# 4. SITE 157

The Shipboard Scientific Party[1]

## SYNOPSIS

**Area:** Carnegie Ridge, eastern equatorial Pacific

**Date Occupied:** 12-14 February, 1971

**Position:**
Lat. 01°45.70′S
Long. 85°54.17′W

**Water Depth:** 1591 meters (corrected)

**Penetration:**
157: 437 meters
157A: 27 meters

**Number of Holes:** 2

**Number of Cores:**
157: 49
157A: 3

**Core Recovery:**
157: 273.6 meters
157A: 19.3 meters

**Acoustic Basement:**
Depth: 0.45 second
Nature: Chert
Inferred acoustic velocity for sedimentary section: 1530 meters

**Age of Oldest Sediment:** Late Miocene

**Basement:** Basalt

Hole DSDP 157 was continuously cored from the surface to 3 meters into basalt; DSDP 157A recored the upper 27 meters. DSDP 157 is lithologically uniform and all changes are gradual.

0-345 meters – Siliceous-calcareous ooze to approximately 240 meters, gradually increasing in lithification to semi-indurated chalk; chalk below 284 meters. Calcareous nannofossils abundant but poorly preserved; radiolarians abundant, poorly preserved below 324 meters.
Age: Quaternary to late Miocene.

345-431 meters – Interbedded cherts and chalk; chalk similar to overlying unit except for absence of siliceous microfossils.
Age: Late Miocene.

431-437 meters – Basalt, flow structures near upper part, rest massive and holocrystalline, moderately altered, extrusive.

The sedimentation rate is about 47 m/m.y. from the surface to 75 meters, changing to about 63 m/m.y. between 75 and 326 meters. Between 325 and 330 meters, the rate is sharply reduced or a hiatus of approximately 1 m.y. is present. Between 330 meters and basement, the rate is at least 29 m/m.y.

## REGIONAL SETTING AND OBJECTIVES

Site DSDP 157 is located at the southern edge of the Panama Basin on the south flank of the Carnegie Ridge (Figure 1). The Panama Basin is bordered by the continental margins of eastern Central America and northern South America and by two isostatically compensated ridges, the Carnegie and Cocos ridges, which enclose a central basin traversed by several north-south trending fracture zones. As shown in Chapter 2 (this volume) and in van Andel et al. (1971), these ridges and several high blocks within the eastern part of the Panama Basin exhibit considerable similarity in the nature of the acoustic basement and the sediment cover. On these grounds and with the aid of a detailed tectonic analysis of the basin, van Andel et al. (1971) have suggested that all high blocks of the basin originally formed part of a single, east-west trending ancestral Carnegie Ridge located approximately at the position of the present one. This ridge was split by the formation of the Galapagos Rift Zone. Opening of the rift began in the east and proceeded westward in a stepwise fashion, affecting the block west of the Coiba Fracture Zone approximately 10 m.y. ago, and subsequent more westerly blocks at later dates. While the southern half of the split ridge remained stationary, successive northern blocks migrated northward until, one by one, they reached and sealed the eastern extension of the Middle Americas Trench.

Three sites in the Panama Basin (one each on the Coiba, Carnegie, and Cocos ridges) were selected by the Pacific Site Selection Panel to test this hypothesis through comparison of sedimentary sections, basement ages, and depositional histories of the three ridges. In addition, the sites were chosen to determine the late Cenozoic biostratigraphy of the eastern equatorial Pacific in locations shallow enough to insure preservation of calcareous microfossils. Additionally, DSDP 157 was selected to examine temporal changes in the location and intensity of the Peru Current as reflected in the biogenous deposits at the site, especially those of Quaternary age. The site is located in the area of interaction between the Peru Current and the equatorial current system.

## TOPOGRAPHIC AND GEOLOGIC SETTING

DSDP 157 is located on the south flank of the Carnegie Ridge slightly less than halfway between the crest of this ridge and the deep Pacific basin and well east of the

