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

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

## INTRODUCTION

Standard procedures for both drilling operations and preliminary shipboard analysis of the material recovered during Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP) drilling have been regularly amended and upgraded since drilling began in 1968. 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* of the Leg 121 *Proceedings of the Ocean Drilling Program*. Methods used by various investigators for shorebased analysis of Leg 121 data will be detailed in the individual scientific contributions published in the *Scientific Results* of this volume.

The Leg 121 *Initial Reports* is organized into an introductory part, in which the background and objectives, this chapter, and the underway geophysics and seismic survey data for the leg are presented. This general section is then followed by the individual site chapters. The volume ends with a summary section, in which the shipboard party discusses the Broken Ridge and Ninetyeast sites and the Cretaceous/Tertiary boundary cored at Site 752.

### Authorship of Site Chapters

Authorship of the site report is shared among the entire shipboard scientific party, although the two co-chief scientists and the staff scientist edited and rewrote part of the material prepared by other individuals. The site chapters are organized as follows (authors are listed in alphabetical order in parentheses; no seniority is necessarily implied):

Site Summary (Peirce, Weissel)

Background and Objectives (Peirce, Weissel)

Operations (Huey, Taylor)

Lithostratigraphy (Dehn, Driscoll, Farrell, Janecek, Owen, Rea)

Biostratigraphy (Fourtanier, Gamson, Nomura, Pospichal, Resiwati, Smit)

Paleomagnetics (Gee, Klootwijk, Smith)

Inorganic Geochemistry (Lawrence)

Organic Geochemistry (Littke)

Physical Properties (Newman, Tamaki, Taylor)

Igneous Petrology (Frey, Gibson, Saunders, Weis)

Logging (Wilkinson)

Seismic Stratigraphy (Driscoll, Newman)

Following the text of each site chapter are summary core descriptions ("barrel sheets"); photographs of each core are also published in the *Initial Reports*.

# Survey and Drilling Data

The survey data used for specific site selections are discussed in each chapter. Surveys using a precision echo-sounder and seismic profiles were made aboard *JOIDES Resolution* for the Broken Ridge sites and while approaching each Ninetyeast Ridge site. Geophysical survey data (seismic profiles) collected during Leg 121 are presented in the "Underway Geophysics" chapter of this volume.

The seismic-profiling systems consisted of two 80-in.<sup>3</sup> water guns with a 100-m-long hydrophone array designed at Scripps Institution of Oceanography, Bolt amplifiers, two band-pass filters, and two Raytheon recorders, usually recording at two different filter settings (20–300 and 30–300 Hz) and two different scales.

The 3.5- and 12-kHz bathymetric data were displayed on Precision Depth Recorder (PDR) systems. The depths were converted on the basis of an assumed 1463 m/s sound velocity in seawater. The water depth (in meters) at each site was corrected (1) for the variation in sound velocity with depth using Matthews' (1939) tables and (2) for the depth of the hull transducer (6.8 m) below sea level. In addition, depths referred to the drilling-platform level are assumed to be 10.87 m above the water line (see Fig. 1).

Magnetic data were recorded using a Geometrics 801 Proton Precession magnetometer and were displayed on a strip chart recorder.

## **Drilling Characteristics**

Because water circulation down the hole is open, cuttings are lost onto the seafloor and cannot be examined. The only available information about sedimentary stratification in uncored or unrecovered intervals, other than from seismic data or wirelinelogging results, is 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, however, determine the rate of penetration, so it is not always possible to relate drilling time directly to the hardness of the layers. Bit weight and revolutions per minute, recorded on the drilling recorder, influence the penetration rate.

#### **Drilling Deformation**

When cores are split, many show signs of significant sediment disturbance, including the downward-concave appearance of originally horizontal bands, haphazard mixing of lumps of different lithologies (mainly at the tops of cores), and the nearfluid state of some sediments recovered from tens to hundreds of meters below the seafloor. Core deformation probably occurs during any of several steps in which the core may experience stresses sufficient to alter its physical characteristics: cutting, re-

<sup>&</sup>lt;sup>1</sup> Peirce, J., Weissel, J., et al., 1989. Proc. ODP, Init. Repts., 121: 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, with the addition of Jean-Yves Royer, Institute for Geophysics, University of Texas at Austin, 8701 Mopac Boulevard, Austin, TX 78759-8345, and Garry D. Karner, Lamont-Doherty Geological Observatory, Palisades, NY 10964.



Figure 1. Terms used in discussion of coring operations and core recovery. trieval (with accompanying changes in pressure and temperature), and core handling on deck.

## **Shipboard Scientific Procedures**

## Numbering of Sites, Holes, Cores, and Samples

ODP drill sites are numbered consecutively from the first site drilled by the *Glomar Challenger* in 1968. A site number refers to one or more holes drilled while the ship was positioned over one acoustic beacon. Multiple holes may be drilled at a single site by pulling the drill pipe above the seafloor (out of the hole), moving the ship some distance from the previous hole, and then drilling another hole (or, less commonly, by returning to a previously deployed beacon, as was done at Hole 752B).

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, for sampling purposes, to distinguish among holes drilled at a site, because recovered sediments or rocks from different holes usually do not come from equivalent positions in the stratigraphic column.

The cored interval is measured in meters below seafloor (mbsf). The depth interval assigned to an individual core begins with the depth below seafloor that the coring operation began and extends to the depth that the coring operation ended (see Fig. 1). For example, each coring interval is generally up to 9.7 m long, which is the maximum length of a core barrel; however, the coring intervals may be shorter and may not necessarily be adjacent to each other, but may be separated by drilled intervals. In soft sediments, the drill string can be "washed ahead" with the core barrel in place, but not recovering sediments, by pumping water down the pipe at high pressure to wash the sediment out of the way of the bit and up the space between the drill pipe and 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 have a cored interval greater than 9.7 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, as a result of caving of cuttings or other hole problems. Maximum full recovery for a single core is 9.7 m of rock or sediment contained in a plastic liner (6.6-cm internal diameter) plus about 0.2 m (without a plastic liner) in the core catcher (see Fig. 2). The core catcher is a device at the bottom of the core barrel which prevents the core from sliding out when the barrel is being retrieved from the hole. In certain situations (e.g., when coring gassy sediments that expand while being brought on deck) recovery may exceed the 9.7-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 7 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 the core is fragmented (recovery less than 100%), the 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



Figure 2. Procedure used in cutting and labeling core sections.

section less than 1.5 m long may be cut in order 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 is 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 recovered in the core catcher only. However, information supplied by the drillers or by other sources may allow for more precise interpretation as to the correct position of the core-catcher material within an incompletely recovered cored interval.

A recovered basalt, gabbro, or peridotite core also is cut into 1.5-m sections that are numbered serially; however, each piece of rock is then assigned a number (fragments of a single piece are assigned a single number, with individual fragments being identified alphabetically). The core-catcher sample is placed at the bottom of the last section and is treated as part of the last section, rather than separately. Scientists completing visual core description forms 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, in order to achieve consistency in handling analytical data derived from the cores. Samples removed from the cores are designated by the 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 do not fit together in order to protect them from damage in transit and in storage; therefore, the centimeter interval noted for a hard-rock sample has no direct relationship to that sample's depth within the cored interval, but is only a physical reference to the sample's location 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, Interval in centimeters measured from the top of the section, and Piece Number (for hard rock). For example, the sample identification "121-757A-5H-3, 100–102 cm" would be interpreted as representing a sample removed from the interval between 100 and 102 cm below the top of Section 3, Core 5 (H designates that this core was taken with the hydraulic piston corer) of Hole 757A during Leg 121.

All ODP core and sample identifiers indicate core type. The following abbreviations are used: R = rotary barrel (RCB); H = hydraulic piston core (HPC; also referred to as APC, or advanced hydraulic piston core); P = pressure core barrel; X = extended core barrel (XCB); B = drill-bit recovery; C = centerbit recovery; I = *in-situ* water sample; S = sidewall sample; W = wash-core recovery; N = Navidrill core (NCB); and M = miscellaneous material. HPC, XCB, RCB, NCB, and wash cores were drilled on ODP Leg 121.

#### **Core Handling**

As soon as a core is retrieved on deck, a sample is taken from the core catcher to the paleontological laboratory for an initial age assessment. The core is then placed on a 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 shorebased study, but others are analyzed immediately as part of the shipboard safety and pollution-prevention program. Next, the core is marked into section lengths, each section is labeled, and the core is cut into sections. Interstitialwater (IW), organic geochemistry (OG), and physical-properties (PP) whole-round samples are then taken. In addition on Leg 121, some headspace gas samples were scraped from the ends of cut sections on the catwalk and sealed in glass vials for light-hydrocarbon analysis. In places, 20-cm3 samples were taken via syringe for pore-fluid analyses. 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 section ends from which a whole-round sample has been removed. 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 are then carried into the laboratory, where the sections are again labeled, using an engraver to 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 core-log database program. If thermal-conductivity measurements are to be taken, the cores are allowed to warm to room temperature before they are split (this took approximately 3–4 hr on Leg 121). During this time, the whole-round sections are run simultaneously through the GRAPE device for estimating the bulk density (see the following text; Boyce, 1976) and the *P*-wave logger for determining sonic velocity. Whole-round core sections were also run through a loop to measure magnetic susceptibility. After the core temperatures have equilibrated, thermal-conductivity measurements are made immediately before the cores are split.

Cores of relatively 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. Because the cores recovered on Leg 121 were split with wire from the bottom to the top, it is possible that older material was transported up the core on the split face of each section. One should, thus, be aware that the very near-surface part of the split core could be contaminated.

The working half is sampled for both shipboard and shorebased laboratory studies. Each extracted sample is logged in the computer database sampling program by its location in the core 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 analyses, for percentage of calcium carbonate present (carbonate bomb), and for grain-size analyses. Many of these data are reported in the site chapters.

The archive half of a core is described visually. Smear slides are made from samples taken from the archive half, and may be supplemented by thin sections taken from the working half. Archive-half sections that show little drilling disturbance 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.

Both halves of the core are then put into labeled plastic tubes, sealed, and transferred to cold-storage space aboard the drilling vessel. Leg 121 cores were transferred from the ship by refrigerated vans to cold storage at the Gulf Coast Repository at the Ocean Drilling Program, Texas A&M University, College Station, Texas.

## CORE DESCRIPTION FORMS ("BARREL SHEETS")

The core-description forms (Fig. 3), or "barrel sheets," summarize the data obtained during shipboard analysis of each sediment core (see also the "Igneous Petrology" section on hardrock core description, this chapter). The following discussion explains the ODP conventions used in compiling each part of the core description forms and the exceptions to these procedures adopted by Leg 121 scientists.

## **Core Designation**

Cores are designated using leg, site, hole, and core number and type as previously discussed (see "Numbering of Sites, Holes, Cores, and Samples" section, this chapter). In addition, the cored interval is specified in terms of meters below seafloor. On Leg 121, these depths were based on the drill-pipe measurements (DPM), as reported by the SEDCO coring technician and the ODP operations superintendent; note that the DPM values were corrected for the height of the rig floor dual elevator stool above sea level (nominally 10.87 m) to yield true water depth.

### **Paleontological Data**

Microfossil abundance, preservation, and zone assignment, as determined by the shipboard paleontologists, appear on the core description form under the heading "Biostratigraphy Zone/ Fossil Character." The chronostratigraphic unit, as recognized on the basis of paleontological results, is shown in the "Time-Rock Unit" column. Detailed information on the zonations and terms used to report abundance and preservation is presented in the "Biostratigraphy" section (this chapter).

### Paleomagnetic, Physical-Properties, and Chemical Data

Columns are provided on the core description form to record paleomagnetic results, physical-properties values (density, porosity, and velocity) and chemical data (percentages of CaCO<sub>3</sub> and organic carbon determined using the Coulometrics analyzer). Additional information on shipboard procedures for collecting these types of data appears in the "Paleomagnetics," "Physical Properties," and "Inorganic Geochemistry" sections (this chapter).

## **Graphic Lithology Column**

The lithologic classification scheme of Mazzullo et al. (1987), accepted for shipboard use by the JOIDES Sediments and Ocean History Panel, is presented in this column. Sediment type is represented graphically on the core description forms using the symbols illustrated in Figure 4.

## **Sediment Disturbance**

In some cases the coring technique used in combination with sediment characteristics such as composition, induration, and consistency may result in varying degrees of disturbance of the recovered core material. This is illustrated in the "Drilling Disturbance" column on the core description form (using the symbols in Fig. 5A). The following disturbance categories are recognized for soft and firm sediments:

1. Slightly disturbed: bedding contracts are slightly bent.

2. Moderately disturbed: bedding contacts have undergone extreme bowing.

3. Highly disturbed: bedding is completely disturbed and may show symmetrical diapirlike structures ("flow-in").

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

The following categories are used to describe the degree of fracturing in hard sediments and igneous and metamorphic rocks (Fig. 5A):

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

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

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

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

## Sedimentary Structures

In the soft- and even in some harder-sedimentary cores, distinguishing between natural structures and those created by the coring process may be extremely difficult. However, where interpreted natural structures were observed, they are indicated in the "Sedimentary Structures" column of the core description form. A key to the structural symbols used on Leg 121 is given in Figure 5B.

## Samples

The position of samples taken from each core for shipboard analysis is indicated in the "Samples" column on the core description form. An asterisk (\*) indicates the location of a smear slide sample and (#) marks that of a thin section. The symbols IW, OG, and PP designate whole-round interstitial-water, frozen organic geochemistry, and physical-properties samples, respectively.

Although not indicated in the "Samples" column, the positions of samples for routine physical-property (porosity [%], wet-bulk density [g/cm<sup>3</sup>], and velocity [m/s]) and geochemical (percent CaCO<sub>3</sub> and percent organic carbon [OC]) analyses are indicated by dots in the "Physical Properties" and "Chemistry" columns. Paleomagnetic results (chrons and/or normal and reversed polarity intervals) are also indicated.

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. Examination of such samples may lead to the recognition of zonal boundaries in the core; these are indicated in the appropriate column.

