

1. INTRODUCTION AND EXPLANATORY NOTES¹

Shipboard Scientific Party²

GENERAL INFORMATION

In this chapter, we have assembled information that will help the reader understand the basis for our preliminary conclusions and also help the interested investigator select samples for further analysis. This information concerns only shipboard operations and analyses described in "Site 504" (this volume). Methods used by various investigators for shore-based analysis of Leg 137 data will be detailed in the individual scientific contributions published in the *Scientific Results* volume.

AUTHORSHIP OF SITE CHAPTERS

The separate sections of the site chapter were written by the following shipboard scientists (in each case, the first author listed had principal responsibility for the section):

Site Summary: Becker, Foss
Background and Objectives: Becker, Foss
Operations: Foss, Pollard, Becker
Igneous Petrology and Alteration: Alt
Physical Properties: Christaras
Fluid Sampling and Chemistry: Magenheimer, Bayhurst, Solbau
Temperature Logging: Gable, Morin, Becker
Borehole Televiwer: Krammer
Flowmeter/Injection Experiment: Morin, Becker
Summary and Conclusions: Becker, Foss

Following the text of the site chapter are igneous rock visual core descriptions, photographs of each core, and thin section descriptions.

SURVEY AND DRILLING DATA

Survey Data Approaching the Site

Bathymetric data were collected during the transit from Honolulu, Hawaii, to Site 504, using the 3.5- and 12-kHz Precision Depth Recorder (PDR) system, and displayed on two Raytheon recorders. Depths are calculated on the basis of an assumed 1500 m/s sound velocity in water. The water depth (in meters) at each site is corrected for (1) the variation in sound velocity with depth using Carter's (1980) tables and (2) the depth of the transducer pod (6.8 m) below sea level. For Hole 504B, the depth to the top of the reentry cone was assumed from previous legs' drill-pipe measurements made from the seafloor to the dual elevator stool (DES) on the drilling-platform. Depths referred to the drilling-platform level are corrected to mean sea level by subtracting the height of the DES above the water line (see Fig. 1).

Magnetics data collected using a Geometrics 801 proton precession magnetometer were displayed on a strip chart recorder and were recorded on magnetic tape for later processing.

Depth Measurements

Depth in the hole is measured by the length of the drill string suspended beneath the ship. The last point at which the drill pipe can be seen or marked by the driller as it is lowered is the top of the DES, about 30 cm above the rig floor. For that reason the DES is used as the drilling datum and is the official datum for all drill-string-related depth information. The permanent datum is, of course, mean sea level (MSL). A correction from MSL to DES is calculated for each site; when a site is occupied for more than a week, the correction is calculated weekly. Usually this correction amounts to between 10 and 11 m. It should be noted that depth measurements based on a long string of suspended pipe are subject to numerous errors and inaccuracies, among them the effects of pipe stretch, water temperatures, positioning over the hole, change in draft (taken into account by the MSL to DES correction factor), and vessel motion owing to tides, currents, or swell.

Logging depth measurements are subject to all the above factors. In most cases, the water depth is much greater than the hole depth, and the majority of depth error accumulates in the water column. Because ODP logs are intended to correlate with cores and drilling parameters that are based on drill-string measurements, and because total-depth accuracy is not a primary consideration in logging, the logging engineer adjusts his depthometer to agree with the driller's pipe depth. The existing errors are thus equalized, and logging depths should agree closely with drilling depths. In very deep holes, however, a differential stretch correction may be needed, as the pipe and logging cable have different stretch coefficients.

Large-volume borehole water samples are taken at discrete depths in the borehole with *in-situ* samplers run on a wireline or logging cable. Depth measurements for these samples are subject to the inaccuracies discussed above, compounded by different stretch corrections necessary for wireline and logging cable and systematic errors in the cable measuring devices. No adjustment was made on any Leg 137 water-sampling run to match logging cable or wireline depths to drilling depths, further complicating problems with accuracy in depth measurements. The depths cited for these water samples are probably accurate to within 10–20 m.

NUMBERING OF SITES, HOLES, CORES, AND SAMPLES

Numbering Sites

DSDP/ODP drill sites are numbered consecutively from the first site drilled by *Glomar Challenger* in 1968. A site number is used for 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 the hole), moving the ship some distance from

¹ Becker, K., Foss, G., et al., 1992. *Proc. ODP, Init. Repts.*, 137: College Station, TX (Ocean Drilling Program).

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

the previous hole, and then drilling another hole. At times, the ship may return to a previously occupied site to work in existing holes or to drill additional holes.

Numbering Holes

It is important 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. For ODP drill sites, a letter suffix distinguishes each hole drilled at the same site. For example, the first hole drilled is assigned the site number modified by the suffix A, the second hole takes the site number and suffix B, and so forth. Note that this procedure differs slightly from that used by DSDP (Sites 1 through 624), in which the first hole spudded was given the site number designation, the second hole at the site was given the site number and suffix A, and so on. Hole 504B, first drilled by DSDP Leg 69, was the third hole of four at Site 504 (Holes 504, 504A, 504B, and 504C have been drilled to date).

