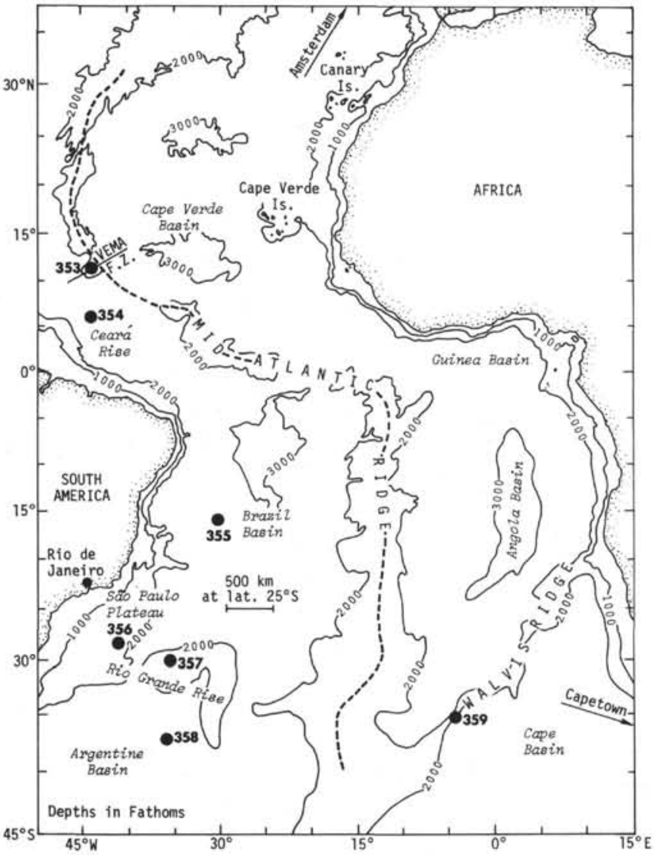
3. SITE 354: CEARA RISE

The Shipboard Scientific Party[1]



SITE DATA

Date Occupied: 27 October 74 (1230Z)

Date Departed: 31 October 74 (1305Z)

Time on Site: 4 days, 35 minutes

Position: 05°53.95′N, 44°11.78′W

Accepted Water Depth: 4052 meters (drill pipe measurement)

Penetration: 900.0 meters

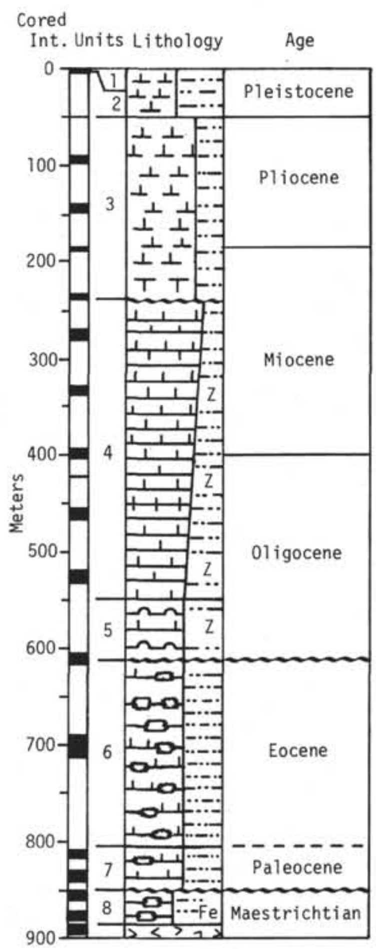
Number of Holes: 1

Number of Cores: 19

Total Length of Cored Section: 211.0 meters

Total Core Recovered: 119.0 meters

Principal Results: At Site 354 on the Ceará Rise, we penetrated 886 meters of sediment above acoustic basement. The first one meter subbottom is Holocene (?) yellow-brown foraminifer-nannofossil ooze, overlying 47 meters of Plio-Pleistocene nannofossil ooze which contains a significant detrital fraction. Marly oozes continue to 240 meters, where a transition from ooze to chalk occurs in mid-Miocene. Foraminifer-nannofossil chalk of Miocene to early Oligocene age extends to 550 meters, at which depth a regional reflector corresponds to an abrupt transition to marly diatom-nannofossil chalk which extends to 630 meters (mid-Eocene). Blue-green marly nannofossil chalk extends to 805 meters (upper Paleocene-lower Eocene), gray nannofossil chalk with some red zones to 850 meters (upper to middle Paleocene), and red marl of late Cretaceous age to 886 meters. Acoustic basement was cored for 14 meters; 9.5 meters were recovered (a diabasic



[1]K. Perch-Nielsen, Eidg. Technische Hochschule, Zürich, Switzerland (Co-chief scientist); P.R. Supko, Scripps Institution of Oceanography, La Jolla, California (Co-chief scientist); A. Boersma, Lamont-Doherty Geological Observatory, Palisades, New York; E. Bonatti, University of Miami, Miami, Florida; R.L. Carlson, University of Washington, Seattle, Washington; F. McCoy, Lamont-Doherty Geological Observatory, Palisades, New York; Y.P. Neprochnov, U.S.S.R. Academy of Sciences, Moscow, U.S.S.R.; H.B. Zimmerman, Union College, Schenectady, New York.

basalt). Reflectors within the basement indicate a series of flows or sills with intercalated sediments.

Average sediment accumulation rate is 1.3 cm/1000 yr; this includes a cored hiatus in the mid-Miocene and periods of slow accumulation, or hiatus, in the late Eocene-Oligocene and Late Cretaceous-middle Paleocene.

BACKGROUND AND OBJECTIVES

Site 354 is on the western edge of the Ceará Rise, a pronounced topographic feature 150 miles east of the Amazon Cone in the western equatorial Atlantic (Figure 1).

A section of about 1 km of sediments conformably overlies this basement high. Sonobuoy data show a normal oceanic section under the rise, and refractions from material with a 4.5 km/sec velocity come from a depth representing the acoustic basement (Embley and Hayes, 1972), except in certain places where a 3.5 km/sec layer forms the smooth acoustic basement (Kumar and Embley, in press). Internal reflections are rather diffuse within the rise sediments, but two can be traced throughout the rise; the shallower reflector can be traced beneath the Amazon Cone (Figures 2, 4).

The Amazon Cone sediments buried a large area of the Ceará Rise during the late Neogene (Damuth and Kumar, 1975; Kumar and Embley, in press). Results of drilling at DSDP Site 142 on the southern flank of the Ceará Rise (Figure 1) suggest cessation of pelagic sedimentation there in the middle Miocene (the hole terminated in sediment of this age) before burial of lower parts of the rise by abyssal plain sediments from the middle to late Miocene onward. Cores taken on cruises by *Vema* 18 and 25 and *Conrad* 8 and 13 on and in the vicinity of the Ceará Rise contain upper Pleistocene pelagic sediments as well as turbidites; one core (V 25/62) consists of a Miocene foraminifer ooze (Embley and Hayes, 1972).

Magnetic anomalies have not yet been recognized in the equatorial Atlantic. A reasonable interpolation between spreading rates for the northern and southern Atlantic, however, gives an approximate age of 80 m.y. for the western edge of the Ceará Rise. The anomalously shallow basement underlying the Ceará Rise is analogous to a section of the Sierra Leone Rise on the eastern side of the Atlantic. Both are bounded north and south by the same fracture zones (the Doldrums at 8°N and one at 4°N—Cochran, 1973). Their older sections lie equidistant from the present ridge axis.

The scientific objectives at this site were:

1) Biostratigraphy: To date the succession of predominately pelagic and occasionally terrigenous sediments—of special interest at this site, where the

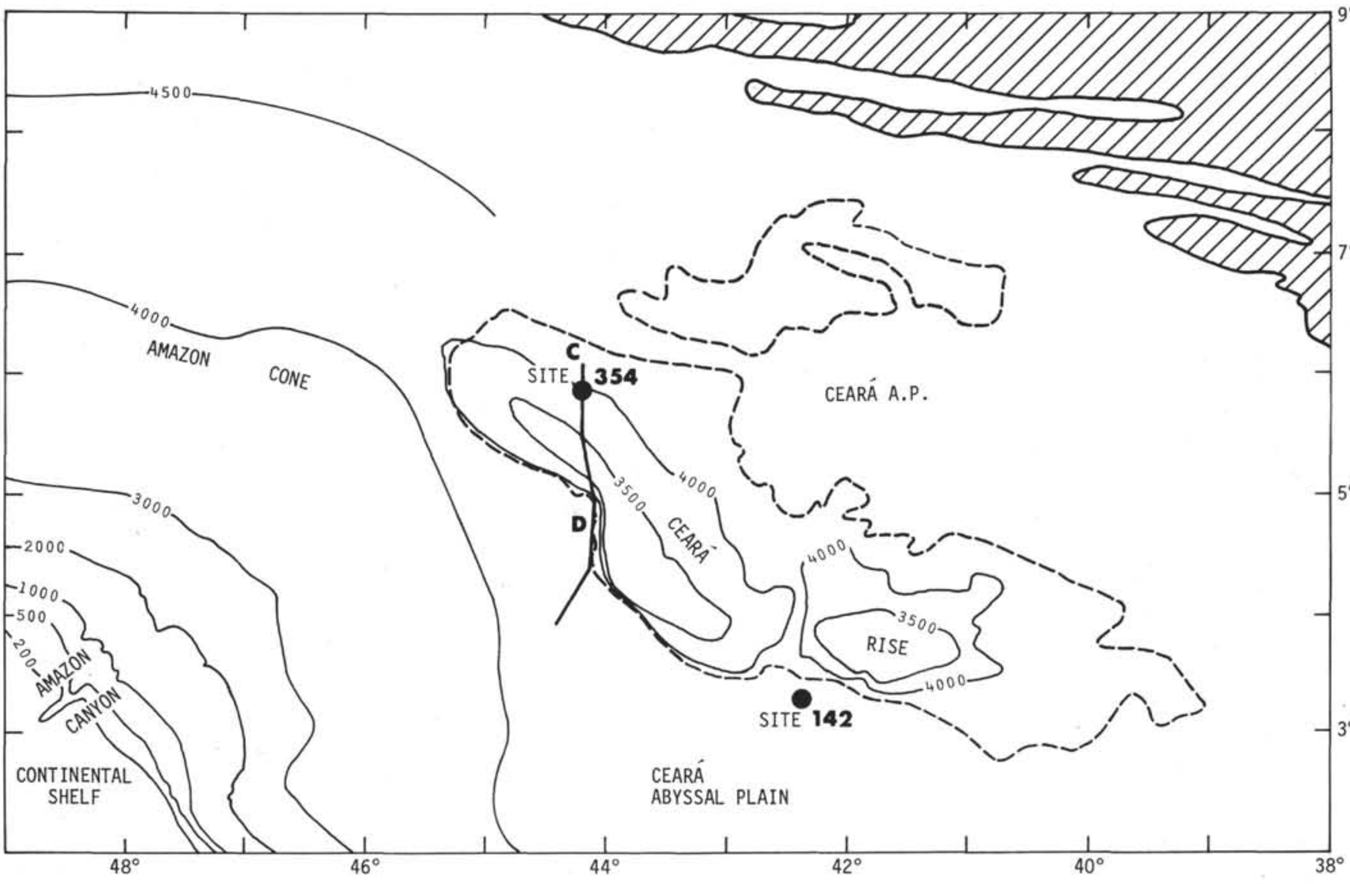


Figure 1. *Base map, Site 354. Dashed line shows approximate morphological limits of Ceará Rise. Amazon Cone shown as contours to 4500 meters. Hatched area delimits Mid-Atlantic Ridge province. Section CD of solid line marks location of reference profile. Simplified from Kumar and Embley (in press).*

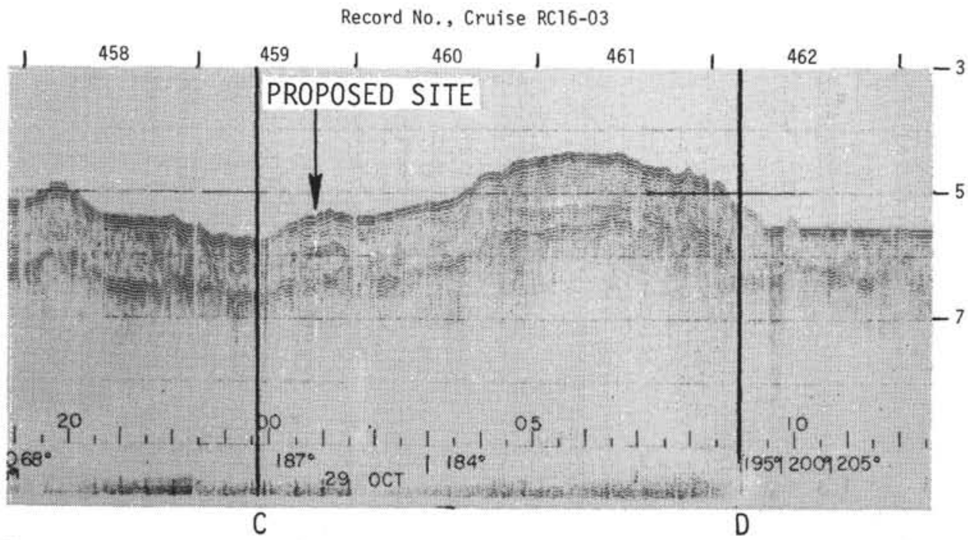


Figure 2. *Reference seismic reflection profile, Cruise RC16-03, Lamont-Doherty Geological Observatory, Record 459, 0048 hrs. Section CD shown on Figure 1.*

sedimentary sequence is probably one of the best available for the western equatorial Atlantic.

2) To date the intermediate reflectors. One of the reflectors is traceable beneath the Amazon Cone.

3) To establish the nature and age of basement, since there is no basement-age information for this region, either from interpretation of magnetic anomalies or from drilling.

OPERATIONS

We approached Site 354 from the Vema Fracture Zone on a course of 235°T. At 1004Z, 26 October 1974, we changed course to 270°T to reach a point from which we could pass over the proposed site on the reference profile heading of 187°T (see Figure 2, segment C-D, record 459 of cruise *Robert Conrad* 16-03, Lamont-Doherty Geological Observatory). We completed our turn onto the 187°T heading at 1039Z, reduced speed to 6 knots about four miles north of the proposed site, and came onto the Lamont track at 1100Z, actually making good about a 176°T course (see Figure 3).

The proposed site was located at 0048 hr on the Lamont profile (see Figure 2), presumably because an intermediate reflector at about 0.5 sec is well developed here. We elected to alter the position of the site slightly, for two reasons. First, other Lamont profiles in the area and our own approach profile (Figure 4) show the intermediate reflector to be well developed regionally and along our line of approach, obviating the necessity of locating the site at so precise a position as that indicated on Lamont record 459. Second, the Lamont record indicates the proposed site is on a basement high. Although we thought hydrocarbon entrapment highly unlikely, we continued to a point off the basement high. (Note that since the site was selected just before the beginning of the cruise, there was not time to allow evaluation by the JOIDES Advisory Panel on Pollution Prevention and Safety).

We dropped the beacon at 1241Z while the ship was underway, retrieved geophysical gear, and returned to position the ship over the beacon.

Stabilizing over the beacon was difficult because of a very strong current (averaged over the next several days at 2.7 knots from 230°), winds at bad angles to the current, problems with the positioning computer, and lack of generator power to one of the bow thrusters. After trying for seven hours, we positioned successfully over the beacon at 1940A, 26 October, and began running in the hole. Hole 354 was spudded at 1018Z, 27 October 74. Water depth by PDR is 4045 meters corrected; the bottom was felt at 4062 meters below the rig floor. The drill pipe measurement was accepted, water depth is thus 4052 meters.

Since the objectives at this site were to penetrate to basement (0.9 sec) as well as to obtain as complete a section as possible, all in limited time, intermittent coring was necessary (see Table 1). We selected core depths on the basis of the approach reflection profile, inferred lithologies and associated estimated velocities, measured seismic velocities on recovered samples, and expected sedimentation rates and locations of probable hiatuses.

Cores 1 and 2 were obtained without circulation or rotation. In Core 3, circulation was broken once, in Core 4 twice. Cores 5 to 19 required pumping; the formation was predictably more difficult to drill with depth, because of overburden compaction and diagenetic cementation.

Another reason for the slow drilling rates, we thought, was that during the drilling of several pipe lengths, the barrel might become partly or completely filled with core inadvertently collected in the drilled interval. This would be the case if the formation were sufficiently competent to resist being broken up and jetted away by pump action. Thus, Core 12 (605.5-615 m) cut quickly for the first 5 meters, then virtually stopped, presumably because the barrel was full. The remaining 4-meter interval was drilled. When the barrel was recovered it was full, with no marked lithologic change in the core to account for an abrupt slowing at 5 meters in the cored interval; the barrel was by then full. We confirmed this by pulling the core barrel after drilling the interval 700.5-738.5 meters, with no attempt

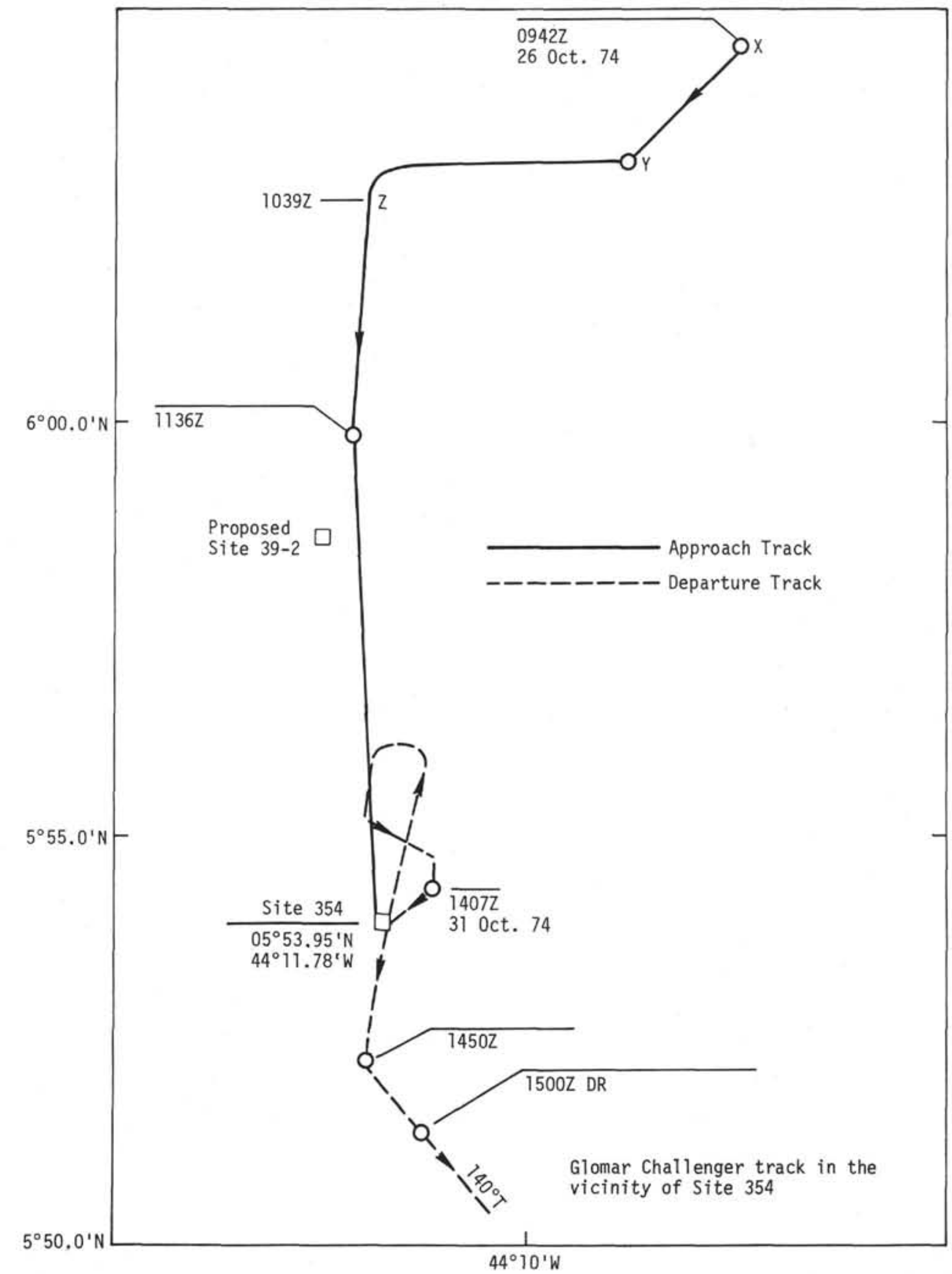


Figure 3. Glomar Challenger *track in the vicinity of Site 354.*

to core. The core barrel was full (Core 14). Thus, Cores 12 to 19, at least, must be viewed as containing sediment recovered from the sum total of, or anywhere within, the drilled-plus-cored interval.

To gain greater control on core location and to improve the unusually low drilling rate, we dropped a chisel-faced center bit and drilled the interval 738.5-814.5 meters.

It became obvious that present drilling rates would preclude our reaching basement within the time left on station. We cabled DSDP Headquarters for a day's postponement of our scheduled 5 November crew-change rendezvous in Recife, Brazil, and attempted to maximize core coverage and section recovery in the remaining time; Cores 15 through 18 were cut in close succession. We received an extension of 24 hours at about the time Core 18 was recovered. On the basis of an observed basement at 1.0 sec on the approach profile (Figure 4) and calculations based upon seismic velocities measured onboard, we believed acoustic basement to lie below 1000 meters, and again dropped the chisel-faced center bit. After only 5 meters of penetration, we encountered a very hard formation. We pulled the center bit to prevent bending and sticking, and found it to contain a small (~1 cm diameter) chip of chert. Core 19 was cut over 14 meters, of which we recovered 9.5

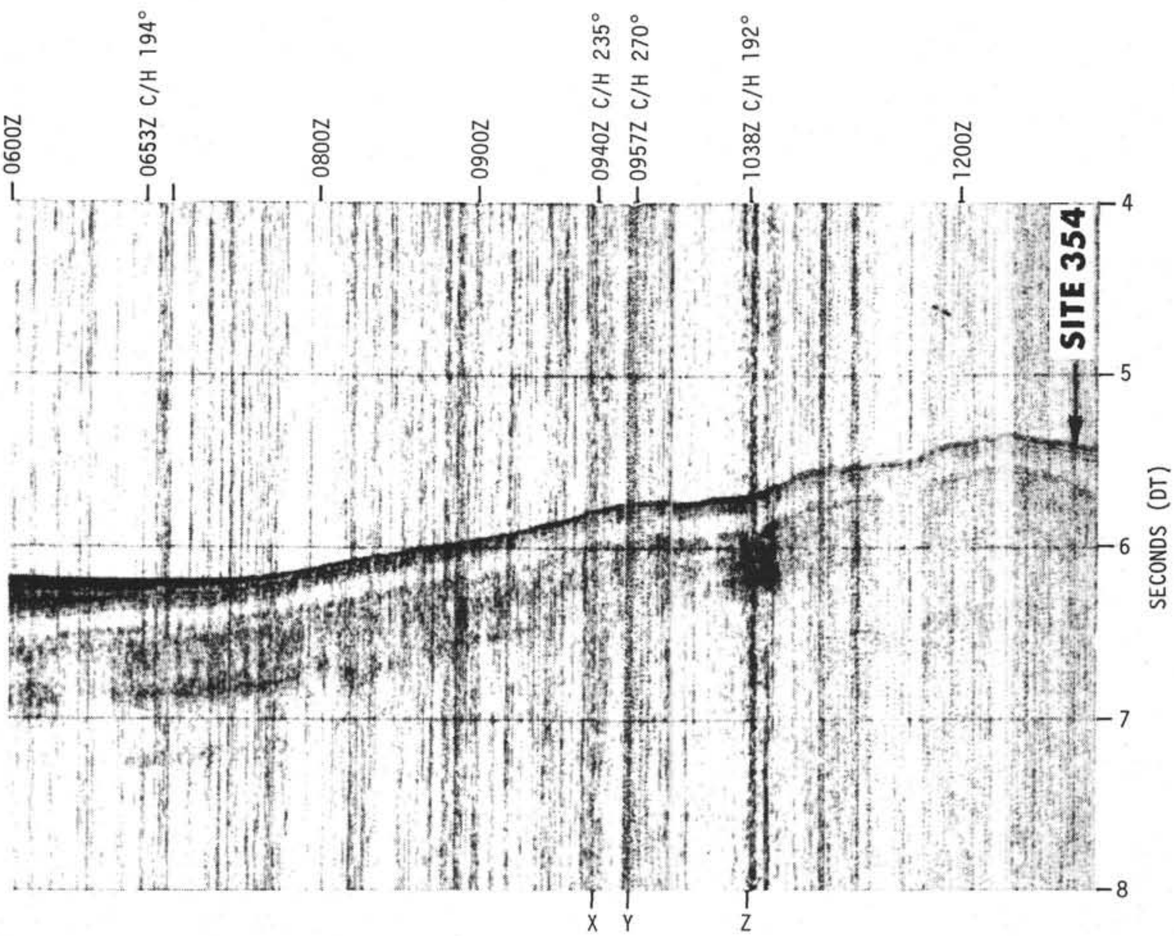


Figure 4. Glomar Challenger *approach profile, Site 354. Points X, Y, and Z refer to Figure 3.*

TABLE 1
Coring Summary, Site 354

Core	Depth Below Sea Floor (m)	Cored (m)	Recovered (m)	Recovered (%)
1	0.0- 7.0	7.0	2.6	37
2	45.0- 54.5	9.5	0.1	1
3	92.5-102.0	9.5	9.5	26
4	140.0-149.5	9.5	9.5	100
5	187.5-197.0	9.5	3.0	32
6	235.0-244.5	9.5	3.3	35
7	282.5-292.0	9.5	5.4	57
8	339.5-349.0	9.5	4.6	48
9	396.5-406.0	9.5	7.8	78
10	453.5-463.0	9.5	9.5	100
11	520.0-529.5	9.5	9.5	100
12	605.5-615.0	9.5	9.5	100
13	691.5-700.5	9.5	9.5	100
14	700.5-738.5	38.0	9.5	25
15	814.5-824.0	9.5	3.4	36
16	833.5-543.0	9.5	7.8	82
17	852.5-862.0	9.5	4.0	42
18	871.5-881.0	9.5	9.5	100
19	886.0-900.0	14.0	8.4	60
Total		211.0	119.4	56

meters of basalt. At least 2 meters of the 14 meters cored was a soft interval, indicating the possible presence of (unrecovered) soft sediment layers within the basalt. During core recovery, the bottom 1.1 meters of the core dropped through the stripped core catcher and bridged the drill pipe at 365 meters, making it necessary to trip the pipe up this far to retrieve the piece of basalt. The major scientific goals at this site had already been satisfied and the site was abandoned.

Glomar Challenger left Site 354 at 1305Z, 31 October 74, on a northerly course (Figure 3), streamed gear, turned to port, and after some current offset, passed over the beacon at 1421Z, changing course to 187°T and holding this course at slow speed (6 knots) for 30 minutes. At 1450Z, we changed course to 140°T and increased speed to full for the steam into Recife, Brazil.

LITHOLOGY

Sedimentary Section

Sampling of the sedimentary section of the Ceará Rise was discontinuous. We recovered 19 cores at various intervals; the last core bottomed in basalt. Nine major lithostratigraphic units occur at this site (Figures 5 and 6, and Table 2).

