OCEAN DRILLING PROGRAM

LEG 121 SCIENTIFIC PROSPECTUS

BROKEN RIDGE / NINETYEAST RIDGE

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March 1988

Scientific Prospectus No. 21
First Printing 1988

Distribution

Copies of this publication may be obtained from the Director, Ocean Drilling Program, Texas A&M University Research Park, 1000 Discovery Drive, College Station, Texas 77840. In some cases, orders for copies may require a payment for postage and handling.

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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:

Department of Energy, Mines and Resources (Canada)
Deutsche Forschungsgemeinschaft (Federal Republic of Germany)
Institut Francais 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, Greece, the Netherlands, Norway, Spain, Sweden, Switzerland and Turkey)

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INTRODUCTION

The Indian Ocean was formed by a complex series of seafloor spreading events, beginning with the separation of Madagascar from Africa and the separation of "greater India" from northwest Australia in the Late Jurassic (Rabinowitz, et al., 1983; Larson, 1977). During the Early Cretaceous following separation from Antarctica, India began to move northward (Sclater and Fisher, 1974; Schlich, 1975), and the hotspot traces represented by the Ninetyeast and Chagos-Laccadive ridges began to form (Luyendyk and Rennick, 1977; Peirce, 1978; Duncan, 1978, 1981). The last major reorganization in spreading occurred when Australia separated from Antarctica during the Late Cretaceous (Cande and Mutter, 1982) followed by the separation of the Kerguelen Plateau from Broken Ridge during the late Eocene (Mutter and Cande, 1983; Mutter et al., 1985) and the nearly contemporaneous cessation of spreading in the Wharton Basin (Schlich et al., 1985; Liu et al., 1983). Figure 1 shows these features and the locations of previous DSDP and ODP drill sites in the eastern Indian Ocean.

The general objective of the first part of Leg 121 is to study rifting mechanisms at Broken Ridge. In particular, drilling results are intended to relate the age of tilting of the syn-rift and pre-rift sediments to the known age of initiation of seafloor spreading between the southern margin of Broken Ridge and the Kerguelen Plateau. These objectives complement the tectonic objectives of ODP Legs 119 and 120.

The general objectives of the second part of Leg 121 are to study the geochemical relationships in space and time between the Ninetyeast Ridge and the Kerguelen hotspot, to derive a detailed northward motion curve for India, thereby providing further insight into the tectonic mechanisms of the Himalayan Orogeny, and to provide a north-south paleontological and paleoclimatological transect of the eastern Indian Ocean at depths shallower than the carbonate compensation depth. These objectives complement the objectives of ODP Legs 115, 116, 117, 119, and 120.

This prospectus is compiled from drilling proposals and ideas submitted to the JOIDES planning structure by Weissel and Karner (1985), Frey and Sclater (1985), Peirce (1985), Weissel (1987), and Curray (1987), with contributions from Frey, Gibson, Rea, and Pospichal. Most of the data upon which these sites are based were collected on site survey cruises RC 2705 (Curray), RC 2707 (Sclater) and RC 2708 (Weissel).

DRILLING ON BROKEN RIDGE

Broken Ridge was originally contiguous with the northern portion of the Kerguelen-Gaussberg Plateau. Lithospheric extension (rifting), followed by seafloor spreading which began at anomaly 18-time (~42 Ma - middle Eocene), together are responsible for the present separation of the two platforms (Fig. 2). Previous drilling at DSDP Site 255 on Broken Ridge (Fig. 3) established that the basement age there is greater than Santonian (~85 Ma). Dredged basaltic rocks suggest that basement on Broken Ridge and the corresponding portion of the Kerguelen Plateau originated from intraplate volcanism in the Early or mid-Cretaceous.

Background: Tectonic Setting and Lithospheric Flexure

The effects of the rifting process on Broken Ridge are clearly seen in the seismic stratigraphy (Figs. 4 and 5). In the parlance of detachment tectonics, Broken Ridge west of about 94°E is a simple, flexurally uplifted footwall block (or lower plate) of an extensional domain. Flexural uplift during rifting was probably due to unloading of the footwall block as the hanging wall block (containing the adjacent portion of Kerguelen Plateau) moved southward along the detachment. We can theoretically model the flexural isostatic response of the lithosphere when the footwall is unloaded by removal of the hanging wall (Fig. 6). The model is shown in the inset (Fig. 6, top), and the resulting topography (Fig. 6, bottom) depends strongly on whether the lithosphere has finite strength (flexural rigidity) at the time of rifting. We can match the morphology of Broken Ridge quite closely with this model (Fig. 7) if we assume that the flexural rigidity at the time of rifting is that of 25-m.y.-old oceanic lithosphere. Gravity anomalies observed over Broken Ridge support the idea that Broken Ridge is a flexurally uplifted footwall block as shown in Figure 7.

Two important consequences of flexural uplift of Broken Ridge during rifting are (1) tilting of pre-existing strata on the flexed region, and (2) exposure of an E-W trending ridge, initially ~1000 m above Paleogene sea level (as depicted in Fig. 7). Erosion of this exposed material and post-rift subsidence of Broken Ridge produced a distinctive angular unconformity overlain by thin mid-Eocene lagoonal sediments (Figs. 4 and 5). Continued subsidence to the present day has allowed a Neogene pelagic cap to be deposited on the crest of Broken Ridge (Figs. 4 and 5). A critical question for future drilling then is: How much of the (>~1500 m-thick) dipping and truncated stratigraphic section (Figs. 4 and 5) is pre-rift, syn-rift, and post-rift (or is it all pre-rift)?

Advantages of Drilling at Broken Ridge

The stratigraphy preserved on Broken Ridge has enormous potential for increasing our understanding of lithospheric extension processes. Since Broken Ridge has remained a relatively shallow-water platform throughout its history, it has accumulated depth-sensitive, carbonate-rich sediments before, after, and possibly during the extensional episode. Therefore, its stratigraphy probably recorded the vertical motions of the ridge as it responded to the rifting processes. Moreover, since Broken Ridge has always been isolated from nearby continents it lacks the thick, non-fossiliferous, clastic sequences which limit studies of rifting processes by drilling along many passive continental margins. One other feature that makes Broken Ridge attractive for studying rifting mechanisms is that the end of rifting and the initiation of seafloor spreading at ~42 Ma is well-constrained from magnetic lineations along the southern margin of Broken Ridge.

Drilling Objectives

The main question for drilling at Broken Ridge is whether it was deepening or shallowing with time prior to rifting. If drilling shows that Broken Ridge was shallowing prior to rifting, we would conclude that the rifting resulted from asthenospheric processes (i.e., heat transported to the base of the lithosphere by mantle convection) because precursory uplift is a likely consequence of such "active" rifting processes. In contrast, if drilling shows that Broken Ridge was deepening prior to rifting, we would conclude that extension was driven by far-field horizontal stress, and that footwall uplift by flexure was the only significant response to the process of rifting at Broken Ridge.

To attain this primary objective requires that we know what part of the stratigraphy is pre-rift versus post-rift (and syn-rift, if any), plus the age and depth of deposition of those units. The middle Eocene lagoonal unit and the Neogene cap are obviously post-rift deposits, and previous drilling at Site 255 (Fig. 5) has shown that the outermost shelf/upper slope limestones and cherts of Santonian age were probably deposited before rifting began. However, the age and facies of most of the dipping and truncated section are unknown. We are therefore proposing to drill a short N-S transect of four holes (BR-1 through BR-4) across the crestal region of Broken Ridge (Figs. 3 and 4, Table 1).

By drilling this transect of holes, we will sample most of the dipping and truncated sequence in single-bit holes, at sites located to ensure some overlap of section. We hope to establish, from the presence or absence of reworked limestone and chert detritus, whether the section is completely pre-rift, or if it includes syn-rift (the middle highly reflective unit and the upper transparent unit), and even post-rift sections as well (Figs. 4 and 5). Drilling at proposed site BR-3 will also verify that the shallow-water lagoonal deposits overlying the erosional unconformity are middle Eocene -- roughly equivalent in age to the oldest magnetic lineation observed between Broken Ridge and the Kerguelen Plateau.

Summary

Although the discrimination between "active" and "passive" driving mechanisms for lithospheric extension forms the basis for drilling during ODP Leg 121, flexural uplift at Broken Ridge has important implications for the rheology of the lithosphere. It is widely believed that the lithosphere has no strength during rifting, and that it responds to subsidence and uplift producing forces in a local isostatic manner. However, the topography observed at Broken Ridge in the vicinity of the drill sites is flexural in origin and requires that the lithosphere maintained finite strength during the extensional episode.

DRILLING ON THE NINETYEAST RIDGE

Background

The Ninetyeast Ridge is an impressive north-south lineament in the eastern Indian Ocean. It extends from 34°S to 10°N, a distance of some 5000 km, before being buried by the sediments of the Bengal Fan. The average relief of the Ninetyeast Ridge varies from 1500 to 3000 m, and some peaks on its southern end rise to a water depth of 700 m.

Previous drilling results from DSDP Legs 22 and 26 showed that the basalts forming the basement of Ninetyeast Ridge erupted in shallow water or subaerially, ages increase northward on the ridge and are roughly the same as basement ages of the Indian Plate to the west, basement paleolatitudes are all near 50°S, and the basalt geochemistry is similar to lavas of oceanic islands.

The interpretation of these results is that the Ninetyeast Ridge formed as the trace of the Kerguelen hotspot on the Indian Plate before rifting at the Southeast Indian Ridge separated Kerguelen from the Indian Plate in the middle Eocene (anomaly 18 time). The interpretation of the origin and structure of the Ninetyeast Ridge is complicated by a major transform fault with left lateral offset which lies immediately east of the Ninetyeast Ridge. The history of the Ninetyeast Transform is poorly understood, but it is presumed to have connected the Central Indian Ridge to the Wharton Basin Ridge until about anomaly 18 time, when spreading in the Wharton Basin ceased.

Petrologic Objectives

The principal petrologic objective of drilling on the Ninetyeast Ridge is to obtain geochemical and petrological data from the basement rocks, to understand the origin of the Ninetyeast Ridge and its relationship, if any, to the Kerguelen Plateau.

Previous Drilling Results

During DSDP Legs 22 and 26 four sites recovered basaltic basement from the Ninetyeast Ridge: Sites 214, 216, 253, and 254 (Fig. 1). The following conclusions were reached from studies of these basalts:

(1) The age of the basalts increases systematically from south to north (Duncan, 1978).

(2) The trace element and radiogenic isotope characters of these Ninetyeast Ridge lavas are similar to those of oceanic island basalts and unlike depleted Indian Ocean MORB. In detail, the radiogenic isotope signature of Ninetyeast Ridge basalts is most similar to lavas from Kerguelen Island; however, Kerguelen lavas exhibit considerable isotopic heterogeneity (Figs. 8, 9; Mahoney et al., 1983; Weis et al., 1987).

(3) Relatively "evolved" lavas may characterize the Ninetyeast Ridge. At Sites 214 and 216, the recovered lavas are ferro-basalts, and at Site 214 these are overlain by oceanic andesite (e.g., Frey et al., 1977; Ludden et al., 1980).

When coupled with the northward age increase of the uppermost basement, the isotopic data favor formation of the Ninetyeast Ridge as a hot-spot trace formed by northward movement of the Indian plate over a hot-spot related to Kerguelen Island (Duncan, 1978; Mahoney et al., 1983).

Questions to Be Answered by Additional Basement Drilling

Is there a systematic variation in age and isotopic character between basement sites on the Ninetyeast Ridge? The very limited isotopic data for Ninetyeast lavas, recovered by DSDP drilling, show that each of the sites is isotopically distinct (Figs. 8 and 9) with the most enriched characteristics at the northernmost site (216). However, the data are insufficient to determine if this variation is systematic. Basement recovery at three additional Ninetyeast Ridge sites on Leg 121 will enable evaluation of temporal geochemical changes and further test the isotopic similarity of Ninetyeast Ridge and Kerguelen lavas. Also, improvements in analytical techniques for extracting the magmatic isotopic signature from altered seafloor rocks (e.g., Mahoney, 1988) will enable more thorough isotopic characterization of the basement rocks recovered by ODP drilling.

The isotopic data obtained for Ninetyeast Ridge basement lavas will also have broader implications because oceanic lavas in the Indian Ocean as a whole have geochemical characteristics distinct from most Pacific and Atlantic oceanic basalts (e.g., Hart, 1984). An understanding of the origin and evolution of the Ninetyeast Ridge will aid in understanding the large-scale problem of why the Indian Ocean lavas are geochemically distinct.

Does the Ninetyeast Ridge contain an unusually high proportion of relatively evolved rocks? The recovery of evolved lavas, ferrobasalts and oceanic andesites at DSDP Sites 214 and 216 may have important implications. These two sites are separated by about 13 degrees of latitude and perhaps in age by 22 m.y. (Duncan, 1978). It is possible that these evolved lavas are characteristic of the uppermost parts of the Ninetyeast Ridge. The extensive melt-mineral segregation required to form ferrobasalts and associated andesite requires a tectonic environment whereby magma storage regions are able to cool significantly without frequent replenishment by primitive magma. Such environments are rare on the mid-oceanic ridges, and are more commonly associated with volcanic islands. One possible explanation for the observed Ninetyeast Ridge basalts is that these evolved lavas formed in isolated magma chambers as a result of low magma production rates as the site moved northward off the "hot-spot."

Can the composition of the basement lavas be related to that of the overlying pyroclastic rocks? It is anticipated that the section immediately overlying the basement at all the proposed sites will contain significant pyroclastic sequences. Interpretation of the seismic record at proposed site NER-2 on the central part of the ridge suggests there is a significant chance of encountering intercalated lavas and pyroclastics. An objective of coring these sediments, therefore, is to determine how this later volcanism on the ridge relates temporally and perhaps chemically to the basement lavas cored at those sites.

The three Ninetyeast Ridge basement sites to be drilled on Leg 121 have estimated upper basement ages of 40 to 75 Ma (Fig. 4 of Duncan, 1978). Study of these basement cores will provide a sampling density sufficient to: (1) narrowly constrain the northward increase in age; (2) evaluate the relative abundance of highly evolved lavas in the uppermost basement; and (3) define temporal geochemical changes in the southern part of the ridge. In addition, penetration and recovery to basement depths of more than 50 m will provide geochemical data for evaluating temporal changes at a single site. By analogy with Hawaiian volcanism, changes in lava type and composition are expected as a site moves away from the principal source of magma production (e.g., Chen and Frey, 1985). By analogy with Icelandic volcanism, the intensity of a plume source waxes and wanes on the scale of a few million years, and systematic geochemical changes are expected (e.g., Hanan and Schilling, 1986, 1987).

Northward Motion Objectives

A primary tectonic objective of drilling on the Ninetyeast Ridge is to complete a high-resolution study of the northward motion of India by studying the paleomagnetic inclinations of the sedimentary and basement rocks recovered on the Ninetyeast Ridge. These results will be combined with similar results obtained from the Chagos-Laccadive Ridge on Leg 115 in order to improve our understanding of the Himalayan Orogeny and the sedimentary and tectonic histories of the surrounding basins.

Results from Previous Studies

Previous geological investigations of the Himalayan Orogeny put the time of initial collision somewhere in the Paleogene. The differences in exact timing seem to arise from two factors -- which part of the suture one is discussing and whether one is referring to the initial collision of a leading block (island arc or microcontinent) or to the final continent-continent collision.

There is a stronger case to be made for earlier initial collision in the west than in the east. In the Ladakh region, stratigraphic evidence suggests that parts of the Asian accretionary wedge south of Tibet were emplaced onto Greater India by early Paleocene time (Fuchs, 1983). This event was followed later by obduction of the Zhob Valley ophiolites during the Paleocene or early Eocene (Alleman, 1979). Geological evidence in the Lhasa region suggests that Asian sediments were emplaced onto Greater India before Eocene time (Burg and Chen, 1984; Allegre et al., 1984), somewhat later than the analogous events to the west.

Paleomagnetic studies of the northward motion of India indicate that an abrupt slowing took place between 40 Ma (Molnar and Tapponnier, 1975; Peirce, 1978; Fig. 10) and 50 Ma (Besse et al., 1984; Patriat and Achache, 1984; Figs. 11, 12). Either result implies that slowing took place several million years later than collision.

Klootwijk et al. (1985) synthesized the above observations into a model which suggests that suturing migrated eastward during the Paleocene and was completed by early Eocene time. Further convergence was accommodated by lateral extrusion of continental blocks in a manner similar to the analogue clay models of Tapponnier et al. (1986), followed by oroclinal bending and continental underthrusting since the late Miocene. Patriat and Achache (1984) proposed a somewhat different synthesis which puts continental subduction somewhat later (middle Eocene), followed by underthrusting and internal deformation during the late Eocene, and then by lateral extrusion, following the Tapponnier et al. (1986) model.

Any model must be consistent with three critical pieces of stratigraphic evidence indicative of the time of earliest uplift of the Himalayas, namely:

(1) The age of the Rawalpindi Group (first molasse sediments) in Pakistan is Miocene, and it rests on Eocene or older rocks, suggesting that the unconformity associated with initial loading of the Indian Plate is of Oligocene age (Igbal and Shah, 1980).

(2) The Bengal Fan was well established by early Miocene time (Cochran, Stow, and Shipboard Scientific Party, 1987, Leg 116 Preliminary Report).

(3) The rifting of the South China Sea margin occurred in the Oligocene in response to extrusion tectonics associated with the Himalayan Orogeny (Fig. 10 of Tapponnier et al., 1986).

Questions to Be Answered by Drilling

The slowing of the Indian Plate was presumably related to a change in the balance of the plate driving forces. Drilling during Leg 121 is aimed at improving our understanding of these forces by combining a study of the details of the slowing with the onshore evidence of collision. Important questions to be answered include: Was the slowing of northward motion coincident with the onset of the extrusion of continental blocks resulting in the widespread deformation of southern Asia, as the first model described above suggests? Or, alternatively, was the slowing related to the onset of continental subduction, as the second model above suggests? Was the slowing really abrupt or did it take place over some 10 million years? The answer to this last question may provide a major constraint for models of plate driving forces and of continental collision.

Paleoceanographic and Paleoclimatological Objectives

Paleoceanographic and paleoclimatological objectives of drilling at Ninetyeast Ridge involve establishing a north-south transect of sites with high core recovery in the eastern Indian Ocean. This transect would extend the results from Legs 119/120 in the austral Indian Ocean and would parallel the transect obtained by Leg 115 in the western Indian Ocean.

Results from Previous Studies

Paleoceanography

Present day middle- and low-latitude Indian Ocean water masses are separated into three zones (Be and Hutson, 1977): Equatorial Water, Central Water and a Tropical-Subtropical Transition Zone. Two major systems characterize Indian Ocean circulation: the seasonally changing monsoon gyre in the equatorial region and the subtropical anticyclonic gyre of the Central Water region (Wyrtki, 1973). High-nutrient, low-oxygen waters are described by Wyrtki to characterize the monsoonal gyre in the northern Indian Ocean and low-nutrient, high-oxygen waters in the subtropical gyre. Sediment patterns on either side of the Ninetyeast Ridge reflect this boundary between high and low productivity with siliceous sediments present in the area of high productivity north of about 15°S and pelagic clays characterizing areas of low productivity to the south.

The sediment record from various Indian Ocean sites indicates that oceanic conditions in the past differed significantly from present-day conditions. Muller (1977) reported that during the Oligocene, lower water temperatures may have contributed to low production of calcareous microfossils, lower species diversity and condensed sections due to dissolution at or below the CCD in the deep sea basins of the Indian Ocean. Kennett et al. (1972) suggested that such conditions resulted from the influx of cold circumpolar water masses deflected into the lower latitudes of the Indian Ocean by Australia. These cold water masses were responsible for strong bottom current activity which, through erosion and/or winnowing, resulted in lower Oligocene sedimentary gaps. This flux of cold water reported by Kennett and Burns, (1972) and the circulation changes due to the final establishment of the Circumpolar Current at the end of the Oligocene should be reflected in the flora and fauna of Broken Ridge and Ninetyeast Ridge.

Cooling during the late Miocene moved the area of optimum conditions for the foraminifer genus Globoquadrina north of 25°S (Vincent, 1977). Muller (1977) reported an increase in diversity and productivity in the nannofossils, notably discoasters, ceratoliths and scyphospheres, from the middle Miocene to the lower Pliocene. Nannoplankton and foraminifer assemblages (Vincent, 1977) reflect tropical to subtropical conditions during that time. The onset of the modern equatorial circulation pattern, concurrent with significant ice accumulation on Antarctica during the late Miocene, is marked by an increase in sediment accumulation rates and in the abundance of siliceous fossils at all low-latitude sites in the Indian Ocean (Vincent, 1977).