Measuring Core Depths

The cored interval is measured in meters below seafloor (mbsf); sub-bottom depths are determined by subtracting the drill pipe measurement (DPM) water depth (the length of pipe from the rig floor to the seafloor) from the total DPM (from the rig floor to the bottom of the hole; Fig. 1). Note that although echo-sounding data (from the precision depth recorders) are used to locate a site, they are not used as a basis for any further measurements. In the case of Leg 137's return to Hole 504B, we relied on the depths to the seafloor, top of the reentry cone, and bottom of the hole used on Leg 111.

The depth interval assigned to an individual core begins with the depth below the seafloor that the coring operation began, and extends to the depth that the coring operation ended for that core (Fig. 1). For rotary (RCB) coring, each coring interval is equal to the length of the joint of drill pipe added for that interval (though a shorter core may be attempted in special instances). The joints of drill pipe in use vary in length from about 9.4 to 9.8 m. The pipe is measured as it is added to the drill string, and the cored interval is recorded as the length of the pipe joint to the nearest 0.1 m.

Coring intervals may be shorter and may not necessarily be adjacent if separated by drilled intervals. In drilling hard rock, a standard drill bit may be used in place of a core bit, or a center bit may replace the core barrel, if it is necessary to drill without core recovery.

Junk baskets and boot baskets are used in fishing and milling operations to retrieve pieces of "junk" from the hole. In this case, junk refers to the broken coring assembly that was lost in the hole at the end of Leg 111. Junk baskets are part of a bit assembly and are used to "fish" and recover larger pieces of drilling or coring equipment, such as bit cones, from the bottom of the hole. Boot baskets are special pieces of drill pipe run in the drill string above a junk mill, drill bit, or core bit to collect smaller pieces such as metal slivers of milled and broken-up junk. In addition to recovering junk, the baskets tend to collect rubble from the bottom of the hole.

Rocks coming up in the junk basket and boot baskets were given core identifiers using the following system. Before coring began again in Hole 504B, Leg 137 spent 6 days fishing, milling, and reconditioning the hole. A quantity of primarily basaltic rubble was brought to the surface in the junk basket and boot baskets with metal pieces of the broken-up drilling assembly. This rubble, from the first fishing junk basket and the five ensuing boot baskets run above junk mills, was curated as a single "core" labeled 137-504B-171M. M signifies the core type, and stands for miscellaneous recovery. This

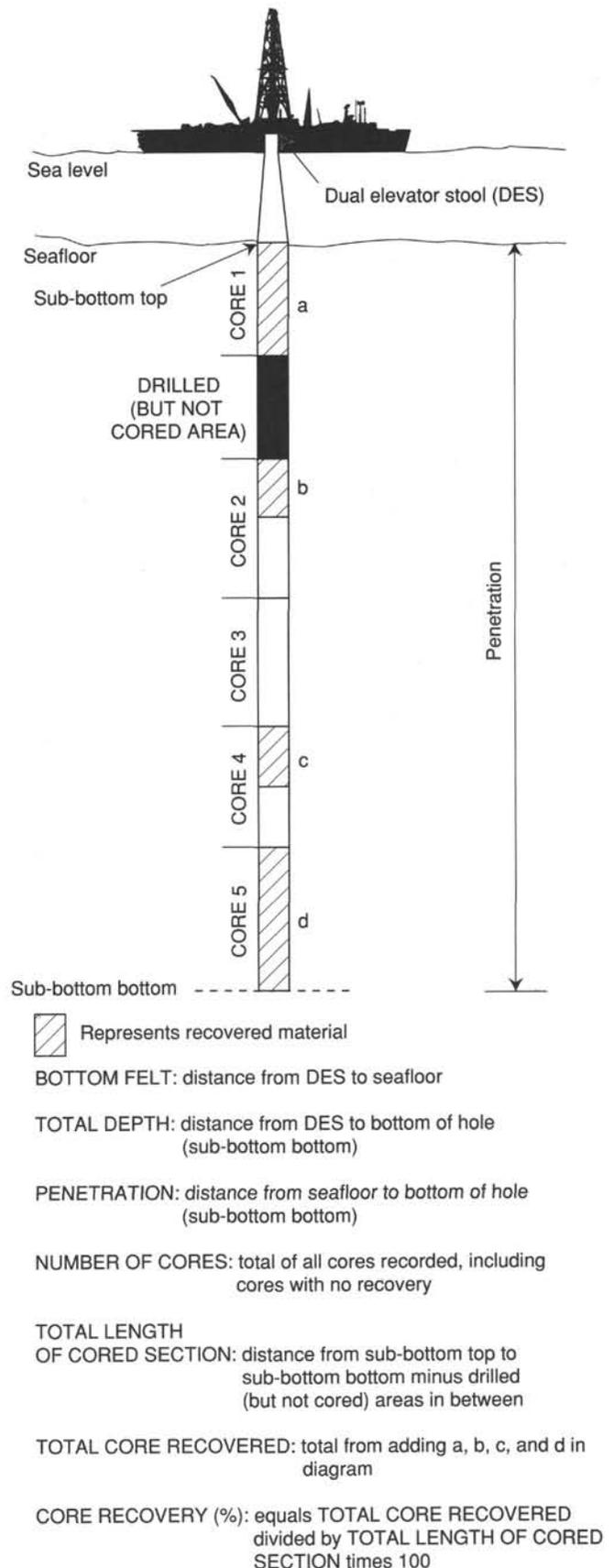


Figure 1. Diagram illustrating terms used in the discussion of coring operations and core recovery.

