1. INTRODUCTION

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DSDP PROGRAM IN THE INDIAN OCEAN

The geologic and oceanographic histories of the Indian Ocean were investigated by drilling 52 sites (Figure 1) during six legs of the Deep Sea Drilling Project (Legs 22-27). Leg 25 was the fourth of the legs. Leg 22 (Sites 211-218) was in the eastern and northeastern Indian Ocean, where studies concentrated on tectonics associated with the Ninetyeast Ridge, on sea floor spreading histories in the Wharton and Central Indian basins, and on the development of the Bengal Fan. Leg 23 was divided into two segments, 23a and 23b. Leg 23a drilled in the Arabian Sea (Sites 219-224), where sites were selected to date the oceanic crust, to investigate the Owen Fracture Zone and Laccadive-Chagos Ridge, and to study the geologic history in the southeastern Arabian Sea and the Indus Cone. The objectives of Leg 23b (Sites 225-229) were to learn more about the origin and extent of the heavy metal-rich deposits in parts of the Red Sea Basin and to ascertain the geologic history of the Red Sea. Leg 24 (Sites 230-239) undertook investigations of the Gulf of Aden, the eastern and northwestern Somali Basin, the Mascarene Plateau, Central Indian Ridge, and Chagos-Laccadive Plateau region. Leg 25 drilled 11 sites (Sites 239-249) in the western and southwestern Indian Ocean. Nine sites (Sites 250-258) were occupied during Leg 26, which investigated the history of the southwest branch of the Indian Ocean Ridge. the nature and history of the southern part of the Ninetyeast Ridge, and the geologic histories of Broken Ridge and the southern Wharton Basin. Leg 27 drilled five sites (Sites 259-263) in the eastern Indian Ocean near the Australian continental margin and in the Timor Trough.

LEG 25 PROGRAM IN THE WESTERN INDIAN OCEAN

Leg 25 provided the first opportunity to study the relatively unknown basins and ridges of the western Indian Ocean (Figure 2). The leg originated in Mauritius and ended in Durban, South Africa after a nearly circuitous route around Madagascar.

The drilling program was set up to drill as many of the physiographic provinces as possible and, therefore, no two successful holes were drilled in any one province. Among the physiographic provinces drilled were the Mascarene Basin (Site 239), Somali Basin (Site 240), East African continental rise (Site 241), Davie Ridge in the Mozambique Channel (Site 242), Mozambique Channel (Sites 243 and 244), Madagascar Basin (Site 245), Madagascar Ridge (Sites 246 and 247), Mozambique Basin (Site 248), and Mozambique Ridge (Site 249).

Because of the nature of this drilling program, Leg 25 results were designed to provide a broad understanding of the western Indian Ocean rather than to concentrate on any one problem or group of related problems as some legs in the Indian Ocean have been able to do (e.g., Legs 22 and 23).

LEG 25 OBJECTIVES AND SITE SELECTIONS

The original objectives of Leg 25 were (a) to determine the age and mode of formation of the western Somali Basin and its western margin on the East African continental rise near Kenya, (b) to establish as deeply as possible the stratigraphic column in the Mozambique Channel, (c) to determine the significance of the Davie Ridge in relation to possible movements of Madagascar, (d) to determine if the basement of the Madagascar and Mozambique ridges are of continental or oceanic type and to establish on these ridges a midlatitude biostratigraphic succession above the carbonate compensation depth (CCD), (e) to check the proposed magnetic anomaly pattern in the Madagascar and Crozet basins, which lie on both sides of the Southwest Indian Ridge, and which are related to spreading from the Central Indian Ridge and the Southeast Indian Ridge, respectively, and (f) to provide lithologic and paleontologic data relating to the initiation of uplift and activity of the Southwest Indian Ridge.

Although most objectives were successfully fulfilled, technical difficulties and time requirements did force the cancellation of some. We were unable to successfully drill a deep hole in the Mozambique Channel and to reach the acoustic basement on Madagascar Ridge because of technical difficulties associated with hole stability. Also, because of time requirements in relation to ship's speed over the exceptionally long distance planned, and to a major mid-cruise change in the drilling program, which originated from the JOIDES Indian Ocean Panel, we were not able to drill the site in the Crozet Basin; rather, the scientific crew on Leg 26 drilled that site (Site 252).

The selection of drilling sites was based primarily upon the results of detailed site surveys and other relevant data provided by the following organizations: Institut de Physique du Globe, Université de Paris; Lamont-Doherty Geological Observatory of Columbia University; Department of Geology, University of Capetown; and the Woods Hole Oceanographic Institution. Although these data were helpful, it still was necessary to do some site surveying at Sites 240, 242, 245, 246, 247, and 248 before dropping the beacon.

LEG 25 OPERATIONAL SUMMARY

Glomar Challenger left Mauritius on June 28, 1972, and terminated its cruise in Durban, South Africa on August 22,

