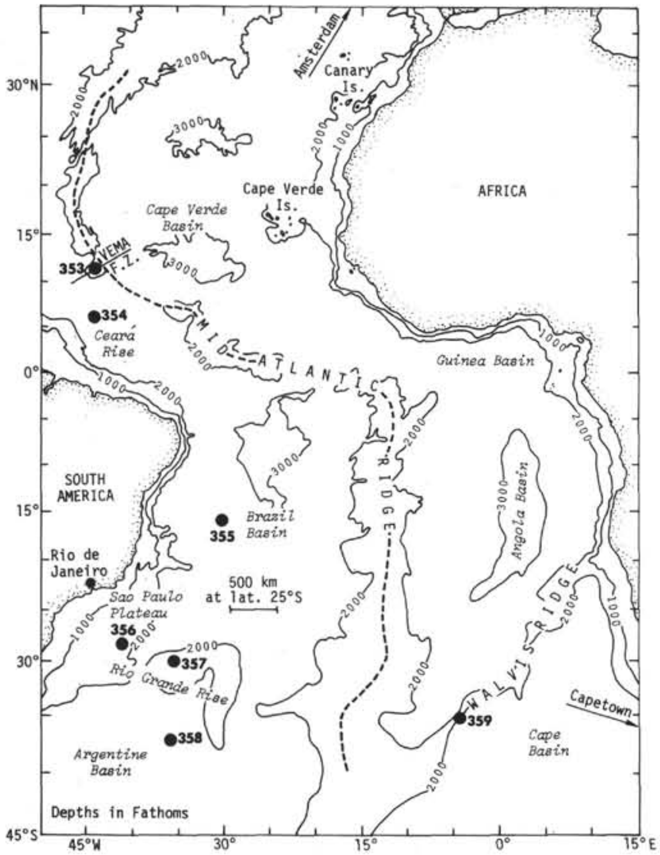
6. SITE 357: RIO GRANDE RISE

The Shipboard Scientific Party[1]



SITE DATA

Date Occupied: 23 November 74 (0821Z)

Date Departed: 28 November 74 (0527Z)

Time on Site: 4 days, 21 hours

Position: 30°00.25'S, 35°33.59'W

Accepted Water Depth: 2086 meters (corrected, echo sounding)

Penetration: 796.5 meters

Number of Holes: 1

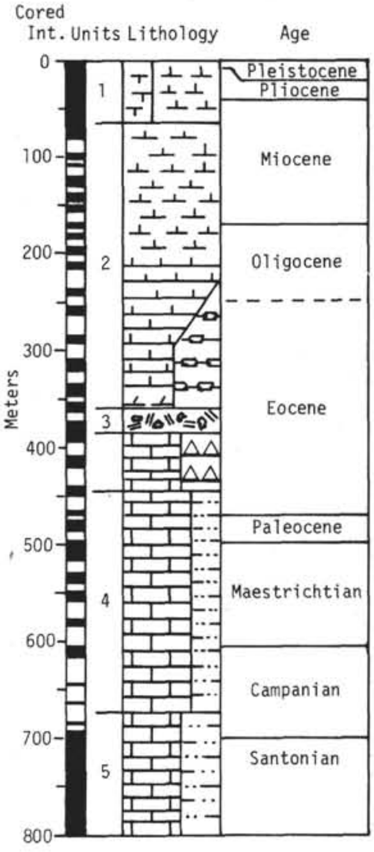
Number of Cores: 51

Total Length of Cored Section: 473.0 meters

Total Core Recovered: 345.2 meters

Principal Results: We cored a 797-meter sedimentary section on the northern flank of the Rio Grande Rise, in a water depth of 2086 meters. Most of the section is pelagic calcareous biogenic oozes, chalks, and limestone; siliceous components are important only in the lower to middle Eocene. Terrigenous components occur sporadically in the upper section, and form an important part of the Santonian to upper Campanian sediments of the lowest 125 meters. Alternate oxidizing and reducing conditions prevailed during deposition of this lowest sediment sequence; the trend through time was toward diminution of reducing conditions, until open marine conditions were reached at the end of the Campanian. The overlying section consists of marine carbonates, with a 15-meter-thick deposit of allochthonous volcanic breccia, containing shallow water indicators, in the middle Eocene.

Hiatuses may be present in the Campanian and across the Cretaceous/Tertiary boundary; an important hiatus includes most of the upper Paleocene and lower Eocene.



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[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; RL. Carlson, University of Washington, Seattle, Washington; M.G. Dinkelman, The Florida State University, Tallahassee, Florida; R.V. Fodor, University of New Mexico, Albuquerque, New Mexico; N. Kumar, Lamont-Doherty Geological Observatory, Palisades, New York; F. McCoy, Lamont-Doherty Geological Observatory, Palisades, New York; J. Thiede, Oregon State University, Corvallis, Oregon; H.B. Zimmerman, Union College, Schenectady, New York.

On the basis of all these indications, we favor an interpretation of this site's history whereby the deposition site subsided below an oxygen-minimum layer in the late Campanian, at the same time that the main platform of the rise subsided below sea level, allowing free surface-water exchange in this area between the north and south portions of the South Atlantic. The shallowest portions of the rise in this area would have been submerged in the Eocene and may have been the source for the volcanic breccia.

BACKGROUND AND OBJECTIVES

The Rio Grande Rise is one of the major structural highs in the South Atlantic Ocean whose strike does not parallel the magnetic anomalies of the normal ocean basement and the Mid-Atlantic Ridge, but more nearly parallels the transform faults in some parts. In other areas it is oblique to both main structural directions. In position and shape—and thus perhaps in geological framework—it resembles the Walvis Ridge, its counterpart on the eastern side of the South Atlantic (Figure 1). Both ridges have been explained as the result of a "hot spot" (Wilson, 1965; Morgan, 1971), or as being related to major fracture zones associated with South Atlantic rifting (Francheteau and Le Pichon, 1972). Although no clear patterns of magnetic anomalies have been found on the Rio Grande Rise proper, anomaly 34 has been mapped in the basins north and south of it (Ladd, 1974).

The Rio Grande Rise, like the Walvis Ridge, is largely sediment covered; as a result, knowledge about its basement is scant. Basement may consist entirely of basaltic rocks, such as those dredged from the tops of both ridges (Francheteau and Le Pichon, 1972). Geophysical data on the western part of the Rio Grande Rise suggest, however, a largely continental rise type of crust (Leyden et al., 1971). Other rock types dredged are Tertiary and Cretaceous (?) shallow water limestones, and massive (several decimeters thick) manganese crusts (M. Melguen, COB-CNEXO, Brest, personal communication). The flanks of the Rio Grande Rise are covered largely by Quaternary pelagic calcareous oozes, but piston coring at several locations has recovered Tertiary sediments (Melguen and Thiede, 1974; Le Pichon et al., 1966; Johnson, 1974).

Attempts to drill and core Rio Grande Rise sediments and basement have been carried out twice on DSDP Leg 3, at Sites 21 and 22 (Maxwell, Von Herzen, et al., 1970), see Figure 2. Spotty core control and low penetration (owing to technical difficulties) have

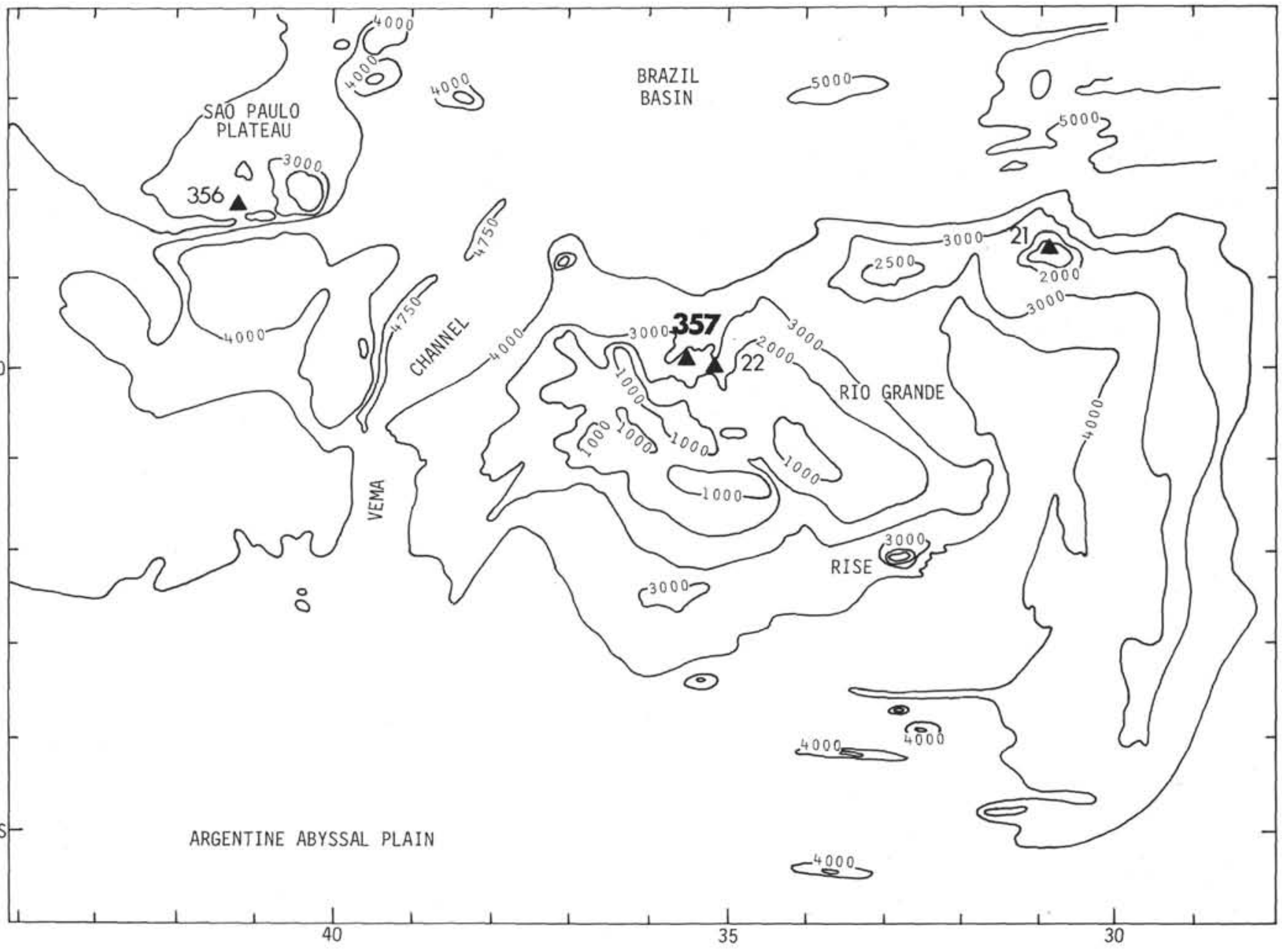


Figure 1. *Base map of Rio Grande Rise showing location of Sites 357, 21, and 22. Contours in meters from Connary and Moody, 1975, Bathymetry of the continental margin of Brazil (unpublished).*

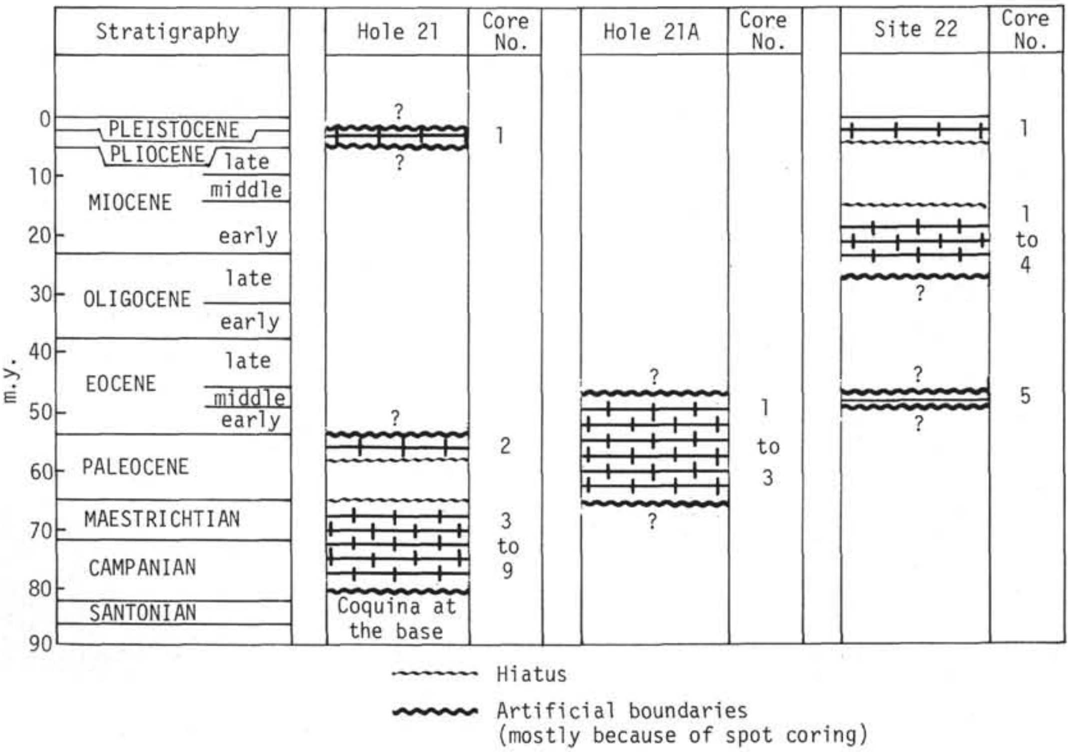


Figure 2. *Lithologies of Sites 21 and 22 (DSDP Leg 3) plotted against age. Because of spot coring, large artificial gaps exist in the cored sections. After data in Maxwell, Von Herzen, et al., 1970.*

greatly limited the usefulness of the results obtained at these two sites. The most significant result was recovery of a white coquina, Campanian or pre-Campanian in age, found as "basement" at Site 21 (eastern Rio Grande Rise). Cores from the sediments overlying the coquina (Holes 21 and 21A) contain Campanian, Maestrichtian, upper Paleocene, lower and middle Eocene, and Pliocene sections of the sedimentary sequence. Five cores from Site 22 add control in the upper Oligocene and lower Miocene.

Because of the limited amount of information available from Sites 21 and 22, an additional site on the northern flank of Rio Grande Rise was very desirable. An apparently pelagic sedimentary sequence covers this area. The site was to be drilled close to Site 22; site location was to be based on existing reflection profiles. The sedimentary section overlies well-defined acoustic basement of unknown age and nature, and contains two to three well-defined intermediate reflectors. Total sediment thickness varies regionally between 0.5 and 1.0 sec. The site was to be located in shallowest water and thinnest possible sediment section where all layers are well developed. The following objectives were to be achieved:

1) To complement the data already available from Sites 21 and 22, and to construct a regionally valid history of Cenozoic and Mesozoic sedimentation on the rise. We expected these sediments to be mostly pelagic calcareous oozes or their consolidated equivalents. The calcareous components were likely to be very well preserved because of the relatively shallow water depth.

2) To recover as complete a calcareous section as possible, for biostratigraphic purposes. It was especially important to recover those portions of the stratigraphic column represented elsewhere in the western South Atlantic Ocean by hiatuses. It was important to recover a complete section of the uppermost Cretaceous and the lowermost Tertiary sediments.

3) To define the age and nature of the prominent regional reflectors.

4) To establish the nature and, we hoped, the age (at least a minimum age) of the seismic basement.

5) To reach crystalline basement if possible; to establish whether it is continental or oceanic in origin, and to determine its age.

OPERATIONS

Glomar Challenger approached the vicinity of the proposed site on a course of 120°T (Figure 3). At 0630Z, 23 November, we changed course to 090° to follow the track of the reference profile (Figure 4, 1510 hr on Lamont-Doherty profile 825, cruise *Vema* 26). We reduced speed to 6 knots at 0645Z, and crossed the intended site at 0745Z; the profile we obtained (Figure 5) was identical to the *Vema* profile. At 0752Z we turned the ship onto a reciprocal course of 270°, dropped the beacon while underway at 0821Z, then retrieved geophysical gear and came about to lock onto the beacon. The site location is 30°00.25′S, 35°33.59′W (average of 31 satellite navigation fixes), atop a north-south trending ridge on the northern flank of the Rio

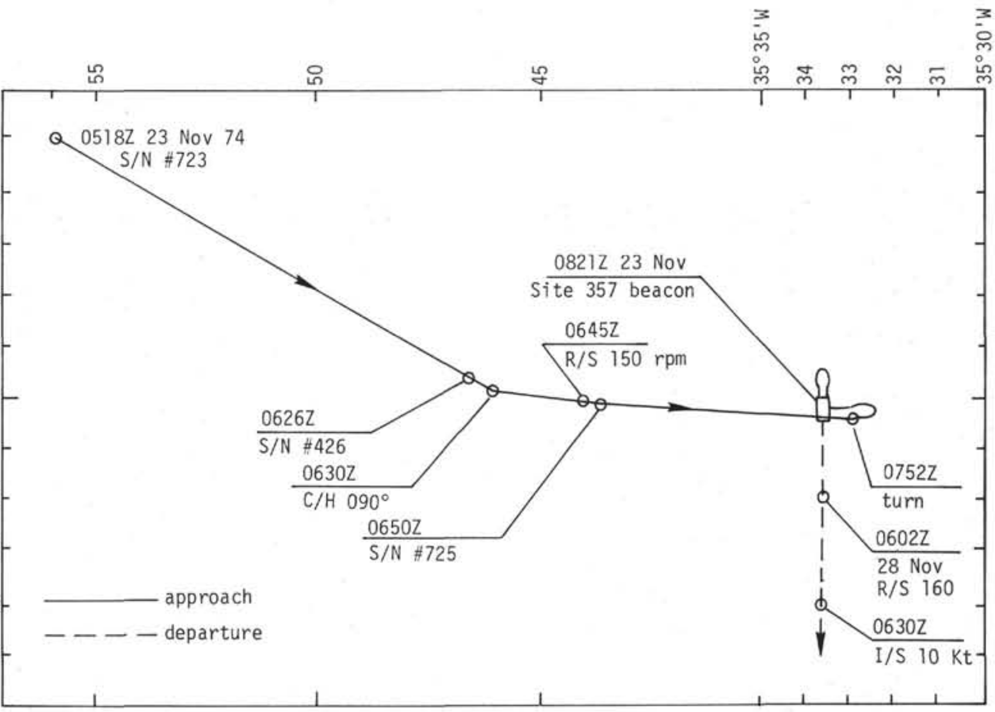


Figure 3. Glomar Challenger *track in the vicinity of Site 357.*

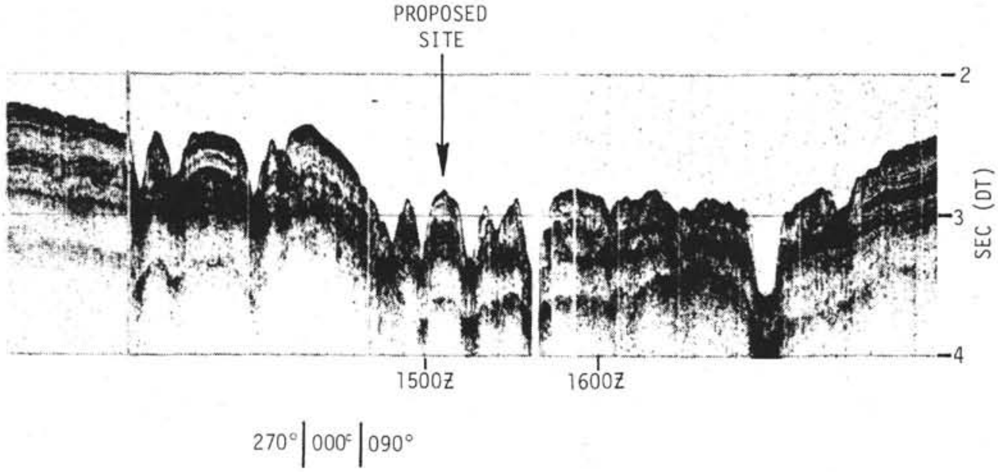


Figure 4. *Lamont-Doherty Geological Observatory seismic profile 825, cruise* Vema *26; proposed site located at 1510 hr.*

Grande Rise, at exactly the spot suggested by the JOIDES Atlantic Advisory Panel (Figure 6).

We spudded the site at 1940 LCT 23 November 74. Water depth by PDR was 2086 meters, corrected; drill pipe measurement from the rig floor to the ocean bottom was 2109 meters; the PDR depth was accepted. We cut a total of 51 cores at Site 357. Table 1 lists depths of the cored and drilled intervals, Figure 7 shows variation of coring rate with depth. No equipment failures occurred during operations, except that an overshot pin sheared on Core 2, necessitating two sandline trips to retrieve this core. Coring and drilling rates were very slow in chalk and limestone—down to 5 m/hr (coring rate) in the marly limestone at the base of the section.

One of the most difficult and painful decisions of Leg 39 was to abandon Site 357. The original schedule required us to begin pulling pipe at 0500 LCT 27 November; instead, we delayed until 2100 hr in order to give ourselves every opportunity to hit acoustic basement. Because of the extremely slow coring rate, we had reached only 796.5 meters by 1900 hr. On the basis of sonic velocity measurements made onboard, we felt that we might have passed the depth of the lowest visible reflector, and that this reflector might well represent the Santonian marly limestone rather than

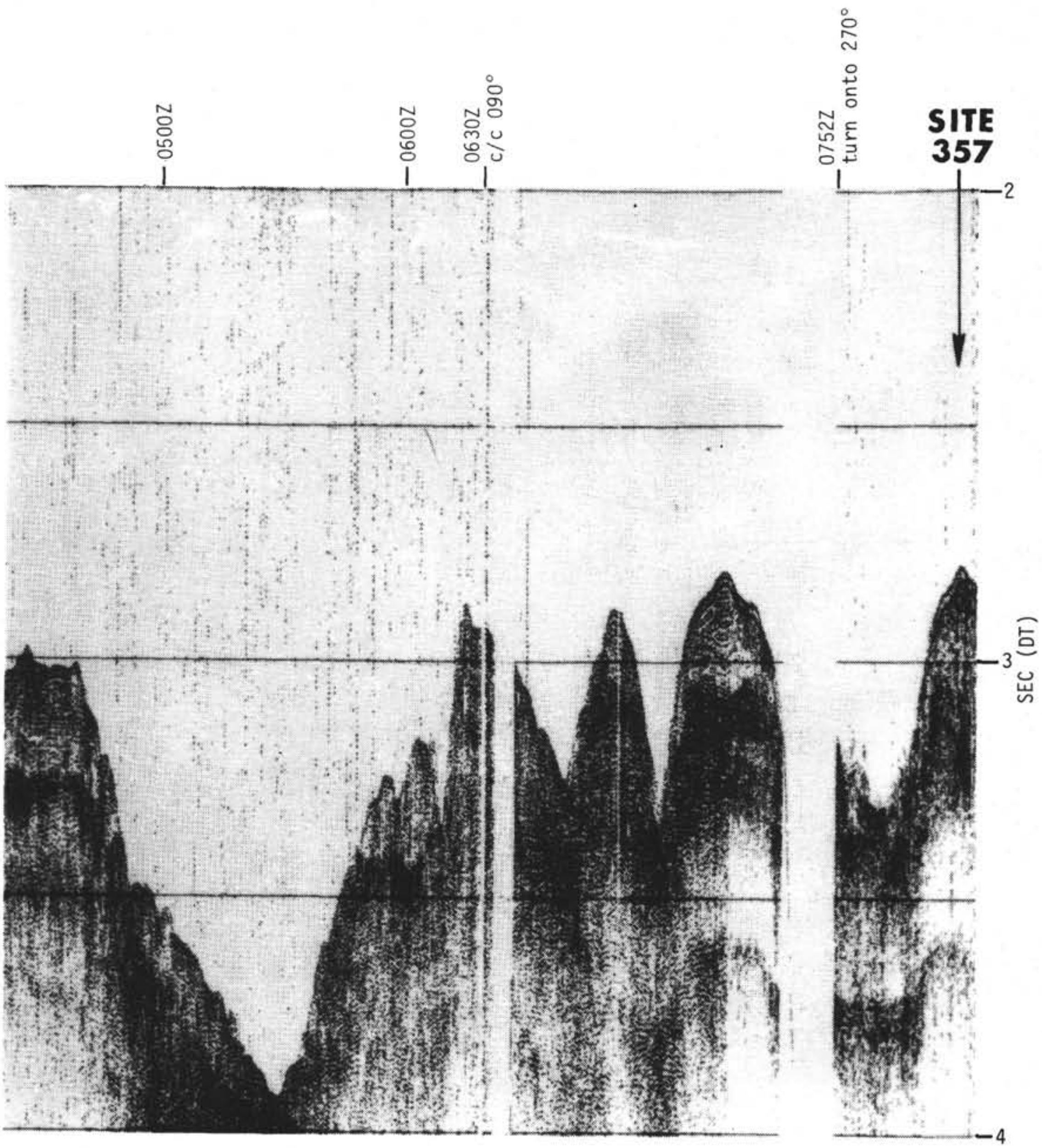


Figure 5. Glomar Challenger *seismic reflection profile, shot on approach to Site 357.*

igneous basement. Any further time at Site 357 would have made impossible any meaningful operations at the last site, the Argentine Basin. We considered cancelling the Argentine Basin site, but in view of our uncertainty as to the nature and depth of the Rio Grande Rise basement, and the critical importance of the Argentine Basin drilling for Atlantic Ocean paleooceanography, we elected to abandon further drilling at Site 357.

Glomar Challenger left Site 357 at 0527Z 28 November on a northerly course to stream gear, then turned onto 182° and proceeded toward Site 358 in the Argentine Basin.

LITHOLOGIC SUMMARY

Although the sedimentary sequence consists chiefly of calcareous pelagic oozes and their consolidated/recrystallized equivalents, it is possible to define five lithologic units, one of them consisting mainly of volcanic breccia (Figures 8 and 9 and Table 2).

Unit 1

The youngest sediments at this site (representing early Miocene through Pleistocene) are soupy, homogeneous, foraminifer-nannofossil oozes, grayish-orange to pinkish-gray, composed primarily of planktonic foraminifers, calcareous nannofossils (whose proportion increases considerably in the lowermost cores), and small amounts of benthic foraminifers, clay minerals, mica, and glauconite. Pteropods in the uppermost Pleistocene portion of this unit typify the excellent preservation of calcareous fossils.

All sedimentary structures have been disturbed by the drilling/coring process, resulting in a rather

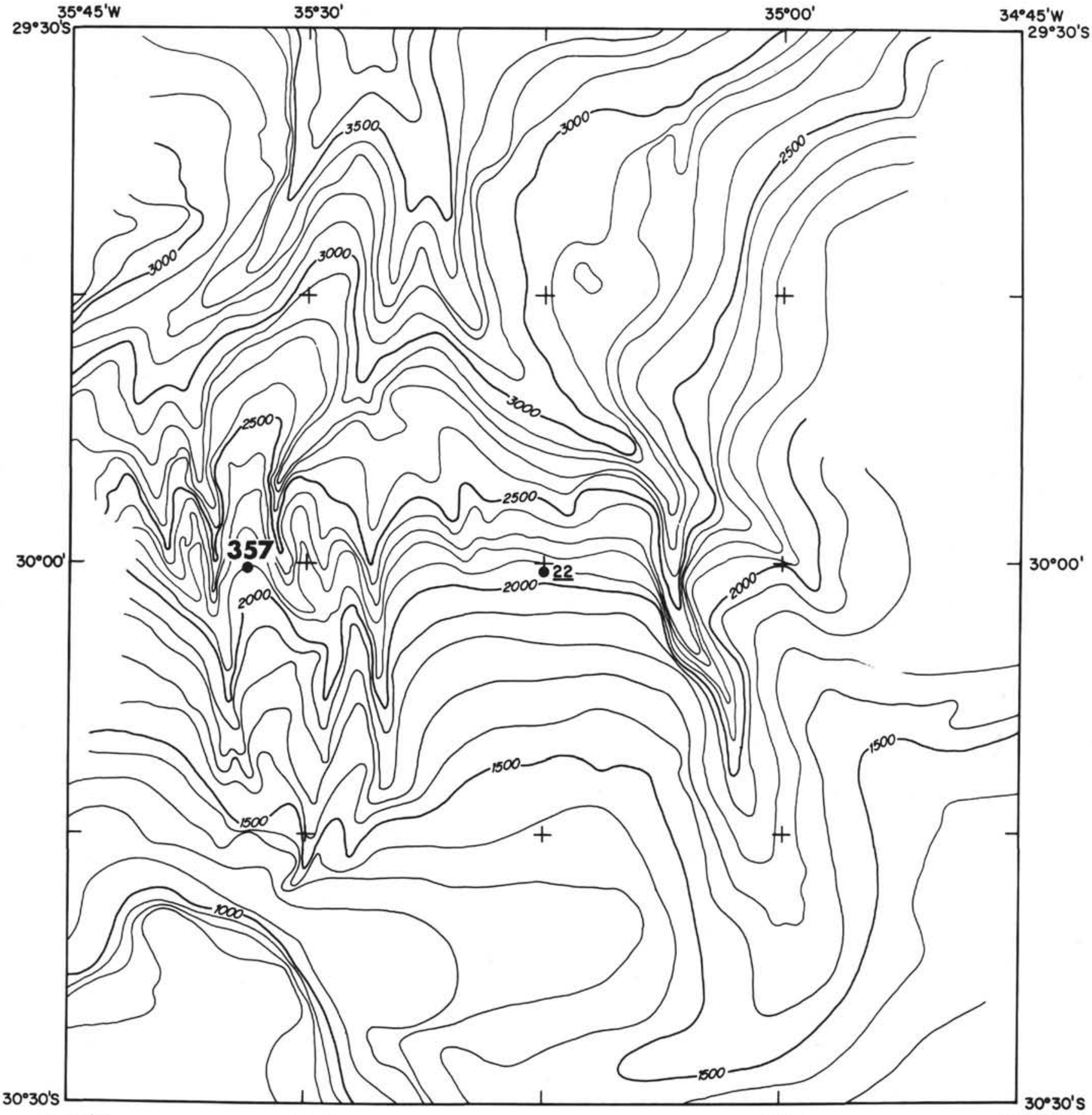


Figure 6. *Detailed bathymetry in the vicinity of Site 357. Courtesy D. Johnson, Woods Hole Oceanographic Institution.*

homogenized sediment in the uppermost cores; in Cores 6 and 7, however, the sediment is stiff enough that sedimentary structures are to a certain degree preserved. Small lumps of whitish nannofossil ooze occur in Core 5. Cores 6 and 7 have numerous, thin (1-2 cm thick) layers, pale yellow-brown to very pale orange. The layers are slightly mottled, but essentially similar in composition to the dominant sediment. They are intercalated with the dominant pinkish-gray foraminifer-nannofossil oozes, which suggests that the soupy homogeneous sediment of the upper five cores may be representative of the composition of this unit, but not of its texture or sedimentary structures. This unit differs from Unit 2 in its considerably higher content of planktonic foraminifers and its different color.

Unit 2

Unit 2 is the thickest lithologic unit at Site 357. It represents deposits of early Eocene to early Miocene

TABLE 1
Coring Summary, Site 357

Core	Depth Below Sea Floor (m)	Length Cored (m)	Length Recovered (m)	Recovery (%)
1	0.0-8.5	8.5	8.5	100
2	8.5-18.0	9.5	9.5	100
3	18.0-27.5	9.5	8.1	85
4	27.5-37.0	9.5	9.0	95
5	37.0-46.5	9.5	8.3	87
6	46.5-56.0	9.5	8.9	94
7	56.0-65.5	9.5	9.1	96
8	65.5-75.0	9.5	8.8	93
9	75.0-84.5	9.5	9.4	99
10	94.0-103.5	9.5	6.0	63
11	103.5-113.0	9.5	1.9	20
12	113.0-122.5	9.5	8.6	91
13	132.0-141.5	9.5	9.5	100
14	151.0-160.5	9.5	3.1	33
15	170.0-179.5	9.5	1.9	20
16	179.5-189.0	9.5	3.0	32
17	189.0-198.5	9.5	8.6	91
18	208.0-217.5	9.5	3.4	36
19	236.5-246.0	9.5	2.6	27
20	255.5-265.0	9.5	3.6	38
21	284.0-293.5	9.5	4.0	42
22	303.0-312.5	9.5	7.5	79
23	331.5-341.0	9.5	9.5	100
24	350.5-360.0	9.5	9.1	96
25	369.5-379.0	9.5	4.5	47
26	379.0-388.5	9.5	9.5	100
27	407.5-417.0	9.5	9.5	100
28	436.0-445.5	9.5	9.5	100
29	464.5-474.0	9.5	3.0	32
30	474.0-483.5	9.5	9.5	100
31	493.0-502.5	9.5	5.0	50
32	502.5-512.0	9.5	7.4	78
33	521.5-531.0	9.5	8.6	91
34	550.0-559.5	9.5	9.5	100
35	578.5-588.0	9.5	6.3	66
36	607.0-616.5	9.5	8.5	89
37	645.0-654.5	9.5	0.2	2
38	664.0-673.5	9.5	Tr	-
39	683.0-692.5	9.5	1.4	15
40	692.5-702.0	9.5	8.1	85
41	703.0-711.5	8.5	7.3	86
42	711.5-721.0	9.5	7.1	75
43	721.0-730.5	9.5	9.5	100
44	730.5-740.0	9.5	7.8	82
45	740.0-743.0	3.0	1.9	63
46	743.0-749.5	6.5	4.9	75
47	749.5-759.0	9.5	9.5	100
48	759.0-768.5	9.5	8.7	92
49	768.5-778.0	9.5	8.0	84
50	778.0-787.5	9.5	9.5	100
51	787.5-797.0	9.5	8.6	91
Total		473.0	345.2	73

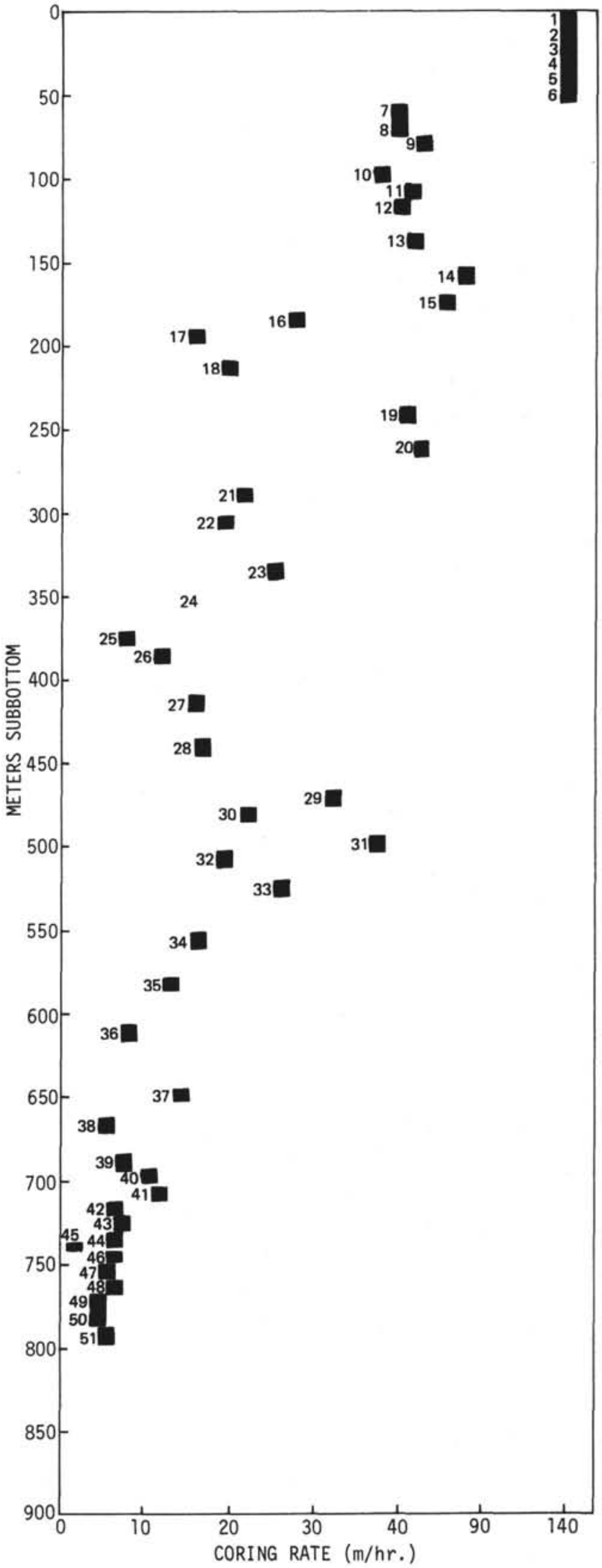


Figure 7. *Coring rates, Site 357.*

age, and includes Unit 3, volcanic breccia and dolostone (see below). The bulk of sediments belonging to Unit 2 are very light gray to bluish-white, and in the lower part, occasionally pinkish-gray calcareous oozes and their consolidated/recrystallized equivalents. Sediments of this unit consist mainly of calcareous nannofossils, which in the lower part increasingly give way to authigenic carbonate. The increasing proportion of authigenic carbonate coincides generally with increasing encrustation of the surviving calcareous nannofossils and planktonic foraminifer shells. Besides these components, siliceous fossils (diatom remains, radiolarians, sponge spicules) are common here and there throughout the whole unit. They are best

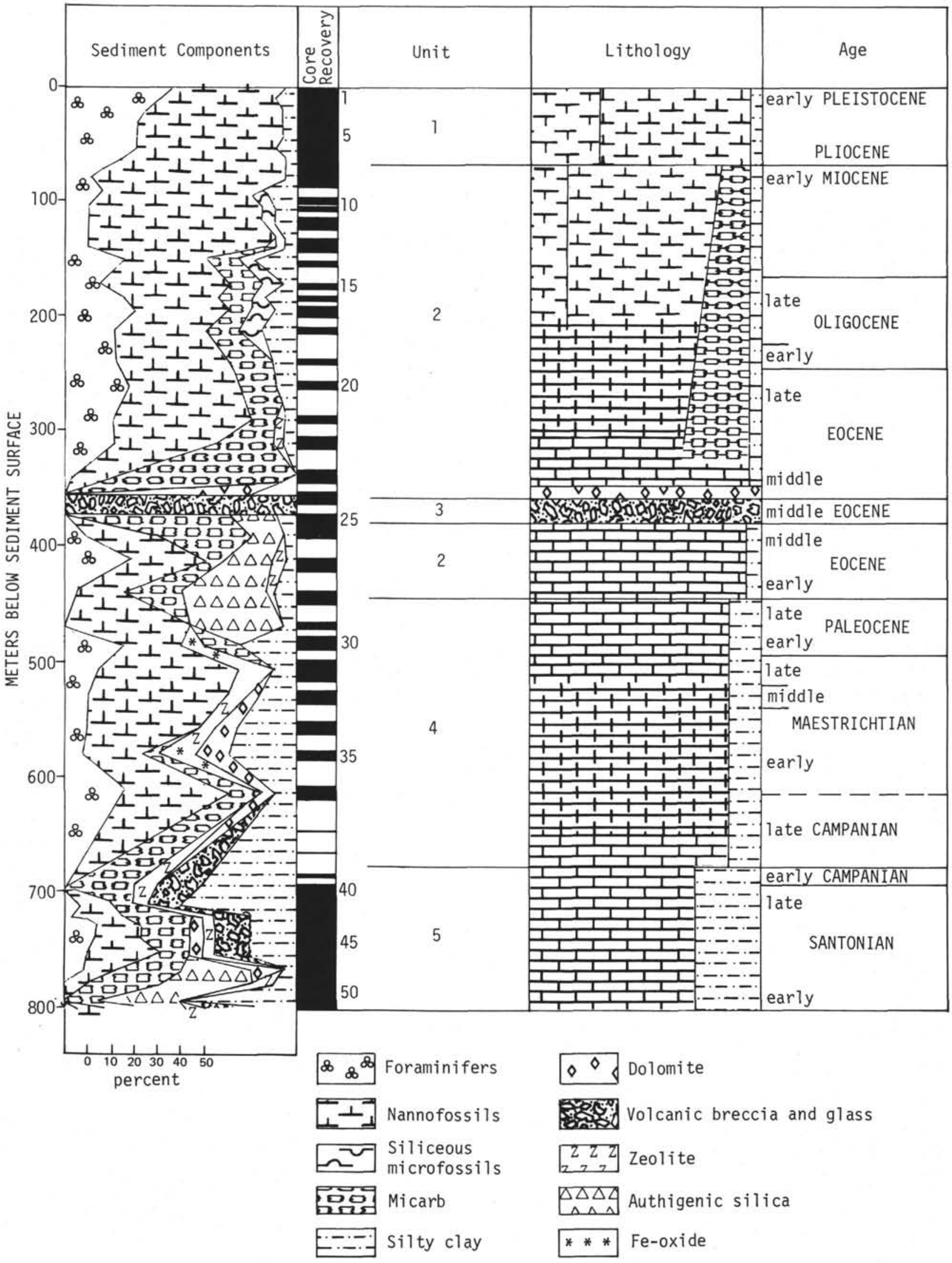
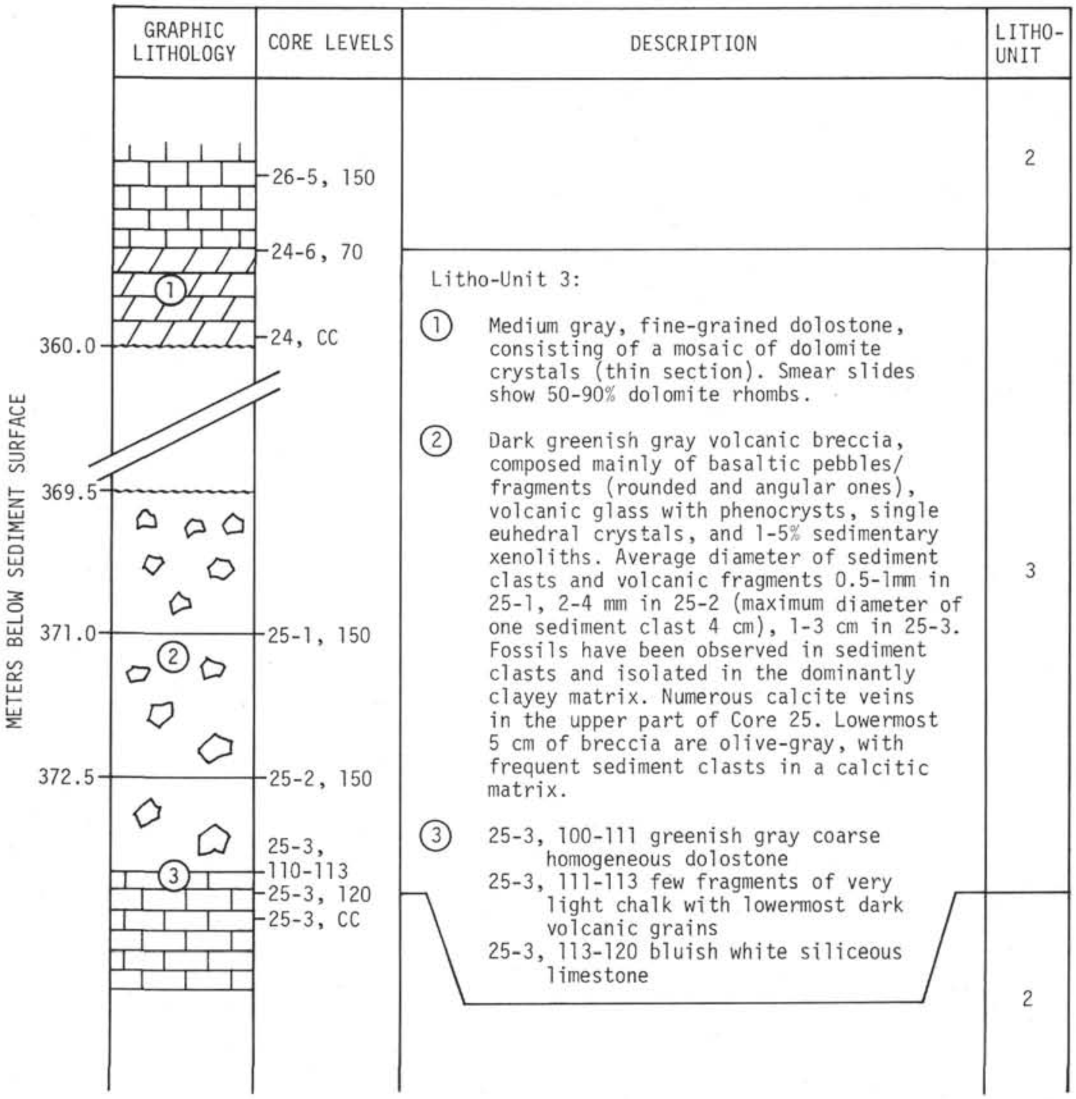


Figure 8. *Simplified lithology and stratigraphy of penetrated sediment section. The left column, showing the distribution of main sedimentary components. is based on smear-slide analyses carried out by the sedimentologists of the shipboard scientific party.*



Litho-Unit 3:

① Medium gray, fine-grained dolostone, consisting of a mosaic of dolomite crystals (thin section). Smear slides show 50-90% dolomite rhombs.

② Dark greenish gray volcanic breccia, composed mainly of basaltic pebbles/fragments (rounded and angular ones), volcanic glass with phenocrysts, single euhedral crystals, and 1-5% sedimentary xenoliths. Average diameter of sediment clasts and volcanic fragments 0.5-1mm in 25-1, 2-4 mm in 25-2 (maximum diameter of one sediment clast 4 cm), 1-3 cm in 25-3. Fossils have been observed in sediment clasts and isolated in the dominantly clayey matrix. Numerous calcite veins in the upper part of Core 25. Lowermost 5 cm of breccia are olive-gray, with frequent sediment clasts in a calcitic matrix.

③ 25-3, 100-111 greenish gray coarse homogeneous dolostone
25-3, 111-113 few fragments of very light chalk with lowermost dark volcanic grains
25-3, 113-120 bluish white siliceous limestone

Figure 9. *Details of lithologic Unit 3, a volcanic breccia into middle Eocene sediments of Unit 2.*

preserved in the upper portion, but almost completely missing in the portion where chert stringers occur (Cores 21 to 24). Minor components are volcanic glass, clay, quartz (mostly angular, silt-sized), and feldspar. Besides authigenic carbonate, the pyrite, silica cement, and chert are diagenetic. The chert, very scarce, occurs as yellowish-brown stringers (Cores 21, CC, 22, 23, 24). The transition from a nannofossil ooze to a nannofossil chalk occurs approximately between Cores 14 and 15, and the transition from nannofossil chalk to limestone occurs between Cores 22 and 23.

Burrows occur abundantly throughout this unit, the cores below Unit 3 are the most intensively burrowed. The most abundant type is *Zoophycos*, which occurs more frequently with increasing depth. Chondroid and large pipe-shaped burrows (including composites up to 5 cm in diameter) also occur, usually parallel to the bedding, but also oriented vertically and oblique to it. Burrows are sometimes pyrite coated, and appear as dark rings on the cut surfaces of the sections. Faint changes in hues indicate bedding planes. Occasional clayey and pyritiferous laminae are present, despite the common burrows.

Thin sandy layers are present in the cores just above and below Unit 3. Their maximum thickness is about 10 cm, decreasing in thickness and number up the cores. In several places, their horizontal continuity has been destroyed by burrowing animals, and their former presence is revealed only by the coarsened contents of a number of burrows at the same level. These layers contain, in addition to the regular sediment components of this unit, glauconite, quartz, feldspar, and more siliceous fossils than the dominant fine-grained portion. Their distinct appearance in the sediment (sometimes with a sharp contact below, but grading into normal sediment above) and their graded bedding (though infrequent) suggest that these layers are composed of displaced material introduced into the normal calcareous pelagic sediment facies. A dark green, very fine grained clay in Section 24-5, however, is assumed to be altered volcanic ash.

Diagenetic changes have not only altered the foraminifer-nannofossil oozes to their chalk and limestone equivalents, but have also resulted in intensive dissolution of siliceous fossils. Authigenic silica occurs in several varieties: small brownish-gray chert stringers

TABLE 2
Lithologic Summary, Site 357

Unit	Cores	Depth Below Sea Floor (m)	Thickness (m)	Age	Description
1	1-7	0- 65.5	65.5	Early Pleistocene to early Miocene	Unconsolidated nannofossil-foraminifer ooze (grayish-orange to pinkish gray)
2	8-24 and 25-28	65.5- 358.0 and 373.5- 443.2	292.5 and 70.0	Early Miocene to middle Eocene and middle Eocene to early Eocene	Unconsolidated foraminifer-nannofossil ooze, grading into nannofossil chalk and limestone (very light gray)
3	24-25	358.0- 373.5	15.5	Middle Eocene	Volcanic breccia (dark greenish-gray) and dolostone (dark gray), which overlay as well as underly the volcanic breccia
4	28-38	443.2- 673.5	230.3	Early Eocene to late Campanian	Limestone to nannofossil chalk (orange-gray to brown)
5	38-51	673.5- 797.0	123.5	Late Campanian to Santonian	Marly limestone (greenish-gray), intensively laminated in its lower part

(only in Cores 21, 22, 23, and 24), siliceous cement (especially in the lowermost part of this unit), and siliceous chamber fillings of foraminifers.

This unit differs from those above and below in content of main components and in color. The contact to Unit 1 is gradational; a sharp color change from very light gray to pinkish-gray hues marks the contact to Unit 4 below.

Unit 3

This unit lies within the lower part of Unit 2. The composition of Unit 3 is different from all other rocks encountered at Site 357; since for the most part it is mainly displaced material, it deserves classification as a separate unit (see Figure 9). Its total thickness is 15.5 meters, 9.5 meters of which were not recovered, however, because coring was discontinuous. The position of the boundary between the uppermost dolostone and the breccia is thus unknown. Portions of the sequence, presumably minor, seem also to be missing between pieces of the breccia, and between the lowermost sediment layers, since the contacts between these look artificial, owing perhaps to drilling disturbance.

The 5-cm-thick sediment layer at the base of this unit is bluish-white siliceous limestone, fine-grained, homogeneous, slightly burrowed, and glauconite-bearing, which differs from the Unit 2 limestone below in color and composition. At its upper boundary are a few fragments of very light gray chalk, containing the lowermost dark volcanic grains (basaltic glass). Since these chalk fragments are loose in the core, we do not know whether they represent a separate thin layer below the volcanic breccia proper or are simply misplaced.

About 12 cm of greenish-gray homogeneous dolostone, directly below the volcanic breccia, overlies these fragments. The lowermost contact of the breccia with calcareous sediment is preserved as a thin, light gray rim of chalk, different in color and composition from the dolostone. The lowermost 5 cm of the breccia are cemented by a calcitic matrix, possibly recrystallized ooze, and contain considerably more sediment clasts than the rest of the breccia.

The dominant components of this breccia are basaltic glass fragments, separate crystals, sediment clasts (partly fossiliferous), and separate fossils. The matrix above the lowermost 5 cm is dark greenish-gray clayey material. The sedimentary clasts and volcanic fragments are sorted according to size: average diameter is 1-3 cm in the basal layer, 2-4 mm in the upper part of Section 25-3, and 0.5-1.0 mm in Section 25-1.

The sediment clasts are silicified and unsilicified fossiliferous limestone; their maximum diameter decreases up the core from 4 cm to 1 cm, paralleling the grading of the volcanic components from 4 cm to less than 1 cm. Besides these limestones, red algae, planktonic and benthic foraminifers, and bivalve and gastropod shell fragments indicate that some of the material must have originated in relatively shallow water, presumably close to the source of the volcanic components. Sediment clasts and fossils occur more frequently in the lowermost and uppermost portions of the breccia. A thin section of the breccia showed mainly angular to subangular fragments (~2 to 5 mm) in a clayey matrix. Other fragments include foraminifers, mollusc shells, calcite crystals, and clinopyroxene and feldspar grains. A point count (1500 counts) of one thin section showed 43 volume percent matrix versus 57 percent fragments.

The basaltic fragments are highly altered to clay minerals, and vary from pale yellow to light green to gray. Each fragment contains tiny vesicles and bubbles, many filled with acicular microcrystalline material, possibly zeolites and carbonates. Unaltered grains of clinopyroxene also remain in the fragments.

Postdepositional white sparitic calcite veins (from <1 mm to several cm thick), mostly parallel or subparallel to the bedding, occur frequently in Sections 24-1 and 24-2, but are absent in the lower portion of the breccia.

Because of intermittent coring, the contact of the volcanic breccia with the overlying dark gray dolostone was not retrieved. The thickness of these two layers therefore remains unknown (but neither could have been thicker than the retrieved thickness plus 9.5 m). However, the 120-cm-thick dark gray dolostone in the lower part of Core 24 resembles the dolostone below the breccia, and contains volcanic glass. It thus seems reasonable to assume that deposition of this rock was associated with deposition of the volcanic breccia, and to include it in Unit 3. The contact of the dolostone with the overlying limestone of Unit 2 is sharp, but may be artificial, because of the coring process.

Unit 4

Unit 4 consists of Campanian to lower Eocene chalk and limestone and is 230.3 meters thick. The dominant color is pinkish-gray, with grayish-orange interchanging with pale yellowish-brown. An abrupt color change, from pinkish-gray to brown to very light gray, characterizes the uppermost contact of this unit. At the unit's lower limit, dominant brown grades into greenish-gray, the amount of terrigenous material, like that in Unit 5, increases considerably. The dominant rock type in the lower part of this unit is chalk, which grades upward into limestone; the transition occurs approximately in Core 32. The limestone is mostly pinkish-gray to brown, and in the lower chalk (from Core 31 downward), light greenish-gray layers are intercalated with the browish sediments. The number of these layers and their proportion of the whole column increase gradually down the hole until the greenish-gray hues dominate, thus marking the lower boundary of Unit 4.

