

# 1. INTRODUCTION AND EXPLANATORY NOTES, DEEP SEA DRILLING PROJECT LEG 75<sup>1</sup>

Shipboard Scientific Party<sup>2</sup>

## OBJECTIVES

Legs 71 through 75 of the International Phase of Ocean Drilling (IPOD) of the Deep Sea Drilling Project (DSDP) were devoted to study of late Mesozoic and Cenozoic paleoenvironments in the South Atlantic Ocean. Leg 75 was specifically concerned with the development of anaerobic conditions in ancient oceans and with the effect of the Walvis Ridge as a barrier to water circulation during the early development of the South Atlantic, particularly in connection with the subsidence of the ridge through time.

The plan called for Leg 75 of D/V *Glomar Challenger* to begin from Walvis Bay, South Africa, and to drill two sites in the Angola Basin (Sites SAI-1 and 2), one on the northern flank of the Walvis Ridge (SAI-5), and possibly a fourth site on the ridge itself (SAI-4), with the leg ending in Recife, Brazil. A complete list of the sites proposed for drilling on Leg 75 is shown in Table 1 and the locations plotted in Figure 1.

Anaerobic sediments indicative of a reducing depositional environment are not extensive in the modern open ocean; however, the location and the extent of such depositional environments are of exceptional interest because high concentrations of organic carbon can accumulate and be preserved under these conditions. Today such environments are restricted either to isolated basins whose bottom waters are not renewed (or are only very slowly renewed) or to substrates beneath the oceanic mid-water oxygen minimum developed under highly fertile and productive surface-water masses along continental margins. The prime examples of the first case, euxinic conditions, are the Black Sea and the Cariaco Trench.

Examples of the second case are known from the continental margins off west India, southwest Africa, western South America, and from the Gulf of California. The two types of depositional environments are similar because laminated anaerobic sediments with a high organic carbon content occur in both, but they can be distinguished by reconstruction of their paleogeographic and paleobathymetric setting and by analysis of the fossil contents of their sediments.

Conditions favorable to the development of black shales in the deep ocean occurred several times during the Cretaceous when anaerobic sediments were laid down over wide regions of several ocean basins. Global paleoceanographic scenarios which might cause these apparently isochronous events are being modeled, and the origin of the organic matter accumulated in the anaerobic sediments is presently under intense investigation.

Results from Leg 40 had shown that at Site 361 (4549 m water depth) in the Cape Basin, the lowermost 313 m are mainly alternating sapropelic shales, sandy mudstones, and sandstones of late Aptian to early Albian age. The shales vary little in composition, and the organic carbon content averages 3% (wt. %).

At Site 363 on the Walvis Ridge (2248 m water depth) no sapropels had been found. Nevertheless, 2- to 4-cm-thick beds of black pyritic mudstones were encountered in upper Albian strata, suggesting at least localized reducing conditions. Deeper in the sequence, Albian and upper Aptian limestones are interlayered with calcarenites.

At Site 364 in the Angola Basin (2439 m water depth) sapropels and sapropelic limestones occur in the upper Coniacian to Cenomanian and in the lower Albian to upper Aptian intervals, with organic carbon content reaching up to 26% (wt. %).

The main scientific objective of Leg 75 was to define the paleoenvironmental history of the South Atlantic in order to determine its paleoceanographic evolution, particularly during the mid-Cretaceous when black shales were deposited in this part of the Atlantic. The main problem was whether the black shales were deposited at the bottom of a barren, anoxic basin or at mid-depths within the oxygen-minimum layer of a quasi-normal oceanic basin and whether the anoxia resulted from an abnormally high influx of organic matter or was caused by salinity or temperature-induced stratification. A detailed stratigraphic analysis of the sedimentary sequence of the Angola Basin is needed to resolve these alternatives.

Linked to this prime question was the other important objective: to study the paleoceanographic effects of the

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Table 1. Proposed sites, Leg 75.

Site	Priority	Coordinates	Water depth (m)	Penetration to objective (m)	Objectives
SAI-1A	1	19°17'S, 8°47.5'E	4850	1300	• Determine the origin and age of Cretaceous black shales in the Angola Basin
SAI-1B	1	19°17'S, 8°56'E	4800	1200	• Define CCD and lysocline variations
SAI-1C <sup>a</sup>	1	19°11.5'S, 9°20.5'E	4610	1300	• Define the role of the Walvis Ridge in controlling circulation and paleoceanographic gradients
SAI-2A <sup>a</sup>	2	17°49'S, 2°13.5'E	5300	600	• Define environmental changes at the Cretaceous/Tertiary boundary and test warming hypothesis (up to 5°C) during the crisis
SAI-2B	2	17°43'S, 2°12'E	5300	600	• Define the role of the Walvis Ridge in controlling circulation and paleoceanographic gradients
SAI-4C	3	19°38.5'S, 10°24.5'E	1350	450	• Determine the nature and age of anticipated continental basement • Establish the facies of the equivalent of the black shales at Site SAI-2 • Determine the subsidence of the Walvis Ridge from the results of drilling at Sites SAI-1 and 4
SAI-5A <sup>a</sup>	1	20°25'S, 7°55'E	3100	900	• Cenomanian-upper Coniacian black shales
SAI-5B	1	20°21'S, 7°49'E	3200	1000	• Establish age of the crust
SAI-5C	1	20°21'S, 7°55.5'E	3300	1100	• Establish the depositional environment of anaerobic sediments
SAI-5D	1	20°24'S, 7°57.5'E	3150	1200	• Define the role of the Walvis Ridge in controlling circulation and paleoceanographic gradients

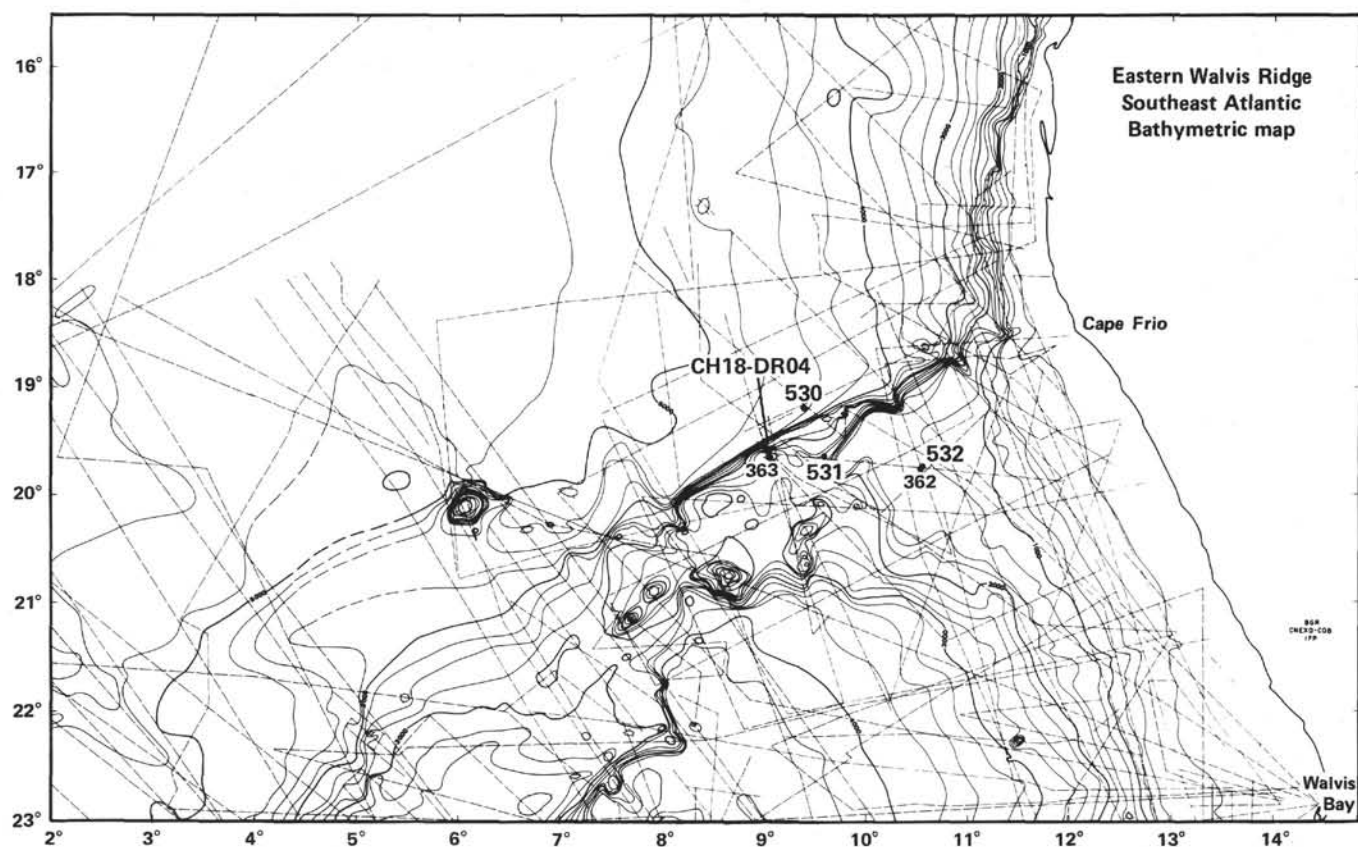
<sup>a</sup> Prime site; the remaining sites are alternates.

Figure 1. Leg 75 proposed sites (depth in corrected m; contour interval, 250 m). The base map is the new bathymetric map of Sibuet et al., this volume.

subsidence of an aseismic ridge attached to a passive continental margin and to determine the extent to which the Walvis Ridge has served as a dam to paleocirculation and to current-transported sediments. The information sought was to complement that gained on Leg 74 and permit definition of the depth zonation of lithofacies (and/or paleoenvironments) across the northern flank of the Walvis Ridge and of the history of calcium carbonate compensation in the Angola Basin. The Cretaceous/Tertiary boundary was examined in order to provide additional information for discriminating between current hypotheses relating it to astronomical or paleoceanographic causes.

### OPERATIONAL SUMMARY

The D/V *Glomar Challenger* sailed for Leg 75 from Walvis Bay, South Africa, on 27 July 1980. Details of

the occupation at the three sites on Leg 75 are given in Table 2; their locations are indicated in Figure 2 and stratigraphic columns at Sites 530 and 532 are given in Figures 3 and 4.

Most of the drilling time was devoted to three holes at Site 530 in the Angola Basin. Site 531 was attempted on a guyot-like feature on the Walvis Ridge but could not be spudded in. The remainder of the time was devoted to hydraulic piston coring at Site 532, near Leg 40, Site 362, in order to obtain a detailed record of the Benguela upwelling system. The ship arrived in Recife, Brazil, on 6 September 1980.

### Site 530

Site 530 is located in the southeastern corner of the Angola Basin, about 20 km north of the Walvis escarpment, near the eastern end of the Walvis Ridge (Fig. 2).

Table 2. Leg 75 coring summary.

Hole	Dates (1980)	Latitude	Longitude	Water depth <sup>a</sup> (m)	Penetration (m)	Number of cores	Meters cored	Meters recovered	Percent recovery
530	29-30 July	19°11.26'S	9°23.15'E	4629	125.0	2	11.0	9.20	83.6
530A	30 July-15 August	19°11.26'S	9°23.15'E	4629	1121.0	108	996.0	619.46	62.2
530B	15-18 August	19°11.26'S	9°23.17'E	4629	180.6	48	180.6	155.08	85.9
531	19 August	19°38.44'S	9°35.31'E	1267	1.0	1	1.0	0.02	2.0
531A	19 August	19°38.44'S	9°35.47'E	1267	1.0	1	1.0	0.27	27.0
532	20-21 August	19°44.61'S	10°31.13'E	1331	250.8	61	250.8	232.44	92.7
532A	21-23 August	19°44.64'S	10°31.13'E	1331	199.6	47	199.6	161.15	80.7
532B	23-25 August	19°44.66'S	10°31.13'E	1331	291.3	74	291.3	267.00	91.7
						342	1859.3	1444.62	78.0

<sup>a</sup> Water depth from sea level.

