# 2. EXPLANATORY NOTES<sup>1</sup>

# Shipboard Scientific Party<sup>2</sup>

# INTRODUCTION

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 the site reports in the *Initial Reports* volume of the Leg 136 *Proceedings of the Ocean Drilling Program.* Methods used by various investigators for shore-based analysis of Leg 136 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 chapters were written by the following shipboard scientists (authors are listed in alphabetical order, no seniority is necessarily implied):

Site Summary (Dziewonski, Wilkens) Operations (Firth, Harding) Lithostratigraphy (Naka, Tribble) Biostratigraphy (Firth, Hull) Paleomagnetism (Briden, Helsley) Inorganic Geochemistry (DeCarlo) Physical Properties (Carson, Collins, Janecek) Igneous Petrology (Alt, Garcia, Waggoner) Logging (Goldberg) Appendix (Shipboard Scientific Party)

At the end of the volume are summary core descriptions ("barrel sheets" and igneous rock visual core descriptions) and photographs of each core.

# SURVEY AND DRILLING DATA

Geophysical survey data collected during Leg 136 include magnetic, seismic reflection profiler, and bathymetric data acquired during the site survey immediately prior to drilling. These data are discussed in the "Underway Geophysics and Seismic Stratigraphy" chapter (this volume). During the Leg 136 JOIDES Resolution survey, single-channel seismic, 3.5- and 12-kHz echo sounder, and magnetic data were recorded across the planned drill site to aid site confirmation prior to dropping the location beacon.

The single-channel seismic profiling system used two 80-in<sup>3</sup> water guns as the energy source and a Teledyne streamer with a 100-m-long active section. These data were recorded digitally on tape using a Masscomp 561 computer, and were also displayed in real time in analog format on two Raytheon recorders using a variety of filter settings (commonly 30–150 Hz) and various vertical scales, dependant on the water depth.

Bathymetric data collected using the 3.5- and 12-kHz Precision Depth Recorder (PDR) system were displayed on two Raytheon recorders. The depths were calculated on the basis of an assumed 1500 m/s sound velocity in water. The water depth (in meters) at each site was 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. In addition, depths referred to the drilling-platform level are corrected for the height of the rig floor above the water line (see Fig. 1).

Magnetic 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.

# DRILLING CHARACTERISTICS

Because water circulation downhole is open, cuttings are lost onto the seafloor and cannot be examined. Information concerning sedimentary stratification in uncored or unrecovered intervals may be inferred from seismic data, wireline-logging results, and from an examination of the behavior of the drill string as observed and recorded on the drilling platform. Typically, the harder a layer, the slower and more difficult it is to penetrate. A number of other factors may determine the rate of penetration, so it is not always possible to relate the drilling time directly to the hardness of the layers. Bit weight and revolutions per minute, recorded on the drilling recorder, also influence the penetration rate.

# **Drilling Deformation**

When cores are split, many show signs of significant sediment disturbance, including the concave-downward appearance of originally horizontal bands, haphazard mixing of lumps of different lithologies (mainly at the tops of cores), and the near-fluid state of some sediments recovered from tens to hundreds of meters below the seafloor. Core deformation probably occurs during cutting, retrieval (with accompanying changes in pressure and temperature), and core handling on deck.

# SHIPBOARD SCIENTIFIC PROCEDURES

# Numbering of Sites, Holes, Cores, and Samples

Drill sites are numbered consecutively from the first site drilled by the *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 the previous hole, and then drilling another hole. In some cases, the ship may return to a previously occupied site to drill additional holes.

For all 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), but prevents ambiguity between site- and hole-number designations. 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.

The cored interval is measured in meters below seafloor (mbsf); sub-bottom depths are determined by subtracting the drill-pipe meas-

<sup>&</sup>lt;sup>1</sup>Dziewonski, A., Wilkens, R., Firth, J., et al., 1992. Proc. ODP, Init. Repts., 136: College Station, TX (Ocean Drilling Program).

<sup>&</sup>lt;sup>2</sup>Shipboard Scientific Party is as given in the list of participants preceding the contents.



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

urement (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; see Fig. 1). Note that although the echo-sounding data (from the precision depth recorders) are used to locate the site, they are not used as a basis for any further measurements.

The depth interval assigned to an individual core begins with the depth below the seafloor where the coring operation began, and extends to the depth where the coring operation ended for that core (see Fig. 1). For rotary coring (RCB and XCB), 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 drill pipe in use varies 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. For hydraulic piston coring (APC) operations, the drill string is advanced 9.5 m, the maximum length of the piston stroke.

Coring intervals may be shorter and may not necessarily be adjacent if separated by drilled intervals. In soft sediments the drill string can be "washed ahead" with the core barrel in place, without recovering sediments. This is achieved by pumping water down the pipe at high pressure to wash the sediment out of the way of the bit and up the annulus between the drill pipe and the wall of the hole. If thin, hard, rock layers are present, then it is possible to get "spotty" sampling of these resistant layers within the washed interval, and thus to 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, because of caving of cuttings or other hole problems. Maximum 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)



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

in the core catcher (Fig. 2). 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. For sediments, the core-catcher sample is extruded into a short piece of plastic liner and is treated as a separate section below the last core section. For hard rocks, material recovered in the core catcher is included at the bottom of the last section. In certain situations (e.g., when coring gas-charged sediments that expand while being brought on deck) recovery may exceed the 9.5-m maximum.

A recovered core is divided into 1.5-m sections that are numbered serially from the top (Fig. 2). When full recovery is obtained, the sections are numbered from 1 through 7, 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 full 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 one 1-m section. If cores are fragmented (recovery less than 100%), sections are numbered serially and intervening sections are noted as void, whether shipboard scientists believe that the fragments were contiguous in-situ or not. In rare cases a section less than 1.5 m may be cut to preserve features of interest (e.g., lithologic contacts).

By convention, material recovered from the core catcher is placed below the last section when the core is described, and labeled core catcher (CC); in sedimentary cores, it is treated as a separate section. The core catcher is placed at the top of the cored interval in cases where material is only recovered in the core catcher. However, information supplied by the drillers or by other sources may allow for more precise interpretation as to the correct position of core-catcher material within an incompletely recovered cored interval.

Igneous rock cores are also cut 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 individual fragments are 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 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.

A full 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 "136-842B-5H-1, 10–12 cm" would be interpreted as representing a sample removed from the interval between 10 and 12 cm below the top of Section 1, Core 5 (H designates that this core was taken during hydraulic piston coring) of Hole 842B during Leg 136.

All ODP core and sample identifiers indicate core type. The following abbreviations are used: R = Rotary Core Barrel (RCB); H = Hydraulic Piston Core (HPC; also referred to as APC, or 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. APC, XCB, RCB, and W cores were collected on Leg 136.

#### **Core Handling**

### Sediments

As soon as a core is retrieved on deck, a sample is taken from the core catcher and given to the paleontological laboratory for an initial age assessment. The core is then placed on the long horizontal rack, and gas samples may be taken by piercing the core liner and withdrawing gas into a vacuum-tube. Voids within the core are sought as sites for gas sampling. Some of the gas samples are stored for shore-based study, but others are analyzed immediately as part of the shipboard safety and pollutionprevention program. Next, the core is marked into section lengths, each section is labeled, and the core is cut into sections. Interstitial-water (I) samples are then taken. In addition, some headspace gas samples are scraped from the ends of sections immediately after cutting, and sealed in glass vials for light hydrocarbon analysis. Each section is then sealed at the top and bottom by gluing on color-coded plastic caps, blue to identify the top of a section and clear for the bottom. A yellow cap is placed on the section ends from which a whole-round sample has been removed, and the sample code (e.g., IW) is written on the yellow cap. The caps are usually attached to the liner by coating the end liner and the inside rim of the cap with acetone, and then the caps are taped to the liners.

The cores then are carried into the laboratory, where the sections are again labeled, using an engraver to permanently mark the full designation of the section. The length of the core in each section and the core-catcher sample are measured to the nearest centimeter; this information is logged into the shipboard CORELOG database program.

Whole-round sections from APC and XCB cores are normally run through the Multisensor Track (MST). The MST includes the GRAPE (gamma-ray attenuation porosity evaluator) and *P*-wave logger devices, which measure bulk density, porosity, and sonic velocity, and also includes a meter that determines the volume magnetic susceptibility. At this point, whole-round samples for physical properties (PP) and structural analysis are taken. In well-lithified sedimentary cores, the core liner is split and the top half removed so that the whole-round core can be observed before choosing the samples. Relatively soft sedimentary cores are equilibrated to room temperature (approximately 3 hr) and thermal conductivity measurements are performed on them.

Cores of soft material are split lengthwise into working and archive halves. The softer cores are split with a wire or saw, depending on the degree of induration. Harder cores are split with a band saw or diamond saw. The wire-cut cores are split from the bottom to top, so investigators should be aware that older material could have been transported up the core on the split face of each section.

The working half of the core is sampled for both shipboard and shore-based laboratory studies. Each extracted sample is logged into the sampling computer database program by the location and the name of the investigator receiving the sample. Records of all removed samples are kept by the curator at ODP. The extracted samples are sealed in plastic vials or bags and labeled. Samples are routinely taken for shipboard physical property analysis. These samples are subsequently used for calcium carbonate (coulometric analysis) and organic carbon (CNS elemental analyzer) and the data are reported in the site chapters.