SITE				H	LE				COR	RE	co	RE	DI	NT	ERVAL
E	BID	STRA	СНА	ZONE	E/ TER		8								
IME-ROCK UNI	ORAMINIFERS	ANNOFOSSILS	ADIOLARIANS	ATOMS		ALEOMAGNETICS	YS. PROPERTI	<b>HEMISTRY</b>	ECTION	ETERS	GRAPHIC LITHOLOGY	VILLING DISTUR	D. STRUCTURE	MPLES	LITHOLOGIC DESCRIPTION
	L	Z	e.			4	ď	0	1	0.5		a	8	*	Smear slide
									2					PP	Physical-properties whole-round sample
PF GM P	RES	ER God Mo Pod	VA der or	TIO	ON:		:m <sup>3</sup> )	uoq.	3		ig. 4)			og	🗲 Organic geochemistry sample
							nd Bulk density (g/c	late and organic car	4		lithology symbols (F	CONTRACTOR CONTRACTOR CONTRACTOR	ools in Figure 5 🗕		Smear slide summary (%): Section, depth (cm) M = Minor lithology, D = Dominant lithology
ALACFRB	BUN = = =	IDA Abu Cor Fre Rar Bar	NC Ind ind equire	E: lan ent	t		Porosity (%) a	Calcium carbor	5		See key to graphic			ıw	Interstitial-water sample
									6						SMEAR SLIDE SUMMARY (%): 1, 50 3, 50 5, 50
									7						TEXTURE: Sand 50 45 20 Silt 50 55 80 Clay 0 0 0 COMPOSITION:
									cc						Glass         Tr         Tr            Mica           Tr           Nannofossils         20         20         65           Quartz          Tr

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

#### PELAGIC SEDIMENTS Calcareous

Nannofossil Ooze	Foraminiferal Ooze	Nanno-Foram or Foram-Nanno Ooze	
		-++- ++- ++- ++- CB3	
Calcareous Ooze	Nannofossil Chalk	Foraminiferal Chalk	
Nanno-Foram or Foram-Nanno Chalk	Calcareous Chaik	Limestone	
Siliceous Diatom Ooze	Radiolarian Ooze	Diatom-Rad or Siliceous Ooze	Diatomite

 $\sim$ 

SB2

lanite

Δ ۸ Δ ^

Grainstone

SR9

Sapropels

1

SB3

SB

P

## **GRANULAR SEDIMENTS**

2

SB4

SB

# SILICICLASTIC SEDIMENTS

T1

**T5** 

Т8

SR1

Gravel

. . .

Silt/Siltstone



Toreating Flatty Fart	a conserve makette	
V1	V2	V3

NERITIC SEDIMENTS ndstone

Coals and Peat

SR6

SB5

SB1

olarite

G в в G N2 N1

ackestone	Mudstone
w	м
w	M
N4	N5

_	
	Р
	N3
	Floatstone
	F
-	

Halite

E1

Concretions Mn=

Manganese

Packstone

	R	
-1 F	B	

Anh drite

F2

B= Barite

CHEMICAL SEDIMENTS

drawn circle with symbol ( others may be designated )

GV

P= Pyrite

# MIXED SEDIMENTS



Z= Zeolite

rcellanite



SPECIAL ROCK TYPES



Figure 4. Key to symbols used in the "Graphic Lithology" column on the core description form shown in Figure 3.



Figure 5. Symbols used for sediments and sedimentary rocks on the core description form shown in Figure 3. A. Drilling disturbance. B. Sedimentary structures.

## Lithologic Description—Text

The lithologic description that appears on each core description form generally consists of two parts: (1) a brief summary of the major lithologies observed in a given core in order of importance, followed by a description of sedimentary structures and features, and (2) a description of minor lithologies observed in the core (where present), including data on color, occurrence in the core, and significant features.

#### **Smear Slide Summary**

A table summarizing available smear slide and thin-section data appears on the core description form. The section and interval from which the sample was taken are noted, as well as identification as a dominant (D) or minor (M) lithology in the core. The percentage of all identified components is indicated. As explained in the following "Sediment Classification" section (this chapter), these data are used to classify the recovered material.

# SEDIMENT CLASSIFICATION

The new ODP classification scheme by Mazzullo et al. (1987), reproduced in part in this section, was used during Leg 121. The sediment classification scheme described here defines two basic sediment types: (1) granular sediment and (2) chemical sediment.

## **Granular Sediments**

## Classes of Granular Sediments

There are four types of grains that can be found in granular sediments: pelagic, neritic, siliciclastic, and volcaniclastic grains. Pelagic grains are composed of the fine-grained skeletal debris of open-marine siliceous and calcareous microfauna and microflora (e.g., radiolarians, nannofossils) and associated organisms. Neritic grains are composed of coarse-grained calcareous skeletal debris (e.g., bioclasts, peloids) and fine-grained calcareous grains of nonpelagic origin. Siliciclastic grains are composed of mineral and rock fragments that are derived from plutonic, sedimentary, and metamorphic rocks. Volcaniclastic grains are composed of rock fragments and minerals that are derived from volcanic sources.

Variations in the relative proportions of these four grain types define five major classes of granular sediments: pelagic, neritic, siliciclastic, volcaniclastic, and mixed sediments (Fig. 6).

Pelagic sediments are composed of more than 60% pelagic and neritic grains and less than 40% siliciclastic and volcaniclastic grains, with a higher proportion of pelagic than neritic grains.

Neritic sediments are composed of more than 60% pelagic and neritic grains and less than 40% siliciclastic and volcaniclastic grains, with a higher proportion of neritic than pelagic grains.



Figure 6. Classes of granular sediments.

Siliciclastic sediments are composed of more than 60% siliciclastic and volcaniclastic grains and less than 40% pelagic and neritic grains, with a higher proportion of siliciclastic than volcaniclastic grains.

Volcaniclastic sediments are composed of more than 60% siliciclastic and volcaniclastic grains and less than 40% pelagic and neritic grains, with a higher proportion of volcaniclastic than siliciclastic grains. This class includes epiclastic sediments (volcanic detritus that is produced by erosion of volcanic rocks by wind, water, and ice), pyroclastic sediments (the products of the degassing of magmas), and hydroclastic sediments (the products of the granulation of volcanic glass by steam explosions).

Mixed sediments are composed of 40% to 60% siliciclastic and volcaniclastic grains and 40% to 60% pelagic and neritic grains.

### **Classification of Granular Sediments**

A granular sediment can be classified by designating a principal name and 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, and/or roundness of the grains (Table 1).

Table 1.	Outline	of th	ie scheme	used	for	granular	sediment	classifica-
tion on l	Leg 121.							

Sediment class	Major modifiers <sup>a</sup>	Principal names	Minor modifiers <sup>b</sup>
Pelagic sediment	<ol> <li>Composition of pelagic and neritic grains</li> <li>Texture of clastic grains</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</li> <li>Texture of clastic grains</li> </ol>
Neritic sediment	<ol> <li>Composition of neritic and pelagic grains</li> <li>Texture of clastic grains</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</li> <li>Texture of classic grains</li> </ol>
Siliciclastic sediment	<ol> <li>Composition of all grains</li> <li>Grain fabric (gravels only)</li> <li>Grain shape (optional)</li> <li>Sediment color (optional)</li> </ol>	<ol> <li>Gravel</li> <li>Sand</li> <li>Silt</li> <li>Clay (etc.)</li> </ol>	<ol> <li>Composition of all grains</li> <li>Texture and composition of siliciclastic grains present as matrix (for coarse-grained clastic sedi- ments)</li> </ol>
Volcaniclastic sediment	<ol> <li>Composition of all volcaniclasts present in major amounts</li> <li>Composition of all pelagic and neritic grains</li> <li>Texture of silici- clastic grains</li> </ol>	<ol> <li>Breccia</li> <li>Lapilli</li> <li>Ash/tuff</li> </ol>	<ol> <li>Composition of all volcaniclasts</li> <li>Composition of all neritic and pelagic grains</li> <li>Texture of siliciclastic grains</li> </ol>
Mixed sediments	<ol> <li>Composition of neritic and pelagic grains</li> <li>Texture of clastic grains</li> </ol>	1. Mixed sediments	<ol> <li>Composition of neritic and pelagic grains</li> <li>Texture of clastic grains</li> </ol>

<sup>a</sup> Describes grain types present in proportions > 25%.

<sup>b</sup> Describes grain types present in proportions between 10% and 25%.

#### Principal Names

Each granular-sediment class has a unique set of principal names. For pelagic sediment, the principal name describes the composition and degree of consolidation using the following terms:

Ooze: unconsolidated calcareous and/or siliceous pelagic sediments.

Chalk: firm pelagic sediment composed predominantly of calcareous pelagic grains.

3. Limestone: hard pelagic sediment composed predominantly of calcareous pelagic grains.

4. Radiolarite, diatomite, and spiculite: firm pelagic sediment composed predominantly of siliceous radiolarians, diatoms, and sponge spicules, respectively.

5. Chert: hard pelagic sediment composed predominantly of siliceous pelagic grains.

For neritic sediment, the principal name describes the texture and fabric, using the following terms (from Dunham, 1962):

1. Boundstone: components organically bound during deposition.

2. Grainstone: grain-supported fabric (no mud), with grains <2 mm in size.

3. Packstone: grain-supported fabric, including intergranular mud, with grains <2 mm in size.

4. Wackestone: mud-supported fabric, with greater than 10% grains, and grain size is <2 mm.

5. Ooze (termed "mudstone" by Dunham, 1962): mud-supported fabric, with less than 10% grains.

6. Floatstone: matrix-supported fabric, with grains >2 mm in size.

7. Rudstone: grain-supported fabric, with grains > 2 mm in size.

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; Table 2) defines the grain-size ranges and the names of the textural groups (gravel, sand, silt, and clay) and subgroups (fine sand, coarse silt, etc.) used as the principal names of siliciclastic sediment.

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

3. The suffix "-stone" can be affixed to the principal names sand, silt, and clay when the sediment is lithified; "shale" can be used as a principal name for a lithified and fissile siltstone or claystone. The term "mudstone" is used for indurated, nonfissile, silty and clayey siliciclastic sediments, if induration or other characteristics preclude grain-size analysis. "Conglomerate" and "breccia" are used as principal names of gravels with well-rounded and angular clasts, respectively.

For volcaniclastic sediment, the principal name describes the texture. The names and ranges of three textural groups (from Fisher and Schmincke, 1984) are as follows:

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

2. Volcanic lapilli: pyroclasts between 2 and 64 mm in diameter.

3. Volcanic ash: pyroclasts <2 mm in diameter. When lithified, the name "tuff" is used. Table 2. Grain-size categories used for classification of siliciclastic sediments (from Wentworth, 1922).

Millin	neters	Microns	Ρhi (φ)	Wentworth size class	5
4	096 024		- 20 - 12 - 10	Boulder ( $-8$ to $-12\phi$ )	)
	256 -		8 -	Cobble $(-6 \text{ to } -8\phi)$	- 13
	64 — 16		6 -	Pebble $(-2 \text{ to } -6\phi)$	Grav
	4 – 3.36 2.83 2.38		2 -1.75 -1.5 -1.25	Granule	
	2.00 — 1.68 1.41 1.19		-0.75 -0.5 -0.25	Very coarse sand	5
1.(2	0.84 0.71 0.59	500	0.0 - 0.25 0.5 0.75	Coarse sand	
1/2	0.42 0.35 0.30	420 350 300	1.0 - 1.25 1.5 1.75	Medium sand	Sand
1/4 —	0.25 — 0.210 0.177 0.149	250 — 210 177 149	- 2.0 - 2.25 2.5 2.75	Fine sand	
1/8 —	- 0.125 - 0.105 0.088 0.074	- 125 105 88 74	- 3.0 - 3.25 3.5 3.75	Very fine sand	
1/16 —	0.0625 — 0.053 0.044 0.037	- 63 - 53 44 37	- 4.0 - 4.25 4.5 4.75	Coarse silt	pi
1/32	0.031 - 0.0156 0.0078	- 31 - 15.6 7.8	- 5.0 - 6.0 7.0	Medium silt Fine silt Very fine silt	Mr
17250	0.0039 0.0020 0.00098 0.00049 0.00024 0.00012 0.00006	2.0 0.98 0.49 0.24 0.12 0.06	9.0 10.0 11.0 12.0 13.0 14.0	Clay	

4. Clastic sediments of volcanic provenance are described in the same fashion as siliciclastic sediments, noting the dominant composition of volcanic grains.

For mixed sediment, the principal name describes the degree of consolidation, using the terms "mixed sediments" or "mixed sedimentary rocks."

#### Major and Minor Modifiers

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

The composition of pelagic grains can be described with the major and minor modifiers "diatom(-aceous)," "radiolarian," "spicules (spicular)," "siliceous," "nannofossil," "foraminifer(-al)," and "calcareous." The terms "siliceous" and "calcareous"

are used generally to describe sediments that are composed of siliceous or calcareous pelagic grains of uncertain origin.

The composition of neritic grains can be described with the following major and minor modifiers:

1. Ooid (or oolite): spherical or elliptical nonskeletal particles smaller than 2 mm in diameter, consisting of a central nucleus surrounded by a rim with concentric or radial fabric.

2. Bioclast (or bioclastite): fragment of skeletal remains. Specific names such as molluscan or algal can also be used.

Pellet(-al): fecal particles from deposit-feeding organisms.
 Intraclast: reworked carbonate-rock fragment or rip-up clast.

5. Pisolite: spherical or ellipsoidal nonskeletal particle, commonly greater than 2 mm in diameter, and with or without a central nucleus but displaying multiple concentric layers of carbonate.

6. Peloid: micritized carbonate particle of unknown origin.

7. Calcareous, dolomitic, aragonitic, sideritic: modifiers used to describe the composition of carbonate mud or mudstone (micrite) of nonpelagic origin.

The texture of siliciclastic grains is described by the major and minor modifiers "gravel," "sand," "silt," and "clay." The composition of siliciclastic grains can be described by the following:

1. Mineralogy: using modifiers such as "quartz," "feldspar," "glauconite," "mica," "kaolinite," "zeolitic," "lithic" (for rock fragments), "calcareous," "gypsiferous," or "sapropelic" (for detrital clasts of calcium carbonate, gypsum, and organic matter, respectively).

2. Provenance: the source of rock fragments (particularly in gravels, conglomerates, and breccias) can be described by modifiers such as volcanic, sed-lithic, meta-lithic, gneissic, basaltic, etc.

The composition of volcaniclastic grains is described by the major and minor modifiers "lithic" (rock fragments), "vitric" (glass and pumice), and "crystal" (mineral crystals) or by modifiers that describe the compositions of the liths and crystals (e.g., "feldspar" or "basaltic"). The fabric of the sediment can be described by the major modifiers "grain-supported," "matrix-supported," and "imbricated." Generally, fabric descriptors are applied only to gravels, conglomerates, and breccias, because they provide useful information on their transport history.

The shapes of grains are described by the major modifiers "rounded," "subrounded," "subangular," and "angular."

The color of sediment is determined with a standard color comparator, such as the Munsell Chart, and can be employed as a major modifier.

## **Chemical Sediments**

## **Classes of Chemical Sediments**

Chemical sediments are composed of minerals that formed by inorganic processes such as precipitation from solution or colloidal suspension, deposition of insoluble precipitates, or recrystallization of detrital evaporites and siliceous, calcareous, or carbonaceous (plant) biogenic debris. These sediments generally have a crystalline (i.e., nongranular) texture.

There are five classes of chemical sediments: carbonaceous sediments, evaporites, silicates, carbonates, and metalliferous sediments. Each class of chemical sediment has its own distinctive classification scheme. On Leg 121, the following chemical sediments were found.