“core” was assigned an interval of 274.5–1562.3 mbsf, since the recovered rubble may have fallen to the bottom of the hole from anywhere on the borehole wall. The seventh run was a drill (rather than core) bit with boot baskets run above it in the drill string. The drill bit deepened Hole 504B from 1562.3 mbsf total depth to 1570.0 mbsf total depth. Rubble recovered in boot baskets during the seventh run was curated as 137-504B-172M.

Numbering Cores

Cores taken from a hole are numbered serially from the top of the hole downward. Full recovery for a single core is 9.5 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 (Fig. 2). (For the Christensen core barrel, maximum full recovery is 30 ft or 60 ft–13.6 m or 27.3 m, respectively, depending on what length of barrel is employed.)

Igneous rock cores, like sediment cores, are divided into 1.5-m sections that are numbered serially. Individual pieces of rock are then each assigned a number. Fragments of a single piece are assigned a single number and the fragments are identified alphabetically. Scientists completing visual core descriptions describe each lithologic unit, noting core and section boundaries only as physical reference points. In fact, the curated length of hard-rock cores bears little resemblance to the length of core originally recovered.

The core catcher is a device at the bottom of the core barrel which prevents the core from sliding out when the barrel is being retrieved from the hole. For hard rocks, the core-catcher sample is placed at the bottom of the last section and is treated as part of the last section.

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. Samples removed from the cores are designated by distance measured in centi-

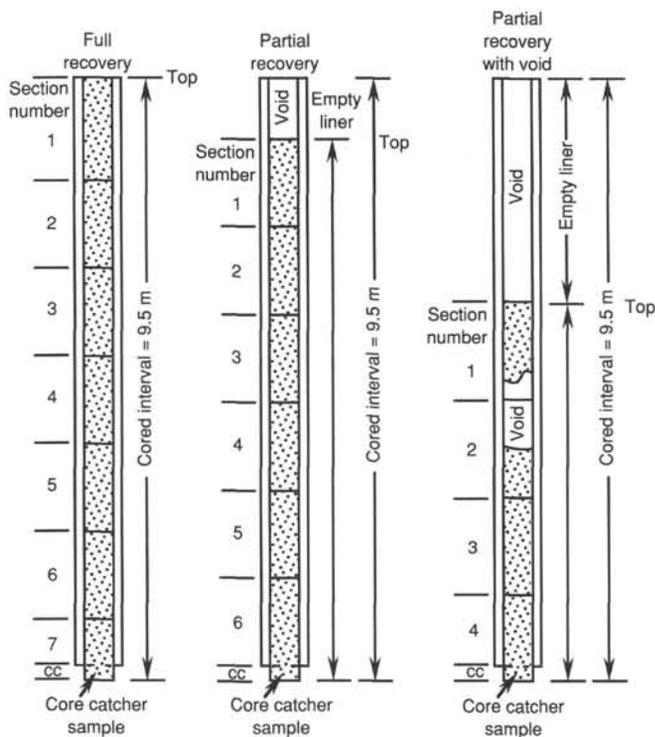


Figure 2. Diagram showing procedure used in cutting and labeling core sections.

meters 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 which did not fit together in order to protect them from damage in transit and in storage; therefore, the centimeter interval noted for a hard rock sample has no direct relationship to that sample's depth within the cored interval, but is only a physical reference to the location of the sample within the curated core.

Identifying Samples

A full identification number for a sample consists of the following information: leg, site, hole, core type, core type, section number, piece number for hard rocks, and interval in centimeters measured from the top of section. For example, a sample identification of “137-504B-173R-1 (Piece 2, 10–12 cm)” would be interpreted as representing a sample removed from the second piece in Section 1, from the interval between 10 and 12 cm from the top of Section 1, Core 173 (R designates that this core was taken during rotary coring) of Hole 504B during Leg 137.

All ODP core and sample identifiers indicate core type. The following abbreviations are used: R = Rotary Core Barrel (RCB); H = Hydraulic Piston Core (referred to as APC, Advanced Hydraulic Piston Core); P = Pressure Core Sampler; X = Extended Core Barrel (XCB); B = drill-bit recovery; C = center-bit recovery; I = *in-situ* water sample; S = sidewall sample; W = wash-core recovery; and M = miscellaneous material.

For Leg 137, the designation M was used for curating basalt debris that fell to the bottom of the borehole and came up in a junk basket or boot basket while recovering broken drill bit parts from the hole. New to the Ocean Drilling Program on Leg 137 was the Christensen core barrel. This standard oilfield-type coring system cuts 4-in. cores taken in 30-ft or 60-ft barrels that are part of the bottom-hole assembly. The core type designation for the Christensen cores is M.

Identifying Large-Volume Borehole Fluid Samples

Borehole water sample depths are unrelated to core depths, because the water sampling usually takes place well after the borehole is drilled. For this reason we have not assigned depth-related core identifiers to each water sample. Rather, the curatorial and analytical data associated with these samples are found in a separate water-chemistry database at ODP, and are available to researchers by request, as are all other ODP data.

