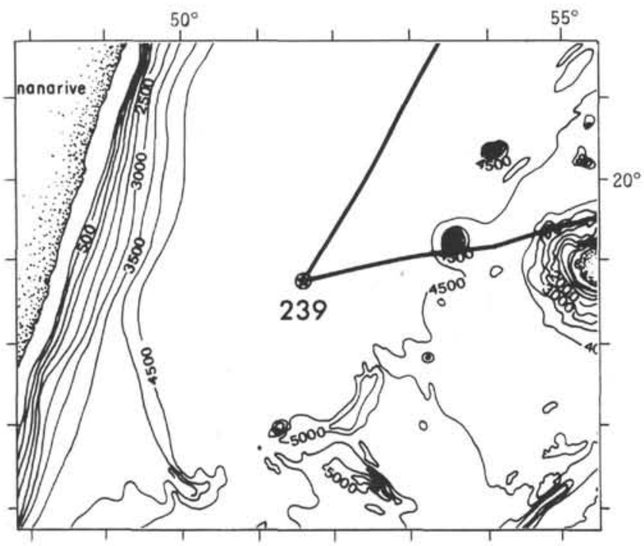
2. SITE 239

The Shipboard Scientific Party[1]

SITE DATA



Location: Southern Mascarene Basin

Position: 21°17.67′S, 51°40.73′E

Water Depth: 4971 meters

Total Penetration: 326 meters

Cores: 21 cores (175 m cut, 106.1 m recovered)

Deepest Unit Recovered: Basalt

BACKGROUND AND OBJECTIVES

Site 239 is located in the deep abyssal plain of the Mascarene Basin, which is bordered on the west by the steep, linear, and presumably faulted eastern margin of the Madagascar Precambrian massif and on the east by the Mascarene Islands and the Mascarene Plateau. In addition to possible lateral drift, Madagascar has been subjected to considerable intermittent epeirogenic uplift since the Cretaceous or Jurassic (Dixey, 1959), and the chronologic history of these movements should be reflected in the sedimentary fill of the Mascarene Basin. Interbedded volcanics, if present, might also provide evidence of the volcanic history of the nearby Mascarene Islands. Site 239, moreover, provides an opportunity to recover a mid-latitude sequence of fossil assemblages, at least for the Cenozoic.

Available magnetic data were insufficient at the time of the cruise to derive the age of the Mascarene Basin and its possible relationship to the spreading pattern of the Central Indian Ridge. However, in the Madagascar Basin south of Réunion, Schlich et al. (1972) have identified a series of spreading anomalies, each progressively displaced en echelon by several northeast-southwest transform faults (Figure 1). Extrapolation of this pattern suggests that anomalies beyond 25 should be located in the southern Mascarene Basin, indicating a Paleocene or Late Cretaceous age. Penetration to basement at Site 239 is thus essential to provide a baseline for interpretation of future magnetic data.

Site 239 was provisionally located in the southern Mascarene Basin, north of the Mahanoro Ridge (which corresponds to a fracture zone) in position 21°16′S, 51°41′E, from seismic reflection data obtained by *Vema* in 1962. Traverses over this site by *Robert D. Conrad* in 1971, using an airgun, and by *Gallieni* in 1972, using flexotir, produced seismic reflection data of superior quality.

The *Conrad* seismic reflection profile (Figure 2) shows that the Mascarene Abyssal Plain near the provisional location of Site 239 is 5000 meters deep and is underlain by strongly stratified sediments (with some identifiable transparent layers) which in places extend down to basement, but more often rest upon a transparent or weakly stratified layer of extremely uneven thickness resting upon basement; the latter is characterized by small-scale roughness and occasional apparent faulting. The upper surface of the transparent layer is very uneven, in a general way tending to follow basement topography. It forms positive relief features where it outcrops on the otherwise even floor of the abyssal plain. Variation in thickness of the upper stratified layer is 0-0.7 sec and of the lower transparent sediments, 0-0.5 sec. The total sediment thickness does not exceed 0.7 sec DT (double way time). These features are well illustrated in Figure 2. The *Gallieni* flexotir record (of much less vertical exaggeration) in the same area (Figure 3) shows the same variation in total sediment thickness, but fails to differentiate the stratified and transparent layers due to lack of frequency response to the small vertical separation of reflectors in the stratified layer.

The upper stratified layer presumably comprises ponded turbidites derived in large part from Madagascar. The transparent layer is presumed to be pelagic sediment draped over basement relief. The peculiar structural and stratigraphic configuration of this layer and its ability to form

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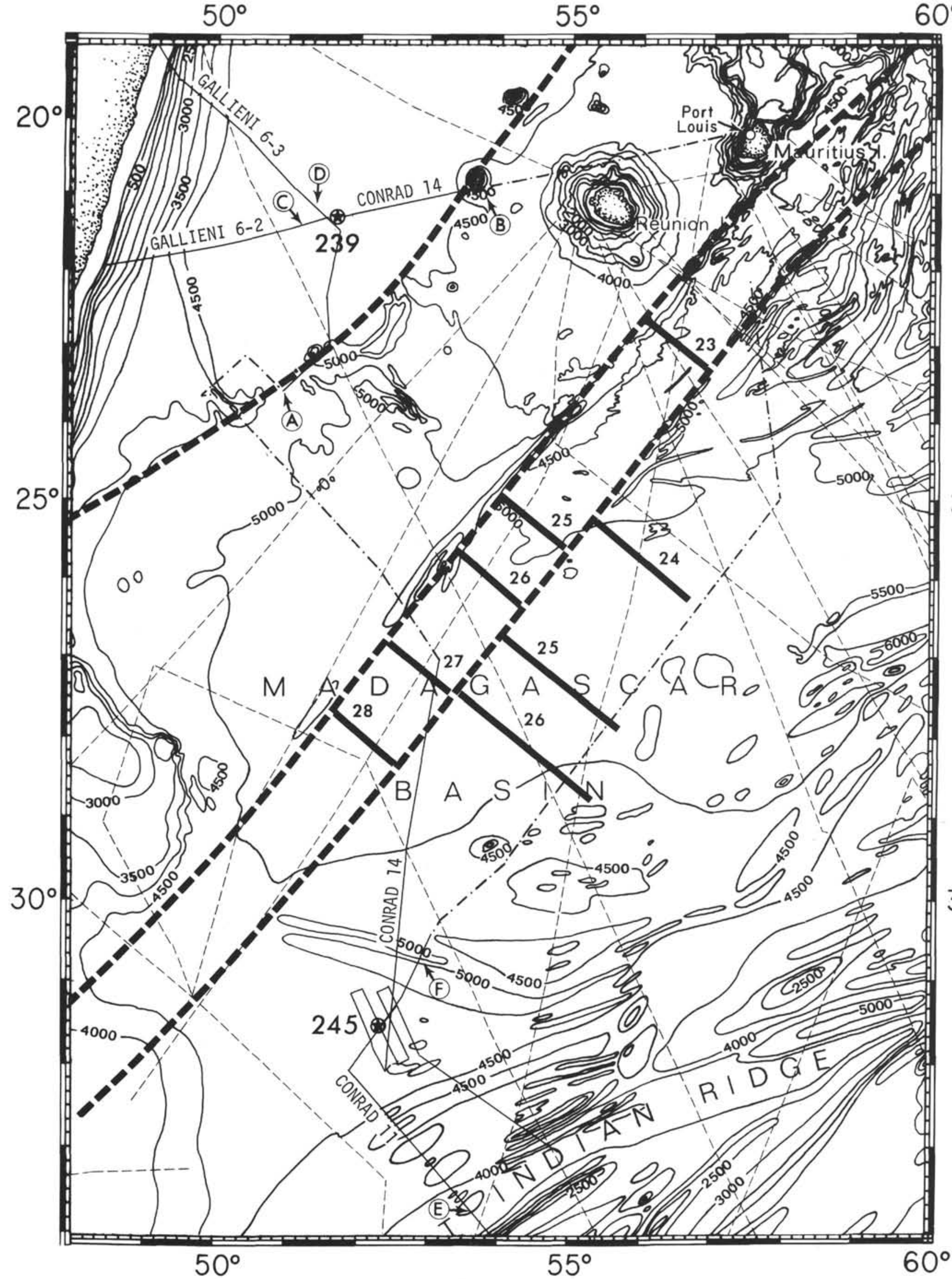

Figure 1. *Location map for Site 239. Isobaths in meters. The letters shown refer to the seismic reflection profiles given in Figures 2 and 3. Magnetic lineations in the Madagascar Basin are from Schlich et al. (1972).*

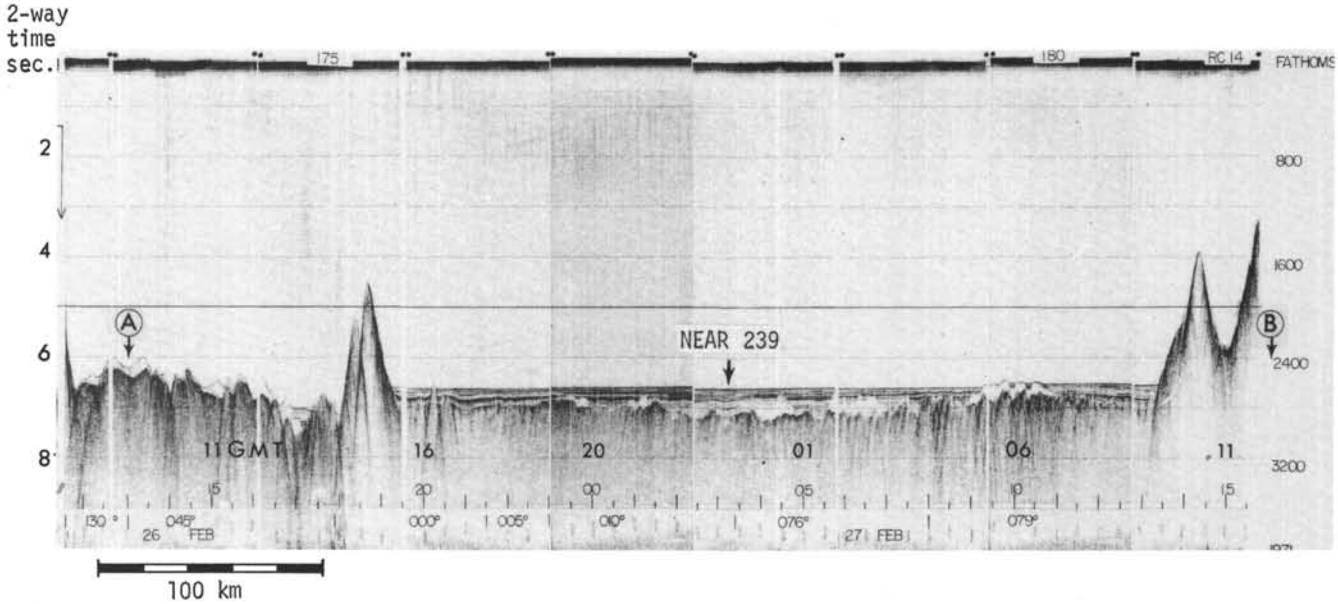

Figure 2. Conrad *14 seismic reflection profile in the vicinity of Site 239. The location of this profile is given in Figure 1 (solid lines).* Conrad *14 record is from unpublished Lamont-Doherty Geological Observatory data.*

positive relief features on the abyssal plain provide added incentive for drilling in order to determine the nature of this layer.

SURVEY DATA AND OPERATIONS

Glomar Challenger departed Port Louis (Mauritius) on Leg 25 on 28 June 1972, 2230 LT (local time) (1830 GMT). Site 239 was approached along a course of 258° on 30 June after 1.5 days steaming across the Mascarene Basin. At 0930 LT (0530 GMT), about 7 miles before reaching the proposed site, speed was reduced to about 6 knots in order to improve the clarity of the airgun records. The airgun records indicated the crossing of a very suitable site at 1040 LT (0640 GMT) and after 28 minutes steaming the course was reversed to 085°; at 1135 LT (0735 GMT) the 13.5-kHz beacon was dropped under way above the identified location (Figure 4) which was occupied immediately after retrieval of the outboard geophysical equipment.

The *Glomar Challenger* track passed very close to the site traversed by *Conrad* 14 in 1971 and *Gallieni* 6 in 1972, and it was clearly confirmed from these records (airgun and flexotir) that the basement could be reached at about 0.40 sec DT. The seismic reflection records show two well-stratified layers overlying a thick and very transparent section resting on basement (Figure 5).

The major site objective was to sample, date, and identify the basement and also to establish the stratigraphic sequence. A program of intermittent coring was planned: three cores at the top (0-27 m below the sea floor), three cores at the interface of the two well-stratified layers (66-93 m), five cores at the interface of the stratified and transparent sections (122-167 m), two cores in the middle of the transparent layer (206-222 m), and, finally, continuous coring from 300 meters to basement. Since the measured velocity of the sediments appeared to be rather lower than the predicted values, it was decided to start continuous coring from 263 meters below the sea floor. The basement was reached at 320 meters, and 2.3 meters of basalt were recovered.

At this site, drilling and coring started at 0430 (LT) on 1 July and ended at 0429 (LT) on 3 July. Twenty-one cores were taken; the total cored section was 175 meters and the total core recovered was 106.1 meters, representing 61 percent recovery. The total time spent on the site was about 76.5 hours (Table 1). Approximately 4 hours were spent in removing 58 joints of drill pipe of questionable condition. On Cores 17 and 19, downhole inclinometer measurements were made in the hole, and both measurements indicated that the hole was 5° off the vertical. The bearings of the four-cone bit were completely worn out, but the tungsten carbide inserts were in fair condition.

Glomar Challenger departed from Site 239 at 1600 LT (1200 GMT) on 3 July in a southerly direction at 5 knots while the airguns, hydrophones, and magnetometer were streamed. At a distance of about 1.5 miles from the beacon, the ship turned to take a northeasterly course (030°) so as to pass over the beacon (Figure 4). The beacon was passed at 1623 LT (1223 GMT) and at the same time a sonobuoy for wide-angle reflection was launched. After 20 minutes operation, the signal of the sonobuoy was lost and it was decided to proceed without trying a second sonobuoy since weather conditions were not good enough. At 1800 LT (1400 GMT) speed was increased to 10 knots, and the ship steamed to Site 240 via a point at 17°00′S and 54°20′E. The purpose of this slight deviation from the direct track was to attempt the recognition of the magnetic anomalies in the Mascarene Basin, especially since the data obtained from the drilling and coring at Site 239 had enabled us to propose a minimum age for the oceanic basement.

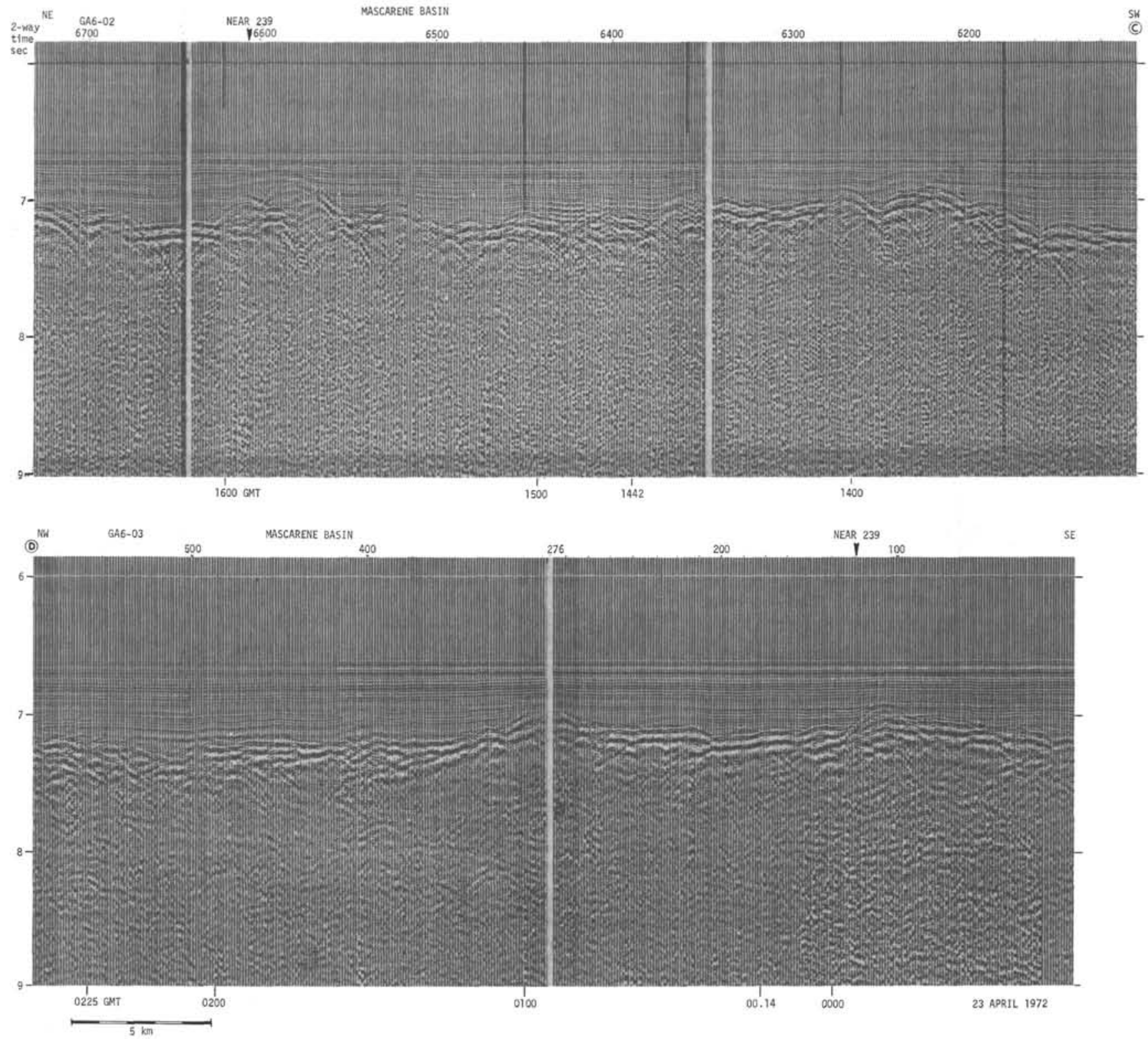

Figure 3. Gallieni *6 seismic reflection profiles (flexotir sound source and variable area recording) in the vicinity of Site 239. The locations of these profiles are given in Figure 1 (solid lines).* Gallieni *6 records are from unpublished Inistitut de Physique du Globe de Paris and Comité d'Études Pétrolières Marines data (Schlich, personal communication).*

LITHOLOGY

Introduction

Six meters of basalt and 320 meters of sediment were drilled and cored at Site 239. Age of sediments range from Late Cretaceous (Campanian) to Pleistocene. Core descriptions indicate three major units: basalt, brown clay, and silty clay-nanno ooze. The sediment units have several significant lithologic changes that warrant further subdivision into subunits (Table 2). Figure 6 establishes a stratigraphic column for the site.

Description of Lithologic Units

Unit I: Silty Clay and Clay-Rich Nanno Ooze (Cores 1 through 10)

Unit I is 158 meters thick and has an age range of middle Miocene to Pleistocene. It consists predominantly of silty clay and clay-rich nanno ooze. Minor lithologies include nanno-bearing clay, foram-rich clayey nanno ooze, and foram/carbonate-rich nanno ooze. Three subunits are distinguished on the basis of changes in silty clay and nanno ooze proportions. Subunit IA is dominated by silty clay

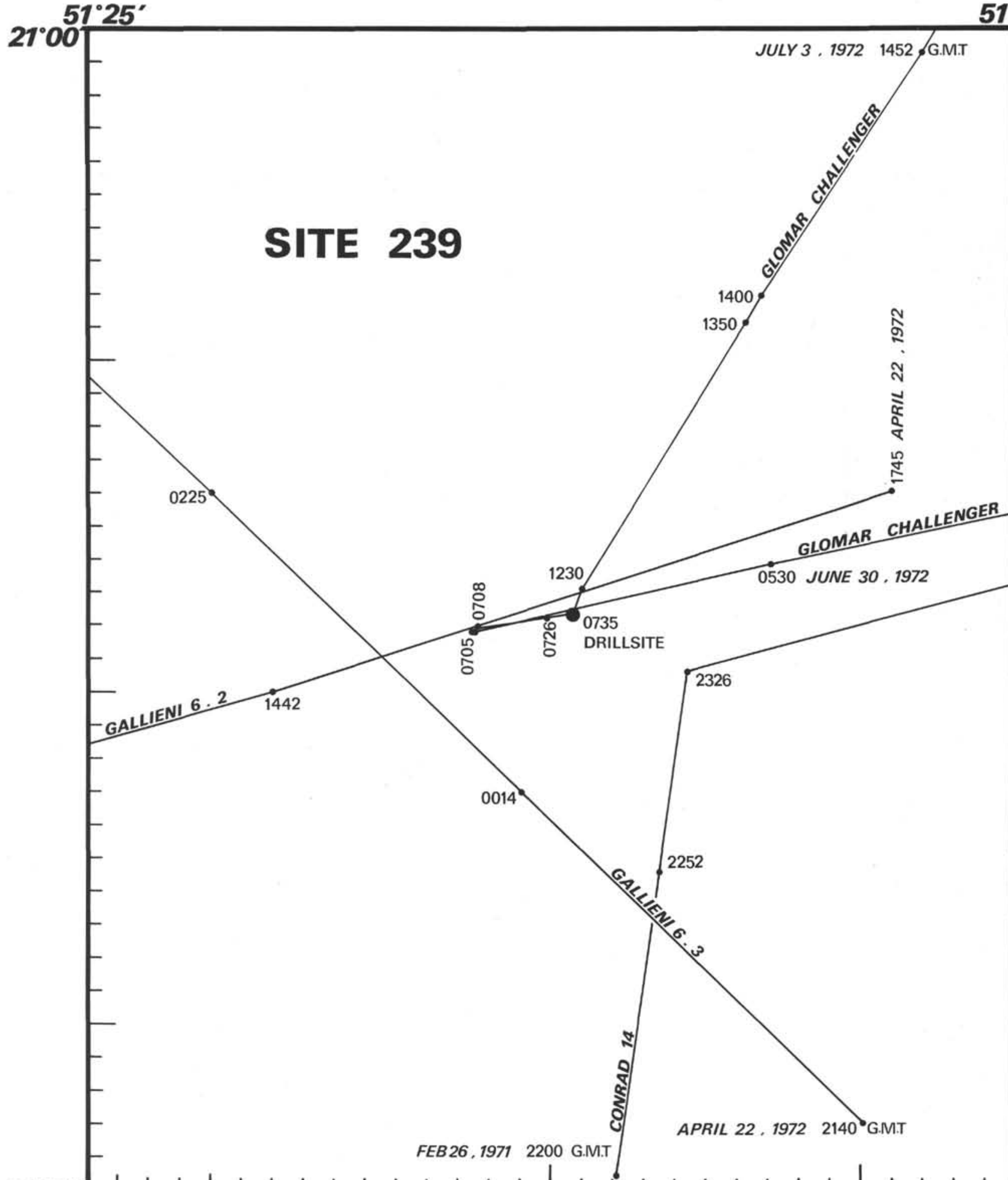

Figure 4. *Details of the* Glomar Challenger *site approach.*

with minor clayey nanno ooze. Subunit IB is mostly clay-rich nanno ooze, and Subunit IC is a mixture of silty clay and clay/carbonate-rich nanno ooze. Colors of the unit are varying hues of greens and grays. The base is well defined and is marked by the gypsum-rich silty limestone, encountered at 158 meters, which forms the top of Unit II.

