OCEAN DRILLING PROGRAM

LEG 179 SCIENTIFIC PROSPECTUS

HAMMER DRILLING and NERO

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January 1998

Scientific Prospectus No. 79

First Printing 1998

Distribution

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

D I S C L A I M E R

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

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

Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the National Science Foundation, the participating agencies, Joint Oceanographic Institutions, Inc., Texas A&M University, or Texas A&M Research Foundation.

This Scientific Prospectus is based on precruise 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.

Technical Editor: Karen K. Graber

ABSTRACT

Leg 179 is a two-part drilling program; first we will test the hammer drill-in casing system recently developed under the direction of the Ocean Drilling Program (ODP), then we will drill and case a hole for the Ninetyeast Ridge Observatory (NERO) project. The sea trials for the hammer drill-in casing system will take place near ODP Site 735, in the rift mountains of the Southwest Indian Ridge. We will evaluate the operational characteristics of the components of the hammer drill-in casing system, as well as the complete system. This test will also address operational limits of the system in terms of water depth, topography, and surface slope. Time permitting, we will recover cores through the cased reentry hole, to as great a depth as possible. Fifteen days on site have been allocated for these tests. Successful completion of the NERO project will fill a major gap in the global coverage of seismic, magnetic, and general geophysical monitoring. Currently, geophysical observatories are only present on continents and islands; thus, data collection is incomplete. Establishing a cased reentry hole into basement at ODP Site 757 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 for studying global geodynamics and earthquakes. A borehole observatory at Ninetyeast Ridge will enhance investigation of the dynamics of the Indian plate. This plate has 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. A seismometer will be installed in the hole at a later date. Several additional seismic experiments are planned for the NERO site during and after drilling operations. These include (1) a vertical seismic profile, (2) a seismic-while-drilling experiment, 3) and a two-ship offset seismic experiment (OSE) using the German research vessel *Sonne*, which will shoot several seismic profiles of varying azimuth and along circles with different radii about the hole. Shots in the OSE will be recorded by both USGS and GEOMAR ocean bottom seismometers (OBS) situated about the hole and a three-component borehole geophone. This unique set of seismic experiments, together with the full suite of seismic experiments planned on board the *Sonne*, will help define the seismic structure in the vicinity of the borehole and will be used to assess how local influences will affect long-term measurements planned for the site. Ten days have been allocated for drilling, casing, and seismic experiments at the NERO Site.

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 that 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 boreholes 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.

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 may increase the likelihood of 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. We will conduct these tests in the rift mountains of the Southwest Indian Ridge where there exists an uncommon combination of hard-rock drilling targets and shallow- to deep-water exposures (Figs. 1-3).

BACKGROUND

Drilling and coring operations in fractured hard rock must overcome many challenges not confronted in piston coring operations. These can be summarized as initiating the borehole, stablilizing the borehole, and establishing reentry capability. Until a drilling/coring bit can gain purchase, since it is not stabilized by sediment, it tends to chatter across the surface of a hard-rock outcrop. Difficulty initiating a hole is exacerbated if the drilling target is on a slope. Rubble from the seafloor, drill cuttings, and material dislodged from the borehole wall must continually be removed, however the size and density of this material complicates this task. Due to bit wear in hard rock, deep penetration (beyond a few tens of meters) absoutely requires the ability to perform multiple entries into a borehole. The ideal system for drilling in hard rock environments would be oblivious to local topographic variation, seafloor slope, and thickness of sediment cover or talus accumulation. Such a system should initiate a hole, then simultaneously deepen the hole and stabilize the upper part of the hole with casing. This requires the bit to cut a hole with a greater diameter than the casing, and then to be withdrawn through the casing string. The casing in turn would facilitate hole-cleaning operations by elevating the annular velocity of the drilling fluid, and ease reentry operations by eliminating the possibility of offsets in the borehole wall (ledges or bridges). Finally, this ideal system would leave behind a structure to simplify the required multiple reentries.

The hammer drill-in casing system (Fig. 4) is composed of a hydraulically actuated percussion hammer drill, a casing string or multiple casing strings, a free-fall deployable reentry funnel, and a casing hammer. 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 install large diameter (18.625 in) casing 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.

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

3. Reduce sensitivity to thin sediment cover, debris, or rubble lying on the spudding surface.

4. Reduce dependency on precise site surveys.

ENGINEERING/SCIENTIFIC OBJECTIVES

Primary Objectives

There are three primary objectives for the hammer drill-in casing evaluation. In priority order these are:

1. Determine the operational characteristics of the hammer drill. The hammer drill will be thoroughly tested on land before it is deployed at sea; however, it is difficult to simulate the shipboard deployment environment. We will deploy the hammer 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, we will deploy the complete hammer drill-in casing system for evaluation. Three boreholes in increasingly difficult environments are planned to completely test the equipment.

3. Determine the maximum allowable slope for hammer drill operations. If information on seafloor slope is available from a planned survey cruise that will occur before Leg 179, then we will drill multiple shallow (1-3 m) holes on progressively steeper slopes to determine maximum operational grade for the system.

Supplementary Objective

A supplementary objective for Leg 179 is to recover cores from a cased reentry hole established by the hammer drill-in casing system. We would like to recover at least two cores from each reentry site. Two cores (19 m penetration) will ensure that we penetrate through the cement bond pinning the casing to the formation. Recovering rock from below the casing string provides final proof of the viability of the system and allows us to identify with certainty the lithologies where the casing has been emplaced. Given the recent success on Leg 176, these cores will also help establish the lateral heterogeneity in lithologies exposed in the vicinity of Site 735.

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 (Figs. 2, 3). Five hundred meters of gabbroic rock was cored in this hole with >86% recovery during Leg 118. In 1997, Leg 176 deepened Hole 735B to more than 1.5 km below seafloor with similarly high recovery. This region 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. We will attempt the first set of holes directly adjacent to Hole 735B on the wave-cut platform, whereas subsequent drilling will occur on the slopes adjacent to the platform.

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, at least two cores may be recovered through the established boreholes. Based on time available, one of the established holes may be deepened. Successful completion of all testing will result in at least two cased boreholes with reentry structures that may be used for future scientific exploration.

The drilling plan will proceed as follows:

1. Initially, we plan to deploy the hammer drill on top of the wave-cut platform. Our projected site, based on the Leg 118 seafloor survey, is in an area of very thin (less than a centimeter or two) sediment cover ~75 m west of Hole 735B in 700 m of water (Figs. 2, 3; Site HDS-1). We plan several shallow (1-3 m) holes to establish the shipboard operational parameters of the hammer drill.

2. Once shipboard operational parameters are determined, we will assemble and deploy the entire hammer drill system and attempt to set and recover, if possible, 40-60 m of casing string at the same location.

3. Our second projected site (Fig. 2, Site HDS-2) is located on the north sloping flank of the platform in 1.5-2.5 km of water. We will again deploy the entire hammer-drill system and attempt to set 40-60 m of casing. Once we complete this operation, we expect to attempt to drill several short boreholes to determine the operational capabilities of the hammer drill on various slopes.

4. Our third site (Fig. 2, HDS-3) is located on the talus-covered, steeply graded western flank of the platform. This will be the most severe test of the system and most closely simulates conditions that restricted operations at Hess Deep and MARK. We hope to install at least 40-60 m of casing at this site. Once the reentry is established, we will continue testing the operational limits of the hammer drill in a sloping, talus-covered environment.

5. Following successful testing to this point, we will attempt to set a longer casing string, 40-80 m long, at this location.

6. Time permitting, we plan the following operations listed in order of priority.

   A. Reenter one established borehole and cement the casing in place. Slightly different tools and techniques from those typically used by ODP will be required.

   B. Drill at least two cores from as many established reentry holes as possible.

   C. Deepen one of the cased boreholes to the extent possible.

Contingency Drilling Plan

In the event that there is operational time remaining after the conclusion of all hammer drill-in casing system tests, our drilling plan is to reenter one of the existing cased holes and core ahead until it is time to depart for the NERO site. If there are four or more days remaining in the operations schedule and there is no viable reentry site, our primary contingency plan is to deploy a new hard-rock guide base either near Site HDS 1 or adjacent to the existing guidebase at Hole 735B. Four days is the minimum time required to deploy the guidebase and drill, case, and cement a large diameter casing. Any residual time will be devoted to conventional rotary coring at this site.

If there is insufficient operational time to set a new guidebase, several short-term options remain as contingencies. These include milling and fishing operations in Hole 735B (±24 hr per attempt); additional logging with the formation microscanner (FMS) in the open part of Hole 735B with fresh water mud to reduce the resistivity contrast in the borehole, or depart early for operations at Ninetyeast Ridge.

PART II: NERO PROJECT

INTRODUCTION

Seismic data from a World-Wide Standardized Seismograph 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 [project name that is run by the Institut de Physique du Globe de Paris], IRIS [Incorporated Research Institutions for Seismology], GeoFon [GEOForschungsNetz; geophysical research network] on a global scale; and MedNet [MEDiterranean NETwork], Poseidon, CDSN [China Digital Seismic Network], GRSN [German Regional Seismic Network] 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.

The observatory planned for the Ninetyeast Ridge 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. 5) should not produce any technical problems, as previous holes in this area were drilled with a single bit. The primary site is ODP Site 757 and the alternate site is Site 756; both were drilled during ODP Leg 121 in 1988 (Peirce, Weissel, et al., 1989). Installing a reentry cone and casing down to basement is the first step toward the installation of a Geophysical Ocean Bottom Observatory (GOBO). A hole will then be established that penetrates at least 100-200 m into the basaltic basement. Although the sedimentary rocks will not be cored, basement rocks will be cored to allow a wide range of petrological, geochemical, and geophysical studies on the rock samples recovered. The extent of the coring and penetration into basement will be much greater than previous drilling at either Sites 757 or 756 along the Ninetyeast Ridge, where only a few tens of meters of penetration were achieved into basaltic basement. The permanent seismometer instrumentation will be installed after drilling at a later date. Establishing this cased reentry hole will require up to a week of ship time. In addition to drilling and casing operations, a series of seismic experiments involving the drill ship, as well as the research vessel *Sonne*, are also planned while on site. These experiments include seismic-while-drilling (SWD), vertical seismic profile (VSP), and offset seismic experiments (OSE), as well as the possible deployment of a broadband wide dynamic range seismometer in the borehole to test the deployment procedure and shock resistance of the instrument, as well as the characteristic of seismic noises under the seafloor. These seismic experiments will require four additional days 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 Newsweek 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 a 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, 1994b, 1994c), 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 [ocean floor seismometer]) 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 ocean-bottom seismometer (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 summary drawing is presented in Figure 6.

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 OFM and borehole seismometer (Observitoire Fond de Mer, OFP) 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 OFM. 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 OFM and OFP, which means that the equilibrium stage was not yet attained by the end of the experiment (Beauduin et al., 1996a, 1996b). The patterns of microseismic noise in oceanic and continental areas are completely different. The background microseismic noise is shifted toward shorter periods for OFM and OFP 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

Primary Objective:

Establishment of Geophysical Ocean Bottom Observatory (GOBO)

The primary objective of the NERO portion of Leg 179 is to drill a single hole 200 m into basement and install a reentry cone and casing to prepare Site 757 (or 756) along the Ninteyeast Ridge as an ocean bottom observatory. The GOBO will be installed at a later time and 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.

1. 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 [Federation of Digital Seismic Networks], Fig. 7), 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.

2. Regional scale (wavelengths between 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. To understand the lithosphere's evolution, it is necessary to improve the lateral resolution of tomographic seismic studies.

   The Indian Ocean crust is considered to be the most complex in any ocean basin. 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. 8), but there seems to be some offset at deeper depths for the Central Indian Ridge, as a consequence of the decoupling between the lithosphere and the underlying mantle. This complexity at deeper depths 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 9, the future observatory is surrounded by seismically active areas. This ensures there will be a reasonable amount of data within one or two years after borehole instrumentation.