The archive half is used for the visual core description. Smear slides are made from samples taken from the archive half and are supplemented by thin sections taken from the working half. Most archive sections are run through the cryogenic magnetometer. The archive half is then photographed with both black-and-white and color film, a whole core at a time. Close-up photographs (black-and-white) are taken of particular features for illustrations in the summary of each site, as requested by individual scientists.

Both halves of the core are then put into labeled plastic tubes, sealed, and transferred to cold-storage space aboard the drilling vessel. At the end of the leg, the cores are transferred from the ship in refrigerated airfreight containers to cold storage at the Gulf Coast Repository (GCR) at the Ocean Drilling Program, Texas A&M University, College Station, TX.

## Igneous and Metamorphic Rocks

Igneous and metamorphic rock cores are handled differently from sedimentary cores. Once on deck, the core-catcher is 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 logged into the shipboard core-log database program. The core is then cut into 1.5-m-long sections and transferred into the lab. The contents of each section are transferred into 1.5-m-long sections of split core liner, where the bottom of oriented pieces (i.e., pieces that clearly could not have rotated top to bottom about a horizontal axis in the liner) are marked with a red wax pencil. This is to ensure that orientation is not lost during the splitting and labeling process. The core is then split into archive and working halves. A plastic spacer is used to separate individual pieces and/or reconstructed groups of pieces in the core liner. These spacers may represent a substantial interval of no recovery. Each piece is numbered sequentially from the top of each section, beginning with number 1; reconstructed groups of pieces are assigned the same number, but are lettered consecutively.

SITE 842 HOLE A CORE 999H					CORED 0.0 - 0.0 mbsf			
Meters	Graphic Lith.	Section	Age	Structure	Disturb.	Sample	Color	Description
0.5		1						
mhunhunh		2						
multin		3						
mhiniti		4						
multin		5						
Indutrie		6						

Figure 3. Core description form ("barrel sheet") used for sediments and sedimentary rocks.

Pieces are labeled only on external surfaces. If the piece is oriented, an arrow is added to the label pointing to the top of the section.

The working half of the hard-rock core is then sampled for shipboard laboratory studies. Records of all samples are kept by the curator at ODP.

The archive half is used for the visual core description, then photographed with both black-and-white and color film, one core at a time. Both halves of the core are then shrink-wrapped in plastic to prevent rock pieces from vibrating out of sequence during transit, put into labeled plastic tubes, sealed, and transferred to cold-storage space aboard the drilling vessel. As for the other Leg 136 cores, they are housed in the GCR.

# SEDIMENT CORE DESCRIPTION FORMS

The sediment core description forms (Fig. 3) or "barrel sheets," summarize the sedimentological data obtained during shipboard analysis of each sediment core. The barrel sheets for Leg 136 were produced using the new Visual Core Description program (Bernstein, unpubl. data) and therefore differ somewhat in format from those of previous ODP legs. The following discussion explains the ODP conventions used in compiling each part of the core description forms and the modifications of these procedures adopted by Leg 136 scientists. Barrel sheets for each core are included in Appendix A.

## **Core Designation**

Cores are designated using leg, site, hole, core number, and core type as previously discussed (see "Numbering of Sites, Holes, Cores, and Samples" section, this chapter). The cored interval is specified in terms of meters below seafloor (mbsf). This depth is based on the drill-pipe measurements (DPM), as reported by the SEDCO coring technician and the ODP Operations Superintendent.

# **Graphic Lithology Column**

The lithologic classification scheme of Mazzullo et al. (1987), accepted for shipboard use by the JOIDES Sediments and Ocean History Panel, was used in a slightly modified version on Leg 136. The classification adopted is outlined in the "Sedimentology" section of this chapter. Sediment type is represented graphically on the core description forms using the symbols illustrated in Figure 4.

In the graphic lithology column a maximum of three different lithologies can be represented within the same interval of core. For homogeneous sediments or sedimentary rocks, the constituent components are separated by a solid vertical line. Interbedded lithologies are separated by a dashed vertical line. Percentages are rounded to the nearest 10% and only lithologies that constitute at least 10% of the core are shown. Only lithologic units that are 16 cm or greater in



Figure 4. Key to symbols used in the graphic lithology column on the core description form shown in Figure 3.

thickness are represented. Lithologies present in abundances too small to be represented in the graphic lithology column are described in the description section of the barrel sheet.

### Age

The chronostratigraphic age, determined by micropaleontological criteria, is shown in the age column. Shipboard paleontologists generally base their age determinations on core-catcher samples, although additional samples from other parts of the core may be examined when required. Boundary indicators for the ages indicated on the core description forms are:

- 1. Sharp boundary: Straight line
- 2. Unconformity or hiatus: Wavy line
- 3. Uncertain: ? (question mark)

## Sedimentary Structures

Sedimentary structures are indicated in the structure column of the core description forms. A key to the symbols used on Leg 136 is given in Figure 5. Note that the positions of ash layers, too thin to be included on the graphic lithology column, are indicated on the structure column. The symbols for bioturbation are used here to reflect degree of homogenization of the sediment as indicated by lack of bedding or laminations and by mottling of the sediment where volcanic ash is present. No definite burrows or other evidence of the role of animals in this homogenization were noted.

### Sediment Disturbance

The coring techniques used may result in varying degrees of disturbance of the recovered core material. Observations of drillingrelated disturbance over an interval of 20 cm or more are recorded in the disturbance column on the barrel sheet. The symbols for the various types of drilling disturbance are shown in Figure 5.

The following disturbance categories are recognized for unlithified and partially lithified sediments:

1. Slightly deformed: bedding contacts are slightly bowed toward their edges.

Moderately deformed: bedding contacts have undergone extreme bowing.

 Highly deformed: bedding is completely disturbed, sometimes showing symmetrical diapir-like structures ("flow-in").

4. Soupy: intervals are water-saturated and have lost all traces of original bedding.

The following categories are used to describe the degree of fracturing in lithified sediments and igneous rocks:

 Slightly fractured: core pieces are in place and have very little drilling slurry or breccia.

 Moderately fractured: core pieces are in place or partly displaced, but original orientation is preserved or recognizable. Drilling slurry may surround fragments.

3. Highly fractured: pieces are from the interval cored and probably in correct stratigraphic sequence (although they may not represent the entire section), but original orientation is totally lost.

4. Drilling breccia: core pieces have completely lost their original orientation and stratigraphic position and may be completely mixed with drilling slurry.

Sedimentary structure symbols Drilling deformation symbols



Figure 5. Symbols used for drilling disturbance and sedimentary structures on core description forms shown in Figure 3.

### Samples

The positions of samples taken from each core for analysis are indicated by letters in the samples column of the core description form, as follows:

S: Smear slide

T: Thin section

P: Physical properties sample

M: Micropaleontology sample

X: Paleomagnetic sample

I: Interstitial water sample

- O: Organic geochemistry sample
- D: X-ray diffraction (XRD) sample
- F: X-ray fluorescence (XRF) sample

# Color

Colors of sediment were determined by comparison with the Munsell Soil Color Chart (1975). This was done immediately after the cores were split and while they were still wet, to minimize alteration due to exposure to air. Colors of indurated sediments were determined from wet samples. Color, hue, and chroma codes are shown in the color column of the core description form. Intervals of 34 cm or greater are represented by a single color code. Intervals of 80 cm or greater may be represented by two color codes, indicating either two colors or a gradation between two colors. The color of thinner units (less than 34 cm) may be given in the description column.

# Lithologic Description

The lithologic description that appears on each core description form consists of a brief summary of the major lithologies observed, followed by a summary of the minor lithologies. Color, composition (determined from the analysis of smear slides, in some cases augmented by XRD analysis), sedimentary structures, or other notable features of each lithology are described and, where possible, the distribution of these features in the core is indicated.

# Smear-Slide Summary

A table summarizing data from smear slides appears in each site summary chapter. The table includes information on sample location, whether the sample represents a dominant ("D") or minor ("M") lithology in the core, and the estimated percentages of sand, silt, and clay, together with all identified components.

# SEDIMENTOLOGY

# **Classification of Sediments and Sedimentary Rocks**

Leg 136 used a slightly modified version of the sediment classification scheme of the Ocean Drilling Program (ODP; Mazzullo et al., 1987), which defines granular and chemical sediment types. Granular sediment consists of discrete organic (e.g., foraminifer tests, mollusc shells) or inorganic (e.g., quartz grains, rock fragments, volcanic ash) grains. Some examples of granular sediment are nannofossil ooze, quartz sandstone, fine vitric ash, and bioclastic grainstone. Chemical sediment consists of minerals formed by inorganic processes, such as precipitation from solution or colloidal suspension, deposition of insoluble precipitates, or recrystallization of detrital grains. Some examples of chemical sediment are coal, halite, pyrite, and gypsum.

The portions of the ODP sediment classification scheme relevant to Leg 136 and our modifications of the scheme are described below.

