LEG 179

HAMMER DRILLING/NINETYEAST RIDGE OBSERVATORY

Hammer Drilling Section by Tom Pettigrew

NERO Section Modified by J.-P. Montagner from Proposal 508 Submitted by:

Jean-Paul Montagner, Roland Schlich, Jean-François Karczewski, Kiyoshi Suyehiro, Pascal Tarits, Geneviève Roult, Philippe Patriat, Marc Schamming.

Staff Scientist: TBN

Chief Engineer, Part I: Tom Pettigrew
Chief Scientist, Part II: John Casey

ABSTRACT

Leg 179 is a two-part leg composed of testing the hammer drill-in casing system developed at the Ocean Drilling Program (ODP) and drilling a hole for the Ninetyeast Ridge Observatory (NERO) Project. Testing of the hammer drill will determine the viability of the tool, the complete casing system, and the maximum slope that can be spudded by the tool. Fifteen days have been allocated for these tests. The NERO project will enable a major gap in the global coverage of seismic, magnetic, and general geophysical data to be filled. Currently, geophysical observatories are only present on continents and islands, thus data collection is incomplete. Establishing a cased reentry hole will be the first step toward the installation of a Geophysical Ocean Bottom Observatory. This observatory will be part of the future network of seafloor observatories proposed in the International Ocean Network (ION) program. From a scientific point of view, the geophysical applications can be considered at two different scales. At a global scale, NERO meets the scientific objectives of ION regarding global geodynamics and earthquake studies and is in good agreement with ODP's Long Range Plan. At a regional scale, NERO enables a more specific investigation of the dynamics of the Indian Plate, which has had a complex geologic history characterized by high intraplate seismicity and may contain a diffuse plate boundary between the Central Indian Ridge and the Indonesian Arc. From a technological point of view, previous experiments (Japan, Leg 128, 1991; France, OFM/SISMOBS; Hole 396B, 1992) demonstrated that the installation of broadband seismometers in boreholes is now feasible. The selected site on the Ninetyeast Ridge should not produce any technical problems, since previous single bit holes were drilled in this area (ODP Sites 756 and 757 during Leg 121 in June 1988). To install a seismometer in the hole at a later date, it is necessary to first install a reentry cone and case down to basement. Seven days have been allocated for this operation. After the leg, the same kind of instrumentation used during the OFM/SISMOBS experiment will be positioned in the hole.

PART I: HAMMER DRILLING ENGINEERING LEG

INTRODUCTION

Experience gained on Ocean Drilling Program (ODP) Legs 147 (Hess Deep) and 153 (located at the Mid-Atlantic Ridge at Kane Transform [MARK]) indicates the current hard-rock base design is not optimal for establishing boreholes in fractured hard-rock environments with moderate slope. This is especially true on thinly sedimented slopes covered with debris or rubble. Therefore, new hardware and techniques have been developed to establish a borehole in these environments to meet the scientific objectives of hard-rock legs. Establishing a borehole refers to actual borehole spudding, emplacement of casing to stabilize the borehole, and establishing reentry capability. Establishing a borehole requires some form of seafloor structure, whether it be an independent structure such as a seafloor template, a hard-rock base, or some form of a hard-rock drill-in casing system.

The tool with the most promise of dramatically increasing ODP's ability to establish a borehole in a hard-rock environment is the hammer drill-in casing system. Thorough testing of this tool prior to deployment at sea in an actual hard-rock environment will greatly increase the success of future hard-rock legs. Therefore, the engineering portion of Leg 179 will be dedicated solely to testing a hammer drill-in casing system in a fractured hard-rock environment. This part of the leg will be carried out on the Southwest Indian Ridge in the vicinity of Site 735 (Fig. 1).

BACKGROUND

Drilling and coring operations in fractured hard rock must overcome many unique challenges. The boreholes must be spudded on hard, sometimes fractured rock, with little or no overlying sediment cover to help stabilize the bit. The dipping slope generally associated with these areas further compounds the problem. An additional challenge is keeping the borehole open long enough for the emplacement of casing. Rubble and debris from the seafloor continuously sift into the borehole as it is being drilled. This rubble, along with the drill cuttings and material dislodged from the borehole wall, must be continuously removed. However, the size and density of this in-fill material make it difficult to remove it from the borehole. Maximum penetration is dependent on borehole stabilization. Stabilizing boreholes in fractured hard rock requires emplacement of casing and some form of reentry structure to support the casing.

The hammer drill-in casing system (Fig. 2) is composed of a hydraulically actuated percussion hammer drill, a casing string or multiple casing strings, free fall deployable reentry funnel, and a casing hammer. Reentry capability is established by a free-fall reentry funnel specially designed for this purpose. Once the casing string has been drilled into place and the reentry funnel installed, the drilling assembly is unlatched from the casing string and removed. The borehole is left with casing and a reentry funnel in place. If required, the casing string may be cemented in place and multiple casing strings may be installed in the same borehole.

This type of drill-in casing system is currently being used in Iceland to drill-in large diameter casing (18-5/8 in) up to 100 m deep in fractured basalt. Unfortunately, the Icelandic system is pneumatically driven and, thus, not suited for use in deep water. However, a hydraulically actuated hammer drill suitable for use by ODP is currently under development in Australia. ODP is assisting in the development of this hammer drill and will incorporate it into the hammer drill-in casing system.

A viable hammer drill-in casing system would:

1. Eliminate the need for any form of independent seafloor structure such as the hard-rock base or seafloor template.

2. Allow spudding boreholes on much steeper slopes than can be achieved using an independent seafloor structure.

3. Be less sensitive to thin sediment cover, debris, or rubble lying on the spudding surface.

4. Be less dependent on precise site surveys.

ENGINEERING OBJECTIVES

In general, there are three objectives, listed in order of priority, that must be explored to establish a borehole in a hard-rock environment.

1. Determine the onboard operational characteristics of the hammer drill by deploying it independently of the drill-in casing system. The hammer drill will be thoroughly land tested

before it is deployed at sea; however, it is difficult to simulate the shipboard deployment environment. Therefore, the hammer drill will be deployed by itself for evaluation prior to using the entire hammer drill-in casing system.

2. Determine the viability of the hammer drill-in casing system. Once the shipboard operational characteristics of the hammer drill are established, the complete hammer drill-in casing system will be deployed for evaluation. Three boreholes of increasing difficulty are planned to completely test the equipment.

3. Determine the maximum slope that can be spudded with the hammer drill. Once the hammer drill-in casing system is fully evaluated, the maximum slope at which the hammer drill can spud will be determined. Multiple shallow (1-3 m) boreholes will be spudded on increasing slopes to determine maximum slope spudding capability.

SITE LOCATION

The test site location is the same shallow-water platform on the east rim of the Atlantis II Transform on which Hole 735B is located. This location provides a range of water depths from 700 m to over 6 km. This site also provides a variety of spudding surfaces ranging from relatively level massive outcroppings with clean surfaces to severely sloped talus covered surfaces.

DRILLING PLAN

The proposed drilling plan addresses the minimum requirements to evaluate the potential of a hammer drill-in casing system. No coring is specifically planned; however, should time allow, a core or two may be recovered through one of the established boreholes. Several reenterable boreholes will be established that may be used for future scientific exploration.

The drilling plan will proceed as follows:

1. Initially the hammer drill only will be deployed on top of the platform in 700 m water depth.

Several shallow holes 1-3 m deep will be drilled to establish the shipboard operational parameters.

2. Once the hammer drill shipboard operational parameters are determined, the entire hammer drill system will be assembled and deployed. One specific location is on the north flank of the platform in 1.5-2.5 km water depth. A short casing string, 20-40 m, will be drilled as a first step in evaluating the system.