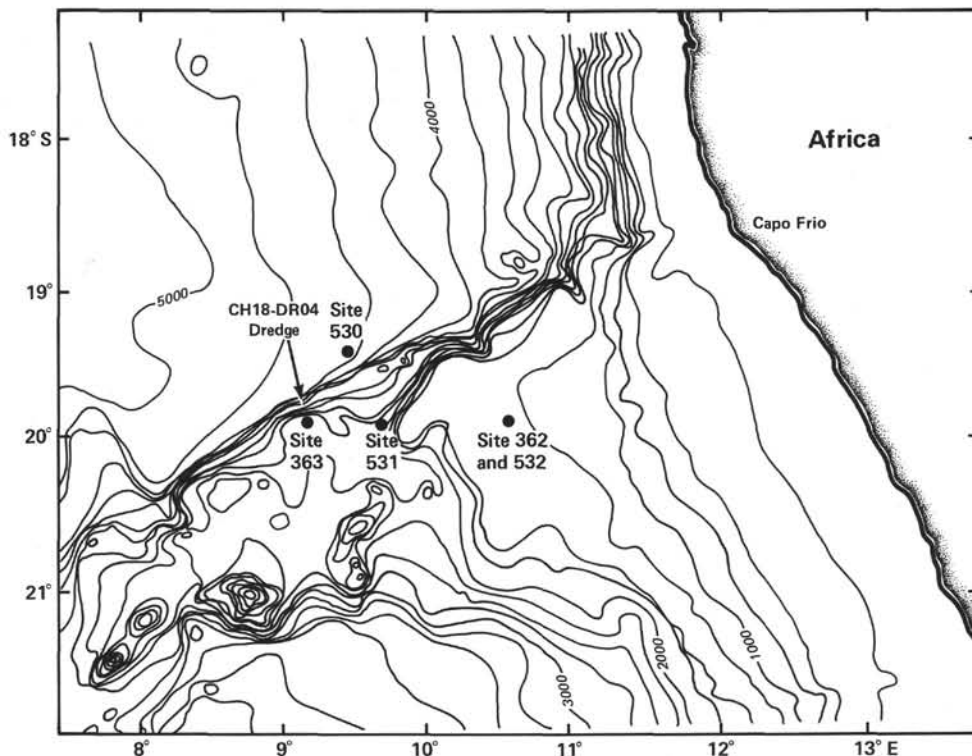


Figure 2. Location of sites drilled on Leg 75 (depth in m).

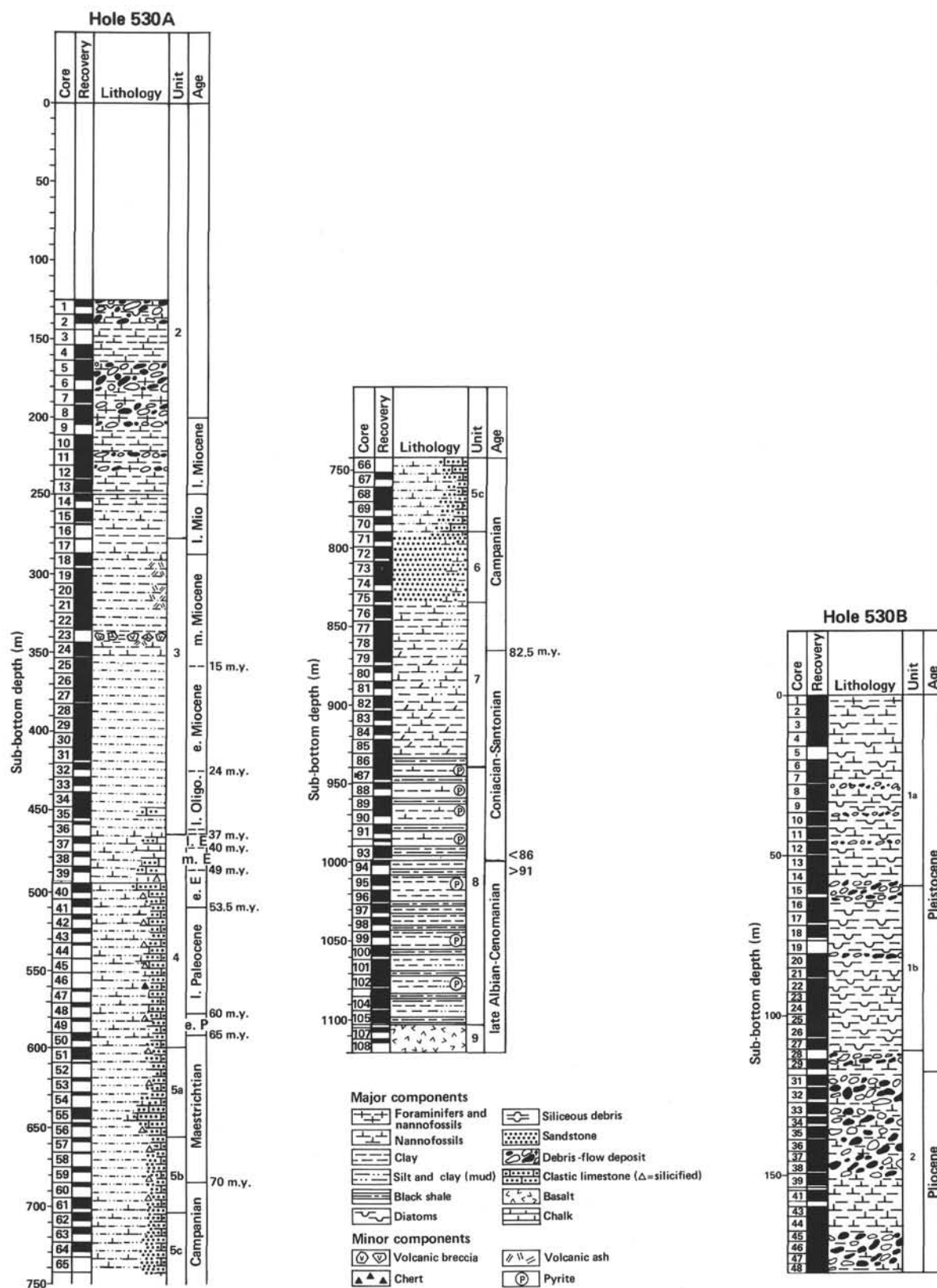


Figure 3. Stratigraphic columns for Holes 530A and 530B.

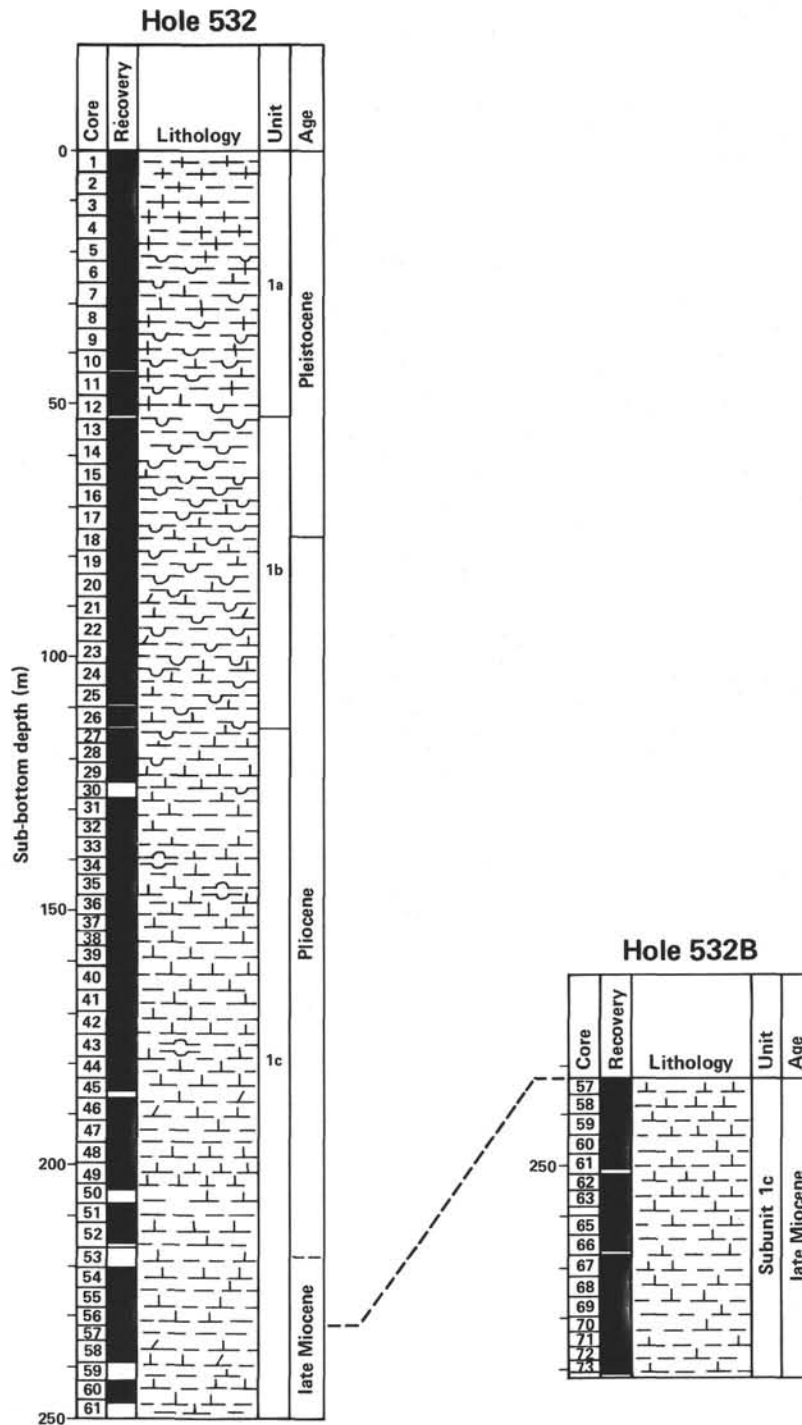


Figure 4. Stratigraphic columns for Holes 532 and 532B.

It lies on the abyssal floor of the Angola Basin and exhibits a seismic stratigraphic sequence typical for the entire deep part of the basin.

Magnetic lineations of the basement are not distinct at Site 530. The M sequence (M0 to M11) has been clearly identified in the Cape Basin south of Walvis Ridge by Rabinowitz (1976). Cande and Rabinowitz (1978) have published an interpretation of the Angola Basin anomalies in which they suggest that a ridge jump occurred approximately at the time of Anomaly M0 or later, so that

the basement at Site 530 would be early Aptian or younger. One of the objectives of drilling at this site was to determine the basement age and establish whether the hypothesis of a ridge jump in the southern Angola Basin is correct.

Three holes were drilled at Site 530: (1) Hole 530 was drilled using a standard coring assembly, but was curtailed (115 m below seafloor) by technical failure; (2) Hole 530A (1121 m penetration) was drilled using standard coring assembly; and (3) Hole 530B (180 m penetra-



tion) was cored using the new (Leg 65) hydraulic piston coring (HPC) device in hopes of obtaining geologically undisturbed cores.

At Hole 530A basalt was encountered at 1103 m and was penetrated to 1121 m.

At Hole 530A the Gamma Ray-Neutron Log was run inside the pipe. Then open-hole logging was attempted first with a rig of the Temperature Density Log, but was stopped by a bridge in the hole a short distance below the pipe. We made several attempts to clear the bridge, cleaning and flushing the hole and setting the bottom of the pipe deeper. After our unsuccessful attempts to lower the tools down the hole, it was found that the Density Log part of the tool with its source had been left in the hole. The hole was again flushed with mud and the bottom of the pipe set at 625 m sub-bottom. The Gamma-Ray Log, Sonic Log, Induction Log, Laterolog, Neutron Log, and Temperature Log were all run in the bottom part of the bare hole after the drill bit was dropped without tripping the string; Hole 530A was then plugged with cement.

### Site 531

Knowledge of the subsidence history of the Walvis Ridge is critical to interpretation of the paleoceanography of the southwest Atlantic. The best calibration points for subsidence of the ridge are the moments when particular topographic features subsided below sea level.

The BGR-36 processed seismic profile shows a flat-topped platform at this site. As this "guyot-like" structure is at a water depth of only 1300 m, it was anticipated that this feature subsided below sea level more recently than other deeper parts of the ridge; preliminary estimates suggested that it subsided below sea level about 20 m.y. after the formation of the adjacent ocean crust and would provide precise calibration for the ridge subsidence curve.

When we arrived at the site two attempts to spud in failed because the bottom was hard. Two cores were attempted; both recovered a small amount of Pleistocene-Holocene foraminifer ooze, but the second core taken at Hole 531A contained a single small rock fragment about 1 cm across.

The rock fragment consists dominantly of rounded to subrounded, coarse, sand-size fragments of volcanic rocks, red coralline algae, mollusks, and possibly coral cemented by calcite. Red coralline algal fragments are approximately 70% of the total. Much of the biogenic material is replaced by cryptocrystalline calcite, although the cellular structure of the red algae is well preserved. The sediment is well sorted, and the rock is grain-supported with sparry calcite cement in the intergrain spaces.

### Site 532

Time remaining for drilling and coring on this leg would not permit our achieving the other objectives proposed for Leg 75. Hydraulic piston coring at a relatively shallow site was deemed the best use of the available time. Operations at Site 530 had yielded the unexpected result that the Pliocene and Pleistocene sediments were

rich in diatoms and organic carbon and reflected the Benguela upwelling system. However, the stratigraphic record has been obscured by turbidite and debris flows, so that no details of the history of upwelling could be ascertained.