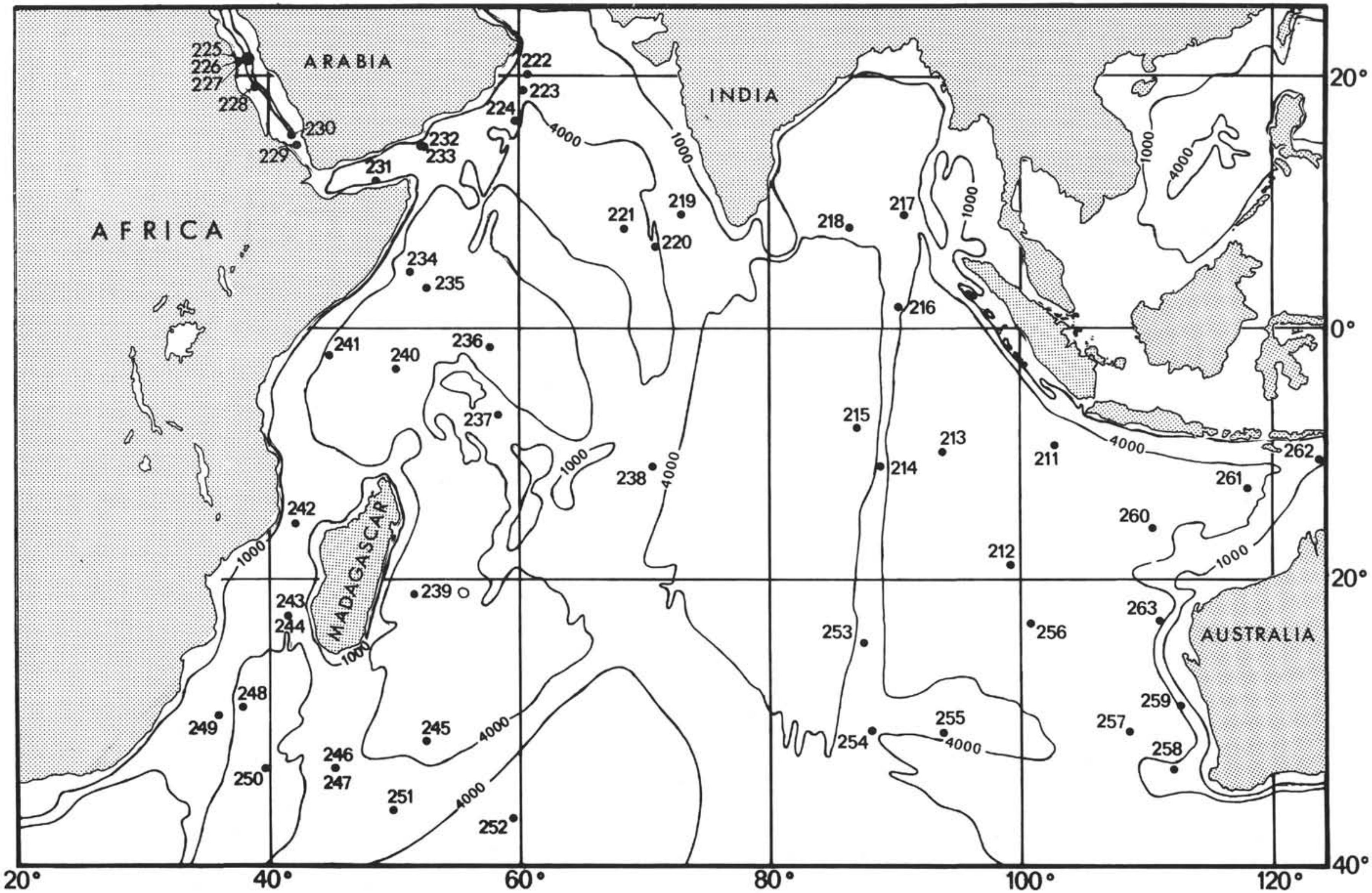


Figure 1. *DSDP drill sites in the Indian Ocean.*

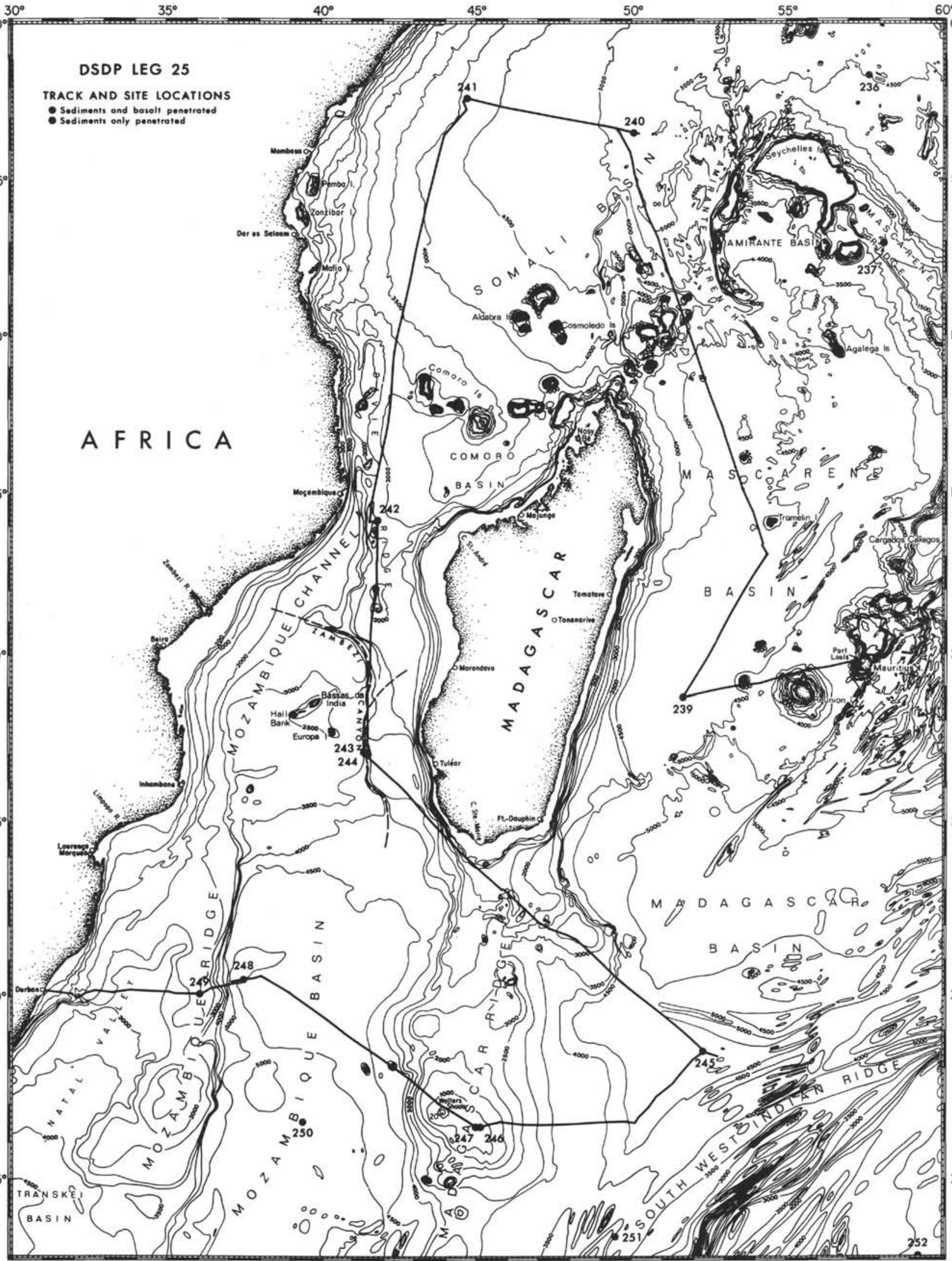


Figure 2. *The western Indian Ocean with sites drilled on Leg 25.*

1972, having steamed 5408 miles and drilled 13 holes at 11 sites. Total time and onsite time distributions are given in Figures 3 and 4 and the coring summary is presented in Table 1. Underway measurements are comprehensively presented by Schlich (Appendix I, this volume), and drilling operations are succinctly given by Shore (Appendix II, this volume).

Stormy weather was not a major factor on Leg 25, but it did cause the cancellation of an intermediate hole between Sites 245 and 246. The major problem, however, was vessel

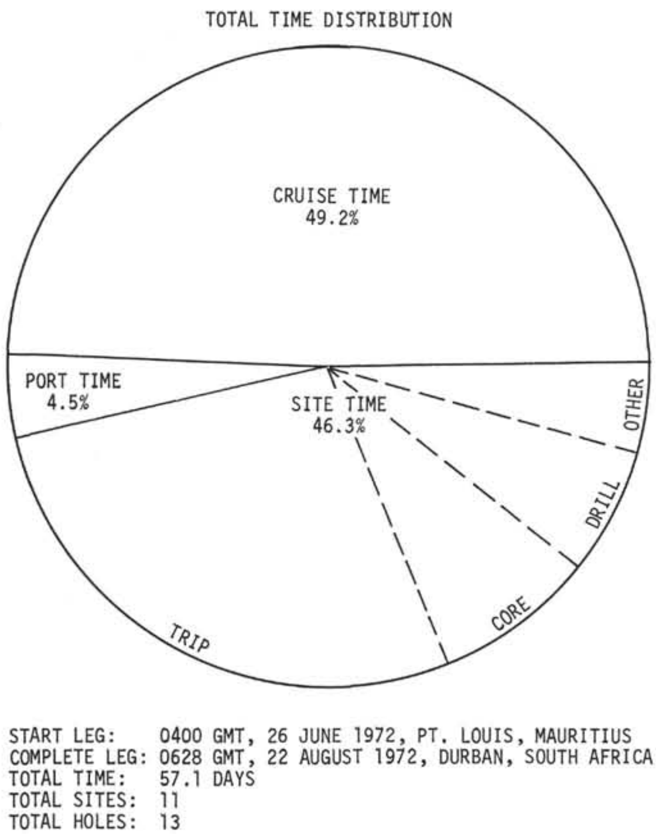


Figure 3. *Total time distribution, Leg 25.*

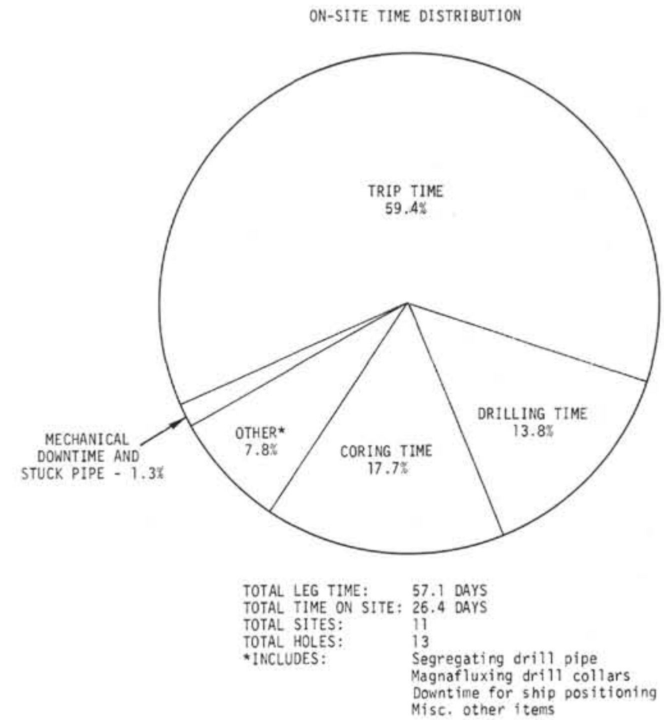


Figure 4. *Onsite time distribution, Leg 25.*

positioning in confused seas. Drilling at 9 of the 13 holes was hindered when the sea, wind, swell, and/or current came from different directions, thus precluding ideal positioning of the vessel and resulting in operations that were hampered by vessel motion. At Site 248, for example, a 4-5 knot current was experienced from one direction while swells came from three other directions.

DRILLING RESULTS AT LEG 25 SITES

Locations, major objectives, and some drilling results are summarized in this section, whereas lithologic and paleontologic descriptions and interpretations are given in summary form in the regional summary (Schlich, et al., this volume).

TABLE 1
Coring Summary, Leg 25

Hole	Dates (1972)	Location	Water Depth (m)	Subbottom Penetration (m)	No. of Cores	Cored (m)	Recovered (m)	Recovery (%)
239	30 June-3 July	21°17.67'S, 51°40.73'E	4971	326	21	175	106.1	61
240	9-10 July	03°29.24'S, 50°03.22'E	5082	195	8	53	25.1	47
240A	11-12 July	03°29.24'S, 50°03.22'E	5082	202	4	34	3.2	9
241	13-18 July	02°22.24'S, 44°40.77'E	4054	1174	29	252	136.7	54
242	23-26 July	15°50.65'S, 41°49.23'E	2275	676	19	134	103.1	77
243	28-29 July	22°54.49'S, 41°23.99'E	3879	32	1	6	0.3	5
244	29 July	22°55.87'S, 41°25.98'E	3768	27	1	3	0.0	0
245	2-6 August	31°32.02'S, 52°18.11'E	4857	397	19	151	82.1	55
245A	6-7 August	31°32.02'S, 52°18.11'E	4857	149	7	63	47.4	75
246	9-10 August	33°37.21'S, 45°09.60'E	1030	203	11	94	23.8	25
247	10-11 August	33°37.53'S, 45°00.68'E	944	26	1	8	0.0	0
248	13-17 August	29°31.78'S, 37°28.48'E	4994	434	17	136	40.8	30
249	17-20 August	29°56.99'S, 36°04.62'E	2088	412	33	285	221.4	78
	Totals			4253	171	1394	790.0	57

Site 239

Site 239 was drilled at a water depth of 4971 meters in the abyssal plain of the western Mascarene Basin, 180 miles east of Madagascar and 200 miles west of the island of Reunion. Reflection profiles indicate 0.39 sec DT (double way time) of sediments that include an upper stratified unit and a lower transparent layer which overlies the acoustic basement. Intermittent coring recovered Pleistocene to Upper Cretaceous sediments between the sea floor and the acoustic basement at 320 meters. Six meters of basalt were cored.

The major site objectives were to sample, date, and identify the basement, and to establish the stratigraphic sequence. Another objective was to determine the nature of the older transparent layer that forms not only diapir-like instrusions, but also an uneven upper surface which crops out as positive relief features above the abyssal plain.

Site 240 (Holes 240 and 240A)

Holes 240 and 240A were drilled in the central abyssal plain of the western part of the Somali Basin, 500 miles from the African coast and 350 miles from the Seychelles Islands and in a water depth of 5082 meters. The primary objectives were to determine the lithology, biostratigraphy and age of the sediments, the probable source of the sediments, and the nature and age of basement.

The first hole (240) penetrated 190 meters of sediments plus five meters of basalt. A second hole (240A) was drilled to sample sediments that directly overlie basement, but a damaged bit precluded any significant core recovery.

Site 241

Site 241 is located on the continental rise of East Africa about 170 miles from the coast in the western part of the Somali Basin and has a water depth of 4054 meters. This site was the deepest drilled (1174 meters) during Leg 25 and records the deepest penetration up to that time into a continental rise. One of the principal objectives was to establish the bio- and lithostratigraphic succession with particular reference to the post-Karroo epeirogenic movements of East Africa and the evolution of the continental margin.

Site 242

Site 242 was drilled on the eastern flank of the asymmetric and weakly seismic Davie Ridge (also called the Mozambique Fracture Zone), a north-south trending positive morphologic feature in the Mozambique Channel between Africa and Madagascar. Acoustic basement here is covered by about 0.75 seconds (DT) of transparent sediments. A principal reason for drilling this hole was to provide data that can be used to solve the enigmatic problem of time and space relationships between Africa and Madagascar. In particular, the objectives were to (a) determine the composition and age of the acoustic basement at 0.75 seconds (DT), and (b) sample and date the acoustically transparent sediment cover in order to establish a midlatitude faunal succession for the western Indian Ocean. The hole was drilled and intermittently cored to a depth of 676 meters.

Sites 243 and 244

Sites 243 and 244 are located about 5 km apart in the Zambesi Canyon, which lies 600 meters deeper than the surrounding sea floor. The purpose of drilling in the deep canyon floor was to achieve maximum penetration into the thick sediments of the southeastern Mozambique Channel for (a) comparison with onshore stratigraphic successions in Madagascar and Mozambique, and (b) possible identification of a prominent acoustic reflector at a depth of 1.4 sec (DT) beneath the canyon floor.

At Site 243, only one punch core, with very poor recovery, was taken between 0 and 6 meters below the sea floor. After penetration to 32 meters in unconsolidated coarse sands and gravels, it was decided, for technical reasons relating to instability of the hole, to abandon the site and attempt another hole in the eastern, lower slope of the canyon. At the second site, only a core catcher sample was obtained, and after 27 meters of penetration, this site also was abandoned due to technical problems.