3. In order to maximize our knowledge of the system, a second hammer drill system emplacement will be attempted at the same location. A longer casing string, 40-80 m, will be drilled in.

4. A talus covered shelf with severe slope will be located on the western flank of the platform for the third hammer drill system emplacement. This will be the most severe test of the system and will most closely simulate conditions found at MARK and Hess Deep.

5. Time permitting, the following tests will also be carried out. The tests are listed in order of priority.

   A. Several shallow boreholes 1-3 m deep will be drilled using the hammer drill on shelves with increasing slope. This test will determine the slope spudding capability of the hammer drill when suspended from the drill ship.

   B. One of the established boreholes will be reentered and the casing cemented in place. Slightly different tools and techniques from those typically used by ODP will have to be employed. This test will verify the proposed procedure.

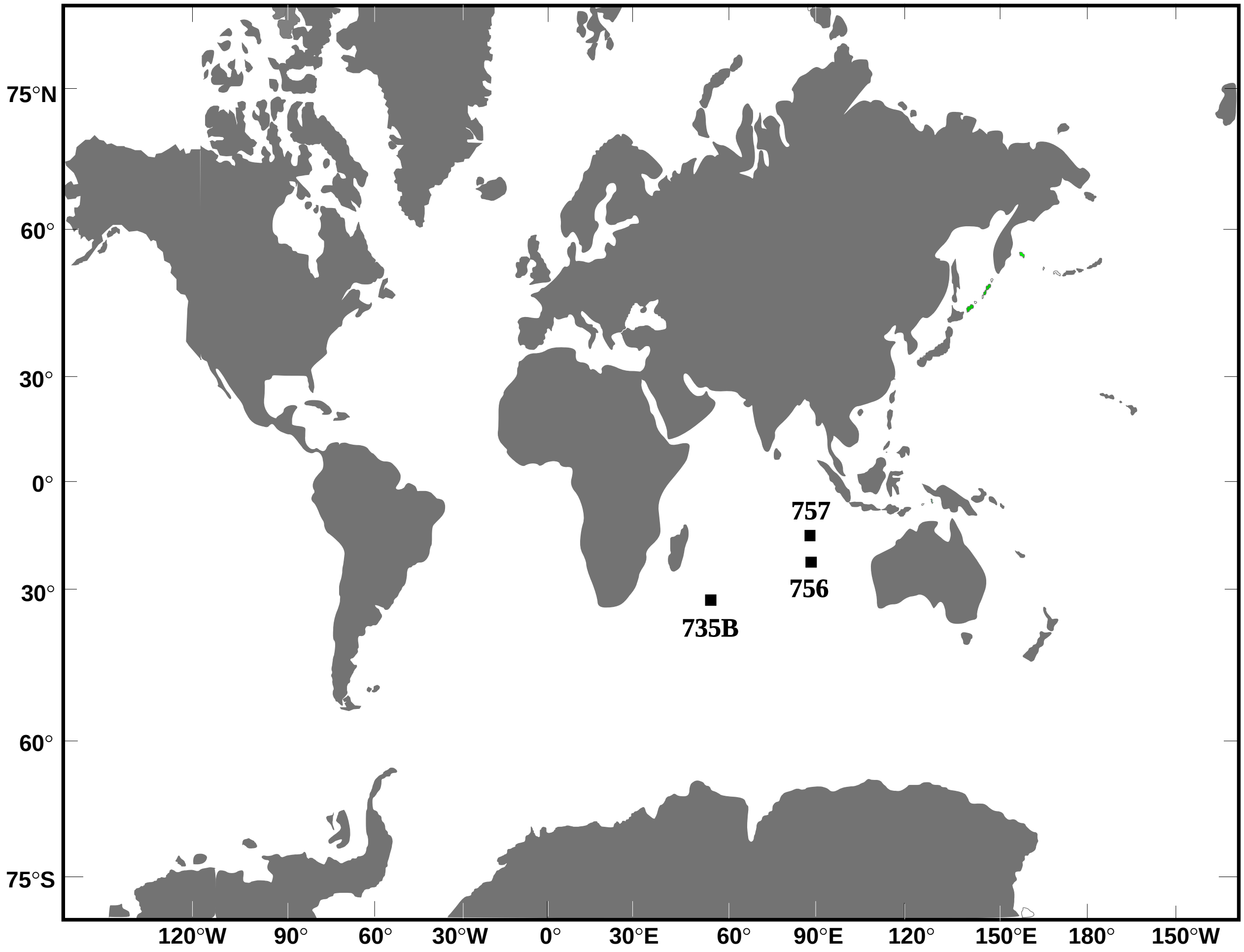

Figure 1. Map showing the site locations for Part I (near Site 735B) and Part II (near ODP Sites 756 and 757).

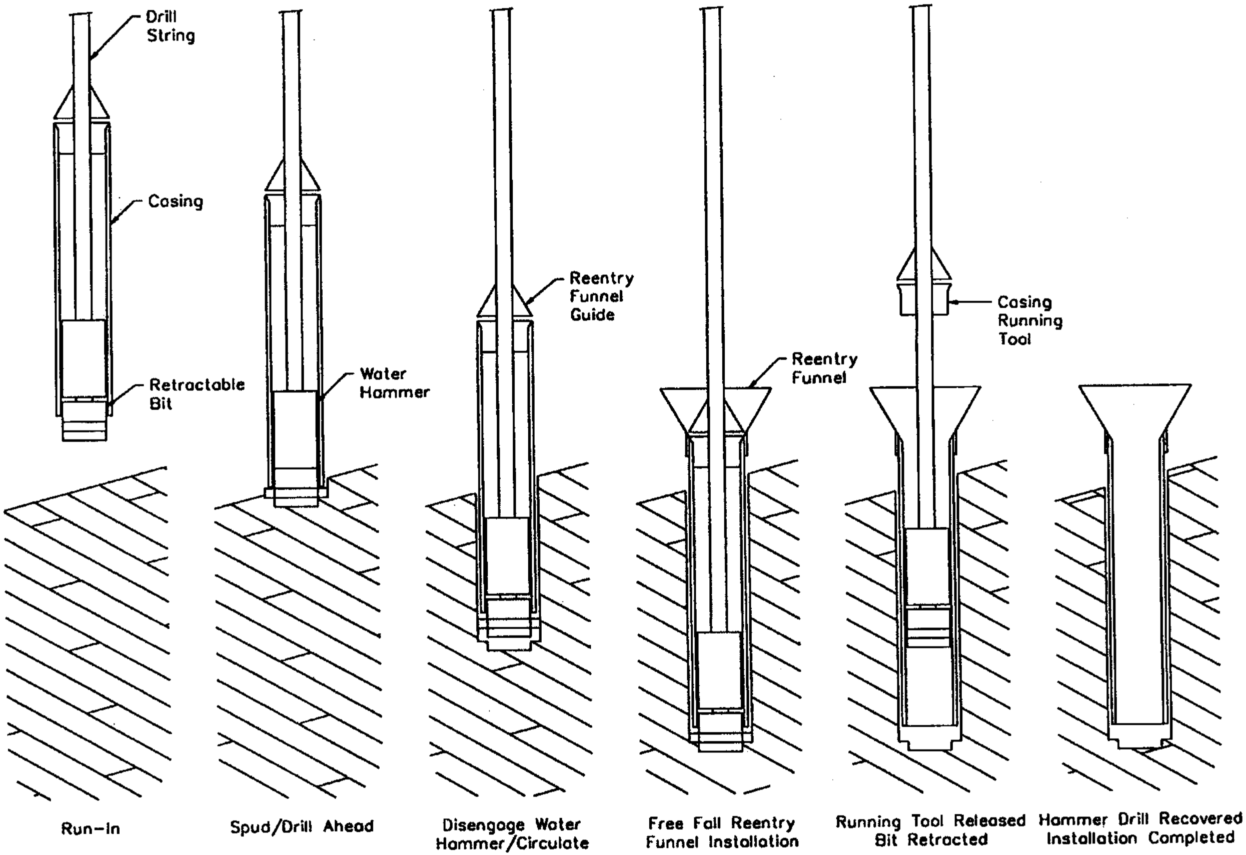

Figure 2. Schematic diagram of Water Hammer Drill-In Casing System deployment.

