OCEAN DRILLING PROGRAM

LEG 153 SCIENTIFIC PROSPECTUS

DRILLING IN THE WESTERN WALL OF THE MARK AREA

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July 1993

Scientific Prospectus No. 53
First Printing 1993

Distribution

Copies of this publication may be obtained from the Director, Ocean Drilling Program, Texas A&M University Research Park, 1000 Discovery Drive, College Station, Texas 77845-9547, U.S.A. Orders for copies may require payment for postage and handling.

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

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

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

ABSTRACT

Leg 153 is scheduled to drill rocks believed to be representative of the lower crust and upper mantle created at a slow-spreading ridge. Two sites (proposed sites MK-1 and MK-2) have been selected in the MARK area (Mid-Atlantic Ridge near the Kane Transform) to achieve deep penetration into: 1) a gabbro massif (as well as a major detachment fault along which the gabbro has been unroofed by mechanical extension); and 2) a serpentinized peridotite section along strike to the south of the gabbroic massif.

Both proposed sites are along the western rift-valley wall; gabbros and serpentinized peridotites are located 10 and 35 km south of the transform, respectively. Studies at these proposed sites will address a variety of tectonic, petrological, hydrothermal, and geophysical problems that are contingent upon the penetration of long continuous cores in deep crustal to upper mantle rocks in slow-spreading lithosphere. Major tectonic questions concerning the mechanisms responsible for deep crustal and upper mantle exposures along the rift-valley wall and the evolution of rift valleys may also be addressed.

In slow-spreading regions like the MARK area, drilling of deep crustal and upper mantle rocks could also test the traditional seismically based concepts of the architecture of slow-spreading crust and upper mantle, and provide a basis for comparison with drilled sections of gabbro and serpentinized peridotite at a fast-spreading ridge (ODP Leg 147, Hess Deep). The gabbro site and surrounding areas also have the future potential to achieve penetration of deeper crustal units through an offset drilling strategy as well as possible penetration of the "petrologic," and perhaps the "seismic," Moho transition. These goals seem realistic, given that the crust in this region appears to be somewhat thinner (less than 4 km) than "normal" oceanic crust, based on seismic and gravity evidence and the occurrence of peridotite exposures at the surface along strike.

INTRODUCTION

Two categories of data are critical to an understanding of oceanic spreading dynamics: 1) data on the magmatic processes which govern the formation of the oceanic crust (partial melting of mantle rocks, melt segregation and pooling, magmatic differentiation); and 2) data on the tectonic processes associated with the rise of new asthenospheric material, and with the stretching of the lithosphere in the axial domain. These data may be derived from geophysical experiments, mechanical modeling, and submersible and sampling surveys. To some extent, the understanding of oceanic-ridge dynamics is also based on data acquired in ophiolite massifs; but the relevance of such field results to mid-oceanic ridges is often questionable, as it is difficult to ascertain the geological context in which these ophiolites were formed (large or small ocean basin, fast- or slow-spreading ridge axis, marginal basin, subduction zone?).

To understand the processes occurring in the lower crust and the mantle, direct information is essential and can be obtained from drill cores. To date, most available oceanic rock samples have been dredged or collected by submersibles, providing only limited information on the spatial relationships and nature of the contacts (tectonic, cumulative, intrusive) between the various rock types and the geometry of the internal structures displayed by the rocks (foliations, lineations, fractures, veins, dikes). Drilling can potentially provide relatively continuous cores and therefore may reveal the details of lithological and structural relationships. Drilled samples are also at least partially oriented with the axis of the core approximately vertical. The dip of the various sets of structures may be measured with respect to this reference line. In addition, there are ways to constrain the azimuth of the observed structures, either by using paleomagnetic data or by matching the cores with the images obtained with the FMS (formation microscanner) logging tool and by implementing the experimental hard rock orientation (HRO) system. A variety of other potential logging experiments (e.g., geochemical, sonic, in-situ stress evaluation) may produce an even better assessment of their lithological and structural context. These geological structures can then be related to processes at nearby plate boundaries.

Recent studies of slow-spreading ridges suggest that magma chambers are not permanent. The study of gabbros drilled at Hole 735B (Leg 118) suggests that they formed by successive injections of magma that was apparently deformed while still partially molten (Dick et al., 1991). This deformation continued at progressively lower temperatures throughout the crystallization history of the magma. Syn-magmatic deformation provided channels for seawater penetration into hot lower crust (Cannat et al., 1991; Mével and Cannat, 1991). These and other investigations suggest that a complex interplay among magmatism, deformation, and hydrothermal processes may characterize seafloor spreading at slow-spreading ridges. Another characteristic of slow-spreading ridges is the common exposure of rocks of deep crustal and upper mantle origin (gabbros and serpentinized peridotites) in the axial valley walls and even within the axial valley.

Although the mechanism responsible for the exposure of these rocks at the surface appears to be linked with the mechanical extension of the axial valley, particular environments may favor this process. This is particularly true for exposures of serpentinized peridotites which, based on seismic velocity arguments, should come from more than 5 km depth. Different mechanisms have been proposed to explain the presence of peridotites cropping out on the seafloor, such as 1) relatively intense extension of the crust related to detachment faulting, 2) modest faulting of very thin crust created in areas of low magma budget, and 3) serpentinite diapirism related to penetration of seawater down to the mantle along major fault planes. In addition, the proximity of a major transform fault may also favor the exposure of rocks of deep origin by the formation of an intersection massif.

Petrological and geophysical studies, as well as direct observation of neovolcanic zones, suggest that magmatic accretion at slow-spreading ridges varies, not only with time, but along axis and is therefore a three-dimensional process (Karson et al., 1987; Dick, 1989; Lin et al., 1990) related to the segmentation. Ridge segments are discrete portions of spreading centers typically a few tens of kilometers in length bounded by non-transform and transform discontinuities. Mantle upwelling at discrete centers is believed to occur beneath ridge segments, suggesting that magma production varies significantly along axis. Therefore, the magmatic crustal thickness is likely to vary along axis as well. All these considerations suggest that the lithosphere created at slow-spreading ridges may not correspond to a simple layered model, but is complicated by spatially and laterally varying magmatic accretion and by tectonism.

To better understand the processes involved in the formation and evolution of slow-spreading oceanic lithosphere, two holes have been proposed, one in rocks believed to be representative of the lower crust and one in rocks interpreted to be derived from the shallow mantle, exposed along strike in the western wall of the Mid-Atlantic Ridge (MAR) (Figs. 1, 2, and 3). It may be argued that a major drawback of drilling directly in exposed gabbros and peridotites is that the processes responsible for their exposure on the seafloor have probably left their imprint on them. The gabbroic rocks or peridotites found in the oceanic lithosphere may therefore not be entirely representative of "normal" mid-oceanic lower crust and upper mantle. However, based on the large number of places where gabbros or ultramafic rocks crop out directly on the seafloor along the Mid-Atlantic Ridge, it can be argued that processes leading to the emplacement of deep crustal and upper mantle derived rocks on the seafloor are inherent to slow seafloor spreading. With detailed studies it may be possible to separate the effects of different processes and events that have created and modified these rock units.

STUDY AREA

Two drill sites (proposed sites MK-1 and MK-2) are proposed along the western wall of the MARK area (Mid-Atlantic Ridge at the Kane fracture zone) (Figs. 2 and 3) where detachment faults as well as gabbro and peridotite outcrops have been documented by both the *Alvin* (Karson and Dick, 1983; Karson et al., 1987) and the *Nautile* (Mével et al., 1991) dives.