The main components of this lithologic unit are calcareous nannofossils, clay minerals, iron oxides, and silica cement; siliceous fossils occur only sporadically. Increasing amounts of terrigenous material occur (clay, quartz, feldspar, mica) below Core 32. In several layers, dolomite rhombs occupy up to 10% to 15% of the total sediment. Volcanic glass is present only in trace amounts.

Burrows—small chondroid forms, *Zoophycos*, and large, sometimes composite burrows—occur throughout this unit; in general, the darker layers (brown) are more intensively burrowed than the intermediate portion of the column. Sometimes a halo of reduced sediment occurs around burrows. Despite the burrows, thin laminae are occasionally preserved; apart from the above-mentioned layers, distinguished by color changes, they are almost the only preserved bedding. A 10-cm-thick, slightly contorted bed occurs in Core 34. Deformation of the sediment interfaces is manifest as vertical to oblique small faults (usually not more than 1 cm vertical displacement). These small movements must have happened—at least partly—before final burial, since a small "graben" structure is filled with clay pebbles (Sample 32-3, 30-40 cm).

From Core 36-1 downward, *Inoceramus* fragments are characteristic macrofossils; they occur dispersed in the sediment or in abundance in intercalated layers (presumably where whole specimens have been crushed; see Figure 10). A small, but well-preserved intact specimen (0-~1 cm) occurs in Sample 36-4, 30 cm.

Unit 5

Greenish-gray marly chalks to silicified limestones, Santonian to Campanian in age, make up the lowermost 123.5 meters of the penetrated sedimentary column. The lower boundary of this unit remains unknown. We place its upper boundary where the abundance of terrigenous material decreases markedly, and where the dominant colors change from grayish-green/pinkish-gray to brown. The sediments are fine grained and rather homogeneous throughout. The main components are authigenic carbonate, amorphous silica, calcareous nannofossils, planktonic foraminifers, and clay, with lesser quantities of quartz, feldspar, heavy minerals, volcanic glass shards, rare zeolites, dolomite rhombs, and pyrite. The $CaCO_3$ content of this unit varies between 39% and 64% (carbonate bomb results). Siliceous fossils are almost completely absent. Abundance of *Inoceramus* and other bivalve shell fragments increases rapidly in the lowermost cores (Cores 43-51, Figure 10).

Most parts of this unit are intensively burrowed. Most burrows are slightly darker than the surrounding sediments, because of a pyrite coating and/or dispersed fine-grained pyrite in the burrow fillings. They comprise chondroid, elongate composite (parallel and perpendicular to the bedding planes) burrows and frequent *Zoophycos*. Only in the lowermost laminated part of this unit are burrows almost completely missing.

Single, slightly darker laminae are preserved in several places, despite the intensive burrowing. Laminae are absent in Cores 44-47, but occupy an increasing proportion of the sedimentary column from Core 48 downwards, until the whole sediment is irregularly but densely laminated.

Besides the laminations and burrows described above, sedimentary structures occur in the form of bedding which is usually visible only as faintly changing hues, or as intercalations of distinct thin layers of clay. These layers are presumably altered volcanic ash. A typical such thin layer occurs in Sample 40-4, 40-50 cm: a dark green claystone bed, laminated in its lower part, has a thin clay pebble layer above. A similar layer occurs in Sample 41-2, 76-82 cm. These beds represent expiring volcanic activity, probably close to this area.

In the oldest sediments of this site (Core 51) carbonate concretions up to 10 cm in diameter occur. The more clayey sediments around these are deformed in a fashion typical of concretions. Movements along small cracks may have resulted from differential settling of the concretions and the normal sediment column beside them.

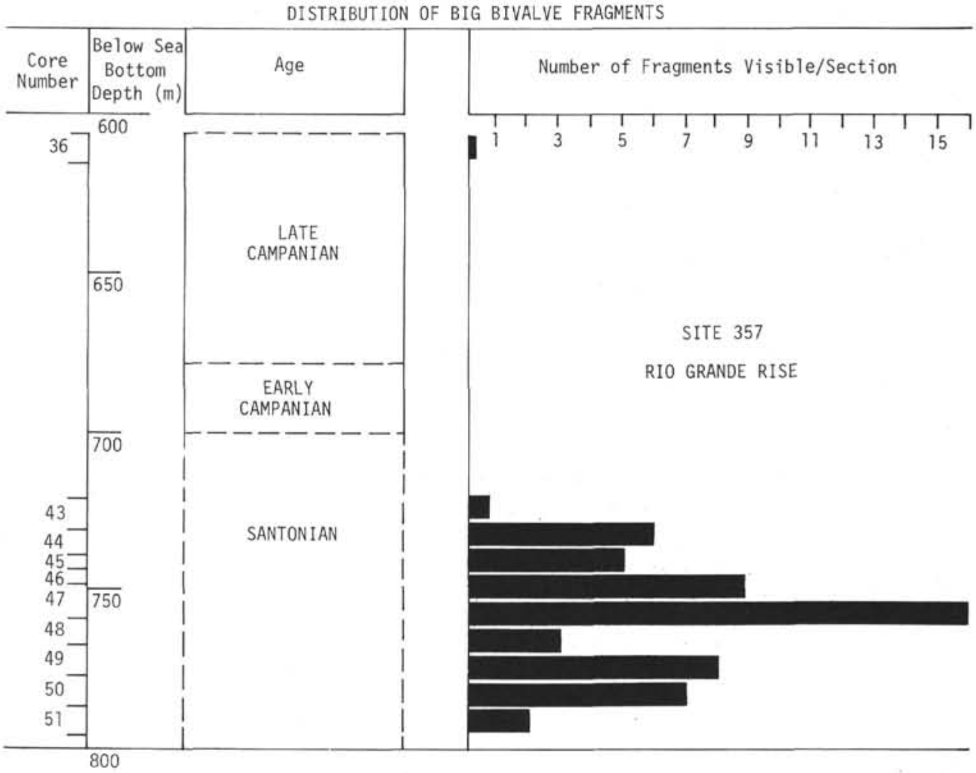


Figure 10. *Distribution of large* Inoceramus *fragments (other bivalve shell fragments are included).*

Discussion

The sediment components dominant in all units except Unit 3 are calcareous and pelagic. They have been diluted, however, by terrigenous and volcanogenic material in varying amounts, and have been deposited in different water depths under both reducing and oxidizing conditions.

The lowermost part of Unit 5 (Cores 49-51) is marly limestone and chalk, laminated throughout, and deposited under reducing conditions that prevented almost all benthic life. Benthic foraminifers in these cores may have been displaced, although they can tolerate an almost complete lack of dissolved oxygen in the water, as in the now-stagnant Santa Barbara Basin (for example: Phleger and Soutar, 1973; Sliter, 1975).

In Core 49 and those above, oxidizing conditions become evident, but layers reflecting oxidizing and reducing conditions alternate. More and more of the sediment is intensively burrowed, and the laminated portion of the sedimentary column diminishes rapidly. The greenish-gray color and the pyrite in this unit indicate, however, that the boundary between oxidizing and reducing conditions was just below the sediment/water interface, occasionally reaching the sediment surface (where laminae are preserved). Although the dominant color throughout Unit 5 remains greenish-gray, which usually indicates a reducing environment, conditions must have been suitable for benthic life at least in the uppermost layer, since the laminated portion rapidly gives way to burrowed sediments. These two facies alternate several times, indicating fluctuations of a boundary between reducing and oxidizing conditions, located either above or just below the sediment-water interface.

The facies of the lowermost part of Unit 4 resulted from a continuation of the same trend. The indications of reducing conditions (lamination of the sediment, pyrite, greenish-gray color) decrease gradually, as does the particulate terrigenous sediment. The change this reflects, however, was not continuous, but again seems to have occurred in pulses. The cause of this alternation between grayish reduced sediment and brownish burrowed oxidized sediment could be variation in the rate of input of terrigenous and organic material from outside the deposition area, or fluctuation of an oxygen boundary. In the lower part of Unit 4, the greenish and brownish layers alternate, but since no shallow water material occurs in these layers, and since they are similar in composition (except for authigenic pyrite and iron oxides) and texture, we favor the explanation involving a fluctuating oxygen boundary.

Large bivalve shell fragments (mainly of *Inoceramus*) occur frequently throughout Unit 5, even in the laminated cores (see Figure 10). How to relate the *Inoceramus* fragments to these sediments remains an open question, since evidence for benthic life, except for sparse benthic foraminifers, seems to be missing at least in the lowermost two cores of this unit. Two possibilities are that *Inoceramus* was living as epibenthos on the sediment (Kauffmann, 1968), or that the shells and fragments are displaced. For further discussion of possible significance of *Inoceramus* in deep-sea sediments, see Thiede and Dinkelman (this volume).

Another important characteristic of Unit 5 is the relatively high terrigenous component, which decreases in its uppermost part. The rapid decrease of terrigenous material in the transitional zone between Units 5 and 4 suggests that the source of this material must have disappeared or become disconnected during the Campanian. Since a considerable portion of this terrigenous material is silt-sized quartz and clay, one might consider it as coming from the continental margin under certain climatic conditions. Another, less likely possibility is that this material is weathered residue of differentiated products from a large volcanic island, represented by the structural high now forming the Rio Grande Rise. As the major part of this island's surface gradually submerged, and with it the source of weathered material, the input of quartz, clay, and finally Fe-oxide would have gradually decreased.

Unit 3 consists mainly of volcanic breccia, graded in size, but relatively homogenous in composition. Since its grain size decreases gradually upward through the whole unit, this breccia probably represents only one short depositional event. Ages of the volcanic components remain unknown. The occurrence of shallow-water limestones and fossils (large, shallow-water, calcareous benthic foraminifers and red algae), together with the volcanic fragments, proves that this deposit came from a former volcanic shoal, or even island, south of the site.

The dolostone below and above the volcanic breccia seems genetically related to deposition of the volcanic components. What appear to be calcite pseudomorphs after olivine suggest olivines in the breccia components. Also, the presence of calcite indicates considerable alteration of the mineral assemblages of these volcanic rocks. The magnesium necessary for dolomitization of the dolostone above and below the breccia may therefore have come from alteration of this volcanic material.

Clear, colorless volcanic glass shards occur in Units 2, 3, 4, and 5, generally becoming less abundant in the younger units. Higher concentrations occur several tmes in thin sandy layers which are also otherwise of different composition than the surrounding sediment. This suggests that concentration of glass shards in these layers may be a result of sorting rather than short-term input of volcanic ash.

Unit 2 is made up of limestone, chalk, and oozes; the degree of consolidation and/or recrystallization increases down the unit, from almost-soupy ooze to limestone. Rocks in this unit are similar to rocks recovered from the Rio Grande Rise during DSDP Leg 3 (Maxwell, Von Herzen, et al., 1970). Well-preserved opaline skeletons (silicoflagellates, diatoms, radiolarians, sponge spicules) occur only in the upper part of the unit. They are poorly preserved or absent in the lower portions, especially in the layers that contain chert stringers. Silica of diagenetic origin occurs as infrequent small chert stringers, as silica cement in the interstices of grains, and as fillings of foraminifer chambers.

The sediments of Unit 1 represent pure calcareous pelagic deposits in a subtropical ocean. The sediments consist essentially of calcareous nannofossils, planktonic foraminifers, and aragonitic pteropods. The calcareous fossils in this unit are all very well preserved. Because of the geographic location of this site, siliceous microfossils cannot be expected in large quantity; when present, they are either dissolved or masked by dilution with calcareous sediments. They occur only occasionally in this unit, in trace amounts.

GEOCHEMISTRY

We measured *p*H, alkalinity, salinity, Ca^{++}, and Mg^{++} contents of 10 interstitial water samples onboard ship. Data appear in Table 3 and Figure 11.

PHYSICAL PROPERTIES

Physical properties data for Site 357 appear in Table 4 and Figure 12. The uppermost unit is foraminifer-nannofossil ooze, which grades into limestone extending to a depth of 358 meters. Moderate velocity, density, and water content gradients characterize the unit throughout. Velocities increase with depth from 1.55 to about 2.0 km/sec; wet bulk density increases from 1.7 to 2.0 g/cc, and the water content decreases from more than 30% to about 20%. In each case, the gradient appears to increase slightly with depth.

A marked increase in the maximum densities of the dolostone, which reach values in excess of 2.0 g/cc, distinguishes the dolostone and breccia unit from the overlying limestone. The velocity of the associated breccia, measured on ship, is about 3.3 km/sec.

TABLE 3
Summary of Shipboard Geochemical Data

Sample (Interval in cm)	Subdepth (m)	*p*H	Alkalinity (meq/l)	Salinity (°/oo)	Ca^{++} (mmoles/l)	Mg^{++} (mmoles/l)
1-5, 144-150	7.5	7.44	2.79	34.6	10.79	53.05
6-5, 144-150	54.0	7.28	3.95	35.2	13.03	50.69
11-1, 144-150	105.0	7.19	4.16	35.2	14.24	48.63
15-1, 144-150	171.5	7.26	3.56	35.5	14.44	46.06
23-4, 140-150	337.5	7.63	1.30	35.2	15.75	43.96
24-5, 144-150	358.0	7.55	1.80	35.8	17.50	45.68
26-5, 144-150	386.5	7.31	2.82	35.5	17.99	47.29
29-1, 0-10	466.0	7.01	6.30	36.0	19.98	38.22
31-3, 144-150	497.5	6.90	7.40	36.3	21.59	38.79
36-4, 140-150	613.0	6.94	5.54	36.5	22.51	38.95

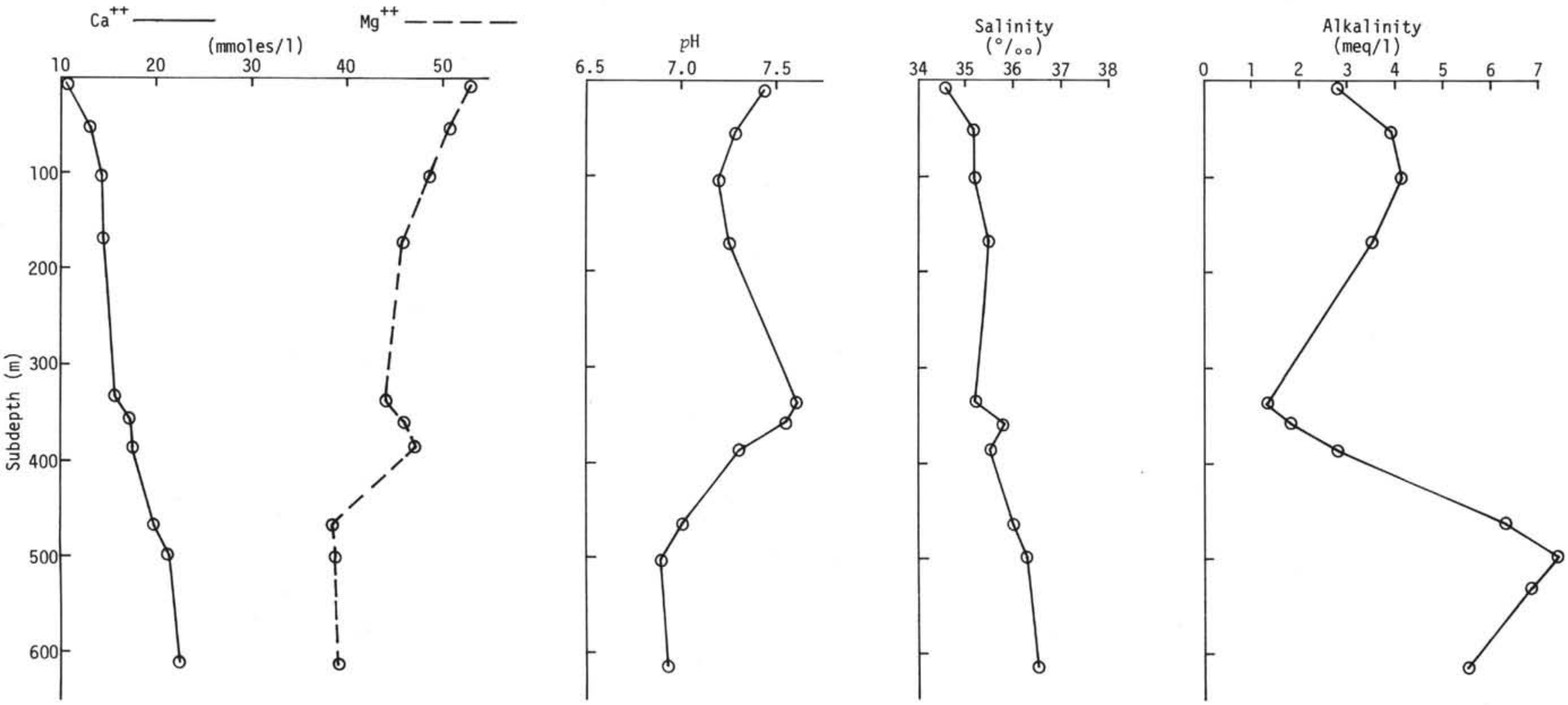


Figure 11. p*H*, *salinity, alkalinity, Ca++, and Mg++ content, of interstitial waters versus depth, Site 357.*

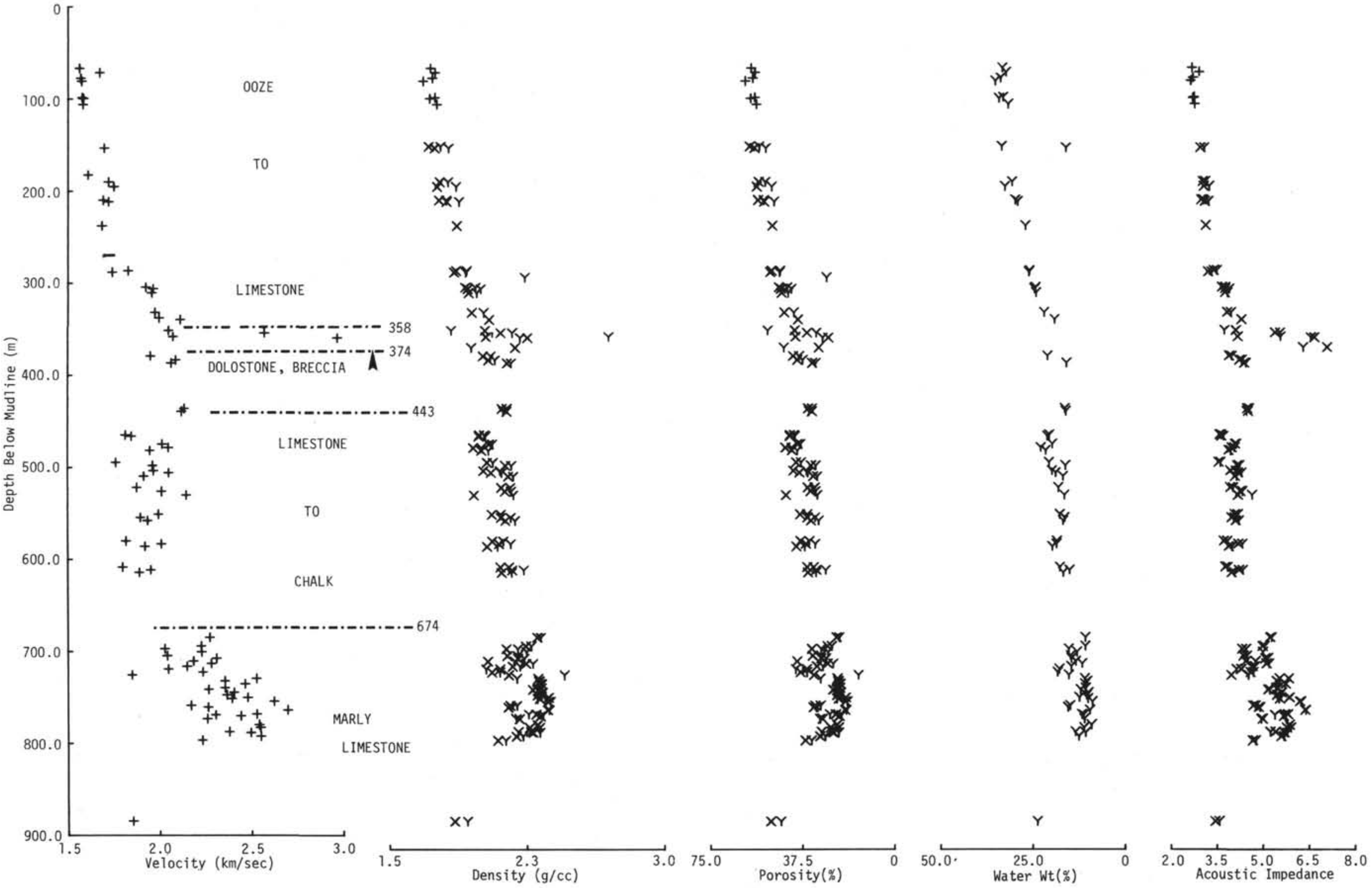


Figure 12. *Physical properties versus depth; +, x, and y represent syringe, immersion, and GRAPE values, respectively.*

TABLE 4
Physical Properties Data, Site 357

Sample (Interval in cm)	Depth (m)	Velocity (km/sec)	Density (g/cc)			Water (Wt %)	Porosity (%)			Acoustic Impedance		
			S	I	G		S	I	G	S	I	G
8-1, 89	66.39	1.562	1.723	–	–	33.25	58.33	–	–	2.69	–	–
8-4, 100	71.00	1.672	1.749	–	–	32.25	56.78	–	–	2.92	–	–
9-2, 83	77.33	1.569	1.734	–	–	33.70	57.67	–	–	2.72	–	–
9-4, 104	80.54	1.574	1.683	–	–	35.13	60.72	–	–	2.65	–	–
10-3, 120	98.20	1.576	1.748	–	–	33.05	56.84	–	–	2.75	–	–
10-4, 87	99.37	1.584	1.719	–	–	34.13	58.57	–	–	2.72	–	–
11-2, 74	105.74	1.581	1.759	–	–	31.63	56.18	–	–	2.78	–	–
14-1, 45	151.45	–	–	1.714	1.779	33.38	–	58.87	54.99	–	–	–
14-2, 67	153.17	1.697	–	1.747	1.823	15.88	–	56.90	52.36	–	2.96	3.09
16-2, 147	182.47	1.690	–	–	–	–	–	–	–	–	–	–
17-1, 94	189.94	1.720	–	1.775	1.820	30.55	–	55.22	52.54	–	3.05	3.13
17-4, 148	194.98	1.749	–	1.761	1.864	32.51	–	56.06	49.91	–	3.08	3.26
18-2, 21	209.71	1.691	–	1.771	1.811	29.70	–	55.46	53.07	–	2.99	3.06
18-3, 48	211.48	1.720	–	1.813	1.881	29.06	–	52.96	48.90	–	3.12	3.24
19-1, 92	237.42	1.684	–	1.684	–	26.90	–	49.61	–	–	3.15	–
21-1, 137	284.37	1.852	–	1.854	1.924	23.82	–	50.51	46.33	–	3.43	3.56
21-2, 98	286.48	1.827	–	1.865	1.923	25.82	–	49.85	46.39	–	3.41	3.51
21-3, 100	288.00	1.740	–	1.854	1.918	25.95	–	50.51	46.69	–	3.23	3.34
21-0, 0	293.50	4.191	–	–	2.241	–	–	–	27.40	–	–	9.36
22-1, 148	304.48	1.924	–	1.915	1.971	24.17	–	46.87	43.52	–	3.68	3.79
22-3, 4	306.04	1.964	–	1.929	2.000	24.38	–	46.03	41.79	–	3.79	3.93
22-5, 148	310.48	1.956	–	1.934	1.978	23.98	–	45.73	43.10	–	3.78	3.87
23-1, 3	331.53	1.974	–	1.951	2.016	21.80	–	44.72	40.84	–	3.85	3.98
23-4, 148	337.48	1.996	–	–	–	–	–	–	–	–	–	–
23-6, 24	339.24	2.112	–	2.046	–	18.95	–	39.04	–	–	4.32	–
24-1, 53	351.03	2.049	–	2.025	1.839	–	–	40.30	51.40	–	4.15	3.77
24-3, 11	353.61	2.572	–	2.110	2.173	–	–	35.22	31.46	–	5.43	5.59
24-5, 140	357.90	2.073	–	2.030	2.700	–	–	40.00	–	–	4.21	5.60
24-6, 105	359.05	2.970	–	2.257	2.216	–	–	26.45	28.90	–	6.70	6.58
25-1, 25	369.75	3.251	–	2.190	1.950	–	–	30.45	44.78	–	7.12	6.34
25-2, 20	371.20	3.191	–	–	–	–	–	–	–	–	–	–
25-2, 110	372.10	3.388	–	–	–	–	–	–	–	–	–	–
25-2, 122	372.22	3.332	–	–	–	–	–	–	–	–	–	–
26-1, 3	379.03	1.950	–	2.014	2.055	20.78	–	40.96	38.51	–	3.93	4.01
26-3, 147	383.47	2.088	–	2.043	2.079	–	–	39.22	37.07	–	4.27	4.34
26-6, 35	386.85	2.063	–	2.145	2.167	15.64	–	33.13	31.82	–	4.43	4.47
28-1, 8	436.08	2.135	–	2.117	2.144	16.04	–	34.81	33.19	–	4.52	4.58
28-3, 5	439.05	2.120	–	2.143	2.124	15.78	–	33.25	34.39	–	4.54	4.50
29-1, 3	464.53	1.813	–	1.993	2.022	20.30	–	42.21	40.48	–	3.61	3.67
29-2, 4	466.04	1.846	–	1.991	2.027	20.83	–	42.33	40.18	–	3.68	3.74
30-2, 31	474.31	2.014	–	2.047	2.065	19.45	–	36.99	37.91	–	4.12	4.16
30-4, 148	478.48	2.048	–	1.961	2.006	22.61	–	44.12	41.43	–	4.02	4.11
30-6, 148	481.48	1.947	–	2.006	2.004	21.27	–	41.43	39.16	–	3.91	3.98
31-1, 132	494.32	1.761	–	2.036	2.069	20.34	–	39.64	37.67	–	3.59	3.64
31-4, 25	497.75	1.962	–	2.137	2.170	15.88	–	33.61	31.64	–	4.19	4.26
32-1, 97	503.47	1.967	–	2.016	2.107	19.56	–	40.84	35.40	–	3.97	4.14
32-3, 11	505.61	2.050	–	2.058	2.115	18.54	–	38.33	34.93	–	4.22	4.34
32-5, 143	509.50	1.914	–	2.152	2.180	16.54	–	32.72	31.04	–	4.12	4.17
33-1, 23	521.73	1.875	–	2.114	2.164	17.80	–	34.99	32.00	–	3.96	4.06
33-3, 127	525.77	2.011	–	2.134	2.168	–	–	33.79	31.76	–	4.29	4.36
33-6, 92	529.92	2.146	–	1.965	2.180	16.18	–	43.88	31.04	–	4.22	4.68
34-1, 102	551.02	1.994	–	2.062	2.111	17.46	–	38.09	35.16	–	4.11	4.21
34-3, 148	554.48	1.895	–	2.112	2.165	16.14	–	35.10	31.94	–	4.00	4.10
34-6, 23	557.73	1.935	–	2.136	2.189	16.55	–	33.67	30.51	–	4.13	4.24
35-1, 148	579.98	1.816	–	2.064	2.125	18.26	–	37.97	34.33	–	3.75	3.86
35-3, 148	532.98	2.010	–	2.010	2.165	18.37	–	35.76	31.94	–	4.22	4.35
35-5, 123	585.73	1.920	–	2.036	2.093	19.51	–	39.64	36.24	–	3.91	4.02
36-1, 128	608.28	1.798	–	2.109	2.155	17.43	–	35.28	32.54	–	3.79	3.87
36-3, 148	611.48	1.952	–	2.173	2.236	14.85	–	31.46	27.70	–	4.24	4.36
36-5, 122	614.22	1.889	–	2.115	2.170	16.53	–	34.93	31.64	–	4.00	4.10
39-1, 148	684.48	2.274	–	2.308	2.327	10.62	–	23.40	22.27	–	5.25	5.29
40-1, 147	693.97	2.226	–	2.246	2.276	10.58	–	27.10	25.31	–	5.00	5.07
40-3, 148	696.98	2.027	–	2.139	2.202	15.15	–	33.49	29.73	–	4.34	4.46
40-6, 45	700.45	2.228	–	–	2.250	12.91	–	–	26.87	–	–	5.01
41-1, 148	704.48	2.040	–	2.144	2.201	14.65	–	33.19	29.79	–	4.37	4.49
41-3, 148	707.48	2.310	–	2.203	2.237	14.45	–	29.67	27.64	–	5.09	5.17
41-5, 147	710.47	2.183	–	2.038	2.185	13.24	–	39.52	30.75	–	4.45	4.77

TABLE 4 – *Continued*

Sample (Interval in cm)	Depth (m)	Velocity (km/sec)	Density (g/cc)			Water (Wt %)	Porosity (%)			Acoustic Impedance		
			S	I	G		S	I	G	S	I	G
42-1, 148	712.98	2.281	–	2.247	2.284	11.49	–	27.04	24.84	–	5.13	5.21
42-3, 147	715.97	2.148	–	2.173	2.214	14.50	–	31.46	29.01	–	4.67	4.76
42-5, 145	718.95	2.046	–	2.105	2.028	17.72	–	35.52	40.12	–	4.31	4.15
43-1, 146	722.46	2.234	–	2.060	2.104	18.18	–	38.21	35.58	–	4.60	4.70
43-3, 148	725.48	1.848	–	2.152	2.456	15.13	–	32.72	14.57	–	3.98	4.54
43-6, 61	729.11	2.527	–	2.313	2.197	10.80	–	23.10	30.03	–	5.84	5.55
44-1, 147	731.97	2.355	–	2.320	2.316	10.14	–	22.69	22.93	–	5.46	5.45
44-3, 148	734.98	2.465	–	2.333	2.323	10.76	–	21.91	22.51	–	5.75	5.73
44-6, 148	739.48	2.355	–	2.330	2.310	10.57	–	22.09	23.28	–	5.49	5.44
45-1, 117	741.17	2.266	–	2.283	2.307	11.95	–	24.90	23.46	–	5.17	5.23
46-1, 149	744.49	2.405	–	2.336	2.332	9.86	–	21.73	21.97	–	5.62	5.61
46-4, 141	746.91	2.366	–	2.309	2.311	10.28	–	23.34	23.22	–	5.46	5.47
46-0, 0	749.50	2.479	–	2.369	–	12.31	–	19.76	–	–	5.87	–
47-1, 148	750.98	2.394	–	2.320	2.309	9.97	–	22.69	23.34	–	5.55	5.53
47-3, 148	753.98	2.623	–	2.367	2.379	8.77	–	19.88	19.16	–	6.21	6.24
47-6, 147	758.47	2.170	–	2.160	2.197	14.78	–	32.24	30.03	–	4.69	4.77
48-1, 147	760.47	2.264	–	2.149	2.168	15.42	–	32.90	31.76	–	4.87	4.91
48-3, 148	763.48	2.698	–	2.365	2.372	9.43	–	20.00	19.58	–	6.38	6.40
48-6, 142	767.92	2.528	–	2.301	2.260	11.66	–	23.82	26.27	–	5.82	5.71
49-1, 22	768.72	2.305	–	–	2.339	11.22	–	–	21.55	–	–	5.39
49-1, 148	769.98	2.442	–	2.325	–	–	–	22.39	–	–	5.68	–
49-3, 149	772.99	2.259	–	2.210	2.192	10.96	–	29.25	30.33	–	4.99	4.95
50-1, 148	779.48	2.541	–	2.309	2.309	9.03	–	23.34	23.34	–	5.87	5.87
50-3, 143	782.43	2.548	–	2.266	2.320	11.05	–	25.91	22.69	–	5.77	5.91
50-6, 149	786.99	2.379	–	2.273	2.203	13.42	–	25.49	29.67	–	5.41	5.24
51-1, 54	788.04	2.496	–	2.285	2.321	10.65	–	24.78	22.63	–	5.70	5.79
51-3, 147	791.97	2.551	–	2.193	2.229	12.52	–	30.27	28.12	–	5.59	5.69
51-6, 148	796.48	2.231	–	2.092	2.135	–	–	36.30	33.73	–	4.67	4.76

NOTE: S = syringe technique, I = immersion technique, G = GRAPE.

Samples of the breccia have also been tested on shore (Carlson and Christensen, this volume).

The third unit in the sequence grades from limestones at the top to chalk, and extends to a depth of 674 meters. It appears to show a slight negative velocity gradient, which may reflect the gradation. No gradient is apparent, however, in the density or water content data. Absence of a compaction trend, particularly in water content, suggests that water may be trapped by the overlying dolostone and breccia.

Absence of strong gradients also distinguishes the lowest unit we reached, a limestone. Though the maximum velocities for this unit increase with depth, and the average density is slightly higher than that of the unit above, density in the unit itself does not increase markedly, nor does the water content decrease. Thus, the chalk-limestone unit at the top of the sequence provides the only significant evidence of compaction at Site 357.

BIOSTRATIGRAPHIC SUMMARY

A nearly complete Tertiary sequence containing abundant calcareous fossils, but few siliceous ones, was recovered at this site. The section lacks the lowermost Danian, the base of the Eocene and the top of the Paleocene, the upper Eocene/lower Oligocene, parts of the middle to upper Miocene, part of the upper Pliocene, and the uppermost Pliocene/lower Pleistocene.

A Cretaceous section ranging from upper Maestrichtian to lowermost Santonian was also retrieved. Parts of the middle Maestrichtian seem to be missing; the section below, except for dissolution levels in the Campanian, appears to be complete.

The upper and lower Pleistocene and parts of the upper and lower Pliocene were recovered. The absence of upper Pliocene-lower Pleistocene sediments has been recorded in several piston cores from the Rio Grande Rise (see Berggren, this volume). The lower Pliocene has been zoned by nannofossils, but also by foraminifers (Berggren, this volume according to his 1973 P1 zonation).

The Miocene/Pliocene boundary occurs in Core 3, but neither the nannofossil nor the foraminifer data are absolutely conclusive. The upper Miocene nannofossils are overgrown, and some key species are missing. The foraminifers in the upper Miocene have been assigned to one new zone by Berggren (this volume). Rather than a long middle Miocene hiatus, such as that found at other South Atlantic sites, a hiatus covering part of the upper middle and lower upper Miocene occurs at Site 357, between Sections 5-4 and 5-5. Berggren (this volume) recognizes another hiatus between N 7-8 and N 11 in the lower middle Miocene, between Sections 6-4 and 6-5.

A thick lower Miocene sequence parallels that found at nearby Site 22 (Leg 3) and at Site 356. Using the foraminifers it is possible to locate both the high latitude zones of Jenkins (1971) and Kennett (1973).

The extensive upper Oligocene at this site contains both abundant calcareous and siliceous fossils. The calcareous fossils are generally better preserved in both the lower Miocene and upper Oligocene sequences, where radiolarians are also present. Radiolarians are never as abundant again below the Oligocene, although they occur throughout the lower and most of the middle Eocene at this site. A minor amount of chert in parts of the Eocene suggests that many of the radiolarians originally present have been dissolved.

Only the upper part of the lower Eocene occurs at this site, since a hiatus spans most of the lower Eocene and upper Paleocene. The middle and lower Paleocene down to the Danian is represented, but the lowermost Danian and the Tertiary/Cretaceous boundary lay between Cores 30 and 31 in a 9.5-meter uncored interval.

As at Site 356, the nannofossils are better preserved in the Paleocene than in the Eocene. The foraminifers are not particularly well preserved in either series at Site 357.

The Cretaceous sequence recovered at Site 357 spans from the upper Maestrichtian to the lowermost Santonian. Most of the Maestrichtian, except for some middle Maestrichtian, was recovered, as were presumably complete sections of Campanian and Santonian. In Cores 35-38, of Campanian age, all planktonic foraminifers have been dissolved, leaving a residue of benthic foraminifers and some nannofossils. An age for these cores was derived from both calcareous nannofossils and benthic foraminifers.

The Santonian was particularly long at this site, and Core 50, at the bottom of this hole, is assumed to belong in the lowermost Santonian, although the calcareous microfossils are very poorly preserved.

Paleoecology

Some information concerning water depths, circulation patterns of water masses in the South Atlantic, and the chemistry and effects of interstitial waters on sediment can be derived from the calcareous and siliceous microfossil faunas at Site 357.

Depths

The indicator assemblages of benthic foraminifers suggest the following depths for this portion of the Rio Grande Rise:

Recent	>2000 meters
Oligocene-Miocene	1500-2000 meters
Paleocene-Eocene	1000-1500 meters
Cretaceous	~1000 meters

Depth estimates for the Recent through the late Eocene are based on total benthic assemblages, planktonic/benthic ratios, and the depth-indicator species *Uvigerina spinulosa* and *Uvigerina rippensis*. In addition, the upper Oligocene benthic assemblages in Hatton-Rockall Basin (DSDP Leg 12, Site 116, Core 23) with estimated depositional depths of ~1800 meters, resembled assemblages at Site 357.

Assemblages of Paleocene benthic foraminifers on Rockall, however, resemble Paleocene Gulf Coast Midway Group shelf depth foraminifers (Berggren, 1972). This is not so at Site 357, where Paleocene benthic species are scarce, indicative of deeper waters, and do not resemble the classic Midway faunas. In fact, they bear closer affinity to the slope depth faunas of benthic foraminifers from the Paleocene of Jordan or the Blake Plateau.

Cretaceous benthic faunas bear the characteristic "deep" water association *Gavelinella*, *Aragonia*, and *Nuttalides*. "Deep" in the Cretaceous of this site suggests depths of close to 1000 meters.

From the examination of the ostracodes of Site 357 and comparison of these with the faunas of Sites 21A and 22 (Leg 3), the depths seem greater than 1000 meters from the Danian to the present time; the faunas are totally blind (indicating depths probably greater than 800 m), with generally large specimens and low diversity (Benson, this volume).

Temperature and Circulation

The Plio-Pleistocene of Site 357 contains subtropical faunas of foraminifers and nannofossils. However, the presence of *S. dehiscens*, a typical latitudinally restricted tropical index species, may indicate warmer water periods in the Pleistocene at this site. By analogy, its predecessors *S. seminulina* and/or *S. praedehiscens* may prove to be climatic indices for the Miocene and Pliocene at this latitude.

For Miocene sequences it was necessary to apply a high-latitude zonation of foraminifers. Indeed, many typical New Zealand species, including the useful *G. conomiozea-G. miozea* series, are present at this site. But the coccoliths at this time are still zoned according to the standard low- and mid-latitude scheme of Martini (1971).

The radiolarians in the lower Miocene include orosphaerids and collosphaerids, indicating tropical to subtropical surface waters. The lower Miocene planktonic foraminifers include predominately cooler water elements.

Several explanations for this apparent paradox are possible: (a) mixing of water masses, tropical and high-latitude, at this intermediate latitude; (b) increased vigor of the North Atlantic Deep Water with cooler temperatures, in addition to the more southerly extent of a vigorous surface tropical gyre; and (c) differing definitions of "subtropical" and "high latitude" among specialists in different subdisciplines.

A major change in deep water circulation flowing from the North Atlantic into the South Atlantic occurred during the early-middle Miocene. This change should be reflected in the faunas at Site 357, since the North Atlantic Deep Water is known to flow this far south in the South Atlantic. What other effects this event may have had at Site 357 remains to be seen. It does not seem likely that it is responsible for the mixed radiolarian and foraminifer climatic indications discussed above.

The Oligocene discoaster/chiasmolith ratio indicates a "cool" Oligocene, as do the radiolarian and foraminifer faunas. The "cooler" foraminifers became essentially latitudinally ubiquitous at this time, as the ocean waters cooled (Shackleton and Kennett, 1975, and Boersma and Shackleton, this volume).

At mid-latitudes in the Eocene, planktonic foraminifer faunas characteristically contain several species of keeled globorotalids. But faunas with reduced numbers of these globorotalids apparently characterize the later early Eocene at these latitudes, and the loss of these keeled forms has been related to cooling of South Atlantic waters after accumulation of the first land ice on Antarctica (Premoli-Silva and Haq, in preparation). Just such a change occurs in the faunas of planktonic foraminifers at Site 357: the middle Eocene contains a diverse assemblage of keeled globorotalids, whereas early Eocene faunas contain only one globorotalid species.

The hiatus representing the upper Paleocene to lower Eocene at this site and at Site 356 is anomalous with respect to other sections of the Atlantic, where corresponding faunas of planktonic foraminifers are diverse and common (Premoli-Silva and Haq, in preparation).

Foraminifers

Cores drilled at Site 357 on the northern flank of the Rio Grande Rise, at a water depth of 2086 meters, contain a stratigraphic sequence ranging from upper Pleistocene through Upper Cretaceous.

Pleistocene

The top core of the section was a water core which contained only a thimbleful of sediment. This sediment contains a well-preserved, diverse upper Pleistocene assemblage of planktonic foraminifers, deep bathyal benthic foraminifers, and several species of pteropods. The planktonic assemblage is dominated by subtropical forms, but the presence of the tropical species *Sphaeroidinella dehiscens* suggests that the fauna existed during a warmer episode in the late Pleistocene.

On the basis of *Globigerinoides ruber* (pink), this assemblage is assessed to be of late Pleistocene age: the presence of *Sphaeroidinella excavata* places it in Zone N23.

Pliocene

Pliocene sediments were recovered from Core 1 to Core 3, Section 5. Although there is still dispute over the location of the Pliocene/Miocene boundary, *Globoquadrina dehiscens* ranges up into Core 3, Section 5, so the boundary is placed somewhere in that section. For detailed discussion of the Miocene-Pliocene faunas from this site, see Berggren (this volume).

In Cores 1 and 2, later Pliocene foraminifers are present; these include *Globorotalia miocenica*, *G. multicamerata*, and *G. tosaensis*. The bottom of Core 2 and the top of Core 3 contain *G. puncticulata* as well as members of the *G. margaritae* complex. *Sphaeroidinellopsis* spp. occur together with members of the *G. crassacrotoensis-crotoensis* plexus. Thus, a fairly full Pliocene section occurs below the hiatus separating the upper Pleistocene from the upper (though not the uppermost) Pliocene.

Miocene

An extensive Miocene sequence was retrieved in Cores 3 through 15. Present in these faunas are the high latitude indicator species of the *G. miozea-conomiozea* group, the *Globigerina woodi* group, the *Globorotalia fohsi*, and *Orbulina-Praeorublina* sequence of fossils. Berggren (this volume) has zoned this sequence and compared it to sequences in piston cores from the Rio Grande Rise. A hiatus spans the upper middle-lower upper Miocene, although the lower Miocene appears to be complete. The fossils are generally well preserved, although a great deal of mixing, reworking, and redeposition of material has occurred.

In addition to the standard zonation of Berggren (this volume), the 1973 zones of Kennett can be recognized, along with the high latitude lower Miocene zones of Jenkins (1971). The table below depicts these higher latitude zones.

Section	Kennett Zone (1973)	Jenkins (1971)	Section
1-1 - 2-5	*G. truncatulinoides*		
2-5 - ?	*G tosaensis-truncatulinoides*		
4-2 - 5-3	*G. inflata* *G. miozea sphericomiozea*		
2-6 - 3-1	*G. crassaformis*		
3-1 - 3-3	*G. puncticulata*		
3-3 - 3-5	*G. margaritae*		
3-6 - 6-1	*G. nepenthes, G. conomiozea, and G. continuosa*	*G. continuosa-G. miotumida*	4-2 - 5-4
		G. mayeri	5-3 - 6-3
		O. suturalis	6-2 - 6-5
6-1 - 6-3	*G. mayeri*	*G. trilobus*	6-4 - 10-1
6-3 - 6-5	*O. saturalis*	*G. woodi-G. woodi connecta*	10-1 - 12-1
6-5 - 10-1	*G. trilobus*		
		G. dehiscens	12-1 - 13-1
		G. euapertura	13-1 - 15-2

The lower Miocene sequence is long and the faunas fairly monotonous. Preservation is markedly improved in those samples containing radiolarians. Faunas characteristically contain high percentages of subtropical to high latitude species.

Throughout the Miocene the benthic foraminifers are somewhat scarce, but indicate bathyal depths. For example, *Uvigerina spinulosa* occurs through most of the Miocene, and indicates depths from 1500 to over 2000 meters.

Oligocene

Cores 16 through 19 contain sediments of Oligocene age. These Oligocene faunas also contain both higher and mid-latitude species, but the Oligocene is subdivided according to a low-latitude zonation. The upper Oligocene *Globigerina angulisuturalis* Zone, indicated by the presence of the nominate taxon and the absence of *Globorotalia* (T.) *opima opima*, is well represented at this site. In appearance, *G. angulisuturalis* resembles the compact high-latitude forms more than the more open and flaring lower latitude ones.

The upper Oligocene Zone P20 and the lower Oligocene Zone P19 are represented in Cores 18 and 19. However, the foraminifers are strongly corroded, bullae are often completely dissolved, and the faunas are not diverse. *G. euapertura*, a higher latitude species, occurs with *G. ampliapertura*, *Chilogumbelina cubensis*, *G. ouachitaensis*, *G. tripartita*, *Globigerina praebulloides*, and *Globorotalia* (T.) *opima nana*.

The benthic foraminifers in Oligocene samples are particularly well preserved and diverse, and indicate bathyal depths.

Eocene

The Eocene sequence at this site is more extensive than that at Site 356; in their lower portions, however, they both record similar sequences of faunal events (see range charts, Boersma, this volume). In addition, both record supposed simultaneous incursions of radiolarian- and diatom-rich sediments; the longer section at Site 357 records a longer episode of incursions of siliceous sediments than at Site 356. Mixing and dissolution make zonation of parts of this Eocene sequence difficult.

Core 20 contains both upper and middle Eocene fossils. The top of the core containing *G.* (*T.*) *cerroazulensis*, *P. mexicana*, *G. index*, and *G. barri*, as well as the higher latitude species *G. angiporoides*, is assigned to the upper Eocene, Zone P16. Dissolution in some samples has been intense, leaving highly reduced faunas. For example, Sample 20-1, 138 cm is essentially an ooze of *Globigerinatheka* spp., and resembles upper Eocene faunas from higher latitudes, as the upper Eocene at Site 277, Leg 29.

The lower sections from Core 20 belong to the middle Eocene, as indicated in the fauna containing *G.* (*M.*) *lehneri*, *T. pseudotopilensis*, *G. index*, and *G. kugleri*. Zones P13 through P11 occur in Cores 21 through 26. In general, preservation is not good; there is a high degree of dissolution and recrystallization, and faunas are reduced in diversity. Radiolarians occur in abundance first in Core 26, where the preservation becomes markedly worse; preservation remains moderate to poor throughout the Eocene sequence.

The older Eocene faunas contain *A. densa*, *A. wilcoxensis*, *A. coalingensis*, *Hantkenina aragonensis*, *G. turgida*, and *G. boweri*. Keeled globorotalids are rare, and globigerinids and acaraninids dominate the faunas.

Benthic foraminifers in this upper to middle Eocene sequence are common, fairly well preserved, and indicative of bathyal depths. Changes in benthic diversity, faunas, and planktonic/benthic ratios are discussed with respect to paleotemperature (in Boersma and in Boersma and Shackelton, this volume).

A hiatus occurs below Core 26. Cores 27-28 contain fossils from the lower Eocene Zones P7-P8. Keeled globorotalids are still not abundant, but both *G.* (*M.*) *subbotina* and primitive *G.* (*M.*) *aragonensis* are present in these samples, along with numerous acaraninids and a few small globigerinids. The first bullate species occur in Core 27, but bullae are not common until the middle Eocene, where many species are abundant.

Typical benthic species in this section include *Nuttalides*, *Osangularia*, *Gyroidina*, *Stilostomella*, and *Uvigerina*.

Paleocene

Only Cores 29 and 30 contain sediments of Paleocene age. Core 29, containing the index species *G.* (*M.*) *pusilla*, *G.* (*M.*) *conicotruncana*, *G.* (*M.*) *velascoensis*, and *G.* (*P.*) *ehrenbergi*, belongs to the upper Paleocene Zone P3. Thus, the uppermost Paleocene Zones P4-P5 and the lowermost Eocene Zone P6 are not preserved at this site.

The lower Paleocene Zones P2 and P1 are represented in Core 30, although Zone P1 is not complete. The top of Core 30 contains *G. uncinata* and other typical Danian planktonic species, and the lower sections contain lower Danian fauna, including *G.* (*T.*) *pseudobulloides*, *G. daubjergensis*, and *Woodringina hornerstownensis*. The lowermost Danian is not preserved at this site.

Benthic foraminifers are particularly scarce. The genera *Nuttalides* and *Gyroidina* are most common. *Nuttalides truempyi* is generally found in deeper marine sections, and a *Nuttalides-Gyroidinoides*—dominant fauna generally represents slope depths, so the Paleocene sediment at this site could have been deposited at about 1000 meters.

Cretaceous

Faunas of late Maestrichtian through Santonian age occur in Cores 31 through 51. The Cretaceous zones and their index fossils are listed in the table which follows. Although late Campanian planktonic foraminifers are not present, nannofossils of this age occur in Core 36.

Core	Sub Stage	Index Fossils	Zone
30-33	Upper Maestrichtian	*A. mayaroensis* *R. fructicosa* *G. contusa*	*A. mayaroensis*
34	Unzoned		
35	Lower Maestrichtian	*G. tricarinata* *P. costulata* *G. fornicata*	*G. tricarinata*
36-39	Unzoned		
40-47	Upper Santonian	*G. concavata carinata* *H. reussi* *G. asperus*	
47-51	Lower Santonian	*G. concavata concavata* *G. sinuosa* *G. coronata* *G. renzi*	

Most of the fossils are not well preserved, particularly in Cores 34-50. In Cores 35-38, the planktonic species have been dissolved, leaving only benthic foraminifers, which are strongly corroded. The benthic assemblages are diverse, and contain the deepwater species of *Aragonia*, *Nuttalinella*, *Gyroidinoides*, *Nodosarella*, *Dorothia*, and *Quadromorphina* (Sliter, this volume). The assemblage is considered to be of upper slope depths. Samples from Cores 40 to 48, however, contain benthic forms from shallower depths, including *Bolivinoides*, miliolids, worn echinoids, and *Inoceramus* prisms. Many of these fossils are considered to have been redeposited from the shelf down the slope (see Sliter, this volume). According to Sliter, the site may have sunk from mid-slope depths in the Santonian to bathyal depths (1000 m) by the end of the Cretaceous.

Globotruncana elevata first occurs in the core-catcher sample of Core 41, but is rare throughout the rest of the

Campanian, owing to dissolution. Both zones of the Santonian are well represented at this site. Although preservation is generally poor, *G. concavata carinata* is present from Core 47 through Core 42, and defines the upper part of the Santonian. The lower Santonian *G. concavata concavata* Zone is very long at this site, but the presence of *R. pilula*, *G. asper*, and *G. fornicata* at the bottom of this hole locates it still in the Santonian.

As Premoli-Silva and Boersma (this volume) point out, the outstanding feature of this Cretaceous section is the unusual degree of reworking and slumping; in consequence, faunal boundaries are often only tentatively placed, and faunas are known to be mixed, particularly in the Campanian and the Maestrichtian.

Calcareous Nannofossils

Calcareous nannofossils of Pleistocene to Santonian age are common in most of the cores recovered at this site. Preservation of the nannofossils is, with a few exceptions, moderately good in the Cenozoic and moderate to poor in the Upper Cretaceous marly limestones in which the hole bottomed. Figure 13 summarizes the coccolith zones found at this site. The distribution of coccolith species appears in tables in Perch-Nielsen (this volume).

Pleistocene (Core 1)

Assemblages of early Pleistocene age occur in the upper part of Core 1. They are dominated by small Prinsiaceae, and also contain some reworked Pliocene and Eocene coccoliths. In the uppermost three sections of Core 1, *Gephyrocapsa oceanica* and *Pseudoemiliania lacunosa* occur together , as is typical for the upper part of the *P. lacunosa* Zone (NN 19) of Martini (1971). A single discoaster occurs in Sample 356-1-4, 70 cm, and is considered to be reworked; the sample thus still belongs to the *P. lacunosa* Zone. Upper Pleistocene foraminifers present in a "water-core" that must have reached bottom indicate that the upper Pleistocene is also present at this site, although we found no coccolith assemblages of this age.

Pliocene (Cores 1 and 2)

Discoaster brouweri and *D. pentaradiatus* are both rare in Sections 5 and 6 of Core 1, which we here consider to represent Zones NN 18 and 17. They become more common in Sample 1, CC, where *D. surculus*, and thus the zone of this name, is also recognized (NN 16). Only at the top of Core 2 do discoasters become more frequent, indicating that climatic conditions here were better earlier in the late Pliocene. *Reticulofenestra pseudoumbilica* is very infrequent, and considered to be reworked down to Core 2, Section 4. It becomes more common in Section 2-5, and abundant in Sample 2, CC, where the earliest *Ceratolithus rugosus* occurs. The first occurrence of *C. rugosus* is usually in the lower Pliocene, just above the Miocene/Pliocene boundary. *C. acutus*, the first birefringent ceratolith, also occurs in Sample 2, CC. It has been reported by Gartner as *Ceratolithus* sp. from the base of the Pliocene, and overlaps with *C. rugosus* in the upper part of its range.