TABLE 1

PROPOSED SITE INFORMATION AND DRILLING STRATEGY

SITE: 1	**PRIORITY**: 1	**POSITION**: 32°43´S, 57°16´E
WATER DEPTH: 700 m	**SEDIMENT THICKNESS**: 0 m	**TOTAL PENETRATION**: 60 m
SEISMIC COVERAGE:		

Objectives: 1. Characterize operating parameters, i.e., flow rates, pump pressures, weight on bit, of the hammer drill as seen from the drill floor. 2. Characterize hammer drill spudding capability on sloped outcroppings. 3. Test entire hammer drill system by drilling in 20 - 40 m of 13-3/8" casing in a fractured hard-rock environment with little or no overlying sediment or talus and with little or no slope.

Drilling Program: Deploy the hammer drill only. Drill several shallow (1-3 m) test boreholes while characterizing the flow rates, pump pressures and drill bit revolutions per minute required to spud and advance the borehole efficiently. Drill several shallow (1-3 m) test boreholes on sloped outcrops. Deploy entire hammer drill system and perform the first full scale drill-in test.

Logging and Downhole Operations: None

Nature of Rock Anticipated: Gabbro and/or peridotite

SITE: 2	**PRIORITY**: 1	**POSITION**: 32°36´S, 57°15´E
WATER DEPTH: 2800 m	**SEDIMENT THICKNESS**: 0 m	**TOTAL PENETRATION**: 60 m
SEISMIC COVERAGE:		

Objectives: 1. Test hammer drill system by drilling in 40 - 60 m of 13-3/8" casing in a sloped fractured hard-rock environment with little or no overlying sediment or talus.

Drilling Program: Deploy entire hammer drill system and perform second full scale drill-in test.

Logging and Downhole Operations: None

Nature of Rock Anticipated: Gabbro and/or peridotite

SITE: 3	**PRIORITY**: 1	**POSITION**: 32°43´S, 57°11´E
WATER DEPTH: 2800 m	**SEDIMENT THICKNESS**: 0 m	**TOTAL PENETRATION**: 80 m
SEISMIC COVERAGE:		

Objectives: 1. Test hammer drill system by drilling in 60 - 80 m of 13-3/8" casing in fractured hard-rock with overlying talus.

Drilling Program: Deploy entire hammer drill system and perform third full scale drill-in test.

Logging and Downhole Operations: None

Nature of Rock Anticipated: Gabbro and/or peridotite

PART II: NERO PROJECT

INTRODUCTION

Seismic data from a worldwide network (WWSSN) established in the early 1960s accelerated advances in seismology and were a great resource of new discoveries up to the 1970s. During the past ten years, our knowledge of the processes of the deep Earth has been greatly improved by the development of new generations of global monitoring networks in seismology and geodesy and the continuation of long-term observations in geomagnetism (GEOSCOPE, IRIS, GeoFon on a global scale; and MedNet, Poseidon, CDSN, GRSN on a regional scale). While the quantity and quality of data have increased, this new information has revealed that there are large departures from lateral homogeneity at every level from the Earth's surface to its center. The intensive use of broadband data has provided remarkable seismic tomographic images of Earth's interior. These models are now routinely used in geodynamics for earthquake studies and to obtain the complex time histories of the inhomogeneous earthquake faulting related to tectonics. Improvements in the observatory locations for seismology, geodesy, and geomagnetics, particularly in the oceans, can greatly enhance our understanding of the Earth's interior.

Installing a reentry cone and casing down to basement is the first step toward the installation of a Geophysical Ocean Bottom Observatory (GOBO). The seismometer instrumentation will be installed at a later date. This observatory will be part of the future network of seafloor observatories proposed in the International Ocean Network (ION) program. The selected site on the Ninetyeast Ridge (Fig. 1, Part I) should not produce any technical problems, as previous holes in this area were drilled with a single bit (ODP Sites 756 and 757 during Leg 121 in June 1988). Establishing this cased reentry hole will require up to a week of ship time.

BACKGROUND

The scientific community has recognized that global seismic observations will remain incomplete until instruments are deployed on the ocean floor. There is asymmetry in station coverage between oceans and continents and more particularly between the Southern and Northern Hemispheres. The need for ocean bottom observatories for geodetic, magnetic, and seismic studies is driven by the same factor: the lack of observations in large tracts of the world ocean where neither continents nor islands are available to place observatories. Some plates, for example the Nazca and Juan de Fuca Plates and the Easter Microplate, have no islands on which observatories are typically stationed, and, thus, the geodetic measurements needed to evaluate absolute plate motion and plate deformation are not available. The problem of extrapolating the magnetic field to the core-mantle boundary is greatly exacerbated by "holes" in observation sites in the Indian Ocean and eastern Pacific Ocean. Images of the interior velocity heterogeneity, in turn related to thermal and chemical convection, are "aliased" by the lack of control from seismic stations in the Indian and Pacific Oceans. Maps of "holes" from all three disciplines include many common sites. For at least the next five years, it is possible to consider installing joint observatories to meet the needs of all these programs. During the last prospective workshops (IRIS/Hawaii, 1993, ION-ODP, Marseilles, 1995), it was recognized that the installation of GOBO is now feasible from a technological point of view and represents the first priority for the next ten years.

The installation of ocean bottom seismic stations, their maintenance, and the recovery of data on a timely and long-term basis represent a formidable technical challenge. However, different pilot experiments carried out by Japanese (Kanazawa et al., 1992; Suyehiro et al., 1992), French (Montagner et al., 1994a, b), and American groups (OSN1, Dziewonski et al., 1992; Orcutt, pers. com., 1997) demonstrate that there are technical solutions to all the associated problems.

The technical goal of the French Pilot Experiment OFM/SISMOBS (Observatoire Fond de Mer) conducted in April and May 1992 was to show the feasibility of installing and recovering two sets of three-component broadband seismometers (one inside an ODP borehole and another inside an OBS sphere in the vicinity of the hole). Secondary goals were (1) to obtain the seismic noise level in the broadband range 0.5-3600 s, (2) to conduct a comparative study of broadband noise on the seafloor, downhole, and on a continent, and (3) to determine the detection threshold of seismic events. A complete description of the experiment can be found in Montagner et al. (1994a) and a drawing is presented in Figure 3 (located at the end of Part II).