Core recovery during Leg 22 on the Ninetyeast Ridge was far from complete. The intended Leg 121 program is to recover a complete section at the northern site (NER-1A for the Neogene and NER-1B for the Paleogene) and at the central site (NER-2). It is unlikely that the section at the southern site (NER-5) will be particularly useful because much of the thin section present there is expected to be volcaniclastic. The sites from Broken Ridge (30°S) plus those proposed on the Ninetyeast Ridge offer an excellent opportunity to promote further study on the evolution and establishment of the present Indian Ocean circulation patterns and sea surface conditions using temperature sensitive planktonic foraminifers, calcareous nannoplankton, and siliceous microplankton groups.

Paleoclimatology

Eolian dust from pelagic sediments provides a quantitative record of both the intensity of zonal winds and the aridity of the eolian source area. Continuous Cretaceous to Holocene records from the Northern Hemisphere (Rea et al., 1985) document generally increasing wind intensity and growing continental aridity concurrent with middle to late Cenozoic polar cooling. A significant change in wind intensity appears to have occurred during the early Eocene, shifting from more vigorous Cretaceous and Paleocene circulation to greatly reduced Eocene and Oligocene circulation. These data, recently confirmed from the North Atlantic (McCave and Lever, 1986), are contrary to the general perception of rather sluggish oceanic circulation during the Late Cretaceous and earliest Tertiary. The North Pacific cores are based largely on red clay cores, and consequently the atmospheric circulation history inferred from them is not well tied to the standard $\delta^{18}O$ history used by paleoceanographers.

Results of similar efforts based on Leg 92 drilling in the South Pacific and tied to standard fossil zonations indicate that important changes in atmospheric circulation may not coincide with the episode of ice volume increase recorded in middle Miocene sediments. There is, however, a close correspondence between that atmospheric circulation record and the record of equatorial sea surface productivity (Rea and Bloomstine, 1986). Further, the results from the South Pacific indicate no change in atmospheric circulation that corresponds with the onset of Northern hemisphere glaciation recorded in middle Pliocene sediments.

Questions to Be Answered by Drilling

The next step in determining the Cenozoic record of atmospheric circulation is to recover continuous, stratigraphically useful sections of pelagic sediment along a longitudinal transect from the Southern Hemisphere. The Southern Indian Ocean is clearly the best place to go because it lies between the deserts of Africa and Australia, implying an adequate source of dust. The locations on top of the Ninetyeast Ridge will ensure minimal abyssal reworking and fewer unrecognized complications from hemipelagic input.

Cores recovered with the HPC/APC system will provide the requisite bio-, magneto-, and isotopic stratigraphy with which to interpret the eolian record for this part of the Southern Hemisphere. A space-time back-track plot of existing drill site data and the planned sites for Leg 121 (Fig. 13) shows that the new samples will fill in gaps in the database for the Southern Hemisphere tradewinds and westerlies throughout the Cenozoic.

The Leg 121 samples will be used to address the following paleoclimatic questions: When did the great deserts of Australia and Africa evolve (Vogel, 1984; Stein and Robert, 1986)? Given that atmospheric circulation responds to the pole to equator temperature gradient, how does the eolian record compare with the oxygen isotope record of ice volume? How have the zonal wind belts migrated north and south through time? What is the record in the Southern Hemisphere of the big changes in atmospheric circulation in the early Eocene which have been recorded at Northern Hemisphere locations? Does the onset of glaciation in the Northern Hemisphere have any effect on the circulation of the Southern Hemisphere?

ADDITIONAL CRUISE OBJECTIVES

There are several significant details about the tectonics of the eastern Indian Ocean which have yet to be resolved. One major problem which has not been adequately resolved is the history of the Ninetyeast Transform Fault, which lies immediately east of the Ninetyeast Ridge. The spreading history associated with this major fault has been discussed by Sclater and Fisher (1974), Peirce (1978), and Liu et al. (1983), among others. Further unpublished work by Schlich et al. (1985) and J. Y. Royer (Univ. of Texas at Austin) has not been able to define the original length of this fault, how many ridge jumps caused major changes in its length or exactly when it ceased to be active.

JOIDES Resolution will transit a little-traveled part of the world between the southern and central Ninetyeast Ridge sites (NER-5 and 2). A geophysical profile (particularly magnetics) of the ocean crust immediately east of the Ninetyeast Ridge collected during the transit will supply critically needed constraints for tectonic models. A summary of the available magnetic profiles is shown in Figure 14.

DRILLING STRATEGY

Our plan on Leg 121 is to drill the sites in the order shown in Table 1. The cruise is scheduled to depart Fremantle, Australia, on May 2, 1988, and end in Singapore on June 24, 1988.

At Broken Ridge, we will first drill BR-1, which includes the youngest of the dipping and truncated stratigraphic units (Fig. 4). There we anticipate penetrating at least 450 mbsf using a combination of APC/XCB coring. In addition, we will test the NCB at BR-1. After drilling and standard logging operations end at BR-1 we will reposition the ship to drill BR-2, BR-3, and BR-4 in succession to build up the stratigraphic sequence below the erosional unconformity, ensuring some stratigraphic overlap between sites. We expect that increasing induration and chert content down section will render drilling slower and more difficult at the more southerly sites on Broken Ridge. An option to wash through the Neogene sediment cap and RCB core the unconformity and underlying sediment at a number of successive sites across the ridge will be considered should penetration and recovery of the sequence below the unconformity prove to limit effective stratigraphic sampling in BR-3 and/or BR-4. Recovery of a complete sequence of the truncated stratigraphic units is the goal of both drilling strategies. In addition, we will attempt to recover the sub-horizontal sequence above the unconformity at BR-3 through APC/XCB coring.

After completing the Broken Ridge sites, we will decide whether the lowest priority site on Ninetyeast Ridge, NER-5, can be drilled in the time left for Leg 121. If time is available, we will RCB core through the sedimentary section at NER-5 and approximately 50 m into basaltic basement. Standard logging runs will follow. On leaving NER-5 (or Broken Ridge if NER-5 is not drilled) we will deploy the magnetometer for an important S-N profile east of Ninetyeast Ridge running from near Broken Ridge to the latitude of NER-2.

Upon arrival at NER-2, we will utilize ~6 hours to lower 500 m of drill pipe below the ship and run a multishot core orientation test and calibration. Information from this test is intended to resolve uncertainties in APC core orientation and related paleomagnetic studies. Drilling operations at NER-2 will first APC/XCB core through the sedimentary section to basement, then attempt to NCB core into basement. A mini-cone will be deployed for a single reentry and RCB coring will be continued to ~100 m into basaltic basement. Multiple bit changes with the mini-cone will be considered if time and drilling conditions permit. Standard logging runs will be complemented by a special borehole televiewer run to image wellbore breakouts in the volcanic basement and the lowermost sedimentary section.

A long transit between NER-2 and the northern Ninetyeast Ridge sites (NER-1A and NER-1B) will follow. Again, an important S-N magnetic profile will be acquired just east of the Ninetyeast Ridge. At NER-1A we will APC/XCB core to basement, and attempt one NCB core in basement if time is available. A standard logging suite will follow. We will then reposition the ship to NER-1B and wash to about 240 mbsf (~30 m above the predicted mid-Eocene unconformity). The RCB system will be used to core the remaining 285 m of sediment to basement, and to continue ~50 m into basement. A suite of standard logs will then be run. In addition the borehole televiewer will be used if time is available to image wellbore breakouts within the basement and the lowermost sedimentary unit at NER-1B.

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TABLE 1

BROKEN RIDGE/NINETYEAST RIDGE DRILL SITES

Number	Latitude	Longitude	Water Depth	Penetration	Priority	Drilling Days	Logging Days	Total Days	Cumulative Days
Leg 121 departs Fremantle, Australia on May 2, 1988									
Transit from Fremantle: 4.5 days									
BR-1	30°50'S	93°35'E	1178 m	450 m (APC/XCB/NCB)	1	2.6	1.4	4.0	8.5
BR-2	30°53'S	93°34'E	1074 m	450 m (APC/XCB)	1	2.4	1.4	3.8	12.3
BR-3	30°56'S	93°34'E	1057 m	450 m (APC/XCB)	1	2.1	1.2	3.3	15.6
BR-4	31°01'S	93°33'E	1056 m	450 m (RCB)	2	2.4	1.5	3.9	19.5
Transit: 1.5 days									21.0

TABLE 1 (continued)

Number	Latitude	Longitude	Water Depth	Penetration	Priority	Drilling	Logging	Total	Cumulative
						Days			
NER-5 (SNR-4)	$27^{\circ}22'$S	$87^{\circ}37'$E	1510 m	250 m + 50 bsmt (RCB)	3	2.9	1.1	4.0	25.0
Transit: 2.7 days									27.7
NER-2 (CNR-2)	$17^{\circ}05'$S	$88^{\circ}07'$E	1676 m	340 m (APC/XCB/NCB) + 100 m RCB in bsmt	1	4.7	1.6	6.3	34.0
Transit: 5.7 days									39.7
NER-1(A) (NNER-9)	$05^{\circ}39'$N	$90^{\circ}02'$E	2830 m	425 m (APC/XCB/NCB)	1	2.3	1.5	3.8	43.5
NER-1(B) (NNER-10)	$05^{\circ}22'$N	$90^{\circ}23'$E	3040 m	285 m + 50 bsmt (RCB)	1	3.5	1.5	5.0	48.5
Transit to Singapore: 3.7 days									52.2
						22.9	11.2	34.1	
						(transit)		18.1	
								52.2	52.2
Engineering (NCB test plus multishot tool calibration)								.8	53.0
TOTAL TIME								53.0	53.0

Leg 121 ends in Singapore on June 24, 1988

Notes:

1. Transit times calculated at 10.5 kts. Includes .6 day allowance for magnetic profiles east of Ninetyeast Ridge.
2. Logging times include Seismic Strat., Lithoporosity and Geochemical combination runs at each site plus BHTV at NER-2. Hole conditioning time of 8 hrs/hole assumed.

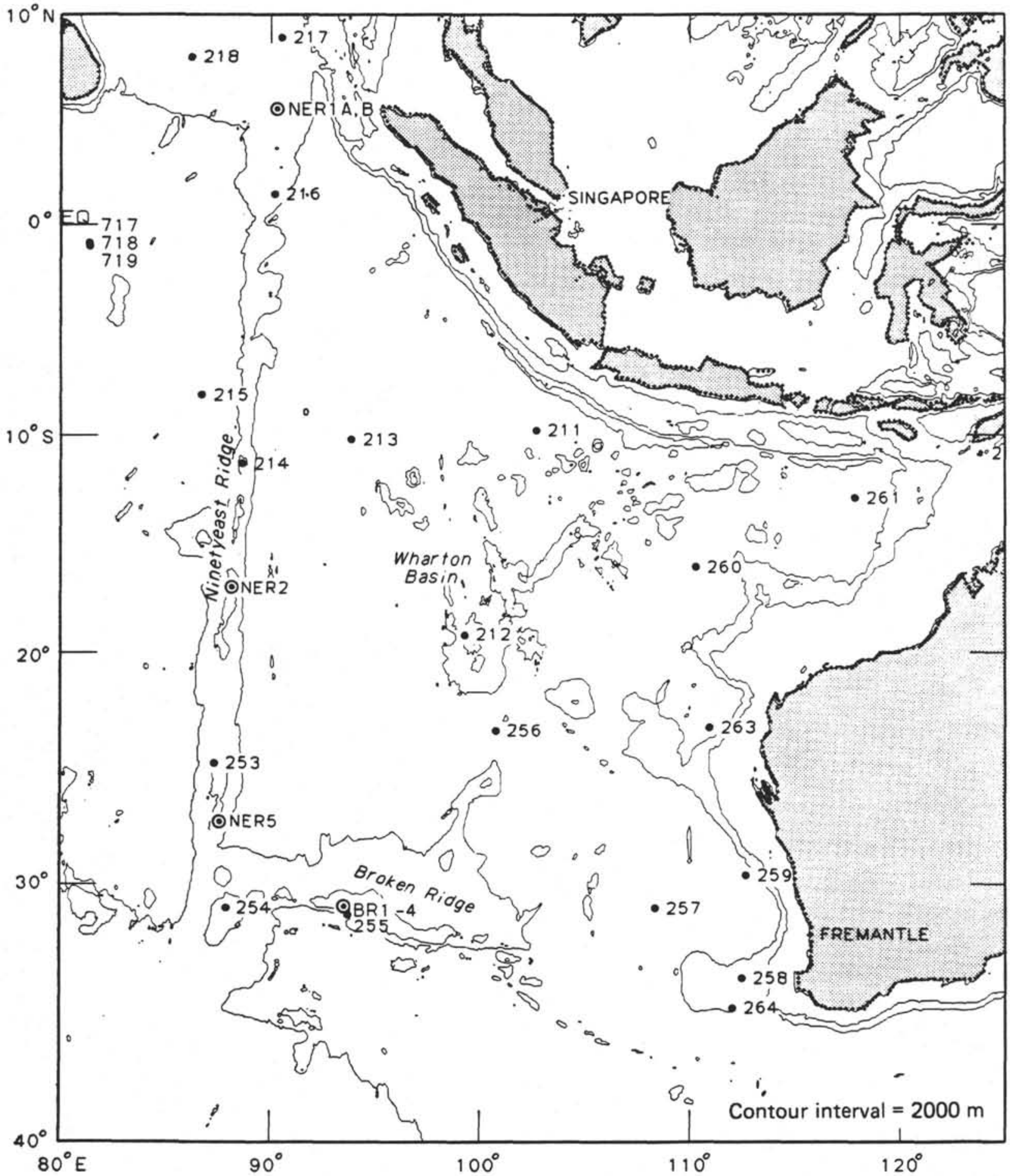


Figure 1. Location map of the eastern Indian Ocean, showing previous DSDP sites, ODP Leg 116 sites, and sites proposed for drilling on ODP Leg 121.

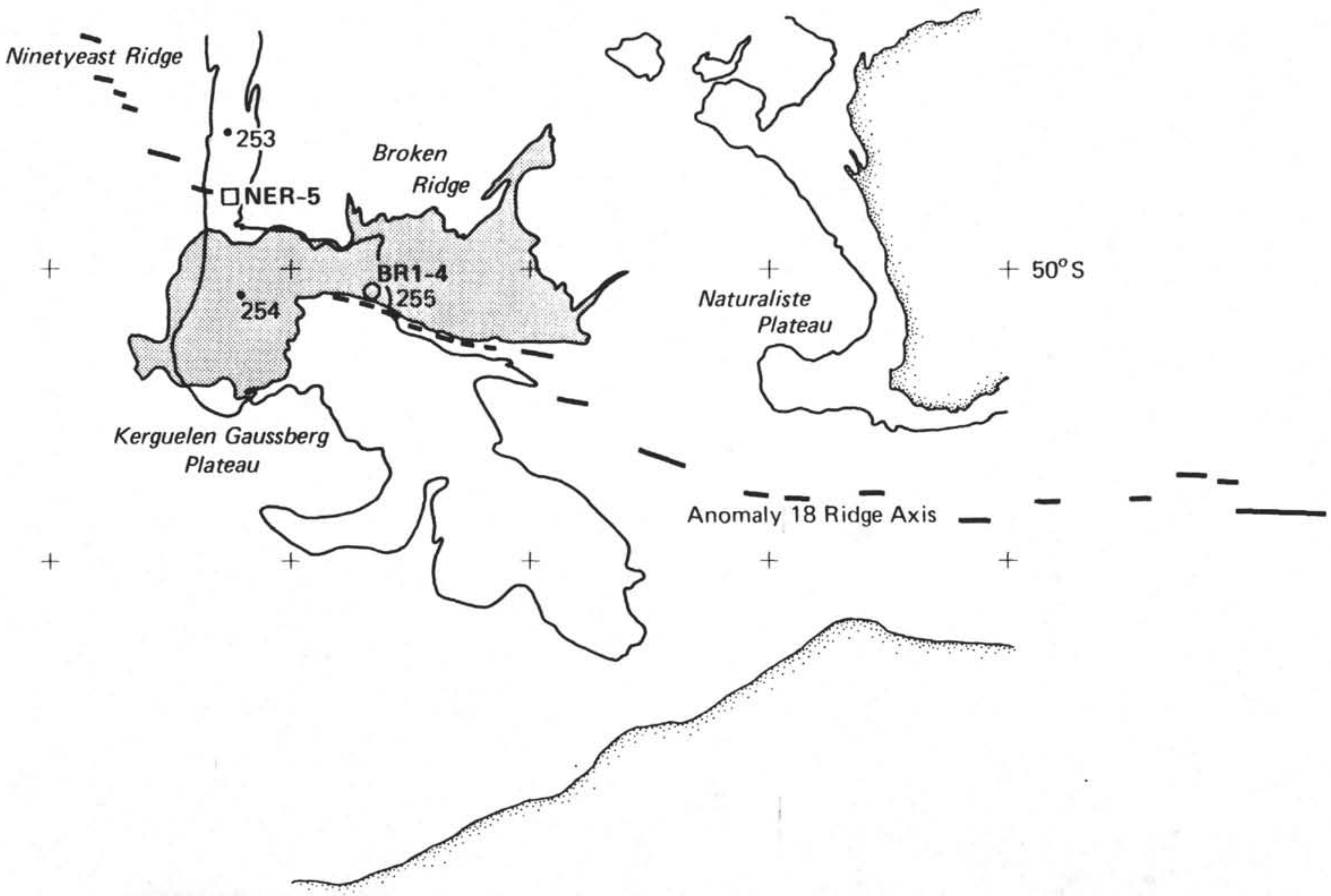


Figure 2. Paleogeographic reconstruction of Broken Ridge and the Kerguelen-Gaussberg Plateau at the time of magnetic anomaly 18 (~42 Ma). (Simplified from J. Y. Royer, personal comm. 1988.)

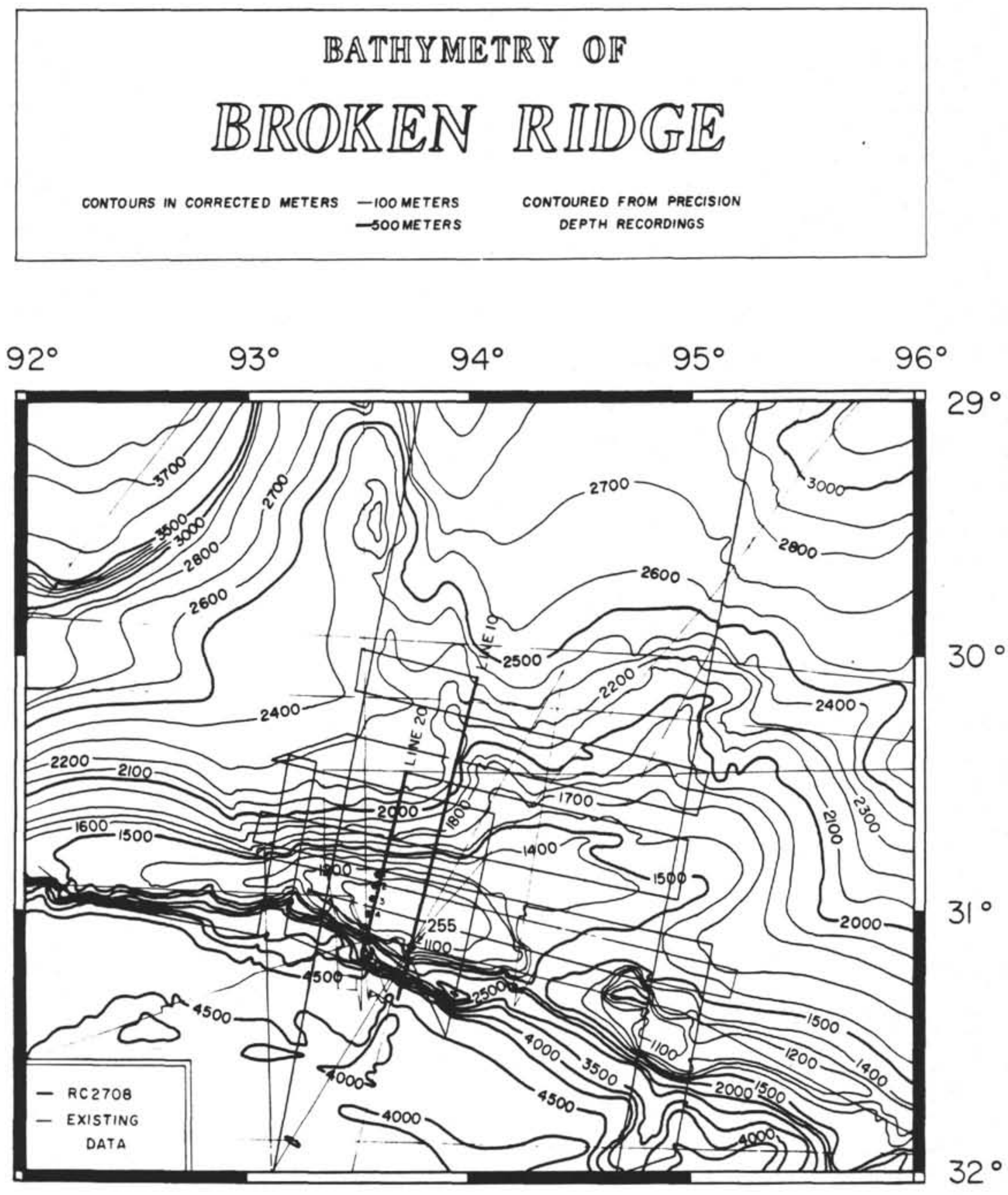


Figure 3. Bathymetry of Broken Ridge, in corrected meters, contoured from precision depth recordings. Location of DSDP Site 255 is shown. Prospective drill sites are shown along RC2708 Line 20 (BR-1, BR-2, BR-3, BR-4). Further details about the proposed sites are given in Table 1.