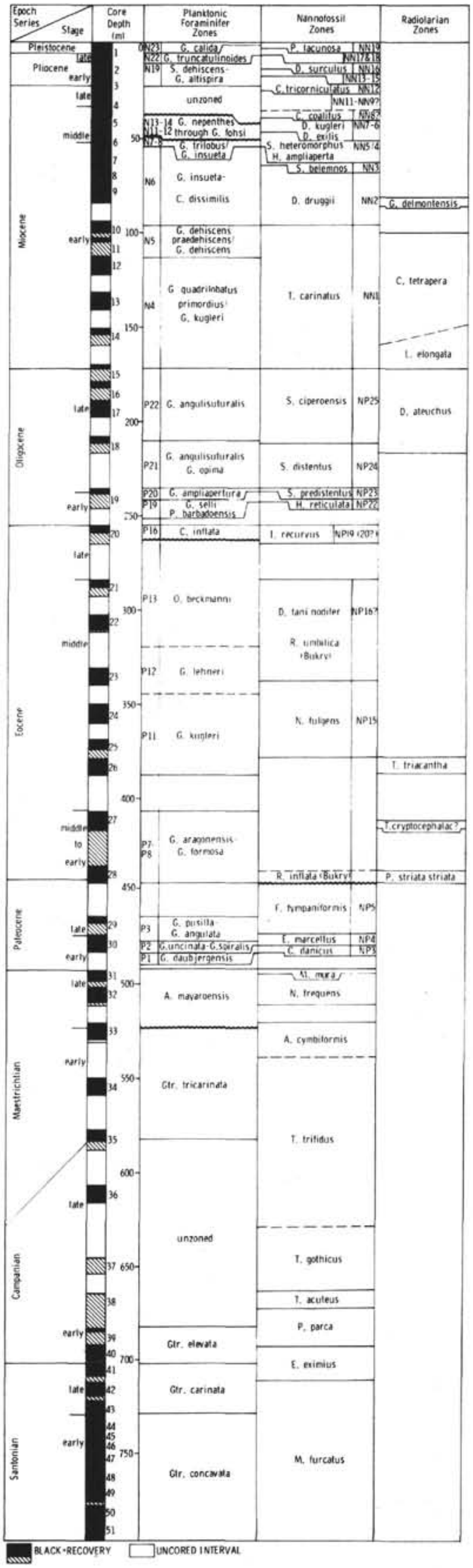


Figure 13. *Biostratigraphic summary, Site 357.*

Miocene (Cores 3-15)

Common discoasters, usually heavily overgrown, and reworked Oligocene/Eocene coccoliths in small amounts characterize the Miocene coccolith assemblages at Site 357.

The nonbirefringent ceratoliths *Amaurolithus amplificus*, *A. delicatus*, *A. primus*, and *A. tricorniculatus* indicate upper Miocene sediments. Absence of birefringent ceratoliths suggests that the uppermost sample from Core 3, Sample 3-1, 70 cm, does not represent the very top of the Miocene. The first occurrence of ceratoliths is in Sample 3-5, 135 cm. It is usually in the *Discoaster quinqueramus* Zone (NN 11). Because of the overgrowth on discoasters, it is almost impossible to distinguish *D. quinqueramus* from other 5-rayed discoasters, such as *D. pentaradiatus*, and thus to recognize the *D. quinqueramus* Zone properly. *D. surculus* usually has its first occurrence near that of *D. quinqueramus*; we found it down to Sample 3-5, 135 cm, the same depth as ceratoliths. From here downward, no age-diagnostic nannofossils were found until Sample 5-2, 135 cm, where the last *Coccolithus miopelagicus* occurs, indicating an early middle Miocene age for this sample. The last *Cyclicargolithus floridanus* was found in Sample 5-5, 70 cm, indicating the lower part of the *Discoaster exilis* Zone to be present. *Sphenolithus heteromorphus* has its last occurrence in Sample 6-2, 74 cm, and overlaps with *S. belemnos* in Sample 6-6, 70 cm. No *Helicopontosphaera ampliaperta* are present to distinguish the *S. belemnos* and *H. ampliaperta* zones. The occurrence of *D. druggi* down to Sample 10-2 65 cm, and the last occurrence of *S. ciperoensis* in Sample 15, CC, reflect further events in the earliest Miocene and latest Oligocene. *Dictyococcites bisecta* has its last occurrence in Sample 14, CC, *Reticulofenestra abisecta* in Sample 10, CC.

Thus the coccolith zones represented here indicate some upper Miocene, the lower middle Miocene, and the lower Miocene. We could not establish zones for parts of the lower upper Miocene and of the upper middle Miocene; these parts may be partly missing.

Oligocene (Cores 15 to 19)

All but the lowermost zones of the standard coccolith zonation of the Oligocene are represented at this site. The marker nannoliths *S. ciperoensis*, *S. distentus*, and *S. predistentus* are usually scarce, but *S. predistentus* becomes common in a few samples. In the lowermost Miocene samples, *Zygrhablithus bijugatus* is already present in small numbers; in the Oligocene and the Eocene it is a common, sometimes even dominant, part of the coccolith assemblage. *Chiasmolithus altus*, a form typical of high-latitude Oligocene assemblages, is present in most samples but is usually rare. *Discoaster deflandrei*, the only consistently occurring discoaster, is rare to common, *Helicopontosphaera euphratis* is present consistently but sparsely. Representatives of the family Braarudosphaeraceae occur in small numbers in some samples, and include *Braarudosphaera* sp. and *Micrantholithus* sp. The low discoaster/chiasmolith ratio indicates relatively cool conditions at this site during the Oligocene (but see discussion in Perch-Nielsen, this volume).

Eocene (Cores 20 to 28)

The incomplete upper and middle Eocene sequence recovered contains common but only poorly preserved to moderately well preserved coccoliths. *Z. bijugatus* is, as in the Oligocene, an important constituent of the assemblage. *Isthmolithus recurvus*, together with *Discoaster barbadiensis* and *D. saipanensis*, characterize the youngest Eocene in Core 20. *Sphenolithus pseudoradians*, a not very reliable marker nannolith of the uppermost Eocene, was not found. From Core 21 through Core 23, *Chiasmolithus solitus* occurs, but no *Nannotetrina*. This interval, where *Discoaster tani* is common to rare was assigned to the *D. tani nodifer* Zone (NP 16), although some *D. tani* occur infrequently below Core 23. *Nannotetrina* sp. and *N. fulgens*, heavily overgrown, occur from Sample 23, CC, to Sample 28-6, 66 cm. The very bottom of the core-catcher of Core 28 contains about 2 cm of sediment with an upper Paleocene (NP 5) assemblage. Since we drilled for 19 meters below cored interval 28 before retrieving Core 28, it is likely that Sample 28, CC, comes from somewhere in the drilled interval, and that the hiatus occurs in this interval rather than at the bottom of cored interval 28.

Paleocene (Sample 28, CC, bottom and Cores 29 and 30)

We encountered only a short Paleocene sequence at this site. It includes the lower upper Paleocene zone of *Fasciculithus tympaniformis* (NP 5) and the Danian *Ellipsolithus macellus* (NP 4) and *Chiasmolithus danicus* (NP 3) zones. No lowermost Danian was cored; the Danian/Maestrichtian contact occurs in the interval between Cores 30 and 31. We did find, however, a lump of Danian sediment (NP 2/3) loose on top of Core 31. The Paleocene coccolith assemblages are better preserved than the Eocene assemblages, as noted before in the thick Paleocene sequence at Site 356 on the São Paulo Plateau.

Upper Cretaceous (Cores 31 to 51)

The coccolith assemblages in the Upper Cretaceous sequence at Site 357 closely resemble those from Site 356. Coccoliths are abundant to few, and preservation deteriorates down section. *Micula mura*, which indicates a latest Maestrichtian age for the youngest Cretaceous present, occurs down to Sample 31-3, 40 cm. *Nephrolithus frequens*, which usually has its first occurrence slightly below *M. mura* at the few places where they occur together, is present in very small quantities down to Sample 32, CC. *Lithraphidites quadratus*, which usually occurs before *N. frequens*, here also has its first occurrence in Sample 32, CC, so the zone of this name cannot be distinguished. Core 33 contains no marker forms other than *Arkhangelskiella cymbiformis*, which ranges from the upper Campanian through the Maestrichtian. *Tetralithus trifidus* and *T. gothicus* have their last occurrences together in Sample 34-1, 70 cm, where *Broinsonia parca* is also present. The *T. trifidus* Zone thus extends from here down to Sample 36-6, 70 cm, where *T. trifidus* first occurs. *T. gothicus* and the zone of this name extend from Section 36-6 to Sample 37, CC, where the last specimens of *Eiffellithus eximius* were also found. Although the last

Marthasterites furcatus occurs in Sample 40-2, 70 cm, the first *Broinsonia parca* occurs in Sample 41, CC. The two species thus overlap at this site; they did not overlap at Site 356 on the São Paulo Plateau. *M. furcatus* is rare to few in most samples down to Sample 51, CC, where the hole bottomed in the Santonian. It is, however, often heavily overgrown and hardly recognizable, and in some samples seems to be missing. Generally, diversity diminishes downhole, except in a few samples, where preservation of the coccoliths is also better.

Kamptnerius magnificus is occasionally rare in the Santonian and the Campanian, rare in most of the Maestrichtian, and absent in the uppermost part of the upper Maestrichtian. *Lucianorhabdus cayeuxi* is common only from the lower Campanian downward.

Radiolaria

Radiolarians occur as a measurable constituent only in the coarse fractions of Cores 9 through 28 (except Cores 21 through 25—see below), corresponding to lithologic Unit 2, a foraminifer-nannofossil ooze which grades to limestone. Traces of radiolarians occur in Cores 1-8, and except for a few very infrequent occurrences in Cores 40 and 50, Cores 29 to 51 are barren of siliceous microfossils. The presence of chert in the sediment of Cores 21-24, and the absence of siliceous microfossils in this interval, indicate that remobilization and migration of silica from adjacent sediment was involved in formation of the chert. Core 25 contained a volcanic breccia and dolostone, except for the lower 40 cm, which consisted of limestone containing radiolarians. In none of the samples examined are the radiolarians abundant in the total coarse fraction, but they are the dominant constituent of the noncalcareous fraction. Diversity is very low and preservation very poor in the top and bottom parts of Unit 2, as well as in the sediment above the cherts (Cores 19-20). The remaining sediments of interval 2 contain assemblages of moderate diversity and moderate to good preservation.

Assemblages of the lower Miocene *C. tetrapera* Zone occur in Cores 10-13. The presence of *Dorcadospyris ateuchus*, *Lychnocanoma bipes*, and *Cyclampterium* (?) *pegetrum* indicates the lower part of the zone. It is difficult to assign Core 14 definitively to either the *C. tetrapera* or the *L. elongata* Zone; Core 15 belongs to the latter. *Cyrtocapsella cornuta*, *C. tetrapera*, and *D. simplex* in the samples still indicate a lower Miocene age; this is substantiated by the foraminifers and calcareous nannofossil zonation. Sponge spicules, orosphaerid fragments, and collosphaerids occur commonly in all samples examined, which indicates tropical to subtropical surface waters.

Assemblages of the *Dorcadospyris ateuchus* Zone are in Cores 16 to 18. In Core 18, abundance, preservation, and diversity of the radiolarians decline. Only fragments occur in Cores 19-20, and they are absent or extremely rare in Cores 21-23. As mentioned previously, this is the interval in which cherts occur. Thin-section examination of the cherts reveals the common presence of radiolarians in advanced stages of dissolution.

From Core 25 to Core 28, lower middle Eocene to upper lower Eocene assemblages of the zones of *Thyrosocyrtis triacantha* (Cores 25, 26), *Theocotyle cryptocephala* and *Phormocyrtis striata striata* (Core 28), and *Cryptocephala* (Core 27), occur. Below Core 28 the sediment is barren of radiolarians, except for very infrequent occurrences in Cores 40 and 50.

The scarcity of siliceous microfossils in the sediment of this site can be explained as a consequence of the following factors:

1) Low productivity of siliceous phytoplankton and microzooplankton in the surface waters in this region through time. This is difficult to evaluate, especially since siliceous microfossils are abundant in upper middle Eocene deposits elsewhere in the Atlantic, but are apparently absent at this site.

2) Relatively shallow depth of this site through time with respect to the CCD, resulting in masking of the siliceous component of the biogenic sediment by the large volumetric input of calcareous microfossils. In order to retrieve an adequate sample of radiolarians, large amounts of sediment (up to 50 cc) from the core catchers were processed.

3) Undersaturation of the interstitial water with respect to silica, resulting in dissolution and migration of silica. Evidcence for this is the domination of all the assemblages examined by heavy walled, robust species. This is strikingly demonstrated in the top part of the section, where orosphaerid spines and mesh fragments provide the first evidence of radiolarians downhole in Core 8; orosphaerid fragments and sponge spicules are abundant in all Miocene samples examined.

The most likely cause for the relatively sparse occurrences of radiolarians is found in a cause and effect relationship between factors 2 and 3.

SEDIMENT ACCUMULATION RATES

Figure 14 summarizes the sediment accumulation history at Site 357 and at Leg 3, Sites 21 and 22 on the Rio Grande Rise. The fairly complete, predominately calcareous pelagic sequence, ranging from the Pleistocene to the Santonian, was cored continuously at the top in order to recover as complete a Neogene sequence as possible. Below Core 12 (lower Miocene) coring was semicontinuous until near the bottom of the hole, where continuous coring was necessary for operational reasons and for attempting to core the sediment/basement contact.

Accumulation was rapid during the Santonian, probably more than 2 cm/1000 yr, and slower during the Campanian. A mid-Campanian hiatus may be present, but cannot be clearly established. The apparent slow accumulation in the Campanian may be an artifact of the long duration here assigned to the Campanian, or the result of apparent dissolution of foraminifers in the Campanian deposit. In the late Campanian and early Maestrichtian, the accumulation of calcareous pelagic sediments continued at the high rate of about 3 cm/1000 yr. According to the foraminifer data, part of the middle Maestrichtian is missing. Sedimentation was slow, on the order of 0.5 cm/1000 yr during the latest Maestrichtian, the earliest

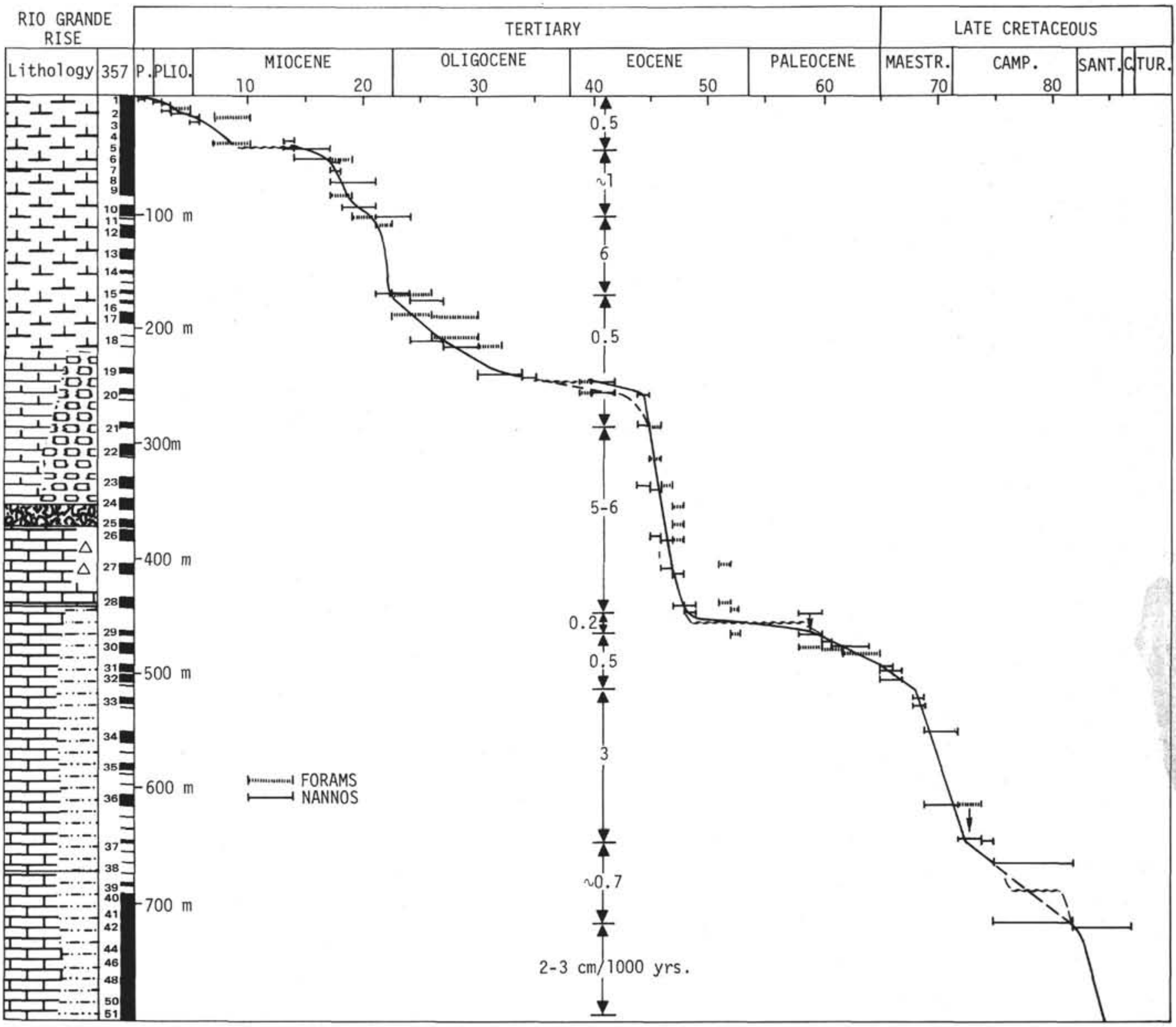


Figure 14. *Sediment accumulation history, Site 357.*

Paleocene, and across the Cretaceous/Tertiary boundary, which lies between Cores 31 and 30. If a hiatus is present at this boundary at this site, it is very short. There are no signs of a very shallow CCD, as proposed by Worsley (1974), during the latest Cretaceous and the earliest Tertiary at this site.

A hiatus through most of the late Paleocene and early Eocene is reflected in Core 28. Since the bottom part of Sample 28, CC, where the only Paleocene assemblage occurs, probably comes from somewhere in the 19-meter drilled interval below the bottom of Core 28 proper, the hiatus is most likely in this uncored interval rather than at the bottom of cored interval 28. If continuous accumulation is assumed instead of a hiatus, it would have occurred at the slow rate of about 0.2 cm/1000 yr from the late Paleocene (58 m.y.B.P.) to the early/middle Eocene (~49 m.y.B.P.). Nondeposition during all or part of this interval is evident in sequences at three other sites on this leg: 354, 356, and 358.

Accumulation rates were very high, 5 to 6 cm/1000 yr, for middle Eocene sediments, which also contain volcanic breccia probably transported from shallower parts of the rise. Upper Eocene sediments occur only in Core 20; Cores 15 to 20 contain a relatively complete middle through upper Oligocene sequence. There is some doubt about the depths at which Cores 20 and 21 were actually cut; i.e., at the bottom of the drilled interval, as intended and recorded, or inadvertently at the top of the interval drilled with the core barrel in place. In the latter case, the accumulation history would change from probably continuous accumulation, at a rate of about 0.5 cm/1000 yr, from the middle Eocene through the Oligocene, to a somewhat higher rate before and after a hiatus across the Eocene/Oligocene boundary. A similar problem exists with Cores 19 to 17, drilling breccias in which it is not possible to assign exact depths to the individual core pieces.

For a short time in the early Miocene, accumulation was very rapid, about 6 cm/1000 yr, then it slowed to about 1 cm/1000 yr later in the early Miocene. According to Berggren (this volume), a hiatus spans the late early Miocene to early middle Miocene, and possibly the late middle Miocene to middle late Miocene and early late Miocene to late Pliocene.

The sedimentary sequence recovered at Site 357 supplements the sequences previously recovered at Sites 21 and 22. Essentially, four periods of faster than "normal" pelagic accumulation and four periods of slower than "normal" calcareous pelagic accumulation occur at Site 357. Compared with Site 21, where Campanian sediment was reached at about 100 meters, the sequence at Site 357 is more complete, especially the Neogene. At Site 22, however, accumulation rates in the Oligocene and in the lower Miocene are about the same as at Site 357, and the rest of the Neogene is missing.

CORRELATION OF REFLECTION PROFILES WITH DRILLING RESULTS

Site 357, on the northern flank of Rio Grande Rise, was chosen on the basis of two R/V *Vema* profile records (V26, #825, and V26, #836). The *Vema* profiles (see Figure 4) were made for a site survey for Site 22, which was drilled during DSDP Leg 3. The present site is approximately 30 km west of Site 22.

The reference profiles as well as the approach profile display a reflector at approximately 0.8 sec, which, because of its character, appears to be igneous basement. On the basis of the depth of this reflector, we thought that crystalline basement would lie approximately 800 meters below the sediment-water interface.

Figure 15 includes a (reversed) tracing of the seismic profile (Figure 5) recorded while approaching Site 357. Three identifiable reflectors are present, at 0.24, 0.38 and 0.78 sec. These reflectors have been assigned numbers 1 through 3, starting with the uppermost reflector. They can be mapped in the area around the site and through most of the area of Rio Grande Rise (see McDowell et al., this volume).

The measured seismic velocities in cores permit us to assign seismic velocities for intervals between these reflectors, and thus to calculate the subbottom depth for each reflector. The average interval velocities used here are as follows: 1.60 km/sec between ocean bottom and reflector 1, 1.75 km/sec between reflector 1 and reflector 2, and 2.14 km/sec between reflectors 2 and 3. These velocities suggest that the three reflectors occur at subbottom depths of 192, 315, and 742 meters, respectively.

The calculated depths for these reflectors correlate fairly well with abrupt changes in average seismic velocities for various segments of the sediment column (see Figure 12). The curve for acoustic impedance, however, (Figure 12), does not show the same breaks as the curve for average seismic velocities.

These reflectors are not related to changes in lithology. The sediment column drilled at Site 357 is composed almost entirely of pelagic calcareous material; the sediments are marly near the bottom of the hole. The reflectors seem to be related only to diagenetic changes in the sediments. These changes have occurred as a result of either overburden and chemical alteration or different rates of accumulation.

Reflector 1 appears to be related to a transition from ooze to chalk, and to a change in accumulation rate at 190 meters. Thin stringers of chert occur at approximately the same depth as the calculated depth of reflector 2. Hence, this reflector may be related to the siliceous material in Unit 2 of the sediment column. Also, a change in accumulation rate is evident at ~300 meters; the calculated depth to reflector 2 is 315 meters.

Reflector 3, which was generally assumed to be crystalline basement, seems only to mark the top of the very well-indurated marly limestone of Unit 5. A change in accumulation rate is also apparent at 750 meters. We drilled another 50 meters beyond the calculated depth of reflector 3 to ensure that basement penetration not be missed because of slight error in measuring the depth to basement on profiler records, or because of minor experimental error in measuring sonic velocities of the sediments.

The volcanic breccia of Unit 3 does not register as a distinct reflector on the seismic profile. The seismic profile at the site shows alternate acoustically transparent and opaque zones. Possibly these zones can be related to homogeneous and inhomogeneous zones within the sediment column. Homogeneous regions of the sediment column should appear acoustically transparent on the seismic profile, whereas inhomogeneous zones should appear opaque.

SUMMARY AND CONCLUSIONS

We drilled and cored a 797-meter section of mainly pelagic biogenic sediment at Site 357 on the Rio Grande Rise. Coring was continuous in the top and bottom parts of the section—in the top to obtain as complete a Neogene sequence as possible, and in the bottom because of very slow penetration rates. The rest of the section was cored at close spacing. We did not reach igneous basement.

The general trend in the pelagic facies, from bottom to top of the section, is toward decreasing importance of the admixed terrigenous component, evidence of progressively more oxygenated open marine conditions, and decrease of the overall diagenesis. Thus, the Santonian marly limestones of Unit 5 have a relatively high terrigenous content, which decreases considerably in the transitional zone between Units 4 and 5. The source of the terrigenous sediments may have been the subaerially exposed Rio Grande Rise (discussed later) or, more probably, the South American mainland. The predominantly gray-green sediments indicate reducing conditions which allowed preservation of the many laminae present. The gray-green sediments alternate with brown (oxidized) sediments, and the percentage of laminated gray-green sediments decreases up the section. The same trend is apparent in an up-hole increase in burrowing in Units 5 and 4. Lamination is undisturbed at the base of Unit 5, and decreases up the section as burrows become more

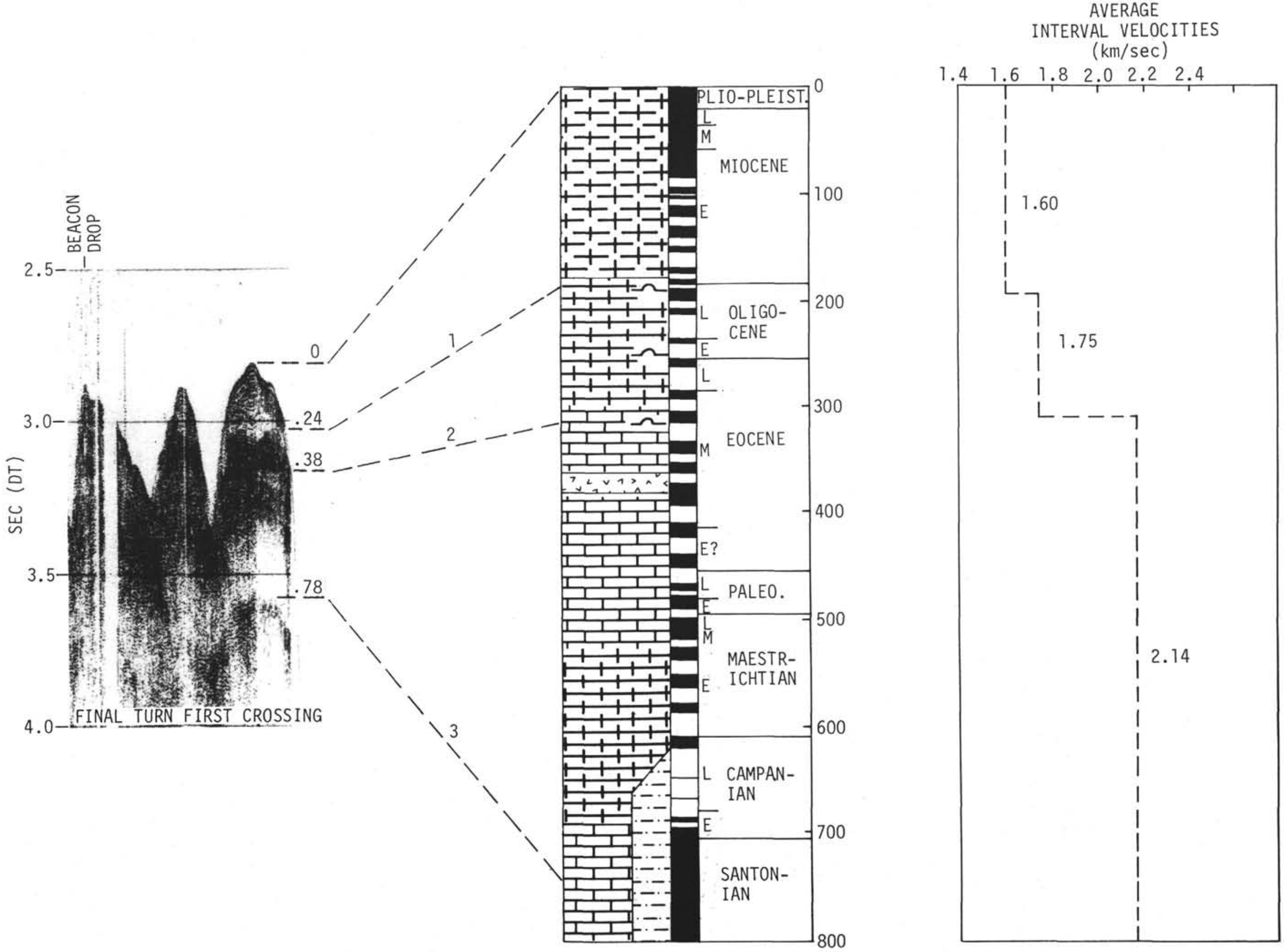


Figure 15. *Correlation of the Site 357 approach profile with the lithostratigraphic section cored. Average interval velocities are based on Hamilton Frame measurements made aboard ship.*

prevalent. The upper Campanian through lowermost Eocene limestone and chalk of Unit 4 are differentiated from Unit 5 by color and lower overall terrigenous component, but the overall trends in Unit 5 continue into Unit 4; the lower part of Unit 4 is greener (again, in repeating cyclic patterns with brown).

The middle Eocene to lower Miocene nannofossil-foraminifer oozes, chalks, and limestones show colors indicating oxidizing conditions, and have relatively little terrigenous component. Contribution of opaline fossils is significant only in this part of the section. The overlying lower Miocene through Pleistocene sediments are foraminifer-nannofossil oozes, with very little terrigenous material. The dominance of foraminifers, the pteropods in the uppermost part of the section, and the lack of dissolution or overgrowth of nannofossils, indicate little or no diagenesis.

Inferred hiatuses occur in the mid-Campanian, mid-Maestrichtian, at the Cretaceous/Tertiary boundary, the Paleocene/Eocene boundary, the Eocene/Oligocene boundary, and in the mid-Miocene. The significance of these hiatuses is discussed in another chapter (Supko and Perch-Nielsen, this volume). Benthic foraminifer assemblages indicate a general subsidence of the depositional site, from about 800 meters water depth in the Cretaceous to the present 2000 meters.

The microfossils lend evidence of changes in paleotemperature and paleocirculation at this site. Absence of keeled globorotalids in the upper lower Eocene, indicating cool water conditions, is typical of middle latitudes (Premoli-Silva, in preparation). Radiolarians, nannofossils, and foraminifers indicate a cold Oligocene; foraminifers and radiolarians show fluctuating temperatures in early Miocene.

Two findings in the Site 357 sediment sequence contribute to an understanding of the age and subsidence history of the Rio Grande Rise. The first is abundant *Inoceramus* fragments in the finely laminated Santonian sediments at the base of the section, presently 2.9 km below the sea surface; the second is the middle Eocene volcanic breccia.

That laminae of enclosing Santonian sediments are undisturbed and no shallow water biogenic elements other than *Inoceramus* are present; this indicates the shell fragments do not represent allochthonous material. Rather, they probably represent an epibenthic fauna indigenous to the site in Santonian times. Epibenthic *Inoceramus* seems to have been common in shallow to moderately deep environments in the late Cretaceous (Kauffmann, 1968; Thiede and Dinkelman, this volume), and for present purposes we may assume that the deposition site was in water about 300 to 500 meters deep in the early Santonian. Leg 3 results may be used to confirm this depth estimate, if we assume that Sites 21 and 357 are on the same piece of ocean crust subject to the same vertical movements. The basal core at Site 21 is a coquina containing shallow water components including red algae, indicating formation at or near sea level. The coquina is Campanian or older in age and was obtained from a present depth below sea level of 2.2 km. Campanian sediments at Site 357 are at a present depth below sea level of 2.7 km. The difference in depth indicates a Campanian paleodepth of deposition of about 500 meters at Site 357; paleodepth in the Santonian was probably about the same.

The middle Eocene volcanic breccia of Unit 3 may also indicate depth. It contains basalt pebbles, volcanic glass, and sedimentary components and clasts in a clayey matrix. The entire unit is size-graded, indicating it was probably emplaced from upslope in a single event. In addition to planktonic foraminifers, the biogenic component contains large benthic foraminifers, bivalve and gastropod shells of middle Eocene age and, very significantly, plates of red algae, which indicate a shallow water source. Although the basalt fragments are too altered for radioactive dating (see Fodor and Thiede, this volume), the biogenic materials indicate a downslope movement of mixed volcanic and biogenic material in large quantity in the middle Eocene. Since both the shallow water sediment components and the volcanic components are size-sorted in a similar way, they probably derived from a common provenance area in very shallow water (see further discussion in Supko and Perch-Nielsen, this volume). Deep pelagic facies of the same middle Eocene age underlie and overlie the allochthonous unit.

Igneous basement rocks have recently been dredged on the Rio Grande Rise from water depths of about 1000 meters (McDowell et al., this volume); they comprise weathered basalts, volcanic glass, and weathered lava. The basalts are alkalic as opposed to tholeiitic, and in bulk composition are similar to the volcanic materials of the islands of Tristan da Cunha, St. Helena, and Gough (Baker, 1973), as well as those of the Walvis Ridge (Hekinian, 1972). These similarities may support a view of the Rio Grande Rise as having once been a high volcanic island group, formed either at a "hot spot" on the spreading ridge (Wilson, 1965; Morgan, 1971) or in connection with movement along fracture zones (Francheteau and Le Pichon, 1972). The Santonian sediments at Site 357 provide a minimum age for the basement here. As discussed earlier, these sediments contain autochthounus *Inoceramus*, thought to indicate deposition at a depth of 300-500 meters. The *Inoceramus*-bearing beds lie at a present depth below sea level of close to 3000 meters. This and the badly weathered volcanic rocks dredged from water depths of 1000 meters indicate that in early Santonian time, portions of the Rio Grande Rise stood as a large volcanic island about 2000 meters above sea level, an elevation near the present elevation of Tristan (2060 m). Using dredge data from the eastern Atlantic (Pastouret and Goslin, 1974; Goslin et al., 1974), it can be argued that the Walvis Ridge, which many think is related to the Rio Grande Rise, had a minimum elevation of 1500 meters in Campanian time (75 m.y.B.P.).

Thiede (in preparation) has used the Site 357 shallow-water age indicators just mentioned (Santonian *Inoceramus* beds at approximately 300-500 m and middle Eocene breccia from about sea level), along with two other sea level-age data points, to determine a curve of submergence of former shoreline positions along the Rio Grande Rise. The additional data points are the presumably shallow water (≤50 m) coquina of Campanian age at the bottom of Hole 21, Leg 3 (Maxwell, Von Herzen, et al., 1970), at a present depth of 2.2 km below the water surface, and the shallowest (to account for possible downslope movement) of several dredgings of shallow water limestones (oölitic and so probably formed in depths ≤100 m), reported from R/V *Jean Charcot* cruises (Melguen, 1973). This latter deposit is Oligocene in age and at present about 1000 meters below sea level. A plot of present depths (corrected for sediment load) of former shoreline positions as a function of age yields a subsidence curve for the Rio Grande Rise. This curve is similar to the age-depth relationship for ocean crust derived theoretically and shown empirically by Sclater et al. (1971), and supports the assumption that aseismic ridges on a volcanic foundation subside at about the same rate as normal surrounding ocean crust (see Vogt, 1974; Sclater and Fisher, 1974; Sclater et al., in press).

If subsidence of the rise follows the same age-depth relationship as oceanic crust, one may put limiting cases on the age and depth of basement at Site 357. This has been done by Thiede (in preparation), and much of the following discussion derives from his work.

First, we must assume that the dredged shallowest peaks of the rise represent the top of basement, as indicated by dredged basaltic rocks—i.e., that significant erosion had not occurred before submergence of the rise; this constraint requires that subsidence curves (Figure 16) be fitted through a present-time point about 650 meters below sea level, the shallowest recorded depth on the rise (Dietrich and Ulrich, 1968). This eliminates the possibility that basement is the same age as the lowest core and lies just below it (i.e., at 2900 m below present sea level), since this would be incompatible with the finding of Eocene oölitic limestone at a present depth of 1000 meters, as well as with the present depths of the peaks.

If the basement were indeed about the same age as the lowest core (early Santonian, ~85 m.y.B.P.), curve 1 indicates it would lie about 3600 meters below present sea level, or that 500 to 1000 meters of unsampled sediment lies between the lowest core and basement. A sufficient number of years must be allowed to account for this sediment accumulation.

The case for a very old crust (case 3), about 110 m.y.B.P., coincident with the earliest stages of Atlantic opening (Larson and Ladd, 1973), is contradicted by accumulation rate data. If the basement were that old (and now close to 4000 m below sea level), the accumulation rate in the Santonian (~30 m/m.y.) would have exceeded the subsidence. Such was not the case, for despite this high accumulation rate, the Santonian water depth continued to increase, as indicated by the disappearance of shallow water fossils up-section. The intermediate case (curve 2, Figure 16) allows a high enough accumulation rate in the

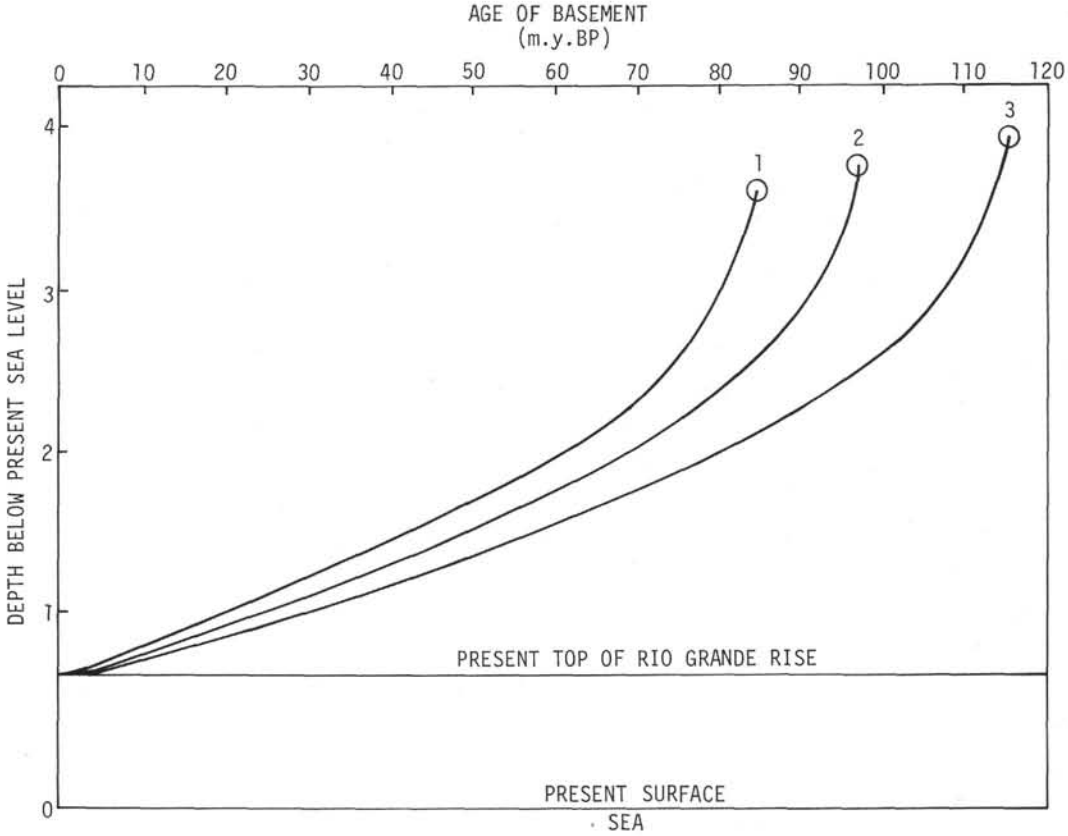


Figure 16. *Basement subsidence curves which place constraints on the depth and age of crystalline basement under the Rio Grande Rise in the vicinity of Site 357. See text for explanation.*

TABLE 5
Depths of Deposition as a Function of Age, Site 357

Stratigraphy	Age of Approx. Midpoint (m.y.)	Present Depth Below Water Surface (m)	Paleodepth (m uncorrected for sediment growth and load)	Sediment Thickness	Paleodepth of Deposition (m)	Hiatuses (in m.y.B.P.) (missing sediment in cumulative m)	Paleodepth of Deposition (m) Corrected for Hiatuses
L. Pliocene	2	2101	2260	782	1869	(362)	2050
E. Pliocene	4	2102	2240	781	1850	(362)	2031
L. Miocene	8	2110	2200	733	1814	(362)	1993
M. Miocene	12	2123	2140	760	1760	(362)	1941
E. Miocene	19	2188	2020	695	1673	(362)	1854
L. Oligocene	28	2284	1880	599	1581	(362)	1762
E. Oligocene	35	2326	1770	557	1492	(362)	1673
L. Eocene	41	2371	1640	512	1384	(362)	1565
M. Eocene	46	2437	1560	446	1337	(362)	1578
E. Eocene	50	2529	1460	354	1283	50-56 (362)	1464
M. Paleocene	59	2531	1300	352	1124	(345)	1296
Danian	62	2566	1200	317	1041	62-67 (345)	1214
Maestrichtian	68	2617	1000	266	867	(195)	965
Campanian	79	2759	700	124	638	72.5-79 (195)	638
Santonian	83	2821	500	62	469	0	469

Santonian, and indicates a basement depth of about 3700 meters and an age of about 95 m.y.B.P. The age is in rough agreement with magnetic anomaly information for the surrounding basins and with age estimates from extrapolation of spreading rates; the necessary accumulation rate of about 6 cm/1000 yr for pre-Santonian sediments is high, but McDowell et al. (this volume) suggest that the layer below the deepest Site 357 core may represent a mixture of sediments and volcanics. Such layers are apparently indicated under other aseismic ridges (Houtz et al., in press), and may be inferred on the Ceará Rise (Site 354 report, this volume).

Assuming a deposition depth of 300-500 meters for the Santonian *Inoceramus*-bearing laminated sediments, one may use the Santonian-Pleistocene portion of curve 2 in Figure 16 to calculate depths of deposition as a function of time. Calculations by Thiede (in preparation) in Table 5 give depth corrected for isostatic effect of accumulated sediment load (Berger and von Rad, 1972) and for hiatuses. In the latter case, sediment is assumed to have accumulated during the hiatus and to have been erosionally removed just at the hiatal close, with isostatic rebound not accompanying the unloading.

A question left unresolved is whether the fine-grained, laminated reduced sediments of Santonian age indicate a period of basinal stagnation for the northern South Atlantic, or whether the sediments were deposited while the deposition site was near a fluctuating open-ocean oxygen-minimum zone. On the one hand, similar sediments of like age have been reported from the São Paulo Plateau (Site 356 report, this volume) and Walvis Ridge (Bolli, Ryan, et al., 1975), and from various sites in the North Atlantic (Saunders et al., 1974). On the other hand, these sediments could have formed as the deposition area passed through and then out of the influence of a well-defined open oceanic oxygen-minimum zone of the type now known to exist in the northern Indian Ocean (Wyrtki, 1971). Similar fine-grained laminated facies have been found in areas where well-developed oxygen minima impinge upon continental margins (van Andel, 1964; von Stackelberg, 1972) and a depositional environment similar to that reflected in the Site 357 Santonian facies has been reported from intermediate water depths on the Ninetyeast Ridge (Site 254) in the eastern Indian Ocean (Davies, Luyendyk, et al., 1974).

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APPENDIX A

Smear-slide Summary

Sample (Interval in cm)	Sand	Silt	Clay	Quartz	Feldspar	Mica	Heavy Minerals	Clay	Volcanic glass	Opaques	Glauconite	Pyrite	Iron Oxides	Dolomites	Zeolites	Authigenic Carbonate	Authigenic Silica	Foraminifers	Calcareous Nannofossils	Diatoms	Radiolaria	Sponge Spicules	Remarks
1-3, 140	40	20	40			1		5										44	50				
2-3, 140	20	5	75			1		10										40	50				
3-3, 140	20	5	75			1		5										35	60	1	1		
4-3, 80	20	5	75			1		5										30	65				
5-4, 78	15	15	70			1		5										30	65				
6-5, 90	10	30	60					10										30	60				
7-5, 100	10	40	50					5										25	70				
8-4, 100	10	20	70					5										15	80	1			
9-3, 100	5	30	65					5										10	85			1	
10-2, 100	5	30	65					5										15	65			5	
11-2, 100	5	20	75					5										10	75		5	5	
12-2, 22		15	85									55						5	40			1	black spot
12-3, 100	5	35	60					5	1									10	80		1	5	
13-3, 70	5	30	65					5	1							1		10	80		1	5	
13-4, 55	5	30	65					5								5		10	75		1	5	
14-1, 7	20	40	40	1				15								15		25	40		1	5	
14-2, 86	10	50	40					20								15		25	35		1	5	
15-2, 105		40	60					5								15		15	55		1	10	
16-2, 36		30	70					20				1				20		20	35		1	5	
16-2, 100	20	50	30					10								15		25	45	1	1	5	
17-1, 90	5	50	45					10	1							10		30	40		1	10	
18-2, 60	5	45	50					15								10	5	20	40		1	10	
18-3, 6												100											burrow filling
19-2, 88	10	50	40			1		10				1				20		25	45				
20-1, 120	20	40	50					5								25		30	40				
20-2, 100	5	45	50	1				10								10		30	50				
21-1, 75	5	25	70					5								15			80				
21-3, 30	25	30	45					5				1				15	1	35	45				
21-3, 80	20	60	20								1				10	25		25	40				
22-2, 83		30	70		1	1		5			1			1	20	25		20	30				
22-3, 100	5	40	55					5							5	20		20	50				
22-3, 118	15	25	60			1		5			1	1			1	40		20	35				
23-2, 62	20	30	50	1	1										1	90			5	1	1	2	
23-4, 62	5	30	65	1												80		5	15				
24-1, 35	5	45	50					5	10		10			5	5	20	15		30				
24-3, 92		50	50					20		5				10		20	10	1	25	1	1	10	
24-5, 82	5	50	45	5	5		1		5	1	5			5	1	5	10	10	20	1	20	10	
24-5, 87		20	80	1	1				1	15	30			1	1	5	25	10			5	5	
24-5, 89		80	20					10						75		10						5	
24-5, 94		80	20					5						75		10						10	
24-6, 100	10	85	5					5						90								5	

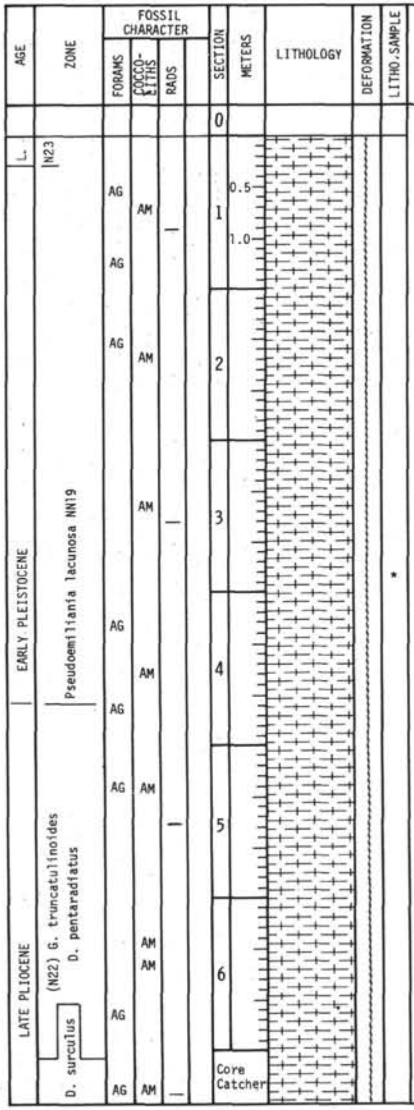
APPENDIX A – *Continued*

Sample (Interval in cm)	Sand	Silt	Clay	Quartz	Feldspar	Mica	Heavy Minerals	Clay	Volcanic glass	Opaques	Glauconite	Pyrite	Iron Oxides	Dolomites	Zeolites	Authigenic Carbonate	Authigenic Silica	Foraminifers	Calcareous Nannofossils	Diatoms	Radiolaria	Sponge Spicules	Remarks
24-6, 140		80	20						5	5				50		20	20						
25-3					1	2			45	1						1	43	1	1				thin section
25-3, 73		40	60					5	5		15			30		20	15	10					large sediment clast
25-3, 99								5	1					5	5	10	5	30	40	1			sediment clast
25-3, 110	5	50	45								5				1	35	20	10	30				sediment clast
25-3, 125								5	1		1				1	15	10	10	20	1	25	10	
26-5, 100		40	60	1				10	1						5	5		30	50	1			
27-6, 72	20	40	40	15					1		1	1				10	60	5	10				
27-4, 60	5	40	55					5						1	5	5	20	30	35				
28-2, 23		30	70	5	5				1				1		5	20	55	10	15		5		
28-4, 58	10	30	60	5				5	1							30	35	5	20				
29-1, 80		20	80					5					1				30		65	1			
30-2, 70	2	25	70					25					10	1		15		25	25				
31-2, 140		10	90	3	2			5						1		20		5	60				
31-3, 30	10	30	60	5	10					5			15					20	55				
32-5, 76	5	55	40	5	5	1		5					10	5		5		15	50				
33-4, 106	5	25	70	5	10			10			1		5	10				10	50				
34-4, 55	5	25	70	5	5	1		5						5	10			20	50				
34-6, 90	5	25	70	5	5	5		10	1				10			10		20	35				
35-3, 75	5	45	50	5	10	5		10	1				15	15		5		10	30				
36-6, 110	5	40	55	1	1			5	5					5		15		25	45				
CB between Cores 38/39	1	30	70											1		90		1	5				
40-3, 105	5	35	60	5	10		1	10	20	5				1	1	10		10	25				
40-4, 45		10	90					55	30	5					10								
41-2, 80		10	90					80	10			10											
41-4, 100	5	35	60	5	10			5	20					1	5	10		10	35				
42-4, 100	5	35	60	1	1	1		20	15			1		1	10	30		5	20				
43-3, 150	5	35	60	5	5			15	5					5	5	10		20	30				
44-6, 90		45	55	5	5			10	15					5	5	20		15	25				
46-3, 100		50	50	5	5			10	15					5	5	15		10	30				
47-3, 2		50	50	5	5	1		10	5	5				15	1	25	15		15				burrow fill
48-6, 70		30	70	1	1			5	1					10		35	25	10	15				
49-6, 60		15	85		1			5	5						10	30	40		10				
50-6, 100	5	35	60	1				5				1		1	1	60	30	2	2		1		
50-6, 130	1	10	90	1				90				2			1	5			2				
51-6, 125		60	40	10	10		1	10	20	5				1	5	5	20	5	10				

APPENDIX B
Carbonate and Quartz Determinations

Section	Sediment Depth (cm)	$CaCO_3$ (%)	Org (%)	Total Carb (%)	Qtz (%)
Hole 357					
1-2	250	88.85	0.05	10.72	
1-2	353	85.71	0.44	10.72	
2-3	1230	85.58	0.89	11.16	
3-1	1945	87.53	0.22	10.72	
3-2	2095	88.35	0	10.60	
3-3	2106	86.17	0.53	10.87	
3-3	2200	89.65	0.03	10.79	
3-3	2245	86.88	0	10.42	
3-4	2395	86.56	0.18	10.57	
3-5	2545	88.20	0.80	10.67	
3-6	2600	69.19	0.67	8.98	14.17
3-6	2655	82.63	0.68	10.60	
4-6	3590	79.43	0.04	9.58	
5-3	4070	77.66	0.53	9.85	11.90
5-5	4370	82.11	0.05	9.91	
6-5	5350	76.82	0.46	9.68	13.54
6-6	5441	78.15	0.03	9.41	
7-5	7050	85.00	0.55	10.75	11.86
8-4	7082	86.57	0.02	10.42	
8-4	7270	90.53	0.57	10.72	11.70
9-4	8010	88.05	0.05	10.62	
9-4	8014	84.40	0.95	11.08	11.09
10-4	8970	83.54	0.51	10.54	11.83
10-1	9510	86.03	0.04	10.36	
11-2	10575	78.24	0.71	10.10	12.01
11-2	10594	83.86	0.04	10.11	
12-3	11670	85.02	0.69	10.89	10.46
13-4	13740	71.34	0.63	9.19	12.78
14-1	15200	75.00	0.07	9.07	
14-2	15367	75.43	0.52	9.57	13.49
15-2	17260	71.62	0.52	9.11	12.03
16-2	18200	76.06	0.41	9.54	12.15
17-2	19150	74.53	0.16	9.11	11.85
17-3	19280	77.25	0.05	9.32	
18-2	21022	75.95	0.25	9.37	10.94
18-2	22036	83.00	0.05	10.02	
19-2	23854	76.71	0.34	9.55	
19-2	23919	77.97	0.06	9.42	
20-2	25780	81.42	0.14	9.91	9.46
20-3	25981	81.76	0.04	9.86	
21-1	28467	69.16	0.10	8.40	1.67
21-2	28675	80.64	0.19	9.87	
21CC	28875	78.94	0.29	9.76	2.48
22-2	30533	78.01	0.38	9.75	
22-4	30840	77.27	0.07	9.34	
22-4	30890	78.71	0.45	9.89	2.59
23-1	33155	82.22	0.22	10.16	1.87
23-3	33361	71.55	0.45	9.03	0.00
23CC	34075	75.98	0.42	9.54	1.49
24-1	35097	67.90	0.22	8.37	1.06
24-1	35198	86.00	0.05	10.38	
24-5	35734	26.05	0.61	3.74	.33
26-3	38347	66.44	0.36	8.33	1.26
26-6	38684	63.90	0.07	7.74	
27-3	41161	48.96	0.26	6.13	.79
27-4	41296	33.03	0.06	4.03	
28-3	44018	57.86	0.69	7.64	.78
28-3	44024	76.02	0.06	9.19	
30-1	47451	73.49	0.82	9.64	5.12
31-2	49574	68.33	0.63	8.83	8.55
31-2	49575	75.25	0.05	9.08	
31-3	49695	75.87	0.04	9.15	
32-1	50349	72.84	0.52	9.26	8.43
33-3	52596	58.19	0.37	7.35	10.62
33-5	52844	69.24	0.05	8.36	
34-4	55465	66.73	0.19	8.20	13.22
34-4	55487	69.81	0.05	8.43	
34-6	55760	46.57	0.07	5.66	
35-2	58033	65.94	0.07	7.99	
35-3	58162	46.61	0.61	6.20	11.74
36-1	60770	44.23	0.08	5.39	
36-5	61324	74.67	0.05	9.01	
36-5	61324	68.91	0.57	8.84	17.71
37CC	64675	65.27	0.70	8.53	5.73
40-1	69354	57.41	0.23	7.12	14.01
40-3	69656	40.56	0.12	4.99	
41-2	70499	32.03	0.51	4.35	12.05
42-2	71432	38.59	0.23	4.86	
42-2	71492	52.02	0.64	6.88	14.92
43-2	72346	55.08	0.40	7.01	10.85
43-2	72354	56.92	0.14	6.97	
44-2	73324	57.99	0.20	7.16	
44-2	73406	53.47	0.55	6.97	15.17
46-3	74630	60.21	0.10	7.33	
46-3	74660	48.45	0.57	6.39	12.85
47-2	75113	30.88	0.11	3.82	
47-2	75170	50.62	0.40	6.47	14.74
48-2	76068	68.24	0.14	8.33	
48-2	76068	57.43	0.60	7.50	13.31
50-1	76922	29.09	1.95	5.44	13.33
51-1	77856	58.35	0.29	7.30	14.20
50-6	78555	36.99	0.11	4.55	
51-6	79578	53.06	0.20	6.57	

Site 357 Hole Core 1 Cored Interval: 0.0-8.5 m



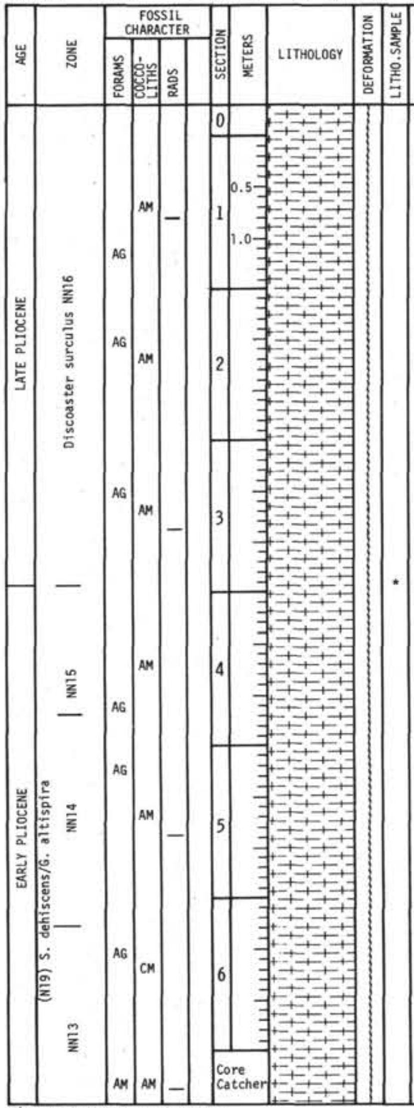
LITHOLOGIC DESCRIPTION

5YR 7/2 Grayish orange pink FORAM NANNO OOZE, soupy-homogeneous.