After the installation of both sets of seismometers, seismic signals were recorded continuously during 10 days. The analysis of these signals shows that the seismic noise is smaller in the period range 4-30 s for both ocean floor seismometers (OFS) and downhole seismometers (DHS) than in a typical broadband continental station such as spinning sidebands (SSB). The noise is still smaller than the noise at SSB up to 600 s for OFS. The noise on vertical components is much smaller than on the horizontal ones. The difference might be explained by instrument settling. It was also observed that the noise level tends to decrease as time goes by for both OFS and DHS, which means that the equilibrium stage was not yet attained by the end of the experiment (Beauduin et al., 1996a,b). The patterns of microseismic noise in oceanic and continental areas are completely different. The background microseismic noise is shifted toward shorter periods for OFS and DHS compared to a continental station. This might be related to the difference in the crustal structure between oceans and continents. The low level of seismic noise implies that the detection threshold of earthquakes is very low and it has been possible to correctly record teleseismic earthquakes of magnitude as small as 5.3 (Montagner et al., 1994b). It was also possible to extract the earth tide oceanic signal. Therefore, the experiment was a technical and scientific success and demonstrated that the installation of a permanent broadband seismic and geophysical observatory at the bottom of the seafloor is now possible and can provide the scientific community with high quality seismic data.

SCIENTIFIC OBJECTIVES

Leg 179 will drill a single hole and install a reentry cone and casing. At a later time, a GOBO will be installed, which will be part of the future network of seafloor observatories proposed in the ION program. The scientific objectives that can be addressed with geophysical data from long-term ocean bottom observatories include two broad subject areas: Earth structures and natural hazards. These two areas can each be divided into subareas according to the scale under investigation: global, regional, and local.

- Global scale: mantle dynamics, core studies, moment tensor inversion. The ION report emphasizes that "oceans are seismic deserts!" Except for a few stations on oceanic islands, very large zones are unmonitored, particularly in the Pacific, South Atlantic, and East Indian Oceans. With the present station coverage (FDSN, Fig. 4), the best expected lateral resolution is larger than 1000 km. The same problem arises for geomagnetic observatories. There are many shadows or poorly illuminated zones in the Earth. Due to the nonuniformity of earthquake and seismic station distribution, seismic waves recorded in stations do not illuminate the whole

Earth. For example, the transition zone (in a broad sense: 400-1000 km of depth) is poorly covered by surface waves and body waves below oceanic areas.

- Regional scale (wavelengths betwen 500 and 5000 km): oceanic upper mantle dynamics, lithosphere evolution, and tsunami warning and monitoring. In terms of oceanic upper mantle seismic investigations, only very long wavelengths have been investigated. In addition, surface waves are the only waves sampling the oceanic upper mantle, and there are no direct measurements of body waves. In order to understand the lithosphere's evolution, it is necessary to improve the lateral resolution of tomographic seismic studies.

The Indian Ocean is considered to be the most complex of the Earth's oceans. Since the 1970s, magnetic anomalies, fracture zone information, and other geophysical information (McKenzie and Sclater, 1971; Norton and Sclater, 1979; Schlich, 1982; Royer and Sandwell, 1989) have been used to understand the tectonic history of the Indian Ocean, which is characterized by irregularities in kinematic behavior (e.g., ridge jumps, reorganization of the ridge system, asymmetric spreading, spreading velocity changes, and finally collision between India and Asia). Few tomographic investigations have been performed so far in the Indian Ocean (Montagner, 1986; Montagner and Jobert, 1988; Debayle and Lévêque, in press). These studies display a good correlation between surface tectonics and seismic velocities down to 100 km (Fig. 5), but there seems to be some offset at larger depth for the Central Indian Ridge, as a consequence of the decoupling between the lithosphere and the underlying mantle. This complexity at large depth is also present in global tomographic models. However, the lateral resolution is still quite poor and it makes it necessary to increase the station coverage of oceanic areas. The next step in tomographic techniques regards the simultaneous use of surface waves and body waves. By installing only one station in the Central Indian Ocean, it will be possible to obtain direct measurements of delay times and, therefore, unique and fundamental information on the local anisotropy (from SKS splitting), particularly for the 410 km and 660 km discontinuities (from converted seismic waves) and for pure oceanic paths. As shown in Figure 6, the future observatory is well surrounded by seismically active areas. This ensures there will be a reasonable amount of data within one or two years.

- Local scale (wavelengths <500 km): oceanic crustal structure, sources of noise, and detailed earthquake source studies (tomography of the source, temporal variations).

DRILLING STRATEGY/PROPOSED SITES

The approximate location of the observatory should be around 28°S, 90°E. It will complete the coverage of the Indian Ocean provided by stations RER, CRZ, PAF, AIS of the GEOSCOPE network. The precise location is not crucial. However, in order to secure the drilling of the borehole, we propose a site close to previous drilling sites. A second constraint on the site location is the need of a sufficient thickness of sediments. This last condition can be easily satisfied by a site on the Ninetyeast Ridge. Close to this point, two sites occupied on ODP Leg 121 fulfill these constraints:

ODP Site 756

Site 756 is located at 27°21.30'S, 87°35.85'E. This site was surveyed in September 1986 as part of the *Robert Conrad* Cruise 2708 (RC 2708). Site survey information is in the Leg 121 *Initial Reports* volume (Shipboard Scientific Party, 1989a,b). *Conrad* and *JOIDES Resolution* tracks are shown in Figure 7, and an example of a seismic profile is shown in Figure 8. At this site, sediment thickness is 139 m. The issue of basement penetration is largely dependent on the nature of the rocks and the need to avoid hydrothermal circulation. To facilitate the future installation of a GOBO, it is necessary to penetrate 200 m into basement.

ODP Site 757

Site 757 is located at 17°01'S, 88°11'E (DSDP Site 253 is located at 24°52.65'S, 87°21.97'E). The area near Site 757 was surveyed in August 1986 as part of *Robert Conrad* Cruise 2707 (RC 2707). Tracks and an example of seismic profile are presented in Figures 9 and 10. The thickness of sediments is about 370 m. Since the drilling conditions in this area were excellent, it is likely that basement penetration of 100 m should be sufficient. The hole must be cased down to basement with a reentry cone attached at the top. Whichever of these two sites is finally selected, the basement part of the hole will be cored.

LOGGING PLAN

The logging program in this hole is designed to measure physical properties, anisotropy, and hole shape, objectives that are identical to the objectives at a previous site, Site OSN-1 (ODP Hole 843B). An azimuthal resistivity tool (ARI) will be used in place of the laterolog to measure electrical anisotropy with approximately 1-m resolution, complementing high-resolution Formation MicroScanner (FMS) images. Standard geophysical logs are planned to measure physical properties; fracturing and borehole shape may be measured using a UBI log in the basement. A sonic bond log and UBI log will also help to evaluate the grouting quality of the casing. In open-hole sections, high-resolution temperature logs will help to identify permeable zones and in-flow/out-flow from both drilling-induced and natural fractures in the hole that may affect the placement of downhole seismometers and data quality. In summary, the logging program at this site is (1) triple-combo with ARI, (2) FMS/Sonic, and (3) UBI. Three logging runs in this shallow hole will require approximately one day of ship operations.