The MARK area is certainly the most comprehensively studied portion of the Mid-Atlantic Ridge. Its surface geology and crustal structure are constrained by bathymetric mapping (Detrick et al., 1984; Gente et al., 1991), SeaMARC I and side-scan sonar imaging (Kong et al., 1988; Karson et al., 1992), seismic surveys (Cormier et al., 1984; Purdy and Detrick, 1986; Detrick et al., 1984), magnetic surveys (Schulz et al., 1988), gravity surveys (Morris and Detrick, 1991), submersible studies with the *Alvin* (Karson and Dick, 1983; Karson et al., 1987) and the *Nautile* (Mével et al., 1991; Auzende et al., in prep.), and previous DSDP (Site 395, Shipboard Scientific Party, 1977) and ODP (Sites 648, 649 and 670, Shipboard Scientific Party, 1988a, 1988b) drilling.

A SeaBeam map of the MARK area was produced during the site survey preliminary to Leg 106 (Detrick et al., 1984) and allowed morphological and large-scale structural investigations (Kong et al., 1988; Pockalny et al., 1988). South of the Kane Transform, the MAR is relatively linear with no major offset. The rift valley varies in width from 10 to 17 km. The inner floor deepens toward the north from 3500-4000 to 6100 m in the nodal basin marking the intersection with the Kane Fracture Zone. The ridge/transform intersection is characterized by a strong topographic asymmetry (Karson and Dick, 1983); the inside corner is a topographic high (1300 mbsl) contrasting strongly with the much lower outside corner (3500 mbsl).

The morphology of the inner floor is well constrained by SeaBeam bathymetric mapping (Detrick et al., 1984), SeaMARC I imaging (Kong et al., 1988), ANGUS deep tow camera surveys (Karson and Dick, 1983; Karson et al., 1987; Brown and Karson, 1988), and *Alvin*

(Karson et al., 1987; Brown and Karson, 1988; Karson and Brown, 1988) and *Nautile* (Mével et al., 1991; Gente et al., 1991) dives. In the northern cell, a continuous neovolcanic ridge forms the axial high. The Snake Pit hydrothermal field (ODP Leg 106 Scientific Party, 1986) is located on this ridge.

Cormier et al. (1984) suggested that the crustal thickness decreases toward the transform intersection. A seismic line along axis distinguished two domains with contrasting deep crustal structure: the northern cell, which extends from the nodal basin down to 23°18'N and possesses a seismic crustal thickness of 4-5 km, and the southern cell, which possesses a seismic crust 6-7 km thick (Purdy and Detrick, 1986). A wide transition zone (23°18'N to 23°05'N) separates these two cells. This transition zone corresponds with both a probable offset of magnetic anomalies (Schulz et al., 1988) and a change of rift-valley morphology (Kong et al., 1988) and has been interpreted as a zero-offset transform fault (Purdy and Detrick, 1986) or an accommodation zone (Karson, 1991).

A map of residual gravity anomalies calculated in the MARK area by Morris and Detrick (1991) shows a high beneath the transition zone separating the northern from the southern cell. This is in accordance with the on-bottom gravity measurements performed with the *Nautile* in 1988, which also showed the presence of a gravity high beneath the northern peridotite outcrop (Bergès, 1989). This high is interpreted by Morris and Detrick (1991) in terms of crustal thinning (1-2 km thinner than normal). Similar crustal thinning beneath non-offset discontinuities have been documented along the MAR south of the Atlantis Fracture Zone (Lin et al., 1990) and is attributed to focused magmatic accretion.

An off-axis bathymetry, gravity, and magnetics survey of the area was conducted with the *R/V Atalante* up to Anomaly 5 (Gente et al., 1991). A series of elongated oblique depressions bound rhomboid- or lozenge-shaped domains which are interpreted to represent the evolution of ridge segments with time. In terms of magma supply, the center of these lozenges may correspond to focused magmatic accretion. The magmatic crust should therefore be thick in the center and thin at the edges. The peridotite outcrops of the MARK area and DSDP Site 395 (where peridotites were drilled close to the surface) are located in one of these depressions, and therefore in an area where the magmatic crust is expected to be thin. Processing of the gravity and magnetics is in progress.

Dredges as well as *Alvin* (Dick et al., 1981; Karson and Dick, 1983) and *Nautile* (Mével et al., 1991) dives identified a section of gabbros and metagabbros, metabasalts, metadiabases, and basalts on the east wall of the intersection massif. These rocks are cut by moderately east-dipping faults, and many collected samples display slickensides. Some fault zones can be followed for several hundred meters and may correspond to major detachment faults. These older structures are commonly cut by higher angle faults. The gabbroic samples collected from this massif vary from olivine gabbros though gabbronorites and ferrogabbros to plagiogranites. The most differentiated gabbros were collected within a few kilometers of the transform fault (Marion et al., 1991; Marion, in prep.). These gabbros display ductile as well as brittle deformation structures, which allow seawater penetration and hydrothermal recrystallization (Marion et al., 1991). A drilling attempt in the gabbros at Site 669 (Leg 109) failed to spud-in. A recent side-scan and photographic survey of the Kane transform wall at the inside corner of the ridge/transform intersection (RTI) has identified extensive regions of distinctive acoustic backscatter patterns interpreted as outcrops of gabbroic rocks (Karson et al., 1992). This interpretation has been confirmed by a series of *Nautile* dives (Auzende et al., in prep.), and provides a three-dimensional perspective of this massif.

During the 1986 *Alvin* cruise, two serpentinite outcrops were discovered on the western wall of the axial valley (Karson et al., 1987), one at 23°10'N in the domain of the zero-offset transform fault, and the other at 23°21'N at the limit of the northern cell. The southern outcrop was drilled during Leg 109. In 1988, three dredge hauls by the Akademik Mstislav Keldysh on the northernmost outcrop recovered more peridotites (Gente et al., 1989). This outcrop was also explored during two dives of the *Nautile* (Mével et al., 1991). Both sites are located in the area of the zero-offset transform fault. It is therefore possible that the emplacement of these serpentinized peridotites is linked with spreading processes specific to the transitional domain between the northern and southern segments. Normal fault planes also occur in the peridotite outcrops, but they are not as low-dipping or as continuous as in the gabbros. Peridotites are predominantly serpentinized, clinopyroxene-bearing harzburgites (Juteau et al., 1990; Tartarotti et al., in prep.; Casey et al., in prep.). Localized high-temperature shear zones contain synkinematic hornblende (Casey, 1986). Some zircon-bearing dikelets cross-cut the peridotites. Neither the lateral contact between the peridotites and the gabbros nor the contact between the peridotites and the overlying basalts has been observed.

Recent investigations of along-axis basalt composition suggest that the lavas erupted in the MARK area are the products of a relatively small degree of mantle melting. This is also reflected in the composition of chrome spinels, which display very low Cr/Cr+Al ratios of 0.2-0.3 (Juteau et al., 1990; Casey et al., in prep.; Tartarotti et al., in prep.). This ratio can be used as an index of partial melting and also shows that the mantle beneath the MARK area is not extensively depleted by partial melting. The MARK area is not only characterized by slow-spreading, low probable degrees of melting and magma supply, but also by N-type MORB. Thus, the geochemical character of the MARK area provides one of the near-end member examples of the N-type (non-plume) crust in a slow-spreading environment.

