1. INTRODUCTION AND EXPLANATORY NOTES¹

Shipboard Scientific Party²

INTRODUCTION

Leg 118 of the Ocean Drilling Program began in Mauritius on 22 October 1987 and ended there on 14 December 1987. The aim of the leg was to drill one or more holes in the Atlantis II Fracture Zone of the Southwest Indian Ridge. The primary goals were (1) to drill a deep (500 + m) hole in exposed upper mantle peridotite on a median ridge of the fracture zone with the aid of a hard-rock guidebase and (2) to conduct a major program of geophysical logging and other downhole measurements. If a deep hole at this site could not be achieved, other locations on the walls and floor of the fracture zone would be attempted. Secondary objectives were (1) to drill a series of shallow basement holes across the floor of the fracture zone and (2) to sample basement in active and fossil nodal basins.

Scientific Objectives

Fracture zones are ubiquitous features of the oceanic lithosphere, yet little is known regarding their petrology, structure, or tectonic evolution. Recent models for ridge dynamics (e.g., Schouten and Klitgord, 1982) suggest that fracture zones play a major role in segmentation of spreading ridges. These zones are considered to be relatively cold zones that separate stationary spreading-center cells beneath spreading-ridge segments. Crustal magma chambers are believed to lie beneath the spreading cells, and new crust is formed by crystallization along the walls of the magma chambers and by vertical and lateral injection of magma along the spreading ridge. In this model, less magma will reach the edges of the spreading cells (i.e., fracture zones), which leads to thinner crustal sections. Such thinning of oceanic crust in the vicinity of fracture zones was demonstrated by seismic studies along the ridge axes (e.g., Detrick and Purdy, 1980; Fox et al., 1980; Cormier et al., 1984). In some cases, the crustal thickness, particularly beneath nodal basins, may be less than 5% to 10% of normal sections.

Because of these relatively thin crustal sections and the great topographic relief of many fracture zones, mantle and lower crustal rocks are commonly exposed on their floors and walls. The abundance of plutonic rocks in fracture zones appears to correlate closely with the spreading rate of the associated ridge. For example, peridotites compose more than 65% of all material dredged from fracture zones of the very slow-spreading Southwest Indian Ridge, whereas they make up only 10%-15%of dredge hauls from typical fracture zones of slow-spreading ridges and are nearly absent from those of the fast-spreading East Pacific Rise (H. Dick, unpubl. data, 1987). Considering the difficulty of achieving deep penetration in normal ocean crust, fracture-zone drilling provides one of the best possibilities for obtaining *in-situ* samples and stratigraphy of the lower crust and mantle. Abyssal peridotites dredged from spreading ridges and fracture zones are generally regarded as residues of partial melting of mantle material from which mid-ocean ridge tholeiite magmas have been extracted. We expected that drilling in fracture zones would allow us to sample petrologically related basaltic, gabbroic, and ultramafic rocks. Study of such cores should lead to a better understanding of the processes of partial melting in the mantle, melt extraction, and later modification in shallow magma chambers.

Other general objectives of this fracture-zone drilling were as follows:

1. To determine the lateral and vertical variability of rock types on the floor of the fracture zone.

2. To investigate the nature and distribution of deformation in a fracture zone and to determine whether there is a single slip plane, multiple planes, or penetrative slip across the entire width of the feature.

3. To determine the thermal structure of transform-generated crust and to assess the extent of alteration and seawater penetration.

4. To determine the nature and thickness of oceanic crust in the nodal basins where the ridge crests meet the transform fault.

5. To determine the physical properties, magnetism, and seismic velocities of transform-generated crust and, particularly, to document any anisotropy in these properties.

Geologic Background

The Atlantis II Fracture Zone is one of a series of major transform faults that offset the very slow-spreading Southwest Indian Ridge (Figs. 1 and 2). This 210-km-long feature trends roughly north-south and crosses the ridge at approximately 57°E. Spreading on the Southwest Indian Ridge is very slow, on the order of 0.8 cm/yr (Fisher and Sclater, 1983).

The *Conrad* cruise 27-09 (H. Dick, Chief Scientist) conducted a detailed survey of the fracture zone and adjacent ridge segments in October 1986. Sea Beam echo sounding, seismic-reflection profiling, magnetics, and gravity were run along closely spaced tracks (5 km) parallel to the fracture zone, with nearly complete coverage over a 55-km-wide strip. The southern and northern rift valleys of the offset spreading ridge are well defined, with over 2200 m of relief and widths of 22 and 38 km, respectively (Fig. 3). A line of small axial volcanoes marks the southern ridge crest. Well-defined nodal basins, lying on the transform side of today's neovolcanic zone, mark the intersections of the transform and ridge axes.

The transform valley is about 30-40 km wide, as measured between the slope breaks from normal ridge topography to the steep transform walls. The valley floor systematically deepens from about 5 to 6 km and narrows from 14 to 7.5 km between north and south. The spreading rate, as determined from the magnetic anomalies mapped to the east and west of the transform, has been about 10 mm/yr over the last 20 m.y. The magnetic anomalies created since anomaly 5 appear to extend into the transform valley near today's inferred slip zone.

¹ Robinson, P. T., Von Herzen, R. P., et al., 1989. Proc. ODP, Init. Repts., 118: College Station, TX (Ocean Drilling Program).

² Shipboard Scientific Party is as given in the list of participants preceding the contents.



Figure 1. Bathymetric map of the southern Indian Ocean showing the location of sites drilled during Leg 118. Contours in 1000-m intervals.

Relief on the transform valley is on the order of 5800 m, and the walls of the transform valley are remarkably steep (typically, $30^{\circ}-40^{\circ}$), although locally, these walls may be much more subdued, particularly along the western side of the valley. The deepest point is 6480 m in the southern nodal basin, and the shallowest is an uplifted bench on the eastern transverse ridge at 680 m.

A bathymetrically prominent "median tectonic ridge" bisects the northern half of the transform valley and can be followed intermittently down the southern half as well (Fig. 3). In the north, this ridge shoals to 4200 m and has a relief of between 1000 and 1500 m, whereas in the southern half, the relief drops abruptly to only a few hundred meters. In this area, two deep (6.3 km), flat-floored, sedimented basins 2.5 × 24 km and 4×18 km are divided by a relatively low (120-250 m) median tectonic ridge. Seismic-reflection profiles along the axes of these basins and across the median tectonic ridge show stratified sediments that are at least 120 m thick in the centers of the basins and that appear to onlap and possibly drape the intervening ridge. A piston core into each of these basins recovered 3 m of sand and pebbly gravel having clasts up to 2 cm in diameter. Each of the trigger cores contained pelagic ooze, and we believe that before the piston core was washed during recovery, the original sediment consisted of a mixture of pebbles, sand, and pelagic ooze.

Dredging of the walls and floor of the fracture zone during the site survey yielded chiefly ultramafic rock and lesser amounts of gabbro, basalt, and greenstone. In all, 2100 kg of rock was recovered from 35 dredge hauls. Peridotite is the dominant lithology in about one-third of these hauls. Four dredge hauls along the median tectonic ridge recovered serpentinized peridotite, gabbro, metamorphosed basalt, and diabase, which suggests that this feature is the locus of extensive hydrothermal alteration and emplacement of serpentinized mantle peridotite. One dredge haul from the southern end of the median ridge recovered only peridotite. Virtually all of the basaltic rocks recovered have been altered, and this alteration was usually oxidative, with many of the rocks stained a bright red or white. In addition, some unusual breccias cemented by a black tarry-appearing hydrothermal oxide were recovered. These observations suggest that the conditions of hydrothermal alteration along the transform plate boundary may differ substantially from those occurring along ocean ridges.