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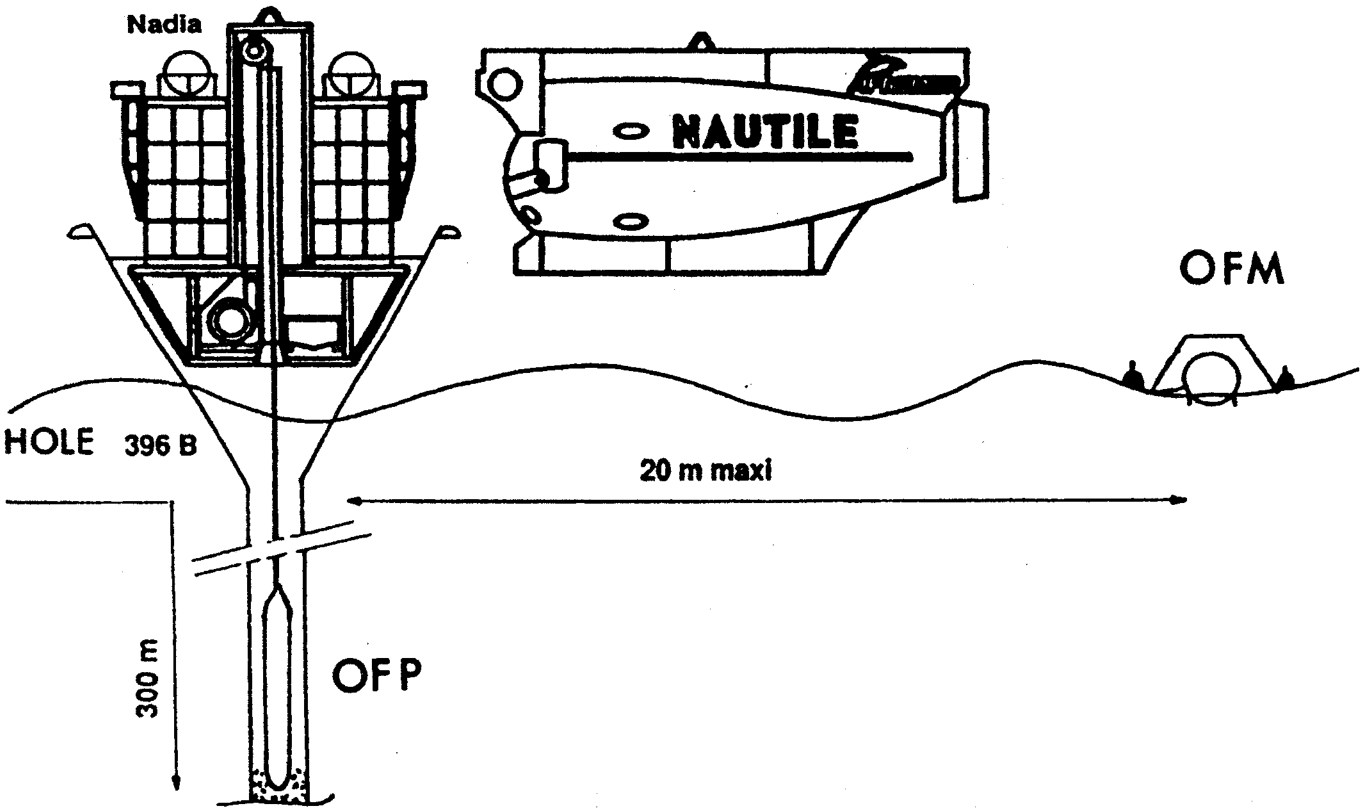

Figure 3. Sketch of the OFM/SISMOBS experiment (April-May 1992).

FDSN stations in 1996

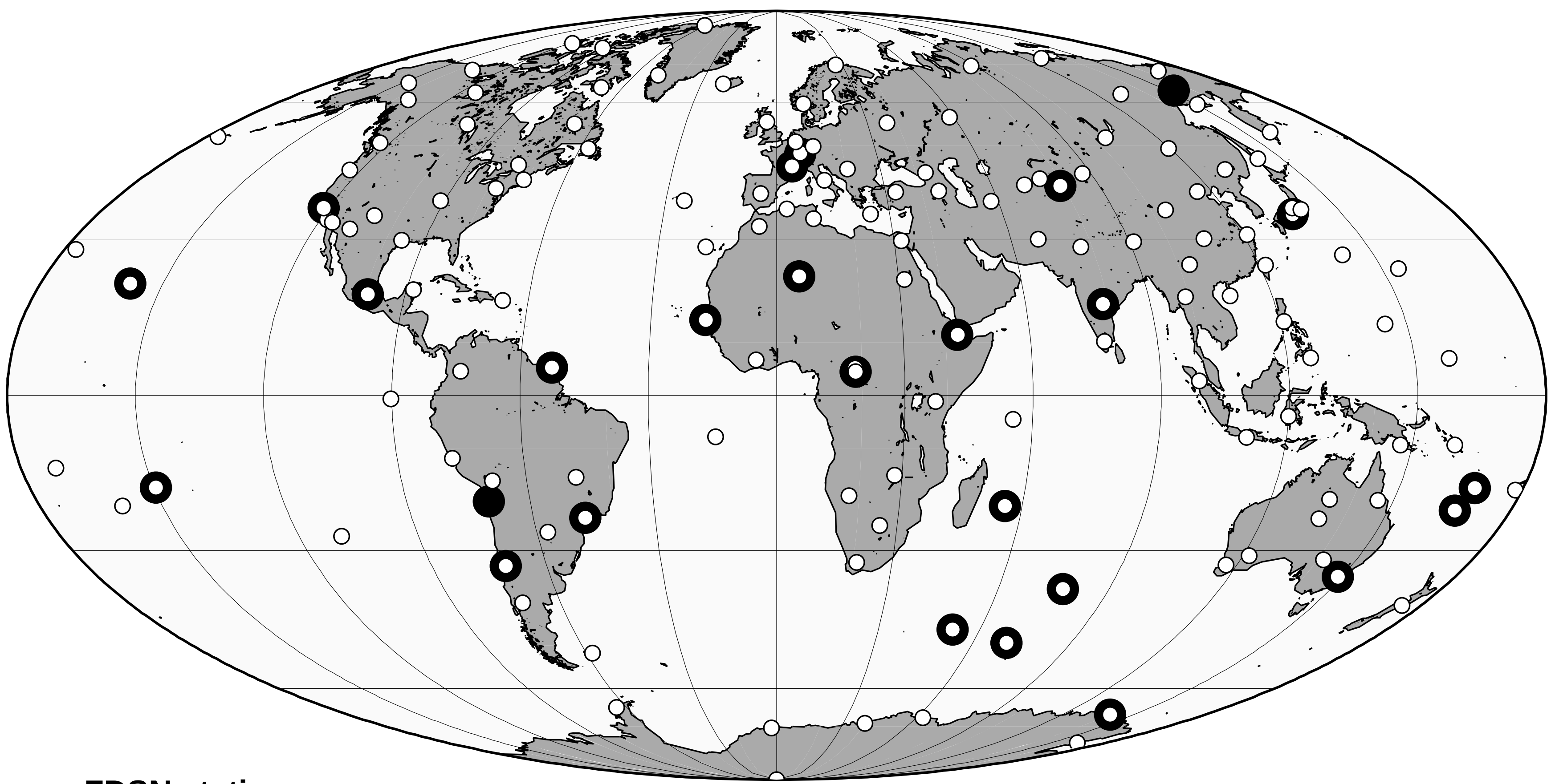

Figure 4. Location of Federation of Digital Seismic Networks (FDSN) and GEOSCOPE stations in the