SCIENTIFIC OBJECTIVES AND METHODOLOGY

Whereas knowledge of the uppermost crust and basalt petrology is extensive at mid-ocean ridges, many of the hypotheses that have been proposed for the generation and evolution of basalts are conjectural and can be tested, and concepts fundamentally advanced, only by conducting detailed studies of long, continuous cores of cumulate mafic and cumulate and residual ultramafic rocks. Likewise, many of the alteration, structural, and physical properties studies rely on continuity of section. For example, detailed mineral chemistry, whole-rock and textural studies require continuous core in order to make fundamental advances. Studies of cryptic chemical variations in plutonic sections of ophiolites and core from Hole 735B have shown that these data can yield information concerning the nature of parental magma and magma input, fractionation, and mixing events within subaxial magma chamber, and can serve to define magma chamber boundaries where multiple chambers existed, to identify magma chamber and cumulate processes, and to define melt/rock ratios and melt migration paths within cumulate rocks. The scale of these variations can range from a centimeter to hundreds of meters and documentation clearly requires intensive sampling of continuous core.

In addition to magmatic objectives, other general structural objectives require continuous core recovery. Very little information exists on the structural character of the lower crust. It is not known if the lower crust is penetratively or locally deformed, how strain is localized in the crust, how structures are oriented, or how structural style and orientation change with depth. Nor is there a clear picture of the relationships between fluid penetration and the evolution of ductile and brittle structures, the mechanism by which fluid penetrates into the ductile crust, or the general alteration state of the lower part of slow-spreading crust. Studies on the role of magmatic and hydrothermal fluids through examination of fluid inclusions (Kelley and Delaney, 1987) from gabbroic rocks sampled in close proximity to proposed site MK-1 (*Alvin* dives 1008, 1011, and 1012) suggest a minimum entrapment depth of 2 km below the basement/water interface, giving some estimate of the degree to which the gabbroic massif has been unroofed.

Drilling at proposed site MK-1 will allow sampling of a continuous section through a major detachment fault zone along which the deep-level gabbroic massif has been unroofed. The proposed drill site has been located by *Alvin* and visited by *Nautile*. It exposes a moderately dipping fault zone as well as gabbroic rocks and greenstones. Both rock types exhibit gneissic to cataclastic textures, developed under amphibolite to greenschist and lower metamorphic facies conditions. A continuous section drilled through this massif could identify the minimum thickness of the fault zone to determine if it is a likely candidate for dipping seismic reflectors. The proposed site is located along *Alvin* dive tract 1014 (Karson and Dick, 1983) and *Nautile* dive tract KN 02 (Auzende et al., in prep.) (Figs. 2 and 4).

A single hole drilled into the gabbro exposed at the intersection massif will address major questions concerning the nature of the plutonic foundation of slow-spreading crust. Traditional geophysically based models portray the oceanic crust as a density layered structure, but recent geological investigations are not consistent with this interpretation. Rather, these investigations suggest a much more complex crustal architecture. The proposed drilling program will investigate the nature, composition, and structure of lower crustal and upper mantle rocks, exposed at a slow-spreading ridge. This strategy will assess the vertical continuity of and place constraints on the paleo-orientation of the lithologies cored. The experimental HRO system is desirable in order to establish with certainty the orientation of igneous and metamorphic features with respect to the nearby plate boundary where these features were formed. This system mechanically orients hard rock cores where recovery is less than 100 percent. The HRO consists of an ODP standard wireline retrievable core barrel with additional, specialized hardware. The hardware includes a scribing mechanism in the core catcher, a Sonic Core Monitor which records entry of the core into the core barrel, and an electronic tool which orients the scribe mark on the core relative to the earth's magnetic field. The HRO, however, is still in the developmental stage and only if all these systems operate flawlessly will implementation of this system yield consistently accurate data.

In recent years, ODP has drilled two relatively deep holes through oceanic lithosphere: Hole 504B in the fast-spreading Pacific lithosphere drilled through 1000 m of effusive lavas and into the dike complex; and Hole 735B in the slow-spreading Southwest Indian lithosphere provided valuable information on the magmatic and tectonic structure of the lower, gabbroic, oceanic crust. Although Leg 109 successfully recovered serpentinized peridotite at Site 670 (Shipboard Scientific Party, 1988b), no deep penetration hole in peridotites from a slow-spreading ridge exists. A hole in the residual peridotite at an active, slow-spreading oceanic ridge will better define the chemical nature and evolution of the mantle beneath the ridge (degree and homogeneity of melting and the degree of serpentinization), the geometry of magmatic structures (magma extraction, percolation, and intrusion), the deformation structures related to asthenospheric flow, and the degree of mantle incorporation into the ridge axis lithosphere. Fresh samples are essential to determine the architecture of the deformation fabrics, the petrological and geochemical compositions of the mantle, and their evolution with depth. The deepest samples recovered at Site 670 (100 mbsf) suggest that peridotites may become less serpentinized with depth. The recovery of very fresh peridotite may be achieved by drilling a deeper hole, reducing the geochemical and textural uncertainties inherent in sampling of highly serpentinized rocks recovered from surface exposures. Proposed site MK-2 is located along Nautile dive track HS 13 (Fig. 5). Another hypothesis that could be tested at MK-2 concerns the structure and composition of the crust in areas of ultramafic exposures (Fig. 6). Studies of peridotite and gabbro samples from the MARK area (Mével et al., 1991; Tartarotti et al., in prep.) and from the 15°N area of the Mid-Atlantic Ridge (Cannat et al., 1992) suggest that there may be gabbro pockets intrusive into the uplifted mantle peridotites. This arrangement is similar to that of some Western Alps ophiolites (Lagabrielle and Cannat, 1990) and differs significantly from the layered magmatic crust model suggested by marine seismic refraction studies and some ophiolite complexes. This model could be tested by a deep hole drilled into an axial valley peridotite outcrop. Implications of this model could also be examined at proposed site MK-1.

Drilling into exposed peridotites in a slow-spreading environment will also address the mode of uplift of upper mantle rocks in the axial region of the MAR. Leg 153 will examine if such properties allow for strain concentration and the development of detachment faults. The order of magnitude of deviatoric stresses and strain rates in the stretched axial region will also be examined and, in addition, the relative importance of the ductile- and brittle-strain domains which should vary as a function both of the rock rheology at the imposed strain rates, and of the temperature distribution in the axial lithosphere. Leg 153 will attempt to clarify the mechanisms by which water penetrates into the mantle (faults?), whether the rising mantle is serpentinized at great depths, and if serpentinite diapirism and swelling play a significant role in the uplift. Samples from proposed site MK-2 should allow petrographic paleo-deviatoric stress levels to be tested. Later investigations, such as borehole seismic experiments and possibly long-term *in situ* observations of seismicity and stress variations with time, could contribute to the understanding of tectonic processes operating near the spreading center.

The influence of serpentinization on the budget of lithosphere/seawater interaction is poorly documented. Several serpentinite outcrops have been discovered on the seafloor of the MAR, and peculiar geochemical anomalies have been recorded in the water column that may be attributed to active serpentinization (Bougault et al., 1990). A direct control on the depth and chemical effect of serpentinization of peridotites obtained by drilling will help constrain the chemical budget of this interaction.