The *Conrad* survey extended about 85 km into the fracture zone trace north of the transform. Curvilinear bathymetric trends along the east wall reflect the transition from seafloor material created at the ridge crest to that formed in the transform (Fig. 3). Two sedimented basins, 4.5 to 5 km deep and 10 to 20 km wide, were found along this part of the fracture zone floor. In one of these basins, several heat-flow measurements were per-



Figure 2. Atlantis II Fracture Zone within the plate tectonic configuration of the southwest Indian Ocean. Magnetic anomalies after Patriat et al. (unpubl. data, 1987). Dashed lines show past plate boundaries. Box shows area of Figure 3.

formed, and a piston core of pelagic ooze was recovered. The obtained heat-flow values ranged from about 15 to 115 mW/ m^2 , with most values toward the lower end.

EXPLANATORY NOTES

General Information

The following notes are intended to aid interested investigators in understanding the terminology, labeling, and numbering conventions used by the Ocean Drilling Program during Leg 118. In general, Leg 118 followed the precedents set by Legs 106, 109, and 111 for drilling basement holes.

Authorship of Site Reports

The separate sections of the Site Reports, where appropriate, were written by shipboard scientists as follows (authors are listed in alphabetical order in parentheses; no seniority is necessarily implied):

Site Summary (Robinson, Von Herzen)

Background and Scientific Objectives (Robinson, Von Herzen)

Geologic and Tectonic Setting (Robinson, Von Herzen) Operations (Adamson, Von Herzen)

Sedimentology (Swift)

Biostratigraphy (Gard)



Figure 3. Bathymetric map at 500-m contour intervals of the Atlantis II Fracture Zone, Southwest Indian Ridge, showing drill sites. Survey from Conrad cruise 27-09, 1986 (H. Dick, Chief Scientist, with D. Gallo and R. Tyce).

Lithostratigraphy (Bloomer, Meyer) Structure and Deformation (Cannat, Dick) Petrography (Bloomer, Kempton, Meyer, Ozawa) Oxide and Sulfide Mineralogy (Natland) Metamorphism and Alteration (Cannat [Sites 732-734], Hebert, Stakes) Geochemistry (Emmermann, Hertogen) Paleomagnetics (Kikawa, Pariso) Physical Properties (Itturino, Kirby) Thermal Conductivity (Von Herzen) Temperature Measurements (Scott) Schlumberger Logs (Goldberg, Kassenaar) Sonic Logs (Goldberg) Vertical Seismic Profiling (Hoskins, Swift) Magnetometer Logs (Pariso, Scott) Permeability Experiments (Becker) Borehole Televiewer (Goldberg) Summary and Conclusions (Robinson, Von Herzen) Sedimentary Barrel Sheets (Gard, Swift) Igneous Barrel Sheets/Thin-Section Descriptions (Adamson, Bloomer, Cannat, Dick, Emmermann, Hebert, Hertogen, Kempton, Meyer, Natland, Ozawa, Stakes)

Numbering of Sites, Holes, Cores, and Samples

ODP drill sites are numbered consecutively from the first site drilled by the *Glomar Challenger* in 1968. A site number refers to one or more holes drilled while the ship was positioned over one acoustic beacon. Multiple holes may be drilled at a single site by pulling the drill pipe above the seafloor (out of hole), moving the ship some distance from the previous hole, and then drilling another hole.

The first hole drilled at an ODP site is assigned the site number modified by the letter A. Subsequent holes at the same site are designated with the site number modified by letters of the alphabet assigned in chronological sequence of drilling. Note that this differs slightly from the DSDP practice of designating the first hole at a given site by the site number, unmodified, and subsequent holes by the site number modified by letters of the alphabet. It is important, for sampling purposes, to distinguish among holes drilled at a site because recovered sediments or rocks from different holes usually do not come from equivalent positions in the stratigraphic column.

Three varieties of coring system were employed during Leg 118. The Rotary-Coring System (RCB) was the basic system used. Two types of coring motors were also used on the lower end of the drill string. The Positive Displacement Coring Motor (PDCM) permits drilling without rotation of the bottom-hole assembly; core may be recovered by wireline as with the rotary system. The Navidrill permits similar drilling capability, but the motor must be brought to the surface to recover core. Cores recovered with the RCB are designated type "R"; those recovered with the PDCM are designated type "D"; and those recovered with the Navidrill are designated as type "N." Loose cuttings washed out of the upper part of the hole and recovered are designated type "W."

The RCB, which is the standard coring device used since DSDP Leg 1, was used with roller-cone and special hybrid bits designed specifically for drilling the types of rock we expected to encounter during Leg 118. The cored interval is measured in meters below seafloor (mbsf). The depth interval assigned to an individual core begins with the depth below the seafloor at which the coring operation began, and extends to the depth at which the coring operation ended. For example, each coring interval is usually 9.5 m long, which is the nominal length of a core barrel; however, the coring interval may be shorter or longer. "Cored intervals" need not necessarily abut one another, but may be separated by "drilled intervals." In soft sediment, the drill string may be "washed ahead" with the core barrel in place, but not recovering sediment, by pumping water down the drill pipe at high pressure to wash the sediment out of the way of the bit and up the space between the drill pipe and the wall of the hole; however, if thin layers of hard rock are present, it is possible to get "spotty" sampling of these resistant layers within the washed interval, and thus have a cored interval greater than 9.5 m. In drilling hard rock, a center bit may replace the core barrel if it is necessary to drill without core recovery.

Cores taken from a hole are numbered serially from the top of the hole downward. Core numbers and their associated cored intervals in meters below seafloor usually are unique in a given hole; however, this may not be true if an interval must be cored twice, due to caving of cuttings or other hole problems. Nominally, a completely recovered core consists of 9.3 m of rock or sediment contained in a plastic liner (6.6 cm internal diameter) plus about 0.2 m (without a plastic liner) in the core catcher. The core catcher is a device at the bottom of the core barrel that prevents the core from sliding out when the barrel is being retrieved from the hole.

A recovered core is divided into 1.5-m sections, which are numbered serially from the top (Fig. 4). When complete recovery is obtained, the sections are numbered from 1 through 7,



Figure 4. Diagram showing procedure used for cutting and labeling core sections.

with the last section possibly being shorter than 1.5 m (rarely, an unusually long core may require more than seven sections). When less than complete recovery is obtained, there will be as many sections as needed to accommodate the length of the core recovered; for example, 4 m of core would be divided into two 1.5-m sections and a 1-m section. If cores are fragmented (recovery less than 100%), sections are numbered serially and intervening sections are noted as void, whether or not shipboard scientists believe that the fragments were contiguous in-situ. Material recovered from the core catcher is placed below the last section when the core is described and then labeled core catcher (CC); in sedimentary cores, it is treated as a separate section. Scientists completing visual core descriptions describe each section as a physical unit; one or more lithologic boundaries may occur anywhere within this physical unit and are not considered when core is assigned sections.