Site 245 (Holes 245 and 245A)

Holes 245 and 245A are located in the southern Madagascar Basin, about 300 miles east of the Madagascar Ridge crest and about 200 miles northwest of the Southwest Indian Ridge axis, and have a water depth of 4857 meters. According to the magnetic anomaly pattern proposed by Schlich et al. (1972), it was anticipated that Site 245 would be on anomaly 28 (~68 m.y.). Principal objectives were to (a) sample, identify, and date the acoustic basement, (b) check the proposed magnetic anomaly pattern in the Madagascar Basin, and (c) establish the biostratigraphic sequence for comparison between the Madagascar and Crozet basins close to the north and south flank, respectively, of the Southwest Indian Ridge. Hole 245 was drilled and intermittently cored to a depth of 396.5 meters, which included 7.5 meters of basalt. A second hole, 245A, was drilled in order to more effectively sample the 20- to 150-meter interval.

Sites 246 and 247

Sites 246 and 247 were drilled nine miles apart near the crest of the Madagascar Ridge, about 480 miles south of Madagascar, in a water depth of 1030 meters. Sediments of variable thickness are underlain by a high sonic velocity layer (5 km/sec), which is either ridge basement or a superimposed layer of compact sedimentary rock. The major objectives in drilling on the Madagascar Ridge were (a) to reach and sample the high velocity layer, and (b) to sample the younger sediments as completely as possible in order to establish a midlatitude biostratigraphic succession that accumulated above the CCD.

The penetration at Site 246 was 203 meters, but at this depth, unstable hole conditions in unconsolidated coarse-grained sediment caused abandonment of the site. An attempt to drill an alternative site (247) nearer the crest of the ridge was abandoned because of the inability to penetrate a hard layer at 26 meters depth.

Site 248

Site 248 is located in the northwestern Mozambique Basin about 30 miles east of the very steep scarp slope of the Mozambique Ridge, and it has a water depth of 4994 meters. Reflection profiles indicate 0.48 sec DT of sediments that include an upper acoustically transparent layer and a lower stratified sequence which overlies the acoustic basement. Intermittent coring recovered pleistocene to middle Paleocene sediments between the sea floor and acoustic basement at 422 meters. Twelve meters of basalt were cored.

The major site objectives were to sample, identify, and date the basement; to establish the stratigraphic sequence; and to identify the nature of the uppermost transparent layer.

Site 249

Site 249 is located in a small sediment-filled basin, close to the crest of the Mozambique Ridge, near Latitude 30°S and has a water depth of 2088 meters. Reflection profiles show a very rough basement topography with overlying sedimentary accumulations of variable thickness. At the site, the sedimentary sequence includes an upper acoustically transparent layer, 0.35 sec DT thick, and a lower stratified series which rests upon the basement at a depth of 0.46 sec DT. Hole 249 was drilled and cored nearly continuously, and the acoustic basement (basalt) was reached at a depth of 408 meters and cored to 412 meters.

The main objectives of drilling this hole on the Mozambique Ridge were to sample, identify, and date the basement material and to recover a nearly complete sedimentary sequence in order to establish high midlatitude biostratigraphic succession above the CCD.

EXPLANATORY NOTES

Organization and Subdivisions of the Report

This Initial Report volume is divided into four parts. Part I consists of the "Introduction" and the various site reports which are based mostly on the work accomplished during shipboard studies at sea, but it also incorporates additional information produced by shore studies following the completion of the shipboard work. Part II contains chapters which were written by an individual author or by small groups of authors. The chapters in Part II are more speculative than those in Part I and should be considered as interpretations based on information that was available at the time the chapters were submitted. Part III consists of three summary chapters (biostratigraphic, lithologic, and regional) which were written by the shipboard scientists. The last part includes the overall volume appendices.

Material in Part I, site report chapters is arranged in a more or less standardized order as follows (authorship of various sections within the Site Reports is indicated in parentheses):

Site Data: Location, position, water depth, total penetration, number of cores taken, total length of recovery, and deepest unit recovered (Simpson and Schlich).

Background and Objectives: Description, location, geophysical knowledge, site survey, description of available data, and objectives (Schlich and Simpson).

Survey Data and Operations: Site approach (track chart), description of data collected by *Glomar Challenger*, drilling and coring program, drilling operations, and core inventory (Schlich).

Lithology: Description of column starting at the top (basalt section by Erlank and Reid, University of Capetown, South Africa and Vallier), stratigraphic column, summary and conclusions (Girdley, Leclaire, Moore, Vallier, and White).

Physical Properties: Density (GRAPE and syringe techniques), sonic velocity, heat flow, etc. (Marshall).

Biostratigraphy: Calcareous nannoplankton (Müller) and Neogene and Quaternary foraminifera (Zobel), both described from the top down, and Cretaceous and Paleogene foraminifera (Sigal) described from bottom to top. Sedimentation rates (Zobel).

Correlation of Seismic Reflection Profiles and Stratigraphy (Schlich).

Discussion and Conclusions: Summary diagram (Simpson and Schlich).

References: Includes references for entire site report.

Appendixes: Three main data presentations are given (for each site chapter).

Physical properties graphic log has a plot of density, porosity, and sonic velocity.

Core photographs (black and white) are arranged in order by hole, core, and section.

Core forms have detailed presentations of the lithology and biostratigraphy of each core recovered. Symbols used on these forms are explained in another section of this chapter (Conventions and Symbols).

Survey and Drilling Data

The survey data used for specific site selections are given in each site report chapter. Short surveys were made on *Glomar Challenger* before dropping the beacon, using a precision echo-sounder, a magnetometer, and an airgun seismic profiler.

During passage between sites, continuous observations were made of depth, magnetic field, and subbottom structure. These data are presented by Schlich (this volume) in Appendix I. Underway depths were recorded on a Gifft precision depth recorder; the depths were read on the basis of an assumed 800 fathoms/second sounding velocity. The sea depth (in meters) at each site subsequently was corrected (1) according to the tables of Matthews (1939) and (2) for the depth of the hull transducer (6 m) below sea level. In addition, any depths referred to the drilling platform were calculated under the assumption that this level is 10 meters above the water line. Water depths cited for each hole were determined from the echo-sounder because it seldom was possible to feel the bottom with the drill string.

The magnetic data were collected with a Varian proton magnetometer with the sensor towed 300 meters behind the ship. The readings, for shipboard use, were taken from an analog recorder every five minutes.

The seismic profiling system consisted of two Bolt airguns, a Scripps-designed hydrophone array, Bolt amplifiers, two bandpass filters, and two EDO recorders, usually recording a different filter settings and different scales.

The hours labeled on the original records are all GMT time and in the site report chapters, GMT time is used when referring to any of these records. For consistency, all data used for the selection of a drill site and which were provided by the previously mentioned institutions are also given in GMT time. The detailed track chart in each site report chapter is also marked in GMT time.

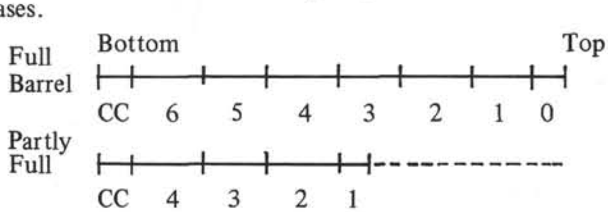
It should be stressed that it became common practice during Leg 25 to drill ahead with the inner core barrel in place. This procedure was established because of the time saved if the empty barrel were dropped down the pipe immediately after the retrieved barrel had been brought on deck. In this way, a joint had to be opened only once per core. Although during drilling it is unlikely that sediment will enter the open core barrel due to the flushing action of the water jets around the bit, this may have occasionally occurred so that part of the recovered sediment is not representative of the specified cored interval. In practice, the possibility of this being a serious problem increases as the sediments become more indurated and the length of the drilled interval increases.

Basis for Numbering Sites, Cores, Sections

Each drilling site was assigned a number, for example, Site 240. The first hole at each site carries the Site number, i.e., Hole 240; additional holes at the same site have a letter following the number. For example, Hole 240A is the second hole drilled at Site 240 and Hole 240B would have been the third hole drilled at this Site.

The cores from each hole were numbered successively in the order in which they were taken: Core 1, Core 2, etc. Because of the many uncertainties in determining depths in drill holes, the depth from which cores were taken is given only to the nearest meter. A core was taken by dropping a core barrel down the drill string, and coring for 9 meters as measured by the lowering of the drill string. Sediments were retained in a plastic liner about 9.3 meters long inside the core barrel and in a 0.40 meter long core catcher assembly below the liner. Generally, the liner was not completely full.

When the core barrel was recovered on deck, the core catcher was removed from the barrel, and any material in the catcher (as much as 25 cm in length) was labeled "core catcher", or CC. The plastic core liner was withdrawn from the steel barrel and cut into 150 cm lengths called sections, beginning at the lower end of the barrel. A liner (average length about 9.3 meters) can be cut into six such sections, with a short section about 30 cm in length left over at the top end. The numbering scheme for the sections depends on how much material is recovered. In a full barrel, the short top section is called the "zero" section, and the first 150 cm section below that is Section 1, the next, Section 2, etc. When the barrel is only partly filled, the cutting of the plastic liner proceeds as usual, starting from the bottom of the liner. The labeling, however, begins with the uppermost 150 cm section in which there is core material. That section, even if only partly full, is Section 1; the next below is Section 2, etc. the following diagram illustrates the two cases.



Within each section, individual samples or observations are located in centimeters down from the top of the section. This is true even when a section is not full of material, either because of original lack of material (a short Section 1, for example), or because of voids produced by compaction or shrinkage.

To designate a sample, a shorthand numbering system is used. Briefly, a sample designated as 25-249-15-2, 50-52 cm is from the 50-52 cm interval below the top of Section 2, in Core 15 of Hole 249, that was drilled during Leg 25. Generally, the leg number is left off the sample designations. The top of Core 15 in Hole 249 is 150 meters below the sea floor so if the depth of the sample is desired, it would be calculated as 150 meters + 1.5 meters (Section 1) + 50 cm (Section 2) = 152 meters. However, it is impossible, particularly when recovery is not complete, to determine the exact depth of the sample.

Sometimes the core barrel will jam up with hard sediment after coring a few meters; the core will then really represent only the first few meters penetrated. At other times, the circulation of water may wash away the upper softer part of a core and recovery will represent the lower part. Separated lengths of core in a core liner may come from the drill bit being lifted away from the bottom of the hole during coring in rough sea conditions. Similarly, there is no guarantee that the core catcher sample represents the material at the base of the cored interval. The labeling of samples is therefore rigorously tied to the position of the sediment or rock within a section as the position appears when the section is first cut open and as logged in the visual core description sheets.

Handling of Cores

The first assessment and age determination of the core material was made on samples from the core catcher as soon as possible after the core recovery. After a core-section had been cut, sealed, and labeled, it was brought into the core laboratory for processing. The core-section was first weighed for mean bulk density measurement. Then GRAPE (gamma ray attenuation porosity evaluation) analysis was made for detailed density determinations.

After the physical measurements were made, the core liner was cut on a jig using Exacto-type blades and the end caps cut by knife. The core was then split with a cheese cutter if the sediment was soft. When compacted or partially lithified sediments were included, the core had to be split by a band saw or diamond saw.