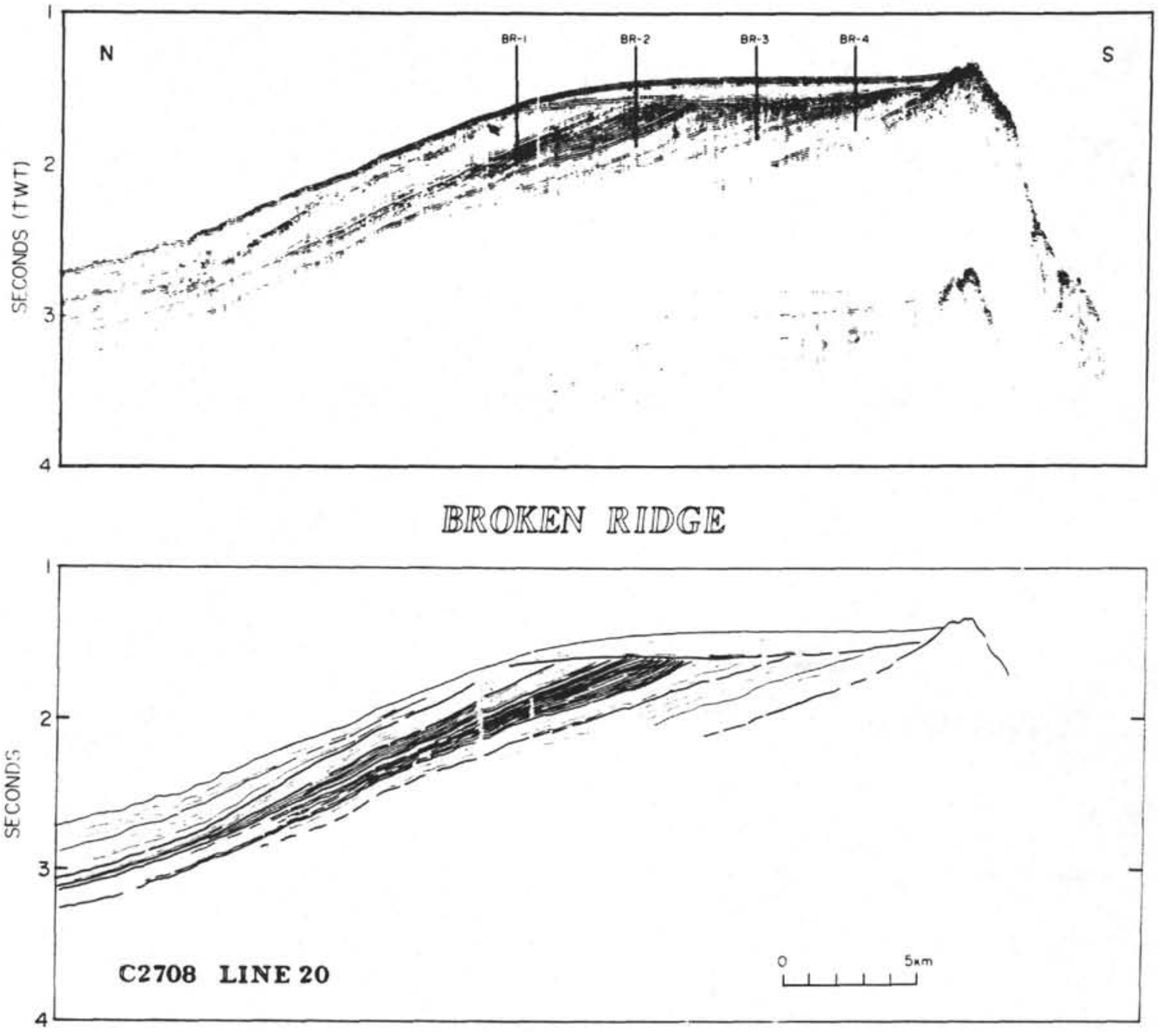


Figure 4. RC2708 Line 20 showing a prominent angular unconformity that separates the northward dipping reflectors, below, from the horizontal reflectors, above. The prospective drill sites (BR-1 through BR-4) are shown, and their locations should ensure that the entire stratigraphic section can be drilled with modest penetration depths at each site. Note the change in acoustic character amongst the northward dipping reflectors, specifically the middle, highly reflective unit that thins away from the ridge crest. Location of profile shown in Figure 3.

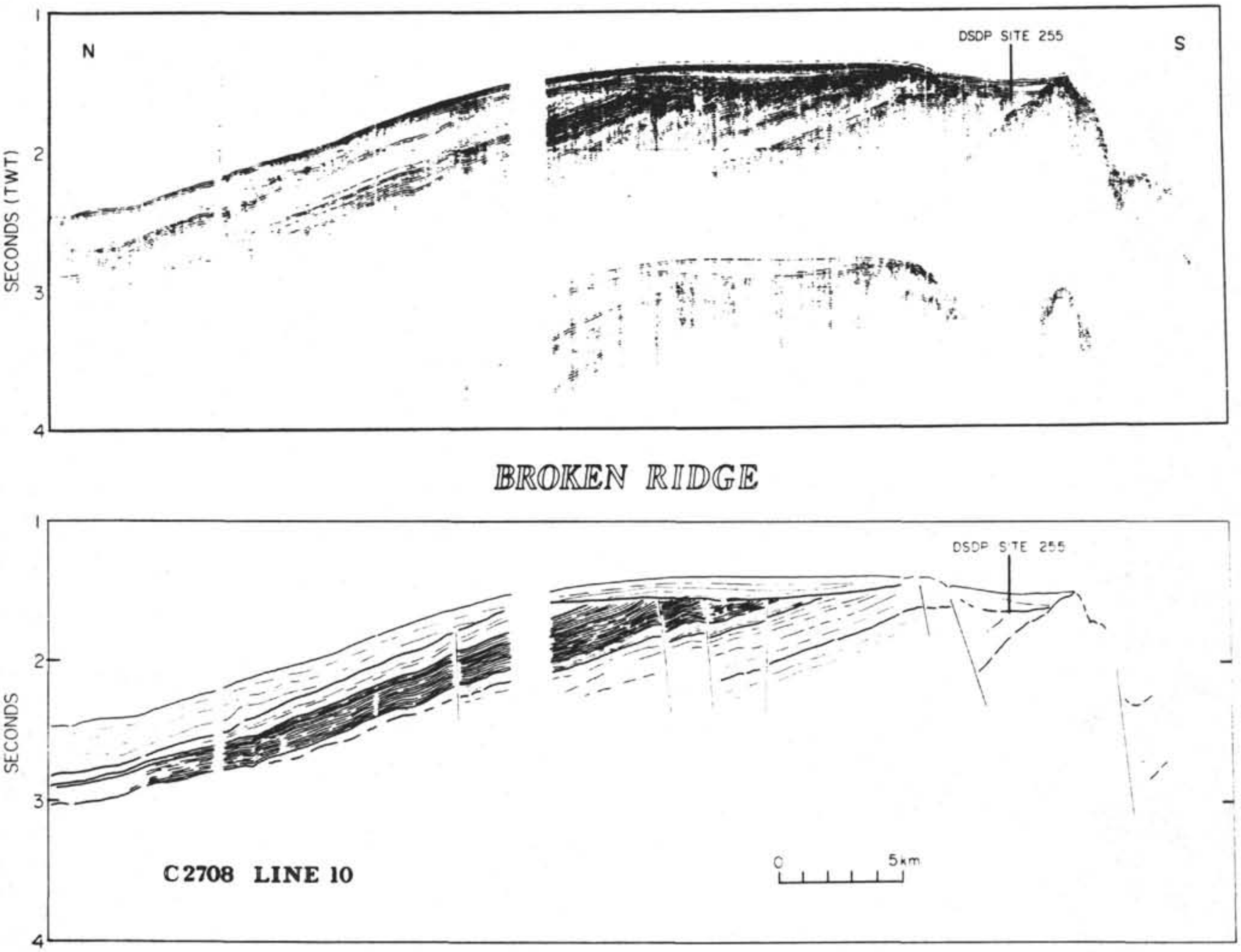


Figure 5. RC2708 Line 10 shows a similar stratigraphic evolution as Line 20 in response to the rifting processes that occurred, except that faults become more prevalent. DSDP Site 255 is located in a small low that formed between a rider block and the platform; thus the majority of the northward dipping sequences have yet to be sampled. Note the similar variations in acoustic character that were also observed in Line 20, especially the middle highly reflective unit that thins downslope. Location of profile shown in Figure 3.

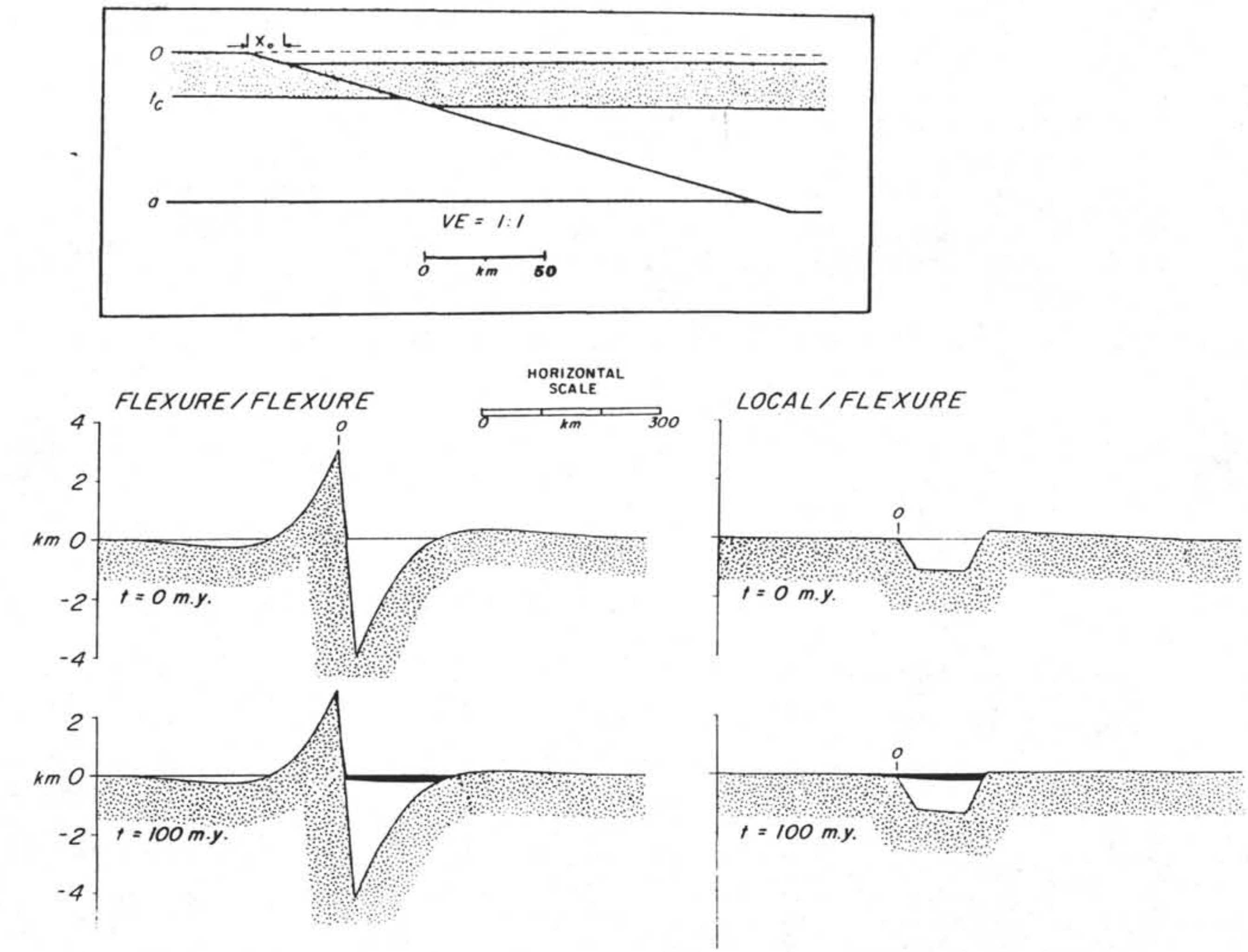


Figure 6. Isostatic response of basement to extension of the lithosphere via simple shear on a plane, dipping normal fault (see inset). In this model the footwall and hanging wall blocks respond to isostatic restoring stresses but are otherwise not deformed. Note that the resulting topography depends critically on whether the lithosphere has finite flexural rigidity at rifting (t=0 m.y.). For local isostasy at t=0 m.y., there can be no footwall uplift for x < 0. This does not agree with observations at Broken Ridge.

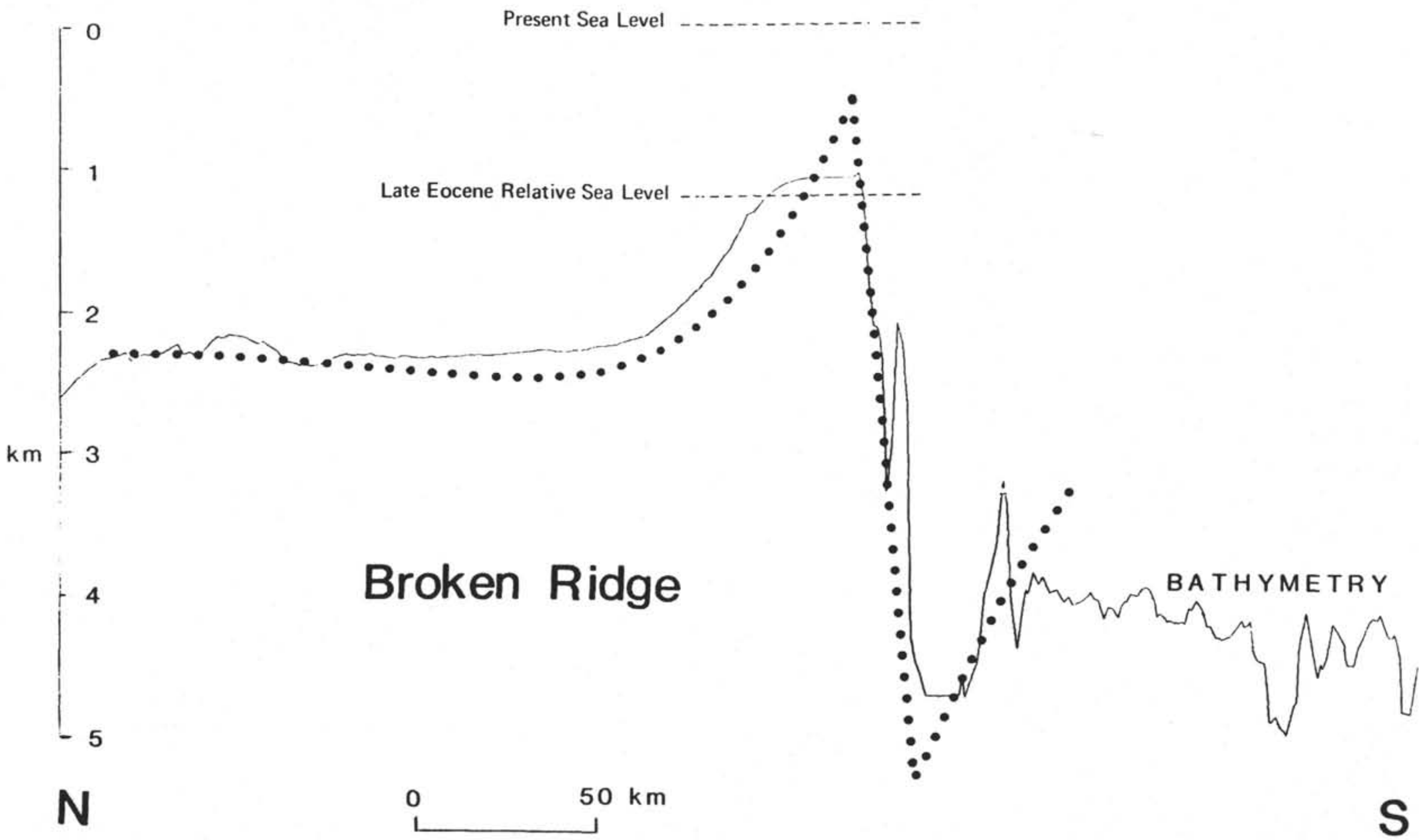


Figure 7. Model of the flexural topography at Broken Ridge (solid dots) for a best-fitting model based on the concepts illustrated in Fig. 6. The observed bathymetry is a N-S profile along 93.3°E longitude in Fig. 3. In order to match the bathymetry across Broken Ridge, a thermal lithospheric thickness of 45 km is required.

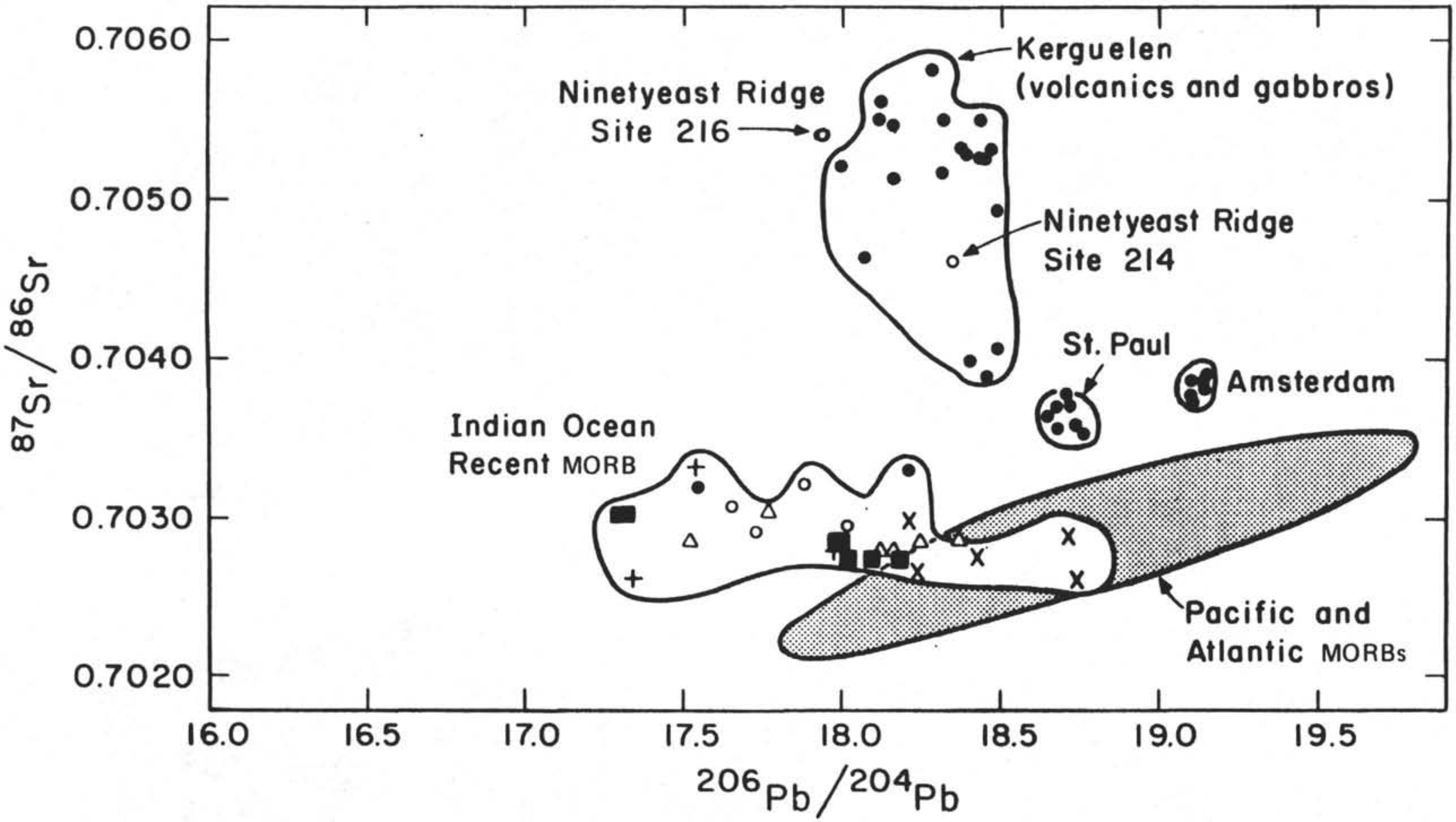


Figure 8. $^{87}Sr/^{86}Sr$ vs. $^{206}Pb/^{204}Pb$. Note that (1) most Indian Ocean MORBs, i.e., formed at a spreading axis, have higher $^{87/86}Sr$ and lower $^{206/204}Pb$ ratios than Pacific and Atlantic MORBs; (2) Kerguelen occupies an unusual location relative to other Indian Ocean islands, e.g., St. Paul and Amsterdam; and (3) based on data for only 2 samples, the Ninetyeast lavas are similar to the Kerguelen field, although the two Ninetyeast sites are different.