A recovered basalt, gabbro, or peridotite core also is cut into 1.5-m sections, which are numbered serially; however, each piece of rock is then assigned a number (fragments of a single piece are assigned a single number, with individual fragments being identified alphabetically). The core-catcher sample is placed at the bottom of the last section and is treated as part of the last section, rather than separately. Scientists completing visual core descriptions describe each lithologic unit, noting core and section boundaries only as physical reference points.

When, as is usually the case, the recovered core is shorter than the cored interval, the top of the core is equated with the top of the cored interval by convention, to achieve consistency in handling analytical data derived from the cores. Samples removed from the cores are designated by distance measured in centimeters from the top of the section to the top and bottom of each sample removed from that section. In curated hard-rock sections, sturdy plastic spacers are placed between pieces that did not fit together to protect them from damage in transit and in storage; therefore, the centimeter interval noted for a hardrock sample has no direct relationship to that sample's depth within the cored interval, but is only a physical reference to the sample's location within the curated core.

A complete identification number for a sample consists of the following information: Leg, Site, Hole, Core Number, Core Type, Section Number, Piece Number (for hard rock), and Interval in centimeters measured from the top of section. For example, a sample identification of "118-732A-5R-3, (Piece 5B, 15-17 cm)" would be interpreted as representing a sample removed from the interval between 15 and 17 cm below the top of Section 3, Core 5 (R designates that this core was taken with the RCB) of Hole 732A during Leg 118, and that this interval fell within Piece 5, Fragment B, of that section.

Basement Description Conventions

Visual Core Descriptions

Representation of igneous rocks in barrel sheets is too compressed to provide adequate information for potential sampling. Consequently, visual core description forms, modified from those used aboard ship, are used for more complete graphic representation. Copies of the visual core description forms, as well as other prime data collected during Leg 118, are available on microfilm at all three ODP repositories.

Core Curation and Shipboard Sampling

Igneous rocks are split into archive and working halves using a rock saw with a diamond blade. A petrologist decides on the orientation of each cut so as to preserve unique features and/or to expose important structures. The archive half is described, and samples for shipboard and shore-based analyses are removed from the working half. On a typical igneous core description form (Figs. 5 and 6), the left column, entitled "Graphic Representation," is a visual representation of the archive half. A horizontal line across the entire width of the column denotes plastic spacers glued between rock pieces inside the liner. Each piece is numbered sequentially from the top of each section, beginning with number 1. Pieces are labeled on the rounded, unsawn surface. Pieces that can be fitted together (reassembled like a jigsaw puzzle) are assigned the same number, but are lettered consecutively (e.g., 1A, 1B, 1C, etc.). Spacers are placed between pieces of different numbers, but not between those having different letters and the same number. Presence of a spacer may represent a substantial interval of no recovery. Whenever the original unsplit piece was sufficiently large that it could not have rotated top to bottom about a horizontal axis in the liner, an arrow was added to the label pointing to the top of the section. Care was taken to ensure that orientation was not lost during splitting and labeling. Oriented pieces are indicated on the description forms by upward-pointing arrows in the "Orientation" column to the right of the piece. Because pieces are free to turn about a vertical axis during drilling, azimuthal orientation is not possible.

Immediately after the core is split and before the rock is dry, sampling is conducted for shipboard physical properties, magnetics, X-ray fluorescence (XRF), and thin-section studies. Minicores are taken from the working half and stored in seawater for measuring physical properties and magnetics. These minicores are later subdivided for XRF analysis and thin sectioning, which ensures that as many measurements as possible are made on the same pieces of rock. At least one minicore is taken from each lithologic unit when recovery permits. On the visual core description forms, the type of measurement and approximate sample interval are indicated in the column headed "Shipboard Studies," using the following notation:



Figure 5. Example of a completed igneous core description (barrel sheet) form for fine- and medium-grained extrusives and dikes.

- XRD = X-ray diffraction analysis
- XRF = X-ray fluorescence analysis
- PM = magnetic measurements
- TS = thin section
- PP = physical-properties measurements
- TC = thermal-conductivity measurements
- SEM = scanning-electron-microscope image

Thermal conductivity was measured using pieces of the working half core and required that the sawn surface be polished using carborundum grits.

Lithologic Description

Lithologic descriptions were prepared in a systematic way, ensuring that all important features (e.g., nature of contacts,



Figure 6. Example of a completed igneous core description (barrel sheet) form for coarse-grained plutonics.

distribution and percentage of phenocrysts, groundmass texture, color, vesicle content, alteration, etc.) were noted for each unit described.

Macroscopic Core Descriptions

Igneous rocks are classified mainly on the basis of mineralogy and texture. When describing the cores, a checklist of macroscopic features is followed to ensure consistent and complete descriptions. Two such checklists, one for extrusive rocks and dikes and one for plutonic rocks, are presented below.

Two forms are used to describe hard rocks: one for macroscopic description of cores and one for the description of thin sections. The data on these forms go directly into a computerized database that is accessible to the entire scientific community.

Checklist Used for Fine- and Medium-Grained Extrusives and Dikes

Enter leg, site, hole, core number and type, and section information. Draw the graphic representation of the core; number the rock pieces; enter orientation arrows where appropriate; and record positions of shipboard samples (see Fig. 5).

Subdivide the core into lithologic units, using the criteria of changing grain size, occurrence of glassy margins, and changes in petrographic type and phenocryst abundances.

For each lithologic unit, answer the following:

1. Enter UNIT number (consecutive downhole), including piece numbers of top and bottom pieces in unit.

2. ROCK NAME (to be filled in last).

3. CONTACT TYPE (e.g., intrusive; discordant; depositional, etc.). Note the presence of glass and its alteration products (in %), give the azimuth and dip of the contact.

4. PHENOCRYSTS. Determine if homogeneous or heterogeneous distribution; if heterogeneous distribution, note variations. For each phenocryst phase determine:

a. Abundance (%).

b. Average size in millimeters.

c. Shape.

d. Percentage degree of alteration and replacing phases and their relationships.

e. Further comments.

f. Fill in (2.) ROCK NAME (see following text for naming basalts).

5. GROUNDMASS texture. Glassy, microcrystalline, finegrained (<1 mm), medium-grained (1–5 mm), or coarse-grained (>5 mm). Note the relative grain size changes within the unit (e.g., coarsening from Piece 1 to Piece 5).

6. COLOR (dry).

7. VESICLES. Give percentage, size, shape, fillings and their relationships (include percentage of vesicles that are filled by alteration minerals), and distribution. Miaroles: give percentage, size, shape, and distribution.

8. STRUCTURE. Massive, pillow lava, thin flow, breccia, etc., and comments.

9. ALTERATION. Fresh (<2% alteration), slightly (2%-10%), moderately (10%-40%), highly (40%-80%), very highly (80%-95%), or completely (95%-100%) altered. Type, form, and distribution of alteration.

10. VEINS/FRACTURES. Percentage present, width, orientation, fillings and relationships, halos.

Basalts are termed aphyric, sparsely phyric, moderately phyric, or highly phyric, depending upon the proportion of phenocrysts visible with the hand lens or binocular microscope (approximately 10X). Basalts are called aphyric if phenocrysts clearly amount to less than 1% of the rock, sparsely phyric if phenocryst content ranges from 1%-2%, moderately phyric at 2%-

10%, and highly phyric if phenocrysts amount to more than 10% of the rock. Basalts are further classified by phenocryst type (e.g., a moderately plagioclase-olivine phyric basalt contains 2%-10% phenocrysts, most of them plagioclase but some olivine).