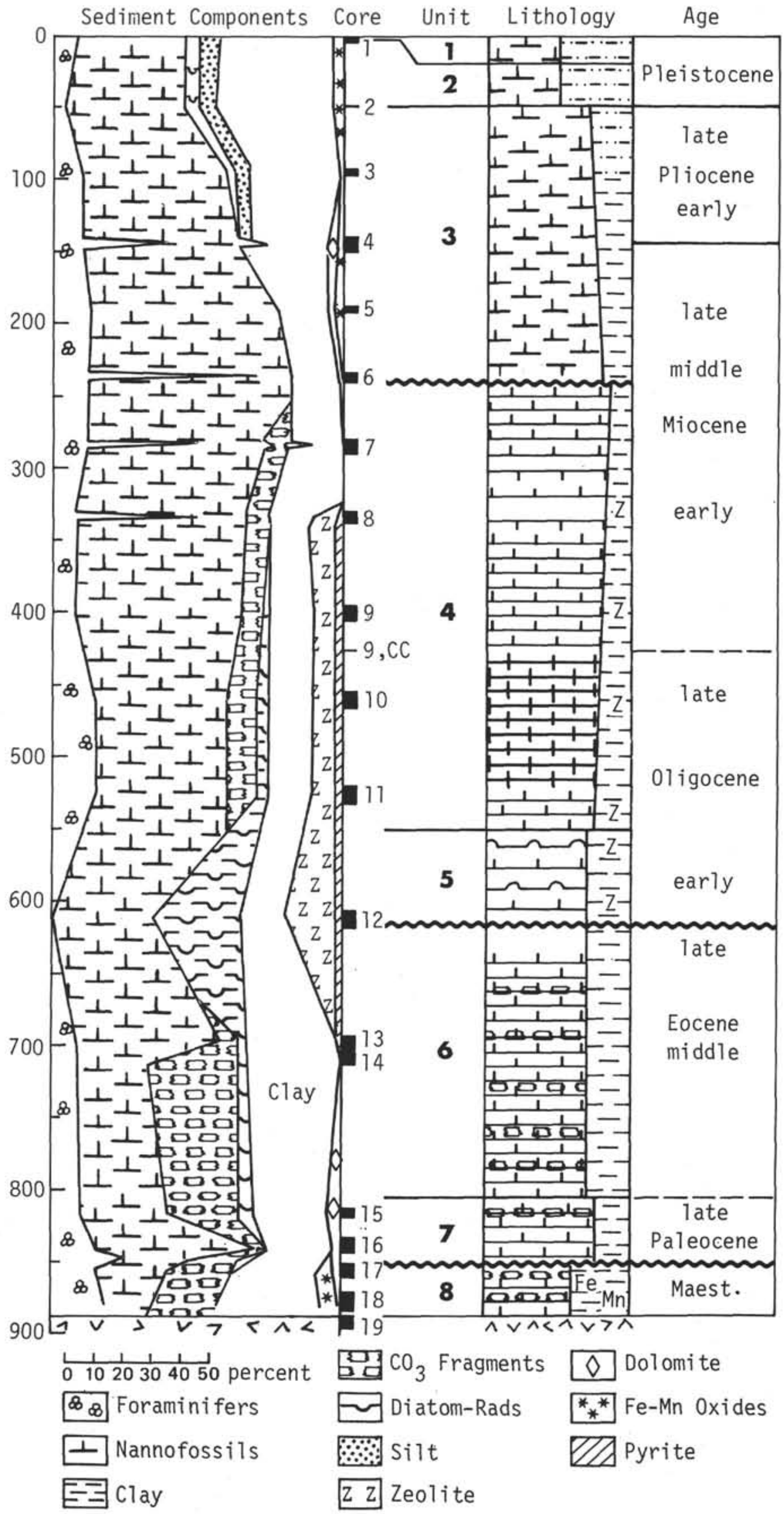


Figure 5. *Lithology, age, and sediment components, Site 354.*

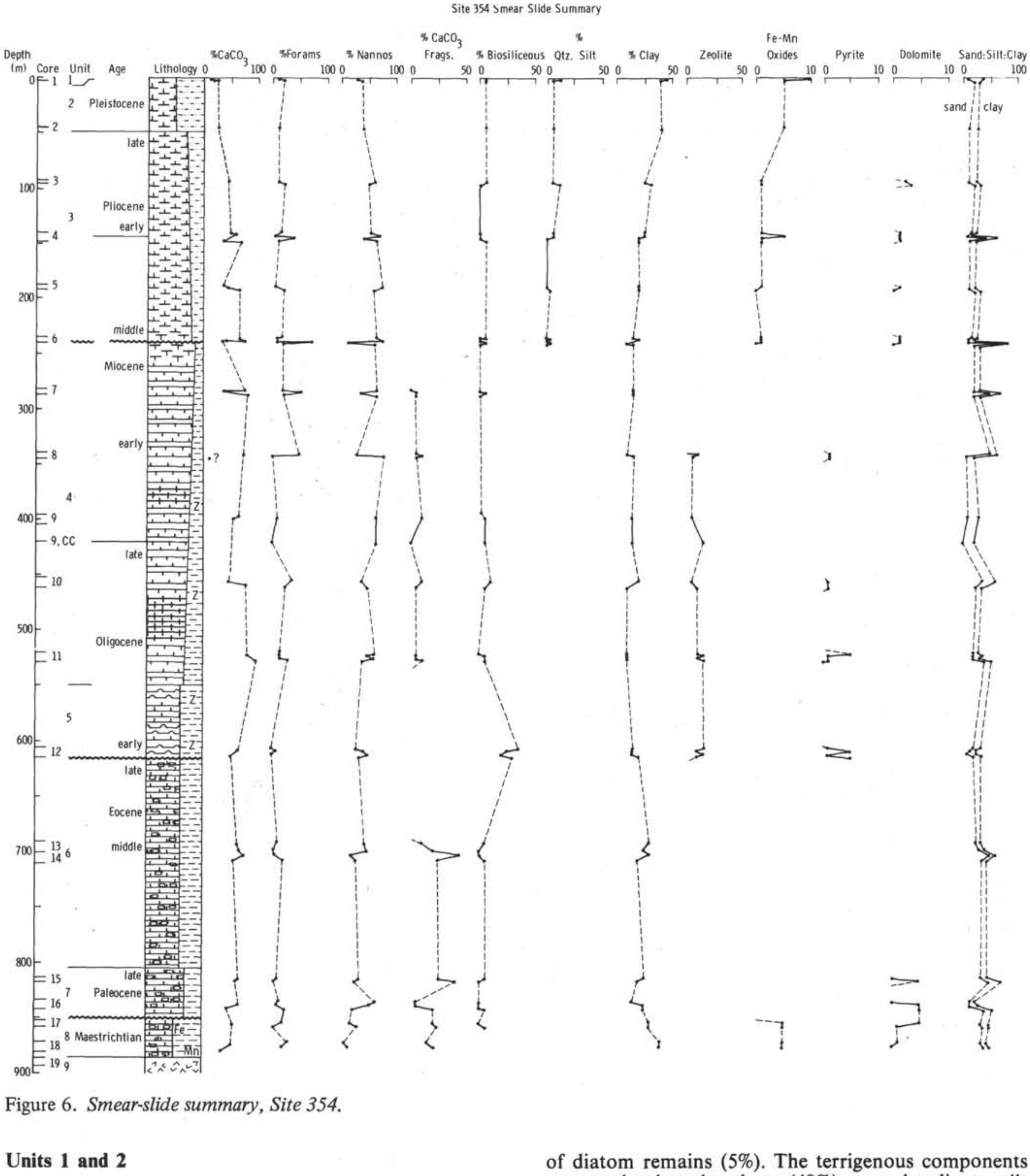


Figure 6. *Smear-slide summary, Site 354.*

Units 1 and 2

These units are calcareous muds, similar in mineralogic and biogenic composition, and of Pleistocene age. Both are essentially silty nannofossil muds, containing about 40% calcareous biogenous material and over 50% terrigenous components. For the most part, these units average 30%-35% nannofossils, together with lesser amounts of foraminifers and foraminifer fragments (5%-10%) and a minor amount of diatom remains (5%). The terrigenous components are predominantly clays (40%), a subordinate silt component (5%-10%), and limonite-hematite particles and aggregates. Smear slides of the silt fraction show quartz, muscovite (?), and glauconite. Unidentified heavy minerals occur in trace amounts as fine silt.

The units differ in color and carbonate content. Unit 1, approximately the first 1 meter of sediment (the top few centimeters are washed or not representative), is yellowish-brown with occasional indistinct brown

TABLE 2
Lithologic Summary Site 354

Unit	Cores	Depth Below Sea Floor (m)	Thickness (m)	Age	Description
1	1	0-128 cm	128 cm	Late Pleistocene	Unconsolidated, silty nanno-fossil mud (yellow-brown)
2	1-2	1-48	47	Pleistocene	Unconsolidated, silty nanno-fossil mud (olive-gray)
3	3-6	48-240	192	Mid-Miocene to late Pliocene	Nannofossil ooze and marly nannofossil ooze (yellow-brown); with interbedded fora-miniferal oozes; bottoms in varicolored calcareous chalks
4	7-11	240-550	310	Middle Oligocene to early Miocene	Pale blue-green, nannofossil chalk, with interbedded fora-miniferal chalks in the upper section; zeolitic, contorted layers, and clay-pebble breccia-tion in the lower portion
5	12	550-615	65	Early Oligocene	Green-gray, zeolitic, diatoma-ceous chalk with pyrite common
6	13-14	615-805	190	Mid to late Eocene	Homogeneous, marly nanno fossil chalk (blue-green); Frag-ments of anhedral carbonate are common
7	15-16	805-850	45	Early to late Paleocene	Light-gray, marly nannofossil chalk, dolomite rhombs common
8	17-18	850-886	36	Maestrichtian	Pale-red, well-indurated, marly calcareous chalk; carbonate fragments, iron and manganese oxides are common
9	19	886-	8.2–		Coarse-grained basalt; prominent veins of calcite

laminae. It is distinguished from the lower unit by its lower carbonate content (less than 20%) and its somewhat greater iron oxide content (5%-10%), which apparently imparts the yellowish hue. The ferruginous oxides occur as individual grains and as distinct coatings on other material. Unit 2 is light olive-gray with occasional brown laminae. It also contains scattered black hydrotroilite blebs and slight mottling; carbonate content ranges from 25% to 35%. The different carbonate contents are not clearly distinguishable from smear-slide examination.

Unit 1 is late Pleistocene in age and is clearly separated from Pleistocene Unit 2 at 128 cm in Core 1, Section 1. Only a core-catcher sample of Unit 2 was recovered in Core 2. On the basis of seismic evidence, we estimate the thickness of Unit 2 at 47 meters.

Unit 3

This unit grades from nannofossil ooze to marly nannofossil ooze, and is of late Pliocene to mid-Miocene age. It is pale yellowish-brown and yellowish-gray and contains an occasional slightly darker brown band. Color contacts within the unit are distinct but moderately deformed, perhaps by drilling disturbance of the unconsolidated material. Lighter gray bands also occur occasionally in the lower half of the unit. Nannofossils are predominant, averaging 50% to 90%; the percentages increase toward the bottom of the unit. Coccoliths or discoasters may be alternately dominant. Foraminifers and foraminifer fragments usually constitute 5% to 15%, but are more important in the light gray bands, where they may constitute up to 75% and may show a graded structure. Carbonate contents determined onboard range from 35% to 75%. Unidentified clays range from 10% to 30%, and a minor silt component of subangular quartz, anhedral calcite grains, and subhedral dolomite rhombs is also present. Blebs and occasional laminae of hydrotroilite or manganese oxide are visible macroscopically and as disseminated opaque grains in the smear slides. The unit's color is probably due to the clay mineral content and trace amounts of iron oxide, present as scattered grains.

The unit bottoms in a varicolored banded chalk in the lower half of Core 6, Section 3. The layers, 1 to 5 cm thick, are brown, yellow, black, gray, and olive. They vary from nannofossil oozes to foraminifer oozes to marls. The almost pure foraminifer layers of Section 3 probably indicate winnowed lag deposits. This sequence, deposited at extremely slow rates, includes a brief hiatus in the middle Miocene. Except for occasional foraminifer layers, the only other composition change is the disappearance of trace amounts of dolomite rhombs in the banded chalks.

Unit 4

The zeolitic nannofossil chalks of Unit 4 are 310 meters thick, extend from 240 to 550 meters (Cores 7-

11), and are late Oligocene to early Miocene in age. The unit consists of foraminifer-nannofossil chalk, with occasional bands of foraminifer chalk in the upper section. Pale blue is the dominant color, except in the foraminifer chalks, which are light gray. Evidence of bioturbation is common; the burrows are greenish-gray or brown. Nannoplankton remains constitute 10% to 50% of the sediment, and foraminifers and foraminifer fragments range from 10% to 30%. In the white chalks, the foraminifer content is higher and may average 50%. Poorly preserved diatom remains and radiolarian fragments also occur in small amounts.

The clay content varies from 5% to 20%, and zeolites are relatively abundant (5%-10%) in the lower two-thirds of the unit. Silt-sized grains of anhedral calcite are also common, and may constitute up to 20% of the carbonate content. Occasional silt-sized quartz grains occur in the upper sections, along with scattered hydrotroilite or manganese oxide grains. The ferruginous components of the overlying units are notably absent.

A distinguishing characteristic of this unit is the prevalence of *Zoophycos* burrows to a much greater degree than in most other units. *Zoophycos* burrows are absent in Units 1, 2, and 3, and occur only rarely in Units 5, 6, and 7, but they become prevalent again in Unit 8, of Late Cretaceous age.

Contorted beds are infrequent in the upper sections of Unit 4, but more predominant close to the base (Core 11, Sections 4, 5, and 6, see Figure 7), where zones of clay-pebble breccia, as well as intense burrowing, occur. All of this suggests intraformation slumping, shear, and deformation of incompetent layers very close to the sediment-water interface.

Unit 5

Unit 5, represented by Core 12, is a zeolitic diatomaceous chalk of early Oligocene age. Based on drilling penetration records and seismic reflectors, the unit is about 65 meters thick and extends from 550 to 615 meters.

The unit is light green-gray, similar in color and induration to the units above and below, but differentiated by its significantly greater quantity of diatom remains (30%-40%). Nannoplankton remains are the other major constituent, also averaging 30% to 40%. Radiolarian debris (5%), sponge spicules (5%), and sporadic foraminifers make up the remainder of the biogenic components. The clay content varies from 10% to 20%, and authigenic zeolites usually make up an additional 10% to 15%. Silt-sized carbonate grains are notably absent. Diatom remains and zeolite minerals in relatively large amounts clearly distinguish this unit.

Also distinctive here are dark gray bands (1-2 cm thick) of laminated black and white material. These have an overall composition similar to the surrounding greenish-gray sediment, except for small amounts of pyrite (Figure 8). Intensely burrowed zones are frequent beneath these dark areas.

Unit 6

The nannofossil chalks of Unit 6 are middle to late Eocene in age, and are represented by Cores 13 and 14.

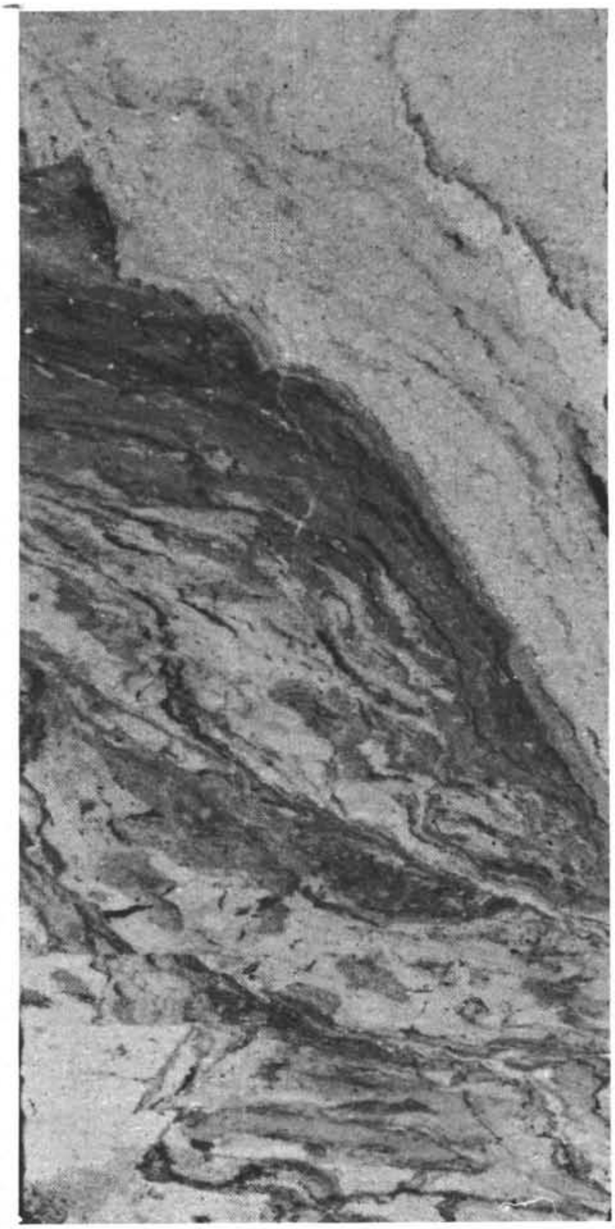


Figure 7. *Soft sediment deformation in middle Oligocene zeolitic nannofossil chalks (Sample 354-11-5, 118-132 cm). Core width 6.35 cm.*

From the base of Unit 5 at 615 meters, the unit extends to 805 meters, where the drilling rate changed.

This unit is homogeneous marly nannofossil chalk, with uniform mottling throughout. It is pale blue-green; some burrows are filled with light olive-gray material. Unit 6 is mineralogically and biologically similar to Unit 4, except for the absence of zeolites and a somewhat greater clay content. It differs also in having far fewer *Zoophycos* burrows, which results in a more uniform appearance. Silt-sized fragments of anhedral calcite constitute 20% to 40% of this unit.

Unit 7

Unit 7, represented by the marly nannofossil chalks of Cores 15 and 16, is middle to late Paleocene in age. Its thickness is estimated at 45 meters, but the upper

Figure 8. *Pyrite partially replacing diatom frustule; in diatomaceous nannofossil ooze, Unit 5 (Sample 354-12-1, 50 cm).*

contact at 805 meters is not well defined. The lower contact, at 850 meters, is better estimated, both by drilling rate data and seismic reflection; further, the cores in this portion of the hole are more closely spaced, allowing for a more precise determination of the lower boundary.

The unit is marly nannofossil chalk, very light gray and moderately mottled throughout; one band of pale red sediment occurs close to the top. Generally, its major components are similar to the unit above. Nannofossils make up 50% to 70%, foraminifers 10% to 20%, clay approximately 20%. Common in the upper portion are anhedral grains of calcite (20%-30%), along with minor amounts of silt-sized quartz. Dolomite rhombs occur throughout, in amounts ranging from traces to 5%. This unit is best defined by its gray color and uniform appearance, and by the consistent presence of dolomite rhombs.

Unit 8

Unit 8 is pale red marly calcareous chalk of Late Cretaceous age and is the lowermost sedimentary unit at this site. It is represented by Cores 17 and 18 and extends from 850 meters to the basalt at 886 meters (36 m thick).

The unit is well indurated, ferruginous, and marly, and is distinguished immediately by its pale red color and black burrows. The biogenic components of these chalks occur in wide ranges: foraminifers (5%-30%) and nannofossils (10%-35%). Anhedral carbonate grains constitute 15% to 25%. The coloring materials are iron and manganese oxides, constituting 5% of the sediment, which occur as discrete subhedral grains and aggregates. A thin section of this chalk shows the oxides as distinct fillings in foraminifer tests (Figure 9). Clays constitute 10% to 30%. A distinguishing feature of this unit is the great number of distinct *Zoophycos* burrows, as well as other burrows. The dark material in the burrows is distinguished only by its somewhat higher content of manganese-oxide.

A center-bit sample taken just above the basalt recovered a small chip of chert. We do not know whether the sample represents a separate basal chert unit (maximum thickness of 5 m) or stringers of chert which may be in the lower parts of Unit 8.

Unit 9—Basalt

In Core 19, cut over a 14-meter interval, we recovered 8.4 meters of basalt.

Macroscopic Description

The basalt section is light gray with some yellowish stain in the upper part; lower down it is darker gray. This difference probably reflects slightly more intense weathering in the upper portion. The degree of crystallinity is high throughout, with visible platelets of plagioclase, 1 to 2 mm long. No obvious breaks into different flows are evident anywhere in the core, since no surfaces chilled to glass (or formerly glass) occur. It would seem, then, that the entire core represents a single thick flow or sill. The sediment/basalt contact was not recovered, so we were unable to check for signs

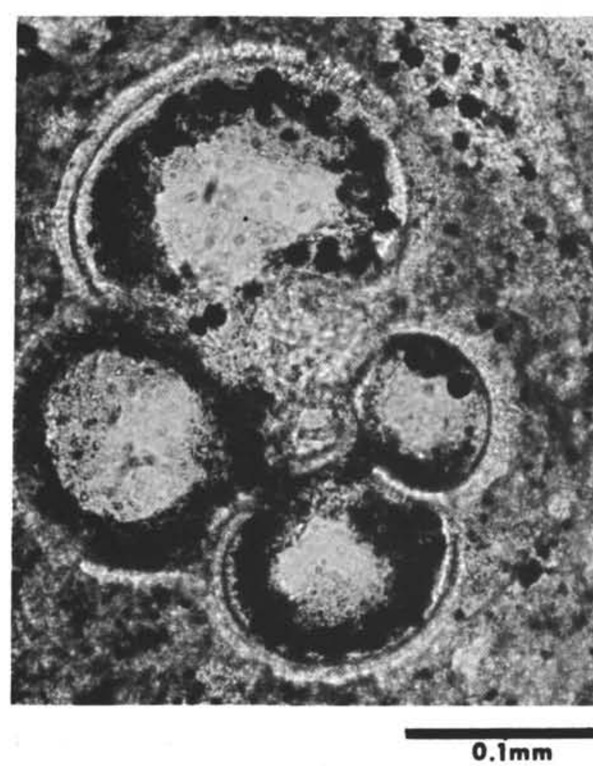


Figure 9. *Concentrations of amorphous Fe-Mn oxides in chambers of foraminifers; in marly chalk, Unit 8 (Sample 354-17-3, 20 cm).*

of thermal metamorphism of the sediment close to the contact, as evidence of a sill rather than basement flow.

Prominent veins of calcite, scattered throughout the basalt, reach thicknesses of 1 cm or more. Also scattered throughout the basalt, but especially abundant below the top 2 meters of the core, are milky-white concentrations, generally a fraction of a millimeter, but in some cases more than 1 mm in diameter.

Microscopic Description

We studied thin sections from different levels in the core. The following describes a section from an intermediate level.

Section 39-354-19-6 Piece # 4, 31-32 cm: Doleritic basalt, rather coarse grained, with doleritic-subophitic texture. Plates of calcic plagioclase, 0.5 to 1.5 mm, with An content ranging around 65% ±10%. These plagioclase crystals show frequent albite and albite-carlsbad twinning and occasional zoning. Large, partly euhedral clinopyroxene crystals occur; C/γ angle is about 45°-50°, in the range of augite. Olivine is absent, except in one doubtful case. Apparently an earlier generation of clinopyroxene has been completely altered into microcrystalline calcite and other secondary products which make up a groundmass. This groundmass now is littered with relatively large magnetite-ilmenite crystals. Frequently these opaque crystals are skeletal, or acicular, in a network of parallel alignments. Scattered throughout the thin section are large (up to about 1 mm), generally rounded aggregates of microcrystalline calcite. Also present are similar but generally smaller masses, consisting mainly of microcrystalline silica (chalcedony), with other minor phases, probably zeolites and epidotes. A vein (roughly 0.5-1 mm thick) containing calcite, chalcedony, magnetite, and traces of epidote, zeolite, and chlorite, crosses the thin section.

Thin sections from other levels in the basalt core show features similar to those of the section described above. One notable difference is that sections from the upper levels of the core tend to contain very little or no recognizable, relatively fresh clinopyroxene. This may mean that either (a) the processes of alteration which resulted in destruction of the clinopyroxene and appearance of the calcitic-silicic groundmass were more intense toward the top of the basalt core, or (b) some horizontal layering exists in this doleritic basalt, with a lower original plagioclase/pyroxene ratio. This second interpretation is consistent with the core being part of a slowly cooled thick flow or sill.

Discussion

The coarse-grained, doleritic (or diabasic) nature of the basalt cored at Site 354 suggests that it was originally part of a slowly cooled thick flow or sill. There is evidence that some horizontal layering may have developed during slow cooling of the magma. The presence of a thick sill is consistent with seismic reflection data at Site 354, suggesting that the igneous rock reached by coring is not true basement but a sill.

Abundant calcitic-silica veins and segregations throughout the rock indicates that it underwent strong hydrothermal alteration. This alteration may have occurred deuterically during slow cooling of the magma, by the action of heated sea water, or subsequently by the action of hydrothermal solutions circulating in the oceanic crust.

The ferromanganoan sediment of Unit 8 is similar to the basal ferruginous facies reported from many previous DSDP sites in all the major ocean basins (Boström et al., 1969; von der Borch and Rex, 1970; Boström and Fisher, 1971; Cronan, 1973). The widespread occurrence of this basal facies in both location and time suggests a continually active mechanism common to all ocean basins. Discussion in the literature has focused on the origin of these metalliferous sediments and their association with active ridge areas. Boström and Peterson (1969) suggest a hydrothermal origin, in which precipitates of mineralizing solutions would have been derived from the mantle. Corliss (1971) also suggests a hydrothermal origin, but with the enriched solutions generated by the leaching of newly extruded basalt where sea water, heated by the cooling rock mass, mobilizes the metals as chloride complexes. The iron-rich solutions then emerge, oxidize, and precipitate as a ferric hydroxide floc, which settles near the vent or is dispersed by bottom water movement. Subsequent spreading and dilution with pelagic material results in an upward gradation to normal marine sediment. At this site the upward termination of the ferromanganoan material is abrupt, marked by an upper Maestrichtian-Paleocene hiatus.

The Maestrichtian to mid-Eocene sediments contain significant quantities of carbonate fragments, fine sand- and silt-sized, subangular, with frequent small overgrowths. These may have been produced by fragmentation of benthic shelled organisms on a slope of a relatively shallow Ceará Rise. If so, they indicate slow but active bottom circulation in the mid-water portion of the opening Atlantic basin.

The nearby Ceará Abyssal Plain (Site 142, in Hayes, Pimm, et al., 1972) accumulated turbidite and mixed pelagic clays and oozes from the Miocene to the present. Presumably, this records the onset of sedimentation at the Amazon Cone (Damuth and Kumar, 1975). This event is also recorded at Site 354, where deposition of terrigenous silt and clay began in the late Miocene-early Pliocene and increased in the late Pliocene, so that the silts and clays dominate in Units 1 and 2 (Pleistocene). The fine size of the terrigenous component, as well as the somewhat later initiation, reflects the distal and elevated position of the Ceará Rise with respect to the main deposition area at the continental margin.

GEOCHEMISTRY

We analyzed 13 interstitial water samples aboard ship for *p*H, alkalinity, salinity, Ca^{++}, and Mg^{++}. The data, presented in Table 3 and plotted in Figure 10, show a general increase in Ca^{++} and decrease in Mg^{++} with depth, and a reversal in both trends just above basement.

TABLE 3
Summary of Shipboard Geochemical Data

Sample (Interval in cm)	Subdepth (m)	pH	Alkalinity (meq/l)	Salinity (°/₀₀)	Ca^{++} (mmoles/l)	Mg^{++} (mmoles/l)	
1-1, 144-150	1.5	7.45	3.76	35.5	10.65	51.38	
3-1, 144-150	94.0	7.43	2.83	34.9	12.41	46.05	
4-5, 144-150	147.5	7.36	3.74	34.9	15.07	45.26	
5-1, 144-150	189.0	7.32	3.15	35.5	11.76	49.59	
6-2, 144-150	238.0	7.05	4.60	35.2	18.54	43.87	
7-4, 144-150	288.5	6.95	5.03	35.5	23.99	39.57	
8-2, 144-150	342.5	6.95	5.36	35.2	27.28	37.52	
9-4, 144-150	402.5	6.85	5.83	35.2	31.90	44.32	Colorimetric Alkalinity Titration
11-5, 144-150	527.5	7.02	4.80	35.2	36.92	27.36	
12-5, 144-150	613.0	6.97	5.87	35.2	41.62	25.56	
13-5, 144-150	698.5	–	–	36.0	42.35	26.10	
16-4, 140-150	839.5	7.01	3.82	35.8	52.80	24.39	
17-1, 144-150	854.0	7.00	3.72	35.2	47.35	32.33	

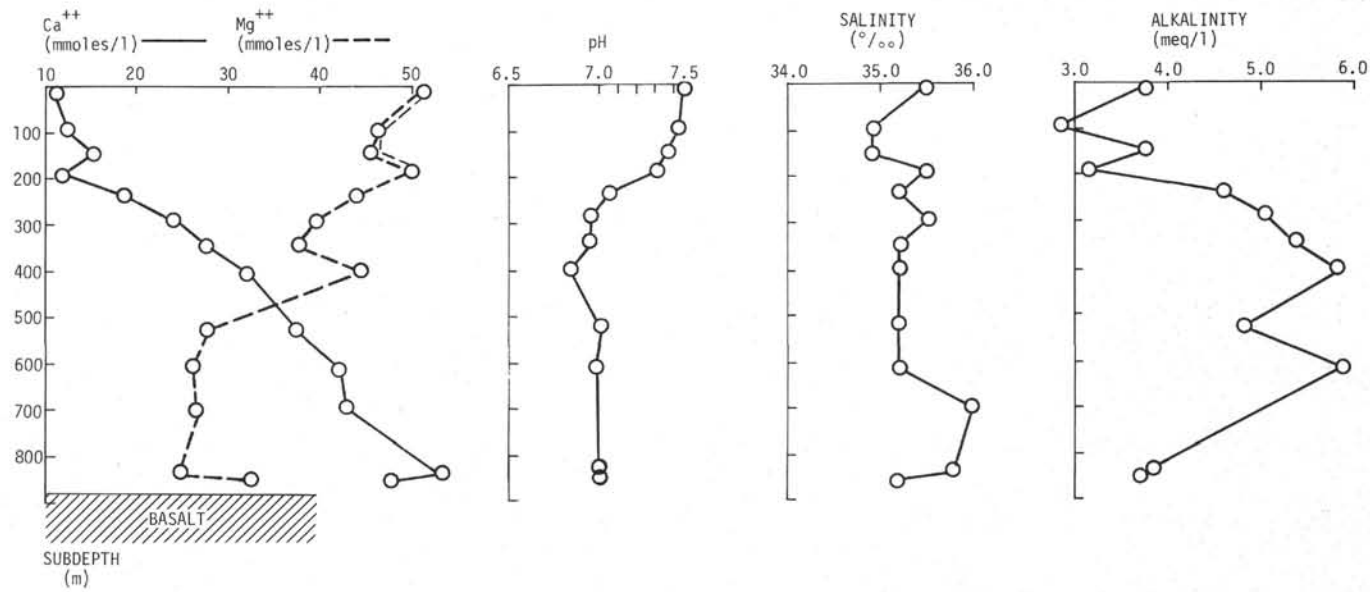


Figure 10. *Geochemical data of interstitial waters versus depth, Site 354.*

PHYSICAL PROPERTIES

Physical properties data at Site 354 show an expected compaction trend, with very minor variations from unit to unit within the sequence. Because cored intervals were often widely separated, we can draw only very general distinctions with regard to lithology.

A word of caution is in order regarding the syringe densities listed in Table 4. Through oversight, no provisions had been made for storing hard sediment samples until we could perform immersion or 2-min GRAPE density measurements on them. Consequently, after we encountered stiff sediments (which precluded use of the syringe technique) in Core 6, few measurements were possible until recovery of Core 12. We took a large number of water content samples, however, and made a least-squares fit of water content versus syringe density for data from Cores 3 through 5. The determined relationship,

$$\rho \text{ (g/cc)} = 2.41 - 0.02 \text{ (wt \% } H_2O)$$

is remarkably good, with a correlation coefficient of 0.91 and a standard error of the estimate of water content on density of only 0.038. We used this equation to estimate syringe densities for the lower part of the sequence. One can assume that the equation holds for lower water contents, provided no significant change occurs in the grain density of the recovered material. The calcareous nature of the entire lithologic sequence permits this assumption. Immersion and 2-minute GRAPE densities agree quite well with the computed values. Still, the computed densities must be regarded with suspicion. The relationship cited above holds for all syringe densities of calcareous sediments recovered on Leg 39.