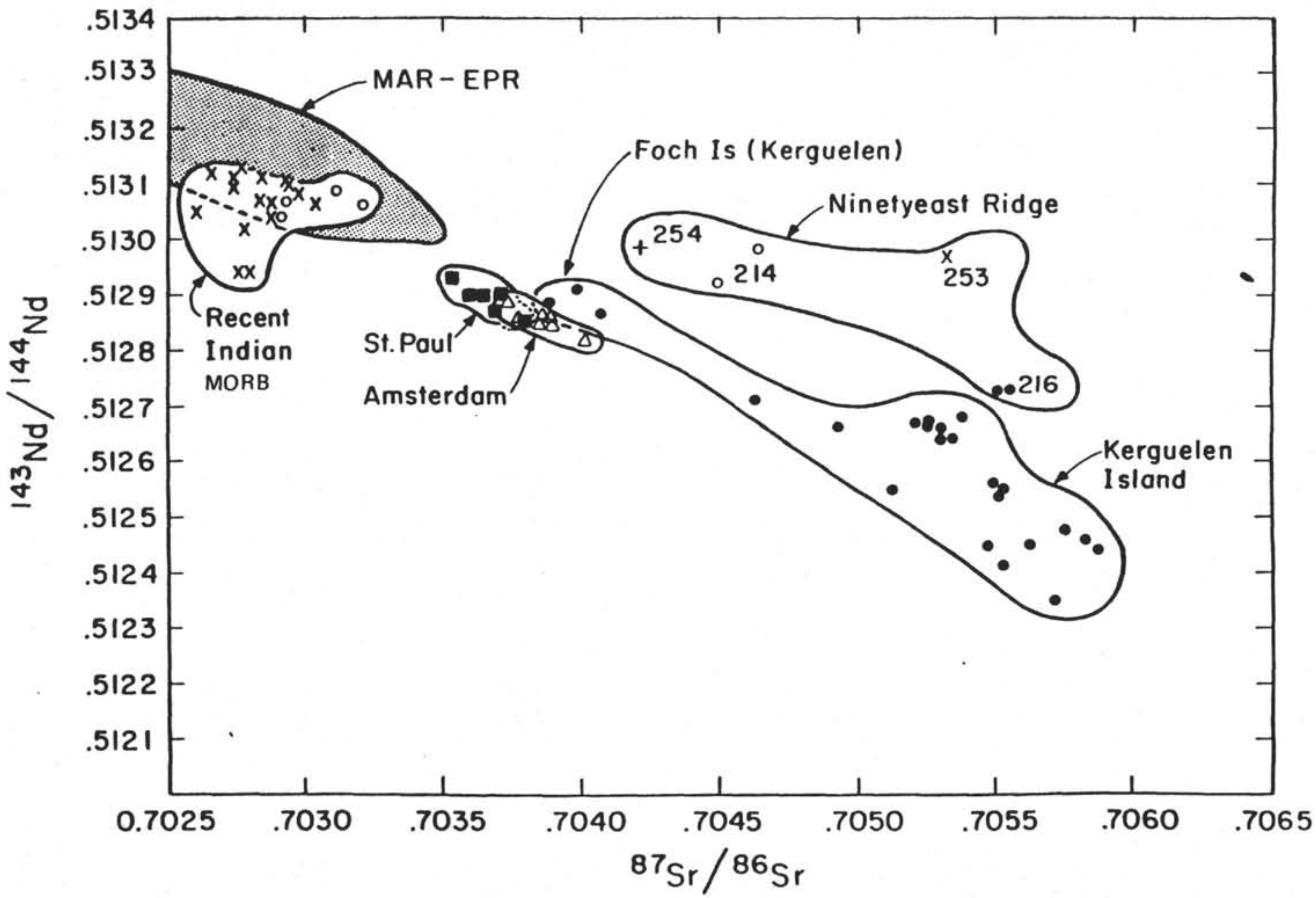


Figure 9. $^{143/144}$Nd vs. $^{87/86}$Sr, showing an elongated but non-overlapping field for Ninetyeast Ridge and Kerguelen. It is uncertain if the elevated 87/86 for the Ninetyeast Ridge reflects alteration or a real difference from Kerguelen. Again, note that Sites 214 and 216 are isotopically distinct. Compared to Figure 8, this plot does not clearly show the differences between recent Indian spreading ridge basalts and Pacific-Atlantic MORB. Also, differences between Kerguelen and Amsterdam-St. Paul are smaller.

PALEOMOTION OF DSDP SITE 216

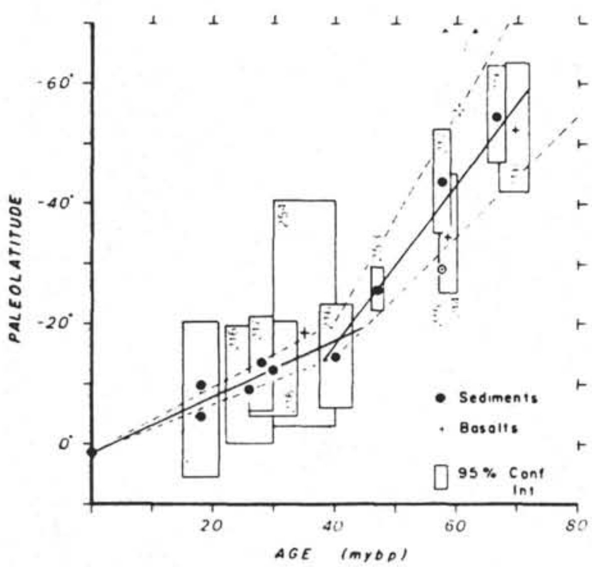


Figure 10. Paleomotion of DSDP Site 216 based on paleolatitudes from all the sites on the Ninetyeast Ridge. Boxes indicate the 95 % confidence intervals of each paleolatitude and the best estimate of the associated age. Crosses indicate basalt data; solid circles indicate sediment data; and numbers indicate the site. Only paleolatitudes based on at least eight samples are plotted. For sites other than 216, a correction equal to the present latitude difference from Site 216 was applied. Site 215 data are not consistent with those from the Ninetyeast Ridge sites and they have been dotted in. The solid lines indicate rates of northward motion of India obtained by weighted least squares linear regression. The dashed lines indicate the 95% confidence region for the position of Site 216, assuming Student t-statistics apply to the rates of motion. The calculated rates are: 0-40 Ma, 5.2 $\pm$ 0.8 cm/yr (N = 6, through the origin); and 40-70 Ma, 14.9 $\pm$ 4.5 cm/yr (N = 6). (From Peirce, 1978.)

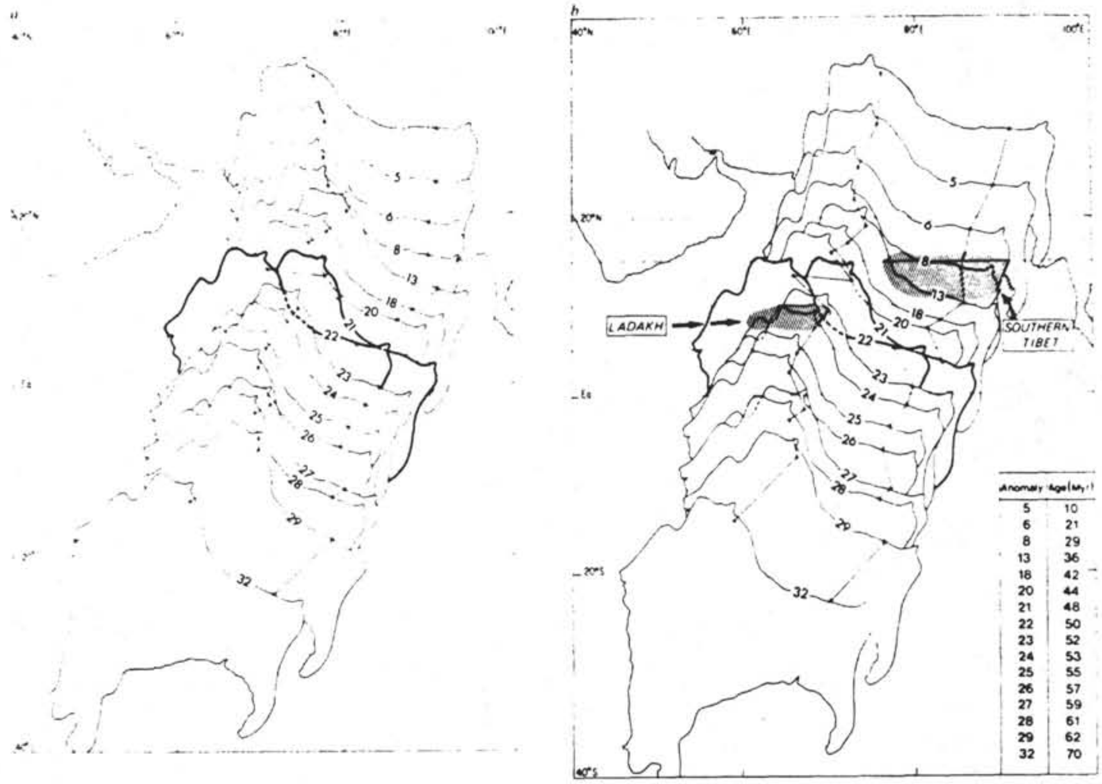


Figure 11. Cenozoic northward drift of India. The northern limit of the Indian continent is taken as the present position of the Indus-YZSZ. The passive margins are drawn at the 500 m isobath (represented at anomaly 32 time). Also plotted is the motion of two points located on the Indian continent near the northern margin: in Ladakh (34°34'N, 76°7'E) and on the suture zone near the position of Lhasa (29°20'N, 91°E). The position of the northern margin of India is emphasized at the time of initial collision with the southern margin of Eurasia (anomalies 22 and 21). a, Relative motion of India with respect to Eurasia, kept arbitrarily fixed in its present position. b, Absolute motion of India in the hotspot frame of reference. The positions of southern Tibet and Ladakh before collision deduced from paleomagnetic data, are also indicated for comparison. (From Patriat and Achache, 1984.)

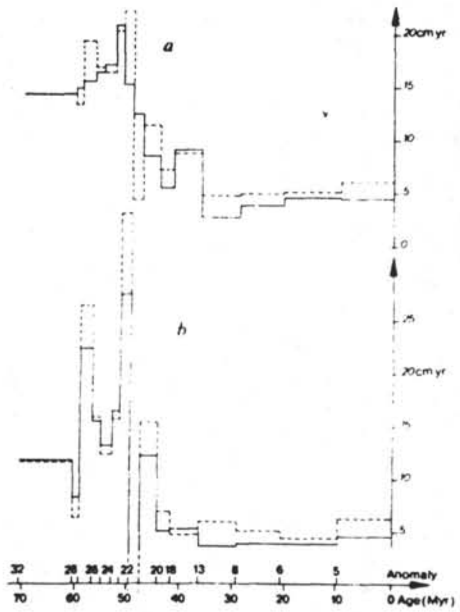


Figure 12. Computed rate of convergence between the Indian and the Eurasian plates during the Cenozoic, at two arbitrary points ($5^{o}N$, $75^{o}E$, solid line; $5^{o}N$, $90^{o}E$, dashed line) along two particular directions. It indicates the rate of subduction perpendicular to the trench for a subduction zone located near the southern margin of Eurasia and trending N120E (a) or east-west (b). (From Patriat and Achache, 1984.)

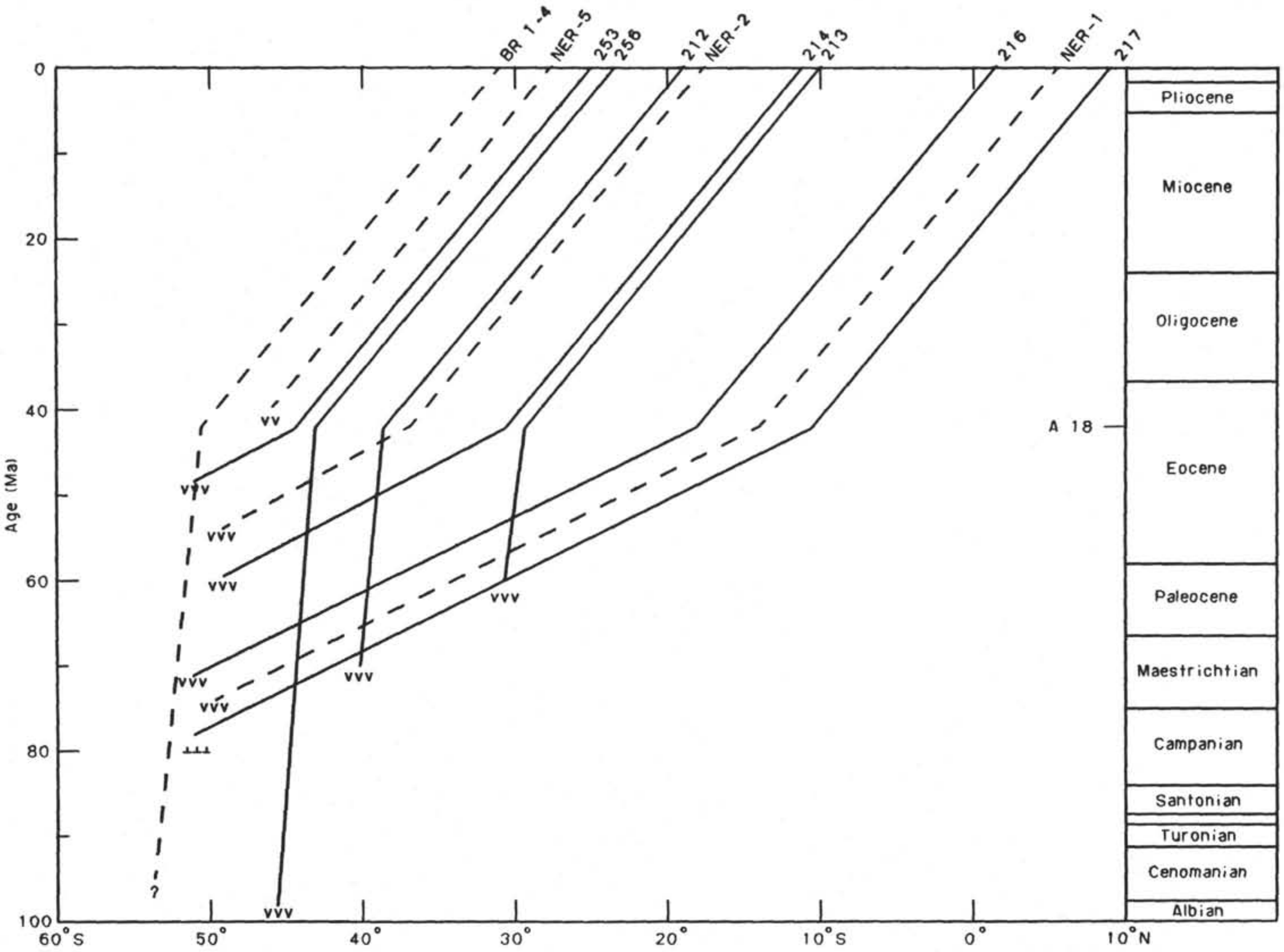


Figure 13. Predicted paleolatitudes for proposed Leg 121 sites and DSDP sites, based on Peirce (1978) and J. Y. Royer (pers. comm., 1988).

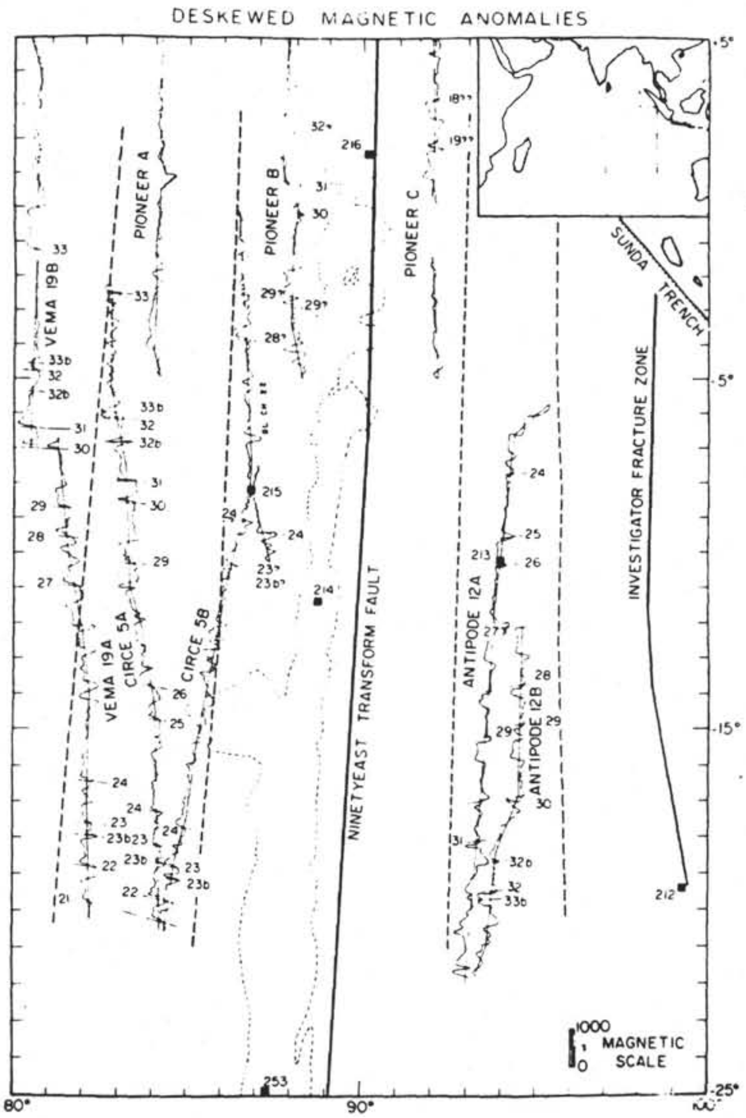


Figure 14. Deskewed magnetic anomalies in the east central Indian Ocean, plotted perpendicular to track. The straight lines are the approximate ship tracks. Representative phase shifts were chosen for each data set; plots of several different phase shifts and the original data are given in Peirce (1977). Phase shifts used: Antipode 12A, -65°, Antipode 12B, -60°; Circe 5A, -75°; Circe 5B, 70°; Glomar Challenger 22, -80°; Pioneer A and B, -80°; Pioneer C, -90°; Vema 19A, -70°; Vema 19B, -80° (from Peirce, 1978).

SITE NUMBER: BR-1 (Broken Ridge)

POSITION: 30°50'S
93°35'E

SEDIMENT THICKNESS: 1500 m

WATER DEPTH: 1178 m

PRIORITY: 1

PROPOSED DRILLING PROGRAM: APC/XCB to 450 mbsf, test NCB

SEISMIC RECORD: RC2708 Line 20, 17 Sept. 1986, 2155z (dip line); near Line 17 (strike line) 11 Sept. at 1425Z.

HEAT FLOW: Yes

LOGGING: Condition hole for about 8 hours, then standard 3 runs (seismic strat., lithoporosity, and geochem.).

OBJECTIVES: Determine age, sedimentary facies, and paleodepth of the dipping, truncated sedimentary sequence at Broken Ridge as a test of rifting mechanisms.

SEDIMENT TYPE: About 30 m. Neogene foram/nanno ooze, >420 m? Paleogene and Cretaceous oozes, chalks, and limestone, with increasing induration and chert content down section.

SITE NUMBER: BR-2 (Broken Ridge)

POSTION: 30°53'S
93°34'E

SEDIMENT THICKNESS: 1500 m

WATER DEPTH: 1074 m

PRIORITY: 1

PROPOSED DRILLING PROGRAM: APC/XCB to about 450 mbsf

SEISMIC RECORD: RC2708 Line 20, 17 Sept. 1986 at 2220z (dip line), near Line 4 10 Sept. at 1005Z (strike line).

HEAT FLOW: No

LOGGING: Condition hole for about 8 hours, then standard 3 runs (seismic strat., porosity, and geochem.)

OBJECTIVES: Determine age, facies and paleodepth of the dipping and truncated sedimentary sequence at Broken Ridge as a test of rifting mechanisms.

SEDIMENT TYPE: About 100 m of Neogene foram/nanno ooze, >420 m? Paleogene and Cretaceous oozes, chalks, and limestone, with increasing induration and chert content down section.

SITE NUMBER: BR-3 (Broken Ridge)

POSITION: 30°56'S
93°33.5'E

SEDIMENT THICKNESS: 1500 m

WATER DEPTH: 1057 m

PRIORITY: 1

PROPOSED DRILLING PROGRAM: APC/XCB (or RCB) to about 450 mbsf.

