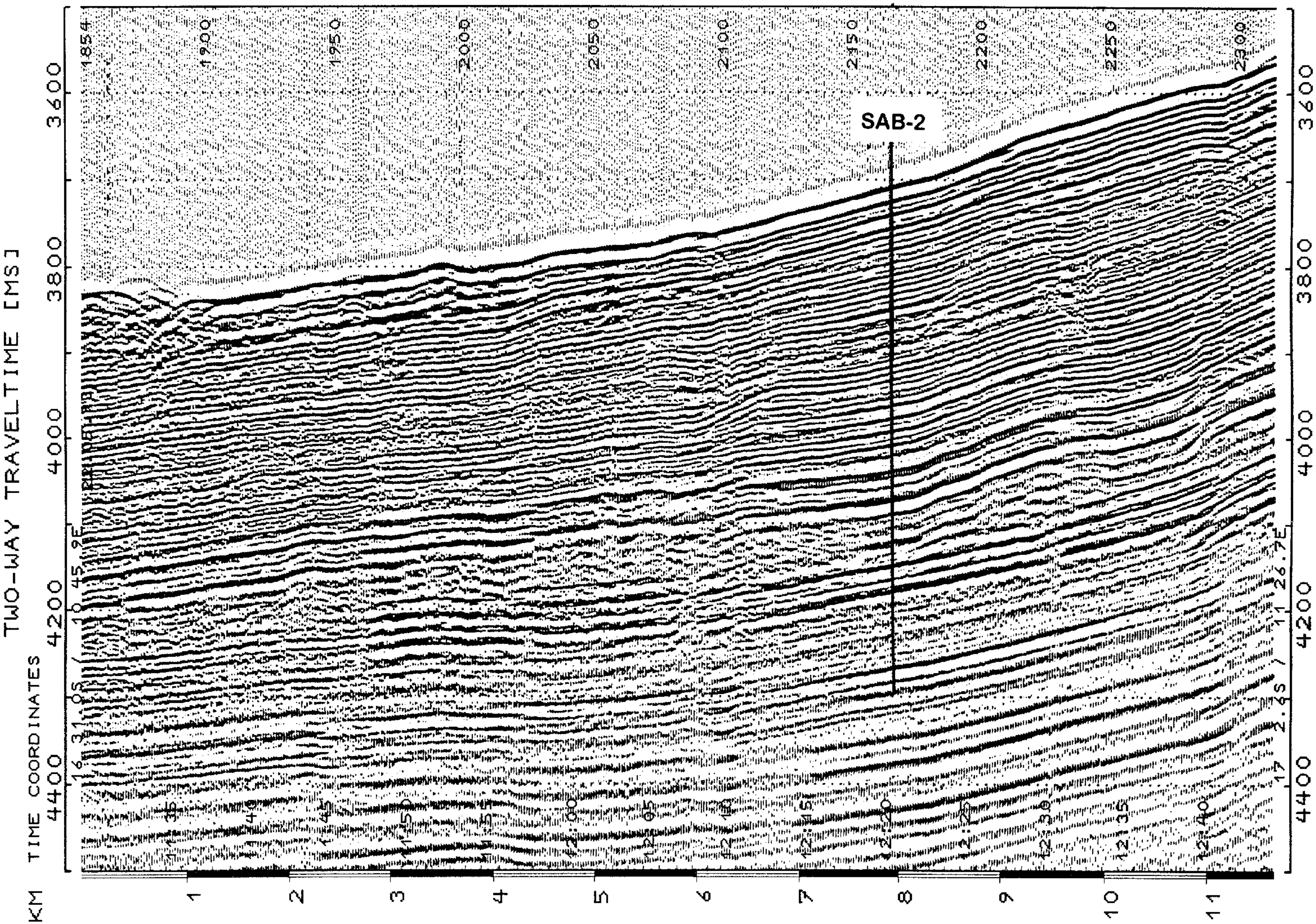
Priority: 1
Position: 16°33.7'S, 10°49.3'E
Water Depth: 2843 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 600 m
Seismic Coverage: High-resolution MCS survey, seismic Lines GeoB 93-030 and -033

Objectives: The objectives of SAB-2 are to determine the history of the northern end of Angola/Namibia coastal upwelling, migration of Benguela-Angola Front, and climatic history of southern Africa.

Drilling Program:
Hole A: APC/XCB to 600 m
Holes B and C: APC to refusal

Logging and Downhole: Triple-combo, GHMT, FMS

Nature of Rock Anticipated: Hemipelagic calcareous silty mud.


SAB-2
TWO-WAY TRAVELTIME [MS]
3600
3800
4000
4200
4400
1854
1900
1950
2000
2050
2100
2150
2200
2250
2300
TIME COORDINATES
KM
1
2
3
4
5
6
7
8
9
10
11

Site SAB-2

Site: WR-1A

Priority: 2
Position: 19°37.0'S, 11°20.4'E
Water Depth: 763 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 600 mbsf
Seismic Coverage: High-resolution MCS survey, seismic Lines GeoB 96-024 and -026

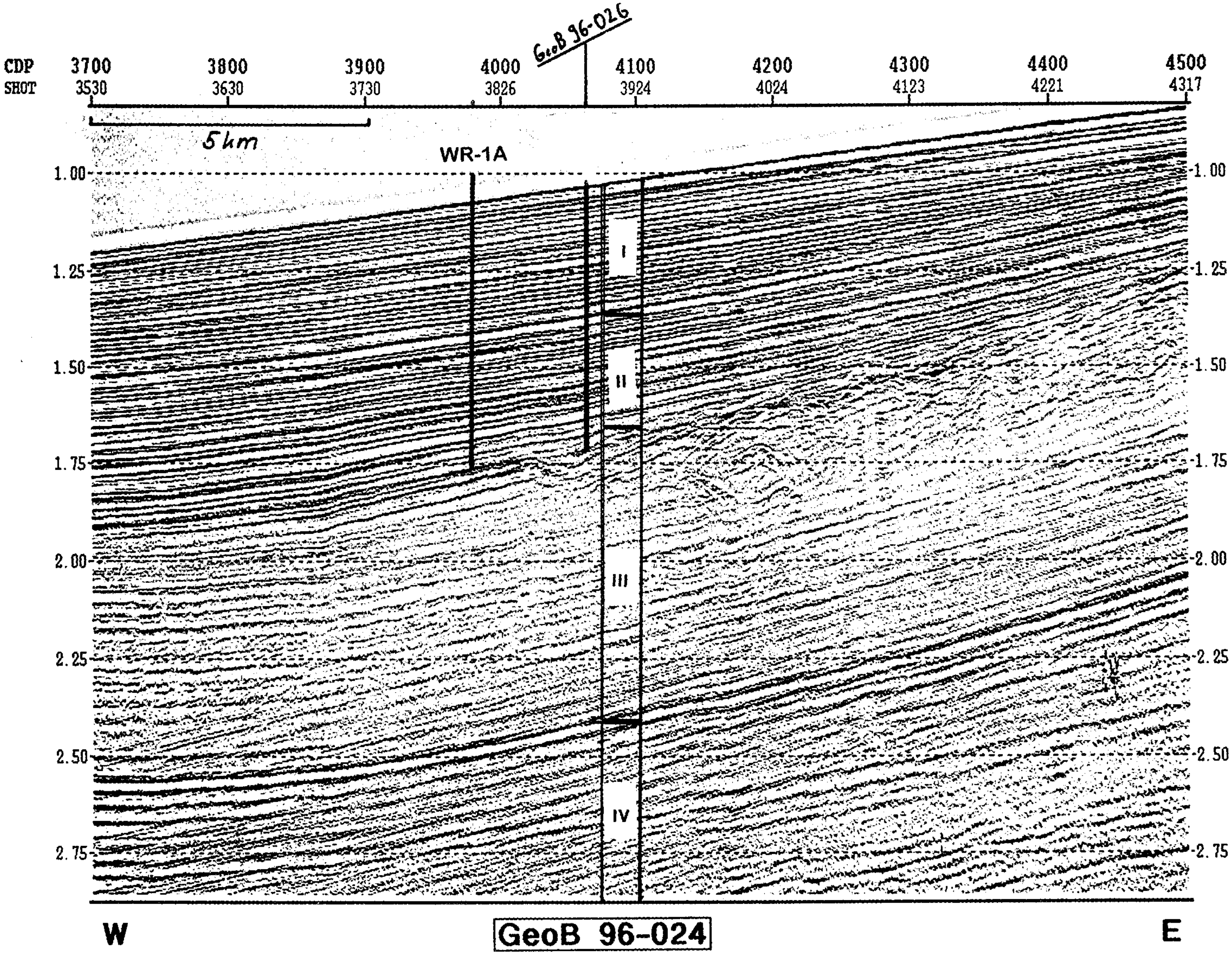
Objectives: The objective of WR-1A is to expand existing information from DSDP Sites 532 and 362 (Legs 75 and 40) providing for a cross-current transect. This site would help resolve the Walvis Ridge opal paradox, that is, the observation that the opal accumulation during glacials is much less than expected from productivity proxies.