#### **Granular Sediments**

Variations in the relative proportions of pelagic, neritic, siliciclastic, and volcaniclastic grain types define four major classes of granular sediments: pelagic, neritic, siliciclastic, and volcaniclastic (Fig. 6). The intermediate sediment class called mixed sediment in the ODP Classification Scheme has been eliminated for Leg 136 use. Pelagic grains are the skeletal remains of open-marine siliceous and calcareous microfauna and microflora (e.g., radiolarians, planktonic foraminifers, nannofossils) and associated organisms. Neritic grains include calcareous grains and skeletal remains (e.g., bioclasts, shallow-water benthic foraminifers, peloids, etc.) of nonpelagic origin. Siliciclastic grains are mineral and rock fragments derived from plutonic, sedimentary, and metamorphic rocks. Volcaniclastic grains include those of pyroclastic (direct products of magma degassing), Ratio of siliciclastic to volcaniclastic sediments



Figure 6. Diagram showing classes of granular sediment (modified from Mazzullo et al., 1987).

hydroclastic (products of granulation of volcanic glass by steam explosions) and epiclastic (detritus derived from erosion of volcanic rocks) origins.

Pelagic and neritic sediments are composed of >50% pelagic and neritic grains and are differentiated by the predominance of either grain type. Similarly, siliciclastic and volcaniclastic sediments contain >50% siliciclastic and volcaniclastic grains, with the relative proportions of the two grain types determining the sediment type.

### **Classification of Granular Sediment**

A granular sediment is classified by designating a principal name with additional major and minor modifiers. The principal name of a granular sediment defines its granular-sediment class. The major and minor modifiers describe the texture, composition, fabric, or roundness of the grains themselves (Table 1).

# **Principal Names**

Each granular-sediment class has a unique set of principal names. A summary of these principal names for the sediments recovered during Leg 136 (pelagic, siliciclastic, and volcaniclastic) is presented below.

#### Pelagic Sediment

For pelagic sediment, the principal name describes the composition and degree of induration using the following terms:

Ooze: unlithified calcareous and/or siliceous pelagic sediments;
 Chalk: partially lithified pelagic sediment predominantly composed of calcareous pelagic grains;

 Limestone: lithified pelagic sediment predominantly composed of calcareous pelagic grains;

 Radiolarite, diatomite, and spiculite: partially lithified pelagic sediment predominantly composed of siliceous radiolarians, diatoms, and sponge spicules, respectively;

Sediment class	Major modifiers	Principal names	Minor modifiers
Pelagic sediment	<ol> <li>composition of pelagic and neritic grains present in major amounts.</li> <li>texture of clastic grains present in major amounts</li> </ol>	<ol> <li>ooze</li> <li>chalk</li> <li>limestone</li> <li>radiolarite</li> <li>diatomite</li> <li>spiculite</li> <li>chert</li> </ol>	<ol> <li>composition of pelagic and neritic grains present in minor amounts</li> <li>texture of clastic grains present in minor amounts.</li> </ol>
Neritic sediment	<ol> <li>composition of neritic and pelagic grains present in major amounts</li> <li>texture of clastic grains present in major amounts</li> </ol>	<ol> <li>boundstone</li> <li>grainstone</li> <li>packstone</li> <li>wackestone</li> <li>mudstone</li> <li>floatstone</li> <li>rudstone</li> </ol>	<ol> <li>composition of neritic and pelagic grains present in minor amounts</li> <li>texture of clastic grains present in minor amounts.</li> </ol>
Siliciclastic sediment	<ol> <li>composition of all grains present in major amounts</li> <li>grain fabric (gravels only)</li> <li>grain shape (optional)</li> <li>sediment color (optional)</li> </ol>	1. gravel 2. sand 3. silt 4. clay (ctc.)	<ol> <li>composition of all grains present in minor amounts</li> <li>texture and composition of siliciclastic grains present as matrix (for coarse-grained clastic sediments)</li> </ol>
Volcaniclastic sediment	<ol> <li>composition of all volcaniclasts present in major amounts</li> <li>composition of all pelagic and neritic grains present in major amounts</li> <li>texture of siliciclastic grains present in major amounts</li> </ol>	<ol> <li>breccia</li> <li>lapilli</li> <li>ash/tuff</li> </ol>	<ol> <li>composition of all volcaniclasts present in minor amounts</li> <li>composition of all neritic and pelagic grains present in minor amounts</li> <li>texture of siliciclastic grains present in minor amounts</li> </ol>

Table 1. Outline of granular-sediment classification scheme (modified from Mazzullo et al., 1987).

Chert: lithified pelagic sediment predominantly composed of siliceous pelagic grains.

#### Siliciclastic Sediment

For siliciclastic sediment, the principal name describes the texture and is assigned according to the following guidelines:

1. The Udden-Wentworth grain-size scale (Wentworth, 1922) defines grain-size ranges and names of the textural groups (gravel, sand, silt, and clay) and sub-groups (fine sand, coarse silt, etc.) that are used as the principal names of siliciclastic sediment. Note that the term "clay" is used only as a grain-size designation and does not denote or imply mineralogical composition.

2. Principal names are listed in order of increasing abundance when two or more textural groups or subgroups are present in a siliciclastic sediment (Shepard, 1954).

3. The suffix -stone is affixed to the principal names sand, silt, and clay when the sediment is lithified.

4. Conglomerate and breccia are used as principal names of gravels with well-rounded and angular clasts, respectively. Degree of lithification is designated by a modifier before the principal name.

#### Volcaniclastic Sediment

Volcaniclastic sediments are subdivided into three groups: pyroclastic, hydroclastic, and epiclastic, with the principal name in each group describing the texture. The following names and ranges of three textural groups for pyroclastics (from Fisher and Schmincke, 1984) are used for all volcaniclastic sediments:

1. Volcanic breccia: pyroclasts >64 mm in diameter.

2. Lapilli: pyroclasts between 2 and 64 mm in diameter; when lithified, described as lapillistone.

3. Ash: pyroclasts <2 mm in diameter; when lithified, described as tuff.

#### Major and Minor Modifiers

The principal name of a granular-sediment class is preceded by major modifiers and followed by minor modifiers (preceded by "with") that describe the lithology of the granular sediment in greater detail (Table 1). Major and minor modifiers are used most commonly to describe composition and textures of grain types present in major (>25%) and minor (10%-25%) proportions. In addition, major modifiers can be used to describe degree of lithification, grain fabric, grain shape, and sediment color. The nomenclature for major and minor modifiers is outlined as follows:

Composition of pelagic grains can be described with the major and minor modifiers: diatom(-aceous), radiolarian, spicule(-ar), siliceous, nannofossil, foraminifer(-al), and calcareous. The terms siliceous and calcareous are used generally to describe sediments composed of siliceous or calcareous pelagic grains of uncertain origins.

Texture of siliciclastic grains is described by the following major and minor modifiers: gravel(-ly), sand(-y), silt(-y), and clay(-ey). Composition of siliciclastic grains can be described by:

1. Mineralogy: using modifiers such as "quartz," "zeolitic," "lithic" (for rock fragments), or "calcareous" (for detrital clasts of calcium carbonate).

2. Provenance: source of rock fragments (particularly in gravels, conglomerates, and breccias) can be described by modifiers such as volcanic, sed-lithic (contains clasts or grains of sedimentary rock), basaltic, etc.

Volcaniclastic grain composition is described by the following major and minor modifiers: lithic (rock fragments), vitric (glass and pumice), volcanic sed-lithic (contains clasts or grains of volcaniclastic rock), and crystal (mineral crystals and cleavage fragments), or by modifiers describing the composition of lithic grains and crystals (e.g., basaltic or feldspar). Sediment fabric can be described by the major modifiers: grainsupported, matrix-supported, and imbricated. Generally, fabric descriptors are applied only to gravels, conglomerates, and breccias.

Degree of consolidation is described using the following major modifiers: "unlithified" designates soft sediment that is readily deformable under the pressure of a finger, "partially lithified" designates firm sediment that is incompletely lithified, and "lithified" designates hard, cemented sediment that must be cut with a saw.

Grain shapes are described by the major modifiers: rounded, subrounded, subangular, and angular. Sediment color is determined with the Munsell Chart, a standard color-comparator, and can be employed as a major modifier.

# X-ray Diffraction Analysis

A Philips ADP 3520 X-ray diffractometer was used for the X-ray diffraction (XRD) analysis of bulk samples. Cu K-alpha radiation with a Ni filter was used with a tube voltage of 40 kV and a tube current of 35 mA. Bulk samples were freeze-dried and ground using the Spex 8000 Mixer Mill or with an agate mortar and pestle, pressed into a sample holder and scanned from  $2^{\circ}$  to  $60^{\circ}$  20, with a step size of  $0.02^{\circ}$  20 and a count time of 1 s per step.

# BIOSTRATIGRAPHY

Calcareous nannofossils, radiolarians, and ichthyoliths were analyzed during Leg 136 for biostratigraphic purposes. Age assignments are based mainly on core-catcher samples that were taken from the bottom of each core that contained sediment. Additional samples were studied when core-catcher samples were barren or when boundaries or unconformities occurred.

### **Calcareous Nannofossils**

The calcareous nannofossil zonal schemes used during Leg 136 are those of Martini (1971) and Sissingh (1977).

Smear slides were prepared for each sample using Norlan Optical Adhesive as a mounting medium. The calcareous nannofossils were examined in the slides using light microscopy techniques (planepolarized light, phase contrast, and cross-polarized light) at approximately 1250× magnification. Abundance of nannofossils was estimated by traversing up to 100 fields of view across a slide and assigning the following categories:

R = rare (<1 specimen per 10 fields of view).