One of the split halves was designated a "working" half. Sonic velocity determinations using a Hamilton frame were made on pieces from this half. Samples, including those for grain size, X-ray mineralogy, interstital water chemistry, and total carbonate content, were taken, labeled, and sealed. The working half was then sent to the paleontology laboratory. There, samples for shipboard and shore-based studies of nannoplankton, foraminifera, and radiolarians were taken.

The other half of a split section was designated an "archive" half. The cut surface was smoothed with a spatula to bring out more clearly the sedimentary features. The color, texture, structure, and composition of the various lithologic units within a section were described on standard visual core description sheets (one per section) and any unusual features noted. A smear slide was made, usually at 75 cm if the core was uniform. Otherwise, two or more smear slides were made, each for a sediment of distinct lithology. The smear slides were examined with a petrographic microscope. The archive half of the core-section was then photographed. Both halves were sent to cold storage on board after they had been processed.

Material obtained from the core catcher and not used up in the initial examination was retained in freezer boxes for subsequent work. Sometimes significant pebbles from the core were extracted and stored separately in labeled containers. On other occasions, the liners would contain only sediment-laden water. This was usually collected in a bucket and allowed to settle, the residue being stored in freezer boxes.

At several sites, hard cores were obtained of either basement or indurated sediment. Each separate core fragment was numbered and labeled consecutively from the top downwards and its orientation indicated by an upward pointing arrow. Where possible, the fragments were arranged into their original relative orientation and a few were then sliced longitudinally for examination.

All sediment samples are now deposited in cold storage at the DSDP West Coast Repository at the Scripps Institution of Oceanography, La Jolla, California. The basalt samples are stored in a dry, nonrefrigerated container.

Drilling Disturbances

When the cores were split, many of them showed signs of postdepositional disturbance. Such signs were the concave downwards appearance of originally plane bands, the haphazard mixing of lumps of different lithologies, and the near fluid state of some sediments. It seems reasonable to suppose that these disturbances came about during or after the cutting of the core. There are three different stages during which the core may suffer stresses sufficient to alter its physical characteristics from those of the in situ state. These stages are the cutting, retrieval (with accompanying changes in pressure and temperature), and handling of the core.

During drilling, six basic parameters (bit type, weight on the bit, pipe revolutions per minute, torque, pump pressure, and pump strokes per minute) reflect the conditions at the contact between bit and sediment. When a core is being cut, water circulation is reduced to a minimum, or zero, and bit weight is normally kept to lower values and increased more steadily than during drilling. Invariably, however, some short periods of circulation are required, and it is then that softer sediments may be washed away from the bit or that water may be forced up inside the core liner, turning the sediment into a slurry. The washing away of softer sediment during periods of circulation can lead to the recovered cores being unrepresentative samples of the drilled strata. This is especially true when alternating hard and soft beds are cut. The heave of the bit while coring during rough weather may also lead to fluid cores.

Four degrees of drilling deformation were recognized in the sediments as follows: (a) slightly deformed, (b) moderately deformed, (c) highly deformed, and (d) soupy. The criteria used in defining these degrees of deformation was that slightly deformed sediments exhibit a small bending of bedding contacts, whereas extreme bending defines moderate deformation. For highly deformed strata, bedding is completely disrupted and/or at times has vertical attitudes. Soupy intervals usually are water saturated and lose practically all aspects of bedding. In intervals of alternating hard and soft beds, such deformation will be characterized by brecciated fragments of the former, surrounded by viscous to soupy flowage of the latter.

Physical Properties

A thorough discussion of physical properties is presented in Volume XV (Boyce, in press). It covers equipment, methods, errors, correction factors, presentation, and coring disturbance relative to the validity of the data. Only a brief review is given here.

The physical properties are presented in graphical form and discussed in each site chapter. Some explanation of the measuring techniques and data processing follows.

1) Sediment water content (W): The water content (W) is defined as the weight of water in the sediment divided by the weight of the saturated wet sediment. The former is obtained by heating a 0.5 ml cylindrical sample (taken with a syringe) to about 110°C for 24 hours and weighing the sample before and after heating. The water content (%) is thus:

$$W = \frac{100\,(\text{weight of wet sediment} - \text{weight of dry sediment + salts})}{\text{weight of wet sediment}}$$

No corrections were made for the salts, but the values are thought to be accurate to within ±3%.

2) Sediment porosity (ϕ): The porosity (ϕ) is defined as the volume of pore space divided by the volume of the wet saturated sample and is expressed as a percentage. Porosities calculated from W are not plotted. The continuous plots of porosity (site summaries only) are obtained from the GRAPE densities (see below) assuming a mean grain density of 2.67 g/cm^3 and a water density of 1.024 g/cm^3.

3) Wet bulk density (p): The wet bulk density (p) is defined as the weight in grams per cubic centimeter of the wet saturated sediment, i.e.,:

$$p = \frac{\text{weight of wet sediment}}{\text{volume of wet sediment (cm}^3\text{)}}$$

The densities of the seawater-saturated cores were measured in three ways: (1) by weighing each 1.5-meter core-section, giving a mean density for the whole section; (2) from the water content W (syringe samples); and (3) by continuous measurement along the length of the core-section with the GRAPE using as standards, water (1.024 g/cm^3) and aluminum (2.6 g/cm^3). It is noted that because of the possible presence of drilling disturbances, low values are suspect and emphasis should be placed on the maximum densities (minimum porosities).

4) Compressional wave velocity (Vp): The sonic velocity (Vp) is obtained by timing a 400-kHz sonic pulse across two transducers and measuring the distance across the sample with a dial gauge (Hamilton frame method). Measurements were made at laboratory temperature and

pressure, a time delay of about 4 hours being allowed for the cores to reach equilibrium.

5) Specific acoustic impedance (*Zp*): This is defined as density multiplied by compressional wave velocity. The parameter is of value in the interpretation of seismic reflection profiles.

6) Thermal conductivity (*k*): The thermal conductivity (*k*) is defined as the quantity of heat transmitted, due to unit temperature gradient (in unit time), in steady conditions in a direction normal to a surface of unit area.

Measurements on the soft sediments were made using the needle-probe technique described by von Herzen and Maxwell (1969). The needle was inserted through a small hole drilled in the plastic core liner, and the temperature was recorded for about 5 minutes.

Shore-Based Studies

Grain-Size Analyses

Grain-size distribution was determined by standard sieving and pipette analysis. The sediment sample was dried and then dispersed in a Calgon solution. If the sediment failed to disaggregate in Calgon, it was dispersed in hydrogen peroxide. The sand-sized fraction was separated by a 62.5μ sieve, with the fines being processed by standard pipette analysis following Stokes settling velocity equation (Krumbein and Pettijohn, 1938, p. 95-96), which is discussed in detail in Volume IX of the *Initial Reports of the Deep Sea Drilling Project*. Step-by-step procedures are covered in Volume IV. In general, the sand-, silt-, and clay-sized fractions are reproducible within ±2.5 percent (absolute) with multiple operators over a long period of time. A discussion of this precision is in Volume IX.

Carbon and Carbonate Analyses

The carbon-carbonate data were determined by a Leco induction furnace combined with a Leco acid-base semiautomatic carbon determinator. Normally, the more precise seventy-second analyzer is used in place of the semiautomatic carbon determinator.

The sample was burned at 1600°C, and the liberated gas of carbon dioxide and oxygen was volumetrically measured in a solution of dilute sulfuric acid and methyle red. This gas was then passed through a potassium hydroxide solution, which preferentially absorbs carbon dioxide, and the volume of the gas was measured a second time. The volume of carbon dioxide gas is the difference of the two volumetric measurements. Corrections were made to standard temperature and pressure. Step-by-step procedures are in Volume IV of the *Initial Reports of the Deep Sea Drilling Project* and a discussion of the method, calibration, and precision are in Volume IX.

Total carbon and organic carbon (carbon remaining after treatment with hydrocloric acid) are determined in terms of percent by weight and the theoretical percentage of calcium carbonate is calculated from the following relationship:

Percent calcium carbonate ($CaCO_3$) =

(%total C -%C after acidification) ×8.33

However, carbonate sediments may also include magnesium, iron, or other carbonates; this may result in "calcium" carbonate values greater than the actual content of calcium carbonate. In our determinations, all carbonate is assumed to be calcium carbonate. Precision of the determination is as follows:

Total carbon (within 1.2% - 12%)	= ±0.3% absolute
Total carbon (within 0% - 1.2%)	= ±0.06% absolute
Organic carbon	= ±0.06% absolute
Calcium carbonate (within 10% - 100%)	= ±3% absolute
(within 0% - 10%)	= ±1% absolute

X-ray Methods

Samples of sediment were examined using X-ray diffraction methods at the University of California at Riverside, under the supervision of H. E. Cook.

Treatment of the raw samples included washing to remove seawater salts, grinding to less than 10 microns under butanol, and expansion of montmorillonite with trihexylamine acetate. The sediments were X-rayed as randomized powders. A more complete account of the methods used at Riverside is found in Appendix III of Volume IV of the Initial Reports.

Lithologic Nomenclature Classification, and Symbols

Stratigraphic Terminology

Many different lithologies were encountered on Leg 25. Although no formal rock stratigraphic units are proposed in this volume, the sediments are informally divided into units and subunits. For each site, these unit designations are outlined in a table in the lithology section and also in the hole summary diagram. Throughout the volume, these unit and subunit designations are used. Boundaries between units and subunits in cored intervals were both sharp and gradational. If a boundary occurred between cores, it was placed in the middle of the drilled interval.

Sediment Classification and Nomenclature Rules

The naming and classification of sediments follows the system of Weser (1973). Certain minor modifications to the basically descriptive approach embodied in this system have since been made and are incorporated in the revision outlined below.

I. Rules for class limits and sequential listing of constituents in a sediment name

A. Major Constituents

1. Sediment assumes the name of those constituents present in major amounts (major defined as >25%). See example in rule IA3.
2. Where more than one major constituent is present, the one in greatest abundance is listed farthest to the right. In order of decreasing abundance, the remaining major constituents are listed progressively farther to the left.
3. Class limits, when two or more major constituents are present in a sediment, are based on 25% intervals, thusly: 0-25, 25-50, 50-75, 75-100.

   Example illustrating rules IA and IB and the resulting sediment names.

% Zeolites	% Nannos	
0-25	75-100	= Nanno ooze
25-50	50-75	= Zeolitic nanno ooze
50-75	25-50	= Nanno zeolitite
75-100	0-25	= Zeolitite

B. Minor Constituents

1. Constituents present in amounts 10%-25% are prefixed to the sediment name by using the term *rich*[1].
   Example: 50% nannofossils, 30% radiolarians, 20% zeolites is called a zeolite-rich rad nanno ooze.
2. Constituents present in amounts 2%-10% are prefixed to the sediment name by using the term *bearing.*[1]
   Example: 50% nannofossils, 40% radiolarians, 10% zeolites is called a zeolite-bearing rad nanno ooze.

C. Trace Constituents. Constituents present in amounts <2% may follow the sedimen name but will be accompanied by the word *trace*. This procedure is optional[1].