Leg 153 also seeks to identify the source of magnetic anomalies. Gabbros and serpentinized peridotites form a significant part of the seafloor in slow-spreading environments, and the magnetic properties of these rocks, along with their ability to produce magnetic anomaly patterns, are an important aspect of the proposed project. Finally, proposed sites MK-1 and MK-2 will provide a data base for evaluation of ophiolites as samples of ridge-generated lithosphere, and for comparison with peridotites and gabbros from other environments such as the Hess Deep (ODP Leg 147), which was created at a fast-spreading center.

DRILLING PLAN/STRATEGY

Two drill sites are proposed (Figs. 2 and 3, Table 1) in the western wall of the rift valley, one through gabbros (MK-1) and the second through peridotites (MK-2). The drillability of peridotites was firmly established during Leg 109, and the depth of drilling at Site 670 was limited only by a lack of time. Successful drilling of a continuous gabbro section was demonstrated at Hole 735B in the Indian Ocean and would seem feasible with a guide base in the MARK area as well. Peridotites and gabbros have proved to be drillable with the standard rotary system, and the diamond coring system is therefore not required.

Each hole should be drilled to a depth of at least 200 m and as deep as possible within time constraints. These two holes should be drilled with the intent to be deepened on future legs to a depth of at least 500 - 1000 m in order to sample a representative section of the ocean crust and upper mantle at a slow-spreading ridge. Two hard-rock guide bases (HRGBs) are necessary, one for each hole, which should be designed to accommodate sloping terranes, locally as much as 15° to 25°. Based on experience from ODP Leg 147, procedures such as casing the hole and cementing the HRGB should be undertaken to ensure hole stability sufficient for the desired penetration.

Three-dimensional orientation is essential and can be done indirectly by matching the cores with the FMS (formation microscanner) images if the recovery is high enough, or through use of the paleomagnetic measurements. However, this assumes that stable remanent magnetization was acquired during a single magnetic interval and that no subsequent tectonic rotation has occurred. The HRO system should, therefore, be used on every other core unless this proves too time consuming or unless this system fails to operate at optimum levels.

The proposed drilling strategy is to begin operations at proposed site MK-2 in the peridotites. After a video survey to locate an optimal site, and marking that site with a beacon released from the vibration-isolated television (VIT) frame (used to mount the camera), a pilot hole will be drilled and cored. The pilot hole should be achieve penetration of at least 30-40 mbsf (or until bit destruction). If conditions are favorable, an HRGB will be deployed. After the HRGB is positioned, the deployment mechanism should be disengaged to allow a complete video inspection of the position of the HRGB to ensure that slope of the outcrop and stability of the guide base are within acceptable limits. Drilling should commence with a large-enough diameter bit to allow installation of multiple casing strings. When sufficient depth is attained, hole deviation should be ascertained, and given favorable drilling conditions, the hole should be cased to a depth appropriate to ensure hole stability, and the guide base cemented in. The same strategy of site and hole preparation should be followed at proposed site MK-1. Drilling should continue until no longer than the mid-point of the scheduled drilling time (allowing for logging and relocation) in order to leave sufficient time for drilling at proposed site MK-1.

After coring operations are completed, a series of logging tools will be lowered downhole to monitor the in situ physical and geochemical properties of formations adjacent to the borehole. Interpretation of these continuous data records can yield stratigraphic, structural, geophysical, and geochemical characterizations of downhole lithologies. These logging tools will also be used to correlate with and constrain orientation of intervals where recovery is incomplete.

Four combinations of downhole tools are projected to be used on Leg 153. The Schlumberger quad combo, geochemical, and formation microscanner combinations, and the Deutsche Montan Technologie slim-hole borehole televiewer (BHTV). A natural gamma ray tool will be included on each string to provide a common basis for depth correlation, except for the BHTV because of connection incompatibilities. Due to the lithologies expected to be drilled on Leg 153, the quad combo, which includes sonic velocity, litho-density, porosity, and electrical resistivity monitors, may need to be run in two passes with different tool combinations to achieve optimum resolution.

Schlumberger's offshore service unit, the Multi-Task Acquisition and Imaging system (MAXIS), will allow the scientific party to view real time logging data, which will facilitate data acquisition and data correlation capabilities. A new Schlumberger software package, GEOFRAME, will also be on board for Leg 153. This program operates in the windows environment, is user friendly, and allows for greater capability of data manipulation. GEOFRAME will be installed on the Downhole Measurements Laboratory Sun IPX for use as an interactive workstation for log interpretation and analysis.

If drilling is successful, these two holes could be deepened and the MARK area could become a natural laboratory for the study of slow-spreading ridges. The two existing holes adjacent to the axial valley could be used for borehole seismic experiments to constrain the structure of the lithosphere and long-term observations, such as the variation of seismicity and stress with time.

The hole in the gabbros could be deepened. It has been suggested that the Moho is shallower in this region (Purdy and Detrick, 1986), and MK-1 may represent a hole that could potentially penetrate through gabbros to the seismic or petrological Moho at relatively shallow depths or, by later offset holes, eventually achieve full penetration of the gabbroic crust and penetrate these important petrological and/or seismic boundaries. If drilling proves successful, the potential exists for a long-term, multi-leg strategy of drilling a series of offset holes (or deepening existing holes) through the gabbros, starting in the proposed hole at MK-1. This series of holes would begin near the contact between gabbro and basaltic/diabasic rocks near the top of the western rift-valley wall.

The hole would be deepened until further penetration proved prohibitive, and drilling would then be offset downslope. This strategy would be repeated with a series of holes designed to test the basic architecture of the crust, to sample the detachment at multiple sites during each penetration in order to investigate its structural and alteration history during the unroofing process, and ultimately to penetrate deeper structural levels, including the mafic/ultramafic transition to achieve a composite, full penetration of the lower crust and uppermost mantle. Based on the considerable relief of the western rift-valley wall and the lateral extent of exposure of plutonic rocks (8 km of section) along the detachment surface, this site appears to have considerable potential in achieving this composite section and penetrating the petrological and/or seismic Moho. Fluid-inclusion work in a series of holes down the dip face of the proposed detachment shear could prove invaluable in quantitatively evaluating and testing the asymmetrical shear zone model of deep crustal exposure and rifting. The changes in the thickness of the shear-zone, and the extent of strain localization at various stratigraphic levels, could also be tested using this strategy. The petrological, chemical, and deformation characters of residual peridotites recovered below the gabbros could be compared with those of the exposed peridotites to shed light on the along-axis variation mechanisms.

PROPOSED DRILL SITES

Proposed site MK-1 will be drilled through the major detachment fault in the gabbros to a depth of at least 200 m (Figs. 2 and 4). During the *Alvin* and the *Nautile* dive programs near the ridge/transform intersection in the MARK area, gabbros have been observed on the east-facing slope between 6000 and 2200 mbsl. East-dipping (25°-45°) fault surfaces subparallel to surface slopes were observed along the western rift-valley wall. These faults exposed gabbroic rocks and greenstones. Gabbroic rocks sampled from these outcrops not only show brittle structures such as slickensides, veins, and microcracks, but also show ductile structures suggesting that this slope may represent a major detachment fault system along which footwall gabbroic massif has been unroofed. This is interpreted to occur largely during asymmetrical amagmatic extension. Recent side-scan, photographic, and *Nautile* surveys of the southern wall of the Kane Transform at the MARK inside corner (Karson et al., 1992; Auzende et al., in prep.) have constrained the nature and extent of the gabbroic massif. Some of these outcrops located during *Alvin* and *Nautile* dives and the particular drill site chosen have the added advantage of being at relatively shallow depths (2500 m).