The upper part of Site 362 had been continuously cored by rotary drilling during Leg 40 in 1975 (Bolli, Ryan et al., 1978), but all of the cores taken above a sub-bottom depth of 200 m were badly disturbed. The cores had been noted to be rich in diatoms and calcareous plankton, and also had a high content of organic carbon. It had been recognized that the sediments were a product of the Benguela upwelling system which started in the Miocene.

We spudded Hole 532, and hydraulic piston coring continued until 61 cores were taken reaching a depth of 250.8 m (Fig. 4).

Hole 532A was offset southwest, spudded in, and continuous hydraulic piston coring proceeded until 47 cores had been taken to reach a depth of 199.5 m. This set of cores was taken for the JOIDES Sedimentary Petrology and Physical Properties Panel; the cores were sealed and only the core catchers were examined aboard ship.

Hole 532B was offset and spudded in, and continuous hydraulic piston coring proceeded until 74 cores were taken, reaching a depth of 291.3 m. The hole was terminated because of time requirements for the transit to Recife. Cores 1 to 56 were not opened but were frozen to be used later for geochemical studies. The remainder of the cores were studied in the usual manner.

Recovery with the HPC was good to excellent but in the cores we opened, the top 50 to 150 cm of nearly all of the cores in the upper 100 m were badly disturbed. Below 100 m, the disturbance was less common, although parts of cores were gas-cracked.

Site 532 was located on the eastern part of the Walvis Ridge in a trough with relatively thick sediment fill, about 1.1 nautical miles from Site 362. Our results are in general agreement with those from the earlier site, although we recovered 235 m of Pleistocene and Pliocene sediments, as opposed to 169 m recovered at Site 362.

### RESPONSIBILITIES FOR AUTHORSHIP

Chapters 2 through 4 in Part I of this volume present the basic shipboard data and discussion of the sites drilled during Leg 75. The authorship of these site chapters is collectively that of the shipboard scientific party, but ultimate responsibility lies with the Co-Chief Scientists, William W. Hay and Jean-Claude Sibuet. Each chapter was compiled according to the standard format listed here (the names of the authors of each section are given in parentheses):

- Background and Objectives (all)
- Operations (Hay and Sibuet)
- Lithology (Barron, Dean, Schallreuter, Stow)
- Biostratigraphy (McNulty, Steinmetz, Stradner)
- Foraminifers (McNulty)
- Nannofossils (Steinmetz and Stradner)
- Paleomagnetism (Keating)
- Sedimentation and Accumulation Rates (Hay)

Inorganic Geochemistry (Nohara)  
 Organic Geochemistry (Brassell, Huc, Meyers)  
 Physical Properties and Downhole Logs (Boyce)  
 Correlation of Drilling Results and Seismic Data (Sibuet)  
 Conclusions (Hay and Sibuet)

## SHIPBOARD SCIENTIFIC PROCEDURES

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

DSDP drill sites are numbered consecutively from the first site at which the *Glomar Challenger* drilled in 1968. A site number refers to the location of one or more holes drilled while the ship was positioned over one acoustic beacon; these holes may be located within a radius as great as 900 m from the beacon. Several holes may be drilled at a single site by pulling the drill pipe above the seafloor, moving the ship 100 m or more from the previous hole, and then drilling another hole.

The first (or only) hole drilled at a site takes the site number. A letter suffix distinguishes each additional hole at the same site. For example, the first hole takes only the site number, the second takes the site number with suffix A, the third takes the site number with suffix B, and so forth. It is important for sampling purposes to distinguish among the holes drilled at a site, because they may have been cored differently.

The cored interval is measured in meters below the seafloor. The depth interval of an individual core is the depth below the seafloor at which the coring operation began to the depth at which the coring operation ended. Each coring interval is generally 9.5 m long, which is the nominal length of a core barrel; however, the cored interval may be shorter or sometimes slightly longer. "Cored intervals" are not necessarily adjacent to each other, but may be separated by "drilled intervals." In soft sediment, the drill string may be "washed ahead" by pumping water down the pipe at high pressure to wash the sediment out of the way of the bit and up the space between the drill pipe and wall of the hole.

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 the seafloor are normally unique for a hole; however, in some instances an interval may be cored twice. When this is done, the core number is assigned a suffix, such as "X" for extra.<sup>3</sup>

Full recovery for a single core is normally 9.28 m of sediment or rock, in a plastic liner the inside diameter of which is 6.6 cm, plus about a 0.2 m-long core-catcher sample. The core catcher is a device at the bottom of the core barrel that prevents the cored sample from sliding out when the barrel is retrieved from the hole. The core is cut into 1.5-m-long sections and numbered serially from the top of the core (Fig. 5). If recovery is complete, the sections are numbered from 1 through 7, with the last section shorter than 1.5 m. The core-catcher sample is placed below the last section when the core is

described and labeled core catcher (CC); it is treated as a separate section.

When there is only partial recovery, the original stratigraphic position of the material in the cored intervals is unknown. If the recovered material is continuous, the top of this material is identified as the top of the cored intervals; and as many 1.5-m sections as needed to accommodate the length of core are cut and are numbered beginning with Section 1 at the top (Fig. 5).<sup>4</sup> For example, 4 m of material are divided into three sections, two upper sections each 1.5 m long and a final lower section only 1.0 m in length. If the material recovered is not contiguous, as determined by the shipboard scientists, then sections are divided and numbered serially, as with contiguous material, and gaps are labeled as voids (for sediments) or marked by spacers (for igneous rocks).

Samples are designated by centimeter distances from the top of each section to the top and bottom of the sample in that section. A full identification number for a sample consists of the following information: leg, site, hole, core number, section number, interval in cm from the top of the section. For example, a sample identification number of "75-530A-20-3, 12-14 cm" is interpreted as follows: 12 to 14 cm designates a sample taken 12 to 14 cm from the top of Section 3 of Core 20, from the second hole drilled at Site 530 during Leg 75. The depth of this sample below the seafloor is the summation of the following: (1) the depth to the top of the cored interval for Core 20, which is 305.5 m; (2) plus 3 m for Sections 1 and 2 (each 1.5 m long); (3) plus the 12 cm depth below the top of Section 3; these add up to 308.62 m.<sup>5</sup>

### Handling of Cores

A core is normally cut into 1.5-m sections, sealed, and labeled on deck. It is then brought into the core laboratory and racked for 4 hrs. to allow it to come to room temperature before processing. Gas analyses and continuous wet-bulk density determinations using the Gamma Ray Attenuation Porosity Evaluator (GRAPE) are made before splitting the sections.

The cores are then split longitudinally into "working" and "archive" halves. Samples are taken from the "working" half, including those for determination of grain-size distribution, mineralogy by X-ray diffraction, sonic velocity by the Hamilton Frame method, wet-bulk density by a static GRAPE technique, water content by gravimetric analysis, carbon-carbonate analysis, calcium-carbonate percentage ("carbonate bomb"), geochemical analysis, paleontological studies, and others. Smear slides (thin sections for lithified sedimentary and igneous rocks) are made from each major lithology and most minor lithologies, and examined microscopically. The archive half is described and photographed. Physical disturbance by the drill bit, color, texture, structures, and composition of the various lithologies are noted on standard Core Description Forms.

<sup>4</sup> This technique differs from the labeling system used on Legs 1 through 45, which had a designation called "zero section," but not a "number 7" section.

<sup>5</sup> Sample requests should refer to a specific interval within a section rather than to a total depth below sea level.

<sup>3</sup> Note that this designation has been used on previous legs as a prefix to the core number for sidewall core samples.

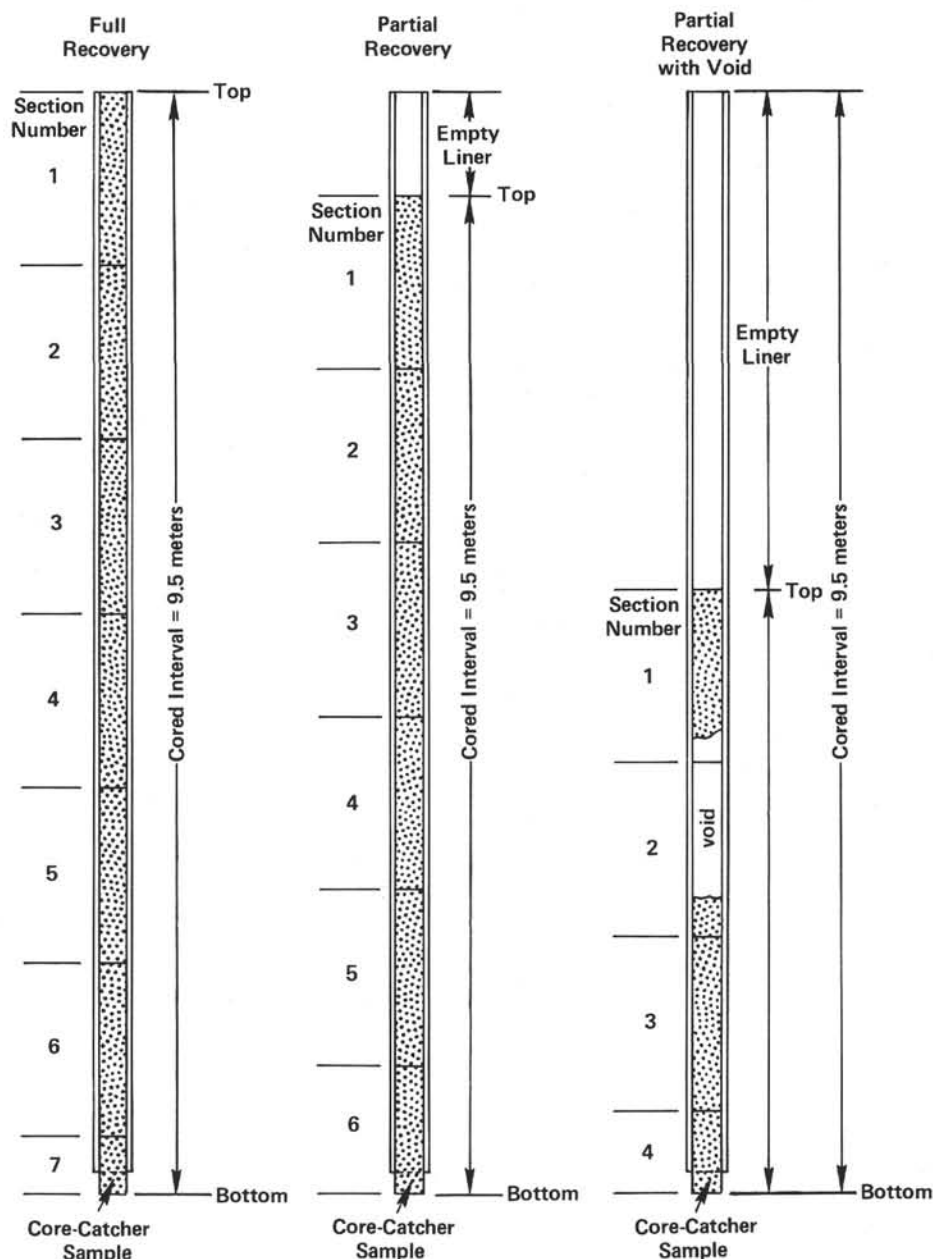


Figure 5. DSDP procedures for cutting and labeling core sections.

After the cores are sampled and described, they are maintained in cold storage aboard the *Glomar Challenger* until they can be transferred to the DSDP repository. Core sections of sediments removed for organic geochemistry study are frozen immediately on board ship and kept frozen. All Leg 75 cores and frozen cores are presently stored at the DSDP East Coast Repository at the Lamont-Doherty Geological Observatory.

#### Core Description Forms

Recovered rocks, particularly the soft sediments, may be disturbed. This mechanical disturbance is the result of the coring techniques which use either a large 25 cm diameter bit with a small 6.0 cm diameter opening for the core sample or a hydraulic piston core which is

pushed into soft sediment. The following disturbance categories are used.

Slightly deformed: Bedding contacts are slightly bent.

Moderately deformed: Bedding contacts have undergone extreme bowing.

Very deformed: Bedding is completely disturbed or homogenized by drilling, sometimes showing symmetrical diapir-like structure.

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

These categories appear on the Core Description Form (Fig. 6) in the column headed "Drilling Disturbance."