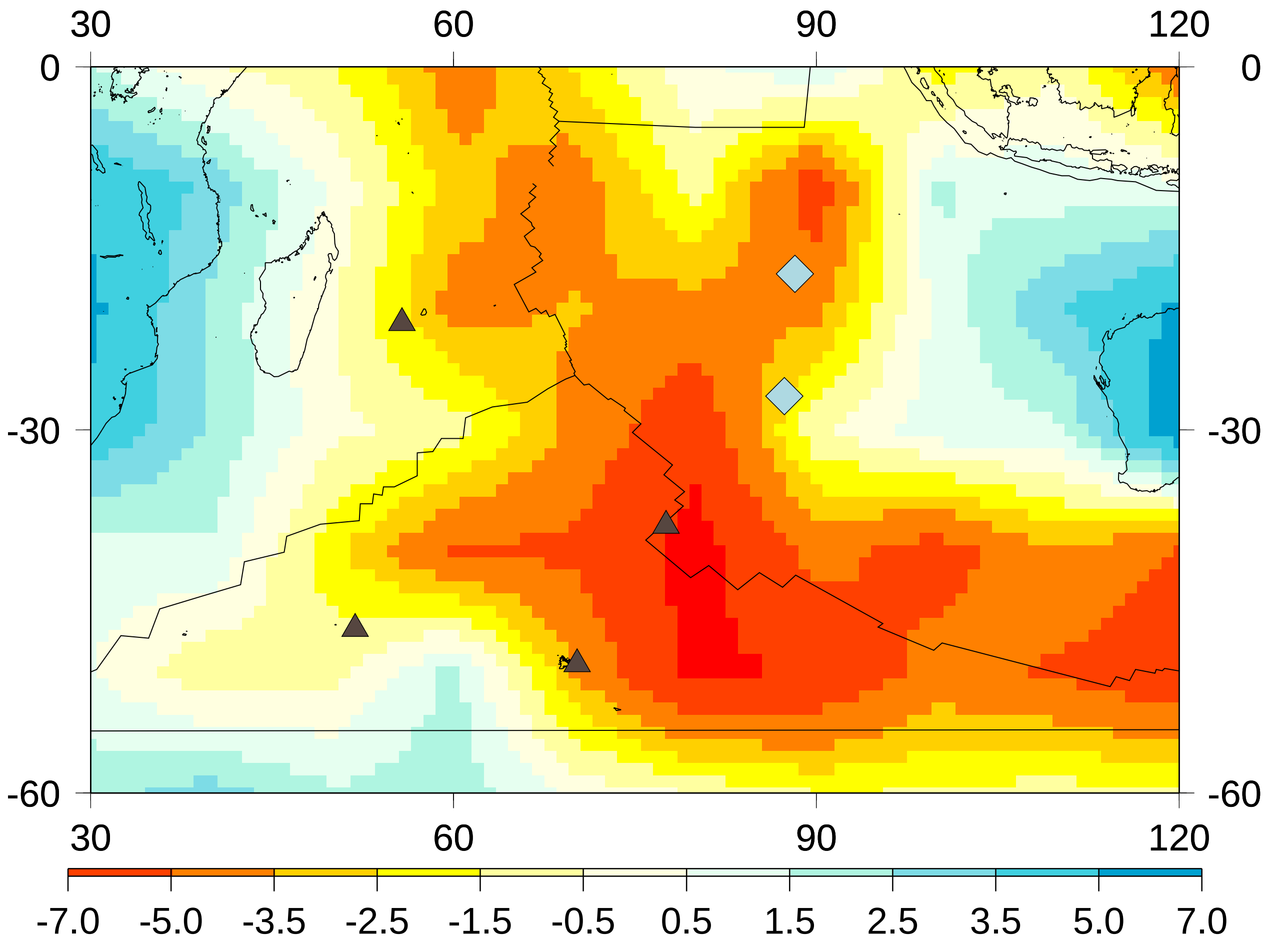

Figure 5. Tomographic model AUM for depth = 100 km (Montagner and Tanimoto, 1991). Triangles show existing broadband GEOSCOPE stations. Diamonds are proposed drilling sites.

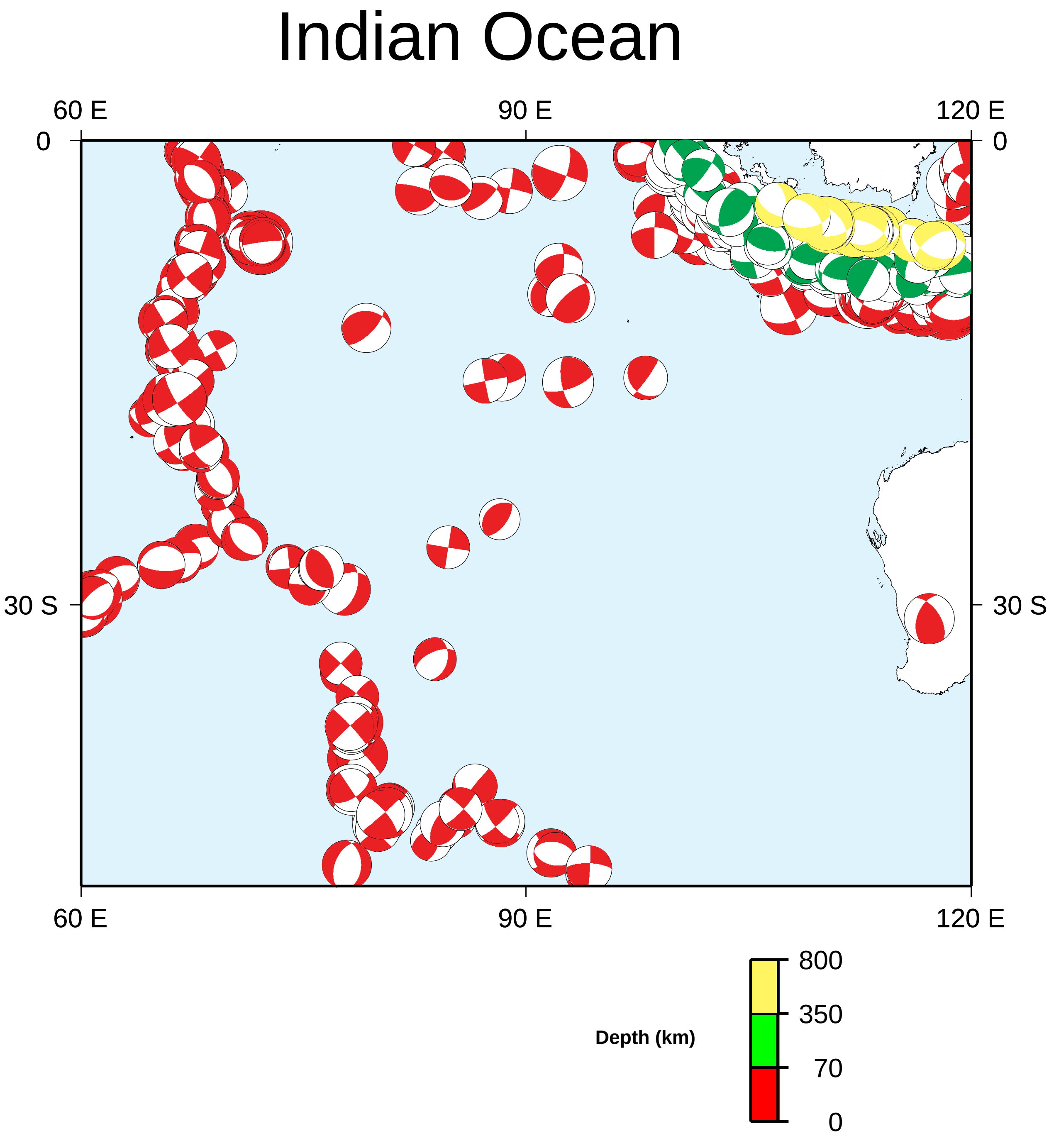

Figure 6. Focal mechanisms of earthquakes that occurred in the Indian Ocean during the last 15 yr (from the Harvard database). It can be noted that the Australo-Indian plate is characterized by a high intraplate seismicity.