F = few (1-10 specimens per 10 fields of view).C = common (1-10 specimens per field of view).

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A = abundant (10-100 \text{ specimens per field of view)}.
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The state of preservation was estimated as follows:

G = good (little or no evidence of dissolution or secondary overgrowth of placoliths and discoasters).

M = moderate (dissolution and/or secondary overgrowth partially alter primary morphological characteristics, but nearly all specimens can be identified at the species level).

P = poor (severe dissolution, fragmentation, and/or secondary overgrowth with primary features largely destroyed; many specimens cannot be identified at the species and/or generic level).

# Radiolarians

Age determinations and zonal assignments of Quaternary radiolarians were derived from Nigrini (1971) and Sanfilippo et al. (1985). Cretaceous identifications were based on Pessagno (1976). Samples were disaggregated by boiling for 2–4 min in a 50:50 mixture of water and hydrogen peroxide. Calgon was also added to break up extremely clay-rich samples. After boiling, samples were sieved and gently washed through 60, 100, and 230 mesh stainless steel sieves. Residues from each sieve were collected into filter paper and dried in a standard laboratory oven. Radiolarians were picked from the residues and concentrated on separate cardboard slides for study under a binocular scope at 70×to 125× magnification.

Abundances of radiolarians were estimated by counting the number of specimens observed per tray  $(9 \times 8 \text{ cm})$  of residue. The abundances were recorded as follows:

R = Rare (1-2 specimens per tray).F = Few (3-4 specimens per tray). C = Common (5-10 specimens per tray). A = Abundant (more than 10 specimens per tray).

Preservation of radiolarians was documented in the following manner:

Good = radiolarians free of clay, pore structures and ornamentation easily visible.

Moderate = Some clay in pores of radiolarians; overall structure still visible.

Poor = radiolarians completely or nearly completely covered in clay; pore structure largely obscured.

#### Ichthyoliths

Age determinations of ichthyoliths were based on Doyle and Riedel (1979, 1985). Samples were processed for ichthyoliths in the same manner as for radiolarians (above). Ichthyoliths were picked from residue and mounted on glass slides, with cover slides fastened with Norland Optical Adhesive. The slides were studied using transmitted light microscopy at 50× magnification. Absolute numbers of each taxon were recorded per slide.

#### PALEOMAGNETISM

Paleomagnetic studies performed on board JOIDES Resolution during Leg 136 included routine measurements of natural remanent magnetism (NRM) and of magnetic susceptibility of sedimentary cores and discrete samples. Because cores are commonly affected by secondary magnetizations, alternating field (AF) demagnetization was also systematically performed. Where magnetic cleaning sufficiently isolates the primary component of remanence, paleomagnetic inclinations are used to assign magnetic polarity to the stratigraphic column and to correlate polarity reversal zones with the magnetic polarity time scale of Berggren et al. (1985).

#### **Remanent Magnetization Measurements**

The JOIDES Resolution maintained two magnetometers for measurement of magnetic remanence during Leg 136, a 2-G Enterprises (model 760R) pass-through cryogenic superconducting rock magnetometer and a Molspin spinner magnetometer. We used the spinner only for cross-calibration. An AF demagnetizer (Model 2G600) capable of alternating fields up to 20 mT is on-line with the cryogenic magnetometer. Both the cryogenic magnetometer and the AF coils are encased in a Mu-metal shield, and an automated sample-handling system moves the core sections through the AF coils and the magnetometer sensor region. The cryogenic magnetometer, AF demagnetizer, and sample-drive system are controlled by a multiserial communication board (FASTCOM 4) in an IBM PC-AT compatible computer. Measurements using the cryogenic magnetometer were controlled by a modified version of a University of Rhode Island BASIC program. Prior to receiving core, we conducted various calibration

experiments to establish the accuracy of the basic measurement apparatus and to check the operation of the processing software.

The superconducting quantum interference device (SQUID) sensors in the cryogenic magnetometer measure magnetization over an interval approximately 20 cm long. The widths of the sensor region suggest that as much as 150 cm<sup>3</sup> of core contributes to the output signal. The large volume of core material within the sensor region allows accurate determination of remanence for weakly magnetized samples despite the relatively high background noise related to the motion of the ship. The cryogenic magnetization is greater than 1 A/m, but this limitation did not affect measurement of Leg 136 cores.

The output from the cryogenic magnetometer during continuous measurement assumes a uniformly magnetized core, and provides reliable directional data when a core section larger than the sensing region is measured. Tests conducted during Leg 131 indicated that in cases where the core is not uniformly magnetized, either through natural processes or artifacts (voids in the core, or differential rotation of segments within the core liner), the values of declination, inclination, and intensity should be treated with caution.

Remanence measurements of sediments were performed by passing continuous archive-half core sections through the cryogenic magnetometer. NRM measurements were taken at intervals of 5 cm along the core and after AF demagnetization at 2, 4 or 5, 7, and 10 mT. Selected sections were treated to 12 and 15 mT, the maximum AF demagnetizing field allowed by the Information Handling Panel (IHP) for archive-half sections. We should report that in our search for the stable remanence we overlooked the other IHP limitation (median destructive field) but as that is more dependent on contamination than on any paleomagnetic property of these cores, we do not expect this violation to handicap future workers. (Indeed much of the remanence is so soft that it would probably decay naturally in the course of a few years).

Discrete samples in soft sediment were taken with oriented plastic sampling boxes, both of standard size  $(7 \text{ cm}^3)$  and miniatures  $(1 \text{ cm}^3)$ . With the exception of NRM of continuous sections of miniature samples across the 5-cm intervals of whole-core taken for pore-water chemistry, measurements of discrete samples were deferred for shore-based study.

We did not use the GSD1 AF demagnetizer above 15 mT, so that the problems of anhysteretic and gyromagnetic remanence reported on Leg 134 did not affect us.

## **Perturbations Produced by Drilling**

Interpretations of measurements with the pass-through cryogenic magnetometer often are difficult because of mechanical disturbances such as twisting of unconsolidated sediments during XCB or rotary coring. A persistent problem is the pervasive overprint produced by drilling, as noted on previous legs. Exposure to large magnetic fields on the rig floor and contamination by rust have often been suggested as sources for these spurious magnetizations. During Leg 115, Schneider and Vandamme (*in* Backman, Duncan et al., 1988) suggested that one particular source of remagnetization was the remanent field of the core barrel.

We made a number of observations on these spurious magnetizations (see "Paleomagnetics" Section, Site 842 chapter) and also took discrete samples for shore-based work to extend the investigations made on Leg 134.

## **Magnetic Susceptibility Measurements**

Whole-core magnetic susceptibility (MS) measurements were made on all APC and selected XCB cores using a Bartington Instruments magnetic susceptibility meter (model M.S. 1) with an M.S. 1/CX 80-mm whole-core sensor loop set at 0.47 kHz. Measurements were routinely made at 2-cm intervals. The susceptibility meter is part of the multisensor track (MST) that also contains a gamma-ray attenuation porosity evaluator (GRAPE) and *P*-wave logger (see "Physical Properties" section, this chapter).

Initial magnetic susceptibility per unit volume, k, is a dimensionless scalar quantity relating the applied magnetic field vector, H, and the magnetization, M, that it induces in a material:

$$M = k \cdot H$$
.

In sediments and rocks, MS is usually a measure of the amount of magnetizable material (usually magnetite), but it is also sensitive to magnetic grain size and shape. Because the shipboard MS data gathering and processing computer programs are set up for cgs units, these are used in the site reports. A conversion to standard SI units is easily made by the multiplication of these values by a constant,

$$k_{\rm cgs} = 4\pi k_{\rm SI}$$

The Bartington MS meter has a sensitivity of  $1 \times 10^{-7}$  cgs, but on Leg 136 the weakest sediments measured had MS values one to two orders of magnitude higher.

### **Core Orientation Tool**

Two APC cores were oriented for paleomagnetic work by using the Eastman-Whipstock multishot camera tool. This unit is a small camera that takes photographs at pre-determined intervals of an orientation unit that consists of a compass and pendulum inclinometer. It is installed in a pressure housing on the sinker bar assembly that attaches the sandline to the APC core barrel. The multishot camera yields the orientation of the APC relative to magnetic north. The APC and core liner are aligned so that the camera records the angle between magnetic north and the double lines on the core liner (the working half side).

# INORGANIC GEOCHEMISTRY

The inorganic geochemistry program for ODP Leg 136 included (1) analysis of interstitial water for pH, alkalinity, salinity, chlorinity, calcium, magnesium, potassium, strontium, sulfate, silica, nitrate, ammonia, phosphate, and (2) X-ray mineralogical analysis of interstitial water squeeze cakes.