Proposed site MK-2 (Figs. 3 and 5) will be drilled in peridotites to a depth of at least 200 m. The second proposed drill site is located on the northern peridotite outcrop discovered with the *Alvin*. In this area, the summit of the western rift-valley wall forms a hill (the "Pink Hill"), which culminates at 2600 m. Morphologically youthful pillow basalts crop out at the top of this hill and in the median valley floor. The base of the slope, at about 3700 m, is talus composed of serpentinite and basalt fragments. Serpentinized peridotites crop out continuously from about 3500 to about 3200 m. The valley wall is a tectonically active slope, dominated by numerous east-facing normal faults. The actual fault planes are moderately to steeply dipping (40° to 70°). The peridotites are also affected by more pervasively distributed serpentinite slickensides, with a dominant north-south trend and moderate eastward dip (20° to 50°). The contact between the serpentinized peridotites and the pillow basalts, which form the top of the wall, is concealed by talus. Two alternatives for the nature of this contact are likely. The basalts may conformably overlie the peridotites. Alternatively, basalts and peridotites may belong to two, tectonically juxtaposed blocks. The first interpretation is favored, based on the existence of a gravity high over the Pink Hill (Bergès, 1989). In either case, however, the scientific relevance of drilling a hole in the peridotites is justified. This hole should be located along the track of *Nautile* dive 13, on a flat surface near the lower limit of the serpentinized peridotite outcrop.

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TABLE 1

LEG 153 TIME ESTIMATES

Site	Drilling [1] (Days)	Logging [2] (Days)	Penetration [3] (m)	Total (Days)	Transit (Days)
St. John's					6.0
MK-1	19.7	2.5	390	22.2	
MK-2	19.7	2.3	390	22.0	
Barbados					4.0
Contingency [4]				1.8	
Sub Total	39.4	4.8		46.0	10.0
Grand Total				56.0 days at sea	

1: Estimated as one-half site occupation time.

2: Includes time for running four tool string combinations; Schlumberger quad combo, geochemical and formation microscanner combinations, and the Deutsche Montan Technologie slim-hole borehole televiewer.

3: Calculated as maximum total depth below sea floor (TDBSF), given time estimates for locating site, establishing pilot hole, setting guide base and casing, and assuming good drilling conditions. This TDBSF satisfies the proposed objectives of this leg to penetrate to a depth of at least 200 m and as deep as time constraints allow.

4: Contingency time for possible recovery of guide bases.

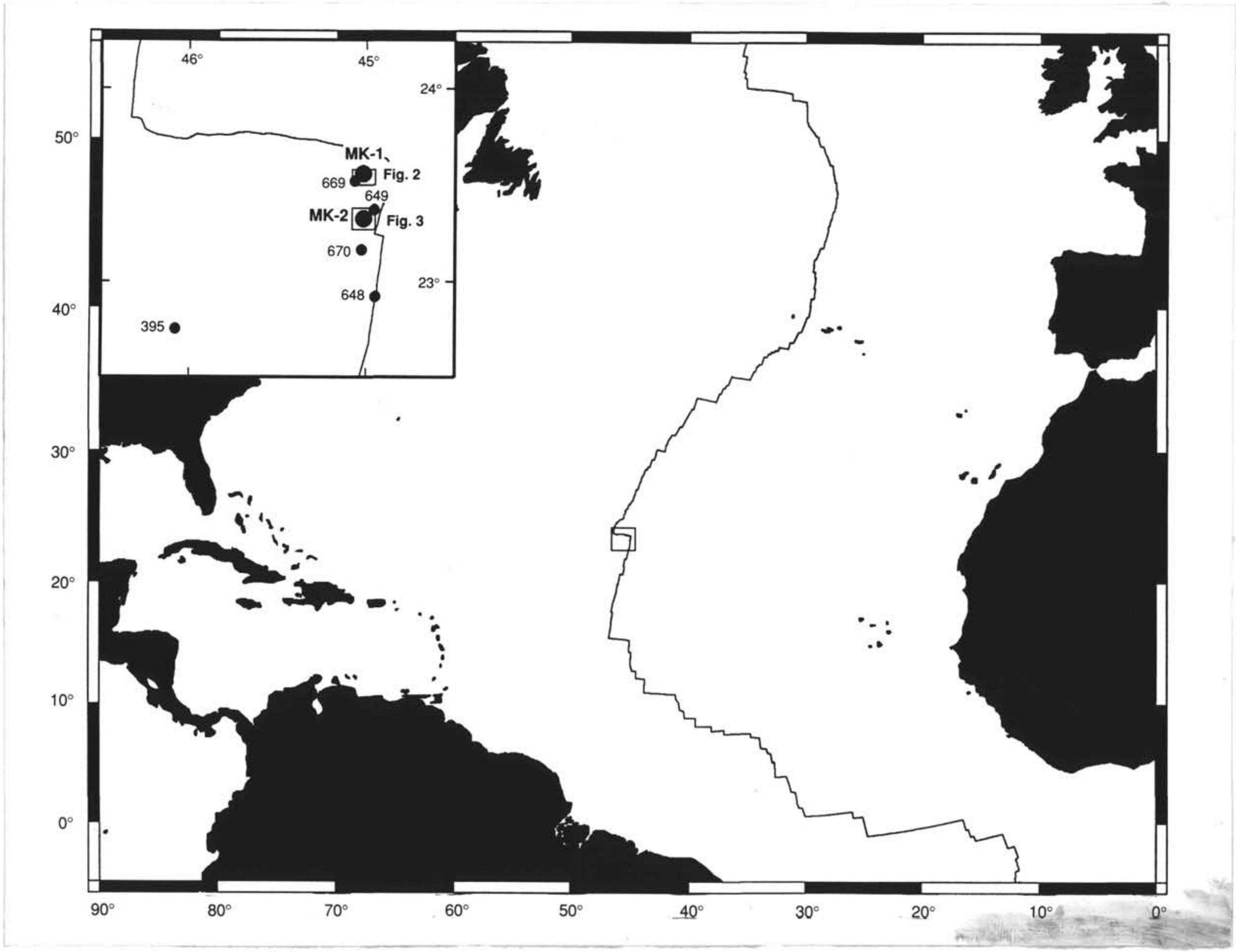


Figure 1. Location of the MARK area on the Mid-Atlantic Ridge. Inset shows Kane Transform, Site 395 (DSDP Legs 45, 78B, and ODP Legs 106 and 109), Sites 648 and 649 (ODP Leg 106), and Sites 669 and 670 (ODP Leg 109). Also shown are locations of Figures 2 and 3, as well as proposed sites MK-1 and MK-2 (larger circles).