$CaCO_3$ 3-120: 90%

SS 3-140	
40% Sand	50% Nannos
20% Silt	44% Forams
40% Clay	5% Clay
	1% Mica

Site 357 Hole Core 2 Cored Interval: 8.5-18.0 m



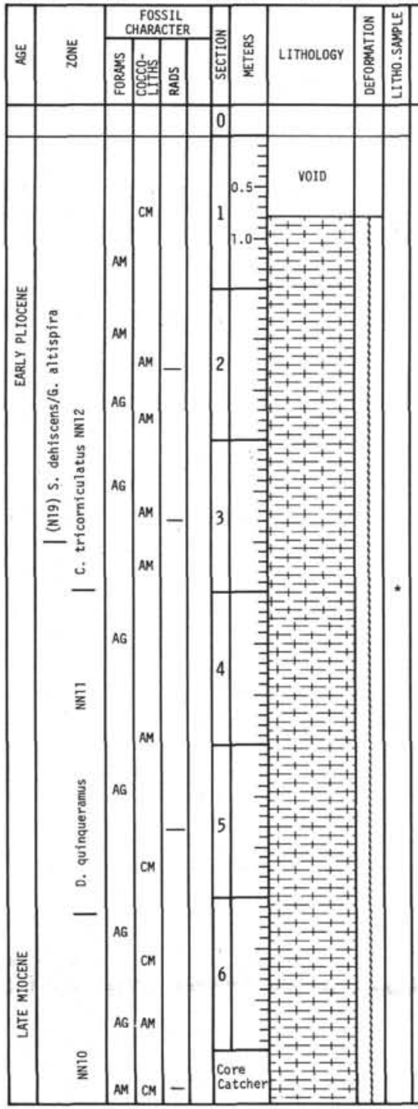
LITHOLOGIC DESCRIPTION

5YR 8/1 Pinkish gray FORAM NANNO OOZE, soupy, homogeneous.

SS 3-140	
20% Sand	55% Nannos
5% Silt	35% Forams
75% Clay	10% Clay
	1% Mica

Explanatory Notes in Chapter 1

Site 357 Hole Core 3 Cored Interval: 18.0-27.5 m



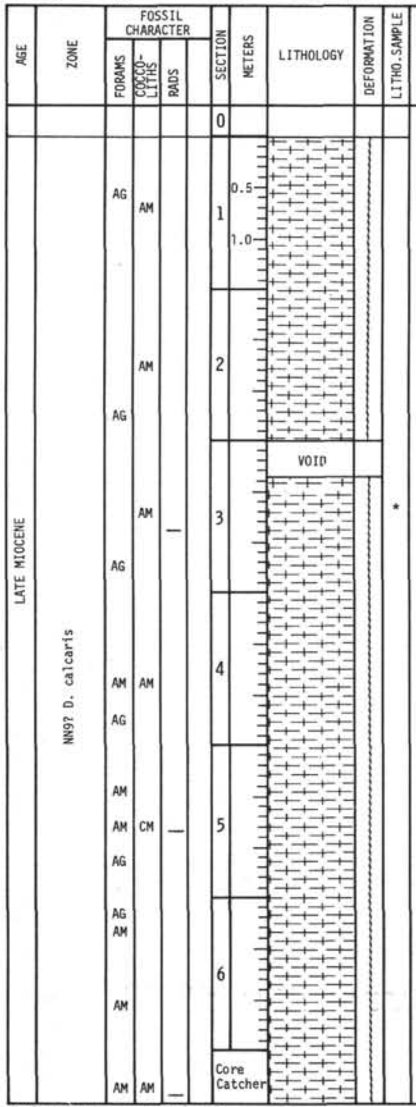
LITHOLOGIC DESCRIPTION

5YR 8/1

Pinkish gray FORAM NANNO OOZE, soupy, homogeneous.

SS 3-140	
20% Sand	60% Nannos
5% Silt	35% Forams
75% Clay	5% Clay
	1% Mica
	1% Diatoms
	1% Rads
	1% Glauconite

Site 357 Hole Core 4 Cored Interval: 27.5-37.0 m



Explanatory Notes in Chapter 1

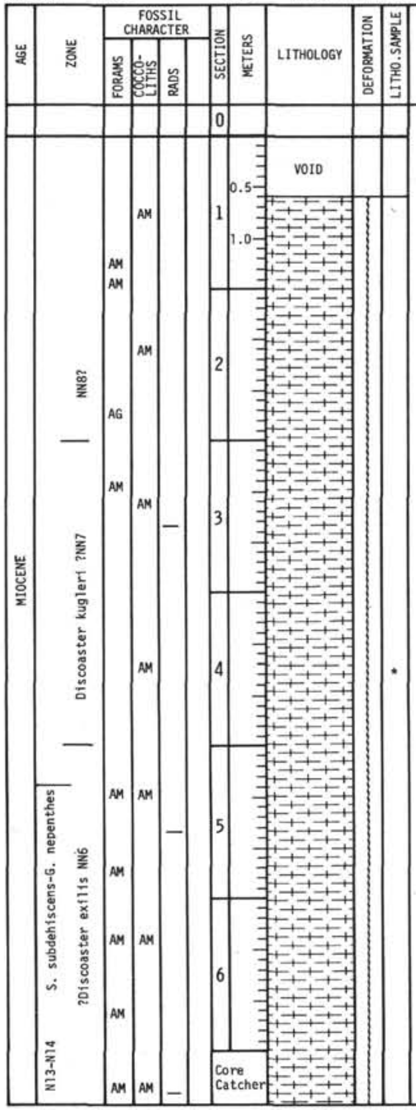
LITHOLOGIC DESCRIPTION

5YR 8/1

Pinkish gray FORAM NANNO OOZE, soupy, homogeneous.

SS 3-80	
20% Sand	65% Nannos
5% Silt	30% Forams
75% Clay	5% Clay
	1% Mica
	1% Quartz
	1% Dolomite rhombs

Site 357 Hole Core 5 Cored Interval: 37.0-46.5 m



LITHOLOGIC DESCRIPTION

Grayish orange, soupy, homogeneous, FORAM NANNO OOZE.

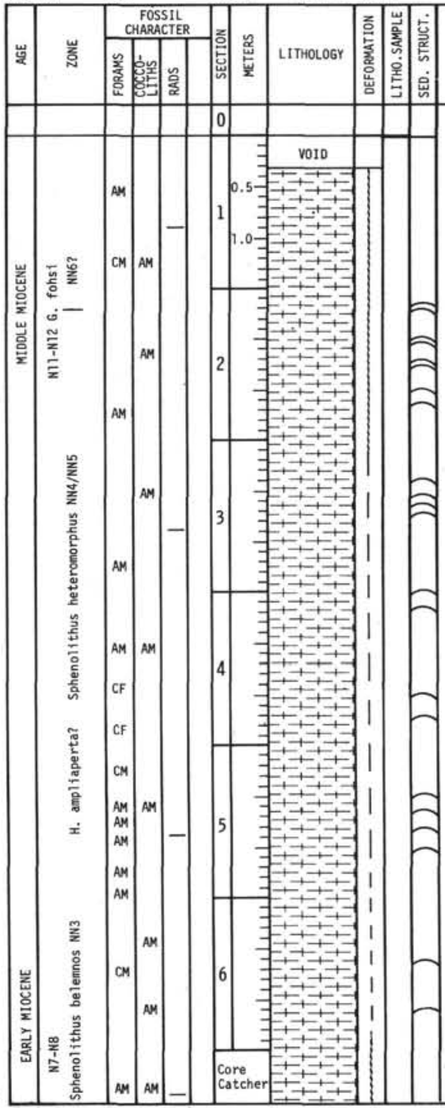
10YR 7/4

Small, nebulous lumps of whitish (N9) NANNO OOZE at 3-90, 3-120 to 130, 4-78, 5-90.

SS 4-78

15% Sand	65% Nannos
15% Silt	30% Forams
70% Clay	5% Clay
	1% Mica

Site 357 Hole Core 6 Cored Interval: 46.5-56.0 m



LITHOLOGIC DESCRIPTION

Pinkish gray FORAM NANNO OOZE.

5YR 8/1

With thin (cm thick) intercalations of grayish orange pink (5YR 7/2) hue.

5YR 7/2 Grayish orange pink gradually changing to

10YR 8/2 very pale orange.

5YR 7/2 Grayish orange pink, few recognizable mottles.

10YR 8/2 Very pale orange

10YR 8/2

SS 5-90

10% Sand	60% Nannos
30% Silt	30% Forams
60% Clay	10% Clay

5YR 7/2

10YR 8/2

5YR 7/2

5YR 6/4 Light brown

10YR 6/2 Pale yellowish brown, slightly mottled

5YR 6/4

10YR 6/2

5YR 6/4 With thin intercalations of very pale orange (10YR 8/2), thinly bedded

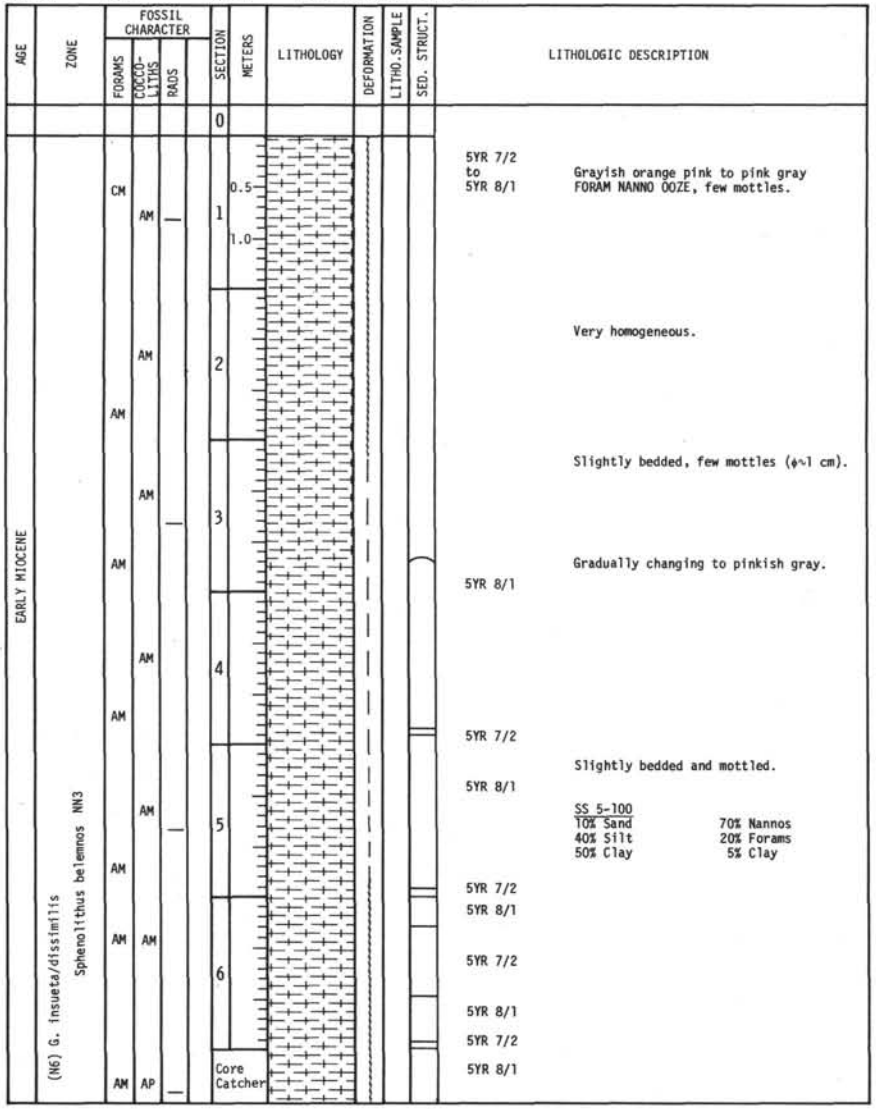
5YR 7/2

10YR 8/2 Slightly bedded and mottled

5YR 8/2

Explanatory Notes in Chapter 1

Site 357 Hole Core 7 Cored Interval:56.0-65.5 m



5YR 7/2 to 5YR 8/1 Grayish orange pink to pink gray FORAM NANNO OOZE, few mottles.

Very homogeneous.

Slightly bedded, few mottles (ϕ~1 cm).

Gradually changing to pinkish gray.

5YR 8/1

5YR 7/2

Slightly bedded and mottled.

5YR 8/1

SS 5-100

10% Sand	70% Nannos
40% Silt	20% Forams
50% Clay	5% Clay

5YR 7/2

5YR 8/1

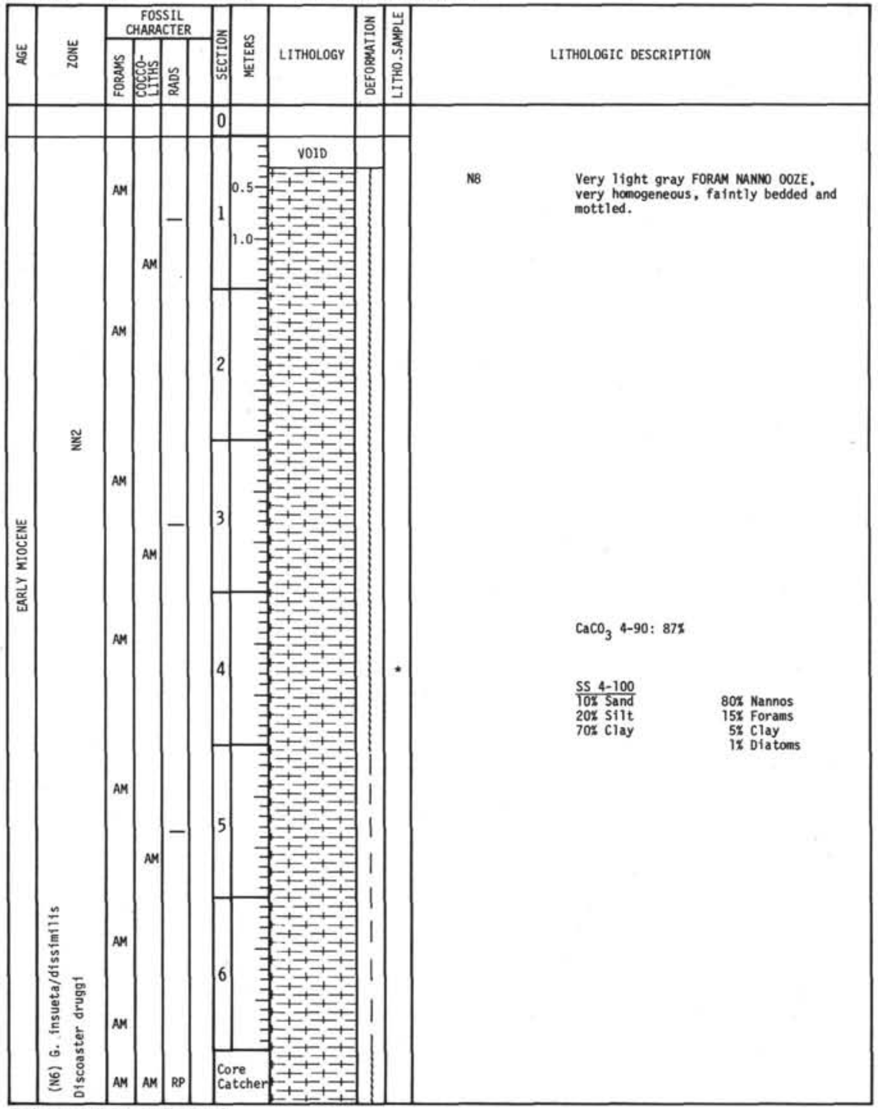
5YR 7/2

5YR 8/1

5YR 7/2

5YR 8/1

Site 357 Hole Core 8 Cored Interval: 65.5-75.0 m



N8 Very light gray FORAM NANNO OOZE, very homogeneous, faintly bedded and mottled.

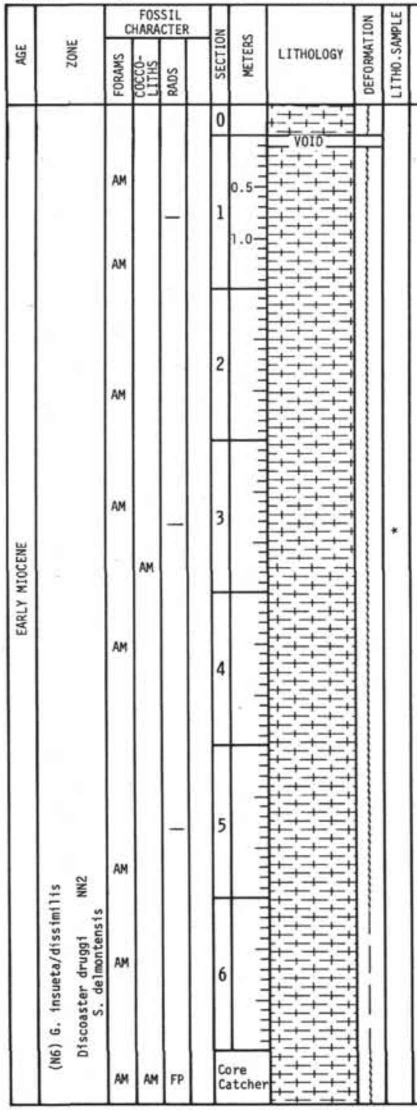
$CaCO_3$ 4-90: 87%

SS 4-100

10% Sand	80% Nannos
20% Silt	15% Forams
70% Clay	5% Clay
	1% Diatoms

Explanatory Notes in Chapter 1

Site 357 Hole Core 9 Cored Interval: 75.0-84.5 m



LITHOLOGIC DESCRIPTION

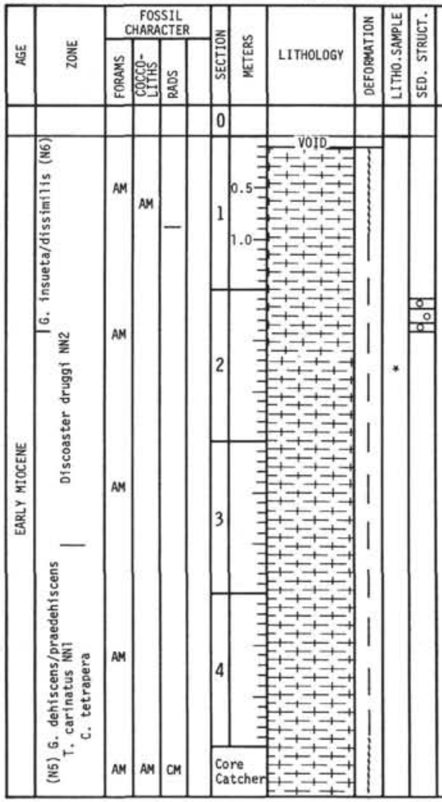
N9-
5B 9/1

White to bluish white FORAM NANNO OOZE, very homogeneous, few darker mottles.

SS 3-100

5% Sand	85% Nannos
30% Silt	10% Forams
65% Clay	5% Clays
	1% Sponge spicules

Site 357 Hole Core 10 Cored Interval: 94.0-103.5 m



LITHOLOGIC DESCRIPTION

5B 9/1 Bluish white FORAM NANNO OOZE, faintly bedded and mottled.

Gradually changing to pinkish gray.

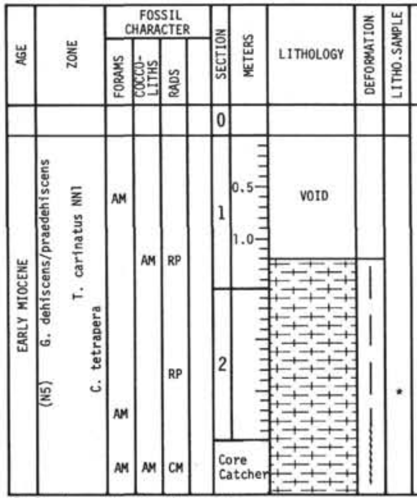
5YR 8/1
5B 8/1 Mottled: in the mottles 5YR 8/1.
5YR 8/1

Few dark mottles (fine grained pyrite)

SS 2-100

5% Sand	75% Nannos
30% Silt	15% Forams
65% Clay	5% Sponge spicules
	5% Clay

Site 357 Hole Core 11 Cored Interval: 103.5-113.0 m



LITHOLOGIC DESCRIPTION

N8

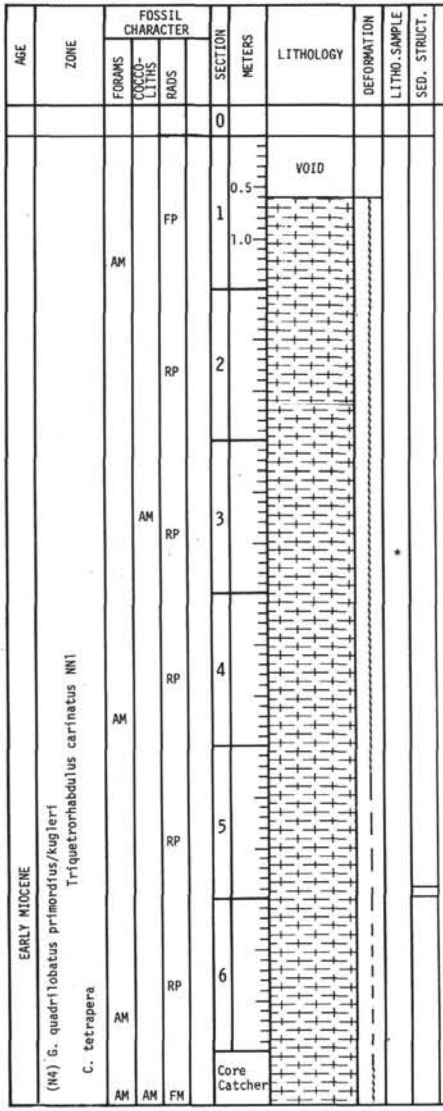
Very light gray FORAM NANNO OOZE, faintly bedded with whitish (N9) hue.

SS 2-100

5% Sand	75% Nannos
20% Silt	10% Forams
75% Clay	5% Rads
	5% Sponge spicules
	5% Clay

Explanatory Notes in Chapter 1

Site 357 Hole Core 12 Cored Interval: 113.0-122.5 m



LITHOLOGIC DESCRIPTION

N7
to
N8

Light gray to very light gray FORAM NANNO OOZE. Faintly bedded and mottled.

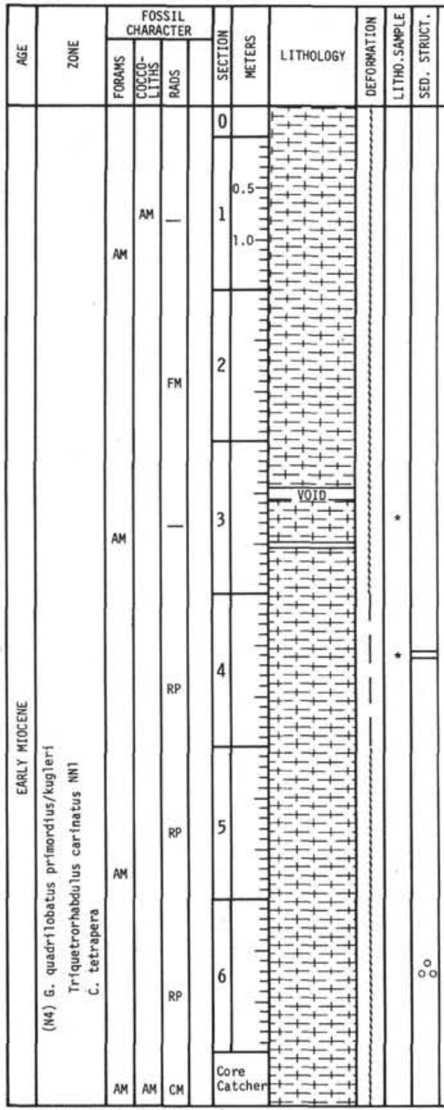
Few dark mottles.

SS 2-22	
15% Silt	55% Pyrite
85% Clay	40% Nannos
	5% Forams
	1% Sponge spicules

SS 3-100	
5% Sand	80% Nannos
35% Silt	15% Forams
60% Clay	5% Sponge spicules
	5% Clays
	1% Volcanic glass
	1% Rads

Bedding

Site 357 Hole Core 13 Cored Interval: 132.0-141.5 m



LITHOLOGIC DESCRIPTION

N8
to
N9

Very light gray, faintly interbedded with white FORAM NANNO OOZE.

SS 3-70	
5% Sand	80% Nannos
30% Silt	10% Forams
65% Clay	5% Sponge spicules
	5% Clays
	1% Volcanic glass
	1% Rads

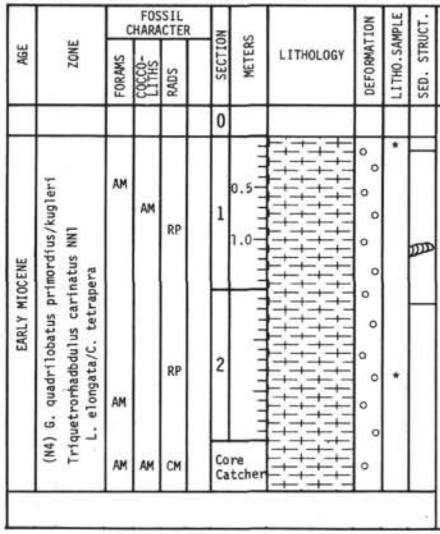
Thin dark layer with light gray horizon below.

SS 4-55	
5% Sand	75% Nannos
30% Silt	10% Forams
65% Clay	5% Sponge spicules
	5% Authigenic carbonate
	5% Clays
	1% Rads

Light gray to black (N1) mottles, ϕ ca. 1 cm.

Explanatory Notes in Chapter 1

Site 357 Hole Core 14 Cored Interval: 151.0-160.5 m



LITHOLOGIC DESCRIPTION

5G 6/1

N8

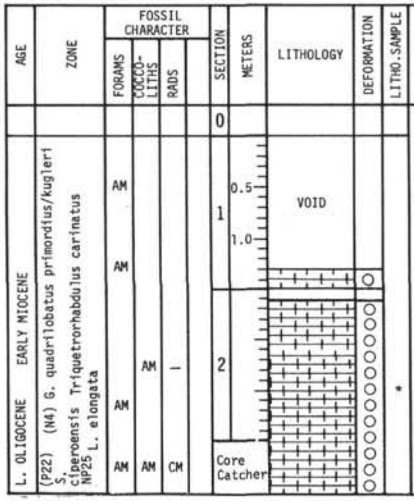
Very light gray FORAM NANNO OOZE, 2 greenish gray laminae at cm 1-7, and 2-10. Burrows (ϕ∼1 cm) at 1-73, Zeoophycos at 1-106. Burrows sometimes pyrite coated. Semiindurated.

SS 1-7	
20% Sand	40% Nannos
40% Silt	25% Forams
40% Clay	15% Authigenic carbonate
	15% Clay
	5% Sponge spicules
	1% Rads
	1% Quartz

$CaCO_3$ 2-80: 76%

SS 2-86	
10% Sand	35% Nannos
50% Silt	25% Forams
40% Clay	20% Clays
	15% Micrite
	5% Sponge spicules
	1% Rads

Site 357 Hole Core 15 Cored Interval: 170.0-179.5 m



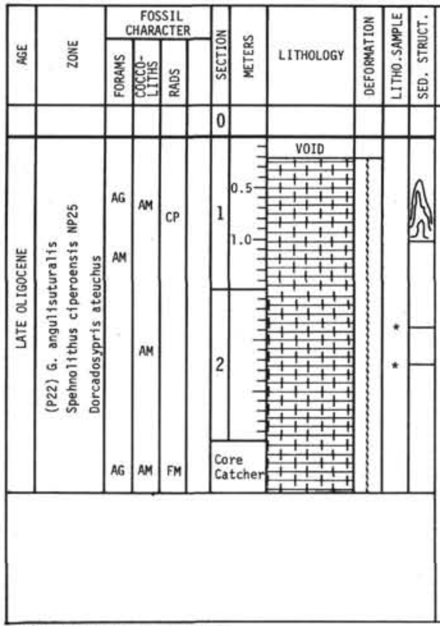
LITHOLOGIC DESCRIPTION

5YR 8/1

Pinkish gray FORAM NANNO CHALK.

SS 2-105	
40% Silt	55% Nannos
60% Clay	15% Forams
	15% Micrite
	10% Sponge spicules
	5% Clays
	1% Rads

Site 357 Hole Core 16 Cored Interval: 179.5-189.0 m



LITHOLOGIC DESCRIPTION

N7

Light gray FORAM NANNO CHALK with medium gray thin layers cm 1-55 to 80.

N5

N5

Medium gray horizon (∼0.3 cm) at cm 2-36 and 2-76.

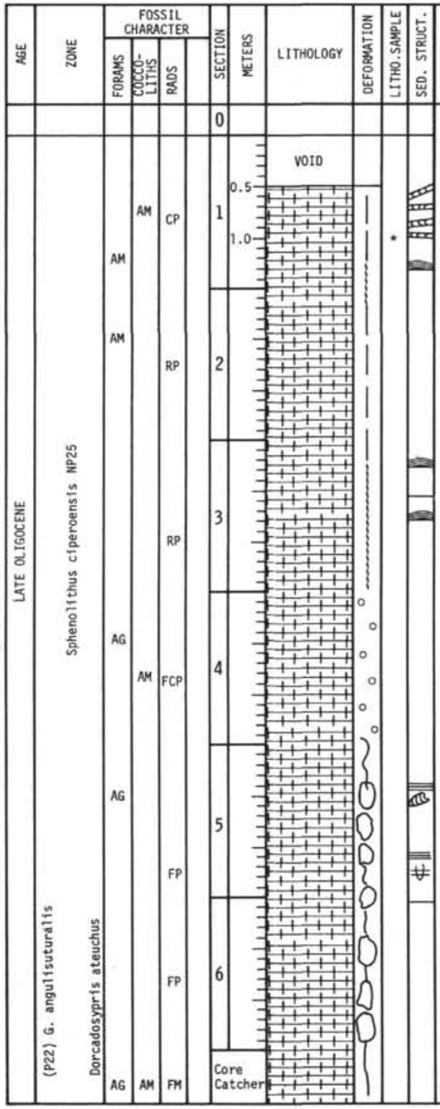
N5

SS 2-36	
30% Silt	35% Nannos
70% Clay	20% Forams
	20% Micrite
	20% Clays
	5% Sponge spicules
	1% Rads
	1% Pyrite
	1% Silico flag.

SS 2-100	
20% Sand	45% Nannos
50% Silt	25% Forams
30% Clay	15% Micrite
	10% Clays
	5% Sponge spicules
	1% Rads
	1% Diatoms

Explanatory Notes in Chapter 1

Site 357 Hole Core 17 Cored Interval: 189.0-198.5 m



LITHOLOGIC DESCRIPTION

5YR 8/1

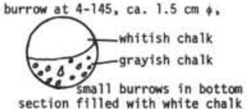
Pinkish gray FORAM NANNO CHALK, intensively burrowed by Zoophycos at 1-70 to 100 (~10 Zoophycos). Burrows some-times slightly pyrite coated.

Slightly darker laminae at 1-124 to 126, 2-15, 3-18 to 19, 3-50, 3-62 to 70, 5-30 to 145.

SS 1-90

5% Sand	40% Nannos
50% Silt	30% Forams
45% Clay	10% Sponge spicules
	10% Clay
	1% Volcanic glass
	1% Rads

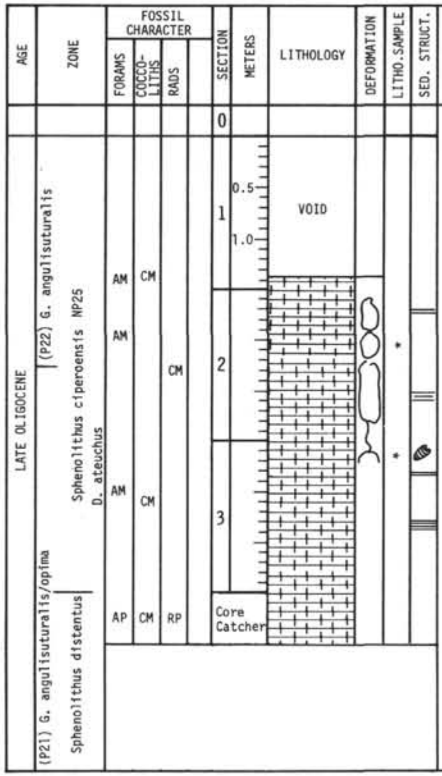
Big burrow at 4-145, ca. 1.5 cm ϕ.



Zoophycos
Single intact pieces of drilling breccia are intensively burrowed, usually filled with white chalk. Vertical burrow, pyrite coated, ~3 cm long, 0.5 cm broad.

Intact pieces of drilling breccia full of horizontal burrows (no Zoophycos) and slightly darker laminae.

Site 357 Hole Core 18 Cored Interval: 208.0-217.5 m



LITHOLOGIC DESCRIPTION

5YR 8/1

Pinkish gray FORAM NANNO CHALK, with slightly darker laminae at 2-28, 2-110 to 120, 3-30, 3-80 to 95.

Burrows 2-60 to 70.
Zoophycos 2-90.

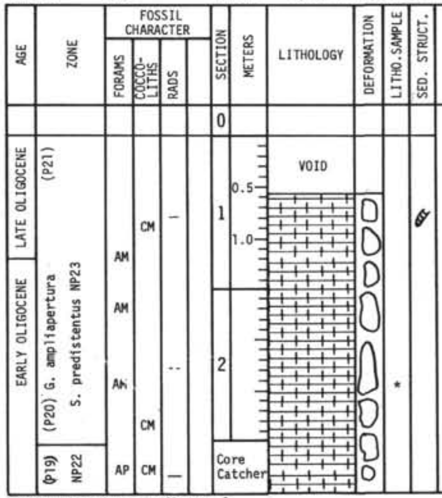
SS 2-60

5% Sand	40% Nannos
45% Silt	20% Forams
50% Clay	15% Clay
	10% Micrite
	10% Sponge spicules
	5% Quartz
	1% Rads

Irregular round to elongated burrows 3-5 to 35, filled with white sediment, ϕ~1 cm, reburrowed in mm-scale.

SS 3-6 (black filling of burrow)
100% Pyrite (very fine grained)

Site 357 Hole Core 19 Cored Interval: 236.5-246.0 m



LITHOLOGIC DESCRIPTION

N7

Light gray FORAM NANNO CHALK, slightly burrowed (ϕ~0.5 cm), Zoophycos 1-88.

Slightly darker laminae at 2-58, 2-85 to 90.

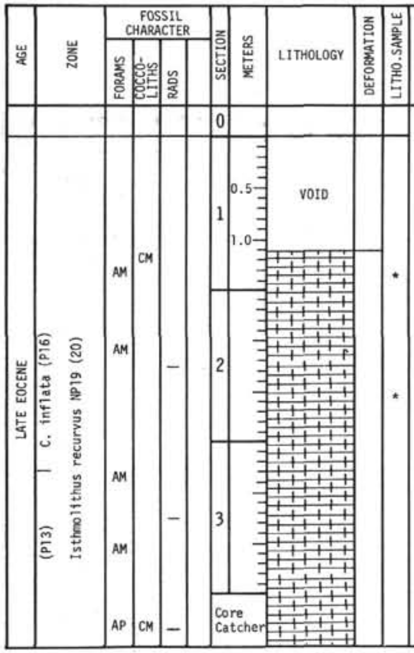
Big burrow(?) filled with whitish sediment, contains again smaller burrows, extends into a Zoophycos.

SS 2-88

10% Sand	45% Nannos
50% Silt	25% Forams
40% Clay	20% Micrite
	10% Clay
	1% Feldspar
	1% Pyrite

Explanatory Notes in Chapter 1

Site 357 Hole Core 20 Cored Interval: 255.5-265.0 m



LITHOLOGIC DESCRIPTION

SS 1-120

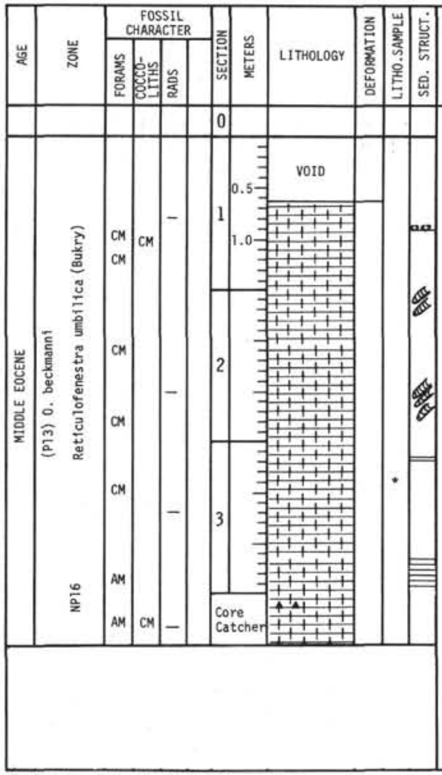
5% Sand	40% Nannos
50% Silt	30% Forams
45% Clay	25% Authigenic carbonate
	5% Clays

5YR 8/1 Pinkish gray FORAM NANNO CHALK, slightly burrowed (ϕ0.5-1.0 cm) throughout - visible due to faintly different hues, very homogeneous.

SS 2-100

5% Sand	50% Nannos
45% Silt	30% Forams
50% Clay	10% Micrite
	10% Clays
	1% Quartz

Site 357 Hole Core 21 Cored Interval: 284.0-293.5 m



LITHOLOGIC DESCRIPTION

SS 1-75

5% Sand	80% Nannos
50% Silt	15% Micrite
45% Clay	5% Clays

5YR 8/1 Pinkish gray (FORAM) NANNO CHALK, slightly burrowed throughout, intensively burrowed in light to medium light gray horizons: 1-70 to 75, 2-40 to 44, 2-70 to 74, 3-90 to 96.

Zoophycos at 2-16, 2-24, 2-93, 2-103, 2-109.

Slightly coarser horizons at 3-10 to 15, 3-75 to 80; coarse sediment mostly in burrows.

Some burrows pyrite coated.

SS 3-30

25% Sand	45% Nannos
30% Silt	35% Forams
45% Clay	15% Authigenic carbonate
	1% Diatoms
	1% Silica-cement
	1% Pyrite

Many thin light greenish gray laminae (1 mm or less) at 3-120 to 147.

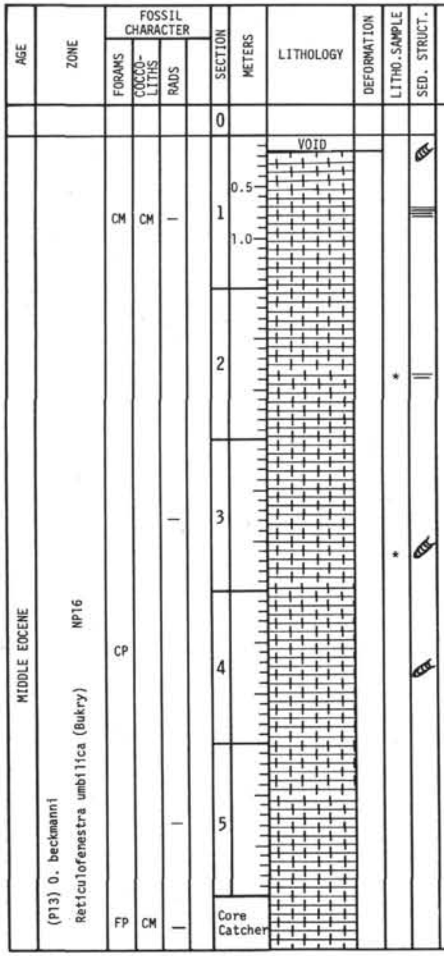
SS 3-80

20% Sand	40% Nannos
60% Silt	25% Forams
20% Clay	25% Authigenic carbonate
	10% Silica-cement
	1% Glauconite

Chert strings in the CC.

Explanatory Notes in Chapter 1

Site 357 Hole Core 22 Cored Interval: 303.0-312.5 m

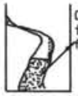


LITHOLOGIC DESCRIPTION

N7

Light gray FORAM NANNO CHALK - MICRITE slightly burrowed throughout.

at cm 30



Thin laminae of slightly darker material at 1-71 to 73.

Zoophycos at 1-17, 1-138, 3-104, 4-80 (totally pyrite coated), 5-110.

Slightly darker horizons with many burrows at 2-17 to 21, 3-111 to 118, 4-34 to 35, 4-60 to 62, 4-68 to 70.

Coarse horizon at 2-82 to 84 with big burrow below.

Pyrite with rings around.

SS 3-118

30% Silt	40% Micrite
70% Clay	35% Nannos
	20% Forams
	5% Clay
	1% Glauconite
	1% Pyrite
	1% Zeolite

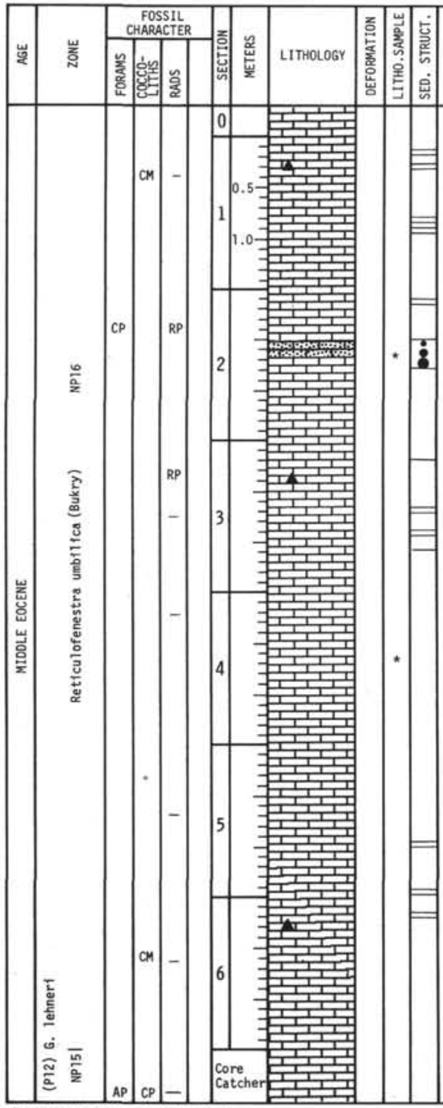
Small chert strings at 4-22.

Thin sandy glauconitiferous horizons at 5-38 and 5-47.

SS 2-83

0% Sand	30% Nannos
30% Silt	25% Micrite
70% Clay	20% Forams
	20% Zeolite
	5% Clay
	1% Feldspar
	1% Mica
	1% Glauconite
	1% Dolomite rhombs

Site 357 Hole Core 23 Cored Interval: 331.5-341.0 m



LITHOLOGIC DESCRIPTION

N7

Light gray MICRITIC CHALK - LIMESTONE, slightly burrowed throughout, many burrows heavily pyrite coated.

Thin slightly darker, often greenish (pyrite!) laminae at 1-13 to 18, 1-27 to 28, 1-70 to 90, 2-9 to 11, 3-15, 3-50 to 60, 3-70 to 75, 3-91, 4-10 to 12, 4-68 to 70, 5-140, 6-2 to 9. Sandy, glauconitiferous, slightly graded sandy horizon at 2-57 to 65.

Darker (medium gray [N5]) horizons with frequent burrows: 1-90 to 96, 2- 78 to 82, 2-105 to 110, 5-90 to 92.

Zoophycos 1-112, 1-116, 1-120.

Chert strings 1-30 to 33, 4-26 to 27, 6-37 to 39.

SS 2-62

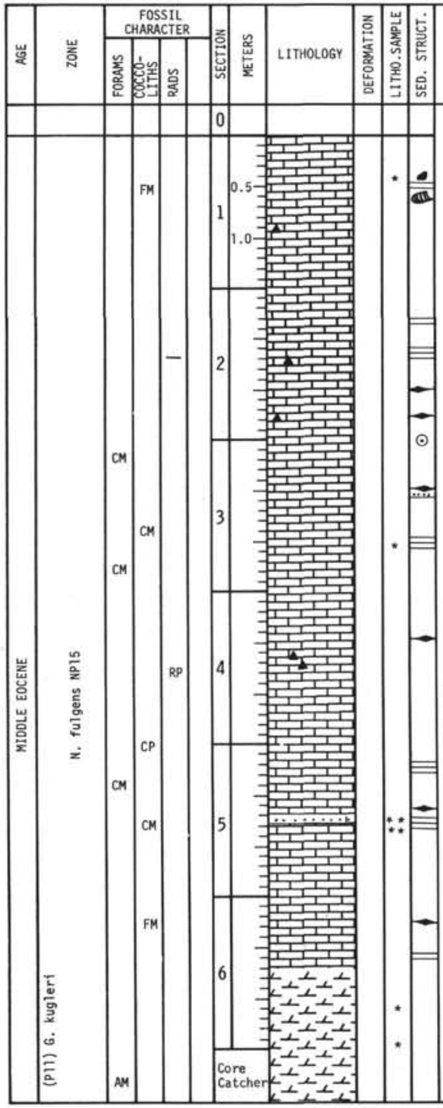
10-20% Sand	80-90% Micrite
30% Silt	1- 5% Nannos
50% Clay	1- 2% Sponge spicules
	1% Diatoms
	1% Rads
	1% Quartz
	1% Feldspar
	1% Zeolite

SS 4-62

5% Sand	80% Micrite
30% Silt	10-15% Nannos
65% Clay	1- 5% Forams
	1% Quartz

Explanatory Notes in Chapter 1

Site 357 Hole Core 24 Cored Interval: 350.5-360.0 m



LITHOLOGIC DESCRIPTION

5YR 8/1 to N8

Pinkish gray to very light gray fine-grained homogeneous LIMESTONE, slightly burrowed throughout, around sand burrows many times a slightly reduced rim.

Medium light gray sandy horizon at 1-40 to 41, lense shaped bedding on top.

SS 1-39

5% Sand	30% Nannos
45% Silt	20% Micrite
50% Clay	10-15% Silica cement
	10% Volcanic glass
	10% Glauconite
	5% Clay
	5% Dolomite rhombs
	5% Zeolite
	1% SPonge spicules

Zoophycos at 1-60, 1-62.

CHERT stringers at 1-98, 2-75 to 77, 2-125, 4-63 to 69.

Big burrow, filled with coarser material, ϕ1 cm at 3-9. Thin, faintly darker laminae at 2-30, 2-63 to 66, 3-90 to 95, 6-53 to 60 (with coarse horizon below).

Medium light gray, intensively burrowed horizons at 2-90 to 93, 2-120 to 127, 3-54 to 56 (coarse horizon at the bottom of this horizon), 4-53 to 55, 5-3 to 11, 5-70 to 75, 6-30 to 35.

SS 3-92

50% Silt	25% Nannos
50% Clay	20% Micrite
	20% Clay
	10% Silica cement
	10% Dolomite rhombs
	10% Sponge spicules
	5% Opaques
	1% Diatoms, Rads

Details on visual core description of section.

Details on visual core description of section.

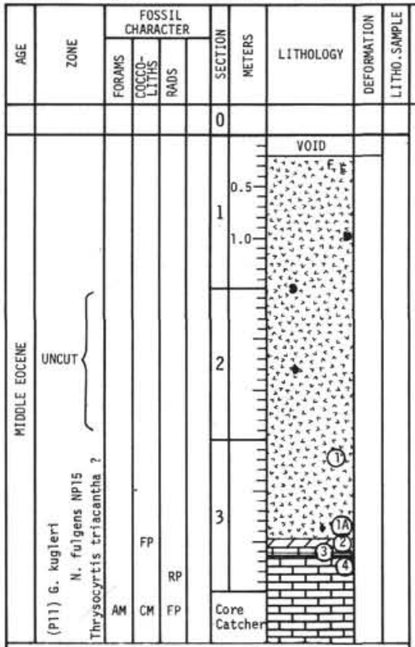
Sandy horizons contain well preserved SiO_2 fossils, heavies, and volcanic components.

N5 to N4

SS 6-100	SS 6-140
10% Sand	80% Silt
85% Silt	20% Clay
5% Clay	50% Dolomite rhombs
90% Dolomite rhombs	20% Micrite
5% Sponge spicules	20% Silica cement
5% Clay	5% Opaques
	5% Volcanic glass

Medium dark gray, fine grained DOLOSTONE.

Site 357 Hole. Core 25 Cored Interval: 369.5-379.0 m



Thin Section at 3-41 to 43.
45% Volcanic glass (basaltic)
43% SiO_2 cement (matrix)
7% Calcite
2% Clinopyroxene
1% Forams
1% Shell fragments
1% Nannos
1% Opaques
1% Feldspar

LITHOLOGIC DESCRIPTION

5GY 4/1

Dark greenish gray VOLCANIC BRECCIA mainly of volcanic rocks (basalt fragments, glass with phenocrysts, single euhedral crystals) and relative little sediment material (1-5%). Numerous calcite veins in upper part of core. Average diameter of sediment clasts and volcanic fragments 0.5-1.0 mm. Fossils (mainly foraminifers) 1-5% of components (except matrix) in cm 1-10 to 20. At 1-27 small round pebble with bright red crystals (oxidized olivine). At 1-48 little gastropod.

BRECCIA with many and thick calcite veins, mainly parallel to bedding, maximum diameter of sediment clast 1 cm (at 2-18 and 2-145).

A coherent rock composed of angular to subangular lithic fragments of mainly altered basaltic glass, and lesser foraminifera, mollusc shells, dolomite crystals, and clinopyroxene crystals, in a clayey (noncarbonate) matrix. Basaltic fragments range in size from 0.1 mm to 1 cm; most are between 2 and 5 mm. Mode = 43 vol. % matrix material; 57% fragments. Calcite veins present in upper portion.

Basaltic fragments altered to clay are pale yellow, to light green, to gray in color. Each fragment contains vesicles, many filled with secondary, microcrystalline phases. Phenocrysts in fragment are dolomite (CaO 31.4 wt.%; MgO 16.8 wt.%) pseudomorphs after olivine. Feldspar microcrysts in fragments show lineation. Clinopyroxene ($Fs_{6-14}En_{36-47}Wo_{47-50}$) fragments are black, vitreous, and have concoidal fracture. Compositions determined by electron microprobe.