Interstitial water was obtained from the sediment by a modification of the standard method described in detail by Manheim and Sayles (1974). Whole-round (5- or 10-cm-long) core samples were collected for interstitial water analyses immediately after the core arrived on deck. Because of the interest in obtaining trace-element profiles, whole-round cores and subsequent treatments of the interstitial water (except actual squeezing) were performed in a Class 100 laminar flow bench. The sediment was extruded from the core liner, the ends and outer layer of the sediment (in contact with the core liner) were carefully removed by scraping, with a plastic spatula, the sample placed in titanium squeezers, and then placing it in a Carver Laboratory Press for removal of interstitial water. The press was operated to a pressure of about 30,000 psi (2.11 kg/m<sup>2</sup>). The sediment sample remained under pressure until water could no longer be squeezed from it. Interstitial water for shipboard determinations was collected in Nanopure water-rinsed plastic syringes, filtered through 0.2 µm Acrodiscs, and stored in plastic vials until used. Interstitial water for shore-based trace-element analysis was collected in 50-mL acid-cleaned syringes, filtered through acid-cleaned 0.22 µm Acrodiscs into 25-mL acid-cleaned linear polyethylene bottles, and acidified with 25 µL Ultrex HNO3. International Association for the Physical Sciences of the Ocean (IAPSO) standard seawater P99 was the primary standard for the shipboard water analyses.

Individual inorganic constituents were analyzed according to procedures outlined by Gieskes and Peretsman (1986) or modifications thereof as described below. Results are expressed in milli- or micromolar units. Alkalinity and pH were determined using a metrohm autotitrator with a Brinkmann combination pH electrode. Alkalinity reproducibility is better than 5%; data are given in milli-equivalents per liter. Salinity was determined using a Goldberg optical hand-held refractometer measuring the total dissolved solids.

Chlorinity was measured by a silver nitrate titration of a 200  $\mu$ L sample to which 500  $\mu$ L of a 5 M NaNO<sub>3</sub> solution was added prior to dilution to approximately 25 mL with 18 MΩ cm distilled deionized water (DD H<sub>2</sub>O). The end point of the Cl<sup>-</sup> titrations was determined electrometrically with an Ag electrode combined with a double junction reference electrode connected to a Brinkman Model 686 titroprocessor. Reproducibility of the IAPSO standard is better than 0.3% relative.

Calcium was determined by complexometric titration of 500 µL aliquots with EGTA (ethylene-bis-(oxyethylenenitrilo)-tetra-acetic acid) using GHA (2-2'-ethane-diylidine-dinitrilo-diphenol) as an indicator. To enhance the determination of the end point, the calcium-GHA complex was extracted onto a layer of butanol (Gieskes, 1973). No correction was made for strontium because it is compensated for by inclusion in the standardization vs. IAPSO.

Magnesium was determined by a total alkaline earth titration of  $250 \,\mu$ L aliquots with EDTA (di-sodium ethylenediamine-tetraacetate) (Gieskes, 1973). Subsequent use of the calculations recommended by Gieskes in the shipboard chemistry manual yielded the magnesium concentration in the interstitial water sample.

Sulfate was determined by ion-chromatography using a Dionex-2120 Ion Chromatograph. Reproducibility on different dilutions of the IAPSO standard is better than 2% relative. Determinations for  $\rm NH_4^+$ ,  $\rm NO_3^-$ ,  $\rm PO_4^{3-}$  and  $\rm SiOH_4$  were performed by colorimetric methods described by Gieskes and Peretsman (1986).

Atomic absorption spectroscopy (AAS) using a Varian Spectra AA-20 spectrophotometer was used for the determination of K and Sr. All measurements were made using an air-acetylene flame. The emission mode was employed for K whereas the absorption mode was used for Sr.

Potassium was determined on 1:500 sample dilutions; five standards ranging from 1:420 through 1:12,000 were prepared from volumetric dilutions of IAPSO with DD H<sub>2</sub>O. The reproducibility of K determinations by flame emission is approximately 2% relative.

Strontium was determined on 1:10 sample dilutions. A releasing agent was used (LaCl<sub>3</sub>~5,000 ppm) in samples and standard solutions. Five standards were prepared by diluting 0.25, 0.50, 0.75, 1.00, and 1.5 mL of IAPSO standard seawater to 10 mL with 5,000 ppm La as LaCl<sub>3</sub> in a volumetric flask. The reproducibility of determinations was approximately 3%-4% relative.

# PHYSICAL PROPERTIES

## **Index Properties**

Water content, bulk density, grain density, and derived physical properties on discrete samples were determined by methods detailed in Kate Moran's 25 November 1990 memorandum: "Recommended methods for the discrete measurement of index properties on the *JOIDES Resolution.*"

Determinations of sediment mass (in standard aluminum beakers) were performed on the matched, top-loading Scitech microbalances. Repeated measurements (n = 53) using 1000 counts indicates an operational standard deviation of 0.043 g in the weighing procedure. The Quantachrome Penta-Pycnometer helium displacement pycnometer was used to determine wet and dry volumes. Three determinations were made on each sample; evaluation of 95 such determination sets yield a standard deviation of 0.037 cm<sup>3</sup>. Samples were dried in the mechanical convection ovens at 105°C for 24 hr prior

to measuring dry weights and volumes. Grain densities were determined on eight samples in which the dry volume was determined first without crushing, and again after physical disaggregation. There was no discernible difference between the two techniques, and we are confident that the dry volume determinations are repeatable. A salt correction assuming 35 ppt interstitial fluid salinity was applied (Hamilton, 1971). Calculations were performed by the PHY SPROPS program on the ODP database, using the beaker calibrations determined on Leg 130.

Despite our concerted efforts to accurately calibrate the balances and pycnometer, bulk density determinations on discrete samples consistently fall 0.05 g/cm<sup>3</sup> below the GRAPE results. As that unit is calibrated directly to density, we suspect a systematic error in either the sample weight or volume determinations on the individual sediment samples.

## Shear Strength

Shear strength was measured on the Wykeham-Farrance apparatus, as the automated vane shear instrument could not be calibrated. All determinations were made on freshly split cores by inserting a 1.28-cm vane (#8; 1:1 blade ratio) about 1 cm beneath the sediment surface. The test was conducted at a rotation rate of  $60^{\circ}$ /min in the motorized mode. Springs 1 and 2 were used to produce shearing within 20–70° rotation; existing calibrations were used although they were apparently last checked in 1973 (Boyce, 1973). Calculations were performed on the PHYSPROPS program within the ODP database.

Vane tests assume that a sediment cylinder is sheared in an undrained condition, and that the shear strength is attributable primarily to cohesion. These assumptions may be invalidated by cracking, dissipation of local pore pressure by drainage, nonuniform failure, and frictional effects induced by large grains. The sediments in the upper 20 m of Site 842 include silts and radiolarians that may exhibit less than ideal behavior. For this reason, and because some of the core has been disturbed by drilling, the minivane test probably does not provide a true sediment shear strength. Nevertheless, the test does provide an estimate of downcore strength.

#### GRAPE

All cores were run through the gamma-ray attenuation porosity evaluator (GRAPE), and associated detectors on the multisensor track prior to splitting, and after thermal equilibration. Scans were made at a rate of 0.763 cm/s and counts were accumulated for 2 s, so that the interval scanned by a single determination is approximately 1.5 cm. An air and aluminum standard was used to calibrate the beam. The standard error of the bulk density determinations is 10% (Boyce, 1976), but because the number of determinations per core section (approximately 90) is large, the results are probably more accurate than the discrete determinations, particularly when a moving average is used to discriminate against high-frequency variability.

#### Sonic Velocities

#### Compressional-Wave Velocity Logger (P-wave logger)

Compressional-wave (*P*-wave) velocities were obtained at alongcore intervals of about 2 cm using the *P*-wave logger (PWL) on the multisensor track (MST) (Boyce, 1976). The measurements were taken on whole-round sections lying inside the core liner. The sound source on the MST is a 500-kHz impulse repeated at a frequency of 1 kHz. The source and receiving transducers are mounted along an axis perpendicular to the core axis; the separation between these transducers is measured using a pair of displacement transducers. Before any measurements were taken, the PWL was calibrated using samples of distilled water, glycerol, and ethylene glycol as standards. These samples fill a short length of core liner. Calibration results in a single correction factor for the combined effects of physical wear on the transducers and traveltime through the core liner. The thickness of the core liner is assumed constant.

# Hamilton Frame Velocimeter

In addition to the data provided by the PWL, *P*-wave velocities were also measured using the screw-press Hamilton Frame Velocimeter (Boyce, 1976). The traveltime of a 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. Nominal measurement errors were 0.4 mm and 0.2  $\mu$ s. For the soft sediments cored at Site 842, velocities were measured about every 75 cm by mounting the splitcore section and core liner between the jaws of the velocimeter; all velocity measurements were taken perpendicular to the core axis. Seawater was used to improve the acoustic contact between the sample and the transducers. Routinely, velocity and index properties samples were taken from adjacent positions in the core.

The Hamilton Frame transducers and calipers were calibrated with lucite and aluminum standards of known velocity and thickness. Thickness and traveltime corrections (i.e., "zero" thickness and "zero" time) were calculated by performing a linear regression between the actual and measured times and the actual and measured distances. For the traveltime calibration, the slope and intercept of the best-fit straight line were 0.98 and -2.46, respectively. For the distance calibration, these parameters were 1 and -0.21 mm, respectively. Application of these correction factors to the measurements made on the aluminum and lucite standards resulted in errors of up to 2.5%.

The traveltime and thickness of the core liner were also measured using the Hamilton Frame. Corrected velocities were calculated by applying the traveltime and thickness corrections to the measured data and subtracting the effects of the core liner. In practice this results in the cancellation of both intercept factors discussed above. An independent measurement of the core liner traveltime would allow a more accurate estimate of sample velocity. As mentioned in the previous section, the traveltime correction for the core liner could not be extracted from the software that controls the MST.

