2. EXPLANATORY NOTES¹

Shipboard Scientific Party²

INTRODUCTION

In this chapter, we have assembled information that will help the reader to understand the basis for our preliminary conclusions and also will help the interested investigator to select samples for further analysis. This information concerns only shipboard operations and analyses described in the site reports in this volume of Leg 128 *Proceedings of the Ocean Drilling Program.* Methods used by various investigators for shore-based analysis of Leg 128 data will be detailed in the individual scientific contributions published in the *Scientific Results* volume.

Authorship of Site Chapters

The separate sections of the site chapters were written by the following shipboard scientists (authors are listed in alphabetical order, no seniority is necessarily implied):

Site Summary: Ingle, Suyehiro

Background and Objectives: Ingle, Suyehiro

Operations: Pollard, von Breymann

Lithostratigraphy: Charvet, Dunbar, Föllmi, Grimm, Isaacs, Matsumoto, Pouclet, Scott, Stein

Biostratigraphy: Burckle, Kato, Kheradyar, Ling, Muza

Paleomagnetism: Hamano, Krumsiek

Sediment-Accumulation Rates: Burckle, Hamano, Kato, Kheradyar, Krumsiek, Ling, Muza

Inorganic Geochemistry: Dunbar, Sturz, von Breymann

Organic Geochemistry: Kettler, Stein

Microbiology: Cragg, Ingle, Parkes

Igneous Rocks: Pouclet, Scott

Physical Properties: Hirata, Holler

Downhole Measurements: Bristow, de Menocal, Grimm Electrical Resistivity Experiment: Hamano

Downhole Seismometer Experiment: Hirata, Suyehiro Seismic Stratigraphy: Suyehiro

Conclusions: Ingle, Suyehiro

Appendix: Shipboard Party

Drilling Characteristics

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

Drilling Deformation

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

Shipboard Scientific Procedures

Numbering of Sites, Holes, Cores, and Samples

Drill sites are numbered consecutively and refer 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.

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 the suffix B, and so forth. Note that this procedure differs slightly from that used by the Deep Sea Drilling Program (DSDP; Sites 1 through 624), but prevents ambiguity between site- and hole-number designations. It is important to distinguish among holes drilled at a site, because recovered sediments or rocks from different holes might 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 the seafloor at which coring began and extends to the depth at which coring ended (see Fig. 1). For example, each coring interval is generally up to 9.5 m long, which is the length of a core barrel. Coring intervals may be shorter and may not necessarily be adjacent if separated by drilled intervals. In soft sediments, the drill string can be "washed ahead" with the core barrel in place, without recovering sediments. This is achieved by pumping water down the pipe at high pressure to wash the sediment out of the way of the bit and up the space between the drill pipe and the wall of the hole. If thin, hard-rock layers are present, then it is possible to get "spotty" sampling of these resistant layers within the washed interval and thus to have a cored interval greater than 9.5 m. When 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

 ¹ Ingle, J. C., Jr., Suyehiro, K., von Breymann, M. T., et al., 1990. Proc. ODP, Init. Repts., 128: College Station, TX (Ocean Drilling Program).
 ² Shipboard Scientific Party is as given in list of participants preceding the

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



Bottom felt: distance from the rig floor to seafloor. Total depth: distance from the rig floor to the bottom of the hole. Penetration: distance from the seafloor to the bottom of the hole. Number of cores: total of all cores recorded, including cores with no recovery. Total length of cored section: distance from sub-bottom top to total depth minus drilled (but not cored) areas in between.

Total cored recovered: total from adding a, b, c, and d in the diagram. Core recovery (%): equals TOTAL CORE RECOVERED divided by TOTAL LENGTH OF CORED SECTION times 100.

Figure 1. Coring and depth intervals.



Figure 2. Examples of numbered core sections.

a given hole; however, this may not be true if an interval must be cored twice because of caving of cuttings or other hole problems. Maximum full recovery for a single core is 9.5 m of rock or sediment contained in a plastic liner (6.6 cm internal diameter), plus about 0.2 m (without a plastic liner) in the core catcher (Fig. 2). The core catcher is a device at the bottom of the core barrel that prevents the core from sliding out when the barrel is being retrieved from the hole. In certain situations (e.g., when coring gas-charged sediments that expand while being brought on deck), recovery may exceed the 9.5-m maximum.

A recovered core is divided into 1.5-m sections, which 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. During Leg 128, surface expansion of gaseous sediments led to recoveries that were higher than 100%. In these cases, as many as eight sections might be needed to accommodate the expanded material. 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 a 1-m section. If cores are fragmented (recovery less than 100%), sections are numbered serially and intervening sections are noted as void, whether or not shipboard scientists think that the fragments were contiguously in-situ. In rare cases, a section of less than 1.5 m may be cut to preserve features of interest (e.g., lithological contacts).

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

Recovered cores of igneous rock are also 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, and individual fragments are identified alphabetically. The core-catcher sample is placed at the bottom of the last section and is treated as part of the last section, rather than separately. Scientists completing visual core descriptions describe each lithologic unit, noting core and section boundaries only as physical reference points.

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

A complete identification number for a sample consists of the following information: leg, site, hole, core number, core type, section number, piece number (for hard rock), and interval in centimeters measured from the top of section. For example, a sample identification of "128-799A-5H-1, 10-12 cm" would be interpreted as representing a sample removed from the interval between 10 and 12 cm below the top of Section 1, Core 5 (H designates that this core was taken with the Advanced Hydraulic Piston) of Hole 799A during Leg 128.

All ODP core and sample identifiers indicate core type. The following abbreviations are used: R = rotary core barrel (RCB); H = hydraulic piston core (HPC; also referred to as APC, or advanced hydraulic piston core); P = pressure core barrel; X = extended core barrel (XCB); B = drill-bit recovery; C = center-bit recovery; I = in-situ water sample; S = sidewall sample; W = wash-core recovery; and M = miscellaneous material. APC, XCB, and RCB cores were cut during Leg 128.

Core Handling

Sediments

As soon as a core is retrieved on deck, a sample is taken from the core catcher and given to the paleontological laboratory for an initial age assessment. The core then is placed on a long horizontal rack, and gas samples may be taken by piercing the core liner and withdrawing gas into a vacuumtube. 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 pollution-prevention and safety program. Next, the core is marked into section lengths, each section is labeled, and the core is cut into sections. Interstitial-water (IW) organic geochemistry (OG), physical properties (PP), and microbiology (MB, Hole 798B) samples then are taken. In addition, some headspace gas samples are sampled from the ends of cut sections on the ship's catwalk and sealed in glass vials for analyzing light hydrocarbons. Each section then is sealed at the top and bottom by gluing on color-coded plastic caps: blue to identify the top of a section and clear for the bottom. A yellow cap is placed on the section ends from which a whole-round sample has been removed. These caps are usually attached to the liner by coating the end-liner and the inside rim of the cap with acetone, after which the caps are taped to the liners.

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

Next, the whole-round sections from APC and XCB cores are run through the Multisensor Track (MST). This includes the GRAPE (gamma-ray attenuation porosity evaluator) and *P*-wave logger devices, which measure the bulk density, porosity, and sonic velocity, and also includes a meter that determines the volume magnetic susceptibility. After the core has equilibrated to room temperature (approximately 3 hr), thermal conductivities are measured, and the cores are split.

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

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

The archive half is described visually. Smear slides are made from samples taken from the archive half; these are supplemented by thin sections taken from the working half. Sections from the archive half that do not show evidence of drilling disturbance are run through the cryogenic magnetometer. The archive half is then photographed using both blackand-white and color film, a whole core at a time. Close-up photographs (black-and-white) are taken of particular features to illustrate the summary of each site.

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

Igneous and Metamorphic Rocks

Igneous and metamorphic rock cores are handled differently from sedimentary cores. Once on deck, the core catcher is placed at the bottom of the core liner, and total core recovery is calculated by shunting the rock pieces together and measuring them to the nearest centimeter; this information is logged into the shipboard core-log data base program. The core is then cut into 1.5-m-long sections and transferred into the laboratory.

The contents of each section are transferred into 1.5m-long sections of split core liner, where the bottom of oriented pieces (i.e., pieces that clearly could not have rotated top to bottom about a horizontal axis in the liner) are marked with a red wax pencil. This is to ensure that orientation is not lost during splitting and labeling. The core is split into archive and working halves. A plastic spacer is used to separate individual pieces and/or reconstructed groups of pieces in the core liner. These spacers may represent a substantial interval of no recovery. Each piece is numbered sequentially from the top of each section, beginning with number 1; reconstructed groups of pieces are assigned the same number, but are lettered consecutively. Pieces are labeled only on external surfaces. If the piece is oriented, an arrow is added to the label pointing to the top of the section.

The working half of the hard-rock core then is sampled for shipboard laboratory studies. Records of all samples are kept by the ODP curator in College Station, TX. Minicore samples are routinely taken to study physical and magnetic properties. Some of these samples are later subdivided for X-ray fluorescence (XRF) analysis and thin-sectioning, so that as many measurements as possible are made using the same pieces of rock. At least one minicore is taken per lithological unit, when recovery permits, generally from the freshest areas of core. Additional thin sections, x-ray diffraction (XRD) samples, and XRF samples are selected from areas of particular interest. Samples for shorebased studies are selected in a sampling party held after drilling has ended.

The archive half is described visually, then photographed using both black-and-white and color film, one core at a time. Both halves of the core then are shrink-wrapped in plastic to prevent rock pieces from vibrating out of sequence during transit, placed into labeled plastic tubes, sealed, and transferred to cold-storage space aboard the drilling vessel.

VISUAL CORE DESCRIPTION Sediment "Barrel Sheets"

The core-description forms (Fig. 3), or "barrel sheets," summarize the data obtained during shipboard analysis of each sediment core. The following discussion explains the ODP conventions used when compiling each part of the core-description forms and the exceptions to these procedures adopted by Leg 128 scientists.

Sediments and Pyroclastic Deposits

Shipboard sedimentologists were responsible for logging cores visually, analyzing smear slides and describing thin sections of all sedimentary and pyroclastic material. Mineral composition data (determined by XRD) and major element data (determined by XRF) were used to augment the visual core descriptions. Data for biostratigraphy (age), geochemistry (calcium carbonate and organic carbon contents), paleomagnetics, and physical properties (wet bulk density and porosity), supplied by other groups, were integrated with the sedimentological information. This information provided the basis for descriptions of core-barrel logs in this volume.

Core Designation

Cores are designated using leg, site, hole, core number, and core type as discussed in a preceding section (see "Numbering of Sites, Holes, Cores, and Samples" section, this chapter). The cored interval is specified in terms of meters below sea level (mbsl) and meters below seafloor (mbsf). On the basis of drill-pipe measurements (dpm), reported by the SEDCO coring technician and the ODP operations superintendent, depths are corrected for the height of the rig-floor dual elevator stool above sea level to give true water depth and correct meters below sea level.