Identifiers for borehole water samples take the following format: the first letter of the identifier is B (borehole sample); the second letter indicates the type of sampler used (B for Lawrence Berkeley Laboratory sampler, S for the stainless steel sampler from Los Alamos National Laboratory, and T for the titanium sampler from Los Alamos National Laboratory). The following table shows the codes used for the sampler runs.

BS-1 Los Alamos Laboratory (LANL) sampler, on the wireline

BS-2 Los Alamos Laboratory (LANL) sampler, on the wireline

BB-3 Lawrence Berkeley Laboratory (LBL) sampler, on the logging cable

BS-4 Los Alamos Laboratory (LANL) sampler, on the wireline

BB-5 Lawrence Berkeley Laboratory (LBL) sampler, on the logging cable

BT-6 Los Alamos Laboratory (LANL) sampler, on the wireline (sample lost)

BB-7 Lawrence Berkeley Laboratory (LBL) sampler, on the logging cable

BS-8 Los Alamos Laboratory (LANL) sampler, on the wireline

BB-9 Lawrence Berkeley Laboratory (LBL) sampler, on the logging cable

In subsample aliquots, third (and fourth) letters are added to indicate the purpose for which the subsample was taken, and the run number moves to the position of core number in the complete identifier. For example, from each sample an aliquot was taken as an acidified sample to be returned to the Gulf Coast Repository; its designation is BBPA, indicating that it was taken from the LBL sampler, acidified, and stored in plastic.

HANDLING IGNEOUS AND METAMORPHIC ROCKS

When an igneous or metamorphic rock core arrives on deck, pieces of rock in the core-catcher are placed at the bottom of the core liner and total core recovery is calculated by shunting the rock pieces together and measuring to the nearest centimeter; this information is added to the shipboard core-log database program. The core liner is cut into sections 1.5 m long; the rock pieces are divided at fractures or other natural breaks, approximating the 1.5-m intervals. The core sections are then carried into the lab.

The contents of each section are transferred into sections of split core liner 1.5 m long. In order to preserve important features and structures, core sections containing igneous rocks are examined prior to splitting. The bottom of oriented pieces (i.e., pieces that clearly could not have rotated top to bottom about a horizontal axis in the liner) is marked with a red wax pencil. This is to ensure that orientation is not lost during the labeling and splitting process. Each piece is then split into archive and working halves, with the goal that each half contains a representative sample of important features and structures. Plastic spacers are used to separate individual pieces and/or reconstructed groups of pieces in the core liner. These spacers may represent substantial intervals of no recovery. Each piece is labeled on an external surface with a small identifying label coated with clear epoxy. If the piece is oriented, an arrow is added to the label pointing to the top of the section. Pieces are numbered sequentially from the top of each section, beginning with number 1; reconstructed groups of pieces are assigned the same number, and are lettered consecutively.

The pieces are split lengthwise into archive and working halves using a rock saw with a diamond blade. The archive half is described, and the working half is sampled for shipboard physical properties, X-ray fluorescence, X-ray diffraction, and thin-section studies. Samples for shore-based analyses also are removed from the working half. Where recovery and time permitted during Leg 137, samples were taken from each lithologic unit for X-ray fluorescence analysis for both major and trace elements. Records of all samples are kept by the curator at ODP.

The archive half is used for the visual core description (see below), then photographed with both black-and-white and color film, one core at a time. Both halves of the core are shrink-wrapped in plastic to prevent rock pieces from vibrating out of sequence during transit, put into labeled plastic D-tubes, sealed, and transferred to cold storage aboard the ship.

HANDLING LARGE-VOLUME WATER SAMPLES

During the early part of Leg 137 operations at Hole 504B, nine large-volume borehole fluid samples were taken. Two

in-situ fluid samplers were used: one took 1-L samples and was run on the wireline; the second took 2-L samples and was run on the logging cable. Samples were taken at preselected intervals downhole, one sample per wireline/cable run. We alternated samplers in order to evaluate the operational characteristics of each. The water samples were divided into aliquots for a wide variety of shipboard and post-cruise analyses.

The inorganic geochemistry program for Leg 137 was devoted entirely to analysis of borehole fluid samples. Borehole fluid samples and local surface seawater were analyzed for pH, alkalinity, salinity, sulfate, chloride, calcium, magnesium, potassium, sodium, strontium, lithium, silica, nitrate, nitrite, and phosphate. All dissolved constituents are expressed in units of millimoles per liter (mM) or micromoles per liter (μM).

Alkalinity and pH were estimated with the Metrohm autotitrator with a Brinkman combination pH electrode. The slope of the electrode was calibrated to 56.85. Precision was generally within 5%. An electrode malfunction during the last sample analysis (sample BB-9) prevented obtaining an alkalinity result for this sample. An attempt was made to rerun all samples after a new electrode was calibrated (slope = 61.0) and tested. The second set of alkalinity data was much lower than the first set presumably due to the precipitation of iron oxyhydroxides during the week that had passed. The first set of alkalinities is reported in the shipboard summary.

Salinity was estimated using a Goldberg optical hand refractometer measuring total dissolved solids.