Checklist Used for Coarse-Grained Plutonics

Enter leg, site, hole, core number and type, and section information. Draw graphic representation of the core; number the rock pieces; enter orientation arrows where appropriate; and record positions of shipboard samples (see Fig. 6).

Subdivide the core into lithologic units. For each lithologic unit or section, whichever is the smaller, answer the following:

1. Enter UNIT number (consecutive downhole), including piece numbers of top and bottom pieces in unit.

2. ROCK NAME (to be filled in last; see Figs. 7-10).

3. COLOR (dry).

4. LAYERING.

a. If massive, nonlayered, or isotropic, skip to 5 on this checklist.

b. Average thickness of different layer types.

c. Azimuth and dip of layering.

d. Types of layering (modal, phase, grain size, graded, rhythmic, cyclic).

e. Sequence of layers and relative abundance.

f. Layer contacts (sharp, abrupt, smooth, gradational, undulating, rough).

5. DEFORMATION. If rock is deformed, note:

a. Nature and inclination of faults, folds, shear, and/or brecciated zones.

b. Nature and inclination of foliations and lineations.

c. Features that define the foliation or lineation.

d. Grain size variations due to granulation and/or recrystallization.

6. PRIMARY MINERALOGY. Includes intergranular and granular phases. Note for each phase, in order of modal abundance:

a. Modal percentage.

b. Range of crystal sizes.

c. Crystal shapes.

d. Preferred orientations.

e. Percentage replacement with what replacement mineral.

7. SECONDARY MINERALOGY

a. Total percentage secondary phases.

b. Textures of secondary phases.

c. Vein material, note total percentage vein material, average vein thickness, types and textures of filling.

8. Note ADDITIONAL FEATURES.

Whenever possible, peridotites are classified according to their primary mineralogy (Figs. 9 and 10). If no primary minerals can be identified because of extensive serpentinization, the serpentinized peridotites are called serpentinites. In the case of partially serpentinized samples, the term "serpentinized" is used to modify the rock name (e.g., "serpentinized harzburgite"). In some serpentinites, serpentine minerals closely pseudomorph primary minerals (e.g., lizardite replacing orthopyroxene in bastite). The primary mineralogy of these samples is estimated from the abundances of various pseudomorph types.

Describers on Leg 118 operated in two teams (shifts), each consisting of four petrologists. Interteam meetings were held frequently to ensure that descriptions were prepared consistently during both shifts and that all petrologists agreed upon the division of recovered core into lithologic units.

Once the lithologic description had been agreed upon by the shipboard scientific party, the final core description was assem-



Figure 7. Classification of gabbroic rocks composed of plagioclase, pyroxene, and olivine (after Streckeisen, 1974).



Figure 8. Classification of gabbroic rocks containing hornblende (after Streckeisen, 1974).

bled on an igneous barrel sheet (Figs. 5 and 6). These barrel sheets are published in this volume.

Thin-Section Description

Thin-section billets of basement rocks recovered during Leg 118 were examined (1) to help define unit boundaries indicated by hand-specimen core descriptions, (2) to confirm the identity of the petrographic groups represented in the cores, and (3) to define their secondary alteration mineralogy. At least one thin section was made of each unit identified in hand specimen where sufficient rock was available.

The rationale for the assignment of unit boundaries, based on modal mineralogy and chemistry, is presented in the "Lithostratigraphy" section, Site 735 chapter (this volume). Percentages of individual mineral phases were estimated visually and are reported on the detailed thin-section description sheets (available on microfilm at the repositories). Modal abundances determined by point counting are reported in the "Petrography" section of each site chapter. For the thin-section modal estimates, we decided to include porphyroclasts with primary minerals and neoblasts with secondary minerals. The terms sparsely, moderately, and highly abundant are used in the same manner as for hand-specimen descriptions. In cases where discrepancies arise over the composition and abundance of mineral phases between hand-specimen and thin-section analyses, thin-section discriptions are used in the "Lithostratigraphy" section, Site 735 chapter (this volume).

Basement Alteration

Alteration effects from seawater interaction with igneous rocks were described in hand specimens and thin sections. The width and color of any alteration halos around fractures or vugs were noted in the core descriptions. The identities of secondary minerals filling fractures, vesicles, and replacing igneous phases were estimated in core descriptions and refined in thin sections, which were augmented in some cases by X-ray diffraction (XRD) and later electron microprobe analyses performed using shipboard thin sections. The total percentages of the various secondary minerals were also estimated from thin-section examinations.

X-Ray Diffraction Analyses

A Phillips ADP 3520 X-ray diffractometer was used for the XRD analyses of unknown secondary mineral phases. Instrument conditions were as follows:

CuK α radiation with nickel filter 40 kV 35 mA Goniometer scan from 2° to 70° 2 θ Step size 0.02° Count time 1 s

Since only bulk mineralogy was required, the samples were ground using the Spex 8000 Mixer Mill or, when there was very little sample material, using the agate mortar and pestle. The material was then pressed into the sample holders for X-ray analysis.

Resulting diffractograms were interpreted with the help of a computerized search and match routine using Joint Committee on Powder Diffraction Standards (JCPDS) powder files and tabulated data for clay minerals in Brindley and Brown (1980).

X-Ray Fluorescence Analyses

During Leg 118, the completely automated, wavelength-dispersive XRF system ARL 8420, available on board the *JOIDES Resolution*, was used to determine the major oxide compositions and trace element abundances of whole-rock samples.

Analyses of the major oxides were performed on lithium borate glass disks doped with lanthanum as a "heavy absorber." The technique is basically that developed by Norrish and Hutton (1969), with some minor modifications: 500 mg of rock powder that had been ignited for 2 hr at about 1030°C was mixed with 6.0 g of dry flux consisting of 80% lithium tetraborate and 20% La_2O_3 . This mixture was then melted at 1150°C in a platinum-gold crucible for about 10 minutes and poured into a platinum-gold mold using a Claisse Fluxer. The 12:1 fluxto-sample ratio chosen was found sufficient to eliminate matrix effects over a certain range of rock compositions in such a manner that the following linear relationship between X-ray intensity and concentration holds:



Figure 9. Classification of ultramafic rocks that contain hornblende (after Streckeisen, 1974).



Figure 10. Classification of ultramafic rocks composed of olivine, orthopyroxene, and clinopyroxene (after Streckeisen, 1974).

$$C_i = (I_i \times m_i) - b_i$$

where

 C_i = concentration of oxide *i* (wt%),

 I_i = net peak X-ray intensity of oxide *i*,

 m_i = slope of calibration curve for oxide *i* (wt%/cps),

 b_i = apparent background concentration for oxide *i* (wt%).

The slope m_i was calculated from a calibration curve derived from the measurement of a set of well-analyzed "standards" (reference rocks). The background b_i was determined either on blanks or derived mathematically from the calibration curves.

Because we anticipated recovery of two chemically distinct rock groups, namely basaltic/gabbroic and ultramafic, whose matrix differences are too large to be completely overcome by the heavy absorber/dilution method applied, we set up separate calibration curves for each of these groups. For calibration of basaltic rocks, the reference samples BHVO, AII-92, K 1919, NBS 688, DR-N, AGV, and GH were used. The calibration curves for ultramafic samples are based on the reference rocks PCC, DTS, UB-N, JP-1, NIM-D, and MUN (from Munster Univ., Federal Republic of Germany), and on BR and BHVO, where appropriate.