Drilling Program:
Hole A: APC, XCB to refusal
Holes B and C: APC to refusal

Logging and Downhole*: Triple-combo, GHMT, FMS

Nature Of Rock Anticipated: Hemipelagic calcareous silty mud.

***Note:** It is anticipated that this site may not be drilled, or only drilled for APC, depending on time available. In the event that there is less than 250 m penetration, no logging or other downhole measurements will be attempted.


GeoB 96-026
CDP
SHOT
3700
3530
3800
3630
3900
3730
4000
3826
4100
3924
4200
4024
4300
4123
4400
4221
4500
4317
5 km
WR-1A
1.00
1.25
1.50
1.75
2.00
2.25
2.50
2.75
I
II
III
IV
W
E
GeoB 96-024

Site WR-1A

Site: WB-A

Priority: 2
Position: 21°29.0'S, 11°15.1'E
Water Depth: 2707 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 600 mbsf
Seismic Coverage: High-resolution MCS survey, seismic Lines GeoB/AWI 96-015 and -020

Objectives: The objective of WB-A is to determine:

1. the history of the Benguela Current, and strength of coastal upwelling, as seen in messages from filaments and in redeposited material from upslope; and

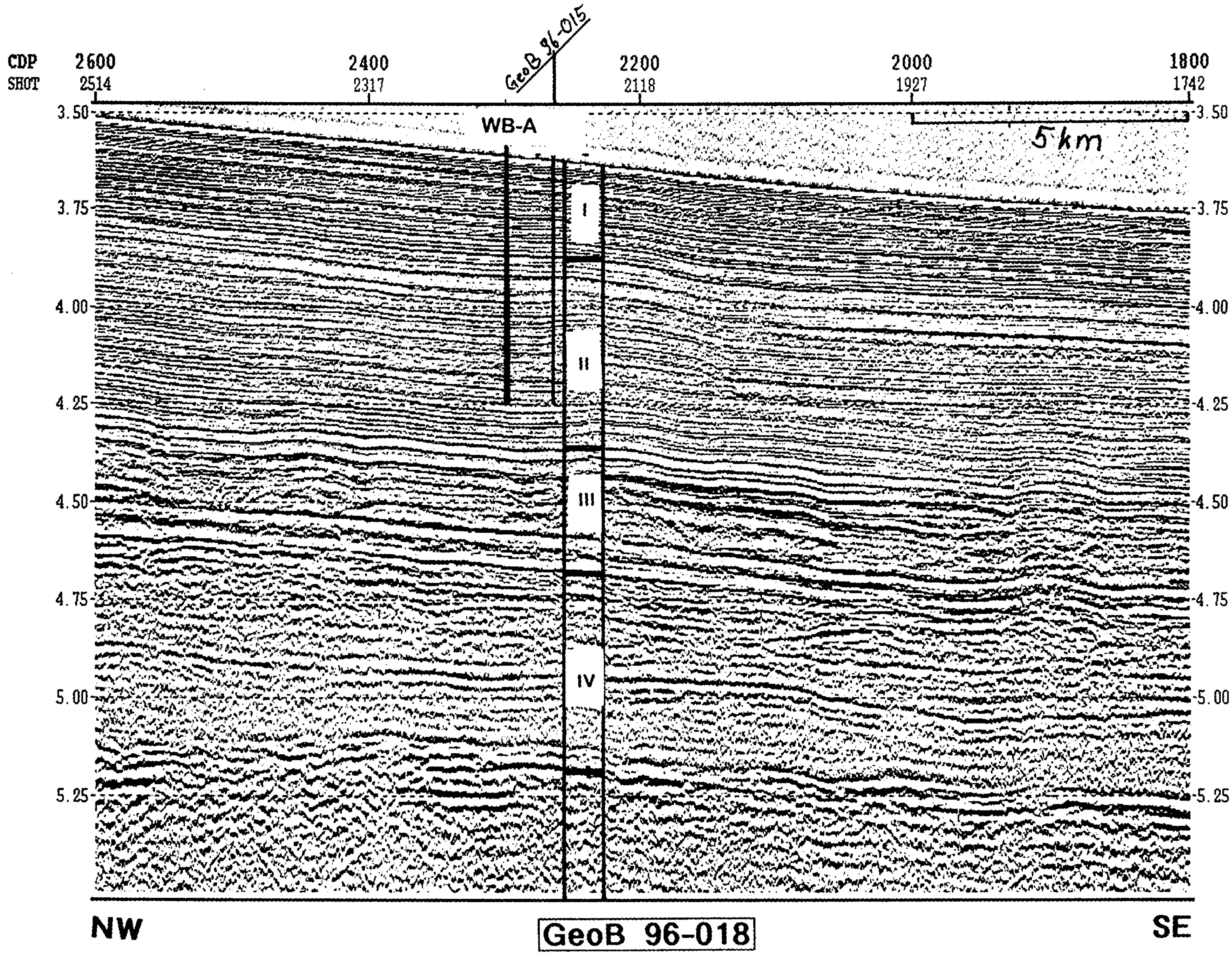
2. the climatic history of South Africa, as seen in terrigenous components.

Drilling Program:
Hole A: APC, XCB to refusal
Holes B and C: APC to refusal

Logging and Downhole*: Triple-combo, GHMT, FMS

Nature Of Rock Anticipated: Hemipelagic calcareous silty mud.

*__Note:__ It is anticipated that this site may not be drilled, or only drilled for APC, depending on time available. In the event that there is less than 250 m penetration, no logging or other downhole measurements will be attempted.