Chloride was measured by silver nitrate titration of 1 mL of sample diluted with 5 mL of deionized water using potassium chromate as an indicator. All titrations were carried out in duplicate or triplicate. Precision was better than 1%.

Sulfate was quantified using a Dionex-2120 ion chromatograph. Precision on separate dilutions was better than 2%.

Calcium was determined by complexometric titration of a 0.5-mL sample with EGTA (ethylene-bis-(oxyethylenetriolo)-tetra-acetic acid) using GHA (2-2'-ethane-diylinidine-dinitrilo-diphenol) as an indicator. The calcium-GHA complex is extracted into a layer of butanol to facilitate detection of the endpoint. The corrections for strontium were carried out as described in Gieskes and Peretsman (1986). All samples were run in duplicate. Precision was estimated to be better than 1%.

Magnesium was determined by EDTA (di-sodium ethylenediamine-tetra-acetate) titration for total alkaline earths. Subsequent corrections (Gieskes and Peretsman, 1986) for calcium and strontium yielded the magnesium concentration. All samples were run in duplicate. Precision was estimated to be better than 2% on replicates.

Hydrogen sulfide was estimated using a modification of the methylene blue technique described in Grasshoff et al. (1983). Two hundred microliters of the sample was fixed in 3.0 mL of 0.1 mM cadmium nitrate solution by precipitation as cadmium sulfide immediately upon retrieval of the samples. The procedure allows determination of hydrogen sulfide to a concentration of 2 μM .

Ammonium, silica, nitrate + nitrite, nitrite, and phosphate were determined by the spectrophotometric techniques described in Gieskes and Peretsman (1986).

Sodium and potassium were determined by flame atomic emission spectrometry. Standards were made from dilutions of standard seawater. Standard seawater was run every two samples to adjust for instrumental drift using the provided software. Samples and standards were diluted to 4000 times with 0.5% lanthanum chloride added as an ionization buffer. Precision was estimated to be $\pm 2\%$ for both potassium and sodium.

Lithium was analyzed by flame atomic emission spectrometry using an air acetylene flame. Standards were made from stock 1000 ppm Li atomic absorption standard in 3.5% NaCl. Samples and standards were diluted six times with nanopure water. Precision was estimated to be $\pm 3\%$.

Strontium was analyzed by flame atomic absorption spectrometry, using an air acetylene flame. Standards were prepared in 3.5% NaCl to simulate the seawater matrix. Samples and standards were diluted five times with 1% lanthanum added as an ionization buffer. Precision was $\pm 2.5\%$.

BASEMENT DESCRIPTION CONVENTIONS

Visual Core Descriptions

Visual core description forms were used in the documentation of the igneous rock cores (see following "Site 504" chapter, this volume). The left column is a graphic representation of the archive half. A horizontal line across the entire width of the column denotes a plastic spacer. Oriented pieces are indicated on the form by an upward-pointing arrow to the right of the piece. Shipboard samples and studies are indicated in the column headed "shipboard studies," using the following notation: XRD = X-ray diffraction analysis; XRF = X-ray fluorescence analysis; TS = petrographic thin section; PP = physical properties analysis.

To ensure consistent and complete descriptions, the visual core descriptions were entered into the computerized database HARVI. The database was divided into separate data sets for fine-grained rocks and coarse-grained rocks. Each record was checked by the database program for consistency and completeness, and was subsequently printed in a format that can be pasted directly onto the barrel sheet for curatorial handling.

When sequences of rocks were described, the core was subdivided into lithologic units on the basis of changes in texture, grain size, mineral occurrence and abundance, rock composition, and rock clast type. For each lithologic unit and section, the following information was recorded in the database system:

A. The leg, site, hole, core number, core type, and section number.

B. The unit number (consecutive downhole), position in the section, number of pieces of the same lithologic type, the rock name, and the identification of the describer.

C. The color of the dry rock and the presence and character of any structural fabric.

D. The number of mineral phases visible with a hand lens and their distribution within the unit, together with the following information for each phase: (1) abundance (volume%); (2) size range in mm; (3) shape; (4) degree of alteration; and (5) further comments if appropriate.

E. The groundmass texture: glassy, fine grained (<1 mm), medium grained (1–5 mm), or coarse grained (>5 mm). Grain size changes within units were also noted.

F. The presence and characteristics of secondary minerals and alteration products.

G. The abundance, distribution, size, shape, and infilling material of vesicles and vugs (including the proportion that are filled by alteration minerals).

H. The rock structure: determining whether the unit is massive, is a dike, or brecciated. Dikes were distinguished where a chilled margin or intrusive contact was recovered, otherwise units were called massive.

I. The relative amount of rock alteration. Alteration was graded as fresh (<2%); slightly altered (2%–10%); moderately altered (10%–40%); highly altered (40%–80%); very

highly altered (80%–95%); and completely altered (95%–100%).