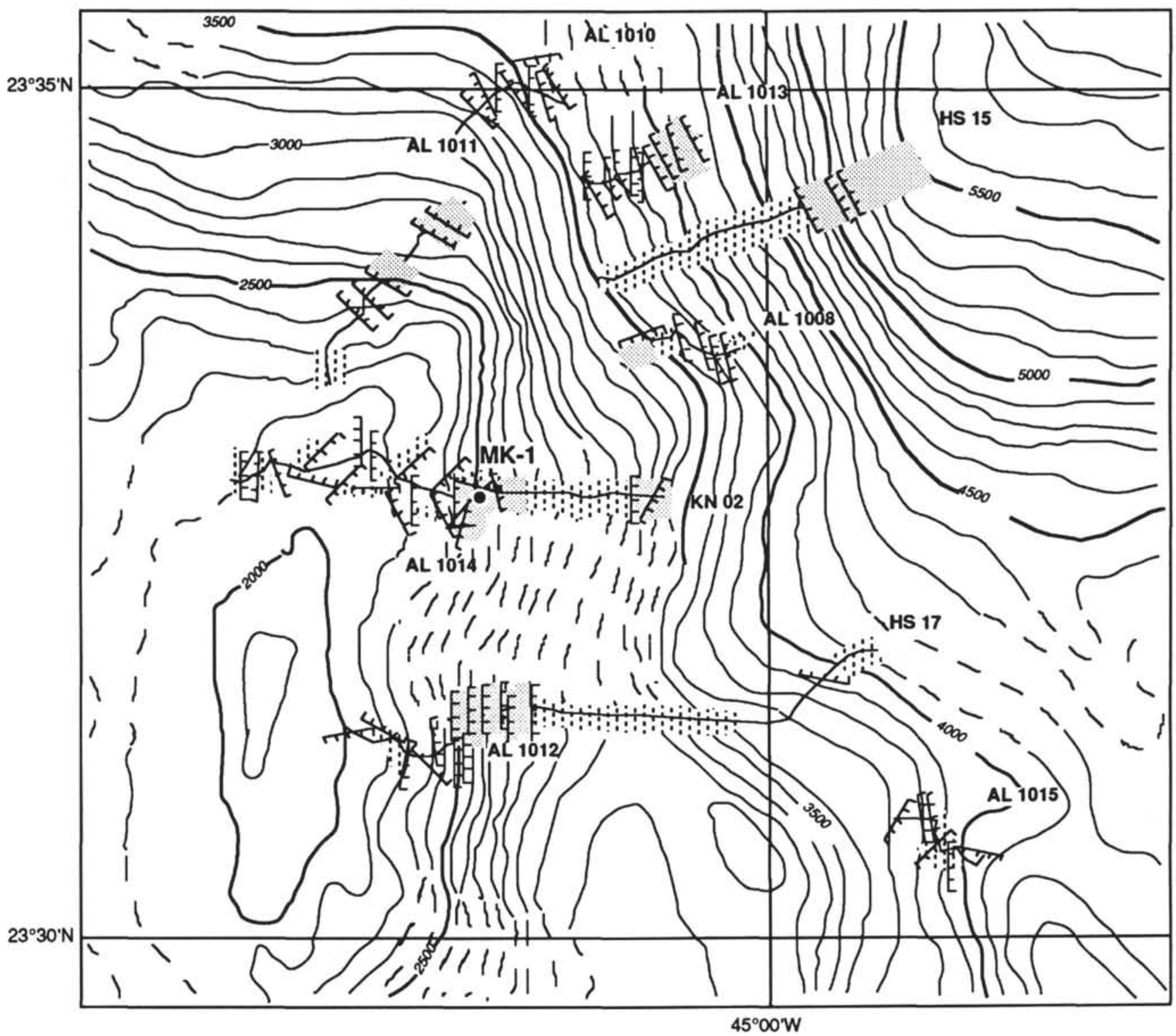


Figure 2. Bathymetric map of area near proposed site MK-1. Lithologies recorded by *Alvin* (AL, Karson and Dick, 1983) and *Nautile* (KN, Auzende et al., in prep., and HS, Mével et al., 1991) dives (tracks shown as solid lines crossing contours). Contour values shown in meters. Stipple = gabbroic outcrops; hachures = rubble and cement. Hachured lines represent faults; hachures on downthrown side.

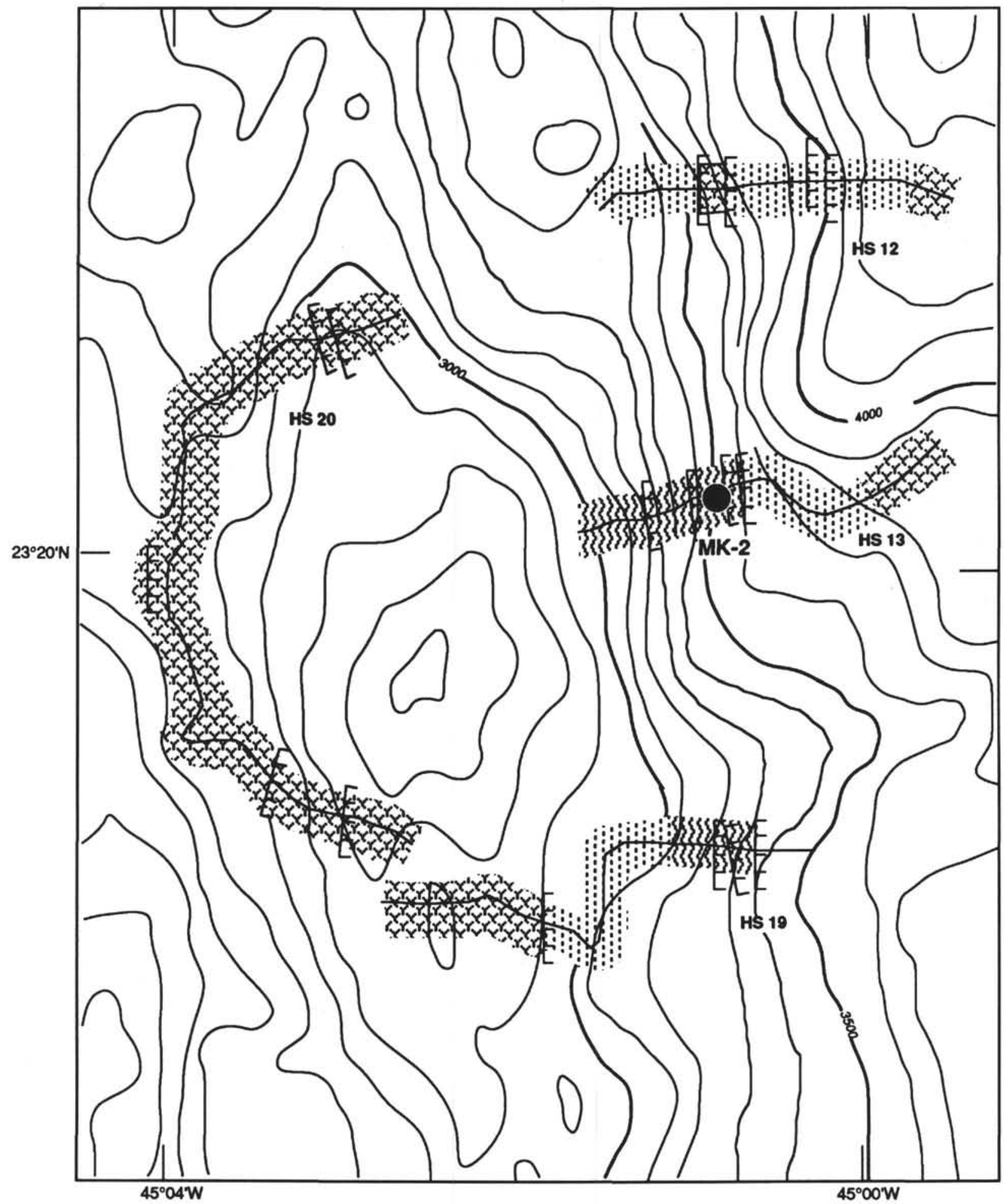


Figure 3. Bathymetric map of area near proposed site MK-2. Lithologies recorded by *Nautile* (HS, Mével et al., 1991) dives (tracks shown as solid lines crossing contours). Contour values shown in meters. Zig-zag lines = peridotite outcrops; y's = basalt outcrops. Hachures and hachured lines same as in Figure 2.