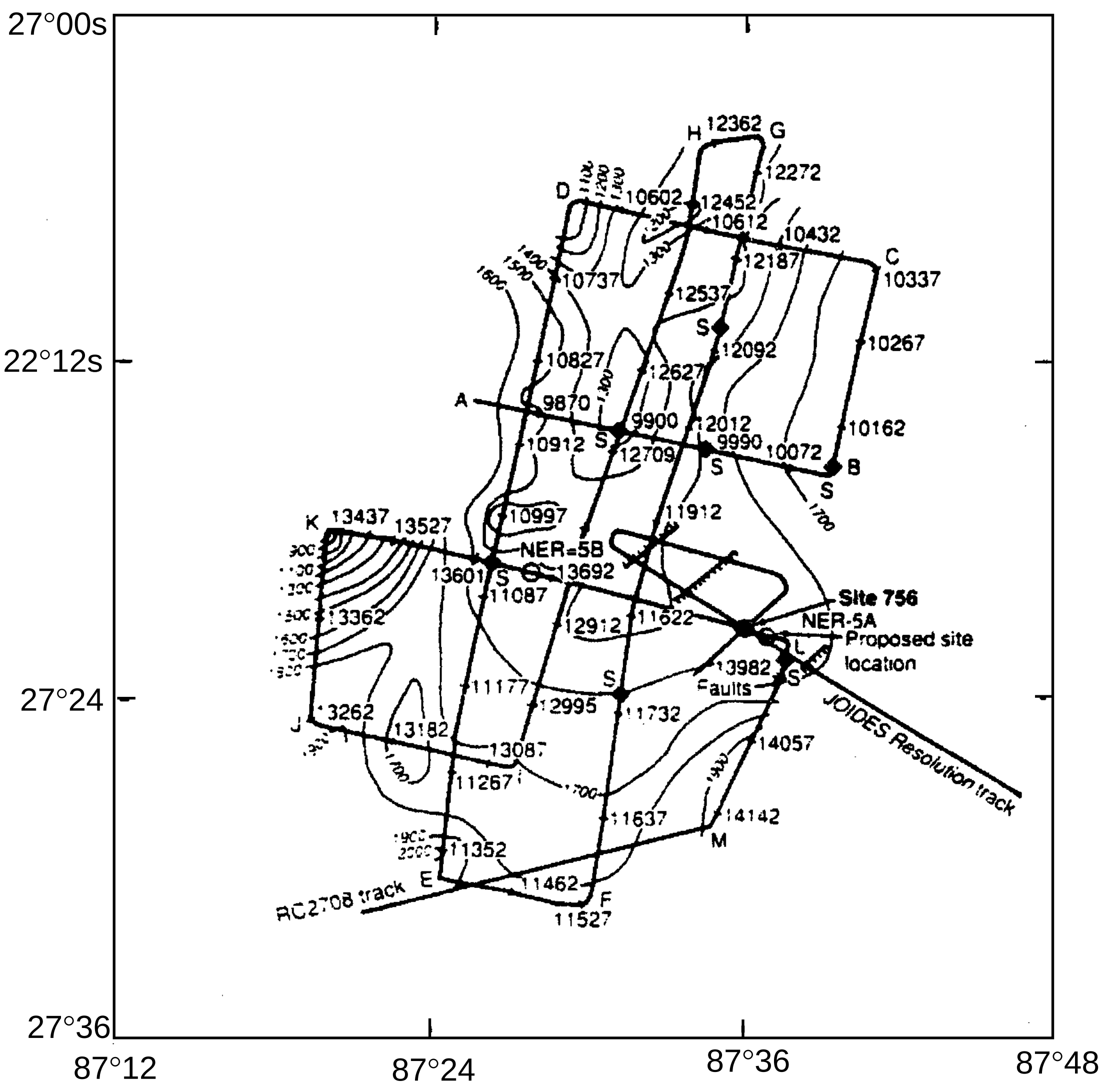

Figure 7. Bathymetric chart of the Site 756 operations area. Diamonds labeled S show RC2708 sonobuoy refraction survey locations. Bathymetric contour interval = 100 m (From Proc. ODP, Init. Repts., Leg 121, 1989)

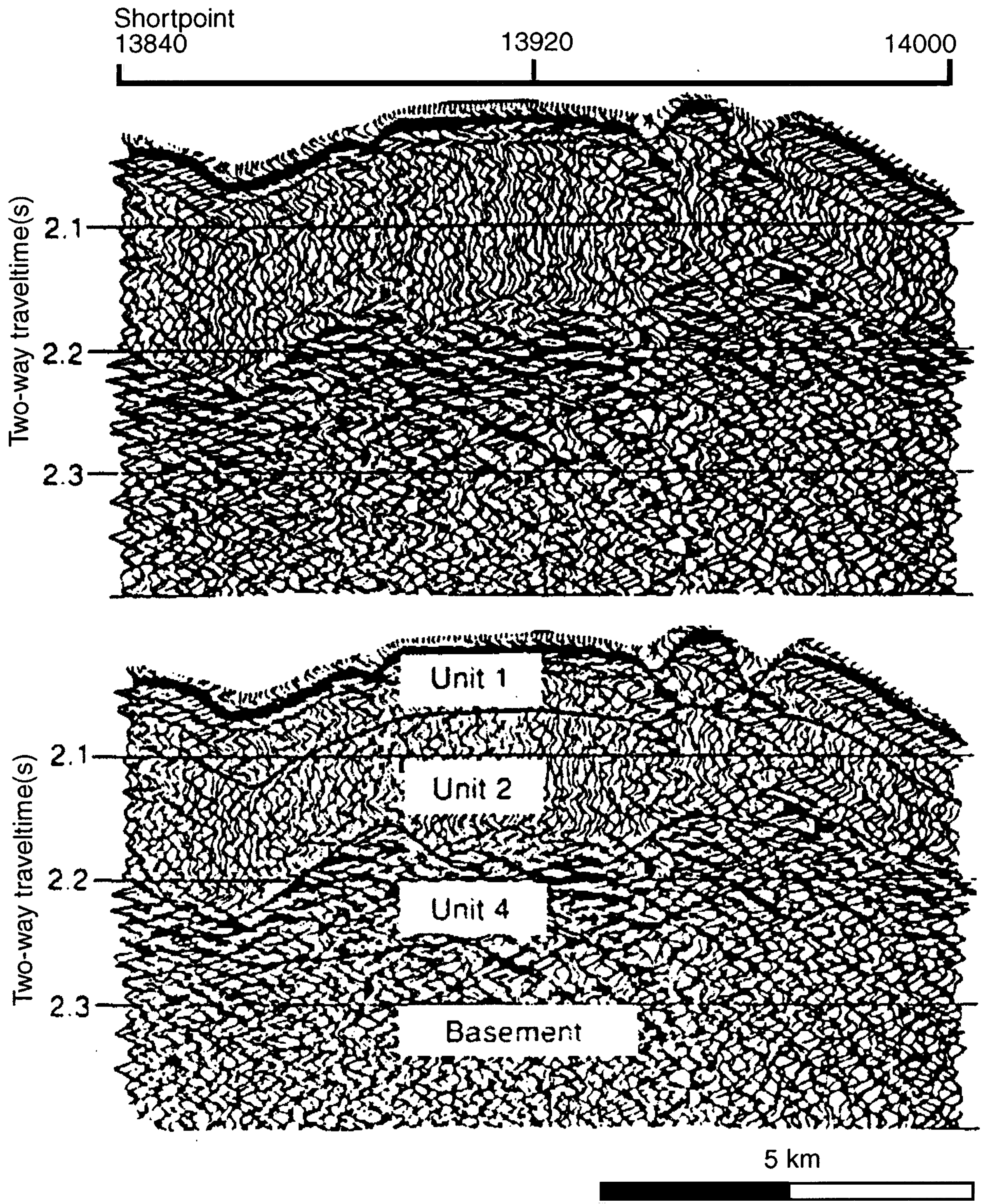

Figure 8. Seismic profile of a proposed location for Site 756. The seismic units are discussed in the "Seismic Stratigraphy" section of the Site 756 chapter in the Proc. ODP Init. Repts., Leg 121, 1989.