Physical properties data for Site 354 indicate three distinct trends with depth. The uppermost sedimentary unit sampled (Unit 3) is a nannofossil ooze which grades into chalk, and extends to a depth of 240 meters. Acoustic velocities in this interval are uniformly less than 1.6 km/sec, and there is little suggestion of a gradient (Figure 11). Similarly, the water content is

TABLE 4
Physical Properties Measurements, Site 354

Sample (Interval in cm)	Depth (m)	Velocity (km/sec)	Density (g/cc) S	I	G	Water Wt %	Porosity (%) S	I	G	Acoustic Impedance S	I	G
3-1, 90	93.40	–	1.648	–	–	38.33	62.81	–	–	–	–	–
3-1, 125	93.75	–	1.607	–	–	39.29	65.25	–	–	2.40	–	–
3-1, 127	93.77	1.495	–	–	–	–	–	–	–	–	–	–
3-2, 21	94.21	1.557	1.689	–	–	34.86	60.36	–	–	2.63	–	–
3-2, 63	94.63	1.566	1.693	–	–	35.03	60.12	–	–	2.65	–	–
3-2, 97	94.97	–	1.688	–	–	35.71	60.42	–	–	2.70	–	–
3-2, 99	94.99	1.600	–	–	–	–	–	–	–	–	–	3.01
3-2, 104	95.04	–	–	–	1.879	–	–	–	49.01	–	–	2.98
3-2, 133	95.33	1.586	–	–	–	–	–	–	–	2.63	–	–
3-2, 134	95.34	–	1.658	–	–	34.71	62.21	–	–	–	–	–
4-1, 30	140.30	1.562	1.642	–	–	34.72	63.16	–	–	2.56	–	–
4-1, 73	140.73	1.583	1.670	–	–	35.07	61.49	–	–	2.64	–	–
4-1, 106	141.06	1.570	1.687	–	–	37.14	60.48	–	–	2.65	–	–
4-1, 143	141.43	1.559	1.754	–	–	32.96	56.48	–	–	2.73	–	–
4-2, 10	141.60	1.542	1.759	–	–	31.03	56.18	–	–	2.71	–	–
4-2, 75	142.25	–	–	–	–	–	–	–	–	2.61	–	–
4-2, 79	142.29	1.539	1.694	–	–	28.40	60.06	–	–	2.61	–	–
4-3, 88	143.88	–	–	–	–	–	–	–	–	–	–	–
4-4, 6	144.56	1.438	–	–	–	–	–	–	–	–	–	–
4-4, 107	145.57	1.464	–	–	–	–	–	–	–	–	–	–
4-5, 40	146.40	1.616	1.854	–	–	29.61	50.51	–	–	3.00	–	–
4-5, 71	146.71	–	–	–	–	–	–	–	–	–	–	–
4-5, 104	147.04	1.563	1.830	–	–	29.18	51.94	–	–	2.86	–	–
4-5, 133	147.33	1.570	1.817	–	–	28.35	52.72	–	–	2.85	–	–
4-6, 24	147.74	1.574	1.816	–	–	28.81	52.78	–	–	2.86	–	–
4-6, 33	147.83	1.635	1.603	–	–	42.72	65.49	–	–	2.62	–	–
4-6, 43	147.93	1.578	1.763	–	–	30.23	55.94	–	–	2.78	–	–
4-6, 49	147.99	1.590	1.759	–	–	33.55	56.18	–	–	2.80	–	–
4-6, 68	148.18	–	–	–	–	–	–	–	–	–	–	–
4-6, 121	148.71	1.611	1.733	–	–	32.15	57.73	–	–	2.79	–	–
4-6, 130	148.80	1.600	1.760	–	–	30.25	56.12	–	–	2.82	–	–
4-0, 0	149.50	1.556	–	–	–	–	–	–	–	–	–	–
5-2, 69	195.69	1.486	1.798	–	–	30.64	53.85	–	–	2.67	–	–
5-2, 142	196.42	1.593	1.876	–	–	28.26	49.19	–	–	2.99	–	–
6-1, 136	240.86	–	–	–	–	27.06	–	–	–	–	–	3.25
6-1, 144	240.94	1.740	–	–	1.866	–	–	–	49.79	–	–	3.25
6-2, 77	241.77	1.617	1.892	–	–	25.42	48.24	–	–	3.06	–	–
6-3, 60	243.10	1.600	1.946	–	–	22.77	45.01	–	–	3.11	–	–
6-3, 84	243.34	1.609	1.879	–	–	26.09	49.01	–	–	3.02	–	–
6-3, 96	243.36	1.669	1.884	–	–	25.83	48.72	–	–	3.14	–	–
6-3, 141	243.91	1.706	1.895	–	–	25.28	48.06	–	–	3.23	–	–
6-0, 0	244.50	1.693	–	–	–	–	–	–	–	–	–	–
7-1, 133	286.83	1.686	–	–	–	–	–	–	–	3.22	–	–
7-1, 137	286.87	–	1.912	–	–	24.45	47.04	–	–	–	–	–
7-2, 105	288.05	–	1.912	–	–	24.45	47.04	–	–	3.86	–	–
7-2, 110	288.10	2.020	–	–	–	–	–	–	–	–	–	–
7-2, 110	288.10	1.987	–	–	–	–	–	–	–	–	–	–
7-2, 124	288.24	1.802	–	–	–	–	–	–	–	–	–	–
7-2, 124	288.24	1.766	–	–	–	–	–	–	–	3.10	–	–
7-2, 128	288.28	–	1.756	–	–	32.13	56.36	–	–	–	–	–
7-3, 97	289.47	–	1.893	–	–	25.41	48.18	–	–	3.56	–	–
7-3, 102	289.52	1.880	–	–	–	–	–	–	–	–	–	–
7-4, 55	290.55	1.894	–	–	–	–	–	–	–	3.71	–	–
7-4, 65	290.65	–	1.960	–	–	22.13	44.18	–	–	–	–	–
8-1, 38	344.38	–	1.926	–	–	23.76	46.21	–	–	3.86	–	–
8-1, 45	344.45	2.004	–	–	–	–	–	–	–	–	–	–
8-1, 107	345.07	–	1.925	–	–	23.84	46.27	–	–	3.92	–	–
8-1, 130	345.30	2.036	–	–	–	–	–	–	–	–	–	–
8-2, 3	345.53	–	–	–	–	–	–	–	–	–	–	–
8-2, 66	346.16	–	1.918	–	–	24.16	46.69	–	–	3.60	–	–
8-2, 72	346.22	1.875	–	–	–	–	–	–	–	–	–	–
8-2, 76	346.26	–	–	–	–	–	–	–	–	–	–	–
9-1, 75	398.75	1.840	–	–	–	–	–	–	–	3.59	–	–
9-1, 78	398.78	–	1.953	–	–	22.45	44.60	–	–	–	–	–
9-2, 31	399.81	–	1.909	–	–	24.62	47.22	–	–	3.68	–	–
9-2, 43	399.93	1.928	–	–	–	–	–	–	–	–	–	–
9-2, 69	400.19	–	–	–	–	–	–	–	–	–	–	–
9-3, 52	401.52	–	1.876	–	–	26.23	49.19	–	–	3.43	–	–
9-3, 70	401.70	1.826	–	–	–	–	–	–	–	–	–	–

TABLE 4 – *Continued*

Sample (Interval in cm)	Depth (m)	Velocity (km/sec)	Density (g/cc) S	Density (g/cc) I	Density (g/cc) G	Water Wt %	Porosity (%) S	Porosity (%) I	Porosity (%) G	Acoustic Impedance S	Acoustic Impedance I	Acoustic Impedance G
9-5, 70	404.70	1.882	–	–	–	–	–	–	–	3.54	–	–
9-5, 78	404.78	–	1.882	–	–	25.95	48.84	–	–	–	–	–
10-1, 63	454.13	2.008	–	–	–	–	–	–	–	4.02	–	–
10-1, 65	454.15	–	2.001	–	–	20.09	41.73	–	–	–	–	–
10-1, 133	454.83	–	1.966	–	–	21.83	43.82	–	–	–	–	–
10-1, 134	454.84	–	–	–	2.085	–	–	–	36.72	–	–	–
10-1, 137	454.37	2.108	–	–	–	–	–	–	–	–	–	–
10-2, 33	455.33	–	1.991	–	–	20.57	42.33	–	–	4.15	–	–
10-2, 40	455.40	2.083	–	–	–	–	–	–	–	–	–	–
10-2, 80	455.80	2.109	–	–	–	–	–	–	–	4.02	–	–
10-2. 107	456.07	–	1.906	–	–	24.77	47.40	–	–	–	–	–
10-3, 85	457.35	–	–	–	–	20.29	–	–	–	–	–	–
10-3, 100	458.00	1.877	–	–	–	–	–	–	–	–	–	–
10-5, 3	459.53	2.068	–	–	–	–	–	–	–	4.13	–	–
10-5, 5	459.55	–	1.998	–	–	20.26	41.91	–	–	–	–	–
10-0, 0	463.00	1.849	–	–	–	–	–	–	–	–	–	–
11-1, 15	520.15	1.891	1.943	–	2.057	22.92	45.19	–	38.39	3.67	–	3.89
11-1, 71	520.71	1.846	1.993	–	–	20.51	42.21	–	–	3.68	–	–
11-1, 120	521.20	1.945	–	–	–	–	–	–	–	–	–	–
11-2, 96	522.46	–	2.019	–	–	19.23	40.66	–	–	4.06	–	–
11-2, 120	522.70	2.009	–	–	–	–	–	–	–	–	–	–
11-3, 20	523.20	1.988	–	–	–	–	–	–	–	–	–	–
11-3, 24	523.24	–	2.005	–	–	19.92	41.49	–	–	–	–	–
11-4, 60	525.10	2.161	–	–	–	–	–	–	–	4.21	–	–
11-4, 74	525.24	–	1.949	–	–	22.65	44.84	–	–	–	–	–
11-5, 60	526.60	2.170	–	–	–	–	–	–	–	4.72	–	–
11-5, 71	526.71	–	2.174	–	–	11.63	31.40	–	–	–	–	–
11-6, 1	527.51	–	2.029	–	–	18.71	40.06	–	–	4.14	–	–
11-6, 10	527.60	2.041	–	–	–	–	–	–	–	–	–	–
12-1, 39	605.89	2.068	–	–	–	–	–	–	–	4.17	–	–
12-1, 40	605.90	–	2.016	–	–	19.35	40.84	–	–	–	–	–
12-1, 104	606.54	2.138	–	–	–	–	–	–	–	–	–	–
12-2, 5	607.05	2.215	1.934	–	–	23.37	45.73	–	–	4.28	–	–
12-2, 12	607.12	–	1.967	–	–	21.75	43.76	–	–	–	–	–
12-3, 120	609.70	2.204	1.998	–	–	20.24	41.91	–	–	4.40	–	–
12-4, 109	611.09	2.163	–	–	–	–	–	–	–	4.17	–	–
12-4, 120	611.20	–	1.927	–	–	23.74	46.15	–	–	–	–	–
12-5, 60	612.10	2.157	–	–	–	–	–	–	–	4.16	–	–
12-5, 60	612.10	–	1.930	–	–	21.57	45.97	–	–	–	–	–
12-6, 15	613.15	2.079	1.905	–	–	24.82	47.46	–	–	3.96	–	–
13-1, 30	691.30	2.336	–	–	–	–	–	–	–	–	–	–
13-1, 67	691.67	–	2.103	–	–	15.08	35.64	–	–	–	–	–
13-1, 150	692.50	–	–	2.060	–	–	–	38.21	–	–	–	–
13-2, 70	693.20	2.164	–	–	–	–	–	–	–	–	–	–
13-3, 60	694.60	–	2.116	–	–	14.45	34.87	–	–	5.03	–	–
13-3, 70	694.70	2.379	–	–	–	–	–	–	–	–	–	–
13-4, 20	695.70	2.376	2.132	–	–	13.70	33.91	–	–	5.07	–	–
13-5, 30	697.30	2.385	–	2.060	2.238	–	–	38.21	27.58	–	4.91	5.34
13-5, 73	697.73	–	2.095	–	–	15.51	36.12	–	–	5.00	–	–
13-5, 100	698.00	2.385	–	–	–	–	–	–	–	–	–	–
13-6, 75	699.25	–	2.107	–	–	14.92	35.40	–	–	4.93	–	–
13-6, 86	699.36	2.341	–	–	–	–	–	–	–	–	–	–
13-6, 130	699.80	–	–	2.110	–	–	–	35.22	–	–	5.47	5.83
13-6, 140	699.90	2.592	–	2.120	2.250	–	–	34.63	26.87	–	5.50	5.83
14-1, 50	701.00	2.409	2.057	–	–	17.37	38.39	–	–	4.96	–	–
14-2, 60	702.60	–	2.049	–	–	17.84	38.87	–	–	–	–	–
14-3, 70	704.20	2.257	–	–	–	–	–	–	–	–	–	–
14-4, 142	706.42	2.240	2.025	–	–	18.91	40.30	–	–	4.54	–	–
14-5, 130	707.80	2.293	–	–	–	–	–	–	–	4.81	–	–
14-5, 149	707.99	–	2.097	–	–	15.56	36.00	–	–	–	–	–
14-6, 107	709.07	–	2.057	–	–	17.36	38.39	–	–	4.67	–	–
14-6, 110	709.10	2.269	–	–	–	–	–	–	–	–	–	–
15-1, 124	820.24	–	2.036	–	–	18.36	39.64	–	–	5.34	–	–
15-1, 127	820.27	2.624	–	–	–	–	–	–	–	–	–	–
15-2, 110	821.60	2.494	–	–	–	–	–	–	–	–	–	–
15-3, 79	622.79	–	2.012	–	–	19.63	41.07	–	–	–	–	–
15-3, 105	823.05	2.572	–	–	–	–	–	–	–	–	–	–
16-2, 40	835.40	2.513	–	–	–	–	–	–	–	–	–	–
16-2, 80	835.80	2.464	2.058	–	–	17.29	38.33	–	–	5.07	–	–

TABLE 4 – *Continued*

Sample (Interval in cm)	Depth (m)	Velocity (km/sec)	Density (g/cc) S	I	G	Water Wt %	Porosity (%) S	I	G	Acoustic Impedance S	I	G
16-3, 35	836.85	–	2.060	–	–	17.21	38.21	–	–	5.52	–	–
16-3, 40	836.90	2.682	–	–	–	–	–	–	–	–	–	–
16-3, 105	837.55	2.459	–	–	–	–	–	–	–	–	–	–
16-4, 113	839.13	–	2.100	–	–	15.26	35.82	–	–	5.12	–	–
16-4, 120	839.20	2.439	–	–	–	–	–	–	–	–	–	–
16-5, 125	840.75	–	2.079	–	–	16.26	37.07	–	–	4.93	–	–
16-5, 127	840.77	2.373	–	–	–	–	–	–	–	–	–	–
16-6, 103	842.03	2.227	–	–	–	–	–	–	–	4.47	–	–
16-6, 110	842.10	–	2.008	–	–	19.75	41.31	–	–	–	–	–
17-1, 87	857.87	2.599	–	–	–	–	–	–	–	–	–	–
17-1, 107	858.07	2.620	–	–	–	–	–	–	–	–	5.55	5.76
17-1, 115	858.15	–	–	2.120	2.197	–	–	34.63	30.03	–	–	–
17-2, 13	858.63	2.897	–	–	–	–	–	–	–	–	–	–
17-2, 50	859.00	–	–	1.960	–	–	–	44.18	–	–	–	–
17-2, 140	859.90	2.417	–	–	–	–	–	–	–	–	4.79	5.14
17-3, 15	860.15	–	–	1.980	2.127	–	–	42.99	34.21	–	4.63	4.97
17-3, 16	860.16	2.337	–	–	–	–	–	–	–	–	–	–
17-3, 95	860.95	–	–	1.970	–	–	–	43.58	–	–	–	–
17-3, 126	861.26	2.399	–	–	–	–	–	–	–	–	–	–
18-1, 20	871.70	2.523	–	–	–	–	–	–	–	–	–	–
18-1, 80	872.20	–	–	–	–	–	–	–	–	–	–	–
18-2, 55	873.55	–	2.063	–	–	17.07	38.03	–	–	5.38	5.48	–
18-2, 60	873.60	2.608	–	2.100	–	–	–	35.82	–	–	5.48	–
18-3, 55	875.05	–	2.065	–	–	16.95	37.91	–	–	5.43	–	–
18-3, 65	875.15	2.630	–	–	–	–	–	–	–	–	5.21	–
18-3, 70	875.20	–	–	1.980	–	–	–	42,99	–	–	–	–
18-4, 50	876.50	2.582	–	–	–	–	–	–	–	5.36	–	–
18-4, 69	876.69	–	2.074	–	–	16.52	37.37	–	–	–	–	–
18-5, 30	877.80	2.545	–	–	–	–	–	–	–	5.29	–	–
18-5, 40	877.90	–	2.077	–	–	–	37.19	–	–	–	–	–
18-6, 45	879.45	2.570	–	–	–	–	–	–	–	5,63	–	–
18-6, 50	879.50	–	2.189	–	–	–	30.51	–	–	–	–	–
19-1, 44	886.44	4.807	–	2.679	2.740	–	–	1.25	–	–		
19-3, 33	889.33	5.119	–	–	–	–	–	–	–	–		
19-3, 131	890.31	5.574	–	2.739	2.787	–	–	–	–	–		
19-5, 93	892.93	5.552	–	2.752	2.812	–	–	–	–	–		
19-6, 70	894.50	4.982	–	2.642	2.692	–	–	3.46	–	–		
19-6, 70	894.50	4.970	–	–	–	–	–	–	–	–		

Note: S = Syringe method; I = Immersion method; G = GRAPE.

slight, with a range of 30% to 40%. Absence of gradients characterizes the underlying unit, a foraminifer-nannofossil chalk which extends to 550 meters. Velocity data here are scattered but uniform; water content ranges from 20% to 25%. The chalks below 550 meters cannot be distinguished from one another because of wide separation between cored intervals. Both acoustic velocity and scatter in the velocity data increase markedly downward through these units. Water content does not change significantly.

BIOSTRATIGRAPHIC SUMMARY

The stratigraphic sequence at this site ranges from Holocene to Late Cretaceous (Maestrichtian). Although coring of the sequence was discontinuous, we recovered samples from all Tertiary epochs. Figure 12 shows the microfossil zones that we recognized.

In Cores 1 to 16, calcareous nannofossil and planktonic foraminifer assemblages are tropical, open marine assemblages. Benthic foraminifer assemblages represent lower bathyal to abyssal depths. But in Sample 17, CC the nannofossil species *Kamptnerius magnificus*, generally found in shelf-depth sediments, occurs in abundance, and the benthic foraminifers of Sample 18, CC are larger agglutinated lituolids, large rotalids, and nodosariids. This latter assemblage lacks both the Late Cretaceous shelf forms and the unique abyssal Cretaceous fauna. We propose outer shelf to slope depths for this sample. Basalt was cored below Sample 18, CC.

Preservation of fossils changes drastically down the sequence, paralleling to some degree the changes in lithology. First evidence of significant solution of foraminifers and coccoliths occurs in Cores 3 and 4, of latest Miocene and earliest Pliocene age. A dissolution interval during this time seems typical of the equatorial Atlantic. Both coccoliths and foraminifers are corroded and/or dissolved, but not overgrown. Preservation becomes significantly worse in lower sections of Core 6, and in Core 7 of middle and early Miocene age. Coccoliths are overgrown with calcite, diversity of faunas and floras decreases, and siliceous fossils become more abundant for the first time in the sequence.

A significant interval of slow sedimentation, including a minor hiatus, occurs in Core 6, which

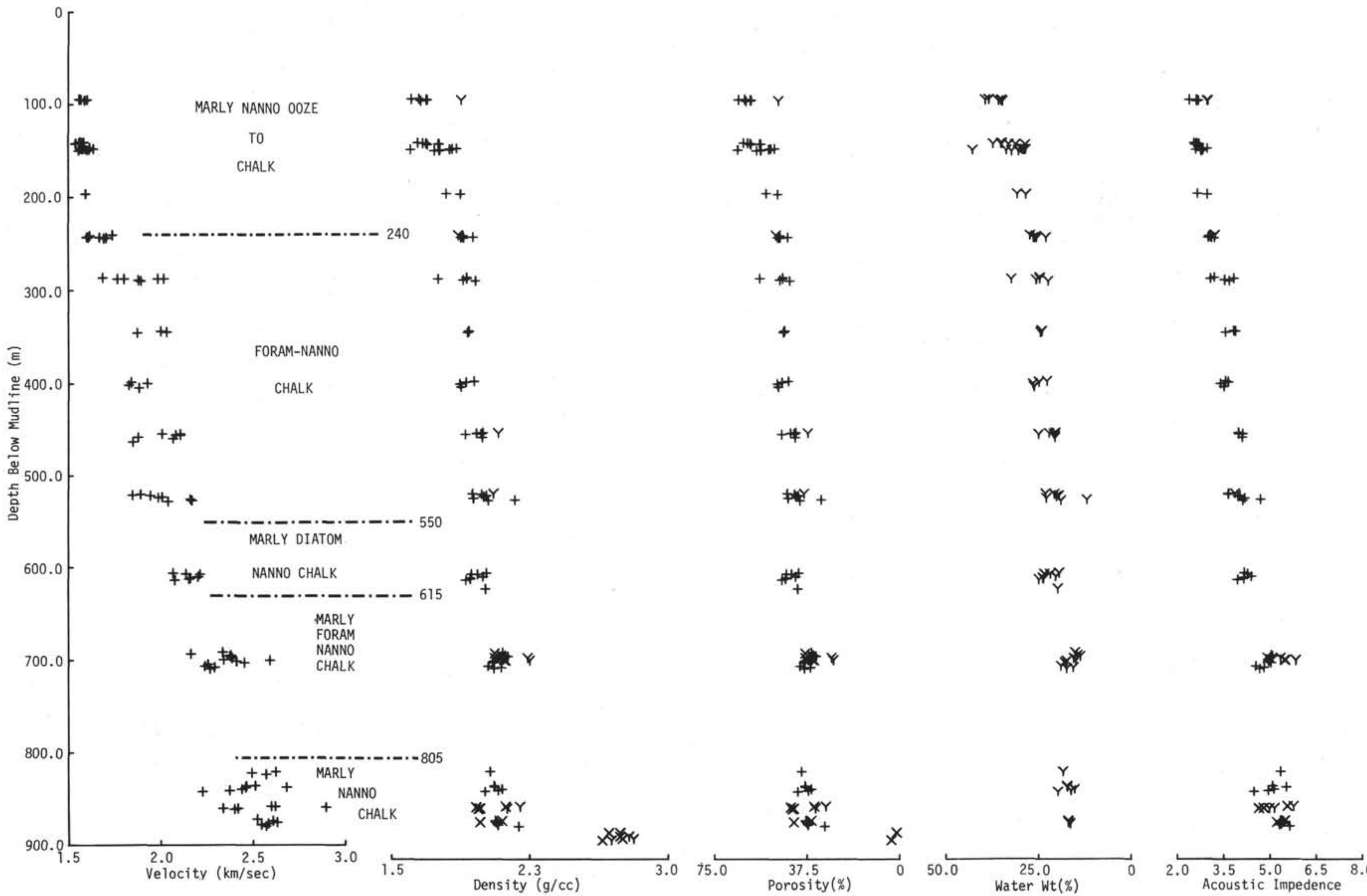


Figure 11. *Physical properties versus depth: +, x, and y represent syringe, immersion, and GRAPE values, respectively.*

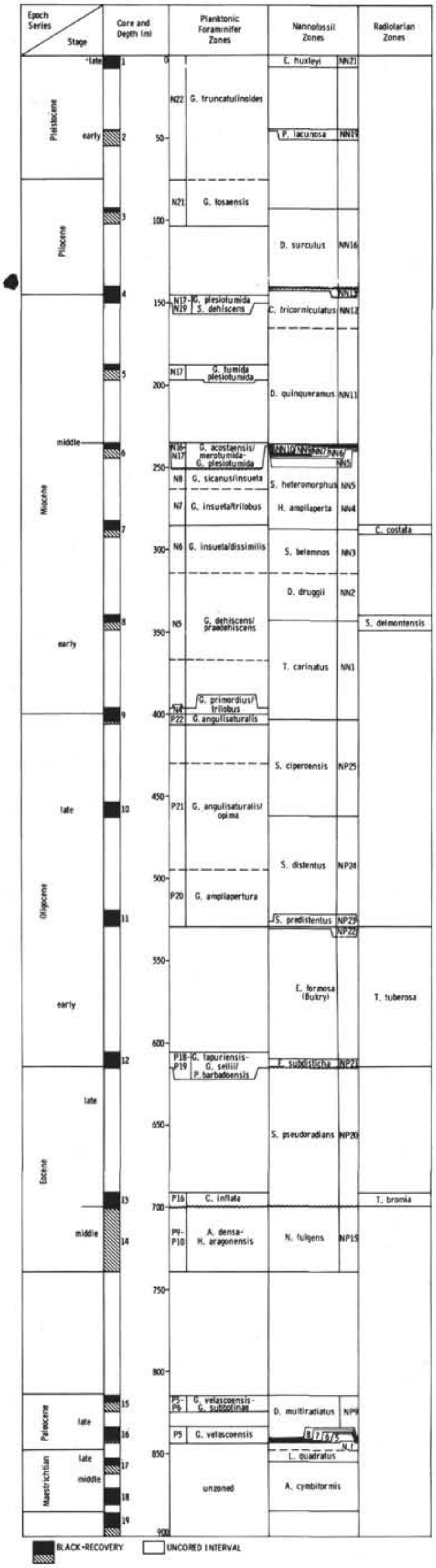


Figure 12. *Biostratigraphic Summary, Site 354.*

represents the late middle Miocene to late Miocene. Berger and von Rad (1972) noted that interrupted sedimentation occurred during the late middle to late Miocene at six other Atlantic DSDP sites, including Site 142 in the Ceará Abyssal Plain, and Sites 14, 17, 19, 20, and 25 in the South Atlantic. These authors postulate a period of peak carbonate dissolution, a result of shallowing of the CCD in the late mid-Miocene, to explain the increased dissolution of calcareous fossils, the relative abundances of siliceous fossils, and the hiatuses at the sites mentioned above. The late mid-Miocene hiatus at Site 354 may also have resulted from shallowing of the CCD at this time in this area of the Atlantic.

Below Core 7, foraminifers are poorly preserved, faunas impoverished, and apertures filled; foraminifers are sometimes barely recognizable. In core-catcher samples from Cores 13 and 17, foraminifers are absent. Episodes of increased dissolution of calcareous foraminifers are indicated by a second influx of siliceous fossils in Cores 11 and 12 (middle and lower Oligocene) and significant numbers of flattened fossils in Core 14 (mid-Eocene). In the Eocene and Oligocene, preservation of the coccoliths is moderate and overgrowth is common.

A second hiatus from upper Eocene to lower Oligocene in Sample 354-12, CC may correlate with a hiatus of similar length found for this time at DSDP Site 144 on the Demerara Rise.

Fossils from the lower Paleogene and Upper Cretaceous are generally poorly preserved. A third hiatus spanning the Cretaceous/Tertiary boundary and the lower Paleocene occurs between Cores 16 and 17. Below this hiatus, calcareous foraminifers are scarce and nannofossil diversity is reduced because of very poor preservation.

Radiolarians are rare in Core 1, absent in Cores 2 through 6, rare in most of Core 7, and common in Sample 7, CC. Only the core-catcher samples of Cores 8 through 11 contain radiolarians. The siliceous sequence recorded in Core 12 includes common and well-preserved radiolarians; abundance and preservation diminish rapidly in Cores 13 and 14, below which no radiolarians occur.

A few silicoflagellates, ebridians, archaeomonads, and endoskeletal dinoflagellates occur in the lower to middle Oligocene Core 12. According to Fenner (this volume), diatom remains occur only in Core 12, and belong to the *Cestodiscus pulchellus* Zone of Jousé (1973).

Foraminifers

We processed and examined core-catcher samples from the 18 cores taken at Site 354. Faunas in these samples range in age from Late Cretaceous to late Pleistocene.

Pleistocene

Cores 1 and 2 contain well-preserved benthic and planktonic foraminifer faunas of Pleistocene age. In Core 1 the fossils are somewhat broken, and fragile species are often corroded. The typical tropical planktonic fauna of this sample includes *Globorotalia truncatulinoides*, *Pulleniatina obliquiloculata*, *Globigerinoides ruber* (pink and white), *Globorotalia crassaformis*, *G. menardii*, *G. cultrata*, *G. scitula*, and *Globigerina bulloides*; *Sphaeroidinella dehiscens* is notably absent. Mixed with these white fossils are gray- to black-splotched planktonic species derived from a reducing layer higher up in the core.

The benthic association indicates deep water: *Pyrgo*, *Osangularia*, lagenids, an occasional agglutinated foraminifer, and smooth and spiny ostracodes.

Core 2 contains a similar fauna, with the addition of *S. dehiscens*, *Globigerina pachyderma* (R), and *G. calida*. Preservation is generally good, and the fragmented forms are the more resistant species. Except for one ridged ostracode, the benthic fauna is a deep one consisting of *Pyrgo*, *Laticarinina*, spiny *Uvigerina*, lagenids, and echinoid fragments.

The section represented in Cores 1 and 2 covers the Holocene/Pleistocene boundary (the reducing layer in Core 1) and Zones N22 and N23 of the Pleistocene. The assemblages are relatively well preserved deep oozes.

Pliocene

Cores 3 and 4 contain diverse assemblages of Pliocene age, whereas Core 5 is late Miocene-early Pliocene. Core 3 contains a moderately well preserved tropical planktonic foraminifer assemblage, including *Globorotalia tosaensis*, *G. multicamerata*, *G. miocenica*, *Sphaeroidinella dehiscens*, *Neogloboquadrina humerosa*, and others. Smaller specimens are often fragmented, larger individuals sometimes corroded. In the deep-water benthic fauna are *Uvigerina* (spinose), *Pyrgo*, *Osangularia*, *Gyroidina*, an occasional echinoid, and fish teeth.

The planktonic foraminifers indicate an age of late Pliocene. This sample appears to belong somewhere between top N19 and lower N21.

Core 4 contains the first strongly dissolved foraminifer assemblages. The resistant species, in consequence, are dominant to a pronounced degree, and include *Sphaeroidinella seminulina*, *S. subdehiscens*, *G. multicamerata*, and *G. miocenica*. More fragile forms are often fragmented, although a diverse fauna containing *Globoquadrina altispira*, *Globigerinoides sacculifer*, *G. obliquus*, *Globorotalia tumida*, and *G. margaritae* can be recognized. Benthic foraminifers are diverse and common, and include *Laticarinina*, *Nonion*, *Triloculina*, *Pyrgo*, *Planulina*, *Gyroidina*, *Textularia*, and various lagenids. Fish teeth and spiny ostracodes, together with the benthic foraminifers, are all of deep origin.

This fauna belongs to the *G. margaritae* Zone, N19, of the lowermost Pliocene. Strong selective solution has apparently altered the dominance of the planktonic faunas and enriched the benthic forms.

Faunas in Core 5 are better preserved than in Core 4. Resistant forms do not dominate to the degree they did in Core 4, spinose and delicate forms occur, but benthic species are still scarce. Globorotalids are still abundant. *S. seminulina*, *S. subdehiscens*, *G. menardii*, *G. tumida*, *O. universa*, *G. sacculifer*, *G. obliquus*, *G. altispira*, *G. multicamerata*, and simple *G. margaritae* are present. The genera *Pyrgo*, *Globocassidulina*, *Uvigerina*, *Stilostomella* (=*Siphonodosaria*), *Bolivina*, some agglutinated forms, and echinoid fragments comprise the benthic element in these sediments.

The planktonic foraminifer population belongs to Zones N17-N19 of the lowest Pliocene-topmost Miocene. Although no *Globoquadrina dehiscens* is present, dissolution of the faunas may have removed this marker species. The fauna is tropical and open-marine, sometimes strongly dissolved.

Miocene

Cores 6, 7, 8, and possibly 9 contain faunas of Miocene age. Core 6 contains a tropical fauna of middle Miocene age, including: *Globorotalia peripheroronda*, *Orbulina universa*, *S. subdehiscens*, *Globoquadrina altispira*, and *Globorotalia mayeri*, among others. The foraminifers are poorly preserved, often calcite-coated and recrystallized. Small and/or delicate forms are usually corroded or fragmented. Benthic species are infrequent, but deep forms of *Pullenia*, *Globocassidulina*, *Stilostomella* (=*Siphonodosaria*), and *Bolivina* are present.

This planktonic fauna suggests an age of middle Miocene, Zone N9, since *O. universa* is present but true *Globorotalia fohsi fohsi* is not.

Foraminifers from Core 7 are filled and coated with calcite; preservation is very poor. The fauna is distinct, however, since it contains the first bullate forms (not present above) and globigerinids with high arched apertures (not present below). The fauna begins to look more "Oligocene" than "Miocene," which is typical of lower Miocene faunas. Species present include *Globigerinatella insueta*, *Globoquadrina dehiscens*, *G. altispira*, *Globigerina venezuelana*, *Globorotalia peripheroronda*, and questionable *Globorotalia* (*Turborotalia*) *kugleri*. Deep benthic foraminifers are rare (*Bolivina*, *Gyroidina*), but solution-resistant siliceous fossils are common, including radiolarians and sponge spicules.

The fauna is assigned to Zone N6, lower Miocene. The partial lithification and the abundance of siliceous material indicate strong solution, carbonate loss, and consequent relative enrichment of the siliceous component.

Abundance of bullate forms, unkeeled globorotalids, and large subspherical species characterizes the lower Miocene fauna of Core 8. Planktonic species include *G. kugleri*, *Globorotalia* (*Turborotalia*) *opima nana*, *Catapsydrax dissimilis*, *G. dehiscens*, *Globigerinita martini*, s.l., and *G.* (*T.*) *siakensis*. Many forms are tightly coiled and apertures are small or covered with bullae. Benthic foraminifers are scarce (*Nodosaria*, *Globocassidulina*), but indicate deep water.