Subunit IA: Green and gray silty clay is the dominant lithology of subunit IA (Cores 1 through 3), and clayey nanno ooze, nanno ooze, clay, and silt are minor. The base of the subunit lies between Core 3 (27 m) and Core 4 (66 m); possibly, the contact is gradational because the abundance of nanno ooze increases with depth in Core 3.

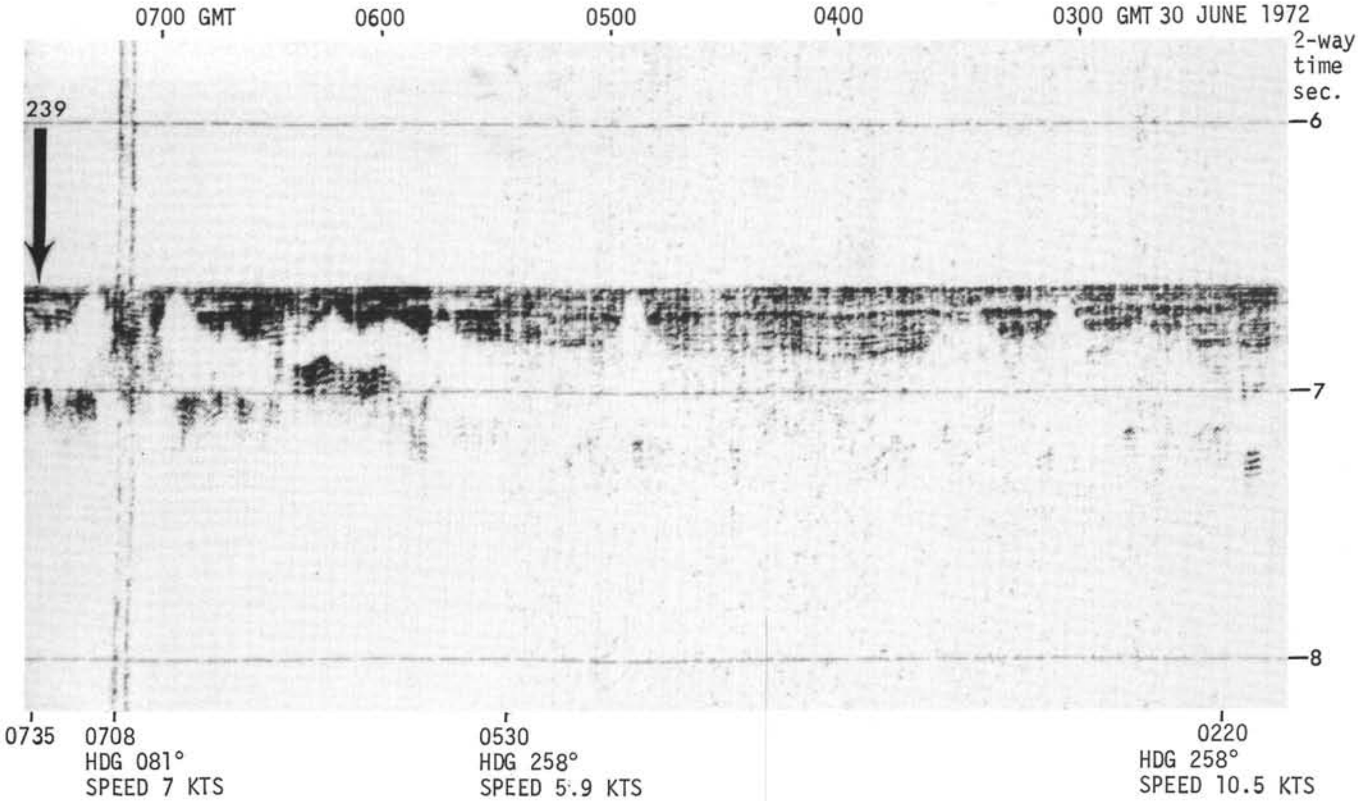

Figure 5. Glomar Challenger *seismic reflection profile on approach to Site 239.*

Because of drilling disturbance, most bedding planes are destroyed. However, one 10-cm-thick bed in Core 1 clearly exhibits grading from sandy silt to silty clay. It seems probable that other coarser-grained beds also are graded.

Some volcanic glass fragments (2%) occur in the Core 2 core-catcher sample, and one small pumice fragment was observed near the base of Core 1. Other evidence, mainly X-ray results, indicate that volcanic components contributed significant amounts to the subunit. For instance, the $<2\mu$ fractions for Cores 1 through 3 contain large proportions (38%-64%) of montmorillonite and the $2\text{-}20\mu$ fraction indicates phillipsite in Cores 1 and 3. Silt-sized

TABLE 1
Coring Summary, Site 239

Core	Depth Below Sea Floor (m)	Cored (m)	Recovered (m)	Recovery (%)
1	0-9	9	5.8	64
2	9-18	9	CC	–
3	18-27	9	4.4	49
4	66-75	9	5.0	55
5	75-84	9	9.0	100
6	84-93	9	8.0	89
7	122-131	9	5.8	64
8	131-140	9	9.0	100
9	140-149	9	9.0	100
10	149-158	9	0.0	0
11	158-167	9	7.1	79
12	206-215	9	5.3	59
13	215-224	9	8.8	98
14	263-272	9	2.7	30
15	272-281	9	3.6	40
16	281-290	9	5.8	64
17	290-298	8	7.9	99
18	300-309	9	4.1	46
19	312-320	8	2.5	31
20	320-322	2	0.8	40
21	322-326	4	1.5	38
Total		175	106.1	61

Note: Echo sounding depth (to drill floor) = 4981 meters; drill pipe length to bottom = 4993 meters.

TABLE 2
Lithologic Units and Subunits, Site 239

Depth (m)	Lithologic Units	Lithologic Sub-Units	Thickness (m)
0	(I) Silty clay and clay-rich nanno ooze	A) Green and gray silty clay and Gray silt-bearing clayey nanno ooze	158
50(?)		B) Light gray clay-rich nanno ooze	
131		C) Green and gray silty clay and clay/carbonate-rich nanno ooze	
158	(II) Brown clay and brown silty clay	A) Brown silty clay and brown clay	162
280		B) Brown clay, brown clay-rich nanno ooze, and brown nanno clay	
320	(III) Basalt	Dark gray fine-grained basalt	6
326			

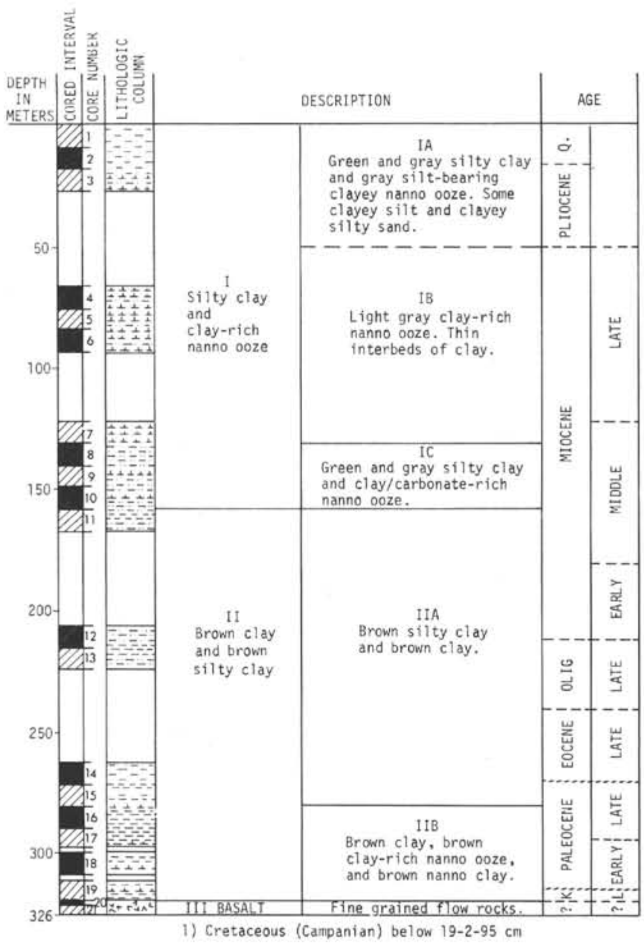

Figure 6. *Stratigraphic column, Site 239.. Dashed lines indicate uncertain boundaries and positions. Wavy lines indicate major hiatuses.*

authigenic carbonate rhombs (dolomite?) occur in Section 2 of Core 1 at 60 cm, and irregular carbonate particles (micarb) comprise as much as 30 percent of some smear slides.

Terrigenous, pelagic, and volcanic contributions are all important in this subunit. No cyclic pattern is apparent, but it is logical to conclude that normal pelagic sedimentation was interrupted by rare turbidites from the Madagascar continental margin and that some finer grains were carried to the site by nepheloid layer transport. Volcanic ash and dust were brought to the locale by winds and ocean currents, possibly from the Mascarene Islands.

Subunit IA was deposited during the Pliocene and early Pleistocene epochs. Rare late Miocene foraminifera are believed to be reworked from older deposits.

Subunit IB: Subunit IB, recovered in Cores 4 through 7 (66-131 m), consists primarily of light gray, clay-rich nanno ooze and clay-rich, carbonate nanno ooze. Minor lithologies are foram/clay/spic-rich nanno ooze, nanno clay, nanno-rich clay, and silty clay. Radiolarians and diatoms are common in the sequence and carbonate rhombs occur in clayey portions of Cores 5 and 6. Pyrite fills radiolarian and foraminifera tests in Cores 6 and 7.

Graded biogenous beds and displaced fauna suggest that at least some parts of this subunit are detrital. However, pelagic biogenous sedimentation is dominant over the detrital portions. The age of the subunit is middle and late Miocene.

Subunit IC: In subunit IC (Cores 8 through 10, 131-158 m) green and gray silty clay is interlayered with light gray foram/carbonate-rich nanno ooze. This subunit is separated from the overlying subunit by a notable change from nanno ooze to silty clay as dominant lithologies and from the underlying unit by changes in color and lithologies.

Silty clay generally has about 20% to 35% silt-sized grains of quartz, feldspar, and assorted heavy minerals (opaques, hornblende, garnet, biotite, staurolite, and zircon) which indicate that Madagascar was the source area for most of the detrital contributions. A notable volcanic influence is shown by a high proportion of montmorillonite (50% to 62%) in the clay fractions and by the presence of phillipsite in Core 9, Section 2. Palagonite was identified in Cores 8 and 9. Subunit IC is early and middle Miocene in age.

Unit II: Brown Clay and Brown Silty Clay (Cores 11 through 19)

Unit II (Cores 11 through 19, 158-320 m) is a brown clay and brown silty clay unit that is separated into two subunits. Subunit IIA (Cores 11 through 15, 158-280 m) consists of brown silty clay and brown clay. Subunit IIB (Cores 15 through 19, 280-320 m) is dominantly brown clay with minor amounts of nanno clay and clayey nanno ooze.

Subunit IIA: This subunit is predominantly brown silty clay and brown clay. The top contact is marked by a gypsum-rich silty limestone. There is a progressive compaction of sediments below the limestone.

Although the brown color suggests that this subunit is of pelagic origin, several data indicate that there was notable terrigenous input. Grain-size analyses show that silt-sized components comprise as much as 50% of some beds, one graded silt-silty clay bed, with a sharp basal contact (Section 1 of Core 11), points to a probable turbidite origin for that bed. Silt-sized components are quartz, feldspar, and heavy minerals (including zircon, garnet, staurolite, epidote, hornblende, and biotite), thereby suggesting that the Precambrian terrane of Madagascar was the source area for coarser-grained sediments. Kaolinite is a strong contributor to the subunit, although montmorillonite is dominant in the clay ($<2\mu$) fractions.

Volcanic materials, mostly altered, comprise a significant part of this subunit. Montmorillonite is the most abundant clay mineral in the X-rayed samples. In Core 13 (217.4 m), montmorillonite content marks a devitrified volcanic ash layer. Rare palagonite is present in the smear slides. Manganese nodules, 0.5-1 cm in diameter, occur in the upper parts of Core 15.

Thin limestones, one a gypsum-rich silty limestone about 5 cm thick, are at two depths (159 and 263 m). The upper limestone has silt-sized quartz, feldspar, and detrital carbonate grains within a sparry calcite and gypsum matrix. The lower bed contains silt-sized quartz, feldspar, and opaque minerals which form an open framework that is supported by the cemented remains of foraminifera and coccoliths.

The age range of subunit IIA is early Paleocene (Danian) to early Miocene. A hiatus between early Paleocene and early Eocene may occur in Core 15.

Subunit IIB: This subunit includes the sediment column from the lower part of Core 15 (280 m) to the bottom of Core 19 (320 m). Major lithology is brown clay; minor lithologies include brown and grayish green clay, nanno clay, clayey nanno ooze, and clay-rich nanno ooze. The abundance of nannofossils and the near absence of silt-sized detrital grains separate subunit IIB from subunit IIA. Volcanic contributions are important as shown by the abundance of montmorillonite in the clay fractions. Discrete volcanic ash layers are not apparent. However, the grayish brown thin beds towards the base of the hole may be montmorillonite-rich beds, which would suggest that they represent devitrified volcanic ash layers. Subunit IIB is Late Cretaceous (Campanian) and early Paleocene in age.

Unit III: Basalt (Cores 20, 21)

Approximately 2.2 meters of dark gray basalt, which forms the acoustic basement at Site 239, were recovered from a 6-meter interval between a depth of 320 and 326 meters below the sea floor. The overlying sediments were disrupted by the coring process, and the basalt-sediment contact was not recovered intact. However, there is no sign of baking or other alteration near the contact, and the basalt here is considered to form "oceanic basement" and is therefore considered to be older than the oldest sediment (Campanian).

The basalt has a fine-grained crystalline texture except in thin zones where glassy textures predominate. Reddish brown zones, caused by iron oxidation during submarine weathering, follow irregular fractures that traverse the rock. Some irregular fractures, filled with iron-stained carbonate and chert, may outline parts of pillows. However, the evidence that these are pillow lavas is not conclusive.

Microscopic examination revealed that both texture and modal composition vary quite considerably but unsystematically and may indicate that a number of flows were penetrated. Variolitic and intersertal textures predominate, although intergranular and pilotaxitic textures also occur. All samples are composed of varying amounts of plagioclase, augite, olivine (pseudomorphed by chlorite), magnetite, and glass with chlorite, smectites, goethite, and calcite occurring as secondary minerals. The range in modal composition is plagioclase, 20%-60%; augite, 1%-30%; olivine (chlorite pseudomorphs), 0%-5%; magnetite, 1%-10%; glass, 5%-70%; and secondary minerals, 0%-2%. Plagioclase and pseudomorphed olivine form rare microphenocrysts. The major and trace element analysis (Erlank and Reid, this volume) indicates that the basalt is similar in composition to the low K tholeiites recovered from the mid-ocean ridges.

Lithologic Interpretations

Beginning with the lowermost unit (III) and progressing with decreasing age, the following preliminary lithologic interpretations are proposed:

1) The basalt flows probably represent true oceanic "basement" at this site. They should be older than the oldest sediment.

2) The nanno clay, clayey nanno ooze, and clay-rich nanno ooze in the lowest sedimentary subunit (IIB) probably were deposited on, or near, a spreading ridge crest above the regional carbonate compensation depth. Brown clay within the subunit is pelagic in origin.

3) The brown clay and brown clayey silt of subunit IIA were deposited below the compensation depth as the sea floor subsided and moved away from the ridge. Much of the silt-sized grains have a terrigenous detrital origin. Apparently, Madagascar was already quite close to the site location in the early Paleocene, and detritus from that island was transported across the Mascarene Basin by turbidity and other bottom currents. Volcanic detritus, mostly devitrified ash, occurs as montmorillonite in the clay samples. The gypsum-rich silty limestone at the top of Unit II represents a turbidite silt that was cemented by secondary calcite and gypsum.

4) Terrigenous sedimentation alternated with pelagic biogenic sedimentation in subunit IC. Many of the coarser grained units represent turbidity current deposition. Source rocks were the Precambrian terranes of Madagascar. Although an increase in submarine slope gradients, changes in climate, and the destruction of submarine barriers could account for the influxes of terrigenous sediments, a more logical conclusion is that Madagascar was uplifted during the middle Miocene.

5) The thick nanno ooze sequence of subunit IB was deposited during a short time interval in the Miocene when either the landmasses were not contributing a great amount of material to the area (low relief or long distance) or submarine barriers blocked terrigenous sediment dispersal. Also, the sea floor was higher than the regional carbonate compensation depth.

6) Influxes of coarse-grained terrigenous sediments effectively masked accumulations of biogenic components during Pliocene and Pleistocene times. Many of the coarser grained silt and sand beds are turbidite deposits. Increased terrigenous sedimentation can be attributed either to increased erosion of landmasses because of renewed uplift or to greater sediment dispersal during lowered sea level (Pleistocene) when sediments were not trapped on the continental shelves and in estuaries, but were debauched directly onto the deep sea floor.

PHYSICAL PROPERTIES

Bulk density values vary throughout the cores and are indicative of lithologic changes and/or lithologic boundaries and possible drilling disturbance.

Core 1 is highly disturbed, and the low bulk density of approximately 1.18 g/cm^3 is of uncertain value. There is, however, an indicated increase in bulk density from Core 1 to Core 3 (18-27 m). Beginning with Core 3 and continuing through Core 14 (269-272 m), the bulk density varies between the approximate limits of 1.37-1.76 g/cm^3. A histogram using 24 field-calculated data points from the GRAPE device and 18 sample bulk density values is shown in Figure 7. These preliminary data show a bimodal character for the bulk density of these sediments. In Cores

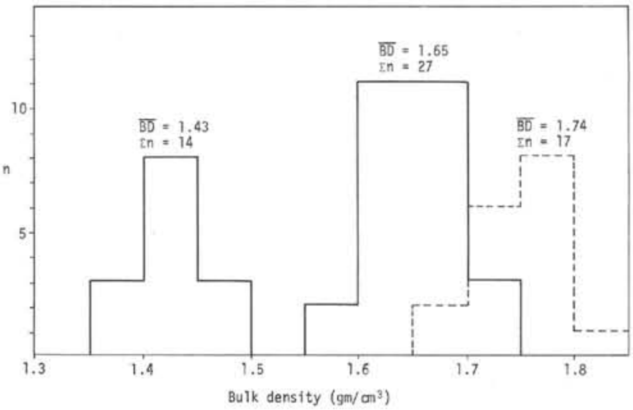

Figure 7. *Histogram of bulk density from GRAPE and samples.*

3 through 9, the higher bulk densities are mainly associated with clayey nanno oozes and nanno oozes, while the lower bulk densities are mostly related to the clayey nanno oozes, silty clays, and clays. Cores 11 through 14 are predominantly silty clays and yet, at least through Core 13, they show the same bimodal character.

A histogram for the bulk density data from Cores 15 (272-281 m) through 19 (312-320 m) are also shown in Figure 7 as the shaded area to the right. Eleven values are from the GRAPE and six are from sample tests. There is a single mode for these with an average of 1.74 g/cm^3 for the 17 values. However, the data suggest a slight increase of bulk density with depth. Most of the sample bulk densities here are lower than the GRAPE data.

The sonic velocity values show very little variation beyond the range 1.50-1.52 km/sec to a depth of about 225 meters. Since velocities from 265-320 meters are generally higher, averaging 1.61 km/sec, the latter values seem indicative of the very compact (stiff) massive brown clay unit. Exceptions in the sediment to these two generalities are found at 163 and 263 meters (silty limestones) where velocities are approximately 2.83 and 3.20-4.01 km/sec, respectively. Except for these two velocities, the lack of significant velocity changes may reflect the generally similar gross-physical character of the sediment throughout the core, irrespective of compositional differences.