In soft and in some harder sediments it may be extremely difficult to distinguish between natural struc-



SITE	TIME - ROCK UNIT	BIOSTRATIGRAPHIC ZONE	HOLE				CORE		CORED INTERVAL				LITHOLOGIC DESCRIPTION			
			FOSSIL CHARACTER				SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	SAMPLES				
			FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS										
		(D) = Diatom zones					1	0.5 1.0	See key for sediment structures (Figure 8)	; Soupy ○○○○	; Very Deformed ~~~~~	See key to graphic lithology symbols (Figure 9)	■ = Organic carbon ● = Carbonate bomb	Color symbols (Munsell and GSA) may be put along this edge.	* = Smear slide	<p>General lithologic description of core Detail at the discretion of sedimentologist for particular site (hole).</p> <p>Smear slide summary (%):            Section, depth (cm) 2, 100            Lith. (D = dominant; M = minor) D            Texture:            Composition:</p> <p>● Carbonate bomb (% CaCO<sub>3</sub>): (% organic carbon):            1, 13-14 cm = 10:1.0            2, 11-13 cm = 11:2.0</p> <p>■ Organic carbon (Leco) (%):            1, 13-14 cm = 1.0</p>
		(R) = Radiolarian zones				2										
		(F) = Foraminifer zones				3										
		(N) = Nannofossil zones				4										
						5	IW									
						6	OG									
						7										
						CC										

Abundance:  
 A = Abundant  
 C = Common  
 F = Few  
 R = Rare  
 B = Barren

Preservation:  
 G = Good  
 M = Moderate  
 P = Poor

See key for sediment structures (Figure 8)

See key to graphic lithology symbols (Figure 9)

■ = Organic carbon  
 ● = Carbonate bomb

Color symbols (Munsell and GSA) may be put along this edge.

\* = Smear slide

General lithologic description of core  
 Detail at the discretion of sedimentologist for particular site (hole).

Smear slide summary (%):  
 Section, depth (cm) 2, 100  
 Lith. (D = dominant; M = minor) D  
 Texture:  
 Composition:

● Carbonate bomb (% CaCO<sub>3</sub>): (% organic carbon):  
 1, 13-14 cm = 10:1.0  
 2, 11-13 cm = 11:2.0

■ Organic carbon (Leco) (%):  
 1, 13-14 cm = 1.0

Interstitial water sample

Organic geochemistry sample

T = Thin section

Figure 6. Typical sedimentary core description sheet with the sediment deformation symbols, sample codes, and other general information.

tures and structures created by the coring process. Structures listed on the core forms for soft lithologies are therefore somewhat tentative. Location and types of these structures appear as graphic symbols in the column headed "Sedimentary Structures"; Figure 7 provides the key for these symbols.

Colors of the geologic material are determined by comparison with a Munsell or Geological Society of America Rock-Color Chart; this is done immediately after splitting the cores (while they are still wet).

The Graphic-Lithology column on the Core Description Form depicts lithologies present in each core. These are represented by a single pattern or by a grouping of two or more symbols corresponding to end members of sediment constituents, such as clay or nannofossil ooze. The abundance of any component equals the percentage of the width of the graphic column its symbol occupies.

Because of the difference in the length-to-width ratio between the actual sediment core and the Graphic-Lithology column, it is not possible to reproduce structures as they actually appeared in the core; rather, they become highly flattened and distorted. The same is true for rock fragments or pebbles in the cores. As a result, the locations of pebbles are shown by a solid square; and the depth of small "patches" of ash, for example, or other lithologic changes are represented by a triangular inset of the appropriate lithologic symbol (Fig. 8) on the right side of the Graphic-Lithology column (this convention applies only to lithologies that do not extend across the entire core).

Format, style, and terminology of the descriptive portion of the Core Description Form are not controlled by the Graphic-Lithology column beyond the minimal name assignment, which is derived from the lithologic classification (described later). Colors and additional information such as structures and texture are included in the text portion of the core description.

Smear-slide (or thin-section) compositions, carbonate content (%  $\text{CaCO}_3$ ), and organic-carbon content determined on board ship are listed below the core description on these forms, where two numbers separated by a hyphen refer to the section and centimeter interval, respectively, of the sample. The locations of these samples in the core and a key to the codes used to identify these

samples are given in the column headed "Samples." Locations and intervals of organic geochemistry (OG) and interstitial water (IW) samples are also shown in this column.

## LITHOLOGIC CLASSIFICATION

### Introduction

The sediment classification used on Leg 75 differs from that previously recommended by the JOIDES Panel on Sedimentary Petrology and Physical Properties (SPPP) in the naming of intermediate mixtures of nonbiogenic, siliceous biogenic, and (or) calcareous biogenic components. As a first approximation, we considered each sediment (with the exception of a few minor lithologies) to be a mixture of nonbiogenic (mostly clay), siliceous biogenic (mostly diatoms), and calcareous biogenic (mostly nannofossils) materials. The JOIDES SPPP Panel's classification of nonbiogenic components is essentially that of Shepard (1954) and was not modified for Leg 75. It provides specific but inconsistent guidelines for naming mixtures of nonbiogenic and siliceous or calcareous biogenic sediments; it does not provide specific guidelines for naming mixtures of all three components. Our modifications of the SPPP Panel's classification are intended to make the naming of mixtures of nonbiogenic, siliceous biogenic, and calcareous biogenic components internally consistent and to provide names for intermediate mixtures of these three components.

Our classification of the three-component system (nonbiogenic, siliceous biogenic, and calcareous biogenic) is shown in Figure 9. The major sediment type determines the name given to the sediment (clay, ooze, marl, etc.), and modifiers depend on the relative abundances of the components present. Any component composing more than 10% of the sediment may be used as a modifier, but no more than two modifiers are used in the descriptive sediment name. The last modifier—i.e., that closest to the main sediment name—is the component in greatest abundance (e.g., a diatom nannofossil ooze contains more than 70% biogenic components, with nannofossils being more abundant than diatoms).

### Basic Sediment Type

#### Nonbiogenic Components

Nonbiogenic (noncarbonate, detrital clastic) components are classified entirely on the basis of texture (sand, silt, and clay) according to Shepard's (1954) classification (Fig. 10). The term *clay* is used for any material less than  $4\ \mu\text{m}$  in size without regard to composition or origin (hence, the term *pelagic clay* does not appear in our classification). Size is determined entirely on the basis of estimates from smear slides. Silt- and sand-sized materials appear in the smear-slide descriptions as percentages of whatever components are in that size fraction.

Many of the lithologic units contain sediments with variable silt and clay contents so that some samples might be classified as silty clay and others as clayey silt. We used the terms *mud* or *mudstone* for sediments in

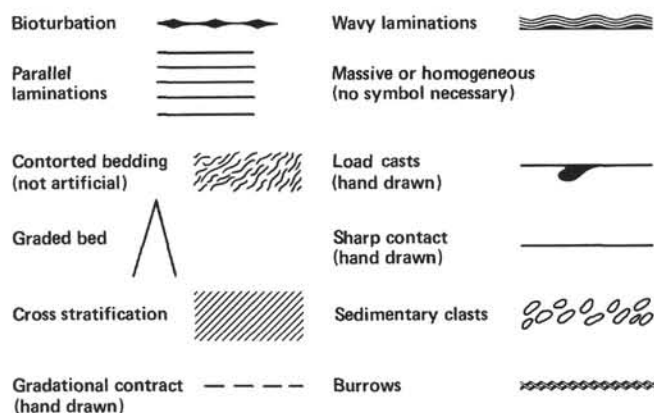


Figure 7. Key to sedimentary structure symbols.

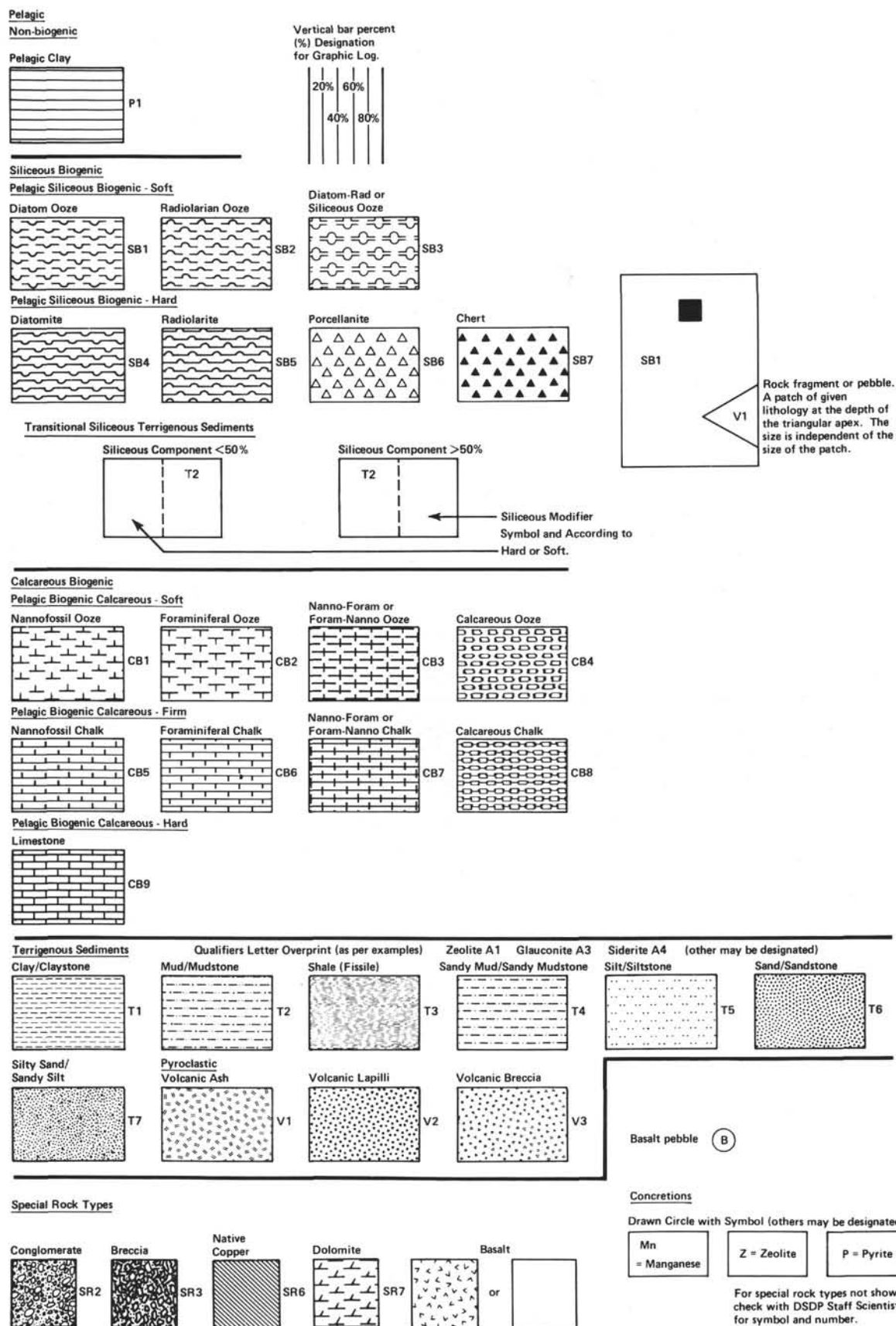


Figure 8. Graphic symbols corresponding to the lithologic visual core descriptions for sediment and sedimentary rocks.

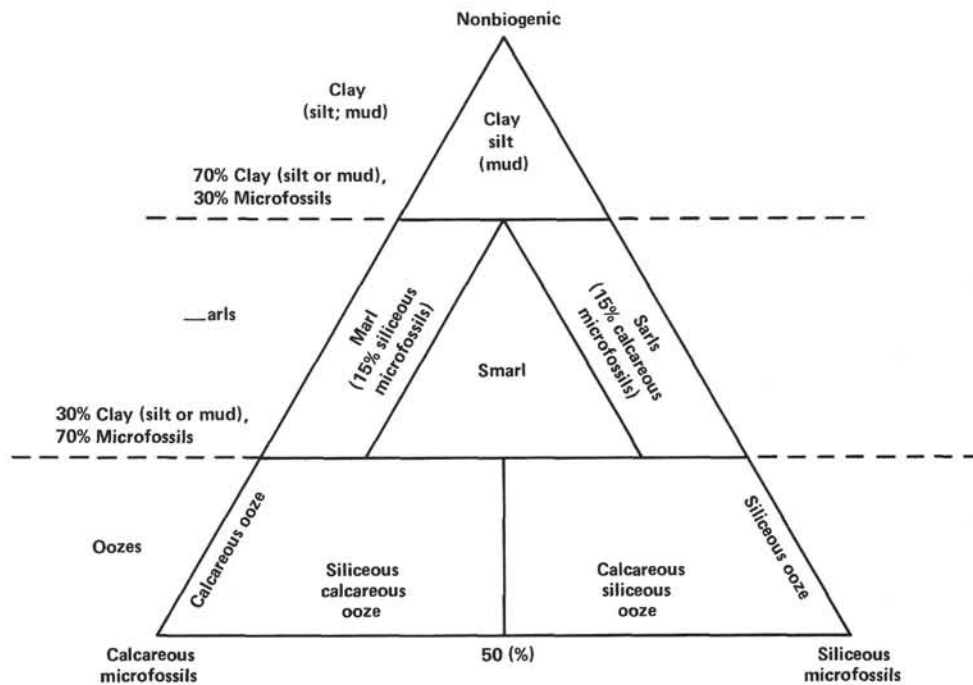


Figure 9. Classification of the three-component system (nonbiogenic, siliceous biogenic, and calcareous biogenic).