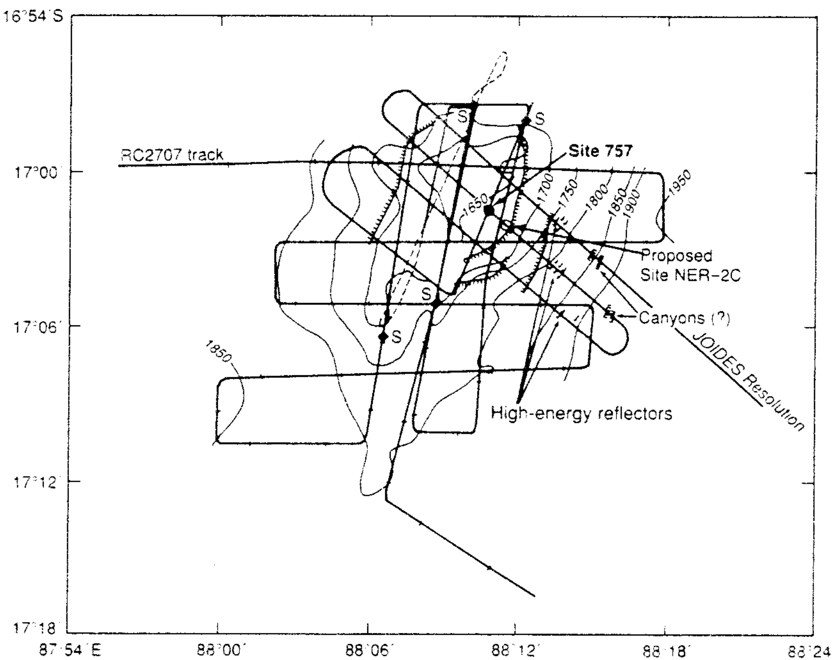

Figure 9. Bathymetric chart of the Site 757 operations area. Diamonds labeled "S" show RC2707 sonobuoy refraction survey locations. Bathymetric contour interval = 50 m (From Proc. ODP Init. Repts., Leg 121, 1989).

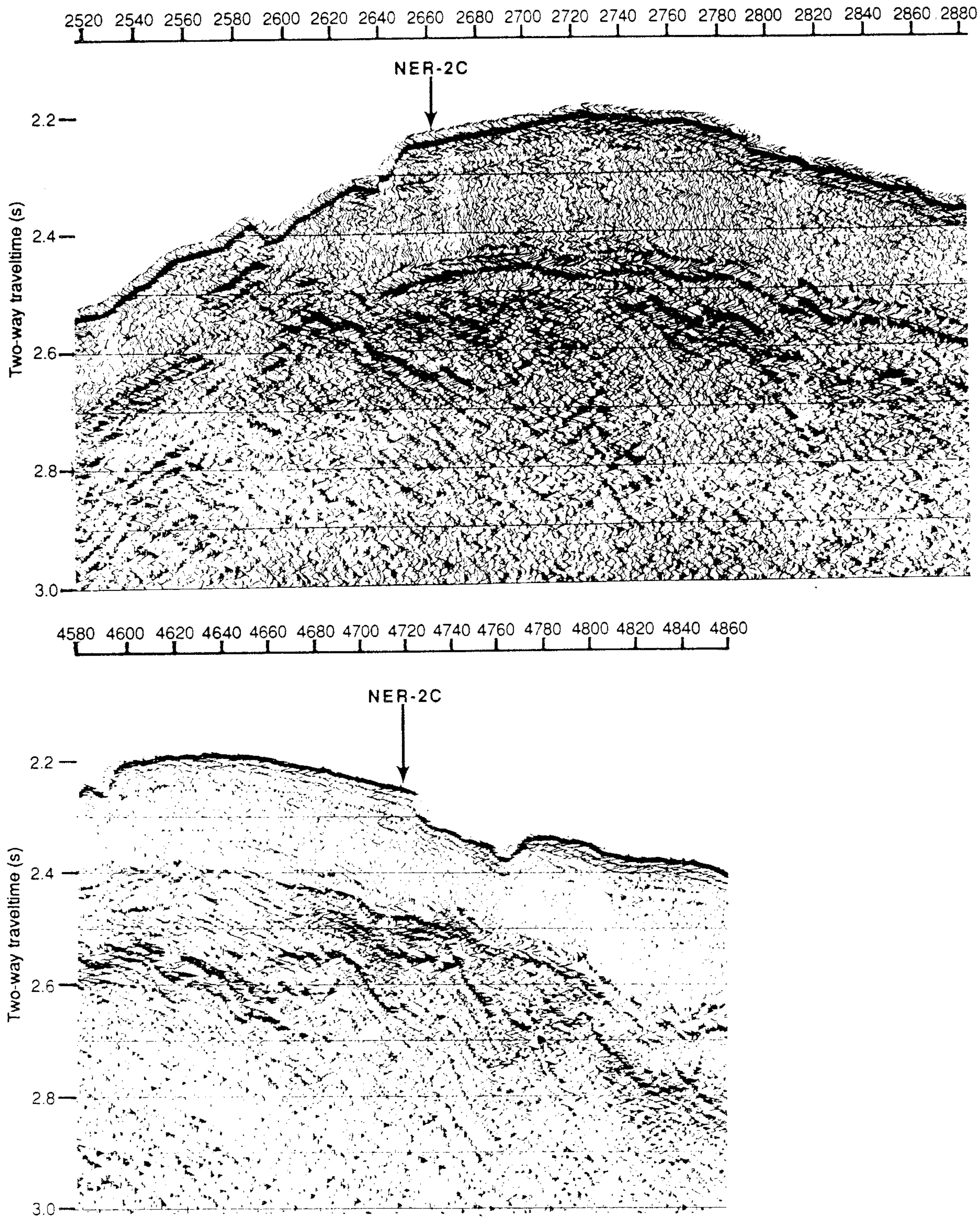

Figure 10. RC2707 siesmic profiles across proposed Site NER-2C. Lines cross at shotpoints 2660 and 4720 (from Proc. ODP Init. Repts., Leg 121 1989.)

TABLE 1

PROPOSED SITE INFORMATION AND DRILLING STRATEGY

SITE: ODP Site 756	**PRIORITY**:	**POSITION**: 27°21.00´S, 87°35.00´W
WATER DEPTH: 1520 m	**SEDIMENT THICKNESS**: 139 m	**TOTAL PENETRATION**: 339 m
SEISMIC COVERAGE:		

Objectives: Drill a borehole into basement on the Ninetyeast Ridge in the Indian Ocean to provide a site for the installation of a broadband ocean seismometer and instrument package for ION program.

Drilling Program: Jet-in first casing string. Drill hole and case to basement. RCB core in basement.

Logging and Downhole Operations: Triple combo with ARI, FMS-sonic, UBI.

Nature of Rock Anticipated: Basalt

SITE: ODP Site 757	**PRIORITY**:	**POSITION**: 17°01´S, 88°11´E
WATER DEPTH: m	**SEDIMENT THICKNESS**: 370 m	**TOTAL PENETRATION**: 470 m
SEISMIC COVERAGE:		

Objectives: Alternate site with the same objectives as Site 756.

Drilling Program: Jet-in first casing string. Drill hole and case to basement. RCB core in basement.

Logging and Downhole Operations: Triple combo with ARI, FMS-sonic, UBI.

Nature of Rock Anticipated: Basalt