GeoB 96-015
CDP
SHOT
2600
2514
2400
2317
2200
2118
2000
1927
1800
1742
WB-A
5 km
I
II
III
IV
3.50
3.75
4.00
4.25
4.50
4.75
5.00
5.25
NW
SE
GeoB 96-018

Site WB-A

Site: WB-B

Priority: 1
Position: 21°05.6'S, 11°49.2'E
Water Depth: 1290 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 600 m
Seismic Coverage: High-resolution MCS survey, seismic Lines GeoB/AWI 96-015 and -020

Objectives: The objectives of WB-B are to determine:

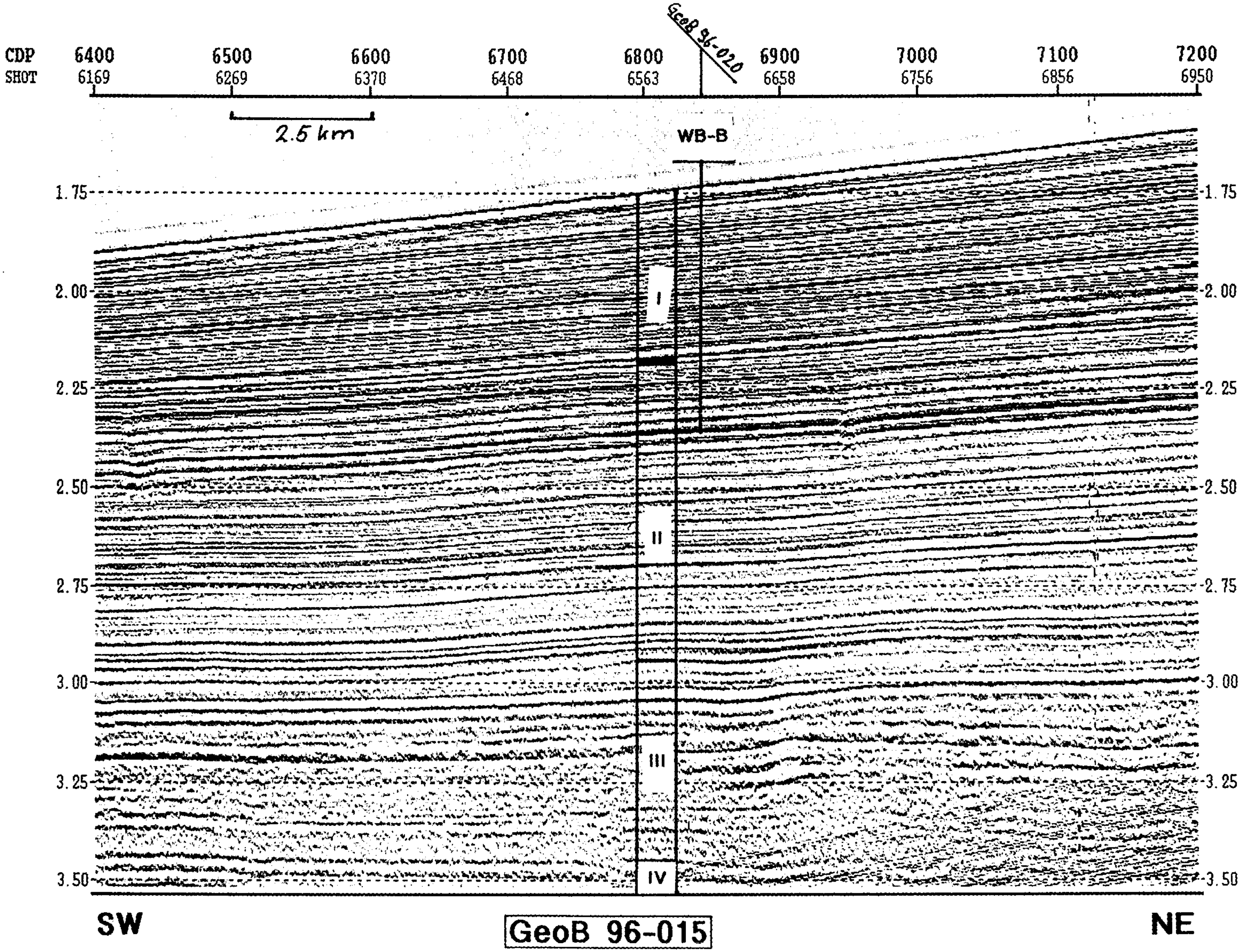
1. the history of the Benguela Current, and strength of coastal upwelling, as seen in filaments and in redeposited material from upslope; and

2. the climatic history of South Africa, as seen in terrigenous components.

Drilling Program:
Hole A: APC, XCB to refusal
Holes B and C: APC to refusal

Logging and Downhole: Triple-combo, GHMT, FMS

Nature of Rock Anticipated: Hemipelagic calcareous silty mud.



GeoB 96-020
CDP 6400 6500 6600 6700 6800 6900 7000 7100 7200
SHOT 6169 6269 6370 6468 6563 6658 6756 6856 6950
2.5 km
WB-B
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50
I
II
III
IV
SW
NE
GeoB 96-015

Site WB-B

Site: WB-C

Priority: 2
Position: 20°53.9'S, 11°13.4'E
Water Depth: 2201 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 600 mbsf
Seismic Coverage: High-resolution MCS survey, seismic Lines GeoB/AWI 96-017 and -021

Objectives: The objectives of WB-C are to determine:

1. the history of the Benguela Current, and strength of coastal upwelling, as seen in messages from filaments and in redeposited material from upslope.

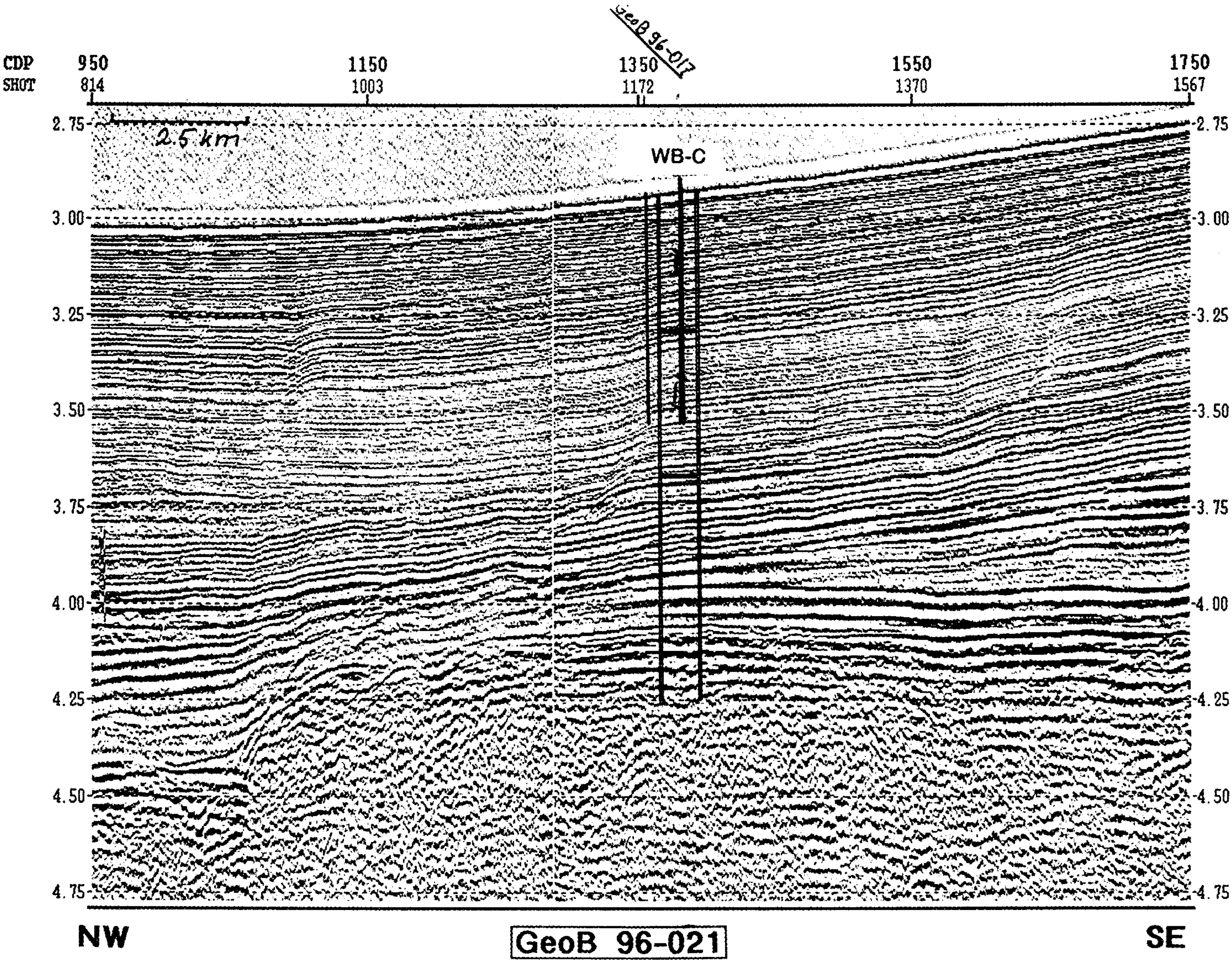
2. the climatic history of South Africa, as seen in terrigenous components.