Eight sonic velocity measurements were made on the basalt recovered between 320 and 326 meters. These values range from 5.06 to 5.46 km/sec and average 5.31 km/sec.

The changes in acoustic impedance (g/cm^2 sec) are essentially reflections or amplifications of the variable bulk density data. In a general way then, the histograms in Figure 7 also indicate the trend for the acoustic impedance data.

From Figure 7, it is apparent that two fairly well defined groups or populations of bulk densities are outlined for Cores 3 to 14. This agrees well with the lithology of subunit IB (Cores 3 to 10) which consists primarily of nanno oozes and nanno clays interbedded with clays and silts. The stratigraphy of subunit IIA (Cores 11 to 15) is less variable and is mainly clay, clayey silt, and silty clay. The lower part of this unit, subunit IIB (Cores 15 to 18), corresponds to the smoother single mode histogram representing less-variable bulk densities.

In the groups of cores where there is some continuous coring, the most obvious changes in bulk density and acoustic impedance are approximately at the following depths: (1) 66 to 80 meters, (2) 122 meters, (3) 132 to 158 meters, (4) 163 meters, and (5) 207 to 213 meters. The single depths noted were at the ends of core groups and are thus less clearly defined.

BIOSTRATIGRAPHY

Calcareous Nannoplankton

At Site 239, the nannoplankton assemblages are generally not very rich. In the Miocene sediments, most of the coccoliths are dissolved, whereas the discoasters are still preserved.

Pleistocene/Pliocene

The assemblages of Cores 1 to 3 are mixed with Pleistocene and Pliocene species and a few reworked forms from the Eocene and Cretaceous (Figure 8). Therefore, it is impossible to determine the Plio/Pleistocene boundary. The nannoplankton of these cores is very abundant and very well preserved. Most Pleistocene species are *Gephyrocapsa oceanica, Helicopontosphaera kamptneri, Cyclococcolithus leptoporus, Pseudoemiliania lacunosa,* and *Thoracosphaera heimi.* Species from the Pliocene are *Discoaster brouweri, Discoaster pentaradiatus,* and *Discoaster surculus.*

Miocene

The samples in the interval of Core 4, Section 1 to Core 5, Section 4, 140 cm belong to the *Discoaster quinqueramus* Zone (NN11). The frequency and preservation of the nannoplankton are different within this interval. *Discoaster quinqueramus* is the most typical form of this zone. Further on, species of the genus *Scyphosphaera* are observed. The *Discoaster calcaris* Zone (NN10) includes Sample 5-5, 70 cm and Core 6. The assemblage is not very rich in calcareous nannoplankton. The most frequent species are *Discoaster calcaris, Discoaster variabilis, Discoaster neohamatus,* and some species of the genus *Scyphosphaera.*

In Core 7, *Discoaster hamatus* was observed, but only a few specimens. This species was never observed frequently. It indicates, together with *Catinaster coalitus, Catinaster calyculus, Discoaster calcaris, Discoaster neohamatus* and *Discoaster variabilis,* the *Discoaster hamatus* Zone (NN9).

Core 8 contains a mixed assemblage of late Oligocene to middle Miocene species. An exact age determination is not possible.

Core 9 is very poor in nannofossils. In some samples, *Sphenolithus heteromorphus* was found, indicating an early Miocene age. In Sample 9-4, 136 cm, many reworked species of the Eocene occur.

Cores 10, 11, and 12 are without nannoplankton.

Paleogene

Only some samples from Core 13 contain nannoplankton indicating the late Oligocene *Sphenolithus ciperoensis* Zone (NP25). The typical species are *Sphenolithus ciperoensis, Helicopontosphaera recta, Coccolithus abisectus, Dictyococcites dictyodus, Triquetrorhabdulus carinatus,* and *Helicopontosphaera euphratis.*

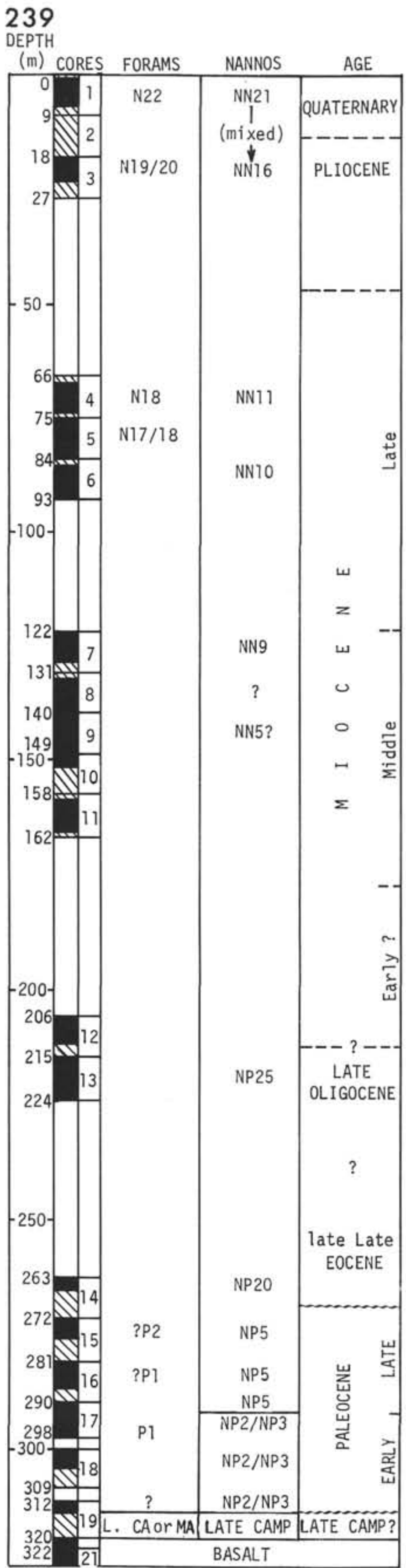

Figure 8. *Biostratigraphic column for Site 239.*

Late Eocene, most probably the *Sphenolithus pseudoradians* Zone (NP20), was determined for Sample 14-1, 13 cm. The assemblage consists of the following species: *Discoaster taninodifer, Discoaster barbadiensis, Discoaster saipanensis, Cyclococcolithus formosus, Dictyococcites dictyodus, Helicopontosphaera compacta, Sphenolithus predistentus,* and *Braarudosphaera bigelowi.*

The *Fasciculithus tympaniformis* Zone (NP5) of middle Paleocene age was determined for the samples of Core 15 to Core 17, Section 2, 70 cm, with *Fasciculithus tympaniformis, Cruciplacolithus tenuis, Chiasmolithus bidens,* and *Coccolithus cavus.* All samples are very poor in calcareous nannoplankton, most of which are dissolved.

Samples 17-2, 120 cm to 19-1, 11 cm contain very few nannoplankton. The assemblage consists of *Cruciplacolithus tenuis, Zygodiscus sigmoides, Cyclococcolithus inversus,* and very few specimens of *Chiasmolithus danicus,* indicating the *Cruciplacolithus tenuis* Zone (NP2)/ *Chiasmolithus danicus* Zone (NP3). In some of these samples were found some specimens of *Tetralithus murus,* which is typical of the late Maestrichtian.

Cretaceous

The Cretaceous/Tertiary boundary lies between Samples 19-1, 110 cm and 19-2, 95 cm. The Cretaceous sediments are not very rich in calcareous nannoplankton. The most frequent species are *Tetralithus aculeus, Watznaueria barnesea,* and *Micula staurophora. Arkhangelskiella cymbiformis* was found only as a few specimens. The frequency of *Tetralithus aculeus* makes it probable that these sediments belong to the late Campanian.

Foraminifera

Quaternary and Neogene

The uppermost core of this site had good recovery but is entirely mixed. The amount within the grain-size fraction $>160\mu$ is small, with a high percentage of mica. There are relatively few foraminifera specimens but a large number of species. The planktonic foraminifera range in age from Pleistocene to Paleogene, but by far most have an early Pleistocene age, which occur, according to Blow (1969), in Zone N.22 (*Globorotalia truncatulinoides* together with *Globorotalia tosaensis, Pulleniatina obliquiloculata obliquiloculata* without *Pulleniatina obliquiloculata finalis, Beella* aff. *digitata* and others). The benthonic foraminifera range from nearshore (*Elphidium macellum* and *Amphistegina* sp.), over mid-shelf (*Hanzawaia concentrica, Planulina exorna, Cancris auriculus, Spiroloculina indica,* and *Ophthalmidium* sp.), outer shelf (Buliminacea), to deep water (*Cibicides wuellerstorfi, Gyroidinoides altiformis, Osangularia* sp., *Globocassidulina subglobosa,* and *Pyrgo* sp.).

The immediately succeeding Core 2 was without sediment recovery except for the core catcher. In this, the assemblage is similar to that described in Core 1; however, the age is Pliocene with mixed in microfossils which include Late Cretaceous *Globotruncana* and a Recent chitinous skeleton of a small crab.

The boundary between Quaternary and Tertiary is probably somewhere in the Core 2 interval.

Core 3, the first core of Tertiary age, also is greatly disturbed. The amounts of microfossils in sample residues >160μ are extremely small. There is only one sample in Section 2 which yields a seemingly unmixed deep-water association with *Cibicides wuellerstorfi, Pyrgo murrhyna,* and *Epistominella exigua.* This sample is of Pliocene age, about N.20, with *Sphaeroidinella dehiscens dehiscens, Sphaeroidinellopsis seminulina, Pulleniatina obliquiloculata obliquiloculata, Globorotalia dutertrei, Globorotalia tumida tumida, Globigerinoides obliquus obliquus, G. trilobus trilobus,* and *G. trilobus immaturus.* Other samples studied from this core point to a similar Pliocene age. The benthonic foraminiferal associations are mixed in all samples except the one described from Section 2. They contain *Amphistegina, Borelis, Ammonia, Elphidium,* and other shallow-water foraminifera together with indicators for deep water like *Eggerella bradyi, Cibicides wuellerstorfi,* and *Globocassidulina subglobosa.*

Preservation of the specimens is variable. The heavily corroded individuals always belong to shallow-water foraminifera like *Borelis, Amphistegina, Quinqueloculina* sp., and *Rotalia* sp. However, not all shallow-water species are corroded. With the planktonics there is no clear trend except that only large forms remain.

All the mixed samples from the Quaternary and Pliocene of the Mascarene Basin show natural mixing of deep- and shallow-water material (besides the benthonic foraminifera already named, residues of bryozoans, echinoderms, mollusks, mica, and quartz, and, without meaning as to depth, radiolarians, pteropods, and sponge spicules) together with technical mixing within every core. This gives about the same age to every sample from one core. Nothing can be said as to the geographic source of the shallow-water material.

From Cores 4 to 9, part of the faunal residue in the sediment material challenges the investigator. The facies of the material looks like the Cretaceous white chalk-facies of northwestern Europe. The sediment is very fine and very difficult to wash. There is no residue >160μ. The grain-size fraction 160μ-63μ contains a very high amount of siliceous sponge spicules, some calcitic sponge spicules, common radiolarians, and some diatoms. Foraminifera are common to abundant in this fraction, but they are surely not a main component of the sediment. The author was not able to precisely identify, in the available time, the very small planktonic foraminifera which, partly because of their small size, do not fit existing descriptions. All the "white chalk facies" samples contain *Chiloguembelina* in varying percentages. Benthonic foraminifera are not common; they belong preferably to *Brizalina* and *? Bolivina.* In some samples, the "white chalk facies" material is mixed with "normal" material, and dating by means of foraminifera was possible, even though the "normal" sediment seems to have suffered increasing carbonate dissolution. No statement can be made at this time as to the age and origin of the "white chalk facies."

Cores 4 to 6 are of late Miocene age. In all washed samples, specimens in the grain-size fraction >160μ are extremely rare or missing; specimens in the fraction 160μ-63μ are also rare. Thus, only a few foraminifera are left for age determinations. Obviously, the autochthonous material has suffered carbonate solution. Nearly all samples contain benthonic foraminifera from deep-water as well as from shelf environments, sponge spicules, and some Paleogene foraminifera. The lower part of Core 4 and the upper part of Core 5 (at least down to Section 2) fit Blow's Zone N.18 with *Globigerina apertura, G. nepenthes, G. venezuelana, Globigerinoides bollii, G. obliquus obliquus, G. obliquus extremus, G. trilobus trilobus, G. trilobus immaturus, G. trilobus sacculifer, Globorotalia acostaensis tegillata, G. crassaformis, G.* aff. *miocenica, G. plesiotumida, Globoquadrina altispira, Sphaeroidinellopsis subdehiscens subdehiscens, G. subdehiscens paenedehiscens,* and *Candeina nitida praenitida.* There are no *Globorotalia tumida tumida* and *Pulleniatina.* In Core 5, Section 5, the first *Globorotalia merotumida* can be observed. From here down to the core catcher of Core 6, the rare foraminifera of the samples do not show important faunal changes. Nearly all the samples investigated contain a higher or lower proportion of the "white chalk facies" as indicated by the absence or presence of *Chiloguembelina* sp.

No reliable age determinations by means of planktonic foraminifera can be given for Cores 7 to 13 because of the lack of foraminifera and/or the difficulties in identifying the extremely small specimens. In Core 8, Section 4, a poorly preserved *Globorotalia* from the *Globorotalia fohsi* group, together with several other Miocene species, points to an age of about early middle Miocene. Core catcher 12 yields *Globigerina ciperoensis angulisuturalis* and questionable *Globorotalia praemenardii?,* thus ranging just above or below the Oligocene/Miocene boundary. No further ages can be given for the Neogene part of Site 239 until a better knowledge of the very small planktonic foraminifera and their stratigraphic ranges is gained. Some comments are worthwhile concerning the appearance of the samples. All samples from Core 7 belong to the "white chalk facies," although in the uppermost part of Section 1 there are no sponge spicules and no radiolarians. The Core 8 material is light brown and sticky, but all samples have a fauna similar to that of the "white chalk facies," including in some a large number of sponge spicules. Core 9 is the same as Core 8 with an exception that there is a typical "white chalk facies" sample in Section 6, whereas, on the whole, sponge spicules are rare. Samples from Cores 11 to 13, as far as they are not pure detrital sands, are characterized by the presence of small (>160μ) yellow spheres which probably are of biogenous origin. These spheres are soluble in HCl. Foraminifera, if present, are very small and are not characteristic.

Cretaceous and Paleogene

This hole cut through sediments belonging to the Cretaceous and Paleogene. It was cored almost continuously with an average recovery rate. Unfortunately, residues from the washed sediments contained very few microfossils, most of which were benthonic and banal. Consequently, the chronostratigraphic data obtained are not very accurate. The boundary between the Cretaceous and Paleogene is located in Core 19, Section 2 between 74 and 124 cm, according to data from the analyses of foraminifers (according to nannoplankton at 74-95 cm). It should be mentioned that, with regards to the upper part of Core 19 and into Core 18, assignment to the Tertiary is based mainly on the nannoplankton. In this particular section (Cretaceous and Paleogene foraminifera), faunas are described from older to younger sediments.

Late Cretaceous

A Late Cretaceous fauna is found only in the very bottom part of Core 19 (recovery of about 50%), hence over a very small thickness. The foraminiferal assemblage is exclusively benthonic and relatively diversified but is not very rich in specimens. It is accompanied by teeth and other remains of fish and some Radiolaria. The following species were recognized:

Spiroplectammina dentata (Alth, 1850)
Bigenerina sp.
Gaudryina sp.
Tritaxia sp.
Marssonella cf. *conica* Olsson, 1960
Arenobulimina aff. *preslii* (Reuss, 1845)
Buliminella sp.
Bulimina cf. *reussi* var. *navarroensis* Cushman and Parker, 1935.
Aragonia ouezzanensis (Rey, 1955)
Bolivina sp.
Bolivinoides senonicus var. *desnensis* Vasilenko, 1950
Discorbis cf. *supracretacea* Schijfsma, 1946
Gyroidina crassa (d'Orb., 1842) (in White, 1928)
Osangularia florealis (White, 1928)
Epistominella sp.
Stensiöina cf. *caucasica* var. *transuralica* Balakhm., 1960
Pullenia dampelae Dain, 1952

This assemblage probably belongs to the lower or middle part of the slope. However, the absence of Nodosariidae is surprising, perhaps indicating a certain depth. But even more striking is the absence of pelagic forms. Perhaps this assemblage was transported from a shallow to a greater depth. The age indicated is Late Cretaceous, corresponding to the uppermost Campanian or the Maestrichtian. Samples examined:

19, CC
19-2, 136 cm
19-2, 124-126 cm

Paleogene

An important change in the biological portion of the sediment occurs beginning with the Tertiary. A slightly greater depositional depth was probably responsible for the monotony and poverty of the assemblage ("Aggl." in the list of samples examined) of agglutinant forms (*Ammodiscus, Glomospira, Haplophragmoides, Trochammina*) that is mainly found; an assemblage that probably belonged to the bathyal environment or to the lower slope. However, in some samples, other agglutinant forms (probably from sediments deposited on the slope) also occur along with a few benthonic calcareous forms ("Benth." in the list of samples examined), including some belonging to the assemblage already mentioned for the Late Cretaceous:

Tritaxia sp.
Dorothia sp.
Robulus velascoensis (White, 1928)
Buliminella parvula Brotzen, 1948
Bolivina sp.
Bulimina arkadelphiana var. *midwayensis* Cushman and Parker, 1936
Aragonia ouezzanensis (Rey, 1955)
Epistominella sp.
? *Stensiöina caucasica* (Subbotina, 1947)
? *Asterigerina* cf. *Eponides brönnimanni* Cushman and Renz, 1946
Charltonina sp.

In Cores 17-14, some planktonics are found ("Plankt." on the list of samples examined). Even though they are sometimes abundant in the residue, no argument can be found for or against their disappearance by dissolution where they are sparse or absent. They can be used to distinguish, in Cores 16 and 17, the early Paleocene (Danian) by an association of very small forms belonging to the group of *Eoglobigerina.* This association includes:

Eoglobigerina tetragona Morozova, 1961
Eoglobigerina cf. *microcellulosa* Morozova, 1961
Eoglobigerina cf. *sabina* Luterb. and Prem.–Silva, 1964
Eoglobigerina eobulloides Morozova, 1957

At level 17-4, 109-112 cm, there also are species which apparently should be assigned to *Globigerina (Globoconusa) daubjergensis* Brönnimann, 1952.

All of these levels thus belong to the Danian and may be correlated with the equivalent levels at Site 245 where, the faunal abundances being much greater, a quasi-simultaneous disappearance of *G. daubjergensis* and the *Eoglobigerinas* group was noted, thereby dating these sediments in the P.1 Zone of the Blow scale, or the *G. daubjergensis* Zone.

A somewhat different but neighboring level occurs in Core 15 due to the presence of a species which appears similar to *Globorotalia (Turborotalia) trinidadensis* Bolli, 1957 or *multiloculata* (Morozova, 1961).

The absence of the *Eoglobigerina* group in Core 15 would tend to suggest an assignment to the later part of the Danian. But since the basis for this is quite uncertain, it should be accepted with some caution.

Core 14 has a late middle Eocene age (but may attain the Oligocene in the upper part of the core) as indicated by the presence not only of planktonic forms but also of several benthonic species, which really show more of an Oligocene affinity. These species include:

Globoquadrina galavisi Bermúdez, 1961
Bolivina cf. *ventricosa* Galloway and Heminway, 1941
Bolivina group of *B. alazanensis* Cushman, 1926.
Bolivina (cf. *venezuelana* Hedberg, 1937)
Rotalia sp.

Some forms from the early Eocene are reworked in Core 14. In the core catcher of this same core, a small form was found which might be a young specimen of *Globigerina ampliapertura* Bolli, 1957.

The hiatus which apparently cuts through this Eocene or Paleogene sequence could consequently be placed between Cores 15 and 14.

Samples examined (the abbreviations indicate the presence of various foraminiferal assemblages which also have been mentioned previously in the text):

19-2, 74-76 cm (Aggl.)	17-1, 75-77 cm (no F.)
19-2, 25-27 cm (Aggl.)	17-1, 17-19 cm (Aggl.)
19-1, 136-138 cm (Aggl.)	16, CC (Benth.)
18, CC (Aggl.)	16-4, 102-104 cm (no F.)
18-3, 124-126 cm (Benth.)	16-4, 20-22 cm (Benth.)
18-3, 24-26 cm (Aggl.)	16-3, 131-133 cm (no F.)
18-2, 124-126 cm (Benth.)	16-3, 13-15 cm (Plankt.)
18-2, 25-27 cm (Benth.)	16-2, 102-104 cm (Aggl.)
18-1, 134-136 cm (Benth.)	16-2, 11-13 cm (Aggl.)
18-1, 61-63 cm (no F.)	16-1, 131-133 cm (Plankt.)
17, CC (Benth.)	16-1, 50-52 cm (Plankt.)
17-6, 124-126 cm (Benth.)	15, CC (Benth.)
17-6, 24-26 cm (Benth.)	15-3, 139-141 cm (Benth.)
17-5, 105-108 cm (Plankt.)	15-3, 21-23 cm (Benth.)
17-5, 24-27 cm (Plankt.)	15-2, 139-141 cm (Benth.)
17-4, 109-112 cm (Plankt.)	15-2, 30-32 cm (Plankt.)
17-4, 10-13 cm (Aggl.)	14, CC (Plankt.)
17-3, 124-126 cm (Benth.)	14-2, 55-57 cm (Aggl.)
17-3, 45-48 cm (Aggl.)	14-2, 22-24 cm (Aggl.)
17-2, 103-105 cm (Benth.)	14-1, 62-64 cm (no F.)
17-2, 35-37 cm (no F.)	14-1, 10-15 cm (Plankt.)