II. Specific rules for biogenous constituents

A. *Nannofossil* is applied only to the calcareous tests of coccolithophorids, discoasters, etc.

B. Abbreviations and contractions as *nanno* for *nannofossil, foram* for *foraminifera, rad* for *radiolarian,* and *spicule* for *sponge spicule* may be used in the sediment name.

C. The term *ooze* follows a microfossil taxonomic group whenever it is the dominant sediment constituent.

D. Usage of the terms *marl* and *chalk* to designate amounts of microfossils, 30%-60% and >60%, respectively, as used by Olausson and others, is dropped. The term *chalk* is retained to designate a consolidated calcareous ooze.

E. Consolidated diatom and rad oozes are termed *diatomite* or *radiolarite,* respectively.

III. Specific rule for volcanic constituents

Pyroclastics are given textural designations which are already established in the literature. Thus, *volcanic breecia* = >32 mm, *volcanic lapilli* = <32 mm, >4 mm, *volcanic ash* = <4 mm. It is at times useful to further refine the textural designations by using such modifiers as *coarse* or *fine*.

IV. Specific rules for authigenic constituents

A. Authigenic minerals enter the sediment name in a fashion similar to that outlined under rules IA and B.

B. The terms *ooze* and *chalk* apply to carbonate minerals of all types using the same rules that apply to biogeneous constituents.

C. *Ferruginous* is the term applied to the microscopic translucent subspherical iron-oxide minerals.

[1]Normally, the trace constituents never appear in the sediment name. As regards minor constituents, the *bearing* and sometimes even the *rich* constituents may be omitted from the sediment name when deposits are complexly constituted.

[2]Detrital = all clastic grains derived from the erosion of preexisting rocks except for those of biogenous, authigenic, or volcanic origin.

V. Specific rules for clastic sediments

A. Clastic constituents, whether detrital, volcanic, biogenous, or authigenic, are given a textural designation. When detrital[2] grains are the sole clastic constituent of a sediment, a simple textural term suffices for its name. The appropriate term is derived from Shepard's triangle diagram (see Figure 5).

B. When the tests of a fossil biocoenosis or authigenic minerals and detrital grains occur together, the fossil or authigenic material is not given a textural designation. Note, however, that the detrital material is classified texturally by recalculating its size components to 100%. With the presence of other constituents in the sediment, the detrital fraction now requires a compositional term. For this purpose, the term *detrital* is employed, which enters the sediment name as per rules IA and B.

C. Clastic fossil tests

1. Redeposited fossil tests become a clastic constituent and are given a textural designation in the manner of detrital grains. Now, however, the textural term is preceded by the appropriate terms identifying the fossil constituents as per rules IA and B.
2. To warrant a textural term, the clastic nature of the fossil remains must be obvious and significant, a test easily met by most nearshore fossils. However, for practical purposes, redeposited pelagic fossils seldom pass this test and, therefore, are rarely suffixed by a textural term.
3. At times other clastics, usually detrital in nature, accompany redeposited fossils tests. Again, the term *detrital* is employed to embrace the detrital fraction. Note (comparing rule VB with VC3) that the sediment name does not distinguish between "in place" and redeposited fossils. This distinction remains to be made on an informal basis.

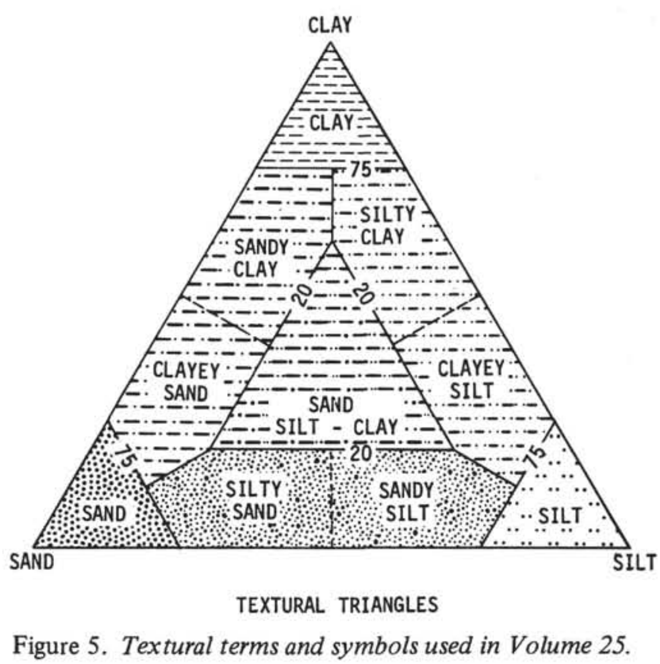


Figure 5. *Textural terms and symbols used in Volume 25.*

4. In shallow water, the skeletal debris of a clastic sediment commonly contains various taxonomic groups. Rather than specifying each group individually in the sediment name, it may be preferable to employ the term *shelly*.

D. Clastic volcanics
Redeposited pyroclastics also become a clastic constituent. As before, they are recognized by the term *volcanic*, but now they receive a textural term such as *gravel, sand, silt,* etc. Classification as clastic again requires evidence of obvious and significant current transport.

E. Clastic authigenic constituents
Where authigenic minerals are recognized as being a redeposited constituent, they are given a textural designation in addition to their species name in the manner set forth for biogenous clastics (rule VC).

VI. Color

A. Color is not formally part of the sediment name. However its employment for sediment description is important, particularly as it provides one of the criteria used to distinguish pelagic and terrigenous sediment. The color designation always precedes the sediment name.

B. Common usage dictates that it is no longer expedient to employ the term *red* as an all-inclusive color term for pelagic sediments which range through various shades of red, yellow, and brown. The proper color designation should be used.

VII. General comments

A. Sediments are not formally divided into the two groups, pelagic and terrigenous, by the sediment classification. This distinction is left to be made on an informal basis.

B. There exists at present, fine-grained carbonate particles, which by virtue of their unknown origin, cannot be classified as either biogenous, clastic, or authigenic. Such particles are prefixed by the term *micarb*. Because they also do not exhibit evidence of obvious and significant current transport, they are not given a textural designation—consequently, the terms *ooze* and *chalk* are applied to them where appropriate. Those which do give evidence of obvious and significant current transport are no longer of unknown origin. These are termed *calcareous particles*.

C. The suffix *stone* is added to the textural term of consolidated clastic sediments.

D. For cemented sediments the adjectives *calcareous* and *siliceous* are used as appropriate.

Graphical Representation of Lithologies

Lithologic symbols used in this volume have been standard since Leg 18. These symbols are shown in Figure 6. Class limits, as shown on the core forms, are represented by vertical bar widths (Figure 7). Letters and symbols used in the lithologic columns to represent constituents present in amounts of 2 to 10 percent are given in Figure 8.

It will be noted that these symbols encompass both compositional and textural aspects of the sediments. To represent both of these aspects simultaneously in a lithologic column is difficult. Consequently, the convention on Leg 25 has been that when a sediment is of clastic origin, a textural symbol is used and when it is of nonclastic origin, a compositional symbol is used. There were a few instances where it was not obvious as to whether or not a sediment was of clastic origin. In such cases the sediment was represented by a compositional symbol.

The sediments on Leg 25, particularly in some holes, were lithologically complex. It was not uncommon for them to contain four or more constituents. Obviously there are difficulties in representing all these constituents simultaneously by a system of overprinting lithologic symbols. Consequently, the technique of vertical stripping was used. With this technique, each sediment component is depicted by a vertical bar where width is dependent on the prevalence of the component it represents. Basically, this technique can accommodate all the major and the "rich" portions of the minor constituents. The bar widths for a two-component sediment are shown on Figure 6. Note that the class limits of other vertical bars coincide with those of the sediment classification.

Core Forms

Lithologies shown in the lithologic column of the core forms are based on percentage composition values determined by shipboard smear slide examinations. Where these values differed from the results of shore-based laboratory studies of grain-size, carbonate, or X-ray mineralogy data, the appropriate correction was made. Entries in the column headed "Litho Sample" indicate where control on lithologies exists. Where adjacent control points indicated a lithologic change, this change generally was made midway between these points. In places, compositional differences appeared to coincide with color changes. In these instances, the lithologic changes were made to coincide with color boundaries.

Several items are entered in the column headed "Lithologic Description". Numerical color designations and names follow the Munsell system as employed by the Geological Society of America. The reader is advised that colors recorded in the core barrel summaries were determined during shipboard examination immediately after splitting the sections. Experience with carbonate sediments shows that many of the colors will fade or disappear with time after opening and storage. Colors particularly susceptible to rapid fading are purple, light and medium tints of blue, light bluish gray, dark greenish black, light tints of green, and pale tints of orange. These colors change to white, yellowish white, or light tan.

Written descriptions always begin with the name of the dominant lithology. This is followed by pertinent remarks concerning various aspects of the sediments. It was the philosophy of Leg 25 to refrain from incorporating genetic or other interpretive aspects, relegating such information to the written text in the site chapters. Next is a smear slide description of the dominant lithology, followed by similar descriptions of important minor lithologies. The reader should be aware that smear slides are not point-counted, and, therefore, percentage values so derived are not accurate. In this sense, the numerical values serve more as an approximation of relative constituent amounts than as an accurate quantitative guide. To improve the quantitative