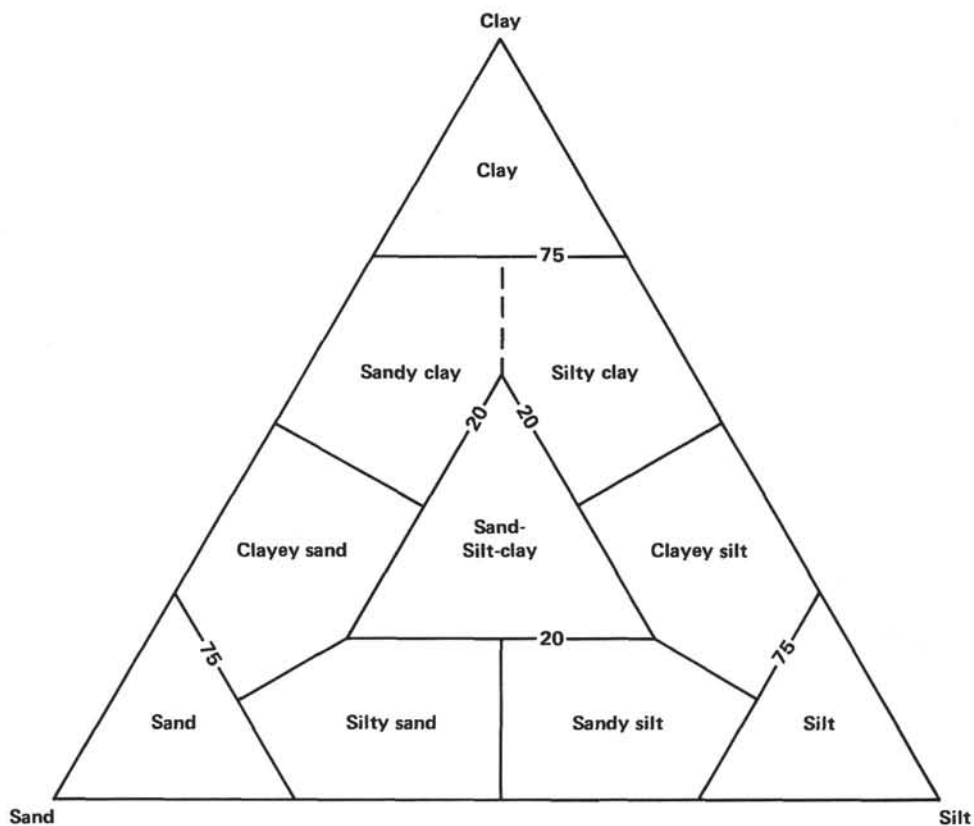


Figure 10. Sediment classification after Shepard (1954), with the sand-, silt-, and clay-size fractions based on the Wentworth (1922) grade scale: Sand-, silt-, and clay-size particles having respective diameters of 2000 to 62.5  $\mu\text{m}$ , 62.5 to 3.91  $\mu\text{m}$ , and less than 3.91  $\mu\text{m}$ . Shepard's (1954) sediment classification is a function of sand, silt, and clay-size percentages and not composition.



which silt and clay constitute more than 70% total, but in which the relative proportions of silt and clay are highly variable.

### Calcareous Biogenic Components

Calcareous biogenic sediments contain more than 30%  $\text{CaCO}_3$ . Calcareous biogenic sediments that contain between 70% and 100%  $\text{CaCO}_3$  are called *ooze* if they are soft, *chalk* if they are firm, and *limestone* if they are hard and cemented. The main modifiers are *nannofossil* and (or) *foraminifer* depending upon which is in greatest abundance. A nannofossil (or foraminifer) ooze contains 70% to 100% nannofossils (or foraminifers). A foraminifer nannofossil ooze contains both foraminifers and nannofossils, with nannofossils more abundant than foraminifers but both totaling between 70% and 100%. Any other component may be used as a secondary modifier if it is present in an amount more than 10%. For example, a clayey nannofossil ooze contains more than 70% nannofossils and more than 10% clay.

### Transitional Calcareous Biogenic Sediments

A sediment containing between 30% and 70%  $\text{CaCO}_3$  and less than 15% siliceous components is called *marl*. The lithified equivalent is *marlstone*. This usage differs from the SPPP Panel's classification, which uses the term *marly* as a modifier to ooze, chalk, or limestone (e.g., *marly chalk*) for sediments with 30% to 60%  $\text{CaCO}_3$ . We have included the *marl* in our classification because of its wide usage, because it is a useful term for many carbonate sediments, and because, when defined, it gives the reader a clearer impression of the nature of the sediment than when used as an adjective. The term *marly ooze* is ambiguous in that it may indicate either a *marl* or a *clayey ooze*.

Using nannofossils and clay as examples, some names of sediments consisting of mixtures of calcareous and nonbiogenic components, are:

Nannofossils (%)	Clay (%)	Name
0-10	90-100	Clay
10-30	70-90	Nannofossil clay
30-70	30-70	Nannofossil marl
70-90	10-30	Clayey nannofossil ooze
90-100	0-10	Nannofossil ooze

### Siliceous Biogenic Components

Siliceous biogenic sediments contain more than 30% siliceous microfossils. Siliceous biogenic sediments that contain between 70% and 100% siliceous microfossils are called *ooze* if they are soft. Lithified equivalents are called *diatomite* if composed predominantly of diatoms or *radiolarite* if composed predominantly of radiolarians.

### Modifiers

The main modifiers are *diatom* if composed predominantly of diatoms, *radiolarian* if composed predominantly of radiolarians, or *siliceous* if composed of more or less equal mixtures of radiolarians and diatoms, or if they are mixed with other siliceous components (sponge

spicules; silicoflagellates). Any other component may be used as a modifier if it is present in an amount greater than 10%.

### Transitional Siliceous Biogenic Sediments

Many of the Holocene, Pleistocene, and Pliocene sediments recovered on Leg 75 contain intermediate mixtures of clay and microfossils and usually could not be classified as clay (more than 70% clay) or ooze (more than 70% microfossils). The SPPP Panel's classification employs only major subdivisions (at 50%) for mixtures of nonbiogenic and siliceous components:

< 50% siliceous fossils = siliceous clay (e.g., diatom clay)

> 50% siliceous fossils = siliceous ooze (e.g., diatom ooze; or clayey diatom ooze if clay = 10-50%)

This two-category subdivision is not consistent with the three-category subdivision used for mixtures of nonbiogenic and calcareous components. Our classification provides the term *sarl* as the siliceous equivalent to *marl* for intermediate mixtures of clay (or any nonbiogenic component) and siliceous microfossils (Fig. 9). A *sarl*, therefore, contains between 30% and 70% siliceous microfossils and less than 15%  $\text{CaCO}_3$ . Because siliceous components usually occur as impure mixtures with nonbiogenic components, the term *sarl* should be useful for classifying many siliceous sediments. The term should be particularly useful for diatom-bearing sediments because they frequently occur in coastal high-productivity areas where they are almost always mixed with terrigenous nonbiogenic components.

Using diatoms and clay as examples, some names of mixtures of siliceous and nonbiogenic components are:

Diatoms (%)	Clay (%)	Name
0-10	90-100	Clay
10-30	70-90	Diatom clay
30-70	30-70	Diatom sarl
70-90	10-30	Clayey diatom ooze
90-100	0-10	Diatom ooze

The final category in the new classification is the term *smarl* for sediments that contain more than 30% nonbiogenic components and more than 30% total siliceous and calcareous microfossils, each more abundant than 15% (Fig. 9). These are mixtures of either marls that contain more than 15% siliceous microfossils or sarls that contain more than 15%  $\text{CaCO}_3$ . Although this type of sediment was not included in the SPPP Panel's classification, sediments containing between 20 and 40% each of diatoms, nannofossils, and clay were very common among the Pliocene to Holocene materials recovered on Leg 75.

### SPECIAL ROCK TYPES

#### Black Shale

The term *black shale* will be used as a "label" for black organic carbon-rich claystone or mudstone and does not necessarily indicate a high degree of fissility.

## Igneous Rock Nomenclature

The terminology used for textures and rock types in the igneous rock section are standard terms. Usage is generally in accordance with the definitions given in the *AGI Glossary of Geology*.

Grain size variations noted in hand specimen descriptions are relative only; no absolute criteria were employed. For lithologic symbols and a typical igneous core description sheet see Figure 11.

## SPECIAL STUDIES OF SEDIMENTS

### Bomb Carbonate and Organic Carbon Content

Percent  $\text{CaCO}_3$  was determined on board ship by the "carbonate bomb" technique (Müller and Gastner, 1971), in which a sample is powdered and treated with HCl in a closed cylinder. The resulting  $\text{CO}_2$  pressure is proportional to the  $\text{CaCO}_3$  content of the sample, and percent  $\text{CaCO}_3$  is determined from the manometer reading. In general an accuracy of  $\pm 5\%$  can be obtained, and percent error can be as low as 1% for sediments high in  $\text{CaCO}_3$ .

Organic carbon was determined on each bomb carbonate sample by a Hewlett-Packard CHN analyzer on board ship and/or at the University of Michigan (Meyers, Brassell, and Huc, this volume). Values are given as percent dry weight.

These data are presented on the core forms (sample code = ●). The sample interval is designated by three numbers: the section number, followed by the top and bottom of the sample interval: a sample from Section 2 from 11 cm to 12 cm with 80% calcium carbonate and 1.1% organic carbon is indicated on the core form as:

- Bomb carbonate (%  $\text{CaCO}_3$ ): (% organic carbon):  
2, 11–12 cm = 80:1.1

### Organic Carbon Content

Percent organic carbon determined by a LECO carbon analyzer is listed in Deroo, Herbin, and Huc, this volume. These analyses are not listed on the core forms.

### Carbon-Carbonate Analysis

Following the cruise, sediment samples were analyzed for total carbon content at the laboratories of the USGS, Branch of Marine Geology, Menlo Park, California, on a LECO WR-12 Carbon Analyzer (Gardner et al., this volume). Sample preparation procedures have been outlined in Boyce and Bode (1972) and Bode (1973). Carbon-carbonate was determined on the same samples at the USGS laboratories by gasometric techniques. Organic carbon was determined by difference between total carbon and carbon-carbonate (Gardner et al., this volume). The carbon-carbonate data are not indicated on the core forms.

### Geochemical Measurements

Aboard ship, analyses for pH, alkalinity, and salinity are conducted routinely.

Two different methods are used to determine pH. One is a flow-through electrode method, the other a punch-in electrode method. On all samples, pH is determined via the flow-through method, which is a glass capillary electrode in which a small portion of unfiltered pore water is passed. In the softer sediments a "punch-in" pH is also determined by inserting pH electrodes directly into the sediment at ambient temperature prior to squeezing.

Alkalinity is measured by a colorimetric titration of a 1-ml aliquot of interstitial water with 0.1N HCl using a methyl red/blue indicator.

$$\text{Alkalinity (meq/kg)} = (\text{ml HCl titrated}) \cdot (97.752)$$

Salinity is calculated from the fluid refractive index as measured by a Goldberg optical refractometer, using the ratio:

$$\text{Salinity (‰)} = 0.55 \cdot \Delta N$$

where  $\Delta N$  = refractive index difference  $\times 10^4$ . Local surface seawater is regularly examined by each of the above methods for reference.

## BIOSTRATIGRAPHY

### Biostratigraphic Zonations

The biostratigraphy of sites cored on this leg is based on calcareous nannoplankton and planktonic foraminifers. The calcareous nannoplankton zonations used for the Tertiary are the standard zonation of Martini (1971) and the zonation of Bukry (1973, 1975). The nannoplankton zones applied to the Upper Cretaceous are based on Čepék and Hay (1969), Martini (1969, 1976), Bukry and Bramlette (1970), Manivit (1971), Perch-Nielsen (1972, 1977, 1979), Roth (1973), Sissingh (1977), Thierstein (1976) and Verbeek (1977).

The foraminiferal biostratigraphic framework used in this volume is the same as that employed by paleontologists of Leg 40 (Bolli, Ryan et al., 1978, pp. 14–61; Jenkins, 1978, p. 728).