SEISMIC RECORD: RC2708 Line 20, 17 Sept 1986 at 2240Z (dip line), near Line 3 9 Sept at 1756Z (Strike line)

HEAT FLOW: Yes

LOGGING: Condition hole for about 8 hours then standard 3 runs (seismic strat., lithoporosity, and geochem.).

OBJECTIVES: a) Recover the sedimentary sequence (Neogene ooze and lagoonal facies deposits) above unconformity , b) Determine age, facies, paleodepth of dipping and truncated units.

SEDIMENT TYPE: About 180 m Neogene foram/nanno ooze, about 30 m upper Eocene lagoonal sands and gravels, 400 m? Paleogene and Cretaceous oozes, chalks and limestones with increasing induration and chalk content down section.

SITE NUMBER: BR-4 (Broken Ridge)

POSITION: 31°01'S
93°33'E

SEDIMENT THICKNESS: 1000 m

WATER DEPTH: 1056 m

PRIORITY: 2

PROPOSED DRILLING PROGRAM: RCB to about 450 mbsf

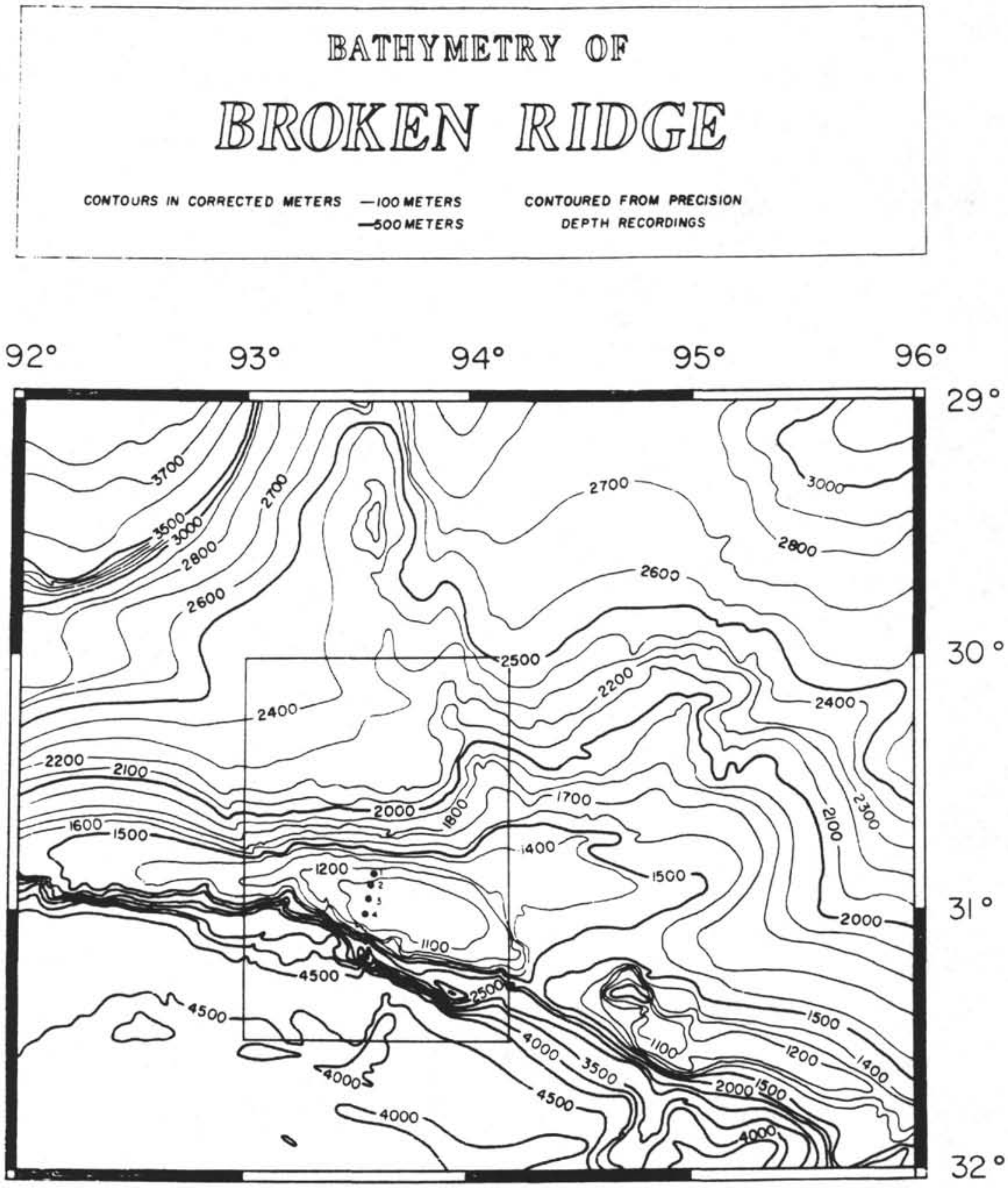
SEISMIC RECORD: RC2708 Line 20 17 Sept 1986 at 2310Z (dip line), near Line 3 9 Sept at 1756Z (strike line).

HEAT FLOW: No

LOGGING: Condition hole for about 8 hours then standard 3 runs (seismic strat., lithoporosity, and geochem.).

OBJECTIVES: Determine age, facies, and paleodepth of dipping and truncated units at Broken Ridge.

SEDIMENT TYPE: About 100 m Neogene foram/nanno ooze, 400 m Cretaceous chalks and limestones interbedded with chert lenses and nodules.



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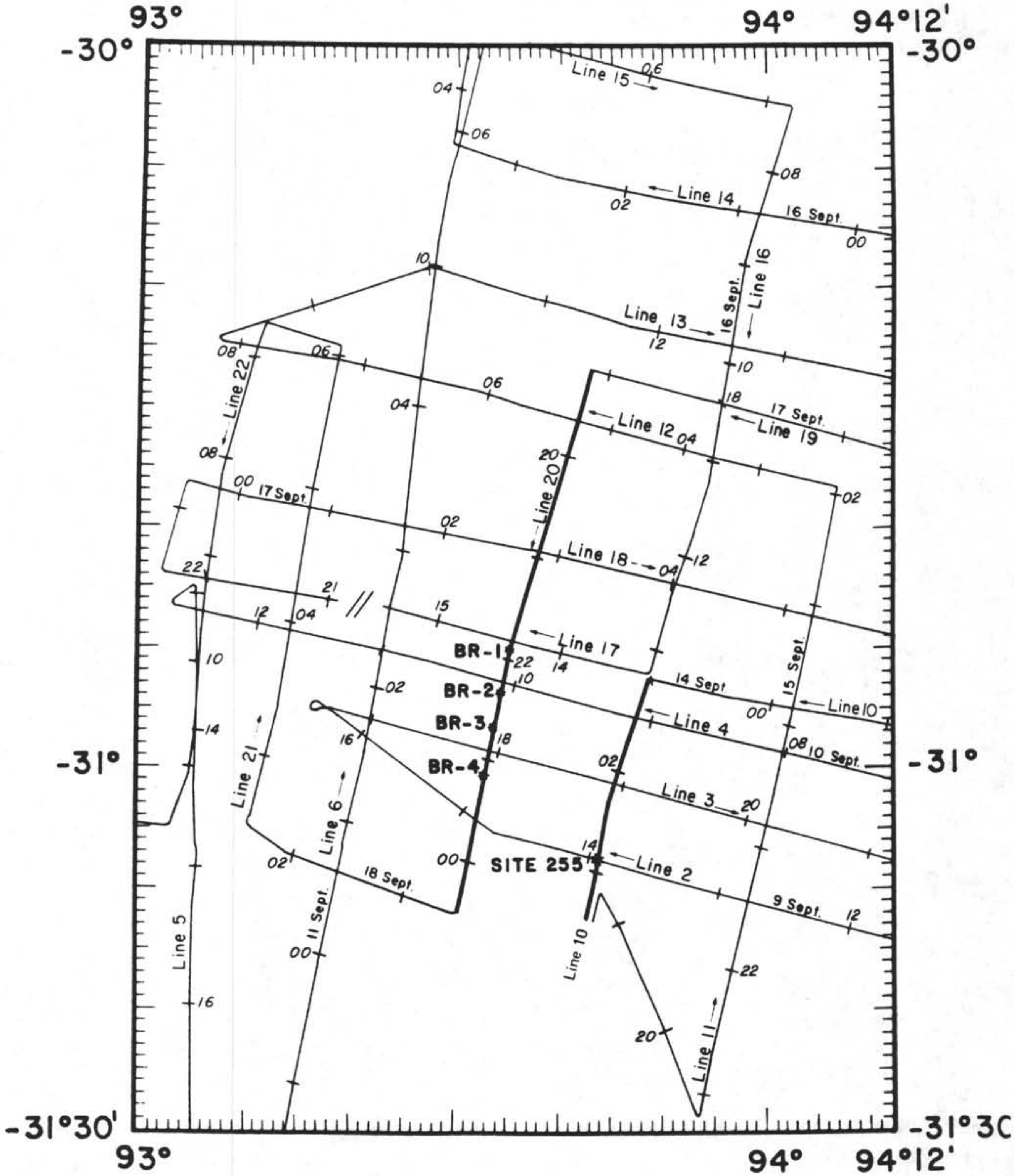
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Line 15
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Line 22
Line 12
17 Sept.
Line 19
Line 20
17 Sept.
Line 18
Line 17
BR-1
BR-2
BR-3
BR-4
14 Sept.
15 Sept.
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SITE 255
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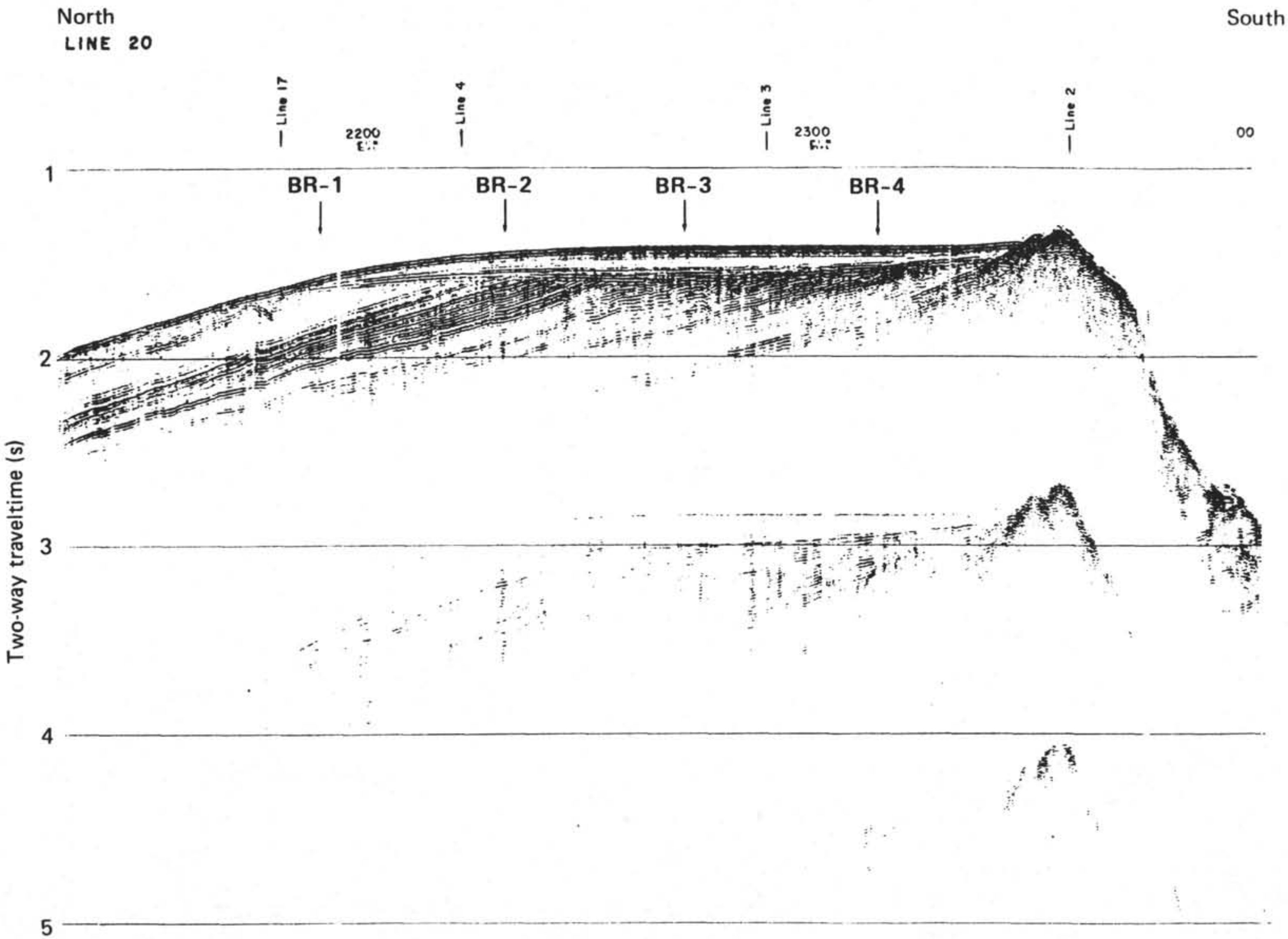
11 Sept.
Line 5
Line 10
Line 11


North
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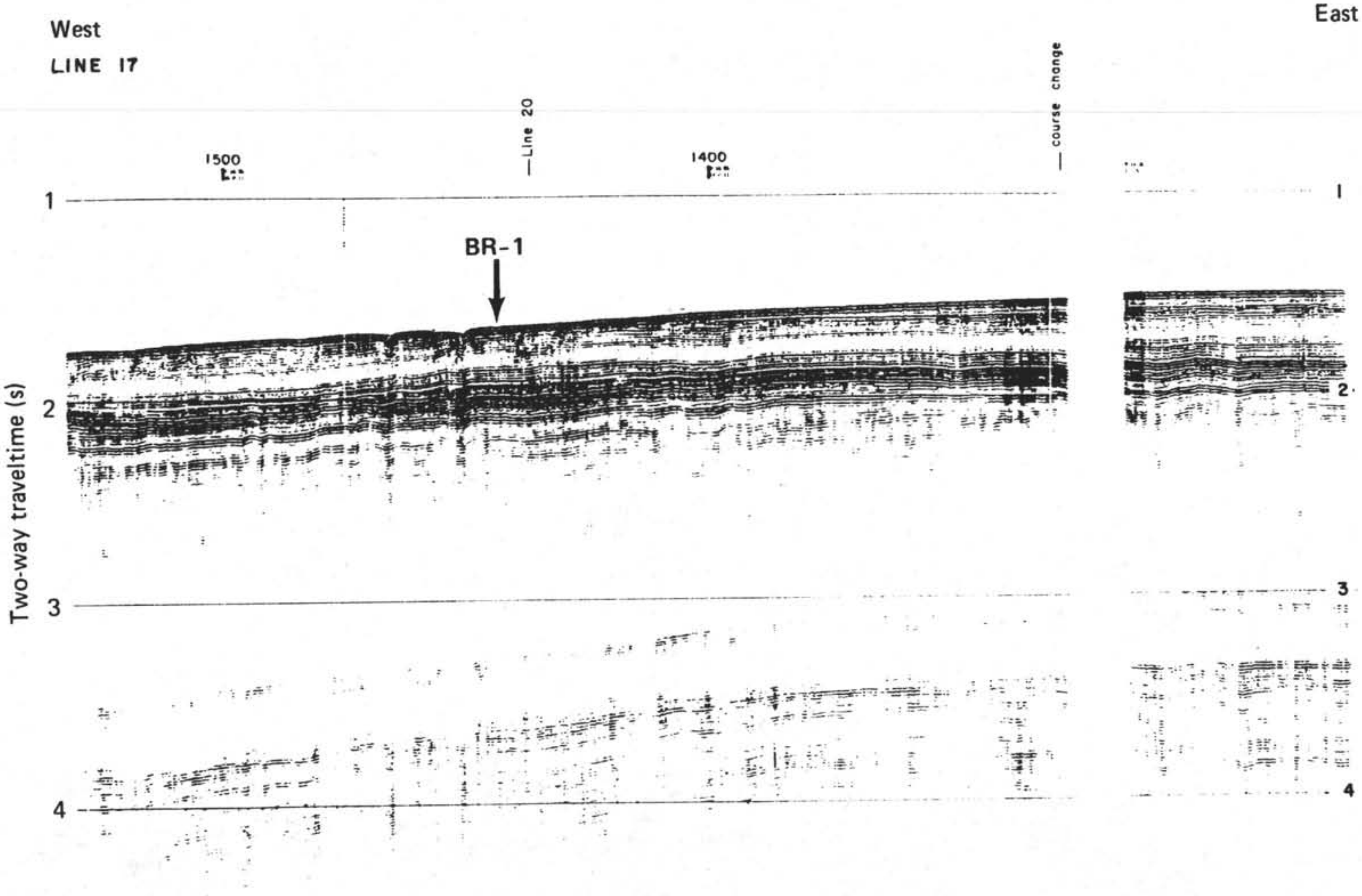
5
Two-way traveltime (s)