Graphic Lithology Column

For Leg 128, the actual lithology of the recovered material is represented on the core description forms (barrel sheets) in the column titled "Graphic Lithology" only for cores below the opal-A/opal-CT boundary (Core 128-798B-50X and below; Sample 128-799A-50X-4, 15 cm, and below; all cores from Hole 799B).

For all other cores, the actual lithology is not represented on the "Graphic Lithology" column. Instead, the average abundance of all constituents exceeding 10% in each interval is represented using the symbols illustrated in Figure 4. Thus, a diatomaceous ooze containing 70% diatoms, 10% nannofossils, and 20% clay is depicted as 70% diatom ooze (SB1), 10% nannofossil ooze (CB1), and 20% clay (T1), rather than as 100% diatom ooze.

To avoid too much clutter in the "Graphic Lithology" column, components have been combined into a maximum of four categories: biosiliceous debris, carbonate debris, siliciclastic debris, and volcaniclastic debris. Each category is depicted on the core description forms by a 25%–75% convention, such that a single constituent (such as nannofossils) is depicted as the sole constituent (such as nannofossil ooze, CB1) if it represents at least 75% of the category (carbonate debris); otherwise, the category is depicted as a mixture (such as nannofossil foraminiferal ooze, CB3). Thus, a diatomaceous clayey mixed sediment containing 50% diatoms and 50% clay is depicted as 50% diatom ooze (SB1) and 50% clay

(T1), whereas the same lithology containing 35% diatoms, 15% spicules, 35% clay, and 15% silt is depicted as 50% biosiliceous ooze (SB3) and 50% silty clay (T8).

Where an interval of sediment or sedimentary rock is a homogeneous mixture, the constituent categories are separated by a solid vertical line, with each category represented by its own symbol. In an interval composed of two or more sediment types having different composition, such as thinbedded and highly variegated sediments, the average relative abundances of the constituents are shown graphically by dashed lines that vertically divide the interval into appropriate fractions as described above.

The "Graphic Lithology" column shows only the composition of layers or intervals thicker than 10 cm. Information about finer-scale lithologic variations is included in the "Visual Core Description" (VCD) forms, which are available from ODP upon request.

Numerous thin ash layers were observed in the sediments recovered during Leg 128. However, owing to space limitations on barrel sheets, only some of these ash layers have been recorded. For additional information about these ash layers, the reader is referred to the ash layer and tephrochronology portions of the "Lithostratigraphy" section for each site chapter.

As noted during previous legs, intercalations of sedimentary material and igneous rocks occurred in some core sections. Where this occurred, the igneous petrologists described the igneous section and recorded results under "Hard Rock Core Description" forms, referred to on the sedimentary barrel sheets as "see igneous rock description."

Sedimentary Structures

In sediment cores, natural structures and structures created by coring can be difficult to distinguish. Any observed natural structures are indicated in the "Sedimentary Structure" column of the core description form. The symbols used to describe the primary biogenic and physical sedimentary structures, and secondary structures such as microfaults, dewatering veinlets, and mineral-filled fractures, are given in Figure 5.

The following notations have been used on the barrel sheets to indicate sedimentary types/zones or nodules: G = glauconite, C = carbonate, D = dolomite, Ch = chert, P = pyrite (see also Fig. 5).

Sediment Disturbance

Sediment disturbance is illustrated in the "Drilling Disturbance" column on the core-description form (using the symbols in Fig. 5). Blank regions indicate a lack of drilling disturbance. Drilling disturbance is recognized for soft and firm sediments using these categories.

- 1. Slightly disturbed: bedding contacts are slightly bent.
- Moderately disturbed: bedding contacts have undergone extreme bowing.
- Highly disturbed: bedding is completely disturbed, sometimes showing symmetrical diapirlike or flow structures.
- 4. Soupy: intervals are water saturated and have lost all aspects of original bedding.

The degree of fracturing in indurated sediments and igneous rocks is described using the following categories:

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

SHIPBOARD SCIENTIFIC PARTY

SITE	HOLE							CORE					С	CORED INTERVAL mbsf;	mbsl		
	BIOSTRAT. ZONE/									П		mi	s				
TIME-ROCK UNIT	FORAMINIFERS NANNOFOSSILS RADIOLARIANS DIATOMS PALEOMAGNETIC		PHYS. PROPERTIE	CHEMISTRY	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTUR	SED. STRUCTURE	SAMPLES	LITHOLOGIC DESCRIPTION						
									1	0.5				мв	3 ← Microbiology sample	- 6.	
									2								
	PR G = P =		ER lood	VA d erat	ATIO	ON:		(%)	3		ure 4)			PP	Physical properties sample		
	AE A = C =	BUNN = Abb = Ccc = Ra = Ba	JINDA Abunn Frequ Rare Barre	ANCE ANCE mmon quent e ren	NCE: dant non ent		y, and wet-bulk density	and total organic carbon	4		See key to graphic lithology symbols (Fi	svmbols in Figures	symbols in Figures	OG	a ← Organic geochemistry sample		
							Porosi	CaCO ₃ (%)	5			Coo bou to	NI KON DOO	IW	Interstitial water sample		
	RB								6					*	Smear slide Smear-slide summary (%) Section, depth (cm) M = minor lithology, D = dominant lithology		
									7					#	Thin section		
															XRD	X-ray diffraction analysis	
									cc					XRF	X-ray fluoresence analysis		

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

GRANULAR SEDIMENTS

PELAGIC SEDIMENTARY COMPONENTS

Calcareous Nanno-Foram or Foram-Nanno Ooz miniferal Ooze Clay/Clayston Chale (fierile) Sand/Silt/Clay nofossil Oo 11 ----÷. -CB2 CB3 CB1 T1 T2 Sand/Sandstone Silt/Siltstone Calcareous Ooze Nannofossil Chalk Foraminiferal Chalk ilty s CB4 CBE CB5 **T5** Τ6 lanno-Foram or oram-Nanno Chall Silty Clay/Clayey Silt Sandy Clay/Clayey Sand Calcareous Chal 0-0-0 -CB7 CBR CRO TR Т9 Grave Conglomerate Breccia . . SR SR2 Siliceous Diatom-Rad or Diatom Ooze us Ooze ----- $\hat{}$ VOLCANICLASTIC SEDIMENTARY COMPONENTS SB3 Volcanic Ash/Tuff Volcanic Lapilli V V SRA CHEMICAL SEDIMENTS ALL MIXED SEDIMENTS IN OPAL-A ZONE Porcellanite uthigenic carbo Δ ΔΔ Symbol for least oundant comp Symbol for most abundant compo Siliceous Symbol for compon claystone/siltst nt of intermediate abundance -----<u>A-A-A-</u>A (dashed vertical lines indicate variegated lithologies interbedded) SB10 SPECIAL ROCK TYPES Acid Igneous Rasic Igneou rphic

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

SR8

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

SR5

SR

- 3. Highly fragmented: pieces are from the interval cored and probably 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 their original orientation and stratigraphic position and may be mixed with drilling slurry.

Slumplike Drilling Disturbance

In addition to natural slumping, slumplike fold deformation probably caused by drilling was observed in Holes 798A and

SILICICLASTIC SEDIMENTARY COMPONENTS



Sedimentary structure symbols

Drilling deformation symbols



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

798C. For example, the interval from Section 128-798A-9H-1, 10 to 40 cm (76 mbsf) includes a gray ash layer that has been disrupted in the swirled geometry involving two different clayey levels (Fig. 6); the structure appears exaggerated by drilling effects, although the rest of this APC core was not deformed.

Similar geometric aspects are present in Section 128-798C-7H-4, at intervals 18 to 36 cm and 96 to 112 cm (about 80 mbsf). In each case, these aspects occur in a clay-rich level located below a more rigid, thick (about 10 cm) undeformed ash layer; the horizontal bedding is usually intact throughout the core, both above and below these intervals. Nevertheless,



Figure 6. Slumplike drilling disturbance at Section 128-798A-9H-1, from 10 to 40 cm (76 mbsf).

a natural origin for these structures is unlikely for the following reasons. At the interval at 96 to 112 cm (Fig. 7), a disharmonic fold, involving a thin ash layer at 106 cm, is found between the thick ash layer at the top and the planar laminated sequence at the bottom. This structure is perfectly symmetrical around the core axis and laterally asymptotic to the liner edges. Plastic deformation of this soft material probably results from drilling disturbance. The concentric (flexural)



Figure 7. Slumplike drilling disturbance at Section 128-798C-7H-4, from 96 to 112 cm (about 80 mbsf).

geometry adopted by the more competent thin ash layer is in opposition to the nonparallel type of folding of the clay laminations. The same conclusion may be valid for the interval at 18 to 36 cm in the same core. In both cases, a likely explanation is plastic deformation of the most ductile material in response to increased confining pressure inside the core barrel during drilling.

Color

Colors were determined by comparison with Munsell soilcolor charts. Colors were determined immediately after the cores were split, because redox-associated color changes may occur when deep-sea sediments are exposed to the atmosphere. Information on core colors is given in the text of the "Lithologic Description" column on the core description forms, and where appropriate in site chapters.

Samples

The position of samples taken from each core for shipboard analysis is indicated in the "Samples" column on the core description form (Fig. 3). The symbol "*" indicates the location of samples used for smear-slide analysis, and the symbol "#" indicates the location of samples taken for thin section analysis. The notations "XRD" and "XRF" indicate the location of samples for shipboard X-ray diffraction and X-ray fluorescence analyses, respectively. The notations IW, OG, PP, and MB designate the location of samples for whole-round interstitial-water geochemistry, frozen organic geochemistry, physical properties, and microbiology analysis, respectively.

Summary of Smear Slide Data

A table summarizing data from smear slides and thin sections (where available) appears on each core-barrel description form. This table includes information about the section and the interval from which the sample was taken, whether the sample represents a dominant ("D") or a minor ("M") lithology in the core, and the estimated percentages of sand, silt, and clay, together with all identified components.

The term "Glass" has been used to define all pyroclasts, including volcanic shards and pumice.

Lithologic Description—Text

The lithologic description that appears on each core description form (barrel sheet) consists of two parts: (1) a heading that lists all the major sediment types (see "Sediment Classification" section, this chapter) observed in the core and (2) a more detailed description of these sediments, including data about color, location in the core, significant features, and so forth. In cases where there are thin beds of minor lithology, a description (including location information) is included in the text, but the beds may be too thin (<10 cm) to appear in the "Graphic Lithology" column.

Paleontological Data

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

Paleomagnetic, Physical-Property, and Chemical Data

Columns are provided on the core description form for recording paleomagnetic results (normal, reversed or indeterminate polarity, shown as "N," "R," or "INT," respectively; arrows represent measurements in whole cores), values for physical properties (wet bulk density and porosity), and chemical data (percentages of $CaCO_3$ determined with the Coulometrics analyzer and total organic carbon determined with a Carlo Erba C/N/S elemental analyzer). Additional information about shipboard procedures for collecting these types of data appears in the "Paleomagnetism," "Physical Properties," and "Organic Geochemistry" sections (this chapter).