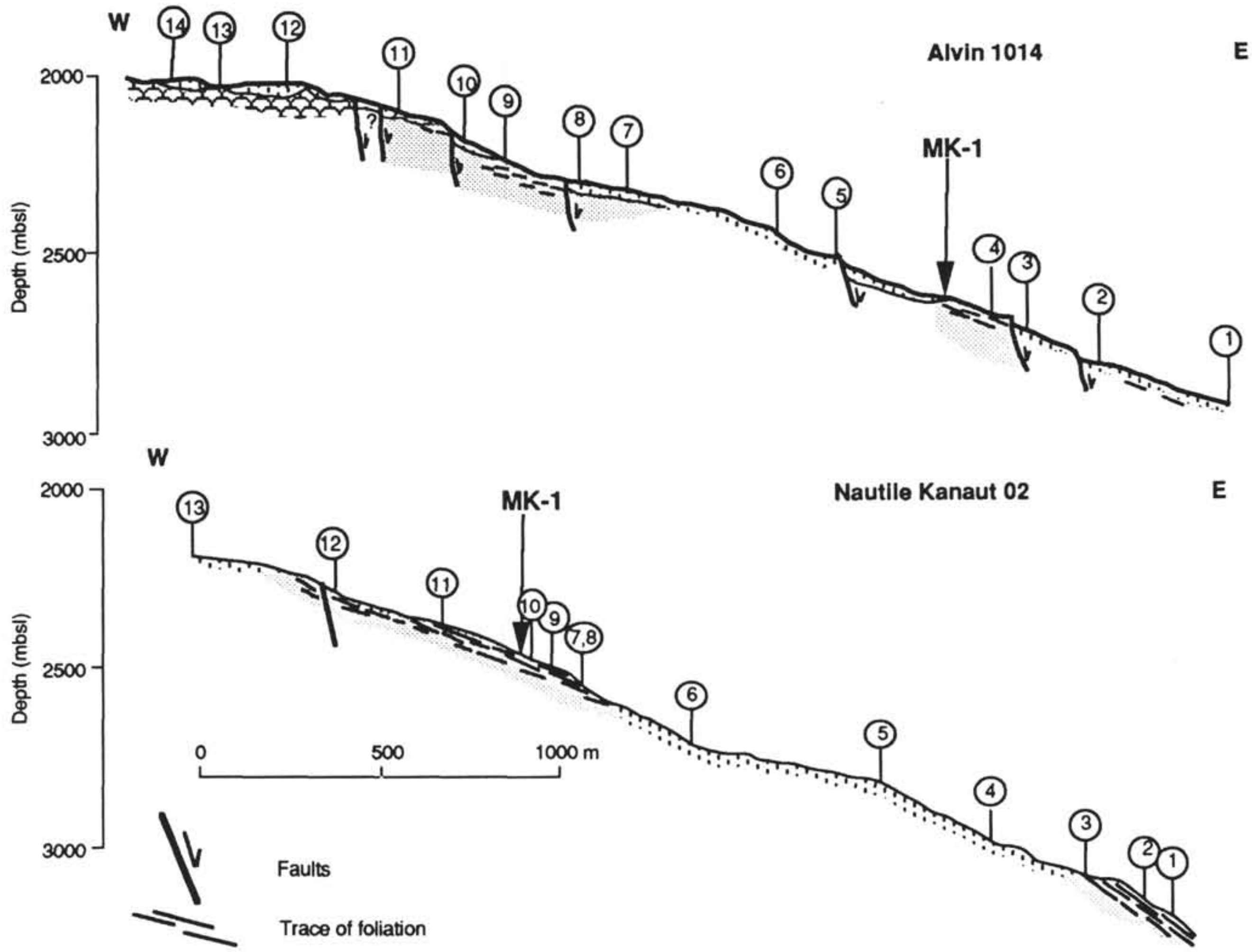


Figure 4. Inferred cross sections from submersible dive tracks (AL 1014, Karson and Dick, 1983; Kanaut 02, Auzende et al., in prep.). Circled numbers represent sample stations. Lithology pattern same as in Figure 2.