West
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course change
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Two-way traveltime (s)
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2
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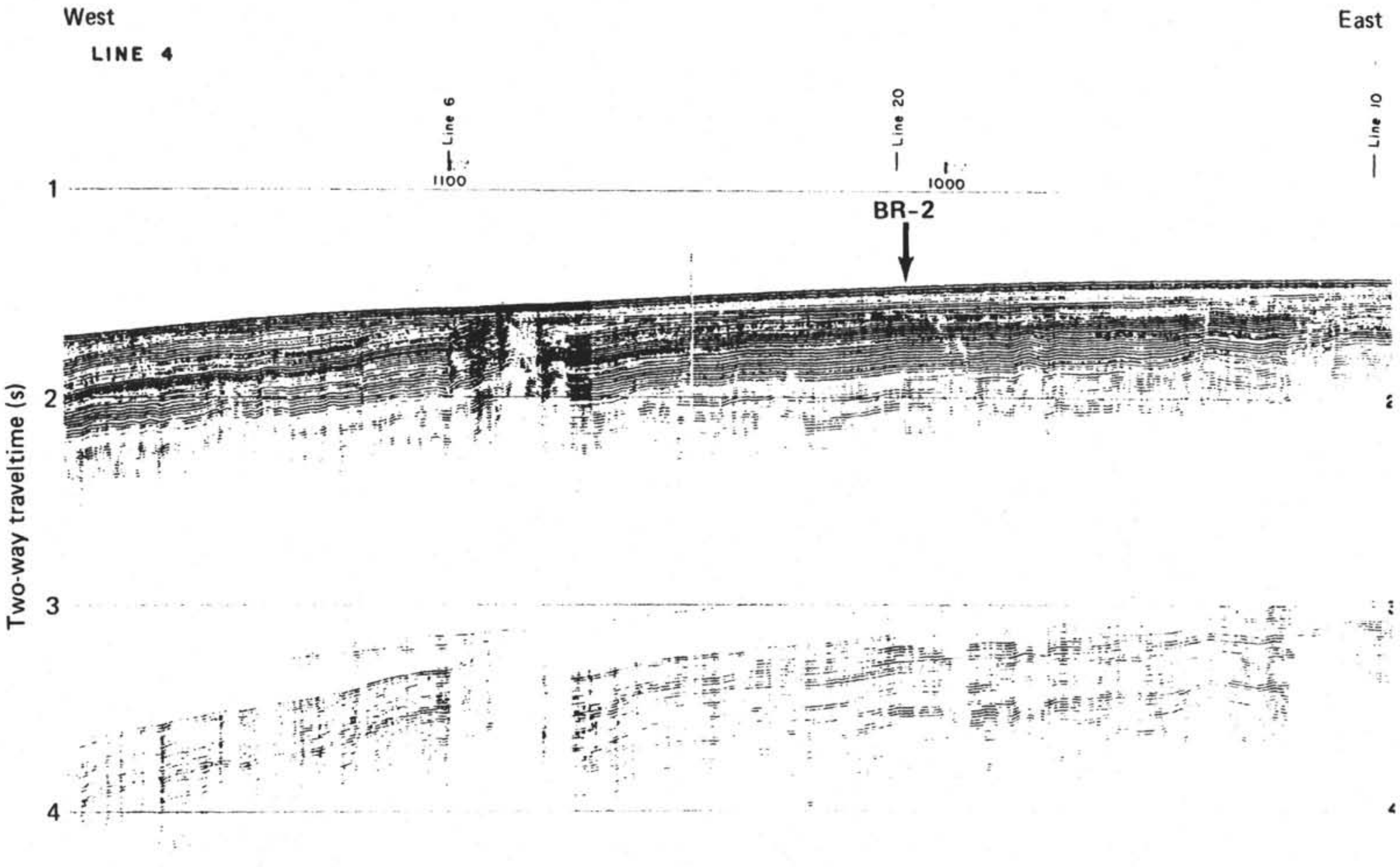
West
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LINE 4
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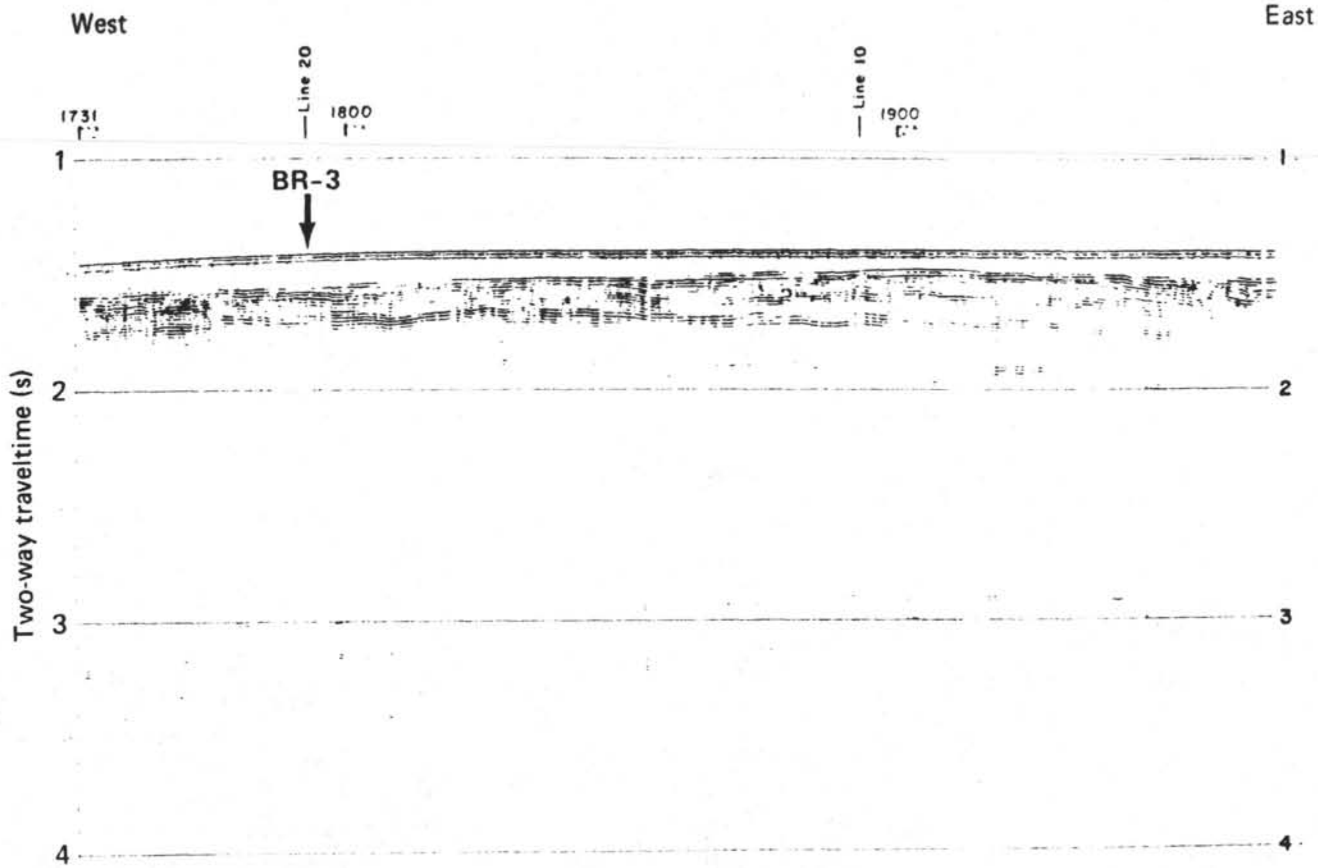
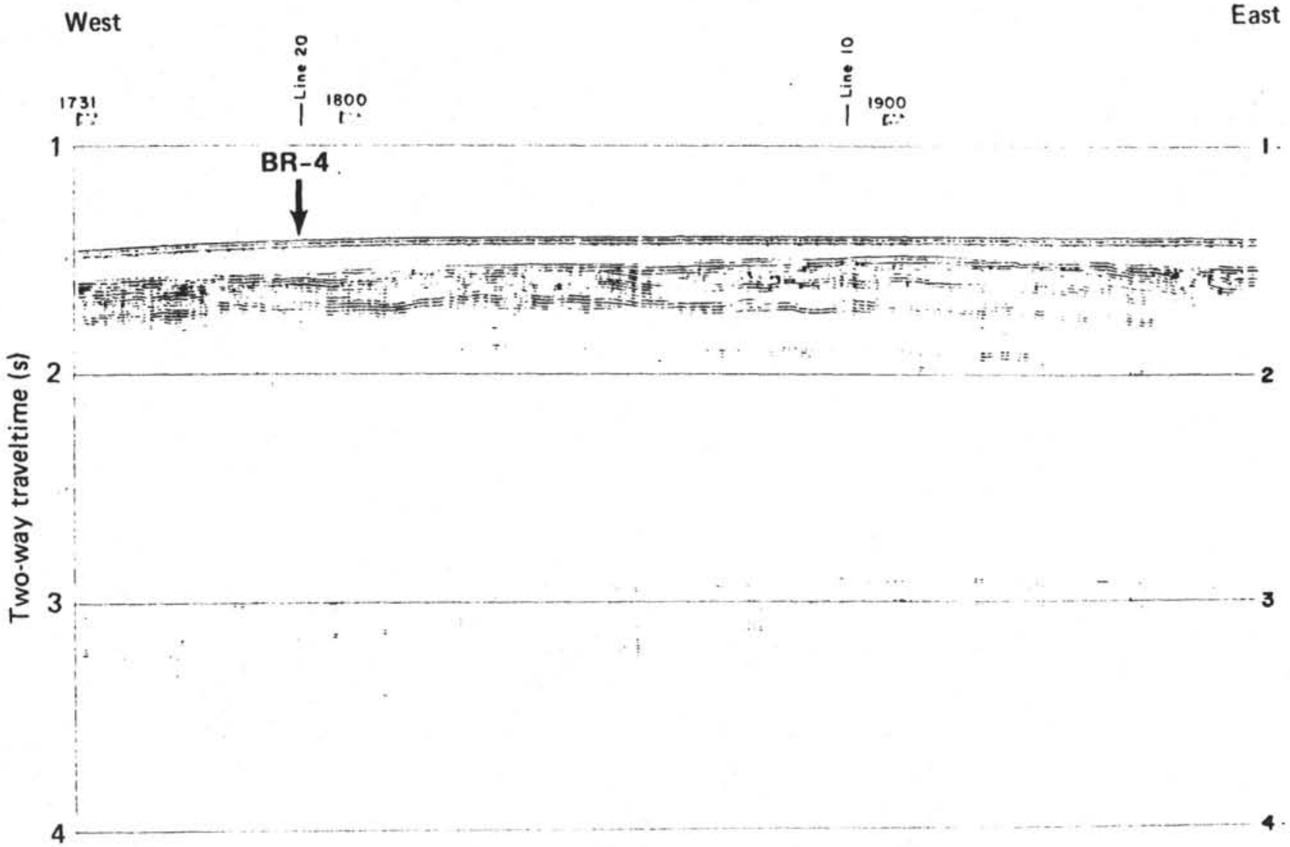
Two-way traveltime (s)

LINE 3


West
East
Line 20
Line 10
1731
1800
1900
BR-3
1
2
3
4
Two-way traveltime (s)

LINE 3



West
East
Line 20
Line 10
1731
1800
1900
BR-4
1
2
3
4
Two-way traveltime (s)

SITE NUMBER: NER-5A (Southern Ninetyeast Ridge, SNR-4)

POSITION: $27^{o}21.6'S$
$87^{o}36.6'E$

SEDIMENT THICKNESS: 250 m

WATER DEPTH: 1510 m

PRIORITY: 3

PROPOSED DRILLING PROGRAM: RCB to 50 m of basement.

SEISMIC RECORD: RC2708, SP13920

HEAT FLOW: No

LOGGING: Condition hole for 8 hours, then standard 3 runs (seismic strat., lithoporosity, and geochem.)

OBJECTIVES: Basalt geochemistry at a position between Sites 253 and 254. Secondary objective is site at southern end of north-south paleoceanographic/climatic transect. Neither sediment type nor expected low Neogene recovery is suited for this objective.

SEDIMENT TYPE: Calcareous ooze, volcaniclastics

ALTERNATE SITE: NER-5B (SNR-3)

POSITION: 27°19.8'S
87°27.6'E

SEDIMENT THICKNESS: 177 m

WATER DEPTH: 1539 m

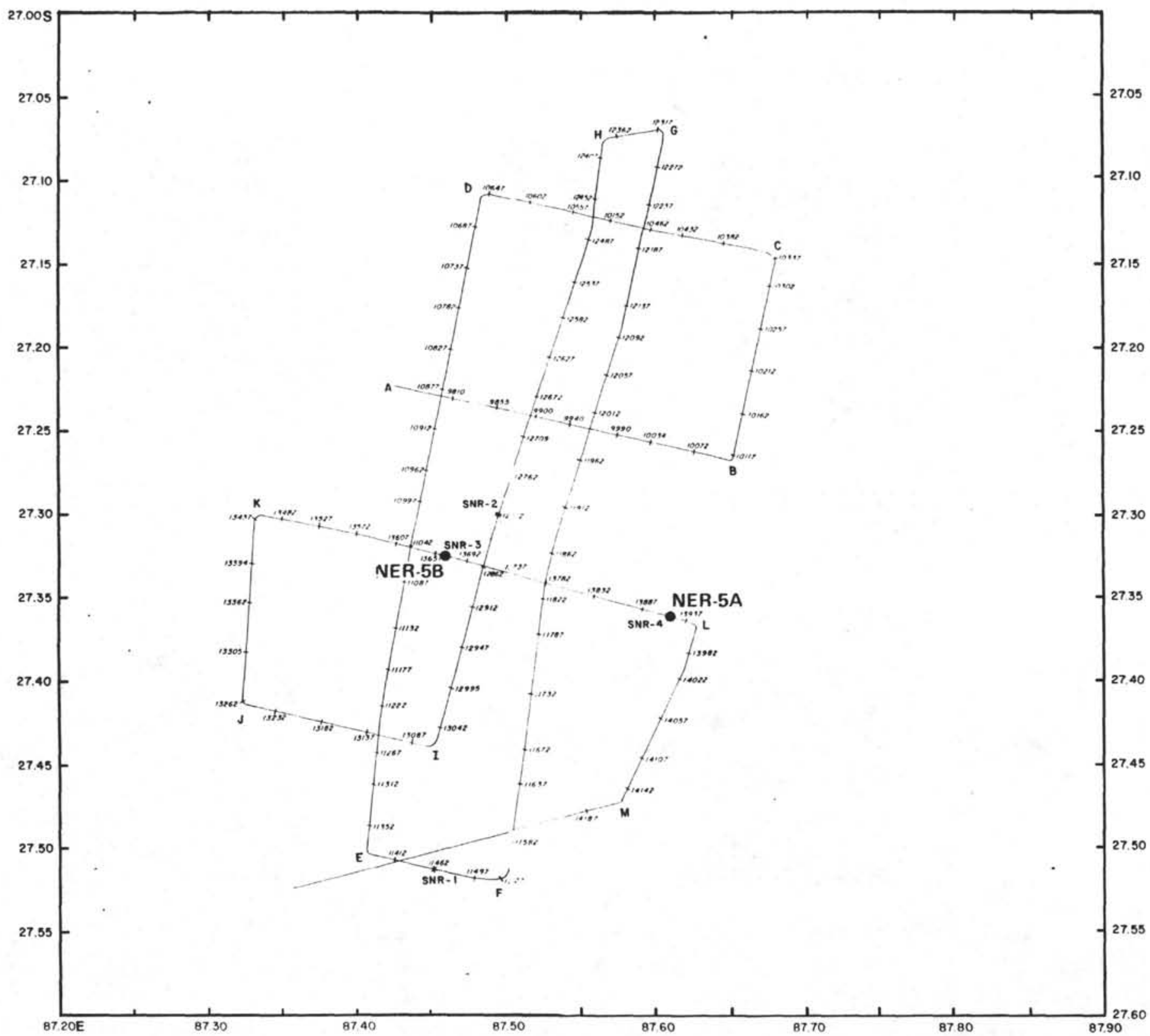
SEISMIC RECORD: RC2708, SP13670

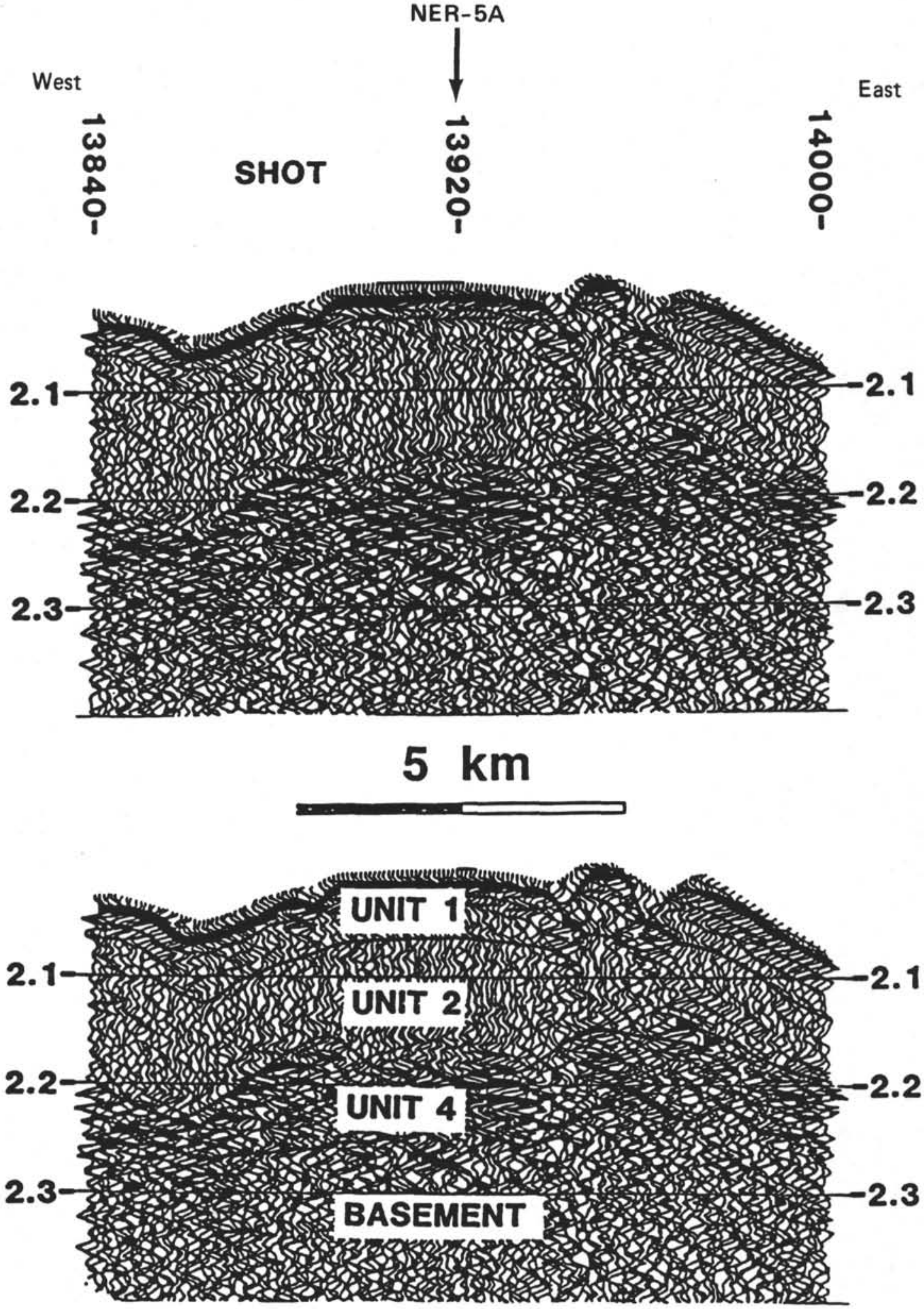
HEAT FLOW: No

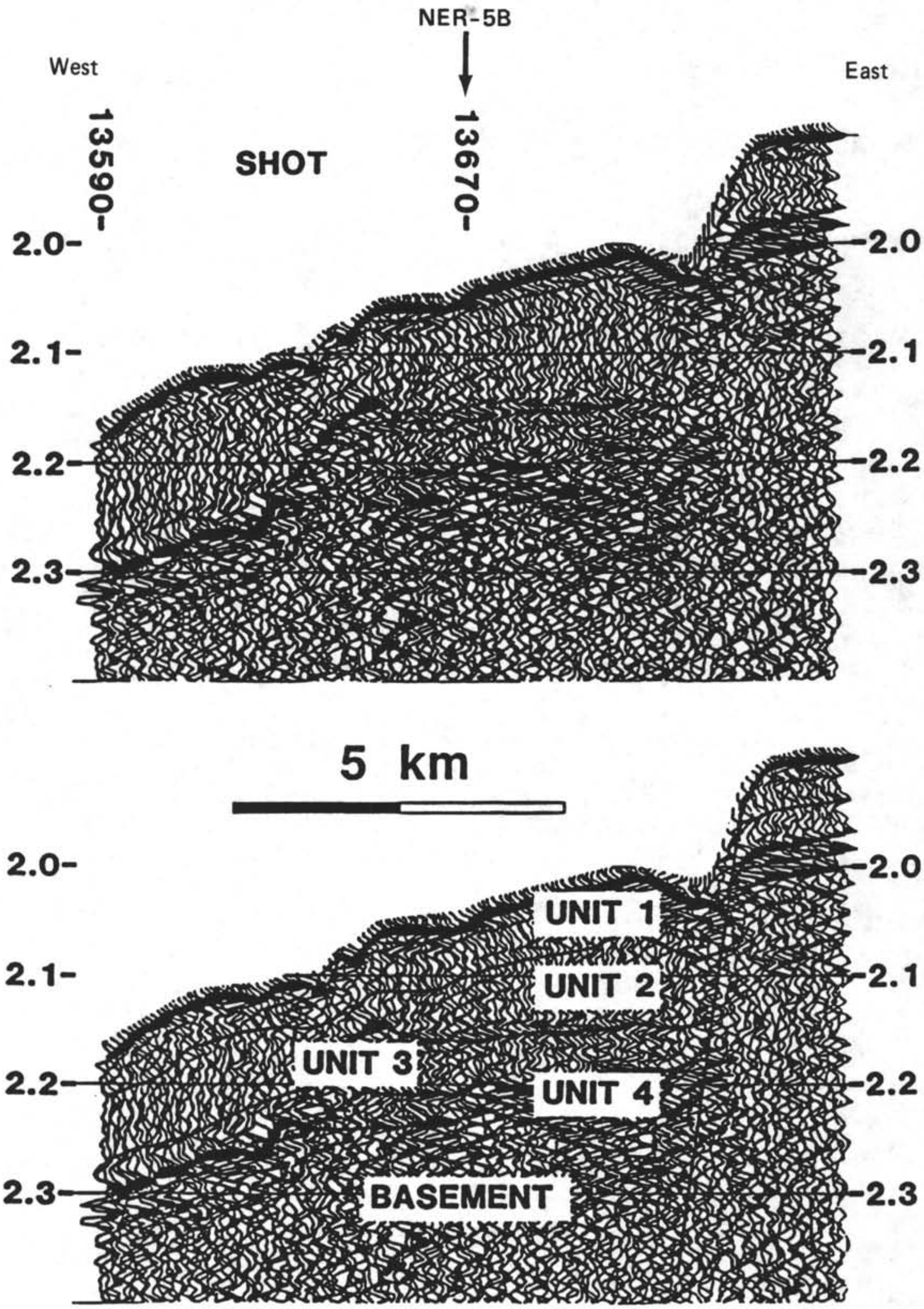
LOGGING: Condition hole for 8 hours, then standard 3 runs (seismic strat., lithoporosity, and geochem.)

OBJECTIVES: Basalt geochemistry at a position between Sites 253 and 254. Secondary objective is site at southern end of north-south paleoceanographic/climatic transect. Neither sediment type nor expected low Neogene recovery is suited for this objective.

SEDIMENT TYPE: Calcareous ooze, volcaniclastics


NER-5A
NER-5B
SNR-1
SNR-2
SNR-3
SNR-4
A
B
C
D
E
F
G
H
I
J
K
L
M
27.00S
27.05
27.10
27.15
27.20
27.25
27.30
27.35
27.40
27.45
27.50
27.55
27.60
87.20E
87.30
87.40
87.50
87.60
87.70
87.80
87.90


NER-5A
West
East
13840-
SHOT
13920-
14000-
2.1
2.2
2.3
5 km
UNIT 1
UNIT 2
UNIT 4
BASEMENT


NER-5B
West
East
13590-
SHOT
13670-
2.0-
2.1-
2.2-
2.3-
-2.0
-2.1
-2.2
-2.3
5 km
UNIT 1
UNIT 2
UNIT 3
UNIT 4
BASEMENT

SITE NUMBER: NER-2A (Central Ninetyeast Ridge, CNR-2)

POSITION: 17°04.8'S
88°06.6'E

SEDIMENT THICKNESS: 340 m

WATER DEPTH: 1676 m

PRIORITY: 1

PROPOSED DRILLING PROGRAM: APC/XCB to basement; 1 NCB core, Wash 2nd hole, RCB 100 m basement, using minicone.