SEDIMENTOLOGY

The new ODP classification scheme by Mazzullo et al. (1988), partly reproduced here, was used without significant modification for ooze and unconsolidated sediment during Leg 128. Rock names were modified slightly as follows:

1. The terms "chert," "porcellanite," and "siliceous claystone" (or "siliceous siltstone") are used without regard to diagenetic silica phase (whether opal-CT or quartz) as textural terms for all rocks having significant amounts (>10%) of diagenetic silica. In many cases, siliceous claystones (or siliceous siltstones) are siliciclastic rocks, but in other cases, these are mixed sedimentary rocks.

2. The term "chalk" is used broadly for firm carbonate sediment or rock that is not highly cemented. Chalk may contain principally calcareous pelagic debris, or recrystallized pelagic debris composed of calcite, dolomite, siderite, or other carbonate minerals.

3. The term "authigenic carbonate" is used for hard carbonate rock that is highly cemented; authigenic carbonate may be principally calcite, dolomite, siderite, or other carbonate minerals. The term "dolomite" is used for beds where its presence has been confirmed by X-ray diffraction.

The sediment classification scheme described here defines two basic sediment types: (1) granular sediments and (2) chemical sediments.

Granular Sediments

Classes of Granular Sediments

Four types of grains are recognized in granular sediments: pelagic, neritic, siliciclastic, and volcaniclastic. Pelagic grains are composed of the fine-grained skeletal debris of openmarine siliceous and calcareous microfauna and microflora (e.g., radiolarians, nannofossils, foraminifers) and associated organisms. Neritic grains are composed of coarse-grained calcareous skeletal debris and calcareous grains of nonpelagic origin (e.g., bioclasts, peloids). Siliciclastic grains are composed of mineral and rock fragments that were derived from plutonic, sedimentary, and metamorphic rocks. Volcaniclastic grains are composed of rock fragments and minerals that were 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. 8).

Pelagic sediments are composed of more than 60% pelagic and neritic grains and less than 40% siliciclastic and volcaniclastic grains, and contain 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, and contain a higher proportion of neritic than pelagic grains. Neritic sediments were not encountered during Leg 128.

Siliciclastic sediments are composed of more than 60% siliciclastic and volcaniclastic grains and less than 40% pelagic and neritic grains, and contain 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, and contain 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).

Lastly, mixed sediments are composed of 40% to 60% siliciclastic and volcaniclastic grains, and 40% to 60% pelagic and neritic grains.



Figure 8. Diagram showing classes of granular sediment (modified from Mazzullo et al., 1988).

Classification of Granular Sediment

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 themselves (Table 1).

Principal Names

Each granular-sediment class has a unique set of principal names, which are outlined as follows.

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

1. Ooze: unconsolidated calcareous and/or siliceous pelagic sediment

2. Chalk: firm (but not hard) pelagic sediment and sedimentary rock composed predominantly of calcareous pelagic grains and recystallized pelagic grains

3. Diatomite and spiculite: firm pelagic sediment composed predominantly of siliceous diatoms and sponge spicules, respectively

4. Chert: vitreous or lustrous, conchoidally fractured, highly indurated rock composed predominantly of diagenetic silica (either opal-CT or quartz). For Leg 128, cherts probably contain 65% to 90% diagenetic silica (see "Silica Diagenesis and Characterization of Siliceous Rocks" part of the "Lithostratigraphy" section, "Site 799" chapter, this volume) and

5. Porcellanite: a well-indurated rock with abundant diagenetic silica (either opal-CT or quartz) but less hard, lustrous, or brittle than chert (in part, such rocks may represent mixed sedimentary rock). For Leg 128, porcellanites probably contain 50% to 75% diagenetic silica (see "Silica Diagenesis and Characterization of Siliceous Rocks" part of the "Lithostratigraphy" section, "Site 799" chapter, this volume). 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.) that are used as the principal names of siliciclastic sediment.

2. For Leg 128, even when two or more textural groups or subgroups are present in a siliciclastic sediment, only the predominant group is generally used as the principal name.

3. The suffix "-stone" is affixed to the principal names sand, silt, and clay when the sediment is lithified. Conglomerate and breccia are used as principal names of gravels with well-rounded and angular clasts, respectively.

4. In many cases, the special terms "siliceous claystone" and "siliceous siltstone" represent mixed sedimentary rock, in which siliciclastic material does not necessarily exceed 40%. Siliceous claystone (or siliceous siltstone) is used here for well-indurated rock with diagenetic silica and abundant siliciclastic material, somewhat harder than nonsiliceous rock, but less hard than porcellanite. For Leg 128, siliceous claystone and siliceous siltstone probably represent a wide range of diagenetic silica abundances, 10% to 25% at Site 798, and 10% to 60% at Site 799 (see "Silica Diagenesis" part of the "Lithostratigraphy" section, "Site 798" chapter, this volume; "Silica Diagenesis and Characterization of Siliceous Rocks" part of the "Lithostratigraphy" section, "Site 799" chapter, this volume).

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 greater than 64 mm in diameter

2. Volcanic lapilli: pyroclasts between 2 and 64 mm in diameter; when lithified, the term "lapillistone" is used; and

3. Volcanic ash: pyroclasts less than 2 mm in diameter; when lithified, the term "tuff" is used.

For mixed sediment, the principal name describes the degree of consolidation, with the term "mixed sediment" used for unlithified sediment, and the term "mixed sedimentary rock" used for lithified sediment. Lithified mixed sediment composed of 40% to 60% pelagic biosiliceous debris and 40% to 60% clay and silt-sized siliciclastic and volcaniclastic grains may also be termed "porcellanite" or "siliceous claystone" in the sediment descriptions for Leg 128.

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 term "with") that describe the lithology of the granular sediment in greater detail (Table 1). The most common use of major and minor modifiers is to describe the composition and textures of grain types that are present in major (greater than 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 is described with the major and minor modifiers diatom(-aceous), spicules(-ar), siliceous, nannofossil, foraminifer(-al), and calcareous. Although the terms "siliceous" and "calcareous" are used in the ODP classification generally to describe sediments that are composed of siliceous or calcareous pelagic grains of uncertain origin, these

Sediment class	Major modifiers	Principal names	Minor modifiers
Pelagic sediment	 Composition of pelagic and neritic grains present in major amounts Texture of clastic 	 Ooze Chalk Diatomite Spiculite Chert 	 Composition of pelagic and neritic grains present in minor amounts Texture of clastic
Neritic sediment	grains present in major amounts 1. Composition of neritic and pelagic grains present in	 6. Porcellarite 1. Boundstone 2. Grainstone 3. Productore 	grains present in minor amounts 1. Composition of neritic and pelagic mine present in
	2. Texture of clastic grains present in major amounts	 Fackstone Wackestone Mudstone Floatstone Rudstone 	 Texture of clastic grains present in minor amounts
Siliciclastic sediment	 Composition of all grains present in major amounts Grain fabric (gravels) 	1. Gravel 2. Sand 3. Silt	 Composition of all grains present in minor amounts Texture and
	 orali faore (gravers only) Grain shape (optional) Sediment color (optional) 	4. Ciay	2. Texture and composition of siliciclastic grains present as matrix (for coarse-grained clastic sediments)
Volcaniclastic sediment	 Composition of all volcaniclasts present in major amounts 	 Breccia Lapilli Ash/tuff 	 Composition of all volcaniclasts present in minor amounts
	 Composition of all pelagic and neritic grains present in major amounts 		 Composition of all neritic and pelagic grains present in minor amounts
	 Texture of siliciclastic grains present in major amounts 		 Texture of siliciclastic grains present in minor amounts
Mixed sediment	 Composition of neritic and pelagic grains present in major amounts 	1. Mixed sediment	 Composition of neritic and pelagic grains present in minor amounts
	 Texture of clastic grains present in major amounts 		 Texture of clastic grains present in minor amounts

Table 1. Outline of granular-sediment classification scheme (modified from Mazzullo et al., 1988).

terms (and also the term "biosiliceous") were used during Leg 128 to group several components together to simplify the sediment name, where appropriate. For example, diatoms and spicules were in places combined into the modifier "biosiliceous." Note that the term "siliceous" in "siliceous claystone" (or "siliceous siltstone") is used for Leg 128 in a different sense and not just as a major (>25%) modifier (see above).

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

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

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," and so forth.

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 lithic grains and crystals (e.g., feldspar or basaltic). The fabric of the sediment can be described by the major modifiers grainsupported, matrix-supported, and imbricated. Generally, fabric descriptors are applied only to gravels, conglomerates, and breccias, for they provide useful information about transport history.

Chemical Sediments

Classes of Chemical Sediment

Chemical sediment is 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, and generally has 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.

Carbonaceous Sediments

Carbonaceous sediments are composed of greater than 50% organic remains, principally plant and algal debris, that have been altered from their original form by carbonization, bituminization, or putrification. The two most common varieties of carbonaceous sediments are the coal series and
 Table 2. Udden-Wentworth scale of grain sizes for siliciclastic sediments (Wentworth, 1922).

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0.42 420 1.25 0.35 350 1.5 Medium sand 2 1/4 - 0.25 250 2.0 2.0
0.35 350 1.5 Medium sand 3 0.30 300 1.75 1/4
1/4 - 0.25 - 250 - 2.0 - 2.0 - 2.0
1/4 0.25 250 2.0
0.210 210 2.25
0.177 177 2.5 Fine sand
0.149 149 2.75
1/8 - 0.125 - 125 - 3.0
0.106 106 3.25 0.068 89 3.5 Mars for and
0.008 88 5.5 Very fine sand
1/16 0.0625 62 4.0
1/10 = 0.0025 = 0.0
0.003 03 4.25 Coarse silt
0.037 37 4.75
1/32 - 0.031 - 31 - 50
1.64 0.0156 15.6 6.0 Medium silt
1/128 0.0078 7.8 7.0 Fine silt
$1/256 - 0.0039 - 3.9 - 8.0$ Very fine silt Ξ
0.0020 2.0 9.0
0.00096 0.96 10.0 Clay
0.00049 0.49 11.0
0.00024 0.24 12.0
0.00012 0.12 13.0
0.00006 0.06 14.0

sapropels. Carbonaceous sediments were not encountered during Leg 128.

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. Evaporite sediments were not encountered during Leg 128.

Silicates/Carbonates

Silicates and carbonates are defined as sedimentary rocks that are nongranular and nonbiogenic in appearance and are 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 alteration products, as in the case of zeolites. For Leg 128, firm carbonate rocks (which may include or be composed of recrystallized pelagic grains) are called "chalk" and hard carbonate rocks are generally called "authigenic carbonate," but this term is modified or replaced where more precise mineralogy is known, mainly by the term "dolomite." Siliceous rocks are described by the terms "chert," "porcellanite," and "siliceous claystone" (or "siliceous siltstone") as appropriate (see under "Principal Names" above).