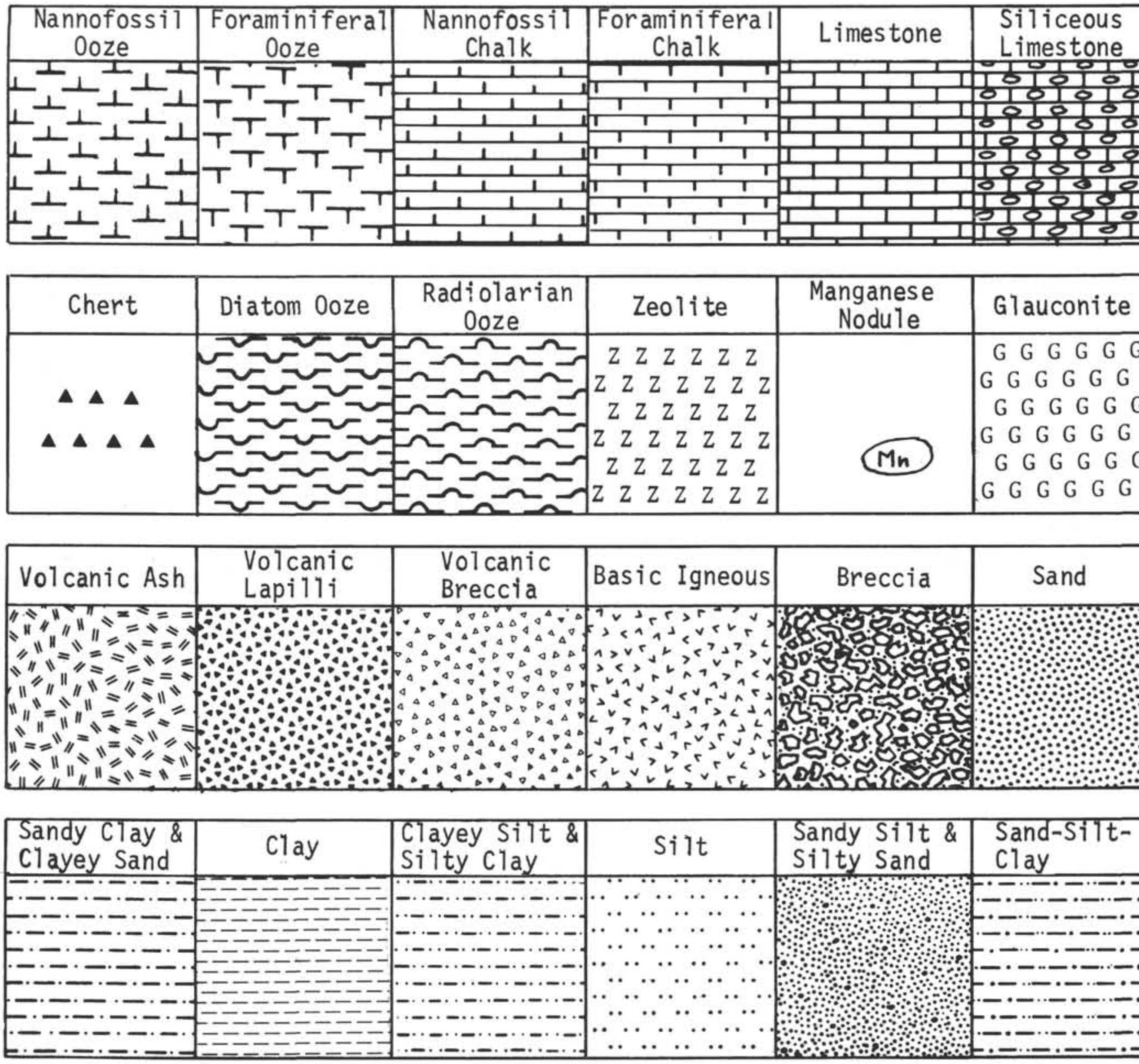


Figure 6. *Lithologic symbols used in Volume 25.*

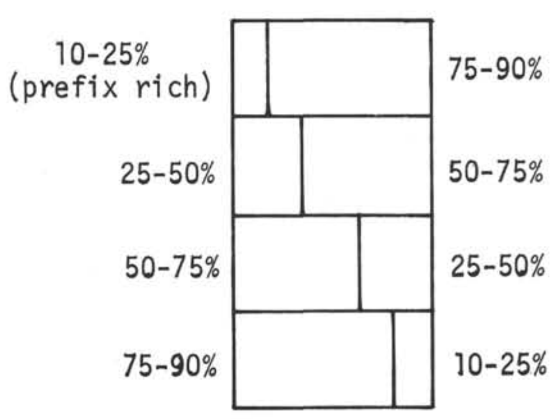


Figure 7. *Vertical bar width representation of class units.*

F = Foraminifera
N = Nannofossils
D = Diatoms
R = Radiolarians
A = Ash
Z = Zeolite
G = Glauconite
S = sponge spicules
▲ = Chert
Mn = Manganese nodule
⬬ = Erratic or pebble
■ = Pyrite

Figure 8. *Letters and symbols used in lithologic columns to represent constituents present in amounts of 2 to 10 percent (i.e., "bearing" constituents).*

aspects of the smear slide data, they were updated by the shore-based laboratory data. Consequently, many of these values, particularly those reflecting texture, are precise. Numerous compositional estimates, when later compared with shore-based laboratory studies, were found to be closely comparable. The largest error in visual estimation normally occurred where one of the sediment components consisted of carbonate grains; however, this error was eliminated by using the shore-based carbon carbonate data, which has a high degree of precision.

The lower half of the "Lithologic Description" column contains the results of shore-based laboratory studies on grain size, X-ray, and carbon carbonate, most of which were carried out at Scripps and Riverside. Results from other laboratories also are shown and are appropriately noted. Of the X-ray data, only the results from bulk analyses are shown.

In the "Fossil Character" columns of the core forms, letters are used to designate the abundance and preservation of the respective fossils. Small marks (-) in the column show the sample location. The capital letter designates "abundance" and the small letter shows "preservation."

The letters used to indicate fossil abundance are the following:

A = Abundant (flood; many species and specimens);
C = Common (many species; easy to make age assignment);
R = Rare (enough for age assignment); and
T = Trace (few species and specimens; not enough for age assignment).

Letters to designate fossil preservation include these four:

e = excellent (no dissolution or abrasion);
g = good (very little dissolution or abrasion);
f = fair (dissolution and/or abrasion and/or recrystallization very noticeable); and
p = poor (substantial or very strong evidence of dissolution and/or abrasion, and/or recrystallization).

In the "Zone" column, foraminifera, nannoplankton, and Radiolaria zones are written, with the foram zone nearest the left margin of the core form, the nannoplankton zone in the center, and the Radiolaria zone nearest the right.

Three numbers are used to characterize grain size on the core forms. The first designates the amount of sand-sized material, the second indicates the percent of silt-sized grains, and the third shows the quantity of clay. For example, (5-45-50) is sand, 5 percent; silt, 45 percent; and clay, 50 percent.

Carbon-carbonate percentages also are designated by a series of three numbers; (11-0.2-56) is 11 percent total carbon, 0.2 percent organic carbon, and 56 percent carbonate.

Bulk X-ray data are given qualitatively on the core forms by the use of four letters, *T, P, A,* and *M*. The letter *T* designates "Trace" which implies a concentration of less than 5 percent; *P* means "Present" which implies an approximate concentration of 5 to 25 percent; *A* is "Abundant" with an approximate concentration of 25 to 65 percent; and *M* designates "Major" which implies concentrations greater than 65 percent.

Basis for Age Determination

Planktonic Foraminifera

Cenozoic age determinations were based upon the standard system which has been published by W. A. Berggren (1972) (Figures 9-11). Cretaceous age determinations were based upon the standard system which has been given by R. Casey (1964). It must be emphasized, that for these latter determinations, the absolute ages which are given for the successive boundaries between the conventional stages are only approximate (Figure 12).

Nannofossils

The determination of nannoplankton zones for the Tertiary is based on the Standard Nannoplankton Zonation (Martini, 1971). Investigations of the cores from Leg 25 have shown that this zonation is very useful. Age determinations of the Cretaceous are based on the publications of Bramlette and Martini (1964); Gartner (1968); Cepek and Hay (1969, 1970); Manivit (1971); and Thierstein (1971). All samples were studied with the light microscope; some were selected to be studied with the scanning electron microscope (SEM). Correlation between the foraminifera and nannoplankton zones for the Quaternary and Tertiary is based upon the table given by Berggren (1972).

Remarks on Biostratigraphy (B. Zobel)

In order to obtain a biostratigraphic subdivision of the cored sediments by means of Neogene foraminifera in a very short time, only qualitative determinations were carried out for the site reports. None of the foraminiferal zonations thus far published was wholly suitable for the area investigated. Therefore, it was decided to take into account as many species of planktonic foraminifera as possible and compare them to the stratigraphic range tables given by Blow (1969). Although some of the upper and lower range limits given in these tables will have to be altered according to the newly sampled materials from the Indian Ocean, there is no denying that the safest and quickest way for getting an appropriate zonation is by considering the foraminiferal associations instead of only the extinction or first appearance of single species. These latter can be heavily affected by dissolution and/or other environmental factors. This procedure gave the best agreement with the results of the nannoplankton zonation. Because of this applied mode of biostratigraphic zonation, it was decided against giving species names to the zones and instead, to take the neutral number system for designation of the zones as used by Blow (1969).

Great value was set on the identification of benthonic foraminifera and on observations of faunal residues other than foraminifera. These gave valuable clues with regard to the environmental conditions during sedimentation and to the existence, and sometimes the source, of allochthonous material. Observation of the degree of dissolution which affected the foraminiferal associations gives some indications of the water depth during sedimentation.

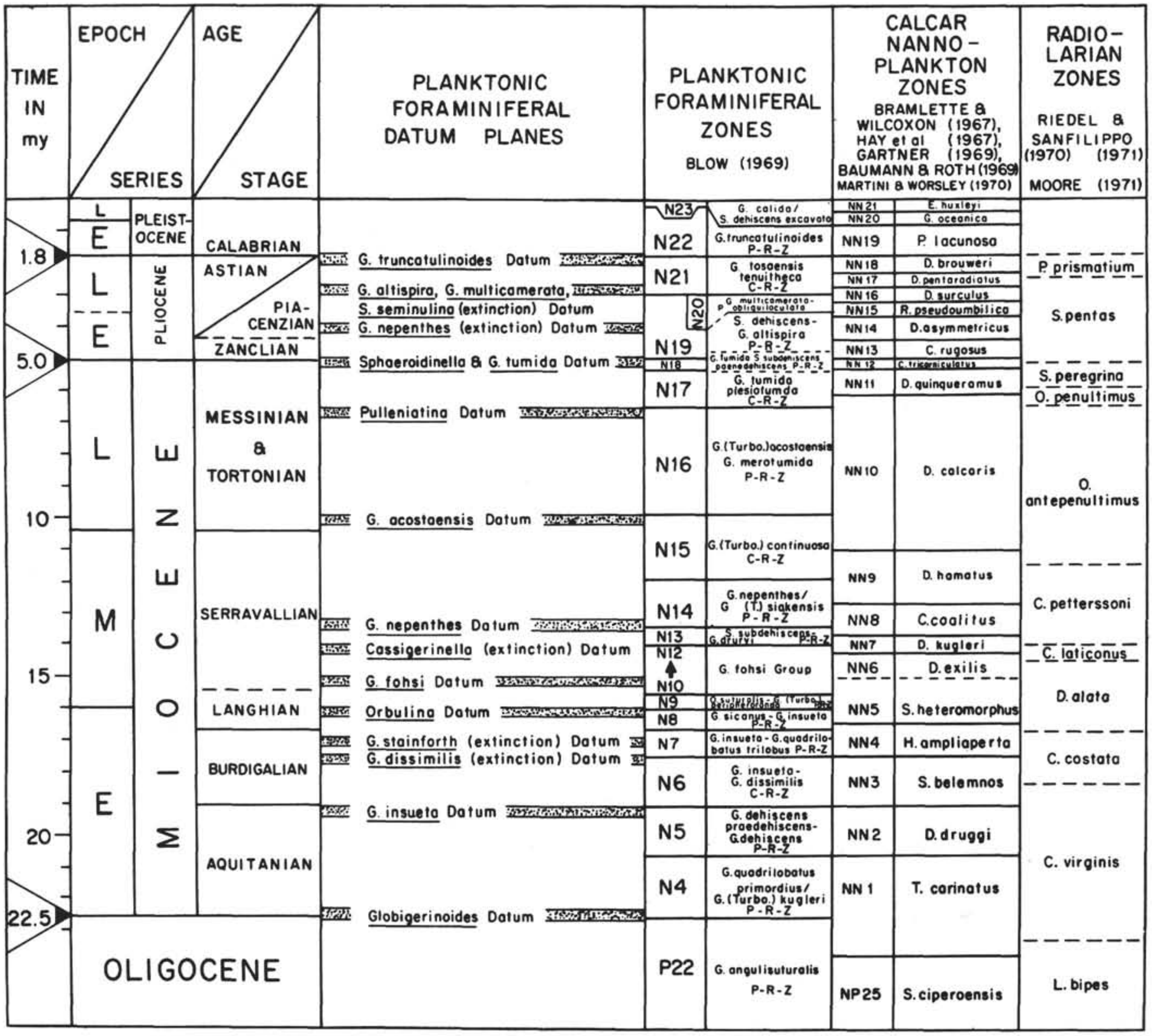


Figure 9. *Correlation of foraminiferal, radiolarian, and nannofossil zones for Miocene, Pliocene and Pleistocene.*

Remarks on Sedimentation Rate Diagrams (B. Zobel)

Sedimentation rate diagrams were constructed for Leg 25 sites with some hesitation because they seemed to be misleading due to discontinuous coring, poor preservation of some fossils, and the often tenuous assignment of absolute ages to the recovered sediments. In spite of these shortcomings, the diagrams have proved to be very valuable for a quick overview of the site results. However, to keep the reader from making too far-reaching conclusions, some details are given here concerning the construction of these diagrams.

