2. EXPLANATORY NOTES[1]

Shipboard Scientific Party[2]

INTRODUCTION

Standard procedures for both drilling operations and preliminary shipboard analysis of the material recovered during Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP) drilling have been regularly amended and upgraded since drilling began in 1968. In this chapter, we have assembled information that will help the reader understand the basis for our preliminary conclusions and also help the interested investigator select samples for further analysis. This information concerns only shipboard operations and analyses described in the site reports in Volume 120 of the *Proceedings of the Ocean Drilling Program, Initial Reports*. Methods used by various investigators for shore-based analysis of Leg 120 data will be detailed in the individual scientific contributions published in the *Scientific Results* volume.

AUTHORSHIP OF SITE CHAPTERS

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

Site Summary (Schlich, Wise)
Background and Objectives (Schlich)
Site Geophysics (Munschy, Schlich)
Operations (Foss, Hayes, Schlich, Wise)
Lithostratigraphy (Breza, Holmes, Howard, Kelts, Julson, Zachos)
Biostratigraphy (Aubry, Berggren, Harwood, Lazarus, Mackensen, Maruyama, Quilty, Takemura)
Paleomagnetics (Heider, Inokuchi)
Sedimentation Rates (Aubry, Berggren, Harwood, Heider, Inokuchi, Lazarus, Mackensen, Maruyama, Quilty, Takemura)
Inorganic Geochemistry (Bitschene)
Organic Geochemistry (Zachos)
Physical Properties (Coffin, Rack)
Logging (Blackburn, Munschy, Pratson)
Seismic Stratigraphy (Munschy, Schlich)
Summary and Conclusions (Schlich, Wise)

In addition, shore-based scientists contributed to the *Initial Reports* as follows: Dirk Hos received palynological samples from Sites 748 and 750 during the helicopter rendezvous, and telexed results to the ship prior to the end of the cruise; Barbara Mohr also analyzed palynological materials from these sites and contributed age information after the Leg 120 post-cruise meeting.

Following the text of each site chapter are summary core descriptions ("barrel sheets") and photographs of each core.

SURVEY AND DRILLING DATA

The survey data used for specific site selection are discussed in each chapter. Short surveys using a precision echo sounder and a single-channel seismic profiler were made on board *JOIDES Resolution* while approaching each site. Geophysical survey data (seismic profiles) collected during Leg 120 are presented in the "Site Geophysics" section of the individual site chapters (this volume).

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

The 3.5- and 12-kHz bathymetric data were displayed on Precision Depth Recorder (PDR) systems. The depths were converted on the basis of an assumed 1463 m/s sound velocity. The water depth (in meters) at each site was corrected (1) for the variation in sound velocity with depth using Matthews's (1939) tables, and (2) for the depth of the hull transducer (6.8 m) below sea level. In addition, depths referred to the drilling-platform level are assumed to be about 10.5 m above the water line (see Fig. 1).

Magnetic data were recorded using a Geometrics 801 proton precession magnetometer and were displayed on a strip chart recorder. During each transit, a Benthos Expendable Bathythermograph (XBT) was deployed every 6 hr in order to record seawater temperatures.

Drilling Characteristics

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

Drilling Deformation

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

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[1] Schlich, R., Wise, S. W., Jr., et al., 1989. *Proc. ODP, Init. Repts.*, 120: College Station, TX (Ocean Drilling Program).

[2] Shipboard Scientific Party is as given in the list of Participants preceding the contents.

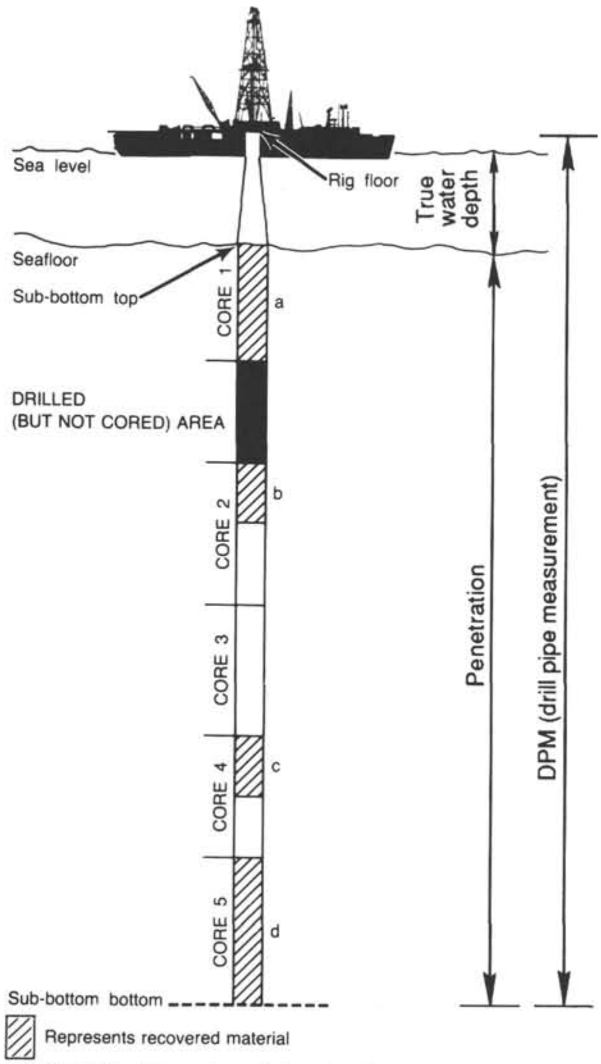


Figure 1. Diagram illustrating terms used in the discussion of coring operations and core recovery.

SHIPBOARD SCIENTIFIC PROCEDURES

Numbering of Sites, Holes, Cores, and Samples

Drilling sites are numbered consecutively from the first site drilled by the *Glomar Challenger* in 1968. A site number refers to one or more holes drilled while the ship was positioned over one acoustic beacon. Multiple holes may be drilled at a single site by pulling the drill pipe above the seafloor (out of the hole), moving the ship some distance from the previous hole, and then drilling another hole (or, less commonly, by returning to a previously deployed beacon, as was done at Hole 750B).

For all ODP drill sites, a letter suffix distinguishes each hole drilled at the same site. For example, the first hole drilled is assigned the site number modified by the suffix A, the second hole takes the site number and suffix B, and so forth. Note that this procedure differs slightly from that used by DSDP (Sites 1 through 624), but it prevents ambiguity between site- and hole-number designations.

For sampling purposes, it is important to distinguish among holes drilled at a site. Sediments or rocks recovered from different holes usually do not come from equivalent positions in the stratigraphic column, even if the core numbers are identical.

The cored interval is measured in meters below the seafloor (mbsf); sub-bottom depths are determined by subtracting the drill pipe measurement (DPM) water depth (the length of pipe from the rig floor to the seafloor) from the total DPM (from the rig floor to the bottom of the hole; see Fig. 1). Note that although echo-sounding data (from the PDRs) are used to locate the site, they are not used as a basis for any further measurements.

The depth interval assigned to an individual core is the depth below the seafloor that the coring operation began to the depth that the coring operation ended for that core (see Fig. 1). For rotary coring (RCB and XCB), each coring interval is equal to the length of the joint of drill pipe added for that interval (though a shorter core may be attempted in special instances). The drill pipe in use varies in length from about 9.4 to 9.8 m. The pipe is measured as it is added to the drill string, and the cored interval is recorded as the length of the pipe joint to the nearest 0.1 m. For hydraulic piston coring (APC) operations, the drill string is advanced 9.5 m (the maximum length of the piston stroke) or by the length of recovered material in the previous core (if less than 9.5 m was recovered).

Coring intervals are not necessarily adjacent to each other but may be separated by drilled intervals. In soft sediments, the drill string can be "washed ahead" with the core barrel in place (but not recovering sediments) by pumping water down the pipe at high pressure. This washes the sediment out of the way of the bit and up the space between the drill pipe and wall of the hole. If thin, hard layers are present, it is possible to get "spotty" sampling of these resistant layers within the washed interval and thus have a cored interval greater than 9.7 m. In drilling hard rock, a center bit may replace the core barrel if it is necessary to drill without core recovery.

Cores taken from a hole are numbered serially from the top of the hole downward. Core numbers and their associated cored intervals in meters below seafloor usually are unique in a given hole; rarely, however, an interval must be cored twice because of caving of cuttings or other hole problems.

Recovery of material equal in length to the cored interval is considered full, or 100%, recovery. However, the length of the recovered material may differ from the length of the cored interval. Recovery less than the cored interval may occur for a variety of reasons, often involving difficult-to-recover lithologies such as sand, chert-ooze alternations, or fractured basalt; equipment problems, such as incomplete APC stroke, may also be responsible. Apparent recovery greater than the cored interval may also occur, typically a result of gas expansion of the sediment.

Although 9.5 m is often cited as standard value for full recovery for a core, please note that this practice is erroneous because full recovery for a given core depends upon the coring technique in use and other factors that may vary from core to core.

The sediment or rock from the cored interval is recovered in a plastic liner (6.6-cm internal diameter); additional material (generally up to 0.2 m in length) may be recovered in the core catcher (without a plastic liner). The core catcher is a device at the bottom of the core barrel that prevents the core from sliding out when the barrel is being retrieved from the hole. For sediments, the core-catcher sample is extruded into a short piece of plastic liner and is treated as a separate section below the last core section. For hard rocks, material recovered in the core catcher is included at the bottom of the last section.

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

The convention of placing recovered material at the top of the cored interval is followed because in most cases of incomplete recovery material enters the core barrel until the core "jams off" at some point, preventing additional material from entering. In cases where the core liner is retrieved empty, the core-catcher material is placed at the top of the cored interval. However, information supplied by the drillers (or by other sources) may allow for more precise interpretation as to the correct position of material within an incompletely recovered cored interval. Such cases are explained within the text of the individual site chapters.

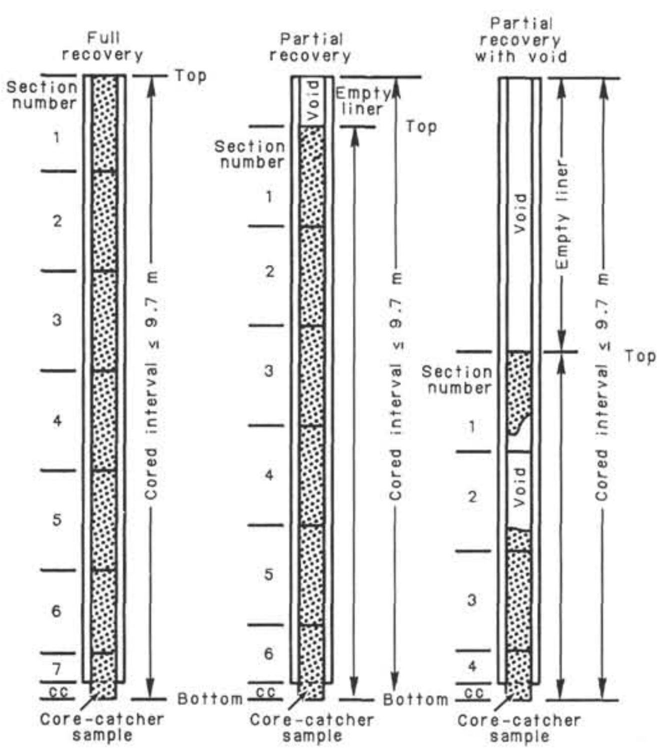


Figure 2. Diagram showing procedure used in cutting and labeling core sections.

A recovered basalt, gabbro, or peridotite core also is cut into 1.5-m sections that are numbered serially; however, each piece of rock is then assigned a number (fragments of a single piece are assigned a single number, with individual fragments being identified alphabetically). The core-catcher sample is placed at the bottom of the last section and is treated as part of the last section rather than separately. Scientists completing visual core 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, in order to achieve consistency in handling analytical data derived from the cores. Samples removed from the cores are designated by distance measured in centimeters from the top of the section to the top and bottom of each sample removed from that section. In curated hard rock sections, sturdy plastic spacers are placed between pieces that did not fit together in order to protect them from damage in transit and in storage; therefore, the centimeter interval noted for a hard rock sample has no direct relationship to that sample's depth within the cored interval, but is only a physical reference to the sample's location within the curated core.

A full identification number for a sample consists of the following information: leg, site, hole, core number, core type, section number, piece number (for hard rock), and interval in centimeters measured from the top of section. For example, a sample identification of "120-747A-5H-3, 100–102 cm," would be interpreted as representing a sample removed from the interval between 100 and 102 cm below the top of Section 3, Core 5 (H designates that this core was taken with the APC) of Hole 747A during Leg 120.

All ODP core and sample identifiers indicate core type. The following abbreviations are used: R = rotary core barrel (RCB); H = hydraulic piston corer (HPC; also referred to as APC, or advanced hydraulic piston corer); 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; N = positive displacement mud motor ("Navidrill") core; D = positive displacement coring motor core; and M = miscellaneous material. Only APC, XCB, RCB, and wash cores were drilled on Leg 120; miscellaneous material was collected from the bottom hole assembly (BHA) of Hole 748C.

Core Handling

As soon as a core is retrieved on deck, a sample is taken from the core catcher and given to the paleontological laboratory for an initial age assessment. The core is then placed on the long horizontal rack, and gas samples may be taken by piercing the core liner and withdrawing gas into a vacuum tube. Voids within the core are sought as sites for gas sampling. Some of the gas samples are stored for shore-based study, but others are analyzed immediately as part of the shipboard safety and pollution prevention 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), and physical properties (PP) whole-round samples are then taken. Each section 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 section ends from which a whole-round sample has been removed. The caps are usually attached to the liner by coating the end liner and the inside rim of the cap with acetone and taping the caps to the liners.

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

Next, if thermal conductivity measurements are to be taken, the cores are allowed to warm to room temperature before they are split (this took approximately 6 hr on Leg 120). During this time, the whole-round sections are run through the gamma ray attenuation porosity evaluator (GRAPE) device for estimating the bulk density, porosity (see following text; also Boyce, 1976), and simultaneous determination of sonic velocity. After the core temperatures have equilibrated, thermal conductivity measurements are made immediately before the cores are split.

Cores of fairly soft material are split lengthwise into *working* and *archive* halves. The softer cores are split with a wire or saw, depending on the degree of induration. Harder cores are split with a band saw or diamond saw. Because cores on Leg 120 were split with wire from the bottom to top, older material could possibly have been transported up the core on the split face of each section. Thus, investigators should be aware that the very near-surface part of the split core could be contaminated.

The working half is sampled for both shipboard and shore-based laboratory studies. Each extracted sample is logged by the location and the name of the investigator receiving the sample in the sampling computer database program. Records of all removed samples are kept by the curator at ODP headquarters in College Station, TX. The extracted samples are sealed in plastic vials or bags and labeled. Samples are routinely taken for shipboard physical property analysis, for percentage of calcium carbonate present (carbonate bomb), and for other purposes. Many of these data are reported in the site chapters.

The archive half is described visually. Smear slides and shipboard grain size analyses are made from samples taken from the archive half and may be supplemented by thin sections taken from the working half. Archive-half sections that show little drilling disturbance are run through the cryogenic magnetometer. The archive half is then photographed with both black-and-white and color film, a whole core at a time.

Both halves of the core are then put into labeled plastic tubes, sealed, and transferred to cold-storage space aboard the drilling vessel. Leg 120 cores were transferred from the ship by refrigerated vans to cold storage at the East Coast Repository at Lamont-Doherty Geological Observatory, Palisades, NY.

CORE DESCRIPTION FORMS ("BARREL SHEETS")

The core description forms (Fig. 3), or "barrel sheets," summarize the data obtained during shipboard analysis of each sediment core recorded in detail on a section-by-section basis on the visual core description form, or VCD (see also the notes on hard rock core description, below). Information recorded on the VCDs is available as a searchable database through the ODP Data Librarian. The following discussion explains ODP conventions used in compiling the core descriptions and the exceptions to these procedures adopted by Leg 120 scientists.

Core Designation

Cores are designated using leg, site, hole, and core number and type as previously discussed (see "Numbering of Sites, Holes, Cores, and Samples," this chapter). In addition, the cored interval is specified in terms of meters below seafloor (mbsf), based on the drill pipe measurements (DPM) reported by the SEDCO coring technician and the ODP operations superintendent. Note that DPM values must be corrected for the height of the rig floor above sea level (nominally 10.5 m) to yield true water depth.

Paleontological Data

Microfossil abundance, preservation, and zonal 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 on 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 to record paleomagnetic results, physical properties values (density and porosity), and chemical data (percentages of $CaCO_3$ and organic carbon determined using the Coulometrics analyzer). Additional information on shipboard procedures for collecting these types of data appears in the "Paleomagnetics," "Physical Properties," and "Inorganic Geochemistry" sections (this chapter).

Graphic Lithology Column

The lithologic classification scheme of Mazzullo, Meyer, and Kidd (1988), accepted for shipboard use by the JOIDES Sediments and Ocean History Panel, is presented here. Sediment type is represented graphically on the core description forms with the symbols illustrated in Figures 4 and 5. Modifications and additions made to the graphic lithology representation scheme used on Leg 120 are discussed below.

The relative abundances of the sedimentary constituents approximately equal the percentage of the width of the graphic column that its symbol occupies. For example, the left 20% of the column may indicate diatom ooze, whereas the right 80% may indicate nannofossil ooze, illustrating a sediment consisting of 20% diatoms and 80% nannofossils. However, in some cases the symbols may be used to represent small-scale alternations of two or more lithologies, as noted in the detailed lithologic descriptions that accompany each barrel sheet (as discussed below).