Drilling Program:
Hole A: APC, XCB to refusal
Holes B and C: APC to refusal

Logging and Downhole*: Triple-combo, GHMT, FMS

Nature Of Rock Anticipated: Hemipelagic calcareous silty mud.

***Note:** It is anticipated that this site may not be drilled, or only drilled for APC, depending on time available. In the event that there is less than 250 m penetration, no logging or other downhole measurements will be attempted.



GeoB 96-017
CDP
SHOT
950
814
1150
1003
1350
1172
1550
1370
1750
1567
2.5 km
WB-C
2.75
3.00
3.25
3.50
3.75
4.00
4.25
4.50
4.75
NW
SE
GeoB 96-021

Site WB-C

Site: NCB-2B

Priority: 1
Position: 25°30.8'S, 13°1.7'E
Water Depth: 2004 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 600 m
Seismic Coverage: High-resolution MCS, seismic Line GeoB/AWI 96-014

Objectives: The objectives of NCB-2B are to:

1. determine the history of Benguela Current, including northward excursions and fluctuations in the intensity of productivity;

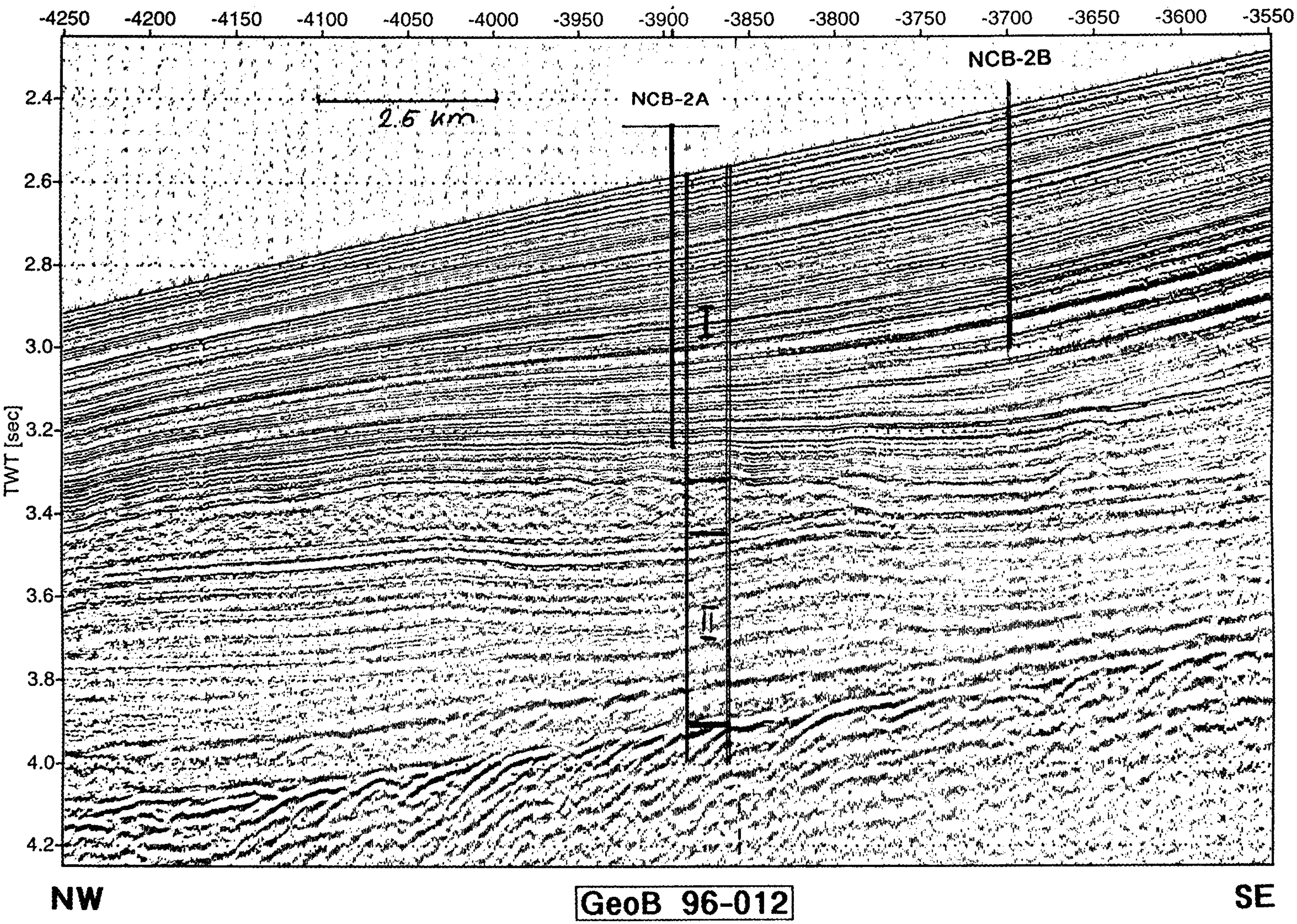
2. document shoreward/seaward migration of the coastal upwelling center; and

3. reconstruct the history of oxygen supply, in particular of periods showing oxygen deficiency.