This fauna belongs to Zone N4, considered Miocene by some researchers (Bolli and Premoli-Silva, 1973) and Oligocene by others (Berggren and Amdurer, 1973). The abundance of bullate forms and covered and small apertures reflects a supposed response to the low temperatures of the Oligocene and the earliest Miocene (Boersma and Shackleton, this volume).

Oligocene

Cores 9-11 contain fossils of Oligocene age. The faunas of Core 9 strongly resemble those of Core 8, except that by Core 9 the globorotalids are substantially less abundant. This older fauna is very poorly preserved, and most specimens are very small, so recognition of species is difficult. Many bullae are dissolved and apertures caked with chalk. Even the benthic forms are corroded and fragmented. The taxa are *Globoquadrina altispira*, *G.* (*T.*) *opima nana*, *G.* (*T.*) *kugleri*, *G. ampliapertura*, and *Globigerinita unicavus* s.l. The deep benthic forms are very scarce (*Globocassidulina*), and one smooth ostracode is present.

If *G. altispira* is a down-core contaminant, then this sample belongs to Zone P22, upper Oligocene. However, the P22 index, *G. angulisuturalis*, is absent.

Poor preservation and scarcity of recognizable forms also characterize the faunas from Core 10. *Cassigerinella chipolensis*, *G.* (*T.*) *opima opima*, *G.* (*T.*) *opima nana*, *Globigerinita martini* s.l., and *Globigerina augustiumbilicata* are recognizable. Deep benthic species are rare (*Pullenia* and *Gyroidina*).

The presence of *C. chipolensis*, *G.* (*T.*) *opima opima* and absence of *G. angulisuturalis* locate this fauna in Zone P20, upper Oligocene.

The fauna from Core 11 is also impoverished, and contains *G.* (*T.*) *opima nana*, *G. martini* s.l., *G. unicavus* s.l., *G. ampliapertura*, and a few *G.* (*T.*) *opima opima*. The deep benthic fauna contains *Nodosaria*, *Stilostomella*, *Gyroidina*, *Nonion*(?) and spiny ostracodes. In contrast to the calcareous fossils, siliceous fossils are common, and include sponge spicules, radiolarians, and diatom remains. Fish teeth also occur.

If *G.* (*T.*) *opima opima* is in place, this fauna belongs to Zone P20. If not, it may lie lower in the Oligocene, Zones P19-20. The reappearance of abundant siliceous fossils and the particularly poor preservation of the foraminifers suggest a second cycle of significant carbonate dissolution.

Eocene

Cores 12-15 contain sediments of Eocene age. Because of extensive dissolution, only large, globular, and bullate species occur in Core 12, which gives the fauna a "high latitude" appearance. Included are *G. martini* s.l., *Globigerinita globiformis*, *G.* (*T.*) *opima nana*, and large globigerinids such as *Globigerina* (*Subbotina*) *turgida* and the *G. ampliapertura* group. An occasional rotalid (benthic) occurs.

The fauna is so reduced in species as to preclude exact age determination. It is tentatively assigned to the upper Eocene, Zones P15-P16.

Sample 13, CC contains no foraminifers. Core 14 contains a dissolved and impoverished fauna of planktonic foraminifers. Species and individual fossils are few and highly recrystallized; many are crushed or broken. Recognizable species are "*Globigerinita*" *howei*, *Acarinina soldadoensis*, and *Acarinina* spp. No benthic species occur.

The presence of "*G.*" *howei* indicates the sample may be middle Eocene in age and tentatively assigned to Zones P10-P11.

Core 15 contains forms assignable to the lowermost Eocene. The planktonic fauna is impoverished, but better preserved than that of Core 14. All the fossils are small and encrusted with calcite, or corroded. *Globorotalia* (*Morozovella*) *conicotruncata*, *G.* (*M.*) *simulatilis*, *G.* (*M.*) *marginodentata*, *G.* (*M.*) *velascoensis*, *Pseudohastigerina wilcoxensis*, and *Acarinina* spp. are present. We found no benthic species. We assign this assemblage to Zone P6 of the Eocene, although we found no *Globorotalia* (*Morozovella*) *subbotinae*.

Paleocene

Core 16 contains fossils of middle Paleocene age. Most planktonic forms have been dissolved, so specimens are not common. But a fauna of *G.* (*Morozovella*) *pusilla* s.l., *G.* (*M*) *velascoensis*, *G.* (*M.*) *aequa*, *G.* (*Subbotina*) *triloculinoides*, *G.* (*Turborotalia*) *pseudobulloides*, *G.* (*Planorotalites*) *compressa*, and *G.* (*M.*) *angulata* (?) was recovered. Benthic foraminifers are very rare; recognizable species are *Nodosaria affinis* and *Bolivina paleocenica*. One Cretaceous globotruncanid occurs in this sediment.

Despite intense dissolution and alteration, these forms may be assigned to Zones P3/P4 of the middle Paleocene.

Cretaceous

Although Cores 17 and 18 both contain Cretaceous nannofossils, only Sample 18, CC contains foraminifers. As a result of diagenetic processes, most foraminifers are gone. The planktonic forms which remain are tiny globigerinids and an occasional crushed globotruncanid.[2] The benthic fauna consists of nodosarids, rotalids, and giant agglutinate forms. Calcareous genera include *Nodosaria*, *Bulimina*, *Pyrulina*, *Lagena*, *Dentalina*, *Pseudogavellinella* (?), and various rotalids. Agglutinated genera are *Ammobaculites*, *Haplophragmium*, *Trochammina*, *Loxostomoides*, and *Glomospira*.

No planktonic foraminifers, on which to base an age, are present.

Calcareous Nannofossils

All sediment cores recovered at this site yielded common calcareous nannofossils in various states of preservation. Although time limitations did not allow us to core the whole sequence continuously, we did recover an important part of the coccolith zones.

Pleistocene (Cores 1 and 2)

The two uppermost cores contain Pleistocene sediments. In Core 1, *Emiliania huxleyi* implies a late Pleistocene to Holocene age for the entire core (2.6 m). The assemblage is rich (tropical), but lacks the least solution-resistant species, such as *Oolithotus antillarum* a.o. Coccoliths are abundant to common and fairly well preserved in Core 1 and in Core 2, from which only a core-catcher sample is available. This sample's rich assemblage includes common *Pseudoemiliania lacunosa*

[2]Benthic foraminifers, however, are relatively common and definitely unique.

and *Emiliania annula*, as well as rare *Gephyrocapsa oceanica*. The overlapping of *P. lacunosa* and *G. oceanica* occurs within the upper part of the *P. lacunosa* Zone (NN19).

Pliocene (Cores 3 and 4)

Abundant and generally well preserved Pliocene coccolith assemblages occur in Cores 3 and 4. They include a rich tropical flora, indicating the *Discoaster surculus* Zone (NN16) in Core 3 and the uppermost two samples studied from Core 4. The assemblage in these samples includes *Pseudoemiliania lacunosa*, together with birefringent ceratoliths (but no well-developed *Ceratolithus rugosus*) and *Discoaster tamalis*, but with no typical *Reticulofenestra pseudoumbilica*, and is assigned to the lower part of the *Discoaster surculus* Zone. In Sample 4-1, 120 cm, the assemblage is quite different, and several species have their first or last occurrences in the interval between this and the samples above. We note the last occurrences of *Ceratolithus tricorniculatus* and typical *R. pseudoumbilica* in Sample 4-1, 120 cm, and the first occurrence of *P. lacunosa* and *D. tamalis* in Sample 4-1, 70 cm. *D. asymmetricus* occurs in both samples, but no typical *C. rugosus*. The lower sample would, according to the zonation of Martini (1971) used elsewhere in this report, belong to the *C. tricorniculatus* Zone (NN12) of Miocene-Pliocene age. Zone NN12 is defined as the interval between the last occurrence of *D. quinqueramus* and the first occurrence of *C. rugosus*. Usually, *C. tricorniculatus* has its first occurrence in Zone NN11; at Site 354, it occurs first above the last occurrence of *D. quinqueramus*, the marker form of the zone of this name. The presence of *C. acutus* from Sample 4-1, 120 cm, to the bottom of Core 4, indicates the *C. acutus* Subzone of Bukry (1973), which can be correlated with the upper part of the *C. tricorniculatus* Zone of Martini. Thus, using both zonations, a hiatus is indicated, including three zones (NN13-15) of Martini and three subzones of Bukry. The hiatus must lie between Samples 4-1, 120 cm and 4-1, 70 cm. A slight change in color, from light gray above to yellowish-gray below, occurs in the foraminifer-nannofossil ooze at about 100 cm in Section 4-1.

Dissolution has affected most Pliocene samples to some extent. In some, many or most discoasters are broken; single shields of *Cyclococcolithina leptopora* and *C. macintyrei* are common, and the samples are enriched in the solution-resistant *Sphenolithus abies*. Samples containing more discoasters than coccoliths have been more heavily affected by dissolution than those in which the coccoliths are more abundant. No significant overgrowth occurs.

Miocene/Pliocene Boundary

We assume that the Miocene/Pliocene boundary here is in the *C. tricorniculatus* Zone in Core 4 or just below, since Gartner (1973) found the first occurrence of *C. acutus* only a few meters above the base of the Pliocene in Sicily. Core 4 provided, together with Cores 3, 5, and 6, excellent material for the study of ceratoliths, added new information to Gartner's and Bukry's (1975) ideas about the evolution of ceratoliths, and provided a new form, *C. atlanticus* (Perch-Nielsen, this volume).

Miocene (Cores 5 to 9)

Though all of Core 5 and most of Core 6 can be assigned to the upper Miocene *D. quinqueramus* Zone (NN11), Core 6, Section 3 also contains Zones NN10 and NN9, and indicates a minor hiatus in the mid-Miocene, probably including part of Zone NN9, all of Zone NN8, and part of Zone NN7. Assemblages of Zones NN7, NN6(?), and NN5 occur in the bottom of this section, which consists of gray, yellow, olive, and brown marly nannofossil chalk bands. Above the minor hiatus, the sediment accumulation rate was extremely slow, and it is possible that the very short interval of Zone NN8—0.2 m.y.—was not sampled.

Preservation of the coccoliths changes from moderate above the hiatus to poor below. Signs of dissolution are present in the whole Miocene sequence, but significant overgrowth—mainly on the discoasters—occurs only below the hiatus.

Cores 7 and 8 are of early Miocene age, and show less diverse assemblages than those of middle and late Miocene age. This is probably a consequence of both a primary lower diversity of calcareous nannoplankton in the early Miocene and the more advanced state of diagenesis. Most of Core 7 belongs to the *Sphenolithus heteromorphus* Zone (NN5), or perhaps to the *Helicopontosphaera ampliaperta* Zone (NN4), although we did not find the latter species. Sample 7, CC, includes *S. belemnos* without *S. heteromorphus* or *Triquetrorhabdulus carinatus*, and thus belongs to the *S. belemnos* Zone (NN3). *Discoaster druggi* occurs in the uppermost sample studied from Core 8, and indicates the zone of this name (NN2). The rest of the core belongs to the *T. carinatus* Zone (NN1), as does Core 9, except for the core-catcher portion.

Oligocene/Miocene Boundary

The Oligocene/Miocene boundary is usually placed within Zone NN1, the *T. carinatus* Zone. An Oligocene assemblage of the *S. ciperoensis* Zone (NP25) occurs in the Core 9 core-catcher sample. Since at least the upper part of Core 9 may have been collected in the drilled interval between Cores 8 and 9, we state only that the boundary occurs in the interval between the two cores.

Oligocene (Cores 9 to 12)

We recognized all Oligocene coccolith zones (NP 25 to NP 21) at this site: *S. ciperoensis* Zone (NP 25) in the core-catcher sample of Core 9 and most of Core 10; *S. distentus* Zone (NP 24) in the core-catcher sample of Core 10 and Sections 1 through 4 of Core 11; *S. predistentus* Zone (NP 23) in the three upper sections of Core 12; and the *Ericsonia subdisticha* Zone (NP 21) in the rest of Core 12, except the bottom of the core-catcher sample, where an upper Eocene assemblage of the *S. pseudoradians* Zone (NP 20) occurs.

Coccoliths in the Oligocene are common to abundant, and the preservation is moderately good to poor. Overgrowth has affected the few discoasters present and often makes it almost impossible to identify the sphenoliths used for zonation. We found only a single *Isthmolithus recurvus*, a species typical of the early Oligocene and late Eocene of intermediate and high latitudes. It has been suggested that *I. recurvus* does not occur in tropical open ocean localities; it was reported, however, in lower Oligocene at nearby DSDP Site 142 (Roth and Thierstein, 1972).

Eocene/Oligocene Boundary

The Eocene/Oligocene boundary is characterized by the sudden disappearance, between two samples from the core catcher of Core 12, of *Discoaster barbadiensis* and *D. saipanensis*, which occur in the upper Eocene sample. The Oligocene sediment in Core 12 is gray nannofossil chalk, the Eocene a somewhat lighter gray nannofossil chalk. No physical sign of a hiatus or indicator of extremely slow sediment accumulation rate is apparent. Also, the contact seems natural rather than artificial, as would be the case if parts of the core catcher were inadvertently picked up at different depths. Although the lowermost coccolith zone of the Oligocene and the uppermost zone of the Eocene are present, the sequence is probably incomplete, judging from the rather abrupt change in the coccolith flora.

Eocene (Cores 12 to 14)

Only two Eocene coccolith zones are represented at this site: the upper Eocene *S. pseudoradians* Zone (NP 20) and the middle Eocene *Nannotetrina fulgens* Zone (NP 15). The former occurs in the core-catcher sample of Core 12 and in Core 13 (except core-catcher sample) and is characterized by scarce *S. pseudoradians*, *Reticulofenestra umbilica*, *Helicopontosphaera compacta*, and another single *I. recurvus*. Zone NP 15 occurs in the core-catcher sample of Core 13 and in Core 14. It includes *Chiasmolithus gigas*, *C. grandis* and *C. solitus*, and *Pseudotriquetrorhabdulus inversus*; *Nannotetrina* sp. is uncommon. *Zygrhablithus bijugatus* occurs consistently in low numbers, as do *S. radians* and *S. furcatolithoides*. The coccolith assemblages are considerably more diverse in the Eocene than in the overlying Oligocene, despite generally poorer preservation, and thus indicate a primary higher diversity.

Paleocene/Eocene Boundary

Although the Eocene/Paleocene boundary may, in principle, be easily recognized with calcareous nannofossils, it is difficult to decide coccolith assemblages of Core 15 belong. All samples from this core contain few to common *Discoaster multiradiatus*, a typical upper Paleocene species that extends, however, into the lowermost Eocene. It is usually associated with fasciculiths in the upper Paleocene, and with species of *Marthasterites* in the lower Eocene. No *Marthasterites* or fasciculiths occur in Core 15. We assign a Paleocene age to Core 15, and assume the Paleocene/Eocene boundary to be between Cores 14 and 15.

Paleocene (Cores 15 and 16)

Core 15 and Sections 1 to the top of 6 of Core 16 belong to the uppermost Paleocene *D. multiradiatus* Zone (NP 9). In the remaining part of Section 6, Core 16, the other four upper Paleocene coccolith zones occur. A piece of upper Maestrichtian gray marly nannofossil chalk was attached at the bottom of Sample 16, CC. At the top of Core 17, which consists of red upper Maestrichtian nannofossil chalk, some pieces of gray nannofossil chalk occur. They include an almost monospecific assemblage of *Thoracosphaera operculata*. This species is usually common in the lowermost Paleocene all over the world and is rock-forming in the Danian of northern Europe. The pieces at the top of Core 17 probably result from downhole slumping, and so represent a part of the uncored interval around the Cretaceous/Tertiary boundary.

The Paleocene assemblages are only somewhat better preserved than those of the Eocene (less overgrowth), but not so diverse as Paleocene assemblages from shelf areas such as Egypt or Tunisia.

Cretaceous/Tertiary Boundary

When we studied an upper Maestrichtian sample from the bottom of Core 16, we thought the Cretaceous/Tertiary boundary had been cored, since the top of the core was of late Paleocene age. Subsequent study revealed, however, that the cut core itself was entirely Paleocene and that the Maestrichtian rock was merely a thin layer attached to the core catcher. Between Cores 15 and 16, we washed nine meters and cored the following nine meters (Core 16). It is thus most likely that the core barrel was filled just below Core 15, and that the lower part of the *Fasciculithus tympaniformis* Zone (NP 5) and younger Paleocene sediments were, if present, pushed away by the full core barrel. Before the core was retrieved, a small amount of Maestrichtian rock from the bottom of the interval remained attached to the core catcher. We thus do not know whether a hiatus exists at the Cretaceous/Tertiary boundary. We do know, however, that the lower Paleocene sediments, if present, must have been deposited at a slow rate, and that any hiatus must have been very short, since both the lowermost Paleocene (in the lump on top of Core 17) and the upper Maestrichtian (at the bottom of Core 16 and in Core 17) are present.

Late Cretaceous (Cores 16, 17, and 18)

We recovered upper Maestrichtian (*Nephrolithus frequens* Zone) to lower Maestrichtian sediments in the core catcher of Core 16 and in Cores 17 and 18. The presence of *N. frequens* at this low latitude deserves special mention, since this species is believed to be a marker for high-latitude upper Maestrichtian sediments only. We did not find *Micula mura*, marker for the upper Maestrichtian in low latitudes, but it may occur in the unrecovered interval. Where the two species occur together, *M. mura* occurs slightly after *N. frequens*. The latter occurs only in Sample 16, CC; the rest of the Maestrichtian sediment belongs to the *Lithraphidites quadratus* Zone, down to Sample 17-2, 85 cm, and to the *Arkhangelskiella cymbiformis* Zone, down to the lowermost sediment sample above basement, Sample 18, CC. *A. cymbiformis* itself is very uncommon, even absent in some samples, so assignment to this zone is not very certain. On the other hand, we found none of the marker species of the lowermost Maestrichtian and upper Campanian, such as *Tetralithus trifidus*, *Eiffellithus eximius*, or *T. gothicus*. We therefore suggest an early, but not earliest, Maestrichtian age for the lowermost sediment samples at this site.

Coccoliths are generally rare to common and poorly preserved. Solution-resistant coccoliths have been affected by overgrowth, and in many samples only these solution-resistant species are left. *Kamptnerius magnificus* is rare to few. This species is believed to have preferred shallow seas, since it has not yet been found in significant numbers in true deep-sea sediments. Its presence may thus indicate relatively shallow water at this site during the Maestrichtian.

Radiolaria

We recovered radiolarians from the Pleistocene (Core 1), lower Miocene (Cores 7 and 8), lower Oligocene (Cores 11 and 12), and the upper to middle Eocene (Cores 13 and 14).

Traces of radiolarians occur in Core 1, but only the large sample of the core catcher yielded enough specimens to assign an age to the core. *Ommatartus tetrathalamus*, *Anthocyrtidium opirense*, and *Collosphaera tuberosa* indicate that this sample is probably of late Pleistocene age.

No radiolarians are present in Cores 2 through 6. Sample 7-1, 130-133 cm, contains a few specimens of *Lychnocanoma* sp. cf. *L. elongata*, *Cornutella profunda*, *Siphocampe* sp., and *Rocella gemma*. Sections 3 and 4 of Core 7 were barren of radiolarians, except Sample 4, 84-86 cm, which contains a poorly preserved assemblage of the *Calocycletta costata* Zone of early Miocene age. In Sample 7, CC, a much better preserved assemblage of this zone occurs, including *D. dentata*, *C. cornuta*, *C. leptetrum*, *L. staurophora*, *D. forcipata*, *S. wolfii*, and *C. virginis*.

Samples 8-1, 110-112 cm and 8-3, 104-106 cm, are barren of radiolarians, and only a small, poorly preserved assemblage, probably belonging to the *Stichocorys delmontensis* Zone, occurs in Sample 8, CC.

Except for small amounts of pyritized radiolarians in the core-catcher samples of Cores 9 and 10, Cores 9 and 10 and all sections of Core 11 are barren of Radiolaria. Sample 11, CC, however, contains abundant and well-preserved radiolarians of the lower Oligocene *Theocyrtis tuberosa* Zone. The rare occurrence of *Lithocyclia crux* and *Dorcadospyris quadripes* and the common occurrence of *Centrobotrys gavida* indicate the middle of this zone, which is also present throughout Core 12. Core 13 contains infrequent, poorly preserved radiolarians, probably of late Eocene age, throughout its length. *Thyrsocyrtis bromia* occurs sparsely in Sample 13-4, 70-72 cm and in the core-catcher sample, and a single specimen of *T. tetracantha* occurs in Sample 13-3, 60-62 cm. These occurrences indicate the upper Eocene *T. bromia* Zone in this core. Radiolarians rapidly decrease in abundance in Core 14, where infrequent occurrences of *Eusyringium lagena* may indicate a middle Miocene age for this interval. No radiolarians occur below Core 14.

Diatoms

According to Fenner (this volume), diatom remains occur only in Core 12 (lower Oligocene) and belong to the *Cestodiscus pulchellus* Zone of Jousé (1973). Benthic diatom remains are rare, and this suggests deep-water conditions and large distance from littoral regions for this site during the early Oligocene. No distinctive differences in the dominance, diversity, or species composition of the marine planktonic diatom fossils are apparent in the different lithologies in Core 12 (intensely burrowed dark green-brown bands; moderately burrowed diatom chalk and laminated bands). Thus changes in deeper water circulation, rather than alteration of the surface water characteristics, probably are responsible for the lithologic changes. The assemblages are markedly different from those of early Oligocene age described by McCollum (1975) and Hajos (personal communication to Fenner) from the Southern Ocean.

SEDIMENT ACCUMULATION RATES

Figure 13 summarizes the accumulation history at Site 354. Two intervals cored in this essentially pelagic sequence show a hiatus or a period of extremely slow accumulation. For details of the mid-Miocene hiatus, see Figure 14; Figure 15 shows the late Paleocene to late Maestrichtian period of slow accumulation.

Zonations in the Maestrichtian sequence are not distinct enough at this site to allow any estimate of the accumulation rate. Accumulation may have been continuous but slow (in the order of 0.2 cm/1000 yr) from the late Maestrichtian through the late Paleocene, or a short hiatus may have occurred in the early Paleocene and/or the latest Maestrichtian (see Figure 15 and discussion under Calcareous Nannofossils.)

From the late Paleocene through the early Miocene, accumulation was continuous at a rate of about 1.5 cm/1000 yr, except for a short hiatus at the Eocene/Oligocene boundary. In Figure 13, the sedimentation line has been drawn through the ages indicated by the core catchers of a core, where the core belongs to a younger zone than the core catcher. In each case, the recorded core depth is at the bottom of the interval drilled with the core barrel in place; the core-catcher sample is most likely to come from the bottom of this interval. The core itself may have been collected anywhere between the next higher core and the top of the core catcher. Where the core catcher sample is one or more coccolith zones older than the core, it seems likely that it was collected well below the rest of the core.

A short hiatus may have occurred at the Eocene/Oligocene boundary (core-catcher sample, Core 12). The Oligocene sediment is greenish-gray marly, diatom-rich nannofossil chalk, the upper Eocene sediment is light gray, nannofossil chalk. A dark gray layer 3 mm thick forms the very base of the Oligocene beds and is visible as fill in tiny burrows in the light gray Eocene sediment. Since both the lowermost Oligocene and the uppermost Eocene coccolith zones are represented, the hiatus must have been short.

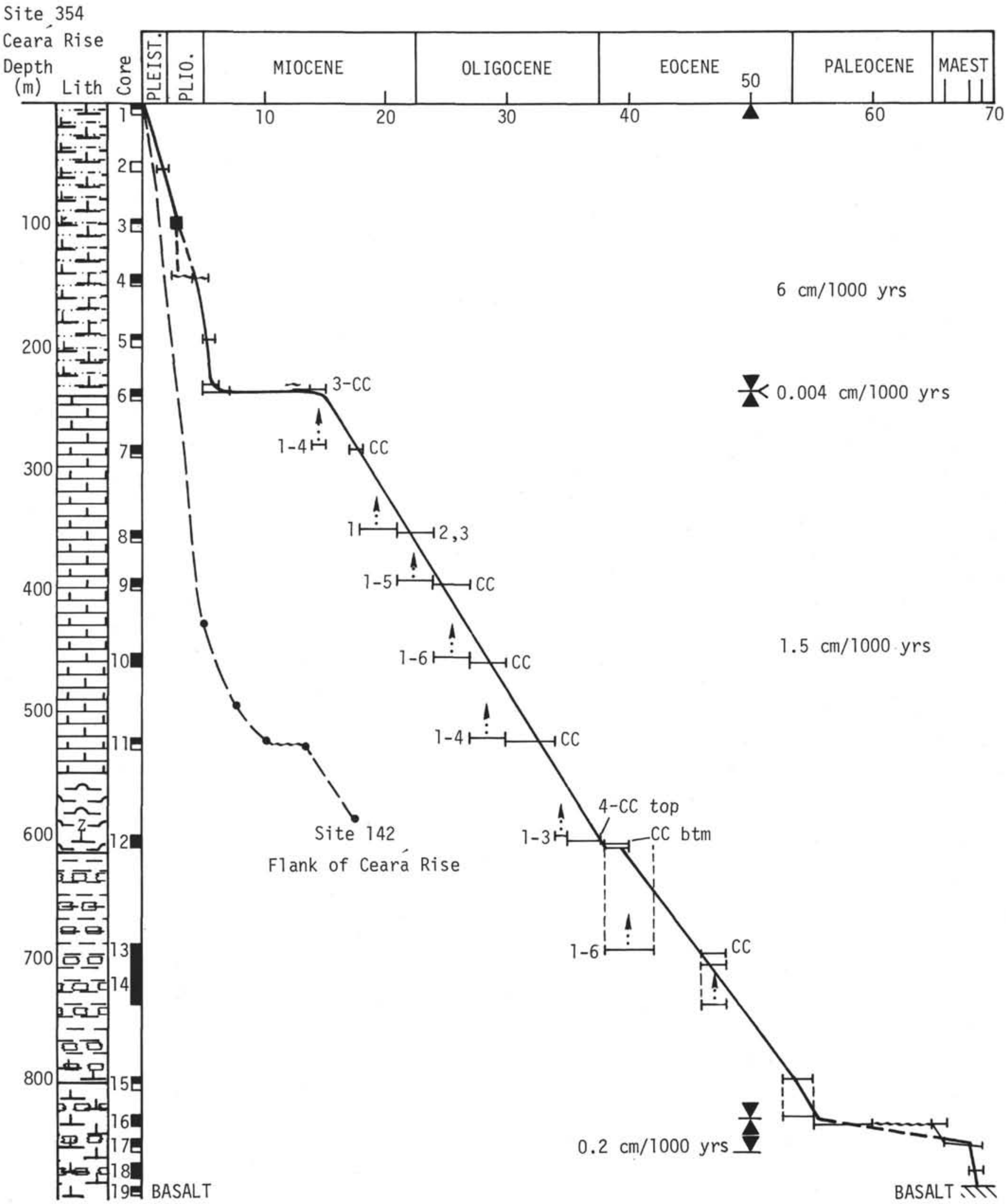


Figure 13. *Sediment accumulation history, Site 354.*

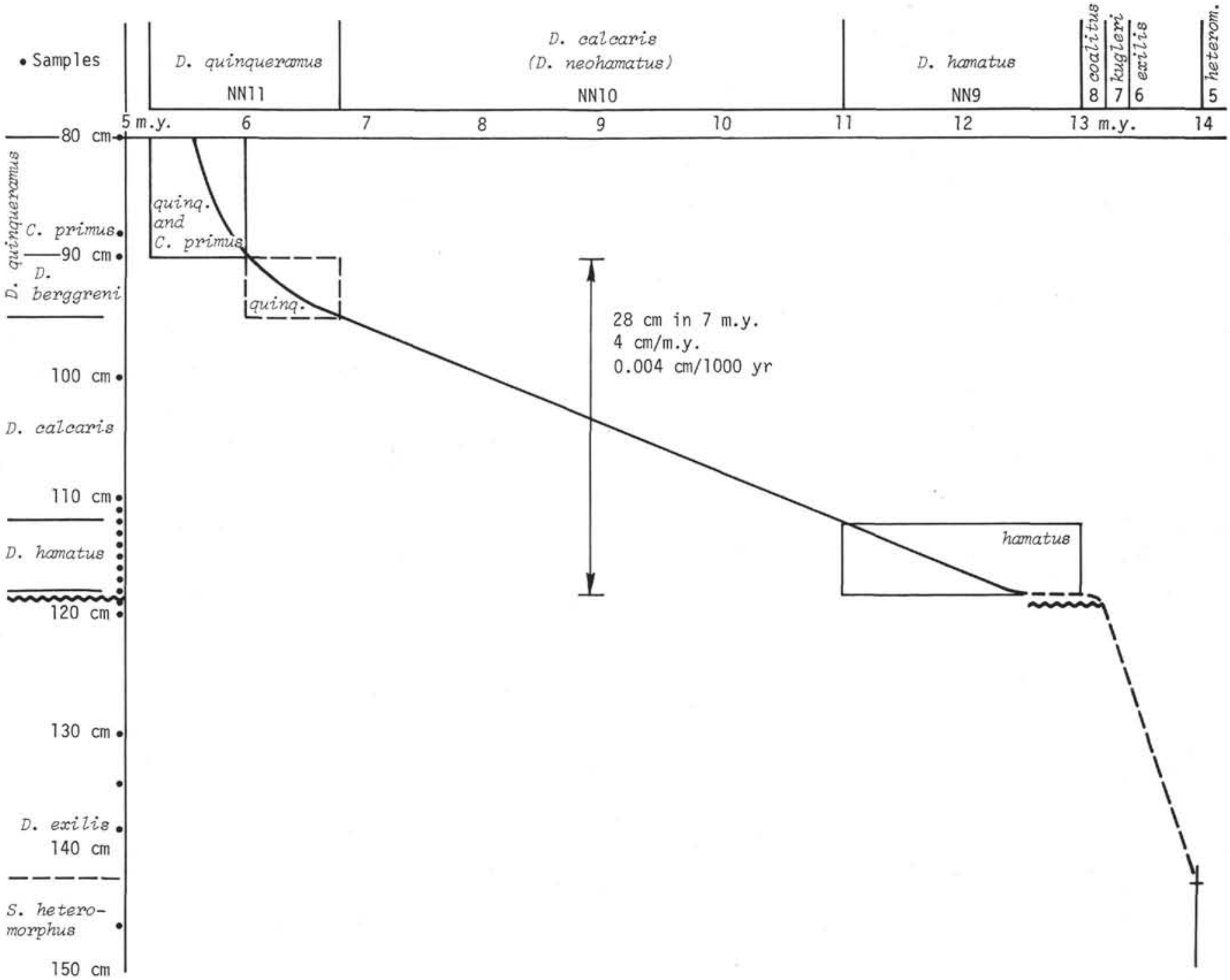


Figure 14. *Miocene sediment accumulation, Site 354, Core 6, Section 3.*

A period of very slow accumulation—in the order of 0.004 cm/1000 yr—is evident in Section 6-3, where coccolith Zones NN5 through NN11 (except NN8) occur (see Figure 14). This mid-Miocene hiatus also occurs at nearby DSDP Site 142 on the flank of the Ceará Rise (see Figure 13). The condensed sequence consists of gray, green, brown, and cream-colored bands of marly nannofossil ooze and chalk. The high, changing discoaster/coccolith ratio in this section indicates extensive solution in most samples studied. Above the hiatus, almost no overgrowth occurs; this suggests that solution had taken place in the water column rather than during diagenesis, when the excess calcite would have caused overgrowth on the discoasters. Overgrowth is common below the hiatus.