### Foraminiferal Abundance and Preservation

The term abundance was used in two different ways: the abundance of foraminifers in the sediment and the abundance of a species in the assemblage of a residue.

For the first case, which was employed in the abundance boxes at the top of the paleo-biostratigraphic forms, terms were:

- A = abundant; about 2  $\text{cm}^3$  of dry foraminiferal residue from a 10  $\text{cm}^3$  sample of sediment or rock
- C = common; about 1  $\text{cm}^3$ , as above
- F = few; about 0.5  $\text{cm}^3$
- R = rare; 2 cm or less.

For the second case, the terminology employed was:

- A = Over 30% of the foraminiferal population of residue
- C = 15–30%
- F = 3–15%
- R = Less than 3%.

Percentages were estimated by visual examination.

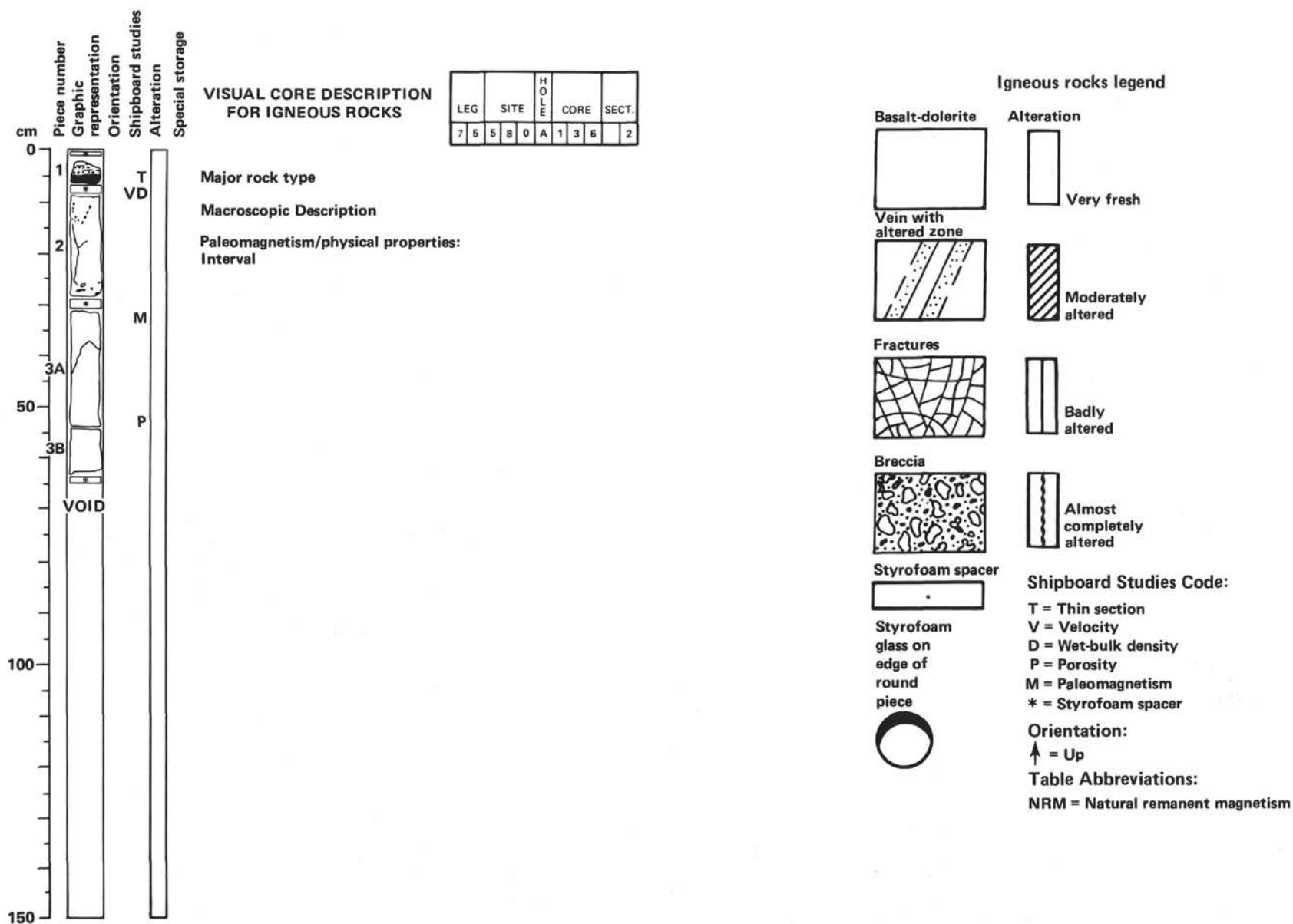


Figure 11. Typical igneous core description sheet, with lithologic symbols, shipboard study-sample codes, and other general information and examples.

The degree of preservation takes into account the effects of dissolution on abundance and diversity of residues as well as the condition of individual tests:

- G = Good; dissolution effects rare and obscure  
 M = Moderate; specimen dissolution common but minor; abundance typically few or common; diversity noticeably reduced, such as 10 species or fewer  
 P = Specimens small, compact, thin-walled, mineral-filled, and encrusted or variously perforated; one to six species.

### Nannofossil Abundance and Preservation

Abundance estimates of the taxa present in the assemblages were made according to the method introduced by Hay (1970). The abundance of the assemblage is estimated by the order of magnitude of its frequency per field of view and is expressed in terms of an exponent to the base ten. The frequency estimate designations used are as follows:

Abundance of Specimens	Logarithm	Designation
10–100 specimens per field of view	+1	Abundant
1–10 specimens per field of view	0	Common
Single specimen in 1–10 fields of view	–1	Few
Single specimen in 10–100 fields of view	–2	Rare

The overall preservation of nannofossil assemblages was recorded using one of three letter designations (Steinmetz, 1979).

- G = Good preservation. Fossils lack evidence of dissolution or overgrowth. All taxa are easily identified.  
 M = Moderately good preservation. A majority of the specimens are slightly etched. Fine structures are missing, but no diagnostic changes of form are evident in light microscopy. Rim margins of placoliths are slightly serrate. All taxa may be easily identified. Diversity is normal.  
 P = Poor preservation. A majority of the specimens are deeply etched. Identity of many centerless and fragmented specimens is questionable. Diversity is low.

### PALEOMAGNETIC STRATIGRAPHY

The paleomagnetic reversal sequence for the Cenozoic and Late Cretaceous (Fig. 12) is from the recent compilation of Ness et al. (1980) based in part on the previous time scales of Blakely and Cox (1972), Heirtzler et al. (1968), Klitgord et al. (1972, 1975), and LaBrecque et al. (1977).

The Santonian/Campanian boundary is considered to be at the top of Anomaly 34, following Alvarez et al. (1977) studies of the Gubbio section in Italy.

### Age Determinations

Many alternative time scales are currently in use, with varying calibrations of planktonic foraminiferal, calcar-

eous nannoplankton, and other fossil zones, stages, and epoch boundaries to magnetic reversal scales and to numerical time scales. For age determinations we have used paleontologic evidence and the time scale of Vincent (1977) for the Neogene (Table 3); paleontologic evidence and the time scale of Hardenbol and Berggren (1978) for the Paleogene (Table 4); and paleontologic and paleomagnetic evidence for stage boundaries in the Cretaceous, with their ages determined from the Obradovich and Cobban (1975) time scale except that to maintain consistency among discussions of the basement age throughout the volume we used van Hinte's (1976) estimate of 100 m.y. for the age of the Albian–Cenomanian boundary. Hay et al. (1982) had used 94 m.y. for the Albian–Cenomanian boundary. Final revisions of the stratigraphic ages are presented in Steinmetz et al., this volume (Table 5).

### ORGANIC GEOCHEMISTRY

The main geochemical objectives of Leg 75 were to investigate the gas composition of gas-rich sediment intervals, to determine the organic carbon and nitrogen contents of the sediments at selected horizons, and to evaluate the origin and maturity of the sedimentary organic matter using the Girdal Rock-Eval.

### Gas Analyses

Gaseous hydrocarbons in the recovered cores are routinely monitored, because the prospect of drilling into a hydrocarbon accumulation without riser capability presents a danger to the ship and personnel and poses a threat of widespread pollution from an uncontrollable oil release. From the data it is also possible to learn about the biogenic or thermal origin of the gases, the extent of diagenesis and maturation of the organic matter, and to distinguish between gases generated *in situ* and those migrated from other sources. The absence of hydrocarbon gases often suggests poor preservation of organic matter arising from highly oxidizing conditions of deposition, low sediment-accumulation rates, low productivity, or a combination of these factors.

### METHODS

The standard shipboard procedure for sampling gas shows involves puncturing the core liner and collecting the gas mixture via a stopcock into a "vacutainer" soon after core recovery or division into sections. In some instances an additional sample was taken several minutes afterwards when further gas shows appeared on standing.

Two gas chromatographs (GC) were used for routine analysis of gas shows; a Carle 8000 for methane and a Hewlett-Packard 5711A for ethane through pentane ( $C_2$ – $C_5$  components). The Carle GC is equipped with a thermal conductivity detector and a QS column (1.5 m  $\times$  3.1 mm O.D.). Typically, it is operated isothermally at 45°C, with nitrogen as the carrier gas (20 psi, 15 ml/min.). The detection unit of the instrument was calculated as 200 ppm for  $CH_4$  from calibration with a standard. In addition to methane, air,  $CO_2$ , and  $H_2S$  were also detected with the Carle 8000; 1-ml and 250-ml injections were used for samples and standards, respectively.

$C_2$  to  $C_5$  hydrocarbon gases were investigated using the Hewlett-Packard 5711A fitted with a flame ionization detector, using helium as a carrier (60 psi, 15 ml/min.). To enhance sensitivity to other hydrocarbon gases, methane was flushed ( $-70^\circ C$ ) through the system with helium, while the other components were condensed in a cooling loop (20 cm  $\times$  3.1 mm O.D.) packed with Analabs 60/80 mesh alumina precooled to ca.  $-70^\circ C$  (refrigerated propan-2-ol bath). After 90 sec-



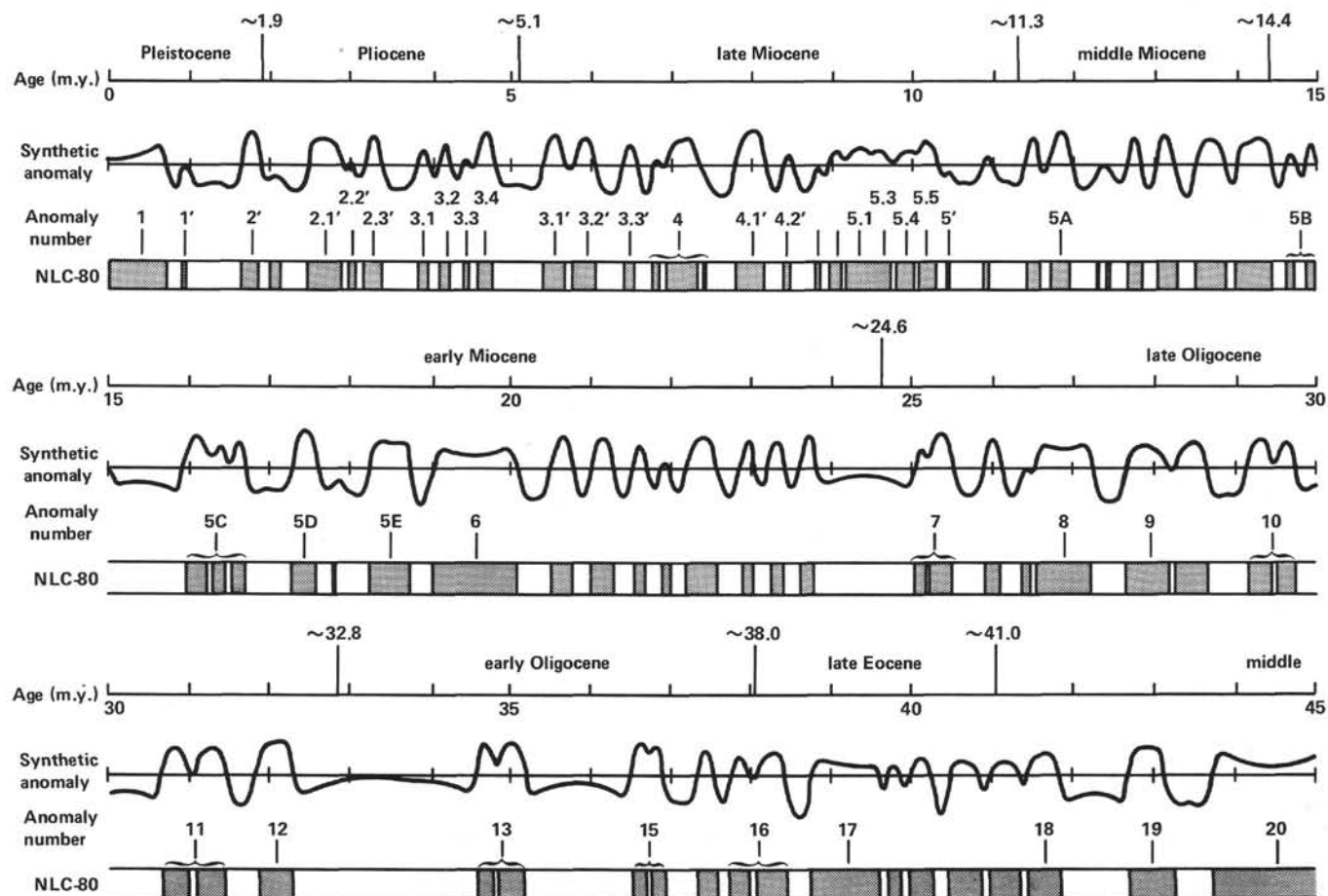


Figure 12. Magnetic reversal time scale (after Ness et al., 1980).