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

Supplementary Objectives:

1. *Sample Characterization*

In addition to the objectives related to the emplacement of a GOBO at the previously drilled site, at least 100-200 m of the basaltic basement will be cored and a significant basaltic sample set is likely to be recovered. These recovery depths into basement are significantly deeper than previous coring into basement at Sites 757 and 756. The basaltic basement at the proposed site along the Ninetyeast Ridge includes eruptive units thought to have formed above a mantle plume in the Southern Indian Ocean (e.g., Saunders et al., 1991). The coring provides the opportunity to conduct an in-depth study of a volcanic section formed over an oceanic mantle plume. Detailed descriptions, as well as geochemical, petrologic, and geophysical studies of these basalts will help to further characterize the origin of these basalts, as well as the volcanic stratigraphy of the Ninteyeast Ridge. Petrophysical studies including measurements of *P* and *S*-wave seismic velocities of the samples recovered should help to characterize the site and local velocity structure.

2. *Geophysical Site Characterization*

An extensive suite of seismic experiments will be conducted in conjunction with drilling activities at the site chosen for the installation of GOBO. These experiments include seismic while drilling, vertical seismic profile, and oblique seismic experiments, as well as the possible temporary deployment of a broadband wide dynamic range seismometer in the borehole to test the deployment procedure and shock resistance of the instrument, as well as the characteristics of seismic noise levels under the seafloor. These seismic experiments will require four additional days of ship time and will provide one of the most complete borehole seismic datasets available. We briefly review these studies and objectives below.

I. Seismic-While-Drilling Vertical Seismic Profile

One objective of Leg 179 is to develop a seismic-while-drilling capability for the Ocean Drilling Program. The SWD project was funded by the National Science Foundation. SWD uses OBSs to listen to the drill ship noise and does not use a VSP tool in the well. However, to evaluate the performance of the SWD system, a conventional VSP, with which to compare results, is critical. The conventional VSP could be carried out with the vertical component instrument already on board, but it would be better to run it with a three component VSP tool. SWD has the potential for observing shear waves generated by the bit and it would be useful to compare this with any shear waves in the VSP converted by scattering.

The SWD experiment will be conducted at the NERO site to develop seismic-while-drilling capability for the Ocean Drilling Program (ODP). Vertical seismic profiles have proven extremely useful over the history of ODP in correlating borehole properties with regional seismic properties. Normally they are carried out with a borehole seismometer and airgun shots fired on the surface from a second ship. Typically they take 6-12 hr of drill ship time depending on the depth of the hole, sampling interval, etc. In an SWD/VSP, the seismic source is the drill bit and the sound is received on geophones at the seafloor. No additional drill ship time is necessary to acquire an SWD/VSP. The SWD technology was developed for land boreholes using surface geophones and has had considerable success. We propose here to extend the SWD capability to deep-ocean boreholes. For the NERO experiment SWD/VSPs and traditional VSPs will be compared for data quality and utility. If successful, the technology will be transitioned to ODP for routine use.

As a test effort, two OBSs and a drill-pipe pilot sensor on Leg 179 will be utilized. OBSs will be deployed, recovered, and redeployed at the NERO site, with initial results and procedures analyzed on board. The OBSs can be deployed and recovered using the ship's workboat. Five additional GEOMAR Ocean Bottom Hydrophones (OBHs; Flueh and Bialas, 1996) will also be deployed around the drill site and used during the SWD experiment.

Initial proof-of-concept of SWD will consist of three objectives:

1. A demonstration of the generation and recording of drill bit signal on the pilot sensors at the rig floor. Analysis will consist of producing filtered autocorrelation functions at depth intervals of less than 5 m over a range of bit depths sufficient to see pipe multiple arrivals and their characteristic moveout. Spectral and temporal characteristics of drill bit signal will be documented.

2. A demonstration of the recording of drill bit direct arrivals (*P*- and *S*-waves) in the OBS data. Analysis will consist of producing filtered cross-correlation functions (between the OBS and pilot sensor data) at depth intervals of less than 5 m over a range of bit depths sufficient to observe *P* and *S*-wave moveout. Filtering would include polarization filtering, bandpass filtering, and multichannel spatial filtering so that direct arrival signals can be distinguished from other interference.

3. A demonstration of the recording of *P* and *S* reflections. Analysis will consist of wavefield separation of direct and converted energy and isolation of primary bit-generated reflections.

The work necessary to establish a SWD capability falls into three categories: (1) acquisition of the OBS data during drilling; (2) acquisition of the pilot sensor data on the rig floor during the drilling operations; and (3) reduction of the OBS and pilot sensor data to a VSP format for seismic analysis.

The USGS-OBSs both have three-component inertial sensors and hydrophones and can record autonomously on the seafloor for about one week. The operations necessary to do the processing are computing autocorrelations and cross-correlations between selected channels and bandpass and notch filtering. The pilot sensor data will be acquired on the rig floor. Measurement-while-drilling technology (but not SWD) was tested on Leg 156 (Shipley, Ogawa, Blum, et al., 1995).

II. Conventional Vertical Seismic Profiling

About 12 hr will be allotted for the conventional VSP during the logging program following completion of drilling. The experiment will be conducted in a similar manner to other VSPs on ODP Legs 118, 123, 148, and 164 (Swift et al., 1991, Bolmer et al., 1992; Swift et al., 1996; Holbrook et al., 1996). A water gun and an airgun will be floated from the aft port crane and the Schlumberger three-component tool will be used as the borehole receiver. The tool will be clamped at 10-m intervals within basement and through the cased sediment section. These data will define the vertical seismic velocity and attenuation properties within a few tens of meters of the borehole. The availability of the VSP tool for the leg is critical in evaluating the SWD experiment and to carry out the oblique seismic experiment (described below).

III. Oblique Seismic Experiment (OSE)

An OSE, using the same single-node three-component borehole seismic tool as the conventional VSP, will be conducted at the NERO hole on the Ninetyeast Ridge. Goals are to: (1) determine interval velocities over the depth of the hole for comparison with well logging and core sample measurements; (2) map lateral heterogeneity at the site with a resolution of ~100 m over ranges up to 12 km; (3) check for anisotropy within the sediments and volcanic sections; and (4) obtain in situ measurements of attenuation in the sediments and volcanic section at very-low frequencies (VLF). These measurements will be necessary to determine the effects of local structure on the ultra-low frequency (ULF; 0.001-5.0 Hz) observations of ambient noise and teleseismic waves (earthquakes) to be made at the site as part of ION, and to place the site in a geological and geophysical context for extrapolation of the ULF results to other regions of the seafloor. Even though the compressional and shear wavelengths in the ULF band are long with respect to the heterogeneities and geological structure at the hole, seismometer coupling and ambient noise are sensitive to sub-wavelength scale features. During ODP Leg 179 on the Ninetyeast Ridge, the *JOIDES Resolution* will drill a hole at least 100-200 m into basaltic basement near Site 757 (17°S). The project is a joint effort between U.S. (Project NOSE) and German (Project SINUS) scientists.

Scientists from GEOMAR will conduct a refraction experiment from the *Sonne* using seafloor receivers. The drill ship will coordinate with the *Sonne* and record their shots using the Schlumberger three-component tool clamped near the bottom of the borehole. The OSE results will be integrated with an experimental seismic-while-drilling VSP experiment, a conventional VSP, Schlumberger logs, and physical properties measurements of cores. In contrast to most 'normal' ocean crust, the igneous section on the Ninetyeast Ridge was created at very high magma extrusion rates that resulted in large, horizontal sheet flows in the upper igneous section. A detailed study of the seismic response of these sheet flows (converted shear waves, anisotropy, interference effects, etc.) will constrain models for inferring the rate of magma injection from single-channel and multichannel seismic reflection surveys elsewhere.

The low cost of this study is made possible by cooperation with a geophysics survey on the Ninetyeast Ridge lead by Dr. Ernst Flueh at GEOMAR, FDR. The *JOIDES Resolution* and the *Sonne* will be at the NERO site at the same time in late May, 1998. Both ships are currently scheduled to arrive at the NERO site on May 16th. Dr. Flueh will obtain the bathymetry and sediment thickness data needed to reduce the OSE traveltime data. Dr. Flueh will also deploy 20-30 OBHs and OBSs on the seafloor around the site and will shoot with a tuned airgun array in a pattern of circles and radial lines around the borehole. The data from these instruments will define the seismic structure on a range of scales from a few hundred meters up to a few tens of kilometers. This is essential to characterization of the site because of the strong lateral gradients on these scales inherent in the construction of the volcanic Ninetyeast Ridge. Other seismic studies proposed will complement Dr. Flueh's by providing much greater detail about the basement and sediment structure out to ranges of a few hundred meters.

The two OBSs deployed close to the drill ship will stay on the seafloor and will be used for recording during the OSE experiment. The type of OBSs used is well suited for recording converted *S*-waves as demonstrated during a similar two-ship experiment in conjunction with Leg 164 (Pecher et al., 1997). The three-component Schlumberger seismic tool will be clamped at a single depth near the bottom of the borehole at about 100 m in basement. GEOMAR scientists aboard the *Sonne* will shoot a series of concentric circles around the borehole at ranges of 2, 4, 6, and 8 km using radar and dithered global positioning system (GPS) navigation to steer. A series of four straight lines will be shot across the borehole at 45° angles. The *Sonne* will coordinate shooting with the *JOIDES Resolution*. Schlumberger will provide seismic recordings for each shot using timing synchronized to a GPS clock. GEOMAR will also survey the bathymetry of the survey region using a multibeam system aboard the *Sonne* and will collect multichannel reflection profiles to determine the thickness of sediment above basement and provide control on compressional velocities. The advantages of this approach are (1) determination of velocity on vertical scales finer than a conventional VSP and, (2) in the future, the ability to obtain crustal velocity information without using drill ship time for a conventional VSP.

IV. Pilot Deployment of a Broadband Seismometer

To test a Japanese borehole seismometer installed via the drill ship, temporary deployment of a broadband wide dynamic range seismometer in the borehole at the NERO site will be conducted. This will allow testing of the deployment procedures and shock resistance of the instrument. The characteristics of seismic noises and their level in the borehole will also be examined. This test will address questions of future installations of borehole seismographs using the drill ship. A minimum of 12 hr will be allotted for the test. The instrument will be retrieved at the end of the test.

DRILLING STRATEGY/PROPOSED SITES

Primary Site (ODP Site 757)

Site 757 is located at 17°01.458'S, 88°10.899'E (Deep Sea Drilling Project [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 the *Robert Conrad* Cruise 2707 (RC 2707). Tracks and examples of seismic profiles are presented in Figures 10, 11, and 12. The thickness of sediments is about 370 m. Because drilling conditions in this area were excellent, it is likely that basement penetration of 150-200 m can be achieved. This should be sufficient for installation of the GOBO. The hole must be cased down to basement with a reentry cone attached at the top, and the basement section of the hole cored.

Alternate Site (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, 1989b). *Conrad* and *JOIDES Resolution* tracks and seismic reflection profiles are also available for this site (Figs. 13, 14). 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.

LOGGING PLAN

The logging program at Site 757 is designed to measure physical properties, anisotropy, and borehole character in the basement basalts. It is likely that core recovery will be less than 100% and therefore log data will be a critical tool in providing a continuous profile of the cored interval. Standard tool strings, including the triple combo and formation microscanner (FMS)/sonic will be run following the completion of coring. The triple combo will be comprised of the natural gamma, density, porosity, and dual induction sondes. The digital array sonic tool (SDT) will be run with the FMS. If desired, the SDT may be configured to operate in cement bond log mode for casing cement evaluation.

SAMPLING STRATEGY

New sampling guidelines specify that formal, leg specific sampling strategies be prepared by the Sample Allocation Committee (SAC = co-chiefs, staff scientist, and ODP curator onshore and curatorial representative on board ship). Modification of the strategy during the leg must be approved by the curatorial representative on board ship, the co-chiefs, and staff scientist. The sampling strategy presented here conforms with the new guidelines and will be refined as sample requests are evaluated and considered by the shipboard party prior to arrival at each site.

Minimum Permanent Archive

The minimum permanent archive will be the standard archive half of each core.

Sample Limit

Shipboard scientists may nominally expect to obtain 100 samples up to 15 cm^3 in size. Additional samples may be obtained upon written request onshore soon after the cores return to the ODP repository. The guidelines will be adjusted upward or downward by the shipboard SAC, depending on the penetration and recovery during Leg 179. All sample requests of whatever number and volume must be justified in writing using the standard sample request form and approved by the SAC.