J. The presence of veins and fractures, including their abundance, width, mineral fillings or coatings, and orientation.

K. Other comments, including notes on the continuity of the unit within the core and the interrelationship of units.

Basalts and diabases were termed aphyric (<1%), sparsely phyrlic (1%–2%), moderately phyrlic (2%–10%), or highly phyrlic (>10%), depending upon the proportion of phenocrysts visible with the hand lens or binocular microscope. Basalts were further classified by pheno-cryst type (e.g., a moderately phyrlic plagioclase olivine basalt contains 2%–10% phenocrysts, mostly plagioclase, with subordinate olivine). Igneous rock names were initially assigned from megascopic phenocryst assemblages. Where chemical analyses or thin sections were available, more specific rock names were given. Finally, the term subophitic was used to refer to groundmass textures where individual plagioclase grains were partially surrounded by clinopyroxene grains with little to no glass.

Visual core descriptions of igneous rocks are given following the "Site 504" chapter (this volume), and descriptions of each rock unit are available from the computerized database at the ODP repositories.

Thin-Section Descriptions

Thin sections of igneous rocks were examined to complement and refine the hand-specimen observations. The percentage of various components present in a thin section was determined by counting 500 points using an automatically advancing stage with an attached counter. The percentages and textural descriptions of individual phases were reported in the computerized database HRTIN. The same terminology was used for thin section descriptions as was used for the megascopic descriptions. Thin-section descriptions are given in the "Site 504" chapter (this volume), and are also available from the ODP computerized database.

X-Ray Diffraction

A Philips ADP 3520 X-ray diffractometer was used for X-ray diffraction analysis of secondary minerals. Instrument conditions were as follows: $\text{CuK}\alpha$ radiation; 40 kV accelerating voltage; 35 mA filament current; Incremental scan from 2° to $60^\circ 2\theta$. Samples were prepared by grinding in an agate mortar, and were either mounted as powders in aluminum sample holders or as smear slides using a slurry with acetone on glass slides.

X-Ray Fluorescence Analysis

Prior to analysis, samples were crushed in a Spex 8510 shatterbox using a tungsten carbide barrel. Where recovery permitted, at least 20 cm³ of material was ground to ensure a representative sample. Sample contamination with Nb, as a result of grinding in the tungsten carbide barrel, is kept below 1 ppm by grinding the samples for not more than 2 min.

A fully automated wavelength-dispersive ARL8420 XRF (3 kW) system equipped with a Rh target X-ray tube was used to determine the major oxide and trace element abundances of whole-rock samples. Analyses of the major oxides were carried out on lithium borate glass disks doped with lanthanum as a "heavy absorber" (Norrish and Hutton, 1969). The disks were prepared from 500 mg of rock powder that had been ignited for 2 hr at about 1030°C and mixed with 6.000 g of preweighed (on shore) dry flux consisting of 80% lithium tetraborate and 20% La_2O_3 . This mixture was then melted in air at 1150°C in a Pt-Au crucible for about 4 min with constant

agitation to ensure thorough mixing and poured into a Pt-Au mold using a Claisse Fluxer. The 12:1 flux to sample ratio and the use of the lanthanum absorber made matrix effects insignificant over the normal range of igneous rock compositions. Hence the relationship between X-ray intensity and concentration becomes linear and can be described by:

$$C_i = (I_i \times m_i) - b_i \quad (1)$$

where C_i = concentration of element i (wt%); I_i = peak X-ray intensity of element i ; m_i = slope of calibration curve for element i (wt%/cps); and b_i = apparent background concentration for element i (wt%).

The slope m_i was calculated from a calibration curve derived from the measurement of well-analyzed reference rocks (BHVO-1, G-2, AGV-1, JB-2, JB-3, UBN, GH, K1919, AII-92, RGM, BEN, and BIR). The analyses of these standards derived from the calibration curves used are given in Table 1. The background b_i was determined by regression analysis from the calibration curves.

Systematic errors resulting from short-term or long-term fluctuations in X-ray tube intensity and instrument temperature were addressed by counting a standard disk among no more than six unknowns in any given run. The intensities of this standard were normalized to its known values, providing correction factors to the measured intensities of the unknowns. To reduce shipboard weighing errors, two glass disks were prepared for each sample. Accurate weighing was difficult on board the moving platform of *JOIDES Resolution*, and was performed with particular care as weighing errors could be a major source of imprecision in the final analysis. Loss on ignition was determined by drying the sample at 110°C for 8 hr, and then by weighing before and after ignition at 1030°C in air.

Replicate analyses of rock standards show that the major element data are precise within 0.5%–2.5%, and are considered accurate to =1% for Si, Ti, Fe, Ca, and K, and between 3% and 5% for Al, Mn, Na, and P. The trace element data are considered accurate between 2% and 3% or 1 ppm (whichever is greater) for Rb, Sr, Y, and Zr, and between 5% and 10% or 1 ppm for the others. The accuracy of Ba and Ce is considerably less, and they are reported primarily for purposes of internal comparison. Precision is within 3% for Ni, Cr, and V at concentrations >100 ppm, but 10%–25% at concentrations <100 ppm. Analytical conditions for the XRF analyses are given in Table 1.

PHYSICAL PROPERTIES

Physical properties of core material collected during Leg 137 were investigated to provide data for the physicomaterial behavior of the rock, completing its characterization at the corresponded coring depth. Rock samples were measured regarding their index properties, thermal conductivity, ultrasonic velocity, and magnetic susceptibility. Index properties were wet/dry bulk density, wet/dry water content, grain density, porosity, and void ratio determination by gravimetric and volumetric methods. Wet bulk density was also measured by the GRAPE method. The ultrasonic velocity refers to both compressional and shear wave.