The sedimentation rates are based on the thickness of sediments between dated samples. Of course, some minor differences in the rates can result from different uses of maximum and minimum ages. At first, the sedimentation rate diagram for each site was constructed separately for the foraminiferal and the nannoplankton zonations. Apart from the scattered deviations between the two biostratigraphic zonation schemes in the cores considered, there seems to be some differences of fundamental importance. This is true especially for the late Miocene, where the foraminiferal zonation always gives higher ages for a sample than those obtained by nannoplankton zonation (Figure 13).

Only rarely is it possible to give the relative age of a certain sample to an exact point in the age versus depth diagram (e.g., the position of the boundary between two zones). Normally, samples can be assigned to a zone and, consequently, the relations between space and time are

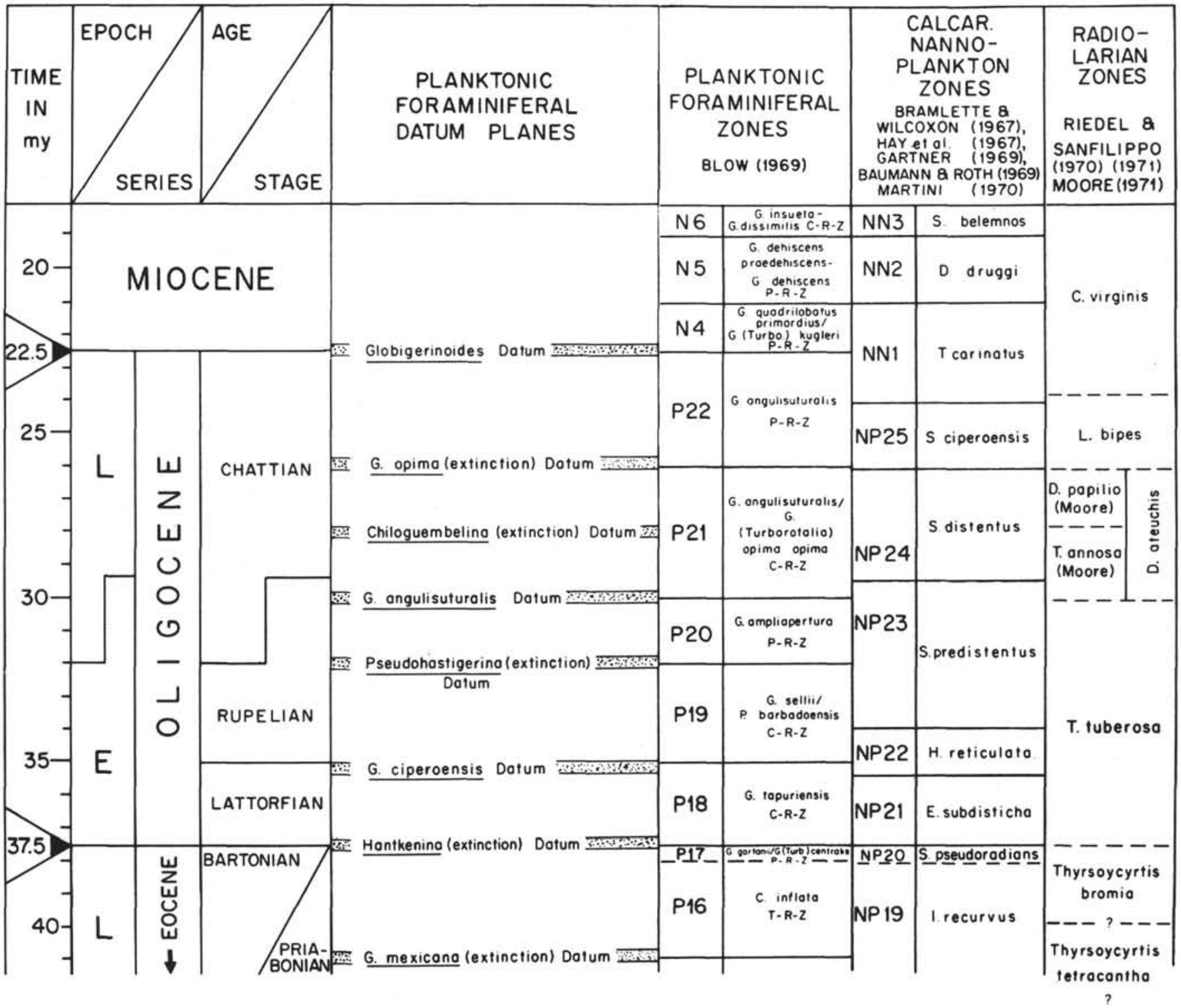


Figure 10. *Correlation of foraminiferal, radiolarian, and nannofossil zones for the Oligocene and Upper Eocene.*

represented by a plane. For the construction of the sedimentation rate curves, the centers of the overlapping planes from the nannoplankton and foraminiferal zonations have been used (Figure 13).

In borehole sections without fossils or samples, the sedimentation rate has been drawn as a broken line. For examples, see the summary diagrams of the site report chapters and the comprehensive sedimentation rate diagram in the "Lithologic Summary" chapter (Girdley, et al., this volume). In such cases, it is unknown whether a very small gradient of the curve means a small sedimentation rate throughout the section in question or whether normal sedimentation is interrupted by a hiatus. This is true for the Oligocene and the early Paleocene in Site 239 and in Site 248 between early Eocene and middle Miocene. It might also be true for the Quaternary to late Eocene section of Site 245.

The original sedimentation rate curve, which allows for more than one sample from each core, may show several steps, e.g., Site 242 (Figure 14), which probably are not real but have their origin in the possible errors discussed by Moore (1972). To get a more realistic picture, these steps were graphically eliminated in the combined sedimentation rate diagram for Leg 25.

No reliable statements can be made concerning the sedimentation rates during the Quaternary and–in many cases–the late Pliocene. The uppermost cores of the drilling sites are nearly always strongly mixed by drilling disturbance.

Magnetic Time Scale

Sea floor spreading magnetic anomalies are numbered according to the scheme proposed by Pitman and Heirtzler (1966), and the time scale of geomagnetic reversals used in

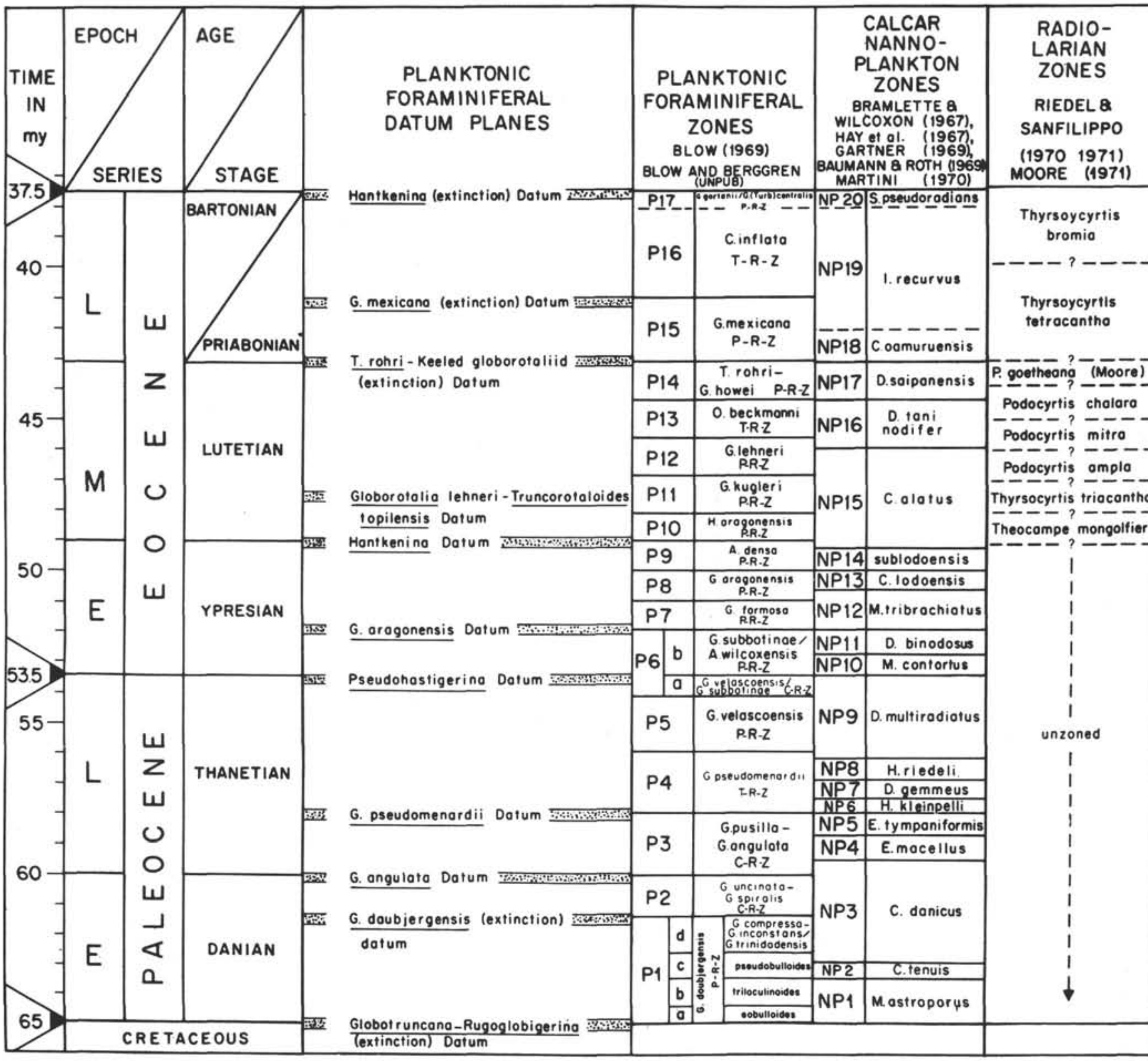


Figure 11. *Correlation of foraminiferal, radiolarian, and nannofossil zones for the Eocene and Paleocene.*

this volume is from Heirtzler et al. (1968) complemented, beyond anomaly 30, by McKenzie and Sclater (1971). Figure 15 gives the intervals of normal polarity with the corresponding magnetic anomaly numbers and the geological epoch according to the time scale of Berggren (1972).