Sediment Disturbance

In some cases, the coring technique, which uses a 25-cm-diameter bit with a 6-cm-diameter core opening, may result in varying degrees of disturbance of the recovered core material. This is illustrated in the "Drilling Disturbance" column on the core description form (Fig. 3). The following disturbance categories (Fig. 6) are recognized for soft and firm sediments:

1. Slightly disturbed: bedding contacts are slightly bent.
2. Moderately disturbed: bedding contacts have undergone extreme bowing, and firm sediment is fractured.
3. Highly disturbed: bedding is completely disturbed or homogenized by drilling and sometimes shows symmetrical diapir-like structures ("flow-in").
4. Soupy: water-saturated intervals have lost all aspects of original bedding.

The following categories are used to describe the degree of fracturing in hard sediments and igneous and metamorphic rocks (Fig. 6):

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

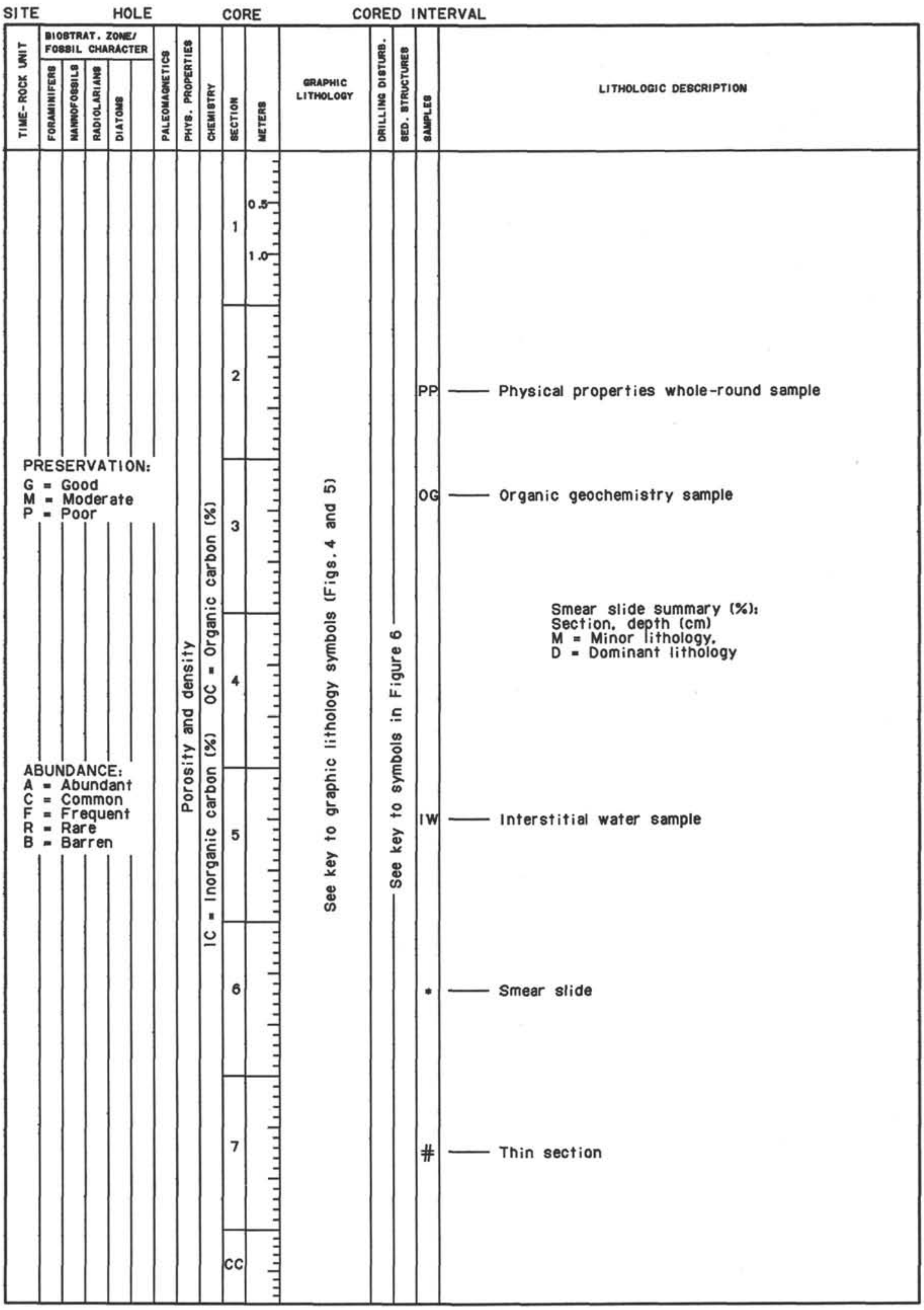


Figure 3. Core description form ("barrel sheet") used for sediments and sedimentary rocks.

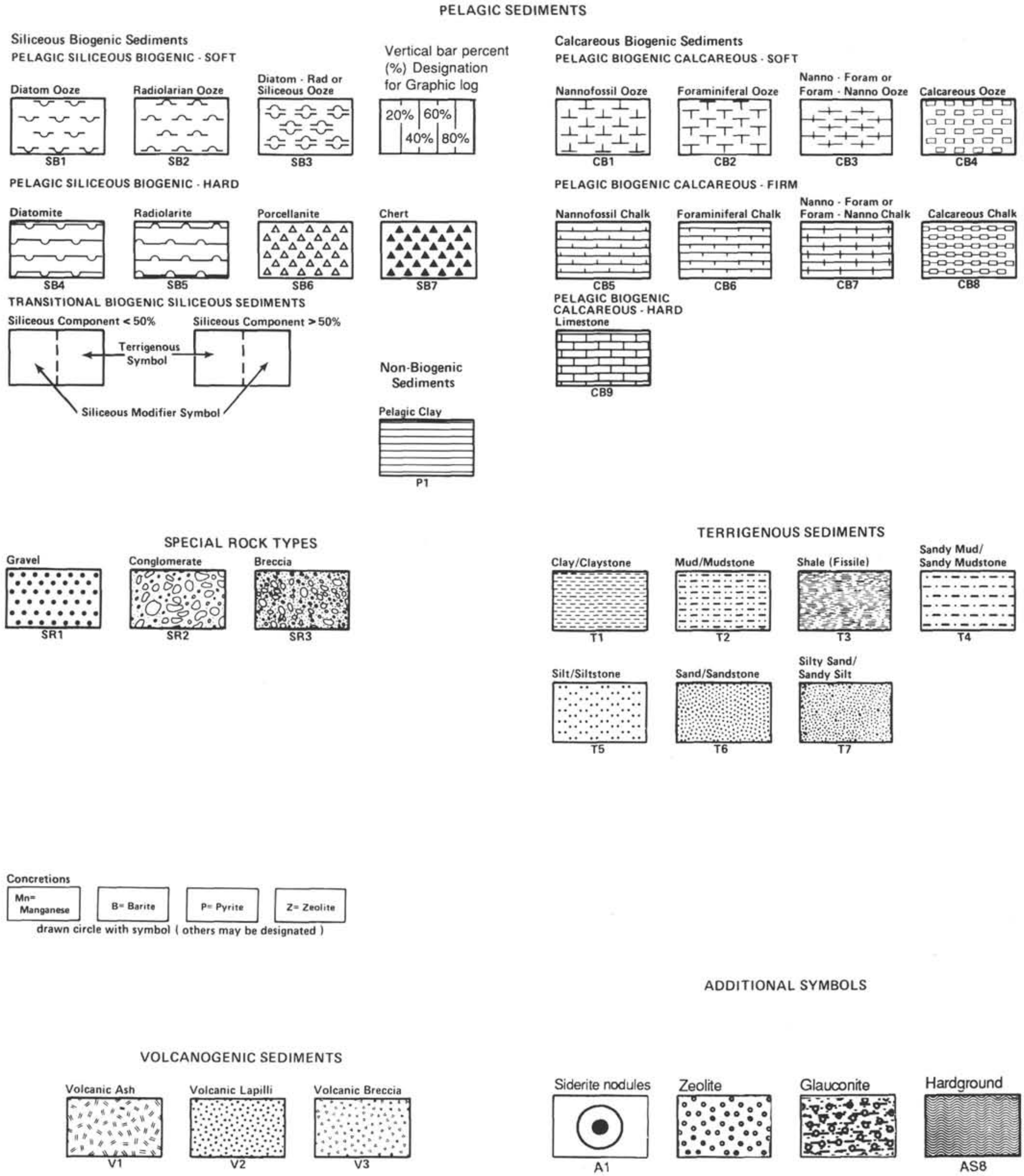


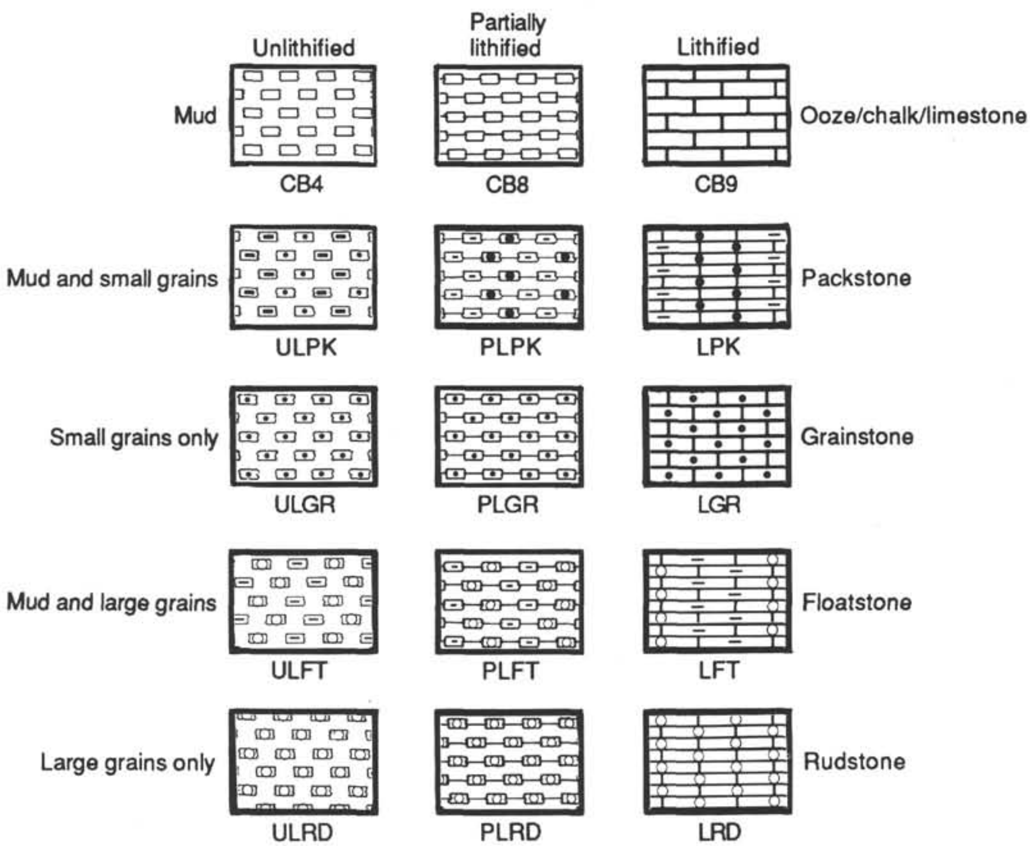
Figure 4. Key to symbols used in "graphic lithology" column on the core description form shown in Figure 3.

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

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

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

A



B

<table>
<tr><td colspan="5">Depositional texture recognizable</td><td>Depositional texture not recognizable</td></tr>
<tr><td colspan="4">Original components not bound together during deposition</td><td rowspan="4">Original components were bound together during deposition... as shown by intergrown skeletal matter, lamination contrary to gravity, or sediment-floored cavities that are roofed over by organic or questionably organic matter and are too large to be interstices.</td><td rowspan="4">Subdivide according to classifications designed to bear on physical texture or diagenesis.</td></tr>
<tr><td colspan="3">Contains mud
(Particles of clay and fine silt size)</td><td>Lacks mud</td></tr>
<tr><td colspan="2">Mud supported</td><td colspan="2">Grain supported</td></tr>
<tr><td>Less than 10% grains</td><td>More than 10% grains</td><td></td><td></td></tr>
<tr><td>Mudstone</td><td>Wackestone</td><td>Packstone</td><td>Grainstone</td><td>Boundstone</td><td>Crystalline carbonate</td></tr>
</table>

Figure 5. **A.** Lithologic symbols for coarse-grained calciclastics, based on the Dunham (1962) carbonate classification (see Fig. 5B). **B.** Textural classification of calciclastic sediments.

Sedimentary Structures

The location and types of sedimentary structures in a core are indicated on the "Sedimentary Structure" column of the core description forms (Fig. 3). A key to the structural symbols used on Leg 120 is given in Figure 6. It should be noted, however, that distinguishing between natural structures and those created by the coring process may be extremely difficult.

Color

Sediment color was determined with the Munsell Soil Color Charts (Munsell Soil Color Charts, 1971). Colors were deter-

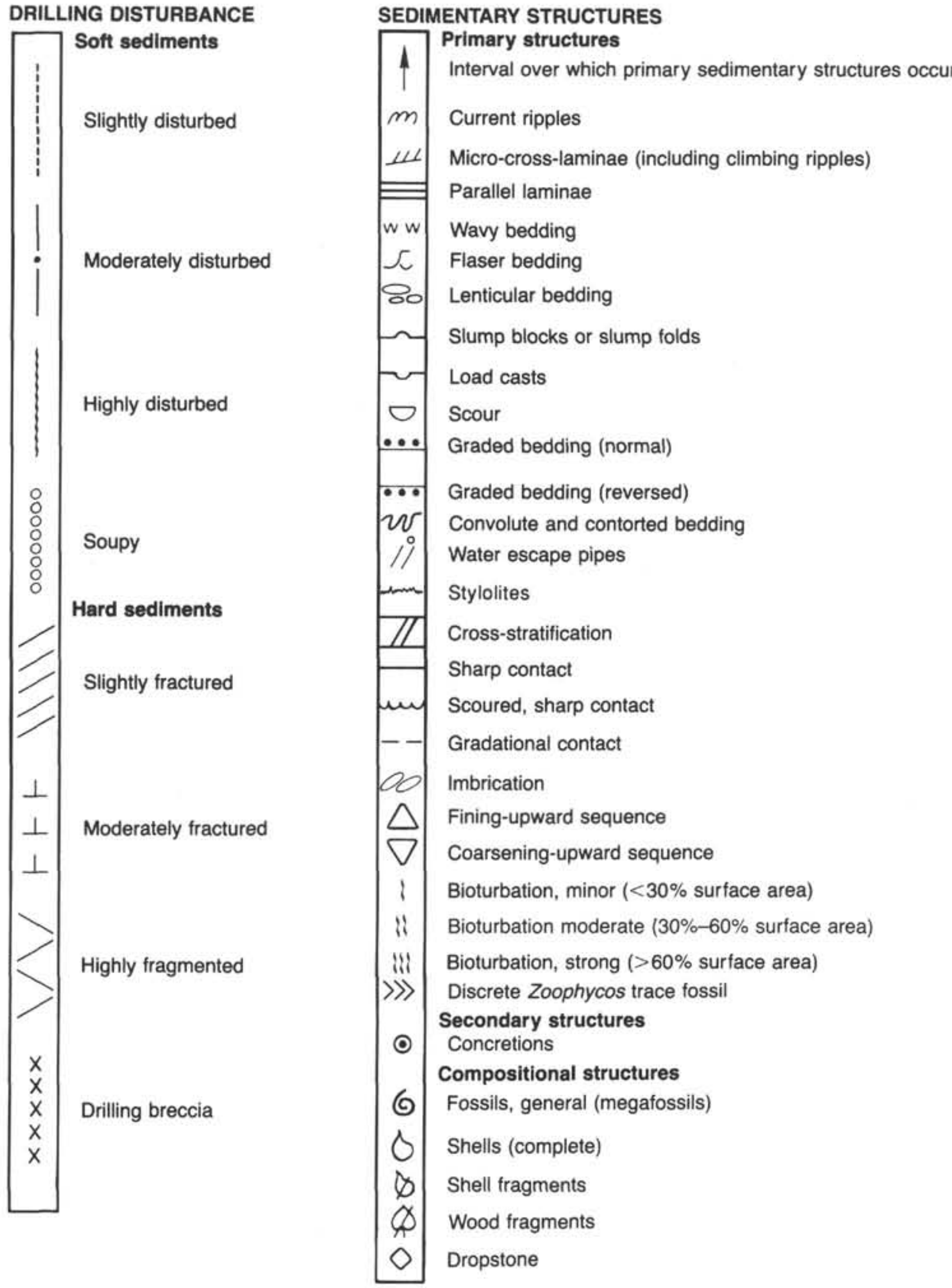


Figure 6. Drilling disturbance and sedimentary structure symbols for sediments and sedimentary rocks used in the core description form shown in Figure 3.

mined immediately after the cores were split and while they were still wet.

Samples

The position of samples taken from each core for shipboard analysis is indicated in the "Samples" column in the core description form (Fig. 3). An asterisk (*) indicates the location of smear slide samples. The symbols IW, OG, and PP designate whole round interstitial water, frozen organic geochemistry, and physical properties samples, respectively.

Although not indicated in the "Samples" column, the positions of samples for routine physical property (porosity and wet-bulk density) and geochemical ($CaCO_3$ and organic carbon) analyses are indicated by dots in the "Physical Properties" and "Chemistry" columns. Paleomagnetic results (normal and reversed polarity intervals) are also indicated.

Shipboard paleontologists generally use core-catcher samples for shipboard age determinations, although additional samples from other parts of the core may be examined as required. Examination of such samples may lead to the recognition of zonal boundaries in the core, as indicated in the appropriate column of the core description form (Fig. 3).