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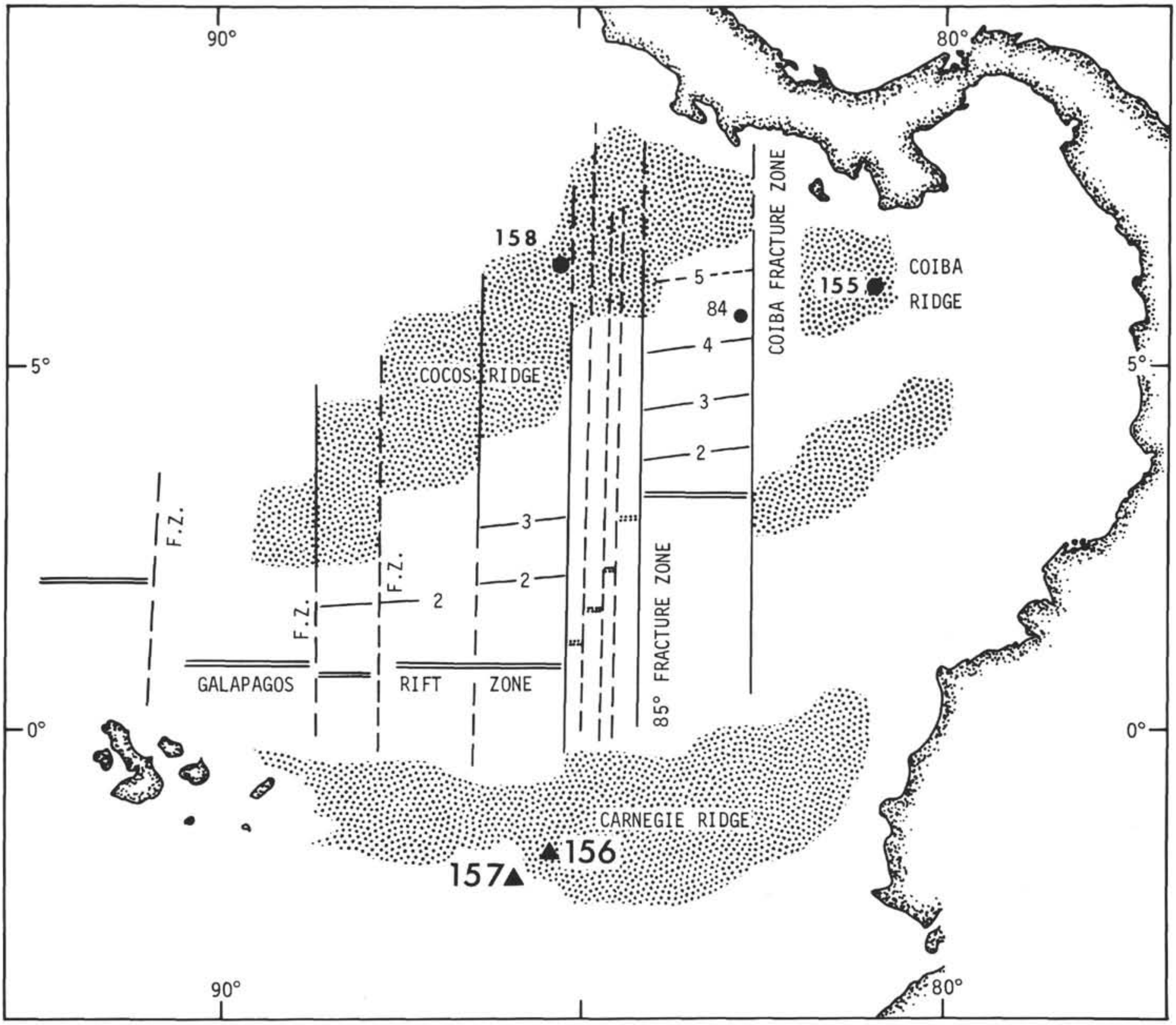


Figure 1. *Tectonic map of the Panama Basin (after van Andel et al., 1971) with locations of drill sites. Numbered contours are magnetic anomalies.*

pedestal of the Galapagos Islands (Figure 2). The Carnegie Ridge has been uplifted along a series of east-west trending normal faults resulting in the formation of several structural terraces on each flank (Figure 3). The terrace surfaces are level and covered with a thick sedimentary blanket. On the crestal side, each is bordered by a steep scarp leading to the next step and on the downward side by a protruding basement ridge or a series of basement pinnacles (Figure 3). The terraces are dissected by numerous gullies or canyons of erosional origin that extend to the acoustic basement. Few of these gullies appear on north-south traverses, but they are numerous on east-west traverses (see Chapter 3, Figure 3, this volume) indicating that they have a general north-south trend down the ridge slope. The relatively flat crest of the Carnegie Ridge, approximately 70 km north of the drill site, was eroded to acoustic basement at an unknown time after most of the sedimentary cover of the ridge had been deposited (van Andel et al. 1971). Regional sediment isopach maps (van Andel et al., 1971) show that a band of anomalously thick sediment, which presumably contains part or all of the eroded material, occurs north of the ridge crest. No such overthickened zone can be distinguished south of the crest, but the numerous canyons suggest that at least part of the material is transported southward into the deep Pacific basin to the south.