Drilling Program:
Hole A: APC, XCB to refusal
Holes B and C: APC to refusal

Logging and Downhole: Triple-combo, GHMT, FMS

Nature of Rock Anticipated: Hemipelagic calcareous silty mud.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-4100
-4050
-4000
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-3900
-3850
-3800
-3750
-3700
-3650
-3600
-3550
NCB-2B
NCB-2A
2.5 km
I
II
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
4.2
TWT [sec]
NW
SE
GeoB 96-012

Site NCB-2B

Site: MCB-A

Priority: 2
Position: 29°22.5'S, 13°59.4'E
Water Depth: 1726 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 600 mbsf
Seismic Coverage: High-resolution MCS survey, seismic Lines GeoB/AWI 96-009 and -011

Objectives: The objectives of MCB-A are to:

1. explore early history of the Benguela Current in the southern Cape Basin, and

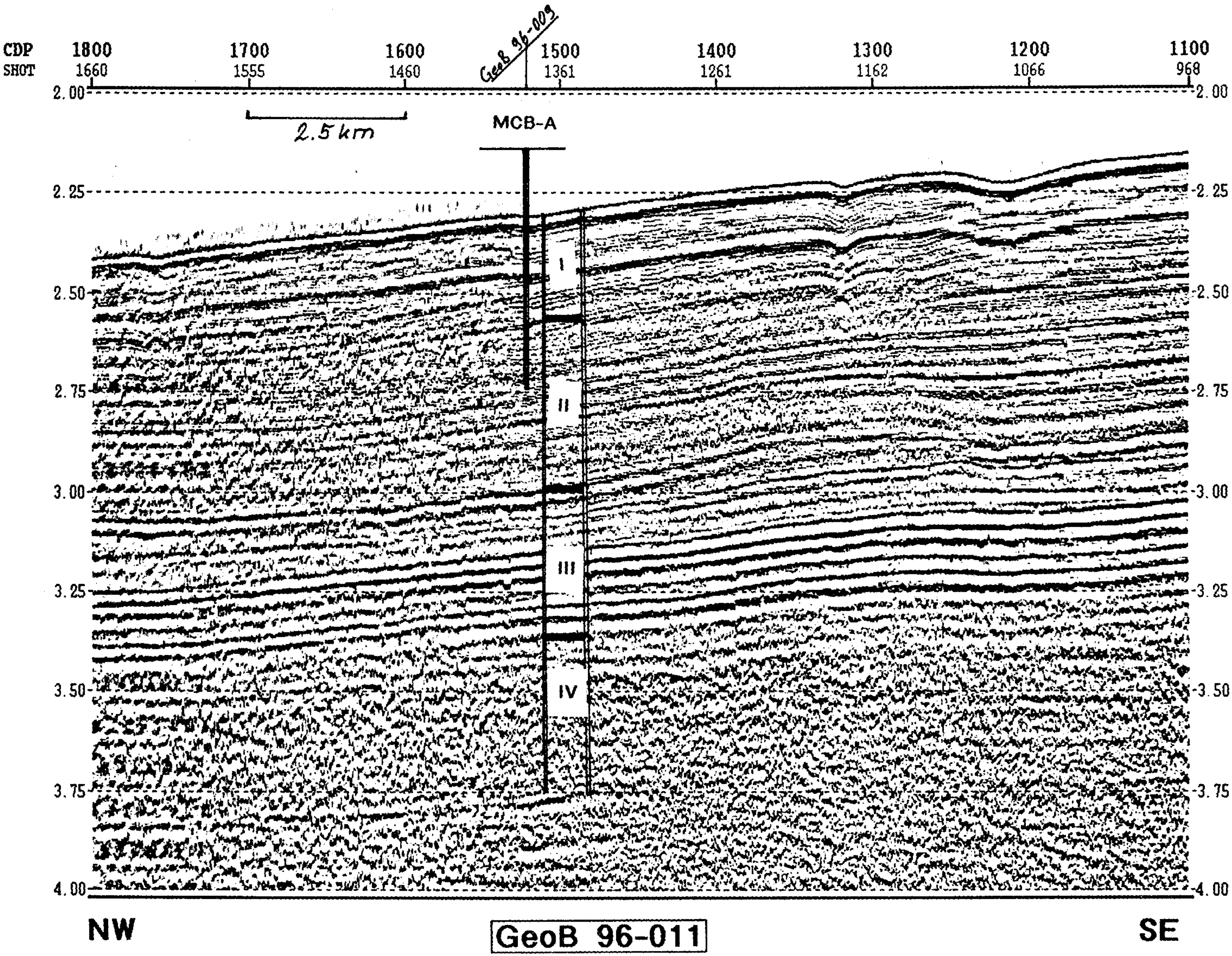
2. detect possible Angola Current influences.

Drilling Program:
Hole A: APC, XCB to refusal
Holes B and C: APC to refusal

Logging and Downhole*: Triple-combo, GHMT, FMS

Nature of Rock Anticipated: Hemipelagic calcareous silty mud.

***Note:** It is anticipated that this site may not be drilled, or only drilled for APC, depending on time available. In the event that there is less than 250 m penetration, no logging or other downhole measurements will be attempted.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SHOT
1800
1660
1700
1555
1600
1460
GeoB 96-009
1500
1361
1400
1261
1300
1162
1200
1066
1100
968
2.5 km
MCB-A
I
II
III
IV
2.00
2.25
2.50
2.75
3.00
3.25
3.50
3.75
4.00
NW
SE
GeoB 96-011

Site MCB-A

Site: SCB-1

Priority: 1
Position: 31°25.0'S, 15°17.0'E
Water Depth: 1350 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 600 mbsf
Seismic Coverage: High resolution MCS, Lines GeoB/AWI 96-003 and -008

Objectives: The objectives of SCB 1 are to:

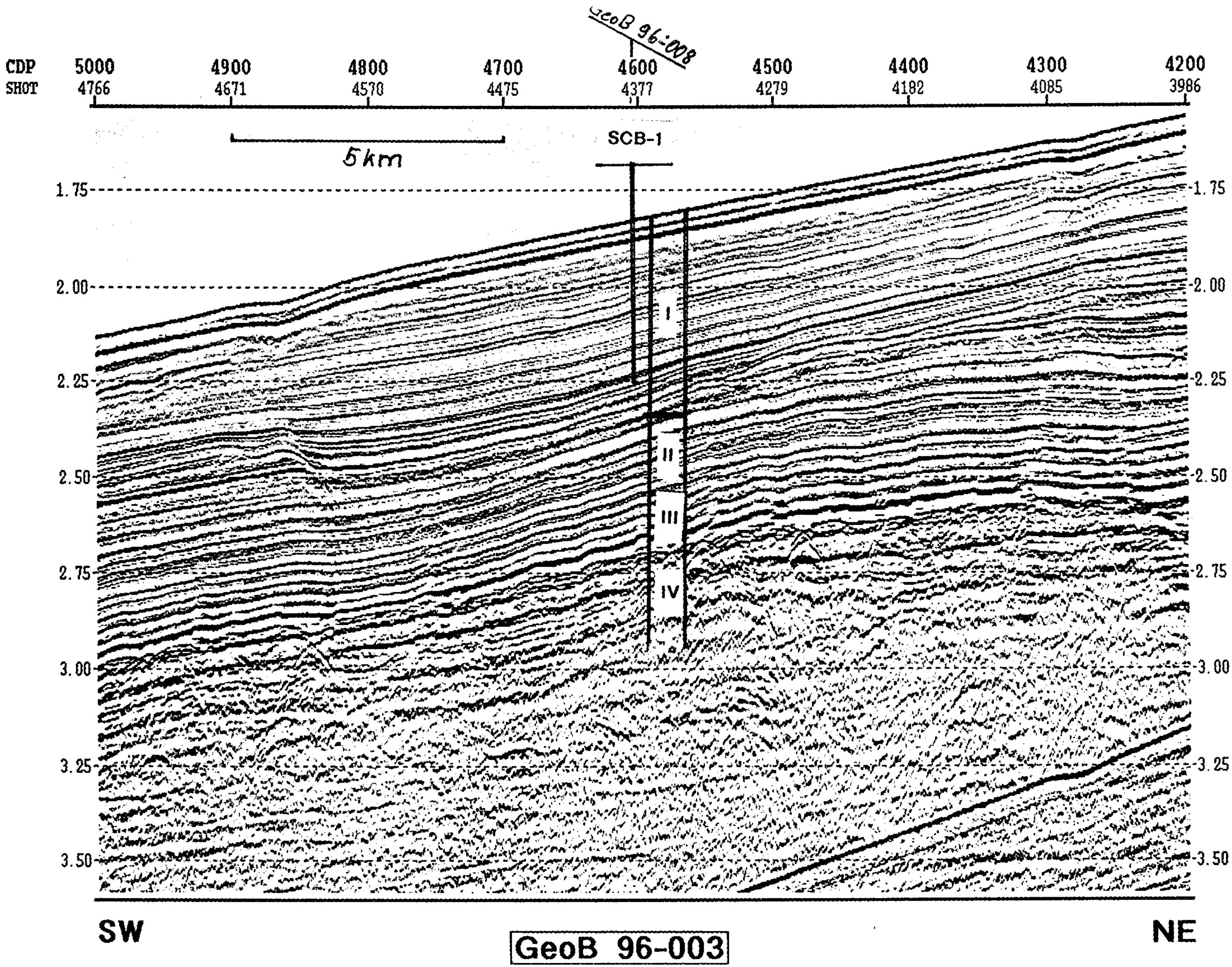
1. explore early history of the Benguela Current in the southern Cape Basin, and