Accumulation was rapid, about 6 cm/1000 yr, during the remainder of the Miocene and the Pliocene and Pleistocene. This high accumulation rate is a consequence of a touch of turbidite that this site received from the turbidites transported from the Amazon Cone to the nearby Demerara and Ceará abyssal plains. An even higher accumulation rate prevailed at Site 142 on the flank of the Ceará Rise (Figure 13). A lithologic change indicates a minor hiatus in Section 4-1, where a yellowish nannofossil ooze below gives way to a light gray foraminifer-nannofossil ooze, containing hydrotroilite, above about 100 cm. But since the latter lithology closely resembles that of Core 3, and the same coccolith zone, NN16, occurs in Core 3 and the uppermost 100 cm of Core 4, these top 100 cm were probably "picked up" in the core barrel well above the rest of Core 4. So the "hiatus" in Core 4 is considered a drilling artifact.

CORRELATION OF REFLECTION PROFILE WITH DRILLING RESULTS

The seismic profile taken on the approach to Site 354 from the north is shown in Figures 4 and 16. Two airguns of 10 in.^{3} and 40 in.^{3} were working at the same time. Recording was in two frequency bands of 80-160 and 80-320 Hz. The weather was bad and acoustic noise was great even at slow ship's speed (5 to 8 knots), so the seismic profile probably shows only the strongest reflectors. On this profile at the site location, we were

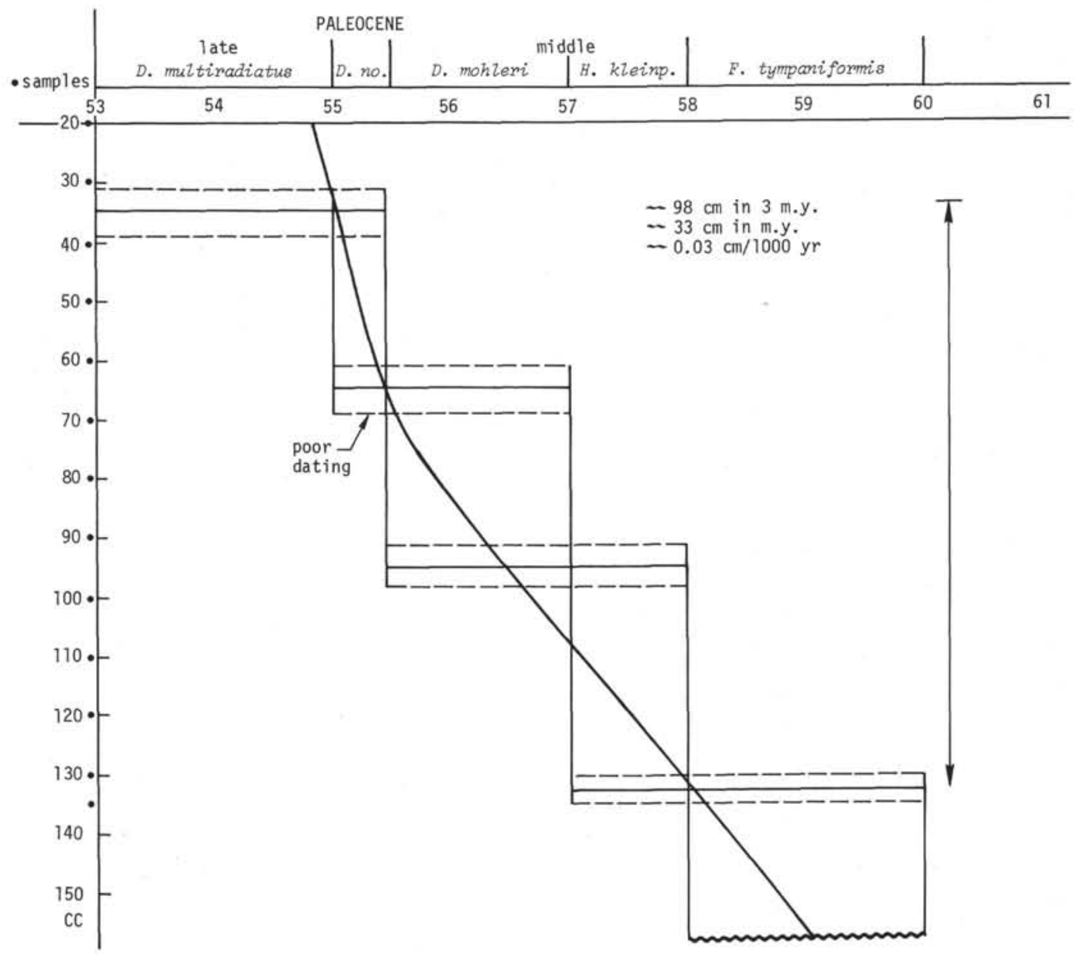


Figure 15. *Paleocene sediment accumulation, Site 354, Core 16, Section 6.*

able to pick out four reflectors, at two-way travel times (DT) of about 0.07, 0.27, 0.60, and 0.90 sec (Figure 16). The distinctive feature of this profile is the almost transparent layer between the second and third reflectors, which rise from the Demerara Abyssal Plain onto the Ceará Rise (Figure 4). The fourth reflector is the acoustic basement of the Ceará Rise. Its correlation with the rough basement of the Demerara Abyssal Plain is not clear. The intermediate third reflector correlates well only from the foot of the Ceará Rise.

During the drilling of Hole 354, we attempted twice to obtain a sonobuoy record. The sonobuoy drifted northwest from the drilling point with the strong current (about 2 knots). One air gun of 40 in^3 was used at a depth of 7 meters. Recording was in a frequency band from 10 to 160 Hz. Unfortunately, we did not hear the radio signals from the sonobuoy at a distance beyond 2-3 km either time. Because of the short length of the sonobuoy profile, we received only reflected arrivals.

The sonobuoy record (Figure 17) shows four strong reflectors at DT about 0.07, 0.20, 0.27, and 0.90 sec. Significantly missing was a good arrival from the intermediate reflector at 0.60 sec. There was also a great deal of acoustic noise on the sonobuoy records, which prevented detection of the weak reflectors.

We obtained an additional seismic record from a hydrophone streamer held in the current about 2 meters below sea surface and at a distance 200 meters from the ship. One airgun of 40 in^3 was used at a depth of 7 meters. Recording was in different frequency bands: 40-320, 40-160, 40-80, 20-40, 80-160, and 160-320 Hz. There profiles (Figure 18) show the same main reflectors as the approach profile and sonobuoy records (Figures 16 and 17): reflector 1 at 0.06 sec, reflector 4 at 0.27 sec, reflector 7 at 0.62 sec, and reflector 11 at 0.91 sec. In addition, there are several weak intermediate reflectors between reflector 1 and reflector 11, and also several rather strong reflections below reflector 11.

Depths of reflectors 1 through 11 are calculated by using interval velocities which are based upon averages of sonic velocity measured onboard ship with the Hamilton Frame (Table 5). Reflectors 1, 4, 7, and 11 are considered the only important reflectors at this site.

Comparison with the lithology shows that some of the reflectors correlate well with lithologic changes (Figure 16). Reflector 1 (the boundary between gray nannofossil ooze, Pleistocene, and yellow-brown nannofossil ooze, Pliocene) divides Units 2 and 3 at 45-50 meters. The main reflector 4 probably marks the transition zone from nannofossil ooze to nannofossil chalk between 200 and 250 meters. Although it is

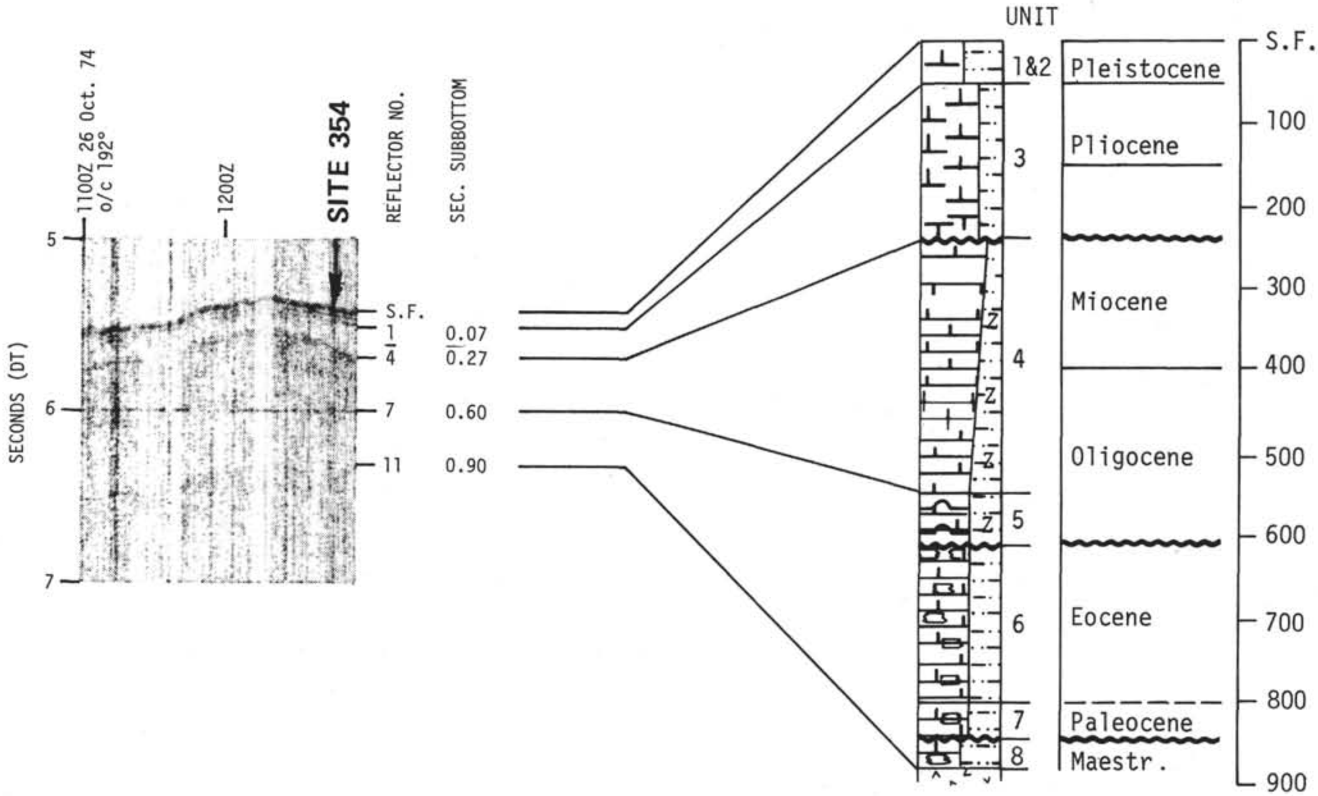


Figure 16. *Suggested correlation of* Glomar Challenger *approach seismic reflection profile with the lithostratigraphic section cored at Site 354. Numbers assigned to reflectors refer to Figure 18.*

calculated to lie at the uncored depth of 210 meters, it appears in Figure 16 at 240 meters, the defined boundary between the oozes of Unit 3 and the chalks of Unit 4. Reflector 7 corresponds to the change from lower Oligocene nannofossil chalk to diatom-nannofossil chalk, and to a sharp drop in drilling rate at a depth of 550 meters.

Reflector 11 corresponds to the basalt layer penetrated at a depth of 886 to 900 meters. Note that the surface of the acoustic basement, reflector 10 (the first clear reflector in the group of basement reflectors), is not the basalt layer itself, but the surface of the overlying red marls (boundary between Units 7 and 8). We may speculate on whether the reflectors below 11 on the streamer profile are real, and if so, whether they may indicate bedding within "basement," i.e., interlayered sediment and basalt. Drilling rates definitely quickened over a few meters while cutting Core 19.

SUMMARY AND CONCLUSIONS

The basement cored at Site 354 is a diabasic basalt, the relative coarseness of which may indicate the slow cooling of a sill. Seismic reflections on a vertical profile continue below "basement," and unless they are spurious, this strengthens the case for the basalt being a sill. If it is a sill, true basement would be some unknown amount older than the early Maestrichtian age indicated by nannofossils in the oldest sediments.

The basal sediments (Unit 8) are ferruginous, clay-rich, and contain marine biogenic material. Although relatively shallow-water indicators occur, the absence of significant quantities of quartz, feldspar, and other typically continental debris suggests a mid-oceanic origin. Considering the relatively small size of the ocean basin at this time, the absence of aeolian silt is somewhat surprising, although a portion of the argillaceous fraction may be wind-borne.

The dominant sediments of the Ceará Rise are pelagic carbonate; a terrigenous component is abundant in the post-middle Miocene, and siliceous sediments are abundant in the Oligocene. Diatomaceous chalks dominate the lower Oligocene sediments of Unit 5. Although silica-rich, this material, because of its age, cannot be correlated with the ubiquitous Eocene chert deposits of the east equatorial Atlantic and the North Atlantic Ocean. The Si-rich sediments may represent a time when this site lay beneath the equatorial area of high biological productivity. This suggests crustal movements of the sea floor or a wider high productivity zone at the sea surface at this time. Poor preservation of the carbonate fauna in Unit 5 also indicates a period of significant carbonate dissolution.

The entire sedimentary section on the Ceará Rise was deposited in a well-oxygenated environment. The occasional iron sulfide probably reflects local reducing microenvironments related to biologic activity.

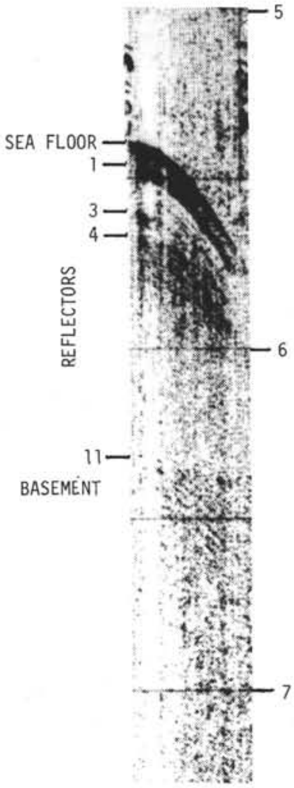


Figure 17. *Sonobuoy record obtained at Site 354. Numbers assigned to reflectors refer to Figure 18.*

Anaerobic bottom conditions existed north and south of the equatorial fracture zone area (Vema, Romanche, etc.) during the Late Cretaceous. At Sites 135-138, 140, 144 (Leg 14, Hayes, Pimm et al., 1972), and 24 (Leg 4, Bader, Gerard et al., 1970), sediments are typically black to gray-green muds with pyrite, overlain by dolomite and cherts. These sediments, formed under anaerobic conditions, are Aptian to Maestrichtian. Thus, strong bottom-water circulation had not yet been established within or between the North and South Atlantic basins by Late Cretaceous time, although surface-water exchange had occurred (Reyment and Tait, 1972). Neither the Ceará Rise nor Site 13 on the Sierra Leone Rise (Leg 3, Maxwell, Von Herzen, et al., 1970) indicates anaerobic bottom-water conditions at that time. During Late Cretaceous spreading, both areas were positive physiographic features, and whatever their origin, they apparently remained above the level of anaerobic bottom water.

Pelagic deposition of nannofossils and foraminifers prevailed from the middle Paleocene through the early Miocene. The Ceará Rise is apparently a distal area with respect to terrigenous sediment deposition. The only terrigenous sediments are clays whose mode of transport may be aeolian and/or suspension. This contrasts with Sites 135-137, 140, 144, and 24 in the equatorial Atlantic, where either before, during, or immediately after anaerobic sediment accumulation, significant terrigenous influx occurred (graded sands, silts, clays, arkosic sands, "graywackes"). Thus in a Late Cretaceous-early Tertiary reconstruction, these sites would be basinal depocenters. By contrast, the

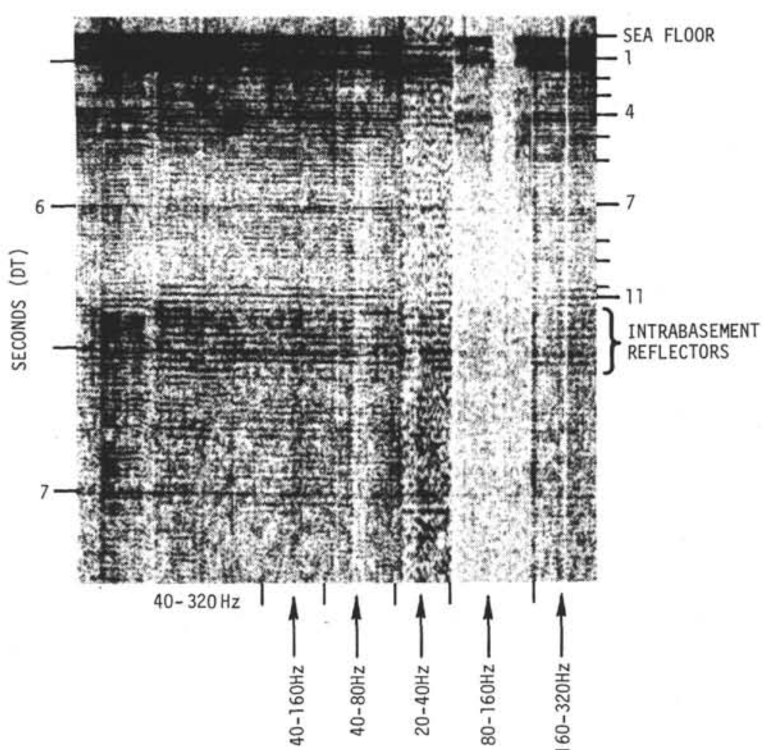


Figure 18. *Vertical reflection profile obtained while on Site 354 by using streamed hydrophone array (see text).*

TABLE 5
Calculated Depths to Reflecting Horizons (velocities are core averages)

Reflector	DT, (sec)	ΔT, (sec)	V, (m/sec)	ΔZ, (m)	Z, (m)	Approach Profile	Sonobuoy Profile	Streamer Profile
1	0.06		1560		47	X	X	X
		0.08	1560	62				
2	0.14				109			X
		0.07	1575	55				
3	0.21				164		X	X
		0.06	1540	46				
4	0.27				210	X	X	X
		0.08	1690	68				
5	0.35				278			X
		0.06	1850	56				
6	0.41				334			X
		0.21	2000	210				
7	0.62				544	X		X
		0.08	2150	86				
8	0.70				630			X
		0.05	2150	54				
9	0.75				684			X
		0.13	2500	163				
10	0.88				847			X
		0.03	2550	38				
11	0.91				885	X	X	X

Ceará Rise would have been either farther from sources of terrigenous sediments or, more probably, physiographically higher.

Periods of slow sediment accumulation, or perhaps hiatuses, are represented in the upper Maestrichtian-lower Paleocene and at the Eocene-Oligocene boundary. A short hiatus occurs in the middle Miocene.

The upper Maestrichtian-Paleocene slow accumulation, or hiatus, is marked by small amounts of siliceous fragments and by an important contribution of benthic foraminifers, occasionally whole but usually fragmented. This may indicate increased current activity. Hiatuses at Ceará Rise and other Leg 39 sites are discussed in this context in the cruise synthesis chapter (Supko and Perch-Nielsen this volume).

The Ceará Rise and the similar Sierra Leone Rise in the eastern Atlantic were probably formed at the Mid-Atlantic Ridge as voluminous outpourings of basaltic magma about 80 m.y.B.P. At that time, the rotational pole controlling Atlantic spreading may have changed (Le Pichon and Hayes, 1971; Le Pichon and Fox, 1971; Pitman and Talwani, 1972), perhaps in response to relaxation of control over spreading direction caused by transverse ridge locking (Le Pichon and Hayes, 1971). The basalt mound, after being rapidly formed, rifted in two; the Ceará Rise moved west and the Sierra Leone Rise moved east, and they subsided as they moved away from the ridge (see also Kumar and Embley, in press). Fossils in the Maestrichtian marls overlying basement indicate a water depth of perhaps 1000 meters. Assuming a ridge crest depth of about 2600 meters, as at present, it would take about 1600 meters of additional build-up to elevate the basement to the 1000-meter contour. This is also the present relief of the Ceará Rise basement over the surrounding basement. Normal spreading subsidence would result in a depression of some 3000 meters in 80 m.y. (Sclater et al., 1971), requiring an additional 1000 meters of subsidence. There is some evidence, from gravity data, of compensation at depths beneath the rise (Embley and Hayes, 1972).

The Ceará Rise has been a positive feature since its formation, and has been a depocenter for pelagic facies, except for short periods of extreme dissolution, nondeposition, or erosion. Post-middle Miocene sediments contain significant contributions of terrigenous material. The terrigenous silt and clay represent Amazon River sediment, since the Amazon River began draining into the Atlantic Ocean in the Miocene (Oliveira, 1956). The terrigenous component may have been added to the bottom sediment both as particles of suspended sediment settling directly through the water column and as distal facies of turbidites.

The origin and sediment accumulation history of the Ceará and Sierra Leone rises are discussed further and compared in the general synthesis chapter (Supko and Perch-Nielsen, this volume).

REFERENCES

Bader, R.G., Gerard, R.D., et al., Initial Reports of the Deep Sea Drilling Project, Volume 4: Washington (U.S. Government Printing Office).

Berger, W.H. and von Rad, U., 1972. Cretaceous and Cenozoic sediments from the Atlantic Ocean. *In* Hayes, D.E., Pimm, A.C., et al., Initial Reports of the Deep Sea Drilling Project, Volume 14: Washington (U.S. Government Printing Office), p. 787-954.

Berggern, W.A. and Amdurer, M., 1973. Late Paleogene (Oligocene) and Neogene planktonic foraminiferal biostratigraphy of the Atlantic Ocean (lat. 30°N to lat. 30°S): Riv. Ital. Paleontol., v. 79, p. 337-392.

Bolli, H. and Permoli-Silva, I., 1973. Oligocene to Recent planktonic foraminifera and stratigraphy of the Leg 15 sites of the Caribbean Sea. *In* Edgar, N.T., Saunders, J.B., et al., Initial Reports of the Deep Sea Drilling Project, Volume 15: Washington (U.S. Government Printing Office), p. 475-497.

Boström, K. and Fisher, DE. , 1971. Volcanogenic, U, V and Fe in Indian Ocean sediments: Am. Geophys. Union Trans, v. 52, p. 245.

Boström K. and Peterson, M.N.A., 1969. The origin of aluminum-poor ferromanganoan sediments in areas of high heat flow on the East Pacific Rise: Marine Geol., v. 7, p. 427.

Boström, K., Peterson, M.N.A., Joensuu, O., and Fischer, D.E., 1969. Aluminum-poor ferromanganoan sediments on active oceanic ridges: J. Geophys. Res., v. 74, p. 3261.

Bukry, D., 1973. Low latitude coccolith biostratigraphic zonation. *In* Edgar, N.T., Saunders, J.B., et al., Initial Reports of the Deep Sea Drilling Project, Volume 15: Washington (U.S. Government Printing Office), p. 685-703.

Cochran, J., 1973. Gravity and magnetic investigations in the Guiana Basin, Western Equatorial Atlantic; Bull. Geol. Soc. Am., v. 84, p. 3249-3268.

Corliss, J.B., 1971. The origin of metal-bearing submarine hydrothermal solutions: J. Geophys. Res., v. 76, p. 8128.

Cronan, D.S., 1973. Basal ferruginous sediments cored during Leg 16, Deep Sea Drilling Project. *In* van Andel, T.H., Heath, G.R., et al., Initial Reports of the Deep Sea Drilling Project, Volume 16: Washington (U.S. Government Printing Office), p. 601.

Damuth, J.E. and Kumar, N., 1975. Amazon Cone; morphology, sediments, age, and growth pattern: Geol. Soc. Am. Bull. v. 86, p. 863-878.

Embley, R. and Hayes, D.E., 1972. Site survey report for Site 142; *In* Hayes, D.E., Pimm, A.C., et al., Initial Reports of the Deep Sea Drilling Project, Volume 14: Washington (U.S. Government Printing Office), p. 377.

Gartner, S., 1973. Absolute chronology of the late Neogene calcareous nannofossil succession in the equatorial Pacific: Geol. Soc. Am. Bull., v. 84, p. 2021-2034.

Gartner, S. and Bukry, D., 1975. Morphology and phylogeny of the coccolithophore family Ceratolithaceae: J. Res., U.S. Geol. Survey, v. 3, p. 451-465.

Hayes, D.E., Pimm, A.C., et al., 1972. Initial Reports of the Deep Sea Drilling Project, Volume 14: Washington (U.S. Government Printing Office).

Jousé, A.P., 1973. Diatoms in the Oligocene-Miocene biostratigraphic zones of the tropical areas of the Pacific Ocean: Beihft. Z. Naua. Hedw., v. 45, p. 333-364.

Kumar, N. and Embley, R.W., in press. Evolution and origin of Ceará Rise: An aseismic rise in the western equatorial Atlantic: Geol. Soc. Am. Bull.

Le Pichon, X. and Fox, P.J., 1971. Marginal offsets, fractures zones, and the early opening of the North Atlantic: J. Geophys. Res., v. 76, p. 6294.

Le Pichon, X. and Hayes, D.E., 1971. Marginal offsets, fracture zones, and the early opening of the South Atlantic: J. Geophys. Res., v. 76, p. 6283.

Martini, E., 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. *In* Farinacci, A. (Ed), Second Plank. Conf., Rome, 1970, Proc.: Roma (Tecnoscienza), v. 2, p. 739-785.

Maxwell, A.E. and Von Herzen, R.P., et al., 1970. Initial Reports of the Deep Sea Drilling Porject, Volume 3: Washington (U.S. Government Printing Office).

McCollum, D.W., 1975. Diatom stratigraphy of the Southern Ocean. *In* Hayes, D.E., Frakes, L.A., et al., Initial Reports of the Deep Sea Drilling Project, Volume 28: Washington (U.S. Government Printing Office), p. 515-571.

Oliveira, A.I. de, 1956. Brazil. *In* Jenks, W.F. (Ed.), Handbook of South American geology: Geological Society of America Mem. 65, p. 2-62.

Pitman, W. and Talwani, M., 1972. Sea floor spreading in the North Atlantic: Bull. Geol. Soc. Am., v. 83, p. 619-646.

Reyment, R.A. and Tait, E.A., 1972. Biostratigraphical dating of the early history of the South Atlantic Ocean: Phil. Trans. Roy. Soc. London, ser. B, Biol. Sci., v. 264, p. 55-95.

Roth, P. and Thierstein, H., 1972. Calcareous nannoplankton: Leg 14 of the Deep Sea Drilling Project. *In* Hayes, D.E., Pimm, A.C., et al., Initial Reports of the Deep Sea Drilling Project, Volume 14: Washington (U.S. Government Printing Office), p. 975.

Sclater, J.G., Anderson, R.N., and Bell, M.L., 1971. Elevation of ridges and evolution of the central eastern Pacific: J. Geophys. Res., v. 76, p. 7888.

Shackleton, N.J. and Kennett, J., 1974. Late Cenozoic oxygen and carbon isotopic changes in DSDP Site 284: implications for glacial history of the northern hemisphere and Antarctica. *In* Kennett, J.P., Houtz, R.E. et al., Initial Reports of the Deep Sea Drilling Project, Volume 29: Washington (U.S. Government Printing Office), p. 1179.

von der Borch, C.C. and Rex, R.W., 1970. Amorphous iron oxide precipitates in sediment cored during Leg 5, DSDP. *In* McManus, D.A., Burns, R.E., et al., Initial Reports of the Deep Sea Drilling Project, Volume 5: Washington (U.S. Government Printing Office), p. 827.

APPENDIX A
Smear-slide Summary

	Sand	Silt	Clay	Quartz	Feldspar	Clay	Iron Oxides	Pyrite	Dolomite	Zeolite	Authigenic Carbonate	Foraminifers	Calcareous Nannofossils	Diatoms	Radiolaria	Sponge Spicules	Fish Remains
Site 354																	
1-1, 59	10	10	80	5		40	5					10	35	5		1	
1-1, 76	10	20	70	10		40	10					5	30	5			
1-1, 119	10	20	70	5		45	10					5	30	5			
1-2, 64	10	20	70	5		40	5					10	35	5			
1, CC		5	95	10		35	5		Tr			10	35	5			
2, CC	10	20	70	5		40	5					5	40	5			
3-1, 85	10	20	70	5		25	Tr		Tr			5	60	5			
3-1, 110	10	20	70	5		30	Tr		Tr		5	10	50				
3-2, 111	10	20	70	5		25	Tr		Tr			15	50	Tr			
4-1, 56	10	20	70			30	Tr		Tr			10	50	5			
4-1, 116	10	20	70			25	Tr		Tr			15	55	5			
4-2, 100	10	20	70	5		20	Tr		Tr			5	70				
4-5, 79	10	20	70	5		20	5					Tr	70				
4-6, 10	10	20	70	5		20	5		Tr		Tr	Tr	70				
4-6, 33	30	20	50			20	Tr		Tr			40	40				
4-6, 90	10	20	70			20	Tr		Tr			10	70				
5-1, 60	10	20	70	5		20			Tr			15	60				
5-1, 100	10	20	70			20	Tr		Tr			5	75				
5-2, 105	10	20	70	Tr		10			Tr			10	80				
5-2, 140	10	20	70	Tr		20	Tr					20	60				
6-1, 142	20	30	50			15	Tr		Tr			15	65	5			
6-2, 35	10	20	70	Tr		15	Tr		Tr			10	75	Tr			
6-3, 30	10	20	30	Tr		20	Tr		Tr			10	70	Tr			
6-3, 55	10	20	30	Tr		15	Tr		Tr			10	75	Tr			
6-3, 100	50	30	20			10						70	15	5			
6-3, 110	20	30	50			15	Tr					20	60	5			
6-3, 136	70	20	10			10						70	20	Tr			
6-3, 141	10	20	70				Tr						90				
6, CC	70	20	10			15	Tr					65	20				
7-1, 130	30	40	30			15	Tr					20	65	Tr			
7-2, 98	10	30	60			20	Tr				5	5	70	Tr			
7-2, 127	60	20	20			15						50	35				
7-3, 131	50	30	20			10			Tr			50	35	5			
7-4, 135	50	30	20			15						50	30	5			
8-1, 58	40	30	30			10				10		50	30				
8-2, 19	10	30	60			15	Tr	Tr		10			80				
9-2, 60	20	30	50			15	Tr	Tr		5		10	65	5			
10-2. 60	40	30	30			20		Tr		5		35	40	10			
10, CC	10	30	60			10	Tr	Tr	Tr	10		35	50	5			
11-2, 100	10	20	70			10				10		15	65				
11-4, 70	40	30	30			10				15		15	50	5			
11-4, 145	40	30	30			10		Tr		10		15	60	5			
11-5, 68	30	35	35			10				15		30	40	5			
11-6, 70	30	40	30		Tr	15		Tr	Tr	10		30	45	Tr			
12-1, 50	10	20	70			15		5		15			30	25	5	5	
12-1, 52	10	20	70			15		Tr	Tr	15			30	30	5	5	
12-2, 40	10	20	70			10		Tr		10		5	45	25		5	
12-1, 110	10	20	70			10				15			50	20		5	
12-4, 13	10	20	70			20		5		10			30	25	5	5	
12-5, 81	10	20	70			15		Tr		15			35	30		5	
12-6, 140	10	20	70			20		Tr		10			50	20			
13-1, 148	10	20	70			30		Tr			10	5	50	5			
13-5, 100	10	20	70			30		Tr			5	15	50				
14-2, 100	20	30	50			30						30	40				
14-4, 27	30	35	35			20						45	30	5			
15-1, 140	20	30	50	Tr		25						35	35	5			1
15-2, 34	20	30	50	5		20			5			25	40	5			
15-3, 40	25	35	40			20			5			40	35	Tr			
16-2, 100	10	20	70			15					5	10	70				
16-5, 147	20	30	50			20		Tr	5			15	60				
16-6, 122	10	20	70			25		Tr	5		5	10	55	Tr			
16, CC	20	30	50			25	Tr		Tr		10	25	35	5			
17-1, 120	20	30	50			30	5		5		10	30	20				
17, CC	20	30	50			30	5		Tr		20	15	25	5			
18-1, 70	20	30	50			40	5		Tr		15	30	10				
18-4, 140	10	20	70			40	5		Tr		15	25	15				

APPENDIX B
Carbonate and Quartz Determinations Leg 39
(See Chapter 1 for explanation.)