Large Samples

Samples larger than 15 cm^3 may be obtained with the approval of the SAC, but shall be considered the equivalent of multiple samples in partial or complete increments of 15 cm^3. Request for large samples must be specified on the sample request form except where there are detailed stratigraphic studies of specific intervals of the core, in which case they must be approved on an individual basis for each interval by the co-chief scientists.

Redundancy of Studies

Some redundancy of measurement is unavoidable, but minimizing the redundance of measurements among the shipboard party and identified shore-based collaborators will be a factor in evaluating sample requests. Request for independent shore-based studies that substantially replicate the intent and measurements of shipboard participants will require the approval of both the shipboard investigators and the SAC.

Shipboard Samples and Data

Following core labeling, measurement of nondestructive properties, and splitting, samples will be selected from core working halves by members of the shipboard party for routine measurement of physical and magnetic properties, bulk chemical analyses by X-ray fluorescence (XRF) and carbon-nitrogen-sulfur (CHNS) analyzer, and X-ray diffraction as necessary. Polished thin sections will be prepared for identification of minerals, determination of mineral modes by point counting, and studies of texture and fabric.

A suite of samples will be identified for full measurement characterization. At approximately 9.5-m intervals (once per full core), slabs measuring 10x6x1.5 cm, with previously sampled central minicore, will be cut to be used for all shipboard measurements, then subdivided and split appropriately for further shipboard geochemical, mineralogic, and petrographic studies. Where necessary to avoid or include features like veins and alteration, quarter cores may be taken instead of slabs.

Data from all shipboard studies, regardless of the method or observer (including core descriptions and measurements) are the property of the entire shipboard party and may be used exclusively by them in publication and for preparation of manuscripts with proper citation in the *Initial Reports* volume up until the publication of the *Initial Reports* volume or 12 months postcruise, whichever is later.

Shipboard Thin Sections

Shipboard thin sections will be selected from representative sections of the core. These sections will remain the property of ODP and may be checked out after the cruise.

Critical Intervals

Short intervals of unusual scientific interests (e.g., veins, ores, dikes) may require a higher sampling density, reduced sample size, continuous core sampling by a single investigator, or sampling techniques not available on board ship. These will be identified during the core description process, and the sampling protocol will be established by the interested scientists and shipboard SAC.

REFERENCES

Beauduin, R., Lognonn, P., Montagner, J.-P., Karczewski, J.F., and Morand, M., 1996a. The effects of atmospheric pressure changes on seismometers: a matter of installation. *Bull. Seismol. Soc. Am.,* 86:760-1769.

Beauduin, R., Montagner, J.-P., and Karczewski, J.-F., 1996b. Time evolution of broadband seismic noise during the French experiment OFM/SISMOBS. *Geophys. Res. Lett.*, 23:2995-2998.

Bolmer, S.T., R.T. Buffler, H. Hoskins, R.A. Stephen, and S.A. Swift, 1992, Vertical seismic profile at ODP Site 765 and seismic reflectors in the Argo abyssal plain. *Proc. ODP, Sci. Results*, 123: College Station, TX (Ocean Drilling Program), 583-600.

Debayle, E., and Lévêque, J.-J., in press. Upper mantle heterogeneities in the Indian Ocean from waveform inversion, *Geophys. Res. Lett.*

Dick, H.J.B, Schouten, H., Meyer, P.S., Gallo, D.G. Berg, H. Tyce, R., Patriat, P., Johnson, K., Snow, J., and Fisher, A., 1991. Tectonic evolution of the Atlantis II Fracture Zone. *In* Von Herzen, R.P., Robinson, P.T., et al., *Proc. ODP, Sci. Results*, 118: College Station, TX (Ocean Drilling Program), 359-398.

Dziewonski, A., Wilkens, R., Firth, J., and Shipboard Scientific Party, 1992. Background and objectives of the Ocean Seismographic Network and Leg 136 drilling results, *Proc. ODP, Init. Repts*, 136: College Station, TX (Ocean Drilling Program), 3-8.

Flueh, E. R., and Bialas, J., 1996: A digital, high data capacity ocean bottom recorder for seismic investigations. *Int. Underwater Systems Design*, 18:18-20.

Holbrook, W.S., Hoskins, H., Wood, W.T., Stephen, R.A., Lizarralde, D., and the Leg 164 Science Party, 1996. Methane hydrate and free gas on the Blake Ridge from vertical seismic profiling. *Science*, 273:1840-1843.

Kanazawa, T., Suyehiro, K., Hirata, N., and Shinohara, M., 1992. Performance of the ocean broadband downhole seismometer at Site 794. *In* Tamaki, K., Suyehiro, K., Allan, J., McWilliams, M., et al., *Proc. ODP, Sci. Results*, 127/128 (Pt. 2): College Station, TX (Ocean Drilling Program), 1157-1171.

MacKenzie, D., and Sclater, J.G., 1971. The evolution of the Indian Ocean since the Late Cretaceous. *Geophys. J.R. Astr. Soc.*, 25:437-528.

Montagner, J.-P., 1986. Three-dimensional structure of the Indian Ocean inferred from long-period surface waves. *Geophys. Res. Lett.*, 13:315-318.

Montagner, J.-P., and Jobert, N., 1988. Vectorial Tomography, 2, Application to the Indian Ocean. *Geophys. J. R. Astr. Soc.*, 94:309-344.

Montagner, J.P., Karczewski, J.F., and Romanowicz, B., 1994a. A first step toward an oceanic geophysical observatory, *Eos*, 75:150-154.

Montagner, J.P., Karczewski, J.F., Floury, L., and Tarits, P., 1994b. Towards a geophysical ocean bottom observatory. *Seismic Waves*, 3:7-9.

Montagner, J.P., Karczewski, J.F., Romanowicz, B., Bouaricha, S., Lognonn, P., Roult, G., Stutzmann, E., Thirot, J.L., Brion, J., Dole, B., Fouassier, D., Koenig, J.C., Savary, J., Floury, L., Dupond, J., Echerdour, A., Floc'h, H., 1994c. The French pilot experiment OFM/SISMOBS experiment: first scientific results on noise level and event detection. *Phys. Earth Planet. Int.*, 84:321-336.

Montagner, J.P., and Tanimoto, T., 1991. Global upper mantle tomography of seismic velocities and anisotropies. *J. Geophys. Res.*, 96:20337-20351.

Norton, I.O., and Sclater, J.G., 1979. A model for the evolution of the Indian Ocean and the breakup of the Gondwanaland. *J. Geophys. Res.*, 84:6803-6830.

Pecher, I.A., W.S. Holbrook, R.A. Stephen, H. Hoskins, D. Lizarralde, D.R. Hutchinson, and W.T. Wood, 1997, Offset-vertical seismic profiling for marine gas hydrate exploration—is it a suitable technique? First results from ODP Leg 164. Proc. *In* 29th Offshore Technology Conference, 193-200.

Peirce, J., Weissel, J., et al. 1989. *Proc. ODP*, *Init. Repts*, 121: College Station, TX (Ocean Drilling Program).

Royer, J.-Y. and Sandwell, D.T., 1989. Evolution of the Eastern Indian Ocean since the Late Cretaceous: Constraints from Geosat Altimetry. *J. Geophys. Res.*, 94:13755-13782.

Saunders, A.D., Storey, M., Gibson, I.L., Leat, P., Hergt, J., and Thompson, R.N., 1991. Chemical and isotopic constraints on the origin of basalts from the Ninetyeast Ridge, Indian Ocean: results from DSDP Legs 22 and 26 and ODP Leg 121. *In* Weissel, J., Pierce, J., Taylor, E., Alt, J. et al., *Proc. ODP, Sci. Results*, 121: College Station, TX (Ocean Drilling Program), 559-590.

Schlich, R., 1982. The Indian Ocean: Aseismic ridges, spreading centers and oceanic basins. *In* A.E.M. Nairn and F.G. Stehli , (Eds.), *The Ocean Basins and Margins,* vol. 6, The Indian Ocean, Plenum, New-York.

Shipboard Scientific Party, 1989a. Ninetyeast Ridge underway geophysics. *In* Peirce, J., Weissel, J., et al., *Proc. ODP, Init. Repts.*, 121: College Station, TX (Ocean Drilling Program), 93-107.

Shipboard Scientific Party, Site 756, 1989b. *In* Peirce, J., Weissel, J., et al., *Proc. ODP, Init. Repts.*, 121: College Station, TX (Ocean Drilling Program), 259-303.

Shipboard Scientific Party, Site 757, 1989c. *In* Peirce, J., Weissel, J., et al., *Proc. ODP, Init. Repts.*, 121: College Station, TX (Ocean Drilling Program), 305-358.

Shipley, T.H., Ogawa, Y., Blum, P., et al., 1995. *Proc. ODP, Init. Repts*., 156: College Station, TX (Ocean Drilling Program).

Suyehiro, K., Kanazawa, T., Hirata, N., Shinohara, M., and Kinoshita, H., 1992. Broadband downhole digital seismometer experiment at Site 794, *Proc. ODP, Sci. Results*, 127/128: College Station, TX (Ocean Drilling Program).

Swift, S.A., Hoskins, H., and Stephen, R.A., 1991. Seismic stratigraphy in a transverse ridge, Atlantis II Fracture Zone. *In* Von Herzen, R., Robinson, P.T., *Proc. ODP, Sci. Results*, 118: College Station, TX (Ocean Drilling Program), p. 219-226.

Swift, S.A., Hoskins, H., and Stephen, R.A., 1996. Vertical seismic profile into upper ocean crust in Hole 504B. *In* Alt, J., Kinoshita, H., Stokking, L.B., and Michael P.J. (Eds.), *Proc. ODP, Sci. Results*, 148: College Station, TX (Ocean Drilling Program), 339-347.

FIGURE CAPTIONS

Figure 1. Map showing the site locations for Leg 179 Part I (near Site 735) and Part II (near ODP Sites 756 and 757).

Figure 2. Hand-contoured Seabeam bathymetric map of the eastern transverse ridge of the Atlantis II Transform, showing the location of Site 732 and Hole 735B (Dick et al., 1991). Contour interval = 250 m. Solid contours include regions covered by seabeam swaths, whereas dashed contours are inferred. Proposed drilling region near the wavecut platform and Hole 735B, which was cored during ODP Leg 118. Solid dots and arrows indicate the starting point and approximate track of dredge hauls. Filled circles indicate the approximate proportions of rock types recovered in each dredge,: white=altered peridotite, +=gabbro, v=basalt and diabase, stippled = greenstone (Dick et al., 1991). Also shown are the proposed sites to be drilled during Leg 179.

Figure 3. Local survey track of video/sonar coverage at Site 735 showing the distribution of rock outcrop vs. sediment cover. Ratio of rock outcrop to sediment is proportional to distribution of patterns. Axes are in meters distance from Beacon 1 and time is annotated. Leg 118 drill hole locations and bathymetry (5 m contour interval, based on drill pipe measurements) are also shown.

Figure 4. Schematic diagram of water hammer drill-in casing system deployment. **A.** Initial deployment. **B.** Spud hole and drill ahead. **C.** Disengage hydraulic hammer and circulate fluid. **D.** Install free-fall reentry funnel. **E.** Retract bit and release casing running tool. **F.** Recover hammer drill and leave a cased reentry hole on the seafloor.

Figure 5. Site map in the Eastern Indian Ocean showing the location of Ninetyeast Ridge and NERO primary Site 757 and alternate Site 756 (from Peirce, Weissel, et al., 1989).

Figure 6. Sketch of the OFM/SISMOBS experiment (April-May 1992). OFM = Observitoire Fond de Mer (ocean bottom seismometer). OFP = Observitoire Fond de Puits (borehole seismometer).

Figure 7. Location of Federation of Digital Seismic Networks (FDSN) and GEOSCOPE stations in the world as of 1996.

Figure 8. Tomographic model AUM for depth = 100 km (from Montagner and Tanimoto, 1991). Triangles show existing broadband GEOSCOPE stations. Diamonds are proposed drilling sites.

Figure 9. 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.