2. detect possible Angola Current influences.

Drilling Program:
Hole A: APC, XCB to refusal
Holes B and C: APC to refusal

Logging and Downhole: Triple-combo, GHMT, FMS

Nature Of Rock Anticipated: Hemipelagic calcareous silty mud.


GeoB 96-008
CDP
SHOT
5000
4766
4900
4671
4800
4570
4700
4475
4600
4377
4500
4279
4400
4182
4300
4085
4200
3986
SCB-1
5km
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50
I
II
III
IV
SW
NE
GeoB 96-003

Site SCB-1

Site: SCB-A

Priority: 2
Position: 31°54.4'S, 15°14.1'E
Water Depth: 2234 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 600 mbsf
Seismic Coverage: High-resolution MCS survey, seismic Lines GeoB 96-001 and -004

Objectives: The objectives of SCB-A are to:

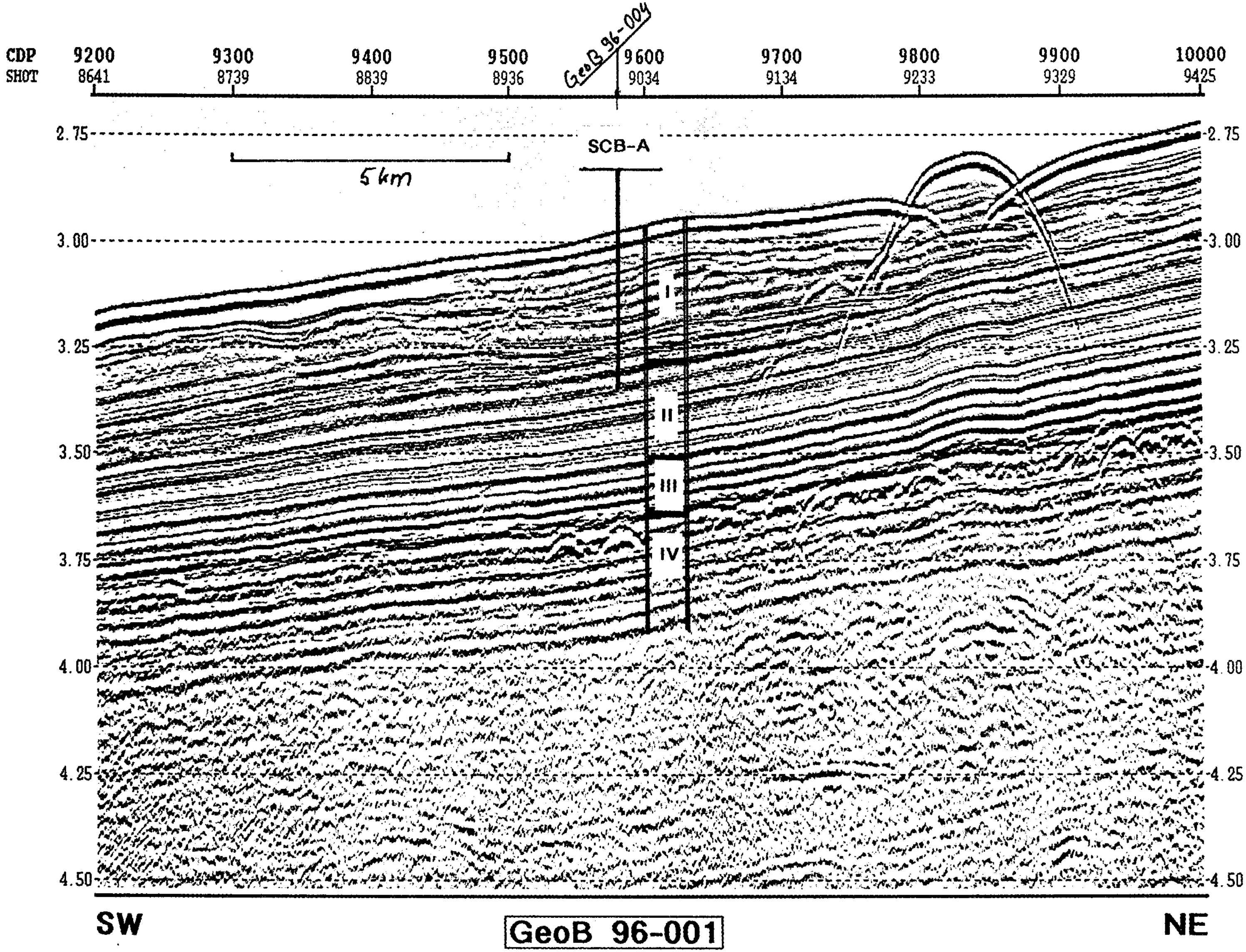
1. explore early history of the Benguela Current in the southern Cape Basin, and
2. detect possible Angola Current influences.

Drilling Program:
Hole A: APC, XCB to refusal
Holes B and C: APC to refusal

Logging and Downhole*: Triple-combo, GHMT, FMS

Nature of Rock Anticipated: Hemipelagic calcareous silty mud.