5Y 4/1

5GY 6/1

5B 9/1

Sec. 3 ① Dark greenish gray BRECCIA with sediment clast, volcanic fragments, and fossils (forams-planktonic forams, discocyclina, miliolids, rads). Average of particles 2-4 mm, maximum ϕ of sediment clast 4 cm. Biggest sediment clasts contain glauconite and discocyclina, has thus been transported together with volcanic material from shallower area. Other sediment clast full of foraminifera. Volcanic glass contains numerous vesicles, (calcite filled) and big euhedral crystals. Foraminifera swim as single grains in the matrix. At 3-3 first calcite vein. Reefal(?) fragments at 3-27.

(1A) 3-95 to 100: olive gray coarse sand- to grain-sized (ϕ of most particles 1-3 cm) BRECCIA, mostly of volcanic components; ~10% sediment clasts (except calcitic matrix): slightly rounded, maximum ϕ 1-2 cm, fossiliferous (bivalve), contact to CHALK below preserved in thin light light gray sediment rim.

② Greenish gray coarse homogeneous DOLOSTONE.

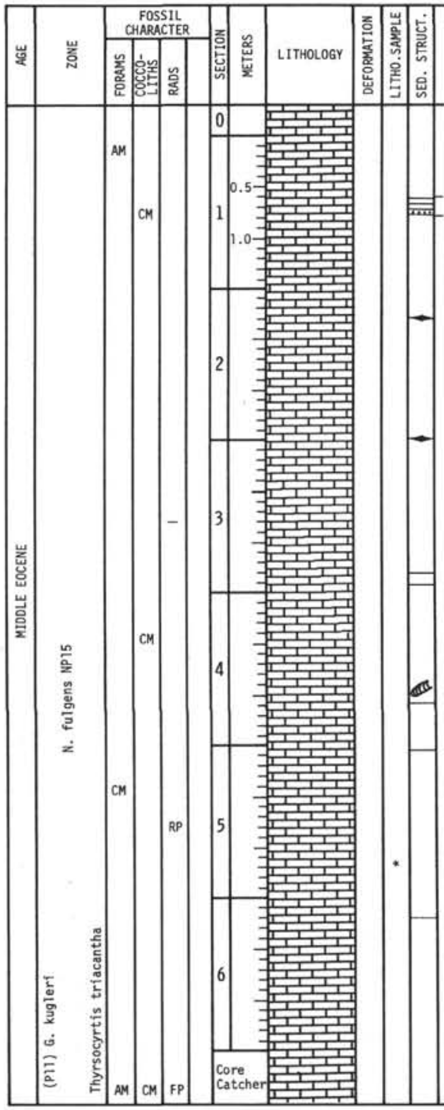
③ Few fragments of very light CHALK with lowermost dark volcanic grains, many of those consist of an outer rim around a vacity filled totally or partly by calcite grains.

④ Bluish white siliceous LIMESTONE, fine grained, homogeneous, slightly burrowed, apparently glauconite grains.

Contacts of units below 'Breccia' look artifical!

Explanatory Notes in Chapter 1

Site 357 Hole Core 26 Cored Interval: 379.0-388.5 m



LITHOLOGIC DESCRIPTION

N6

Medium light gray LIMESTONE, slightly burrowed throughout.

N3

Dark gray horizon with thin sand layer below. In burrows in its upper part is limestone: 1-68 to 76.

Medium gray, burrowed horizons at 2-28 to 32, 2-140 to 142.

Thin gray laminae at 3-131, 3-145, 4-105, 5-6, 6-18.

Zoophycos at 4-90 to 95 (beautiful specimen).

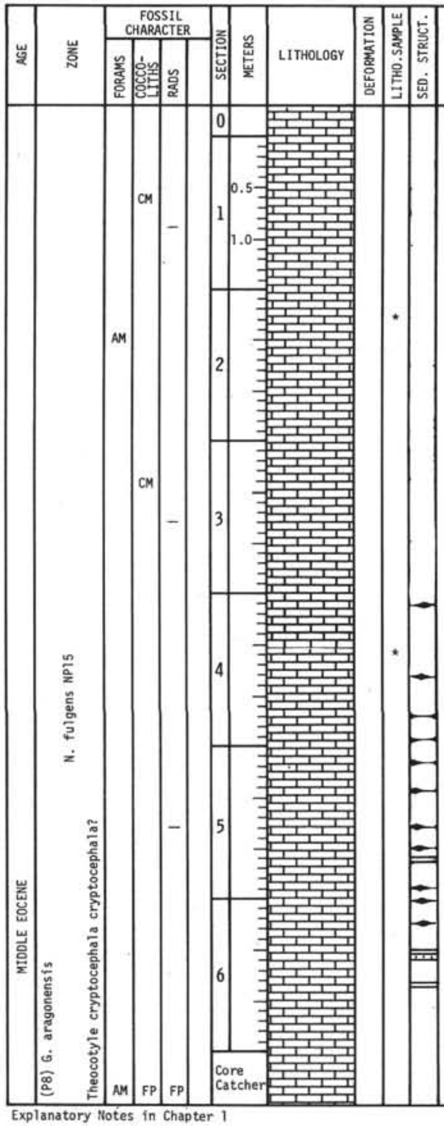
Slightly darker hue at 5-60.

SS 5-100 FORAM NANNO LIMESTONE

40% Silt	50% Nannos
60% Clay	30% Forams
	10% Clay
	5% Micrite
	5% Zeolite
	1% Quartz
	1% Volcanic glass
	1% Diatoms

$CaCO_3$ 6-35: 67%

Site 357 Hole Core 27 Cored Interval: 407.5-417.0 m



LITHOLOGIC DESCRIPTION

N7

Light gray LIMESTONE, homogeneous, fine grained partly silicified, slightly burrowed throughout, intensively burrowed in slightly darker horizons: 1-51 to 55, 1-73 to 74, 1-115, 1-139 to 143, 2-74 to 79, 2-119, 2-124, 2-129, 2-134, 2-143 to 146, 3-7 to 10, 3-30 to 37, 3-96 to 105, 3-123 to 128, 3-133 to 136, 3-138 to 141, 4-0 to 13, 4-76 to 78, 4-121 to 129, 4-140 to 142, 5-18 to 20, 5-38 to 41, 5-76 to 78, 5-92 to 101, 5-145 to 148, 6-0 to 10, 6-20 to 30.

SS 4-60

5% Sand	35% Nannos
40% Silt	30% Forams
55% Clay	20% Silica cement
	5% Clay
	5% Zeolite
	5% Micrite
	1% Dolomite rhombs

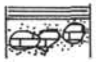
Thin laminae below burrowed horizon 5-100 to 101.

SS 6-72

20% Sand	60% Silica cement
40% Silt	15% Quartz
40% Clay	10% Nannos
	10% Micrite
	5% Forams
	1% Volcanic glass
	1% Glauconite
	1% Pyrite

5G 6/1 Greenish gray, sandy silt horizon.

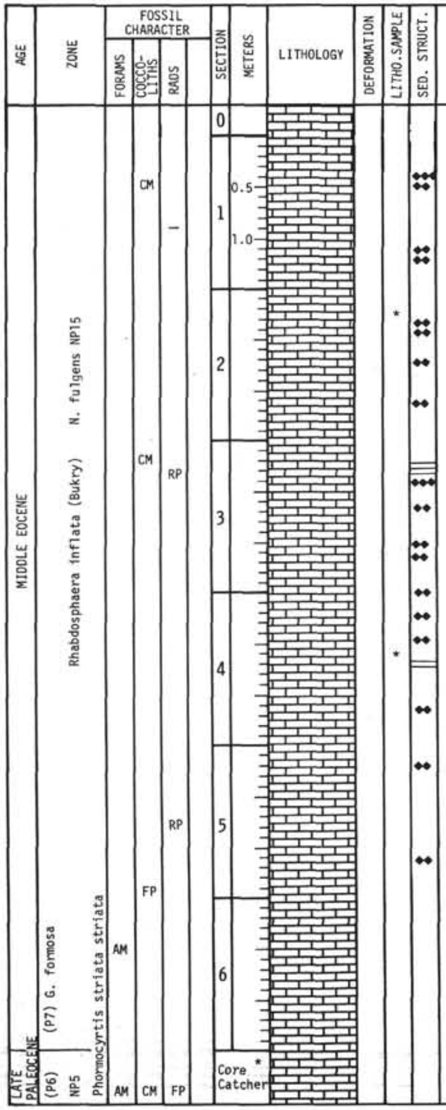
5G 6/1



6-78 to 25 lower part sandy with many burrows, above laminated and fine grained.

Explanatory Notes in Chapter 1

Site 357 Hole Core 28 Cored Interval: 436.0-445.5 m



LITHOLOGIC DESCRIPTION

N7

Light gray LIMESTONE partly silicified homogeneous, fine grained, slightly burrowed throughout, with darker *horizons which are intensively burrowed*: 1-20 to 45, 1-83 to 113, 2-17 to 23, 2-34 to 37, 2-60 to 72, 2-91 to 95, 3-25 to 28, 3-43 to 54, 3-74 to 116, 3-136 to 145, 4-0 to 10, 4-36 to 39, 4-85 to 99, 5-0 to 15, 5-80 to 91. These horizons contain many times more sand in their bottom part - even small sand layers, or intraformational conglomeratic pebbles.

SS 2-23	
30% Silt	50-55% Silica cement
70% Clay	20% Micrite
	15% Nannos
	10% Forams
	5% Rads
	5% Quartz
	5% Feldspar
	1% Limonite
	1% Volcanic glass

Thin grayish laminae at 3-8, 3-10, 3-12, 3-16, 4-48.

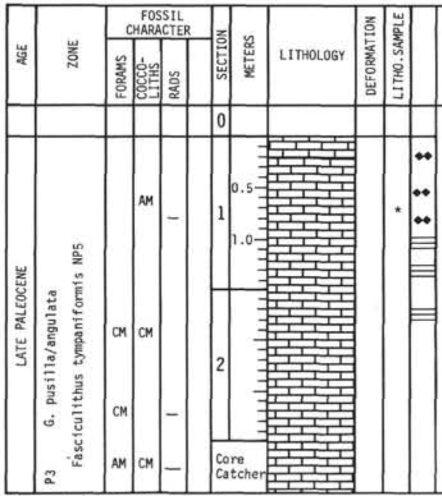
SS 4-58	
10% Sand	35% Silica cement
30% Silt	30% Micrite
60% Clay	20% Heavies
	5% Forams
	5% Quartz
	5% Clay
	1% Volcanic glass

Sharp color change to pinkish gray.

5YR 8/1

*bottom of core catcher
probably from 64.4 m

Site 357 Hole Core 29 Cored Interval: 464.5-474.0 m



LITHOLOGIC DESCRIPTION

5YR 7/2
interchanging
with
10YR 6/2

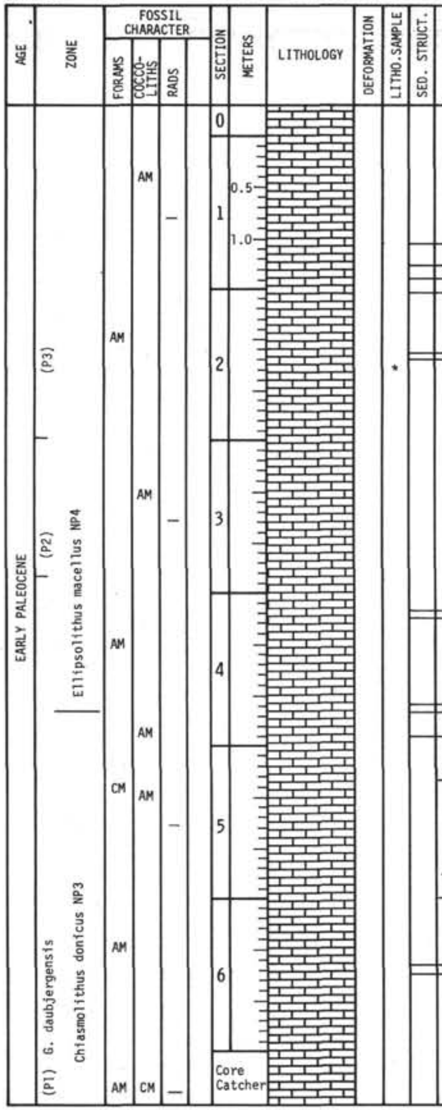
Grayish orange pink interchanging with pale *yellowish brown* LIMESTONE, slightly burrowed throughout, more intensively in darker horizons 1-13 to 20, 1-58 to 61, 1-75 to 81.

Brown laminae at 1-98 to 102, 1-126 to 130, 2-20 to 30.

SS 1-80 SILICIFIED NANNO LIMESTONE	
20-30% Silt	65% Nannos
70% Clay	30% Silica cement
	5% Clay
	1% Limonite
	1% Diatoms

Explanatory Notes in Chapter 1

Site 357 Hole Core 30 Cored Interval: 474.0-483.5 m



LITHOLOGIC DESCRIPTION

5YR 6/4

Light brown LIMESTONE, fine grained homogeneous, with moderate brown horizons, rarely interbedded with grayish orange pink horizons. Slightly burrowed throughout, darker horizons usually more intensively burrowed.

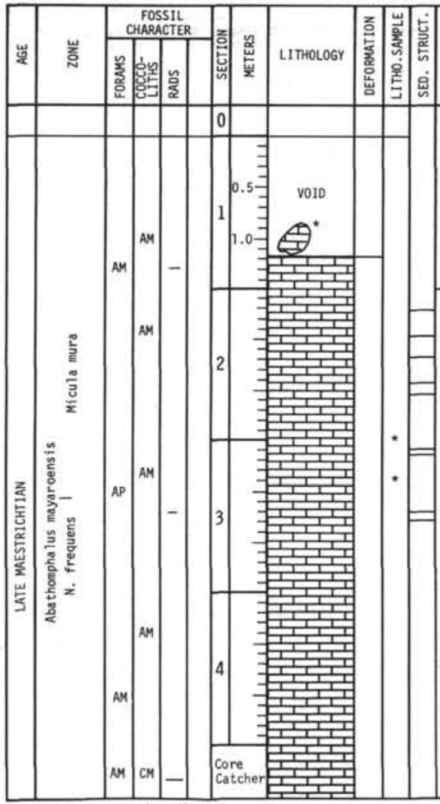
5YR 7/2
5YR 6/4
5YR 4/4
5YR 6/4

SS 2-70

5% Sand	25% Nannos
25% Silt	25% Forams
70% Clay	25% Clay
	15% Micrite
	10% Limonite
	1% Dolomite rhombs

5YR 4/4
5YR 6/4
5YR 7/2
5YR 6/4
5YR 7/2
5YR 6/4
5YR 7/2
5YR 6/4
5YR 4/4
5YR 6/4
5YR 72/
5YR 6/4

Site 357 Hole Core 31 Cored Interval: 493.0-502.5 m



LITHOLOGIC DESCRIPTION

Pinkish gray LIMESTONE fine grained, homogeneous, slightly burrowed throughout, more intensively burrowed in some darker horizons. Slightly bedded.

SS 2-140

10% Silt	60% Nannos
90% Clay	20% Micrite
	5% Forams
	5% Dolomite rhombs
	5% Clay
	5% Quartz, Feldspar

5YR 8/1

5B 9/1	Bluish white
5G 6/1	Light greenish gray
5YR 6/4	Light brown
5B 9/1 5YR 8/1 5B 9/1 5YR 7/2	Various shades of light to moderate brown with thin intercalations of bluish white at 3-14 to 18, 3-66 to 72, 4-17 to 20, 4-114 to 120, 4-138 to 145.

5YR 6/4-
5YR 4/4

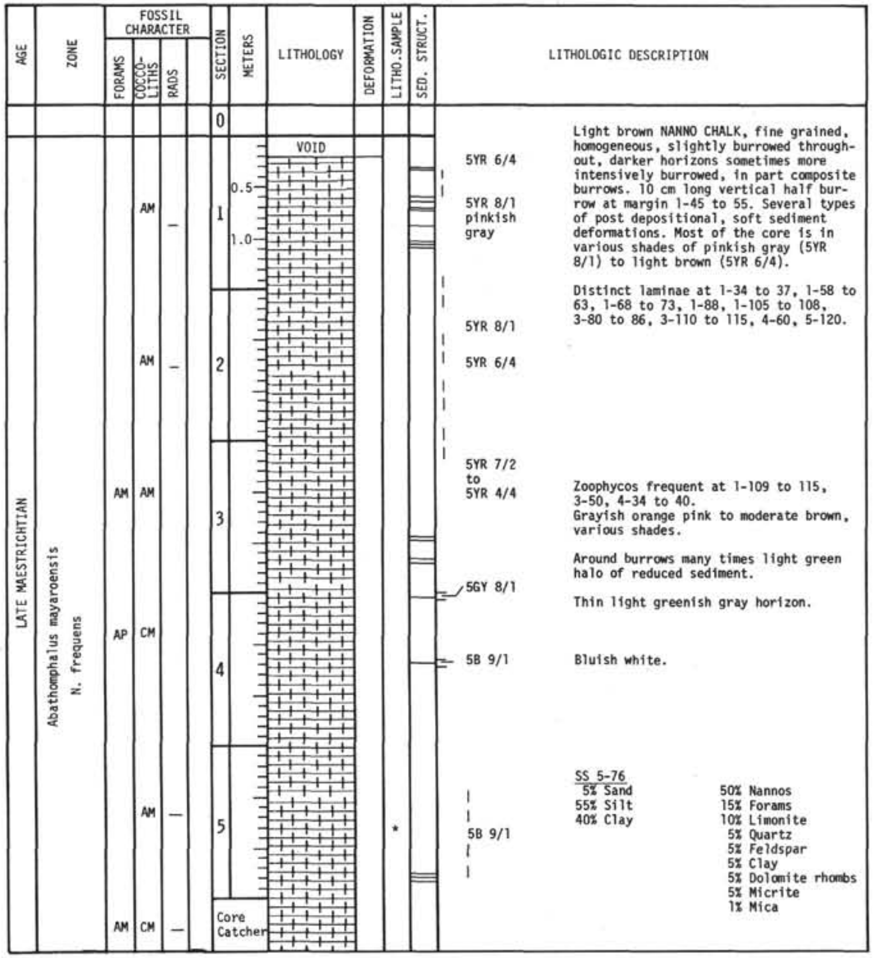
SS 3-30

10% Sand	55% Nannos
30% Silt	20% Forams
60% Clay	15% Limonite
	10% Feldspar
	5% Quartz
	5% Opaques

*EARLY PALEOCENE lump

Explanatory Notes in Chapter 1

Site 357 Hole Core 32 Cored Interval: 502.5-512.0 m



5YR 6/4

5YR 8/1 pinkish gray

Light brown NANNO CHALK, fine grained, homogeneous, slightly burrowed throughout, darker horizons sometimes more intensively burrowed, in part composite burrows. 10 cm long vertical half burrow at margin 1-45 to 55. Several types of post depositional, soft sediment deformations. Most of the core is in various shades of pinkish gray (5YR 8/1) to light brown (5YR 6/4).

Distinct laminae at 1-34 to 37, 1-58 to 63, 1-68 to 73, 1-88, 1-105 to 108, 3-80 to 86, 3-110 to 115, 4-60, 5-120.

5YR 8/1

5YR 6/4

5YR 7/2
to
5YR 4/4

Zoophycos frequent at 1-109 to 115, 3-50, 4-34 to 40.
Grayish orange pink to moderate brown, various shades.

Around burrows many times light green halo of reduced sediment.

5GY 8/1

Thin light greenish gray horizon.

5B 9/1

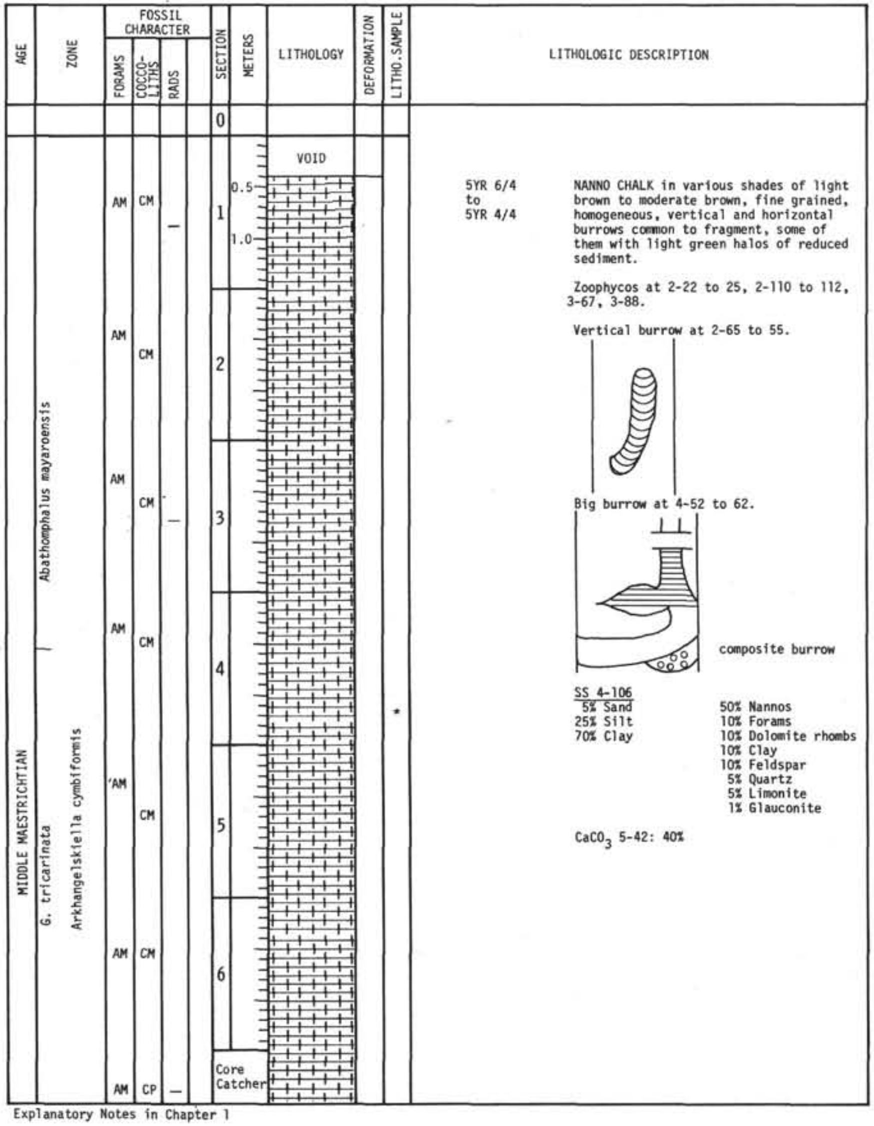
Bluish white.

SS 5-76

5% Sand	50% Nannos
55% Silt	15% Forams
40% Clay	10% Limonite
	5% Quartz
	5% Feldspar
	5% Clay
	5% Dolomite rhombs
	5% Micrite
	1% Mica

5B 9/1

Site 357 Hole Core 33 Cored Interval: 521.5-531.0 m



5YR 6/4
to
5YR 4/4

NANNO CHALK in various shades of light brown to moderate brown, fine grained, homogeneous, vertical and horizontal burrows common to fragment, some of them with light green halos of reduced sediment.

Zoophycos at 2-22 to 25, 2-110 to 112, 3-67, 3-88.

Vertical burrow at 2-65 to 55.

Big burrow at 4-52 to 62.

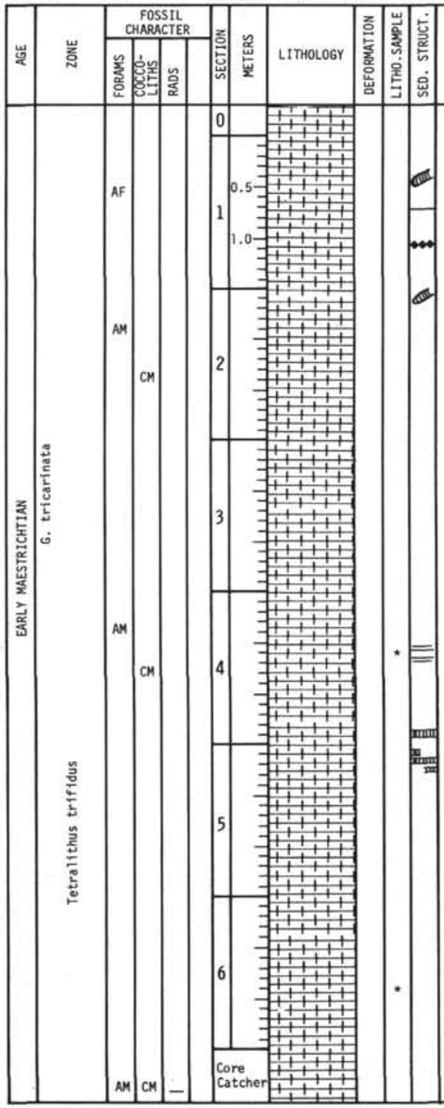
SS 4-106

5% Sand	50% Nannos
25% Silt	10% Forams
70% Clay	10% Dolomite rhombs
	10% Clay
	10% Feldspar
	5% Quartz
	5% Limonite
	1% Glauconite

$CaCO_3$ 5-42: 40%

Explanatory Notes in Chapter 1

Site 357 Hole Core 34 Cored Interval: 550.0-559.5 m



LITHOLOGIC DESCRIPTION

5B 7/1
to
5B 9/1
5YR 8/1
pinkish gray
5YR 6/1
5YR 8/1
5YR 7/1
5GY 8/1
5YR 5/2
5B 9/1
5YR 8/1
10YR 6/2
5GY 8/1
10YR 6/2
5GY 6/1
5YR 6/1
5GY 6/1
5B 9/1
5GY 6/1
5B 9/1
5GY 6/1
5B 9/1
5GY 6/1
5YR 8/1
10YR 6/2
5B 9/1
5YR 6/1
5B 9/1
5YR 6/1
5YR 8/1
5YR 6/2
5YR 5/2
10YR 6/2
5YR 8/1
10YR 6/2
5GY 8/1
5YR 6/1

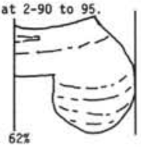
Light bluish gray to bluish white FORAM NANNO CHALK, homogeneous, fine grained, interbedded with sediment of brownish and pinkish hues. Slightly burrowed throughout, intensively burrowed in several horizons (1-104 to 108).

Zoophycos 1-38, 1-42, 2-9 to 14, 4-76.

Sharp sediment contact at 1-70, bluish white sediment above.

Big burrows, up to 30 cm ϕ, filled with slightly darker material at 2-20.

Big burrow at 2-90 to 95.



$CaCO_3$ 4-55: 62%

Slightly contorted bed at 4-60 to 67.

Inoceramus at 4-138, 5-7.

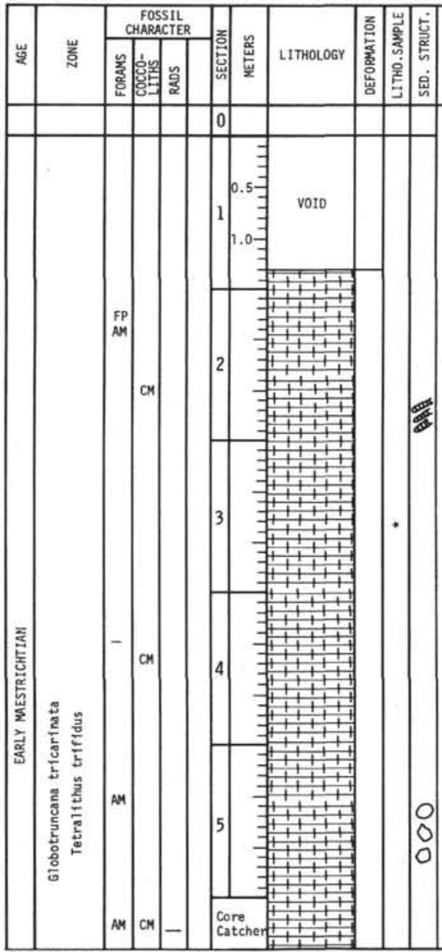
SS 4-55

5% Sand	50% Nannos
25% Silt	20% Forams
70% Clay	10% Zeolite
	5% Dolomite rhombs
	5% Clay
	5% Quartz
	5% Feldspar
	1% Mica

SS 6-90

5% Sand	35% Nannos
25% Silt	20% Forams
70% Clay	10% Micrite
	10% Opaques and Limonite
	10% Clay
	5% Quartz
	5% Feldspar
	5% Mica
	1% Volcanic glass

Site 357 Hole Core 35 Cored Interval: 578.5-588.0 m



LITHOLOGIC DESCRIPTION

5YR 4/4
5YR 6/4
5YR
5YR 8/1
5YR 4/4
5YR 7/2
5YR 8/1
5YR 6/4
5YR 4/4
5B 9/1
5YR 4/4
5YR 8/1
5YR 4/4
5YR 7/2
5YR 6/4
5YR 7/2
5B 9/1
5YR 8/1
5YR 4/4
5YR 8/1
5YR 4/4
5YR 8/1
5YR 6/4
5YR 4/4
5YR 7/2
5YR 4/4

Moderate brown NANNO CHALK interbedded with bluish white, 10-20 cm thick horizons. Fine grained, homogeneous. Colors in various shades. Slightly to intesively burrowed throughout.

Zoophycos at 2-129 to 140 (10x)

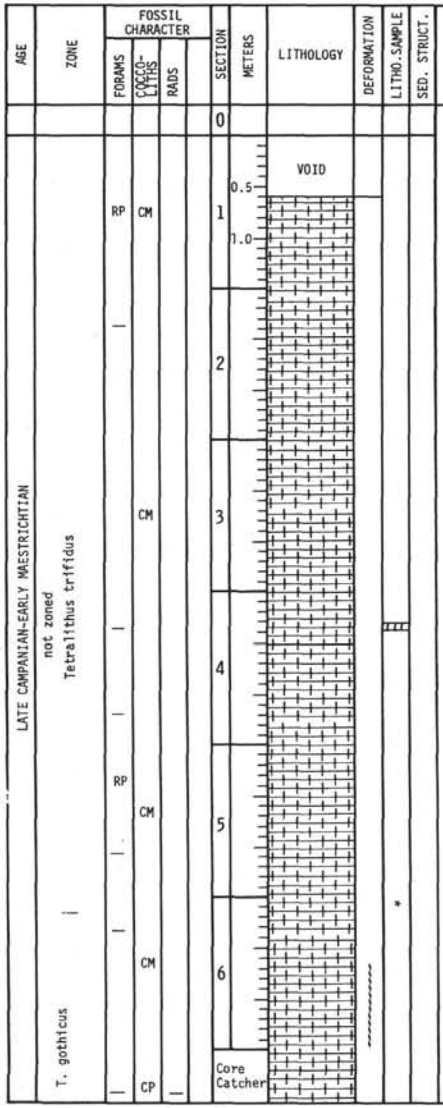
SS 3-75

5% Sand	30% Nannos
45% Silt	15% Dolomite rhombs
50% Clay	15% Limonite and Opaques
	10% Feldspar
	10% Clay
	10% Forams
	5% Micrite
	5% Quartz
	5% Mica
	1% Volcanic glass

Some composite burrows.

Explanatory Notes in Chapter 1

Site 357 Hole Core 36 Cored Interval: 607.0-616.5 m



LITHOLOGIC DESCRIPTION

5YR 4/4
5YR 8/1
5YR 4/4
5YR 8/1
5YR 4/4
5YR 3/4
5YR 7/2
5YR 3/4
5YR 7/2
5YR 4/4
5YR 7/2
5YR 5/6
5YR 7/2
5YR 4/4
5YR 7/2
5YR 4/4
5YR 7/2
5YR 3/4
5YR 7/2
5YR 6/4
5YR 8/1
5YR 4/4
5YR 6/4
5YR 4/4
5YR 6/4
5YR 4/4
5YR 8/1
5YR 3/4
5YR 6/4
5YR 3/4
5YR 7/2
5B 9/1
5YR 4/4
5B 9/1
5YR 4/4

Moderate brown interbedded with pinkish gray to greenish gray FORAM NANNO CHALK, fine grained, homogeneous, slightly to intensively burrowed throughout.

Numerous Zoophycos: 6 in Section 1, 27 in 2, 40 in 5.

Composite burrows at 1-140.

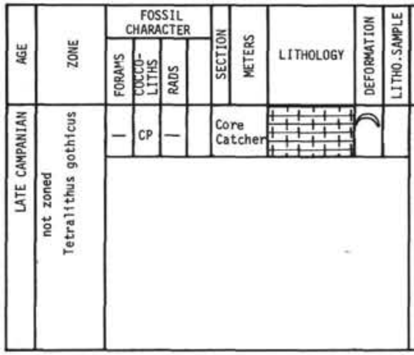
Intact small Inoceramus at 4-30.

SS 6-10

5% Sand	45% Nannos
40% Silt	25% Forams
55% Clay	15% Micrite
	5% Clay
	5% Volcanic glass
	5% Dolomite rhombs
	1% Quartz
	1% Feldspar

$CaCO_3$ 6-12: 77%

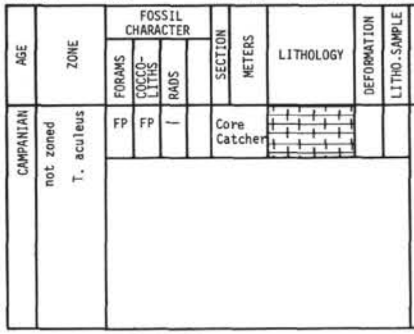
Site 357 Hole Core 37 Cored Interval: 645.0-654.5 m



LITHOLOGIC DESCRIPTION

5YR 6/4 and 5GY 8/1 Light greenish gray and light brown NANNO CHALK, homogeneous, fine grained, layered.

Site 357 Hole Core 38 Cored Interval: 664.0-673.5 m

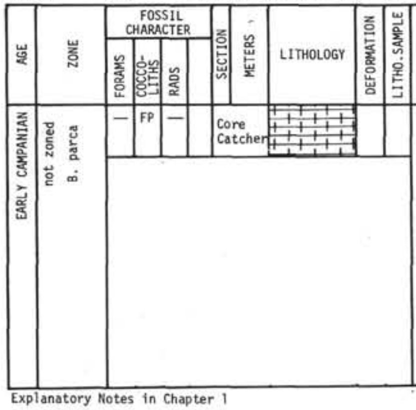


LITHOLOGIC DESCRIPTION

Only about 30-50 cc, processed for fossils.

Same as 37 Core catcher.

Site 357 Hole Core CB 38/39 Cored Interval: 673.5-683.0 m



LITHOLOGIC DESCRIPTION

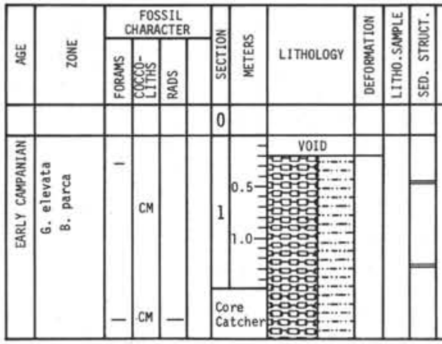
0.5 cc on top of CB

SS CB 38/39 (Gray MICRITE)

1% Sand	90-95% Micrite
30% Silt	1- 5% Nannos
70% Clay	1% Forams
	1% Dolomite rhombs

Explanatory Notes in Chapter 1

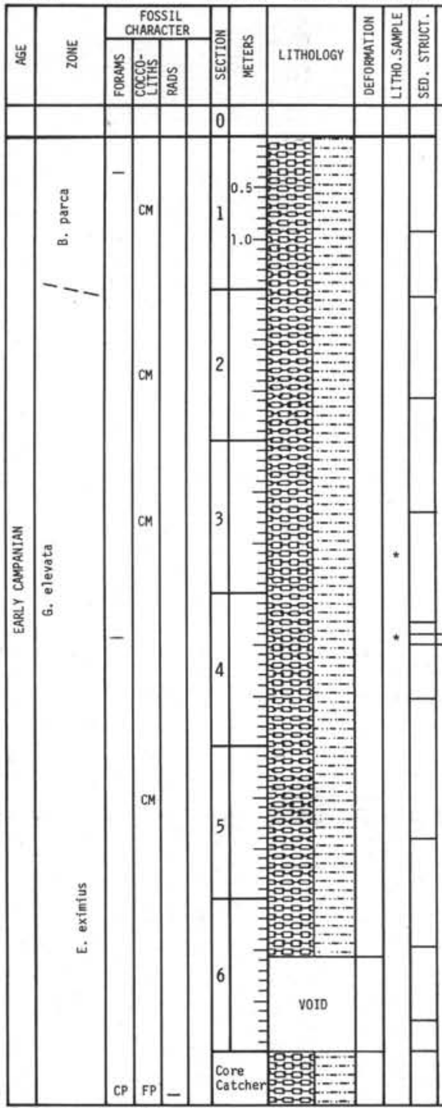
Site 357 Hole Core 39 Cored Interval: 683.0-692.5 m



LITHOLOGIC DESCRIPTION

5Y 4/1 Olive gray silty MICRITE CHALK, fine grained, homogeneous; intensively burrowed throughout, most burrows slightly darker than the surrounding sediment; many chondroid burrows in mm-scale, but often up to 5 cm ϕ, or up to 7 cm long (composit burrow) . Laminations preserved throughout the core in several places, slightly varying shades of color in several parts of the section.

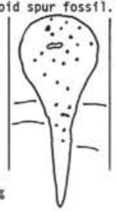
Site 357 Hole Core 40 Cored Interval: 692.5-702.0 m



LITHOLOGIC DESCRIPTION

5Y 4/1 Olive gray silty MICRITIC CHALK, fine grained, homogeneous; intensively burrowed throughout, burrows mostly slightly darker due to pyrite coating, chondroid burrows in the mm scale, but also big horizontal and vertical burrows. Zoophycos. Laminations are partly preserved at several places. Various shades of the color.

Big burrow at 3-40 to 50, composite of small chondroid spur fossil.



Big Zoophycos at 4-30.

$CaCO_3$ 4-111: 64%

SS 3-105	
5% Sand	25% Nannos
35% Silt	20% Volcanic glass
60% Clay	10% Feldspar
	10% Clay
	10% Micrite
	5% Quartz
	5% Opaques
	1% Apatite
	1% Dolomite rhombs
	1% Zeolite

5GY 2/1

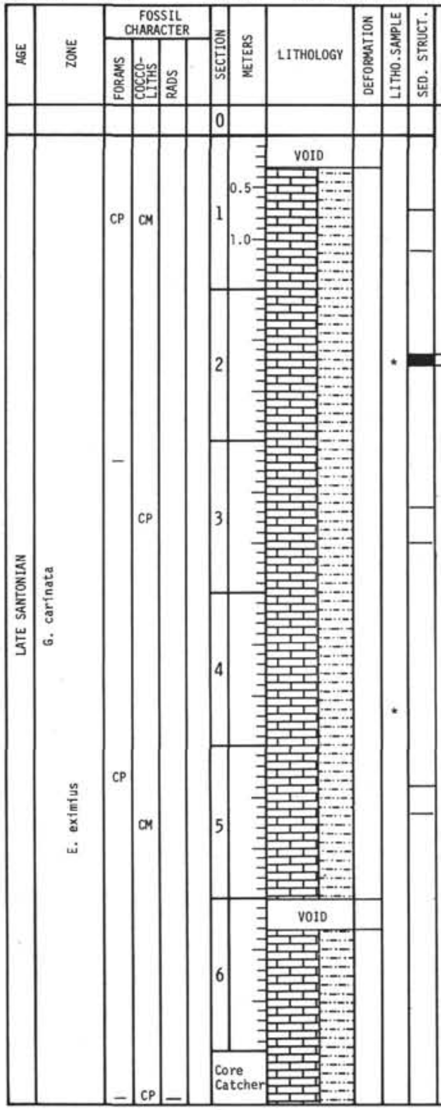
Laminations very clear in several places (f.e. 6-0 to 10).

Greenish black 5 cm thick CLAYSTONE horizon at 4-40 to 50. Thin laminae and contortions below, thin clay pebble horizon above, and again laminations.

SS 4-45	
10% Silt	55% Clay
90% Clay	30% Volcanic glass
	10% Zeolite
	5% Opaques

Explanatory Notes in Chapter 1

Site 357 Hole Core 41 Cored Interval: 703.0-712.5 m



LITHOLOGIC DESCRIPTION

5GY 6/1
to
5GY 4/1

5G 2/1

5GY 6/1
5GY 4/1
5GY 6/1
5GY 4/1
5GY 6/1
5GY 4/1
5GY 6/1

5GY 4/1
Laminations
5GY 6/1

5GY 4/1
5GY 6/1
5GY 4/1
5GY 6/1

Greenish gray to dark greenish gray silty MICRITIC CHALK grading into MARLY LIMESTONE, homogeneous. Intensively burrowed throughout, many chondroid burrows, but also bigger ones - horizontal and vertical to bedding. Zoophycos (especially in Section 5).

Thin laminations preserved in several portions of the core. Various lighter shades of greenish gray in several portions of the core.

2-76 to 82, greenish black CLAYSTONE (soapy feeling), homogeneous, sharp basal boundary, grading upwards into normal sediment, which also has been burrowed down into this horizon. Pyritiferous (small concretions).

SS 2-80
10% Silt
90% Clay

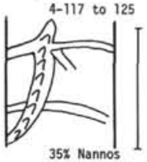
80% Clay
10% Volcanic glass
10% Pyrite
1% Dolomite rhombs

Big burrows especially developed in Section 4.

composite burrow

5 cm

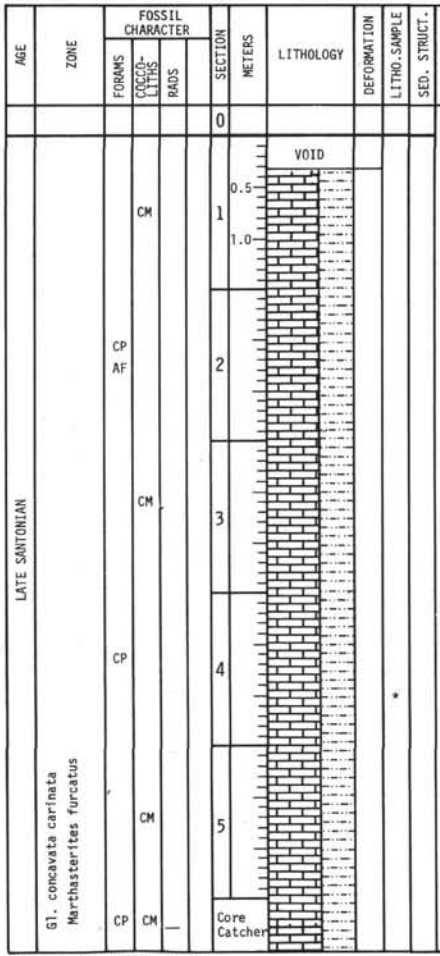
4-117 to 125



SS 4-100
5% Sand
35% Silt
60% Clay

35% Nannos
20% Volcanic glass
10% Forams
10% Micrite
10% Feldspar
5% Quartz
5% Clay
5% Zeolite
1% Dolomite rhombs

Site 357 Hole Core 42 Cored Interval: 712.5-722.0 m



LITHOLOGIC DESCRIPTION

5G 6/1
5GY 6/1
5GY 4/1
5GY 6/1

5GY 4/1
5GY 6/1

Silty MICRITIC CHALK - MARLY LIMESTONE, fine grained, homogeneous; intensively burrowed throughout: chondroid burrows, Zoophycos, big horizontal burrows.

Bedding indicated by thin laminations and slightly various shades of color.

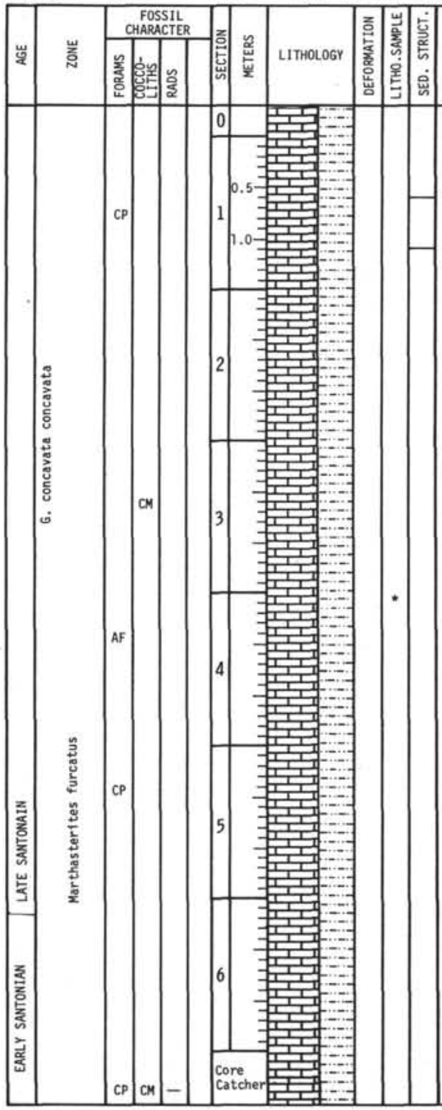
Alternating in 10-30 cm distances with no sharp boundaries.

SS 4-100
5% Sand
35% Silt
60% Clay

30% Micrite
20% Nannos
20% Clay
15% Volcanic glass
10% Zeolite
5% Forams
1% Quartz
1% Feldspar
1% Mica
1% Pyrite

Explanatory Notes in Chapter 1

Site 357 Hole Core 43 Cored Interval: 722.0-731.5 m



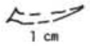
LITHOLOGIC DESCRIPTION

5GY 4/1

Dark greenish gray MARLY FORAM NANNO LIMESTONE, various shades of color to faintly lighter and darker hues alternating in 10-30 cm distances. Intensively burrowed throughout. Except color changes (mostly grading) almost no bedding preserved. Chondroid burrows, Zoophycos.

Sheel fragments (Inoceramus and other bivalves) at 2-60, 4-19, 6-34, 6-130.

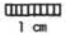
$CaCO_3$ 2-125: 48%



SS 3-150
5% Sand
25% Silt
70% Clay

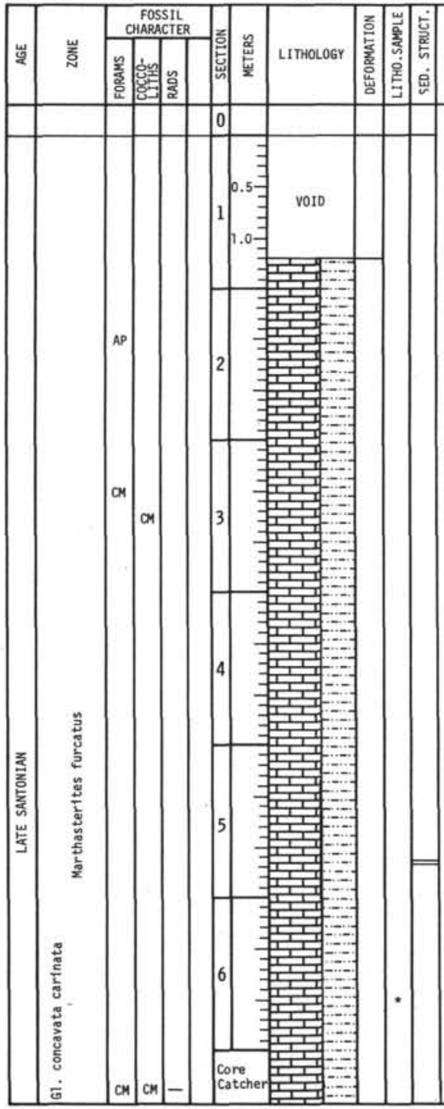
30% Nannos
20% Forams
15% Clay
10% Micrite
5% Quartz
5% Feldspar
5% Volcanic glass
5% Dolomite rhombs
5% Zeolite

○ small, round fossil? (ϕ~3 mm)



Inoceramus fragment.

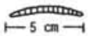
Site 357 Hole Core 44 Cored Interval: 731.5-740.0 m



LITHOLOGIC DESCRIPTION

5GY 4/1

Dark greenish gray MARLY LIMESTONE, with fossil fragments (Inoceramus). Intensively burrowed throughout. Burrows usually slightly darker than matrix.



Big Inoceramus fragments at 2-35, 2-36, 2-78, 2-103, 2-110, 2-136, 3-22, 3-52, 6-10, 6-32, 6-56, 6-110 to 113. Many other calcareous microfossils.

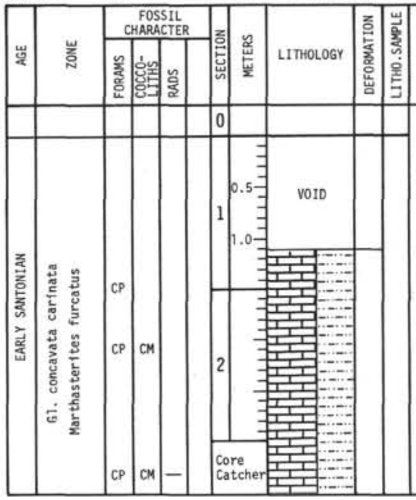
Big vertical burrow at 5-80 to 90
Laminae 5-103

SS 6-90
45% Silt
55% Clay

25% Nannos
20% Micrite
15% Forams
15% Volcanic glass
10% Clay
5% Quartz
5% Feldspar
5% Dolomite rhombs
5% Zeolite

Explanatory Notes in Chapter 1

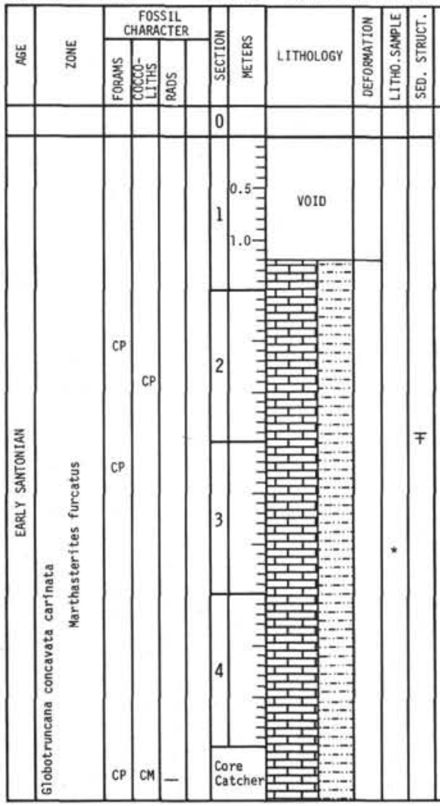
Site 357 Hole Core 45 Cored Interval: 740.0-743.0 m



LITHOLOGIC DESCRIPTION

5GY 6/1 | 5GY 4/1 Greenish gray to dark greenish gray MARLY LIMESTONE, fine grained, homogeneous, intensively burrowed with Inoceramus fragments - especially frequently at 2-90 to 124.

Site 357 Hole Core 46 Cored Interval: 743.0-749.5 m



LITHOLOGIC DESCRIPTION

5GY 5/1 Medium greenish gray MARLY LIMESTONE, very fossiliferous with big Inoceramus fragments, (and other bivalves?). Especially at 46-2 to 24, 2-81, 2-88 to 92, 2-123, 2-128, 2-138 to 141, 3-25, 3-120 to 122.

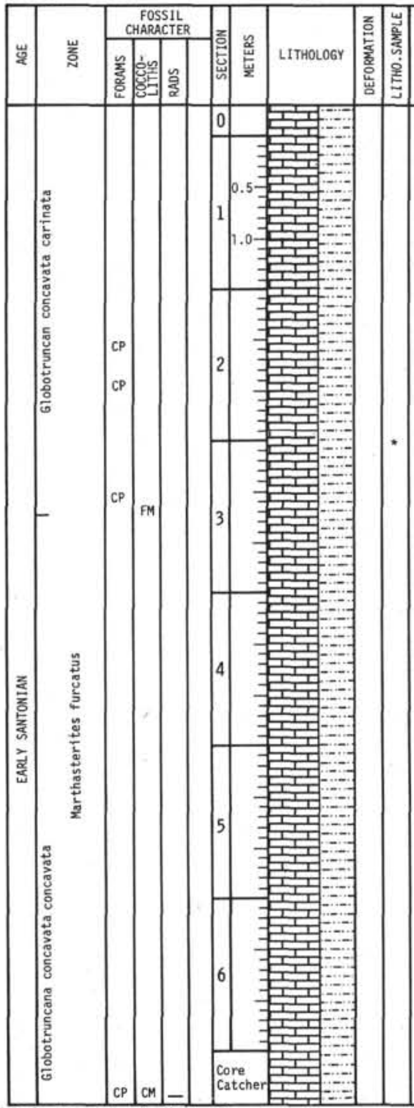
2-139 5 cm long 'folded' Inoceramus fragment.

$CaCO_3$ 2-99: 59%

SS 3-100

50% Silt	30% Nannos
50% Clay	15% Micrite
	15% Volcanic glass
	10% Forams
	10% Clay
	5% Quartz
	5% Feldspar
	5% Dolomite rhombs
	5% Zeolite

Site 357 Hole Core 47 Cored Interval: 749.5-759.0 m



LITHOLOGIC DESCRIPTION

5GY 5/1 Medium greenish gray MARLY CHALK, fine grained, homogeneous, intensively burrowed throughout; many fragments of Inoceramus (partly silicified): 1-6, 1-106 to 109, 1-140 to 149, 2-0 to 55, 2-88, 2-138 to 140, 3-12, 3-46 to 80, 3-110, 4-42, 4-56, 4-80 to 90, 4-102 to 109, 4-122, 4-133 to 146, 5-64, 5-69, 5-78, 6-53 to 64.