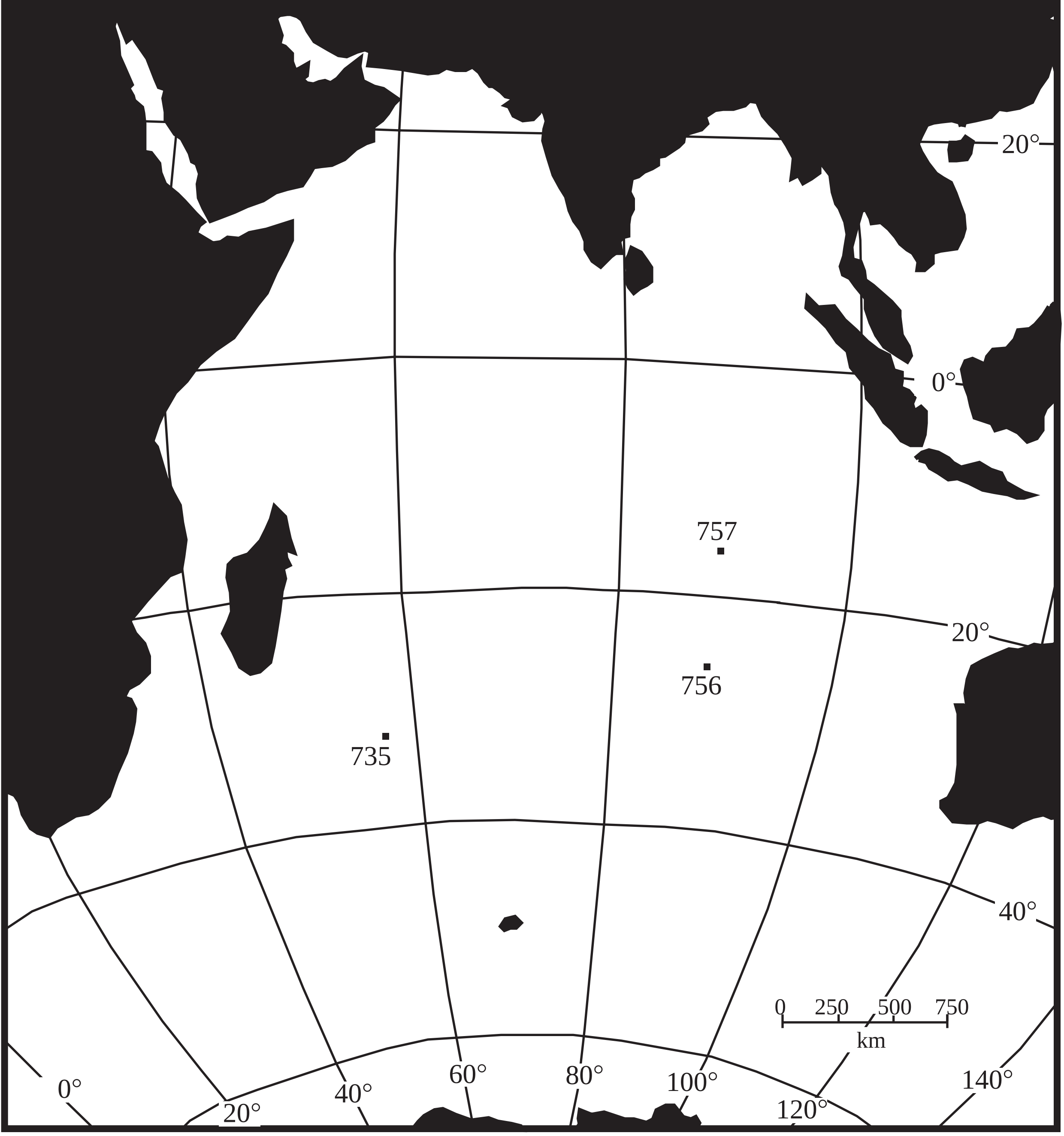
Figure 10. Survey tracks and bathymetric chart of the Site 757 operations area (after Shipboard Scientific Party, 1989b). Dashed line indicates survey track conducted during cruise 2707 of the *Robert D. Conrad*. Solid line indicates survey track of the *JOIDES Resolution* for ODP Leg 121.

Figure 11. Seismic dip line across the primary Site 757. **A.** Shipboard analog record, uninterpreted on left and interpreted on right. **B.** Same line reprocessed postcruise with less vertical exaggeration. The seismic units are discussed in the "Seismic Stratigraphy" section, Leg 121 *Initial Reports* (Shipboard Scientific Party, 1989c).

Figure 12. Seismic strike line across Site 757. **A.** Shipboard analog record, uninterpreted on left and interpreted on right. **B.** Same line reprocessed postcruise with less vertical exaggeration (after Shipboard Scientific Party, 1989c).

Figure 13. Bathymetric chart of the alternate Site 756 operations area (after Shipboard Scientific Party, 1989b). Dashed line indicates survey track conducted during cruise 2708 of the *Robert D. Conrad*, reference shotpoints are noted as tickmarks along the track line. Solid line indicates survey track of the *JOIDES Resolution* for ODP Leg 121.

Figure 14. Seismic profile of a proposed location for alternate Site 756. The seismic units are discussed in the "Seismic Stratigraphy" section, Leg 121 *Initial Reports* (Shipboard Scientific Party, 1989b).



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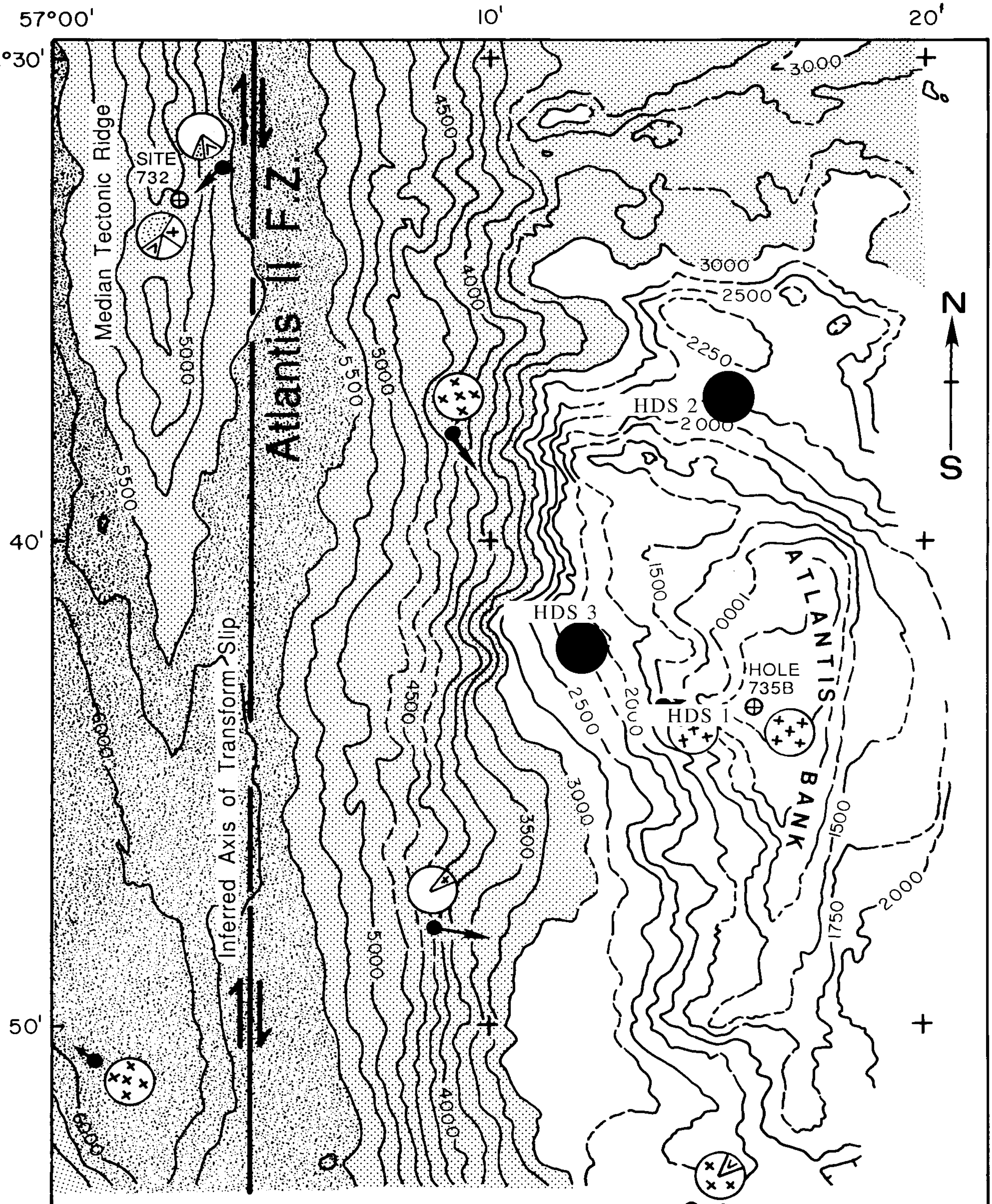
57°00'
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20'
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40'
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Median Tectonic Ridge
SITE
732
Atlantis II F.Z.
Inferred Axis of Transform Slip
HDS 2
HDS 3
HDS 1
HOLE
735B
ATLANTIS
BANK
N
S
3000
2500
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2000
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5000
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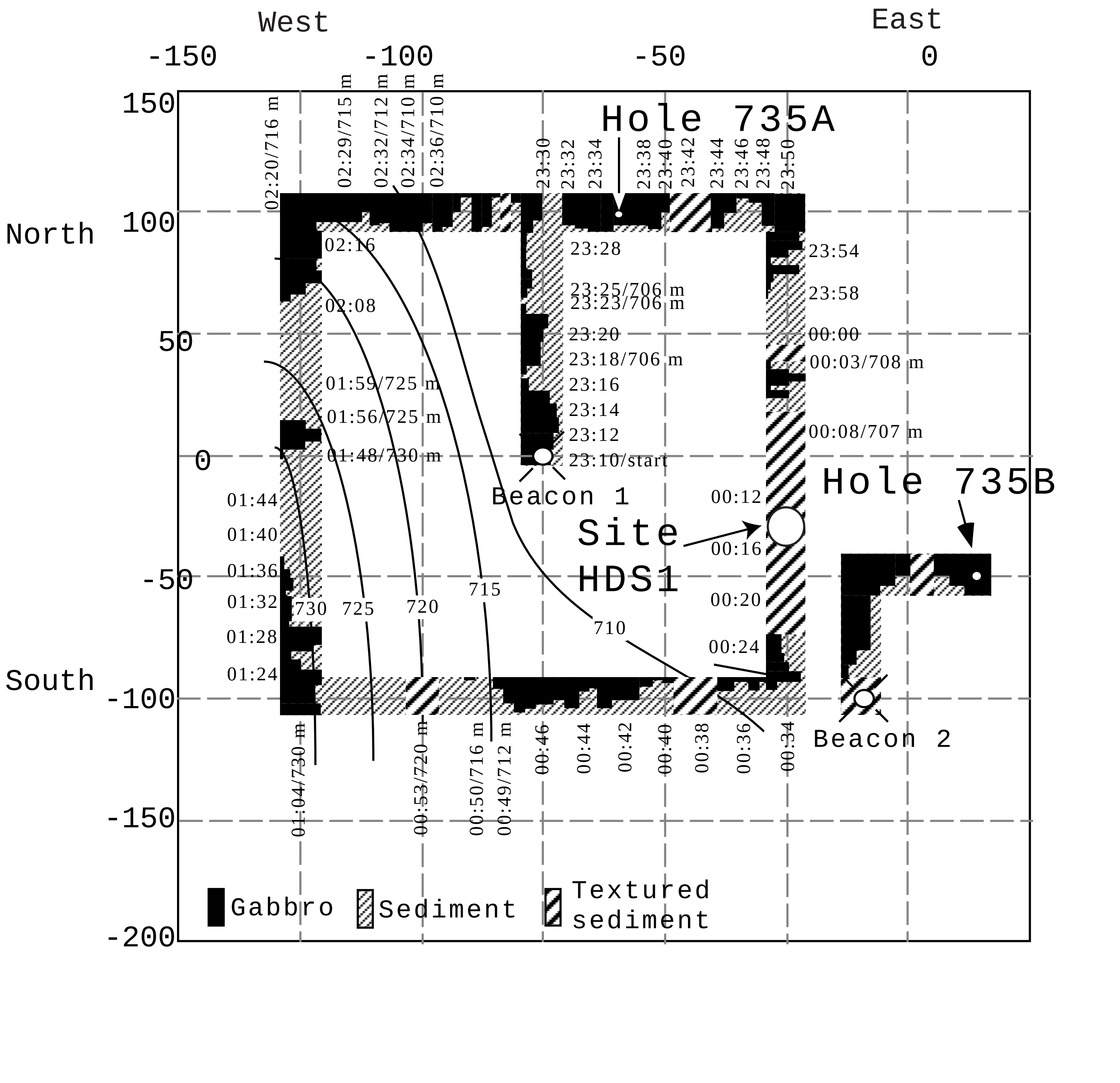
6000