The acoustic section (Figure 3) contains numerous closely spaced and continuous reflectors. The character of these reflectors changes little with depth and is strongly reminiscent of the calcareous deposits of the equatorial zone of high biological productivity farther to the west

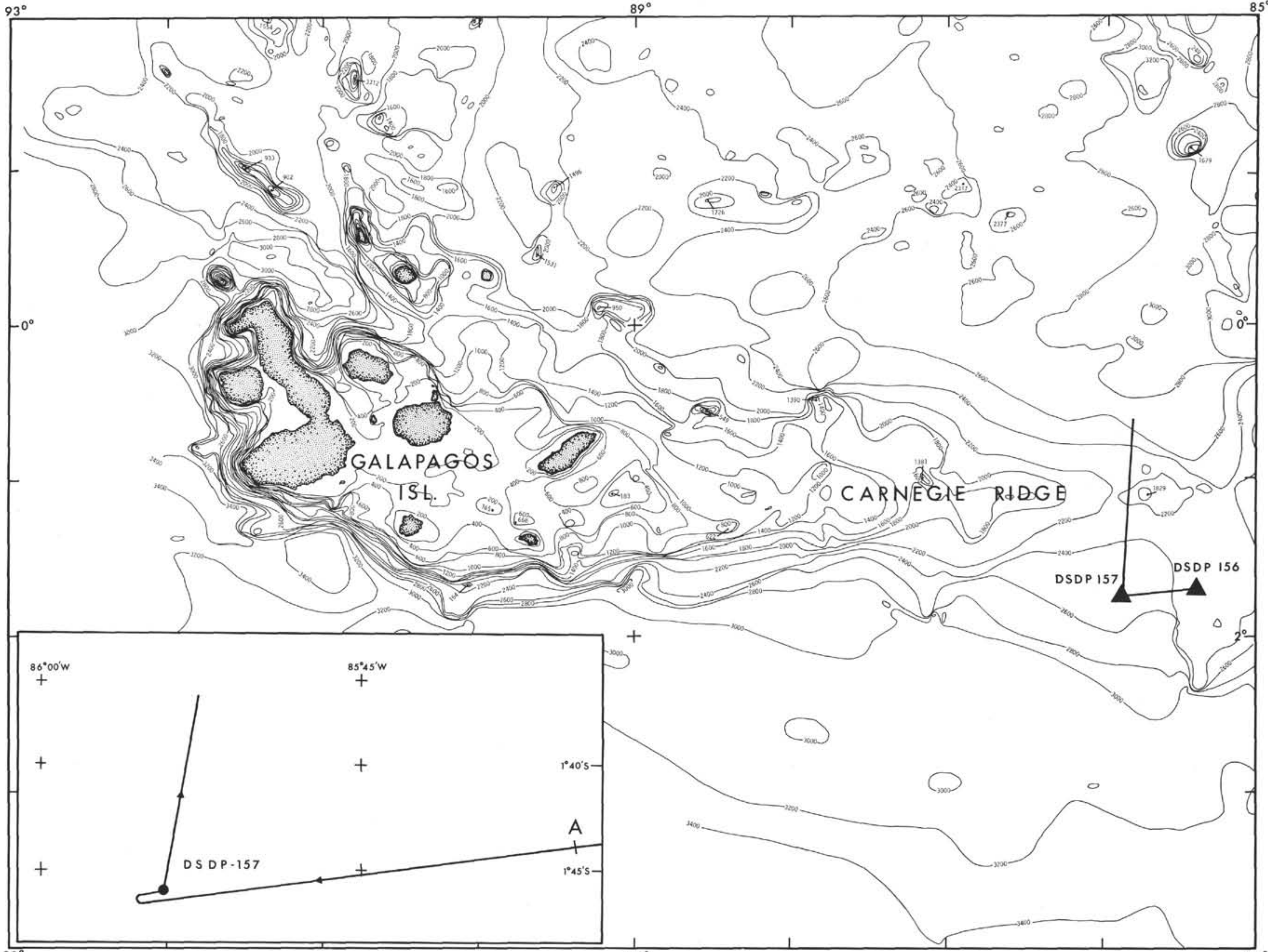


Figure 2. *Location of DSDP 157 on Carnegie Ridge. Depth controus in meters (uncorrected after van Andel et al. (1971). Heavy lines 156-157 and 157-C refer to acoustic profiles of Figure 3. Insert: site approach track; A-157 is location of profile of Figure 3.*