Section	Sediment Depth (cm)	$CaCO_3$ (%)	Org (%)	Total Carb (%)	Qtz (%)
1-1	86	18.27	0.22	2.42	
1-1	115	19.51	0.18		
1-2	269	8.75	0.36		
1, CC	325	18.02	0.99	3.14	15.60
1-2	328	26.62	0.25	3.45	
2, CC	4525	27.89	0.69	4.03	15.33
3-1	9370	46.53	0.12		
3-1	9380	43.72	0.14	5.39	
3, CC	9575	46.11	0.85	6.39	11.56
4-1	14040	43.78	0.06		
4-1	14120	59.73	0.10	7.28	
4-2	14190	61.04	0.06		
4-6	14770	31.83	0.09	3.91	
4-6	14810	67.59	0.07	8.19	
4, CC	14925	53.80	0.75	7.21	13.70
5-2	18971	40.78	0.06		
5-2	18975	43.40	0.09	5.30	
5-2	19048	67.49	0.07	8.17	
5, CC	19075	68.63	0.75	8.99	14.77
6-2	23672	65.76	0.08	7.98	
6-2	23757	56.54	0.03		
6-3	23870	36.40	0.10	4.47	
6-3	23891	67.02	0.06		
6-3	23901	74.24	0.07	8.98	
6-3	23907	75.31	0.06	9.10	
6-3	23944	35.86	1.10	4.41	
6, CC	23975	75.67	0.36	9.44	5.24
7-1	28387	73.05	0.03		
7-1	28389	73.42	0.07	8.89	
7-3	28566	47.28	0.03		
7-4	28796	80.19	0.09	9.72	
7, CC	29175	61.95	0.49	7.93	5.57
8-1	34056	73.69	0.10	8.95	
8-2	34106	17.27	0.15	2.23	
8-2	34130	51.28	0.15		
8, CC	34425	63.57	0.47	8.10	7.70
9-2	39895	56.78	0.09	6.91	
9-3	40062	54.78	0.15		
9, CC	40575	53.97	0.24	6.72	7.34
10-2	45506	45.80	0.31	5.81	
10-2	45598	85.05	0.18		
10-3	45671	77.11	0.10	9.36	
10, CC	46275	64.15	0.31	8.01	5.39
11-2	52161	80.42	0.08	9.73	
11-4	52595	94.92	0.06	11.45	
11-5	52625	67.54	0.15		
11, CC	52925	57.37	0.45	7.33	5.63
12-1	60648	63.93	0.09	7.77	
12-4	61011	55.03	0.18		
12-5	61239	50.91	0.20	6.31	
12, CC	61475	59.23	0.40	7.51	4.90
12, CC	61490	60.33	0.45	7.69	5.51
	69249	62.40	0.10	7.59	
13-6	69974	64.70	0.12	7.89	
13-6	69975	67.54	0.15		
13, CC	70025	65.35	0.37	8.22	5.69
14-1	70156	71.55	0.12		
14-1	70157	73.40	0.09	8.91	
14-5	70677	55.22	0.09	6.72	
14, CC	70975	50.70	0.22	6.31	4.72
15-2	81626	63.29	0.06	7.66	
15-2	81645	63.79	0.12		
15-3	81821	62.00	0.21	7.65	
15-3	81834	63.29	0.15		
15, CC	81925	51.39	0.39	6.56	45.09
16-3	83698	65.58	0.08	7.95	
16-6	84221	43.32	0.10	5.30	

APPENDIX B – *Continued*

Section	Sediment Depth (cm)	$CaCO_3$ (%)	Org (%)	Total Carb (%)	Qtz (%)
16, CC	84275	53.75	0.39	6.84	
17-2	85517	53.78	0.15		
17-3	85630	58.06	0.14	7.11	
17, CC	85725	45.91	0.88	6.37	
18-1	87240	53.59	0.16	6.59	
18-1	87280	52.78	0.21		
18-4	87728	35.84	0.31	4.61	
18-4	87728	37.02	0.27		
18, CC	88075	53.07	0.72	7.08	

Site 354 Hole Core 1 Cored Interval: 0.0-7.0 m

AGE	ZONE	FOSSIL CHARACTER: FORAMS	FOSSIL CHARACTER: COCCO-LITHS	FOSSIL CHARACTER: RADS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO.SAMPLE	SED. STRUCT.
LATE PLEISTOCENE	(N22) G. truncatulinoides Emilania huxleyi NN21			—	0		VOID			
			CG		1	0.5 1.0			59 76 119	
		AG	AG	—	2				64	
		AM	AG	RP	Core Catcher				CC	

LITHOLOGIC DESCRIPTION

58-73, MARLY-FORAMINIFERAL NANNO OOZE, moderate yellow-brown (10YR 5/4), mixed and disturbed, coarse appearance.

SS 59
40% Clay
5% Silt quartz
10% Forams
35% Nannos
5% Fe Oxides
5% Diatoms
TR% Heavy minerals

73-128, NANNO OOZE to MARLY NANNO OOZE, finely laminated, moderate brown (5YR 4/4), and light brown (5YR 5/6) laminae in a general moderate yellowish brown (10YR 5/4); bioturbation (burrows) 102-114; distinction moderate brown (5YR 4/4) laminae at 119-120 and 126-128.

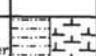
SS 76	SS 119
40% Clay	40% Clay
10% Silt quartz	10% Silt
10% Fe Oxides	10% Fe Oxides
30% Nannos	30% Nannos
5% Forams	5% Forams
5% Diatoms	5% Diatoms
TR% Heavy minerals	

128-150 (Sec. 1), MARLY-NANNO OOZE, light olive gray (5Y 6/1) to pale yellow brown (10YR 6/2), some black hydrotroilite blebs, slightly darker brown laminae with gradation of contacts at 14 cm (Sec. 2) and 90 cm, slight mottling and burrows throughout.

SS 64	SS CC
35% Clay	40% Clay
10% Silt quartz	5% Silt quartz
35% Nannos	5% Diatoms
10% Forams	TR% Glauconite
5% Diatoms	40% Nannos
5% Fe Oxides	5% Forams
	5% Fe Oxides

Bomb CO_3:
Sec. 1, 75 cm = 14%
Sec. 1, 115 cm = 18%
Sec. 1, 140 cm = 27%
Sec. 2, 55 cm = 33%

Site 354 Hole Core 2 Cored Interval: 45.0-54.5 m

AGE	ZONE	FOSSIL CHARACTER: FORAMS	FOSSIL CHARACTER: COCCO-LITHS	FOSSIL CHARACTER: RADS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO.SAMPLE
EARLY PLEISTOCENE	(N22) Pseudoemiliania lacunosa NN19	AG	AG	—	Core Catcher				CC

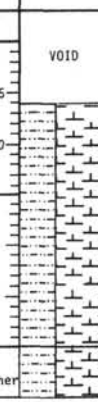
LITHOLOGIC DESCRIPTION

CC, MARLY NANNO OOZE, light olive gray (5Y 5/2), some hydrotroilite(?) grains.

SS CC
40% Clay
5% silt quartz
TR% Glauconite
40% Nannos
5% Forams
5% Diatoms
5% Fe Oxides

Bomb CO_3: Sec. CC = 26%

Site 354 Hole Core 3 Cored Interval: 92.5-102.0 m

AGE	ZONE	FOSSIL CHARACTER: FORAMS	FOSSIL CHARACTER: COCCO-LITHS	FOSSIL CHARACTER: RADS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO.SAMPLE	SED. STRUCT.
PLIOCENE	(N21) G. tosaensis Discoaster surculus NN16				0		VOID			
		AG	AG		1	0.5 1.0			85 110	
		AG	AG	—	2				111	
			AG							
	N19-N21	AM	AG	—	Core Catcher					

LITHOLOGIC DESCRIPTION

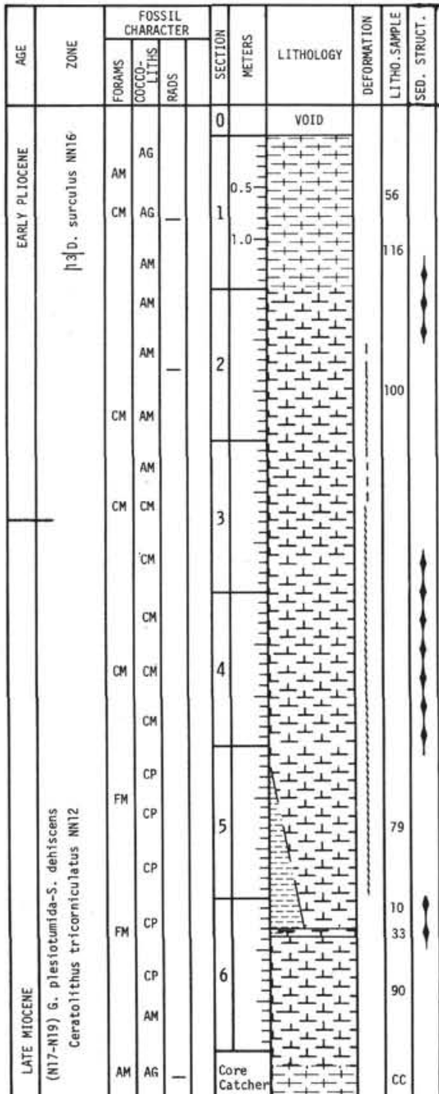
65-CC, pale yellowish brown (10YR 6/2), MARLY NANNO OOZE, blebs of hydrotroilite throughout, thin (2 mm) laminae at 85 cm, moderate yellowish brown (10YR 5/4), similar bands in Sec. 2 delineate disturbance.

AUG Smear Slide
5-15% Forams
50-60% Nannos
5% Quartz silt
25-30% Clay
TR% Fe Oxides
TR% Dolomite

Bomb CO_3:
Sec. 1, 100 cm = 39%
Sec. 2, 110 cm = 56%

Explanatory Notes in Chapter 1

Site 354 Hole Core 4 Cored Interval: 140.0-149.5 m



LITHOLOGIC DESCRIPTION

Sec. 1, 0-150, FORAMINIFERAL NANNO OOZE, light gray (N7) grading to yellowish gray (5Y 7/2), color boundary at ~100 cm, hydrotroilite in upper 1 m, lighter color bands appear to be foram-rich.

SS 56, 116
20% Clay
5% Silt quartz
60% Nannos
15% Forams

Bomb CO_3: Sec. 1, 5 cm = 49%

Sec. 2, 0-150, NANNO OOZE, generally (5Y 7/2) continues, 18-50 light gray (N8) with burrows.

SS 100
20% Clay
5% Silt quartz
70% Nannos
5% Forams
TR% Fe Oxides

Bomb CO_3: Sec. 2, 90 cm = 51%

Sec. 3, NANNO OOZE, yellowish gray (5Y 7/2) and very light gray (N8) continues alternating bands.

Sec. 4, NANNO OOZE, yellowish gray (5Y 7/2) at top to light brown (5YR 6/4) at base, some scattered hydrotroilite, moderately bioturbated.

Sec. 5, MARLY NANNO OOZE, alternating yellowish gray (5Y 7/2) and very light gray (N6), paste and biscuit structure disturbance.

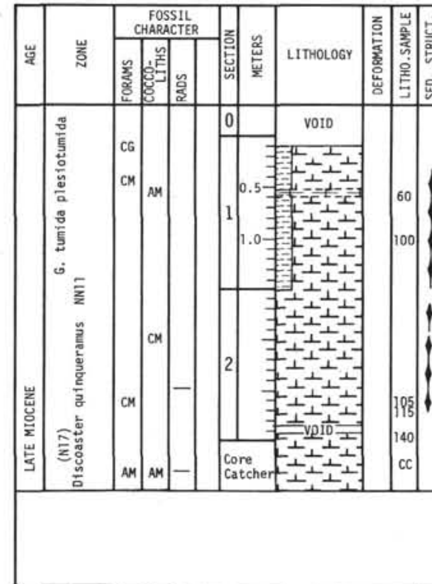
SS 79
30% Clay
5% Silt quartz
65% Nannos

Bomb CO_3: Sec. 5, 66 cm = 45%

Sec. 6:
0-26, moderate yellowish brown (10YR 5/4), moderate bioturbation.
26-30, pale yellowish brown (10YR 6/2), moderate bioturbation.
30-35, very light gray (N8), sandy.
35-40, very light gray/moderate yellow brown/black (hydrotroilite), lower contact black laminae.
40-150, alternating very light gray (N8)/yellowish gray (5Y 7/2), slight bioturbation.

SS 10, 90	SS 33
5% Silt	TR% Silt
20% Clay	40% Forams
70% Nannos	40% Nannos
5% Forams	20% Clay
TR% Fe Oxides	TR% Fe Oxides
TR% Dolo rhombs	

Site 354 Hole Core 5 Cored Interval: 187.5-197.0 m



LITHOLOGIC DESCRIPTION

Sec. 1:
15-150, MARLY NANNO OOZE, yellowish gray (5Y 7/2) to pale yellowish brown (10YR 6/2) at base; gray and brown colors alternate throughout, slight bioturbation throughout. 57-61 cm, FORAM-NANNO OOZE, a light gray (N7) zone.

SS 60
20% Clay
5% Silt quartz
60% Nannos
15% Forams
TR% Dolo rhombs

SS 100
20% Clay
75% Nannos
5% Forams

Bomb CO_3: Sec. 1, 106 cm = 34%

Sec. 2, NANNO OOZE continues from above, some large blebs of hydrotroilite, surrounded by whitish material (SS 115).

SS 105, 115	SS 115
10% Clay	5% Silt
TR% Silt	10% Clay
5% Forams	20% Forams
85% Nannos	60% Nannos
	5% Diatoms

136-CC, NANNO-FORAM OOZE, similar colors to above.

SS 140, CC
20% Clay
TR- 5% Silt
20% Forams
60-50% Nannos
TR% Diatoms

CO_3: Sec. 2, 71 cm = 41%

Explanatory Notes in Chapter 1

Site 354 Hole Core 6 Cored Interval: 235.0-244.5 m

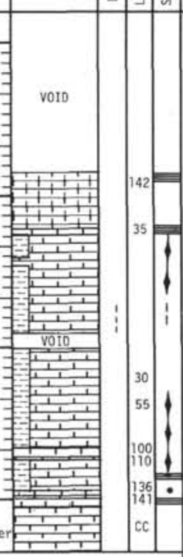
AGE: LATE / MIDDLE MIOCENE / MIDDLE / EARLY

ZONE: (N16-N17) G. acostaensis-plesiotumida; Discoaster quinqueramus NN11; Discoaster calcoris NN10; Discoaster hamatus NN9; Hiatus; Discoaster exilis? NN6; (N8) Sphenolithus heteromorphus NN5

FOSSIL CHARACTER — FORAMS: AM, CM, CM, CM, AP; COCCOLITHS: AM, AM, AG, AG, CM, AG, CM, CM, CM; RADS: —, —

SECTION: 0, 1, 2, 3, Core Catcher

METERS: 0.5, 1.0



LITHO. SAMPLE: 142, 35, 30, 55, 100, 110, 136, 141, CC

LITHOLOGIC DESCRIPTION

127 (Sec. 1) to 30 (Sec. 2), FORAM-NANNO CHALK, very light gray (N8); 133-135, fine laminae with sharp contacts.

SS 35, 142

15-20% Clay	65-75% Nannos
TR% Silt	5% Diatoms
10-15% Forams	TR% Dolo rhombs

Sec. 2:
30-37, NANNO CHALK, pale blue (5PB 7/2) to white (N9), fine laminae inclined ~20°.
37-59, NANNO CHALK, pinkish gray (5YR 8/1), some hydrotroilite and burrows.
59-66, NANNO CHALK, similar to 30-37.
66-129, MARL NANNO CHALK, varigated pale yellowish brown (10YR 6/2) to pale brown (10YR 6/3), some burrowing and coring disturbance.

Sec. 3, MARLY NANNO CHALK continues from above with additional: alternating color banding, various shades of brown-yellow brown, yellow gray, and pale olive (5Y, 5YR, 10Y and 10YR hues); fine burrows throughout; generally sharp contacts between bands.
54-56 Light bluish gray (5B 7/1) bands,
64-65 top two are NANNO CHALK, bottom two
90-101 show graded texture with high foram
134-136 content at base, hydrotroilite laminae.
136-150, NANNO CHALK, bands of pale olive (10Y 6/2) and pale brown (5YR 5/2).
CC, FORAM CHALK, light greenish gray (5GY 8/1).

SS 30, 55, 110
15-20% Clay
TR% Silt
10% Forams
75-65% Nannos
TR% Fe Oxides

SS 100, 136, CC
70% Forams
20% Nannos
10% Clay
TR% Diatoms

SS 141
10% Clay
90% Nannos
TR% Fe Oxides

CO_3: Sec. 2, 107 cm = 57%
Sec. 3, 91 cm = 67%

Site 354 Hole Core 7 Cored Interval: 282.5-292.0 m

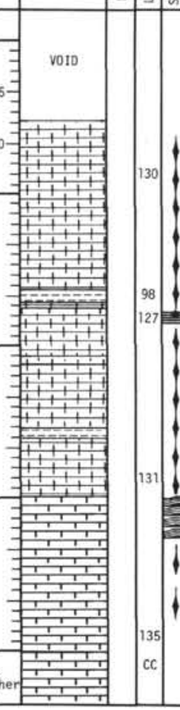
AGE: EARLY MIOCENE

ZONE: (N7) G. insueta/trilobus; NN5 S. heteromorphus; (N6) G. insueta/dissimilis; Sphenolithus belemnos NN3; C. costatal

FOSSIL CHARACTER — FORAMS: CP, AP, CP, CP, AP; COCCOLITHS: CM, CM, CM, CM, CM; RADS: RP, —, RP, FP, CM

SECTION: 0, 1, 2, 3, 4, Core Catcher

METERS: 0.5, 1.0



LITHO. SAMPLE: 130, 98, 127, 131, 135, CC

LITHOLOGIC DESCRIPTION

Sec. 1, FORAM-NANNO CHALK, very pale blue (5B 8/2), moderate bioturbation.

SS 130

15% Clay	65% Nannos
20% Forams	

Bomb CO_3: Sec. 1, 136 cm = 72%

Sec. 2, FORAM-NANNO CHALK (similar to above), burrows filled with a greenish-gray mud (5GY 6/1) or moderate yellow brown mud (10YR 5/4).
95-102, zone of yellow-brown mud.
116-128, FORAM CHALK, laminated white (N9), upper 2 cm bioturbated.

SS 98
20% Clay
5% CO_3 - silt
70% Nannos
5% Forams

Sec. 3, FORAM-NANNO CHALK (similar to above), color grading to very light gray (N7), burrows throughout, but particulary at 14-17, 82-87, with yellowish-brown mud (5YR 5/4), foram sand layers (<1 cm thick) at 51, 60, 75, 94, 116, 120, 132 cm.
132-150, appears to have increased foram content.

SS 127, 131
50% Forams - Frags.
35% Nannos
5% Diatoms
10% Clay

Bomb CO_3: Sec. 3, 18 cm = 36% (?)

Sec. 4, FORAM CHALK (similar to Sec. 3) but with increased foram content.
0-38, contorted bedding, flow, small faults, *in situ* deformation, foram sand ($\bar{\leq}$1 cm thick) at 96, 103, 123, and 130.

SS 135
50% Forams - Frags.
30% Nannos
5% Diatoms
15% Clay

CO_3: Sec. 1, 137 cm = 73%
Sec. 3, 16 cm = 47%

Explanatory Notes in Chapter 1

Site 354 Hole Core 8 Cored Interval: 339.5-349.0 m

AGE	ZONE	FORAMS	COCCO-LITHS	RADS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	SED. STRUCT.	LITHOLOGIC DESCRIPTION
EARLY MIOCENE	(N5) G. dehiscens/praedehiscens; Triquetrorhabdulus carinatus; S. delmontensis; NN1 | NN2	AF, AG, AG, AM	AM, AM, AM, CM	—, —, FP	0		VOID				Entire core - ZEOLITIC NANNO-FORAM CHALK grading to NANNO CHALK, pale blue (5PB 7/2) and pale blue-green (5BG 7/2), alternation in color due to burrowing, moderate bioturbation throughout.
					1	0.5, 1.0			58		SS 58: 10% Zeolite, 50% Forams (Frags.), 30% Nannos, 10% Clay
					2				19		SS 19: 15% Clay, 5% Forams, 75% Nannos, TR% Dolomite rhombs, 5% Zeolite, TR% Pyrite
					3						CO_3: Sec. 2, 30 cm = 51%
					Core Catcher						

Site 354 Hole Core 9 Cored Interval: 396.5-406.0 m

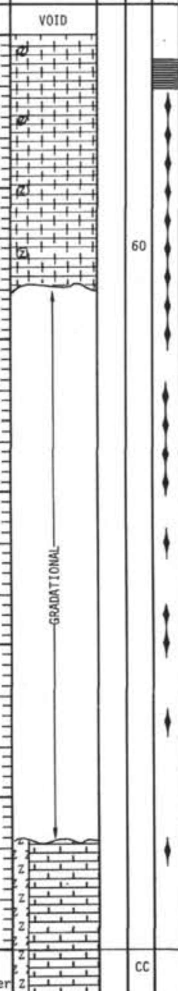
AGE	ZONE	FORAMS	COCCO-LITHS	RADS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	SED. STRUCT.	LITHOLOGIC DESCRIPTION
EARLY MIOCENE	(N4) G. primordius/trilobus; NN1; Triquetrorhabdulus carinatus	AM, AG, AG	AM, AM, AM	—, —, —	0		VOID				NANNO-FORAM CHALK, pale blue (5PB 7/2) and pale blue-green (5BG 7/2), color alternations with burrowing, moderate bioturbation throughout.
					1	0.5, 1.0					SS 60: 15% Clay, 10% Forams, 65% Nannos, 5% Diatoms, 5% Zeolite
					2				60		Bomb CO_3: Sec. 2, 63 cm = 61%
					3						
					4						SS CC: 65% Nannos, 5% Diatoms, 15% Clay, 15% Zeolite, TR% Dolo rhombs
					5						
LATE OLIGOCENE	(P22) G. angulisuturalis; NP25 *	FP	CM	RP	Core Catcher				CC		

*Sphenolithus ciperoensis

Explanatory Notes in Chapter 1

Site 354 Hole Core 10 Cored Interval: 453.5-463.0 m

AGE	ZONE	FORAMS	COCCO-LITHS	RADS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	SED. STRUCT.
LATE OLIGOCENE	(P21) G. angulisuturalis/opima; Sphenolithus ciperoensis NP25	CF	CM	–	0		VOID			
					1	0.5, 1.0				
		AG			2				60	
		AG	AM	–	3		GRADATIONAL			
					4					
		AG		–	5					
			AP		6					
	NP24 *	AP	AM	–	Core Catcher				CC	



LITHOLOGIC DESCRIPTION

NANNO-FORAM CHALK to NANNO CHALK, pale blue (5PB 7/2) and pale blue-green (5BG 7/2), alternations in color due to burrowing or fine laminations at 24-48 (Sec. 1), moderate bioturbation throughout.

Sec. 2, 0-13, intensely bioturbated, these burrows filled with a grayish blue-green ooze (5BG 5/2).

SS 60
10% Clay
5% Zeolite
35% Forams
40% Nannos
10% Diatoms
TR% Barite
TR% Dolo rhombs
TR% Pyrite

Sec. 5, bioturbation decreasing.

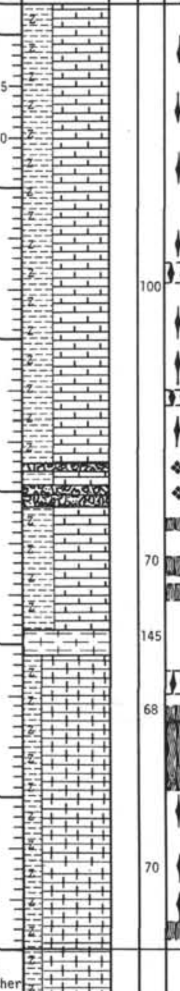
SS CC
10% Zeolite
25% Forams
50% Nannos
10% Clay
5% Diatoms
TR% Pyrite
TR% Dolo rhombs

CO_3: Sec. 2, 98 cm = 85%

*Sphenolithus distentus

Site 354 Hole Core 11 Cored Interval: 520.0-529.5 m

AGE	ZONE	FORAMS	COCCO-LITHS	RADS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	SED. STRUCT.
OLIGOCENE	NP24; Sphenolithus distentus	AF	CM	–	1	0.5, 1.0				
		CP		–	2				100	
		CP	AM	–	3					
			AM	–	4				70	
		AF	AM	–					145	
	(P20) G. ampliapertura; Sphenolithus predistentus		AM	–	5				68	
			AM	–	6				70	
	NP22? T. tuberosa	AF								
		CP	CP	AG	Core Catcher					



LITHOLOGIC DESCRIPTION

ZEOLITIC MARLY NANNO CHALK grading to ZEOLITIC MARLY FORAM NANNO CHALK in lower half, pale blue-green (5BG 7/2), moderate yellowish brown (10YR 5/4) in burrows, moderate mottling throughout, some hydrotroilite blebs.

Sec. 4 (136) to Sec. 5 (10), NANNO FORAM OOZE, very light gray (N8) without mottling.

Zones of intense mottling:
Sec. 2, 75-91, dusky yellow green (5GY 5/2).
Sec. 3, 50-65.
Sec. 5, 27-47.

Zones of breccia (clay-pebble):
Sec. 3, 123-127, sediment fragments, 1/2-1 cm in size, angular and subrounded.
Sec. 3, 145-Sec. 4, 03, clasts streaked and elongated, some suggestion of shear, clasts similar to surrounding sediment, some clasts burrowed.
Sec. 4, 7-12, small clasts (1-2 mm), zone burrowed.

Zones of contorted bedding:
Sec. 4, 28-36, broad and tight "folds".
Sec. 4, 64-81, intruded zeolitic foram ooze, dusky yellow green (5GY 5/2), with flow lines, small (1/2-1.5 cm) sediment clasts of lighter pale blue-green (5BG 7/2) as in surrounding sediment.
Sec. 4, 91-105, deformed bedding and shear.
Sec. 5, 61-74, intensely deformed with ooze "dike", mix of competent and incompetent sediment layers.
Sec. 5, 74-140, deformed with broad "folds", microfault displacing laminae of hydrotroilite.
Sec. 6, 125-137, intensely deformed and burrowed.

SS 100
10% Clay
10% Zeolite
15% Forams
65% Nannos

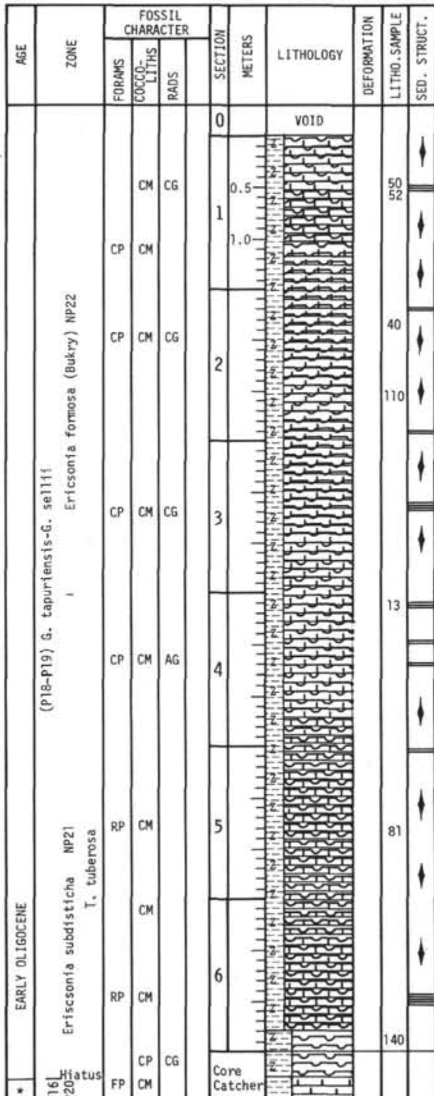
SS 70 (Sec. 4), 145
15% Clay
10% Zeolite
15% Forams
55% Nannos
5% Diatoms
TR% Pyrite

SS 68, 70 (Sec. 6)
10% Clay
10% Zeolite
30% Forams
50% Nannos
TR% Pyrite

CO_3: Sec. 5, 5 cm = 68%

Explanatory Notes in Chapter 1

Site 354 Hole Core 12 Cored Interval: 605.5-615.0 m



*LATE EOCENE

LITHOLOGIC DESCRIPTION

ZEOLITIC MARLY DIATOMACEOUS NANNO CHALK, light greenish gray (5G 8/1), moderate mottling; burrows filled with light olive-gray material (5Y 6/1).

Sec 3, 63-66, darker zone of light bluish-gray (5B 7/1), with lighter laminae.

Sec. 6, 130-150, appears more indurated, greenish gray (5G 6/1).

Zones of dark laminations:
Sec. 1, 49-52, a dark gray (N3) layer with fine (~1 mm) white laminae.
Sec. 2, 20 and 140, dark gray zones, gradational contacts.
Sec. 4, 13-14, 49-50, 70-71, as above.

Zones of intense mottling:
Sec. 2, 55-64, a greenish gray zone (5G 6/1).
Sec. 3, 71-79, as above.
Sec. 4, 71-84, as above.
Sec. 5, 78-89, as above.
Sec. 6, 41-51, as above.