Figure 2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East
-150
-100
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150
100
50
0
-50
-100
-150
-200
North
South
Hole 735A
Hole 735B
Site HDS1
Beacon 1
Beacon 2
02:20/716 m
02:29/715 m
02:32/712 m
02:34/710 m
02:36/710 m
23:30
23:32
23:34
23:38
23:40
23:42
23:44
23:46
23:48
23:50
02:16
02:08
01:59/725 m
01:56/725 m
01:48/730 m
01:44
01:40
01:36
01:32
01:28
01:24
23:28
23:25/706 m
23:23/706 m
23:20
23:18/706 m
23:16
23:14
23:12
23:10/start
23:54
23:58
00:00
00:03/708 m
00:08/707 m
00:12
00:16
00:20
00:24
730
725
720
715
710
01:04/730 m
00:53/720 m
00:50/716 m
00:49/712 m
00:46
00:44
00:42
00:40
00:38
00:36
00:34
Gabbro
Sediment
Textured sediment

Figure 3

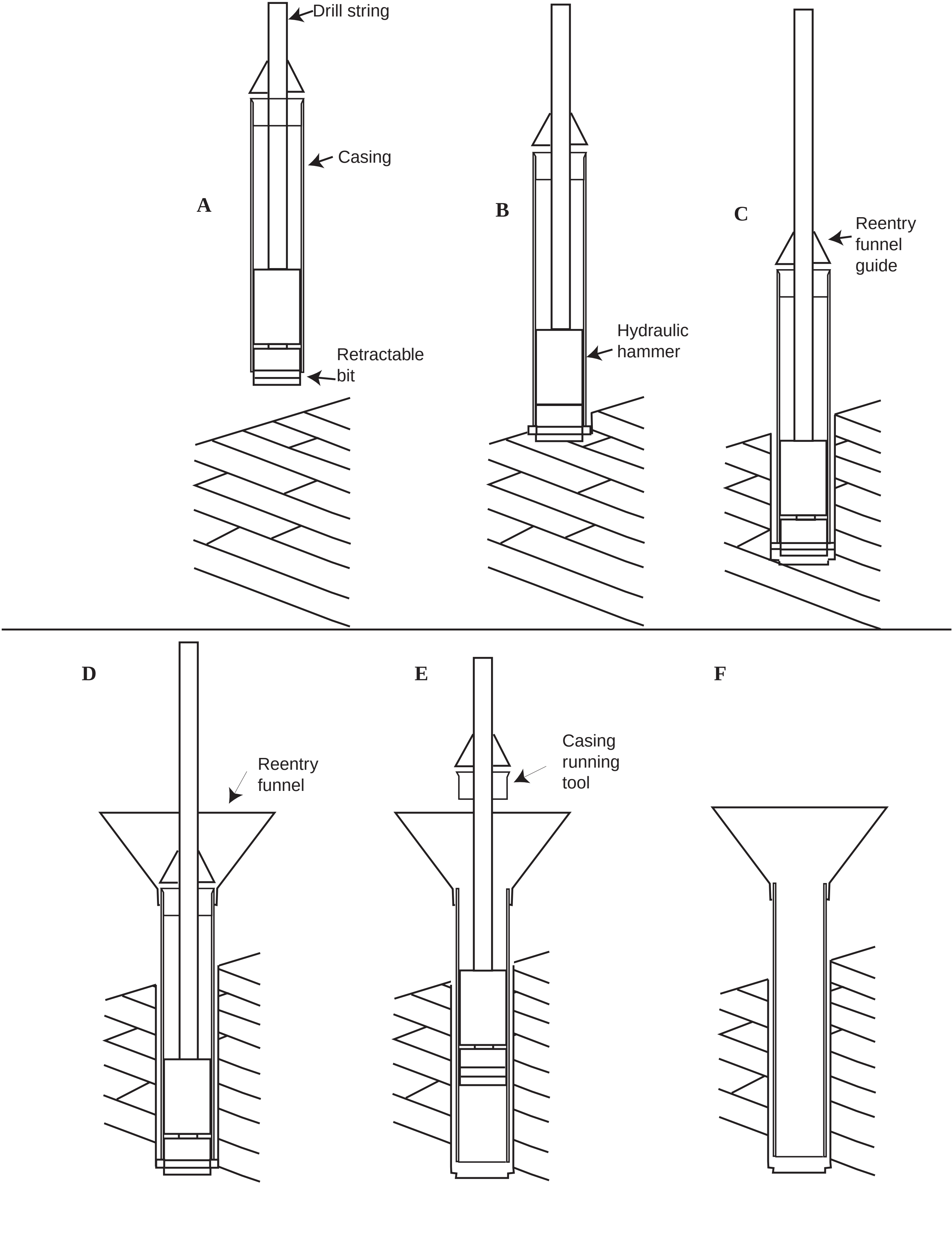
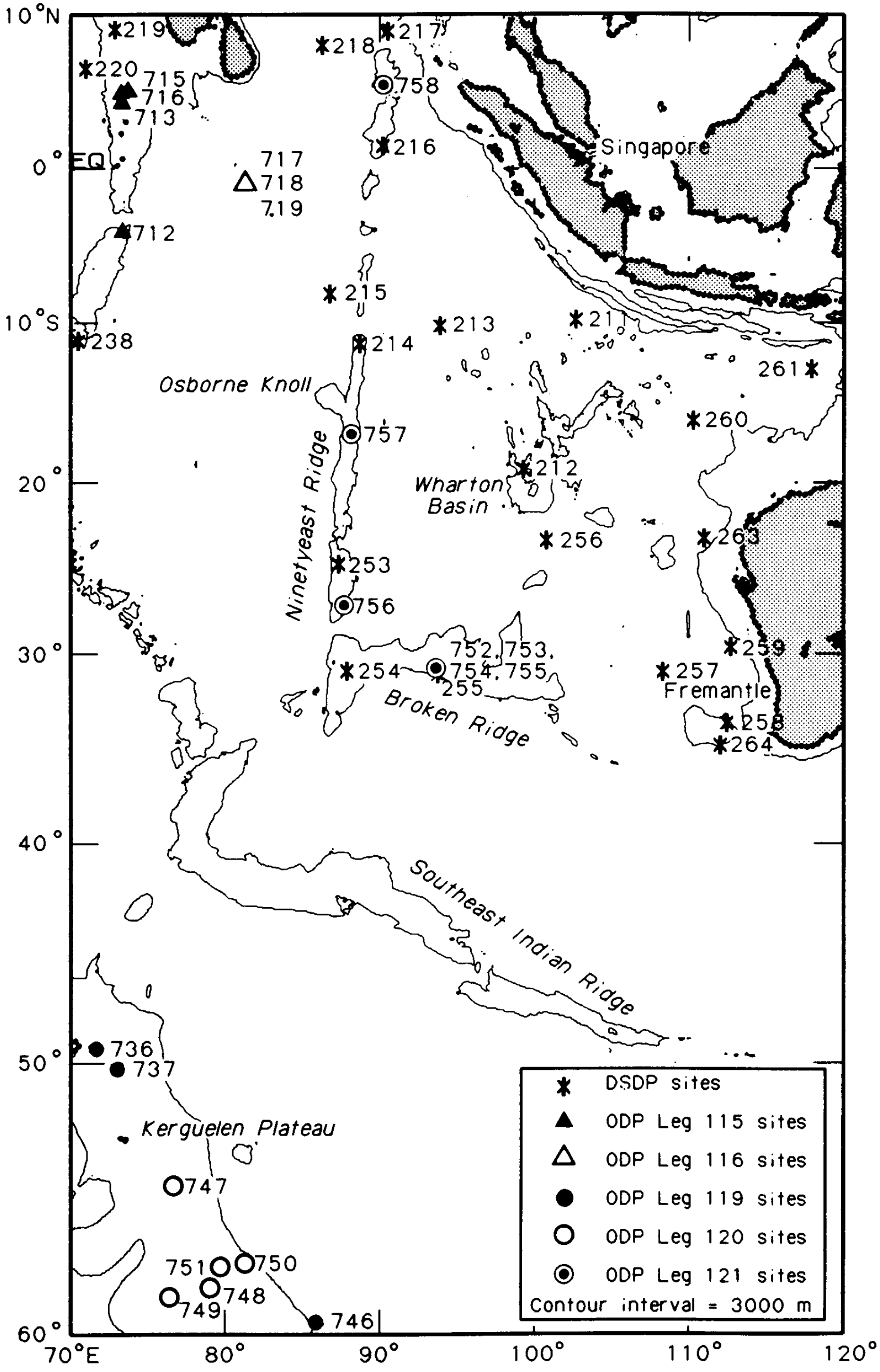

Drill string
Casing
A
Retractable
bit
B
Hydraulic
hammer
C
Reentry
funnel
guide
D
Reentry
funnel
E
Casing
running
tool
F

Figure 4



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758
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Singapore
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719
712
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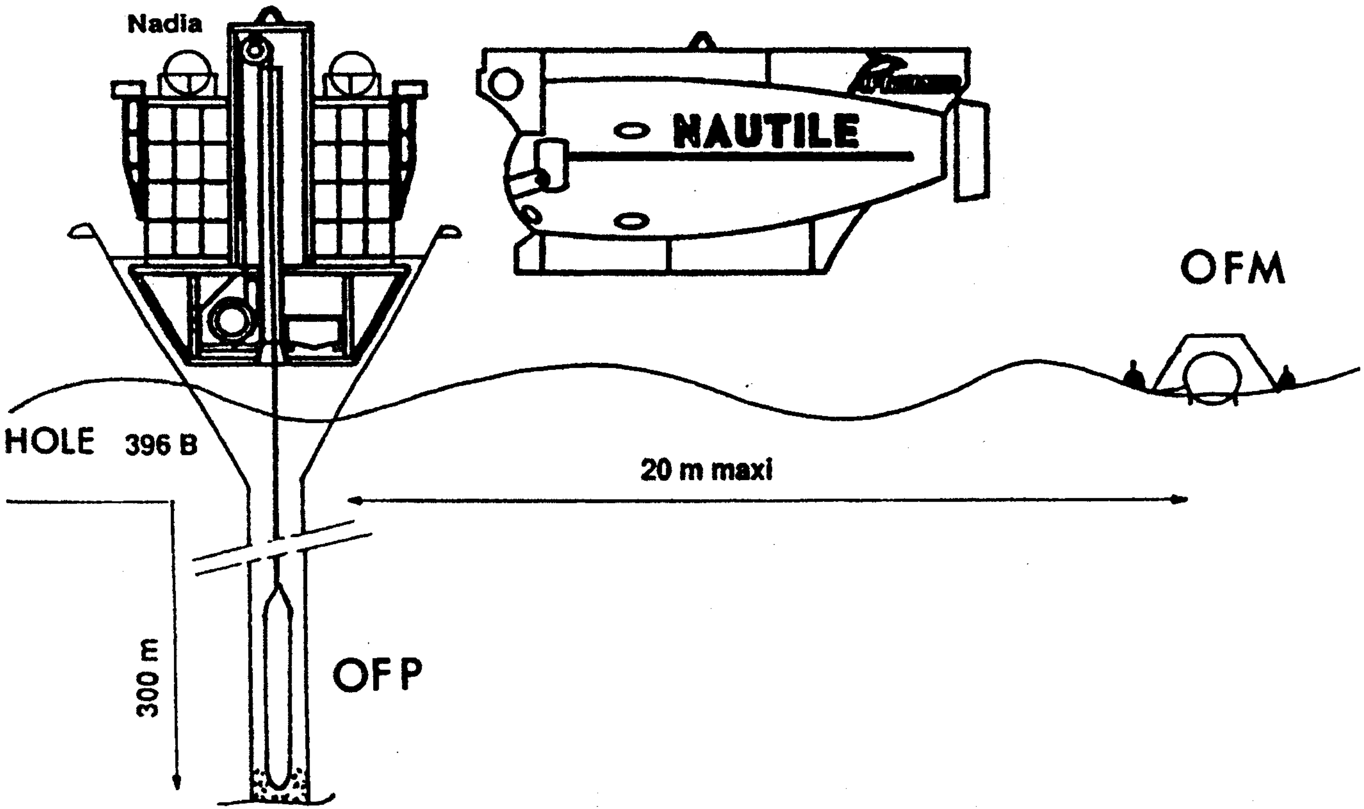
213
211
10°S
238
214
261
Osborne Knoll
757
260
Ninetyeast Ridge
212
Wharton
Basin
256
263
253
756
752, 753,
754, 755,
255
254
259
257
Fremantle
Broken Ridge
258
264
Southeast Indian Ridge
736
737
Kerguelen Plateau
747
751
750
749
748
746
DSDP sites
ODP Leg 115 sites
ODP Leg 116 sites
ODP Leg 119 sites
ODP Leg 120 sites
ODP Leg 121 sites
Contour interval = 3000 m