Metalliferous Sediments

Metalliferous sediments are a broad category of nongranular, nonbiogenic sedimentary rocks that includes pyrite, goethite, manganite, chamosite, glauconite, and other metalbearing minerals. These are classified according to their mineralogy.

X-Ray Diffraction Analysis

For XRD measurements, subsamples of the physical property (PP) samples and other selected samples were taken, ground, and prepared as randomly oriented, pressed powder slides. Scans were run between 15 and $60^{\circ} 2\theta$, using the step-scan mode (step size 0.02° , count time, 1.0 s). For evaluation of the diffractograms, peak areas of the lattice reflections for opal-CT (4.04-4.10 Å), quartz (4.26; 3.34 Å), calcite (3.03 Å), dolomite (2.89 Å), and siderite (2.79 Å) were determined. Because only relative intensity counts are presented, these data should be used only as rough estimates of the mineralogy of the bulk sediment.

X-Ray Fluorescence Analysis

Analyses of selected sediments from Sites 798 and 799 for major elements were performed during Leg 128. Prior to analysis, samples were crushed in the shipboard Spex 8510 Shatterbox, using a tungsten carbide barrel. This process produces some tantalum and massive tungsten contamination of the sample.

A fully automated ARL 8420 wavelength-dispersive XRF system was used to determine the abundances of major oxides in whole-rock samples. Analyses of these major oxides were performed on lithium borate glass disks doped with lanthanum as a "heavy absorber" (Norrish and Hutton, 1969). The disks were prepared from 500 mg of rock powder, 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 was then melted at 1150°C in a platinum-gold crucible for about 10 min and poured into a platinum-gold mold using a Claisse Fluxer. This XRF was calibrated using between 7 and 10 standards for each element. Results have been reported as the weight percentage of SiO₂, TiO₂, Al₂O₃, Fe₂O₃, MnO, MgO, CaO, Na₂O, K₂O, P₂O₅, and the sum of these oxide concentrations.

Systematic errors from short- or long-term fluctuations in X-ray tube intensity were corrected by normalizing the measured intensities of the samples to that of a drift standard that is always run together with a set of six samples. To reduce weighing errors, two glass disks may have been prepared for each sample. Weighing was performed with particular care as this can be a major source of error.

BIOSTRATIGRAPHY

Biostratigraphic Framework

A summary of the general correlation of planktonic microfossil zones, datum levels, and the magnetic polarity reversal record for the Miocene to Quaternary in the Japan Sea is presented in Figures 9, 10, and 11. Age assignments for Leg 128 were based mainly on core-catcher samples. Additional core samples were studied when the core-catcher samples were either barren or restricted to narrow time intervals, or where boundaries or unconformities occurred. Sample locations within cores, preservation, and abundance for each fossil group have been recorded on ODP paleontology and





biostratigraphy data forms, and zones, abundance, and preservation have been indicated on the barrel sheets.

Diatoms

A summary of the lower Miocene to Quaternary diatom zonation (Koizumi and Tanimura, 1985), applied when dating Leg 128 cores, is presented in Figure 9. Samples were disaggregated in water and a dilute solution of 10% hydrogen peroxide. Carbonate nodules and concretions were treated with 10% hydrochloric acid. Smear slides were prepared using Hyrax or Pleurax as a mounting medium. Relative abundances reflect percentage estimates of diatom valves within all material on the slide. The following convention was used:

- A = Abundant, >50%
- C = Common, 25%-50%
- F = Few, 1% 25%
- R = Rare, <1%
- B = Barren, no diatoms present

Preservation of diatoms was classified into three major categories based on the presence of complete or broken, thinly silicified or heavily silicified valves as follows:

Good: well preserved with numerous delicate valves Moderate: some thinly silicified valves present Poor: only heavily silicified valves present

Planktonic Foraminifers

Absence of marker species and low diversity of planktonic foraminiferal assemblages in cores recovered during Leg 128 made recognition of zones defined by Kennett and Srinivasan (1983) for temperate regions impossible. Zonations of Maiya et al. (1976) for the Oga Peninsula and the coiling direction zones of Lagoe and Thompson (1988) for the California borderland were used with limited success (see "Biostratigraphy" section, Sites 798 and 799 summaries, this volume). For estimating the dominance of dextral vs. sinistral coiling *Neogloboquadrina pachyderma*, up to 100 specimens were randomly counted in the core-catcher samples.

Samples were disaggregated in either water, 1% Calgon solution, or 10% hydrogen peroxide and were washed through a sieve having openings of 63 μ m. Abundance and preservation of the foraminifers were visually estimated as follows:

- A = Abundant, >50%
- C = Common, 20% 50%
- F = Few, 5% 20%
- R = Rare, <5%
- B = Barren, no tests present

Preservational characteristics were divided into three categories based on the extent of breakage and the proportion of delicate to robust tests:

Good: <10% of specimens broken and delicate specimens common

Moderate: <30% of specimens broken and delicate specimens rare

Poor: samples dominated by fragments and barren of delicate specimens

Radiolarians, Silicoflagellates, and Ebridians

Previously, scientists had observed that radiolarian zonations established for the Neogene of the North Pacific may not apply for the Sea of Japan. Unfortunately, this was also the case for Leg 128, with the possible exception of the *Sphaeropyle langii* Zone. However, the late Miocene/early Pliocene interval may be correlated with zones established from the coastal region of western Honshu, Japan (Nakaseko and Sugano, 1973). Rare but continuous occurrences of *Cycladophora davisiana* (=*Cycladophora davisiana*) may perhaps be used as an age-diagnostic species, but this needs to be confirmed by additional study.

A zonation for the Sea of Japan based upon silicoflagellates and ebridians was originally proposed by Ling (1975). This zonation was applied successfully to Leg 128 sediments and further refined by the application of shipboard magnetostratig-



Last appearance datum

First appearance datum

Figure 10. Zonation schemes used during Leg 128 for planktonic foraminifers.

raphy. This zonation is incorporated in Figure 9 and will be published in the *Scientific Results* volume.

Radiolarians, silicoflagellates, and ebridians were extracted from core-catcher samples using a 10% solution of hydrogen peroxide and hydrochloric acid (also 10%), followed by sieving through a $63-\mu m$ sieve. A small amount of residue then was withdrawn with a pipette and mounted on a permanent slide using Canada balsam as a mounting medium. Taxonomic identifications were made using a Zeiss photomicroscope III, and population counts as well as preservation were determined based on the protocol of one microslide for radiolarians and one-half a microslide for silicoflagellates and ebridians. Because of the high sedimentation rates and the partial isolation of the Sea of Japan basin, concentrations of biosiliceous remains, other than diatoms, are low when compared with other parts of the world ocean, including the northwest Pacific. Because of this, the designations used for specimen abundance in sediments of the Sea of Japan are as follows:

A (abundant)-more than 51 specimens

C (common)-21 to 50 specimens

F (few)—11 to 20 specimens R (rare)—1 to 10 specimens

B (barren)-no specimens

For preservation state, the categories used are as follows:

G (good)-most specimens are complete

M (moderate)-majority of specimens are complete, but have a noticeable number of incomplete or broken forms P (poor)-majority of specimens are broken or incomplete

Calcareous Nannofossils

Nannofossil assemblages were described from smear slides from samples taken from core catchers of all cores drilled at Sites 798 and 799. Where the core catchers were barren of nannofossils, at least one sample was taken within the core



Figure 11. Zonation schemes used during Leg 128 for calcareous nannofossils.

sections for that particular core. Smear slides were made directly from the raw sediment sample and were examined at a magnification of 1000×. Estimates of the abundances of individual nannofossil species on the smear slides were tabulated using the method of Hay (1970). Letters used to denote abundances are keyed to the base 10 log of the number of specimens of a taxon likely to be observed in any one field of view on the microscope and are determined as follows:

H-Highly abundant, +2 (more than 100 specimens per field of view)

V-Very abundant, +1 (more than 10 specimens per field of view)

A-Abundant, 0 (1 to 10 specimens per field of view)

C-Common, -1 (1 specimen per 2 to 10 fields of view) F-Few, -2 (1 specimen per 11 to 100 fields of view)

R-Rare, -3 (1 specimen per 101 to 1000 fields of view)

Through visual inspection at 1000×, a qualitative determination was made of the state of preservation of the nannofossils in each sample. In any given sample, the state of preservation may be different for each individual species, genus, or morphologic group. For example, discoasters may exhibit calcite overgrowths, whereas in the same sample, the placoliths may appear to be etched or may be absent through selective dissolution. Thus, any qualitative measurement of a given sample must be based on the overall preservational qualities of the nannofossil assemblage. The following basic criteria, taken from Muza et al. (1987), were used to describe qualitatively the degree of preservation, dissolution, or overgrowth recrystallization of a nannofossil assemblage:

G-Good: individual specimens exhibit no dissolution or recrystallization

M-Moderate: individual specimens yield slight evidence of dissolution (etching) and/or recrystallization

P-Poor: individual specimens exhibit considerable dissolution and/or recrystallization; placoliths dissolved and ragged; some discoasters overgrown; species determination difficult, if not impossible

In an effort to maximize the Neogene biostratigraphic resolution at Sites 798 and 799, the calcareous nannofossil schemes of Okada and Bukry (1980) and Gartner (1977) were utilized. Subzone CN13b (Okada and Bukry, 1980) was divided using the last appearance datum (LAD) of Helicosphaera sellii, a Gartner (1977) middle Quaternary marker species. All other datums used in this section are from Okada and Bukry (1980).

Benthic Foraminifers

Core-catcher samples of approximately 10 cm3 were collected from every core and examined for benthic foraminifers. Sediment samples were disaggregated by soaking in hot water, sieved through a 63-µm screen, and dried under an infrared lamp.

The paleodepth estimates at each site refer to the upper and lower depth limits of the cosmopolitan species given by van Morkhoven et al. (1986) as:

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

The abundance of benthic foraminifers was estimated in samples normalized to 10 cm³ in volume using the following categories:

A-Abundant (>1000 specimens)

C-Common (200-1000 specimens)

F-Few (10-200 specimens)

R-Rare (<10 specimens)

B-barren (no specimens present)

The state of preservation for benthic foraminifers was determined by the degree of fragmentation and abrasion of test:

G-Good (most specimens are intact)

M—Moderate (about 50% of the tests are broken and/or etched) P—Poor (mostly fragments and/or strongly etched)

PALEOMAGNETISM

Natural remanent magnetization (NRM) and volume magnetic susceptibility (K) measurements are routinely performed on board the *JOIDES Resolution*. Because most rocks have been affected by secondary magnetizations, magnetic cleaning by alternating field (AF) or thermal demagnetizations is necessary to obtain the characteristic remanent magnetization (ChRM) of the rock.