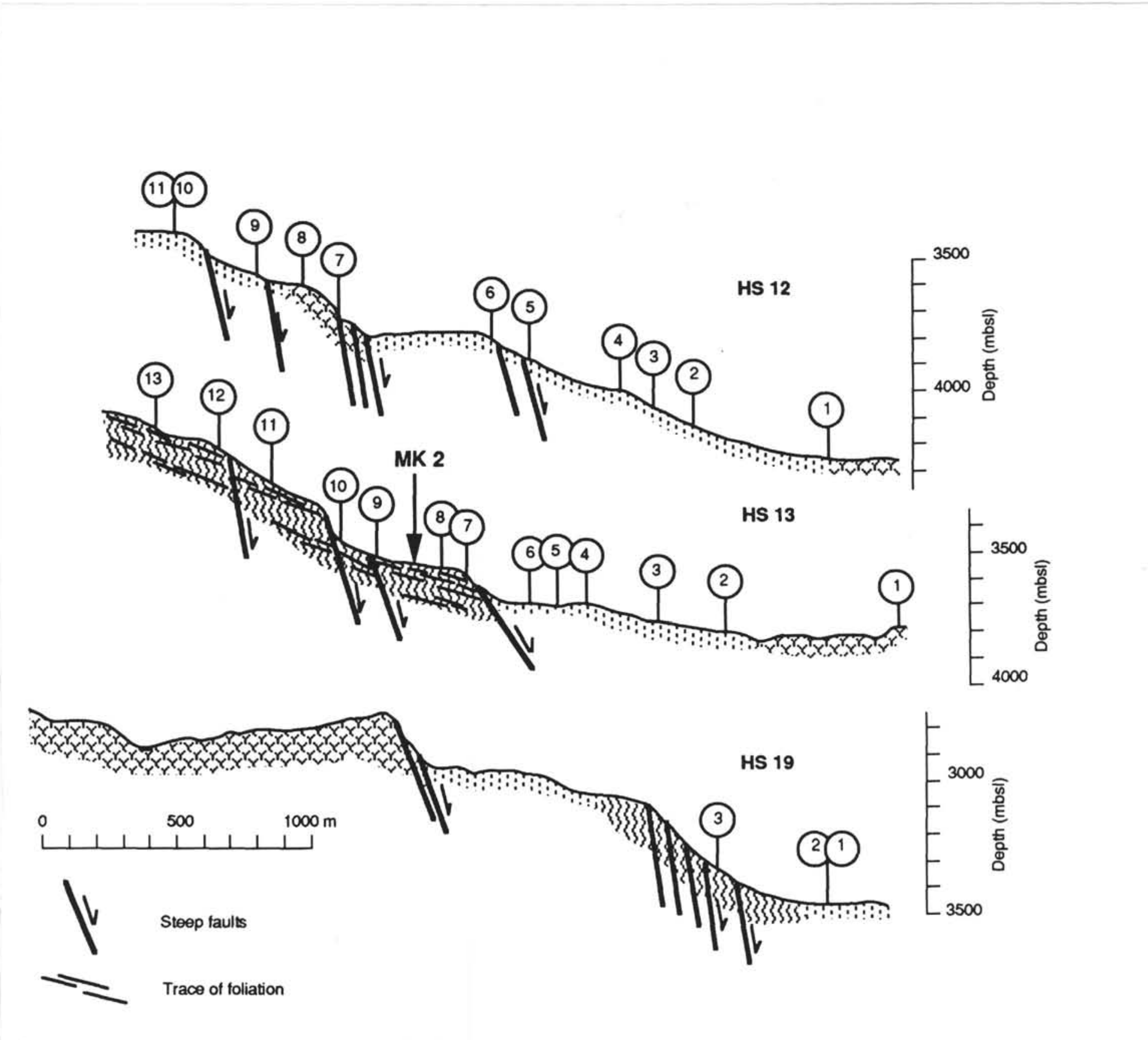
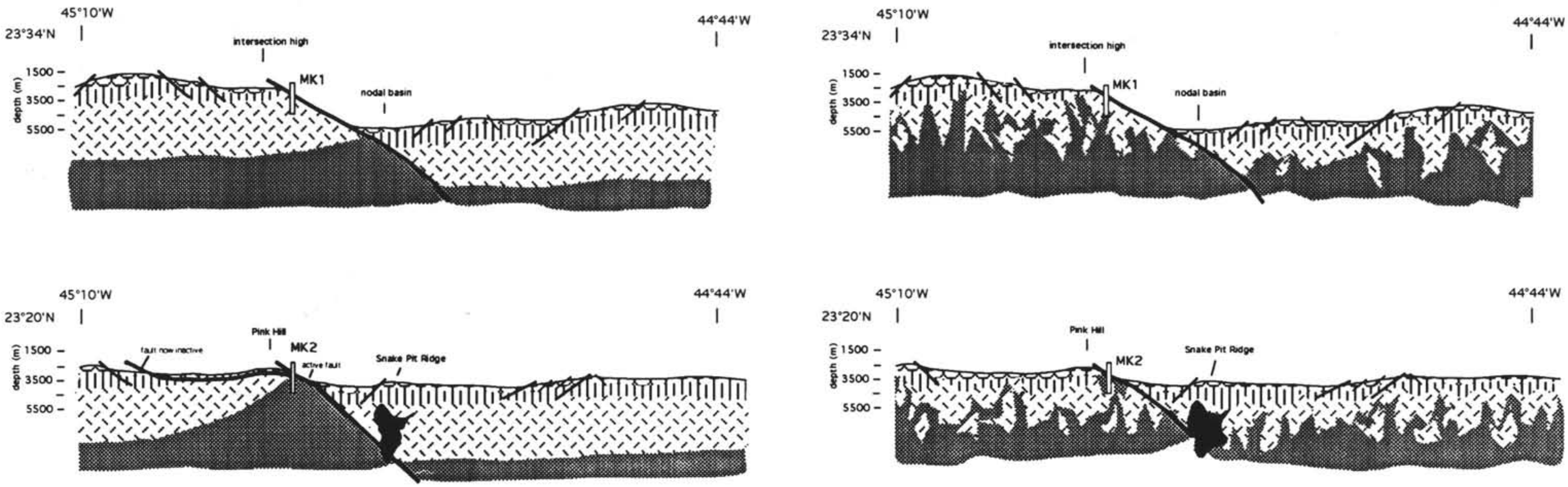
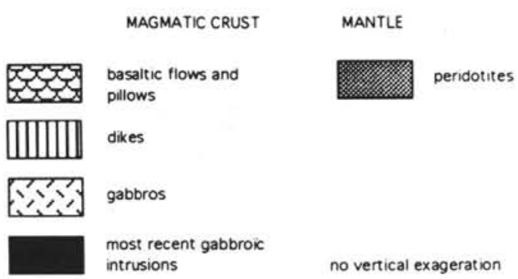


Figure 5. Inferred cross sections from submersible dive tracks (HS, Mével et al., 1991). Circled numbers represent sample stations. Lithology pattern same as in Figure 3.



CASE 1: after a period during which enough magma was provided to form a continuous "normal" thickness magmatic crust, the ridge became magmatically starved. Spreading has therefore been totally accommodated by lithospheric stretching. Gabbros formed during the magma-rich episode, and mantle rocks, have been tectonically uplifted.
Vertical displacement along the western median valley wall master faults is of the order of 3000m at 23°34'N, and of 6000m at 23°20'N. Assuming that these faults have an average 45° dip and accommodate fully the 3cm/yr spreading rate, this corresponds to a 100 000 to 200 000 years-long amagmatic period.

CASE 2: the magma supply to the ridge axis has consistently been too low for a "normal" thickness magmatic crust to be formed. Spreading has therefore been partially accommodated by lithospheric stretching, leading to the emplacement of mantle peridotites into the uppermost axial lithosphere. Gabbros have crystallized in shortlived discontinuous pockets, locally intrusive into tectonically uplifted mantle rocks.
Vertical displacement along the western median valley wall master faults is of the order of 3000m at 23°34'N, and of 1000m at 23°20'N.



Ridge perpendicular cross sections in the MARK area with location of the proposed drill sites :
Cases 1 and 2 are two end members and may be combined. A recent magmatic intrusion is drawn in every case beneath the Snake Pit neovolcanic ridge. Asymmetry of faulting in the median valley is suggested by asymmetrical topography. Marked differences in vertical displacement along the western wall master faults at 23°34'N and 23°20'N (especially in case 1) make it necessary that there should be a "transfer" fault(s) between these two regions.

Figure 6. Alternative models for the crustal structure at proposed sites MK-1 and MK-2.

Site: MK-1
Priority: 1
Position: 23°34'N, 45°02'W
Water Depth: 2500 m
Sediment Thickness: 0 m
Total Penetration:>200-400 m

Objectives: Long section of oceanic gabbros and major detachment fault at a slow-spreading ridge. To characterize the magmatic, tectonic, and metamorphic evolution of the lower crust and constrain the processes of exposing deep crustal rocks in the rift valley wall.

Drilling Program: RCB coring and reentry.

Logging and Downhole Operations: Standard suite + FMS + BHTV + magnetic logging.

Nature of Rock Anticipated: Gabbros.

Site: MK-2
Priority: 1
Position: 23°21'N, 45°01'W
Water Depth: 3500 m
Sediment Thickness: 0 m
Total Penetration:>200-400 m

Objectives: Long section of oceanic upper mantle at a slow-spreading ridge. To characterize the petrological, structural, and physical properties of the upper mantle and constrain the processes responsible for mantle exposures at slow-spreading ridges.

Drilling Program: RCB coring and reentry.

Logging and Downhole Operations: Standard suite + FMS + BHTV + magnetic logging.

Nature of Rock Anticipated: Peridotites, more or less serpentinized.

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