As a result of the sample preparation procedure chosen, the actual chemical composition of these rocks had to be recalculated to a water-free and CO_2 -free basis, with all iron as Fe_2O_3 and normalized to sum = 100%. When summing up, we also included the nickel and chromium contents (as oxides) because these elements constitute about 0.5 wt% of the ultramafic rocks. Table 1 presents the values used for calibration of ultramafic rocks. The silicon, magnesium, calcium, and aluminum calibration curves for ultramafic rocks are shown in Figures 11 and 12.

The XRF working conditions used are listed in Table 2. Systematic errors due to short-term or long-term fluctuations in X-

Table 1. Chemical composition of reference rocks used for calibration lines of ultramafic rocks.

	UB-N	JP-1	NIM-D	MUN	DTS	PCC
wt%						
SiO ₂	44.78	43.48	38.56	41.90	40.50	43.85
TiO ₂	0.12	0.01	0.02	0.02	0.01	0.02
Al ₂ Õ ₃	3.29	0.64	0.30	0.40	0.24	0.77
Fe ₂ O ₃	9.47	8.55	16.80	7.37	8.64	8.74
MnO	0.14	0.13	0.22	0.10	0.11	0.12
MgO	39.98	45.84	43.08	49.48	49.80	45.19
CaO	1.36	0.57	0.28	0.05	0.15	0.53
Na ₂ O	0.11	0.02	0.04	0.05	0.0	0.01
K ₂ Õ	_	-	_	—	_	_
P_2O_5	-	-	-	—		
ppm						
Cr	2612	3046	2872	2340	4000	2920
Ni	2271	2523	2030	2430	2269	2448
Zn	92	30	90	36	45	36
Zr	8	6	20	15	<10	<7
Y	11	1	nd	2	< 0.5	nd
Sr	10	<1	3	5	<1	<1
Rb	6	<1	nd	1	<1	<1

MUN = periodite reference rock, Univ. of Munster, Federal Republic of Germany.



Figure 11. XRF calibration lines of silicon (A) and magnesium (B) in ultramafic rocks. Calibration line shown is the least-squares fit. See Table 1 for the composition of the reference rocks.



Figure 12. XRF calibration lines of calcium (A) and aluminum (B) in ultramafic rocks. Calibration line shown is the least-squares fit. See Table 1 for the composition of the reference rocks.

ray tube intensity were corrected by normalizing the measured intensities of the samples to that of a standard that was always run together with a set of six samples. To reduce preparation errors, especially weighing errors, two glass disks were prepared for each sample. Standard deviations (in rel %) and detection limits (in wt%) that apply to rocks of basaltic composition are listed in Table 3.

Trace-element determinations were performed on pressedpowder pellets prepared by pressing (with 7 tons of pressure) a mixture of 5.000 g of dry rock powder (dried at 110° C for >2 hr) and 30 drops of polyvinylalcohol binder into an aluminium cap. A modified Compton scattering technique based on the intensity of the rhodium Compton peak was used for matrix absorption corrections (Reynolds, 1967). A comprehensive description of the analytical procedure and the program developed is given in the "Introduction and Explanatory Notes," *Proc. ODP*, *Init. Repts.*, 111 (Shipboard Scientific Party, 1988a) and need not be repeated here as we adopted this method without modifications.

Description of Sediments and Sedimentary Rocks

Introduction

The sediment classification system used for Leg 118 is a modified version of that devised by the former JOIDES Panel on Sedimentary Petrology and Physical Properties and adopted

Table 2. X-ray fluorescence working conditions.

Element	Detector	Collimator	Crystal	20	CT (s)	
Fe	FC	F	LiF	57.52	40	
Mn	KrC	F	LiF	62.98	40	
Ti	FC	F	LiF	86.14	40	
Ca	FC	С	LiF	113.16	40	
K	FC	F	LiF	136.65	40	
Si	FC	С	PET	109.25	40	
AI	FC	C	PET	145.27	100	
Р	FC	C	Ge	140.94	200	
Mg	FC	C	TIAP	44.87	200	
Na	FC	С	T1AP	54.71	200	
Nb	SC	F	LiF	21.37	200	
Zr	SC	F	LiF	21.53	100	
Y	SC	F	LiF	23.78	100	
Sr	SC	F	LiF	25.13	100	
Rb	SC	F	LiF	26.60	100	
Zn	SC	F	LiF	41.79	60	
Cu	SC	F	LiF	45.02	60	
Ni	SC	C	LiF	48.67	60	
Cr	FC	F	LiF	69.35	60	
V	FC	F	LiF*	122.84	60	

All elements measured on K-alpha line, using a rhodium x-ray tube operated at 60 kV and 50 mA: SC = NaI scintillation counter; FC = flow proportional counter (P10 gas); KrC = sealed krypton gas counter; Collimator: F = fine; C = coarse; LiF = LiF (200); $LiF^* = LiF$ (220); CT = counting time.

for use by the JOIDES Planning Committee in March 1974. This classification scheme was designed to adhere closely to ODP standards and to describe the nature of the sediments recovered during Leg 118. The classification is descriptive (based on sediment properties) rather than generic, and often tends to make the divisions between sedimentary categories artificial. Sediment and rock names were defined solely on the basis of composition and texture. These data were primarily determined on board ship by (1) microscopic observation of smear slides and thin sections, (2) visual observation of cores using a hand lens and binocular microscope, and (3) unaided visual observation. Calcium carbonate content was estimated in smear slides. Other geologic features determined were color, sedimentary structures, and firmness.

Sediment Classification Parameters

Induration

The criteria used to determine the induration of calcareous deposits found during Leg 118 are those of Gealy et al. (1971). For all other deposits, subjective estimates of induration are based on the behavior of the deposits during the core-cutting procedure. There are three classes of calcareous sediments: (1) soft-oozes with little strength that are readily deformed under the finger or the broad blade of a spatula; (2) firm-chalks that are partly indurated oozes or friable limestones, readily deformed under the fingernail or the edge of a spatula blade; and (3) hard-restricted to limestones as a term for cemented rocks. Noncalcareous sediments are divided into two classes of induration: (1) if the material is at such a low state of induration as to allow the core to be split with a wire cutter, the sediment name only is used (e.g., silty clay, mud); and (2) if the core must be cut on the bandsaw or diamond saw, the suffix "stone" is used (e.g., silty claystone, mudstone, or shale, if fissile).

Drilling Disturbance

Recovered rocks and sediments may be slightly to extremely disturbed from coring and drilling. Five types of disturbance categories were used (Fig. 13) for consideration when complet-

Table 3. Analytical errors and detection limits of oxide and trace elements.

	Analytical error (rel%)	Detection limit (wt% or ppm)
SiO ₂	0.30	0.03
TiO ₂	0.37	0.01
Al2O2	0.40	0.01
Fe2O1	0.20	0.01
MnO	0.10	0.005
MgO	0.60	0.01
CaO	0.30	0.005
Na ₂ O	3.8	0.03
K ₂ Õ	0.10	0.01
P205	0.10	0.01
Nb	0.2	0.5
Zr	0.5	0.6
Y	1.0	0.6
Sr	0.3	0.6
Rb	3.6	0.6
Zn	1.0	1.0
Cu	1.5	1.2
Ni	0.6	1.2
Cr	1.3	2.0
v	2.0	3.0

ing the core description barrel sheets under the column entitled "Drilling Disturbance." The disturbance categories are defined as follows.