Lithologic Description—Text

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

Smear Slide Summary

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

SEDIMENT MEASUREMENTS

Grain Sizes

For routine assignment of sediments to textural classes, grain sizes were estimated visually from the core material and smear slides. For the finer sediments, a Lasentec Lab-Tec™ 100 particle-size analyzer was used to provide data on the sand/silt/clay ratio and mean grain size. In this instrument a stirred, horizontally rotating, dilute suspension of the sediment is scanned in a vertical plane by a finely focused laser-diode beam. Individual particle cross sections are measured from the duration of the back-scattering events. The analyses are rapid and appear to be accurate to $\pm 5\%$ (at full range) in the range of 4–250 μm under controlled operation. Total particle counts are obtained in about 10 s from sediment samples of about 100 mg. Measurements are not accurate with dull, black particles (e.g., MnO_2-coated grains).

To minimize clay flocculation, samples are treated with Calgon solution for 24 hr; if not disaggregated, they were put in the ultrasonic bath for a short time. Gentle crushing in an agate mortar and pestle were required for a few of the more indurated samples.

The raw size/frequency data is dependent on the optical cross section of each size class. In order to convert this into traditional sedimentological size-wt% data, compensation factors were applied. In the general case, they correspond to each class median size, but some sediment types require calibration through sieve and pipette analyses (e.g., hollow grains in biogenic ooze).

Other Measurements

Procedures for X-ray diffraction (XRD) and X-ray fluorescence (XRF) analyses appear in the discussion of igneous rock studies. Magnetic susceptibility measurements are discussed in the "Paleomagnetics" section (this chapter).

SEDIMENT CLASSIFICATION

The new classification scheme for ODP by Mazzullo, Meyer, and Kidd (1988), partly reproduced below, was used during Leg 120. However, note the following amendments and comments:

1. As adopted by Leg 119 sedimentologists, the term *neritic* in the scheme is substituted by *calciclastic*. The use of neritic for nonpelagic carbonate grains differs significantly from use elsewhere (Bates and Jackson, 1980) and could be misunderstood.
2. Leg 120 cherts and porcellanites did not always fall clearly into either granular or chemical sediments; relict microfossils and/or chalk patinas commonly were present.
3. The classification scheme did not adequately treat components such as glauconite (common in Hole 748C), which were granular components of probable chemical origin (see discussion below).

Classification of Granular Sediments

Classes of Granular Sediments

There are four types of grains that can be found in granular sediments: *pelagic, calciclastic, siliciclastic*, and *volcaniclastic* grains.

1. Pelagic grains are composed of the fine-grained skeletal debris of open-marine siliceous and calcareous microfauna and microflora (e.g., radiolarians, nannofossils) and associated organisms.
2. Calciclastic grains are composed of coarse-grained calcareous skeletal debris (e.g., bioclasts, peloids), and fine-grained calcareous grains of nonpelagic origin (e.g., micrite).
3. Siliciclastic grains are composed of mineral and rock fragments that were derived from plutonic, sedimentary, and metamorphic rocks.
4. 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, calciclastic, siliciclastic, volcaniclastic*, and *mixed sediments* (Fig. 7).

1. Pelagic sediments are composed of >60% pelagic and calciclastic grains and <40% siliciclastic and volcaniclastic grains and contain a higher proportion of pelagic than calciclastic grains.
2. Calciclastic sediments are composed of >60% pelagic and calciclastic grains and <40% siliciclastic and volcaniclastic grains and contain a higher proportion of calciclastic than pelagic grains.
3. Siliciclastic sediments are composed of >60% siliciclastic and volcaniclastic grains and <40% pelagic and calciclastic

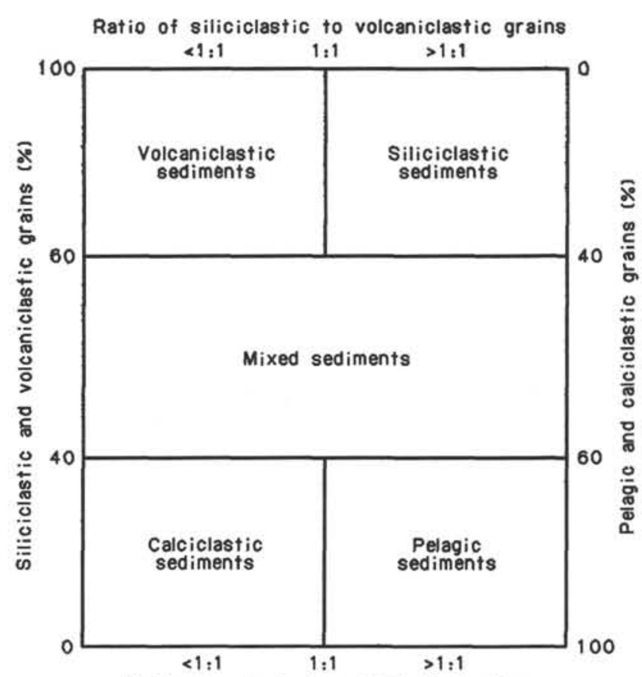


Figure 7. Diagram showing classes of granular sediments.

grains and contain a higher proportion of siliciclastic than volcaniclastic grains.

4. Volcaniclastic sediments are composed of >60% siliciclastic and volcaniclastic grains and <40% pelagic and calciclastic 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).

5. Mixed sediments are composed of 40%-60% siliciclastic and volcaniclastic grains and 40%-60% pelagic and calciclastic grains.

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. 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 sediments;
2. *Chalk:* firm pelagic sediment composed predominantly of calcareous pelagic grains;
3. *Limestone:* hard pelagic sediment composed predominantly of calcareous pelagic grains;
4. *Radiolarite, diatomite,* and *spiculite:* firm pelagic sediment composed predominantly of siliceous radiolarians, diatoms, and sponge spicules, respectively;
5. *Chert:* hard pelagic sediment composed predominantly of silicified pelagic grains (on Leg 120, this term was applied only to vitreous sediments; opaque chertlike sediments were identified as porcellanite, a softer, less dense variety of chert).

For calciclastic sediment, the principal name describes the texture and fabric, using the following terms (from Dunham, 1962; see Fig. 5B):

1. *Boundstone:* components organically bound during deposition;
2. *Grainstone:* grain-supported fabric, no mud, grains <2 mm in size;
3. *Packstone:* grain-supported fabric, with intergranular mud, grains <2 mm in size;
4. *Wackestone:* mud-supported fabric, with >10% grains, grains <2 mm in size;
5. *Ooze* (termed "mudstone" by Dunham, 1962): mud-supported fabric, with <10% grains;
6. *Floatstone:* matrix-supported fabric, grains >2 mm in size.
7. *Rudstone:* grain-supported fabric, grains >2 mm in size.

Table 1. Outline of the granular sediment classification scheme used on Leg 120.

Sediment class	Major modifiers	Principal names	Minor modifiers
Pelagic sediment	1. Composition of pelagic and calciclastic grains present in major amounts 2. Texture of clastic grains present in major amounts	1. Ooze 2. Chalk 3. Limestone 4. Radiolarite 5. Diatomite 6. Spiculite 7. Porcellanite 8. Chert	1. Composition of pelagic and calciclastic grains present in minor amounts 2. Texture of clastic grains present in minor amounts
Calciclastic sediment	1. Composition of calciclastic and pelagic grains present in major amounts 2. Texture of clastic grains present in major amounts	1. Boundstone 2. Grainstone 3. Packstone 4. Wackestone 5. Floatstone 6. Rudstone	1. Composition of calciclastic and pelagic grains present in minor amounts 2. Texture of clastic grains present in minor amounts
Siliclastic sediment	1. Composition of all grains present in major amounts 2. Grain fabric (gravels only) 3. Grain shape (optional) 4. Sediment color (optional)	1. Gravel 2. Sand 3. Silt 4. Clay (etc.)	1. Composition of all grains present in minor amounts 2. Texture and composition of siliciclastic grains present as matrix (for coarse-grain clastic sediments)
Volcaniclastic sediment	1. Composition of all volcaniclasts present in major amounts 2. Composition of all pelagic and calciclastic grains 3. Texture of siliciclastic grains present in major amounts	1. Breccia 2. Lapilli 3. Ash/tuff 4. Volcanic sand (etc.)	1. Composition of all volcaniclasts present in minor amounts 2. Composition of all calciclastic and pelagic grains present in minor amounts 3. Texture of siliciclastic grains grains present in minor amounts
Mixed sediment	1. Composition of calciclastic and pelagic grains present in major amounts 2. Texture of clastic grains present in major amounts	1. Mixed sediments	1. Composition of calciclastic and pelagic grains present in minor amounts 2. Texture of clastic grains present in minor amounts

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. When two or more textural groups or subgroups are present in a siliciclastic sediment, they are listed as principal names in order of increasing abundance (Shepard, 1954; Fig. 8).
3. The suffix *"-stone"* can be affixed to the principal names sand, silt, and clay when the sediment is lithified; *shale* can be used as a principal name for a lithified and fissile siltstone or claystone. The term *mudstone* is used for indurated, nonfissile, sandy and silty, fine-grained, siliciclastic sediments, if induration, etc., preclude grain-size analysis. *Conglomerate* and *breccia* are used as principal names of gravels with well-rounded and angular clasts, respectively.

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

1. *Volcanic breccia:* pyroclasts >64 mm in diameter;
2. *Volcanic lapilli:* pyroclasts between 2 and 64 mm in diameter;
3. *Volcanic ash:* pyroclasts <2 mm in diameter (when lithified, the name *tuff* is used);

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

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

Major and Minor Modifiers

The principal name of a granular sediment class is preceded by major modifiers and followed by minor modifiers (preceded by the suffix "with") that describe the lithology of the granular sediment in greater detail (Table 1).

The most common use of major and minor modifiers is to describe the composition and textures of grain types that are present in major (>25%) and minor (10%–25%) proportions. In addition, major modifiers can be used to describe grain fabric, grain shape, and sediment color. The nomenclature for the major and minor modifiers is outlined as follows.

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

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

1. *Ooid* (or *oolite*): spherical or elliptical nonskeletal particles <2 mm in diameter, having a central nucleus surrounded by a rim with concentric or radial fabric;
2. *Bioclast* (or *bioclastite*): fragment of skeletal remains (specific names such as molluscan or algal can also be used);
3. *Pellet* (or *pelletal*): fecal particles from deposit-feeding organisms;
4. *Intraclast:* reworked carbonate-rock fragment or rip-up clast;

Table 2. Udden-Wentworth grain-size scale used for classification of terrigenous sediments (from Wentworth, 1922).

Millimeters		Microns	Phi (ϕ)	Wentworth size class	
			−20	Boulder (−8 to −12ϕ)	
	4096		−12		
	1024		−10		
	256		−8		
	64		−6	Cobble (−6 to −8ϕ)	Gravel
	16		−4	Pebble (−2 to −6ϕ)	
	4		−2		
	3.36		−1.75	Granule	
	2.83		−1.5		
	2.38		−1.25		
	2.00		−1.0		
	1.68		−0.75	Very coarse sand	
	1.41		−0.5		
	1.19		−0.25		
	1.00		0.0		
	0.84		0.25	Coarse sand	
	0.71		0.5		
	0.59		0.75		
1/2	0.50	500	1.0		
	0.42	420	1.25	Medium sand	Sand
	0.35	350	1.5		
	0.30	300	1.75		
1/4	0.25	250	2.0		
	0.210	210	2.25	Fine sand	
	0.177	177	2.5		
	0.149	149	2.75		
1/8	0.125	125	3.0		
	0.105	105	3.25	Very fine sand	
	0.088	88	3.5		
	0.074	74	3.75		
1/16	0.0625	63	4.0		
	0.053	53	4.25	Coarse silt	
	0.044	44	4.5		
	0.037	37	4.75		
1/32	0.031	31	5.0		
1/64	0.0156	15.6	6.0	Medium silt	Mud
1/128	0.0078	7.8	7.0	Fine silt	
1/256	0.0039	3.9	8.0	Very fine silt	
	0.0020	2.0	9.0	Clay	
	0.00098	0.98	10.0		
	0.00049	0.49	11.0		
	0.00024	0.24	12.0		
	0.00012	0.12	13.0		
	0.00006	0.06	14.0		

5. *Pisolite:* spherical or ellipsoidal nonskeletal particle, commonly >2 mm in diameter, with or without a central nucleus but displaying multiple concentric layers of carbonate;
6. *Peloid* (or *pel*): micritized carbonate particle of unknown origin;
7. *Calcareous, dolomitic, aragonitic*, and *sideritic:* used to describe the composition of carbonate muds or mudstones (micrite) or nonpelagic origins.

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

1. Mineralogy: with such modifiers as quartz, feldspar, mica, kaolinite, zeolitic, lithic (for rock fragments), calcareous, gypsiferous, or sapropelic (for detrital clasts of calcium carbonate, gypsum, and organic matter, respectively);
2. Provenance: the source of rock fragments (particularly in gravels, conglomerates, and breccias) can be described by such modifiers as volcanic, sed-lithic, meta-lithic, gneissic, basaltic, etc.;
3. Morphology: *glauconite* in this volume refers to rounded, greenish, sand-size grains and not to the mineral composition of

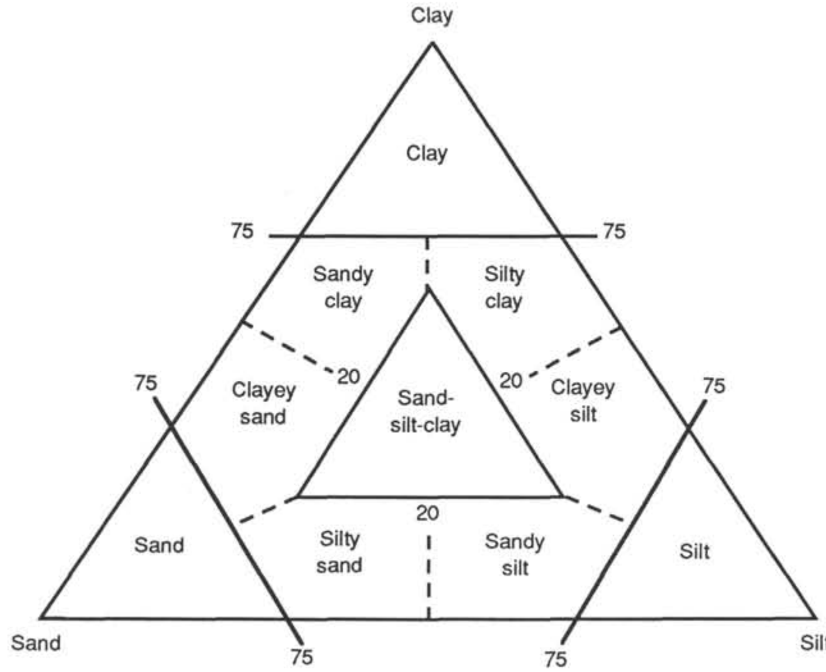


Figure 8. Ternary diagram showing principal names for siliciclastic sediments (from Shepard, 1954).

such grains. Where the mineralogy of the pellets is known, the term *mineralogical glauconite*, after McRae (1972), is used.

The composition of volcaniclastic grains is described by the major and minor modifiers *lithic* (rock fragments), *vitric* (glass and pumice), and *crystal* (mineral crystals), or by modifiers that describe the compositions of the liths and crystals (e.g., *feldspar* or *basaltic*).

The fabric of the sediment can be described by the major modifiers *grain-supported, matrix-supported*, and *imbricated*. Generally, fabric descriptors are applied only to gravels, conglomerates, and breccias, for they provide useful information on their transport history.

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

The color of sediment is determined with a standard color-comparitor, such as the Munsell Soil Color Chart (1971) and can be employed as a major modifier.

For this volume, "chemogenic" sediments such as salt, and organic sediments of the coal series were not encountered; the only representatives recovered on Leg 120 were chert, porcellanite, and glauconite.

BASEMENT DESCRIPTION CONVENTION

Visual Core Descriptions

Visual core descriptions serve as a graphic representation of the basement cores. Copies of the visual core description forms, as well as other prime data collected during Leg 120, are available on microfilm at all three ODP repositories and from the Data Librarian.

Core Curation and Shipboard Sampling

Igneous rocks were split into archive and working halves using a rock saw with a diamond blade. The core was cut in such a manner to preserve unique features and/or to expose important structures. The archive half was described and the working half was sampled for shipboard analyses. On a typical igneous core description form (Fig. 9), the left column is a visual representation of the archive half.

A horizontal line across the entire width of the column denotes a plastic spacer glued between rock pieces inside the liner. Each piece was numbered sequentially from the top of each section, beginning with number 1. Pieces were labeled on the rounded, not sawn surface. Pieces that could be fitted together were assigned the same number and were lettered consecutively (e.g., 1a, 1b, 1c, etc.). Spacers were placed between pieces with different numbers, but not between those with different letters and the same number.