#### Evaporites

Evaporites are composed of minerals produced from a saline solution that became concentrated by evaporation of the solvent. The evaporites are classified according to their mineralogy using terms such as "halite," "gypsum," and "anhydrite." They may be modified by terms that describe their structure or fabric, such as "massive," "nodular," "nodular-mosaic," and "chicken wire."

## Silicates/Carbonates

Silicates and carbonates are defined as sedimentary rocks that are nongranular and nonbiogenic in appearance and composed of silicate and carbonate minerals. Silicates and carbonates may have formed from the recrystallization of siliceous and calcareous grains, but are distinguished by the absence of clearly identifiable granular and biogenic components. They may also form as primary precipitates, as in the case of dolomite or proto-dolomite, or as hydrothermal or diagenetic alteration products, such as in the case of zeolites. They are classified according to their mineralogy, using principal names such as "porcellanite," "chert," "calcite," and "dolomite." Their principal name may also be modified with terms that describe their crystalline (as opposed to granular) nature, such as "crystalline," "microcrystalline," "massive," and "amorphous."

## Metalliferous Sediments

Metalliferous sediments are a broad category of nongranular nonbiogenic sediments that include a variety of iron- and manganese-rich, commonly poorly crystalline oxy-hydroxides and sulfides. They are classified according to their composition.

#### Sediment Measurements

# Grain Size

For routine assignment of sediments to textural classes, grain sizes were estimated visually from the core material and smear slides. For the finer sediments, a Lasentec Lab-Tec 100 particlesize analyzer was used to provide data on the sand/silt/clay ratio and mean grain size. This instrument scans a stirred, horizontally rotating, dilute suspension of the sediment in a vertical plane with a finely focused laser-diode beam. Individual particle cross-sections are measured from the duration of the backscattering events.

About 1 cm<sup>3</sup> of fresh sediment was used for each grain-size analysis. To minimize clay flocculation and help disaggregate the sediment, samples were dispersed in 100 mL of Calgon solution (5 g/L) and then sonically treated for 30 s. Total particle counts were obtained in about 10 s for 1-cm<sup>3</sup> sediment samples.

The analyses are rapid and appear to be accurate to  $\pm 5\%$ over the size range of six phi units, either from  $2\phi$  to  $8\phi$  (250 to  $4 \mu m$ ) or  $3\phi$  to  $9\phi$  (125 to  $2 \mu m$ ). However, the accuracy deteriorates as the grains become coarser. The stirring mechanism and sample container shape are not adequate to keep sand-sized grains randomly suspended in the focused laser beam, so they are not counted. As a result, grains larger than 80 to 100  $\mu m$ , about 3.5 $\phi$ , are moderately to severely under represented, and the resulting size value is too small for the coarser samples. In addition, measurements are not accurate with dull, black particles (e.g., manganese oxide-coated grains).

The raw size/frequency data are dependent on the optical cross-section of each size class. To convert to traditional sedimentologic size/weight percent data, compensation factors were applied (see the Lab-Tec manual for a detailed discussion). Generally, they correspond to each class median size.

## BIOSTRATIGRAPHY

Leg 121 provides an opportunity to compare midlatitude to high-latitude microfauna and microflora assemblages from Broken Ridge with the lower latitude assemblages from Ninetyeast Ridge. In addition, the sites on Broken Ridge and Ninetyeast Ridge offer an excellent opportunity to promote further study on the evolution and establishment of the present Indian Ocean circulation patterns and sea surface conditions using the temperature- and depth-sensitive siliceous and calcareous microfossil groups.

## **Planktonic Foraminifers**

#### Zonation

#### Neogene

Dominating the Neogene assemblages at Broken Ridge are typical, midlatitude, temperate faunas that have an affinity with other Neogene faunas at high latitudes in the Southern Hemisphere. The general absence of low-latitude marker species, therefore, prohibits the application of tropical zonation schemes proposed by Banner and Blow (1965), Blow (1969), and Bolli and Saunders (1985). Instead, the higher latitude zonal schemes of Srinivasan and Kennett (1981) and Kennett (1973) were applied to sediments of early to middle Miocene age and late Miocene to Holocene age, respectively. These high-latitude zonation schemes are compared with that of Bolli et al. (1985) in Figure 7.

The presence of most, if not all, low-latitude marker species at Ninetyeast Ridge made it possible to apply the zonation schemes of Banner and Blow (1965) and Blow (1969). Difficulties arose in trying to recognize the low-latitude zonal boundaries of Bolli and Saunders (1985) because of the lack of their zonal taxa. The schemes of Banner and Blow (1965) and Blow (1969) avoid lengthy zonal names; instead, the zones are sequentially designated by a number and letter (P for Paleogene and N for Neogene). These closely match the zonal boundaries of Bolli and Saunders (1985), as shown in Figure 8.

#### Paleogene

The zonation scheme of Bolli et al. (1985) is used for the Paleogene, along with emendations to some zones based on Jenkins' (1985) zonation. The geomagnetic reversal time scale of Berggren et al. (1985) is further used to provide "absolute" ages for datum levels in the Neogene and Paleogene and, thus, greater resolution.

#### Mesozoic

In the Mesozoic, the zonation scheme of Caron (1985) is used. Absolute ages are derived from the polarity time scale of Harland et al. (1982) for consistency with our use of the Berggren et al. (1985) time scale in the Cenozoic.

#### Abundance and Preservation

The abundance of a particular species in the assemblage is based on a visual estimate of the >125-µm size fractions. The following letters are used to indicate abundance:

- A = Abundant (>20% of the washed and sieved fauna)
- C = Common (10% 20%)
- F = Few (1% 10%)
- R = Rare (<1%)
- B = Barren.

The preservation state of the planktonic foraminifer assemblage is estimated as follows:

- G = Good (little or no evidence of overgrowth, dissolution, or abrasion)
- M = Moderate (calcite overgrowth, dissolution, or abrasion are common but minor)
- P = Poor (substantial overgrowth, dissolution, or fragmentation).

### Sample Preparation

Samples were prepared by washing through a  $63-\mu m$  sieve and drying on a hot plate. They were then picked for foraminifers. Consolidated sediments were soaked either in Calgon or hydrogen peroxide and then boiled and treated ultrasonically before being washed and dried, or they were cut into thin slabs and stained with methylene blue for identification purposes.

### **Calcareous Nannofossils**

## Zonation

## Cenozoic

The nannofossil biostratigraphic zonation used for Leg 121 is that proposed by Okada and Bukry (1980). The scheme is tied to the geomagnetic reversal time scale of Berggren et al. (1985).

#### Mesozoic

The zonation scheme of Sissingh (1977) is used for Cretaceous sediments. This scheme is tied to the magnetic polarity scale of Harland et al. (1982), using the revisions proposed by Kent and Gradstein (1985). Numerical age assignments for calcareous nannofossil datum levels are given in Table 3.

### Abundance and Preservation

The relative abundance of calcareous nannofossils in the fine fraction of each sample is given on the core description forms. A letter code is assigned to the visual relative abundance estimates as follows:

- A = Abundant (at least one specimen per field of view)
- C = Common (one specimen per 2-10 fields of view)
- F = Few (one specimen per 11-100 fields of view)
- R = Rare (one specimen per 101+ fields of view).

Preservation is measured by the average degree of etching and/or overgrowth of the calcareous nannofossils. The visual estimates of preservation are assigned a letter code as follows:

- G = Good (slight overgrowth and/or etching; all calcareous nannofossils can be taxonomically differentiated)
- M = Moderate (overgrowth and/or etching have slightly altered the structure of the calcareous nannofossils, but most can be taxonomically identified)
- P = Poor (strong overgrowth, fragmentation, and/or etching highly altering most calcareous nannofossils beyond recognition; only a few may be identified).

#### Sample Preparation

Smear slides were prepared for all samples and studied in transmitted light, phase contrast, and cross-polarized light, using a Zeiss photomicroscope.

## **Benthic Foraminifers**

#### Water Paleodepth Estimates

The water paleodepth estimates at each site refer to the upper and lower depth limits of the cosmopolitan species given by van

				Bolli et al. (1985)	Temperate zonation		
		Holocene		Globorotalia fimbriata			
	0.01 —		Globorotalia	Globigerina bermudezi			
		Pleistocene	truncatulinoides	Globigerina calida calida	Globorotalia truncatulinoides		
			u unicatum roides	Globorotalia crassaformis hessi	4		
	1.9 —	late Pliocene	Globorotalia tosae	ensis tosaensis	Globorotalia tosaensis		
	2.4 —	middle Pliocene	Globorotalia	Globorotalia exilis	Globorotalia crassaformis		
	3.2 —	middle r nocerie	miocenica	Globigerinoides trilobus fistulosus	Globorotalia inflata		
			Claboratalia	Globorotalia margaritae evoluta			
		early Pliocene	margaritae		Globorotalia puncticulata	(62	
				Globorotalia margaritae margaritae			
	5.1 —					(197	
					Globorotalia conomiozea	lett	
						enn	
			Globorotalia humi	erosa	Globiaerina nepenthes	×	
		late Miocene					
					1 1		
			Globorotalia acos	taensis	Globorotalia continuosa		
					Cibbolotana continuosa		
(a)							
e	11.3 —		Globorotalia mena	ardii			
Ag			Globorotalia maye	eri			
		middle Missone	Globigerinoides ru	uber	Globorotalia mayeri		
		middle Miocene	Globorotalia foshi	robusta	4 1		
			Globorotalia foshi	lobata			
			Globorotalia foshi	foshi	Globorotalia peripheroacuta / G. ronda		
	10.0				O huling autovalia		
	14.4 —		Globorotalia foshi	peripheroronda	Orbulina suturalis		
	14.4 —		Globorotalia toshi	peripheroronda	Orbulina suturalis		
	14.4 —		Praeorbulina glon	nerosa	Orbulina suturalis Praeorbulina glomerosa		
	14.4 —		Praeorbulina glon	peripheroronda	Orbulina suturalis Praeorbulina glomerosa		
	14.4 —		Globorotalia toshi Praeorbulina glon	peripheroronda	Orbulina suturalis Praeorbulina glomerosa	381)	
	14.4 —		Globorotalia toshi Praeorbulina glon	peripheroronda	Orbulina suturalis Praeorbulina glomerosa	t (1981)	
	14.4 —		Globorotalia toshi Praeorbulina glon Globigerinatella in	nerosa	Orbulina suturalis Praeorbulina glomerosa Globorotalia miozea	inett (1981)	
	14.4 —		Globorotalia toshi Praeorbulina glon Globigerinatella in	nerosa nsueta	Orbulina suturalis Praeorbulina glomerosa Globorotalia miozea	Kennett (1981)	
	14.4 —		Globorotalia toshi Praeorbulina glon Globigerinatella in	nerosa nsuela	Orbulina suturalis Praeorbulina glomerosa Globorotalia miozea	nd Kennett (1981)	
	14.4 —	early Mincene	Globorotalia toshi Praeorbulina glon Globigerinatella in	peripheroronaa nerosa nsueta	Orbulina suturalis Praeorbulina glomerosa Globorotalia miozea	an and Kennett (1981)	
	14.4 —	early Miocene	Globorotalia toshi Praeorbulina glon Globigerinatella in Catapsydrax stain	peripheroronda nerosa nsueta nforthi	Orbulina suturalis Praeorbulina glomerosa Globorotalia miozea	/asan and Kennett (1981)	
	14.4 —	early Miocene	Globorotalia toshi Praeorbulina glon Globigerinatella in Catapsydrax stain	peripheroronaa nerosa nsueta nforthi	Orbulina suturalis Praeorbulina glomerosa Globorotalia miozea	rinivasan and Kennett (1981)	
	14.4 —	early Miocene	Globorotalia toshi Praeorbulina glon Globigerinatella in Catapsydrax stain	peripheroronda nerosa nsueta nforthi	Orbulina suturalis Praeorbulina glomerosa Globorotalia miozea Catapsydrax dissimilis	Srinivasan and Kennett (1981)	
	14.4 —	early Miocene	Globorotalia toshi Praeorbulina glon Globigerinatella in Catapsydrax stain	peripheroronda nerosa nsueta	Orbulina suturalis Praeorbulina glomerosa Globorotalia miozea Catapsydrax dissimilis	Srinivasan and Kennett (1981)	
	14.4 —	early Miocene	Globorotalia toshi Praeorbulina glon Globigerinatella in Catapsydrax stain Catapsydrax dissi	peripheroronda nerosa nsueta nforthi	Orbulina suturalis Praeorbulina glomerosa Globorotalia miozea Catapsydrax dissimilis	Srinivasan and Kennett (1981)	
	14.4 —	early Miocene	Globorotalia toshi Praeorbulina glon Globigerinatella in Catapsydrax stain Catapsydrax dissi	peripheroronda nerosa nsueta nforthi imilis	Orbulina suturalis Praeorbulina glomerosa Globorotalia miozea Catapsydrax dissimilis	Srinivasan and Kennett (1981)	
	14.4 —	early Miocene	Globorotalia toshi Praeorbulina glon Globigerinatella in Catapsydrax stain Catapsydrax dissi	peripheroronda nerosa isueta iforthi	Orbulina suturalis Praeorbulina glomerosa Globorotalia miozea Catapsydrax dissimilis	Srinivasan and Kennett (1981)	
	14.4 —	early Miocene	Globorotalia toshi Praeorbulina glon Globigerinatella in Catapsydrax stain Catapsydrax dissi	peripheroronda nerosa nsueta nforthi	Orbulina suturalis Praeorbulina glomerosa Globorotalia miozea Catapsydrax dissimilis Globigerinoides triloba	Srinivasan and Kennett (1981)	
	14.4 —	early Miocene	Globorotalia toshi Praeorbulina glon Globigerinatella in Catapsydrax stain Catapsydrax dissi Globigerinoides p	peripheroronda nerosa nsueta nforthi imilis	Orbulina suturalis Praeorbulina glomerosa Globorotalia miozea Catapsydrax dissimilis Globigerinoides triloba Globorotalia incognita	Srinivasan and Kennett (1981)	
	24.6	early Miocene	Globorotalia toshi Praeorbulina glon Globigerinatella in Catapsydrax stain Catapsydrax dissi Globigerinoides p	nerosa nerosa nsueta nforthi imilis	Orbulina suturalis Praeorbulina glomerosa Globorotalia miozea Catapsydrax dissimilis Globigerinoides triloba Globorotalia incognita Globoquadrina dehiscens	Srinivasan and Kennett (1981)	
	24.6 —	early Miocene	Globorotalia toshi Praeorbulina glon Globigerinatella in Catapsydrax stain Catapsydrax dissi Globigerinoides p Globorotalia kugle	peripheroronda	Orbulina suturalis Praeorbulina glomerosa Globorotalia miozea Catapsydrax dissimilis Globigerinoides triloba Globorotalia incognita Globorotalia kugleri	Srinivasan and Kennett (1981)	
	24.6 — 25.5 —	early Miocene	Globorotalia toshi Praeorbulina glon Globigerinatella in Catapsydrax stain Catapsydrax dissi Globigerinoides p Globorotalia kugle	peripheroronda nerosa nsueta nforthi imilis rimordius	Orbulina suturalis Praeorbulina glomerosa Globorotalia miozea Catapsydrax dissimilis Globigerinoides triloba Globorotalia incognita Globorotalia kugleri	Srinivasan and Kennett (1981)	
	24.6 — 25.5 —	early Miocene	Globorotalia toshi Praeorbulina glon Globigerinatella in Catapsydrax stain Catapsydrax dissi Globigerinoides p Globorotalia kugle	peripheroronda nerosa nsueta nforthi imilis rimordius	Orbulina suturalis Praeorbulina glomerosa Globorotalia miozea Catapsydrax dissimilis Globigerinoides triloba Globorotalia incognita Globorotalia kugleri	Srinivasan and Kennett (1981)	
	24.6 — 25.5 —	early Miocene	Globorotalia toshi Praeorbulina glon Globigerinatella in Catapsydrax stain Catapsydrax dissi Globigerinoides p Globorotalia kugle	peripheroronda nerosa nsueta nforthi imilis rimordius eri	Orbulina suturalis Praeorbulina glomerosa Globorotalia miozea Catapsydrax dissimilis Globigerinoides triloba Globorotalia incognita Globorotalia kugleri Globorotalia kugleri	Srinivasan and Kennett (1981)	
	24.6 — 25.5 —	early Miocene	Globorotalia toshi Praeorbulina glon Globigerinatella in Catapsydrax stain Catapsydrax dissi Globigerinoides p Globorotalia kugle Globorotalia cipero	peripheroronda nerosa nsueta nforthi imilis rimordius eri	Orbulina suturalis Praeorbulina glomerosa Globorotalia miozea Catapsydrax dissimilis Globigerinoides triloba Globorotalia incognita Globorotalia kugleri Globorotalia kugleri	Srinivasan and Kennett (1981)	

Figure 7. Comparison of Srinivasan and Kennett's (1981) and Kennett's (1973) high-latitude Neogene zonations with that of Bolli et al. (1985).