1. Slightly deformed, bedding contacts are slightly bent.

2. Moderately deformed, bedding contacts have undergone extreme bowing.

3. Very deformed, bedding is completely disturbed, sometimes showing symmetrical diapirlike structure.

 Soupy, water-saturated intervals that have lost all aspects of original bedding.

5. Breccia, firm sediments or rocks fractured by drilling.

Lithified sediments were not recovered during Leg 118.

Sedimentary Structures

In soft and even in some harder sedimentary cores, it is sometimes difficult to distinguish between natural structures and structures created by coring. However, where such structures were observed, they are entered into the column entitled "Sedimentary Structures" on the barrel sheets (Fig. 14). The symbols for sedimentary structures used during Leg 118 are given in Figure 13.

Color

The color of recovered material from Leg 118 was determined according to standard Munsell and Geological Society of America Rock Color charts while the cores were still wet and was recorded on the visual core description forms.

Lithology

Lithologies are shown in the core description forms by one or more of the symbols shown in Figure 15. These lithologies were determined by the relative abundances of calcium carbonate, biogenic opal, and authigenic and terrigenous detrital components and by the degree of induration. The percentage of abundances of these components was routinely determined from smear slides. Relative proportions of lithologies are simplified on the barrel sheets; thus, one should refer to the sediment descriptions on the visual core description forms (available through the ODP Database Group) and smear-slide data for more detailed lithologic information. The locations of all smear-slide samples taken for analysis were indicated in the column marked



Figure 13. Sedimentary deformation and structure symbol codes.

"Samples" on the barrel sheets, and the results of the analyses are listed below the core descriptions.

Pelagic Clay

Sedimentary Description Conventions

A summary of the lithologic classification scheme adopted by ODP at the time of Leg 118 is shown in Figure 16. The major component of a sediment type is always listed last in the sediment name, whereas qualifiers are used as long as the components are present with greater than 10% abundance in smear slides. The least abundant qualifier is always listed first. As many qualifiers as necessary to adequately describe the sediments were used. Common qualifiers used include clay, radiolarian, diatom, sponge, foraminifer, and calcareous nannofossil. Pelagic clay is principally composed of authigenic pelagic material that accumulated at very slow rates. The boundary of pelagic clay with terrigenous sediments is where authigenic components (iron-manganese micronodules, zeolites), fish debris, etc., become common (more than 10% in smear slides). The boundary of pelagic clay with siliceous biogenic sediments is the point at which there is less than 30% identifiable siliceous remains. No pelagic clay was recovered during Leg 118.

Siliceous Biogenic Sediments

Siliceous biogenic sediments are distinguished from pelagic clay because they contain common (more than 30% in smear

SITE	HOLE CORE						RE	CORED INTERVAL														
5	BIO	BIOSTRAT. ZONE/ FOSSIL CHARACTER					ES							T					88.	07		
TIME-ROCK UN	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS		PALEOMAGNETICS	PHYS. PROPERI CHEMISTRY		SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTUR	SED. STRUCTURE	SAMPLES	LITHOLOGIC DESCRIPTION							
									1	0.5												
PG	PRESE G = Go M = Mo		SERV Good Moder		TIO	101	Ž	N	N	Z	1				2			PF	PP	Physical properties whole = round sample		
P	P = Poor			ر (Fig. 15) مرد (Fig. 15) م		OG	Organic geochemistry sample															
3							rosity and density	n (%) OC = Organi	4		iic lithology symbols	symbols in Figure 1:	symbols in Figure 13		Smear slide summary (%): Section, depth (cm) M = Minor lithology, D = Dominant lithology							
ABUNDANC A = Abunda C = Commo F = Frequen R = Rare B = Barren		dant mon lent	t 1		Pc) = Inorganic carbo	5		See key to graph	See key to :		IW	— Interstitial water sample									
												IC	6					• G	— Smear slide — Headspace gas sample			
									7 CC													

Figure 14. Barrel sheet form for sediments/sedimentary rocks.

Nanno - Foram or

CB3

Nanno - Foram or

Foram - Nanno Chalk

+

Foram - Nanno Ooze

Calcareous Ooze

-

10⁰

CR/

Calcareous Chalk

PELAGIC SEDIMENTS

Calcareous Biogenic Sediments

1

1 1

1

1

Nannofossil Ooze

1

1

PELAGIC BIOGENIC CALCAREOUS - SOFT

т.

Foraminiferal Ooze

TTT-

CB2

Т

Siliceous Biogenic Sediments PELAGIC SILICEOUS BIOGENIC - SOFT



PELAGIC SILICEOUS BIOGENIC - HARD



SE

20 -0-0-0 CB CB6 CB7 TRANSITIONAL BIOGENIC CALCAREOUS SEDIMENTS Calcareous Component > 50% Calcareous Component < 50% Terrigenous Symbol Calcareous Modifier Symbo

TERRIGENOUS SEDIMENTS



Silty Sand/

Sandy Silt

Sandy Mud/ Sandy Mudstone

_	ey.	SIIT	_
1111			11
hh	14	ηı	14

SR5 EVAPORITES Halite



SR6

P= Pyrite B= Barite Z= Zeolite

drawn circle with symbol (others may be designated)



Sandy Clay/

Clayey Sand

Figure 15. Graphic symbols corresponding to the barrel sheets for sediments and sedimentary rocks.



Figure 16. Summary chart of lithologic classification for oceanic sediments used during Leg 118.

slides) siliceous microfossils. Siliceous biogenic sediments are distinguished from the calcareous category by a calcium carbonate content of less than 30%. There are two categories of siliceous biogenic sediments: (1) pelagic siliceous biogenic sediments that contain greater than 30% siliceous microfossils and less than 30% silt and clay, and (2) transitional siliceous biogenic sediments that contain between 10% and 70% siliceous microfossils and greater than 30% silt and clay.

When only one siliceous component exceeds 10%, this component is used to describe the major category of the sediment and is listed last in the sediment name. If more than one siliceous component is in excess of 10%, these qualifiers are listed in order of increasing abundance. If no single siliceous component exceeds 10% but all together total more than 30% (and are present in greater quantities than calcium carbonate), the qualifier siliceous is used.

When pelagic siliceous biogenic sediments are soft, they are called oozes, such as radiolarian or diatom ooze. When sediments of this type are hard, they are called radiolarite or diatomite, depending on the dominant component. If the major component is unspecified, the sediments are called siliceous ooze, porcellanite, or chert, depending on their hardness.

In the transitional biogenic siliceous category, silt and clay make up more than 30% of the sediment, whereas siliceous skeletons make up between 10% and 70% of the sediment. These sediments are called siliceous muds, siliceous mudstones, or muddy siliceous oozes. Where the siliceous component exceeds 50%, the term muddy is used as a qualifier.

Calcareous Biogenic Sediment

Calcareous biogenic sediment is distinguished by a biogenic calcium carbonate content in excess of 30%. There are two

classes: (1) pelagic calcareous biogenic sediments and (2) transitional calcareous biogenic sediments, which were not encountered during Leg 118. Soft pelagic biogenic calcareous sediments are called oozes, whereas sediments of this category that are firm are called chalk. Transitional biogenic calcareous sediments are those that contain more than 30% silt and clay.