SS 50, 52
15-10% Clay
15% Zeolite
30% Nannos
30% Diatoms
5% Rads
5% Sponge spicules

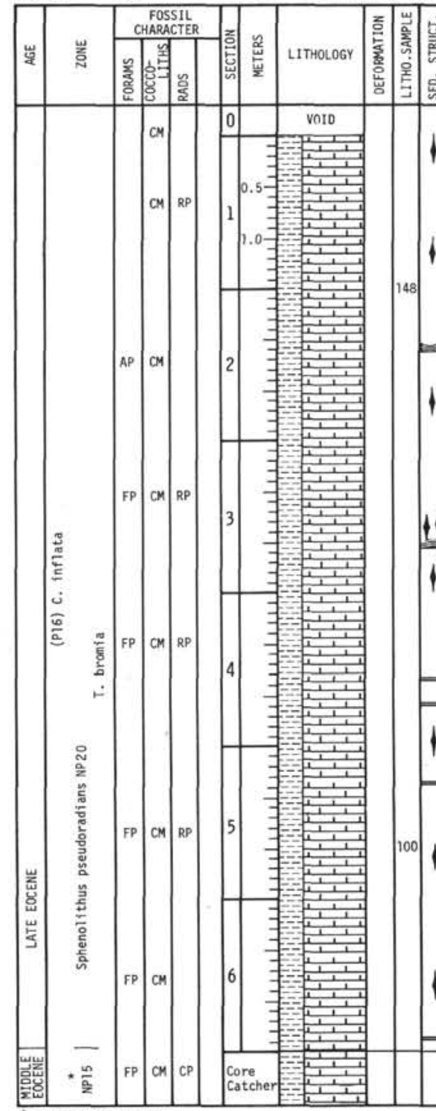
SS 40
10% Clay
10% Zeolite
5% Forams
40% Nannos
30% Diatoms
5% Sponge spicules

SS 13, 110
20% Clay
TR- 5% Pyrite
10-15% Zeolite
30% Nannos
30% Diatoms
5% Sponge spicules

SS 81, 140
15% Clay
10% Zeolite
35-50% Nannos
20-40% Diatoms

CO_3: Sec. 4, 11 cm = 55%

Site 354 Hole Core 13 Cored Interval: 691.0-700.5 m



*Nannotetrina fulgens
Explanatory Notes in Chapter 1

LITHOLOGIC DESCRIPTION

MARLY NANNO CHALK, pale blue-green (5BG 7/2), moderate mottling throughout, some burrows filled with a light olive gray (5Y 5/2).

SS 148
30% Clay
10% Forams
55% Nannos
5% Diatoms
TR% Pyrite

Sec. 3, 87-98, slightly more intensely mottled.

SS 100
25% Clay
5% Forams
50% Nannos
15% CO_3 Frags.
5% Sponge spicules
TR% Pyrite

Sec. 6, 33-37, 105-107, zones of grayish olive-green (5GY 3/2).

CO_3: Sec. 6, 125 cm = 67%

Site 354 Hole Core 14 Cored Interval: 700.5-738.5 m

AGE	ZONE	FORAMS	COCCO-LITHS	RADS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	SED. STRUCT.
MIDDLE EOCENE	(P9-P10) A. densa-H. aragonensis; Nannotetrina fulgens NP15				0		VOID			
		FP	CM		1	0.5, 1.0				
		FP	CM	RP	2				100	
		CP	CM	RP	3					
		FP	CM		4				27	
		RP	CP		5					
		RP	CP		6					
		FP	CP	RP	Core Catcher					

LITHOLOGIC DESCRIPTION

MARLY-NANNO CHALK, pale blue-green (5BG 7/2), moderate mottling throughout.
Sec. 1, 83-87, light gray (N6) zone.

SS 100
30% Clay
5% Forams
20% Nannos
TR% Diatoms
45% CO_3 Frags.
TR% Pyrite

Sec. 4, 27 cm, indistinct softer zone.
SS 27
20% Clay
20% Forams
30% Nannos
25% CO_3 Frags.
5% Diatoms

CO_3: Sec. 1, 106 cm = 71%

Site 354 Hole Core 15 Cored Interval: 814.5-824.0 m

AGE	ZONE	FORAMS	COCCO-LITHS	RADS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE
LATE PALEOCENE	(P5-P6) G. velascoensis-G. subbotinae; ?Discoaster multiradiatus; NP 9				0				
		RP	CM		1	0.5, 1.0	VOID		140
		FP	CM, CM		2				34
		AP	CM		3				40
		CM	CM	—	Core Catcher				

LITHOLOGIC DESCRIPTION

MARLY NANNO CHALK, very light gray (N7), moderate mottling.
SS 140
25% Clay
10% Forams
35% Nannos
25% CO_3 Frags.
5% Diatoms
TR% Dolo rhombs

Sec. 2, 33-35, zone of pale red (5R 6/2).
SS 34
5% Silt (Quartz)
20% Clay
15% Forams
30% Nannos
5% Diatoms
20% CO_3 Frags.
5% Dolo rhombs

Sec. 3, 19 and 27 cm, zones of light brownish gray (5YR 6/1), ~1 cm thick.
SS 40
20% Clay
5% Forams
30% Nannos
40% CO_3 Frags.
TR% Diatoms
5% Dolo rhombs

Sec. 3, 136-150, broken and distorted layers, light olive gray (5Y 6/1).
CO_3: Sec. 2, 45 cm = 64%

Explanatory Notes in Chapter 1

Site 354 Hole Core 16 Cored Interval: 833.5-843.0 m

AGE | ZONE | FOSSIL CHARACTER (FORAMS, COCCO-LITHS, RADS) | SECTION | METERS | LITHOLOGY | DEFORMATION | LITHO.SAMPLE | SED. STRUCT. | LITHOLOGIC DESCRIPTION

AGE: LATE PALEOCENE

ZONE: (P5) G. velascoensis; Discoaster multiradiatus NP 9; NP8 △; NP7 ▲; NP6 ●; NP5 ○; Hiatus

Section	Forams	Cocco-liths	Rads
1	AP	CM	
2		CM	
3	AP	CM	
4	AP	CM	
5	AP	CM	
6	AP	AG AG CM CM CM CM CM CM AG	
6	AP	CM CM CM	
Core Catcher	CP	CM CM	—

Section 0; Section 1: 0.5, 1.0, VOID

Litho. sample: 100 (Sec. 2), 147 (Sec. 5), 122 (Sec. 6), CC (Core Catcher)

MARLY NANNO CHALK grading to MARLY FORAM-NANNO CHALK, medium light gray (N6) to light gray (N7), moderate mottling throughout.

SS 100
15% Clays
15% Forams
5% CO_3 Frags.
65% Nannos
TR% Dolo rhombs

Sec. 6, 69-84, 101-102, 109-129, greenish gray (5G 6/1).

SS 122, 147	SS CC
25% Clay	25% Clay
10% Forams	25% Forams
55% Nannos	25% Nannos
5% Dolo rhombs	5% Diatoms
5% CO_3 Frags.	20% CO_3 Frags.
	TR% Dolo. rhombs
	TR% Fe Oxides

*Bottom of CC probably from deeper than actual core.

●LATE MAESTRICHTIAN
●Nephrolithus frequens
○Fasciculithus tympaniformis
●Heliolithus kleinpelli
▲Discoaster mohleri
△Discoaster nobilis

Site 354 Hole Core 17 Cored Interval: 852.5-862.0 m

AGE | ZONE | FOSSIL CHARACTER (FORAMS, COCCO-LITHS, RADS) | SECTION | METERS | LITHOLOGY | DEFORMATION | LITHO.SAMPLE | SED. STRUCT. | LITHOLOGIC DESCRIPTION

AGE: E. PAL.; MAESTRICHTIAN

ZONE: P1 NP4; Arkhangelskiella cymbiformis | Lithraphidites quadratus

Section	Forams	Cocco-liths	Rads
1	RP	CM	
1–2			—
2	CP	CM	
3		CM	
Core Catcher		CM	—

Section 0; Section 1: 0.5, 1.0, VOID

Litho. sample: 120 (Sec. 1), CC (Core Catcher)

FERRUGENOUS MARLY NANNO CHALK grading to CALCAREOUS FERRUGENOUS MARL, pale red (5R 6/2), slight mottling.

SS 120
30% Clay
5% Fe Oxides
20% Forams
20% Nannos
20% CO_3 - Debris
TR% Diatom debris
5% Dolo rhombs

CO_3: Sec. 2, 117 cm = 54%

Sec. 3, moderate mottling.

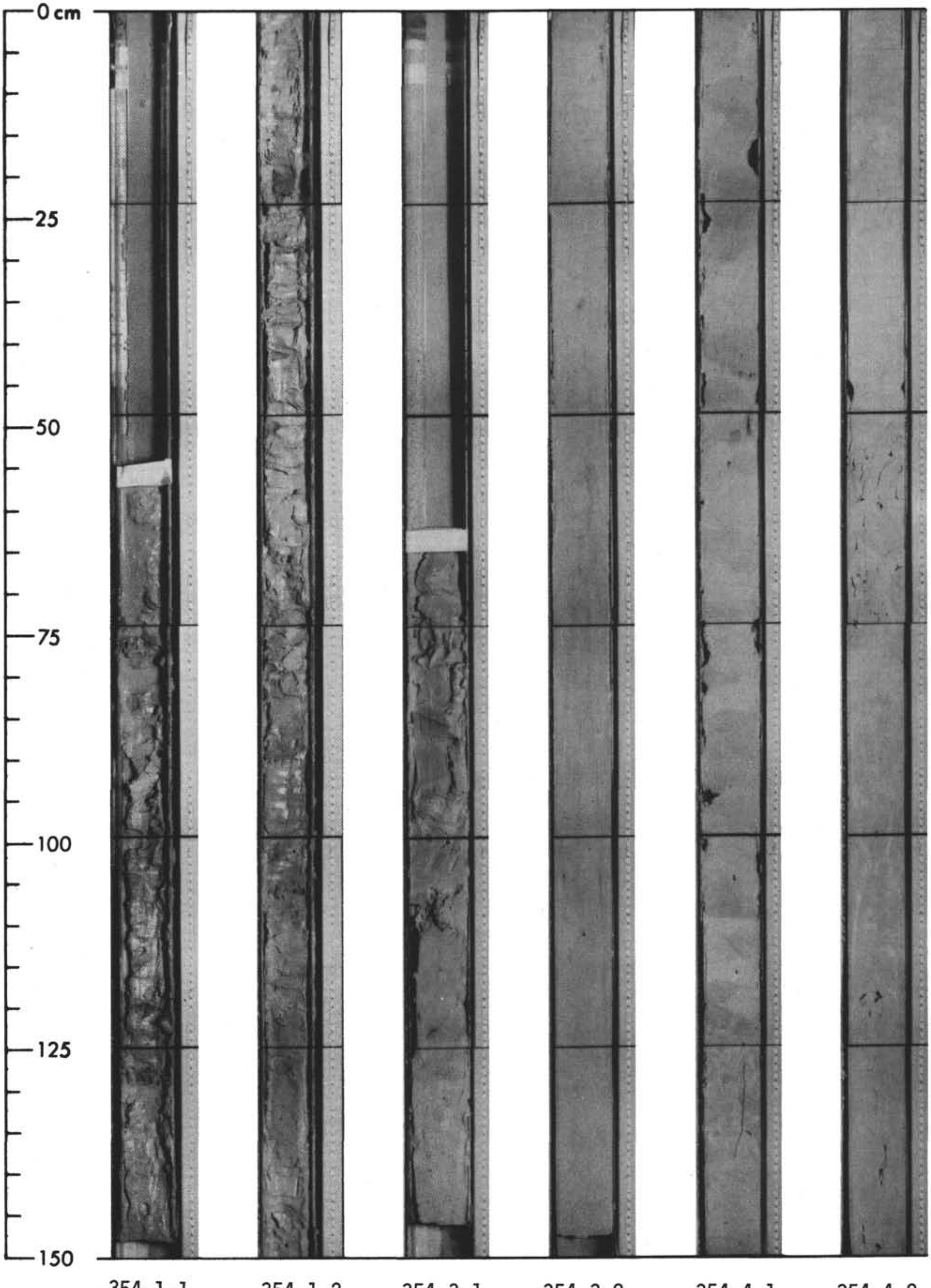
SS CC
30% Clay
10% Fe Oxides
25% CO_3 - Debris
5% Forams
30% Nannos
TR% Diatom debris
TR% Dolo rhombs

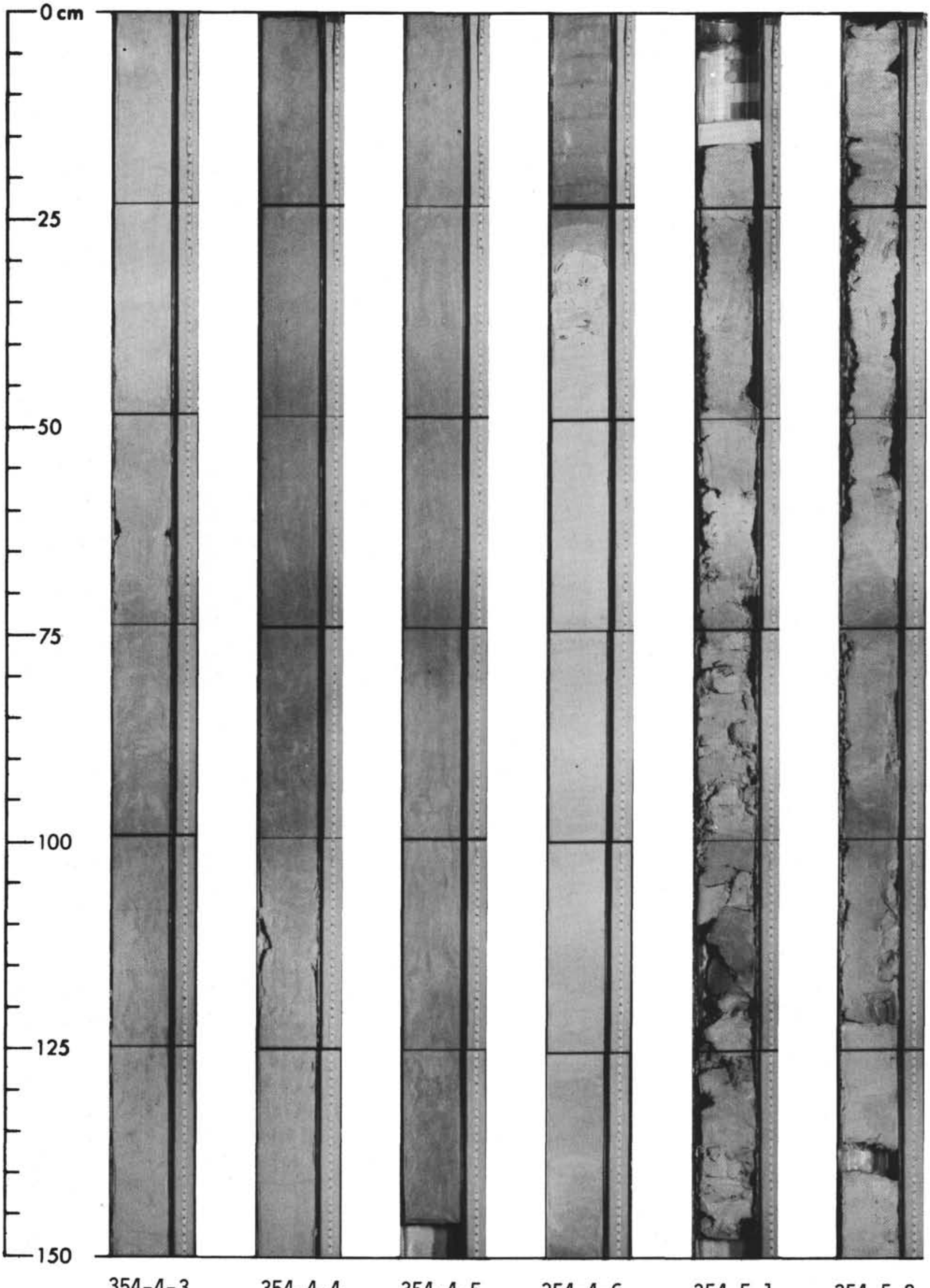
Explanatory Notes in Chapter 1

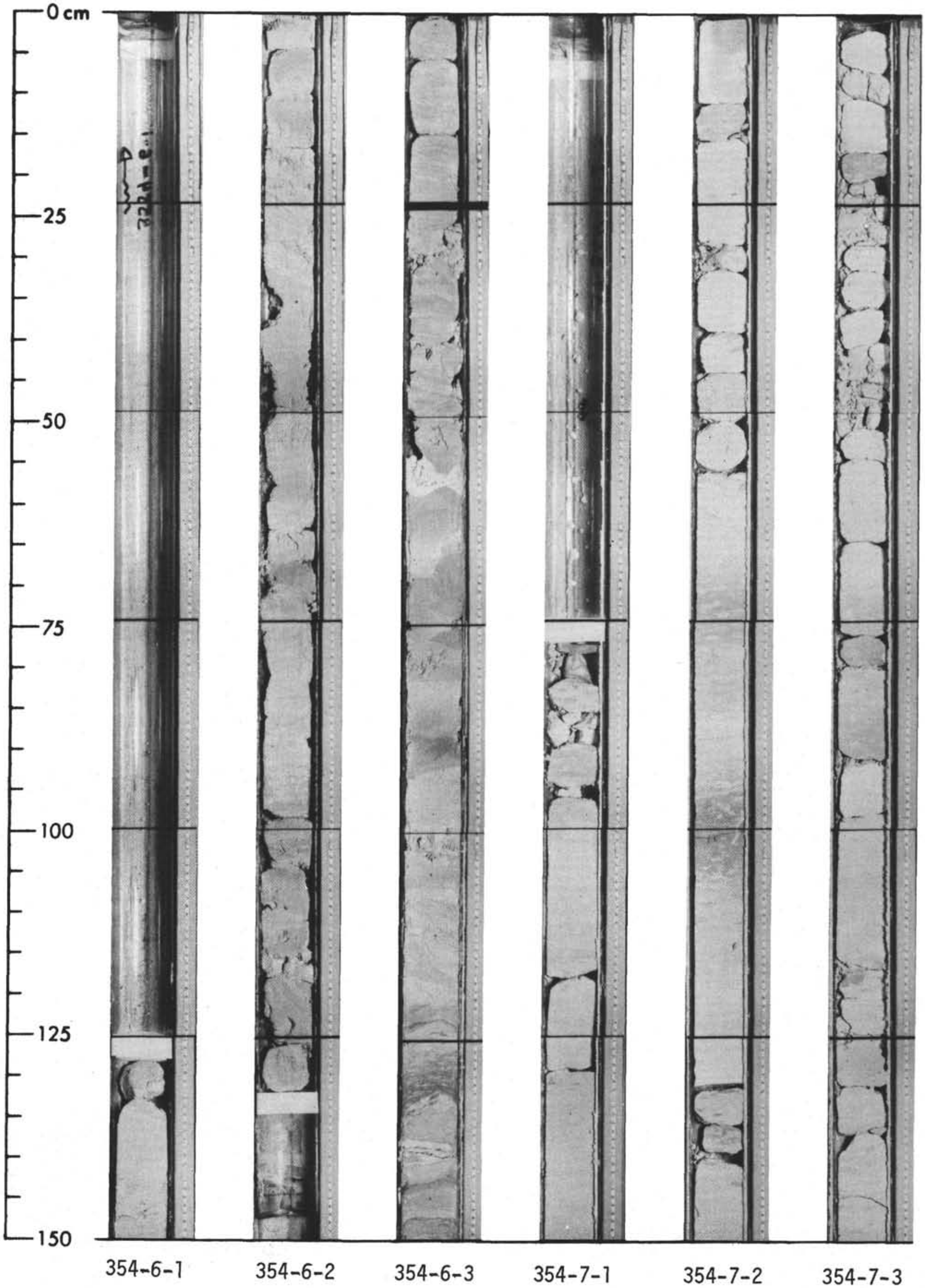
Site 354 Hole Core 18 Cored Interval: 871.5-881.0 m

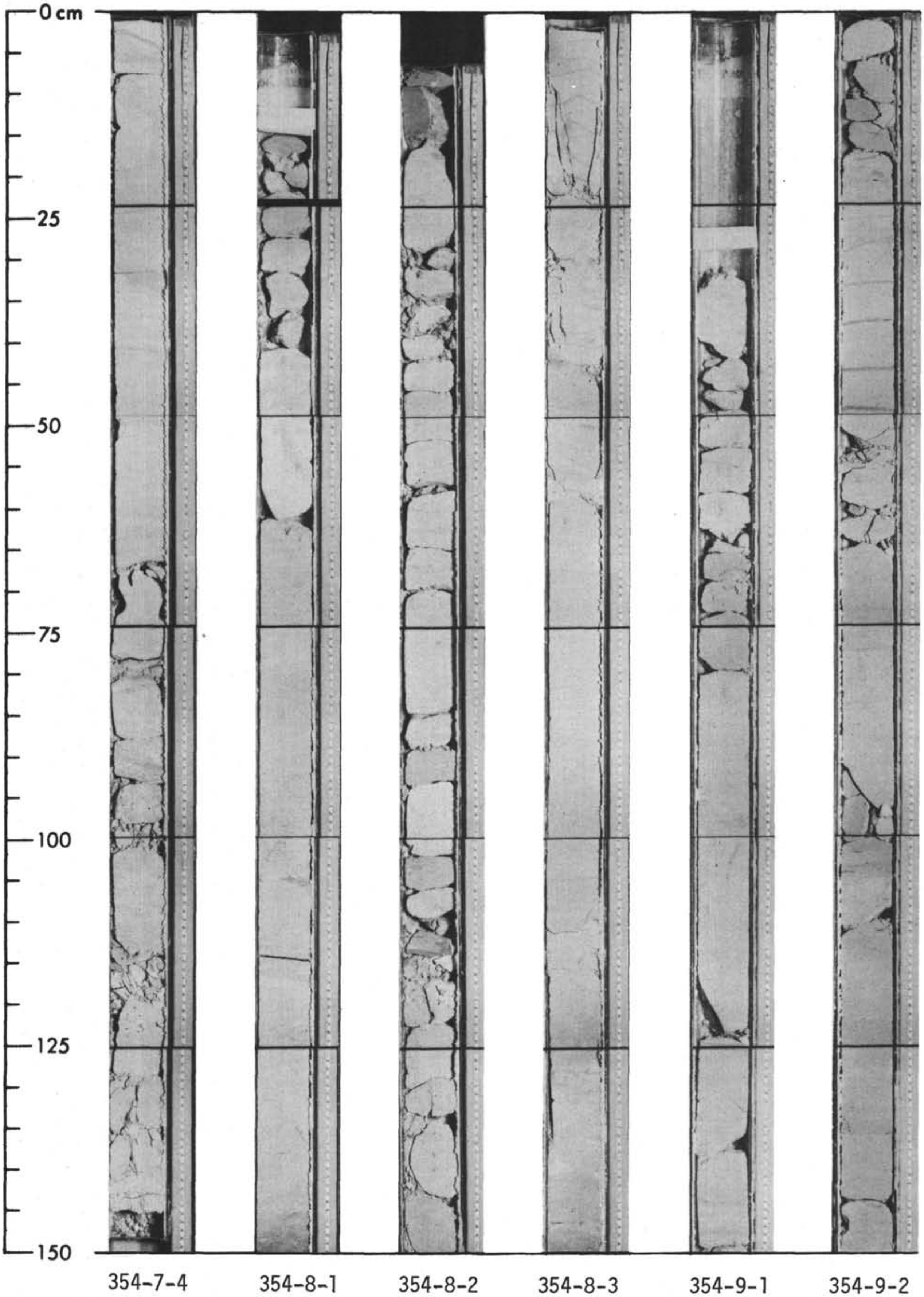
AGE	ZONE	FOSSIL CHARACTER: FORAMS	FOSSIL CHARACTER: COCCOLITHS	FOSSIL CHARACTER: RADS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	SED. STRUCT.	LITHOLOGIC DESCRIPTION
EARLY MAESTRICHTIAN	*Arkhangelskiella cymbiformis*				0		VOID				
			CP		1	0.5, 1.0			70		MARLY CALCAREOUS CHALK, pale red (5R 6/2), moderate mottling, some burrows filled with black material. SS 70 35% Clay 10% Fe Oxides 25% Forams 10% Nannos 20% CO_3 - Debris
			CP		2						
			CP		3						
			CP		4				140		Grayish purple (5P 4/2), somewhat less mottling. Dark material in burrows. SS 140 35% Clay 10% Fe Oxides 20% CO_3 - Debris 20% Forams 15% Nannos
			CP		5						Color becoming lighter to pale red (5R 6/2) near base 40-60, 80-105, somewhat more burrowing. CO_3: Sec. 1, 130 cm = 53% Sec. 4, 128 cm = 37%
			AM		6						
		RP	FP		Core Catcher				CC		