Morkhoven et al. (1986) and Tjalsma and Lohmann (1983). The South Atlantic faunas reported by Sliter (1977), DSDP Leg 36, and Dailey (1983), DSDP Leg 72, are used as a reference for Late Cretaceous paleowater depths:

Neritic (0-200 m) Upper bathyal (200-600 m) Middle bathyal (600-1000 m) Lower bathyal (1000-2000 m) Abyssal (>2000 m).

## Abundance and Preservation

The abundance of benthic foraminifers in the sediments is recorded as follows:

A = Abundant (>15%)

C = Common (5% - 15%)

F = Few (1% - 5%)

R = Rare (< 1%).

The degree of preservation is defined as follows:

- G = Good (dissolution effects rare)
- M = Moderate (specimens with broken walls or minor dissolution)
- P = Poor (specimen identification very difficult or impossible).

## Sample Preparation

Samples (50-100 cm<sup>3</sup>) from the core catcher and from the core (20 cm<sup>3</sup>) were wet-sieved over a  $63-\mu$ m mesh and dried. Hard samples are were crushed with a hammer and then sieved over the same mesh size. For quantitative studies, aliquots from the >150- $\mu$ m size fraction were picked and mounted on a reference slide. Approximately 300 specimens were picked from each sample.

### Diatoms

## Zonation

### Neogene

The low-latitude diatom zonation of Burckle (1972), later refined by Barron (1985a, 1985b), was used during Leg 121 (Fig. 8). Correlations of the Neogene diatom datums to the magnetic record are based on Barron (1985a, 1985b) and Barron et al. (1985a, 1985b) (Table 4).

#### Paleogene

Fenner's (1985) low-latitude diatom zonation for the Eocene and Oligocene is partly recognized in the sediments recovered on Leg 121. We used part of Strelnikova's (1987) zonation for the early Eocene. Because of the lack of zonal markers, Paleocene zonations of Gombos (1977) and Strelnikova (1987) were not useful here. Therefore, a tentative new zonation is proposed for the Broken Ridge Paleocene sediments recovered in Hole 752A (Table 5).

### Abundance and Preservation

The abundance of species was estimated as follows:

- A = Abundant (at least 20 specimens present in one horizontal traverse at  $400 \times$ )
- C = Common (3-19 specimens per traverse)
- F = Few (1 or 2 specimens per traverse)
- R = Rare (<1 specimen per traverse)
- B = Barren (no diatoms found).

Preservation was estimated as follows:

- G = Good (more than 50% of the diatoms are whole, and valves show only moderate breakage and slight dissolution)
- M = Moderate (10% to 50% whole valves, with extensive breakage and partial dissolution)
- P = Poor (less than 10% of the values are whole).

Fragile species with delicate structures are generally not preserved.

## Sample Preparation

In order to concentrate the diatoms, samples of about 5 cm<sup>3</sup> were treated with 20% hydrochloric acid (30 cm<sup>3</sup>) and 30% hydrogen peroxide (15 cm<sup>3</sup>). The residue was cleansed by centrifuging the suspension (75% full speed for 5 min), decanting the liquid, and washing by addition of distilled water; this cycle was repeated three times. A few drops of the residue were mounted between slides using Hyrax mounting medium.

Slides were examined using a Zeiss microscope. For each sample, at least half of the slide was scanned at a magnification of  $400 \times$ , and species identification was verified at a magnification of  $1000 \times$ .

## **IGNEOUS PETROLOGY**

## Core Curation and Shipboard Sampling

Basement rocks recovered during drilling are examined by petrologists to determine whether it is necessary to preserve unique features and/or to expose important structures of the cored material. Otherwise the rocks are routinely split into archive and working halves using a rock saw with a diamond blade. Care is always taken to ensure that orientation is preserved during splitting and prior to labeling, usually by marking the base of each piece with red crayon. Each piece is numbered sequentially from the top of each section, beginning with number 1. Pieces are labeled at the top on the rounded, not the sawn, surface. Pieces that can be fitted together (reassembled like a jigsaw puzzle) are assigned the same number, but are lettered consecutively (e.g., 1A, 1B, 1C, etc.). Spacers are placed between pieces with different numbers, but not between those with different letters and the same number. The presence of a spacer may represent a substantial interval of no recovery. An original unsplit piece that is sufficiently large such that the top and bottom can be distinguished before removal from the core liner (i.e., the piece could not have rotated top to bottom about a horizontal axis in the liner during drilling) has an arrow added to the label pointing to the top of the section. Because pieces are free to turn about a vertical axis during drilling, azimuthal orientation is not possible.

After the core is split, the working half is sampled for shipboard physical properties, magnetics, X-ray fluorescence (XRF), X-ray diffraction (XRD), and thin-section studies. These samples may take the form of minicores and, if appropriate, are stored in seawater prior to measurement. Normally, samples are taken from each lithologic unit, where recovery permits. The archive half is described on the visual core description (VCD) form and used for nondestructive physical-properties measurements, such as magnetic susceptibility, before being photographed and stored.

### **Visual Core Descriptions**

Igneous VCD forms are used in the description of the basement cores (Fig. 9). 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 glued between rock pieces

#### SHIPBOARD SCIENTIFIC PARTY

Ag	ge	Planktonic foraminifers Bolli and Saunders (198				Calca	areous nannofossils	Diatoms	
н	ol.	SS	Globorotalia fimbriata		CN15	NN21	Emiliania huxleyi		
5	Ð	ia oide oide	Globigerina bermudezi	N23	on the b	NN20	Gephyrocapsa oceanica	Pseudoeunotia doliolus	
Pleistoce		otal tulin tulin	Globigerina calida calida	T	CN14 _	1			
		obol nca nca	Globorotalia crassaformis hessi	N22	China t	NN19	Pseudoemiliania lacunosa	Nitzschia reinholdii	
		522	Globorotalia crassaformis viola	1		1			
	late	Globorotalia tosaensis tosaensis			c	NN18	Discoaster brouweri		
	0		Claboratalia quilia		CN12 c	NN17	Discoaster pentaradiatus	Rhizosolenia praebergonii	
	lbbi	Globorotalia	Cibborbland Banis		b	NN16	Discoaster surculus	1	
Cen	E	mooomou	Globigerinoides trilobus fistulosus	N20	CN11	NN15	Reticulofenestra pseudoumbilica	Nitzschia iouseae	
Plio						NN14	Discoaster asymmetricus	mizouna jouoodo	
	arly	Globorotalia	Globorotalia margaritae evoluta	N19	Chito -	NN13	Ceratolithus rugosus	Thalassiosira convexa	
	90	margaritae	Globorotalia margaritae margaritae	N18		NN12	Amaurolithus tricorniculatus	Nitzschia miocenica	
<u> </u>	_	Claboratalia humanaa			a		Discoaster quinqueramus	Nitzschia porteri	
	late	Globorotalia acostaensis			CN9	NN11			
					Chia b		Dissociator colociia	-	
						NN10	Discoaster carcaris	Coscinodiscus yabei	
	_	Globorotalia menardii			CN7	NN9	Discoaster hamatus		
			N14	Chic		Catinaster coalities	Actinocyclus moroensis		
			Globigerinoides ruber N13		CNB	NN8	NN8 Caunaster coantus	Craspedodiscus coscinodiscus	
	iddle	Globorotalia fohsi robusta Globorotalia fohsi lobata			a –	NN7	Discoaster kugleri	Coscinodiscus gigas var. diorama	
0	E								
Cen		Globorotalia fohsi fohsi		N11	CN5 t	NN6	Discoaster exilis	Coscinodiscus lewisianus	
ž		Glob	porotalia fohsi peripheroronda	NO	1			· · · · · · · · · · · · · · · · · · ·	
-		ALC: NOT A	Praeorbulina glomerosa	NO		hibir		Cestodiscus peplum	
				INO	CN4	NN5	Sphenolithus heteromorphus		
			Globigerinatella insueta	N7	CN3	NN4	Helicosphaera ampliaperta	Denticulopsis nicobarica	
	early		Catapsydrax stainforthi			NN3	Sphenolithus belemnos	Triceratium pileus	
			Catapsydrax dissimilis	N5	c	NN2	Discoaster druggii	Craspedodiscus elegens	
		6	Blobigerinoides primordius	N4	CN1 b	NN1	Triquetrorhabdulus carinatus	Rossiella paleacea	
			2010 - 20 <b>-20</b> - 2010 - 200		а		inquotionaudulus camatus	Rocella gelida	

Figure 8. Correlation of the biostratigraphic zonal schemes for the Paleocene to Holocene.

inside the liner. 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 "Shipboard Studies" column using the following notation: XRD = X-ray-diffraction analysis, XRF = X-ray-fluorescence analysis, TSB = petrographic thin section, PP = physical-properties measurement, PM = paleomagnetic study.

As igneous rocks are classified mainly on the basis of mineralogy and texture, a checklist of macroscopic features is followed to ensure consistent and complete descriptions, which are later stored on a computerized data base that is widely accessible.

For description of fine- and medium-grained extrusive rocks and dikes, the core is subdivided into lithologic units, using the criteria of change in grain size, occurrence of glassy margins, and changes in petrographic type and phenocryst abundances. For each lithologic unit, the following information is recorded:

1. Leg, site, hole, core number and type, and section.

2. Unit number (consecutive downhole), rock name, and the section(s) and piece numbers making up the complete unit.

3. Contact type (e.g., intrusive, discordant, depositional, etc.) and dip; the presence of any associated glass or its alteration products.

4. The number of phenocryst phases and their distribution within the unit. The following are determined for each phenocryst phase: (a) abundance (%), (b) average size (mm), (c) shape, (d) the degree of alteration, and (e) further comments.

5. Groundmass texture: glassy, microcrystalline, fine-grained (<1 mm), medium-grained (1-5 mm), or coarse-grained (>5 mm). Relative grain size changes within the unit (e.g., coarsening from Piece 1 to Piece 5).

6. Color and variation within the unit. Colors are recorded from the dry core using the Munsell color chart codes.

7. Vesicles: percentage abundance, distribution, size, shape, and fillings and their relationships (including the proportion of vesicles filled by alteration minerals).

8. Structure: massive flow, pillow lava, thin flow, breccia, hyaloclastite, etc., and comments.

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

10. Veins/Fractures: percent present, width, orientation, fillings, and relationships. The relationship of the veins and fractures to the alteration is also noted.

11. Comments: appropriate notes on the continuity of the unit within the core and the interrelationship of units.

Age		Planktonic foraminifers Bolli and Saunders (1985)			Calcareo	us nannofossils	Diatoms	
	0	Globorotalia kulgeri	1	h	NOOR	Sabanalithus cineraensis	Rocella gelida	
	lat	Globigerina ciperoensis ciperoensis	P22	CP19	NP25	Spheriolitios Opercensis	Bogorovia veniamini	
ene	9	Globorotalia opima opima		a	NP24	Sphenolithus distentus		
ligo	- ai	Globigerina ampliapertura		CP18	NP23	Sobenolithus predistentus	Rocella vigilans	
0	~			CP17	111 20	opininia produktine	Contadianus antiquilatura	
	earl	Cassigerinella pseudohastigerina micra	P18	CP16 C	NP22	Helicosphaera reticulata		
-		Turborotalia correctulancia a l	P17		NP21	Ericsonia subdisticha	Coscinodiscus excavatus	
	2	Turborotalia cerroaz diensis s.i.	P16	b b	NP19/20	Isthmolithus recurvus	Baxteriopsis brunii	
	<u>a</u>	Globigerinatheka semiinvoluta	P15	CP15a	NP18	Chiasmolithus oamaruensis		
		Truncorotaloides rohri	P14	b CP14	NP17	Discoaster saipanensis	Asterolampra marylandica	
		Orbulingidas backmanni	D12				Brightwellia imperfecta	
9		Morozovella lehneri Globioerinatheka s. subconglobata		a	NP16	Discoaster tani nodiler	Hemiaulus gondolaformis	
DCer	. t			CP12 b		Nannotetrina fulgens	Haminutus slatus	
ш	1pp	Clobygonnanona s. subconglobala	PII	a a	NP15		Pyxilla caputavis	
	E	Hantkenina nuttalli		b b		Disconstant autola da amaia	Triceratium kanayae	
	_	Acarinina pentacamerata	P9	a a	NP14	Discoaster subiodoensis	Craspedodiscus oblongus	
	earl	Marazavella argonensis	Do	CP11	NP13	Discoaster lodoensis	Craspedodiscus undulatus	
	F	Morozovella formosa formosa	P0 D7	CP10	NP12	Tribrachiatus orthostylus		
	1	Morozovella subbotinae	P/	b b	NP11	Discoaster binodosus		
	- t	Morozovella edgari	P6	CP9	NID40	Tribrochistus contartus	?	
-	-	Marazavalla valazazaraia		a b	NP10	moracmatos comonos		
	ate	NOI OZOVENA VERASCOENSIS	P5	CP8 a	NP9	Discoaster multiradiatus	Hemiaulus inaequilaterus	
		Planorotalites pseudomenardii	P4	CP7	NP8	Heliolithus riedelii	1	
		i anorotaneo poesaomenaran	4.45	CP6	NP7	Discoaster mohleri		
æ	-	Planorotalites pusilla pusilla	-	CP5	NP6	Heliolithus kleinpellii	Sceptroneis sp. A	
oce	e l		Pa			Fasciculithus tympaniformis		
ale	pit	Morozovella angulata	10	CP4	NP5	Ellipsolithus macellus	]	
	- F	Morozovella uncinata	P2			Chiasmolithus danicus		
		Morozovella trinidadensis	c	CP3	NP4		Odontotropis klavensii	
	₹Ì	Morozovella pseudobulloides	P1 h	CP2	NP3	Cruciplacolithus tenuis	-	
	<b>ea</b>	Globigerina eugubina		CP1 b	NP2 NP1	Markalius inversus		
		alobigonna obgabina		a	INP 1			

Figure 8 (continued).