For Site 842, the velocities measured using the Hamilton Frame were about 3% larger than the MST values. This discrepancy is probably due to inaccurate correction of the sample thickness and traveltime measurements. An additional source of discrepancy is the difference in the correction factors for the core liner. Accordingly, the PWL data are probably more reliable than the Hamilton Frame measurements.

## **Thermal Conductivity**

Thermal conductivity (k) was measured by monitoring the change in temperature of the sample as a function of time when the sample is heated at a known rate by means of a needle probe. The probe contains both a heater wire and a calibrated thermistor. Prior to taking the measurements, the cores were allowed to equilibrate at 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 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 standards. Conductivity measurements were made using both the "full space" method described by Von Herzen and Maxwell (1959) and the "half space" method described by Vacquier (1985). The former technique was used on whole-round sediment samples cored at Site 842, and the latter technique was used to measure the conductivity of the basalts cored at Site 843. The probes used for the full space method were calibrated using the red rubber (k = 0.96 W/m·°C) and black rubber (k = 0.54 W/m·°C) standards. In addition to the above standards, the probes used for the half space method were calibrated using a sample of basalt of known conductivity (k = 2.05 W/m·°C). For each probe, about three measurements were made on each standard. Applying these correction factors to the measured values of the standards results in errors of about 5% in the case of the full space method.

The full space method, which assumes a medium of infinite extent, predicts that the temperature variation is a linear function of the natural logarithm of the time. The conductivity is estimated by calculating the slope of the best-fit straight line to a plot of temperature versus the natural logarithm of time; the value of the slope is inversely proportional to the conductivity. Specifically, the data are fit to the following equation:

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

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 linear term in the variable t accounts for the temperature drift of the sample during the measurement. The procedure for the half space method is similar except that the slope is multiplied by a probe-specific constant that has a value of 2 in the ideal case of no heat loss to the insulating material that supports the sample. In practice, the assumptions of infinite and semi-infinite media break down after a few minutes. This is readily recognized on inspection of the temperature vs. time plot by a decrease in the rate of change of temperature as a function of the logarithm of the time. Consequently, for both methods, the estimated conductivity is dependent on the time interval over which the slope is calculated.

This dependency of the conductivity estimate on the time interval is especially pronounced for the case of the half space method. For this technique, factors in addition to edge effects lead to a nonlinear relationship between temperature and the logarithm of the time (Shipboard Scientific Party, 1989). For the half space measurements, it was impossible to choose a consistent sample interval over which to estimate the conductivity. Inclusion or exclusion of a couple of points resulted in changes in the estimate of thermal conductivity of up to 20%. Repetition of the experiment using either the same or a different probe sometimes resulted in a similar variability. This sensitivity to the time interval over which the conductivity was estimated was not observed for the full space measurements made on the sediment samples.

The precision of the full space measurements is estimated to be about 5%. It is difficult to estimate the precision of the half space method. A crude estimate was derived by calculating the standard deviation about the mean of about ten measurements, each measurement being based on either a different time interval or a different run. A measurement was deemed acceptable if (1) the standard deviation about the best-fit straight line to the plot of temperature vs. the logarithm of the time was less than 0.015, and (2) the linear drift coefficient was less than 0.04°C/min. This approach results in a precision of about 10%. However, this value is only an estimate because it was not feasible to measure all the values that met the above criteria. Based on the sensitivity of the conductivity estimate to the time segment, it seems more likely that the real precision is closer to 20% than 10%. The thermal conductivity data were not corrected to *in-situ* temperature and pressure. All measurements are reported in units of W/m.°C.

# **IGNEOUS ROCKS**

## **Core Curation and Shipboard Sampling**

To preserve important features and structures, core sections containing igneous rocks were examined prior to splitting. During core handling and splitting, core orientation was preserved by carefully marking the original base of individual pieces. Each piece was numbered sequentially from the top of each core section and labeled at the top surface. Pieces that could be fitted together were assigned the same number and were lettered consecutively (e.g., 1A, 1B, and 1C), even if they occupied more than one section. Plastic spacers were placed between pieces with different numbers. The presence of a spacer, therefore, may represent a substantial interval of no recovery. If it was evident that an individual piece had not rotated about a horizontal axis during drilling, an arrow was added to the label pointing to the top of the section. As all pieces were free to turn about a vertical axis during drilling, azimuthal orientation of the core was not possible. After the vertical core orientation was noted, the pieces were split with a diamond saw into archive and working halves, with care taken to ensure the division of key features.

After the core was split, the working half was sampled for shipboard physical properties, magnetic studies, X-ray fluorescence, Xray diffraction, and thin-section studies. Nondestructive physical property measurements, such as magnetic susceptibility, were made on the archive half of the core. Where recovery permitted, samples were taken from each lithologic unit for XRF analysis for major elements. The archive half was described on the visual core description form and was photographed before storage.

## Visual Core Descriptions

Visual core description forms were used in the documentation of the igneous rock cores (see site summary appendixes). 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: X = X-ray diffraction analysis; F = X-ray fluorescence analysis; T = petrographic thin section; P = physical properties analysis; and M = paleomagnetic analysis.

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

When describing sequences of rocks, 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 Munsell 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 {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 (including the proportion of vesicles that are filled by alteration minerals).

H. The rock structure: determining whether the flow is massive, pillowed, thin or sheetlike, brecciated, or a hyaloclastite.

I. The relative amount of rock alteration, expressed both in the description and next to the graphic description of the archive half. 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%). These grades of alteration were expressed in columnar form as F, S, M, H, V, and C, respectively. The type, form, and distribution of alteration were also noted.

J. The presence of veins and fractures, including their abundance, width, mineral fillings or coatings, and orientation. The orientation of veins and fractures was measured with a protractor, such that the top of each core is considered 0 degrees.

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

Basalts and diabases are termed aphyric (<1%), sparsely phyric (1%–2%), moderately phyric (2%–10%), or highly phyric (>10%), depending upon the proportion of phenocrysts visible with the hand lens or binocular microscope. Basalts are further classified by phenocryst type (e.g., a moderately phyric plagioclase olivine basalt contains 2%–10% phenocrysts, mostly plagioclase, with subordinate olivine). Volcanic rock names were initially assigned from megascopic phenocryst assemblages. Where chemical analyses or thin sections were available, more specific rock names were given.

Lavas erupted on the seafloor typically show a sparsely crystalline glassy margin overlying a variolitic (synonymous with spherulitic) zone of quench phases, which may then grade into a coarser microlitic zone toward the interior of the flow. In many samples, these zones are not well defined, and may be expressed as alternating layers or areas. Varioles commonly show a sheaf-like or radial form, and microlites commonly show crystal clustering networks in areas of microlitic texture. We follow Bryan (1972) and Natland (1978) in interpreting these textures as quenchgrowth features. Finally, we use the term subophitic to refer to groundmass textures where individual plagioclase grains are partially surrounded by clinopyroxene grains with little to no glass.

Visual core descriptions of igneous rocks are given in the site summary appendixes, 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 HRTHIN. The same terminology was used for thin section descriptions as was used for the megascopic descriptions. Thin-section descriptions are included in the site summary appendixes and are also available from the ODP computerized database.

## 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 cm<sup>3</sup> of material was ground to ensure representativeness of the 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 an 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<sub>2</sub>O<sub>3</sub>. 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. It was then 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:

$$C_{\rm i} = (I_{\rm i} \cdot m_{\rm i}) - b_{\rm i}$$

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, JGB-1, JP-1, BR, and DRN). The analyses of these standards derived from the calibration curves used are given in Table 2. 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 the *JOIDES Resolution*, and was performed with particular care as weighing errors could be a major source of imprecision in the final analysis. To maintain internal consistency, all weighing was done by Joan Perry (Leg 136) or Don Sims (Leg 137), the XRD/XRF technicians. 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  $\approx 1\%$  for Si, Ti, Fe, Ca, and K, and to between 3% and 5% for Al, Mn, Na, and P. Analytical conditions for the XRF analyses are given in Table 2 and the results of measurements of the internal rock standard BHVO-1 are reported in Table 3.

## DOWNHOLE MEASUREMENTS

#### **Tool Strings**

Downhole logs can be used to characterize the geophysical, geochemical, and structural properties of a drilled sequence. Log measurements have the advantage over core-based measurements in that they represent continuous and *in-situ* measurements of the borehole. After coring is completed at a hole, a tool string is lowered downhole on a seven-conductor cable, and each of several tools in the tool string continuously monitors some property of the borehole. Three Schlumberger tool strings were used on Leg 136: (1) the Quad-tool (seismic-stratigraphic and litho-density tools), (2) geochemical, and (3) formation microscanner (FMS) combinations. The Lamont-Doherty temperature tool (TLT) was attached to the base

of each Schlumberger tool string. The analog borehole televiewer (BHTV) was also used in the basement interval of Site 843.

The Quad-tool combination used on Leg 136 comprised a digital string, consisting of long-spaced sonic transducer/receiver with a digital sonic cartridge (LSS), high-temperature lithodensity tool (HLDT), dual induction tool (DIT), compensated neutron porosity tool (CNT), mechanical caliper (MCD), and natural gamma-ray tool (NGT). This tool combination measures compressional-wave velocity and provides indicators of the two variables that most often control velocity: porosity, as indicated by density or resistivity, and clay content, as indicated by the natural gamma tool. The Quad-tool combination can be broken down into two strings: the seismic stratigraphic combination and the litho-porosity combination. The seismic stratigraphic string comprises the LSS/SDT, DIT, and NGT. The litho-porosity string combines the HLDT, CNT, and NGT.