Figure 5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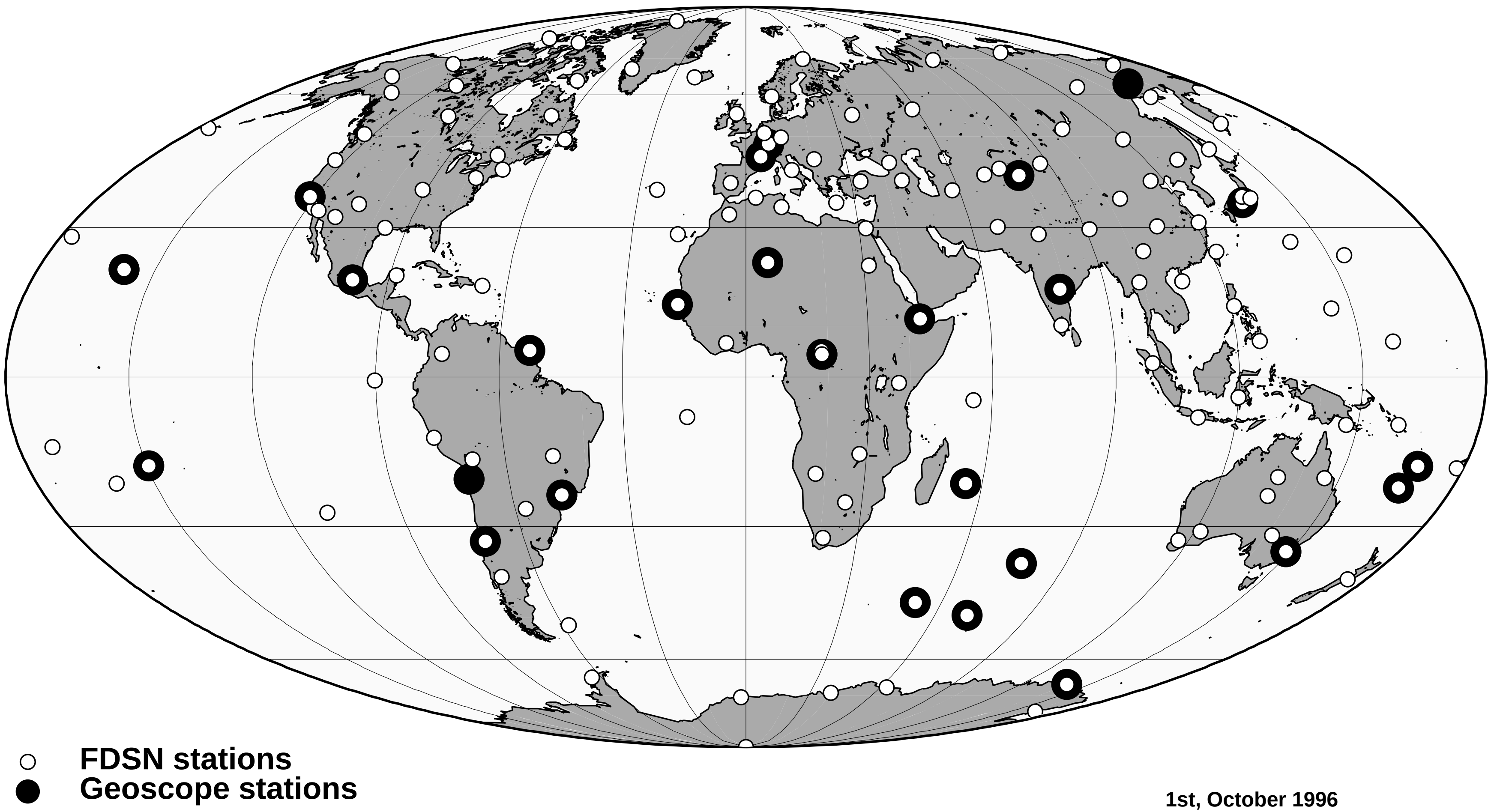
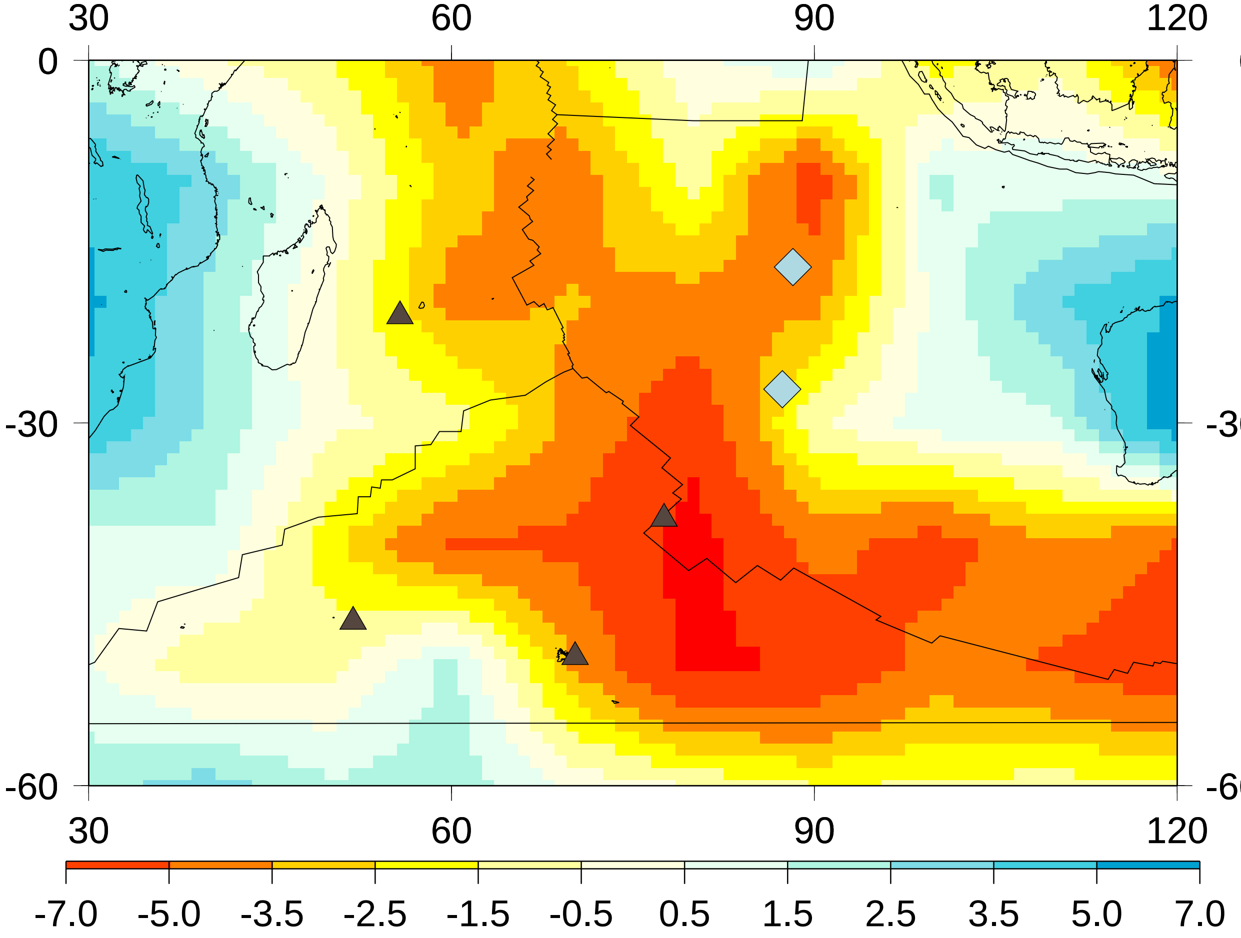
OFP