Qualifiers are used when components are present in excess of 10%. If no calcareous component is present with more than 10% but the sum of all calcareous components exceeds 30% (and is greater than the biogenic silica component), the qualifier calcareous is used to define the major component of the sediment. If no siliceous component exceeds 10% but the total of all siliceous components exceeds 10%, then the qualifier siliceous is used.

Terrigenous Sediments

Terrigenous sediments are divided into textural groups on the basis of the relative proportions of three grain-size constituents, i.e., clay, silt, and sand. The size limits for these constituents are those defined by Wentworth (1922) (Fig. 17). No terrigenous sediments were recovered during Leg 118.

Volcanogenic Sediments

Volcanogenic rocks are described according to the textural and compositional scheme of Wentworth and Williams (1932). The textural groups are (1) volcanic breccia (greater than 32 mm in size), (2) volcanic lapilli (4–32 mm in size), and (3) volcanic ash, tuff if indurated (less than 4 mm in size), and (3) volcanic canic sediments apply the same way as in terrigenous sediments, where possible noting the dominant composition of the grains. During Leg 118, the category "volcanic breccia" was extended to include sand and gravel of which more than 90% of the grains were of volcanic origin.

MILLIMETERS		μm	PHI (Ø)	WENTWORTH SIZE CLAS	s
			-20		
	4096		-12	Boulder (-8 to -12 Ø)	
3	1024		-10		
	256		- 8	Cobble / 6 to 9 M	_
	64 —		-6	CODDIE (-0 10 -6 07	ν.
	16		-4	Pebble (-2 to -6 Ø)	RA
	4		-2		0
	3.36		-1.75		
	2.83		-1.5	Granule	
	2.38		-1.25		
	2.00	_	-1.0		i i
	1.68		-0.75		
	1.41		-0,5	Very coarse sand	
(L. 1	1.19		-0.25		
0	1.00		- 0.0		
	0.84		0.25		
	0.71		0.5	Coarse sand	
	0.59		0.75		
1/2 -	- 0.50	- 500	1.0 -		
	0.42	420	1.25		
	0.35	350	1.5	Medium sand	ND
	0.30	300	1.75		SA
1/4	-0.25	- 250	2.0 -		
	0.210	210	2.25		
	0.177	177	2.5	Fine sand	
	0.149	149	2.75		
1/8 -	-0.125-	125	3.0 -		
	0,105	105	3.25		
	0.088	88	3.5	Very fine sand	
	0.074	74	3.75		
1/16-	0.0625	- 63	4.0 -		
	0.053	53	4.25		
	0.044	44	4.5	Coarse silt	
	0.037	37	4.75		
1/32	0.031	31	5.0 -		
1/64	0.0156	15.6	6.0	Medium silt	
1/128	0.0078	7.8	7.0	Very fine silt	۵
1/256 -	0.0039	3.9	8.0 -	vory mic site	MU
	0.0020	2.0	9.0		-
	0.00098	0.98	10.0	Clay	
	0.00049	0.49	11.0	22	
	0.00024	0.24	12.0		
	0.00012	0.12	13.0		
	0.00006	0.06	14.0		

Figure 17. Wentworth size scale (1922).

BIOSTRATIGRAPHY

Calcareous Nannofossils

The calcareous nannofossil zonation of Martini (1971) was used during Leg 118. The latest Miocene through Pleistocene marker species used in the zonal scheme and their assigned age estimates are shown in Figure 18.

METHODS

Abundance

The abundances of individual nannofossil species are defined as follows:

Rare: <0.1% (of the total assemblage)

Few: 0.1-1.0% (of the total assemblage)

Common: 1.0-10.0% (of the total assemblage)

Abundant: >10.0% (of the total assemblage).

INTRODUCTION AND EXPLANATORY NOTES

Preparation

Smear-slide preparation followed standard procedures: a small piece of sediment was smeared onto a glass slide with a drop of water using a flat toothpick. A cover-slip was then mounted. Samples studied using scanning electron microscopy (SEM) were dispersed in water in a glass vial using ultrasonic vibration for about 30 s. A few drops of the suspension were pipetted onto an aluminium SEM stub, dried, and coated.

PHYSICAL PROPERTIES

We measured compressional-wave velocities and index properties (bulk density, porosity, water content, and grain density) on the crystalline rocks recovered from Sites 733 and 735. Experimental details are described next.

Compressional-Wave Velocity

The pulse-transmission method was used to determine the compressional-wave velocity using ultrasonic piezoelectric transducers as sources and detectors in a screw-press Hamilton Frame described by Boyce (1976). Early tests indicated that the flatness and parallelism of the specimens determined the accuracy and reproducibility of the measurements. Accordingly, grinding fixtures for finishing the samples were designed and built and their use permitted achievement of flatness and parallelism to within 0.005% to 0.025% of the transmission distance. This small tolerance resulted in sharply defined first arrivals of the direct Pwave mode. Three types of specimens were used in this apparatus: (1) minicores (24.6 mm in diameter, 15-20 mm long) drilled normal to the core splitting plane (i.e., horizontal) and parallel to foliation, (2) cubes ($21 \times 21 \times 21 \pm 1$ mm) cut with faces parallel to foliation (pulse transmission direction A), perpendicular to lineation (direction B) and perpendicular to foliation (direction C), and (3) half-round cores cut from the working half of the core, with lengths varying between 25 and 61 mm but typically 58.4 mm. The pulse transmission direction was along the core axis (direction A) and therefore vertical. Halfround cores were prepared for samples having a grain size greater than 5 mm, and cubes were prepared for rocks that were strongly foliated. Measurement uncertainties in transmission length (± 0.05 mm, $\pm 0.25\%$ of length) and timing uncertainties (± 0.035 s or 0.1%) yielded nominal uncertainties in V_p of about 0.3%. Calibration against velocity standards (leucite $V_p = 2.745$ km/s and silica glass $V_p = 5.97$ km/s) were reproduced to within 0.3%. Measurement of V_p in an aluminum standard resulted in a velocity of 6.379 \pm 0.022 km/s, about 1% higher than the nominal velocity of 6.295 km/s. We believe this calibration value is in error. In practice, heterogeneity of the rock samples and irregularities in the sample shapes and finishes degrade this experimental accuracy to about 0.8% or 5 \times 10⁻² km/s.

Index Properties

Wet and dry densities, porosities, and water contents were determined on all of the minicore samples using a motion-compensated microbalance measurement of mass (± 0.010 g accuracy) and a Penta-pycnometer measurement of sample volumes ($\pm 0.03\%$) in both the saturated and dry states. Samples were dried at 110° ± 5 °C for 24 hr to drive off water. Purge times of 5 min were used, and overall accuracies of bulk and grain densities are about 0.2% or 6 $\times 10^{-3}$ Mg/m³. Porosities were determined to probably no better than $\pm 0.2\%$, assuming that the porosity is interconnected and fluid saturated.

THERMAL CONDUCTIVITY

Core samples were measured nondestructively for thermal conductivity in the shipboard laboratory. Measurements were performed over about 5 to 6 min with a heated needle probe sandwiched between the sample and a slab of low-conducting



Figure 18. Pleistocene nannofossil zonation events used during Leg 118 with estimated absolute ages. FO = first occurrence; LO = last occurrence.

material (Vacquier, 1985). This method is most convenient for the hard-rock cores, which were cut in the form of a half-round cylinder because this shape is easily adapted for the apparatus.