The geochemical tool combination used during Leg 136 consists of the NGT, aluminum clay tool (ACT), gamma-ray spectrometry tool (GST), and compensated neutron porosity (CNT). This tool string measures the relative concentrations of 12 elements: silicon, calcium, aluminum, iron, titanium, sulfur, hydrogen, chlorine, potassium, thorium, uranium, and gadolinium.

The formation microscanner tool string includes both the FMS and a general purpose inclinometer tool (GPIT) that spatially orients the FMS resistivity image of the borehole wall. The tool string also contains a natural gamma-ray tool (NGT) to allow depth correlation of the FMS data with other logs.

#### Logs

A condensed description of the physical principles of the various logging tools follows; more detailed descriptions have been prepared by Schlumberger (1989), Serra (1984, 1989), and Timur and Toksoz (1985).

## **Electrical Resistivity**

The dual induction tool (DIT) provides three different measurements of electrical resistivity, each one capable of penetrating a different depth into the borehole wall. Two induction devices: deep (ILD), and medium (ILM, resistivity) send high-frequency alternating currents through transmitter coils, creating magnetic fields that induce secondary (Foucault) currents in the formation. These ground-loop currents produce new inductive signals, proportional to the conductivity of the formation, which are recorded by the receiving coils. Measured conductivities then are converted to resistivity. A third device (spherically focused resistivity, SFL) measures the current necessary to maintain a constant voltage drop across a fixed interval between electrodes. Vertical resolution is around 2 m for the ILM and ILD and about 1 m for the SFL.

Water content and salinity are by far the most important factors controlling the electrical resistivity of rocks. To a first order, resistivity responds to the inverse square root of porosity (Archie, 1942). Other factors influencing resistivity include the concentration of hydrous and metallic minerals, vesicularity, and the geometry of interconnected pore space.

### Sonic Velocity

The long-spaced sonic (LSS) tool uses two acoustic transmitters and two receivers to measure the time required for sound waves to travel over source-receiver distances of 2.4, 3.0, and 3.6 m. The raw data are expressed as time required for a sound wave to travel through 0.31 m of formation; these traveltimes are then converted to sonic velocities. First arrivals for the individual source-receiver paths are used to calculate the velocities of the different waves traveling in the formation (compressional, shear, etc.). Only compressional-wave velocity is determined during data acquisition, but the recorded fullwaveforms may be processed post-cruise to improve the compressional-wave

					Peak	Background	Total count time (seconds)	
Element	Line	Crystal	Detector	Collimator	(deg.)	(dcg.)	Peak	Background
SiO <sub>2</sub>	Κα	PET(002)	FPC	Coarse	109.10	0	40	0
TiO <sub>2</sub>	Κα	LiF(200)	FPC	Fine	86.16	0	40	0
Al2Õ3	Kα	PET(002)	FPC	Coarse	144.49	0	100	0
Fc203*	Κα	LiF(200)	FPC	Fine	57.53	0	40	0
MnO	Kα	LiF(200)	KrSC	Fine	63.03	0	40	0
MgO	Kα	TLAP	FPC	Coarse	44.88	$\pm 0.80$	200	400
CaO	Kα	LiF(200)	FPC	Coarse	113.18	0	40	0
Na <sub>2</sub> O	Kα	TLAP	FPC	Coarse	54.73	- 1.20	200	200
K20	Kα	LiF(200)	FPC	Fine	136.66	0	40	0
P205	Kα	Ge(111)	FPC	Coarse	141.00	0	100	0
Rh	K-C	LiF(200)	Scint	Fine	18.60	0	100	0
Nb	Κα	LiF(200)	Scint	Fine	21.39	$\pm 0.35$	200	200
Zr	Kα	LiF(200)	Scint	Fine	22.54	± 0.35	100	100
Y	Kα	LiF(200)	Scint	Fine	23.83	$\pm 0.40$	100	100
Sr	Kα	LiF(200)	Scint	Fine	25.15	$\pm 0.41$	100	100
Rb	Kα	LiF(200)	Scint	Fine	26.60	$\pm 0.60$	100	100
Zn	Kα	LiF(200)	Scint	Fine	41.81	$\pm 0.40$	60	60
Cu	Kα	LiF(200)	Scint	Fine	45.02	$\pm 0.40$	60	60
Ni	Kα	LiF(200)	Scint	Coarse	48.64	$\pm 0.60$	60	60
Cr	Kα	LiF(200)	FPC	Fine	69.38	± 0.50	60	60
Fe	Kα	LiF(220)	FPC	Fine	85.73	$-0.40 \pm 0.70$	40	40
V	Kα	LiF(220)	FPC	Fine	123.20	- 0.50	60	60
TiO <sub>2</sub>	Kα	LiF(200)	FPC	Fine	86.16	± 0.50	40	40
Ce	Lα	LiF(220)	FPC	Coarse	128.35	$\pm 1.50$	100	100
Ba	Lβ	LiF(220)	FPC	Coarse	128.93	$\pm 1.50$	100	100

#### Table 2. Leg 136 XRF analytical conditions.

\*Total Fe as Fe<sub>2</sub>O<sub>3</sub>

FPC: Flow proportional counter using P10 gas

KrSC: Scaled krypton gas counter

Scint: NaI scintillation counter

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

velocity or for determination of shear-wave velocities in hard formations. The vertical resolution of the tool is 0.61 m. Compressional-wave velocity is dominantly controlled by porosity and lithification; decreases in porosity and increases in lithification cause the velocity to increase.

### Natural Gamma Ray

The natural gamma-ray tool (NGT) measures the natural radioactivity of the formation. Most gamma rays are emitted by the radioactive isotope <sup>40</sup>K and by the radioactive elements of the U and Th series. The gamma-ray radiation originating in the formation close to the borehole wall is measured by a scintillation detector mounted inside the sonde. The analysis is achieved by subdividing the entire incident gamma-ray spectrum into five discrete energy windows. The total counts recorded in each window, for a specified depth in the well, are processed to give the elemental abundances of K, U, and Th.

Because radioactive elements tend to be more abundant in clay minerals relative to other common sedimentary minerals, the gammaray curve is commonly used to estimate the clay or shale content. Other rock or sediment types may also have radioactivity values ranging from moderate to extremely high, because of the presence of volcanic ash, potassium feldspar, or other radioisotope-containing minerals.

## Lithodensity Tool

The high-temperature lithodensity tool (HLDT) uses a <sup>137</sup>Ce gamma-ray source and measures the resulting flux at fixed distances from the source. Under normal operating conditions, attenuation of gamma rays is caused chiefly by Compton scattering (Dewen, 1983). Formation density is extrapolated from this energy flux by assuming that the atomic weight of most rock-forming elements is approximately twice the atomic number. A photoelectric effect index is also

provided. Photoelectric absorption occurs in the energy window below 150 keV and depends on the energy of the incident gamma ray, the atomic cross section, and the nature of the atom. Because this measurement is almost independent of porosity, it can be used directly as an indicator of matrix lithology. The radioactive source and detector array are placed in a tool that is pressed against the borehole wall by a strong spring arm; position of this spring arm indicates hole diameter. Excessive roughness of the hole will cause some drilling fluid to infiltrate between the skid and the formation. As a consequence, density readings can be artificially low. Approximate corrections can be applied by using caliper data. The vertical resolution is about 0.30 m.

#### **Compensated Neutron Porosity**

A radioactive source mounted on the compensated neutron porosity tool (CNT) sonde emits fast neutrons (4 MeV) into the formation, where they are scattered and slowed by collisions with other nuclei. When the neutrons reach a low energy level (0.025 MeV) they are captured and absorbed by atomic nuclei such as hydrogen, chlorine, silicon, and boron. The scattering cross section is the quantity that describes the rate at which neutrons are slowed. Because the scattering cross section for hydrogen is about 100 times larger than for any other common element in the crust, most energy dissipation is caused by collisions with water molecules. Therefore, a change in the number of neutrons detected at a receiver can be related to porosity. In practice, an array of detectors is used to minimize hole size or drilling fluid effects. Because water is present both in pores and as bound water (e.g., clay minerals), porosity measurements made in the presence of hydrous minerals are overestimates of the true porosity. The vertical resolution of the tool is theoretically about 0.25 m, but low signal-to-noise ratio degrades this potential resolution.

Table 3. Leg 136 analyses of standards derived from the calibrations used for whole-rock analysis.