***Note:** It is anticipated that this site may not be drilled, or only drilled for APC, depending on time available. In the event that there is less than 250 m penetration, no logging or other downhole measurements will be attempted.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SHOT
9200
8641
9300
8739
9400
8839
9500
8936
GeoB 96-004
9600
9034
9700
9134
9800
9233
9900
9329
10000
9425
SCB-A
5 km
I
II
III
IV
2.75
3.00
3.25
3.50
3.75
4.00
4.25
4.50
SW
NE
GeoB 96-001

Site SCB-A

Site: SCB-B

Priority: 2
Position: 31°47.1'S, 15°30.0'E
Water Depth: 1507 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 600 mbsf
Seismic Coverage: High-resolution MCS survey, seismic Lines GeoB 96-001 and -008

Objectives: The objectives of SCB-B are to:

1. explore early history of the Benguela Current in the southern Cape Basin, and

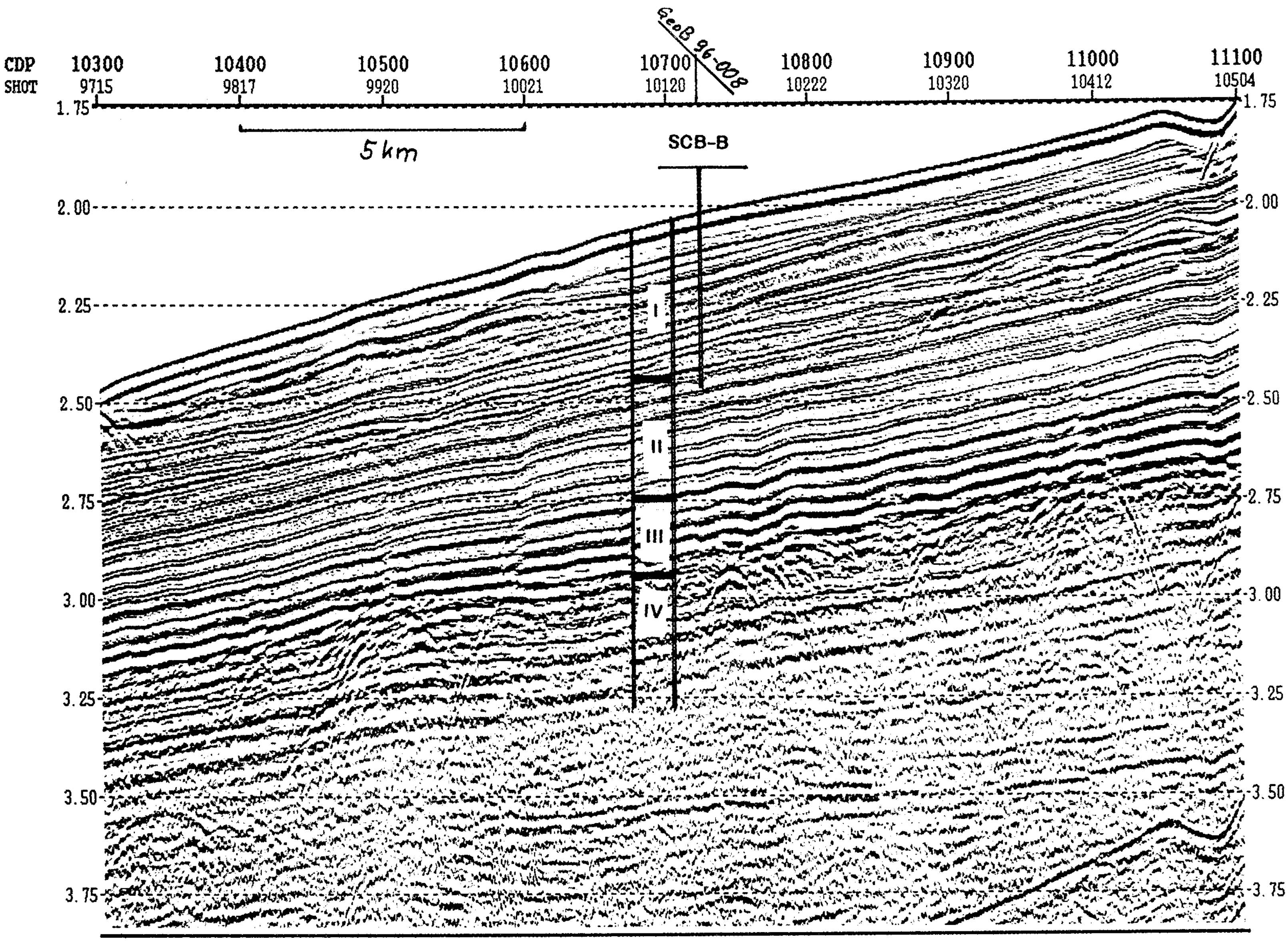
2. detect possible Angola Current influences.

Drilling Program:
Hole A: APC, XCB to refusal
Holes B and C: APC to refusal

Logging and Downhole*: Triple-combo, GHMT, FMS

Nature of Rock Anticipated: Hemipelagic calcareous silty mud.

***Note:** It is anticipated that this site may not be drilled, or only drilled for APC, depending on time available. In the event that there is less than 250 m penetration, no logging or other downhole measurements will be attempted.



GeoB 96-001

Site SCB-B

Site: SCB-C

Priority: 2
Position: 31°41.4'S, 15°41.9'E
Water Depth: 887 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 600 mbsf
Seismic Coverage: High-resolution MCS survey, seismic Lines GeoB 96-001 and -006

Objectives: The objectives of SCB-C are to:

1. explore early history of the Benguela Current in the southern Cape Basin, and

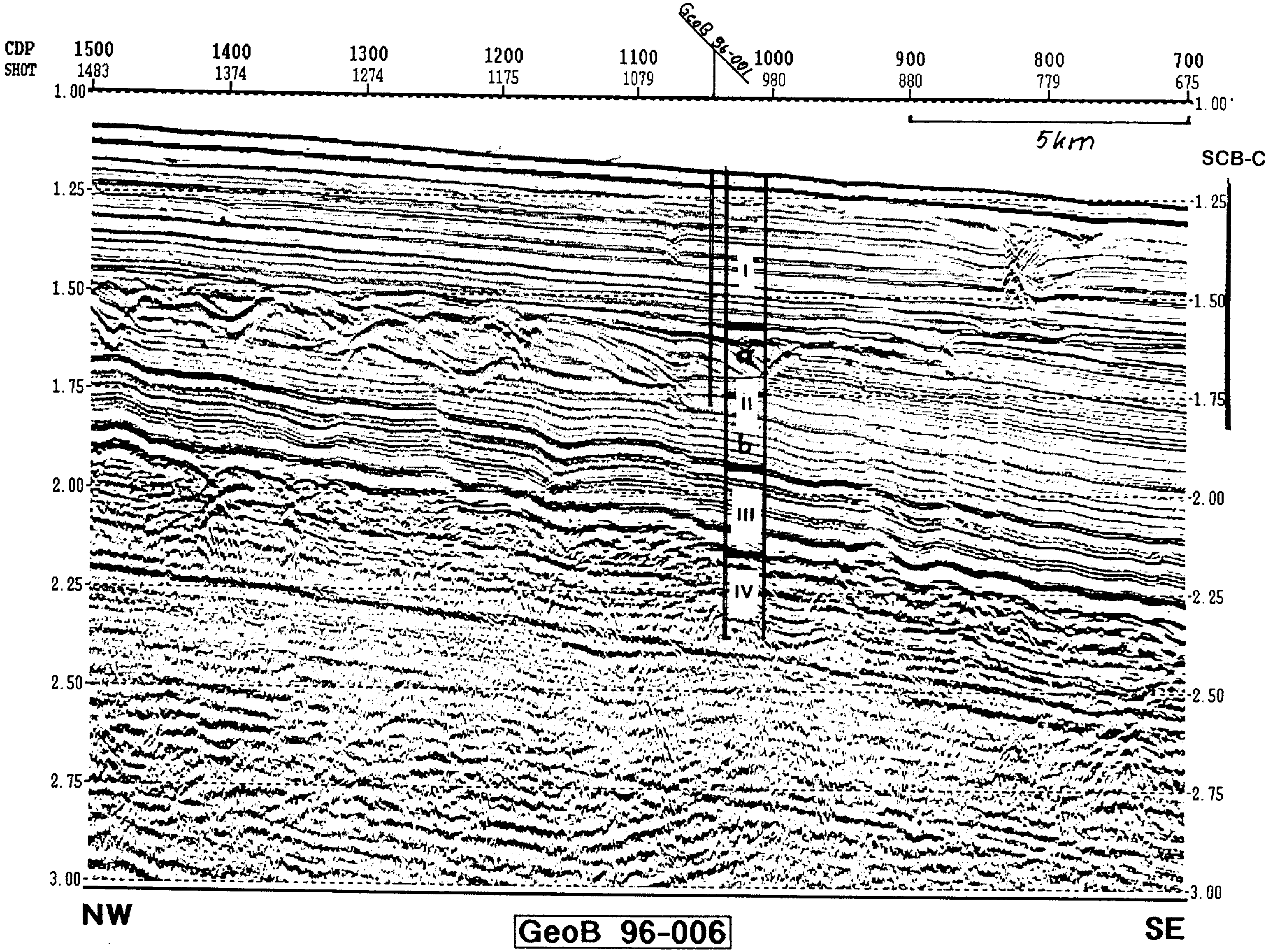
2. detect possible Angola Current influences.