The theory of the method closely approximates the heating of a line source in a plane separating half-spaces of the sample material and a thermal insulator, which in turn is a relatively straightforward extension of the method of heating of a uniform full-space by a line source (Jaeger, 1956; Von Herzen and Maxwell, 1959). If the substrate on which the sample is placed were a perfect thermal insulator, the rise in temperature with time at the needle probe would be exactly twice that experienced by the probe in an infinite medium having the same thermal conductivity of the sample. In practice, the low-conducting substrate absorbs a fraction of the heat during measurement, which depends on the ratio of sample to substrate conductivity. For most of the rock samples measured during Leg 118, this ratio was large enough (>15-20) so that the adjustment from the simple theory requires a relatively small correction. This correction was determined by carefully measuring materials of known conductivity having values close to those measured in the samples.

Measurements of rock thermal conductivity by this technique were conducted sporadically during previous ODP legs. Measurements on nine basalt samples were reported from Leg 109, Site 648 (Shipboard Scientific Party, 1988b, Table 20), as well as from Leg 111, Hole 504B (Shipboard Scientific Party, 1988c, Table 27). These studies indicated that the multiplying factors to convert the conductivity value calculated from the full-space theory to the actual value represented by the samples ranged from about 2.1 to 2.7, apparently depending on the time period used after initiation of the transient experiment. These factors were obtained by comparing values for standard materials determined over the same time periods in the same apparatus. The following discussion presents some reasons why such unexpectedly large and variable correction factors were determined, and some suggestions for improving the measurements.

Measuring Techniques

Calibration Standards

To improve the accuracy of the data obtained, two new calibration standards were used during Leg 118. One was a plate of fused silica glass, about $10.3 \times 10.3 \times 2.5$ cm, with uniform and well-established conductivity (1.38 W/m/K; Clark, 1985). This was used in place of the thin (0.6-cm-thick) plate available previously, which gave confusing results during previous legs for any measurements lasting more than 1–2 min (see below). The other new standard is a slab of synthetic material designated "Macor" having a conductivity reported as 1.68 W/m/K by the manufacturer, near the values expected for igneous rocks of the oceanic crust. This material was obtained in the form of a short cylinder about 10.3 cm in diameter by 8 cm long, which was cut in half along the axis to give it the same shape (although somewhat larger) as the half-round core sample sections.

Calibration Tests

Before and during the measurements on samples, several measurements were performed using both of the above calibration standards. These measurements were run over a transient needle-probe heating duration of 6 min to determine the best period over which data should be obtained. Almost all of the measurements produced the same heating pattern: an initially steep slope of temperature vs. *In* time over the first 60 to 90 s that gradually decreased to a more uniform slope and sometimes trailed off to a slightly reduced slope over the last minute (Fig. 19). To reduce the effects of any external temperature changes, all calibration runs were performed when the temperature of the standard in the bath was changing at a rate less than 0.01° C/min. The data reduction program will remove a linear temperature change, but inaccuracies occur if the change is too rapid or nonlinear.

Measurements using these calibration standards were analyzed for two different time periods of data acquisition: one during the early (30 to 66 s) period of rapid, quasilinear change



Figure 19. Typical plot of the data from measuring thermal conductivity of a rock sample using the needle probe and half-space method. Note that the slope of the temperature vs. *In* time relationship is steeper over the first few data points and tends to a linear relationship after 60 to 90 s.

of temperature vs. *In* time, and the other over the later (60–90 s to 5–6 min) period with a nearly linear relationship (Fig. 20). The results show that the F factors (i.e., the factors necessary for multiplying the result to obtain the standard value, assuming that the needle probe was measuring in an infinite medium of the calibration material) are separated into two groups, depending on the time interval of the data. For the early transient period, the F factors range widely from about 2.2 to 2.8, which is significantly greater than expected theoretically (Vacquier, 1985), whereas for the later linear period of the data, the F factors cluster around a value of 2.0 (Fig. 20).

These results suggest that more accurate and uniform values could be obtained by using the data over the period of measurement from about 1 to 6 min. The more scattered results over the early time period with anomalously high F factors may be explained by several effects. Most important is probably that the needle probe is not mounted exactly symmetrically between the low-conductivity substrate of the experimental apparatus and the sample (or standard); rather, it is flush with the surface of the substrate, so that the initial period of heating will be affected more strongly by its low conductivity, which explains the systematically higher slopes and higher F factors. The scatter of the early time results may also result from the variability in surface roughness of the sample, or in the amount of grease used to improve thermal contact between the substrate and the sample or calibration standard. A low-conducting silicon grease was used for convenience; a higher-conductivity grease might alleviate this problem to some extent. However, although use of a higher-conducting grease might reduce some of the scatter in the results, it seems unlikely to eliminate the anomalous systematic differences between early and late time measurements described above.

Note that the mean F factor for the silica glass standard is 1.94, whereas for the Macor standard it is 2.01, using the standard values given above. The former value is near that expected (1.95) when using the empirical relationship proposed by Vacquier (1985, Eq. 5), whereas a factor of 2.0 could only be approached (not exceeded) for a very large ratio of sample to substrate conductivity. We surmise that the conductivity of the Macor standard is somewhat lower than the value quoted. Assuming that the average F factor for Macor should be about 1.96 because it has significantly higher conductivity than silica glass, we estimate the conductivity of this standard as 1.64 W/m/K.

HARD-ROCK PALEOMAGNETISM

Paleomagnetic measurements were performed on minicore samples taken from selected areas within recovered cores. These areas were chosen on the basis of lithologic homogeneity and the ability to orient the samples with respect to the vertical direction. When possible, at least one shipboard sample was taken from each core. However, a few cores consisted only of unoriented fragments and thus were not sampled.

Magnetic susceptibility (X_0) was measured using a Bartington Magnetic Susceptibility Meter (Model MS1). This value of initial susceptibility was used in conjunction with natural remanent magnetism (NRM) values to calculate the Q ratio (Koenisberger) of the samples. A field value of 0.38 Oe was assumed for Site 735 so that

$$Q = \frac{\text{NRM}}{(X_0 \times 0.38)}.$$

Remanent magnetization was measured with a MOLSPIN Portable Rock Magnetometer. This spinner-type magnetometer interfaced with a DEC PRO-350 microcomputer using software written by Yozo Hamano for Leg 109. Step-wise alternating field (AF) demagnetization was performed with a single-axis Schonstedt Geophysical Specimen Demagnetizer (Model GSD-1) at 25, 50, 75, 100, 150, 200, 250, 300 Oe, and upward in 100-Oe steps until the specimen decreased to below 15% of the NRM and a stable inclination was identified on a Zijderveld plot. In addition, thermal demagnetization was performed on selected samples using a Schonstedt Thermal Specimen Demagnetizer (Model TSD-1) and steps of 100, 150, 200, 250, 300, 350, 400, 440, 480, 520, 540, 560, 580, and 600°C.

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Figure 20. Histograms of the "F" factors (see text) calculated for measurements of thermal conductivity standards over different periods of time after initiation of heating of the probe. Note that the horizontal scale divisions for the early data (A) are twice those for the late data (B). Values for standards assumed as 1.38 W/m/K for silica glass, and 1.68 W/m/K for Macor.