A late Eocene age for the upper part of the Eocene sequence is determined by the nannoplankton (NP20). As indicated earlier, foraminifers show an Oligocene affinity. It can thus logically be concluded that the Oligocene is present in the interval separating Cores 14 and 13. Indeed, in the latter core, the nannoplankton are characteristic of the late Oligocene. Nevertheless, because cores are lacking, it is obviously not possible to say whether the series is complete here or whether a hiatus is also present, such as is frequent in these levels at other sites in the southwestern Indian Ocean.

Biostratigraphic Summary Site 239

Sea floor at Site 239 lies at about the CCD, and the foraminiferal population is diminished in Cores 1 through 3, whereas the nannoplankton assemblages are rich in specimens and species. Cores 1 through 3 are mixed and belong to the Quaternary and Pliocene epochs. For this time period, a very small sedimentation rate of about 7 m/m.y. is calculated.

Beginning with Sample 3, CC and progressing downwards in the Miocene succession, the facies has a very poor foraminiferal population of remarkably small specimens. The nannoplankton assemblages are abundant, and discoasters are partially overgrown. In upper Pliocene to upper Miocene sediments, shallow-water foraminifera are often mixed into the deep-water associations. In this part of the hole, the sedimentation rate is about 18 m/m.y.; during the rest of the Miocene, the sedimentation rate is again small, about 7 m/m.y.

Late Oligocene is determined (Core 13) by means of nannoplankton only; foraminifera are missing. In Core 14 and below, the sediment belongs to the upper Eocene, according to both foraminifera and nannoplankton. The uncored 40-meter interval between Cores 13 and 14 may contain a "gap" or may be a condensed sequence. The latter interpretation is put forth by Leclaire (this volume), who suggests that faunas of late Eocene age in Core 14 (including some early Eocene foraminifera) could be entirely reworked and that the "gap" between the late Paleocene and late Oligocene can instead be a condensed deep sequence.

Two well-established gaps (the upper one of 20-23 m.y.) occur in the thick Paleocene series, the lowest part of which (earliest Danian) seems to be missing. This Paleocene is mainly characterized by the nannofossils, which are strongly dissolved; foraminifera are generally poor and monotonous, probably impoverished through the dissolution process. Reworked Maestrichtian materials (nannofossils) in Cores 17-19 are noteworthy. Sedimentation rates for the Paleocene cannot be calculated with precision and can only be estimated between 3 and 8 m/m.y.

Finally, below a hiatus of 7-11 million years duration, a short sediment sequence of probable late Campanian age directly overlies basalt. Both foraminifera (benthonics only) and nannoplankton give this age; the benthonic assemblage characterizes a shallower environment (lower or middle slope) than the overlying sediments of Paleocene age, but these older sediments may have been deposited (by turbidites) below the CCD.

CORRELATION OF REFLECTION PROFILES AND LITHOLOGIES

Characteristics of the airgun reflection profiles run by *Glomar Challenger* in the near-site area and on site are essentially similar to the data obtained by *Conrad* 14 in 1971, and to some extent by *Gallieni* 6 in 1972 (see Figures 2 and 3). The sequence observed consists mainly of two units: a variable thickness of well-stratified or layered sediments, which can be subdivided into two members of nearly equal thickness, and below it a variable thickness of acoustically transparent material laying directly upon basement and following to some extent basement topography (Figure 5).

At Site 239, the uppermost stratified layer is well defined and is 0.10 sec DT thick (double way time). The second stratified layer has a rather poorly defined lower surface, and the thickness is about 0.09 ± 0.01 sec DT. The acoustically transparent layer resting upon basement is 0.20 sec DT. Finally, the depth of basement below sea floor is 0.39 sec DT (Figure 5).

The first clear reflector at 0.10 sec DT, which separates the two well-stratified layers, should occur, according to the measured sonic velocity of 1.51 km/sec for Cores 1, 2, 3, and 4, at a depth of about 75 meters, a depth which corresponds exactly with a notable change of acoustic impedance at the base of Core 4. Moreover, the lithologic description shows a progressive change from Cores 2 to 5 with decreasing amounts of greenish-gray silt and clay and increasing nanno ooze content, which becomes dominant in Core 5. The interface between Cores 4 and 5 (75 m) is marked by well-developed layering, which may explain the observed seismic reflection.

The second reflector, less distinct at 0.19 sec DT, which separates the stratified and transparent layers, corresponds to the lithologic change between Cores 9 and 11 (149 m to 158 m), where the silty clay and nanno ooze of Unit I are replaced by the brown silty clay of Unit II. This transition is emphasized by the sharp contrast in acoustic impedance observed in Cores 9 and 11. Consequently, this second reflector should correspond to the interface of these two lithological units at about 149 to 158 meters depth; because no recovery was achieved for Core 10, it is not possible to place the boundary more precisely. Taking this clear correlation into account, the inferred vertical sonic velocity for the stratified sediments (Unit I) is 1.62 km/sec ± 0.05 km/sec, which is greater than the corresponding mean measured velocity of 1.53 km/sec.

The third and last reflector at 0.39 sec DT corresponds to the contact of the transparent layer with the basaltic "basement". This contact is located at 320 meters depth below the sea floor. The inferred vertical sonic velocity for the transparent layer is thus 1.67 km/sec, which again is greater than the mean measured velocity of 1.58 km/sec (Figure 9).

Finally, the inferred vertical velocity for all the sedimentary layers overlying "basement" is 1.64 km/sec, which is greater by 5 percent than the weighted average of 1.56 km/sec for all measured velocities. This may be explained by core disturbances due to drilling. Allowance for measured inclination of the hole near the bottom (5°) provides a negligible factor of correction to arrive at a real basement depth (about 1 m less).

SUMMARY AND CONCLUSIONS

Site 239 is located at a water depth of 4971 meters in the abyssal plain of the southern Mascarene Basin, 180 miles east of Madagascar and 200 miles west of the island of Réunion. The single hole penetrated 320 meters of Pleistocene to Campanian sediments and 6 meters into the underlying basaltic basement. Scientific results are summarized in Figure 10.

The airgun seismic reflection profile (Figure 5) shows a variable thickness of well-stratified sediments, which can be subdivided into two subunits (each about 75 m thick at the site), overlying a variable thickness of acoustically transparent sediment (0.20 sec DT or about 170 m thick), which rests upon basement and to some extent follows basement topography. The transparent layer forms positive relief features where it is exposed on the otherwise smooth floor of the abyssal plain and, in places, it occurs as discontinuous diapir-like bodies within the stratified layer. In general, whereas the transparent layer is draped over basement relief features, the overlying stratified sediments are ponded and form the smooth flat abyssal plain. A disconformable relationship between the acoustically transparent and stratified sedimentary layers was predicted from the seismic reflection records. However, this prediction proved to be erroneous in spite of the color, compaction, and other contrasting properties of the two. The correlation between the seismic reflection record and lithologic divisions is good (Figure 9) except that the reflecting horizon in the upper stratified layer was not identified.

The stratified layer comprises Pleistocene to middle Miocene green and gray detrital sandy silt, silt, and clay in which graded bedding can occasionally be recognized. These sediments show a progressive change with depth by increasing amounts of gray nanno ooze (with sponge spicules), which becomes the dominant component in the thick middle subunit. In the lowest subunit of the stratified layer (middle Miocene), light gray nanno ooze and nanno clay grades downwards into gray and green silt and clay which change abruptly at 158 meters to brown silty clay; the transition is emphasized by sharp variations in acoustic impedance, but not by a stratigraphic hiatus. Some fragments of volcanic glass, and one of pumice, were observed in the uppermost cores, and X-ray data indicate important volcanogenic components in the form of montmorillonite, phillipsite, and palagonite in the uppermost (Plio-Pleistocene), and in the lowest (middle Miocene), sediments of this layer. These are almost certainly related to the volcanic history of the neighboring Mascarene Islands. The silt fraction of the lower sediments includes heavy minerals characteristic of a granitic/metamorphic terrain such as Madagascar, from which landmass the detrital components of the stratified sediments were no doubt derived.

A thin gypsum-rich silty limestone bed marks the top of the lower, acoustically transparent layer which was sampled by Cores 11 through 19 (158-320 m). This transparent layer comprises compact brown clastic silt and clay with minor interbedded nanno ooze containing sponge spicules and at least two beds of lithified silty limestone. Heavy minerals from the silts include zircon, garnet, staurolite, hornblende, and biotite, all of which are characteristic of Precambrian granitic and metamorphic provenance areas. Small manganese nodules were found in the brown clay of Core 15 (275 m). A basal layer, 12 meters thick, is brown nanno ooze and clay. The acoustically transparent layer extends from early middle Miocene to Late Cretaceous (probably late Campanian or Maestrichtian) with a well-established break of about 20 m.y. duration between the late Eocene and late Paleocene at about 270 meters, below which the bulk density, sonic velocity, and acoustic impedance of the sediments show a sudden increase. Apart from the characteristic brown color, the acoustically transparent layer has essentially the same turbidite (though finer grained) and nanno ooze lithologies as the overlying stratified layer, and its contrasted acoustic response on the seismic profile record is not readily explained. The presence of lithified limestone beds and a generally higher degree of compaction are probably responsible for its survival as positive relief forms in outcrop on the floor of the abyssal plain. High plasticity and flowage under differential load of clay members are no doubt responsible for the apparently diapiric behavior of this layer at some localities (see Figures 2 and 5).

At a subbottom depth of 320 meters, the brown upper Campanian nanno ooze rests upon gray basalt, which was cored for 6 meters with 2.2 meters recovery. The basalt is fine-grained, partly glassy tholeiite and shows some weathering and alteration. The presence of thin red glassy zones and occasional wedges of chert and glassy breccia suggest that pillow structure may be present. The sediments in contact with the basalt show no signs of baking or other alteration.

Foraminifera are rare or absent in several cores and are commonly found only in the uppermost part of the

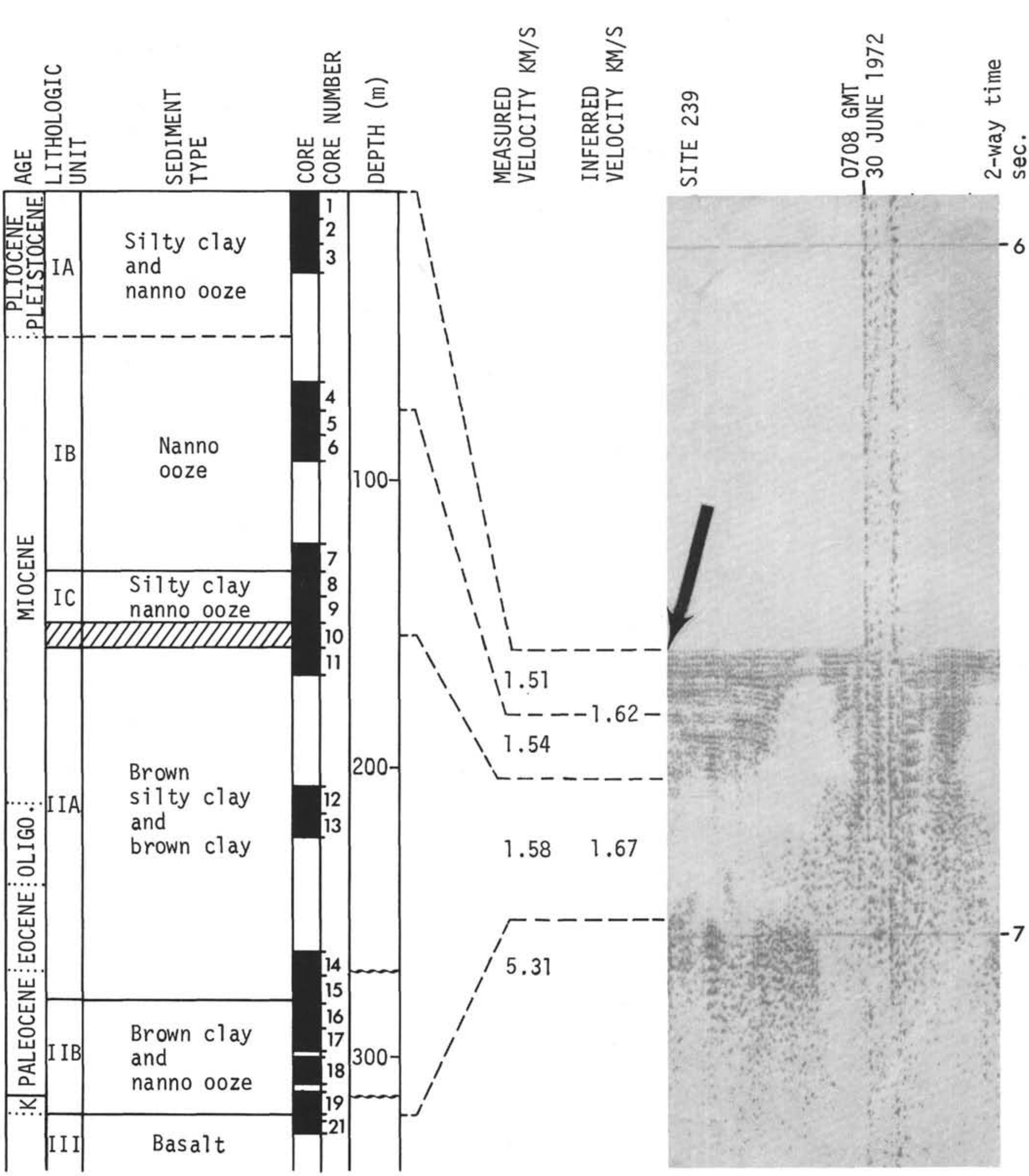

Figure 9. *Correlation of the seismic reflection profile with lithology. Wavy lines in the depth column indicate hiatuses.*

succession. However, they provide some useful data. The percentage of shallow-water (outer shelf) foraminifera in the upper Miocene silt and clay supports the sedimentological evidence for their identification as terrigenous turbidites, probably derived from Madagascar. Core 8 (early/middle Miocene) contains an abundant, very small planktonic foraminiferal fauna which also includes some Paleogene forms; presumably, the older fauna has been introduced into the Miocene by reworking and transport from a different faunal environment.

Nannofossils are well preserved and provided most of the dates shown on Figure 10. Some samples in the Miocene

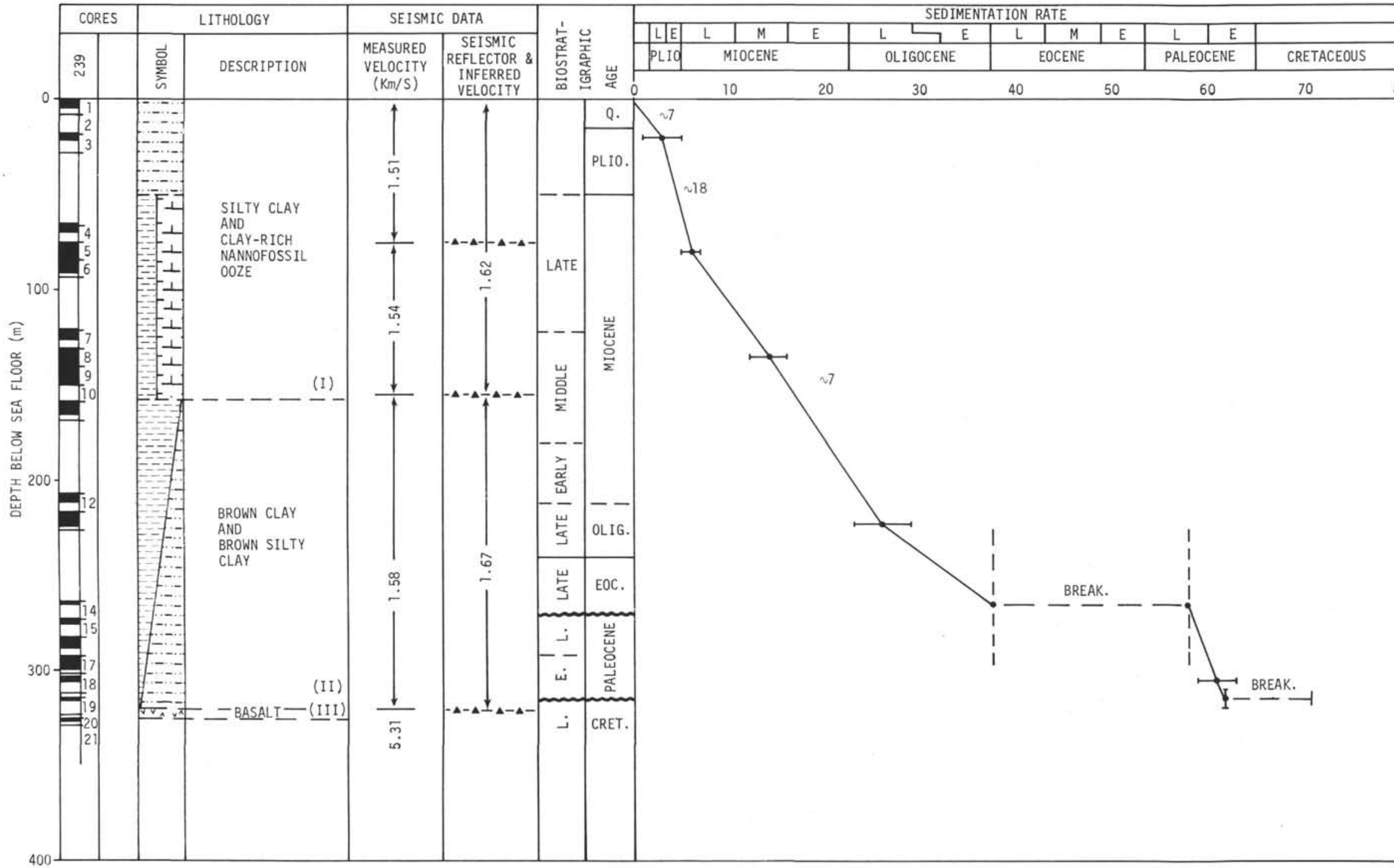

Figure 10. *Summary diagram, Site 239.*

section include many displaced fauna, and the Pliocene/Miocene/Oligocene/Eocene boundaries could not be precisely established and located in the cored section. The stratigraphic section below the Miocene is much compressed due to compaction, to the disconformity between the upper Eocene and upper Paleocene, and probably also to dissolution of biogenic carbonates below the CCD. The average sedimentation rate for well-defined sequences in the Tertiary is 7 m/m.y. However, from late Miocene to late Pliocene, the sedimentation rate rises to 18 m/m.y. In this section, the benthonic foraminifera are from a shallow-water environment and consequently indicate a high influx of sediment to this site.

It is probable that the Pleistocene and Tertiary clastic sediments and continental shelf benthic foraminifera were derived from Madagascar. According to Dixey (1959), the central highlands of Madagascar have been subjected to intermittent uplift and periods of accelerated erosion since at least the early Jurassic. The most extensive of the major erosion surfaces on the island is mid-Tertiary, transgressing Eocene and older rocks, and overlain by Miocene marine limestones. The low sedimentation rate and thickness of Oligocene sediment in the southern Mascarene Basin does not support this conclusion but suggests rather that the island underwent major uplift and accelerated erosion during the Miocene.

The age of basaltic basement at Site 239 is established as pre-late Campanian (>71 m.y.). Magnetic anomalies observed on the way to Site 239, and enroute to Site 240, show some evidence of lineation. Identification of these anomalies was not possible onboard.

Based upon a sea floor spreading model, the sedimentological characteristics correlate well with the following sequence of events:

1. Formation of basaltic crust at the crest of the Central Indian Ridge no later than 71 m.y. B.P.

2. Deposition of pelagic brown clay and nanno ooze near the spreading ridge crest above the CCD (Late Cretaceous to late Paleocene).

3. Spreading ridge flanks subsided below CCD with concomitant deposition of pelagic brown clay and terrigenous detrital brown clay, which were transported from Madagascar by turbitity and other bottom currents. Volcanogenic components were contributed probably from mid-ocean ridge volcanism (late Paleocene to early middle Miocene).

4. Comparatively rapid accumulation of clastic silt and/or clay with consequent preservation of calcareous nannoplankton below the CCD throughout the Neogene and Quaternary. Uplift and erosion of Madagascar was most evident during middle Miocene, followed by relative quiescence (late middle and late Miocene) and renewed epeirogenic activity during Pliocene and Quaternary. Commencement of Mascarene Island volcanic activity occurred in middle Miocene time.

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Site 239 Hole Core 1 Cored Interval: 0-9 m

AGE	ZONE: FORAMS	ZONE: NANNOS	ZONE: RADS	FOSSIL CHARACTER: FORAMS	FOSSIL CHARACTER: NANNOS	FOSSIL CHARACTER: RADS	FOSSIL CHARACTER: OTHERS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
PLIOCENE/PLEISTOCENE	N22			Rf, Rg, Rg, Rg, Tf, Cg	Rg, Ae, Ae, Rg, Ae, Ag, Ag			1, 2, 3, 4, Core Catcher	0.5, 1.0	VOID		25, 40, 46, 70, 130, 60, 149, 90, 140, CC	see below

N5
N9
N4

Core is greatly deformed except near the top where silts and sands are interlayered. Grayish-olive color (10Y4/2) is dominant, but gray (N4 and N5), white (N9), and dark yellow brown (10YR4/2) also occur in the sequence.

10Y4/2

NANNO-BEARING DETRITAL SILTY CLAY and CLAYEY SILT are dominant.
Smears 1-70, 2-60

Texture	Composition	
(0-20-80)	det. clay	75%
	calc. nannos	10%
	qtz. & feld.	10%
	micarb.	5%
	forams	Tr.
	vol. gls.	Tr.
	sp. spic.	Tr.