Drilling Program:
Hole A: APC, XCB to refusal
Holes B and C: APC to refusal

Logging and Downhole*: Triple-combo, GHMT, FMS

Nature of Rock Anticipated: Hemipelagic calcareous silty mud.

***Note:** It is anticipated that this site may not be drilled, or only drilled for APC, depending on time available. In the event that there is less than 250 m penetration, no logging or other downhole measurements will be attempted.



CDP
SHOT
1500
1483
1400
1374
1300
1274
1200
1175
1100
1079
GeoB 96-006
1000
980
900
880
800
779
700
675
5km
SCB-C
1.00
1.25
1.50
1.75
2.00
2.25
2.50
2.75
3.00
I
a
II
b
III
IV
NW
SE
GeoB 96-006

Site SCB-C

Site: SCB-D

Priority: 2
Position: 31°21.3'S, 15°36.5'E
Water Depth: 778 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 600 mbsf
Seismic Coverage: High-resolution MCS survey, seismic Lines GeoB 96-003 and -006

Objectives: The objectives of SCB-D are to:

1. explore early history of the Benguela Current in the southern Cape Basin, and

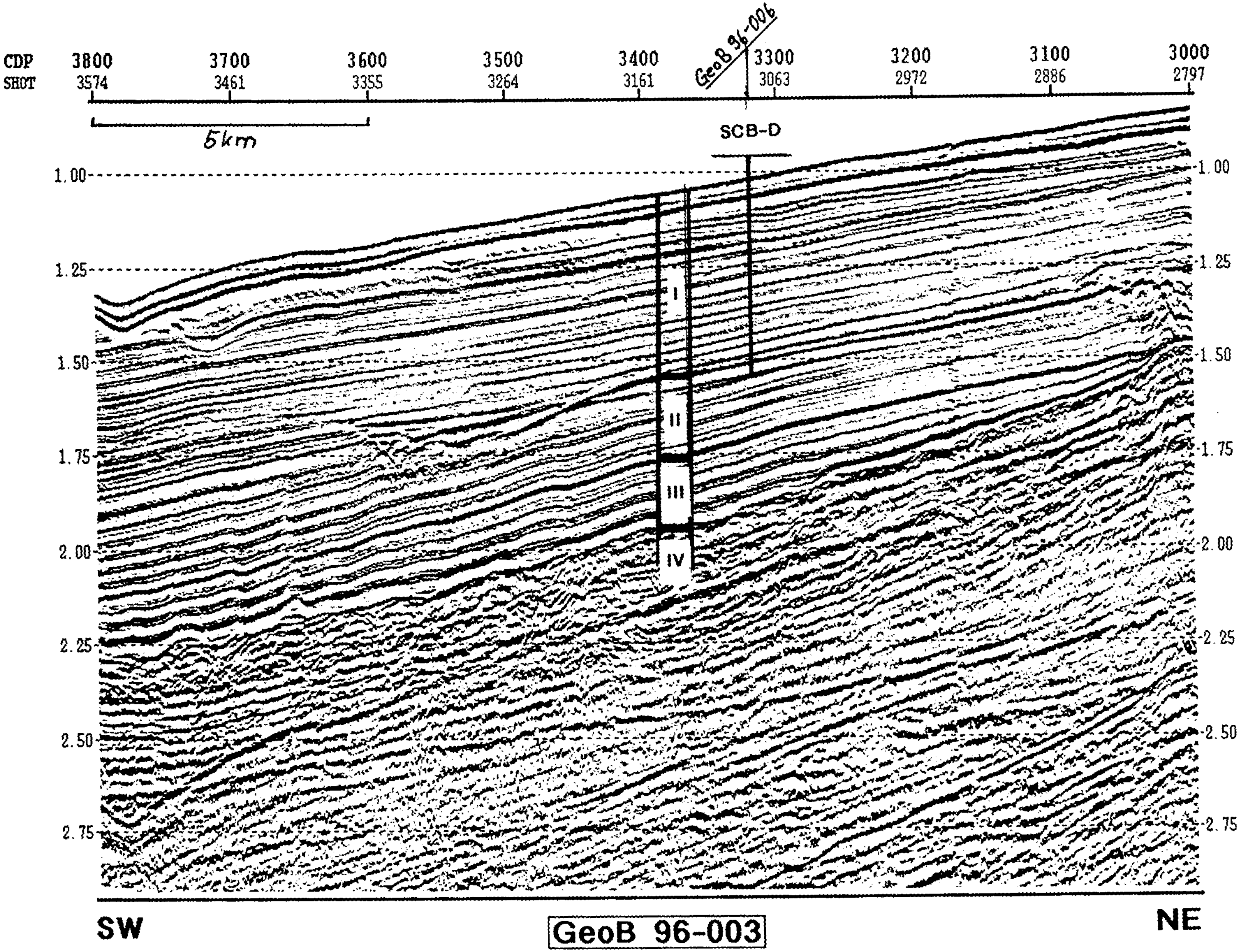
2. detect possible Angola Current influences.

Drilling Program:
Hole A: APC, XCB to refusal
Holes Band C: APC to refusal

Logging and Downhole*: Triple-combo, GHMT, FMS

Nature of Rock Anticipated: Hemipelagic calcareous silty mud.

***Note:** It is anticipated that this site may not be drilled, or only drilled for APC, depending on time available. In the event that there is less than 250 m penetration, no logging or other downhole measurements will be attempted.



CDP
SHOT
3800
3574
3700
3461
3600
3355
3500
3264
3400
3161
GeoB 96-006
3300
3063
3200
2972
3100
2886
3000
2797
5km
SCB-D
1.00
1.25
1.50
1.75
2.00
2.25
2.50
2.75
I
II
III
IV
SW
NE
GeoB 96-003

Site SCB-D

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