Tests, except thermal conductivity, were applied on minicores of 24.67 mm diameter and ±20 mm height. Specimens were prepared with the use of the shipboard minicore drill press. Thermal conductivity was measured on half-round pieces of core. Minicores without visible fractures were collected carefully, to be representative of the core or section lithology. The minicores were cut with the axis perpendicular to the splitting surface.

The use of the "Multisensor Track" (MST) scanner for continuous whole-round core measurements was impossible because most of the material was broken into small pieces, usually without orientation. Some discrete GRAPE and magnetic susceptibility measurements were taken. Magnetic susceptibility measurements were made using a supplementary MS1B holder/sensor, of minicore size, which was connected to the main instrument for this purpose. Two-minute discrete GRAPE measurements also were taken. *P*-wave logger discrete measurements were impossible using the MST method because the cores were not the proper size.

Index Properties

Wet/dry water content, wet/dry bulk density, grain density, porosity, and void ratio were determined on discrete samples by methods detailed by Kate Moran.³ Wet/dry mass and volume data were collected by volumetric and gravimetric methods for this purpose.

Determinations of minicore mass were performed using a programmed, dual-pan Scientech electro-balance with the following calibration data: slope 0.08786, intercept 0.00555, and coefficient of determination 1.00. Repeated measurements of a 20-g standard weight gave an average error of 0.012 g with standard deviation $\sigma_{n-1} = 0.0013$ g.

Wet and dry volumes were determined with the use of the Quantachrome Pentapycnometer helium displacement pycnometer. This apparatus is designed for the precise evaluation of volumes of dry powders and as such it works well for dry samples. Problems can arise with wet samples where the helium gas used as a displacement fluid apparently dissolves in the pore water present. Measurements on wet samples thus result in false low volume determinations. With increased purge times, the fluid apparently becomes helium-saturated, and the determined volume approaches a steady state. If due caution is not observed in the procedure adopted, is possible to achieve a false low wet volume smaller than the pycnometer-measured dry volume.

Minicore volumes were measured without beakers, using special holders to minimize the error derived from the empty space in the cells. Repeated measurements of a standard volume of 4.75 cm³ gave average errors of 0.027 cm³, 0.010 cm³, 0.035 cm³, 0.0008 cm³, and 0.0124 cm³ with a corresponding standard deviation $\sigma_{n-1} = 0.030$ cm³, 0.014 cm³, 0.014 cm³, 0.045 cm³, and 0.009 cm³.

Samples were dried in a mechanical convection oven at 105°C for 24 hr prior to the measurement of dry weights and volumes. A salt correction assuming 35 ppt interstitial fluid salinity was applied (Hamilton, 1971). Calculations were performed using the PHYSPROPS program in the ODP database.

GRAPE

The Gamma Ray Attenuation Porosity Evaluator (GRAPE) was used to determine the density of both minicore and whole-round discrete samples of basalt. Samples were positioned between a shielded gamma-ray source and a shielded scintillation detector. The beam attenuation is primarily due to Compton scattering and, as such, is directly related to the material's density. The principles of the technique are thoroughly described by Evans (1965), while its application to the ODP program, together with the necessary calibration procedures, is documented by Boyce (1976).

³ The memorandum dated 25 November 1990, "Recommended methods for the discrete measurements of index properties on the *JOIDES Resolution*," is available from Science Operations, Ocean Drilling Program, 1000 Discovery Drive, College Station, TX 77845-9547.

Table 1. XRF analytical conditions.

Element	Line	Crystal	Detector	Collimator	Peak angle (°)	Background offset (°)	Total count time (s)	
							Peak	Background
SiO ₂	Kα	PET(002)	^a FPC	Coarse	109.10	0	40	0
TiO ₂	Kα	LiF(200)	FPC	Fine	86.16	0	40	0
Al ₂ O ₃	Kα	PET(002)	FPC	Coarse	144.49	0	100	0
^b Fe ₂ O ₃	Kα	LiF(200)	FPC	Fine	57.53	0	40	0
MnO	Kα	LiF(200)	FPC	Fine	63.03	0	40	0
MgO	Kα	TLAP	FPC	Coarse	44.88	±0.80	200	400
CaO	Kα	LiF(200)	FPC	Coarse	113.18	0	40	0
Na ₂ O	Kα	TLAP	FPC	Coarse	54.73	-1.20	200	200
K ₂ O	Kα	LiF(200)	FPC	Fine	136.66	0	40	0
P ₂ O ₅	Kα	Ge(111)	FPC	Coarse	141.00	0	100	0
Rh	K-C	LiF(200)	^c Scint	Fine	18.60	0	100	0
Nb	Kα	LiF(200)	Scint	Fine	21.39	±0.35	200	200
Zr	Kα	LiF(200)	Scint	Fine	22.54	±0.35	100	100
Y	Kα	LiF(200)	Scint	Fine	23.83	±0.40	100	100
Sr	Kα	LiF(200)	Scint	Fine	25.15	±0.41	100	100
Rb	Kα	LiF(200)	Scint	Fine	26.60	±0.60	100	100
Zn	Kα	LiF(200)	Scint	Fine	41.81	±0.40	60	60
Cu	Kα	LiF(200)	Scint	Fine	45.02	±0.40	60	60
Ni	Kα	LiF(200)	Scint	Coarse	48.64	±0.60	60	60
Cr	Kα	LiF(200)	FPC	Fine	69.38	±0.50	60	60
Fe	Kα	LiF(220)	FPC	Fine	85.73	-0.40+0.70	40	40
V	Kα	LiF(220)	FPC	Fine	123.20	-0.50	60	60
TiO ₂	Kα	LiF(200)	FPC	Fine	86.16	±0.50	40	40
Ce	Lα	LiF(220)	FPC	Coarse	128.35	±1.50	100	100
Ba	Lβ	LiF(220)	FPC	Coarse	128.93	±1.50	100	100