10YR4/2

Section 1 has silty and clayey sand, foram nanno ooze, and a graded silt bed (65-75 cm). In Sections 2-4 are thin beds of white and gray nanno clay and clayey nanno ooze. A pumice fragment occurs at 4-74.

10Y4/2

FORAM-BEARING CLAY-RICH NANNO OOZE
Smear 2-149

Composition	
calc. nannos	70%
det. clay	20%
micarb.	5%
forams	5%
sp. spic.	Tr.
rads	Tr.

10YR4/2

Grain Size
1-50 (0-37-63) silty clay
1-97 (34-55-11) sandy silt
1-99 (28-58-14) sandy silt

Carbon-Carbonate
1-32 (11.0-0.1-91) 4-80 (5.8-0.1-48)
1-60 (0.3-0.2-1.0) 4-142 (2.7-0.1-22)

10Y4/2

X-ray 1-80		X-ray 4-120	
qtz.	P	calc.	A
k-feld.	P	k-feld.	P
plag.	P	plag.	P
kaol.	P	mont.	P
calc.	P	phil.	P
mica	P	augite	P
gibb.	P	qtz.	T
mont.	T		
amph.	T		
augite	T		

Age is Early Pleistocene according to Foraminifera.

Site 239 Hole Core 2 Cored Interval: 9-18 m

AGE	ZONE: FORAMS	ZONE: NANNOS	ZONE: RADS	FOSSIL CHARACTER: FORAMS	FOSSIL CHARACTER: NANNOS	FOSSIL CHARACTER: RADS	FOSSIL CHARACTER: OTHERS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
LATE PLIOCENE				Rp	Ag			Core Catcher				CC	see below

CARBONATE-BEARING SILT-RICH CLAYEY NANNO OOZE

Composition	
calc. nannos	50%
det. clay	25%
micarb	10%
qtz. & feld.	10%
forams	2%
vol. gls.	2%
chlor.	1%
diatoms	Tr.

Forams are mixed, Recent to Cretaceous.

Site 239 Hole Core 3 Cored Interval: 18-27 m

AGE	ZONE: FORAMS	ZONE: NANNOS	ZONE: RADS	FOSSIL CHARACTER: FORAMS	FOSSIL CHARACTER: NANNOS	FOSSIL CHARACTER: RADS	FOSSIL CHARACTER: OTHERS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
LATE PLIOCENE	N19/20 ∿N20	?		Tp, Tp, Tp, Rf, Tf	Cg, Ae, Re, Ag, Ap, Rf, Rf			1, 2, 3, Core Catcher	0.5, 1.0	VOID		24, 140, 40, 130, CC	see below

5Y4/4

Core is greatly deformed by drilling process. Colors are moderate olive gray (5Y4/4), gray olive (10Y4/2), light olive (10Y5/4), light gray (N7), medium dark gray (N4), gray black (N2), and brown black (5YR2/1).

N4

SILT-BEARING CLAYEY NANNO OOZE
Smear 2-40

10Y5/4
&
10Y4/2

N2

Composition	
calc. nannos	55%
det. clay	35%
qtz. & feld.	5%
micarb.	3%
forams	2%
palag.	Tr.

10Y5/4

NANNO-BEARING DETRITAL SILTY CLAY
Smear 1-24

N7

5YR2/1

N2

Texture	Composition	
(0-30-70)	det. clay	70%
	qtz. & feld.	12%
	micarb.	10%
	calc. nannos	8%
	vol. gls.	Tr.
	forams	Tr.
	diatoms	Tr.

Carbon-rich clay at 1-140.
Nanno-bearing clayey silt in CC.

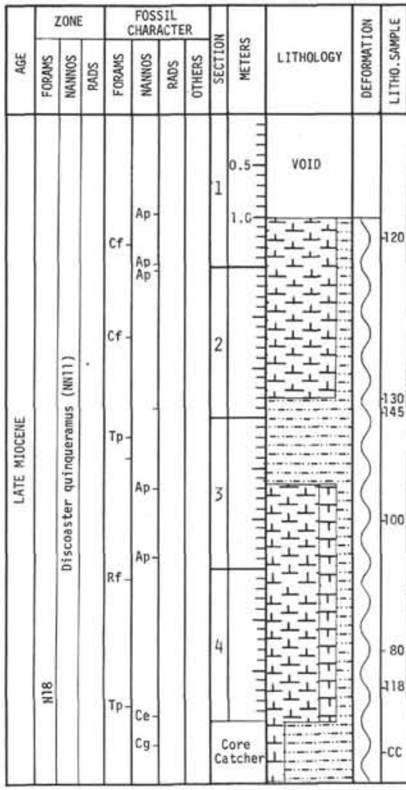
Grain Size
1-132 (0-37-63) silty clay
2-30 (0-33-67) silty clay
3-60 (0-46-54) silty clay

Carbon-Carbonate
1-143 (0.9-0.1-7)
2-41 (2.9-0.2-23)
2-85 (0.8-0.1-6)

X-ray 1-112		X-ray 3-65	
calc.	M	mont.	A
arag.	A	plag.	A
		k-feld.	P
		phil.	P
		calc.	P
		qtz.	T

Explanatory notes in chapter 1

Site 239 Hole Core 4 Cored Interval: 66-75 m



N9 & N8

5Y3/2 & 10Y4/2

N9 & N8

5YR2/1

5GY6/1

LITHOLOGIC DESCRIPTION

Core is deformed, but stiff; some bedding shows grading. Colors are very light gray (N8) and white (N9), olive gray (5Y3/2), gray olive (10Y4/2), green gray (5GY6/1), and brown black (5YR2/1).

CLAY-RICH NANNO OOZE
Smears 1-120, 3-100

Composition			
calc. nannos	70%	micarb.	5%
det. clay	20%	forams	3%
		sp. spic.	2%

FORAM-RICH CLAY-RICH NANNO OOZE
Smears 2-130, 4-118

Composition			
calc. nannos	55%	micarb.	10%
det. clay	20%	sp. spic.	Tr.
forams	15%	rads	Tr.

Displaced benthonic forams are common as are tunicate spicules.

SILTY CLAY
Smear 2-145

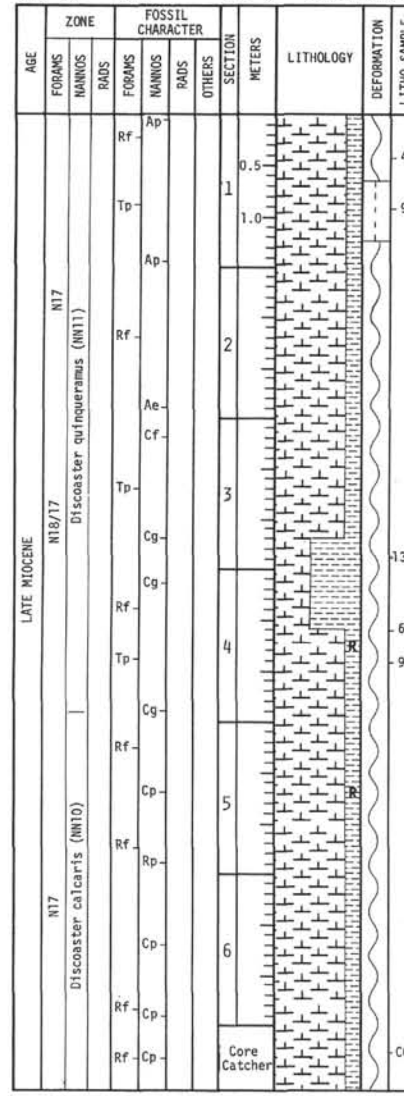
Texture	Composition	
(0-40-60)	det. clay	60%
	qtz. & feld.	30%
	micarb.	5%
	carbonaceous mat.	3%
	carb. rhombs	2%
	sp. spic.	Tr.
	rads	Tr.

Most of the core is detrital. Evidence includes graded biogenous beds, and displaced fauna.

Grain Size	Carbon-Carbonate
2-146 (1-44-55)	2-50 (11.2-0.2-92)
3-30 (0-43-57)	4-90 (4.7-0.1-38)
4-60 (0-36-64)	

Foraminifera from "Chalk" facies.

Site 239 Hole Core 5 Cored Interval: 75-84 m



N8

5Y5/2 & N8

N8

5Y5/2 & 5G6/1

LITHOLOGIC DESCRIPTION

Core is deformed, very soupy in Section 1 to 70 cm, then stiff. Colors are very light gray (N8), light olive gray (5Y5/2) and rare green gray (5G6/1).

CLAY-RICH NANNO OOZE
Smears 1-40, 1-90, 4-90

Composition			
calc. nannos	70%	sp. spic.	Tr.
det. clay	25%	carb. rhombs	Tr.
micarb.	5%		
forams	Tr.		

SILT-BEARING CLAYEY NANNO OOZE
Smear 4-60

Composition	
calc. nannos	55%
det. clay	30%
qtz. & feld.	5%
micarb.	5%
sp. spic.	5%
rads	Tr.

NANNO-RICH DETRITAL CLAY
Smear 3-134

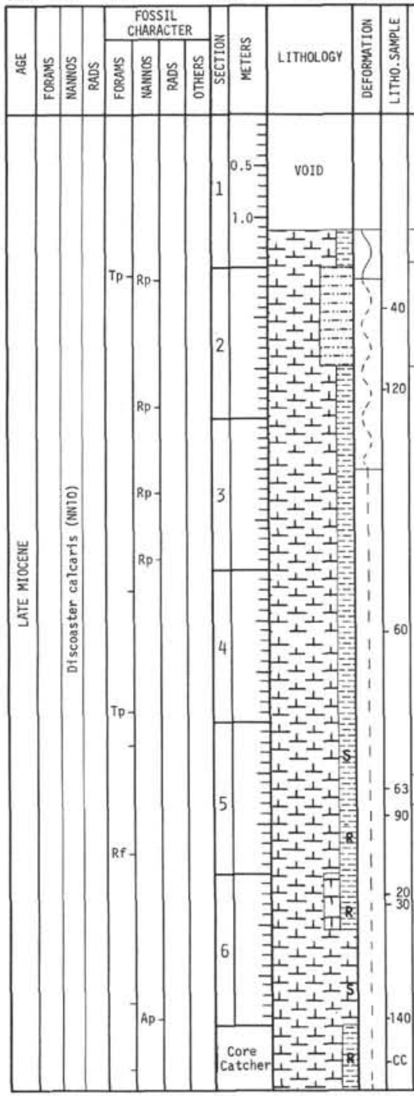
Composition	
det. clay	80%
calc. nannos	15%
micarb.	5%
carb. rhombs	Tr.
hem.	Tr.

Carbon-Carbonate
4-59 (8.3-0.1-68)

Foraminifera mostly from "Chalk" facies.

Explanatory notes in chapter 1

Site 239 Hole Core 6 Cored Interval: 84-93 m



N8

5GY6/1 & 5Y4/1

N8

5YR6/1

N8

LITHOLOGIC DESCRIPTION

Core is slightly to moderately deformed. Colors are very light gray (N8), green gray (5GY6/1), olive gray (5Y4/1), and light brown gray (5YR6/1).

CLAY-RICH NANNO OOZE
Smears 2-40, 2-120, 4-60, 5-63, 5-90
Composition

calc. nannos	70%	forams	Tr.
det. clay	15%	pyrite	Tr.
micarb.	10%	carb. rhombs	Tr.
sp. spic.	5%		

Silty clay and clay-rich nanno ooze interlayered in Section 2. Rads, diatoms, and ostracodes in Sections 5 and 6. Pyrite replaces rads and sp. spic.

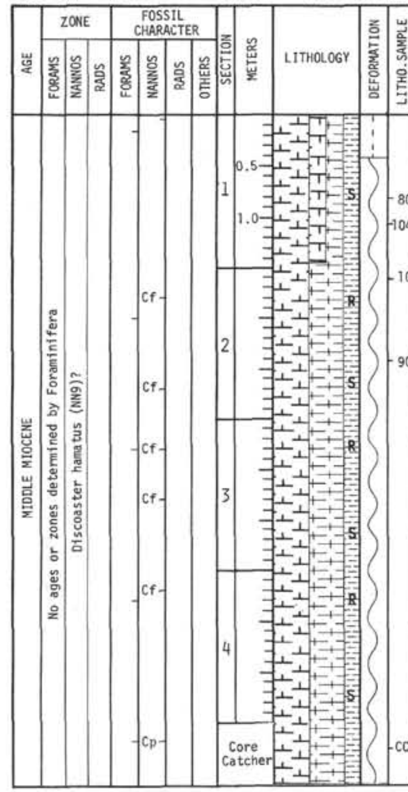
CLAY/FORAM/SPICULE-RICH NANNO OOZE
Smears 6-20, 6-30
Composition

calc. nannos	60%	forams	10%
sp. spic.	15%	micarb.	5%
det. clay	10%	pyrite	Tr.

Carbon-Carbonate
2-60 (6.7-0.2-54)
2-120 (11.2-0.1-93)
5-6 (9.5-0.1-78)
6-130 (11.5-0.1-95)

Foraminifera mostly from "Chalk" facies.

Site 239 Hole Core 7 Cored Interval: 122-131 m



N8

N8 and N9

LITHOLOGIC DESCRIPTION

Core is deformed and quite homogeneous in bottom three sections. Color is mainly very light gray (N8) with greenish gray streaks in Section 1. White (N9) occurs with the gray in Sections 2-4.

CLAY-RICH CARBONATE NANNO OOZE
Smear 2-10
Composition

calc. nannos	55%	det. clay	10%
micarb.	30%	forams	3%
		sp. spic.	2%

FORAM-BEARING CLAY/CARBONATE-RICH NANNO OOZE (minor lithology)
Smear 1-80
Composition

calc. nannos	45%	forams	10%
det. clay	20%	sp. spic.	7%
micarb.	15%	pyrite	3%

Small streaks and blebs are silty clay beds. Some pyrite occurs as black or dark gray blebs. Clay and sponge spicules are ubiquitous; some rads appear in Sections 2 and 3. Abundant micarb. particles plus some silt grains suggest reworking.

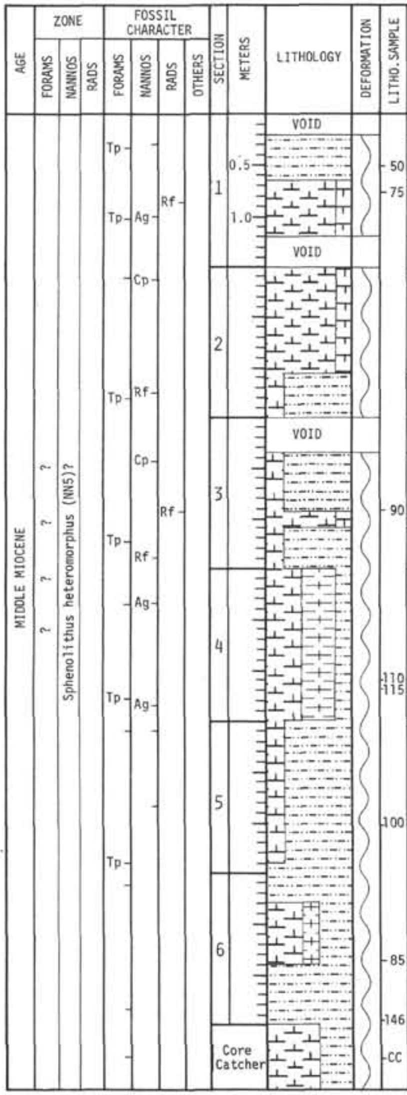
Grain Size
4-135 (0-49-51) silty clay

Carbon-Carbonate
2-95 (10.9-0.1-90)
4-120 (10.9-0.1-90)

Foraminifera from "Chalk" facies.

Explanatory notes in chapter 1

Site 239 Hole Core 8 Cored Interval: 131-140 m



LITHOLOGIC DESCRIPTION

Core is deformed throughout, ranging from drilling breccia to vertical streaking. Colors are N8 very light gray (Foram nanno ooze) and dark greenish gray (5G4/1) silty clay. Moderate yellow brown (10YR5/4) near base of Section 6.

DETRITAL SILTY CLAY
Smears 1-50, 3-90

Texture (5-20-75)	Composition	
	det. clay	70%
	qtz. & feld.	15%
	sp. spic.	5%
heavies include	calc. nannos	5%
	micarb.	3%
staurolite &	vol. gls.	2%
hornblende	heavies	Tr.

FORAM-RICH NANNO OOZE
Smears 1-75, 4-110

Composition	
calc. nannos	80%
forams	13%
det. clay	5%
micarb.	2%

CLAY-RICH CARBONATE NANNO OOZE (minor lithology)
Smear 4-115

Composition	
calc. nannos	55%
micarb.	30%
forams	5%
det. clay	10%

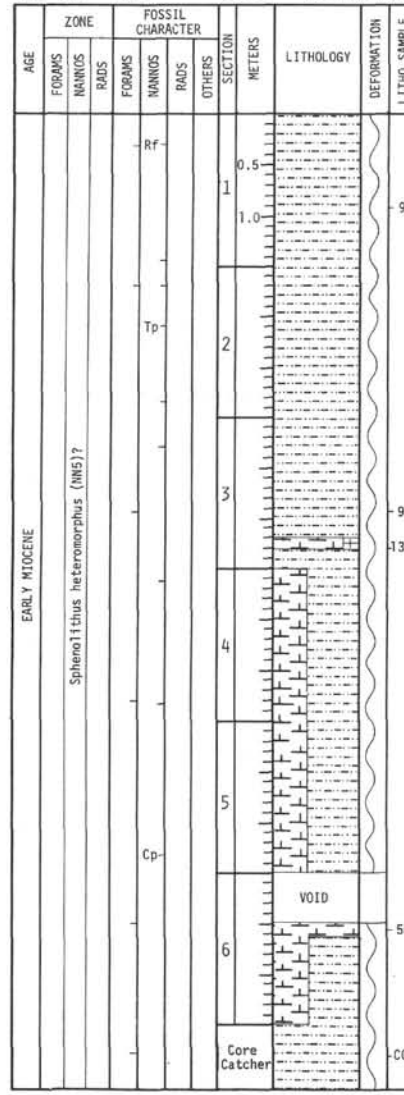
Grain Size
1-45 (0-44-56) silty clay
2-138 (1-42-57) silty clay
5-90 (1-39-60) silty clay

Carbon-Carbonate
5-125 (0.5-0.2-3.0)

X-ray 2-134		X-ray 6-147	
calc.	M	k-feld.	A
arag.	T	plag.	P
plag.	T	kaol.	P
mont.	T	qtz.	P
kaol.	T	mont.	P
k-feld.	T	mica	P
qtz.	T	amph.	T

Foraminifera mostly from "Chalk" facies. Radiolaria of mixed ages, Early Eocene to Middle Miocene.

Site 239 Hole Core 9 Cored Interval: 140-149 m



LITHOLOGIC DESCRIPTION

Core is deformed but stiff. Much is marbelized and Sections 1, 2 and 5 are drilling breccias. Light olive gray color (5Y5/2) is dominant through Section 3; then moderate yellow brown (10YR5/4) is dominant. Streaks and beds of very light gray (N8), gray orange (10YR7/4), and dark green gray (5G4/1) are common.

DETRITAL SILTY CLAY
Smears 1-90, 3-90, CC

Texture (3-22-75)	Composition	
	det. clay	80%
	qtz. & feld.	15%
heavies include	vol. gls.	2%
	hem.	1%
hornblende &	calc. nannos	1%
garnet	heavies	1%

CARBONATE-RICH NANNO OOZE
Smears 3-130, 6-55

Composition	
calc. nannos	80%
micarb.	15%
sp. spic.	3%
forams	2%
rads	Tr.
pyrite	Tr.

Beds of silty clay and nanno ooze are interlayered in Sections 4 and 5. Yellow brown silty clay beds are dominant. Core is mostly detrital.

Grain Size
2-85 (0-29-71) silty clay

Carbon-Carbonate
1-110 (0.2-0.1-0)
3-85 (0.2-0.1-0)

X-ray 2-120			
calc.	A	kaol.	P
plag.	P	mont.	P
k-feld.	P	mica	P
qtz.	P	amph.	T

Explanatory notes in chapter 1

Site 239 Hole Core 10 Cored Interval: 149-158 m

AGE	ZONE: FORAMS	ZONE: NANNOS	ZONE: RADS	FOSSIL CHARACTER: FORAMS	NANNOS	RADS	OTHERS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
?								Core Catcher				CC	5Y4/1 olive gray

DETRITAL SILTY CLAY

Texture	Composition	
(3-22-75)	det. clay	75%
	qtz. & feld.	20%
heavies include opaque iron ores (dominant) & biotite (Tr.)	heavies	2%
	vol. gls.	1%
	calc. nannos	1%
	rads	1%

Site 239 Hole Core 11 Cored Interval: 158-167 m

AGE	ZONE: FORAMS	ZONE: NANNOS	ZONE: RADS	FOSSIL CHARACTER: FORAMS	NANNOS	RADS	OTHERS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE
?								1	0.5, 1.0	VOID		40, 42, 105
								2				15
								3				70
								4				
								5				70
								Core Catcher				CC

LITHOLOGIC DESCRIPTION

Core is deformed but very stiff. Major change top to brown color. Limestone bed in Section 1 may be a major reflector. Color is moderate yellow brown (10YR5/4) with some green gray and very light gray (N8) streaks and blebs.

10YR5/4 with dark gray streaks

BROWN SILTY CLAY
Smears 1-105, 5-70, CC

Texture	Composition	
(0-20-80)	clay min.	80%
	qtz. & feld.	12%
	opaques	7%
	heavies	1%

BROWN CLAYEY SILT
Smears 1-40, 2-15, 3-70

Texture	Composition	
(5-55-40)	qtz. & feld.	45%
	clay min.	40%
	micarb.	7%
	opaques	5%
	heavies	3%

Heavies include hornblende, biotite, rutile, garnet, zircon, and epidote.