onds flushing the trapping loop was closed (via Carle 2014 micro-volume sampling valve) and heated for 60 seconds in a hot water bath (90–100°C). Then the sample was introduced into the GC column (1.8 × 3.1 mm O.D. 40–100 mesh Spherosil linked to 3.6 m × 3.1 mm O.D. 20% OV-101 on 100/110 mesh Anakrom AS) using the sampling valve. The column was programmed from 60–200°C at 8°C min<sup>-1</sup>, and then held isothermally at 200°C for about 10 min. Peak mensuration was performed by an integrator (Columbia Scientific Instruments Supergrator 1), and the sensitivity and performance of the gas chromatograph was monitored using four different standard mixtures (Scott mixtures 1, 2, 7, and 60) that contained various normal, branched, and cyclic gaseous alkanes. These standard mixtures were used to provide retention times employed for gas identifications and to construct GC response plots for these light hydrocarbons. The gas detection limits, calculated from the standards, ranged from ca. 0.025 ppm for ethane to 0.007 ppm for 3-methylpentane, assuming a 10-ml sample injection volume. For standards, 1 ml or 100 ml injections were routine. Blank analyses always gave four spurious peaks in the C6 regions attributable to the vacutainer septa, which precluded analysis of hydrocarbons with GC retention times greater than that of pentane. Further details of the analytical procedures for the Hewlett-Packard GC are given by Whelan (1979).

### Organic Carbon and Nitrogen Contents

A fundamental parameter of organic geochemical investigations of sediments is the organic carbon content, because it is directly related to the amount of organic matter present. In addition, it can be indicative of the depositional environment of the sediment, because the degree of preservation of organic matter is determined by interrelated physical, chemical, and biological factors. The autochthonous generation of organic matter,

the allochthonous input of organic matter, the oxicity/anoxicity of the depositional environment, and the sedimentation rate are four major factors that affect the quantity of organic carbon incorporated into sediments. These factors effectively determine the amount of organic material originally present in a sediment and the extent of preservation of that organic material, but they do not determine the final organic carbon content of a sediment because chemical modification of the organic matter takes place during diagenesis. Post-depositional changes generally influence the nature of the organic matter rather than the quantity present, unless migrational processes occur.

The factors governing the nitrogen content of sediments are less well understood than those controlling the amount of organic carbon present, but, in general, similar criteria apply. The geochemically important biogenic nitrogen compounds include the amino acids and their proteins and the tetrapyrroles, namely chlorophylls, chlorins, and porphyrins. Recent studies have shown that the majority of the nitrogen content of sediments is contained within polymeric kerogen molecules rather than in extractable components. One parameter of use is the C/N atomic ratio because high values are characteristic of terrestrial material, whereas low values typify marine organic matter. Unfortunately, changes during diagenesis significantly affect the ratio and limit its utility.

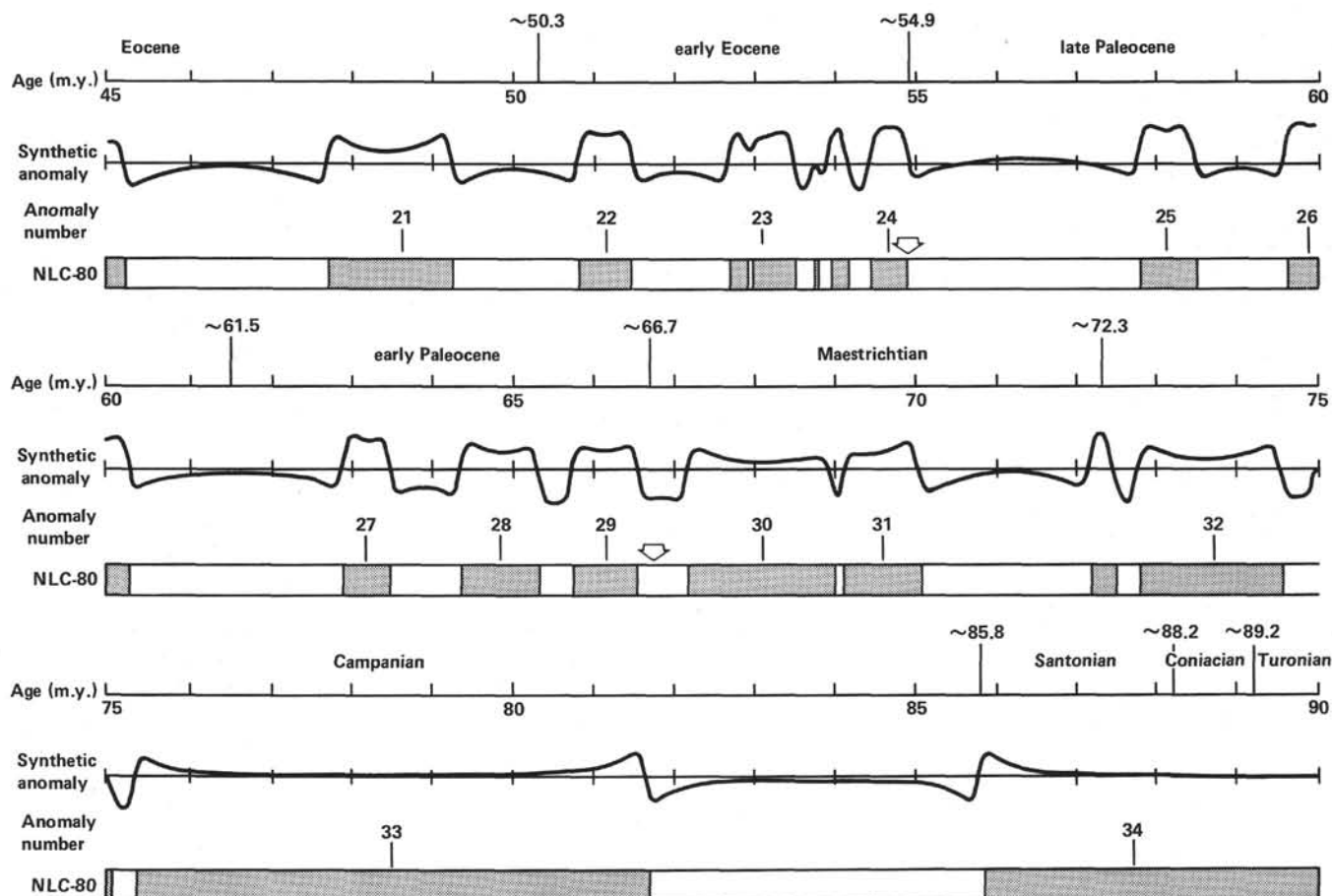


Figure 12. (Continued).

### METHODS

Shipboard organic carbon analyses were done using a Hewlett-Packard 185-B CHN analyzer with helium as the carrier gas (60 psi, 120 ml/min.). Portions of samples selected from each core for carbonate bomb measurements were treated with dilute HCl to remove carbonate, washed with deionized water, and dried at 110°C. A Cahn electrobalance, mounted on a gimbal, was used to weigh 20 mg samples of sediment for CHN analysis. It has an estimated accuracy of  $\pm 0.2$  mg, depending upon sea conditions. Samples were combusted at 1050°C with preconditioned oxidant (25 mg), and the volumes of the evolved gases determined by gas chromatography as measures of the C, H, and N contents of sedimentary organic matter. Areas of gas peaks were determined with a CSI mini-lab integrator and compared to those of standards of known carbon content (Table 6). Concentrations of H and N are not known in these standards with the exception of USGS SDO-1. Leventhal et al. (1978) reported total N of 0.34% and organic N of 0.21%. These values were used to standardize instrument response for determining C/N atomic ratios. This approach differs from earlier shipboard procedures which used a synthetic CHN standard to determine nitrogen response factors. Values for hydrogen contents obtained by the shipboard methods are untrustworthy because of the presence of clay minerals and their hydrates.

The Rock-Eval is a pyrolysis instrument capable of identifying the terrestrial, marine, or mixed origin of organic matter; the total quantity of oil that it could generate given suitable thermal maturation (petroleum potential); the effect of maturation processes (maturity); and the presence of oil shows within reservoir rocks ("free" hydrocarbons). The investigation of a selection of downhole samples enables monitoring of changes in these parameters with increasing depth and thermal maturity.

Sedimentary organic matter can be conveniently subdivided into solvent-extractable, lipid, or free hydrocarbon fractions and solvent-

inextractable or bound hydrocarbon fractions released by thermal alteration of the kerogen. The proportion of these two fractions of organic matter changes with the thermal maturity of a sediment. The free hydrocarbon content can be enhanced or depleted by migration processes, whereas the bound hydrocarbons represent a potential oil source that will yield petroleum under sufficient thermal treatment. The Rock-Eval provides a means of determining the amounts of free ( $S_1$ -peak) and bound ( $S_2$ -peak) hydrocarbons in a single analysis. In addition, the  $S_3$  peak obtained is related to the amount of oxygen present in the kerogen. For Rock-Eval pyrolysis each sample is heated at 25°C/min. in a helium atmosphere from 250°C up to 550°C. The gas stream containing the released compound is split, with part directed toward a flame ionization detector (FID) for monitoring the hydrocarbons (yielding  $S_1$  and  $S_2$  peaks) and part toward a device for trapping  $CO_2$ . At the end of the FID run the  $CO_2$  trap is heated up and the absorbed  $CO_2$  is measured by a thermal conductivity detector ( $S_3$  peak).  $S_2$ ,  $S_3$ , and organic carbon content values enable the calculation of Hydrogen Index (HI) in mg hydrocarbon/g organic carbon and of Oxygen Index (OI) in mg  $CO_2$ /g organic carbon. A plot of HI versus OI provides an indication of the source of the organic matter, consistent with the H/C versus O/C atomic ratios of the kerogens. Kerogen types I and II derived from aquatic organisms possess high H/C ratios (high HI) and low O/C ratios (low OI), whereas those of terrestrial origin (type III) possess high O/C ratios (high OI) and low H/C ratios (low HI). With increasing maturity the organic matter tends toward lower H/C and O/C ratios, to a point where the three types are indistinguishable. Type I kerogens are excellent oil source rocks, type II moderate source rocks, and type III poor source rocks. When data from the Rock-Eval are combined with a value of organic carbon, the origin and maturity of the organic matter can be deduced. In addition, the temperature of the maximum of the  $S_2$  peak from the Rock-Eval increases with increasing sample maturity. The Leg 75 samples were allowed to dry at room temperature and then coarsely ground. The

Table 3. Time scale for the Neogene (Vincent, 1977).