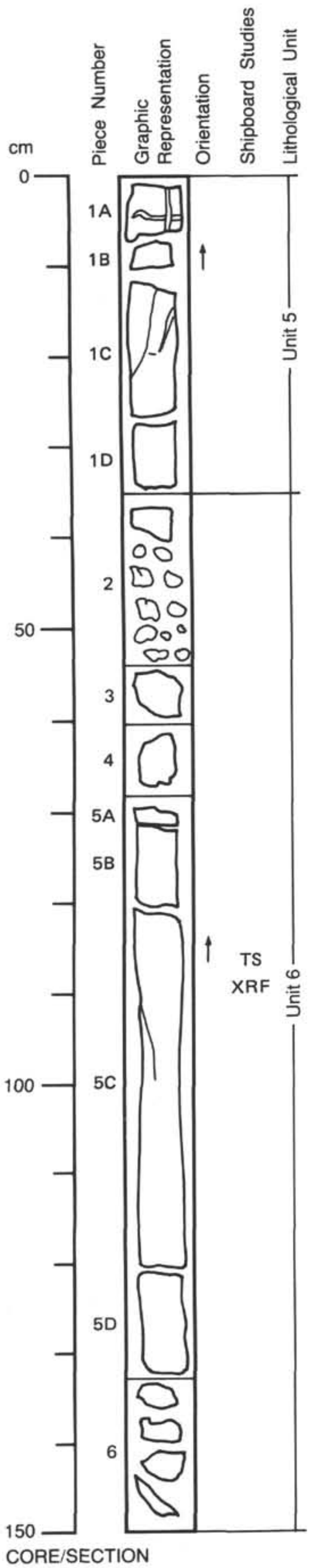
The presence of a spacer may represent a substantial interval of no recovery. Whenever the original unsplit piece was sufficiently large, the bottom was marked with an indelible pencil before removal from the core liner (i.e., if the piece could not have rotated top to bottom about a horizontal axis in the liner during drilling). Afterward, an arrow was added to the label pointing to the top of the section.

Care was taken to ensure that orientation was not lost during the splitting and labeling processes. Oriented pieces are indicated on the description forms by upward-pointing arrows to the right of the piece. Because pieces are free to turn about a vertical axis during drilling, azimuthal orientation is not possible.

Immediately after the core was split, sampling was carried out for shipboard physical properties, paleomagnetics, XRF, XRD, and thin section studies. On the visual core description forms, the type of measurement and approximate sample interval are indicated in the column headed "shipboard studies," with the following notation: XRD = X-ray diffraction analysis, XRF = X-ray fluorescence analysis, and TS = thin section.

Lithologic Description

Lithologic descriptions were undertaken in a systematic fashion, ensuring that all important features (e.g., nature of contacts, distribution and percentage of phenocrysts, groundmass texture, color, vesicle or amygdule content, alteration, etc.) were described.



120-750B-17R-2

UNIT 5: CONTINUED

Pieces 1A-1D

CONTACTS: Not determined.
PHENOCRYSTS:
Plagioclase - 7%, 1-2 mm, euhedral.
Clinopyroxene - 5%, 0.5-1.5 mm.
GROUNDMASS: Fine-grained to microcrystalline.
VESICLES: (?)%, up to 2 mm, vesicles filled with green clay.
COLOR: Gray.
STRUCTURE: Not determined.
ALTERATION: Slight.
VEINS/FRACTURES: Rare.

UNIT 6: APHYRIC BASALT

Pieces 2-5

CONTACTS: Piece 2: upper contact of Unit 6. Fine-grained chilled zone, crystals are not present. Glass altered to clay minerals.
PHENOCRYSTS: Aphyric.
GROUNDMASS: Microcrystalline.
VESICLES: None.
COLOR: Green gray.
STRUCTURE: None.
ALTERATION: Moderate.
VEINS/FRACTURES: < 1 mm thick calcite and zeolite veins; up to 1 cm thick veins of calcite and green clays and zeolites.

Figure 9. An example of an igneous rock core description form.

Macroscopic Core Descriptions

Igneous rocks were classified on the basis of mineralogy and texture. The description outline and the classification used for extrusive rocks and dikes is presented in Table 3. There are two forms used in the description of hard rocks: one for macroscopic description of cores and one for the description of thin sections. The data on these forms go directly into a computerized database that is accessible to the entire scientific community.

Thin Section Description

Shipboard thin section studies were undertaken to identify the magmatic mineralogy and textures and to observe the relationship between secondary and magmatic mineralogy. In accordance with the procedures generally adopted by petrologists during earlier DSDP/ODP legs, the petrographic units as identified in thin section are described strictly by the presence of phenocryst assemblages or an individual phenocryst phase in phyric basalt. The terms *sparsely, moderately, highly phyric*, and *aphyric* are used in the same manner as for the core descriptions.

Alteration of Igneous Rocks

Alteration of the basalts was described in hand specimen and thin sections. The identities of secondary minerals filling fractures, vesicles, and replacing igneous phases were estimated in core descriptions and refined in thin section, augmented in most cases by XRD shipboard studies. The percentage of secondary minerals was estimated from thin sections.

SHIPBOARD ANALYTICAL STUDIES OF BASEMENT ROCKS

X-Ray Diffraction

A Phillips ADP 3520 X-ray diffractometer was used for the X-ray diffraction (XRD) analysis of secondary minerals. Instrument conditions were as follows: CuK_α radiation with Ni filter, 40 Kv, 35 mA, goniometer scan from 2° to 70° 2θ, step size = 0.02°, and count time = 1 s.

Samples of secondary minerals such as clays, zeolite, or carbonates were carefully removed from amydgules or veins, ground in an agate mortar and pestle, and adhered to doubled-sided transparent tape for X-ray analysis. The diffractograms were interpreted with the help of a computerized search and match routine using Joint Committee on Powder Diffraction Standards (JCPDS) powder files and tabulated data for clay minerals in Brindley and Brown (1980).

X-Ray Fluorescence Analysis

Samples considered to be least altered and most representative of the individual lithologic units were analyzed for major and trace elements with an automated wavelength-dispersive ARL 8420 X-ray spectrometer equipped with a 3 kW rhodium X-ray source. Geochemical analyses presented in the site chapters were measured on board the *JOIDES Resolution*.

The samples were prepared by taking a representative volume of rock and removing any saw marks by wet grinding on a silicon carbide disk mill. The sample was then ultrasonically washed in distilled water and methanol for 10 min each and dried at 110°C for at least 2 hr. Larger pieces were reduced to <1 cm in diameter by crushing between two plastic disks in a hydraulic press. Powders were produced by grinding for 50-60 s in a Spex tungsten carbide shatterbox.

Major element analyses were determined on fused beads with a technique similar to that of Norrish and Hutton (1969). The beads were made by fusing a mixture of 500 mg of pre-ignited (1000°C for 2 hr) rock powder and 6.000 g of flux consisting of 80% lithium tetraborate and 20% La_2O_3 in Pt-Au crucibles at 1150°C for about 10 min. The fused mixture was poured into a Pt-Au mold with a Claisse Fluxer. The 12:1 flux-to-sample ratio eliminates matrix effects over a limited range of rock compositions such that a linear relationship exists between net X-ray intensity and concentration.

Calibration curves were determined from a set of standard samples during the transit to the first site. During analyses, any errors due to short- or long-term machine drift or X-ray tube intensity were corrected by normalizing the measured intensities of the unknown to that of a standard that was always run coincidently with the unknowns. A suite of well-characterized basalts (V. Salters, unpubl. data) were analyzed prior to the measurement of unknowns and excellent agreement was found between known and measured concentrations for both major and trace elements.

Table 3. Description outline and classification for fine- and medium-grained extrusive rocks and dikes.

1. Enter leg, site, hole, core number and type, and section information. Draw the graphic representation of the core; number the rock pieces; and record positions of shipboard samples.
2. Subdivide the core into lithologic units, using the criteria such as primary structures, macroscopic and microscopic textural variations, and mineralogic variations.
3. For each lithologic unit, answer the following:
   - A.1. Enter unit number (consecutive downhole), including piece numbers of top and bottom pieces in unit.
   - A.2. Rock name (to be filled in last).
   - A.3. Contact type (e.g., intrusive; discordant; depositional, etc.). Note the presence of glass and its alteration products (in %), give the azimuth and dip of the contact.
   - A.4. Phenocrysts: determine if homogeneous or heterogeneous distribution; if heterogeneous distribution, note variations. For each phenocryst phase determine:
     - i. abundance (%).
     - ii. average size in mm.
     - iii. shape.
     - iv. percent degree of alteration and replacing phases and their relationships.
     - v. further comments.
     - vi. fill in A.2. rock name (see footnote naming basalts).
   - A.5. Groundmass texture: glassy, microcrystalline, fine grained (<1 mm), medium grained (1-5 mm), or coarse grained (>5 mm). Note the relative grain size changes within the unit (e.g., coarsening from Piece 1 to Piece 5).
   - A.6. Color (dry).
   - A.7. Vesicles: give percent, size, shape, fillings and their relationships (include % of vesicles that are filled by alteration minerals), and distribution. Miaroles: give percent, size, shape, distribution.
   - A.8. Structure: massive, pillow lava, thin flow, breccia, etc., and comments.
   - A.9. Alteration: fresh (<2%), slightly (2%-10%), moderately (10%-40%), highly (40%-80%), very highly (80%-95%) or completely (95%- 100%) altered. Type, form, and distribution of alteration.
   - A.10. Veins/fractures: percent present, width, orientation, fillings and relationships, halos.
4. Basalts are termed aphyric, sparsely phyric, moderately phyric, or highly phyric, depending upon the proportion of phenocrysts visible with the hand lens or binocular microscope (approximately 10X). Basalts are called aphyric if phenocrysts clearly amount to <1% of the rock, sparsely phyric if phenocryst content ranges from 1%-2%, moderately phyric at 2%-10%, and highly phyric if phenocrysts amount to >10% of the rock. Basalts are further classified by phenocryst type (e.g., a moderately plagioclase-olivine phyric basalt contains 2%-10% phenocrysts, most of them plagioclase, but with some olivine).

Trace elements were determined on pressed-powder pellets made by pressing a mixture of 5.000 g of dry rock powder (dried at 110°C for >2 hr) and 30 drops of polyvinylalcohol binder into an aluminum cap under a pressure of 7 tons. Trace element concentrations were calculated by means of an off-line program written by J. W. Sparks that uses routines modified from Norrish and Chappell (1967) and Reynolds (1967). Dead-time X-ray intensities were corrected for drift, backgrounds (both sides of characteristic line), spectral interferences, and matrix effects. With the exception of Ba and Ce, results obtained from analyses of basalts from V. Salters (unpubl. data) are within analytical uncertainty.

BIOSTRATIGRAPHY

Leg 120 should provide a unique opportunity to study high-latitude microfaunas and microfloras from the Southern Hemisphere and to compare them with those occurring at middle and low latitudes. The Leg 120 paleontologists have established a preliminary, integrated biostratigraphic framework that incorporates elements of low- and mid-latitude zonations as well as those developed in southern high (subantarctic) latitudes. This framework is established only as a means of comparing the occurrence and/or stratigraphic range of taxa within an approximate chronostratigraphy. Correlation to a standard chronostratigraphic framework will be made by means of post-cruise integrated magnetobiostratigraphic studies to the extent possible.

Correlation of biostratigraphic zonations/datum events with the General Polarity Time Scale (GPTS) follows that of Berggren et al. (1985a, 1985b, 1985c) and Aubry et al. (1988) for the Cenozoic (Figs. 10–13) and that of Kent and Gradstein (1985), supplemented by the integrated magnetobiostratigraphic correlations in Berggren et al. (1983b), for the Cretaceous (Fig. 14). The epoch/stage boundary age estimates used by the Leg 120 investigators are as in Table 4, and age estimates for the magnetic polarity intervals are in Table 5. The biostratigraphic framework developed by the Leg 120 biostratigraphers for each fossil group is discussed below.

Calcareous Nannofossils

Cenozoic

The biostratigraphic zonation used in this report is that proposed by Martini (1971), which is tied to the geomagnetic reversal time scale of Berggren et al. (1985a, 1985b), as shown in Figures 10–13. In addition, correlation to the Paleogene chronostratigraphic units of northwestern Europe is based on Aubry (1983, 1985).

Mesozoic

Biostratigraphic subdivision of the Cretaceous sediments follows the zonation of Sissingh (1977), with additional biohorizons as suggested by Perch-Nielsen (1985).

Planktonic Foraminifers

Cenozoic

The Paleogene low-latitude zonation scheme of Berggren and Miller (1988) was used for the Paleocene through lower Eocene interval encountered on the Kerguelen Plateau, although the zonation of Jenkins (1971; see also Jenkins and Srinivasan, 1985) was used in some instances beginning with the lower Eocene. The Austral zonal scheme of Jenkins (1971) and Jenkins and Srinivasan (1985) was found to be quite appropriate for the middle Eocene through Oligocene interval in this region. The Neogene M-zonation scheme developed by Berggren (in Berggren et al., 1983a) for the mid-latitude South Atlantic region was found applicable over the interval of the lower Miocene (Zones M2–M4). No existing zonation was found suitable to use for the middle to late Neogene (0–15 Ma) for this region of the south Indian Ocean–subantarctic region, and a system of assemblage zones was used to delineate biostratigraphic sequence in the middle Miocene to Pleistocene.

A notable occurrence is that of *Neogloboquadrina nympha*, a (predominantly) middle Miocene austral form that may be easily confused with its (predominantly) late Miocene low-latitude homeomorph, *Neogloboquadrina acostaensis. Neogloboquadrina nympha* has been found to have its first appearance datum (FAD) in close association with the base of Anomaly Correlative 5A (around 12.1 Ma).

The assemblages recognized in middle to late Neogene sections (above the *N. nympha* Zone) on the Kerguelen Plateau include (in ascending order):

1. *Globigerina woodi*: an assemblage dominated almost exclusively by *G. woodi* following the local (and temporary) disappearance of *N. nympha*;
2. *Globigerina woodi-Globorotalia scitula*: an assemblage composed almost exclusively of the nominate taxa with rare (or no) *N. nympha* prior to the initial appearance of *N. pachyderma*. This assemblage is similar to that recorded by Tjalsma (1974) from the late Miocene of the Falkland Plateau;
3. *Neogloboquadrina pachyderma*: an assemblage dominated almost exclusively by the nominate taxon following its initial appearance in the late Miocene.

Mesozoic

No planktonic-foraminifer-based zonation of the Cretaceous has been developed for southern middle and high latitudes because Cretaceous sections with either significant planktonic faunas or continuous sequences are virtually nonexistent. For the late Campanian–Maestrichtian, Sites 747, 748, and 750 will be useful in remedying part of the problem. The works of Herb (1974) and Sliter (1976) have proved to be invaluable aids on closely related faunas from the Indian and southern Atlantic oceans, respectively. Herb and Scheibnerova (1977) and McGowran (1977) have been useful integrating papers.

In southern middle and high latitudes, it has been necessary and customary to try to relate to low-latitude zonal schemes; for example, that of Caron (1985).

In applying the zonation of Caron (1985), there are intervals (i.e., late Maestrichtian, early Turonian) when water temperatures were warm and the Tethyan index species were present. However, for the earlier Maestrichtian and Campanian, when Austral and Transitional Faunal Province faunas were prevalent, if correlation with standard zonal schemes has been possible, it has been via the use of secondary indexes.

Generally, in the Cretaceous, the integration of bio- and magnetostratigraphy has not been possible as yet for sites on Leg 120, because in some sections magnetic susceptibility was too low for shipboard analysis.

Benthic Foraminifers

Cenozoic

There is no benthic foraminifer biostratigraphic zonation for the Antarctic region. The Leg 120 data were compared with the zonation for cosmopolitan Cenozoic species of Van Morkhoven et al. (1986), the high-latitude stratigraphy for the Paleogene in the Labrador Sea (Kaminski et al., in press), and the zonation of Tjalsma and Lohmann (1983) for the Paleocene-Eocene of the South Atlantic Ocean. The benthic foraminifer assemblage zonation proposed by Leg 113 scientists for the Maud Rise and the Weddell Sea (Shipboard Scientific Party, 1988a, 1988b) was also used for comparison.

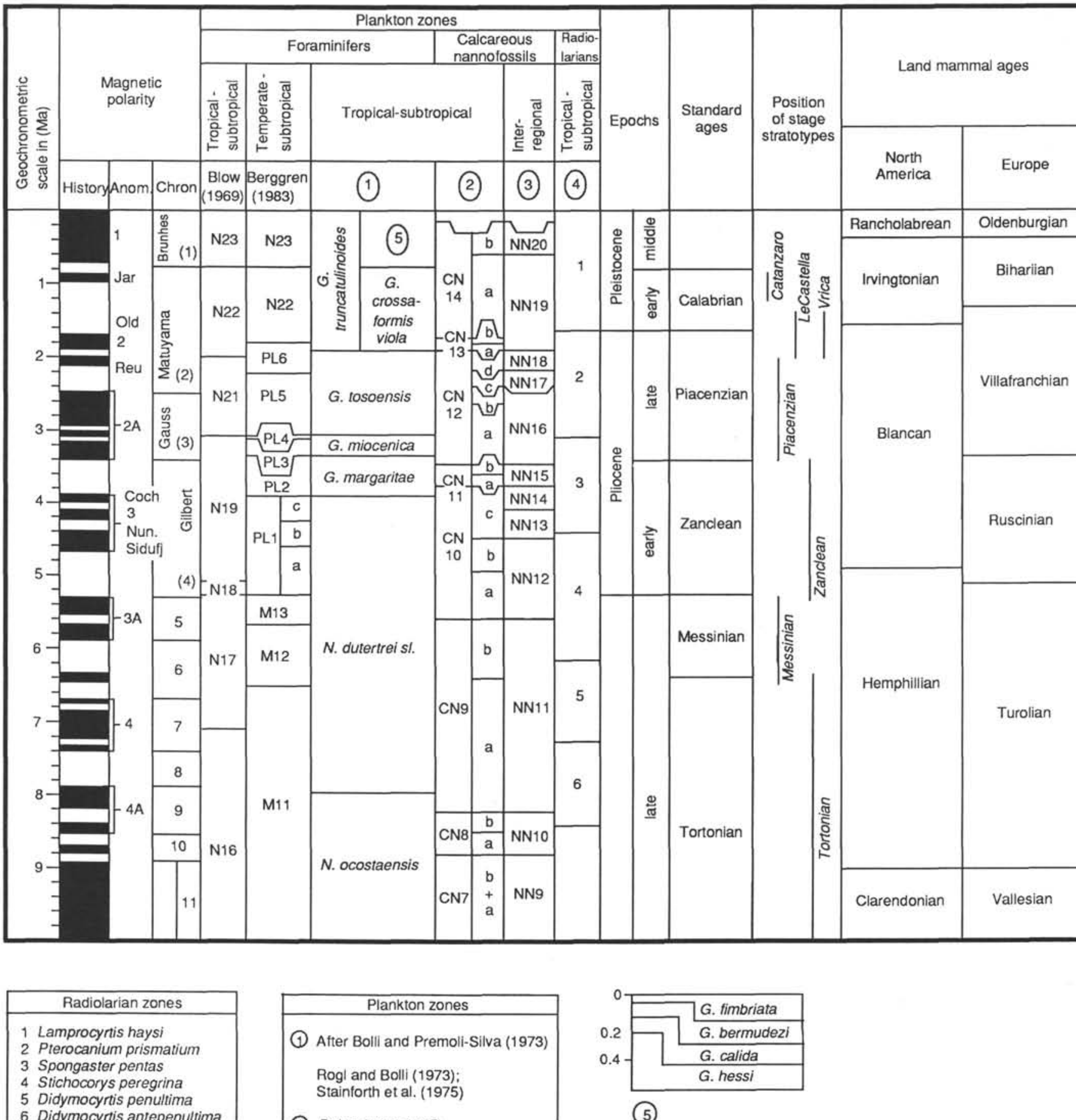


Figure 10. Neogene geochronology (from Berggren et al., 1985a, 1985c).