10YR5/4 with green gray and very light gray streaks

GYPSUM-RICH SILTY LIMESTONE (minor lithology)
Thin Section 1-42

Composition	
carbonate	50%
qtz. & feld.	25%
gypsum	20%
clay min.	5%

Carbon-Carbonate
1-90 (0.1-0.1-0)
2-69 (0.2-0.1-0)
3-66 (1.4-0.1-11)

X-ray 1-115		X-ray 4-10	
k-feld.	A	kaol.	A
mont.	P	mont.	P
qtz.	P	k-feld.	P
kaol.	P	qtz.	P
plag.	P	mica	P
mica	P	plag.	P

10YR5/4

Sediment has no calcareous nannos or Foraminifera.

Site 239 Hole Core 12 Cored Interval: 206-215 m

AGE	ZONE: FORAMS	ZONE: NANNOS	ZONE: RADS	FOSSIL CHARACTER: FORAMS	NANNOS	RADS	OTHERS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE
?								1	0.5, 1.0	VOID		30
								2		VOID		
								3				
								4				80
			Tp					Core Catcher				CC

LITHOLOGIC DESCRIPTION

10YR5/4
10YR4/2

Core is moderately deformed with some areas stiff and soupy. Colors are moderate yellow brown (10YR5/4) and dark yellow brown (10YR4/2) with rare green gray (5G6/1) fragments.

BROWN SILTY CLAY
Smears 1-30, 4-80, CC

Texture	Composition	
(0-25-75)	clay min.	75%
	qtz. & feld.	20%
	opaques	4%
	heavies	1%
	palag.	Tr.

10YR5/4

Carbon-Carbonate
1-103 (0.1-0.1-0)

10YR5/4 with 10YR4/2 and 5G6/1 streaks and fragments

Explanatory notes in chapter 1

Site 239 Hole Core 13 Cored Interval: 215-224 m

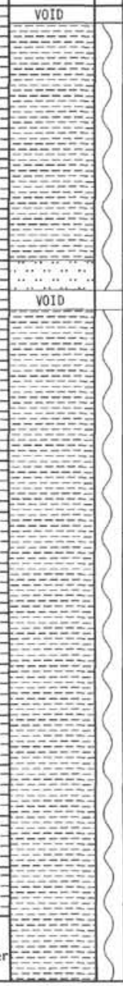
AGE: LATE OLIGOCENE

ZONE: NANNOS: Sphenolithus ciperoensis (NP25); FORAMS: ?

FOSSIL CHARACTER (NANNOS): Tp, Rf, Tf, Rf, Rf, Tp

SECTIONS: 1, 2, 3, 4, 5, 6, Core Catcher (METERS 0.5, 1.0)

LITHOLOGY



LITHO. SAMPLE: 65, 90, 109, 124, 25, 70, CC

LITHOLOGIC DESCRIPTION

Core is deformed but stiff. Colors are moderate yellow brown (10YR5/4), moderate brown (5YR3/4), dark yellow brown (10YR4/2), and green gray (5GY6/1). Because of deformation (drilling breccia), core appears variegated in these colors. Browns are dominant; greens are very minor.

10YR5/4
5YR3/4
10YR4/2
5GY6/1

BROWN CLAY (SILT-BEARING)
Smears 1-65, 2-90, 2-124, 3-25

Texture	Composition	
(0-10-90)	clay min.	90%
	qtz. & feld.	8%
	opaques	2%
	heavies	Tr.

Some gypsum in Section 1.

10YR4/2

BROWN CLAY (SILT-RICH)
Smear 4-70

5YR3/4

Texture	Composition	
(2-20-78)	clay min.	78%
	qtz. & feld.	20%
	opaques	1%
	heavies	1%
	palag.	Tr.

Heavies include hornblende, zircon, garnet, and biotite.

BROWN CLAYEY SILT
Smear 2-109

10YR4/2 with 5YR3/4 10YR5/4 5GY6/1

Texture	Composition	
(5-60-35)	qtz. & feld.	60%
	clay min.	35%
	heavies	3%
	opaques	2%

Heavies include hornblende, apatite, garnet, zircon, and epidote.

Grain Size
2-108 (5-50-45)

Carbon-Carbonate
2-90 (0.1-0.1-0)
3-5 (0.1-0.1-0)

X-ray 2-85	
mont.	M
k-feld.	P
plag.	P
qtz.	T

X-ray 3-20.5	
k-feld.	A
mont.	P
kaol.	P
paly.	P
mica	P
qtz.	P
plag.	P

Samples contain no Foraminifera.

5GY6/1

Site 239 Hole Core 14 Cored Interval: 263-272 m

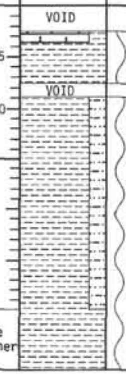
AGE: LATE EOCENE

ZONE: NANNOS: >late Middle Eocene, Sphenolithus pseudoradians (NP20)

FOSSIL CHARACTER: FORAMS: Cp, Tp, Tp, Tp; NANNOS: Rf

SECTIONS: 1, 2, Core Catcher (METERS 0.5, 1.0)

LITHOLOGY



LITHO. SAMPLE: 30, 60, 105, 136, CC

LITHOLOGIC DESCRIPTION

Core is deformed and stiff. Entire core is moderate brown (5YR4/4).

BROWN SILTY CLAY
Smears 1-105, 2-136

Texture	Composition	
(0-25-75)	clay min.	75%
	qtz. & feld.	22%
	opaques	3%
	heavies	Tr.
	gypsum	Tr.

BROWN CLAY (SILT-RICH)
Smears 1-60, CC

Texture	Composition	
(0-15-85)	clay min.	85%
	qtz. & feld.	12%
	opaques	3%
	heavies	Tr.

CLAY-RICH CARBONATE NANNO CHALK
Smear 1-30

Composition	
calc. nannos	45%
micarb.	35%
clay min.	15%
opaques	3%
forams	2%

Grain Size
2-146 (0-15-85) clay

Carbon-Carbonate
1-30 (9.0-0.1-74)

X-ray 1-50

paly.	A	kaol.	P
qtz.	P	mica	P
k-feld.	P	mont.	P
plag.	P	chlor.	T

Explanatory notes in chapter 1

Site 239 Hole Core 15 Cored Interval: 272-281 m

AGE	ZONE: FORAMS	ZONE: NANNOS	ZONE: RADS	FOSSIL CHARACTER: FORAMS	FOSSIL CHARACTER: NANNOS	FOSSIL CHARACTER: RADS	FOSSIL CHARACTER: OTHERS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
LATE PALEOCENE	Paleocene	Fasciculithus tympaniformis (NP5)		Tf, Rf, Rf, Rp, Rg	Cf, Rf, Cf, Cf, Rf			1, 2, 3, Core Catcher	0.5, 1.0	VOID		130, 75, 70, 120, CC	5YR3/4; 5YR3/4 & 5YR5/6

Core is stiff and has good bedding, particularly in Section 3. Section 2 is soupy. Colors are moderate brown (5YR3/4) and light brown (5YR5/6).

BROWN CLAY (SILT-BEARING)
Smears 1-130, 2-75, 3-120

Texture	Composition	
(0-10-90)	clay min.	90%
	qtz. & feld.	5%
	opaques	5%

CLAY-RICH NANNO OOZE
Smear 3-70

Composition	
calc. nannos	70%
micarb.	15%
clay min.	15%

Small manganese nodules in Sections 1 and 3.

Carbon-Carbonate
2-75 (0.1-0.1-0)
2-127 (0.1-0.1-0)

X-ray 2-69

mont.	A
k-feld.	A
plag.	P
qtz.	P
mica	P
kaol.	T

Site 239 Hole Core 16 Cored Interval: 281-290 m

AGE	ZONE: FORAMS	ZONE: NANNOS	ZONE: RADS	FOSSIL CHARACTER: FORAMS	FOSSIL CHARACTER: NANNOS	FOSSIL CHARACTER: RADS	FOSSIL CHARACTER: OTHERS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
LATE PALEOCENE	? Globigerina daubjergensis (P1)	Fasciculithus tympaniformis (NP5)		Rf, Rf, Rp, Tp, Rp, Tp, Rp	Cf, Tp, Tf			1, 2, 3, 4, Core Catcher	0.5, 1.0	VOID		90, 80, 135, CC	5YR3/4; 5YR2/2; 10YR4/2

Core is stiff and moderately deformed. Some bedding is preserved. Colors are dusky brown (5YR2/2), moderate brown (5YR3/4), and dark yellow brown (10YR4/2).

BROWN CLAY (SILT-BEARING)
Smears 2-80, 4-135

Texture	Composition	
(0-10-90)	clay min.	90%
	qtz. & feld.	5%
	opaques	5%
	calc. nannos	Tr.

NANNO-BEARING CARBONATE-RICH BROWN CLAY
Smear 1-90

Composition	
clay min.	70%
micarb.	20%
calc. nannos	5%
qtz. & opaques	5%

Explanatory notes in chapter 1

Site 239 Hole Core 17 Cored Interval: 290-298 m

AGE | ZONE (FORAMS, NANNOS, RADS) | FOSSIL CHARACTER (FORAMS, NANNOS, RADS, OTHERS) | SECTION | METERS | LITHOLOGY | DEFORMATION | LITHO. SAMPLE | LITHOLOGIC DESCRIPTION

LATE PALEOCENE — Paleocene s.l. — Fasciculithus tympaniformis (NP5)

EARLY PALEOCENE — Globigerina daubjergensis (P1) — Paleocene s.l. — Cruciplacolithus tenuis/Chiasmolithus danicus (NP2/NP3)

Fossil character: Tp Tp; Tp; Rf; Tp; Tp Cf; Tp; Tf; Rf Cf; Rf Rf; Pf Rf; Tp Tp; Tp Tp; Rf Tp

Sections: 1, 2, 3, 4, 5, 6, Core Catcher (0.5, 1.0 m); VOID

Litho. samples: 85, 123, 2, 90, 52, 142, 60, 130, 30, 120, CC

5YR3/2 & 5YR2/2

10YR4/2 & 5YR4/4

5YR3/4, 5YR3/2, & 5G6/1

5YR3/2

5YR3/4

5YR4/4 & 5YR3/4

5YR3/4

Core is soupy near top but becomes stiffer and less deformed with depth. Colors are moderate brown (5YR3/4 and 5YR4/4), gray brown (5YR3/2), and dusky brown (5YR2/2), with small amounts of dark yellow brown (10YR4/2) and green gray (5G6/1).

BROWN CLAY (SILT-BEARING)
Smears 1-85, 1-123, 6-30, CC

Texture	Composition	
(0-10-90)	clay min.	90%
	qtz. & feld.	5%
	opaques	5%

NANNO BROWN CLAY
Smears 4-52, 4-142, 5-60

Composition	
clay min.	55%
calc. nannos	40%
qtz. & opaques	5%

CLAYEY NANNO OOZE
Smear 5-130

Composition	
calc. nannos	55%
clay min.	40%
qtz. & opaques	5%

Brown clay is dominant. Thin interbeds of nanno clay begin in Section 2 and become abundant in Sections 4 and 5. Some brown clay beds are silt-bearing to silt-rich. Clayey nanno ooze beds are lighter colored. Nannos are poorly preserved.

Carbon-Carbonate
5-81 (2.7-0.3-20)

Site 239 Hole Core 18 Cored Interval: 300-309 m

AGE | ZONE (FORAMS, NANNOS, RADS) | FOSSIL CHARACTER (FORAMS, NANNOS, RADS, OTHERS) | SECTION | METERS | LITHOLOGY | DEFORMATION | LITHO. SAMPLE | LITHOLOGIC DESCRIPTION

EARLY PALEOCENE — Paleocene s.l. ? — Cruciplacolithus tenuis/Chiasmolithus danicus (NP2/NP3)

Fossil character: Cf; Tp Af; Cf; Rf; Cf; Tp; Tp; Tp; Tp Tp; Tb

Sections: 1, 2, 3, Core Catcher (0.5, 1.0 m); VOID

Litho. samples: 54, 100, 77, 100, CC

5YR3/4

5YR3/4 with some streaks of 5YR5/6

5YR4/4

Core is stiff, only slightly deformed. Colors are moderate brown (5YR3/4) and (5YR4/4) and light brown (5YR5/6).

BROWN CLAY
Smears 1-54, 1-100, 2-77, CC

Texture	Composition	
(0-5-95)	clay min.	95%
	qtz. & opaques	5%

NANNO-RICH BROWN CLAY
Smear 3-100

Composition	
clay min.	80%
calc. nannos	15%
qtz. & opaques	5%

Carbon-Carbonate
1-90 (0.1-0.1-0)

X-ray 2-110

k-feld.	A	plag.	P
qtz.	P	mont.	T
mica	P	paly.	T
		chlor.	T

Silt-rich (15%) brown clay in core catcher. Silt grains include qtz., feld., hematite, opaques.

Site 239 Hole Core 19 Cored Interval: 312-320 m

AGE | ZONE (FORAMS, NANNOS, RADS) | FOSSIL CHARACTER (FORAMS, NANNOS, RADS, OTHERS) | SECTION | METERS | LITHOLOGY | DEFORMATION | LITHO. SAMPLE | LITHOLOGIC DESCRIPTION

EARLY PALEOCENE — Paleocene — (NP2/NP3)

LATE CRETACEOUS — Late Senonian — Campanian

Fossil character: Cg; Tp; Tp; Tp Ag; Rf; Cf; Ce Cf

Sections: 1, 2, Core Catcher (0.5, 1.0 m); VOID

Litho. samples: 100, 40, 95, CC

Core is greatly deformed drilling breccia. Colors are moderate brown (5YR4/4 and 5YR3/4) and green gray (5G6/1).

NANNO-RICH BROWN CLAY
Smears 2-40, 2-95

Composition	
clay min.	80%
calc. nannos	15%
qtz. & opaques	5%

CLAYEY NANNO OOZE
Smear CC

Composition	
calc. nannos	65%
clay min.	30%
qtz. & opaques	5%

Cretaceous forams are all benthonic from upper and middle slope. Nannos are well preserved.

BLACK VARIOLITIC BASALT

Explanatory notes in chapter 1

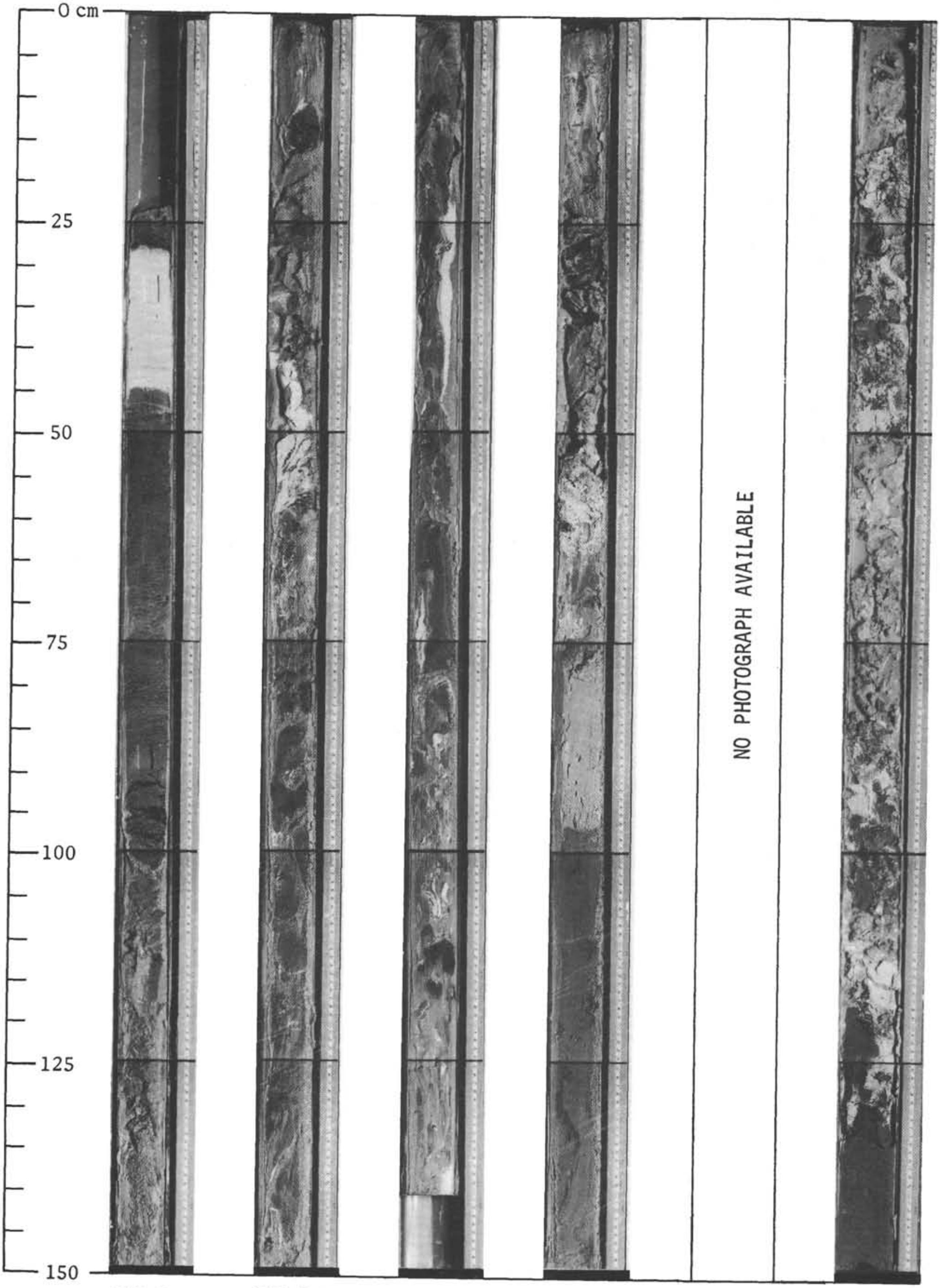
Site 239 Hole Core 20 Cored Interval: 320-322 m

AGE	ZONE: FORAMS	ZONE: NANNOS	ZONE: RADS	FOSSIL CHARACTER: FORAMS	FOSSIL CHARACTER: NANNOS	FOSSIL CHARACTER: RADS	FOSSIL CHARACTER: OTHERS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
								1	0.5 1.0	VOID		115	Colors are medium dark gray (N4) on fresh surface, and medium light gray (N5) on weathered surface. N4 medium dark gray fresh surface; N5 medium light gray to 5GY6/1 green gray on weathered surface BASALT, fine grained, crystalline, in places cut by irregular iron-stained carbonate fractures <2 mm wide. Cross cutting glassy zone @ 135 cm, now chloritized.
								Core Catcher				CC	

Site 239 Hole Core 21 Cored Interval: 322-326 m

AGE	ZONE: FORAMS	ZONE: NANNOS	ZONE: RADS	FOSSIL CHARACTER: FORAMS	FOSSIL CHARACTER: NANNOS	FOSSIL CHARACTER: RADS	FOSSIL CHARACTER: OTHERS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
								1	0.5 1.0	VOID		60 86	Colors are dark gray (N3) and medium dark gray (N4). BASALT, fine grained, dense, crystalline. Moderate yellow brown sediment at 45 cm; glassy contact zones at 50 cm and 80-85 cm; fractured; deeply weathered; calcite and chlorite occur as veins in some fractured areas.
								Core Catcher				CC	