Big vertical burrow

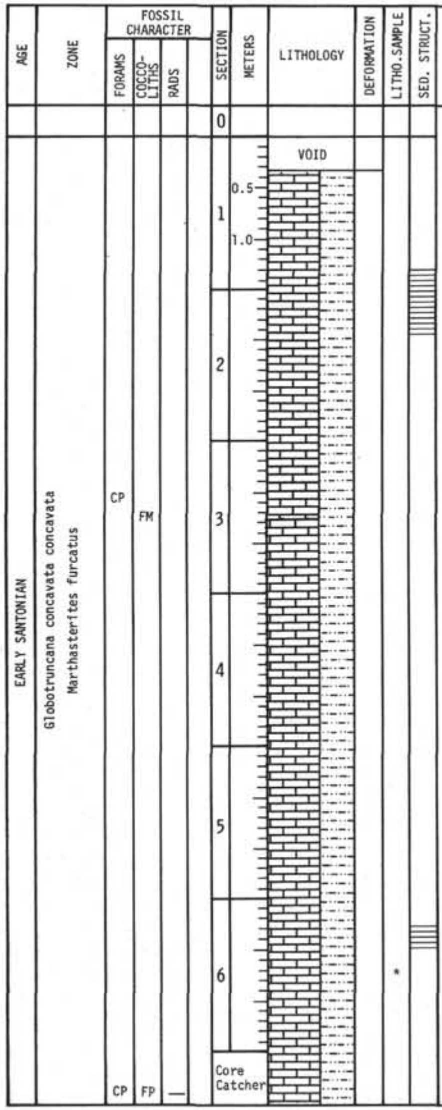
SS 3-2 (burrow fill)

5% Sand	25% Micrite
25% Silt	15% Nannos
70% Clay	15% Silica cement
	15% Dolomite rhombs
	10% Clays
	5% Quartz
	5% Feldspar
	5% Volcanic glass
	5% Opaques
	1% Mica
	1% Zeolite

Big bivalve (no Inoceramus) 6-14, other bivalves at 6-123 to 145.

Explanatory Notes in Chapter 1

Site 357 Hole Core 48 Cored Interval: 759.0-768.5 m



LITHOLOGIC DESCRIPTION

5GY 5/1 Medium greenish gray, silicified MARLY LIMESTONE, intensively burrowed, laminae sometimes preserved (f.e. at 1-130 to 140, 2-0 to 45 irregular, 6-36 to 47.

Inoceramus fragments: 1-60, 1-79, 2-80, 2-139, 2-150, 3-10 to 12, 3-27, 3-88, 3-117, 3-141, 4-104.

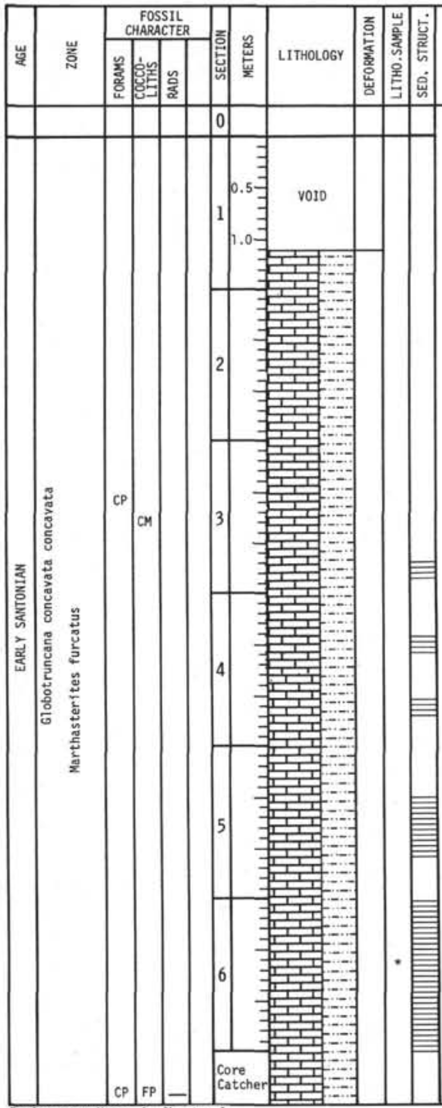
At 2-20 concretion - $CaCO_3$ ϕ~3-5 cm.

Big pelecypod at 2-32 (no Inoceramus) and 5-78.

<u>SS 6-70</u>	35% Micrite
30% Silt	25% Silica cement
70% Clay	15% Nannos
	10% Forams
	10% Dolomite rhombs
	5% Clay
	1% Quartz
	1% Feldspar
	1% Volcanic glass

N7 6-70 to 84 light gray horizon

Site 357 Hole Core 49 Cored Interval: 768.5-778.0 m

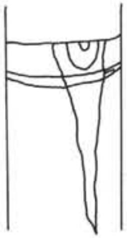


LITHOLOGIC DESCRIPTION

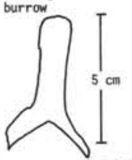
5GY 5/1 Medium greenish gray MARLY LIMESTONE, silicified intensively burrowed, but in some parts of the core an irregular lamination has been preserved: 3-130 to 150, 4-48 to 58, 4-104 to 117, 5-50 to 110, 6-0 to 150.

Inoceramus fragments, 1-114, 1-143, 3-26, 3-122, 3-140 to 144, 4-35, 4-128, 4-150, 5-76, 5-102, 6-44 to 54, 6-107 to 110.

Burrows slightly darker than matrix due to pyrite coatings.



4-0 to 10 big vertical burrow

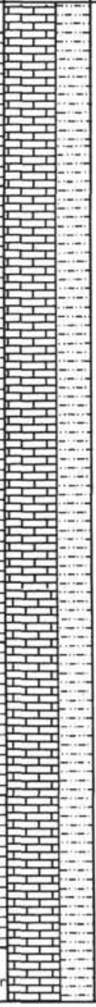


5-138 to 145 big vertical burrow

<u>SS 6-60</u>	40% Silica cement
15% Silt	30% Micrite
85% Clay	10% Nannos
	10% Dolomite rhombs
	5% Clay
	5% Volcanic glass
	1% Feldspar

Explanatory Notes in Chapter 1

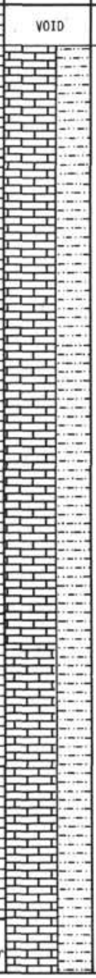
Site 357 Hole Core 50 Cored Interval: 778.0-787.5 m



AGE	ZONE	FORAMS	COCCO-LITHS	RADS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	SED. STRUCT.	LITHOLOGIC DESCRIPTION
EARLY SANTONIAN	Globotruncana concavata concavata Marthasterites furcatus				0						5GY 4/1 5GY 6/1
					1	0.5 1.0					Dark greenish gray to greenish gray SILICEOUS MARLY LIMESTONE, partly laminated, alternating with slightly burrowed section. Inoceramus fragments: 1-0 to 28, 1-45, 1-103, 2-11, 2-56, 2-98 to 111, 2-123, 3-77, 4-134 to 144, 5-99 to 105, 6-38, 6-61, 6-80, 6-102, 6-110.
					2						Laminated sections: 1-0 to 110, 2-0 to 33, 2-53 to 100, 2-110 to 145, 3-0 to 31, 3-77 to 84, 3-105 to 140, 4-0 to 15, 5-50 to 86, 4-100 to 110, 4-125 to 150, 5-0 to 150, 6-0 to 150. $CaCO_3$ 2-130: 39%
			FP		3						
					4						
					5						Inoceramus-shales partly pyritized.
					6				* *	=	Thin green layer
		CP	CP	—	Core Catcher						

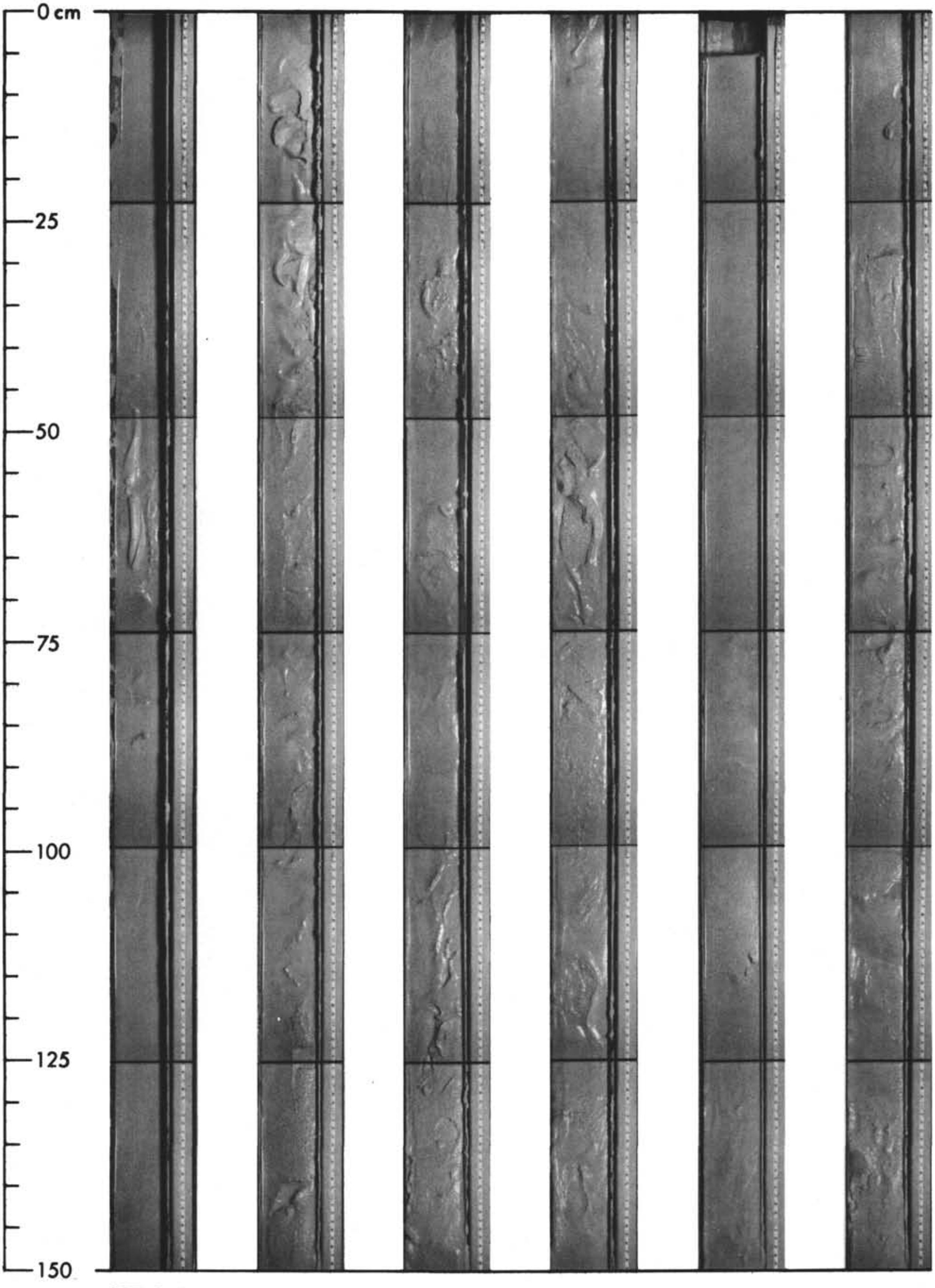
SS 6-100	SS 6-130
5% Sand	1% Sand
35% Silt	10% Silt
60% Clay	90% Clay
50-60% Micrite	90% Clay
20-30% Silica cement	1- 5% Micrite
1- 5% Clay	1- 2% Pyrite
1- 2% Nannos	1- 2% Nannos
1- 2% Forams	1% Zeolite?
1% Rads	1% Quartz
1% Quartz	
1% Pyrite	
1% Dolomite rhombs	
1% Zeolite	

Site 357 Hole Core 51 Cored Interval: 787.5-797.0 m



AGE	ZONE	FORAMS	COCCO-LITHS	RADS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	SED. STRUCT.	LITHOLOGIC DESCRIPTION
					0						
EARLY SANTONIAN	Globotruncana concavata concavata Marthasterites furcatus				1	0.5 1.0	VOID				5GY 6/1 Greenish gray SILICIFIED MARLY LIMESTONE, in upper part of core laminated parts alternating with partly lighter, 5-10 cm thick burrowed layers (about 10 per section), in lower part completely laminated (Sec(s). 3 and 4) and again alternating with burrowed horizons (Sec. 5). In Sec. 2 debris of fossils other than Inoceramus, shale at 2-90, completely pyritized. Inoceramus fragments at 1-55, 2-52, 3-6, 3-15, 3-30, 3-64, 3-100, 4-20, 4-78, 5-52, 5-105, 6-79.
					2						
			FP		3						
					4						?Crinoid - fragment at 4-67.
		CP			5						5-105 Big folded, slightly compressed shale of Inoceramus (only fragment).
	VOID 0-10				6						6-127 to 136 big concretion with settling cracks
		—	FP	—	Core Catcher						

Explanatory Notes in Chapter 1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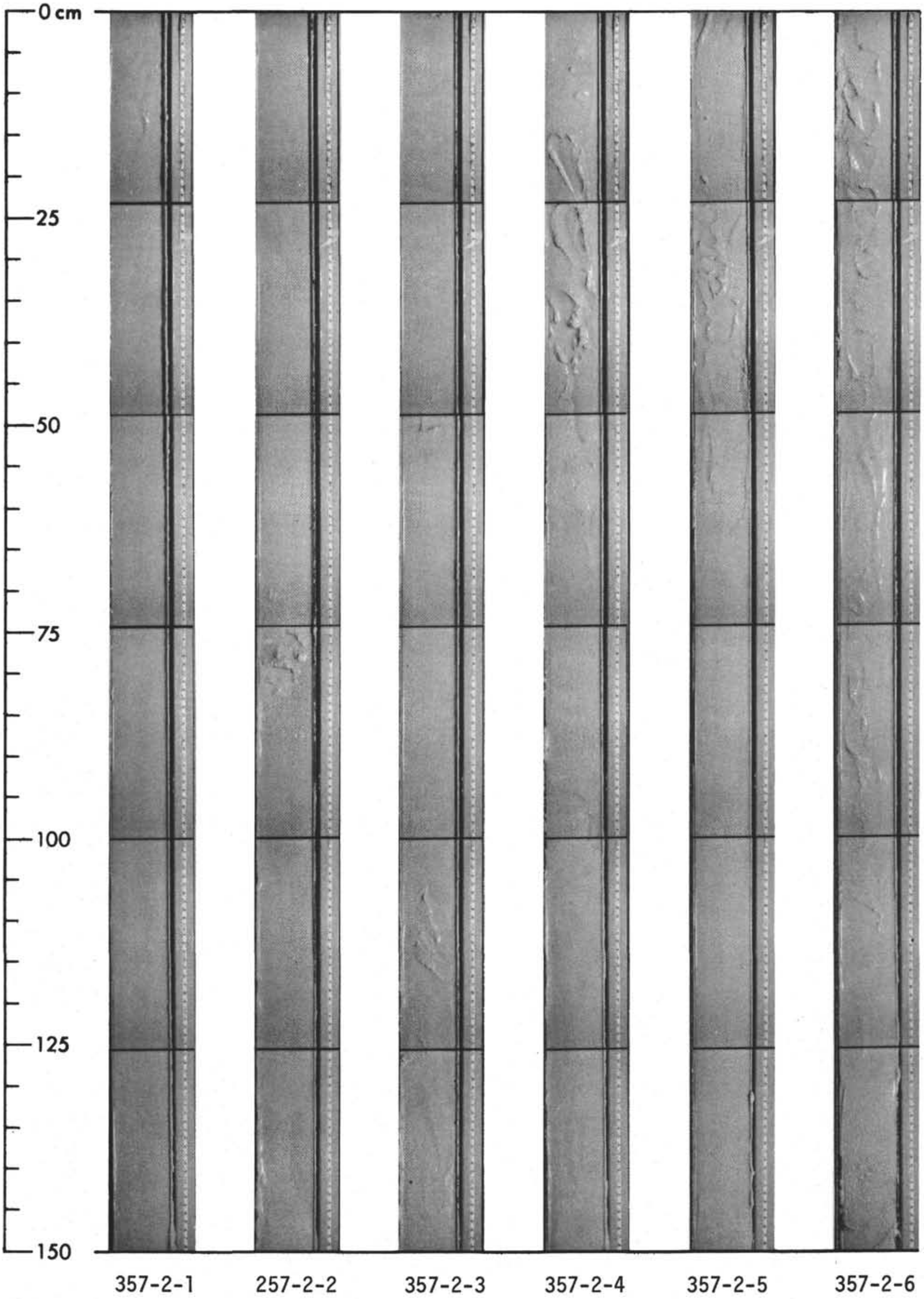
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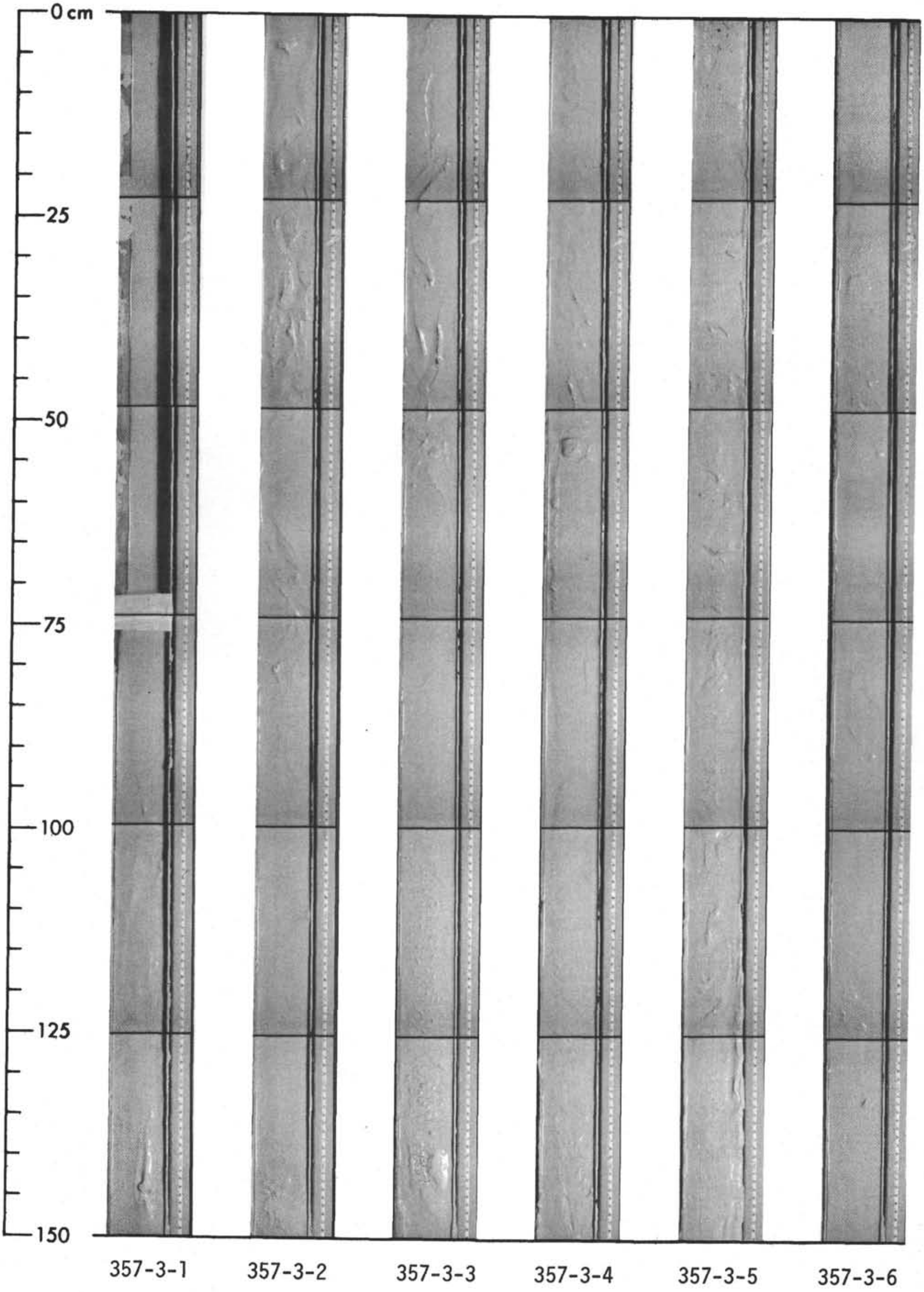
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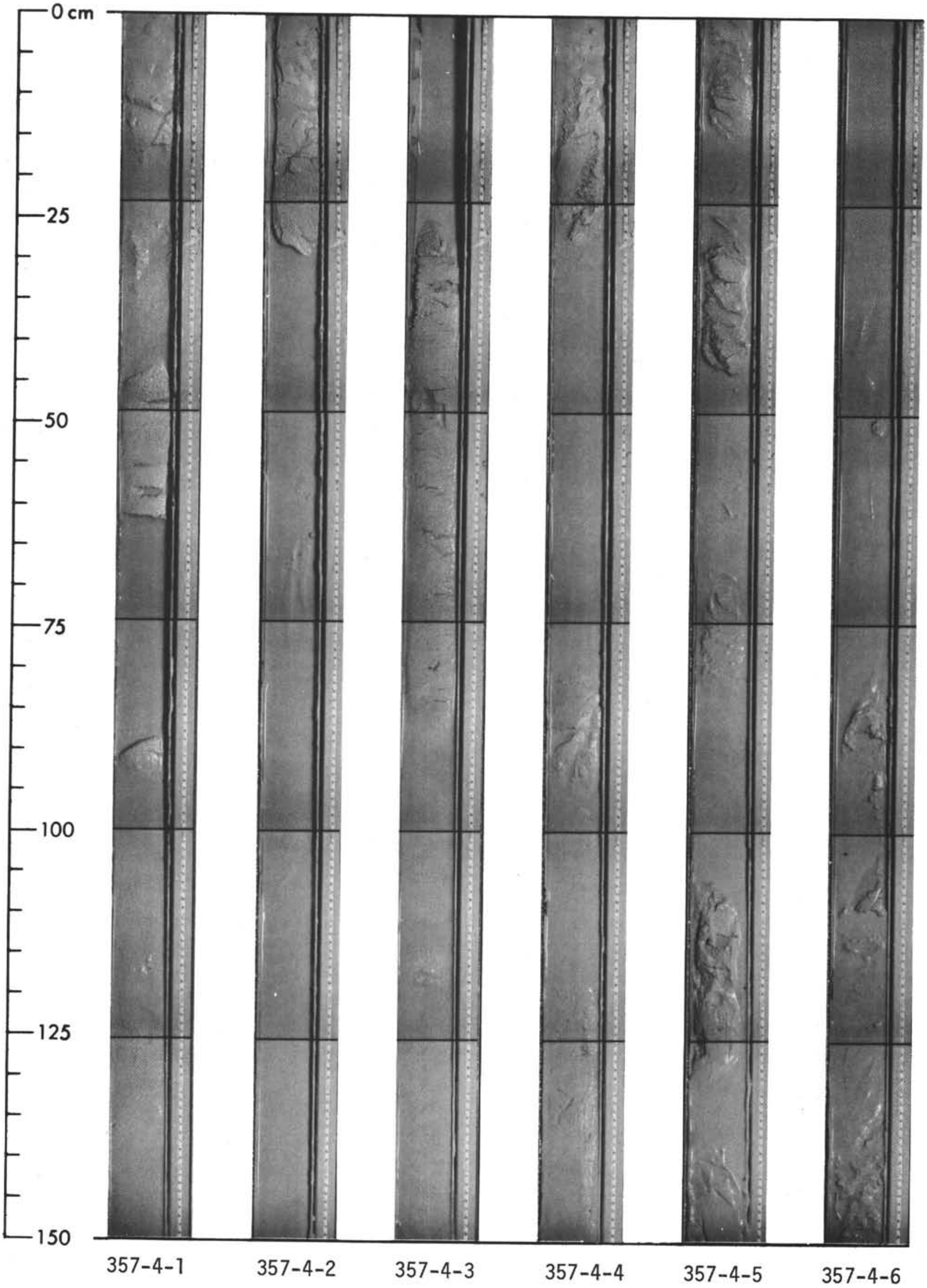
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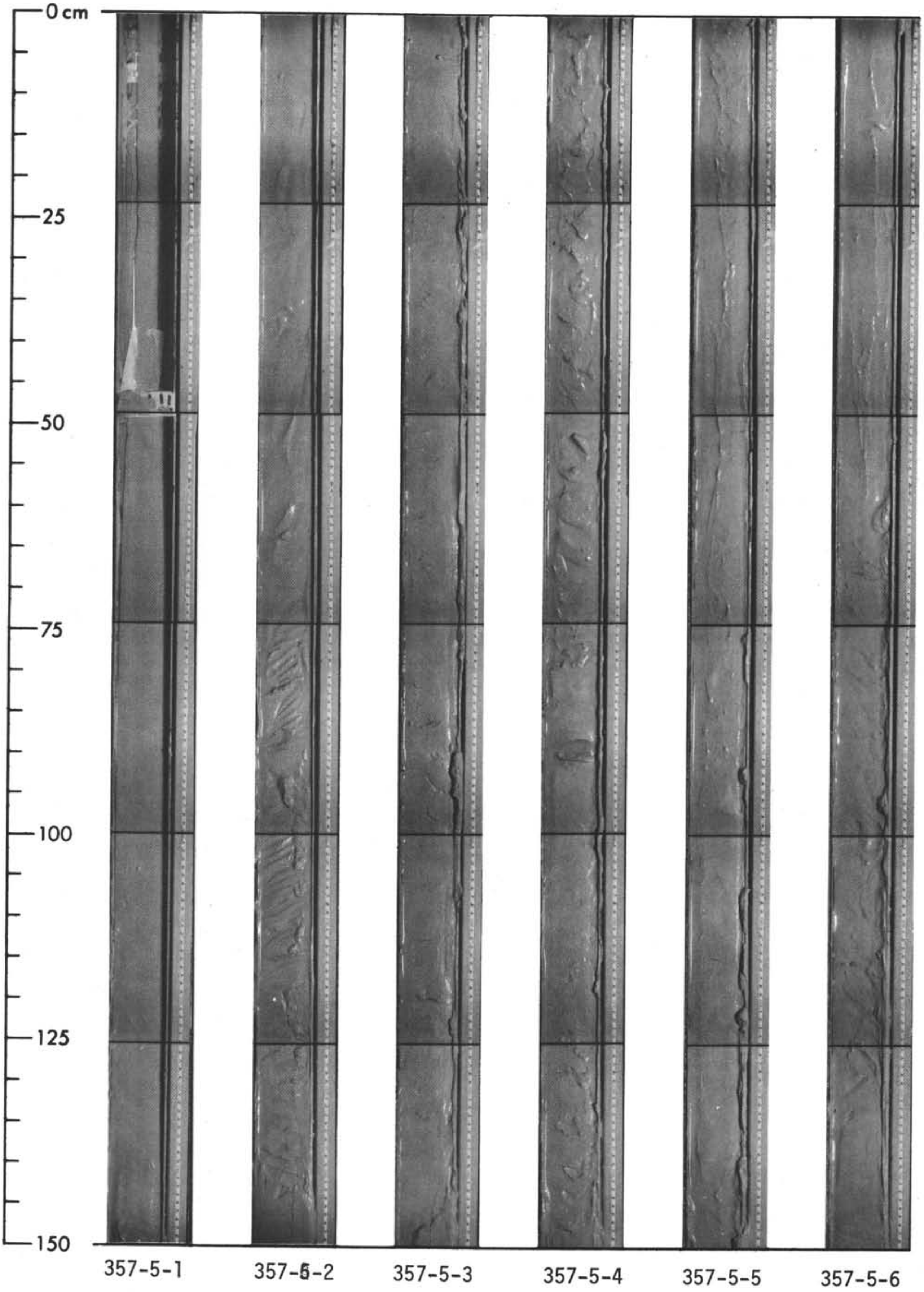
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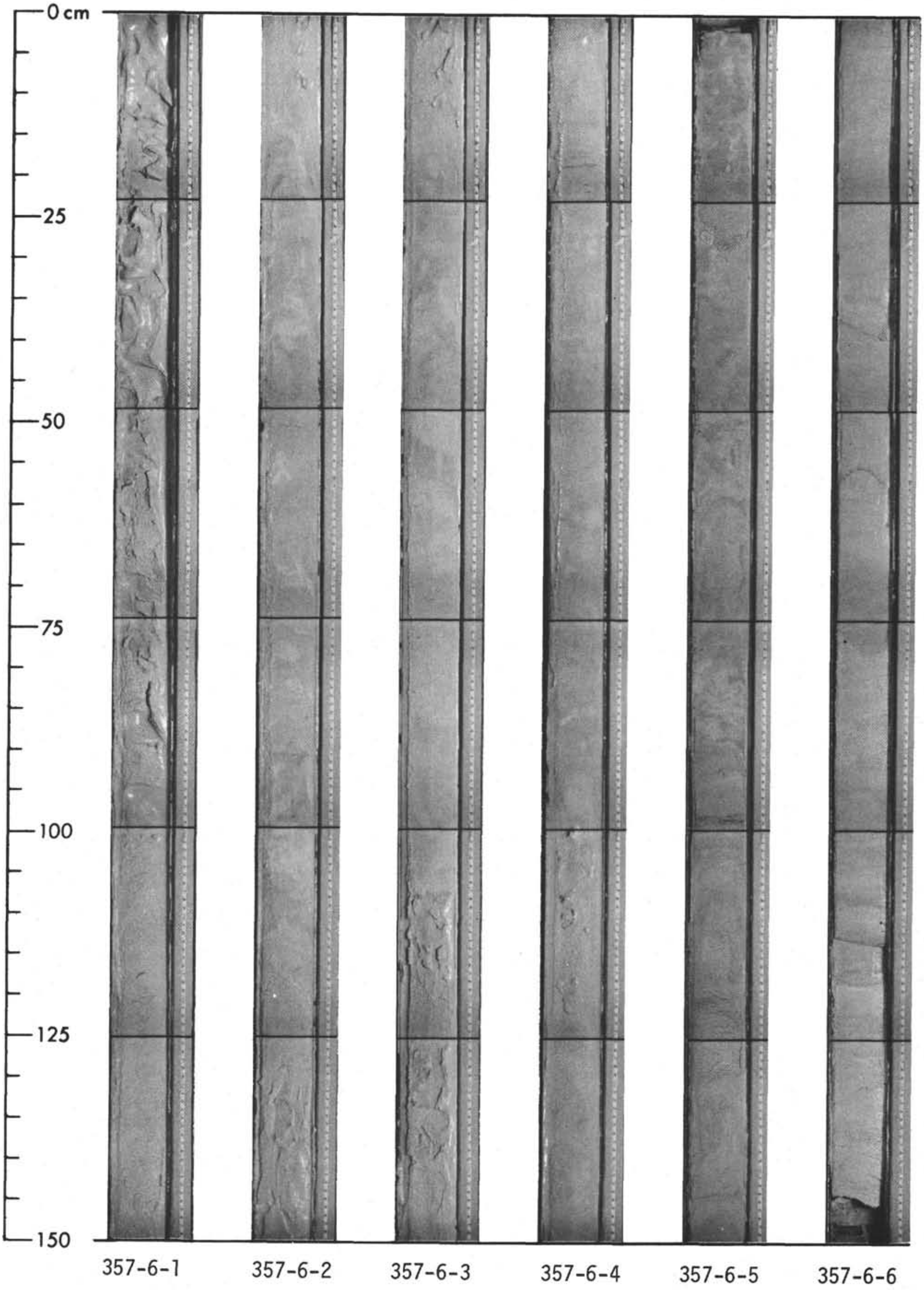
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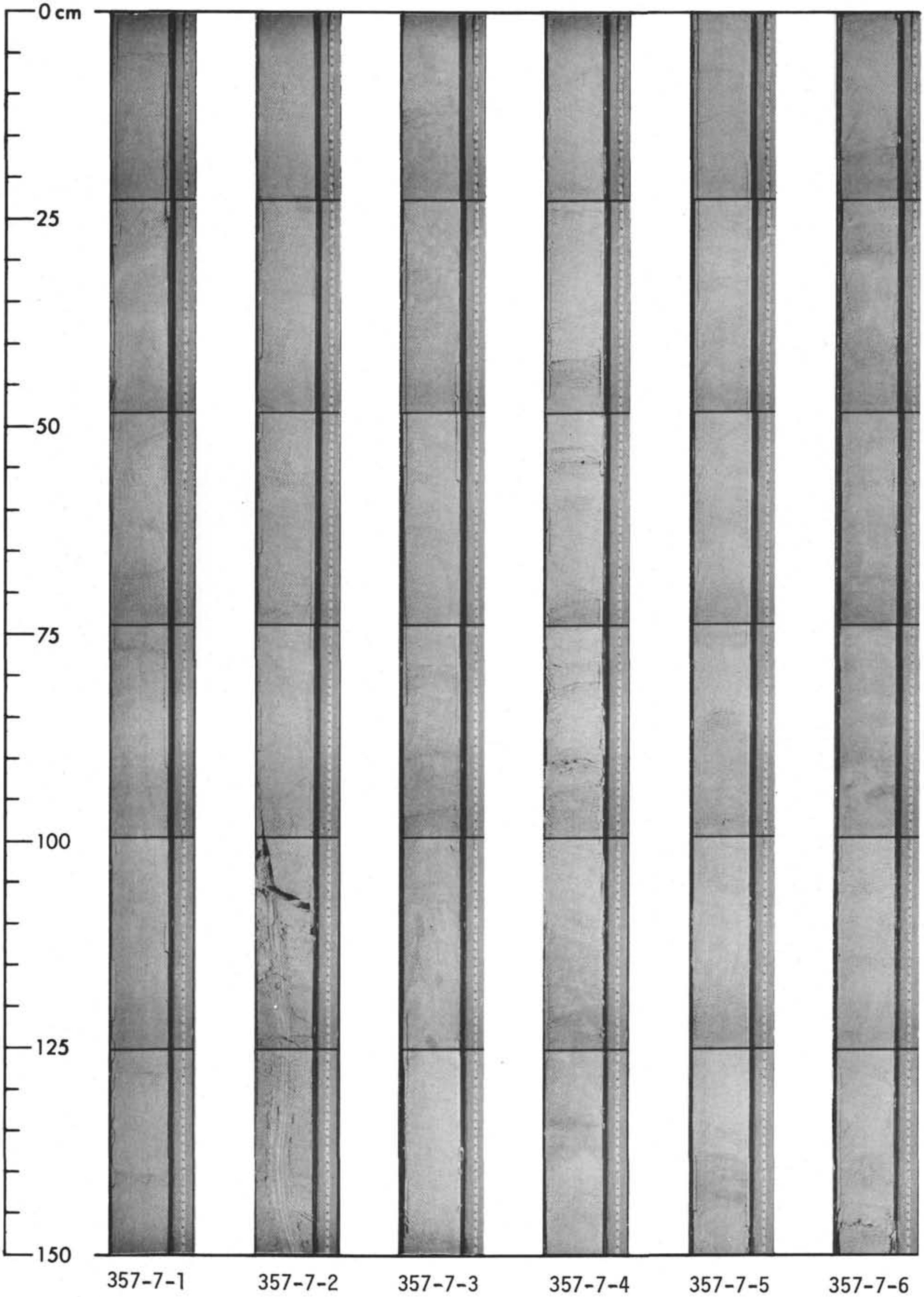
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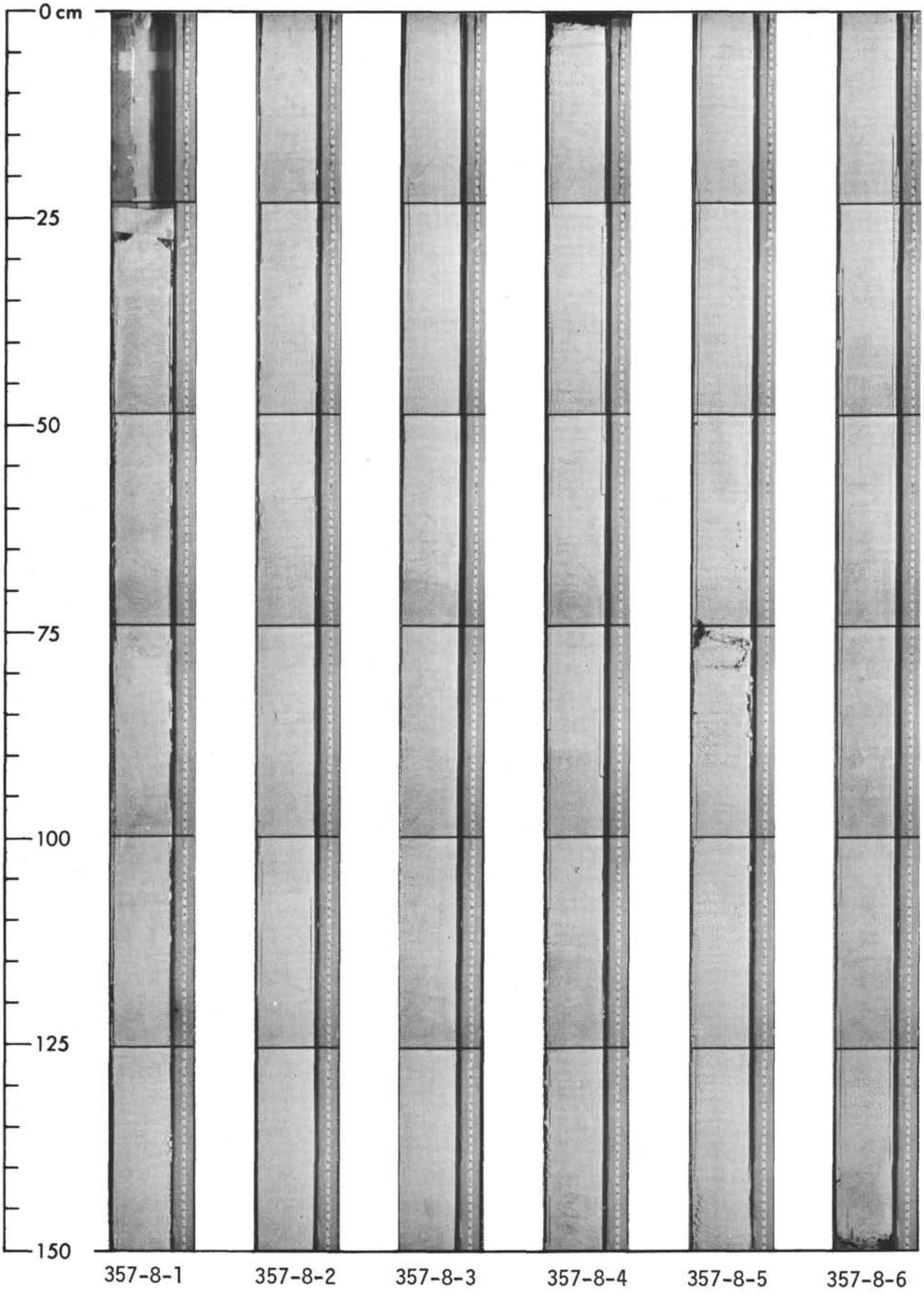
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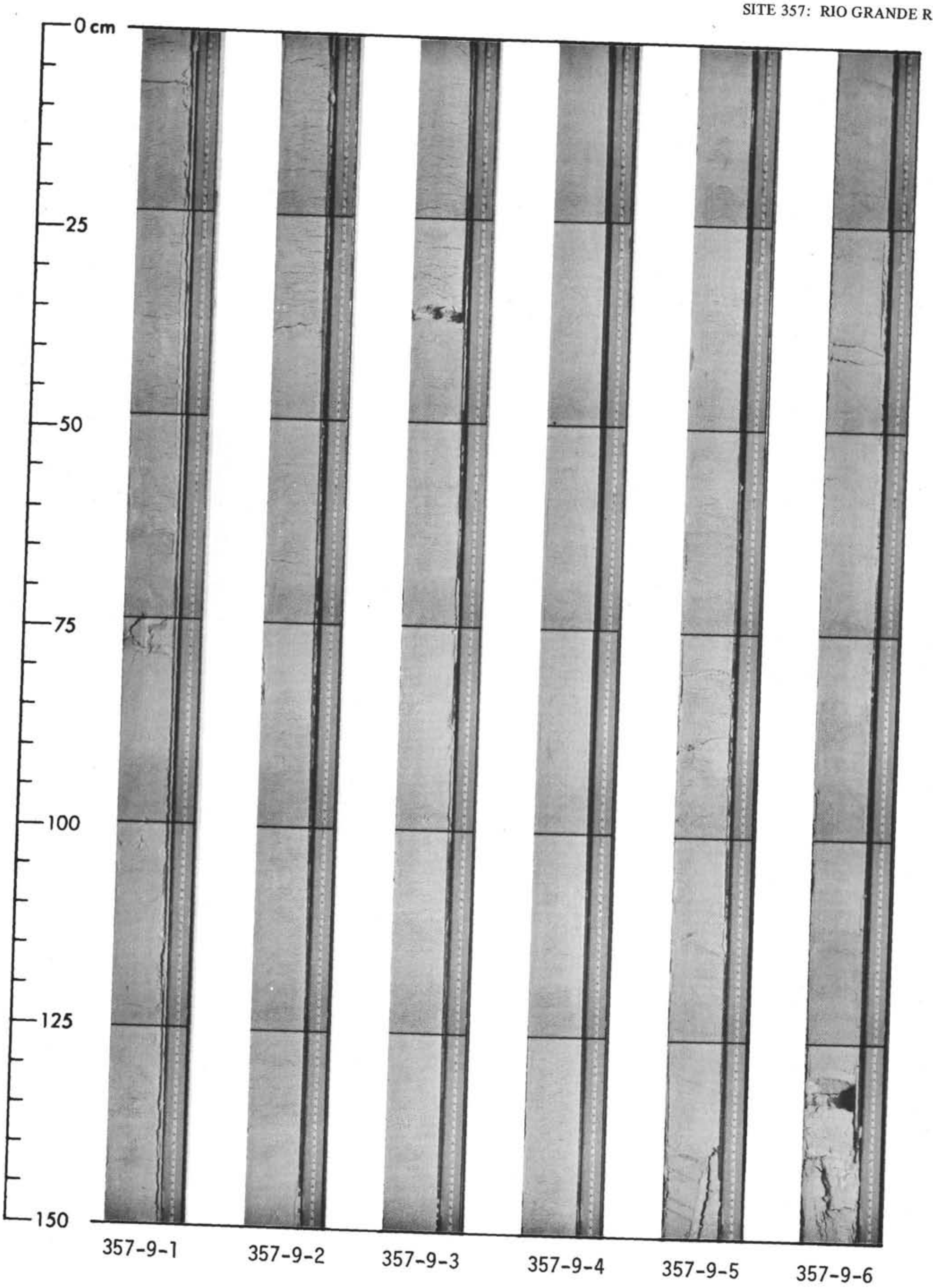
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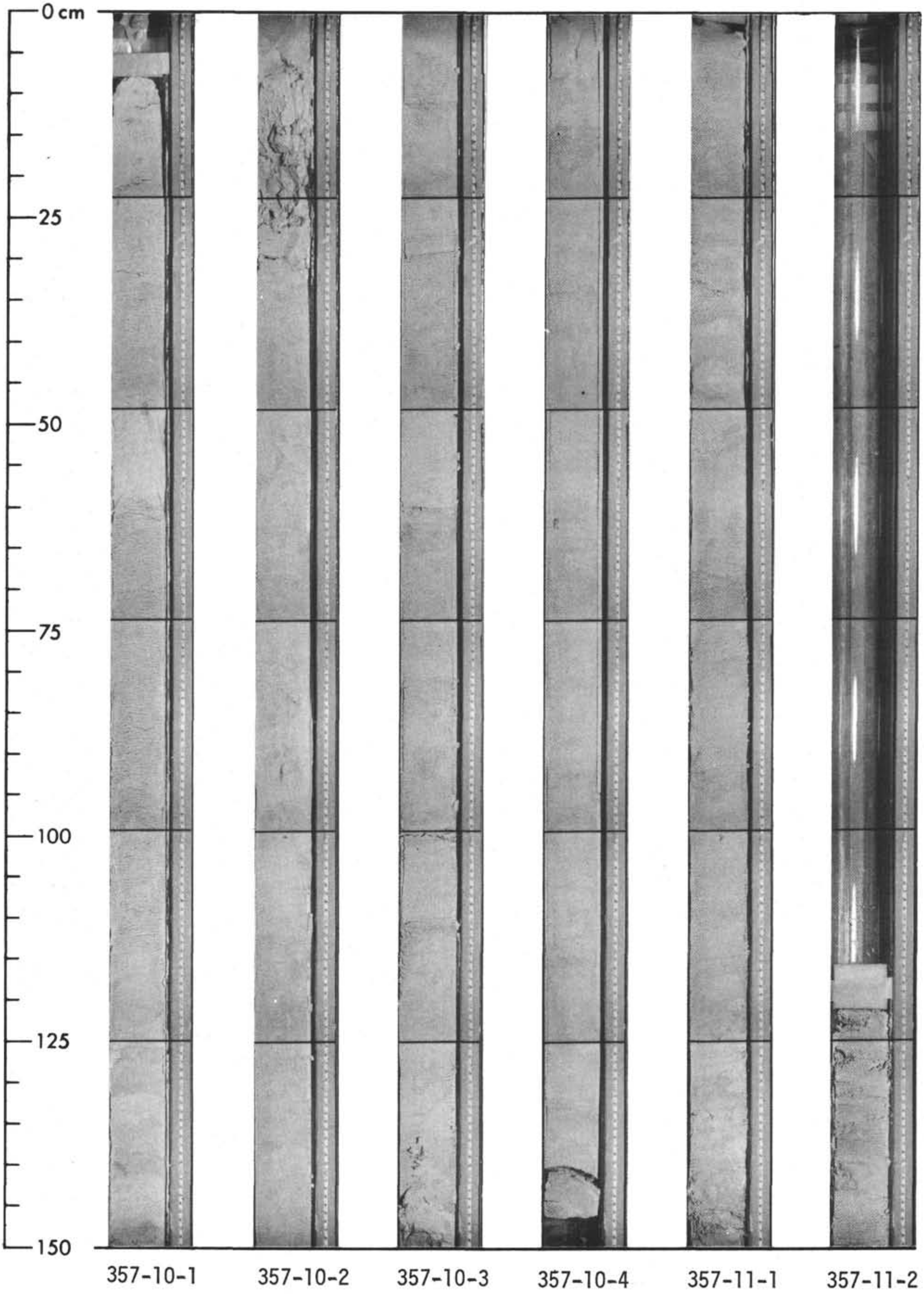
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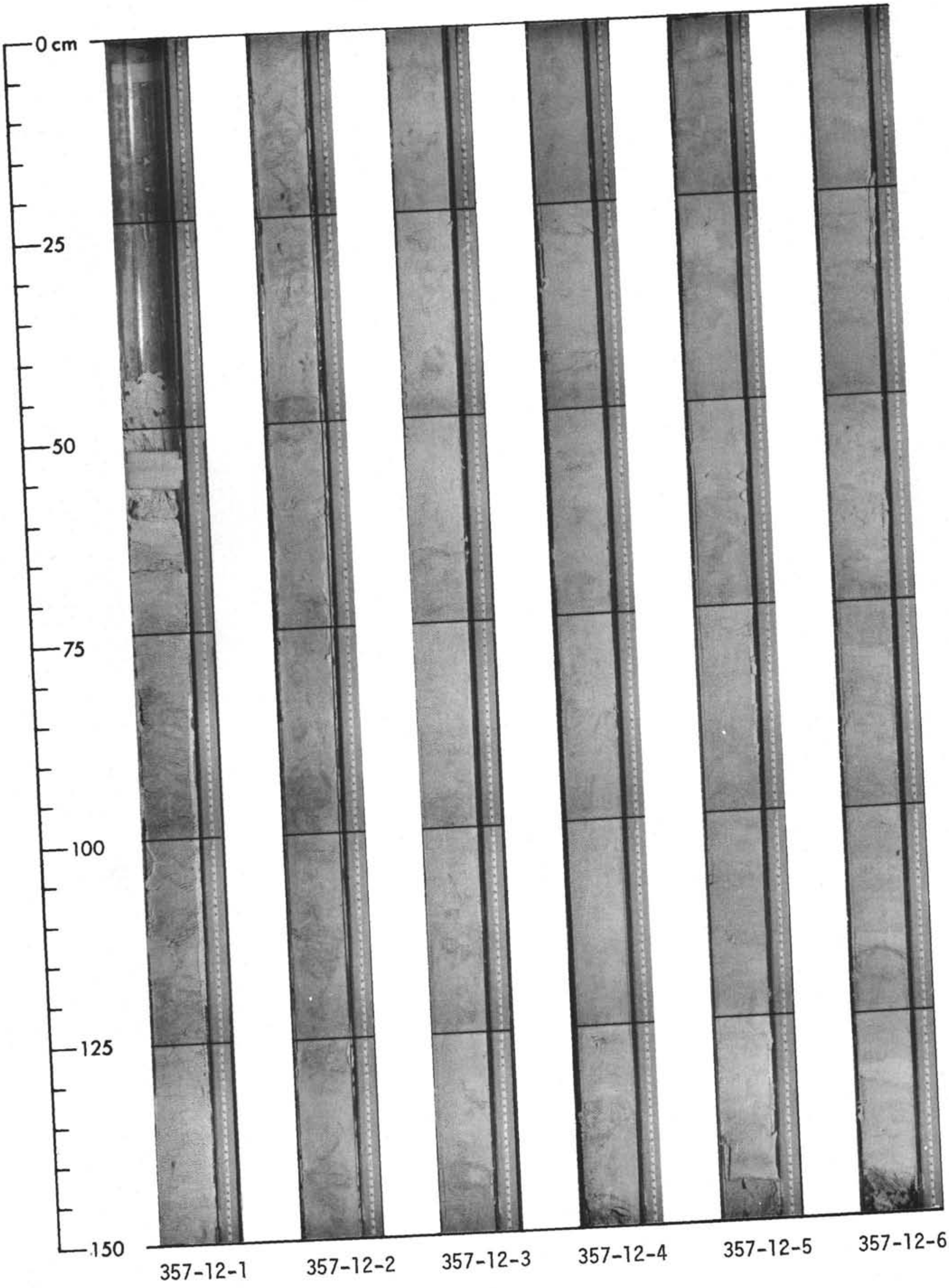
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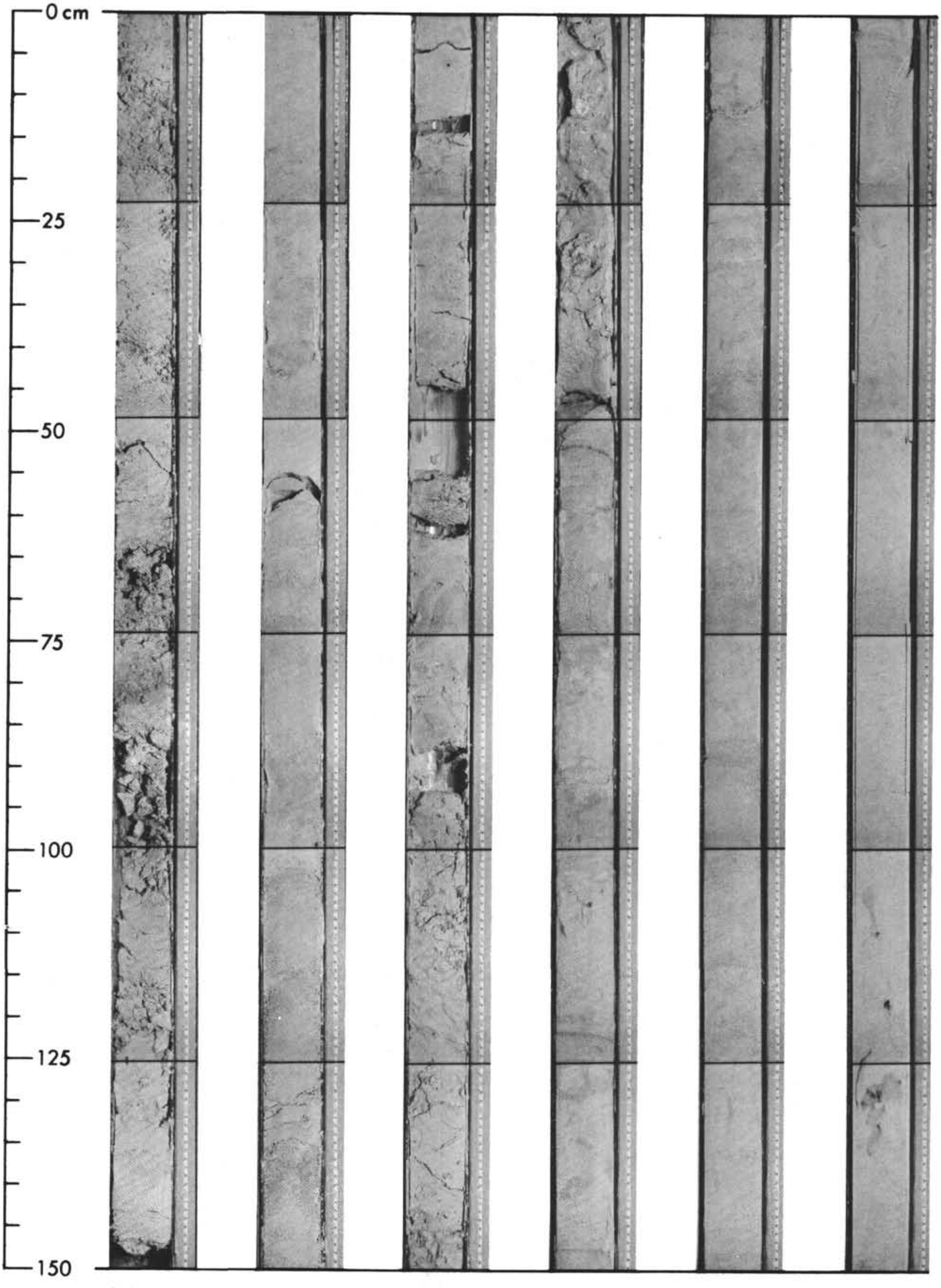
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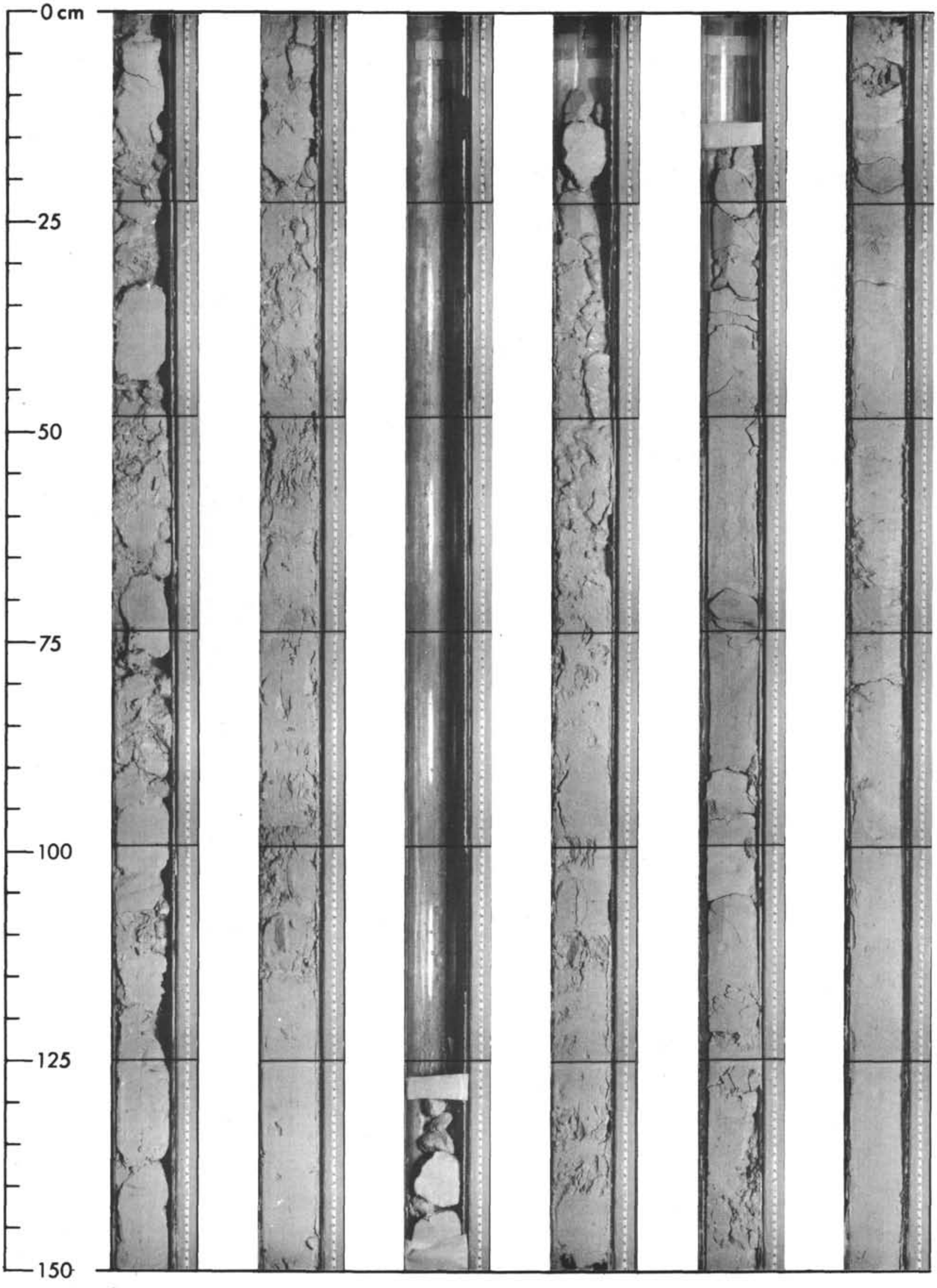
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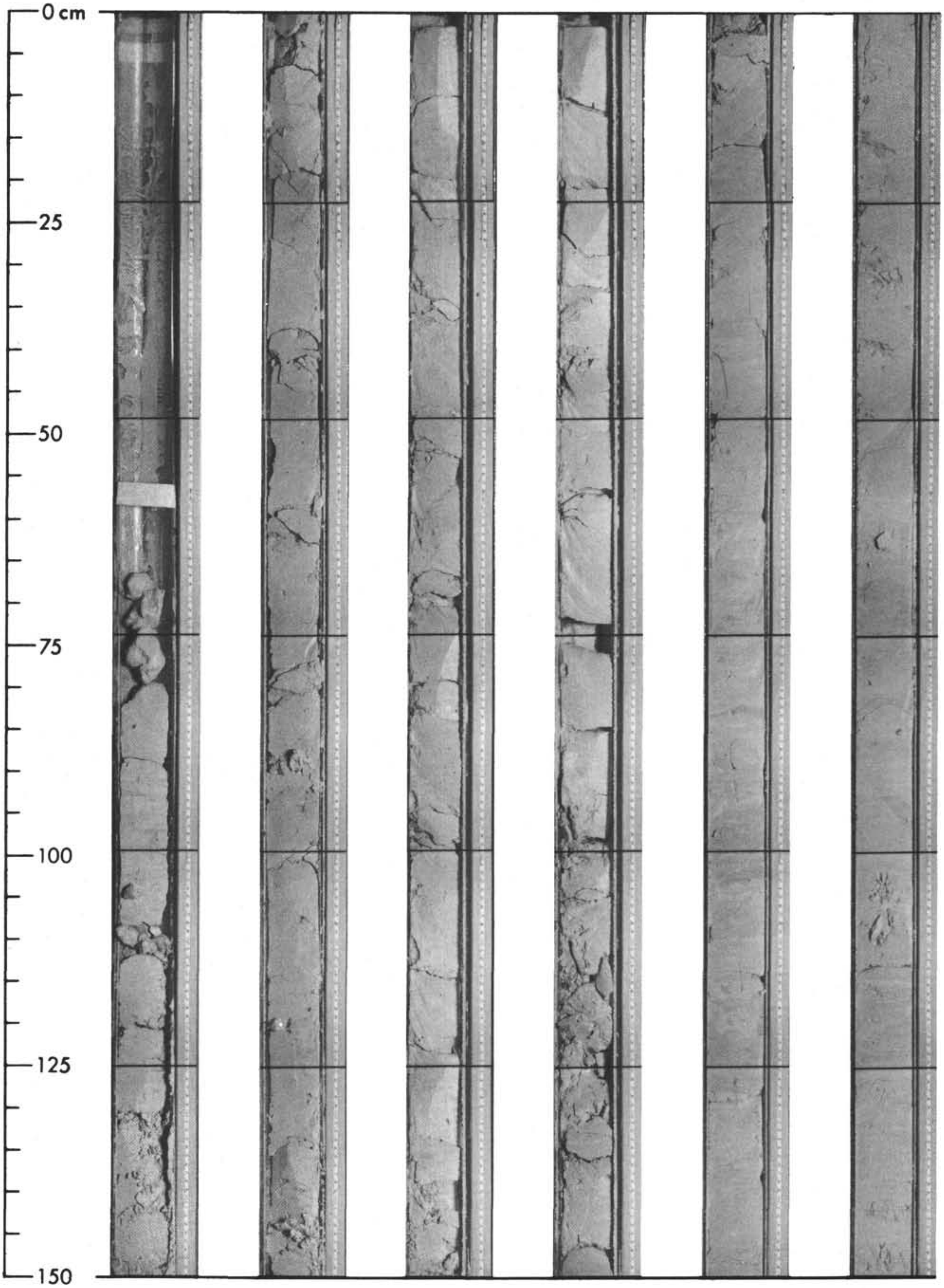