The depth zonations of Holocene benthic foraminifers were used for paleodepth estimation. The Leg 120 data were compared with the polar and subpolar depth zonation of living benthic foraminifers from the eastern continental margin of the Weddell Sea (Mackensen, unpubl. data), and from the Norwegian/Greenland Sea (Mackensen et al., 1985; Mackensen, 1987). In addition, upper depth limits of cosmopolitan extinct species were used according to the concept of vertical migration of species during time, outlined by Douglas and Woodruff (1981), Tjalsma and Lohmann (1983), and Van Morkhoven et al. (1986).

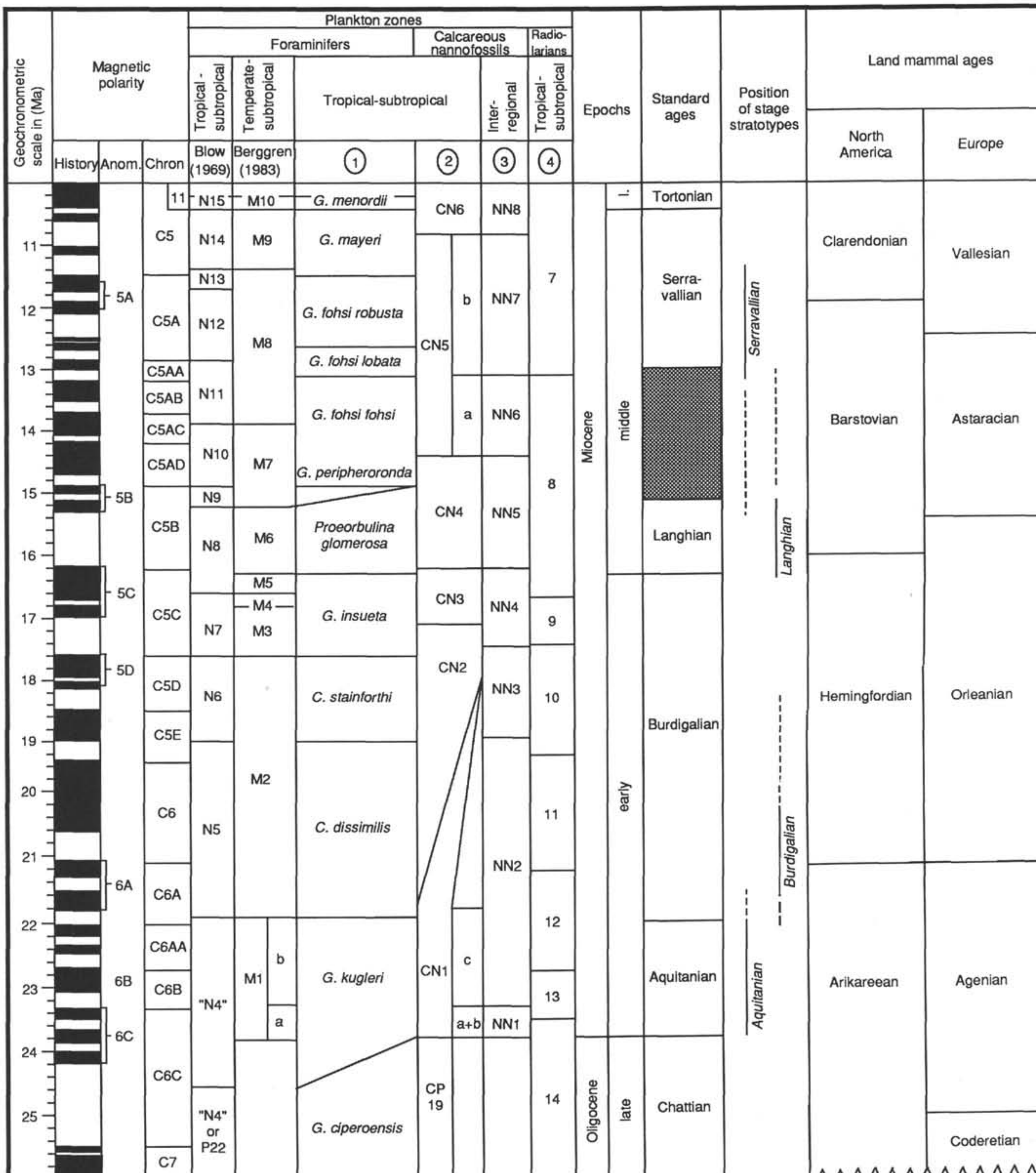


Figure 10 (continued).

Mesozoic

At Leg 120 sites, the New Zealand benthic-based scheme of Webb (1971) was inapplicable; the work of Belford (1960) was found to be more useful for benthic species. No attempt has been made to zone the Cretaceous of Leg 120 on the basis of benthic foraminifers, but the depth zonation of Sliter and Baker (1972) was used for paleodepth reconstruction.

Radiolarians

Radiolarian biostratigraphy in the Antarctic is based on local zonations, as low-latitude marker species usually are absent.

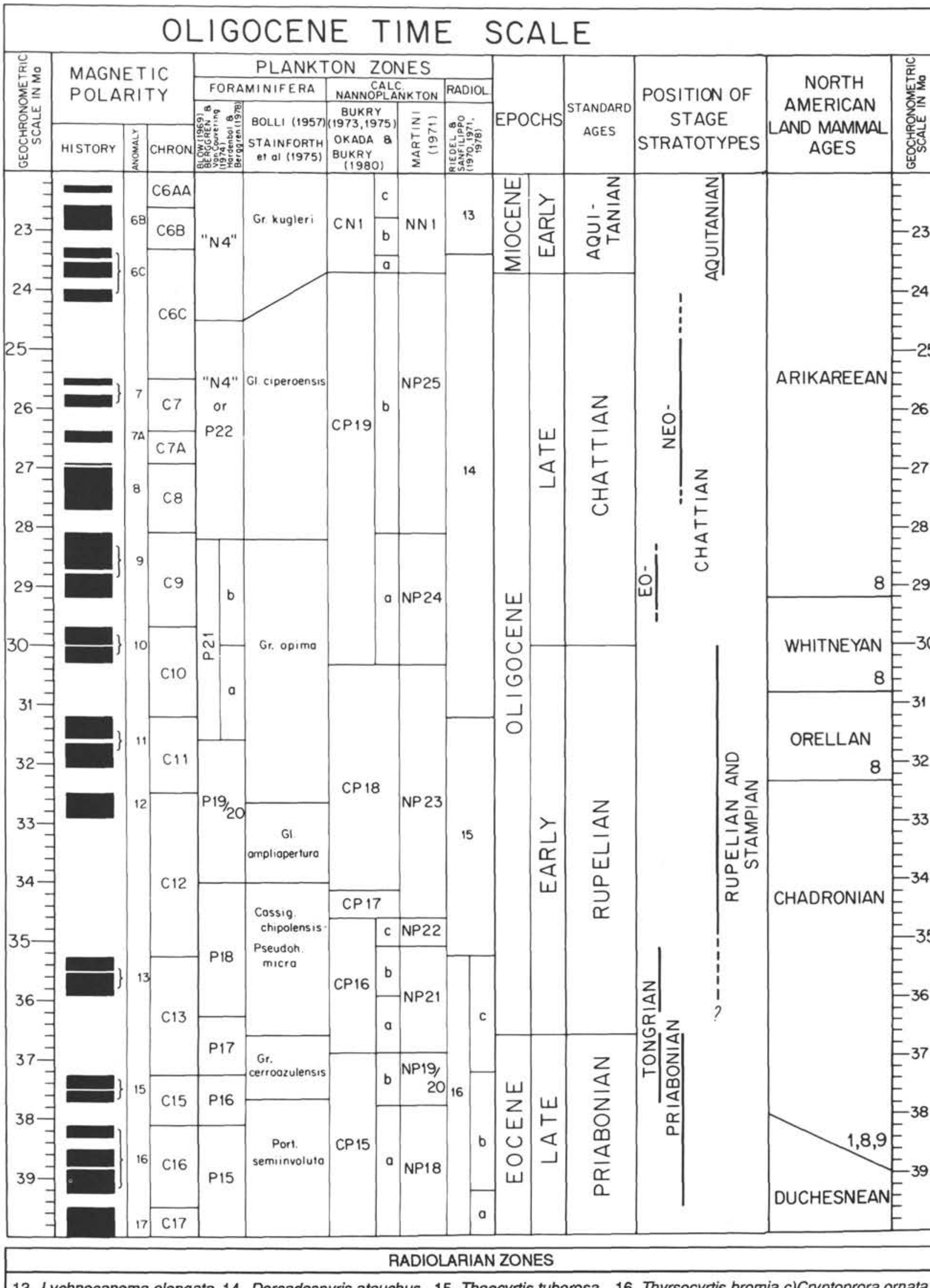


Figure 11. Oligocene geochronology (from Berggren et al., 1985a, 1985c).

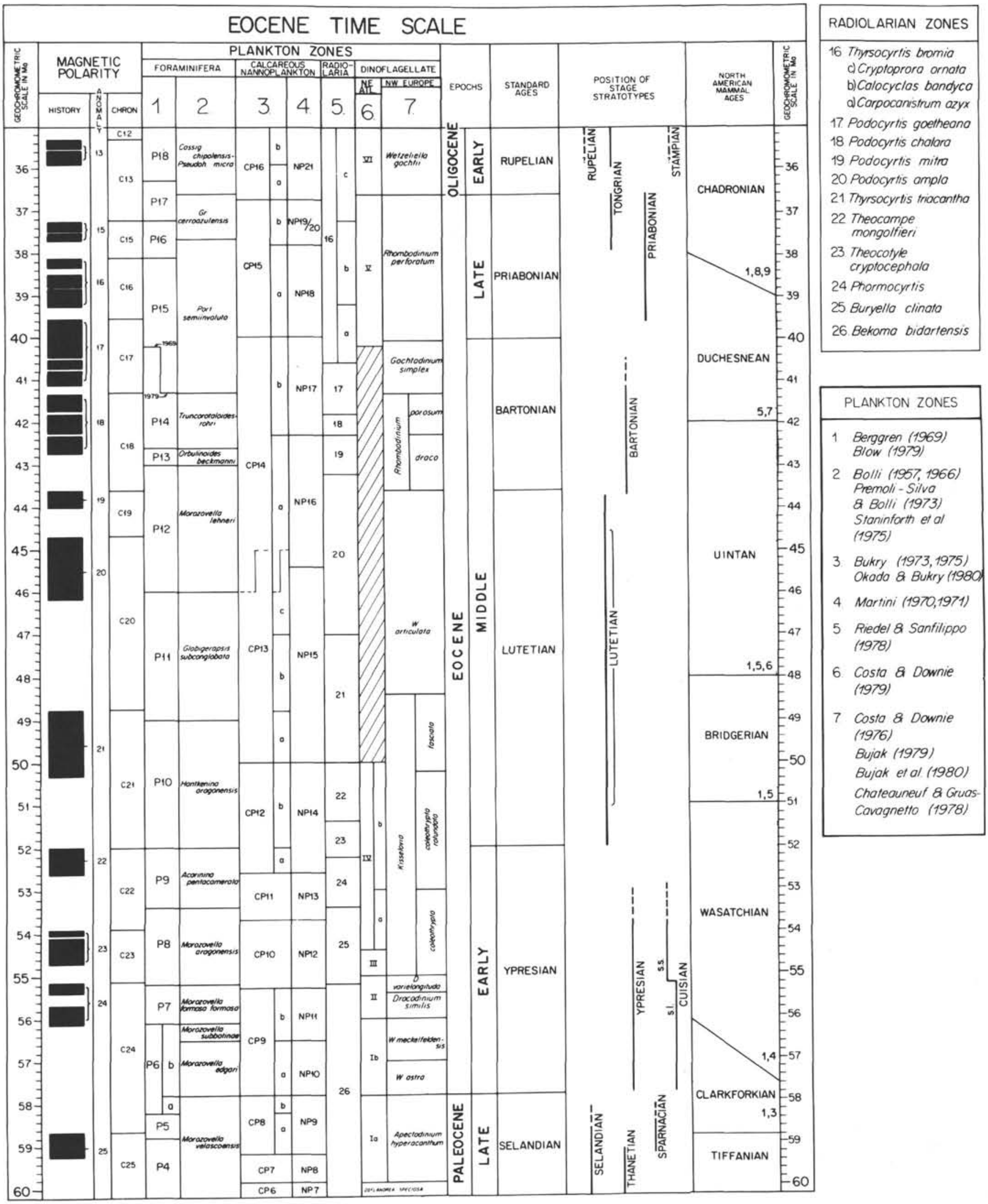


Figure 12. Eocene geochronology (from Aubry et al., 1988).

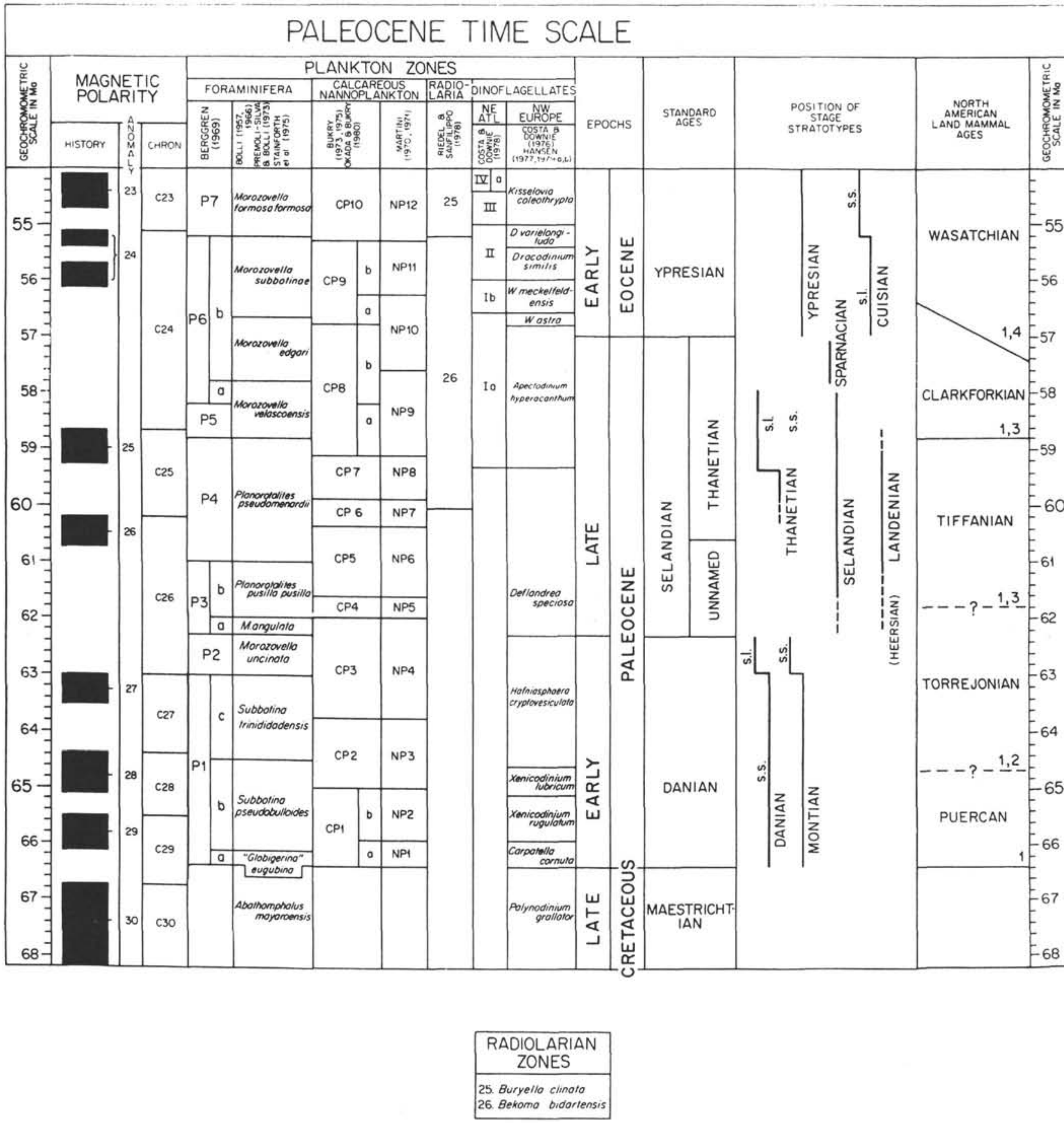


Figure 13. Paleocene geochronology (from Aubry et al., 1988).