Instruments

Two magnetometers, a Molspin spinner magnetometer, and a 2-G Enterprises (Model 760R) pass-through cryogenic superconducting rock magnetometer were available for measuring remanence on board the *JOIDES Resolution* during Leg 128. An AF demagnetizer (Model 2G600) capable of alternating fields up to 25 Mt is on-line with the cryogenic magnetometer. Both are controlled by a FASTCOM4 multiserial communication board in an IBM PC-AT compatible computer. When measuring the archive half of a core, Leg 128 paleomagnetists used a BASIC program modified from the original SUPERMAG program. The spinner magnetometer is controlled by a Digital PRO350 computer and is used to measure discrete samples.

The SQUID (superconducting quantum interference device) sensors in the cryogenic magnetometer measure magnetization over an interval approximately 20 cm long. Each axis has a slightly different response curve. The widths of the sensor regions imply that as much as 150 cm³ of the core contributes to the sensor signals. The large volume of core material within the sensor region permits one to determine accurately the remanence for weakly magnetized samples despite the relatively high background noise related to the motion of the ship. The SQUID electronics operate at a 1× scale for sediments and at a 100× scale for basaltic rocks.

Some APC cores (Cores 128-798A-5H to 128-798A-15H and 128-799A-5H to 128-799A-20H) were oriented with respect to magnetic north by the multishot orientation tool. The accuracy of the measurement was tested during Leg 128 (see individual site chapters).

Remanent Magnetization Measurements

The maximum AF demagnetizing field allowed by ODP for sections from the archive half is 15 Mt, or the median destructive field, whichever is lower. Discrete samples from the working half of the core may also be demagnetized using the Schonstedt GSD-1 AF demagnetizer and TSD-1 thermal demagnetizer.

Sediments

Remanence measurements of sediments were performed by passing continuous archive-half core sections through the cryogenic magnetometer. NRM measurements were taken at 10 cm intervals along the cores before and after AF demagnetization in two steps, generally of 10 and 15 Mt. Discrete samples were taken from XCB and RCB sediment cores by pressing a standard plastic sampling box (7 cm^3) into the soft core material. The uphole direction was marked on the box. For more consolidated sediments, a spatula was used to cut the cubes, or minicores were extracted with a drill press. These discrete samples were measured with the cryogenic magnetometer. Up to two discrete samples per section were collected from the working half of the cores.

Basement Rocks

Minicores were drilled from basalts and other igneous rocks recovered from the basement and were measured with a minispin magnetometer to determine their stable magnetizations. AF demagnetization steps of 0, 2, 5, 10, 15, 20, 30, and 40 Mt were employed using a Schoenstedt AC demagnetizer (Model GSD-1).

Magnetic Stratigraphy

The combined magnetostratigraphic and biostragraphic time scale of Berggren et al. (1985) was adopted for use during Leg 128.

Magnetic Susceptibility Measurements

Magnetic susceptibilities were measured routinely for all cores employing a Bartington Instruments magnetic susceptibility meter (Model MS1) with a MS1/CX 80 mm whole-core sensor loop set at 0.47 kHz (range 1). The susceptibility meter is on-line with the GRAPE and *P*-wave logger on the multisensor track (MST). The general trend in the susceptibility data was used to characterize the cored sediments. Susceptibilities of igneous rocks were measured using a sensor unit (type MS1B) attached to the Bartington susceptibility meter.

ORGANIC GEOCHEMISTRY

Shipboard analyses of organic geochemistry were performed to supply a real-time monitoring of the volatile hydrocarbons for safety considerations and for an initial characterization of the content and type of organic matter in the sediments.

Hydrocarbon Gases

As required by safety considerations, the concentrations of the hydrocarbons methane (C_1) , ethane (C_2) , and propane (C_3) were monitored in the sediment cores at intervals of approximately 10 m. Concentrations of butane (C4), pentane (C5,) and other hydrocarbons were monitored as warranted by drilling conditions. Two types of samples were analyzed: gases in headspace and in gas voids in the core liner. Headspace samples were obtained by removing a 5-mL plug of sediment from the core as it arrived on deck, using a No. 4 cork borer. The sample was placed immediately in a 21-mL glass vial that was sealed with a septum and metal crimp and then heated to 70°C for at least 40 min. The gas driven off was drawn into a syringe and analyzed. Gas voids in the core liner were sampled using a liner penetrator equipped with a syringe and an evacuated glass container (vacutainer). A gas sample was removed from the vacutainer with a syringe for analysis.

The gas samples obtained were injected into a Hach-Carle AGC Series 100 Model 211 gas chromatograph equipped with a flame ionization detector and a 6-ft \times 1/s-in. steel column packed with Porapak N:Q (80%/20%). The Carle gas chromatograph was run through elution of propane, except at depths below 430 mbsf at Site 798 and below 335 mbsf at Site 799, where it was run through elution of *n*-butane. At depths below 170 mbsf at Site 799, a second headspace sample was taken by the same method. If multiple gas voids were observed, a second vacutainer sample was collected. These

additional samples were analyzed for C₁ through C₇ hydrocarbons using a Hewlett-Packard 5980A natural gas analyzer; a gas chromatograph equipped with a 6-ft \times $\frac{1}{8}$ -in. steel column packed with Poropak T, a 3-ft \times $\frac{1}{8}$ -in. steel column packed with a 13 \times molecular-sieve, a 6-ft \times $\frac{1}{8}$ -in. steel column packed with 80/100-mesh Hayesep R(AW), and a DB1 (film thickness of 1 μ m, J&W) fused silica capillary column (60 m \times 0.32 mm internal diameter). Compounds were detected using both thermal conductivity and flame ionization detectors. Details of this method and the complete configuration of both gas chromatographs are given in the "Explanatory Notes" of the *Initial Reports of the Ocean Drilling Program*, Volume 112 (Suess, von Heune, et al., 1988).

Elemental Analysis

Sediments were analyzed on board the ship for contents of inorganic carbon and total nitrogen, carbon, and sulfur.

Inorganic carbon was determined using a Coulometrics 5011 carbon dioxide coulometer equipped with a System 140 carbonate carbon analyzer. A known mass, ranging from 15 to 70 mg, of freeze-dried, ground, and weighed sediment was reacted in a 2N HCl solution. The liberated CO_2 was titrated in a monoethanolamine solution with a colorimetric indicator, while the change in light transmittance was monitored with a photo-detection cell. The percentage of carbonate was calculated from the inorganic carbon (IC) content, assuming that all carbonate occurs as calcite as follows:

$$CaCO_3 = IC \cdot 8.334$$

Carbonate values were not corrected for siderite or dolomite contents, the two dominant carbonate phases in some intervals at Site 799 (see all "Lithostratigraphy" sections, this volume).

Total nitrogen, carbon, and sulfur were determined using a C/N/S analyzer, Model NA1500 from Carlo Erba Instruments. Mixtures of vanadiumpentoxide and crushed samples were combusted in an oxygen atmosphere at 1000°C, converting organic and inorganic carbon to CO_2 , sulfur to SO_2 , and nitrogen to NO_2 . The NO_2 was reduced to N_2 using copper. The gases were then separated by gas chromatography and measured with a thermal conductivity detector. Total organic carbon (TOC) was calculated by difference between total carbon (TC) and inorganic carbon:

TOC = TC - IC.

Rock-Eval Analysis

Type of organic matter, thermal maturity, and hydrocarbon-producing potential were assessed using a Delsi Inc. Rock-Eval II Plus TOC instrument (Espitalié et al., 1977). Approximately 100 mg of freeze-dried and ground whole sediments were analyzed according to standard procedures, as described in Emeis and Kvenvolden (1986).

Results are presented as a diagram of hydrogen index (mg HC/g TOC) vs. oxygen index (mg CO₂/g TOC). In general, TOC values determined using the Rock-Eval II are low relative to those determined by difference (see comparison of Rock-Eval values with CNS values, "Organic Geochemistry" section, "Site 798" chapter, this volume). Thus, TOC values determined by difference of total organic from inorganic carbon were used to calculate both hydrogen and oxygen index values.

Analysis of High-Molecular-Weight Hydrocarbons

Samples of hydrocarbons having a high molecular weight were obtained from interstitial water squeeze cakes. Samples of freezedried sediment weighing approximately 20 g were extracted with 100 mL of HPLC-grade dichloromethane. The solvent was decanted into a centrifuge tube and centrifuged for 30 min. The supernatant liquid was transferred by pipette to a 50-mL, pearshaped flask and evaporated until dry using a rotary evaporator. The residue was dissolved in HPLC-grade hexane and loaded on a Baker-10 SPE, pre-packed, silica gel column and then eluted with hexane. The hexane eluent was passed through a Baker-10 SPE CN, pre-packed column. The hexane eluent was evaporated until dry. This residue again was dissolved in approximately 300 µL of hexane from which 1 µL was injected into a Hewlett-Packard 5890 gas chromatograph equipped with a 25-m Hewlett-Packard Ultra 1, cross-linked, methyl silicone capillary column. The injection temperature was 225°C, the FID temperature was 300°C, and the oven temperature was increased from 40°C to 300°C at a rate of 10°C/min and held at 300°C for 5 min. Compound identification was accomplished by comparing retention times with those observed in standard hydrocarbon mixtures.

INORGANIC GEOCHEMISTRY

The shipboard analytical program for inorganic geochemistry focused solely on the chemical characterization of interstitial waters extracted from 5- to 10-cm-long, whole-round sediment samples. During Leg 128, interstitial waters were obtained both by squeezing with the standard ODP stainless-steel (SS) squeezer (Manheim and Sayles, 1974) and with a plastic-lined squeezer named Brumsack/ Murray (BM) (Brumsack et al., unpubl. data) designed specially for obtaining uncontaminated interstitial water (IW) samples for shorebased analysis of trace metals. At Site 798, all samples were obtained using the ODP stainless-steel squeezer, with a highdensity sampling in the first 100 mbsf of Hole 798B. The sampling scheme was coordinated with the microbiology study in this dedicated hole, and the specific procedures applied while collecting the samples are given in the "Microbiology" section of "Site 798" chapter (this volume). Below 100 mbsf, samples were taken every third core using standard ODP procedures (See "Visual Core Description" section, this chapter). At Site 799, IW samples were taken from every core in the upper 100 mbsf and every third core thereafter. Wherever possible, samples taken with the SS and BM squeezers were adjacent to each other.

Whole-round sections were cut immediately from the core when it arrived on deck. Each sample was removed from the core liner, scraped with a spatula to remove the potentially contaminated exterior of the sample, placed into the squeezer, and pressed in a Carver hydraulic press at pressures up to 20,000 and 40,000 psi for the BM and SS squeezers, respectively. The extracted SS samples were collected directly into a 50-mL plastic syringe and filtered through an on-line 0.45 μ m Gelman Acrodisc disposable filter. The procedure for handling the BM effluent differs slightly from the SS procedure described above, because the BM samples had already been ejected through a 0.45- μ m Millipore polycarbonate membrane placed inside the squeezer. The BM samples were collected in pre-cleaned plastic vials.