SEISMIC RECORD: RC2707, SP3112 (dip line), RC2707, SP4208 (strike line)

HEAT FLOW: Yes

LOGGING: Condition hole for 8 hr, then standard 3 runs (seismic strat., lithoporosity, and geochem.), then BHTV.

OBJECTIVES:
1. Basalt geochemistry at site between Sites 253 and 214, including vertical changes in basement section.
2. Detailed northward motion curve from paleomagnetic studies, with particular emphasis on Eocene-Oligocene section and basement.
3. Central site North-South paleoceanographic/climatic transect.
4. BHTV experiment to look for breakouts for stress analysis.

SEDIMENT TYPES: Calcareous ooze and volcaniclastics (possibly including tuffs and/or thin lignite beds) above first basalts. Intercalated volcaniclastics (perhaps quite thick) and/or paleosols between basalt flows.

ALTERNATE SITE: NER-2B (CNR-3)

POSITION: 17°04.8'S
88°08.4'E

SEDIMENT THICKNESS: 454 m

WATER DEPTH: 1792 m

PROPOSED DRILLING PROGRAM: APC/XCB to basement; 1 NCB core, Wash 2nd hole, RCB 100 m basement, using minicone.

SEISMIC RECORD: RC2707, SP3175 (dip line)
RC2707, SP5145 (strike line)

HEAT FLOW: Yes

LOGGING: Condition hole for 8 hr, then standard 3 runs (seismic strat., lithoporosity, and geochem.), then BHTV.

OBJECTIVES: 1. Basalt geochemistry at site between Sites 253 and 214, including vertical changes in basement section.
2. Detailed northward motion curve from paleomagnetic studies, with particular emphasis on Eocene-Oligocene section and basement.
3. Central site North-South paleoceanographic/climatic transect.
4. BHTV experiment to look for breakouts for stress analysis.

SEDIMENT TYPES: Calcareous ooze and volcaniclastics (possibly including tuffs and/or thin lignite beds) above first basalts. Intercalated volcaniclastics (perhaps quite thick) and/or paleosols between basalt flows.

ALTERNATE SITE: NER-2C (CNR-5)
N.B. This proposed site location will be presented to PPSP in March, 1988.

POSITION: $17^{\circ}2.4'$S
$88^{\circ}12.0'$E

SEDIMENT THICKNESS: 393 M

WATER DEPTH: 1676 m

PROPOSED DRILLING PROGRAM: APC/XCB to basement; 1 NCB core, Wash 2nd hole, RCB 100 m basement, using minicone.

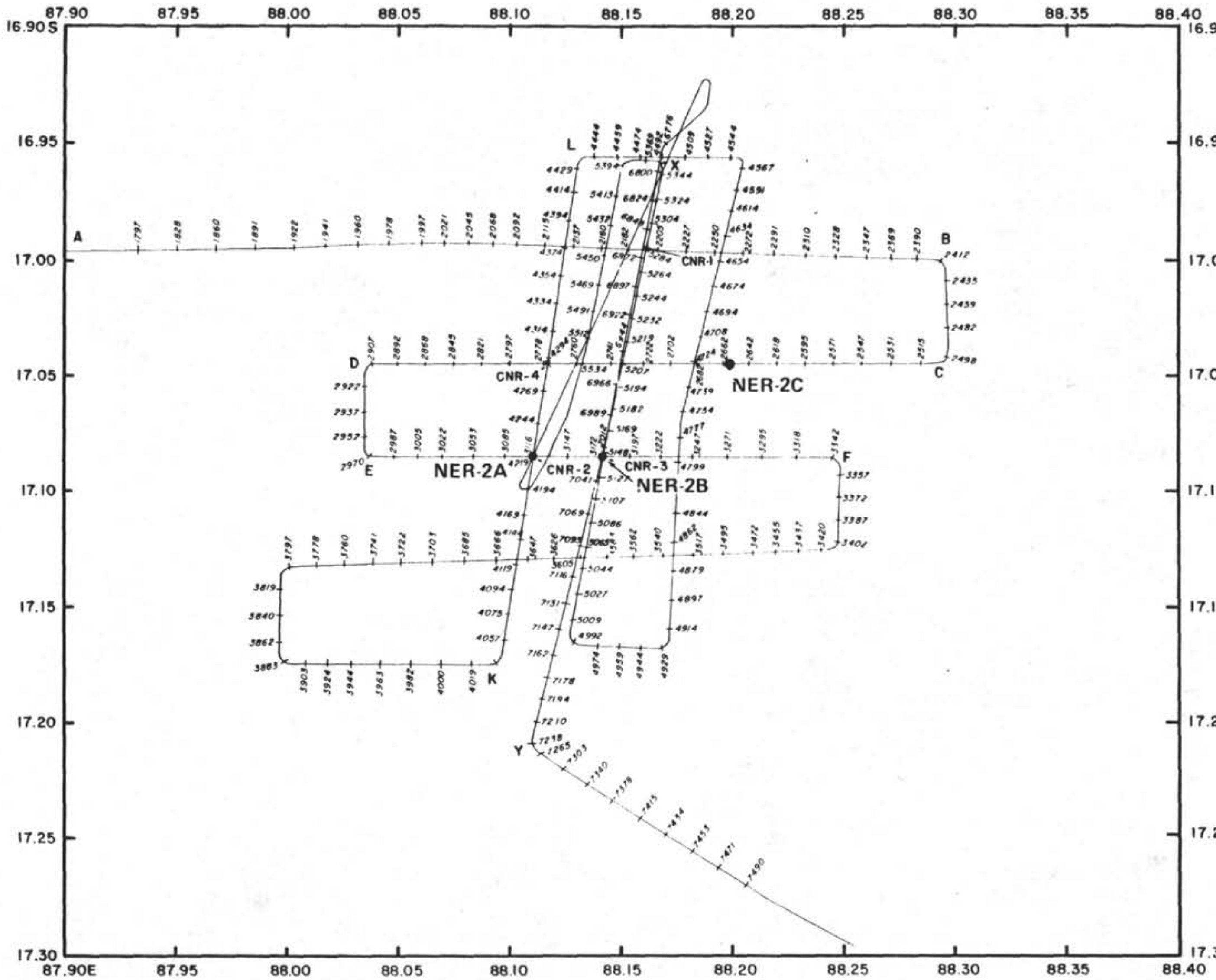
SEISMIC RECORD: RC2707, SP2660 (dip line)
RC2707, SP4720 (strike line, 1 km west)

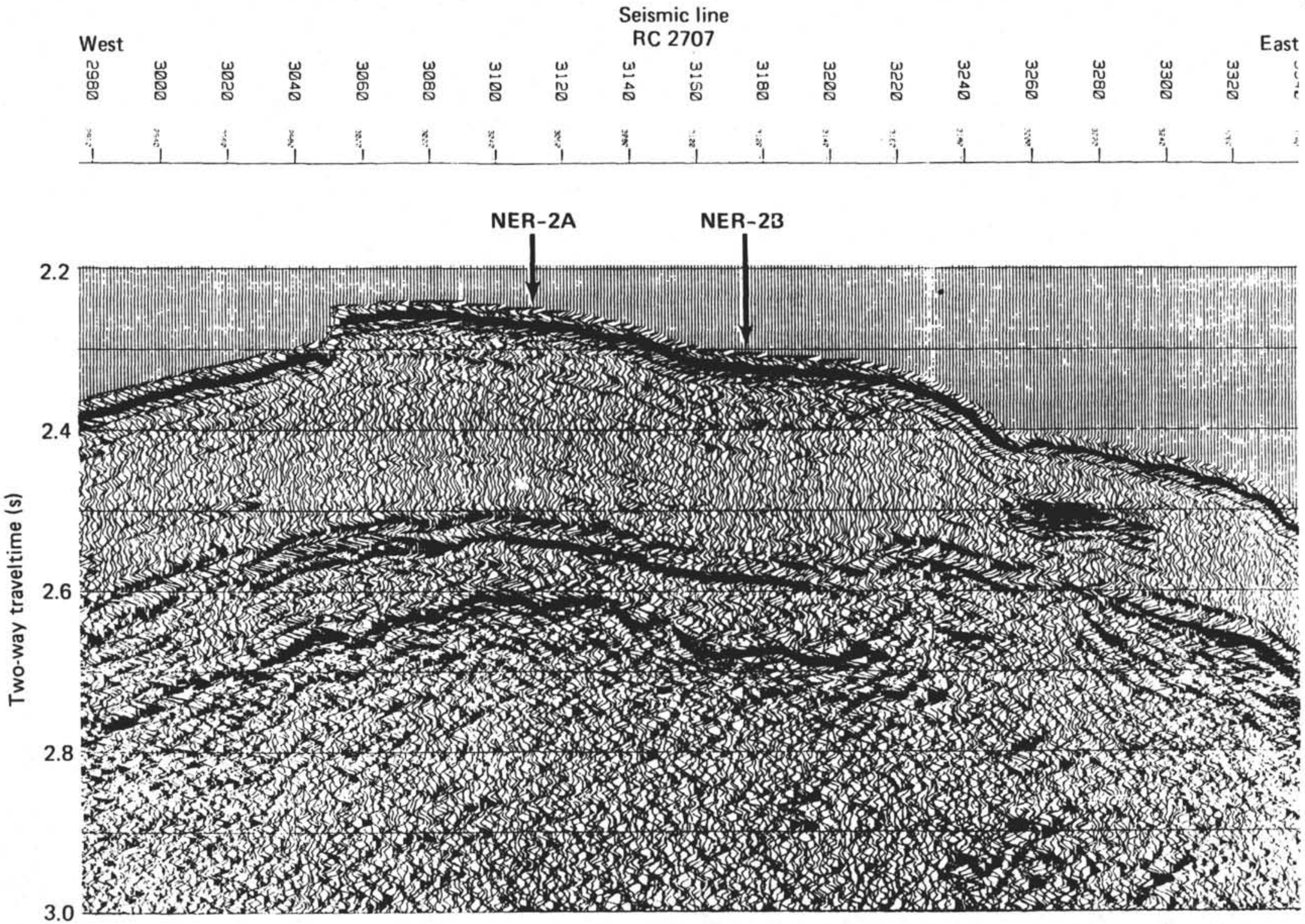
HEAT FLOW: Yes

LOGGING: Condition hole for 8 hr, then standard 3 runs (seismic strat., lithoporosity, and geochem.), then BHTV.

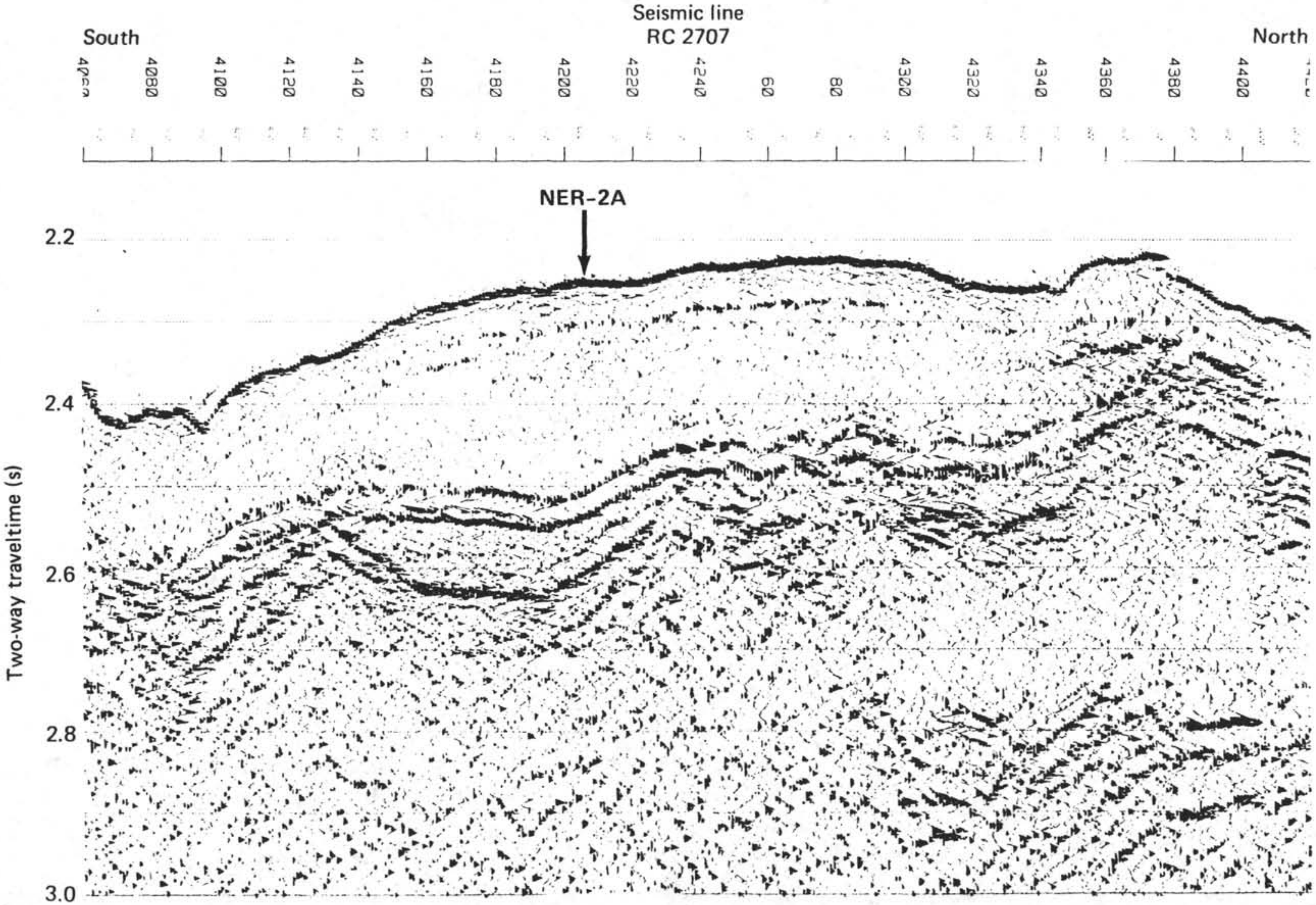
OBJECTIVES:
1. Basalt geochemistry at site between Sites 253 and 214, including vertical changes in basement section.
2. Detailed northward motion curve from paleomagnetic studies, with particular emphasis on Eocene-Oligocene section and basement.
3. Central site North-South paleoceanographic/climatic transect.
4. BHTV experiment to look for breakouts for stress analysis.

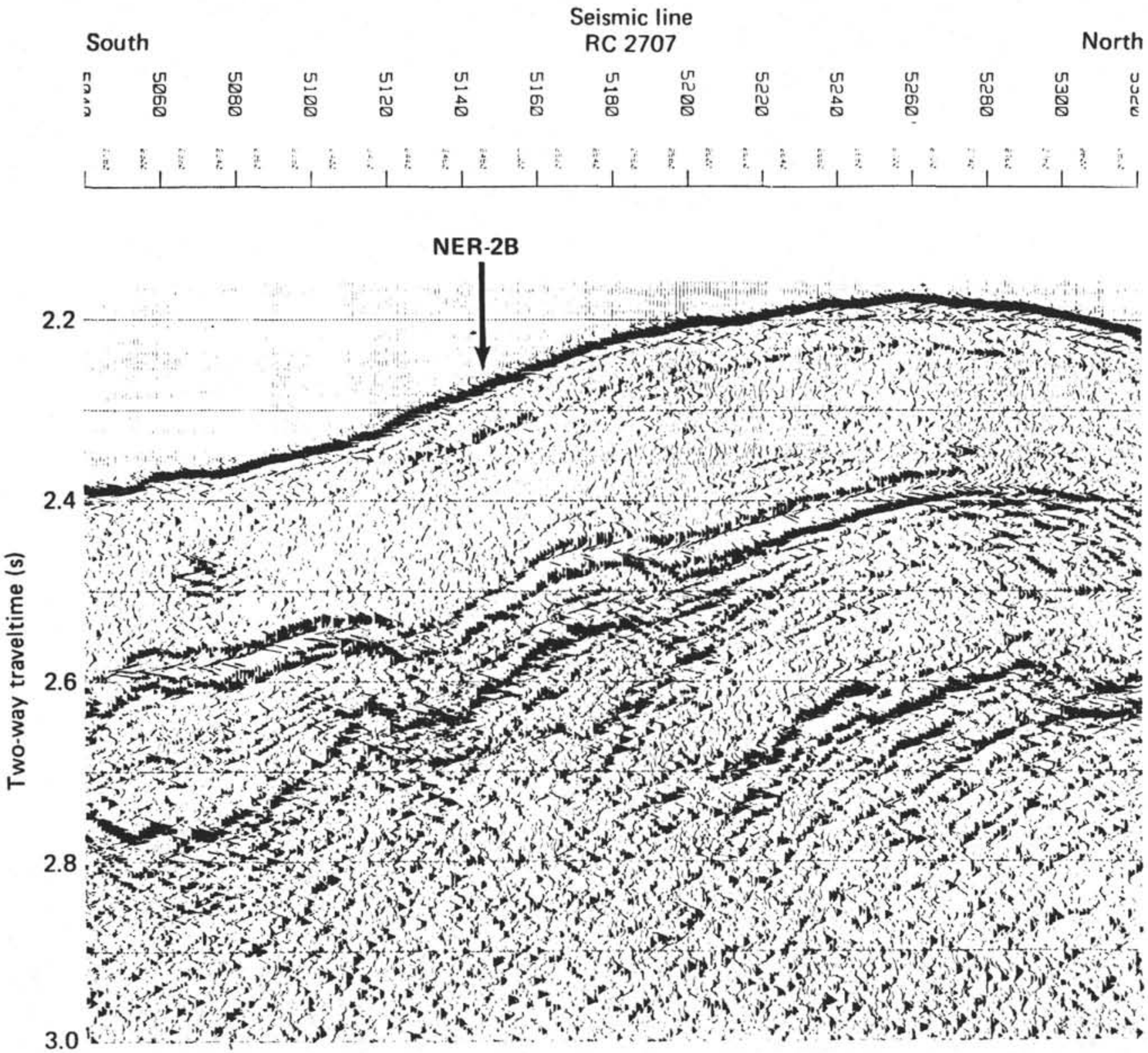
SEDIMENT TYPES: Calcareous ooze and volcaniclastics (possibly including tuffs and/or thin lignite beds) above first basalts. Intercalated volcaniclastics (perhaps quite thick) and/or paleosols between basalt flows.