Several zonal schemes have been proposed for the Pliocene and Pleistocene. A modified form of Hays's (1965) zonation of the Pliocene-Pleistocene was used during Leg 120. Petrushevskaya (1975) and Chen (1975) both proposed radiolarian zonations for the Miocene. Most subsequent workers have used Chen's Miocene zonation, and a modified form of this zonation was also used on Leg 120.

No Paleogene or Mesozoic radiolarian zonations have been proposed for the Antarctic, and low-latitude zonations cannot be applied, due to the absence of typical zonal marker species.

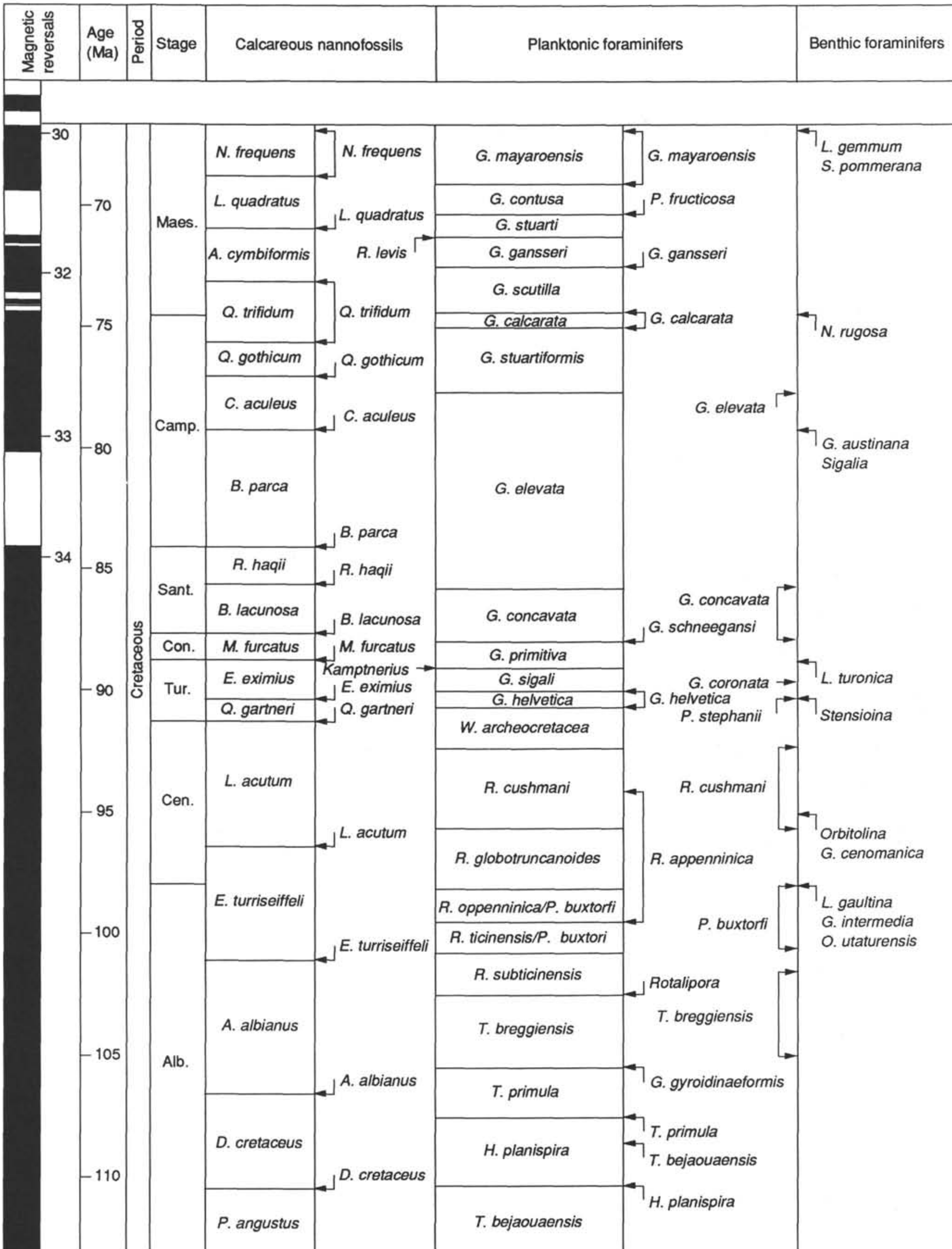


Figure 14. Cretaceous geochronology (from Kent and Gradstein, 1985).

Table 4. Epoch/stage boundary age estimates used for Leg 120.

Boundary	Age (Ma)
Pliocene/Pleistocene	1.6
early/late Pliocene	3.4
Miocene/Pliocene	5.3
middle/late Miocene	10.4
early/middle Miocene	16.3
Oligocene/Miocene	23.7
early/late Oligocene	30.0
Eocene/Oligocene	36.6
early/middle Eocene	52.0
Paleocene/Eocene	[a]57.0
early/late Paleocene	62.2
Cretaceous/Paleogene	66.4
Campanian/Maestrichtian	74.5
Santonian/Campanian	84.0
Coniacian/Santonian	87.5
Turonian/Coniacian	88.5
Cenomanian/Turonian	91.0
Albian/Cenomanian	97.5
Aptian/Albian	113.0

[a] Paleocene/Eocene boundary age estimate was revised from 57.8 Ma (Berggren et al., 1985a, 1985b, 1985c) to 57.0 Ma in Aubry et al. (1988).

Table 5. Age estimates for the magnetic polarity intervals.

Normal polarity interval (Ma)	Anomaly	Normal polarity interval (Ma)	Anomaly
0–0.73	1	24.04–24.21	6C
0.91–0.98		25.50–25.60	7
1.66–1.88	2	25.67–25.97	7
2.47–2.92	2A	26.38–26.56	7A
2.99–3.08	2A	26.86–26.93	8
3.18–3.40	2A	27.01–27.74	9
3.88–3.97	3	28.15–28.74	9
4.10–4.24	3	28.80–29.21	9
4.40–4.47	3	29.73–30.03	10
4.57–4.77	3	30.09–30.33	10
5.35–5.53	3A	31.23–31.58	11
5.68–5.89	3A	31.64–32.06	11
6.37–6.50		32.46–32.90	12
6.70–6.78	4	35.29–35.47	13
6.85–7.28	4	35.54–35.87	13
7.35–7.41	4	37.24–37.46	15
7.90–8.21	4A	37.48–37.68	15
8.41–8.50	4A	38.10–38.34	16
8.71–8.80		38.50–38.79	16
8.92–10.42	5	38.83–39.24	16
10.54–10.59		39.53–40.43	17
11.03–11.09		40.50–40.70	17
11.55–11.73	5A	40.77–41.11	17
11.86–12.12	5A	41.29–41.73	18
12.46–12.49		41.80–42.23	18
12.58–12.62		42.30–42.73	18
12.83–13.01	5AA	43.60–44.06	19
13.20–13.46	5AB	44.66–46.17	20
13.69–14.08	5AC	48.75–50.34	21
14.20–14.66	5AD	51.95–52.62	22
14.87–14.96	5B	53.88–54.03	23
15.13–15.27	5B	54.09–54.70	23
16.22–16.52	5C	55.14–55.37	24
16.56–16.73	5C	55.66–56.14	24
16.80–16.98	5C	58.64–59.24	25
17.57–17.90	5D	60.21–60.75	26
18.12–18.14	5D	63.03–63.54	27
18.56–19.09	5E	64.29–65.12	28
19.35–20.45	6	66.50–66.17	29
20.88–21.16	6A	66.74–68.42	30
21.38–21.71	6A	68.52–69.40	31
21.90–22.06	6AA	71.37–71.65	32
22.25–22.35	6AA	71.91–73.55	32
22.57–22.97	6B	73.96–74.01	
23.27–23.44	6C	74.30–80.17	33
23.55–23.79	6C	84.00–118.00	34

Secondary marker species are present in the Antarctic Paleogene and Cretaceous, which permits approximate age assignments to be made. Comparisons between Leg 120 assemblages and radiolarian assemblages recovered during Leg 28 were also used to determine approximate ages during these time intervals. The details of the Neogene radiolarian biostratigraphy used on Leg 120 are discussed below.

For Leg 120, a two-tiered zonal scheme was employed, with zones and subzones. Zonal boundaries are marked by radiolarian biostratigraphic events that are well known and thought to be most reliable, while subzone boundaries are marked by radiolarian events that are either not widely tested or are known to be less reliable. The datum levels used are summarized in Table 6. The zonation for the middle Miocene (from 14 Ma) to Holocene time interval, appears in Figure 15, while Figure 16 gives ranges of marker species for the last 6 m.y. To facilitate comparison between Leg 119 and 120 sites, Figure 17 compares the Leg 120 radiolarian zonation to the Leg 119 radiolarian zonation used by Caulet (in Barron, Larsen, et al., 1989).

Pleistocene

Hays (1965) recognized two radiolarian datum levels in the Antarctic Pleistocene: the last appearance datum (LAD) of *Stylatractus universus*, and the simultaneous LADs of *Pterocanium trilobum* (since renamed to *P. charybdeum trilobum* by Lazarus et al., 1985) and *Saturnalis planetes* (referred to as *S. circularis* by subsequent workers). These events form the base of the Pleistocene Omega and Psi Zones. However, all three species are often quite rare, and thus these zones are usually difficult to recognize.

Caulet (1979, 1985) proposed a different Neogene radiolarian zonation for the Antarctic and introduced the LAD of *Phormostichoartus pitomorphus* to define the base of his Pleistocene NR2 Zone. This radiolarian event, however, was not seen in Leg 120 sections. Thus, at this time, Hays's Pleistocene zonation is retained, although the LAD of *S. universus* appears to be unreliable in the sections examined so far. The last occurrence of *Antarctissa cylindrica* appears to be a reliable early Pleistocene event, although it has not yet been calibrated to magnetostratigraphy.

Pliocene

Hays (1965) divided the Pliocene into four zones (Chi, Phi, Upsilon, and Tau), and these zones are used in the Leg 120 zonation. The radiolarian datum levels used to characterize the boundaries of these zones are generally reliable throughout the Antarctic, although the base of the Upsilon Zone defined by the evolutionary FAD of *Helotholus vema*, can sometimes be hard to recognize. Other biostratigraphic markers for the Pliocene have been proposed by Weaver (1983), Keany (1979), and Caulet (1979, 1985).

Keany (1979) subdivided Hays's (1965) Tau Zone into four new zones. Only one of his markers is used (as a subzonal marker) in the Leg 120 zonation. The last common occurrence (LCO) of *Lychnocanium grande* is used to divide the Tau Zone into upper and lower intervals and corresponds (at least approximately) to Keany's "extinction of *L. grande rugosum*." A few individuals of this species are typically seen well above its LCO. *Lychnocanium grande* is an unusually robust form that may be easily reworked into younger sediments, and thus its LCO is used instead of its LAD, although it is not known whether the difference between *L. grande*'s LCO and LAD is solely due to reworking or, instead, represents a true terminal decline in the living species abundance prior to its extinction.

Table 6. Radiolarian biostratigraphic datums used on Leg 120.

Age (Ma)	Event	Species	Comment
0.4	Top	*Stylatractus universus*	Often very rare
0.8	Top	*Pterocanium charybdeum trilobum*	Often rare
1.2	Top	*Antarctissa cylindrica*	Or LCO (not calibrated)
1.6	Top	*Cycladophora pliocenica*	Top Olduvai, Hayes, new name
1.9	Top	*Eucyrtidium calvertense*	base Olduvai, Hays
2.4	Top	*Helotholus vema*	Hays
2.4	Top	*Desmospyris spongiosa*	Hays
2.6	Bottom	*Cycladophora davisiana*	Hays (unpubl. data)
3.2	Top	*Prunopyle titan*	Site 514, interpreted without hiatus
4.2	[a]Bottom	*Helotholus vema*	Site 514, interpreted without hiatus; Keany, 1979; evolutionary transition occasionally hard to pick (Leg 113)
4.2	Top	*Triceraspyris coronata*	Leg 71; not seen on Leg 113
4.3	[a]Bottom	*Desmospyris spongiosa*	Weaver, Leg 71; evolutionary transition occasionally hard to pick
4.4	LCO	*Lychnocanium grande*	Top Gilbert C event, Keany (1979); Lazarus (unpubl. data)
4.5	Top	*Stichocorys* sp. cf. *S. peregrina*	Warmer-water species; not seen on Leg 113 (diachronous?)
5.4	Top	*Cycladophora spongothorax*	Calibration is questionable; new name for *T. b. spongothorax* Chen
6.0	Bottom	*Stichocorys* sp. cf. *S. peregrina*	Warmer-water species; not seen on Leg 113 (diachronous?)
9.0	[a]Bottom	multishelled *Collosphaera* sp.	Age calibrated at Sites 689 and 690
9.7	Bottom	*Eucyrtidium pseudoinflatum*	Age calibrated at Sites 689 and 690
10.4	Top	*Actinomma golownini*	Correct name for *A. tanyacantha* Chen
12.3	Bottom	*Cycladophora spongothorax*	Age calibrated at Sites 689 and 690
13.4	Bottom	*Actinomma golownini*	Age calibrated at Sites 689 and 690
23.0	Bottom	*Cyrtocapsella tetrapera*	Age from Leg 85, recalibrated to Berggren time scale

[a] Evolutionary bottom.

Keany's other two stratigraphic markers for this interval (the LADs of *Anthocyrtidium ehrenbergi* and "*Eucyrtidium* spp.") represent the local last occurrences of warmer water species that persist into younger time intervals outside of the Antarctic. These disappearances are probably diachronous with latitude and are thus not used in the Leg 120 zonation, although the ranges of these two species were recorded.

Caulet (1979, 1985, and in Barron, Larsen, et al., 1989) and Weaver (1983) also subdivided the Tau Zone, by means of the LAD of *Stichocorys peregrina* and the FAD of *Desmospyris spongiosa* as markers. Caulet and Weaver's "*Stichocorys peregrina*" is the same species as Keany's "*Eucyrtidium* spp." (based on photographs by Weaver, Caulet, and Keany), and thus the preceding comments about the stratigraphy of this form apply (this species is referred to as *Stichocorys* sp. cf. *S. peregrina* on Leg 120).

The first appearance of *D. spongiosa* is an evolutionary transition and often is very difficult to decipher. Although the base of the range of this species was noted in the Leg 120 sites, the FAD of *D. spongiosa* was not formally used as a stratigraphic marker.

In the earlier Pliocene, Caulet and Weaver have used the LAD of *Prunopyle titan;* Caulet used it to mark the boundary between his NR5 and NR6 Zones. This datum is seen throughout the Antarctic, occurring in the lower part of the Gauss (Hays and Opdyke, 1967; Weaver, 1983) and is used on Leg 120 as a subzonal marker within the Upsilon Zone. The species is, in many cases, rare in the upper part of its range, however.

Two other biostratigraphic events are used within the younger part of the Pliocene. The LAD of *Cycladophora pliocenica* is used as a subzonal marker within the Chi Zone. This LAD, calibrated by Hays and Opdyke (1967), appears to be a reliable marker throughout the Southern Ocean (Hays and Opdyke, 1967; Caulet, 1979, 1985, and in Barron, Larsen, et al., 1989; Lazarus, in Barker, Kennett, et al., 1988). This species is the same as *Clathrocyclas bicornis* Hays, 1965; the present name *Cycladophora pliocenica* was introduced by Lombari and Lazarus (1988) as a replacement name required by their taxonomic revision of Neogene cycladophorid species. The FAD of *Cycladophora davisiana* is also used as a subzonal marker (within the Upsilon Zone). The age of this event was provided by Hays (J. D. Hays, pers. comm., 1987) and is based on a global study of this species' evolution.

Miocene

A portion of Chen's (1975) zonation of the Miocene was used, with modification, in middle and upper Miocene sediments. The *Cycladophora spongothorax* Zone, defined by the total range of *C. spongothorax*, is subdivided into three subzones. The lower/middle subzone boundary is defined by the LAD of *Actinomma golownini*, while the middle/upper boundary is defined by the FAD of *Eucyrtidium pseudoinflatum*. The middle *C. spongothorax* Subzone is rather short and requires closely spaced samples and/or a high sedimentation rate to be recognized (Lazarus, in Barker, Kennett, et al., 1988). It was observed in shipboard sampling only at Site 751, where the sedimentation rate in this time interval is ~20 m/m.y. *Cycladophora spongothorax* is the same species as *Theocalyptra bicornis spongothorax* Chen (1975), the new name being introduced by Lombari and Lazarus (1988).