Basalts are termed "aphyric," "sparsely phyric," "moderately phyric," or "highly phyric," depending upon the proportion of phenocrysts visible with the hand lens or binocular microscope (approximately  $10 \times$ ). Basalts are termed "aphyric" if phenocrysts constitute less than 1% of the rock, "sparsely phyric" if phenocryst content ranges from 1% to 2%, "moderately phyric" at 2% to 10%, and "highly phyric" if phenocrysts constitute more than 10% of the rock. Basalts are further classified by phenocryst type (e.g., a moderately plagioclase-olivine phyric basalt contains 2%-10% phenocrysts, mostly plagioclase, with subordinate olivine).

Synoptic versions of the Leg 121 igneous VCD forms are published with this volume and are available on microfilm at the ODP repositories.

## **Thin-Section Descriptions**

Thin-section billets of basement rocks are examined to (1) confirm the identity of petrographic groups in the cores, (2) better understand the textures and interrelationships of the mineral phases, (3) help define unit boundaries indicated by hand-specimen core descriptions, and (4) define the secondary alteration mineralogy. Estimated percentages of individual phenocryst phases are reported on the detailed thin-section description sheets (available in microform at the repositories). The terms "sparsely,"

"moderately," and "highly" phyric are used in the same manner as for hand-specimen descriptions. In cases where discrepancies arise in the lithostratigraphic summary over the composition and abundance of phenocryst phases between hand-specimen and thin-section analyses, thin-section descriptions are used.

### **X-Ray-Diffraction Analyses**

A Philips ADP 3520 X-ray diffractometer is used for the XRD analysis of mineral phases. Instrument conditions in normal use are CuK $\alpha$  radiation with a Ni filter, 40 kV, 35 mA, goniometer scan from 2° to 70° 2 $\theta$ , 0.02° step size, and 1 s/step count time.

Samples are ground with the Spex 8000 Mixer Mill, or an agate mortar and pestle is used for very small samples. The ground material is pressed into the sample holders for X-ray analysis.

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

## **X-Ray-Fluorescence Analysis**

Prior to analysis, samples normally are crushed in the Spex 8510 Shatterbox, using a tungsten carbide barrel. This produces

Table 3. Cenozoic calcareous nannofossil datum levels and corresponding zonal boundaries of Okada and Bukry (1980) with age estimates (Berggren et al., 1985).

Datum <sup>a</sup>	Zone (base)	Age (Ma)
FO Emiliania huxleyi	CN15	0.275
LO Pseudoemiliania lacunosa	CN14b	0.474
LO Calcidiscus macintyrei		1.45
<sup>b</sup> Pliocene/Pleistocene boundary		1.9
LO Discoaster brouweri	CN13a	1.9
LO Discoaster pentaradiatus	CN12d	2.2
LO Discoaster surculus	CN12c	2.4
LO Discoaster tamalis	CN12b	2.6
LO Reticulofenestra pseudoumbilica	CN12a	3.5
FO Discoaster tamalis	CN11b	3.8
LO Amaurolithus primus	CN11a	4.4
FO Ceratolithus rugosus	CN10c	4.5
Miocene/Pliocene boundary	1223124621	5.0
FO Ceratolithus acutus	CN10b	5.0
LO Discoaster quinqueramus	CNI0a	5.6
FO Amaurollinus primus	CN90	0.5
FO Discoaster derggrenti	Cinya	8.2
FO Discoaster quinquerumus	CNIPh	0.2
FO Discoaster loeblichii	CINOU	0.5
10 Discoaster hamatus	CN8a	8.85
FO Discoaster hamatus	CN7	10.0
FO Catinaster coalitus	CNG	10.8
10 Coccolithus floridanus	CNSb	13.1
FO Discoaster kugleri	01150	13.1
IO Sphenolithus heteromorphus	CN5a	14.4
10 Helicosphaera ampliaperta	CN4	16.2
FO Sphenolithus heteromorphus	CN3	17.1
FO Sphenolithus helemnos	CN2	21.5
FO Discoaster druggii	CNIc	23.2
Oligocene/Miocene boundary		23.7
LO Reticulofenestra bisecta	CN1a	23.7
LO Sphenolithus ciperoensis	23.7	
LO Sphenolithus distentus	CP19b	28.2
LO Chiasmolithus altus		28.2
FO Sphenolithus ciperoensis	CP19a	30.2
FO Sphenolithus distentus	CP18	34.2
LO Reticulofenestra umbilica	CP17	34.6
LO Coccolithus formosus	CP16c	35.1
Acme top Ericsonia subdisticha	CP16b	35.9
Eocene/Oligocene boundary		36.7
LO Discoaster saipanensis	CP16a	36.7
FO Isthmolithus recurvus	CP15b	37.8
LO Chiasmolithus grandis	CP15a	40.0
LO Coccolithus solitus	CP14b	42.3
LO Nannotetrina fulgens	CP14a	45.4
FO Reticulofenestra umbilica		45.4
LO Chiasmolithus gigas	CP13c	47.0
FO Chiasmolithus gigas	CP13b	48.8
FO Nannotetrina fulgens	CP13a	49.8
FO Discoaster sublodoensis	CP12	52.6
LO Tribrachiatus orthostylus	CP11	53.7
FO Discoaster lodoensis	CP10	55.3
LO Tribrachiatus contortus	CP9b	56.3
Paleocene/Eocene boundary		57.8
LO Fasciculithus ssp. FO Tribrachiatus bramlettei	CP9a	57.8 57.8
FO Discoaster multiradiatus	CP8	59.2
FO Heliolithus reidelii	CP7	60.0
FO Discoaster mohleri	CP6	60.4
FO Heliolithus kleinnellii	CP5	61.6
FO Fasciculithus ssn.	CP4	62.0
FO Prinsius martinii	CP3	63.8
FO Chiasmolithus danicus	CP2	64.8
FO Cruciplacolithus tenuis	CP1b	65.9
FO Biantholithus sparsus	CP1a	66.4
Cretaceous/Tertiary boundary	1999-9397 C	66.4
LO Discoaster quinqueramus FO Amaurolithus primus FO Discoaster berggrenii FO Discoaster neorectus FO Discoaster neorectus FO Discoaster neorectus FO Discoaster hamatus FO Discoaster hamatus FO Discoaster hamatus FO Catinaster coalitus LO Coccolithus floridanus FO Discoaster kugleri LO Sphenolithus heteromorphus LO Helicosphaera ampliaperta FO Sphenolithus heteromorphus FO Sphenolithus heteromorphus FO Discoaster druggii Oligocene/Miocene boundary LO Reticulofenestra bisecta LO Sphenolithus ciperoensis LO Sphenolithus distentus LO Sphenolithus distentus LO Sphenolithus distentus LO Sphenolithus distentus LO Sphenolithus distentus LO Sphenolithus distentus LO Coccolithus formosus Acme top Ericsonia subdisticha Eocene/Oligocene boundary LO Discoaster saipanensis FO Isthmolithus greadis LO Coccolithus solitus LO Coccolithus solitus LO Chiasmolithus gigas FO Asthmolithus gigas FO Ananotetrina fulgens FO Discoaster lodoensis LO Tribrachiatus orthostylus FO Discoaster lodoensis LO Tribrachiatus contortus Paleocene/Eocene boundary LO Fasciculithus spanelis FO Discoaster multiradiatus FO Heliolithus kleinpellii FO Fasciculithus sparsus Cretaceous/Tertiary boundary	CN10a CN9b CN9a CN8b CN8a CN7 CN6 CN5a CN4 CN3 CN2 CN1c CN1a 23.7 CP19b CP19a CP19a CP17 CP16c CP16b CP16a CP16b CP16a CP15b CP15a CP14b CP15a CP14b CP15a CP14b CP15a CP14b CP15a CP13a CP12 CP10 CP10 CP16 CP16a CP15b CP15a CP15b CP15a CP12 CP10 CP16 CP16 CP16 CP15a CP12 CP10 CP16 CP16 CP16 CP15a CP12 CP11 CP10 CP16 CP16 CP15a CP12 CP11 CP10 CP16 CP15 CP16 CP15a CP12 CP11 CP10 CP16 CP15 CP16 CP15 CP15 CP16 CP15 CP16 CP15 CP16 CP15 CP16 CP15 CP16 CP15 CP16 CP15 CP16 CP15 CP16 CP15 CP16 CP15 CP16 CP15 CP16 CP15 CP16 CP15 CP16 CP16 CP15 CP16 CP15 CP16 CP15 CP16 CP16 CP16 CP15 CP16 CP16 CP16 CP16 CP16 CP16 CP16 CP16	5.6         6.5         8.2         8.5         8

 $^{a}$  FO = first occurrence; LO = last occurrence.

<sup>b</sup> The Pliocene/Pleistocene boundary age estimate is approximated here by the last occurrence of *Discoaster brouweri*.

Table 4. Diatom datum levels used for Leg 121, with age estimates. Data from Barron (1985a, 1985b) and Barron et al. (1985a, 1985b).

Datum <sup>a</sup>	Age (Ma)	
LO Nitzschia reinholdii		
LO Rhizosolenia praebergonii var. robusta	1.55	
FO Pseudoeunotia doliolus	1.80	
LO Rhizosolenia praebergonii	1.85	
LO Thalassiosira convexa	2.1	
LO Nitzschia jouseae	2.6	
FO Rhizosolenia praebergonii	3.0	
FO Nitzschia jouseae	4.5	
FO Thalassiosira fraga	19.9	
LO Bogorovia veniamini	19.9	
LO Melosira architecturalis	20.9-20.6	
FO Rossiella paleacea	22.7	
FO Bogorovia veniamini	26.5	

<sup>a</sup> FO = first occurrence; LO = last occurrence.

Table 5. Lower Paleogene zonation used for Leg 121 Hole 752A (Broken Ridge).

Zone	Author	Age	Defination <sup>a</sup>
Pyxilla gracilis	Strelnikova (1987)	early Eocene	Top: FO Pyxilla oligocenica var. tenius Base: FO Pyxilla gracilis
Triceratium tesselatum	Fourtanier ("Site 752" chapter, this	late Paleocene	<sup>b</sup> Top: FO Pyxilla gracilis
	volume)		Base: FO Triceratium tesselatum
Hemiaulus incurvus	Fourtanier ("Site 752" chapter)	middle to late Paleocene	<sup>c</sup> Top: FO <i>Triceratium</i> <i>tesselatum</i> Base: not defined

<sup>a</sup> FO = first occurrence: IO = last occurrence.

<sup>b</sup> LO Hemiaulus incurvus is a secondary marker for the zone top.

<sup>c</sup> Hemiaulus incurvus is commonly found in this interval.

some Ta and massive W contamination of the sample. If postcruise studies for these elements or instrumental neutron activation analyses are envisaged for these shipboard XRF powders, the samples are crushed using an agate-lined barrel. All Leg 121 samples were crushed in an agate-lined barrel.

A fully automated wavelength-dispersive ARL8420 XRF system is used to determine the major oxide and trace element abundances of whole-rock samples. Analyses of the major oxides are carried out on lithium borate glass disks doped with lanthanum as a "heavy absorber" (Norrish and Hutton, 1969). The disks are prepared from 500 mg of rock powder, ignited for 2 hr at about 1030°C, mixed with 6.000 g of dry flux consisting of 80% lithium tetraborate and 20% La2O3. This mixture is then melted at 1150°C in a Pt-Au crucible for about 10 min and poured into a Pt-Au mold using a Claisse Fluxer. The 12:1 flux to sample ratio and the use of the lanthanum absorber make matrix effects insignificant over the normal range of igneous rock compositions. Hence, the following linear relationship between X-ray intensity and concentration holds:

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

where  $C_i$  = concentration of oxide *i* (wt%),  $I_i$  = net peak X-ray intensity of oxide i,  $m_i$  = slope of calibration curve for oxide i(wt%/cps), and  $b_i$  = apparent background concentration for



Figure 9. Igneous-rock core description form.

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oxide *i* (wt%). The slope  $m_i$  is calculated from a calibration curve derived from the measurement of well-analyzed reference rocks. The background  $b_i$  is either determined on blanks or derived by regression analysis from the calibration curves.

Systematic errors resulting from short- or long-term fluctuations in X-ray tube intensity are corrected by normalizing the measured intensities of the samples to that of a standard that is always run together with a set of six samples. In order to reduce weighing errors, two glass disks may be prepared for each sample. Weighing is performed with particular care because it can be a major source of error. Loss on ignition values, if required, are determined by weighing the sample before and after ignition at 1030°C.

Trace element determinations use pressed-powder pellets prepared by pressing (with 7 tons of pressure) a mixture of 5.0 g of dry rock powder (dried at 110°C for >2 hr) and 30 drops of polyvinylalcohol binder into an aluminum cap. A modified Compton scattering technique based on the intensity of the Rh Compton peak was used for matrix absorption corrections (Reynolds, 1967). A comprehensive description of the analytical procedure and the program developed is given in the "Explanatory Notes" chapter of the Leg 111 *Initial Reports* (Shipboard Scientific Party, 1988).

#### PALEOMAGNETICS

#### Sampling

Generally, two samples were taken from each section of the working halves. Soft sediments were sampled by pushing plastic Mineralogical Research cubes of 7-cm<sup>3</sup> volume into the section using a plastic jig for proper alignment along the core axis. Prior to sampling, the cubes were demagnetized at 20 or 60 mT with the Schonstedt GSD-1 alternating field demagnetizer. Harder sediments and basalts were sliced with a twin-bladed saw into cubes of 10.6-cm<sup>3</sup> volume. A set of plastic tools was machined for proper alignment and marking of minicores, and a supplied stainless-steel core barrel was fitted into a newly machined collet. The drilling of minicores, however, proved more time consuming and probably less accurate than the slicing of cubes and was not continued.