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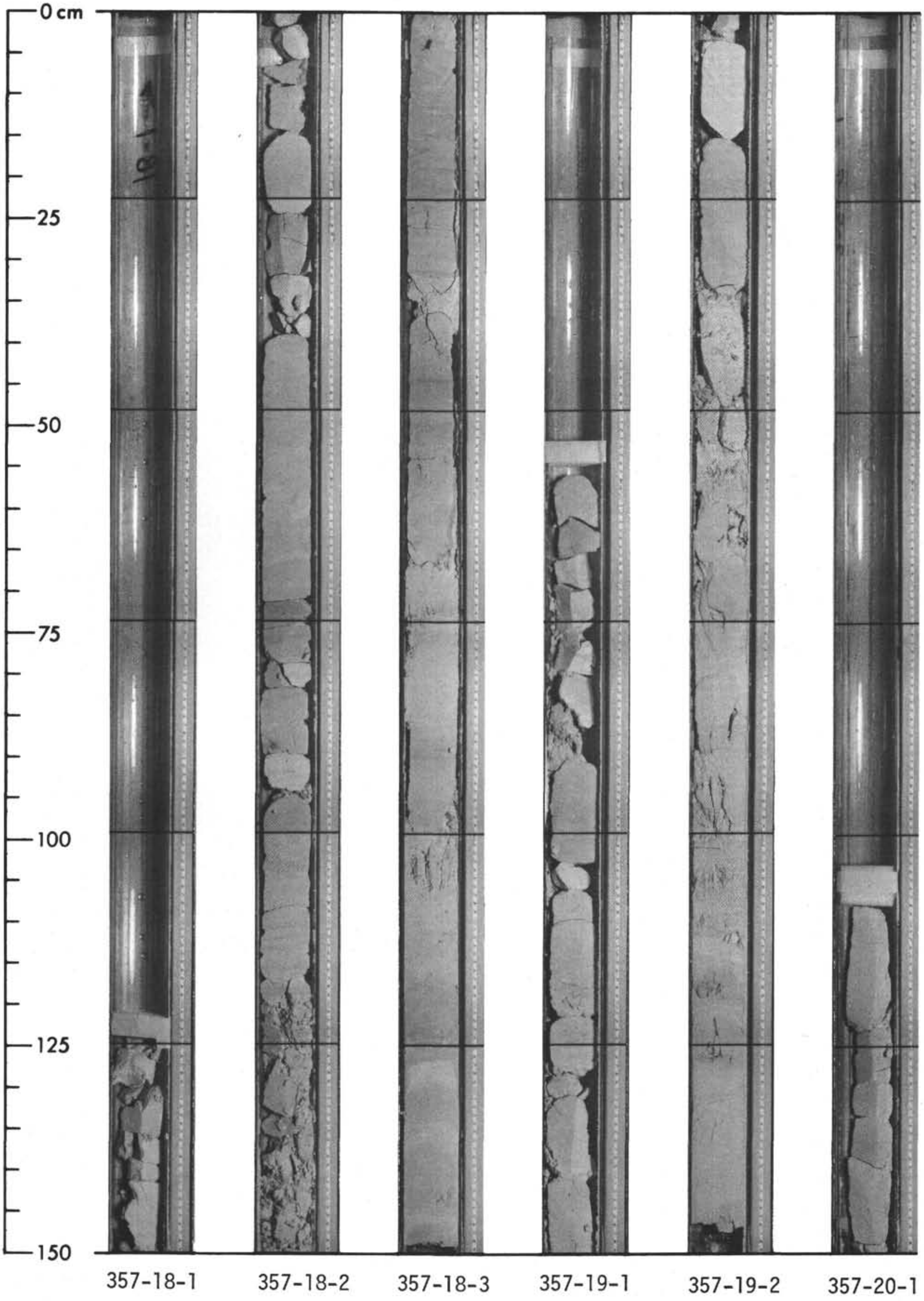
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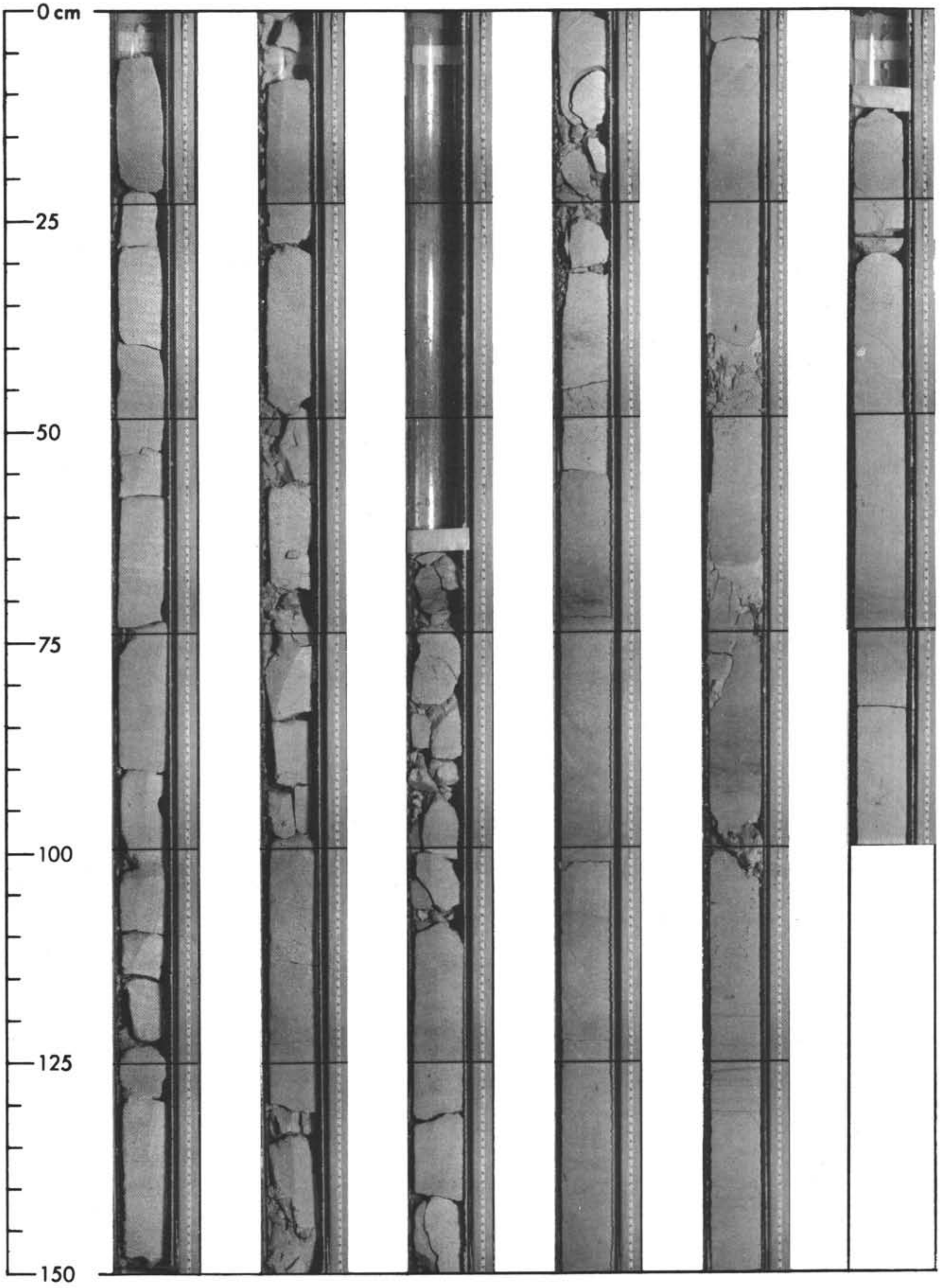
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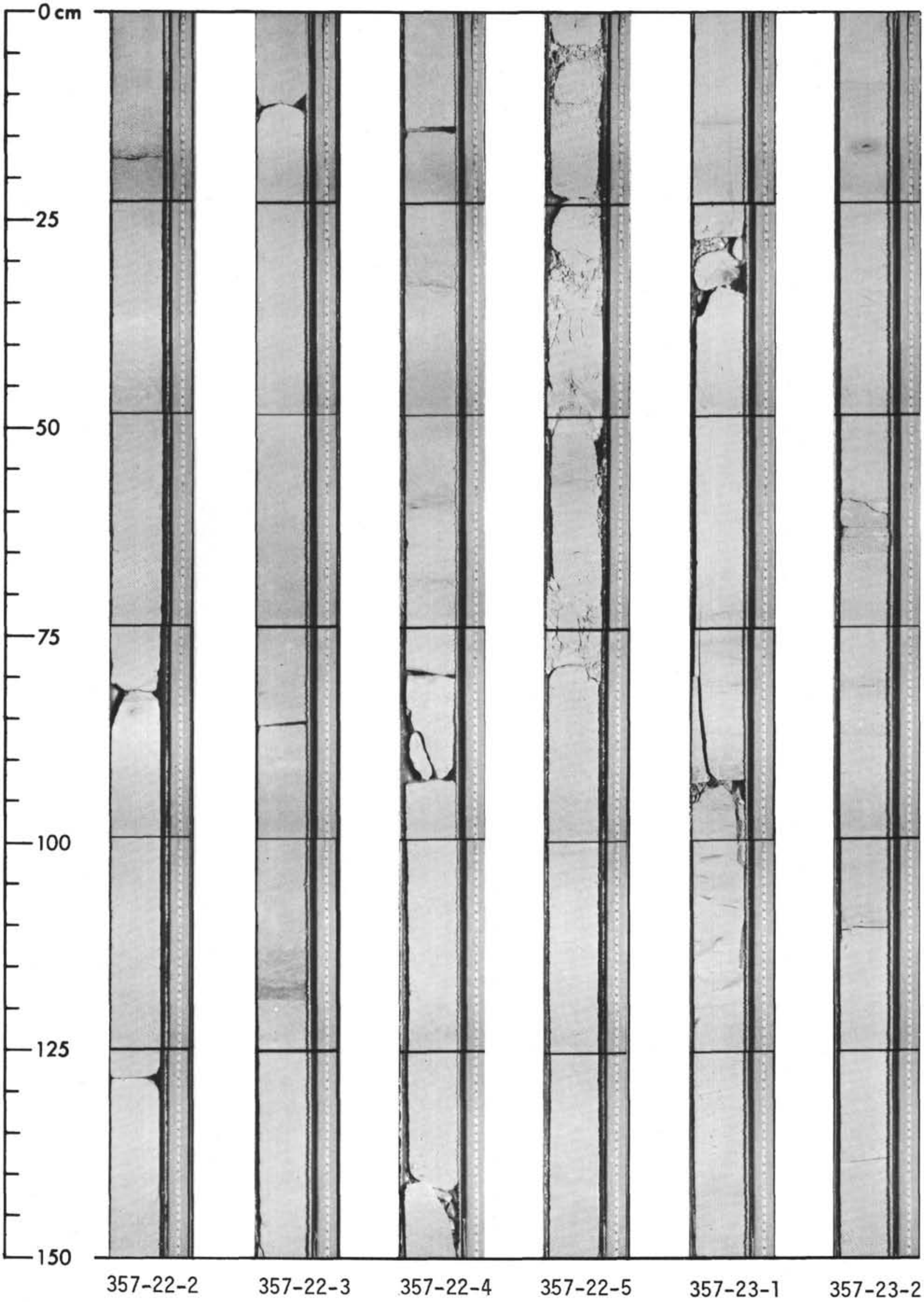
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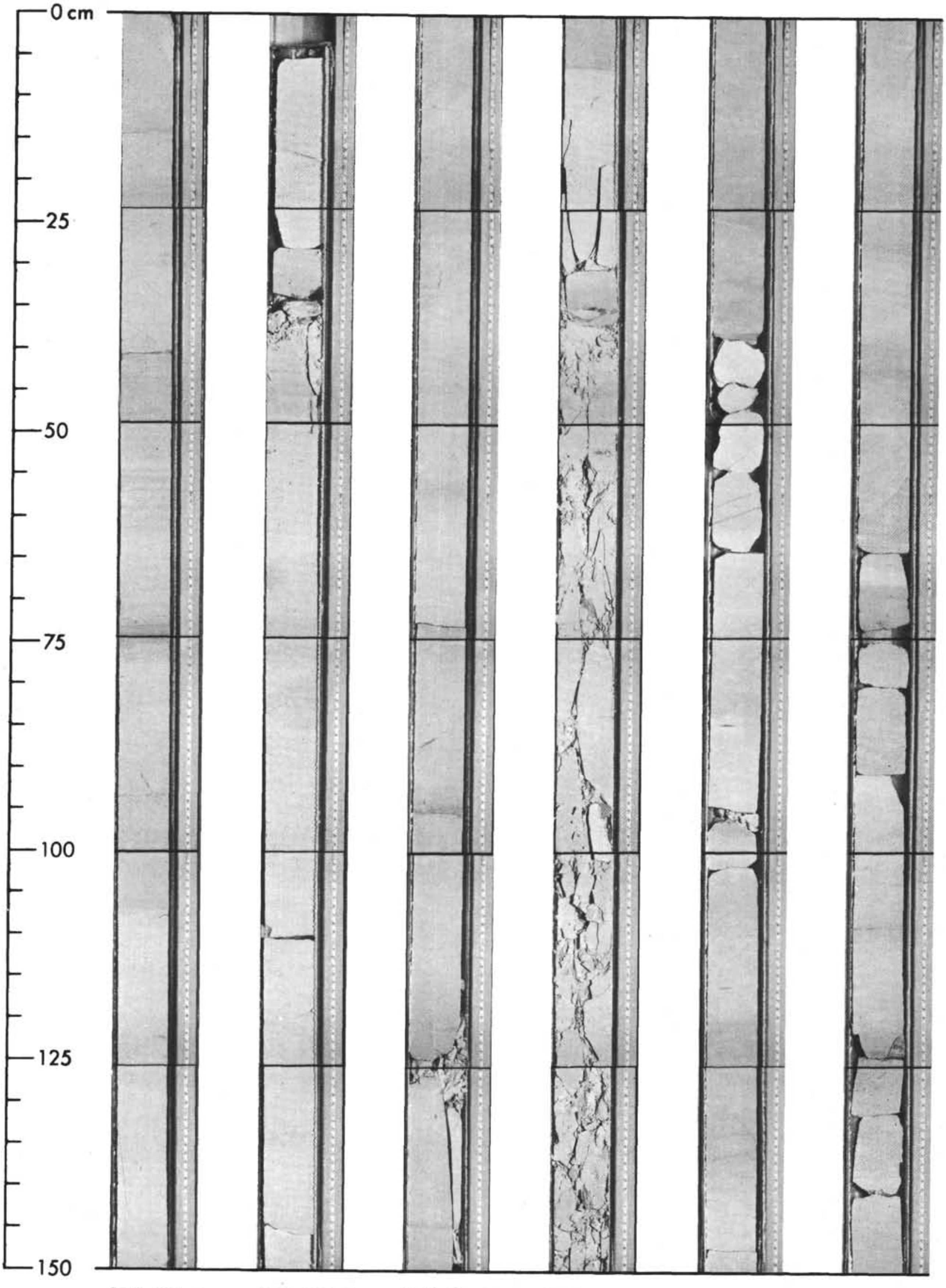
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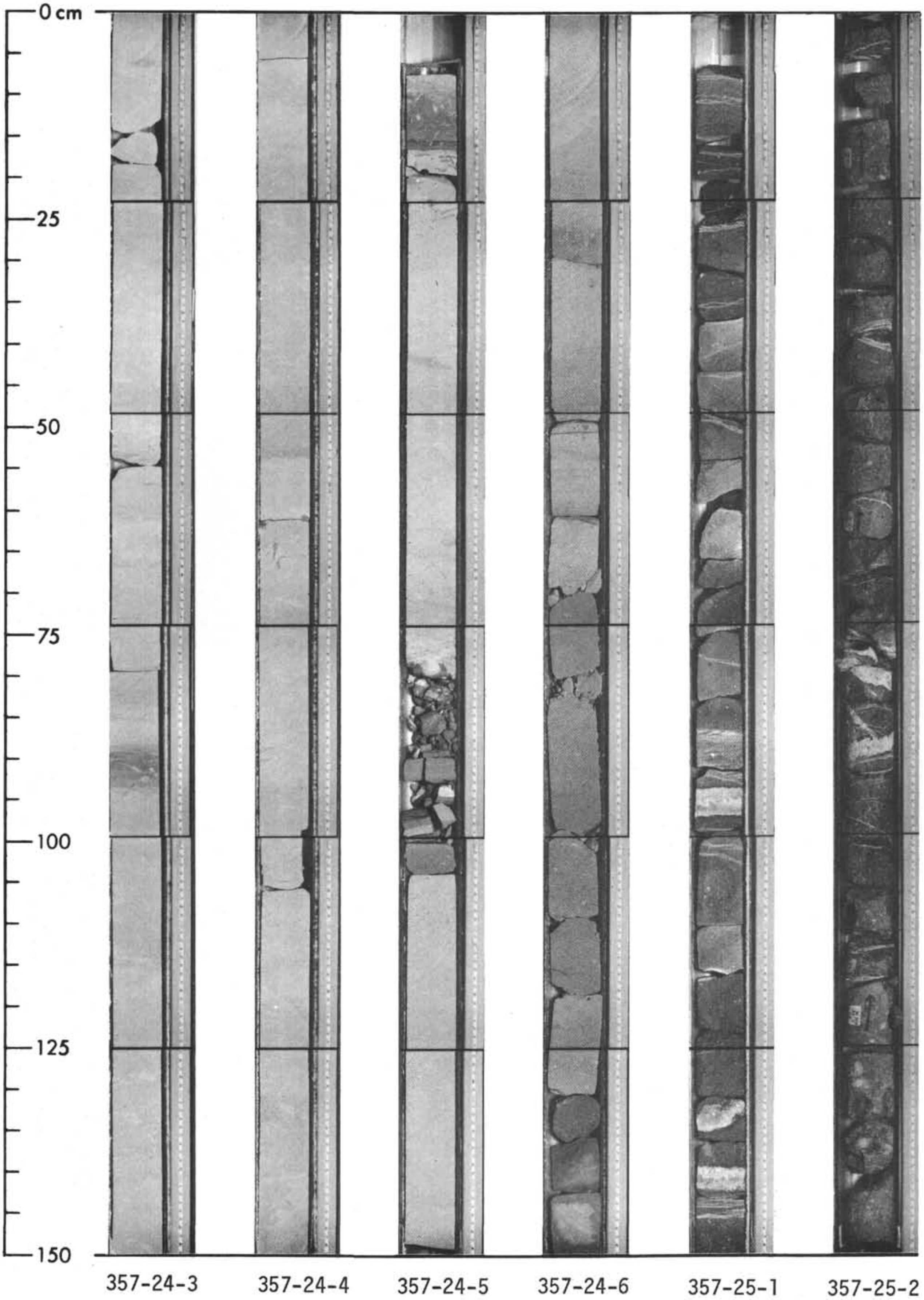
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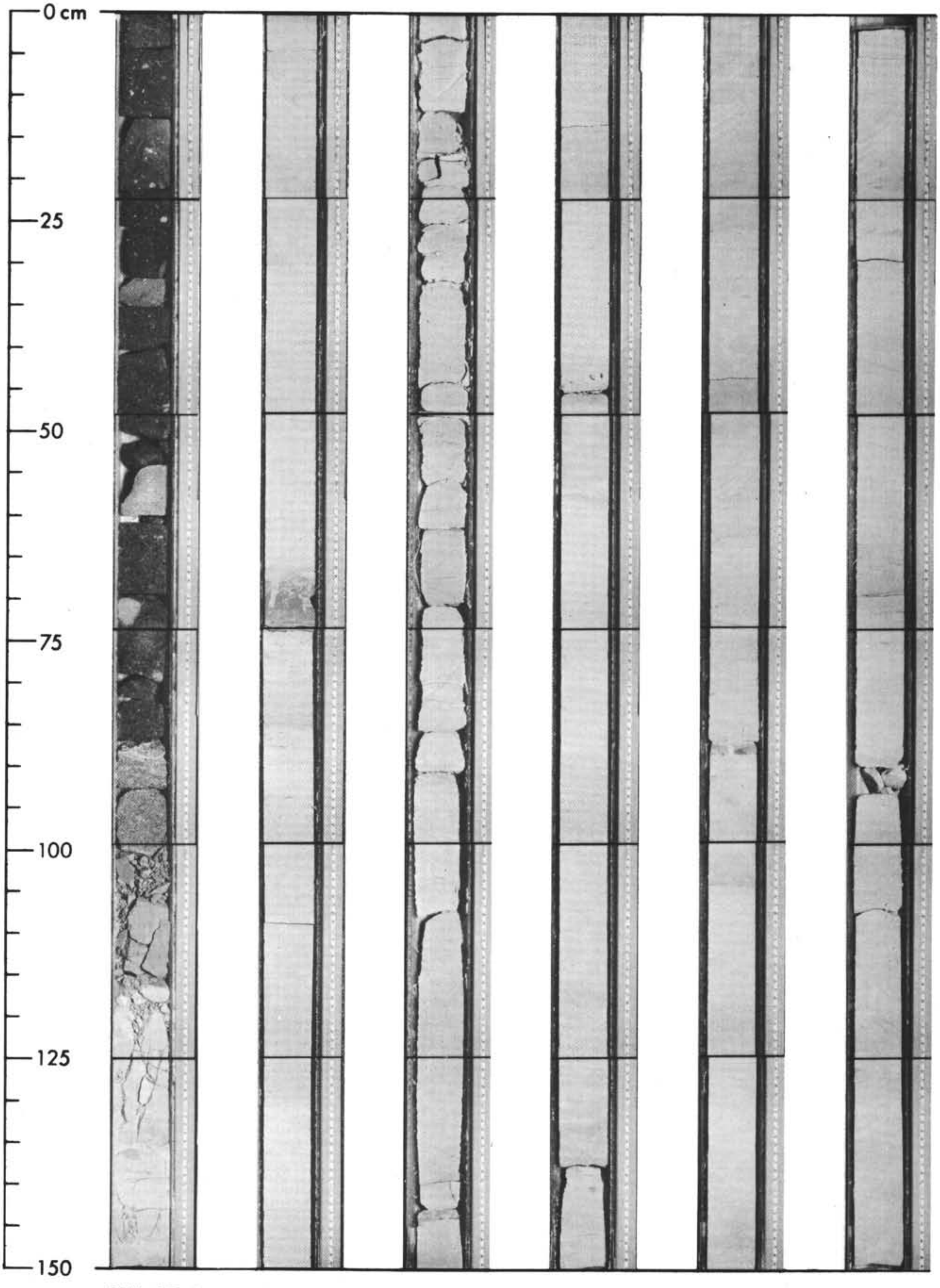
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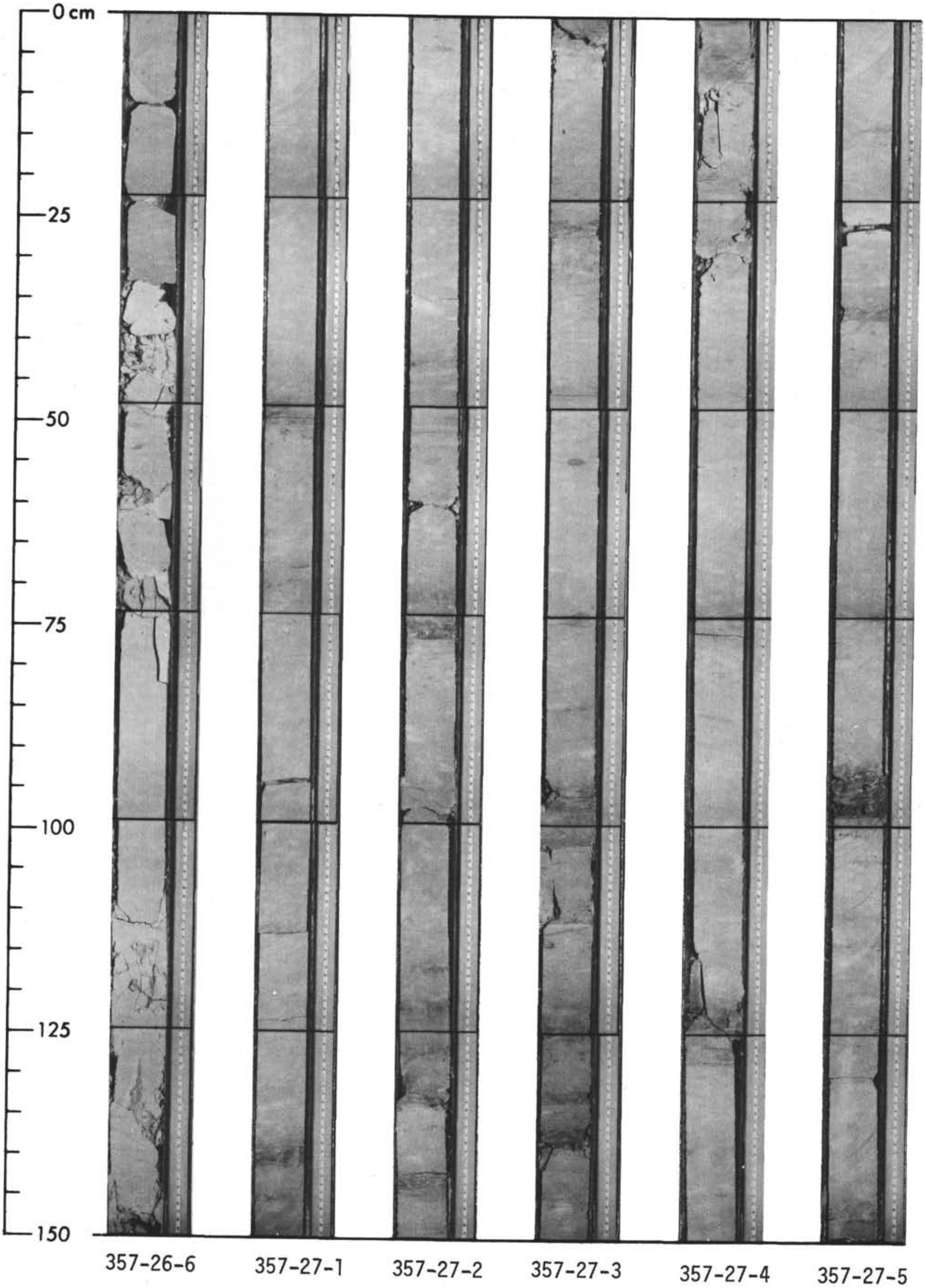
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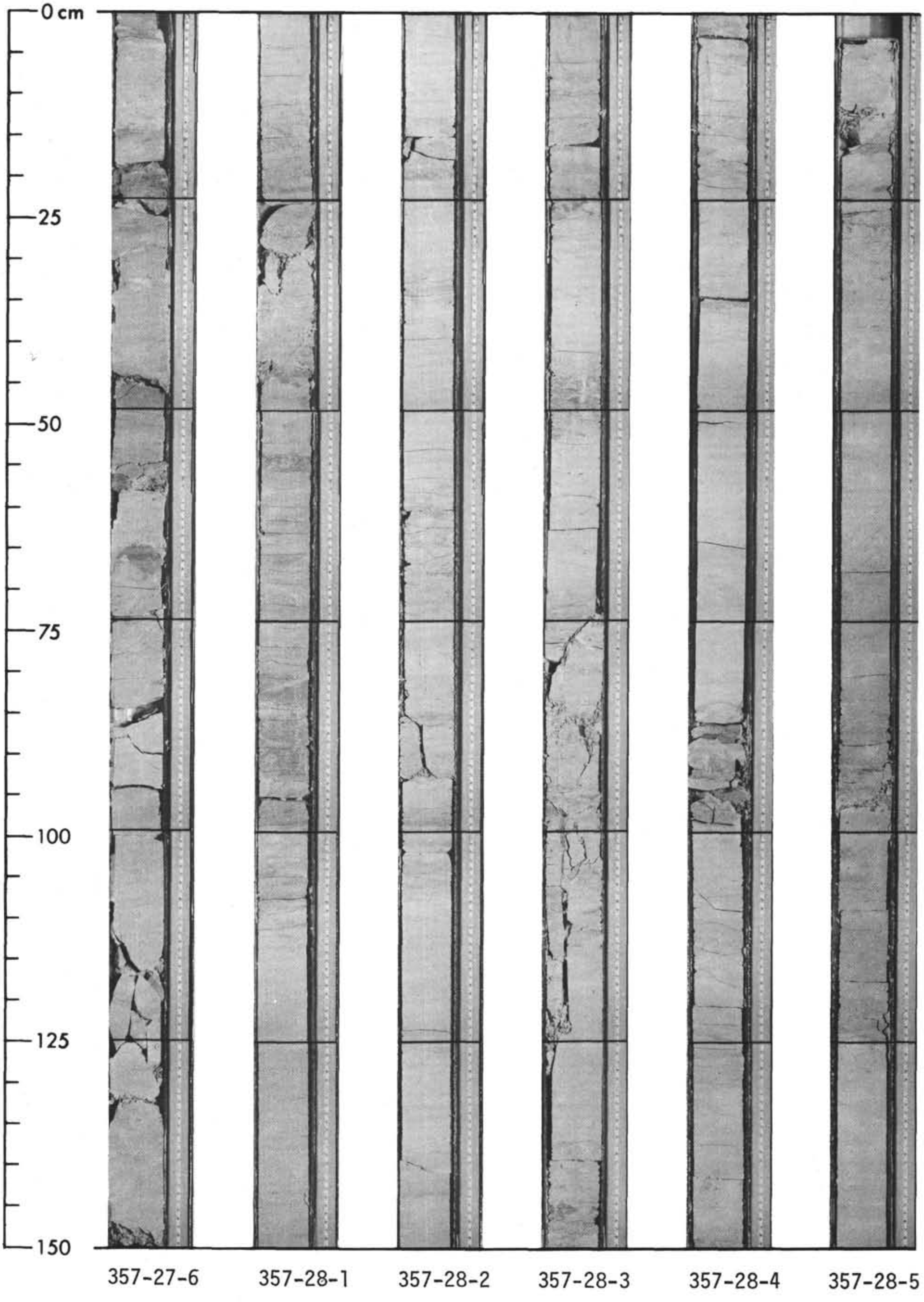
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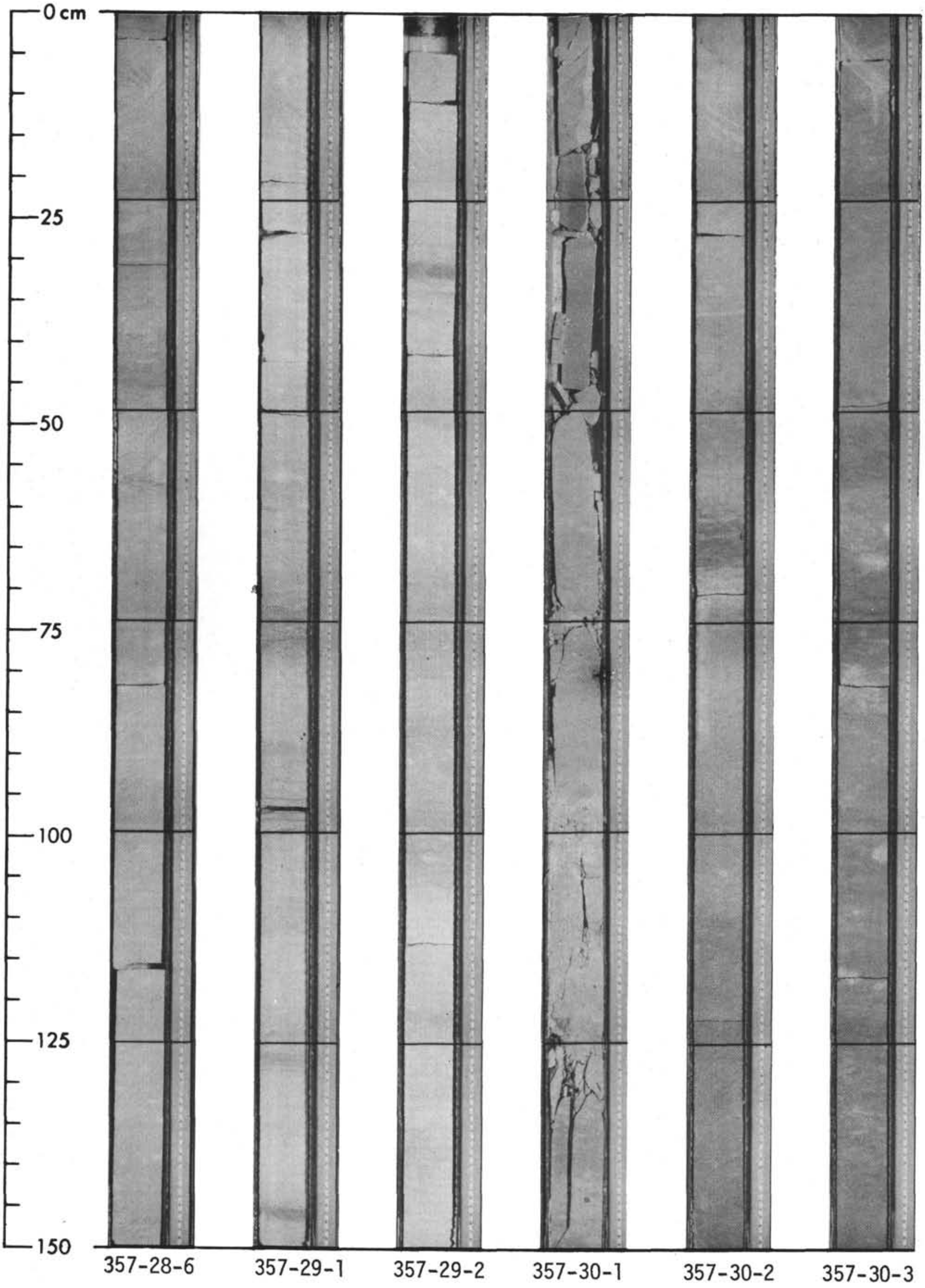
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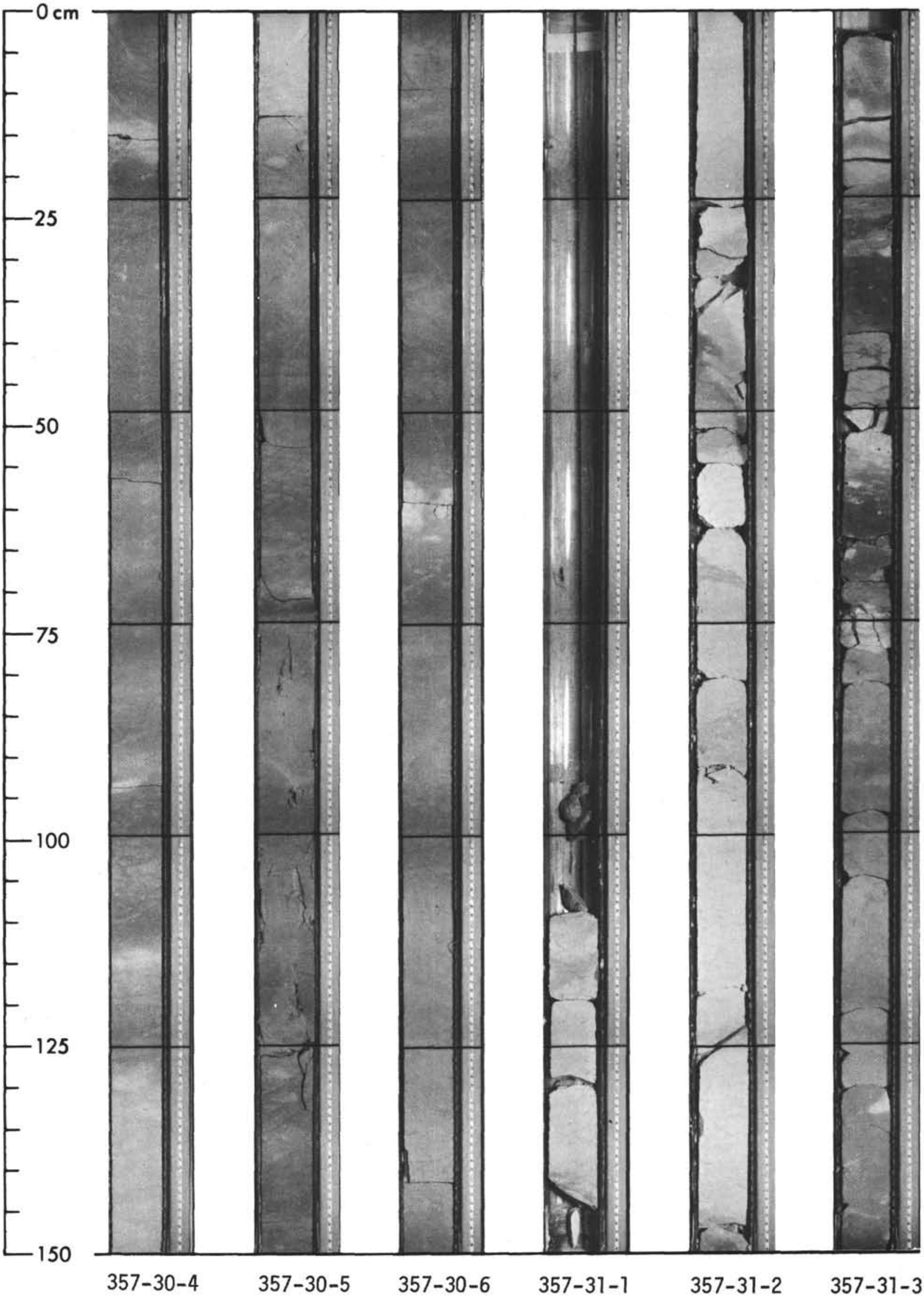
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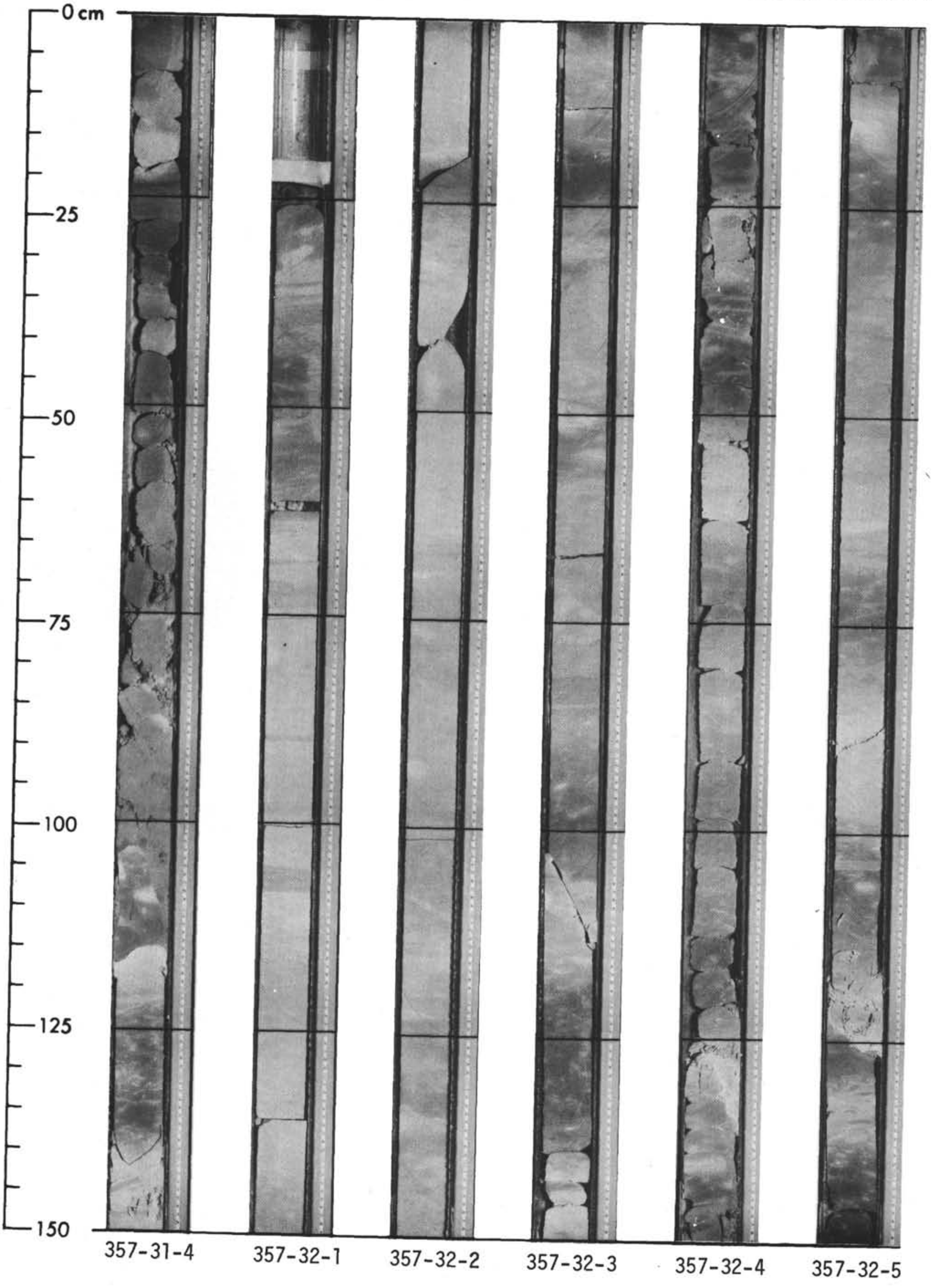
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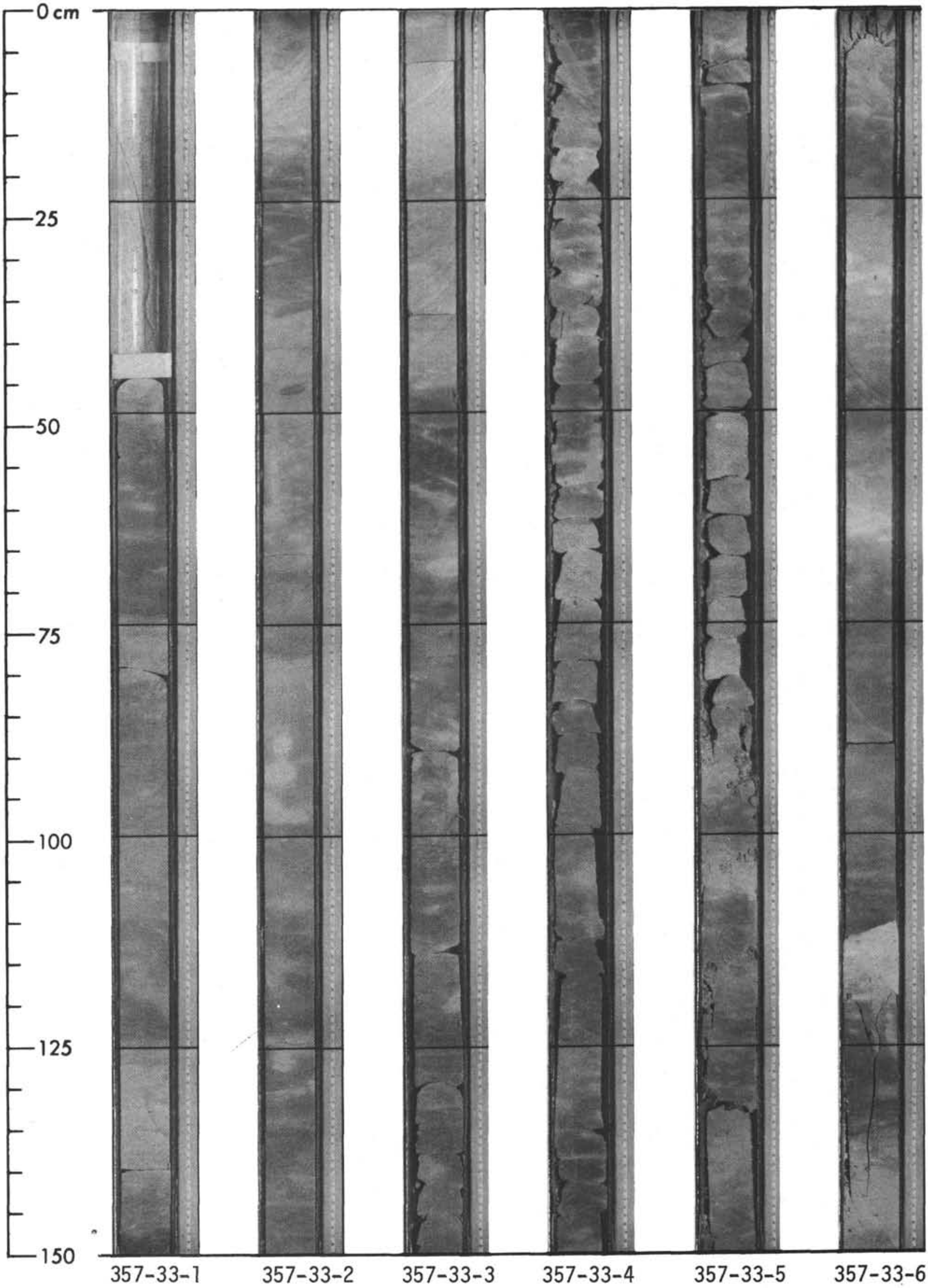
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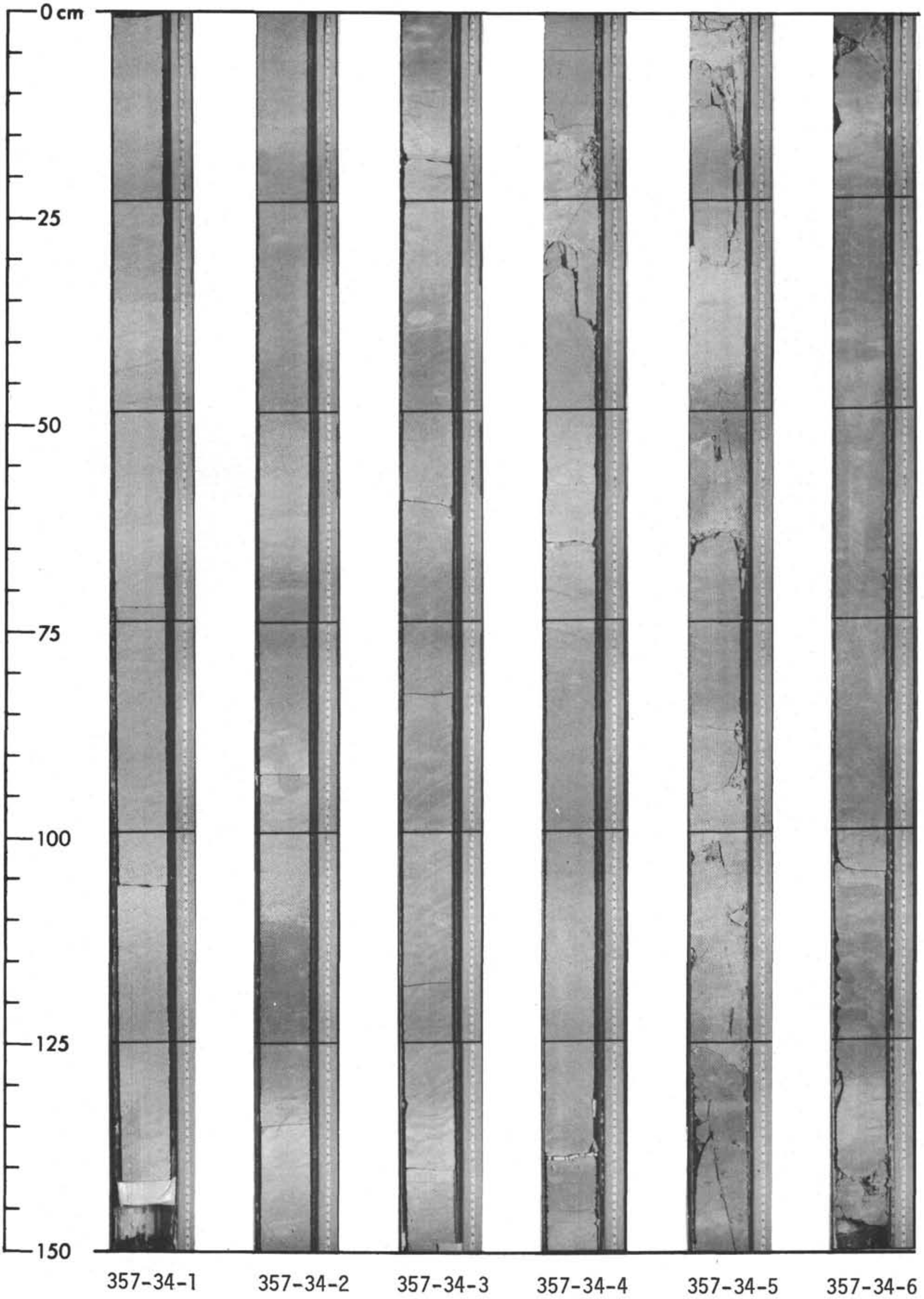
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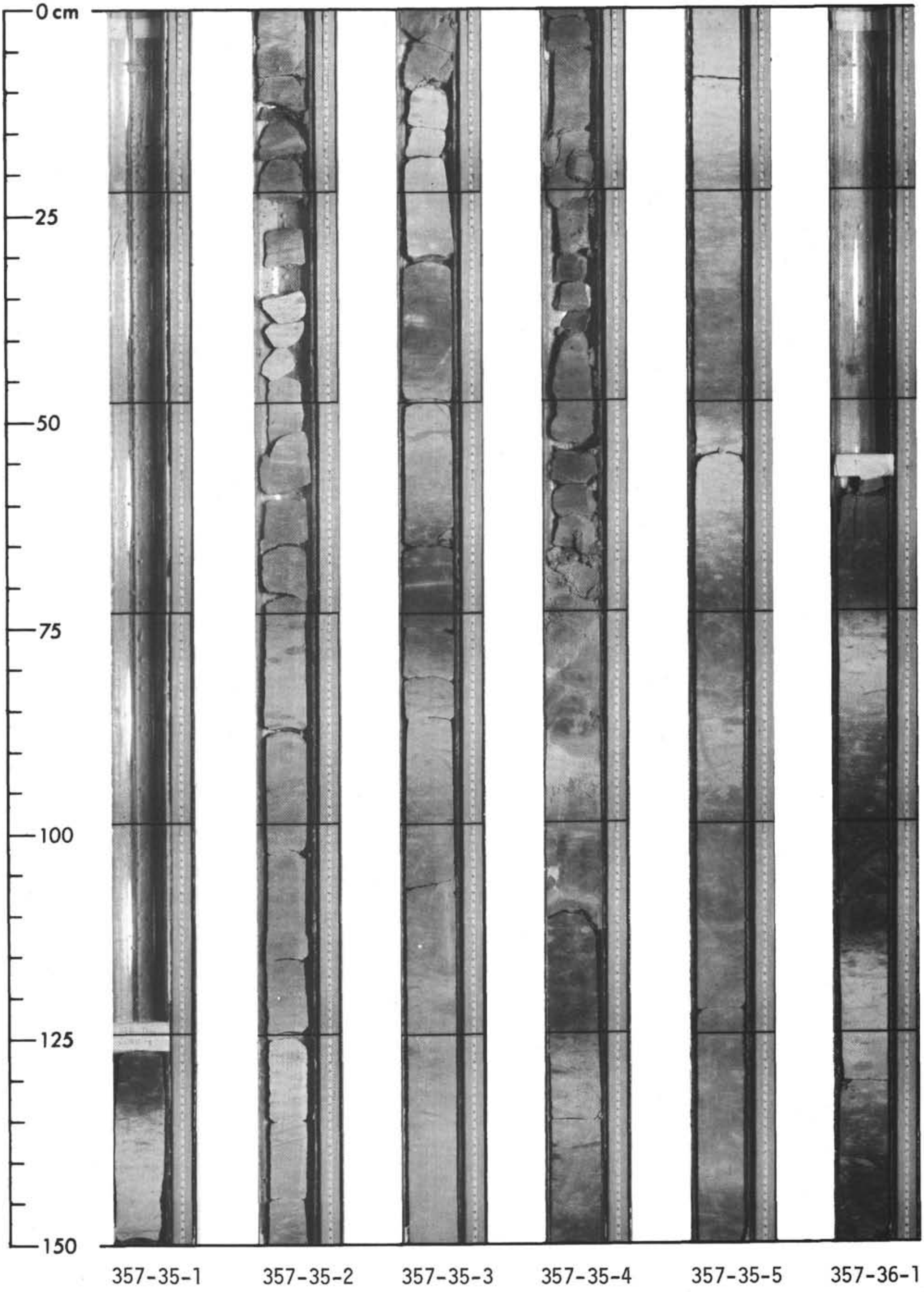
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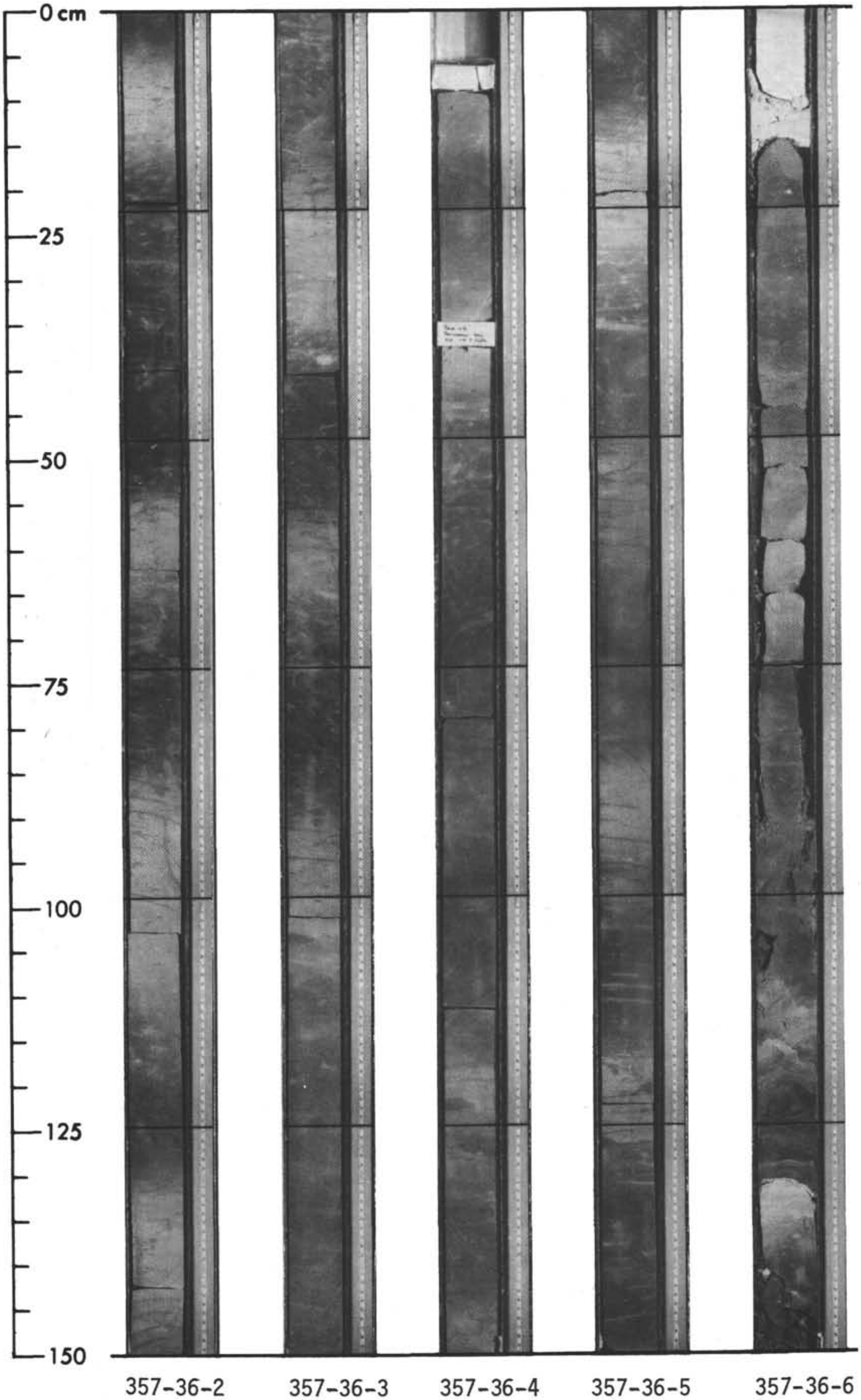
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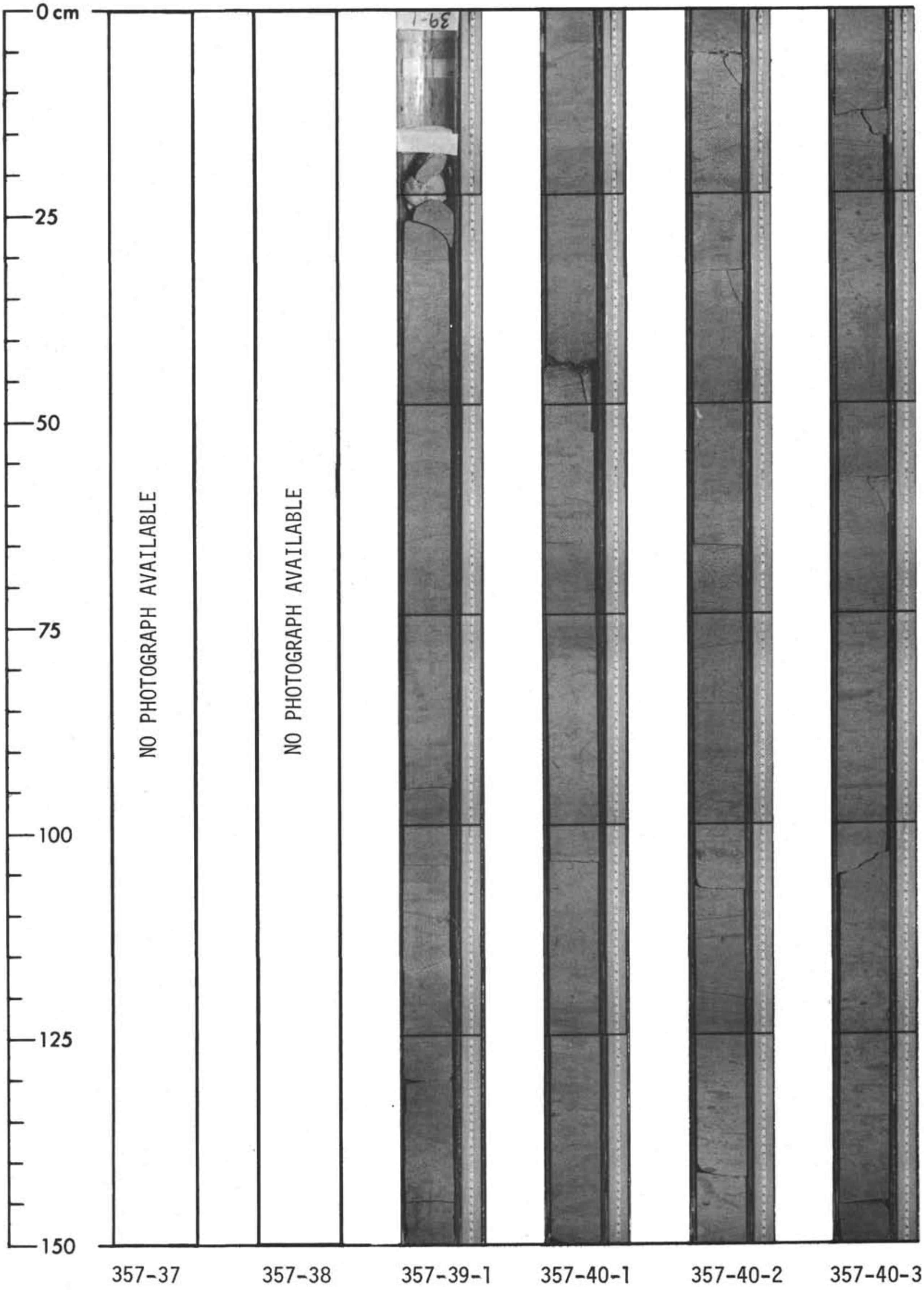
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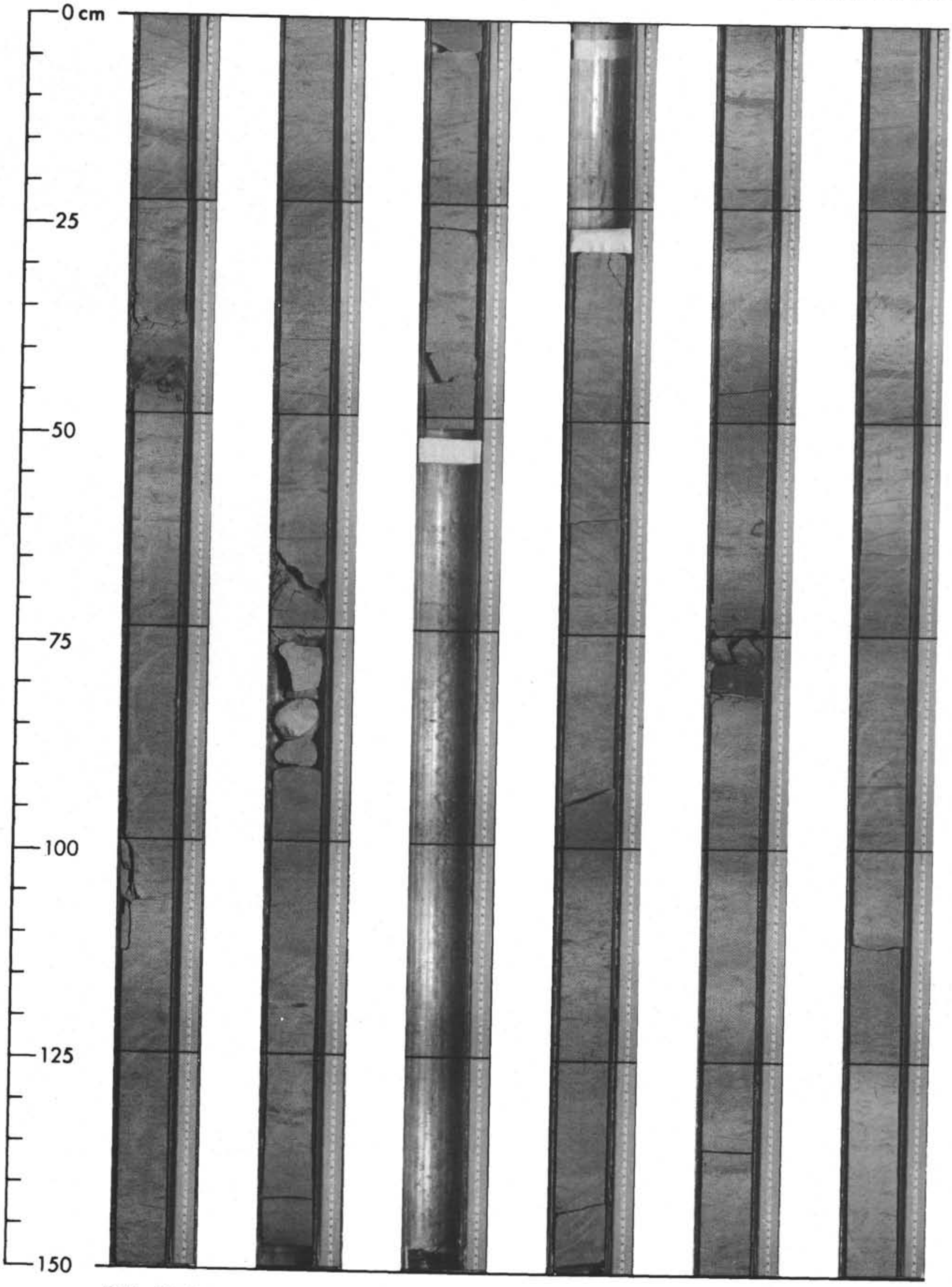
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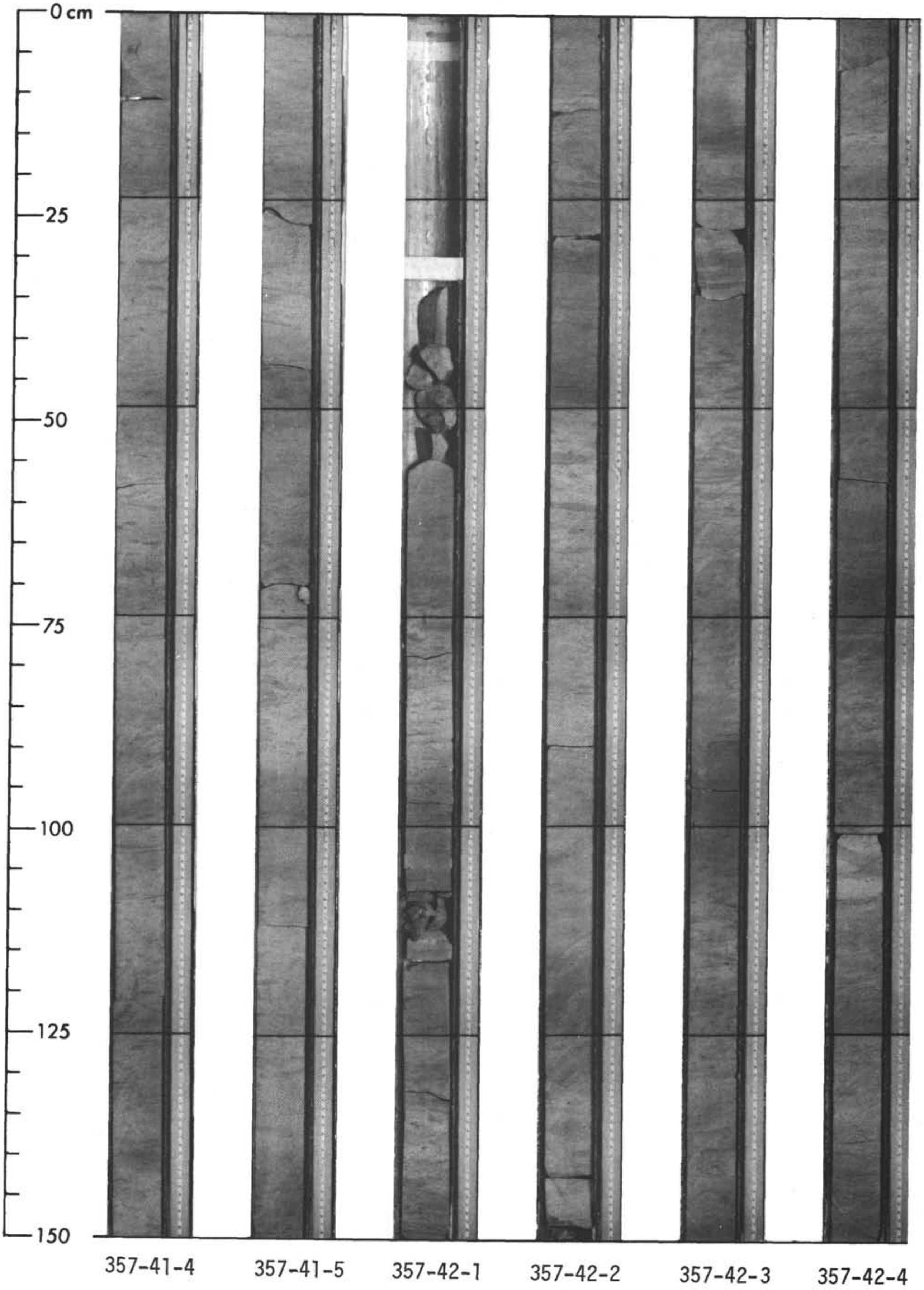
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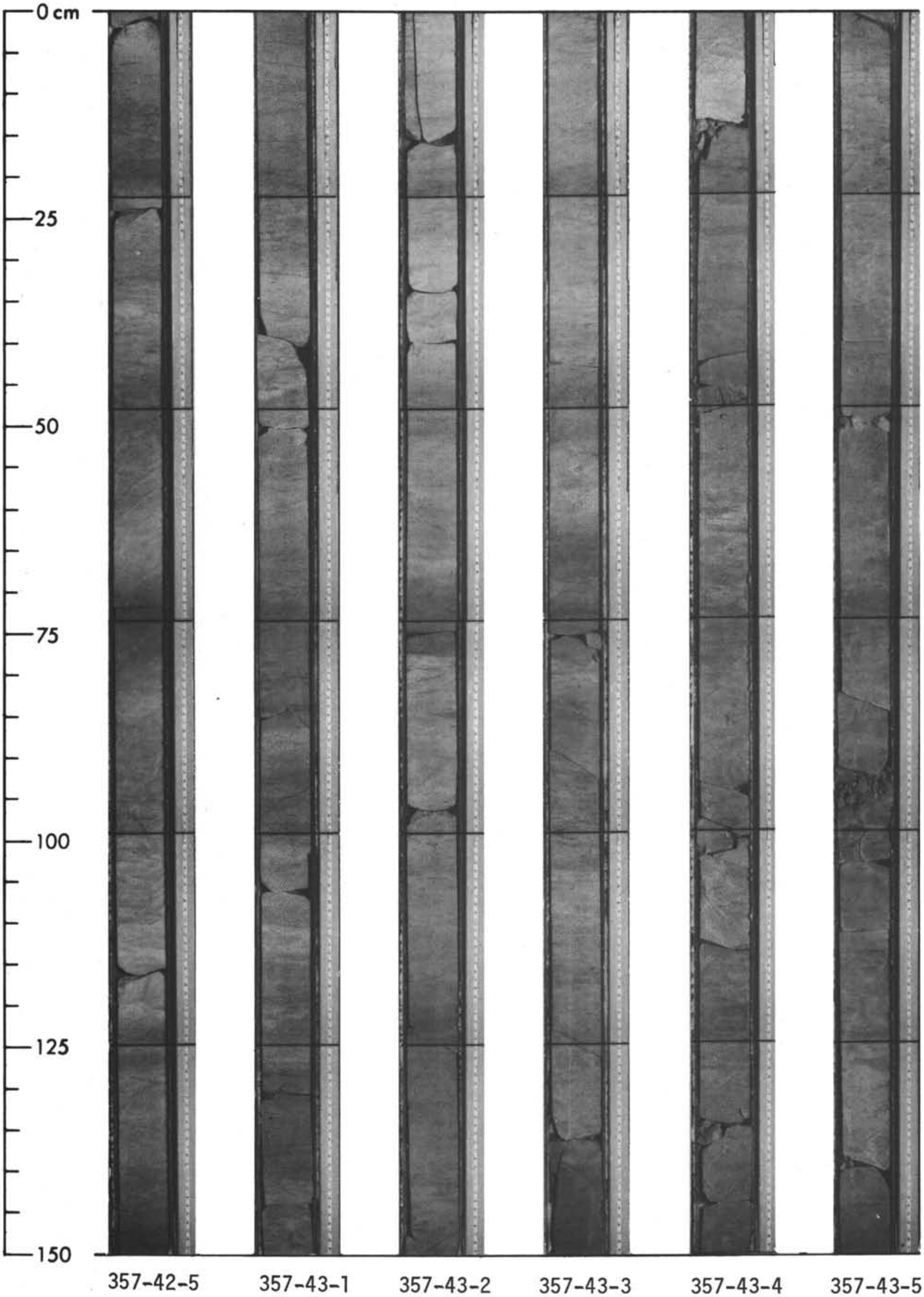
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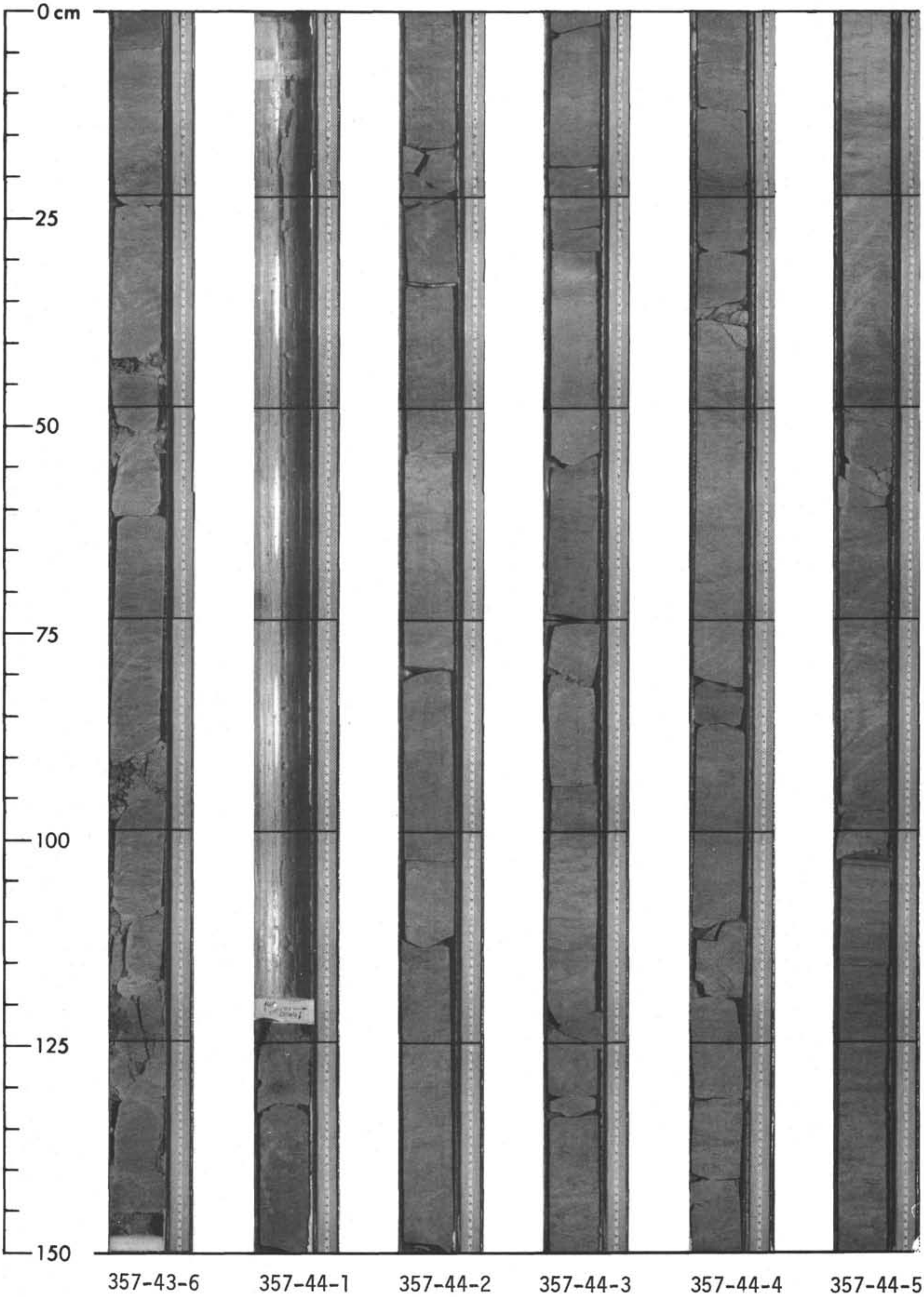
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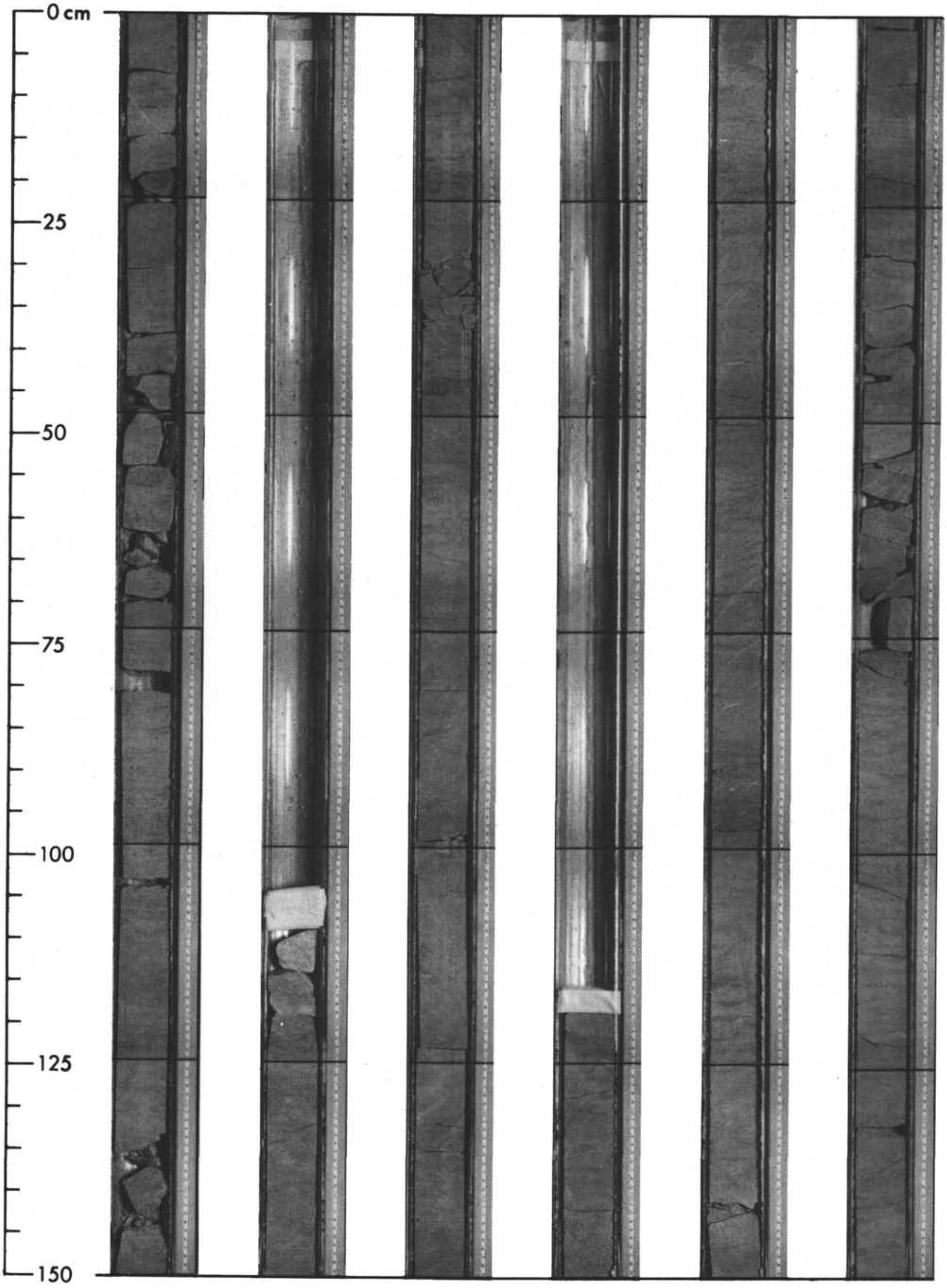