Caulet's Leg 119 NR10 Zone is similar to the *C. spongothorax* Zone of Leg 120, but his upper boundary for the NR10 Zone (the FAD of "*S. peregrina*") is a significantly older event than the LAD of *C. spongothorax*, and thus the NR10 Zone is somewhat shorter than the *C. spongothorax* Zone. The LAD of *C. spongothorax* occurs within Magnetochron 5 (Lazarus, unpubl. data; see also magnetostratigraphic results in individual site chapters, this volume). The age of the other datum

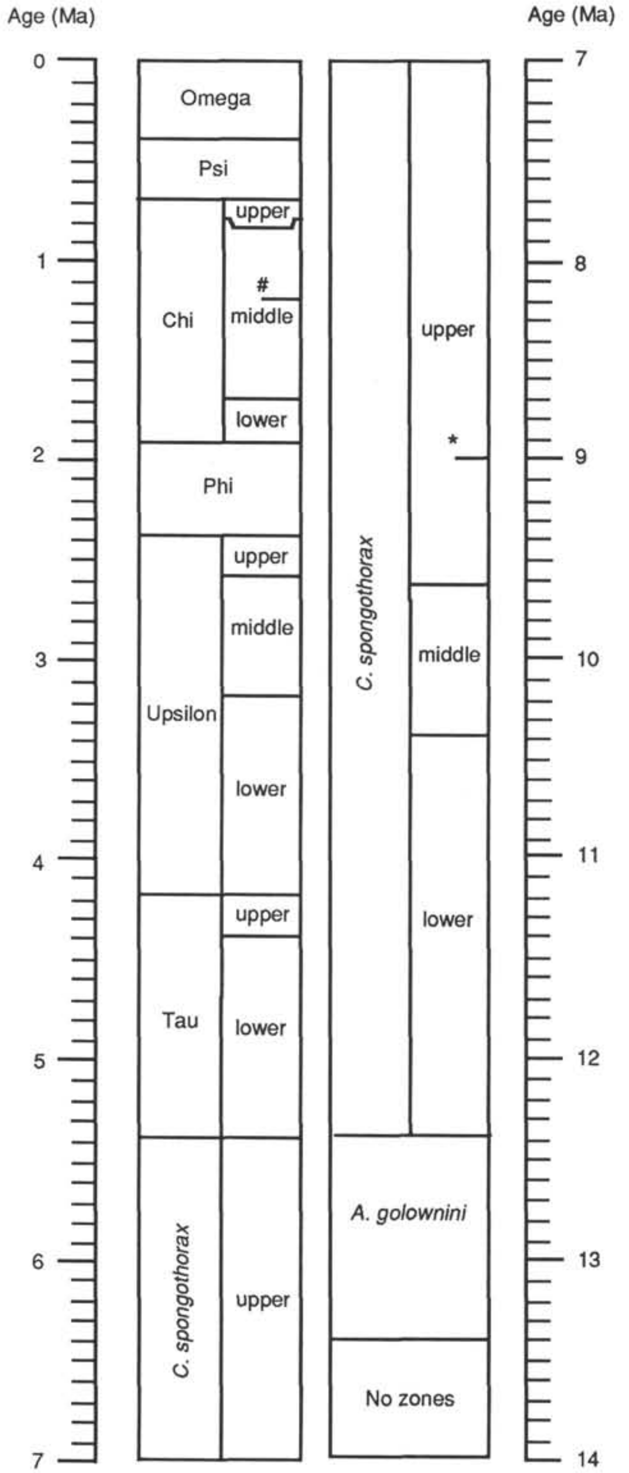


Figure 15. Radiolarian zonation for the time interval 14 Ma–Holocene used for Leg 120. # = LAD *A. cylindrica* and * = FAD multishell *Collosphaera* sp.

events (Table 6) is based on the interpretation of the magnetostratigraphy obtained at Sites 689 and 690, Leg 113.

The *Actinomma golownini* Zone (= Caulet's Zone NR11) is the oldest zone defined in the Leg 120 radiolarian stratigraphy. Its top coincides with the base of the *C. spongothorax* Zone, while its base is defined by the FAD of *A. golownini*. *Actinomma golownini* Petrushevskaya is the senior synonym of *A. tanyacantha* Chen. The age of this datum is based on Leg 113 magnetic stratigraphy. Older Miocene sediments are not formally zoned.

Chen's *Spongomelissa dilli* and *Calocyclas disparidens* Zones are generally unrecognizable in Antarctic sediments, as the nominate species are usually very rare, or more typically, completely absent. This is due at least in part to the typically poor preservation of lower Miocene Antarctic radiolarians. Other species used in Chen's (1975) zonation, such as *Eucyrtidium punctatum*, "*Lophocyrtis golli*," and "*Lophocyrtis regipileus*" (renamed by Lombari and Lazarus [1988] as *Cycladophora golli golli* and *C. g. regipileus*) occur in early Miocene sediments recovered by Leg 120, although their ranges are affected to some extent by the poor preservation in the earliest Miocene sediments (e.g., Site 747). Other species that are less susceptible to dissolution may need to be used in creating a workable early Miocene radiolarian zonation.

Diatoms

Cenozoic

Diatom biostratigraphic studies during Leg 120 followed the zonal schemes of Ciesielski (1983) for the Pliocene and Pleistocene; Weaver and Gombos (1981) for the Miocene; and Gombos and Ciesielski (1983) for the late Eocene to early Miocene. In some cases, these zonations could not be successfully applied, and several zones were revised or replaced by other zones to suit the diatom assemblages recovered on the Kerguelen Plateau better. Additional revisions to these zones are based on data provided by Leg 113 and 119 diatomists R. Gersonde, J. Barron, and J. Baldauf.

Shipboard Procedures

Calcareous Nannofossils

The relative abundance of calcareous nannofossils in the fine fraction of each sample is given in the core description forms ("barrel sheets"). These visual relative abundance estimates are given a letter code with the following meaning: A = abundant (>75% of the fine fraction); C = common (75%–25%); F = few (5%–25 %); R = rare (<5%).

Preservational observations refer to the average degree of overgrowth and/or etching that calcareous nannofossils show in an assemblage. These visual estimates are given a letter code with the following meaning: G = good (slight overgrowth and/or etching; all calcareous nannofossils can be taxonomically differentiated); M = moderate (overgrowth and/or etching have somewhat altered the structure of the calcareous nannofossil; most specimens can be taxonomically identified); P = poor (strong overgrowth and/or etching resulting in highly birefringent structureless particles or high fragmentation; most calcareous nannofossils cannot be taxonomically differentiated).

Foraminifers

The abundance of Cenozoic foraminifers is based on visual estimates of the >150-μm size fraction in several fields of view. Siliceous microfossils and fine detritus usually constitute the finer size fraction, rendering abundance estimates of smaller foraminifers difficult (at least in the middle and late Neogene). For Cretaceous samples, the >125-μm fraction was studied. The scale of abundance is as follows: A = abundant (>40%); C = common (15%–40%); F = few (1%–15%); and R = rare (<1%).

The same scheme is used to express the abundance of particular species as a percentage of the total population. The degree of preservation is estimated as follows: G = good (no evidence

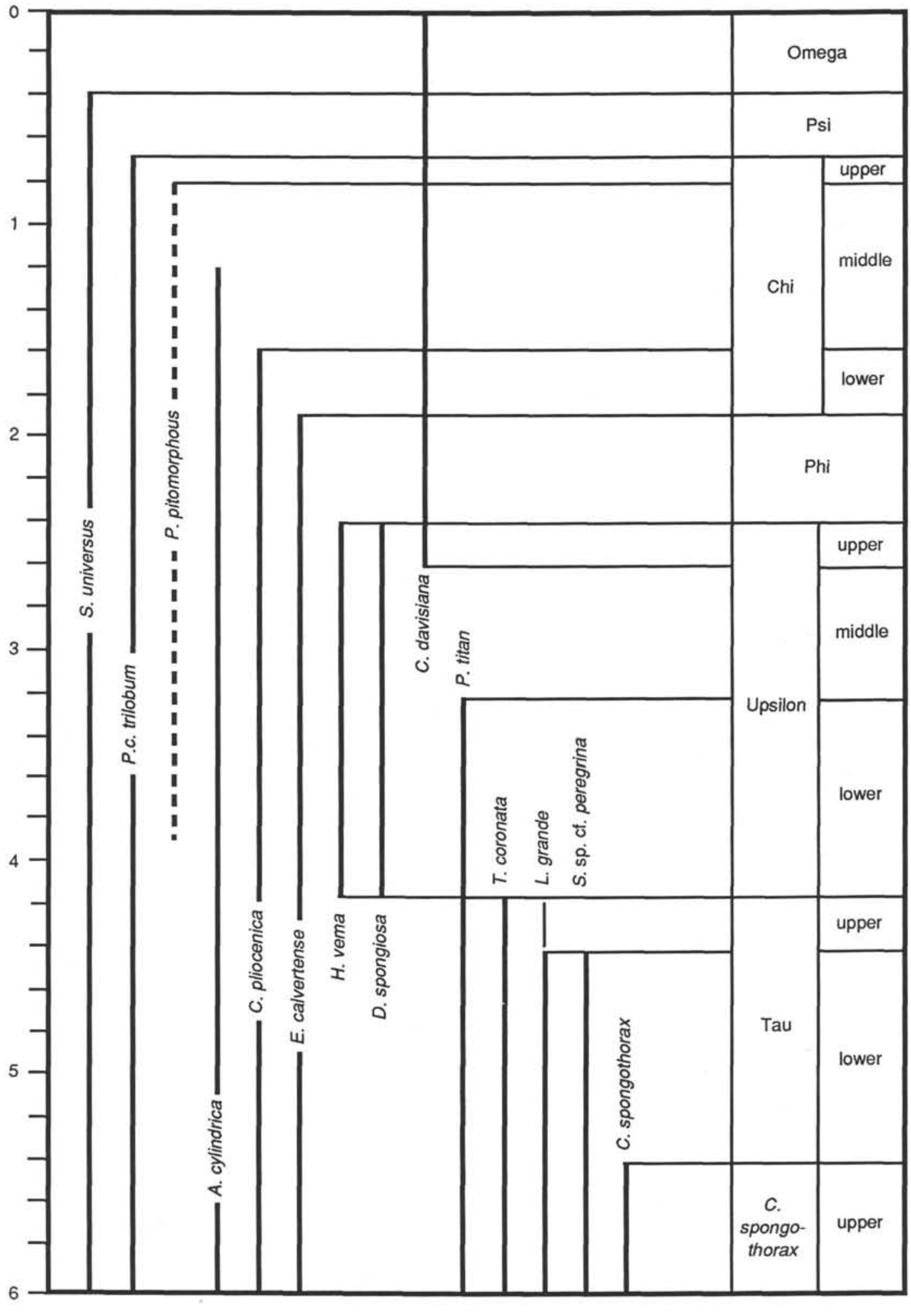


Figure 16. Stratigraphic ranges of radiolarian species used as zonal and subzonal markers in Leg 120 for the 6 Ma–Holocene time interval. Heavy lines show continuous range, whereas dashed lines indicate species is rare or absent in that time interval. Age in Ma given on left of figure. Additional information on each datum and a discussion of earlier Neogene datums are given in the text.

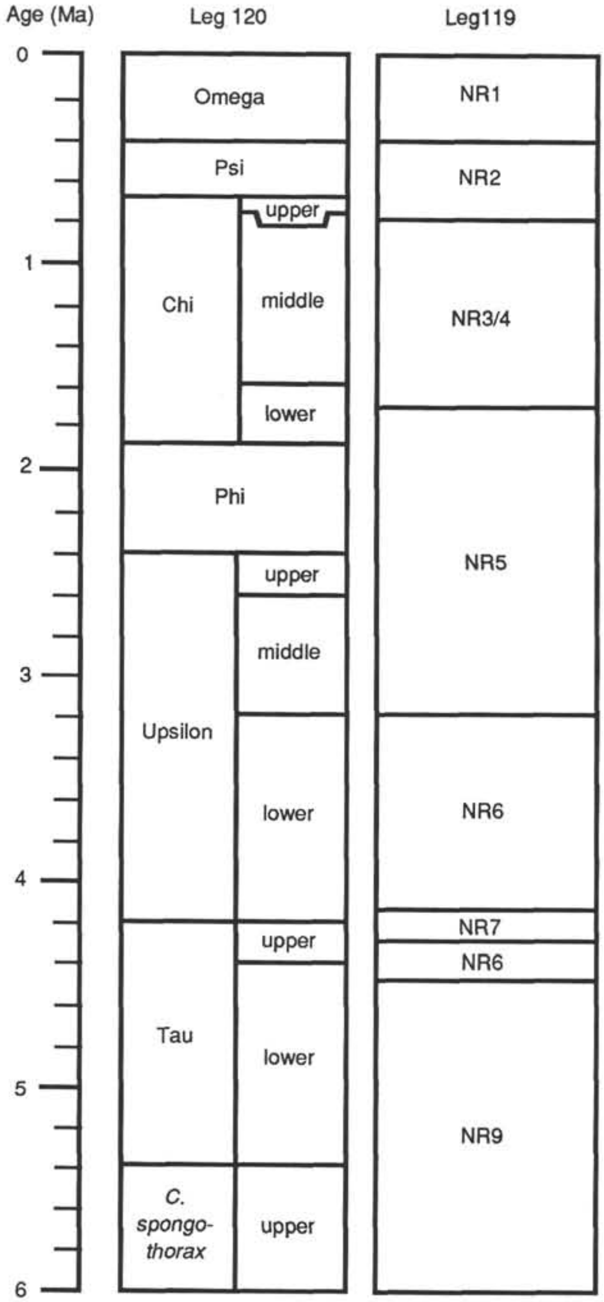


Figure 17. Comparison between radiolarian zonations used for the 6 Ma–Holocene time interval by Legs 119 and 120.

of surface abrasion or dissolution); M = moderate (dissolution, calcite overgrowth, or fragmentation common but minor); P = poor (tests highly fragmented; identification difficult).

Radiolarians

Each slide was typically examined in its entirety for radiolarians (i.e., ~20,000–40,000 specimens), although in a few slides only a few tracks at 10X (approximately one fourth the area of the slide) were examined. Radiolarian abundance in the sediment is only a very rough estimate, based on the fraction of sample retained in the sieve after preparation and on the fraction of residue that is actually radiolarian. The abundance of individual species is recorded relative to the fraction of the total assemblage: *abundant*, ~5% or more; *common*, 1%–5%; *few*, 0.2%–1%; *rare*, two or more specimens per slide; and *very rare*, a single occurrence.

Preservation estimates were based on the following criteria: *good*, most specimens complete or nearly so, thin spines and delicate shells common; *moderate*, most specimens broken but identifiable, diversity still high, although lightly silicified specimens are rare; and *poor*, low-diversity assemblages dominated by robust shells and unidentifiable fragments, typically with abundant orosphaerid spines and sponge spicules.

Sample Preparation

Calcareous Nannofossils

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

Planktonic and Benthic Foraminifers

Samples were prepared by washing through a 63-μm-mesh sieve and drying under a heat lamp or in an oven at 50°C. They were then picked for foraminifers and other microfossil constituents. Somewhat consolidated sediments were first soaked in Calgon and/or kerosene before being washed and dried. The fraction >125 μm was investigated for its benthic foraminifer content. Aboard ship about 100 specimens per sample were counted and mounted on cardboard slides.

Radiolarians

Samples were prepared from 10–20 cm^3 of sediment, with 30% H_2O_2, 10% HCl, and ~1% Calgon solutions, and a shipboard strewn slide made from the >63-μm residue. Additional random-strewn slides were prepared onshore to locate biostratigraphic events more accurately within cores.

Diatoms, Silicoflagellates, and Other Siliceous Microfossils (Except Radiolarians)

For intervals enriched in biogenic silica, samples were examined largely on smear slides. In intervals rich in carbonate and poor in silica, a small volume of sediment was placed in a centrifuge tube and covered with a small volume of 10% HCl. After the removal of all of the carbonate, the sample was repeatedly washed with distilled water to remove the acid. Slides were then made from this residue. In cases where only traces of diatoms were indicated after this acid treatment, a larger volume of sediment was treated in a similar fashion and then sieved through a 38-μm-mesh screen to concentrate the larger (identifiable) diatoms and silicoflagellates. This technique resulted in the recovery of useful biostratigraphic information from virtually barren samples.

PALEOMAGNETISM

Procedures

The three-axis, pass-through cryogenic magnetometer worked very well during Leg 120. Natural remanent magnetizations (NRM) of all undisturbed archive halves were measured at 5-, 10-, or 15-cm sample spacing. Following the NRM measurement, each sedimentary section of the core was demagnetized with the three-axis alternating field (AF) unit. The maximum available peak alternating field of 9 mT proved most suitable for removing present field magnetic overprints and for revealing more details of the magnetostratigraphic record. Undisturbed hydraulic piston cores with intensities of magnetization above 0.5 mA/m had usually steep (60°) positive or negative inclinations that were interpreted as reversed or normal polarity intervals, respectively. The noise level of the cryogenic magnetometer for split halves of the core was about 0.1 mA/m or less, depending on the movement of the ship.

Cubic Perspex sampling boxes (7 cm^3) were used to sample poorly lithified sediments. Two sample cubes were taken on average from each section of the working halves of soft sediments. Two cylindrical 1-in. minicores per section were drilled from lithified sediments and basalts. Discrete samples of sediments, which were too strongly magnetized for the SQUID (superconducting quantum interference detector) magnetometer, and basalts were measured with the Molspin fluxgate magnetometer. The NRMs of all collected basalt samples were measured on board the ship. About one quarter of these basalts were stepwise AF or thermally demagnetized with the Schonstedt demagnetizers to obtain their characteristic magnetizations.

In addition, we measured and AF demagnetized basalt samples prior to their being ground for XRD studies. Both AF and thermal demagnetizers worked well during this cruise and gave reliable results. In total, we obtained 121 basalt samples from 20 different flows, which might be sufficient for a paleolatitude determination of the Southern Kerguelen Plateau. Initial magnetic susceptibilities of the basalt samples and one K/T boundary section were measured with the Bartington susceptibility bridge.

All cores are unoriented with respect to azimuth, and therefore the declinations are arbitrary. Unoriented cores were sufficient for magnetostratigraphy because of the steep inclinations at high southern latitudes. Despite the expected random declinations between cores, we found sometimes continuous declinations around 0° over several cores. These relatively constant declinations could be due to a secondary magnetization, acquired in the ambient field of the laboratory.