Elements analyzed under vacuum using both goniometers at generator settings of 60 kV and 50 mA.

^aFPC = flow proportional counter using P₁₀ gas.

^bTotal Fe as Fe₂O₃.

^cScint = NaI scintillation counter.

Samples were placed between the source and detector, and the number of counts was monitored over a 2-min period. Consideration of this value in relation to the sample thickness and associated calibration results enables a bulk density value to be determined. The mean attenuation coefficient, according to the calibration data using a quartz standard, is $MU_{std} = 0.077$.

Ultrasonic velocity

Both compressional and shear wave measurements were made using the screw press Hamilton Frame velocimeter. The traveltime of the 500-kHz source pulse was measured using an oscilloscope. Sample thickness was measured by using a variable resistor attached to the calipers that hold the sample between the transducers on the frame. Measurements were applied on minicores of basalt along the axis perpendicular to the splitting surface. Seawater was used to improve the acoustic contact between the sample and the transducers. The design and operating procedure are described by Boyce (1976). The instrument was calibrated with aluminum standards. Thickness and traveltime corrections were calculated by performing a linear regression between the actual and measured times and the actual and measured distances. The calculated regressions have the following characteristics:

$$at = -0.12205 + x \quad r^2 = 1.000 \quad (2)$$

$$ad = 0.23571 + 9.967 x \quad r^2 = 1.000 \quad (3)$$

Magnetic susceptibility

Magnetic susceptibility (X_o) was measured on minicore samples using a Bartington Magnetic susceptibility meter (Model MS1) that is part of the MST. A special MS1B sensor/holder for minicore size samples was connected on the MS1 gauge for this purpose. A 312 cgs calibration standard was measured several times and found consistently to be 310 cgs.

Thermal conductivity

Thermal conductivity was measured on half-round basalt samples from the same piece as the minicore used for the other physical properties measurements, according to the technique described by Vacquier (1985). Measurements were made with a Thermcon-85 unit, and all data were reported in units of W/m²K. The estimated error in the measurements is about 5%–10%. Thermal conductivity (k) was measured by monitoring the change in temperature of the sample as a function of time after the sample was heated at a known rate by means of a needle probe, according to the following relationship:

$$T = (q/4\pi k) \ln(t) + At + B \quad (4)$$

where T is the temperature, q is the heat input to the sample per unit length per unit time, and k is the thermal conductivity. The probe contains both a heater wire and a calibrated thermistor. Prior to taking measurements, the cores were allowed to equilibrate to room temperature for at least 4 hr. The criterion for thermal equilibrium was that thermal drift of the sample prior to the thermal conductivity measurement be less than 0.004°C/min. For each sample, the temperature variations were recorded for a period of 6 min. A correction factor for each probe used was calculated by performing a linear regression between the conductivities measured for a set of standards and the actual conductivities of the standard materials.

Rock samples with one flat surface were placed on top of needle probes that were embedded along the surface of a slab of low conductivity material. The flat surfaces of the samples were polished with sandpaper to minimize pockets of water or air and thus to assure good contact with the slab containing the needle probes. EE&G thermal conducting compound was also used to improve the thermal contact between the slab and the sample. The samples and needles were immersed in a

water bath to maintain a uniform temperature, to avoid cooling by evaporation, and to keep the sample saturated. As mentioned previously, thermal conductivity is calculated from the rate of temperature increases in the probe while a heater current is flowing. We always used the time interval of 60–240 s after the heater was turned on, because (1) before 60 s, the temperature vs. log (time) curve is rarely linear and (2) after about 240 s, the thermal front from the thermal needle tends to “feel” the edge of the smaller more conductive samples. For calibration, standard samples of red and black rubber, silica, macor, and basalt were used. According to these data the following linear regressions between actual full-space and measured half-space values were observed for the three needles:

$$\text{Needle 205: act.k} = -0.13199 + 2.0106 \text{ meas.k} \quad r^2 = 0.989 \quad (5)$$

$$\text{Needle 206: act.k} = -0.26726 + 2.4878 \text{ meas.k} \quad r^2 = 0.981 \quad (6)$$

$$\text{Needle 207: act.k} = -0.14989 + 2.1028 \text{ meas.k} \quad r^2 = 0.987 \quad (7)$$

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