Interstitial waters were analyzed routinely for alkalinity, pH, salinity, chlorinity, silica, phosphate, ammonium, sulfate, calcium, and magnesium, following the analytical techniques described in Gieskes and Peretsman (1986). The potentiometric titration of alkalinity and measurement of pH were performed using a Metrohm autotitrator and a Brinkman combination pH electrode. The amount of total dissolved salts (salinity) was determined using a Goldberg optical refractometer. Calcium, magnesium, and chloride concentrations were determined titrimetrically, and sulfate was determined using a Dionex ion chromatograph. Colorimetric methods employing a Baush and Lomb Spectronic 1001 were used to determine the concentration of silica, ammonium, and phosphate.

Lithium, potassium, strontium, and manganese were determined using the shipboard atomic absorption spectrophotometer (Varian SpectrAA-20), after adequate dilution and matrix modification.

Analysis of adjacent samples extracted with both squeezers allowed us to compare SS squeezing techniques and apparatus with those of the BM squeezer. International Association of Physical Sciences Organizations (IAPSO) standard seawater was used to standardize all analyses.

IGNEOUS ROCKS

Curation of Cores and Shipboard Sampling

To preserve important features and structures, core sections containing igneous rocks were examined prior to splitting them with a diamond saw into archive and working halves. During core handling and splitting, care was taken to ensure that core orientation was preserved by marking the original base of individual pieces. Each piece was numbered sequentially from the top of each core section and labelled at the top surface. Pieces that could be fit together were assigned the same number, but were lettered consecutively (e.g., 1A, 1B, and 1C). Plastic spacers were placed only between pieces having different numbers. Thus, the presence of a spacer may represent a substantial interval of no recovery. If we could determine that individual pieces did not rotate about a horizontal axis during drilling, an arrow pointing to the top of the section was added to the label. As pieces were free to turn about a vertical axis during drilling, orientation of the azimuth of a core was not possible.

After the core was split, the working half was sampled for shipboard physical properties, magnetic studies, and XRF, XRD, and thin section studies. Nondestructive measurements of physical properties, such as magnetic susceptibility, were performed using the archive half of the core. Where recovery permitted, samples were taken from each lithologic unit. Some of these samples were minicores. The archive half was described on the visual core description form and was photographed before storage.

Visual Core Descriptions

Visual core description forms were used during description of the basement cores (Fig. 12). The left column of the form is a graphic representation of the archive half. A horizontal line across the entire width of the column denotes a plastic spacer. Oriented pieces are indicated on the form by an upwardpointing arrow to the right of the piece. Shipboard samples and studies are indicated in the column headed "Shipboard Studies," using the following notation: To ensure consistent and complete descriptions, the visual core descriptions were entered into the computerized data base HARVI. The data base is organized into records for fine-grained rocks and those for coarse-grained rocks. Each record is checked in the data-base program for consistency and is printed in a format that can be pasted directly onto the visual core description form for subsequent curatorial handling.

When describing sequences of rocks, we subdivided the core into lithologic units using changes in petrography, abundance of minerals, composition of rocks, and type of rock clasts. For each lithologic unit and section, the following information was recorded in the data-base system:

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

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

3. The dry color of the rock and the presence and character of layering and deformation.

4. The number of mineral phases visible with a hand lens and their distribution within the unit. For each mineral phase, we noted (1) abundance (vol%), (2) size range (mm), (3) shape, (4) the degree of alteration, and (5) further comments.

5. The groundmass texture, including the presence of glass, the nature of crystallinity, and the grain size, where fine is <1 mm, medium is 1 to 5 mm, and coarse is >5 mm. Relative changes in grain size within the unit also were noted.

6. The presence and characteristics of secondary minerals and alteration.

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

8. The structure extant, including any internal layering and whether the flow is massive, pillowed, thin or sheetlike, brecciated, or a hyaloclastite.

9. The relative amount of rock alteration: <2%, fresh; 2% to 10%, slightly altered; 10% to 40%, moderately altered; 40% to 80%, highly altered; 80% to 95%, very highly altered; and 95% to 100%, completely altered. The type, form, and distribution of alteration was also noted.

10. The presence of veins and fractures, including their abundance, width, and orientation. Orientation of veins and fractures was measured with a protractor within the sector 270° to 90° relative to the top of each core, taken as 0° . The relationship of the veins and fractures to the alteration and fillings also was noted.

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

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

Igneous-rock visual core descriptions are presented in Section 3 of this volume, and descriptions of each rock unit are available from the computerized data base at the ODP repositories.

XD-X-ray diffraction analysis;

XF—X-ray fluorescence analysis;

TS-petrographic thin section;

PP-physical properties analysis; and

PM—paleomagnetic analysis.



128-794D-1R-1

UNIT 1: HIGHLY PLAGIOCLASE PHYRIC DOLERITE

Pieces 1-8

CONTACTS: None. PHENOCRYSTS: Plagioclase - 35-40%; 1-5 mm; Euhedral to subhedral. Pyroxene - 2%; 1-4 mm; Subhedral. GROUNDMASS: Not discernable (alteration). VESICLES: None. COLOR: Gray to greenish gray. STRUCTURE: Massive. ALTERATION: Moderate. VEINS/FRACTURES: 0.1%; 1 mm; 60 degrees; thin fractures filled with green material (epidote and chlorite).

Information on Core Description Forms, for ALL sites, represents field notes taken aboard ship. Some of this information has been refined in accord with post-cruise findings, but production schedules prohibit definitive correlation of these forms with subsequent findings. Thus, the reader should be alerted to the occasional ambiguity or discrepancy.

Figure 12. Igneous-rock visual core description form.

Thin-Section Descriptions

Thin sections of igneous rocks were examined to complement and refine the hand-specimen observations. The percentages and textural descriptions of individual phases were reported in the computerized data base HRTHIN. Terminology for descriptions of thin sections was used in the same manner as in the megascopic descriptions. Descriptions of thin sections are included in the Section 3 of this volume and are also available from the ODP computerized data base.

X-Ray Diffraction Analyses

A Philips ADP 3520 X-ray diffractometer was used for the X-ray diffraction (XRD) analysis of mineral phases. CuK- α radiation was measured through a nickel filter at 40 kV and 35 mA. The goniometer scanned from 2° to 70° 2 Θ , with a step size of 0.02°, and the counting time was 1 s/step. However, because of a technical problem, peaks below 10° were not well resolved, which made identification of layered silicates difficult.

Samples were ground in a Spex 8000 mixer mill or with an agate mortar and pestle. The powder then was pressed into the sample holders or smeared onto glass plates for analysis. Diffractograms were interpreted with the help of a computerized search-and-match routine using the Joint Committee on Powder Diffraction Standards powder files.

X-Ray Fluorescence Analysis

Before analysis, samples normally were crushed in the Spex 8510 shatterbox using a tungsten carbide barrel. This produces some tantalum and massive tungsten contamination.

A fully automated wavelength-dispersive ARL8420 XRF (3 kW) system equipped with an Rh target X-ray tube was used to determine the abundances of major oxides and trace elements in whole-rock samples. Analyses of the major oxides were performed on lithium borate glass disks doped with lanthanum as a "heavy absorber" (Norrish and Hutton, 1969). The disks were prepared from 500 mg of rock powder, ignited for 2 hr at about 1030°C, and mixed with 6 g of dry flux consisting of 80% lithium tetraborate and 20% La2O3. This mixture was then melted in air at 1150°C in a platinum-gold crucible for about 10 min and poured into a platinum-gold mold using a Claisse fluxer. The 12:1 flux-to-sample ratio and the use of the lanthanum absorber made matrix effects insignificant over the normal composition range of igneous rocks. Hence, the relationship between X-ray intensity and concentration becomes linear and can be described by

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

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 oxide *i* (wt%).

The slope, m_i , was calculated from a calibration curve derived by measuring well-analyzed reference rocks (BHVO-1, G-2, AGV-1, JGB-1, JP-1, BR, and DRN). The background, b_i , was determined either from blanks or derived by regression analysis from the calibration curves.

Systematic errors resulting from short- or long-term fluctuations in X-ray-tube intensity were corrected by normalizing the measured intensities of the samples to those of a standard that was always run together with a set of six samples. To reduce shipboard weighing errors, two glass disks were prepared for each sample. Accurate weighing was difficult on board the moving platform of the JOIDES Resolution, and was performed with particular care as weighing errors can be a major source of imprecision in the final analyses. Losson-ignition values were determined by drying the sample at 110°C for 8 hr and then by weighing before and after ignition at 1030°C in air.

Determinations for trace elements were performed for 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 polyvinyl alcohol 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).

Replicate analyses of rock standards show that data for major elements are precise to within 0.5% to 2.5% and are considered accurate to $\pm 1\%$ for silica, titanium, iron, calcium, potassium and to $\pm 3\%$ to 5% for aluminum, manganese, sodium, and phosphorus. The data for trace elements are considered accurate to $\pm 2\%$ to 3% or 1ppm (whichever is greater) for rubidium, strontium, yttrium, and zirconium, and $\pm 5\%$ to 10% or 1ppm for the others, except for niobium, barium, and cerium. Precision is also within 3% for nickel, chromium, and vanadiumat concentrations > 100ppm, but 10% to 25% at concentrations < 100ppm. The concentration range of trace elements over which these claims hold encompasses those encountered during Leg 128. Analytical conditions for the XRF analyses are presented in Table 3.

PHYSICAL PROPERTIES

The shipboard measurement of physical properties provides information that (1) can aid in the characterization of different lithologic units, (2) can allow for verification of the downhole geophysical logging results, and (3) can provide important constraints on interpretation of seismic reflection and other geophysical data. Furthermore, these data may be used to estimate the degree of consolidation, to correct sedimentation rates, to aid in heat-flow calculations, and to provide additional data for paleoceanographic interpretation of the cores. Depth profiles of the geotechnical properties may be used for distinguishing lithologic boundaries at drill sites as well as for correlating and establishing facies changes between sites.

Physical-property measurements performed on cores recovered during Leg 128 included multisensor track (MST) logging of GRAPE bulk density, compressional acousticvelocity, and magnetic susceptibility; thermal conductivity; Hamilton Frame compressional velocity; undrained shear strength; and index properties. Samples were chosen to be representative of the core or section as a whole, and were taken in areas of least disturbance. Sample selection and spacing depended on the core recovery, the type of measurement (see below), and the thickness and homogeneity of the recovered sequences.

The testing methods employed during Leg 128 are discussed in the order in which they were performed on each core. MST logging and determinations of soft-sediment thermal conductivity were performed first on whole cores still within their liners. All other measurements were conducted on discrete samples taken from the split cores.