### **Bulk-Susceptibility Measurement**

The susceptibility of all of the cores was measured with the Bartington Instruments magnetic susceptibility meter model M.S.1, using the M.S.1/CX 80-mm whole-core sensor loop set at 0.47 kHz. Whole-round cores were typically measured at 10cm intervals. Cores and core sections of particular interest or of high susceptibility contrast were measured at 5-cm intervals. The APC cores from Site 758 were measured at 3-cm intervals to facilitate high-resolution correlation of the three holes. Basalt cores were measured at 5-cm intervals after curating. Magnetic susceptibility values for Leg 121 are reported in cgs units.

#### **Magnetic Remanence**

Remanence of all but the most disturbed archive-core halves was measured with the 2G-Enterprises 760R cryogenic magnetometer. Natural remanent magnetization (NRM) and remanence after 9-mT demagnetization were measured at 10-cm intervals. Cores 121-752A-5H through 121-752A-10H were measured at 5-cm intervals. This proved time consuming, however, and initial NRM measurements had to be skipped in order to keep up with the core flow. The higher sample density gave no clear improvement in resolution of the polarity record. The procedure was discontinued once it became clear that the combination of initial NRM and 9-mT alternating field (AF) demagnetization data gave more insight into the polarity record.

The SOUID consoles were read in flux-counting mode, on either 100× (range 100) or ER (extended range). Low-intensity sediments were measured on range 1 or range 100 as per individual preference. 2G-Enterprises recommends measuring in fluxcounting mode on range 1 only, as proper counting of flux jumps is not guaranteed at higher range settings, but the instrument appears to function properly at range 100 as well. The installation of a line conditioner in the power supply to the SQUID consoles greatly reduced flux jumps that resulted from spikes in the mains and were particularly noticeable during switching of the in-line AF demagnetization coils. The rolling movement of the ship resulted in a high noise level on the order of 0.1 mA/m or more for the cryogenic magnetometer. This noise level exceeds the potential sensitivity of the cryogenic magnetometer at range 1 by about two orders of magnitude. Consequently, the advantage of a higher dynamic range at range 100 or extended range was preferred by most of us. Results were monitored for missed flux jumps and sections; when observed, sections were remeasured. The band filter of the SQUID electronics was kept in the 10-Hz position throughout Leg 121, and the data acquisition program was run in single measurement/ position mode.

Selected discrete samples of Sites 752 through 755 (Broken Ridge) were demagnetized with the AF demagnetizer to confirm polarity interpretation or to clarify split-core measurements that did not give an unequivocal polarity interpretation. Ten samples from Hole 754B were thermally demagnetized with the Schonstedt TSD-1 demagnetizer. This time-consuming procedure was discontinued once it became clear that we had insufficient control over the magnetic environment to prevent buildup of viscous magnetic components during the measurement of carbon-ate-rich samples heated above 450°C.

The limited collection of basalt and ash samples from Sites 756 through 758 (Ninetyeast Ridge) was not, for the most part, demagnetized. It was decided that the acquisition of alternating field remanent magnetization (ARM) caused by the Schonstedt AF demagnetizer above 15 mT and the lower accuracy of the Molspin with respect to shorebased cryogenic magnetometers could impair our chances of determining an accurate paleolatitude during post-cruise studies.

### **Time Scale**

A combination of two Cenozoic time scales (Berggren et al., 1985; Bolli et al., 1985) was adopted for Leg 121. The biostratigraphic zonations of both scales are identical with the following exceptions:

1. Bolli et al.'s (1985) foraminifer zonation offers greater resolution in the vicinity of the Miocene/Pliocene boundary, but is elsewhere identical to the scheme in Berggren et al. (1985).

2. Bolli et al. (1985) include a diatom zonation scheme, facilitating correlations among the major groups.

The Bolli et al. (1985) scheme was preferred by the paleontologists. The geomagnetic reversal time scale of Berggren et al. (1985), however, provides significantly greater resolution and was preferred by the paleomagnetists.

The paleontological zonations were determined following the Bolli et al. (1985) scheme with some minor modifications. The paleomagnetic data were correlated to the geomagnetic reversal time scale of Berggren et al. (1985), which was also followed for assignment of absolute ages. The Berggren et al. (1985) and the Bolli et al. (1985) schemes were correlated via the calcareous nannofossil zonations, which are nearly identical. This procedure provided good time resolution as well as consistency with recent ODP legs. For the Cretaceous, paleontological zonations were determined following the Bolli et al. (1985) scheme. Absolute ages were derived from the Kent and Gradstein (1985) scheme. The magnetic polarity patterns in Kent and Gradstein (1985), Berggren et al. (1985), and Bolli et al. (1985) are identical, so the only necessary adaptations to the Bolli et al. (1985) time scale were the absolute ages assigned to the following boundaries: Cretaceous/Tertiary (66.4 Ma), Campanian/Maestrichtian (74.5 Ma), Santonian/Campanian (84.0 Ma), and Hauterivian/Barremian (124.0 Ma).

The chron terminology used throughout the text and figures is that of Berggren et al. (1985). A chron number followed by R or N (e.g., C32N) denotes the reversed or normal part only, respectively, and a chron number alone (e.g., C32) refers to both normal and reversed parts. Berggren et al. (1985) did not define a specific notation scheme for subcrons. Following the spirit of their paper, an informal notation scheme was adopted. For example, C32N-1r denotes the reversed polarity subchron between normal polarity subchrons C32N-1 and C32N-2.

### **Operational Problems**

### Calibration of the Cryogenic Magnetometer

The X, Y, and Z channels of the cryogenic magnetometer were cross-calibrated using two samples that were essentially uniaxially magnetized. One sample was a standard supplied by the Bureau of Mineral Resources (Australia) and the other was the ODP Molspin standard. Calibration was limited to a check of the Z-channel output against the combined output of the X and Y channels, because there was a significant amount of play in the orientation of the discrete sample boat in the XY plane. Following the calibration figures initially supplied by 2G Enterprises (X =  $177 \times 10^{-6}$ , Y =  $165 \times 10^{-6}$ , and Z =  $115 \times 10^{-6}$ emu/phi0), both standards showed the Z calibration to be 6% too low with respect to the X and Y calibrations (at range 100).

New calibration factors were determined heuristically as  $X = 174.0 \times 10^{-6}$ ,  $Y = 164.6 \times 10^{-6}$ , and  $Z = 121.5 \times 10^{-6}$  emu/ phi0. With these figures, measurement of the ODP Molspin standard both in random orientations and with its magnetic moment aligned along the X, Y, and Z axes, respectively, produced similar total moment readings. It appears from these results that the X-Y-Z cross-calibration is off by less than 1% on the 1, 10, and 100 ranges, and intercalibration between the 1, 10, and 100 ranges is also off by less than 1%. These results are as good as can be expected from such a method, and the new calibration figures were introduced into the data acquisition program.

As far as we could determine, results from Legs 103 to 120 were obtained with the original, and now superseded, calibration figures. This may have resulted in inclination values that were too low by up to 3°. Such errors may not have noticeably affected magnetostratigraphic studies using whole-core measurements, considering the overall inaccuracy of such measurements, and may only become apparent once a proper deconvolution procedure has been developed. However, discrete sample measurements with the cryogenic magnetometer were affected systematically.

### Remanence Disturbance during Section Cutting

Declination-inclination-intensity (DII) plots commonly show large-scale directional disturbances and intensity reductions of one or two orders of magnitude at the ends of sections (Fig. 10). These anomalies can be partially explained by the lack of a proper deconvolution procedure for whole-core measurements. However, these anomalies are also noticeable in measurements as much as several tens of centimeters from the section ends. The response curve of the SQUID pickup coils reduces to less than 10% at 10 cm from the center of the coils and has a negligible response at a 20-cm distance. Some of these effects, therefore, must be real. The probable cause is disturbance during splitting of the core.

Section splitting is done with a stainless-steel core-liner cutter, which has a frame with negligible remanence. However, the cutter blade (X-ACTO type 23) is made of ordinary steel, which can produce a local field as high as 0.12 mT. We do not expect this to be the main cause of the observed magnetic anomalies, but suggest replacement of the cutter blade with a stainless-steel variety of lower remanence. Use of a nonmagnetic blade would also reduce anomalies caused by the introduction of a broken blade tip into the core. We cannot suggest any measure, however, to reduce the more likely magnetic anomalies resulting from mechanical disturbance upon section cutting.

#### Remanence Disturbance during Section Splitting

In cores obtained with the APC, and to a lesser extent with the XCB method, we observed a gradual increase in NRM intensity from top to bottom of many individual sections. This effect is visible in initial NRM measurements and remains after AF demagnetization at 9 mT (Fig. 10). At first we suspected this effect was introduced by the GRAPE measurement procedure. GRAPE measurements of whole-core sections are made with the sections placed upward and systematically oriented with the double line marked on the core liner pointing forward. We measured the ambient field in the GRAPE unit and found that it nearly doubled in intensity from the top to the bottom of the measurement region (approximately 0.35 Oe at the top and 0.8 Oe at the bottom). We suspected that the observed NRM intensity increase toward the base of core sections might be due to an ARM-like component introduced by the high-frequency P-wave transducer operating in this strong local magnetic field. This hypothesis was tested on spot Cores 121-757C-1R and 121-757C-2R. No GRAPE-induced increase was noticeable in the more consolidated Core 121-757C-2R, and a directional disturbance in the mud-line Core 121-757C-1R most probably resulted from mechanical disturbance instead of the GRAPE measurement procedure.

We tested the possibility that the core-splitting process might be producing a change in remanence with the first four sections of Core 121-758B-2H. The whole core was measured first, and then the cores were split and measured again. Sections 121-758B-2H-1 and 121-758B-2H-3 were split in normal orientation (bottom to top), and Sections 121-758B-2H-2 and 121-758B-2H-4 were split in reverse orientation (top to bottom). Comparison of the whole-core and archive-half data (Fig. 11) shows only small differences, some of which may be due to the fact that the archive half was measured at a 5-cm interval and the whole core at a 10-cm interval. The slight offset in declination is probably due to a slight difference in orientation of the two cores in the XY plane. These cores are clay rich and well consolidated. Different results might well be obtained from other sediment types.

### Constant Declination in the Alternating Field Demagnetizer: ARM Acquisition?

A fairly consistent alignment of declination values ranging from 0° to 180° throughout unoriented cores and sections was observed in initial NRM measurements and was typically clearer after AF demagnetization at 9 mT. This alignment was most pronounced in cores with a low initial intensity of magnetization (less than 1 mA/m; e.g., Cores 121-752A-11H to 121-752A-11H). This effect has been noticed before (ODP Leg 116 Sites 718 and 719) and attributed to an ARM acquired during wholecore AF demagnetization.

Because of the consistency of declination values, this effect must be introduced during operations in which the cores are oriented in a systematic way: (1) core slicing/sawing, (2) GRAPE



Figure 10. Declination-inclination-intensity plot for Core 121-757B-15H. Note the intensity increase from top to bottom of individual sections and the large directional disturbance in intensity at the base of Section 5. A. Initial NRM data. B. After 9-mT AF demagnetization. C. Combination of Figures 10A and 10B.



Figure 10 (continued).



Figure 11. Comparison of NRM data for whole-round (A) and split (archive-half) (B) sections of Core 121-758B-2H. Sections 1 and 3 were split from top to bottom and 2 and 4 from bottom to top.

measurement, (3) whole-core AF demagnetization, and (4) viscous remanent magnetization (VRM) pickup during storage. Alternatively, the effect may be an artifact introduced during data acquisition. We checked the possibilities of (1) incorrect counting of flux jumps on the X, Y, and Z channels and (2) loss of resolution on the X and Y channels as a result of measurements with the SQUID consoles set inappropriately at  $100 \times$  or ER, but neither of these could be sustained. Introduction during GRAPE measurement can be excluded based on the GRAPE tests conducted on Core 121-757C-2R.

Tests were conducted to check acquisition of an XY component during core slicing/sawing, which is usually done from bottom to top, with the double-line mark on the liner oriented toward starboard. Sections 121-752A-21X-1, 121-752A-22X-1 through 121-752A-22X-4, and 121-752A-23X-2 were sawn following the normal procedure. The top half of Section 121-752A-23X-1, however, was sawn from top to bottom and the bottom half was sawn from bottom to top, throughout which the double mark was kept starboard. We could not identify any systematic acquisition of a magnetic component from the various sawing operations. At least in the samples we tested, the core-splitting operation on both indurated and soft sediments does not impart a noticeable remanence.

A distinct VRM component was acquired during storage experiments on both discrete samples and archive-half cores from the sedimentary sequence at Site 757 (see "Paleomagnetics" section, "Site 757" chapter). A change in inclination of 15° was induced in one archive half (Section 121-757C-2R-2) after only 2 hr of storage in the laboratory field (about 0.4 Oe). The inclination of the field was up, which is in the right sense to induce a VRM component with approximately 0° declination in cores stored in the usual manner. VRM acquisition during systematic orientation of cores in the storage rack before measurement might well explain at least part of the preferential directional alignment noticeable in initial NRM measurements. The alignment effect was not noted in the more clay-rich sediments at Site 758, suggesting that the lithology is an important factor. The origin of the VRM is not clear, but the fact that it is most pronounced in cores with a relatively high water content and low shear strength suggests that mechanical reorientation of the magnetic carriers, instead of thermal relaxation or disaccomodation, is responsible.

Overall comparison of initial NRM and 9-mT data from Sites 752 through 757 shows the declination alignment to be more pronounced after AF demagnetization at 9 mT than in the initial NRM measurements. This alignment could be due to "unmasking" of various VRM components of diverse stability, but it may also be due to acquisition of an ARM during wholecore AF demagnetization. Acquisition of an XY component during whole-core AF demagnetization may be due either to insufficient cancellation of the ambient field at the position of the AF coils or, more probably, to irregularities in the power supply.

The magnetic field within the mu-metal container surrounding the cryogenic magnetometer was measured with a Schonstedt DM-2220 fluxgate magnetometer. It proved difficult to obtain a full record of the XY component of the ambient field along the full length of the container because the length of the sensor precludes any X- or Y-axis measurements in the sample tube. At the position of the AF demagnetization coils, we found the X and Y components too small ( $<50 \gamma$ ) to cause significant ARM acquisition. We suspect, therefore, that any spurious magnetization pickup during demagnetization must result from irregularities in the power supply to the AF demagnetization coils. It proved too cumbersome to analyze the power supply for unwanted higher harmonics using the spectrum analyzer aboard ship, which may not be sensitive enough. A spare line conditioner of sufficient capacity was not available. A request to hardwire the power supply of both the cryogenic magnetometer and the AF demagnetizer into an existing line conditioner in the laboratory stack was not acted on during Leg 121. Clearly, the problem of apparent ARM in the XY plane needs to be tested and, if necessary, rectified at the earliest possible opportunity.