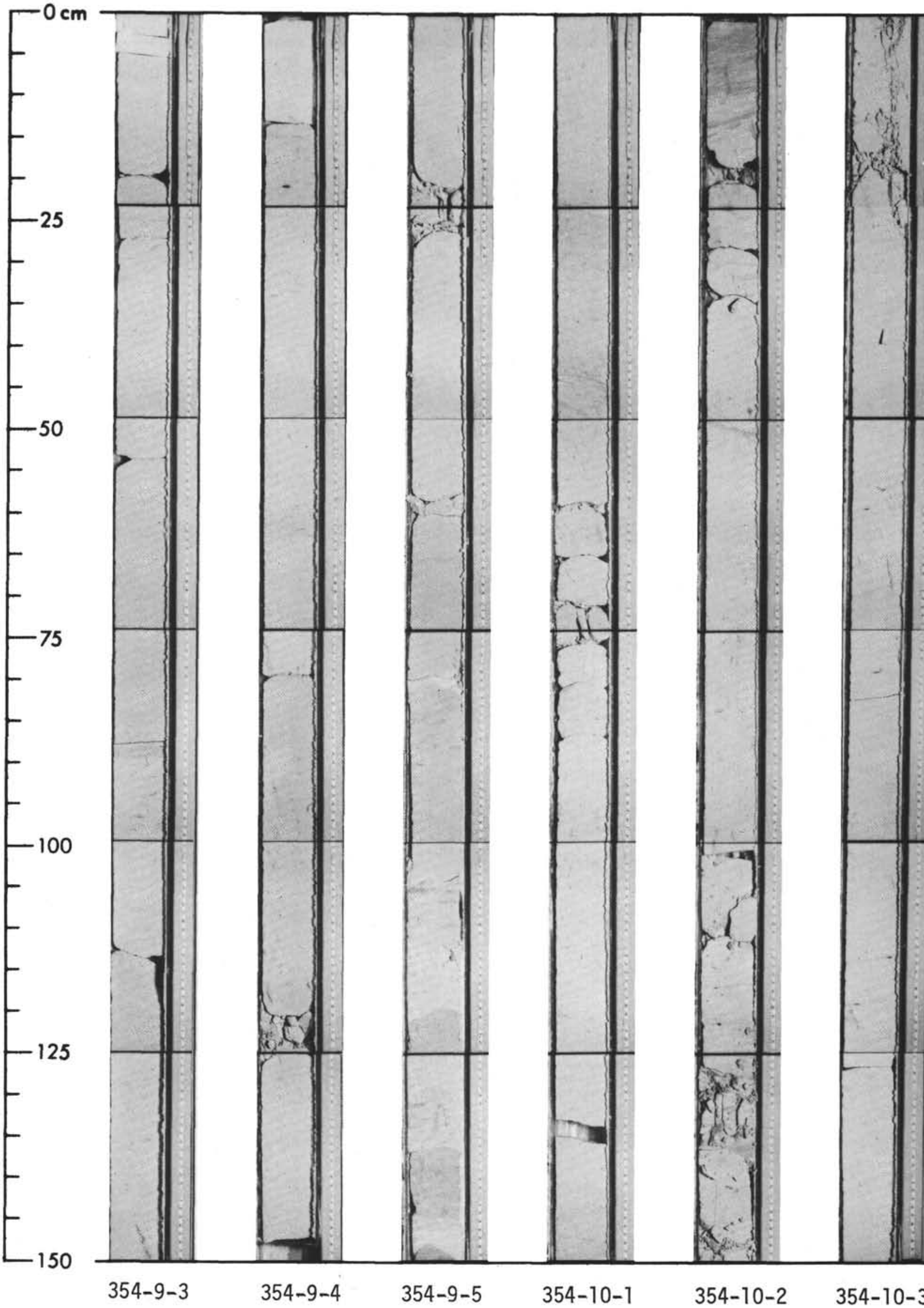
Explanatory Notes in Chapter 1

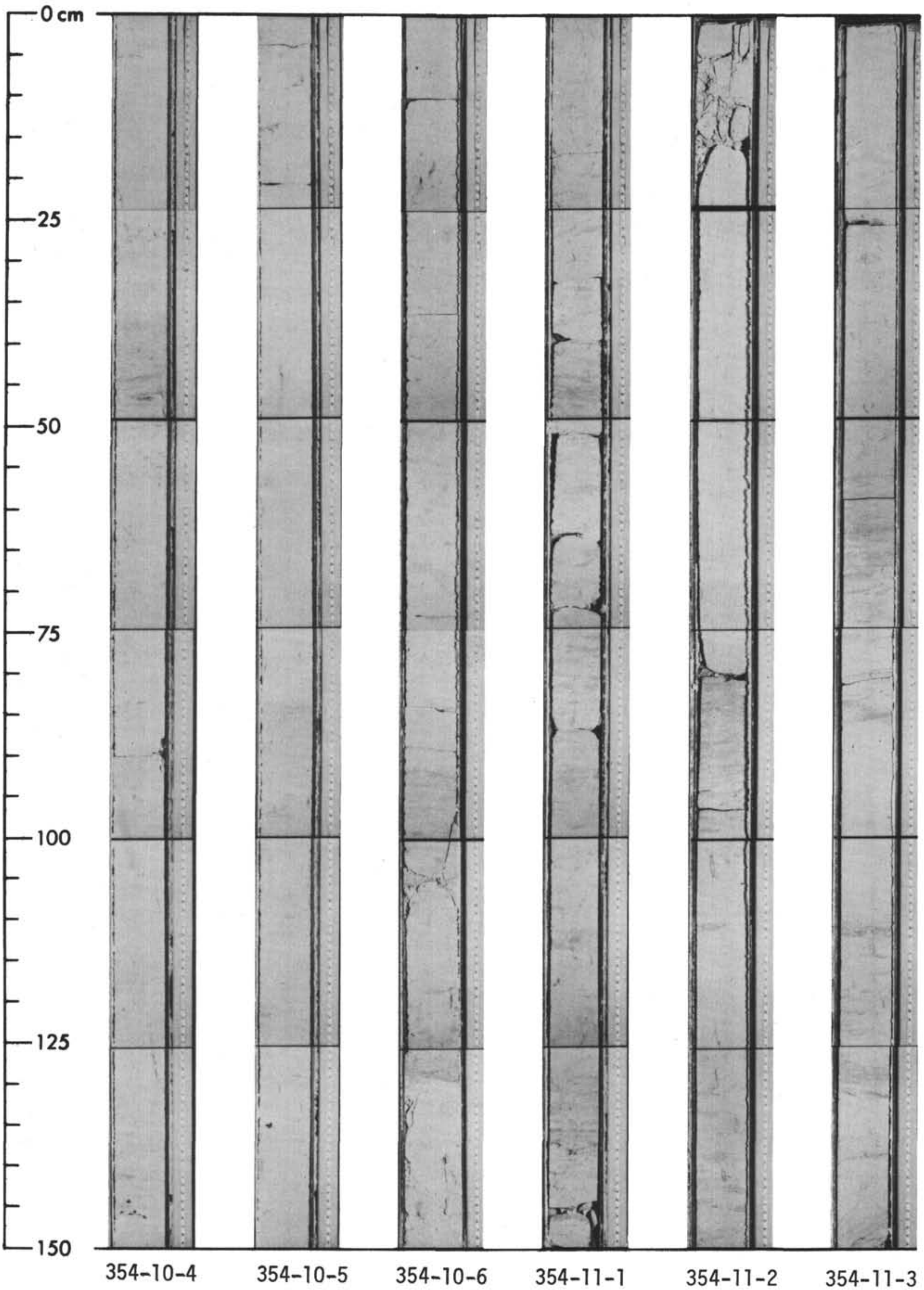

0 cm
25
50
75
100
125
150
354-1-1
354-1-2
354-3-1
354-3-2
354-4-1
354-4-2

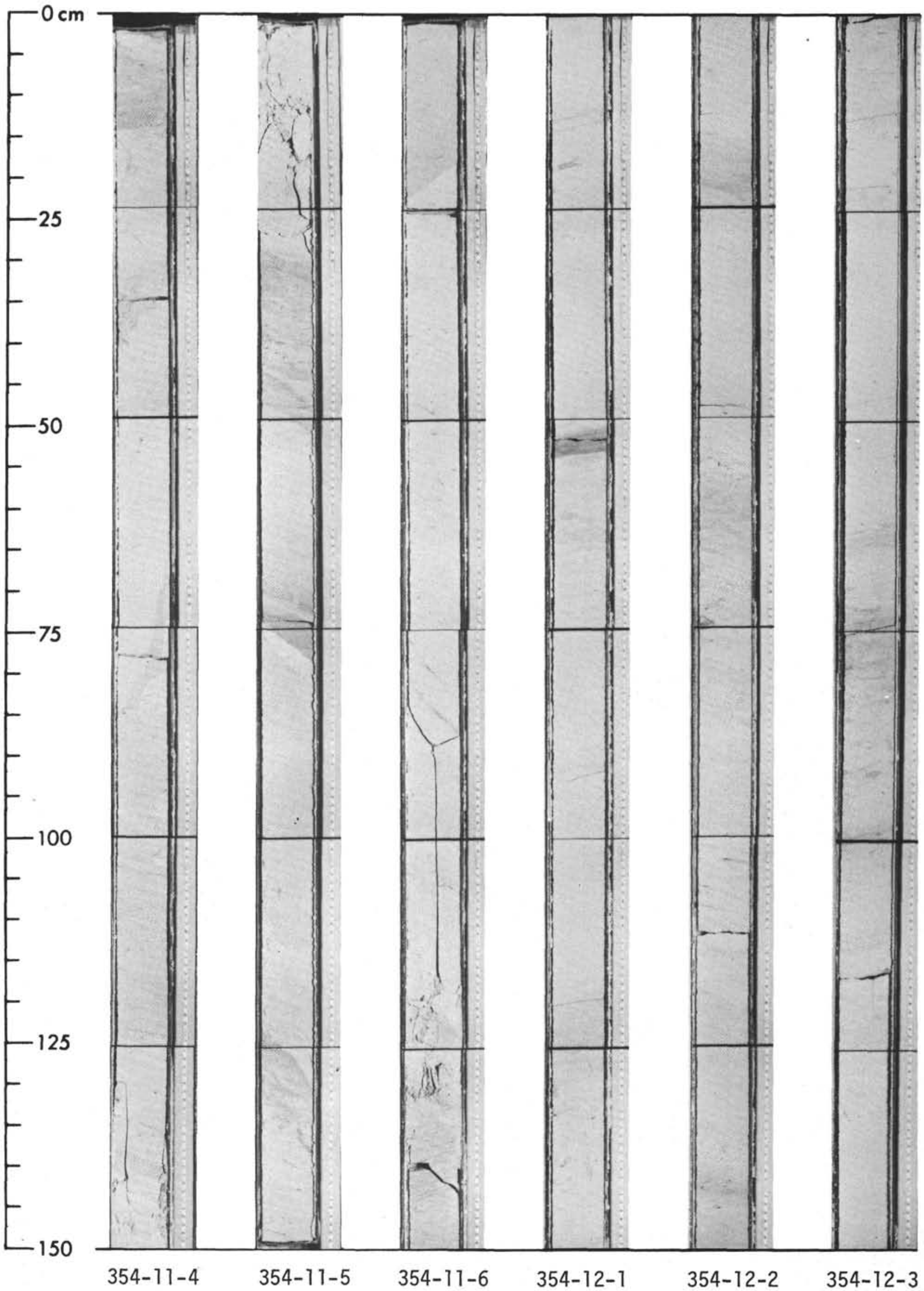

0 cm
25
50
75
100
125
150
354-4-3
354-4-4
354-4-5
354-4-6
354-5-1
354-5-2

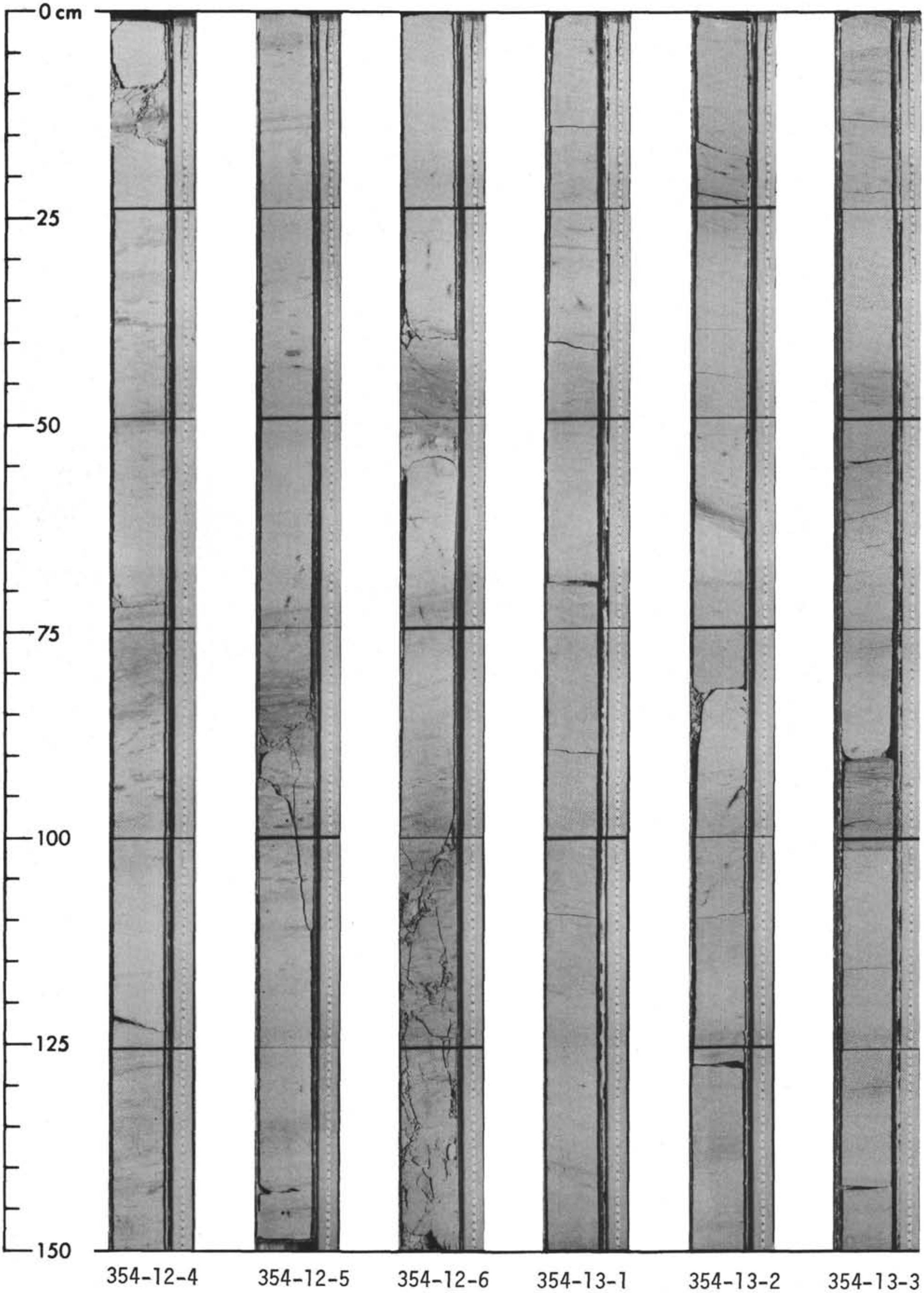

0 cm
25
50
75
100
125
150
354-6-1
354-6-2
354-6-3
354-7-1
354-7-2
354-7-3

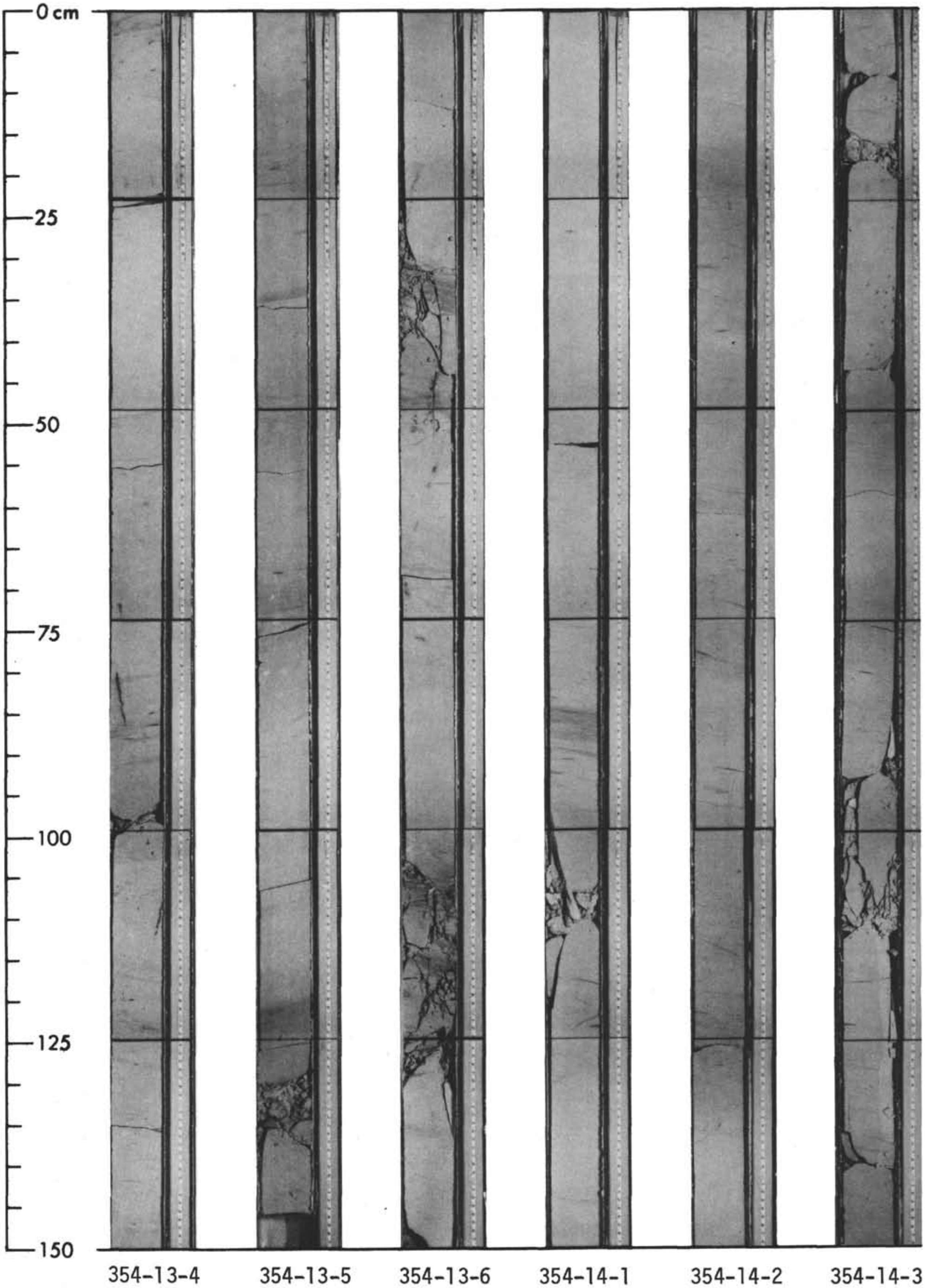

0 cm
25
50
75
100
125
150
354-7-4
354-8-1
354-8-2
354-8-3
354-9-1
354-9-2

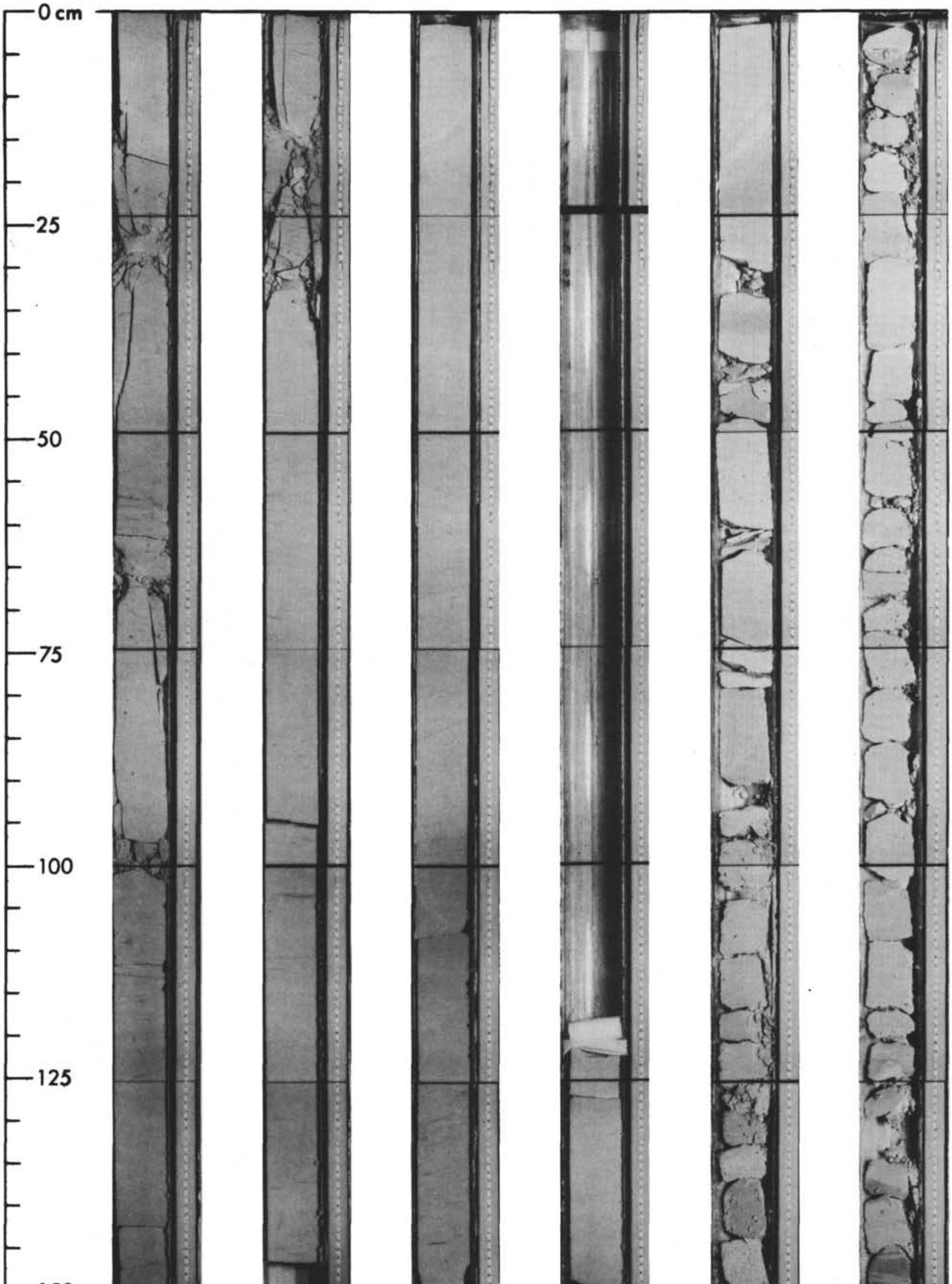

0 cm
25
50
75
100
125
150
354-9-3
354-9-4
354-9-5
354-10-1
354-10-2
354-10-3


0 cm
25
50
75
100
125
150
354-10-4
354-10-5
354-10-6
354-11-1
354-11-2
354-11-3

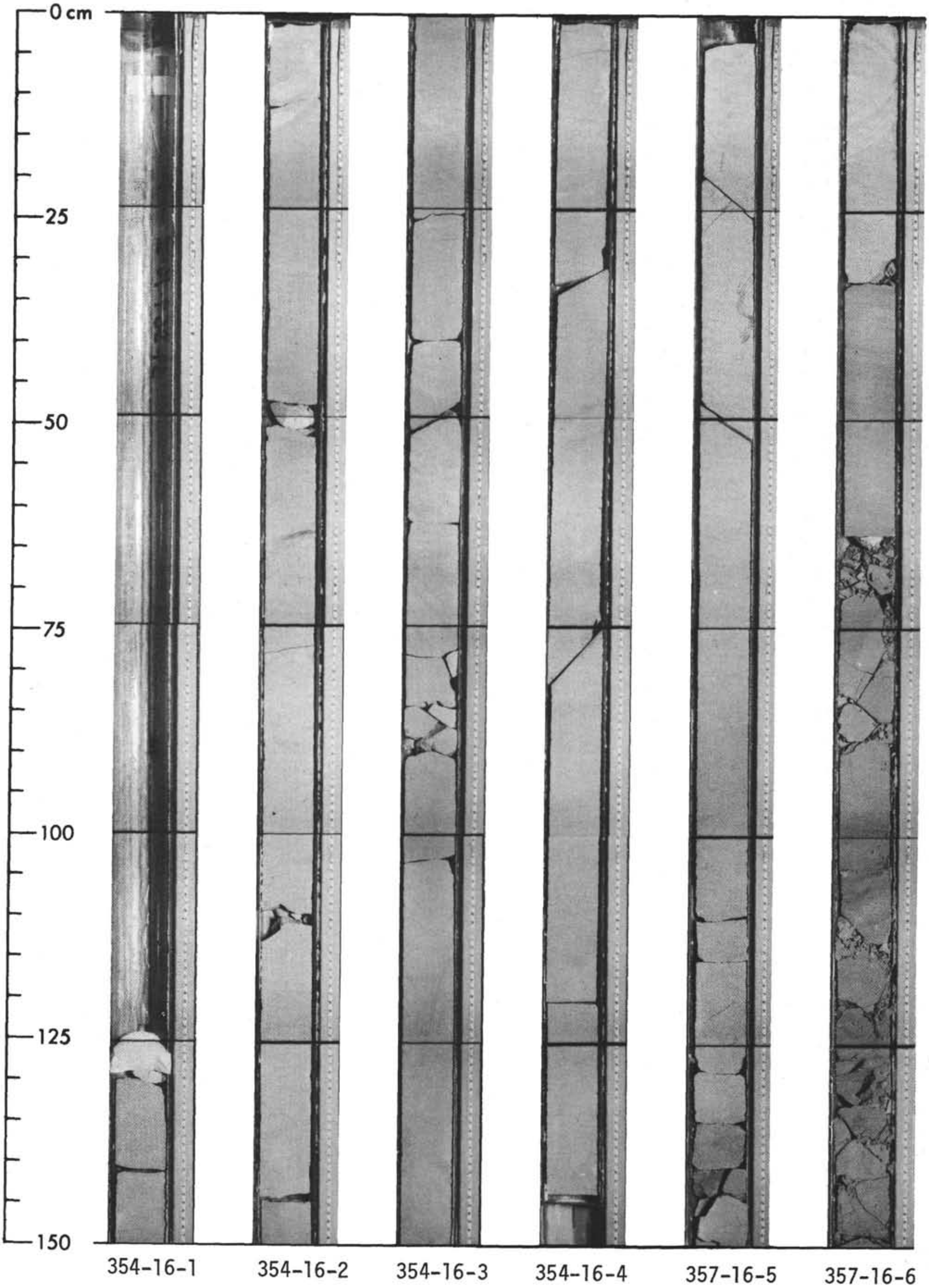

0 cm
25
50
75
100
125
150
354-11-4
354-11-5
354-11-6
354-12-1
354-12-2
354-12-3

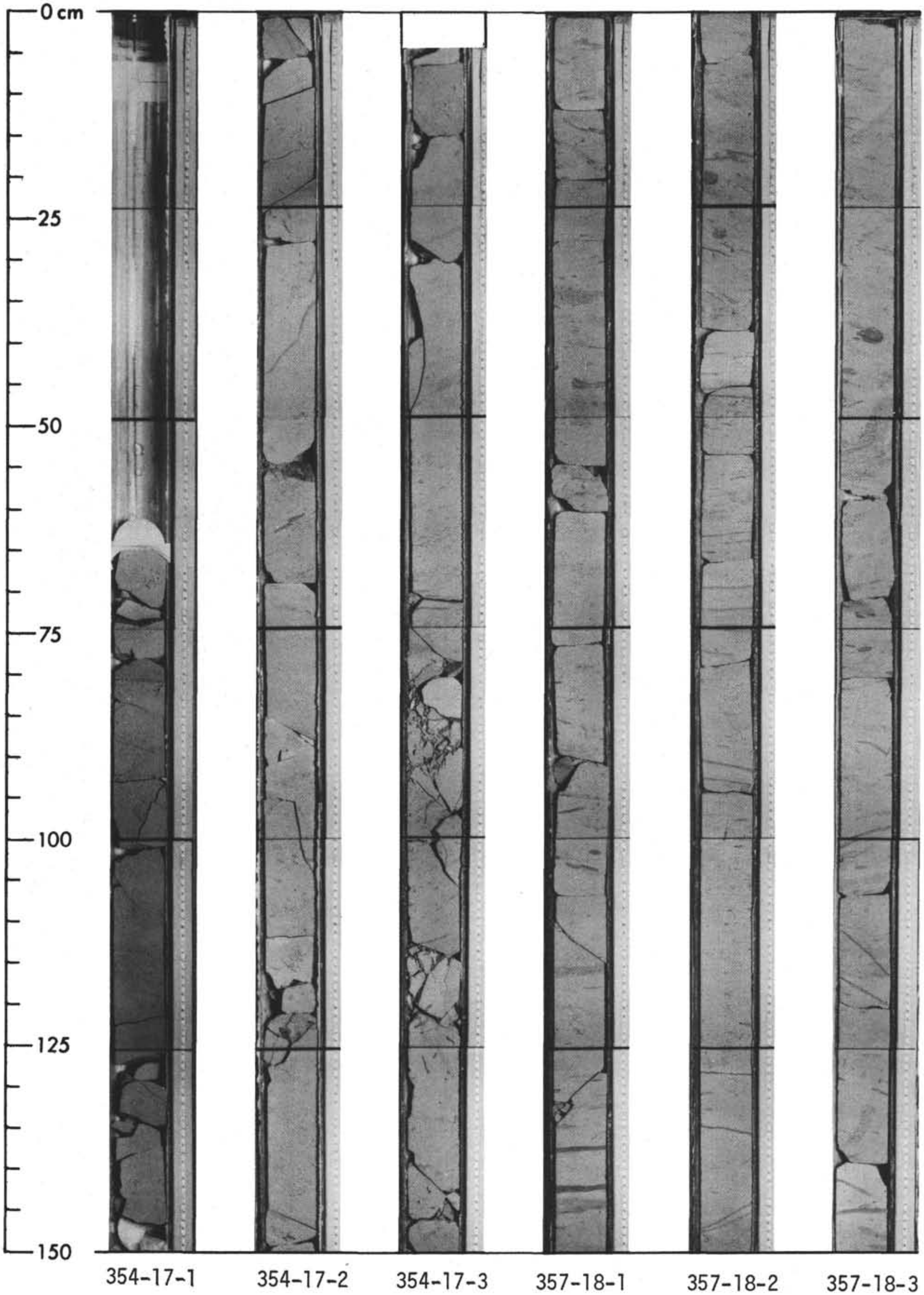

0 cm
25
50
75
100
125
150
354-12-4
354-12-5
354-12-6
354-13-1
354-13-2
354-13-3

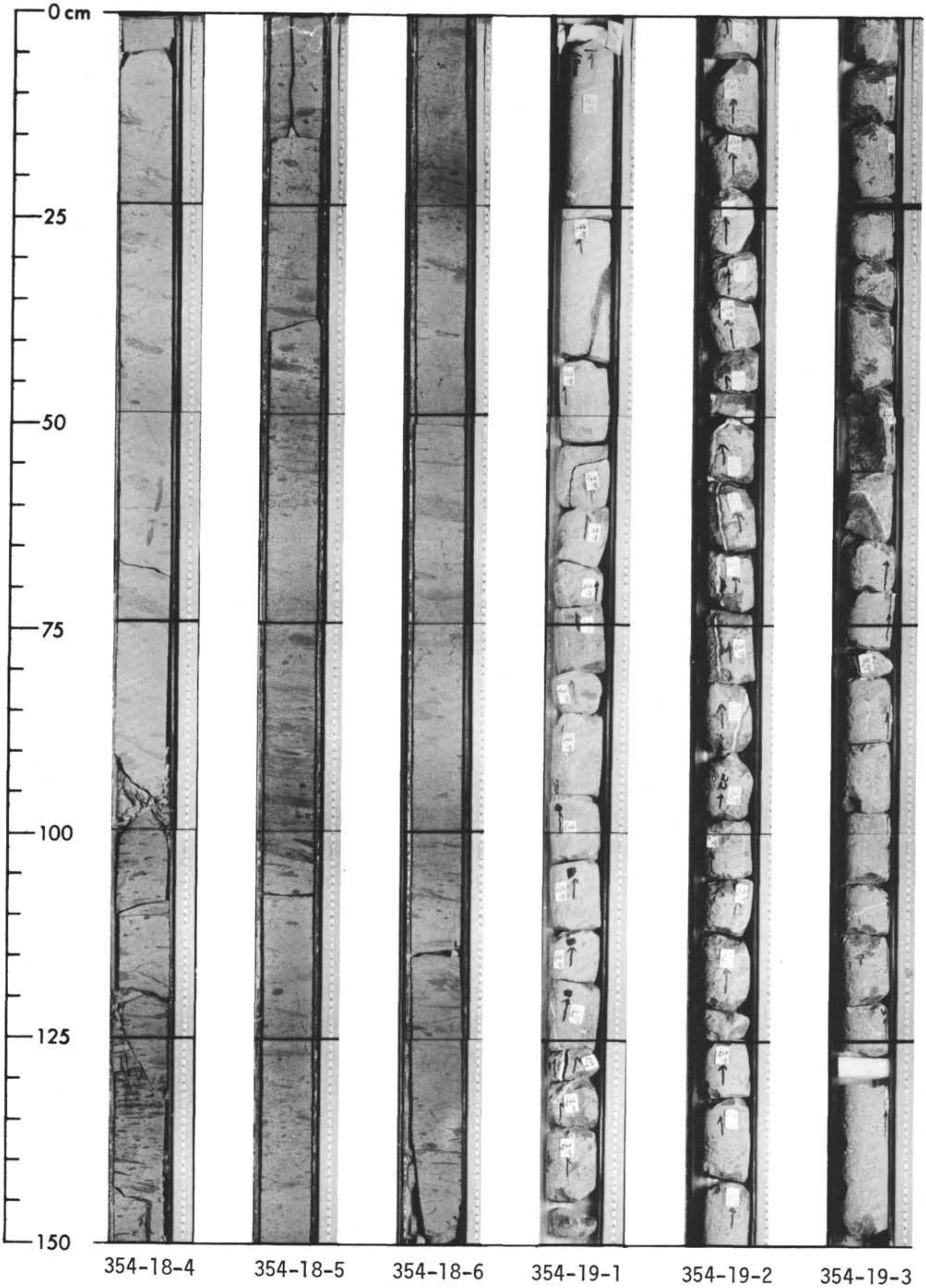

0 cm
25
50
75
100
125
150
354-13-4
354-13-5
354-13-6
354-14-1
354-14-2
354-14-3

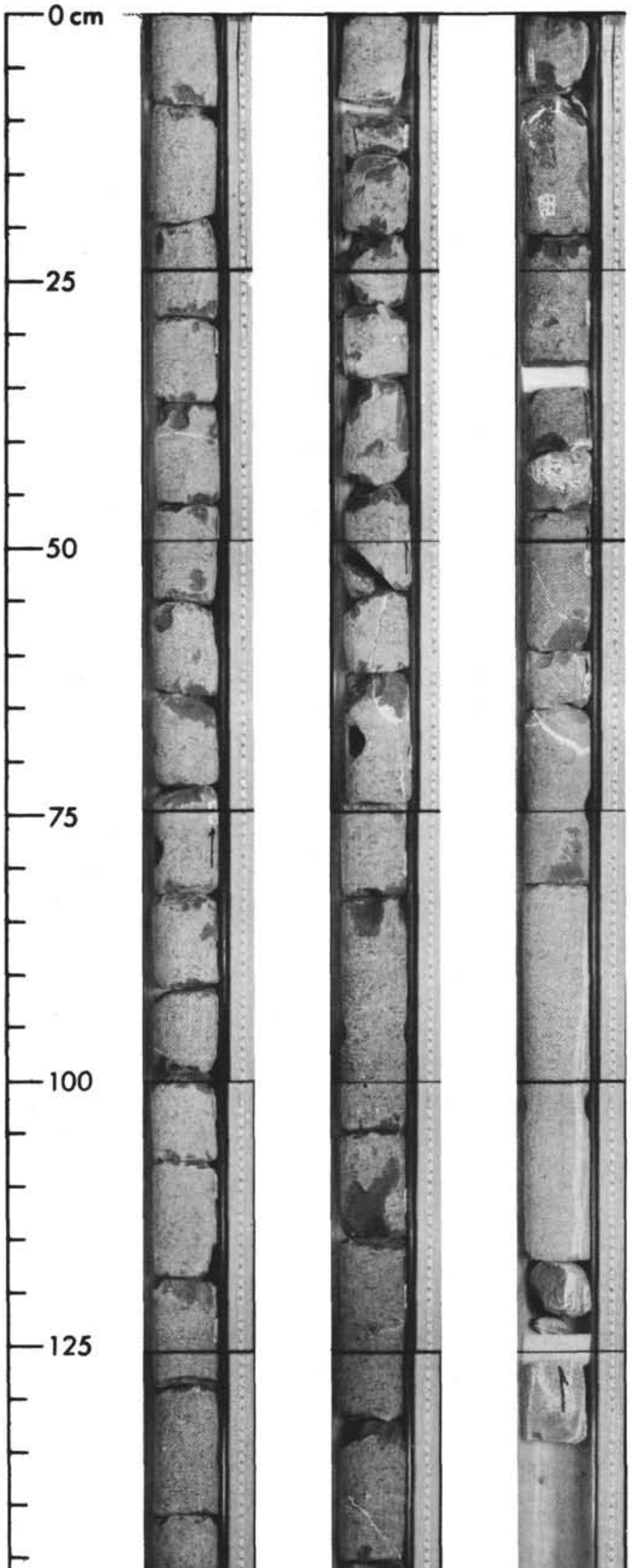


354-14-4 354-14-5 354-14-6 354-15-1 354-15-2 354-15-3


0 cm
25
50
75
100
125
150
354-16-1
354-16-2
354-16-3
354-16-4
357-16-5
357-16-6


0 cm
25
50
75
100
125
150
354-17-1
354-17-2
354-17-3
357-18-1
357-18-2
357-18-3


0 cm
25
50
75
100
125
150
354-18-4
354-18-5
354-18-6
354-19-1
354-19-2
354-19-3


0 cm
25
50
75
100
125
150
354-19-4
354-19-5
354-19-6