ACKNOWLEDGMENTS

In the "Explanatory Notes" section of this chapter, paragraphs and sentences have been freely borrowed from explanatory notes of previous volumes, particularly Volume 12. We thank those authors for previously compiling the data and thereby making our task less difficult and less time-consuming.

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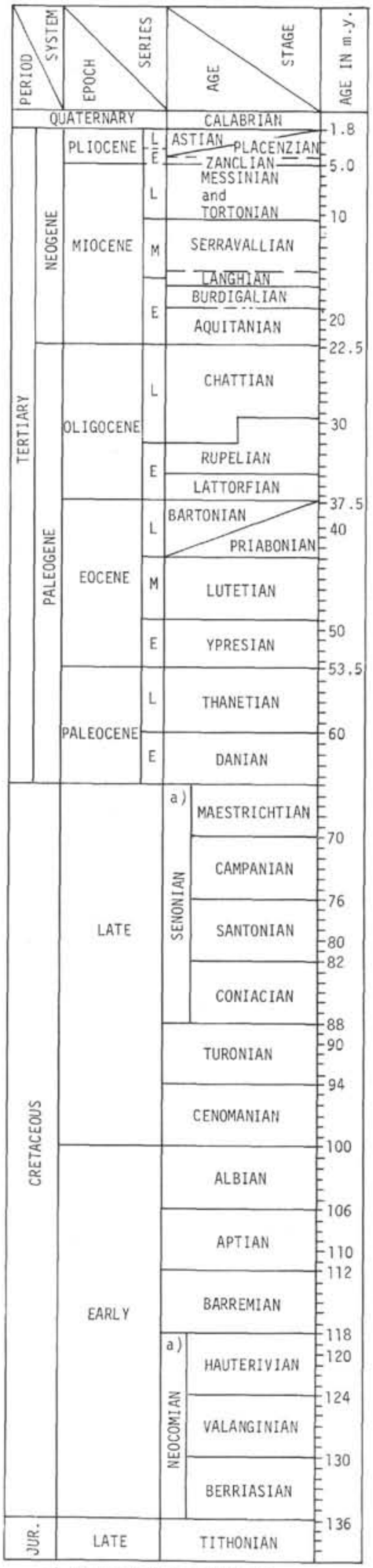

a) Occasional groupings of Cretaceous stages.

Figure 12. *Absolute ages used in this volume (after Berggren, 1972, for the Cenozoic, and Casey, 1964, for the Cretaceous).*

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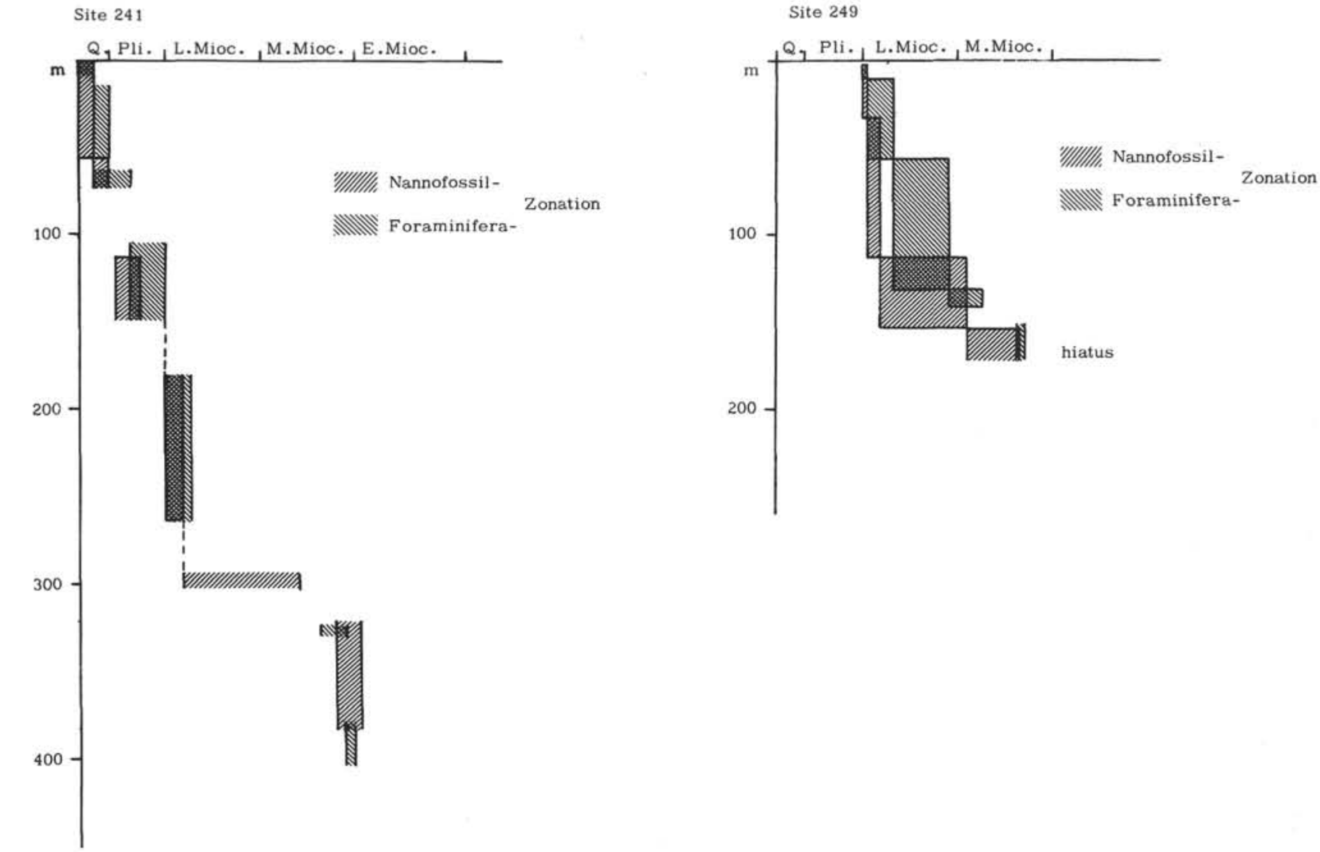

Figure 13. *Construction of age versus depth curves for sedimentation rate curves, showing differences between foraminiferal and nannoplankton zonation.*

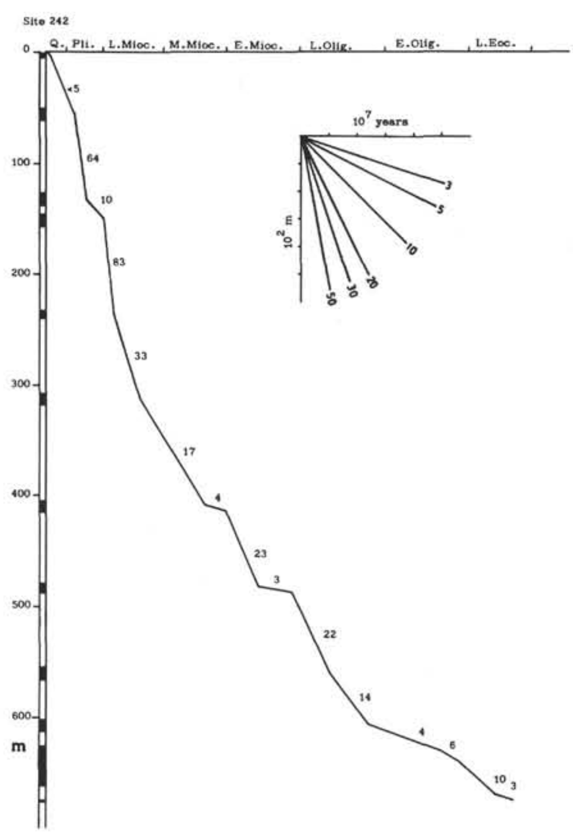

Figure 14. *Irregularities in the steepness of the sedimentation rate curve of Site 242.*

1—	0.00- 0.69	
	0.89- 1.93	PLEISTOCENE
2—	1.78- 1.93	———
	2.48- 2.93	
	3.06- 3.37	
		PLIOCENE
	4.04- 4.22	
	4.35- 4.53	
	4.66- 4.77	
3—	4.81- 5.01	———
	5.61- 5.88	
	5.96- 6.24	
	6.57- 6.70	
	6.91- 7.00	
4—	7.07- 7.46	
	7.51- 7.55	
	7.91- 8.28	
	8.37- 8.51	
5—	8.79- 9.94	
	10.77-11.14	
	11.72-11.85	
		MIOCENE
5a—	11.93-12.43	
	12.72-13.09	
	13.29-13.71	
	13.96-14.28	
	14.51-14.82	
	14.98-15.45	
	15.71-16.00	
5b—	16.03-16.41	
5c—	17.33-17.80	
	17.83-18.02	

5d—	18.91-19.26	
	19.62-19.96	
6—	20.19-21.31	
	21.65-21.91	
	22.17-22.64	———
	22.90-23.08	
	23.29-23.40	
6a—	23.63-24.07	
	24.41-24.59	
	24.82-24.97	
	25.25-25.43	
	26.86-26.98	
7—	27.05-27.37	
	27.83-28.03	
	28.35-28.44	OLIGOCENE
8—	28.52-29.33	
9—	29.78-30.42	
	30.48-30.93	
10—	31.50-31.84	
	31.90-32.17	
11—	33.16-33.55	
	33.61-34.07	
12—	34.52-35.00	———
13—	37.61-37.82	
	37.89-38.26	
14—	38.68-38.77	EOCENE
	38.83-38.92	
	39.02-39.11	
	39.42-39.47	
15—	39.77-40.00	

	40.03-40.25	
	40.71-40.97	
	41.15-41.46	
16—	41.52-41.96	
17—	42.28-43.26	
	43.34-43.56	
	43.64-44.01	
	44.21-44.69	
	44.77-45.24	
18—	45.32-45.79	
19—	46.76-47.26	
20—	47.91-49.58	
21—	52.41-54.16	———
22—	55.92-56.66	
23—	58.04-58.94	
	59.43-59.69	PALEOCENE
24—	60.01-60.53	
25—	62.75-63.28	
26—	64.14-64.62	———
27—	66.65-67.10	
28—	67.77-68.51	
29—	68.84-69.44	
30—	69.93-71.12	
31—	71.22-72.01	LATE
	74.01-74.21	CRETACEOUS
32—	74.35-75.86	
	76.06-76.11	
33—	76.27-79.00	

Figure 15. *Geomagnetic time scale used in this volume. From left to right: magnetic anomaly numbers, intervals of normal polarity (m.y.) and geological epochs.*