We were able to measure magnitude and variation of the ambient field's Z component along the axis of the mu-metal container. Figure 12 clearly shows a variation of  $\pm 500 \gamma$  in phase with the ship's roll. At the position of the SQUID pickup coils, a 500- $\gamma$  Z component was frozen in by the superconducting shield (X and Y components could not be measured with the fluxgate magnetometer). It is unlikely that this field could be lowered during warm up/cool down of the superconducting shield while at sea, especially without a triaxial fluxgate magnetometer. Despite its magnitude, we felt that this Z component was acceptable for measurement of whole-core NRM values for magnetostratigraphic purposes, assuming that we would be able to identify strongly viscous cores. More disturbing, however, was a high Z component at the position of the AF demagnetization coils (600  $\gamma \pm 500 \gamma$ ), which may introduce a significant ARM component during AF demagnetization of some cores. However, pickup of such a spurious component along the axis of core sections has not been clearly established as yet and will have to await comparison with shorebased discrete sample demagnetization studies.

### APC Orientation with the Eastman-Whipstock Multishot Core Orientation Tool

The well-defined magnetostratigraphy of Site 758, which was determinable even from unoriented cores, provided to be an ideal test of the Multishot tool. Initial results were disappointing because the declinations appeared to be random. After correction of an error in the core orientation program, however, the declinations were close to their expected values. For the purpose of constructing a magnetostratigraphy (i.e., distinguishing reversed from normal polarity), the tool seems to function adequately. One puzzling aspect of the data is an apparent systematic rotation of declination through the sections studied (see Fig. 40, "Paleomagnetics" section, "Site 758" chapter). The rotation of the reversed intervals amounts to about 80° clockwise over 100 m of Hole 758A and 80° counterclockwise over the same interval of Hole 758B. The normal polarity intervals do not show a consistent drift. Deviations of average declination from true north determined for each polarity interval in a single core (Table 6) do not show the trend as clearly as "Site 758" chapter Figure 40. It is possible that the apparent rotation is an artifact produced by incomplete removal of an overprint at 9mT. This possibility will have to be tested on shore where demagnetization of discrete samples can clearly establish the primary declination. Otherwise, we can offer no plausible explanation as to how such a rotation can occur.

#### Alternating Field Demagnetizer

The ambient field within the mu-metal shield at the position of the demagnetization coil proved to be less than 10  $\gamma$ , which was acceptable. Upon AF demagnetization above 15 to 20 mT, however, measurements indicated the acquisition of a spurious remanence. Tests showed the spurious component to be toward the back of the coil and directly related to the magnitude of the peak field. This DC bias may result from irregularities in the power supply or from detuning of the oscillation circuit. A suitable line conditioner was not available, nor did we have the expertise to tune the oscillator. Consequently, the demagnetizer was used only in the lower 20% (15–20 mT) of its intended range.

In the course of Site 757 studies we realized that the demagnetization coil was placed directly against the end cap of the



Figure 12. Component of ambient field along the axis of the mu-metal container around the cryogenic magnetometer. Measurements were made in transit.

	Normal (degrees)		Reversed (degrees)	
Core	Hole 758A	Hole 758B	Hole 758A	Hole 758B
3H	_	25	0	35
	_	_		50
4H	-15	0	- 45	0
5H	30	- 5	15	35
	35	-15	15	20
	35	-15	-	15
6H	_	30	20	20
	_	_		5
7H	20	0	35	25
	15	- 5	45	-
	-	- 20		_
8H	60	_	15	0
9H	25	0	25	-10
	20	15	35	15
10H	55	- 20	60	0

Table 6. Deviations of the Multishot declination from that determined from whole-core cryogenic measurements after 9-mT demagnetization.

mu-metal shield. It is possible that this close position could introduce eddy currents in the shield, resulting in ARM acquisition. Later tests with the coil moved away from the back of the shield produced the same results, however, with an ARM directed into the shields.

#### ACKNOWLEDGMENTS

This somewhat critical analysis of ODP's paleomagnetic operation would be severely unbalanced if we failed to express our appreciation for the best person in the laboratory. We are most impressed by the way John Tauxe has developed the laboratory over these initial years of operation. Technicians with his capabilities and attitude are hard to find, and he will be sorely missed now that he has chosen "the beach." It was a pleasure working with you, John, and good luck, Bettina.

## GEOCHEMISTRY

The geochemistry program for Leg 121 included (1) pore-water analyses for total dissolved solids (salinity), pH, alkalinity, calcium, magnesium, chlorinity, sulfate, ammonia, and phosphate; (2) analyses of hydrocarbon gases; (3) determination of total organic carbon; and (4) characterization of the organic matter by Rock-Eval pyrolysis.

### **Inorganic Geochemistry**

### Interstitial Waters

The Leg 121 shipboard interstitial-water sampling program obtained a 5- to 10-cm whole-round minicore from every third core (about 30 m) for routine interstitial-water analyses. In addition, 20-40-cm<sup>3</sup> plugs were taken from intermediate cores if large chemical changes were observed. On occasion, two 10-cm<sup>3</sup> plugs were taken from a half-round section when other sampling approaches were not permitted. Samples were squeezed for interstitial-waters using a stainless-steel press at room temperature (Manheim and Sayles, 1974). Subsequent to filtration, the interstitial-water samples from the routine sampling program were analyzed for total dissolved solids (salinity), pH, al-kalinity, calcium, magnesium, chlorinity, sulfate, ammonia, and phosphate.

All shipboard chemical analyses of interstitial waters were performed by means of standard ODP techniques. Alkalinity and pH were measured by potentiometric titration using a Metrohm titrator and a Brinkman combination pH electrode (Gieskes, 1974). Total dissolved solids (salinity) were measured using a Goldberg refractometer (Sayles et al., 1970). Calcium, magnesium, and chloride concentrations were determined by wet chemical titrations described by Gieskes (1974) and modified by Gieskes and Peretsman (1986). Sulfate concentrations were measured with a Dionex ion chromatograph (Gieskes and Peretsman, 1986). Ammonia and phosphate concentrations were measured by colorimetric methods employing a Bausch and Lomb Spectronic 1001 spectrophotometer (Mann and Gieskes, 1975; Gieskes and Peretsman, 1986). IAPSO (International Association of Physical Sciences Organizations) standard seawater was the primary standard for all shipboard analyses.

XRD studies were conducted on the squeeze cakes from the pore-water analyses. Samples were usually treated with 1 N HCl to dissolve calcium carbonate, and then X-ray studies were conducted on the treated sample. XRD operating conditions are described in the "Petrology" section of this chapter.

## **Organic Geochemistry**

### Hydrocarbon Gases

For safety considerations, concentrations of  $C_1$  (methane) and  $C_2$  (ethane) hydrocarbon gases were monitored at 30-m intervals or whenever gas pockets were encountered. Gases were extracted either using headspace sampling techniques for bulk sediments (Kvenvolden and Bernard, 1983; Kvenvolden and McDonald, in press) or through the core liner by Vacutainer sampling directly from gas pockets. Each headspace analysis required a 5-cm-long whole-round core sample, from which 5 cm<sup>3</sup> was placed in a glass container, sealed with a septa and metal crimp, and then heated to 70°C. All analyses were conducted on a Carle AGC 1000/Model 211.

## Inorganic and Organic Carbon

Percent carbonate and organic carbon analyses were carried out on freeze-dried bulk samples using a Coulometrics 5010 Coulometer coupled with the 5030 Carbonate Carbon and 5020 Total Carbon apparatus. Measurements were made on organic geochemistry samples as well as on samples used for physicalproperties measurements and on XRF samples. The weight percent of carbonate carbon was determined by reacting 20 to 50 mg of ground sample in a 2 N HCl solution. The quantity of CO<sub>2</sub> liberated was measured by titration in a monoethanolamine solution with a colorimetric indicator. The change of transmittance was monitored by a photodetection cell. Total carbon measurements were made by combustion of bulk samples at 960°C in an oxygen atmosphere, converting both organic and inorganic forms of carbon to CO2, which was then quantitatively analyzed by the Coulometrics titration method as outlined. The total organic carbon contents were then determined by subtracting the values for carbonate carbon from the total carbon content. Carbonate carbon and total carbon values were highly reproducible, and standard deviations for replicate analyses usually did not exceed 1%.

### Rock Eval

The bulk geochemical character of sedimentary organic matter was determined using the Rock-Eval pyrolysis techniques outlined by Espitalié et al. (1977). The following parameters were measured during the programmed pyrolysis (300° to 550°C) of 100-mg ground bulk samples: the amount of "free" hydrocarbons released at 300°C (S1); the amount of hydrocarbons released during heating to 550°C (S2), which is mainly due to the cracking of kerogen; total CO<sub>2</sub> released from organic matter during pyrolysis (S3); and the temperature of maximum hydrocarbon release during pyrolysis ( $T_{max}$ ). From these values, hydrogen, oxygen, and productivity indices were established. The hydrogen index represents the ratio of pyrolyzable organic matter, or "hydrocarbons" (S2), to total carbon (mg HC/g C<sub>org</sub>). The oxygen index represents the ratio of carbon dioxide released (S3) to total organic carbon (mg  $CO_2/g C_{org}$ ). The productivity index is defined as the ratio S1/(S1 + S2).

## PHYSICAL PROPERTIES

Shipboard determinations of physical properties are the basis for geotechnical stratigraphy studies and provide an important link among the geophysical site survey data, downhole logging results, and the geologic record obtained by coring. Cores are generally sampled with sufficient density to encompass the range of lithologic units recovered from each hole. Typically, samples were taken from every other section (about 3 m) during Leg 121. The properties determined include wet- and dry-bulk densities, grain density, compressional-wave velocity, thermal conductivity, water content, porosity, formation factor, and undrained shear strength. In all discrete measurements used in physical-properties determinations, an effort is made to analyze only undisturbed sediment and rock. A significant effort was made to carry out parallel studies on residues or splits of physical-properties samples. Smear slide and grain-size analyses were commonly done at, or near, physical-properties samples, and the samples were analyzed for carbonate and organic carbon contents after drying. Limited carbon-free residues were later analyzed for mineralogy using the XRD.

Techniques employed in determinations of index properties and compressional-wave velocity follow those described by Boyce (1976). The determination of undrained vane shear strength is described in Boyce (1977) and Lee (1985). The two techniques used in the shipboard determination of thermal conductivity are those of Von Herzen and Maxwell (1959) and Vacquier (1985). A synopsis of the methods employed during Leg 121, in the same sequence as the cores are analyzed in the shipboard laboratory, follows.

#### Whole-Core Scanning

## Gamma-Ray Attenuation Porosity Evaluator (GRAPE)

Whole APC and the first several XCB cores that filled the core liner were analyzed by the GRAPE device to provide data for density determinations. The core section to be measured is mounted vertically in a stand, and the gamma-ray source and sensor move along a track from the top to the bottom of the core section. A gamma ray passes through the diameter of the core (including the core liner), and the attenuation of the beam is measured every 1.5 to 2.0 cm. The density of the core material is calculated from the gamma-ray attenuation.

The GRAPE was calibrated by running an aluminum standard once prior to coring Sites 752 and 754. Site 753 calibration values were reset to default values which produced erroneously low densities. The problem was tracked down, a standard was run, and new calibration factors were entered to reprocess the Site 753 bulk densities. Following this mishap, a calibration standard was run every 12-hr shift change. Accuracy of the GRAPE technique is a complex issue, and the reader is referred to Boyce (1976) for a full discussion.

## Compressional-Wave Velocity Logger

The compressional-wave velocity logger (*P*-wave logger, or PWL) operates simultaneously with the GRAPE, with both mounted on the same frame. Acoustic transducers are aligned perpendicular to the gamma-ray beam (thus commonly parallel to the bedding plane). The transducer's contact with the core liner is improved by the application of water to the core liner. The acoustic source produces a 500-kHz pulse at a repetition rate of 1000 Hz. The sampling interval employed was 2 cm. The data recorded include core diameter, pulse delay time, and received signal amplitude. Data were edited on the basis of signal

strength; all values for which strength was below 75-100 (on a relative scale of 0-255) were dropped.

The PWL was calibrated with a drill-water standard several times during the leg. The standard deviation obtained from different measurements of the water standard ranged from 31 to 35 m/s.

## **Discrete Sample Measurements**

### Thermal Conductivity

Soft-sediment whole-core and hard-rock split-core sections were analyzed, following at least 3 hr of thermal equilibration, for thermal conductivity. Up to four needle probes were inserted into a soft-sediment core through small holes drilled through the core liner. An additional needle was inserted in a standard. The needles were heated, and measurements of resistance changes in the needles were made over a 5–6-min period, with the sampling rate varying from 12 to 21 s depending on the number of needles used. Thermal conductivity was calculated from the variations in resistance in the needles. To judge the reliability of the measurements, the temperature drift of the needles and a curve-fit parameter (rms of the temperature deviations) were calculated. Only determinations for which drift was less than  $\sim 0.04^{\circ}$ C/min and the curve-fit parameter was less than  $\sim 0.015$  were retained for analysis.

Hard-rock split-core samples were measured for thermal-conductivity determinations individually in a salt-water bath. A needle probe was sandwiched between a slab of low-conductivity material and the sample, with a thin layer of heat-sink compound applied to the probe to improve the thermal contact. The probe was heated, and measurements of resistance changes in the needle were made every 9 s over a 6-min period. These measurements were edited, and reliability tests similar to those applied to the soft-sediment data were performed.

All needles were tested for reliability in a Macor and rubber standard prior to use on the leg. Only those needles yielding thermal conductivities within  $\pm 0.06$  W/m°C of each other were used. The calculated standard deviation of these needles in the rubber standard was 0.025 W/m°C. Larger errors in thermal-conductivity measurements may result, however, from poor thermal contact between the needles and sample.

### Vane Shear Strength

A motorized vane device was used in the determination of undrained shear strength. The technique assumes that the sediment is primarily clay, a criterion that was met only by the sediment analyzed at Site 758 during Leg 121. The method used employs a four-bladed vane that is inserted into the split-core section perpendicular to its face (thus parallel to bedding planes), to a point where the top of the blade is covered by sediment. The vane is then rotated to attain a peak torque and residual torque. Torque and rotation output are plotted continuously during the test on a flatbed recorder. Undrained shear strength was calculated from the peak torque, and residual strength from the torque recorded after more than 90° of vane rotation.

The motorized vane device was calibrated prior to use by applying a known torque (weight  $\times$  moment arm) to the transducer and scaling the recorder appropriately. The recorder scales provided a sensitive range (0.1 V/div) and high range (1 V/div) for both torque and rotation. All blades were measured, and the recalibrated vane factors were modified in the data reduction software.

### Formation Factor

The resistivity of soft sediment relative to seawater resistivity is the formation factor (F factor). The measurement technique followed is similar to that described by Manheim and Waterman

(1974). This measurement was made using a new piece of equipment for routine ODP analysis, a Wayne-Kerr Precision Component Analyzer Model 6425. Although originally intended for measuring electronic component characteristics, it was used as a bridge to measure the resistance of the sediment medium between two electrodes. The tungsten electrodes are buried approximately 1.5 cm into the surface of the split-core section after measuring the resistance of seawater in another split liner, thereby avoiding geometric differences between sediment and water samples. The electrodes were aligned across-core, that is, generally parallel to bedding. The electrodes were kept in the seawater solution between measurements because drift in the early resistance measurements might have been due to a reaction on the tungsten surface. Later in the cruise, the bridge was adapted to a four-electrode configuration following the removal of two 100-ohm resistors originally located between measurement leads in the unit. The bridge was operated at 0.5 V AC and 1000 Hz for all tests. Laboratory temperatures were also recorded for all measurements.