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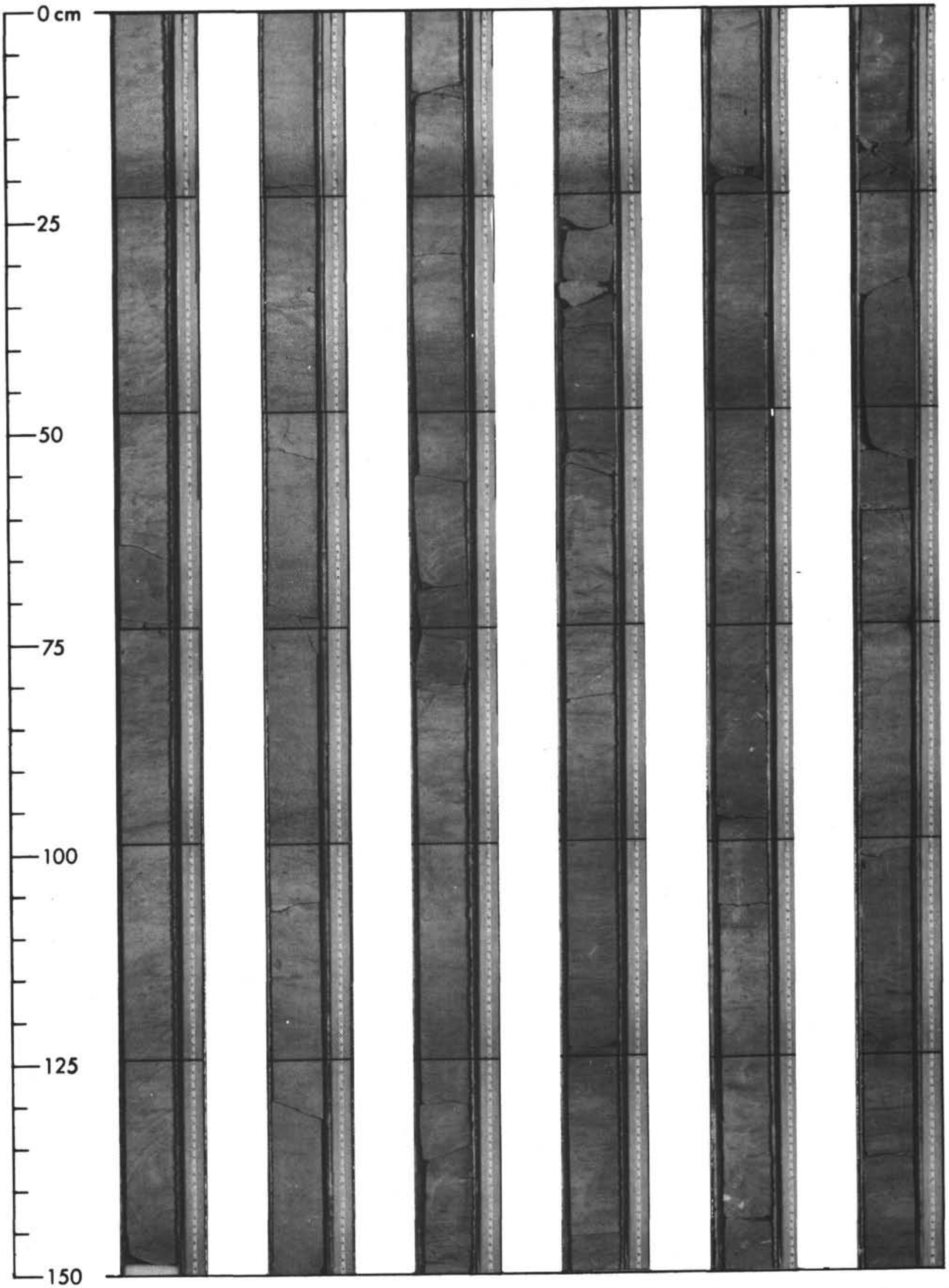

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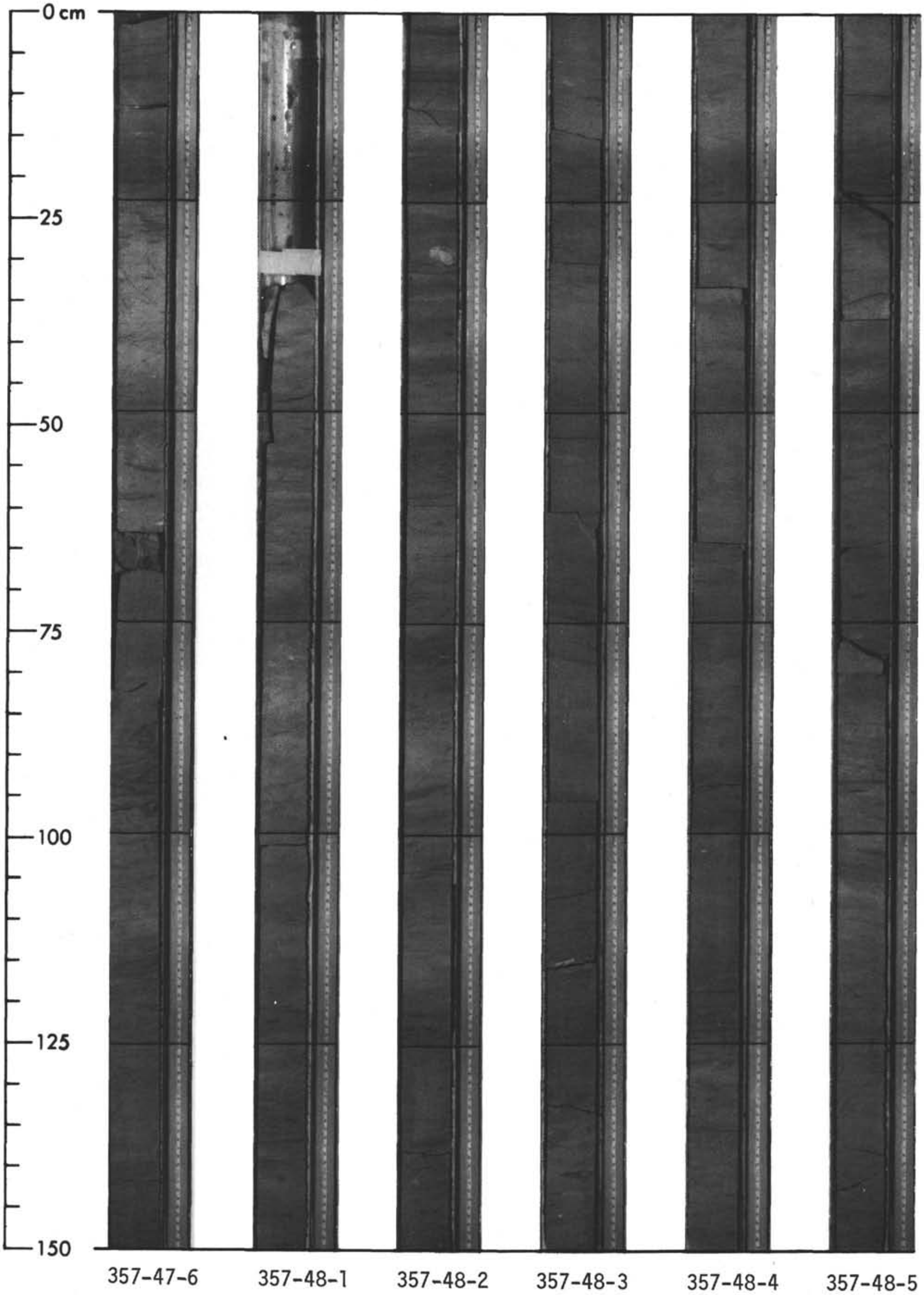
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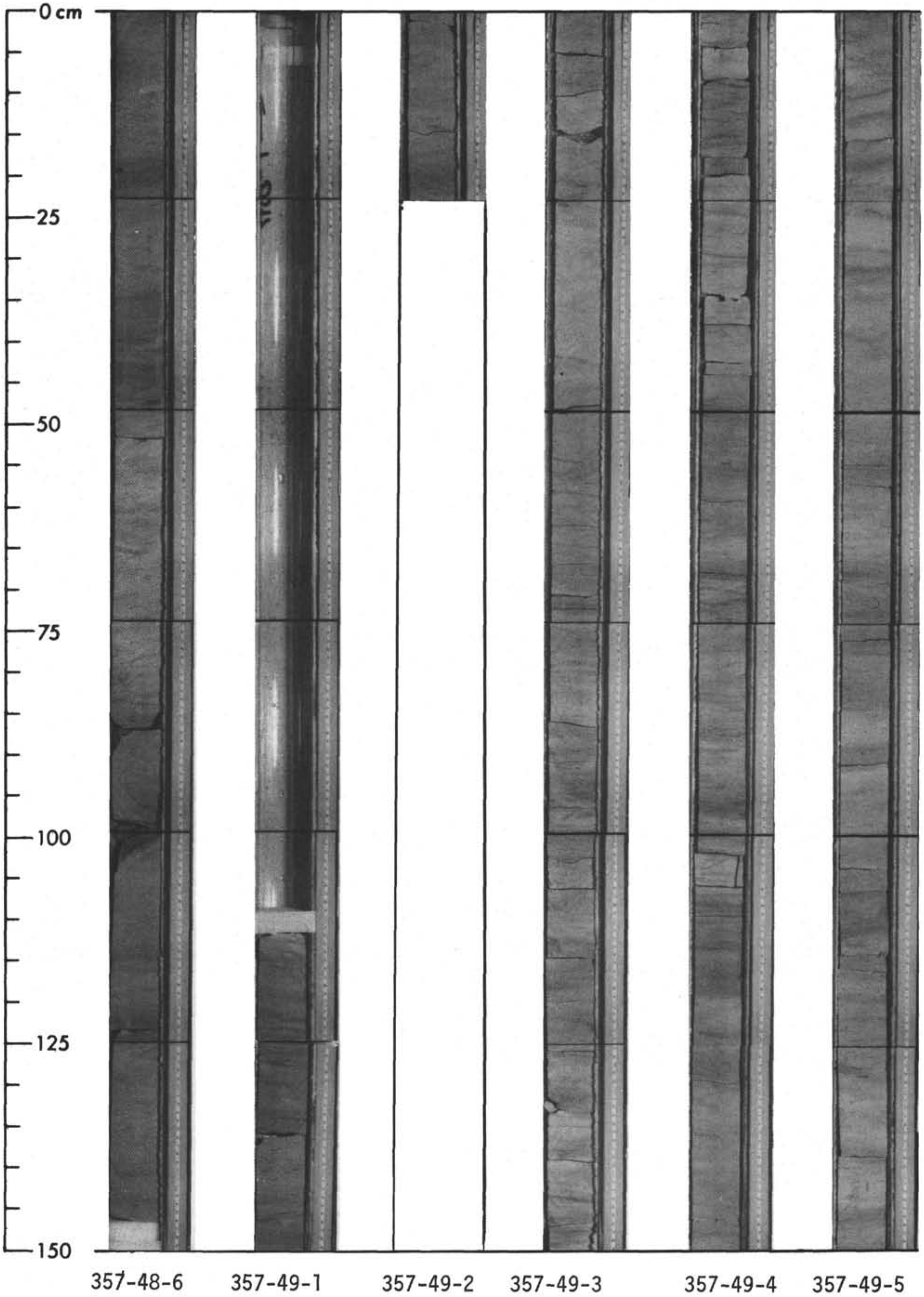
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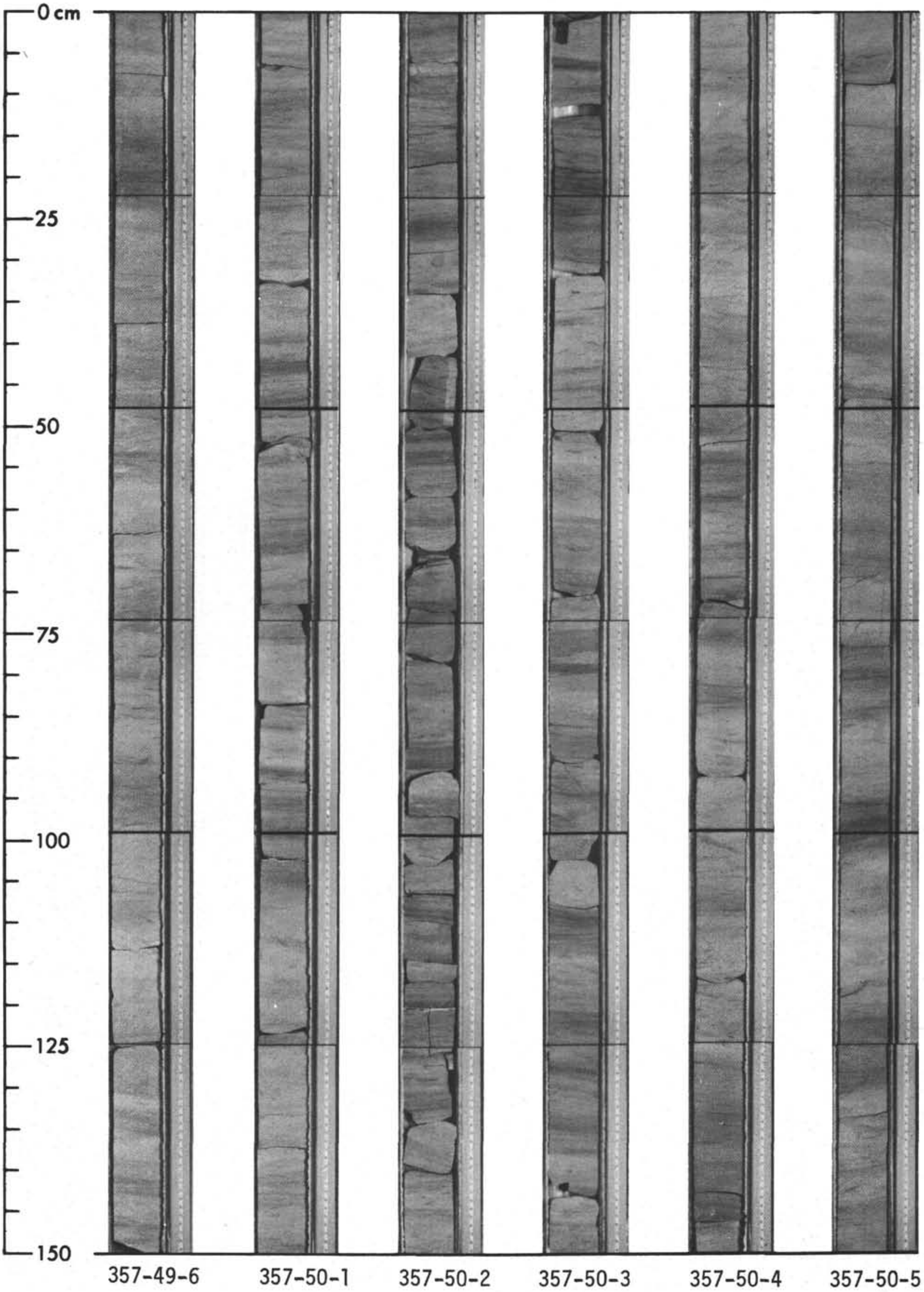
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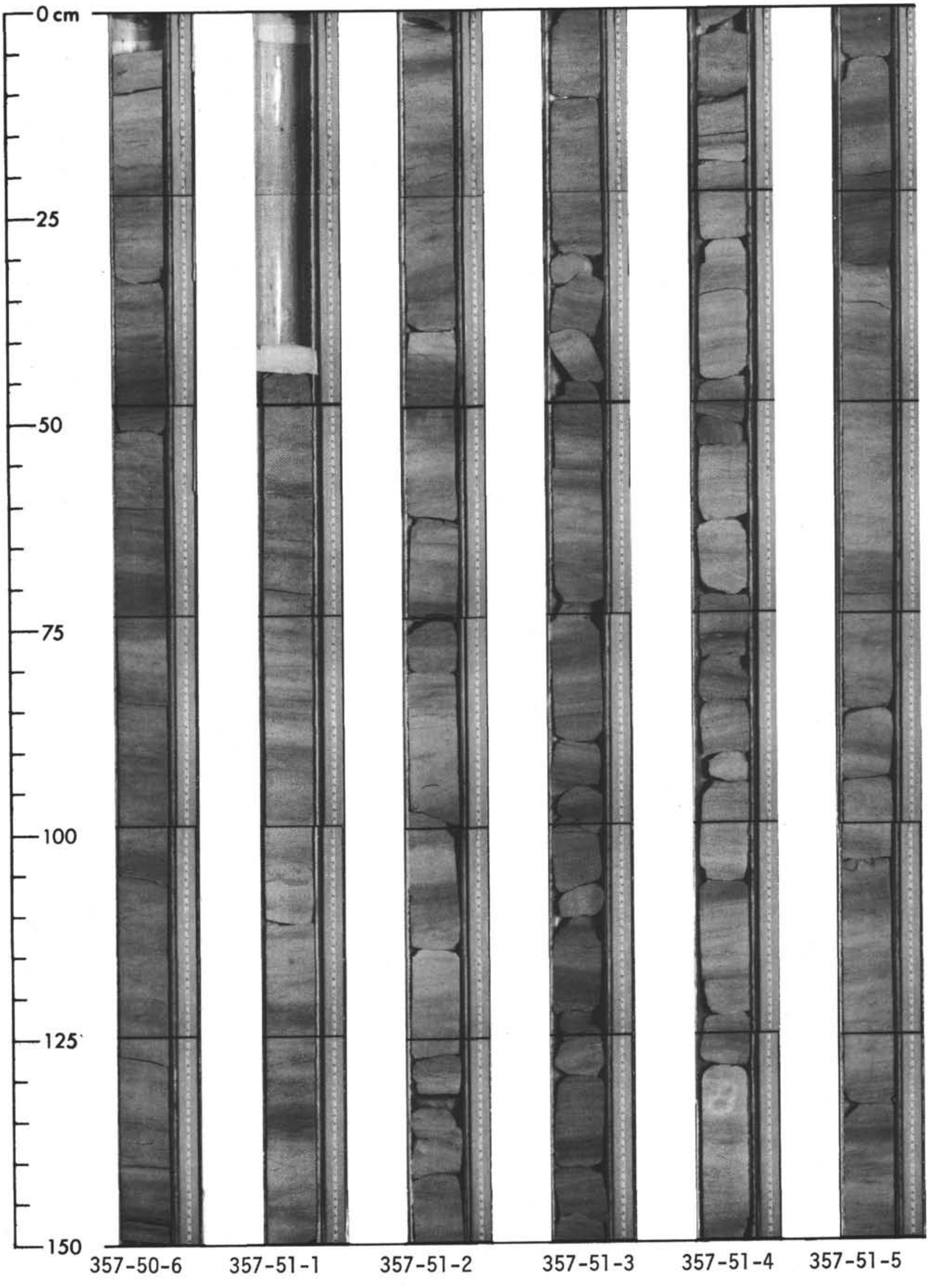
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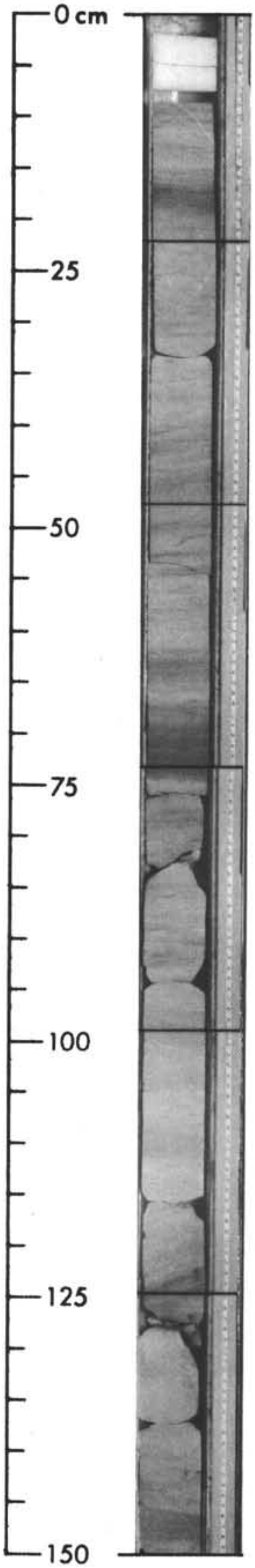

357-51-6