Element	Given	А	в
SiO <sub>2</sub>	49.62	50.20	49.75
TiO <sub>2</sub>	2.68	2.76	2.73
Al <sub>2</sub> Õ <sub>3</sub>	13.67	13.66	13.98
Fc2O3	12.23	12.37	12.25
MnO	0.17	0.17	0.17
MgO	7.21	7.11	7.12
CaO	11.32	11.60	11.48
Na <sub>2</sub> O	2.17	2.22	2.24
K <sub>2</sub> Õ	0.53	0.54	0.53
P205	0.27	0.27	0.27
Total	99.87	100.90	100.52

### Mechanical Caliper Device

The mechanical caliper device (MCD) provides a two-dimensional caliper log of the borehole by means of a bowspring-mounted measurement system. The hole diameter (HD) log is used to detect washouts or constrictions. Borehole diameter significantly affects many of the other logging measurements, and the hole diameter is an important source of data for log correction routines. The MCD caliper tool is subject to sticking when formation mud gets into its mechanical parts, resulting in bimodal (fully open or nearly fully closed) readings. In contrast, the hole diameter measurement produced by the high-temperature lithodensity tool is much more reliable. Consequently, on Leg 136 the MCD tool was used primarily to provide tool centralization and to improve the quality of the sonic log, rather than to measure hole diameter.

### Gamma Spectrometry Tool

The induced gamma-ray spectrometry tool (GST) consists of a pulsed source of 14-MeV neutrons and a gamma-ray scintillation detector. A shipboard computer performs spectral analysis of gamma rays resulting from the interactions of neutrons emitted by the source with atomic nuclei in the formation (Hertzog, 1979). Characteristic sets of gamma rays from six elements dominate the spectrum, permitting calculation of yields from six elements: Ca, Si, Fe, Cl, H, and S. The tool normalizes their sum, so they do not reflect the actual composition but only relative abundances of these elements. Therefore, ratios of these yields are commonly used in interpreting the lithology, porosity, and salinity of the formation fluid. Shore-based processing is used to derive actual elemental abundances from this and the other logs.

#### Aluminum Clay Tool

Aluminum abundance as measured by the aluminum clay tool (ACT) is determined by neutron-induced (Cf nuclear source) late gamma-ray spectrometry. By placing NaI detectors both above and below the neutron source, contributions from natural gamma-ray activity can be removed. Calibration to elemental weight percent is done by taking irradiated core samples of known volume and density and measuring their gamma-ray output while placed in a jig attached to the logging tool, usually after logging.

#### Formation Microscanner (FMS)

The FMS produces high-resolution microresistivity images of the borehole wall that can be used for detailed sedimentological or structural interpretations, and for determining the orientation of fractures and breakouts. The tool consists of sixteen electrode "buttons" on each of four orthogonal pads that are pressed against the borehole wall. The electrodes are spaced about 2.5 mm apart and are arranged in two diagonally offset rows of eight electrodes each. The focused current that flows from the buttons is recorded as a series of curves that reflect the microresistivity variations of the formation. Shipboard or shorebased processing converts the current intensity measurements into complete, spatially-oriented images. Further processing can also provide measurements of dip angle and dip direction or azimuth of bedding surfaces.

Applications of the FMS images include: detailed correlation of coring and logging depths; orientation of cores; mapping of fractures, faults, foliations, and formation structures; and determining strikes and dips of bedding. An important limitation is the restriction to a hole diameter of less than 41 cm (16 in.); thus little useful information can be obtained from washed-out hole sections.

# General Purpose Inclinometer Tool (GPIT)

This tool provides a measurement of borehole inclination, the orientation of the tool with respect to the earth's magnetic field using a three-component magnetometer, and tool motion using an accelerometer. It is run with the FMS to provide spatial orientation of the borehole pads.

# **Borehole Televiewer**

The borehole televiewer (BHTV) produces an ultrasonic acoustical image of the borehole wall. A transducer emits ultrasonic pulses at a frequency of 1.3 MHz that are reflected at the borehole wall and then received by the same transducer. The amplitude and traveltime of the reflected signal are determined and stored on video tape or in the logging computer. A continuous rotation of the transducer and the upward motion of the tool produces a complete map of the borehole wall.

The amplitude depends on the reflection coefficient of the borehole fluid-rock interface, the position of the BHTV tool in the borehole, the shape of the borehole, and the roughness of the borehole wall. The change of the borehole wall's roughness (e.g., at fractures intersecting the borehole) is responsible for the modulation of the reflected signal; therefore fractures or changes in character of the drilled rocks can easily be recognized in the amplitude image. On the other hand, the recorded traveltime image gives detailed information about the shape of the borehole: knowing the velocity of the ultrasonic signal in the borehole fluid allows calculation of one caliper value of the borehole from each recorded traveltime. As 128 points are typically recorded per transducer revolution, the BHTV can be regarded, in effect, as a "multi-arm caliper log."

Amplitude and traveltime are recorded together with a reference to magnetic north by means of a magnetometer, permitting orientation of images. If features (e.g., fractures) recognized in the core are observed in the BHTV images, orientation of the core is possible. The BHTV can also be used to measure stress in the borehole through identification of borehole wall breakouts. In an isotropic, linearly elastic rock subjected to an anisotropic stress field, breakouts form in the direction of the axis of least principal horizontal stress.

Initial data analysis (breakouts, azimuth, hole radius, fracture/foliation azimuth, and inclination) can be performed using the Masscomp and Macintosh computers after the data have been transferred from videotape (or for the digital tool, from the data acquisition PC).

### LDGO Temperature Tool

The LDGO temperature tool is a self-contained tool that can be attached to any Schlumberger tool string. Data from two thermistors (one taking measurements once every second and the other once every 5 s) and a pressure transducer (sampling every 5 s) are collected and stored in a Tattletale computer within the tool. Following the logging run, data are dumped from the Tattletale to the Masscomp computer

for analysis. The fast-response, lower accuracy thermistor is able to detect sudden, very small temperature excursions caused by fluid flow from the formation. The slow-response, higher accuracy thermistor can be used to estimate heat flow if one knows the history of drilling-fluid circulation in the hole and if one has at least two temperature logs (Jaeger, 1961). Data are recorded as a function of time; conversion to depth can be based on the pressure transducer or, preferably, on simultaneous recording of an elapsed time vs. depth, usually provided by Schlumberger.

# Log Data Quality

The quality of the log data may be seriously degraded in excessively large sections of the borehole by high wall rugosity or by rapid changes in the hole diameter. Resistivity and velocity measurements are less sensitive to changes in borehole size, whereas the nuclear measurements (density, neutron porosity, and both natural and induced spectral gamma ray) are most seriously impaired because of the large attenuation by the borehole fluid. Corrections can be applied to the original data to reduce the effects of these conditions and, generally, any departure from the conditions under which the tool was calibrated.

Different logs may have small depth mismatches, caused by either stretching of the cable or heaving of the ship during recording. Small errors in depth matching can impair the results in zones of rapidly varying lithology. To minimize such errors, a wireline heave motion compensator (HMC) adjusts for rig motion. Precise depth matching of logs with cores is not possible in zones where core recovery is low because of the inherent ambiguity of placing the recovered section within the interval cored.

### Log Analysis

During logging, incoming data are observed in real time on a monitor oscilloscope and simultaneously recorded on digital tape in the Schlumberger logging unit. After logging, these tapes are read by the Masscomp computer system or the Vaxstation 3200 in the downhole measurements laboratory and reformatted to a file format compatible with the Terralog log-interpretation software package. Terralog is an interactive system permitting many log manipulation and plot options. Thus, the log analysis and interpretation varies in duration and procedure for each site. Most of the log interpretation is carried out aboard ship; further analysis and interpretation are done after the cruise using a companion system in the Borehole Research Laboratory of Lamont-Doherty Geological Observatory.

## **Reprocessing of Logs**

Sonic logs obtained in real time are not based on full-waveform analysis, but on a threshold-picking technique that detects the compressional-wave arrival by a first-break criterion. Occasionally this technique fails because the threshold is exceeded by noise, or the first compressional arrival is attenuated. These phenomena, noise precursors and cycle skipping, create spurious spikes on the sonic log. On Leg 136, raw traveltimes were reprocessed when necessary with an algorithm designed to reject cycle skips (Shipboard Scientific Party, 1987).

Raw geochemical logs for Leg 136 are shown following the barrel sheets for each site at which the geochemical tool string was run. Raw count rates for six elements (Ca, Si, Fe, S, Cl, and H) are obtained in real time by the Schlumberger data acquisition software. Post-cruise reprocessing utilizes a Schlumberger Elite 1000 workstation and proprietary Schlumberger software. The gamma spectrum at each depth is inverted for titanium, gadolinium, and potassium in addition to the six elements in the shipboard inversion. Though gadolinium is present in concentrations of only a few parts per million, its neutroncapture cross section is so large that it can account for 10%–30% of the total gamma spectrum. Inclusion of these additional elements improves the quality of the overall inversion, particularly improving the accuracy of calculated calcium abundance, by converting sources of unaccounted variance to signals. Aluminum concentrations from the aluminum clay tool are adjusted for variations in cable speed. Changes in logging speed affect the time lag between neutron irradiation of the formation and recording of the induced gamma spectrum because the number of induced gamma rays decreases rapidly with time. However, the small amount of ship heave during logging may make this correction less reliable in ODP holes than in land wells.

When the lithodensity tool is also run at the same site where the geochemical tool string is run, further reprocessing of geochemical logs is possible. The relative abundances of Ca, Si, Fe, Ti, Al, K, S, Th, U, and Gd are used to calculate a log of predicted photoelectric effect. The difference between this log and the actual log of photoelectric effect can be attributed to the only two major elements not directly measured, Mg and Na. Major elements are expressed in terms of oxide dry weight percent, based on the assumption that oxygen is 50% of the total dry weight.

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