Explanatory notes in chapter 1



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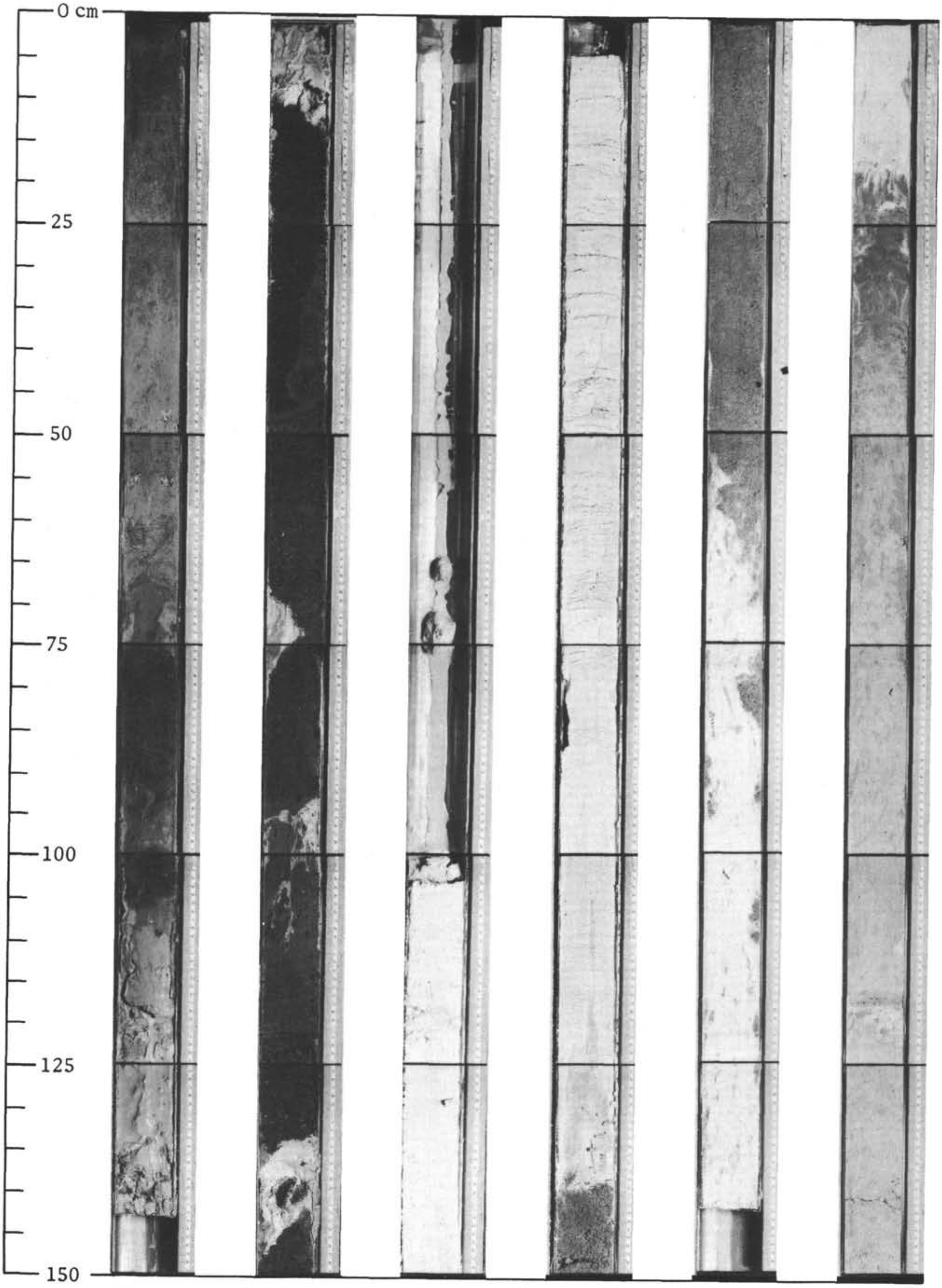
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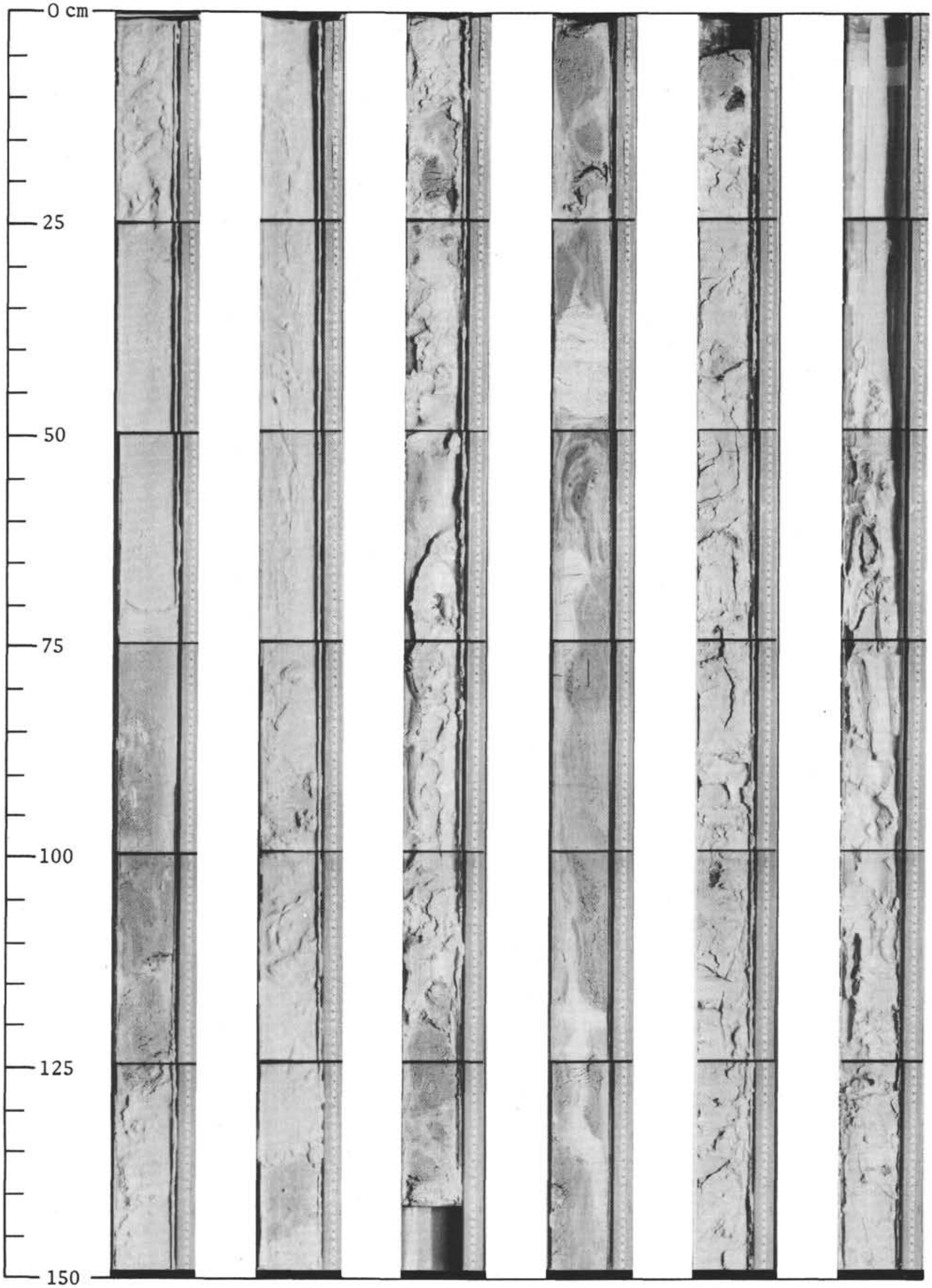
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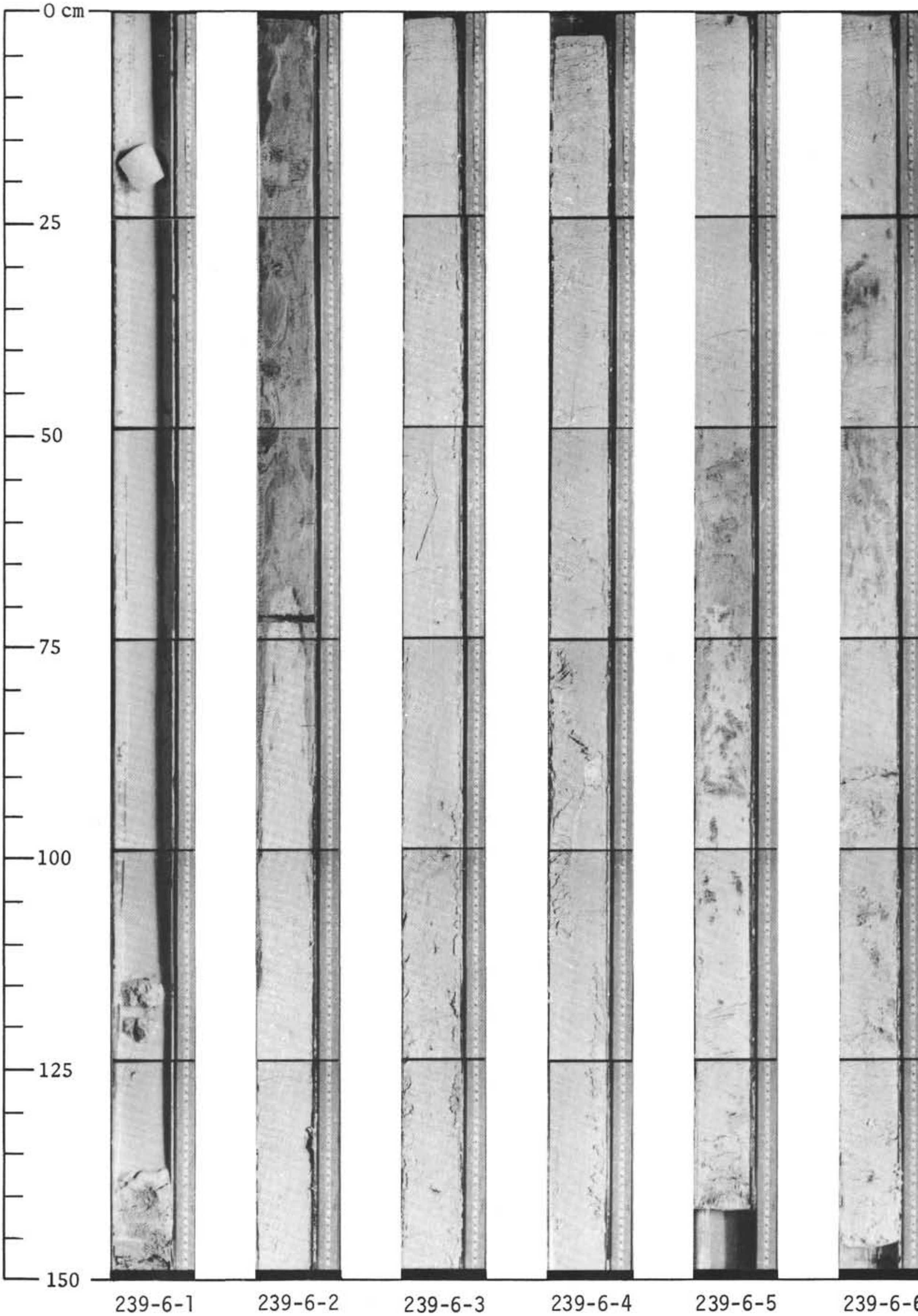
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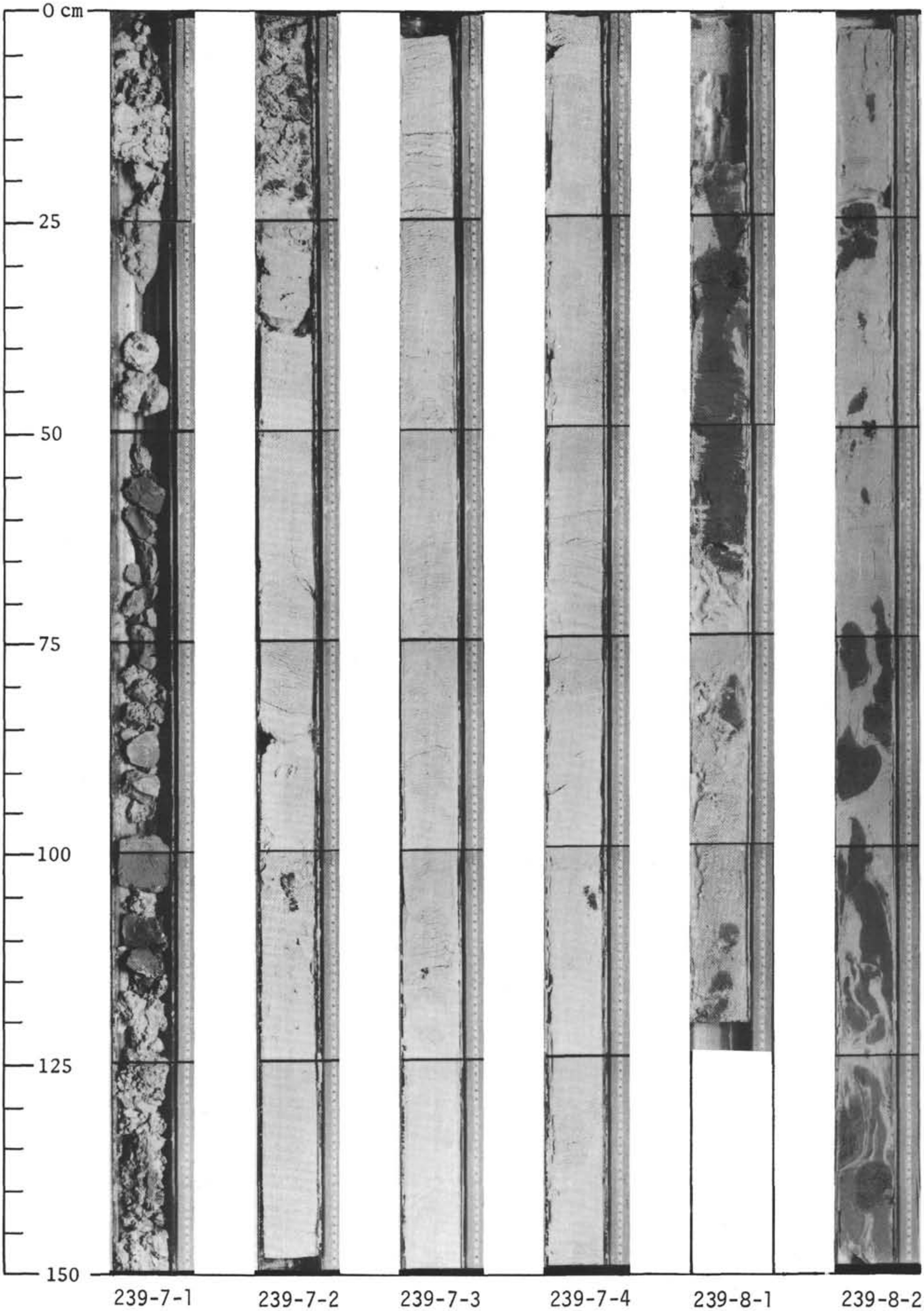
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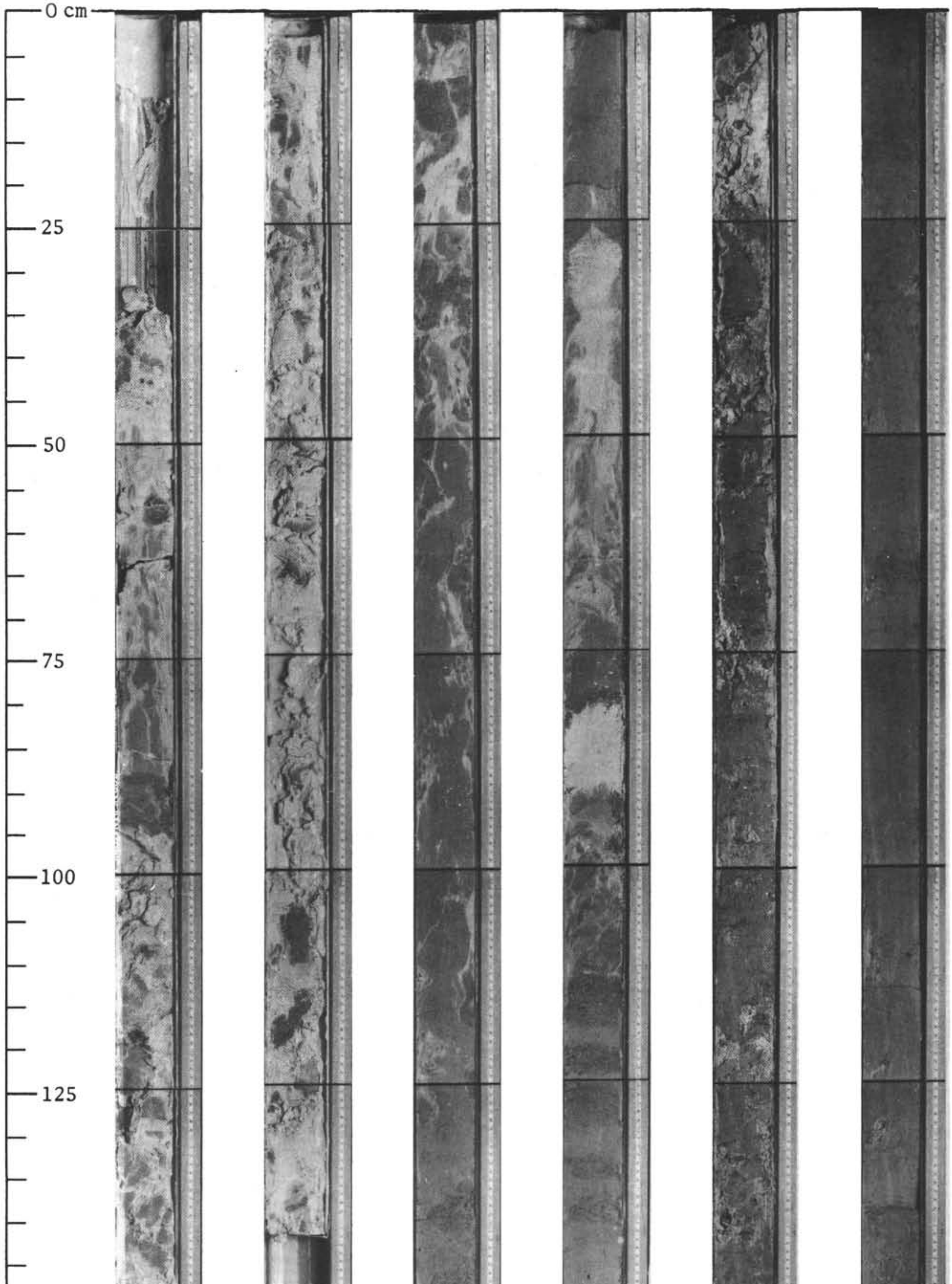
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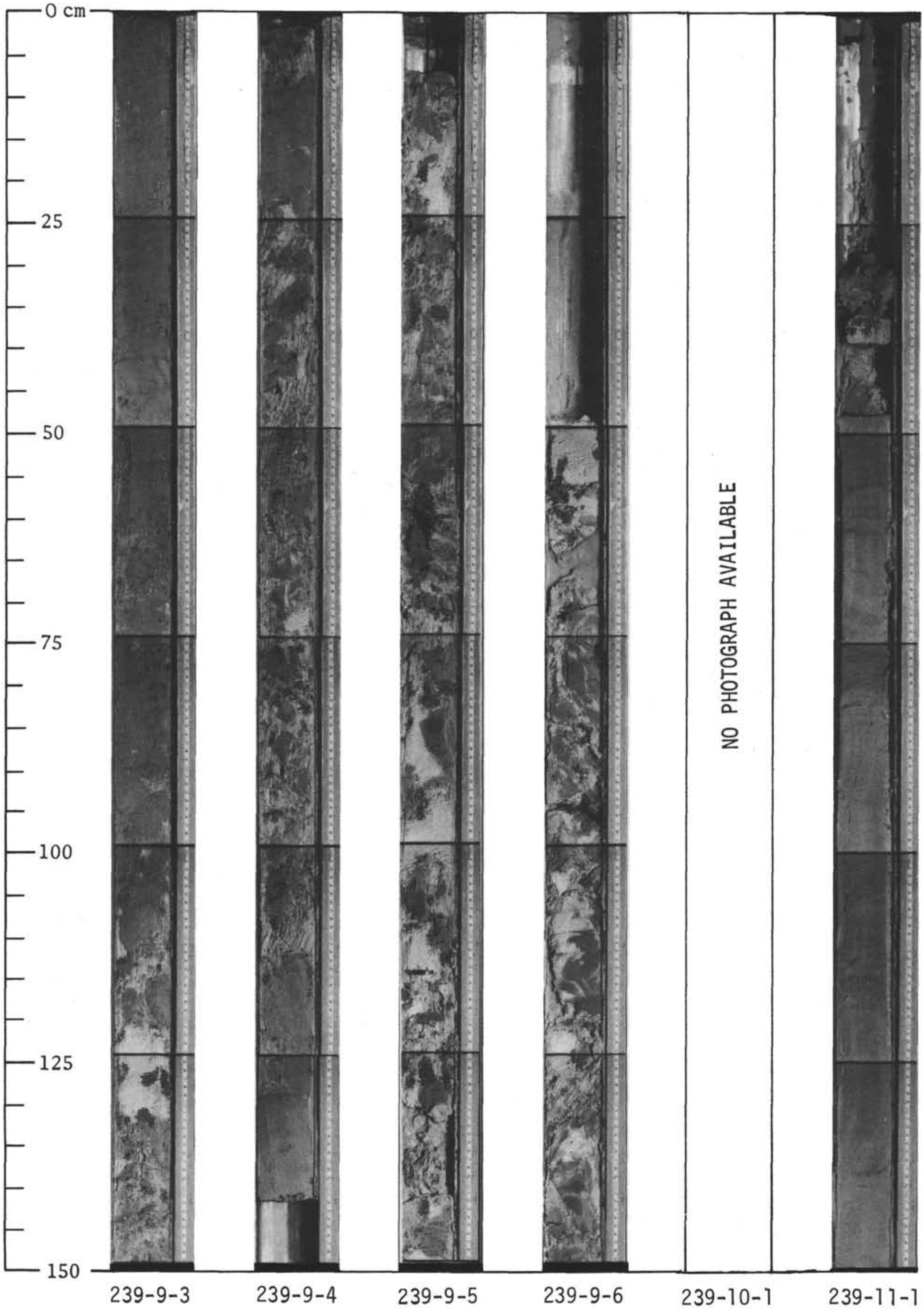