#### Compressional-Wave Velocity (Hamilton Frame)

Discrete samples were measured with the Hamilton Frame for compressional-wave velocity determinations adjacent to intervals for which undrained shear strength was determined and in the same interval from which index-property samples were obtained. Numerous paleomagnetic cube samples were also tested prior to paleomagnetic work. The Hamilton Frame consists of two frame-mounted transducers with an apparent optimal resonance of 450 kHz. Traveltime of an outgoing pulse is measured by a counter/timer and oscilloscope. Travel distance is measured by an attached dial gauge. Samples were removed from the cores, placed in the frame, and time and distance were measured. Measurements of indurated lithologies, from cubes cut with a parallel-bladed saw, were made in both the horizontal and perpendicular *in-situ* planes to investigate velocity anisotropy.

The Hamilton Frame was calibrated with aluminum and leucite standards at the beginning of Leg 121 and checked during the cruise. Values of compressional-sound velocity were accurate to 2%-3%.

#### **Index Properties**

Splits of the discrete compressional-wave velocity samples were measured for index-property determinations. Indurated lithologies, cut in cubes, were also processed for index properties, except for the paleomagnetic cubes. Weights were measured by an electronic balance system. The balance provides an average value for 200 measurements of each sample's weight. Volumes were measured by a helium pycnometer employing a 2.0-min purge for sediments and a 4-min purge for dry basalts. Wet basalt samples in the pycnometer yielded unstable volumetric results, and sample cube volumes obtained by measuring the three sides of the cube indicated that the pycnometer values were erroneously low. Therefore, wet basalt volumes were measured using a rock-chunk technique in which the wet sample is weighed in air and then in distilled water using an O'Haus triple-arm balance. The weight difference is equivalent to sample volume. Weights and volumes were measured as soon as possible following splitting of the core, vane-shear analysis, and resistivity and velocity measurements. Weights and volumes were measured again after the samples were freeze-dried for a minimum of 24 hr. Salt-corrected (assuming pore-water salinity of 35%) wetand dry-bulk densities, grain density, water content, and porosity were then calculated.

The balance was calibrated with mass standards at the beginning of the leg and checked frequently for drift during the leg. The accuracy of the balance was nominally near 0.1% for typical sample weights of 5–20 g. The pycnometer was calibrated with volume standards at the start of the leg. Accuracy of the instrument also near 0.1%. Beaker calibrations were checked at the beginning of the leg by using a weight/volume calculation. The aluminum beakers should have densities near 2.7 g/cm<sup>3</sup>. All beakers with calibrated densities outside the range of 2.70  $\pm$  0.03 g/cm<sup>3</sup> were either rejected for use or recalibrated.

# **GEOPHYSICAL WELL LOGGING**

The Lamont-Doherty Borehole Research Group is contracted by ODP to provide the geophysical well logging aboard JOIDES Resolution. Lamont-Doherty, in turn, subcontracts Schlumberger Offshore Services to provide the downhole logging measurements, with the exception of data from specialty tools such as the borehole televiewer. Although the logging tools used by Schlumberger are designed for use in petroleum exploration, many have proved useful for gathering information of scientific interest. In some cases, individual logging sondes have been modified to meet ODP requirements, including the reduction of tool diameter to allow insertion in the 3.8-in. drill-string bore.

Geophysical well logging provides continuous, *in-situ* measurement of physical and chemical formation parameters that, upon interpretation, yield a stratigraphic, lithologic, geophysical, and mineralogic characterization of the site. Logging data may be directly correlated with available core measurements or used to supplement the data set when core recovery is poor.

A brief outline of the operation of each tool used on Leg 121 follows. Further information can be obtained from the Lamont-Doherty Borehole Research Group (1986) or directly from Schlumberger.

## **Aluminum Clay Tool**

The aluminum clay tool (ACT) is a combination of the natural gamma tool, the gamma spectroscopy tool, and, most significantly, a modified natural gamma tool that carries a Cf source. The radiation emitted by this source activates the Al, Mn, and Ca in the formation. In all, eleven elemental yields (K, U, Th, Fe, Si, Ca, S, H, Cl, Mn, and Al) are obtained from the spectrum reaching the NaI detector.

The ACT data are routinely used to determine clay mineralogy and to detect the presence of hydrothermal alteration and vein-filling minerals (E. Pratson, pers. comm., 1988). New methods are being developed to characterize the spatial fluxes of elements using data from the ACT.

#### Auxiliary Measurement Sonde

The auxiliary measurement sonde (AMS) provides continuous measurement of mud resistivity and temperature.

## **Borehole Compensated Sonic Tool**

The borehole compensated sonic tool (BHC; also known as the short-spacing sonic tool) measures the elastic compressional velocity of the formation. Two sources and two receivers are configured to provide four symmetric and redundant measurements of traveltime across a 2-ft interval centered at each depth. The source-receiver spacing on this tool provides two 3-ft- and two 5-ft-interval transit-time measurements. These data are processed to yield formation velocity, which, in combination with the formation density, can be used to generate a synthetic seismogram.

# **Borehole Televiewer**

The borehole televiewer (BHTV) is an acoustic device that scans the wall of the borehole, producing an image of the reflectivity of the rock surrounding the hole as a function of depth and azimuth. The BHTV log is obtained while logging at a rate of approximately 1.5 m/min with the sonde centralized in the hole by means of two three-armed bowspring sections. A piezoelectric transducer, which is mounted on a central shaft rotating three cycles per second, transmits and receives a high-frequency acoustic pulse 600 times per revolution. Two transducers are mounted on this shaft, allowing either a 1.3-MHz or a 400-kHz pulse to be used as a source. The higher frequency source reveals more details of the wall surface whereas the lower frequency source has better penetration and can produce an improved image in a rough-walled borehole.

The pulse is transmitted through the borehole fluid, reflected from the wall of the borehole, and received again at the transducer. The amplitude of the returning signal is recorded and displayed as brightness on a three-axis oscilloscope. Thus, the oscilloscope image is an acoustic picture of the reflectivity of the borehole wall, with the azimuth varying along the x-axis and the depth varying along the y-axis. The left-hand edge of the image is aligned with magnetic north using a downhole fluxgate magnetometer.

The raw data are recorded on a specially formatted video cassette for final playback after the logging is completed. In addition, a real-time (Polaroid) amplitude log is recorded from the oscilloscope screen. This photographic record serves as the primary log record at sea, where processing capacity is limited. The amplitudes and traveltimes of the received pulses are also recorded on magnetic tape by digitizing the televiewer signal during playback. In addition to obtaining a digital image of borehole reflectivity, the BHTV data can be processed to obtain an image in which the intensity is proportional to the traveltime of the reflected pulse. This traveltime log yields a three-dimensional image of the shape of the borehole as a function of depth and azimuth in the well, producing a 360° caliper log.

The scientific objectives addressed by BHTV logs include the location and orientation of fractures intersecting the hole; the determination of structural features, such as bedding or brecciation; the measurement of borehole diameter, surface roughness, and ellipticity; and the determination of the orientation of the principal horizontal stresses from the azimuth of borehole breakouts observed in the time-domain images. Some of the limitations of the BHTV must be considered, however. First, because the log is essentially a point measurement with depth, ship heave will cause irregular tool motion and thereby confuse the analysis and interpretation of the log. Second, severe borehole ellipticity or decentralization of the tool will degrade the image because the transmitted beam will no longer be perpendicular to the borehole wall at all azimuths. This effect can be recognized in the time-domain image. Third, the BHTV cannot recognize features that do not affect either the roughness, reflectivity, or radius of the borehole.

### Compensated Neutron Tool, Model G

Neutrons (5 MeV) from an Am-Be source collide with H in the formation and lose energy. These slowed neutrons are then captured by Cl, Li, B, and Gd, and capture gamma rays are emitted. Thus, H content (both bound and free) of the formation is the primary quantity obtained with the compensated neutron tool, Model G, (CNT-G) and is expressed as thermal neutron porosity. The epithermal (intermediate energy) neutron flux is an indicator of free water only, which is expressed as epithermal neutron porosity. The difference between thermal neutron porosity and epithermal neutron porosity is therefore proportional to the bound water in clays in the formation. The vertical resolution of this tool is 0.25 m.

### Dual Induction Tool, Model E

The dual induction resistivity tool, model E, (DIT-E, or phasor induction tool) provides three measurements of formation resistivity: deep induction (induction log-deep: ILD), medium induction (induction log-medium: ILM), and shallow induction (spherically focused log: SFL). Each measurement has a characteristic depth of investigation that depends on the formation, pore fluid, and mud resistivities. The ILD generally has the greatest depth of investigation and is therefore considered to give the best estimate of true formation resistivity. Typical depths of investigation of the three logs are 5, 2.5, and 0.5 m, respectively. Vertical resolution is 1.5 m. The induction measurements are, strictly speaking, measurements of formation conductivity that are converted to resistivity values for ease of presentation.

The induction measurement is made using a system of transmitter/receiver coil pairs. An alternating current (10, 20, or 40 kHz) is produced in the transmitter coils, inducing eddy currents in the formation. The magnetic field produced by these circulating eddy currents, in turn, induces a voltage at the receiver coil. The magnitude of the eddy current flow, and hence the receiver voltage and current, is proportional to the formation conductivity. The DIT-E tool records both a formation response signal R (90° out of phase) and a noise signal X (180° out of phase) and thus, allows processing to obtain a more accurate reading of formation conductivity.

The SFL uses a focusing configuration and constant potential electrodes to obtain a shallow, focused resistivity measurement. The DIT-D, the analog version of the DIT-E, uses only alternating current at 20 kHz in the transmitter coils.

#### **General Purpose Inclinometer Tool**

The general purpose inclinometer tool (GPIT) provides a measure of borehole deviation as well as a three-component magnetic field determination.

#### Gamma Spectroscopy Tool

Thermal neutrons (14 MeV) generated by the gamma spectroscopy tool (GST) interact with the formation and are captured by Ca, Cl, Si, Fe, H, and S, with the resulting emission of capture gamma rays. This gamma radiation is measured by a NaI detector, and the spectrum is windowed for the energies of the individual elements. Because other elements have some contribution to the signal, only various elemental ratios are used at sea as preliminary indicators of lithology, porosity, clay mineral content, pore-fluid salinity, and evaporite content. In post-cruise processing, a linear inversion method is used to obtain the dryweight percent as oxides for each of the aforementioned six elements.

## **Lithodensity Tool**

The <sup>137</sup>Cs source in the lithodensity tool (LDT) emits gamma rays that interact with the electrons in the elements in the formation by Compton scattering. This transfer of energy forms the basis of the density measurement. 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. At low energies, gamma radiation is absorbed by the photoelectric effect. The photoelectric factor (PEF) is used primarily as a matrix lithology indicator. The vertical resolution of this tool is about 0.3 m.

## Long-Spacing Sonic Tool

The long-spacing sonic tool (LSS) tool measures the elastic compressional velocity of the formation. Two sources and two receivers are configured to provide four source-receiver offsets of 8, 10, 10, and 12 ft. These data are processed to yield formation velocity, which, in combination with the formation density, can be used to generate a synthetic seismogram.

#### **Mechanical Caliper Device**

The mechanical caliper device (MCD) provides a two-dimensional caliper log of the borehole by means of a bowspringmounted measurement system. The hole diameter (HD) log is used to detect washouts or constrictions. Borehole diameter significantly effects many of the other logging measurements, and, therefore, the hole diameter is an important input to log-correction routines.

## Natural Gamma Spectroscopy Tool

This gamma-ray (GR) log records the natural radioactivity of a formation using a scintillation detector. This radiation is recorded initially as counts/second and is subsequently presented on an API radiation scale. Use of the natural gamma spectroscopy tool (natural gamma tool or NGT) allows the total gammaray response (SGR) of a formation to be separated into three components: the contributions of potassium (K), uranium (U), and thorium (Th). 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 at the surface to give the relative elemental abundance of K, U, and Th.

### **Standard Gamma Tool**

The standard gamma tool (SGT) measures gamma radiation in a total-spectrum window. Thus, no distinction can be made among K, U, and Th with this tool.

#### **Telecommunications Cartridge**

The telecommunications cartridge (TCC) is located at top of the tool string and channels the data from all the tools to the surface.

## Synthetic Seismograms

Synthetic seismograms are generated from logging data obtained with the LSS tool. As many as eight individual logs are used in the process: four transit-time measurements from near and far receivers, two slowness logs calculated from these transit times, an electrical resistivity log, and a bulk-density log. If no density log is available, a pseudodensity log can be created using the data obtained from core measurements.

The logs are initially examined for continuity and quality. An interval is chosen where the four transit-time logs are similar and contain no noise spikes. In this case, the two slowness curves (for near and far receiver combinations) are considered accurate, and the transit-time logs can be ignored. If there are discontinuities or noise spikes in the transit-time logs, they can be edited (if few in number) or reprocessed using software that truncates noise spikes and/or discards data from one or more receivers for a given interval. In either case, the resulting slowness logs must be examined carefully before they are considered accurate. Because the two slowness logs are nearly identical, only one is routinely used in the synthetic seismogram generation.

The interval from the seafloor to the first quality log data is replaced with a smooth ramp with slowness values starting at 190  $\mu$ s/ft (slowness of water) at the seafloor and gradually decreasing to the value of the first log data point. Thus, the synthetic seismogram begins at the seafloor and contains no spurious reflectors in the unlogged interval.

The bulk-density log from the LDT or a pseudolog created from laboratory measurements is required in addition to the slowness log. In many cases, a simple constant-density log can be generated using the average value of the laboratory data, provided that the range is small. Experience shows that this often gives surprisingly good results. If the laboratory data from discrete measurements are used, some form of averaging or smoothing is necessary to create a continuous density log.

The slowness and density logs are used in the program generating an impedance log (velocity  $\times$  density) that is convolved with a zero-phase Ricker wavelet. The frequency of this wavelet can be varied depending on the source that generated the original seismic profile. A 30-Hz wavelet is capable of a vertical resolution on the order of 30 m, so reflectors cannot generally be attributed to any small-scale lithologic horizons.

Synthetic seismograms in this volume are plotted with twoway traveltime on the left scale and depth below seafloor on the right. The scale on the depth axis is not linear. Impedance increases create positive (black) peaks indicating reflectors. An artifact of the convolution process is an extra interval of data on the synthetic seismogram, which is on the order of one wavelength of the selected Ricker wavelet. This data should be disregarded. The depth scale on the right, however, indicates the depths of logging data, and is correct.

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