FDSN stations in 1996





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-30
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-7.0
-5.0
-3.5
-2.5
-1.5
-0.5
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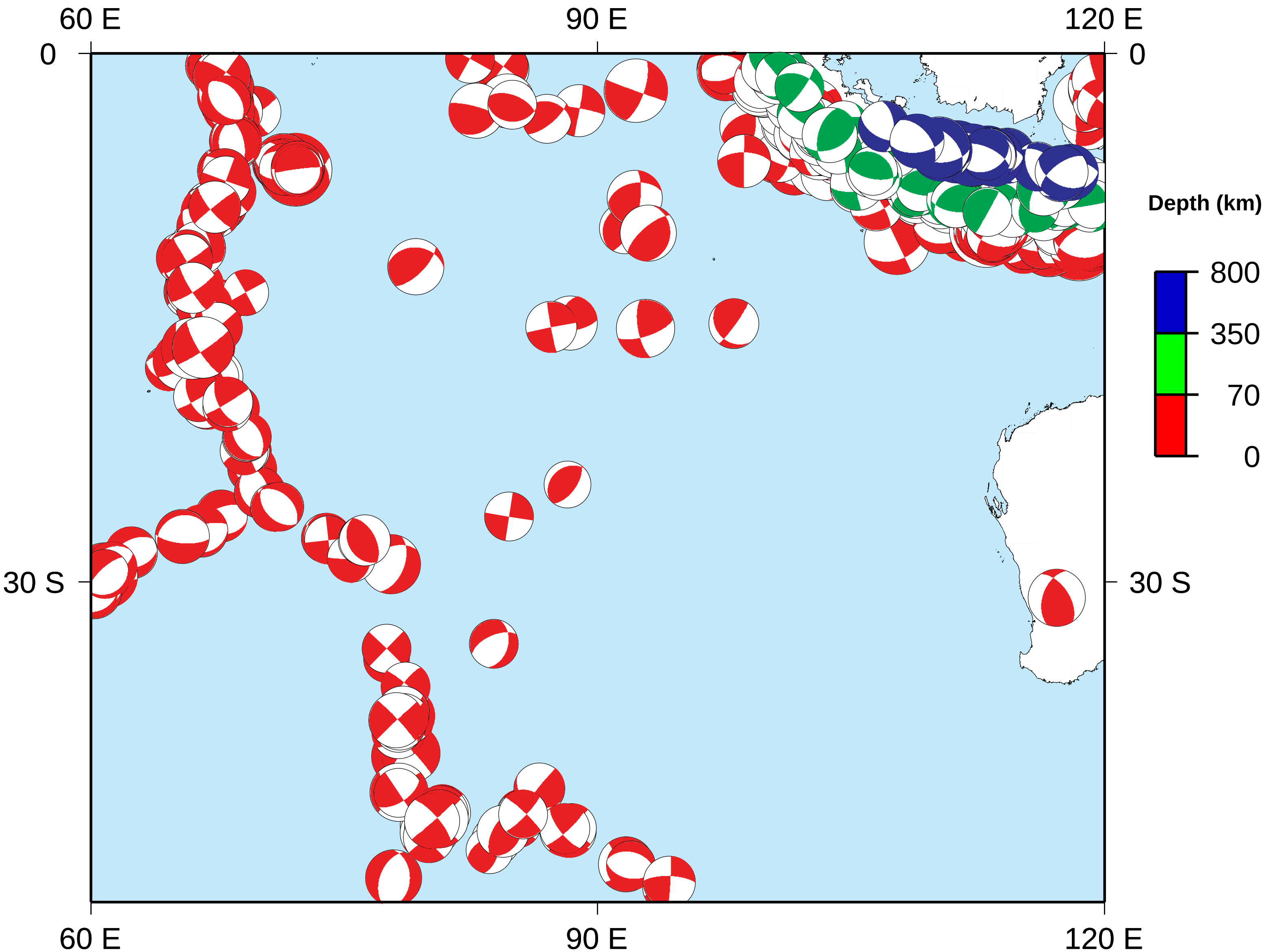
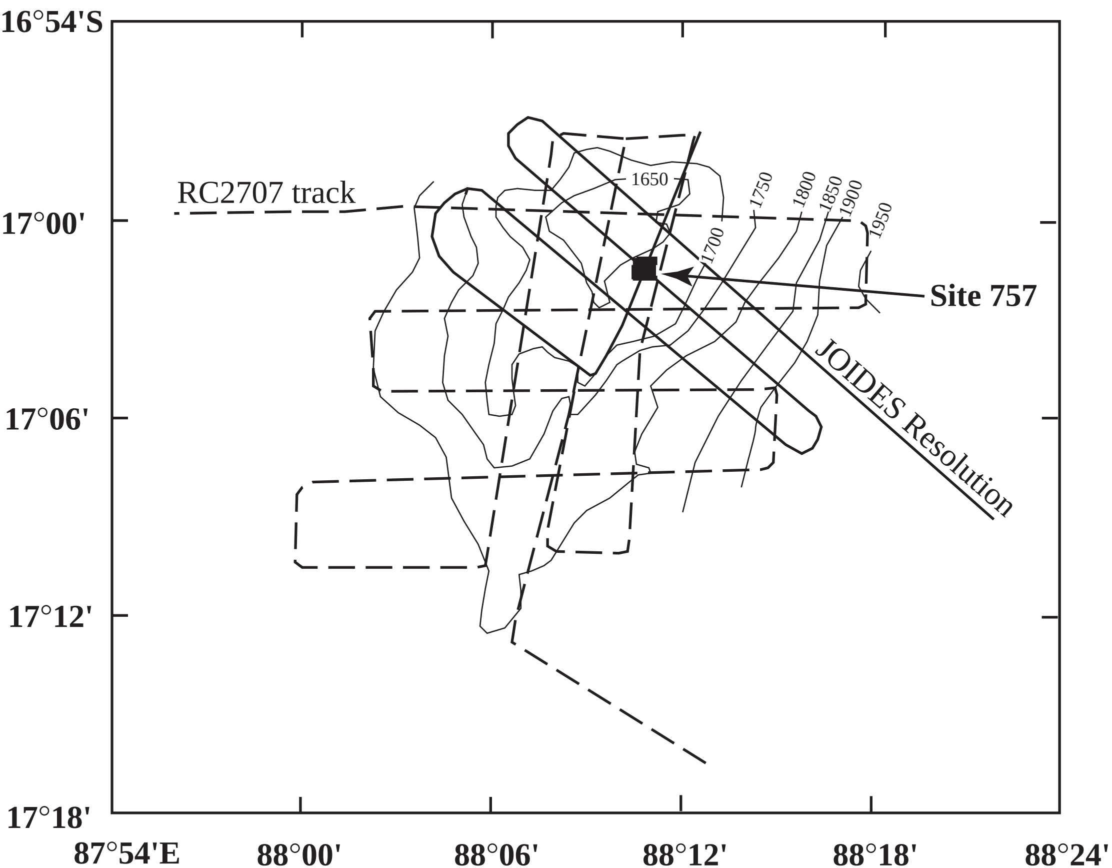
1.5
2.5
3.5
5.0
7.0

Indian Ocean

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17°00'
17°06'
17°12'
17°18'
87°54'E
88°00'
88°06'
88°12'
88°18'
88°24'
RC2707 track
1650
1700
1750
1800
1850
1900
1950
Site 757
JOIDES Resolution

Figure 10

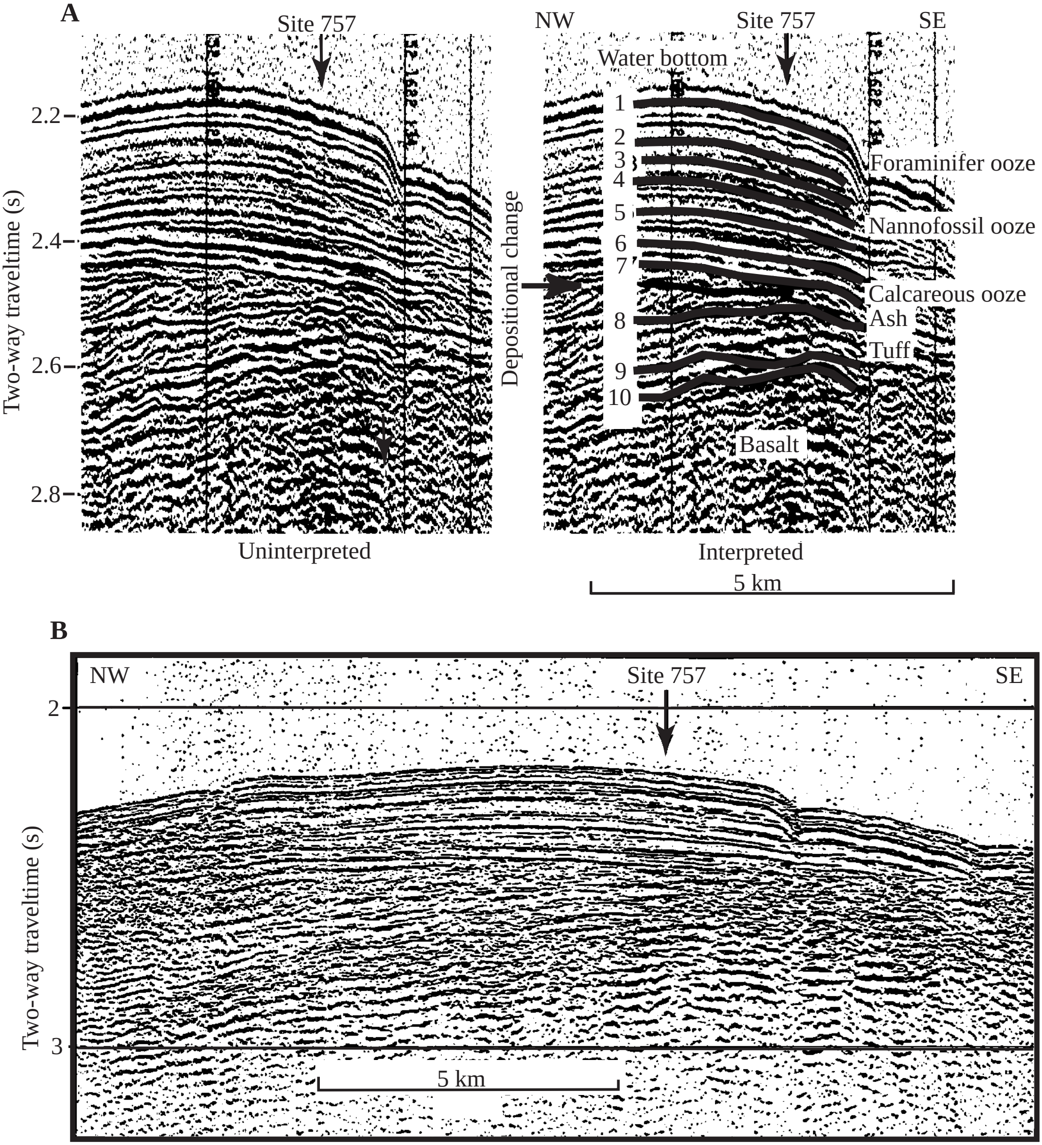

A
Site 757
2.2
2.4
2.6
2.8
Two-way traveltime (s)
Uninterpreted
Depositional change
NW
Site 757
SE
Water bottom
1
2
3
4
5
6
7
8
9
10
Foraminifer ooze
Nannofossil ooze
Calcareous ooze
Ash
Tuff
Basalt
Interpreted
5 km
B
NW
Site 757
SE
2
3
Two-way traveltime (s)
5 km

Figure 11

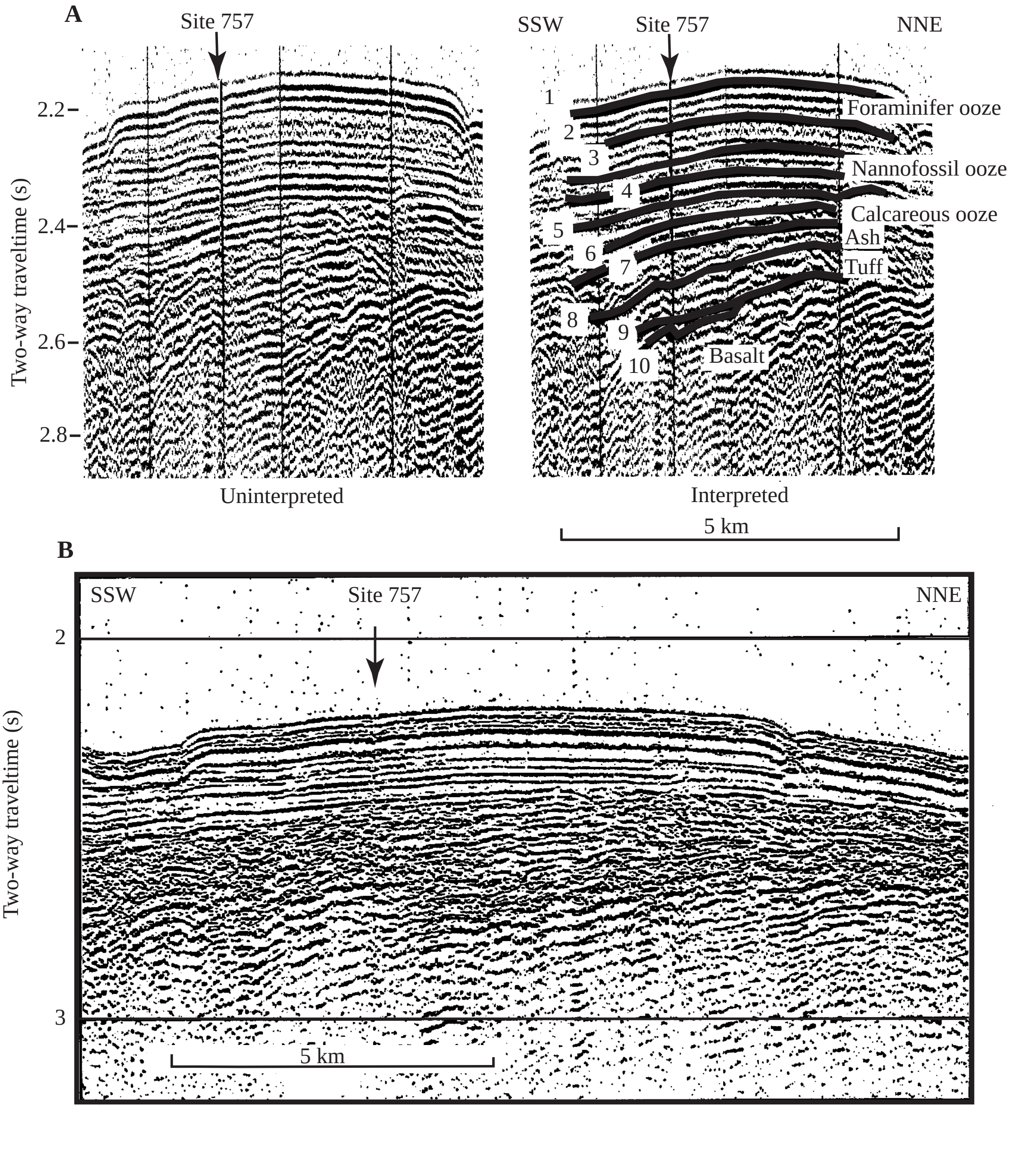

A
Site 757
2.2
2.4
2.6
2.8
Two-way traveltime (s)
Uninterpreted
SSW
Site 757
NNE
1
2
3
4
5
6
7
8
9
10
Foraminifer ooze
Nannofossil ooze
Calcareous ooze
Ash
Tuff
Basalt
Interpreted
5 km
B
SSW
Site 757
NNE
2
3
Two-way traveltime (s)
5 km