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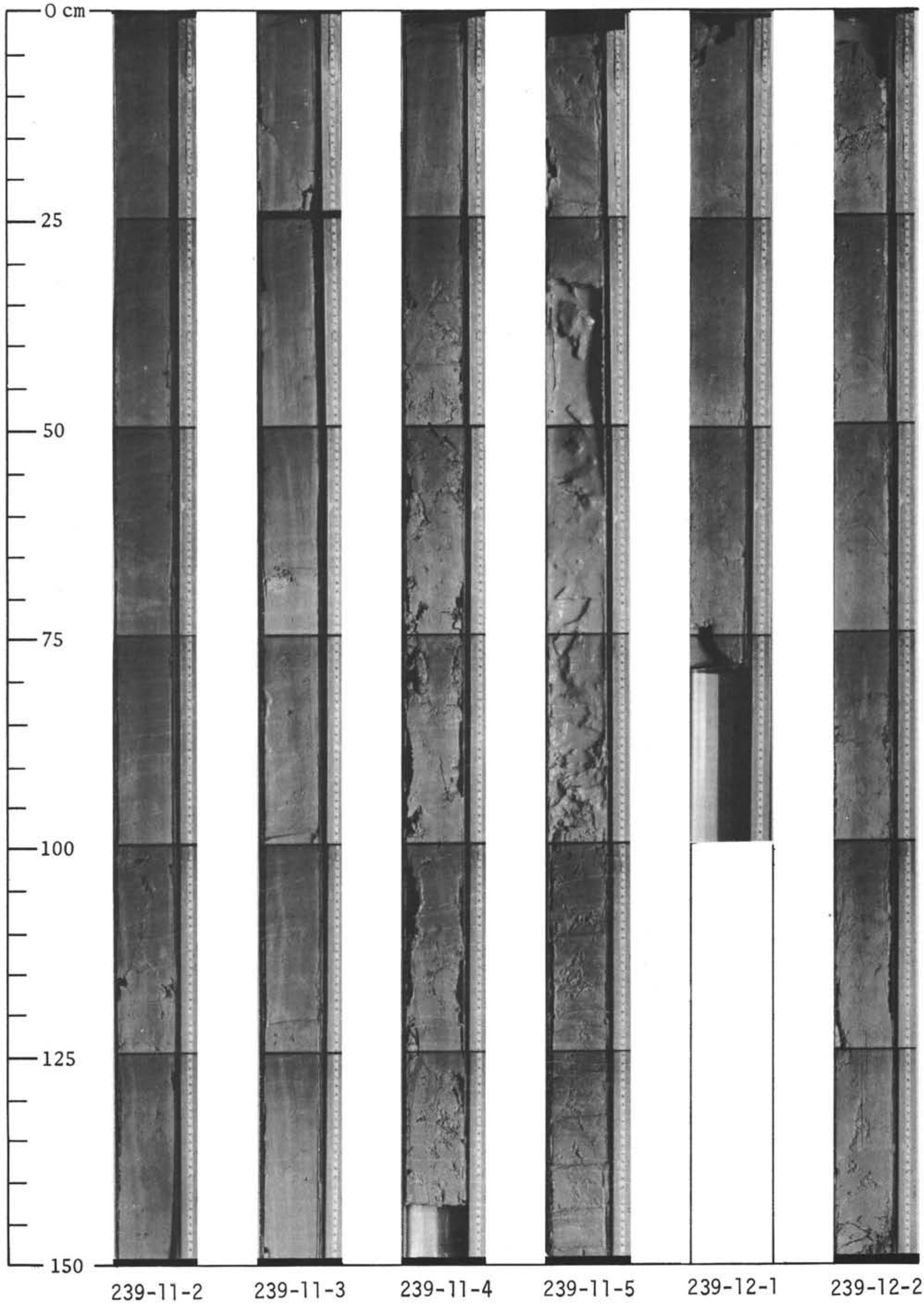
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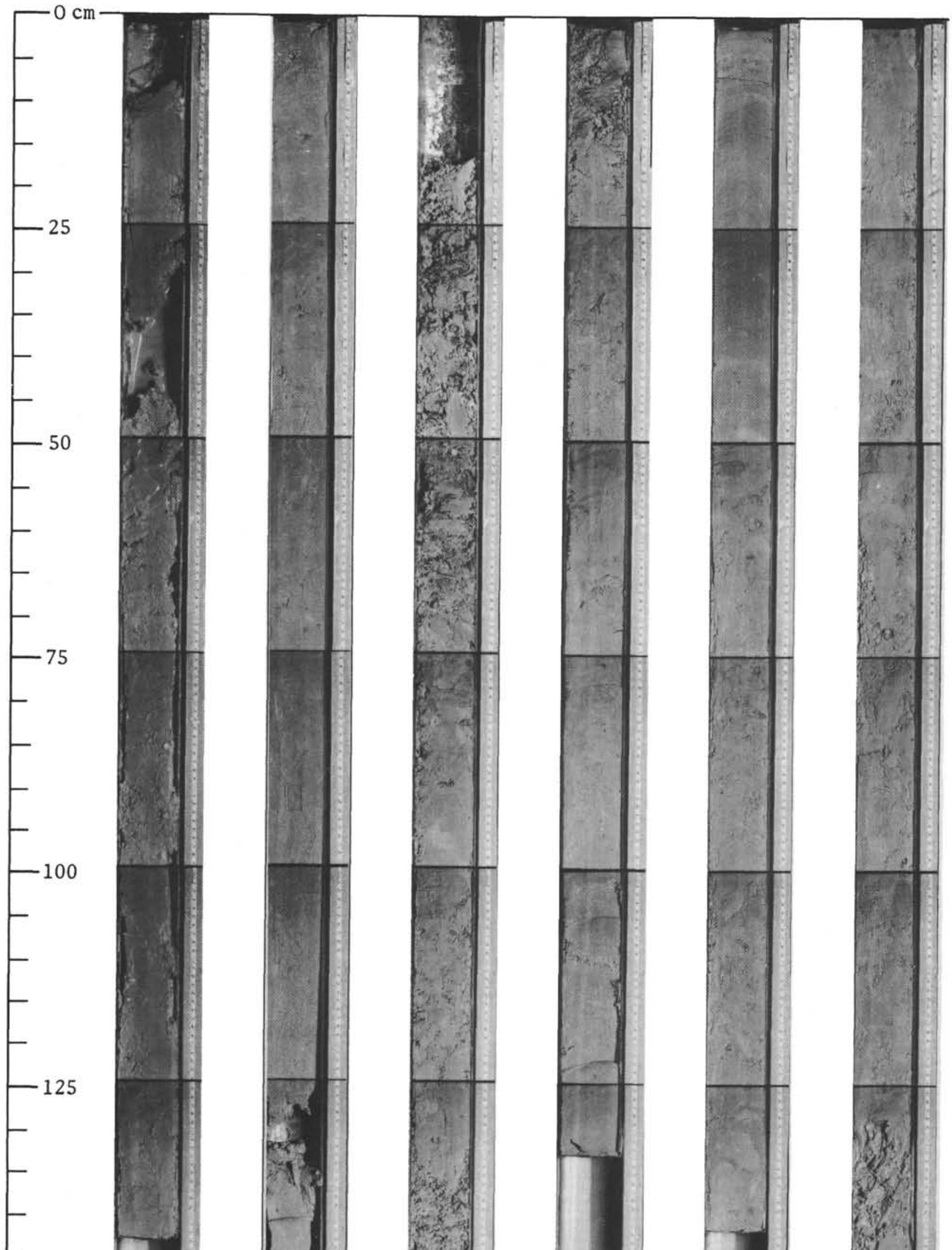
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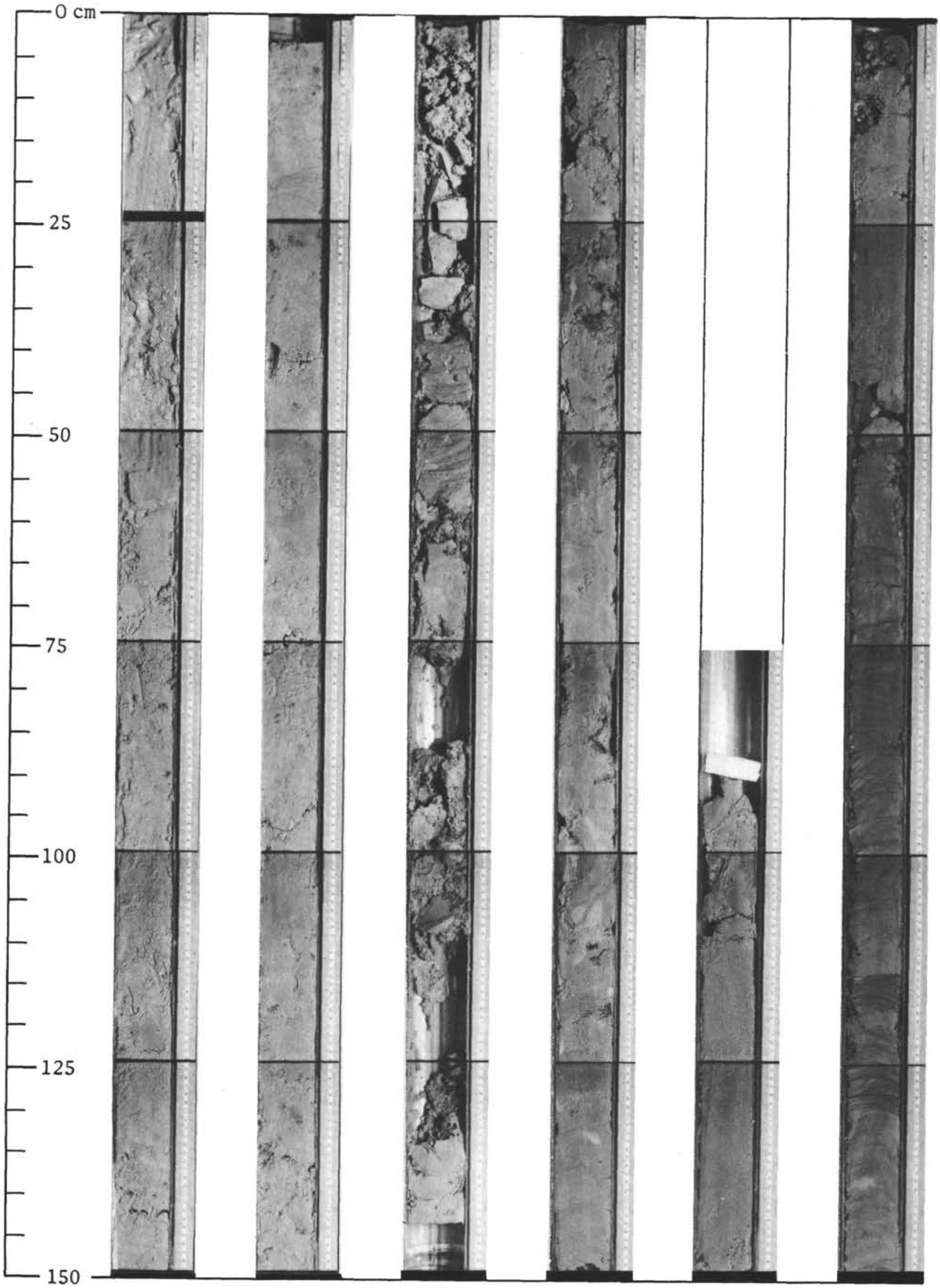
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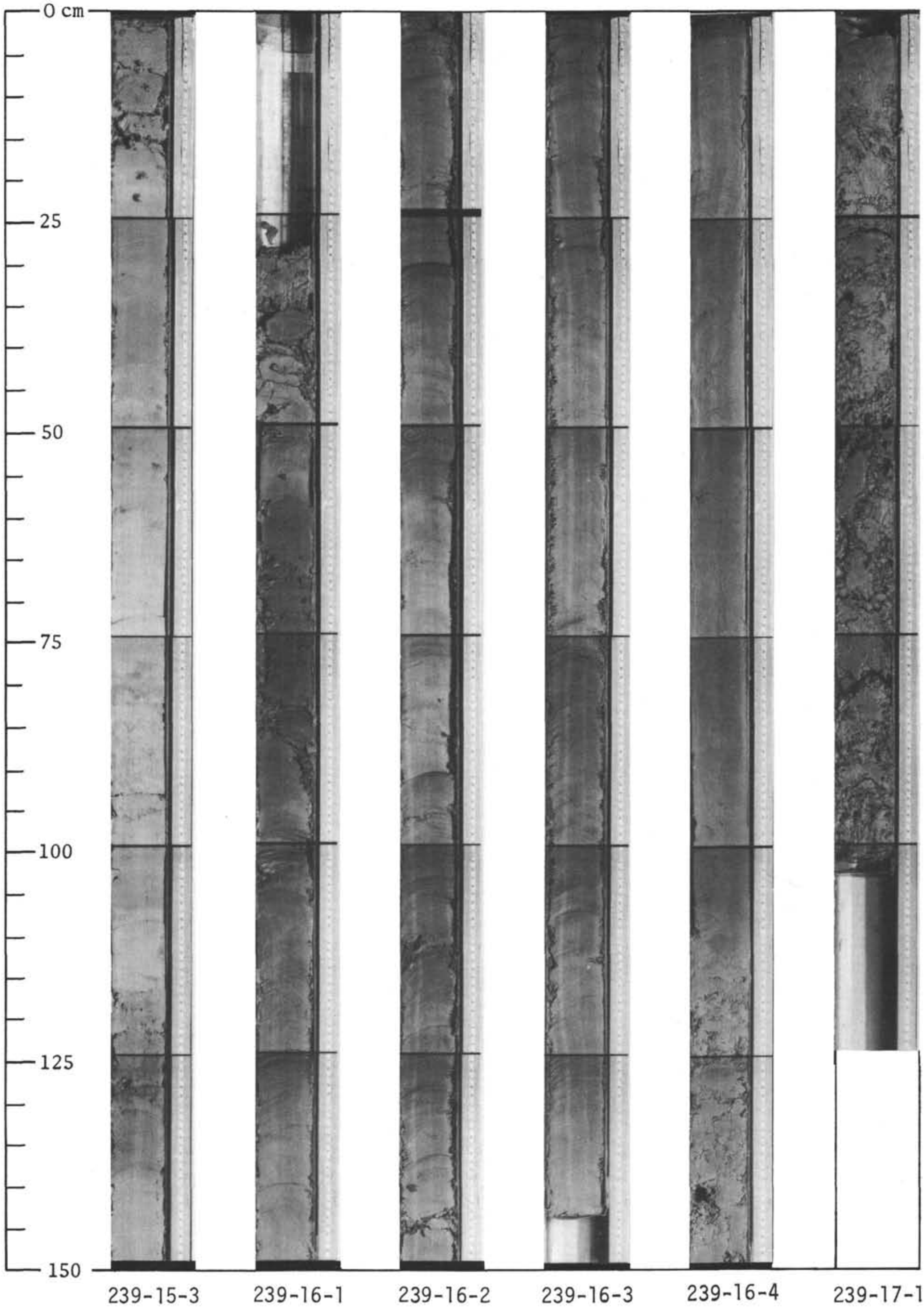
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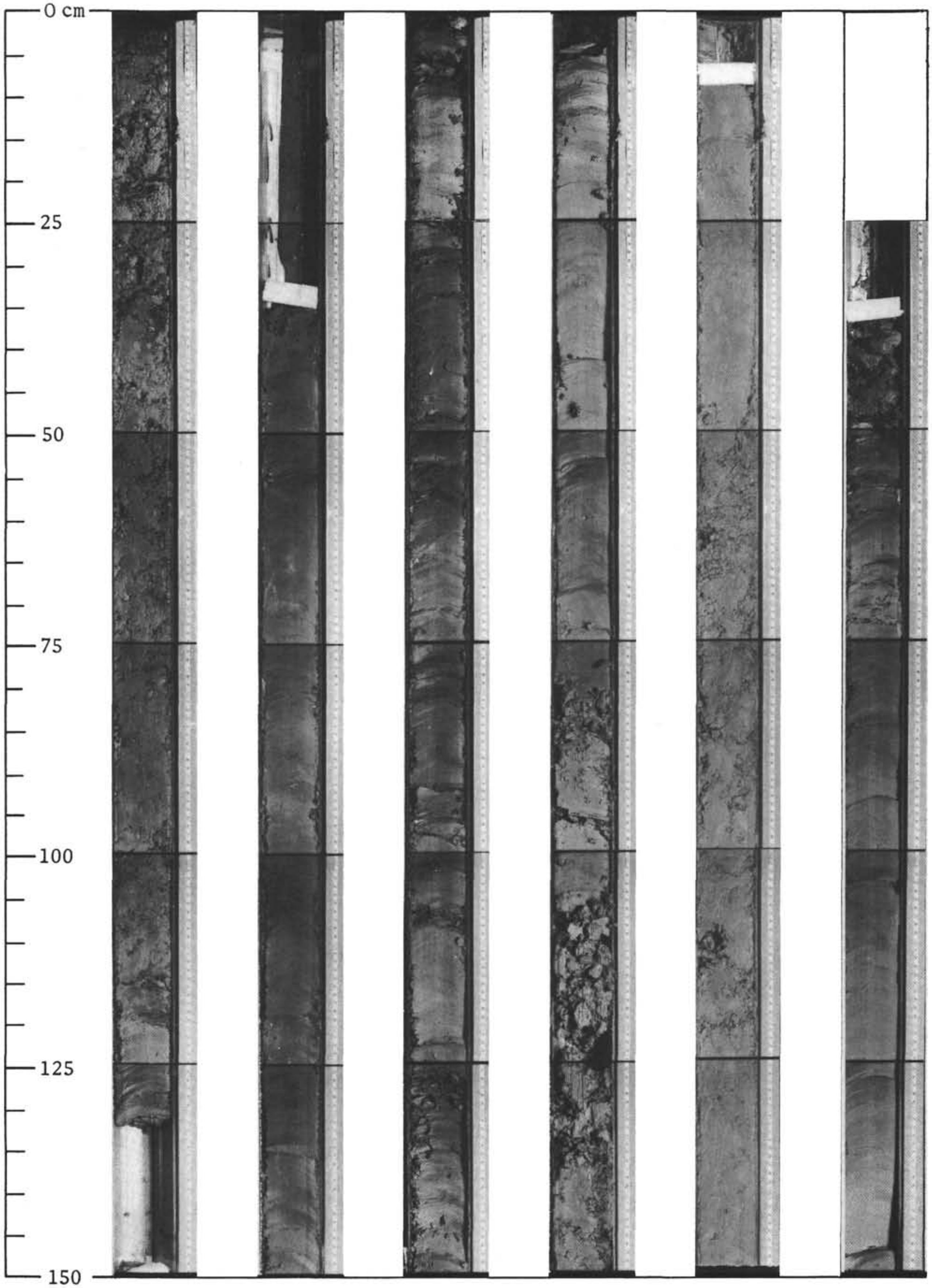
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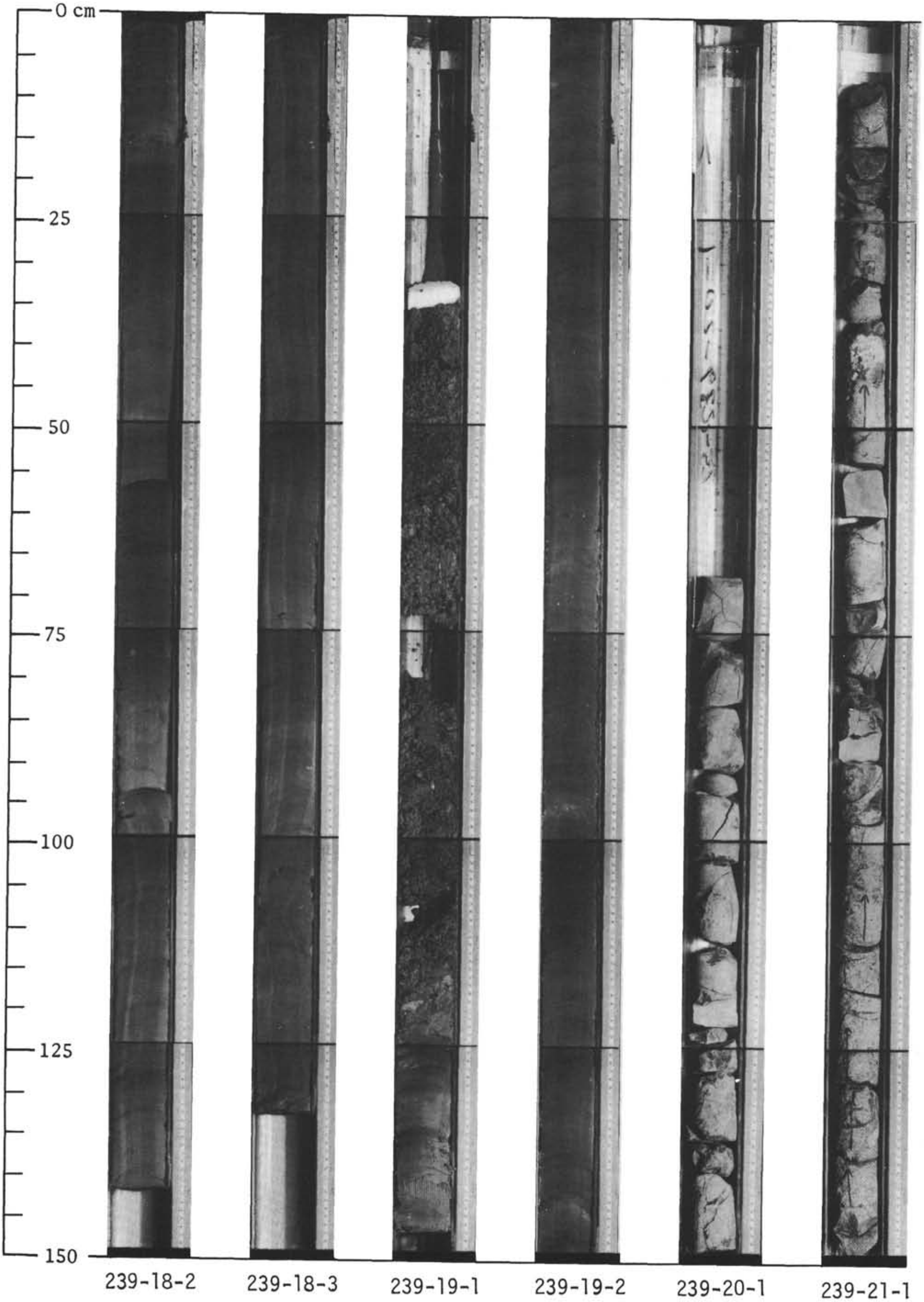
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239-19-2
239-20-1
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