Magnetic epoch	Time (m.y.)	Epoch	Plank. foram. zones Blow (1969)	Calcareous nannoplankton zones			Radiolarian zones Riedel and Sanfilippo (1971)	Diatom zones Schrader (1974)
				Martini (1971)	Gartner (1974)	Bukry (1973a)		
Brunhes		Pleistocene	N23	NN21 <i>E. huxleyi</i> NN20 <i>G. oceanica</i>	<i>E. huxleyi</i> <i>G. oceanica</i>	<i>E. huxleyi</i> <i>G. oceanica</i>	"Quaternary"	TID 1
Matuyama	1		N22	NN19 <i>P. lacunosa</i>	<i>P. lacunosa</i>	<i>G. caribbeanica</i> <i>E. annula</i>		
	2	late	N21	NN18 <i>D. brouweri</i> NN17 <i>D. pentaradiatus</i>	<i>D. brouweri</i>	<i>C. macintyreii</i> <i>D. pentaradiatus</i>	<i>P. prismatium</i>	TID 7
Gauss	3			NN16 <i>D. surculus</i>	<i>D. surculus</i>	<i>D. tamalis</i>		TID 8
Gilbert	4	early	N20	NN15 <i>R. pseudoumbilica</i> NN14 <i>D. asymmetricus</i>	<i>R. pseudoumbilica</i> <i>D. asymmetricus</i>	<i>D. asymmetricus</i> <i>S. neobabies</i>	<i>S. pentas</i>	
	5		N19	NN13 <i>C. rugosus</i>	<i>C. rugosus</i>	<i>C. rugosus</i>		TID 12
	6	late	N18	NN12 <i>C. tricorniculatus</i>	<i>C. tricorniculatus</i>	<i>C. acutus</i> <i>T. rugosus</i>	<i>S. peregrina</i>	TID 13
5	7				<i>D. quinquenarius</i>	<i>C. primus</i>		TID 15
6	8	late	N17	NN11 <i>D. quinquenarius</i>	<i>D. neohamatus</i>	<i>D. berggrenii</i>	<i>O. penultimus</i>	TID 16
7	9					<i>D. neoerectus</i>		
8	10	late	N16			<i>D. bellus</i>	<i>O. antepenultimus</i>	
9	11			NN10 <i>D. calcaris</i>				TID 21
10	12	middle	N15	NN9 <i>D. hamatus</i>	<i>D. hamatus</i>	<i>D. hamatus</i>	<i>C. petterssoni</i>	
11	13		N14	NN8 <i>C. coalitus</i>	<i>C. coalitus</i>	<i>C. coalitus</i>		
12	14	middle	N13	NN7 <i>D. kugleri</i>	<i>D. exilis</i>	<i>D. kugleri</i>		
13	15		N12	NN6 <i>D. exilis</i>		<i>C. miopelagicus</i>		
14	16	early	N11				<i>D. alata</i>	
15	17		N10					
	18	early	N9	NN5 <i>S. heteromorphus</i>	<i>S. heteromorphus</i>	<i>S. heteromorphus</i>		
	19		N8					
16	20	early	N7	NN4 <i>H. ampliaperta</i>		<i>H. ampliaperta</i>	<i>C. costata</i>	Unzoned
17	21							
18	22	early	N6	NN3 <i>S. belemnus</i>	<i>S. belemnus</i>	<i>S. belemnus</i>		
19	23							
20	24	late	N5	NN2 <i>D. druggi</i>	<i>T. carinatus</i>	<i>D. druggi</i>	<i>C. virginis</i>	
21	25					<i>D. deflandrei</i>		
		late	N4	NN1 <i>T. carinatus</i>		<i>C. abisectus</i>	<i>L. elongata</i>	
22								
		Oligo.	P22	NP25 <i>S. ciperoensis</i>	<i>S. ciperoensis</i>	<i>S. ciperoensis</i>	<i>D. ateuchus</i>	

Note: References cited in this table appear in Vincent, 1977.

Table 4. Time scale for the Paleogene (after Hardenbol and Berggren, 1978).

Paleogene time scale																			
Geochronometric scale (m.y.)	Magnetic anomalies	Epochs	Plankton zones																
			Foraminifers				Calc. nanofossils Martini and Worsley, 1970; Martini, 1970, 1971; Müller, 1974	Radiolarians <sup>a</sup>											
			Blow, 1969; Berggren and Van Couvering, 1974	(After Bolli 1957a, b, c, 1966; Stainforth et al., 1975)															
25	6B	Oligocene	late	N4		<i>Globigerina ciperoensis</i>	NP25	12											
26	7			P22															
27	8			P21	b	"Globovalia" <i>opima opima</i>	NP24												
28	9								a										
29	10																		
30	11			P20	<i>Globigerina ampliapertura</i>		NP23												
31	12		early	P19	<i>Cassigerinella chipolensis</i>  —	NP22													
32	13						P18		<i>Pseudohastigerina micra</i>										
33	14									P17	<i>Turborotalia cerroazulensis</i> s.l.	NP21							
34	15												P16	<i>Globigerinatheka seminvoluta</i>	NP20				
35	16															P15	NP19		
36	17	Eocene	late	P14	<i>Truncorotaloides rohri</i>	NP17	15 16 17												
37	18							P13	<i>Orbulinoides beckmanni</i>	NP16									
38	19										P12	<i>Morozovella lehneri</i>							
39	20												P11	<i>Blobigerinatheka subconglobata</i>	NP15				
40																			
41																			
42			early	P10	<i>Hantkenina aragonensis</i>	NP14													
43								P9	<i>Acarinina pentacamerata</i>	NP13									
44											P8	<i>Morozovella aragonensis</i>	NP12						
45														P7	<i>M. formosa formosa</i>	NP11			
46																	P6	<i>M. subbotinae</i>	NP10
47																			

grain size of the resulting sample was therefore not too fine for the pyrolysis because such a sample releases small particles of sediment during the analysis and, as a consequence, interferes with the FID response and contaminates the detector. A sample size of 100 mg was typically used except for sediments suspected to be rich in organic matter ( $C_{org} < 10\%$ ), when between 10 and 50 mg was deemed sufficient. A detailed account of the operation of the instrument and the principles on which it is based has been published elsewhere (Espitalié et al., 1977).

The standard used for calibration was I.F.P. 27251, a lower Toarcian shale from the Paris Basin which is widely used as a Rock-Eval standard. A second standard was tested during this leg: USGS SDO-1, a Devonian black shale from Ohio which was itself standardized using 27251. Both give similar Rock-Eval patterns, although SDO-1 contains about four times the organic carbon content of 27251 (Table 6).

Table 4. (Continued).

Paleogene time scale									
Geochronometric scale (m.y.)	Magnetic anomalies	Epochs		Plankton zones					
				Foraminifers				Calc. nanofossils Martini and Worsley, 1970; Martini, 1970, 1971; Müller, 1974	Radiolarians <sup>a</sup>
				Blow, 1969; Berggren and Van Couvering, 1974	(After Bolli 1957a, b, c, 1966; Stainforth et al., 1975)				
48		Paleocene	early	P10	<i>Hantkenina aragonensis</i>				21
49				P9	<i>Acarinina pentacamerata</i>			NP14	22
50				P8	<i>Morozovella aragonensis</i>			NP13	23
51	21			P7	<i>M. formosa formosa</i>			NP12	24
52				P6	<i>M. subbotinae</i>			NP11	25
53	22				<i>M. edgari</i>			NP10	
54			P5	<i>Morozovella velascoensis</i>			NP9		
55	23								
56			late	P4	<i>Planorotalites pseudomenardii</i>			NP8	
57	24						NP7		
58							NP6		
59	25			P3	<i>Planorotalites pusilla pusilla</i>			NP5	
60		early	P2	<i>Morozovella uncinata</i>			NP4	Not zoned	
61	26						NP3		
62			P1	d	<i>Subbotina trinidatensis</i>				
63	27			c					
64				b	<i>S. pseudobulloides</i>				NP2
65	28			a	"Globigerina" <i>eugubina</i>				NP1
66	29								
67									
68									
69									
70									
71									
72									
73									
74									
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Note: References cited in this table appear in Hardenbol and Berggren, 1978.

<sup>a</sup> Riedel and Sanfilippo (1970, 1971); Moore (1972); Foreman (1973); Theyer and Hammond (1974).

<sup>b</sup> Radiolarian zones (numbers refer to footnotes only): 12. *Dorcadospirites atechus* 13. *Theocyrtis tuberosa* 14. *Theocyrtis bromia* 15. *Thyrsoyrtis tetracantha* 16. *Podocyrtis goetheana* 17. *Podocyrtis chalara* 18. *Podocyrtis mitra* 19. *Podocyrtis ampla* 20. *Thyrsoyrtis triacantha* 21. *Theocampe mongolfieri* 22. *Theocotyle cryptocephala* 23. *Phormocyrtis striata striata* 24. *Burycella clinata* 25. *Bakoma bidartensis*.

## PHYSICAL PROPERTIES

### METHODS



Table 5. Mesozoic time scale, biostratigraphic zonation, and magnetic anomaly sequence used on Leg 75.

Age (m.y.)		Planktonic foraminiferal zones <sup>a</sup>	Calcareous nannoplankton zones	Magnetic anomaly sequence
	Stage			
65	Maestrichtian	<i>Globotruncana mayaroensis</i>	<i>Micula mura</i>	29
		<i>Globotruncana gansseri</i>	<i>Lithraphidites quadratus</i>	30
		<i>Globotruncana havanensis</i>	<i>Arkhangelskiella cymbiformis</i>	31
				32
70	Campanian	<i>Globotruncana calcarata</i>	<i>Tetralithus trifidus</i>	33
75		<i>Globotruncana ventricosa</i>	<i>Eiffellithus eximius</i>	
		<i>Globotruncana fornicata</i>		
82	Santonian	<i>Globotruncana concavata carinata</i>	<i>Marthasterites furcatus</i>	34
		<i>Globotruncana concavata</i>		
86	Coniacian	<i>Globotruncana primitiva</i>		
		<i>Globotruncana sigali</i>	<i>Micula staurophora</i>	
87	Turonian	<i>Globotruncana helvetica</i>		
		<i>Hedbergella portsdownensis</i>	<i>Corollithion exiguum</i>	
89.5	Cenomanian	<i>Rotalipora cushmani</i>	<i>Lithraphidites alatus</i>	
		<i>Rotalipora reicheli</i>		
		<i>Rotalipora greenhornensis</i>		
		<i>Rotalipora gandolfii</i>		
		<i>Rotalipora brotzeni</i>		
100	Albian	<i>Rotalipora apenninica</i>	<i>Eiffellithus turrisseiffeli</i>	

<sup>a</sup> The foraminiferal zonal widths are not indicative of the duration within individual stages.

Table 6. Organic carbon standard.

Standard	Total C(%)	C <sub>org</sub> (%)	Source
AWM	0.45	0.27	Phillips Petroleum Co.
AVB	0.57	0.45	Phillips Petroleum Co.
66-488-16	2.97	2.50	DSDP
63-467-58-3	8.90	4.31	DSDP
SDO-1	10.40	10.06	USGS
27251	2.68	2.48	Rock-Eval standard

Gravimetric wet-bulk density, wet water content (ratio of the "weight of pore water" to "weight of the wet saturated sediment or rock," expressed as a percent), and porosity (ratio of "pore volume" to the "volume of the wet-saturated rock," expressed as percent) were determined by traditional gravimetric techniques by William Meyer onboard ship. These gravimetric measurements were on 10 to 30 g samples using weight in air and weight in water to determine volume.

The sample was then dried at 105°C for 24 hours and cooled in a desiccator for at least two hours before weighing (Ohaus Triple Beam Balance; Rocker, 1974). (While waiting to be processed, the samples were wrapped in plastic, placed in plastic vials with damp tissue, sealed, and stored in refrigerator at a temperature above freezing.) A salt correction for 35 ppt interstitial water salinity was applied to porosity and wet water content (see Appendix I, this volume). The gravimetric density, with good firm samples, have an accuracy and precision of <0.01 g/cm<sup>3</sup>.

However, shipboard gravimetric determinations of density may be less accurate with softer samples, which may crumble or flake off during measurement or simply prove too soft to handle properly.

To avoid these problems in softer sediment a "Cylinder Technique" (15 cm<sup>3</sup>) sample is taken and stored under seawater; its gravimetric porosity and density are determined at DSDP headquarters in La Jolla. Precision is ±1% relative error. This technique uses a 2 cm high and ~3 cm diameter metal cylinder which is inserted in the sediment, then carefully removed, and cleaned; the sediment is carefully scraped flush to the top of the cylinder, then two plastic plates are placed over the cylinder ends.

Before the plates are placed on the cylinder, they have a 2-min. GRAPE count done through them. Then another 2-min. count is made through the same plates plus the sediment (through axis of the cylinder), so that a 2-min. GRAPE density value can also be calculated. Almost all HPC data were acquired using this technique.

In general, sound velocity samples were allowed to reach room temperature (four hours in unsplit core) before sampling. Because of curatorial procedures required for basalt, and because drying seriously affects basalt velocities, the velocity of the basalts was measured as soon as they arrived on deck (~10°C, cold) across the diameter of the core. If they are slightly air-dried, errors as great as 0.3 km/s (<8%) may occur; the error caused by temperature differences is less than 1% for 24°C to 2°C. The error of the shipboard measurements is chiefly a result of temperature and is <1%, because the core is as fully water-saturated as is possible at the time the measurement is made.

## GEARHART-OWEN WELL LOG EQUIPMENT

During Leg 75 of the DSDP Gearhart-Owen Industries wire-line well logging tools were run in Hole 530A. The tools and logging results are discussed in the chapter on Site 530 and in Appendix I.

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**Date of Initial Receipt: July 21, 1982**