87.90E
87.95
88.00
88.05
88.10
88.15
88.20
88.25
88.30
88.35
88.40
16.90S
16.95
17.00
17.05
17.10
17.15
17.20
17.25
17.30
A
B
C
D
E
F
K
L
X
Y
NER-2A
NER-2B
NER-2C
CNR-1
CNR-2
CNR-3
CNR-4

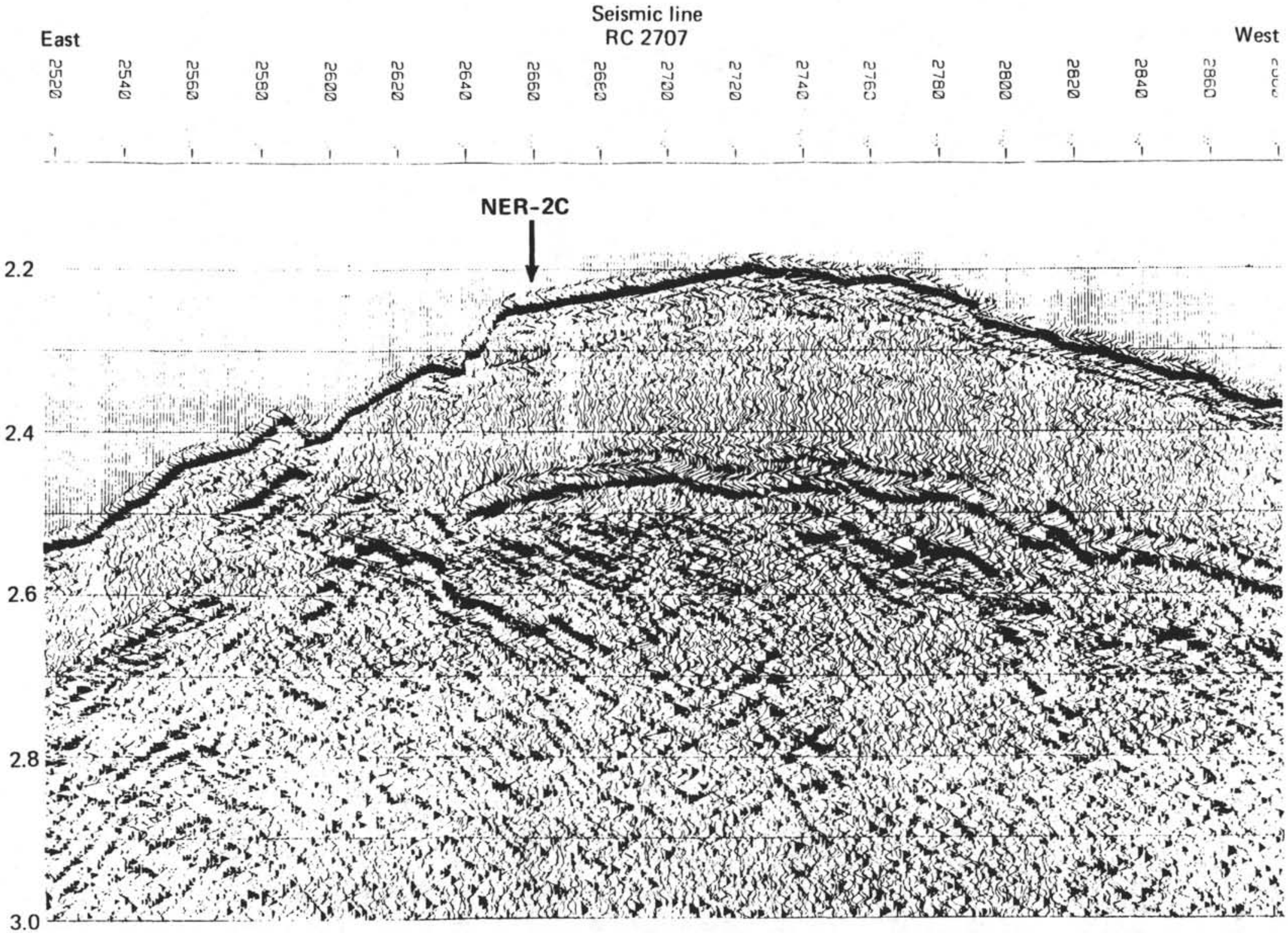


Seismic line
RC 2707
West
East
2980
3000
3020
3040
3060
3080
3100
3120
3140
3150
3180
3200
3220
3240
3260
3280
3300
3320
NER-2A
NER-2B
2.2
2.4
2.6
2.8
3.0
Two-way traveltime (s)

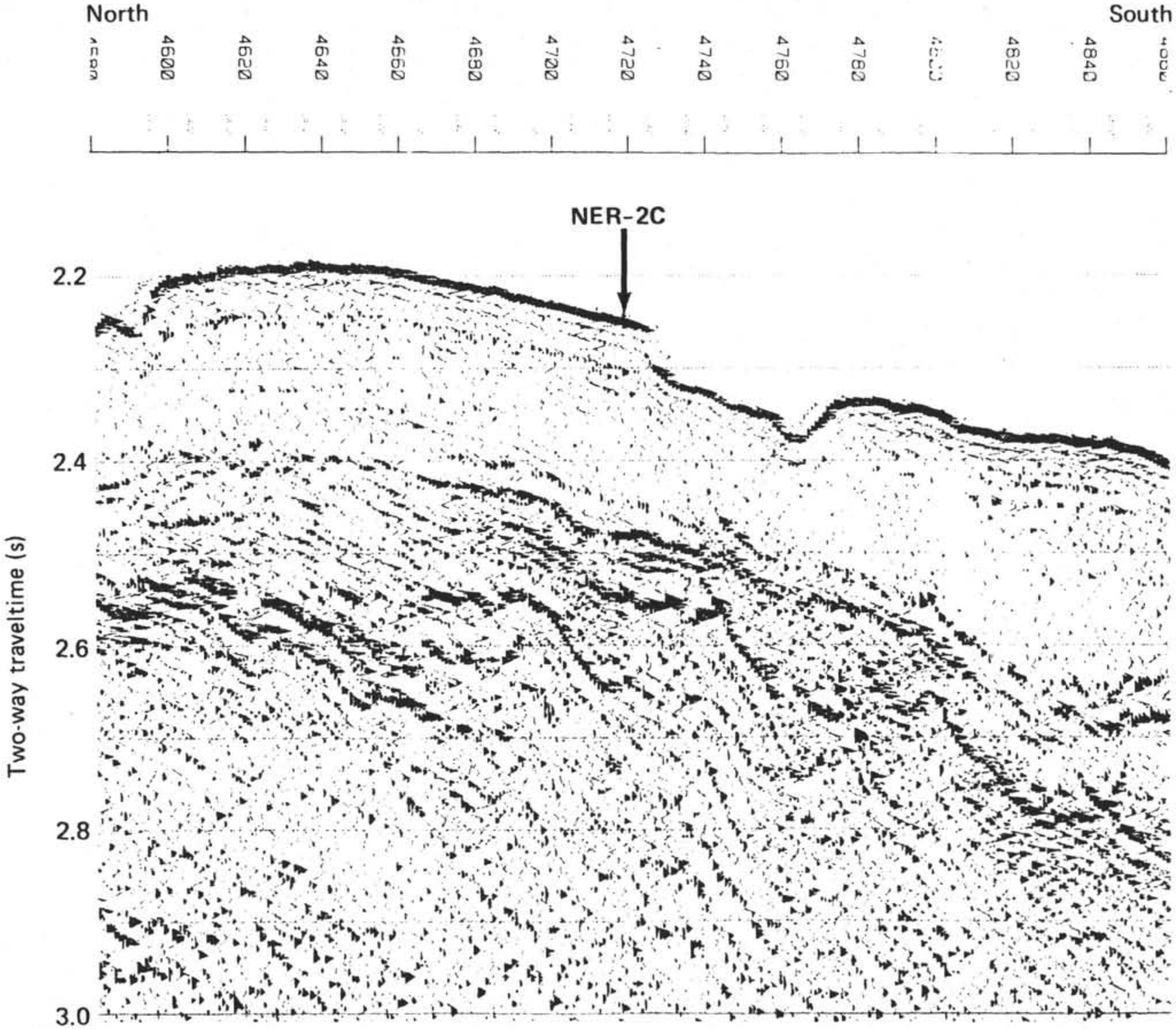

Seismic line
RC 2707
South
North
4080
4100
4120
4140
4160
4180
4200
4220
4240
60
80
4320
4340
4360
4380
4400
NER-2A
2.2
2.4
2.6
2.8
3.0
Two-way traveltime (s)



Seismic line
RC 2707
South
North
5060
5080
5100
5120
5140
5160
5180
5200
5220
5240
5260
5280
5300
NER-2B
2.2
2.4
2.6
2.8
3.0
Two-way traveltime (s)



Seismic line
RC 2707
East
West
2520
2540
2560
2580
2600
2620
2640
2660
2680
2700
2720
2740
2760
2780
2800
2820
2840
2860
NER-2C
2.2
2.4
2.6
2.8
3.0


North
South
4600
4620
4640
4660
4680
4700
4720
4740
4760
4780
4820
4840
NER-2C
2.2
2.4
2.6
2.8
3.0
Two-way traveltime (s)

SITE NUMBER: NER-1A (Northern Ninetyeast Ridge, NNER-9)

POSITION: 5°38.9'N
90°01.7'E

SEDIMENT THICKNESS: 425 m

WATER DEPTH: 2830 m

PRIORITY: 1

PROPOSED DRILLING PROGRAM: APC/XCB to basement; 1 NCB core if time.

SEISMIC RECORD: RC2705, 1010 25 June 86.

HEAT FLOW: Yes

LOGGING: Condition hole for 8 hours, then standard 3 runs (seismic strat., lithoporosity and geochem).

OBJECTIVES:
1. Expanded Neogene section at north end of N-S paleoceanographic/climatic transect.
2. Date presumed mid-Eocene unconformity.
3. Detailed northward motion curve from paleomagnetics if sufficient magnetic signal is present in carbonates.

SEDIMENT TYPE: Calcareous ooze becoming chalk deeper in hole. Possible volcaniclastics at bottom of hole.

SITE NUMBER: NER-1B (Northern Ninetyeast Ridge, NNER-10)

POSITION: 5°22.3'N
90°22.5'E

SEDIMENT THICKNESS: 525 m

WATER DEPTH: 3040 m

PRIORITY: 1

PROPOSED DRILLING PROGRAM: Wash 240 m to point about 30 m above unconformity. RCB through 285 m of sediment to basement and 50 m into basement.

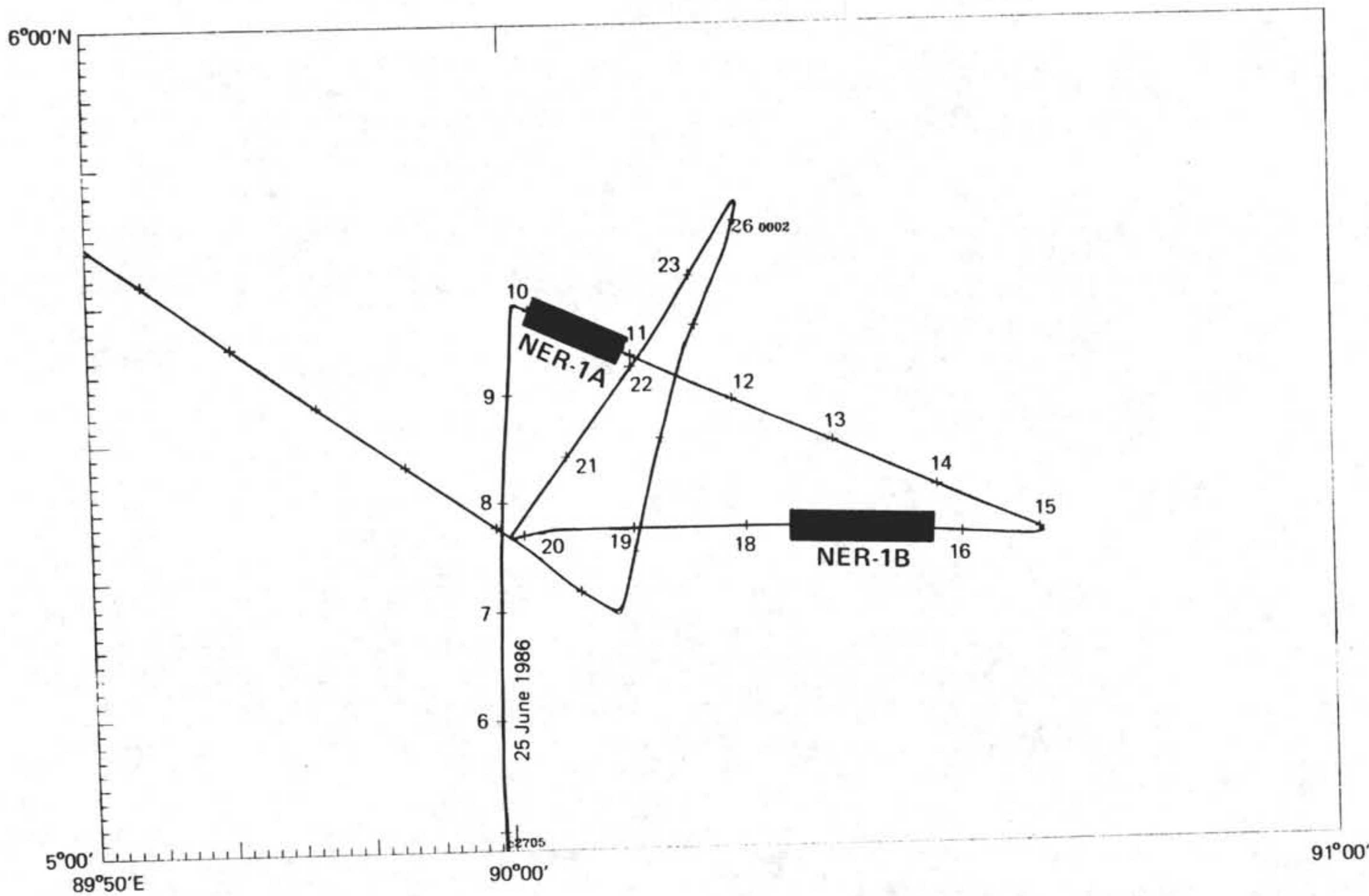
SEISMIC RECORD: RC2705, 1722.5, 25 June 86

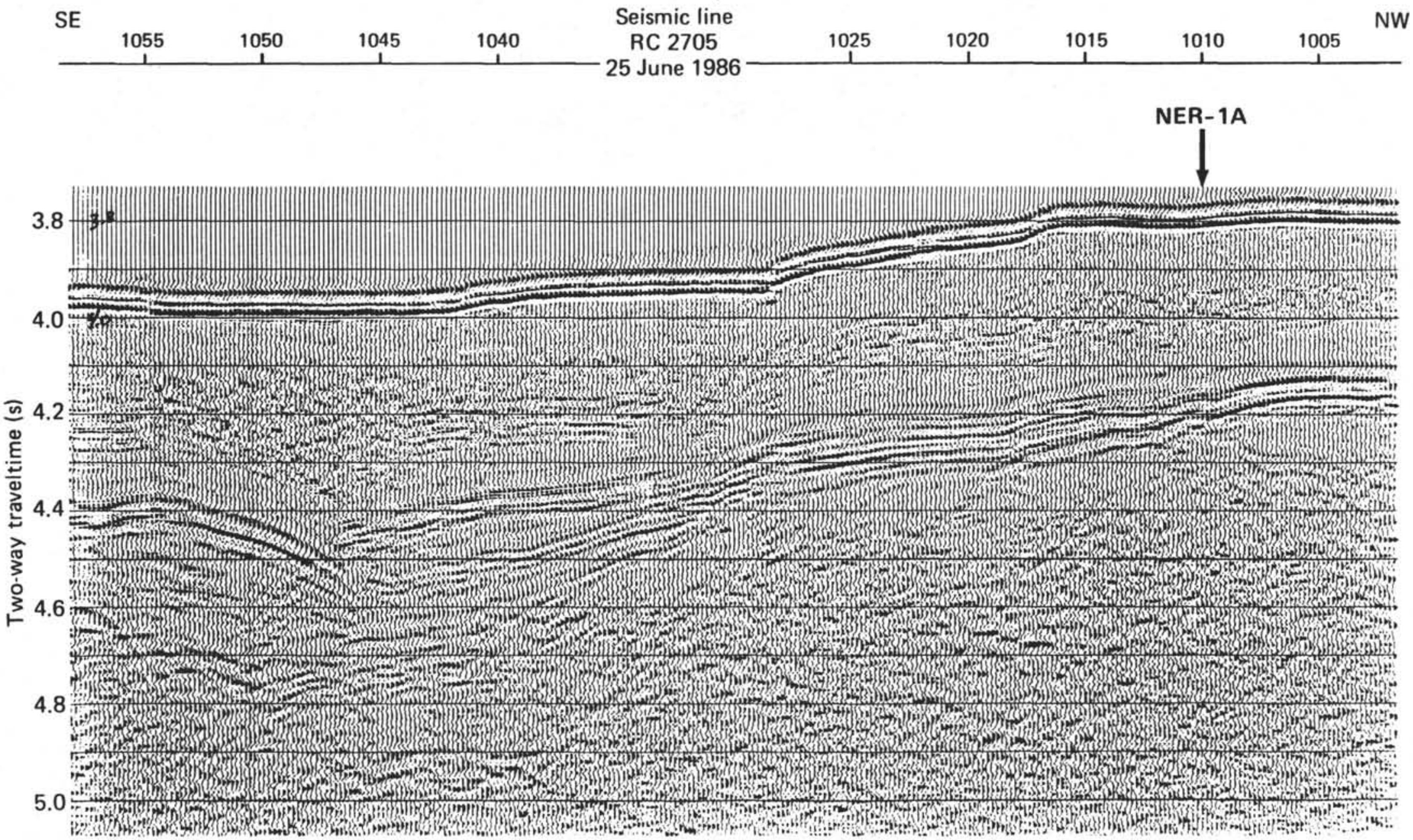
HEAT FLOW: No

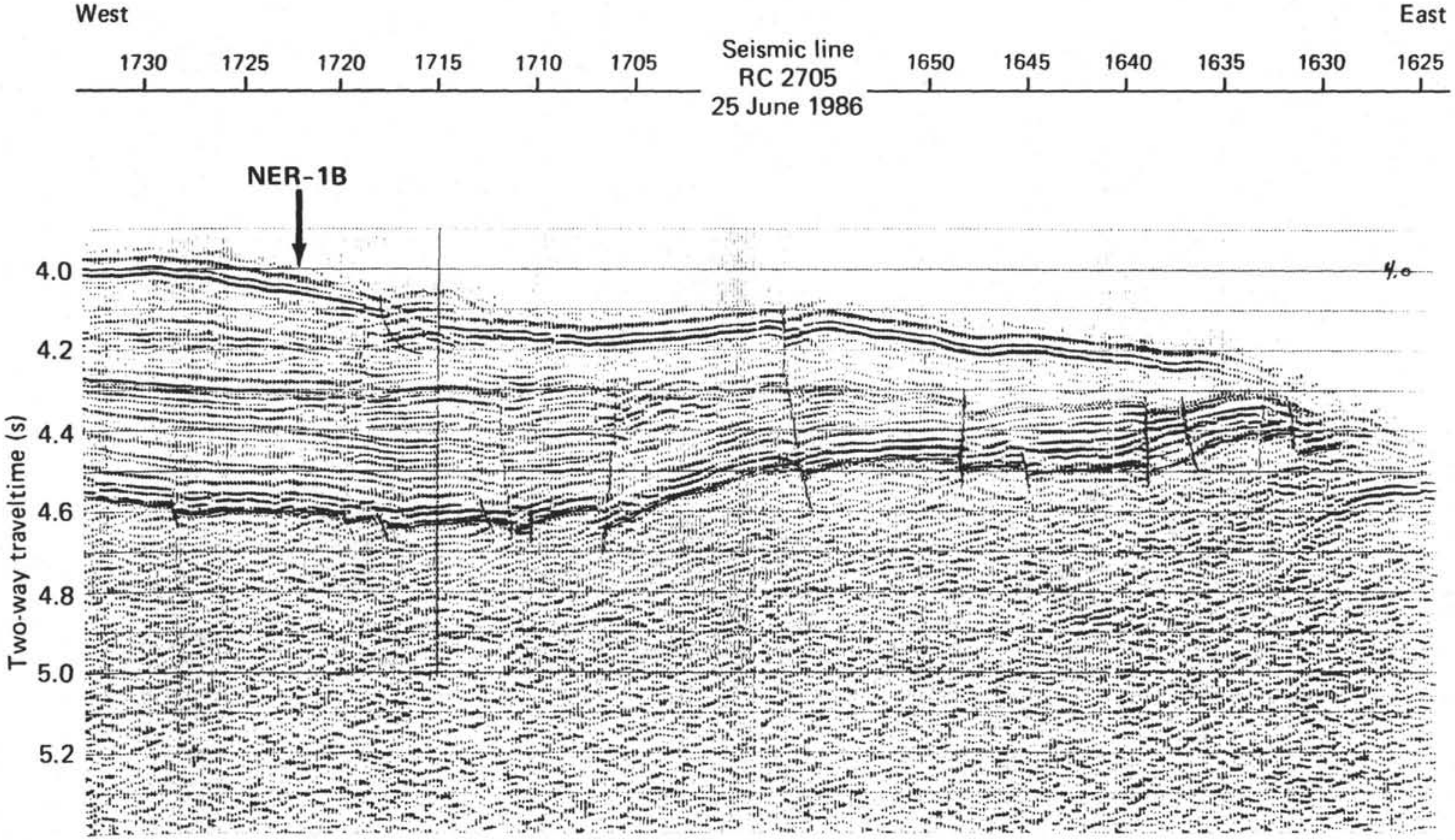
LOGGING: Condition hole for 8 hours, then standard 3 runs (seismic strat., lithoporosity and geochem). BHTV if not done at NER-2 or if time permits.

OBJECTIVES:
1. Basalt geochemistry at northern end of Ridge.
2. Sample expanded Paleogene-Cretaceous section at northern end of north-south paleoceanographic/climatic transect.
3. Detailed northward motion curve from paleomagnetics.

SEDIMENT TYPE: Calcareous ooze becoming chalk deeper in hole. Possible volcaniclastics at bottom of hole.


6°00′N
5°00′
89°50′E
90°00′
91°00′
NER-1A
NER-1B
25 June 1986
26 0002
2705
6
7
8
9
10
11
12
13
14
15
16
18
19
20
21
22
23


SE
NW
Seismic line
RC 2705
25 June 1986
1055
1050
1045
1040
1025
1020
1015
1010
1005
NER-1A
Two-way traveltime (s)
3.8
4.0
4.2
4.4
4.6
4.8
5.0


West
East
1730
1725
1720
1715
1710
1705
Seismic line
RC 2705
25 June 1986
1650
1645
1640
1635
1630
1625
NER-1B
4.0
4.2
4.4
4.6
4.8
5.0
5.2
Two-way traveltime (s)
4.0

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