Gamma-Ray Attenuation Porosity Evaluator (GRAPE)

The GRAPE makes continuous measurements of wet-bulk density on whole cores by comparing attenuation of gamma rays through the cores with attenuation through an aluminum standard (Boyce, 1976). Individual core sections were placed horizontally on the MST and moved on a conveyor belt through the GRAPE sensors. Attenuation of the gamma rays passing through the liner and core is measured every 1 cm, and bulk density is calculated from the attenuation values. The raw GRAPE data were not filtered or averaged. All bulk density data are reported in units of grams per centimeter. Because of variations in grain density, porosity cannot be reliably determined from the GRAPE density measurements, and because of variable drilling disturbance downcore, the absolute density values should be used for qualitative purposes only. The GRAPE is best used to show relative, rather than absolute, density changes along the core for correlation with lithologic changes (Ciesielski, Kristoffersen, et al., 1988). GRAPE data are used to correlate among holes and sites by observing peak-to-peak spacings and general trends in data.

P-Wave Logger

The *P*-Wave Logger (PWL), which also operates on the MST, transmits a 500-kHz compressional-wave pulse through the core at a repetition rate of 1 kHz. The transmitting and receiving transducers are aligned perpendicular to the core axis. A pair of displacement transducers monitors the separation between the compressional-wave transducers; therefore, variations in the outside liner diameter do not degrade the accuracy of the velocities. Measurements are taken at 2-cm intervals. Keeping the core liner wet during the PWL run improves acoustic contact between the transducers and the liner.

As with the GRAPE, generally only APC and the first few XCB cores were measured. The deeper XCB cores and all RCB cores have annular voids between the core and the liner that cause transmission losses. The PWL data were filtered to remove data resulting from the effects of gas, gaps, or endcaps. Weak returns with signal strengths below a threshold value of 100 were removed. All velocity data are reported in units of meter per second. As with the GRAPE data, PWL data are used to correlate among holes and sites.

Magnetic Susceptibility

MST magnetic susceptibilities were routinely measured for all cores at 3- to 10-cm intervals by employing a Bartington Instruments magnetic susceptibility meter (Model MS1) with an MS1/CX 80-mm, whole-core sensor loop set at 0.47 Khz. Magnetic susceptibility values are recorded in cgs units. In addition to characterizing the cored sediments, susceptibility data are used to correlate among holes and sites.

Thermal Conductivity

The techniques used to measure thermal conductivity are described by Von Herzen and Maxwell (1959) and Vacquier (1985). All thermal conductivity data are reported in units of $W/(m \cdot K)$. The error in the reported measurements was estimated as about 5%.

Soft-Sediment Thermal Conductivity

Measurements were performed with a Thermcon-85 unit. To reduce background thermal transients, cores were allowed to equilibrate to room temperature in their liners for at least 3 hr. On average, one needle probe per section was inserted into the sediment through holes drilled through the core liner. After a brief wait for temperatures to stabilize, the probe heaters were turned on at a constant power, and the increase in probe temperature was recorded. Thermal conductivity was calculated from a 6-min temperature history after the heaters were energized.

After the heater had been turned on for about 30 s, the needle probe response was almost that of a line source having a constant heat generation per unit length. This increase in temperature varies logarithmically with time as follows:

$$T(t) = (q/4\pi k) \ln(t) + \text{constant}, \qquad (1)$$

Element	Line	Crystal	Detector ^a	Collimator	Peak angle (deg)	Background offset (deg)	Total Peak	count time (s) Background
SiOn	к	PET(002)	FPC	Coarse	109.25	0	40	0
TiO	K	LIE(200)	FPC	Fine	86 14	õ	40	0
Ala	K	PET(002)	FPC	Coarse	145 27	Ő	100	0
FeaOab	K	LiE(200)	FPC	Fine	57.52	0	40	0
MnO	K	LiF(200)	KrSC	Fine	62.98	ŏ	40	õ
MgO	K	TLAP	FPC	Coarse	44.87	± 0.80	200	200
CaO	K	LiF(200)	FPC	Coarse	113.16	0	40	0
Na ₂ O	K	TLAP	FPC	Coarse	54.71	-1.20	200	200
K ₂ O	K	LiF(200)	FPC	Fine	136.65	0	40	0
PaOs	K	Ge(111)	FPC	Coarse	140.94	0	100	0
Rh	K-C	LiF(200)	Scint	Fine	18.59	Ő	100	0
Nb	K.,	LiF(200)	Scint	Fine	21.37	±0.35	200	200
Zr	K.	LiF(200)	Scint	Fine	22.53	±0.35	100	100
Y	K	LiF(200)	Scint	Fine	23.78	± 0.40	100	100
Sr	K.	LiF(200)	Scint	Fine	25.13	± 0.40	100	100
Rb	Ka	LiF(200)	Scint	Fine	26.60	± 0.60	100	100
Zn	K	LiF(200)	Scint	Fine	41.79	± 0.40	60	60
Cu	K.a	LiF(200)	Scint	Fine	45.02	± 0.40	60	60
Ni	Ka	LiF(200)	Scint	Coarse	48.67	± 0.60	60	60
Cr	Ka	LiF(200)	FPC	Fine	69.35	±0.50	60	60
Fe	Ka	LiF(220)	FPC	Fine	85.37	-0.40+0.70	40	40
v	Ka	LiF(220)	FPC	Fine	122.84	-0.50	60	60
TiO ₂	Ka	LiF(200)	FPC	Fine	86.14	±0.50	40	40
Ce	La	LiF(220)	FPC	Coarse	127.92	±1.50	100	100
Ba	La	LiF(220)	FPC	Coarse	128.53	± 1.50	100	100

Table 3. X-ray fluorescence analytical conditions, Leg 128.

Note: All elements were analyzed under vacuum on goniometer 1, at generator settings of 60 kV and 50 mA. ^a FPC = Flow proportional counter using P_{10} gas; KrSC = sealed krypton gas counter; Scint = NaI scintillation counter.

^b Total Fe as Fe₂O₃.

where k = thermal conductivity, T and t = temperature and time, respectively, and q = heat generated per unit length of the probe in joules permeter. From Equation 1, thermal conductivity is derived from the slope of temperature vs. the logarithm of time:

$$k = (q/4\pi)/(dT/dln[t]).$$
⁽²⁾

When the sediment became too firm to permit easy insertion of the probe, holes were drilled into the core material prior to its insertion. We attempted to insert the probes at locations where the core section was least disturbed. However, an annulus of disturbed sediment and drill fluid was often present along the inside of the liner, which prevented visual identification of disturbed zones; consequently, spurious values associated with voids are possible.

Hard-Rock Thermal Conductivity

Thermal conductivities of lithified sediments and rocks were measured on split cores using the "half-space technique" (Vacquier, 1985). In this method, a rock sample with one flat surface is placed on top of a needle probe that has been embedded along the surface of a slab of low conductivity material. The flat surface of the sample is polished with 240 and 600 grit to minimize pockets of water or air and thus to assure good contact with the slab containing the needle probe. A heat-conducting compound then is used to improve the thermal contact between the slab and the sample. During leg 128, this experiment was immersed in a saltwater bath to maintain a uniform temperature, thereby avoiding cooling by evaporation, and to keep the sample saturated with water.

The experimental procedure for the half-space method is exactly the same as that for the needle probe. The probe heater is turned on, and the temperature of the probe is recorded over a 6-min interval.

Vane Shear Strength

The hand-held "Torvane" vane shear device was used during routine procedures for obtaining indications of undrained shear strength. Note that this test is only valid in fine-grained sediments, where permeability is low enough to restrict drainage severely during the test.

Hamilton Frame Compressional-Wave Velocity

Compressional-wave velocities were measured for discrete samples that were sufficiently competent to provide adequate signal strength. Velocities were calculated by determining the traveltime of a 500-Khz compressional wave through a measured thickness of sample, using a Hamilton Frame velocimeter and Tektronix DC 5010 counter/timer system. Samples of soft sediment were taken with a special parallel-sided sampling tool. A double-bladed diamond saw was used to obtain samples from more lithified sediments. Basement rock samples were obtained using either a double-bladed diamond saw or a 2.5-cm-diameter rock corer. Sample thicknesses (distance) were measured directly from the frame lead screw.

Zero traveltimes for the velocity transducers were estimated by linear regression of the traveltime vs. distance for a series of aluminum and lucite standards. Filtered seawater was used to improve the acoustic contact between the sample and the transducers. Velocities were not recorded when insufficient or extremely variable signals were obtained.

Index Properties

Index properties (wet- and dry-bulk densities, grain density, porosity, water content, and void ratio) were determined for sediment and rock samples (Ciesielski, Kristoffersen, et al., 1988). Where possible, samples for analyzing index properties were taken once per section adjacent to those used for measuring undrained shear strengths. Samples were weighed using two calibrated Scientech 202 electronic balances. Samples were deep-frozen and thereafter freeze-dried for 24 hr. Wet and dry volumes were measured using a Quantachrome helium pentapycnometer. All values have been corrected for salt content of the pore fluid, assuming a seawater salinity of 3.5%.

DOWNHOLE MEASUREMENTS

Downhole logs can be used to characterize the geophysical, geochemical, and structural properties of a drilled sequence. Log measurements have a distinct advantage over core-based measurements in that they represent continuous and in-situ measurements of the borehole. After coring is completed, a combination of sensors is lowered downhole on a 7-conductor cable and each of several measuring devices continuously monitors properties of the adjacent formation. Under conditions of rough seas, a wireline heave compensator can be employed to minimize the effects of ship heave on the tool position in the borehole. The depths of investigation are sensor-dependent, and data typically are recorded at intervals of 15 cm. Four combinations of Schlumberger sensors were used during Leg 128: (1) the seismic stratigraphic suite, (2) the lithoporosity suite, (3) the formation microscanner (FMS), and (4) the geochemical suite (see Fig. 13). The Barnes/Uyeda temperature probe was deployed on every other APC core, and run up to the limit of APC coring (typically ~100-200 mbsf). Below this depth, borehole temperatures were measured using the Lamont-Doherty temperature tool, which is attached to the end of each combination tool string. Each combination tool string was not necessarily deployed in each hole drilled; one should refer to individual site chapters for details.

Seismic Stratigraphic Tool String

The seismic stratigraphic combination suite of tools used during Leg 128 consisted of the phaser dual induction tool (DIT), the long-spacing digital sonic tool (SDT), and the natural gamma-ray spectrometry tool (NGT) (Fig. 13). This combined tool string is designed to measure the sonic-wave propagation properties of the borehole by measuring deep, intermediate, and shallow electrical resistivity and compressional-wave velocity. In combination with density data from the lithoporosity suite, sonic velocity data are used to calculate an impedance log and generate a synthetic seismogram for the logged sequence. The natural gamma-ray radiation tool is run on each combination tool string to provide a common basis for log correlations.