Measurements on working halves, which had been stored with the split surface up like the archive halves, strongly suggest remagnetization on board the ship in the present field. In the case of archive halves with the horizontal component of magnetization in the $+x$ direction (i.e., declination = 0° in ODP convention), in addition to a strong $+z$ or $-z$ component, the working halves also had a horizontal component in the $+x$ direction when they were treated as an archive half for measurement on the cryogenic magnetometer.

This means that the horizontal components of magnetization (in the x direction) in the working and archive halves differ by approximately 180°. The presence of antiparallel components of magnetization in the azimuthal plane of the core can only be explained by acquisition after splitting. The two halves of the core usually remained for several hours with the split surfaces pointing up in the steep upward-dipping laboratory field of approximately 0.08 mT. During this storage period, the physical properties of the two core halves (e.g., porosity, bulk density, and water content) equilibrate toward new laboratory values, since the *in-situ* pressure is removed (see "Physical Properties" section, this chapter).

It seems quite feasible that a fraction of the magnetic grains becomes realigned in the present field, leading to a "post-splitting remanent magnetization" (PSRM) as the bulk of the sediment grains become rearranged physically. This rather speculative model for PSRM and the possible contribution from viscous remanent magnetization remain to be investigated in more detail in future experiments.

Bulk Magnetic Susceptibility

Bulk susceptibility measurements were made on selected core sections. Measurements were made with a Bartington magnetic susceptibility meter. The half- and whole-round cores were passed through the sensor loop, and measurements were taken at 5-cm intervals; the cores were exposed to a 1-Oe alternating field. Magnetic susceptibility (χ) is reported in cgs units.

ORGANIC GEOCHEMISTRY

The organic geochemistry program for Leg 120 included: (1) analyses of hydrocarbon gases, (2) determination of total organic carbon, and (3) characterization of the organic matter by Rock-Eval pyrolysis.

Hydrocarbon Gases

For safety considerations, concentrations of C_1 (methane) and C_2 (ethane) hydrocarbon gases were monitored at 30-m intervals or whenever gas pockets were encountered. Gases were extracted either from bulk sediments with headspace sampling techniques (Kvenvolden and Barnard, 1983; Kvenvolden and McDonald; 1985) or directly from gas pockets through the core liner by vacutainer sampling. Each headspace analysis required taking a 5-cm-long, whole-round section of core, a 5-cm^3 portion of which was placed in a glass container sealed with septa and a metal crimp and then heated in an oil bath to 70°C. All analyses were conducted on a Carle AGC Series 1000/Model 211.

Inorganic and Organic Carbon

Percent carbonate and organic carbon analyses were carried out on freeze-dried bulk samples with a Coulometrics 5010 Coulometer coupled with the 5030 Carbonate Carbon and 5020 Total Carbon apparatus. Measurements were made on samples taken from each core catcher as well as on samples used for physical properties measurements. The wt% $CaCO_3$ was determined by reacting 20–50 mg of ground sample in a 2N HCl solution. The quantity of CO_2 liberated was measured by titration in a monoethanolamine solution with a colorimetric indicator. The change in transmittance was monitored by a photodetection cell.

Total carbon measurements were made by combustion of bulk samples at 950°C in an oxygen atmosphere converting both organic and inorganic forms of carbon to CO_2, which was quantitatively analyzed by the coulometrics titration method outlined above. The total organic carbon contents were then determined by subtracting the values for carbonate carbon from the total carbon content. The standard deviation for replicate analyses was less than 1% for carbonate carbon and from 5% to 10% for total organic carbon measurements.

Rock-Eval

The maturity and source character of sedimentary organic carbon was determined with the Rock-Eval pyrolysis techniques outlined by Espitalie et al. (1977). During programmed pyrolysis of 100-mg ground bulk samples from 300°C to 550°C, the following parameters were measured: the amount of free hydrocarbons released (S_1 = mg desorbed organic materials/g rock); hydrocarbon released from the cracking of kerogen (S_2 = mg pyrolitic organic materials/g rock); total CO_2 released from organic matter during pyrolysis (S_3 = mg CO_2/g rock); and the temperature of the maximum hydrocarbon released during pyrolysis (T_{max}).

From these values hydrogen, oxygen, and productivity indexes were established. The hydrogen index (HI = $100 \times S_2$/TOC) represents the ratio of pyrolyzable organic matter or "hydrocarbons" (S_2) to total organic carbon (TOC). The oxygen index (OI = $100 \times S_3$/TOC) represents the ratio of carbon dioxide released (S_3) to total organic carbon. The productivity index (PI = $S_1/[S_1 + S_2]$) represents the relative proportion of desorbable organics.

INORGANIC GEOCHEMISTRY

Interstitial Waters

The routine shipboard interstitial water sampling program carried out during Leg 120 used 5–10 cm whole-round mini-cores from every third core (about 30 m) for interstitial water analyses. Samples were squeezed for interstitial waters with a stainless steel press at room temperature (Manheim and Sayles, 1974). Subsequent to filtration through 0.45-μm nucleopore filters, the interstitial water samples were analyzed for total dissolved solids (salinity), pH, alkalinity, calcium, magnesium, chlorinity, sulfate, and silica with the methods outlined below.

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

PHYSICAL PROPERTIES

Shipboard determinations of physical properties are the basis for geotechnical stratigraphy studies and provide an important link among the geophysical site survey data, downhole logging results, and the geologic record obtained by coring. Cores are generally sampled with sufficient density to encompass the range of lithologic units recovered from each hole. The properties determined include wet- and dry-bulk density, grain density, compressional wave velocity, thermal conductivity, water content, porosity, and undrained shear strength.

In all discrete measurements used in physical properties determinations, an effort is made to analyze only undisturbed sediment and rock. Boyce (1976) has described in detail the techniques employed in determinations of index properties and compressional wave velocity. Boyce (1977) and Lee (1984) have discussed the determination of undrained shear strength. The two techniques used in the shipboard determination of thermal conductivity are those of Von Herzen and Maxwell (1959) and Vacquier (1985). A synopsis of the methods employed during Leg 120, in the same sequence as the cores are analyzed in the shipboard laboratory, follows.

Gamma Ray Attenuation Porosity Evaluator (GRAPE)

Following thermal equilibration if thermal conductivity was to be determined, whole HPC and XCB cores that fill the core liner were analyzed by the GRAPE to provide data for density determinations. The core section to be measured was mounted vertically in a stand, and the gamma ray source and sensor moved along a track from the top to the bottom of the core section. A gamma ray beam passed through the diameter of the core (including the core liner), and the attenuation of the beam was measured every 1.5–2.0 cm. The density of the core material was calculated from the gamma ray attenuation.

The GRAPE was calibrated by running an aluminum standard at least once per drill site. The GRAPE software allowed the user to choose the maximum time for which a standard was valid; for Leg 120 a value of ~7 days was employed. Accuracy of the GRAPE technique is a complex issue; the reader is referred to Boyce (1976) for a full discussion.

Compressional Wave Velocity Logger

The compressional wave velocity logger, or *P*-wave logger (PWL), operated simultaneously with the GRAPE; both were mounted on the same frame. Acoustic transducers were aligned perpendicular to the gamma ray beam (thus, commonly parallel to the sediment bedding plane). The transducers coupled with the core liner across the diameter of the filled HPC and XCB core sections; coupling was achieved with saltwater applied to the core liner. The acoustic source produced a 500-kHz pulse at a repetition rate of 1000 Hz. The sampling interval employed was 2 cm. The data were edited on the basis of signal strength; all values for which strength was below 150 were dropped.

The PWL was calibrated with a saltwater standard at least once per drill site. The receiver detected the acoustic signal to an accuracy of 50 ns, corresponding to an instrument resolution of 1.5 m/s for sediment obtained by HPC and XCB techniques. Absolute accuracy of the technique was estimated at 5 m/s due to variations in core liner thickness.

Thermal Conductivity

Soft sediment whole cores and hard-rock split cores were analyzed for thermal conductivity following 4 hr or more of thermal equilibration. For soft sediment, up to four needle probes were inserted into the core(s) through small holes drilled through the core liner. An additional needle was inserted in a standard. The needles were heated and measurements of resistance changes in the needles were made over a 6-min period, with the sampling rate varying from 12 to 21 s depending on the number of needles used.

Thermal conductivity was calculated from the variations in resistance in the needles. To judge the reliability of the measurements, the temperature drift of the needles and a curve-fit parameter (root-mean square of the temperature deviations) were calculated. Only determinations for which drift was less than ~0.04°C/min and the curve-fit parameter was less than ~0.015 were retained for analysis.

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

Both the soft sediment and hard-rock methods were calibrated at least once per drill site. Accuracy of the needle techniques was estimated to be 4%.

Vane Shear Strength

The Wykeham-Farrance vane apparatus and a motorized vane device were used in determining undrained shear strength. Both measurement techniques assume that the sediment is primarily clay, a criterion that was not met by the sediment analyzed during Leg 120. Both methods employ a four-bladed vane that should be inserted perpendicular to sediment bedding planes to a depth at least equal to the blade height.

In practice, the vane was inserted into the split-core section perpendicular to its face (thus parallel to bedding planes) to a point where the top of the blade was just covered by sediment. The vane was then rotated until a peak torque was attained. The torque sensor used for the motorized vane device was a potentiometer, and for the Wykeham-Farrance apparatus, a calibrated spring was used. Undrained shear strength was calculated assuming full strength mobilization along a circular cylinder inscribed about the vane. On Leg 120 the motorized shear device was used for only Hole 747A. Wide scatter in the data produced from Hole 747A cores forced a change to the Wykeham-Farrance apparatus, which produced more consistent data from subsequent cores.

The motorized vane device was calibrated in port prior to the start of Leg 120. All blades were measured, and the values were not significantly different from previous measurements. The spring constants for the Wykeham-Farrance vane apparatus were not redetermined for Leg 120.

Compressional Wave Velocity

Discrete samples were measured for compressional wave velocity, or Hamilton Frame (HF), determinations adjacent to intervals for which undrained shear strength was determined, and in the same interval from which index property samples were obtained. The HF consisted of two frame-mounted transducers, and the sample was placed between them. The source frequency was 400 kHz, and traveltime was measured by a counter/timer and oscilloscope. Travel distance was measured by a hand-held rule. Samples were removed from the cores, placed in the frame, and time and distance were measured. In hard rock, measurements were made in both the horizontal and perpendicular *in-situ* planes to investigate for velocity anisotropy.

The HF was calibrated with standards at the start of Leg 120 and checked during the cruise. Values of compressional sound velocity were accurate to $\pm 2\%$.

Index Properties

Splits of the discrete compressional wave velocity samples were measured for index property determinations. Weights were measured by an electronic balance system. The balance weighed each sample 250 times and provided an average value. Volumes were measured by a helium pycnometer employing a 3.0-min purge. Weights and volumes were measured as soon as possible following splitting of the core, vane shear analysis, and HF measurements. Weights and volumes were measured again after the samples were freeze dried for 12 hr. Salt-corrected wet- and dry-bulk densities, grain density, water content, and porosity were then calculated.

The balance was calibrated with mass standards at the beginning of the leg and checked frequently for drift during the leg. The accuracy of the balance was $\pm 0.05\%$ for typical sample weights of 5–20 g. The pycnometer was calibrated with volume standards at the start of the leg. Accuracy of the instrument was $\pm 0.5\%$. Each numbered beaker was weighed twice at the start of the leg, and the new values were used in the index property calculations.

LOGGING

Logging services on board *JOIDES Resolution* are provided by the Lamont-Doherty Borehole Research Group under contract to ODP. Lamont-Doherty, in turn, subcontracted Schlumberger to provide the downhole logging services for Leg 120. The logging tools available from Schlumberger are principally designed for use in petroleum exploration. Many of the standard logging tools available are very useful for gathering scientific information in ODP boreholes. In some cases, individual logging sondes have been modified to meet ODP requirements, notably to allow the tools to be run down through the drill string with a minimum internal diameter of 3.8 in.

Logging can provide a continuous, *in-situ* measurement of physical and elemental formation parameters; it also gives valuable stratigraphic and pore fluid information. The results obtained from logging may be directly correlated with core data over intervals of good core recovery or, alternatively, may be used to supplement the data set where core recovery is poor.

A discussion of the basic operating principle of each tool run on Leg 120 is given below. Further information regarding tool operation can be obtained from the Borehole Research Group of the Lamont-Doherty Geological Observatory (L-DGO) or directly through Schlumberger.

Only one tool string, the seismic-stratigraphic combination (DITE-SDT-NGT), was run on Leg 120. All the tools run on this leg were the newly introduced digital tools. Their operation is similar to their older analog counterparts, the main difference being that the information is now digitized downhole before transmitting the data to surface.

Phasor Induction Tool (DITE)

The phasor induction resistivity tool provides three measurements of formation resistivity: (1) ILD = deep induction, (2) ILM = medium induction, and (3) SFLU = spherically focused log. Each measurement has a characteristic depth of investigation that depends on formation, pore, and borehole fluid resistivities. Generally, the ILD is the deepest-reading resistivity tool and is therefore considered to give the best estimate of true virgin formation resistivity.

The induction measurements are, strictly speaking, measurements of formation conductivity; they are generally converted to resistivity (ohm) values for ease of presentation. The induction measurements are made by means of a system of transmitter/receiver coil pairs. An alternating current (10, 20, or 40 kHz) is produced in the transmitter coils; this induces eddy currents in the formation. The magnetic field produced by these circulating eddy currents, in turn, induces a voltage at the receiver coil. The magnitude of eddy current flow (and, hence, the receiver voltage and current) is proportional to the formation conductivity. The new phasor induction tool (DITE) is designed to record both the in-phase (R signal) induction measurement and the out-of-phase (X signal) quadrature signal. Conventional processing of the induction log data considers only the R signal. Phasor processing combines both X and R signals to obtain a more accurate reading of formation conductivity.

The SFLU is a resistivity device; it measures current flow through the formation by means of electrodes held at a constant potential. The SFLU has a smaller depth of investigation than either of the induction tool measurements.

Natural Gamma Ray Spectroscopy Tool (NGT)

A basic gamma ray (GR) log records the natural radioactivity of a formation using a scintillation detector. This radiation is recorded initially as counts/s and is subsequently presented on an American Petroleum Institute (API) radiation scale. The NGT allows the total gamma ray response (SGR) of a formation to be separated into the contributions made by each of three components: potassium (K), thorium (Th), and uranium (U). The analysis is achieved by subdividing the entire incident gamma ray spectrum into five discrete, preselected energy windows. The total counts recorded at each window, for a specified depth in the well, are processed at the surface to give the relative elemental abundance of K, Th, and U.

Digital Sonic Tool (SDT)

The basic sonic logging tool determines the transit time of a sonic pulse through the formation; this transit-time measurement is usually expressed in μs/ft. The SDT is a more sophisticated version of the basic sonic tool (Fig. 18). The addition of an eight-array receiver section to a conventional paired dual transmitter/receiver sonic tool gives the SDT the capability to record many more sonic waveforms (and their associated transit

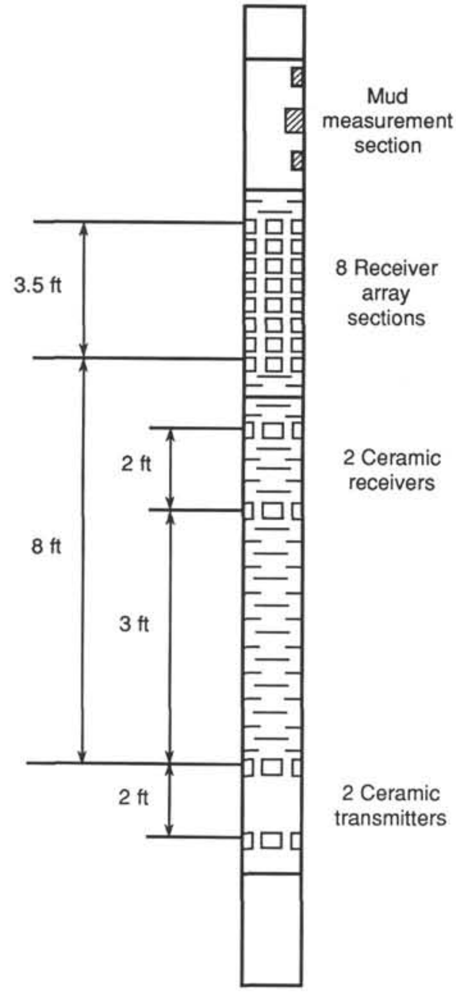


Figure 18. Diagram illustrating SDT-multipurpose sonic sonde configuration.

times) at a given depth. Available SDT measurements can be summarized as (1) 3-5-7-ft-spaced Dt measurements plus waveforms; (2) 8-10-12-ft-spaced Dt measurements plus waveforms; (3) array waveform recording for improved shear and Stoneley wave identification; and (4) borehole fluid Dt measurement.

The recovery of more data allows seismic signal processing techniques to be applied in order to enhance data quality. Sonic waveform recording, as opposed to just recording the first arrival times, allows the identification of later shear and Stoneley wave arrivals.

Multi-Caliper Tool (MCD)

This tool provides a basic two-dimensional caliper log of the borehole by means of a bowspring measurement system. The hole diameter (HD) log is used to detect washouts (or constrictions) in the borehole. Borehole size has an important effect on many of the other logging parameters measured downhole; it is, therefore, important to measure the hole size accurately in any logged hole. In additional, fluctuations in hole size may often be correlatable with formation alterations.

Auxiliary Measurement Sonde (AMS)

The AMS provides the logging scientist with a continuous downhole measurement of wellbore fluid (mud) resistivity and temperature.

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