Figure 12

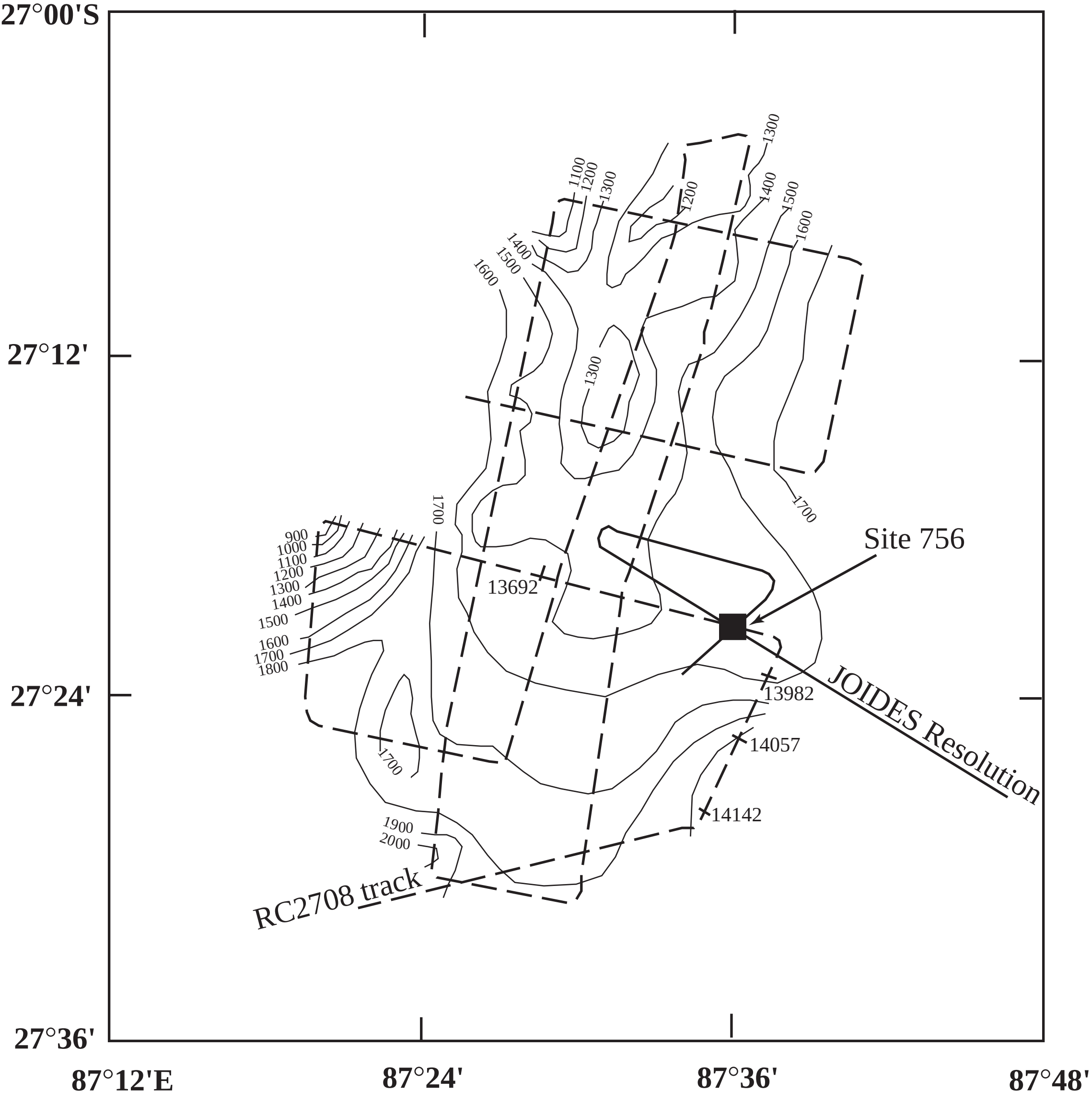
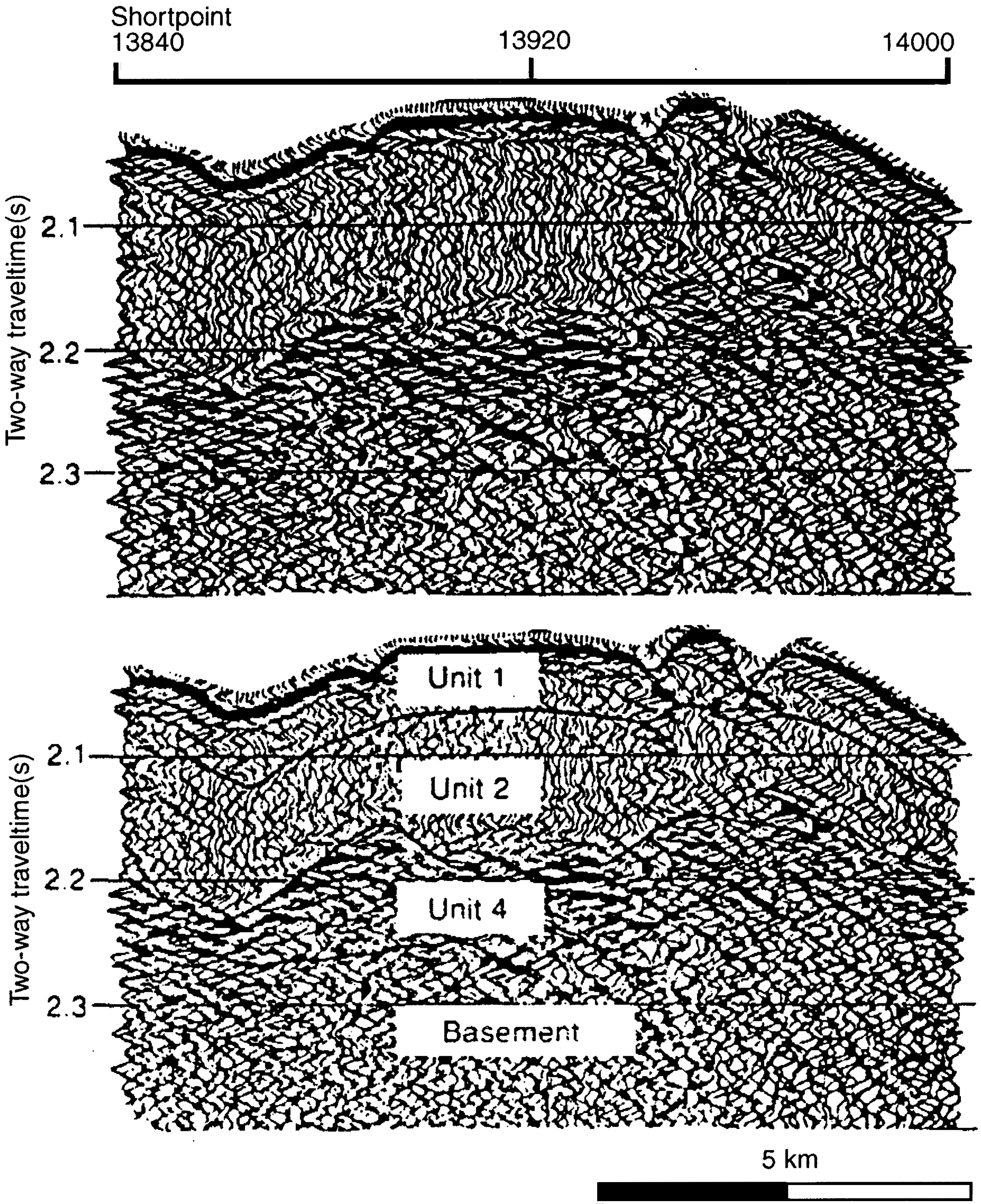

27°00'S
27°12'
27°24'
27°36'
87°12'E
87°24'
87°36'
87°48'
Site 756
JOIDES Resolution
RC2708 track
13692
13982
14057
14142
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

Figure 13



Shortpoint
13840
13920
14000
Two-way traveltime(s)
2.1
2.2
2.3
Two-way traveltime(s)
2.1
2.2
2.3
Unit 1
Unit 2
Unit 4
Basement
5 km

Leg 179 Site Time Estimates

Cape Town, South Africa (16 April 1998) to Darwin, Australia (6 June 1998)

Site Name	Latitude Longitude	Water Depth (m)	Penetration (mbsf)	Location	Operations	Transit Time @ 10.5 kt (days)	Drilling Coring Time (days)	Logging Time (days)	Total Days
Depart Cape Town, South Africa, 16 April, arrive Site 735B, 23 April.						8.0			8.0
HDS-1	32°43.3928'S 57°15.9606'E	700	40	ODP 735	Test hammer drill system		5.0		5.0
HDS-2	32°36'S 57°15'E	2400	60	ODP 735	Test hammer drill system		5.0		5.0
HDS-3	32°43'S 57°11'E	2800	80	ODP 735	Test hammer drill system		5.0		5.0
Depart Site 735B, 8 May, arrive Site 757, 16 May.						7.5			7.5
NERO ION	17°01.458'S 88°10.899'E	1660	370 sed 200 bsmt	ODP 757	Set reentry cone, casing, core, SWD		3.0 drill 3.5 core		6.5
					SWD OBS deployment & recovery			0.5	0.5
					Std logging			0.5	0.5
					Oblique (NOSE/SINUS)			2.0	2.0
					VSP			0.5	0.5
					Strain meter				0.5
Depart Site 757, 25 May, arrive Darwin, Australia, 6 June.						10.0			10.0
Total Days									**51.0**

SITE SUMMARIES

Site: HDS-1

Priority: 1
Position: 32°43.3928´S, 57°15.9606´E
Water Depth: 700 m
Sediment Thickness: 0 m
Maximum Penetration: 200 m pending approval

Objectives: The objectives of Site HDS-1 are to:

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 flat outcrops.

3. Test entire hammer-drill system by drilling in 20-40 m of 13-3/8 in. 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 flat 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

Site: HDS-2

Priority: 1
Position: 32°36´S, 57°15´E
Water Depth: 2400 m
Sediment Thickness: 0 m
Maximum Penetration: 200 m pending approval

Objectives: The objective of Site HDS-2 is to:

1. Test hammer drill system by drilling in 40-60 m of 13-3/8 in. 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

Site: HDS-3

Priority: 1
Position: 32°43´S, 57°11´E
Water Depth: 2800 m
Sediment Thickness: 0 m
Maximum Penetration: 200 m pending approval

Objectives: The objective of Site HDS-3 is to:

1. Test hammer-drill system by drilling in 60-80 m of 13-3/8 in. 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

Site: 757

Priority: 1
Position: 17°01.458´S, 88°10.899´E
Water Depth: m
Sediment Thickness: 370 m
Maximum Penetration: 570 m pending approval
Seismic Coverage:

Objectives: The objectives of Site 757 are to:

1. 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 the ION program.

2. Core 200 m into basement.

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

Logging and Downhole Operations: Triple combo and FMS-sonic.

Nature of Rock Anticipated: Basalt

Site: 756

Priority: 2
Position: 27°21.00´S, 87°35.00´E
Water Depth: 1520 m
Sediment Thickness: 139 m
Maximum Penetration: 339 m
Seismic Coverage:

Objectives: The objectives of Site 756 are to:

1. 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 the ION program.

2. Core 200 m into basement.

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

Logging and Downhole Operations: Triple combo and FMS-sonic.

Nature of Rock Anticipated: Basalt

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