The dual induction instrument (DIT) provides three different measurements of electrical resistivity, each having a different radial depth of investigation. Two induction devices ("deep" and "medium" resistivity) send high-frequency alternating currents through transmitter coils, creating magnetic fields that induce secondary (Foucault) currents in the formation. These ground loop currents produce new inductive signals, proportional to the conductivity of the formation, which are recorded by a series of receiving coils. The measured conductivities are converted to resistivities. A third device (the "spherically" focused resistivity, SFR) measures the current necessary to maintain a constant decrease in voltage across a fixed interval. The vertical resolution is of the order of 2 m for the two induction devices, and about 1 m for the spherically focused resistivity device. These data can be corrected for irregularities in borehole diameter.

To first order, resistivity responds to the inverse square root of porosity (Archie, 1942). Water salinity, clay content,

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Figure 13. Schematic diagram of the logging tool strings used during Leg 128. Note that the tools are not drawn to scale; their overall lengths vary from ~ 10 to 35 m.

hydrocarbon content, and temperature are also important factors for controlling the electrical resistivity of rocks. Other factors that may influence the resistivity of a rock include the concentration of hydrous and metallic minerals, formation vesicularity, and the geometry of interconnected pore space.

The digital sonic tool (SDT) uses two acoustic transmitters and two receivers to measure the time required for sound waves to travel along the borehole wall over source-receiver distances of 8, 10, and 12 ft (2.4, 3.0, and 3.6 m). Sonic traveltimes for the individual source-receiver paths are used to calculate the velocities of the different waves traveling in the formation (e.g., compressional, shear, etc.); this tool measures four sonic velocities at each measurement depth as there are four possible paths. Only compressional-wave velocity is determined aboard the ship, but the full sonic waveforms are recorded for post-cruise processing to determine the velocities of shear and Stoneley waves. The vertical resolution of the tool is about 2 ft (0.61 m). Logs can be corrected for cycle skipping caused by the redundancy of four-way measurements. Compressional-wave velocity is predominantly controlled by porosity and lithification; decreases in porosity and increases in lithification generally cause velocity to increase with depth.

The natural gamma-ray tool (NGT) measures the natural radioactivity of the formation. Most gamma rays are emitted by the radioactive isotope 40 K, and by the radioactive elements of the uranium and thorium series. The gamma radiation originating in the formation near the borehole wall is measured by a sodium iodide scintillation detector mounted inside the sonde. The analysis is achieved by subdividing the entire incident gamma-ray spectrum into five discrete energy windows. The total counts recorded in each window for a specified depth in the well, are processed at the surface to give abundances of the elements potassium, uranium, and thorium. The tool has a depth of investigation of ~0.3 to 0.5 m. The NGT data are corrected for borehole diameter variations.

Because the tool is run on every combination tool string, it is used as a basis for log correlations.

Radioactive elements tend to be most abundant in clay minerals and consequently, the gamma-ray curve is commonly used to estimate the sediment clay content. Potassium and thorium are common constituents in clay minerals, whereas uranium is commonly concentrated in organic-rich sediments (Fertl, 1979). There are rock matrixes, however, for which the radioactivity values range from moderate to extremely high, such as high abundances of volcanic ash, potassic feldspar, or other radioactive minerals.

Lithoporosity Tool String

The lithoporosity combination tool string includes the lithodensity (LDT), compensated neutron (CNT-G) porosity, and natural gamma-ray spectrometry (NGT) tools (see Fig. 13). This tool string provides measurements of porosity and density variations, as well as weight percent abundance estimates of the primary gamma-ray emitting elements (potassium, thorium, and uranium).

The lithodensity tool uses a ¹³⁷Ce source of 0.66 MeV gamma rays for its density measurements. The source is mounted in the tool body, where a pair of eccentralizing bowsprings presses it and a pair of detectors against the borehole wall. The density measurement is based on the transmission and scattering of gamma rays through the formation. Briefly, the gamma rays interact with the formation atoms via Compton scattering, which is an elastic collision whereby energy is transferred between the incident gamma rays and the electrons. The tool actually measures the electron density of the formation, which can be directly converted to bulk density because most rock-forming elements have atomic weights that are twice their atomic numbers. A photoelectric effect index (Pe) is also provided. Photoelectric absorption occurs in the energy window below 150 keV and depends on the energy of the incident gamma ray, the atomic cross section, and the nature of the atom. This measurement is almost independent of porosity and can therefore be used directly as a matrix lithology indicator. Density and photoelectric effect measurements require excellent contact with the borehole wall; the tool provides a measure of this, and one can correct for excessive borehole roughness. The vertical resolution of the measurement is about 0.30 m.

The compensated neutron porosity tool (CNT-G) contains an americium-beryllium neutron source (5 MeV) and two scintillation detectors that, like the density tool, are eccentralized and pressed against the borehole wall. Collisions of neutrons with heavy atoms do not exchange much energy, but collisions of neutrons with hydrogen significantly reduce the energy levels of neutrons. When neutron energies have been reduced to 0.025 MeV, they can be captured by chlorine, lithium, boron or gadolinium nuclei, and gamma rays are subsequently emitted. Total hydrogen content (total water) of the formation is determined by the flux ratio of emittedto-detected neutrons. A measure of "free" water content (i.e., not structurally bound) is determined by counting the intermediate-energy (thermal) neutron flux at the detectors. Subtracting the total from free water neutron porosities results in the more familiar "bound" water porosity. The porosity measurement is very sensitive to borehole conditions, and the data can be corrected for varying borehole diameter. The vertical resolution is ~0.25 m.

Formation Microscanner

The formation microscanner (FMS) produces high-resolution images of the microresistivity character of the borehole wall, which can be used for detailed sedimentological or structural interpretations (Ekstrom et al., 1986; Pezard and Luthi, 1988). Schlumberger originally introduced the tool in 1986, but it was not suitable for use in the narrower-gauge drill pipe used by ODP. Consequently, a modified sensor was developed by Schlumberger for ODP and first deployed during Leg 126.

The FMS tool consists of 16 electrode "buttons" on each of four orthogonal pads that are pressed against the borehole wall. The electrodes are spaced by approximately 2.5 mm and are arranged in two diagonally offset rows of eight electrodes each. Shorebased processing corrects the offset rows to one level, which doubles the horizontal resolution to ~1.25 mm. The FMS tool string contains a general purpose inclinometry tool (GPIT), which spatially orients the resistivity measurements from accelerometry measurements and from the declination and inclination components of the Earth's magnetic field vector. In addition, the tool contains a natural gamma-ray spectrometer (NGT) so that the FMS data may be correlated with other logs. The raw data undergo extensive processing to transform the individual microresistivity traces into complete, spatially oriented images; thus, there is a dedicated shipboard microVax workstation in the downhole measurements laboratory for this purpose.

Possible applications of the FMS-derived images include detailed correlation of coring and logging depths, orientation of cores, mapping of fractures, faults, foliations, and formation structures, and the analysis of depositional environments (with information about transport direction, structure of the pore space, nature of contacts, and depositional sequences). The FMS data were particularly useful during Leg 128 for establishing core-log correlations using thin (1-5 cm) highly resistive ash layers; these correlations were used as the basis for a detailed sampling program designed to determine the sedimentological origin of climate cycles observed at Hole 798B.

The FMS tool also provides precise measurements of borehole diameter in two orthogonal directions. In an isotropic, linearly elastic rock subjected to an anisotropic stress field, breakouts form along the borehole wall as a result of compressive stress concentrations exceeding the strength of the rock. Under these conditions, the breakout orientation develops in the direction of the least principal horizontal stress. In the past, scientists have demonstrated that stress orientations deduced from rock breakouts are consistent with other independent indicators (Bell and Gough, 1979; Zoback et al., 1988).

Geochemical Tool String

The geochemical combination consists of an induced gamma-ray spectroscopy tool (GST), an aluminium clay tool (ACT), and a natural gamma-ray spectrometry tool (NGT) (see Fig. 13). Relative concentrations of silicon, calcium, iron, sulfur, hydrogen, chlorine, and weight percent concentrations of aluminum, potassium, thorium, and uranium are derived from these measurements.

The induced gamma-ray spectroscopy tool (GST) consists of a pulsed "minitron" tritium source of 14 MeV neutrons and a gamma-ray scintillation detector. The incident neutrons lose energy through scattering interactions and, when they reach thermal energies, they are captured by elemental nuclei, while gamma rays of capture are emitted. A surface computer separates the counts of incident gamma rays into spectral energy windows that correspond to specific elements. Characteristic sets of gamma-ray energies from six elements dominate the spectrum: calcium, silicon, iron, chlorine, hydrogen, and sulfur. Because their sum is always unity, they reflect relative, not absolute, abundances of elements. The depth of investigation is relatively shallow, so the logs must be corrected for variability in borehole diameter. The raw logs are extensively reprocessed by the Borehole Research Group at Lamont-Doherty Geological Observatory. In particular, chlorine has a disproportionate absorption response, and one must correct for its effect on the relative abundances of the other elements.

Aluminum abundance, as measured by the aluminum clay tool (ACT) is determined by neutron-induced (2 MeV californium chemical source) gamma-ray spectrometry. The contribution to the gamma-ray spectrum by natural radiation is removed by placing NaI gamma-ray detectors both above and below the neutron source; the detector above measures the natural radiation before activation, and the detector below measures the induced radiation after activation. One can then subtract the naturally occurring component from the total measured after activation. The log output is measured in dry weight percent of aluminum.

Barnes/Uyeda and Lamont-Doherty Temperature Tools

The Barnes/Uyeda water sampler and temperature probe (WSTP) permits one to measure temperatures and sample pore waters in shallow unconsolidated or semiconsolidated sediments. The probe is mounted on the end of the APC coring device, lowered on the sand line, and latched onto the drilling shoe. Then, it is pressed ~ 1 m into the undisturbed sediments directly below the drill bit. The probe is left in position for 15 to 20 min to allow for equilibration, and then retrieved. Temperature data are recorded internally. Although the water sampler portion of the tool was not used during Leg 128, temperature gradients in the sediments, and together with measurements of thermal conductivity were used to determine heat flow through the measured section (Hyndman et al., 1987).

The Lamont-Doherty Geological Observatory (L-DGO) temperature logging tool (TLT) is a self-contained tool that can be attached to the base of any sensor combination. Data from two thermistors and a pressure transducer are collected every 0.5 s and are internally recorded. Once in-situ measurement has been completed, data are transferred to a shipboard computer for analysis. The fast-response thermistor, although less accurate, can detect small, abrupt temperature excursions caused by fluid flow from the formation. The slow-response thermistor is more accurate and can be used to estimate the temperature gradient. Data are recorded as a function of time, with conversion to depth based on the pressure transducer. Unlike the Barnes/Uyeda probe, the TLT measures borehole water temperature, rather than formation temperature; thus, one often observes a gradual warming of the TLT temperatures as logging proceeds. Hence, the most reliable TLT temperatures are those taken from the last logging run, and even these should be considered minimum estimates.

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