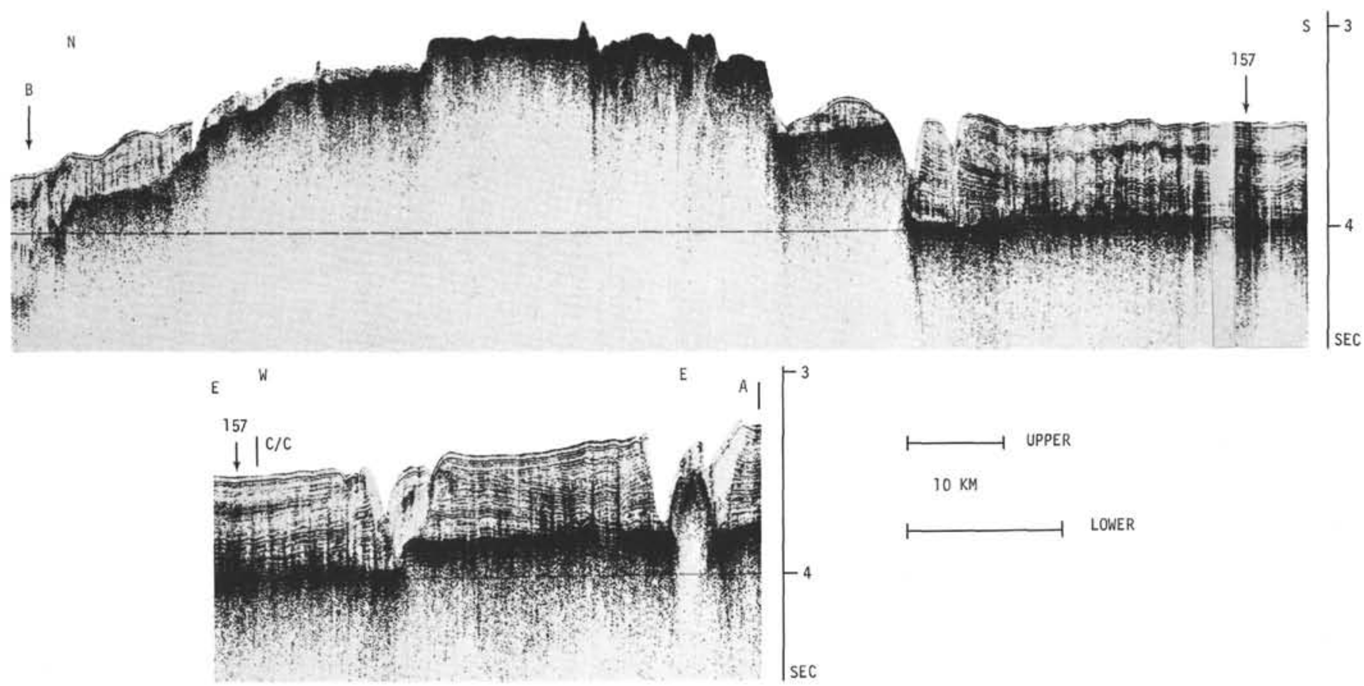


Figure 3. *Acoustic reflection profiles between sites DSDP 156 and 157 (top) and from DSDP 157 across Carnegie Ridge (bottom). Locations on Figure 2. Depths in seconds 2-way travel time (1 sec = approx. 800 m of sediment). Horizontal scale approximate.*

(Ewing et al., 1968). In drill holes on DSDP Legs 7, 8, and 9, the layering has been correlated with variations either of the carbonate content or of the degree of induration of the deposits (Winterer et al., 1971; Tracey et al., 1971; Hays et al., 1972).

Low-angle unconformities of limited horizontal extent are common in the sedimentary cover of the Carnegie Ridge. They are evident on north-south traverses (Figure 3) and are probably related to the regime of crestal erosion and flank redeposition described above. They are most common at a depth of approximately 110 to 125 meters below the sea floor and are generally restricted to the upper part of the section.

The acoustic basement in the site area is very smooth and shows strong internal reverberation. Such a smooth basement is widespread on the ridges of the Panama Basin area, but is absent from the deeper, younger crust. It generally terminates sharply against basement scarps and pinnacles which exhibit a quite different acoustic signature. The sedimentary origin for this basal reflector proposed by van Andel et al. (1971) was confirmed by the discovery of chert at this site and at DSDP 158. The diagenetic character of the reflector is responsible for the generally unconformable relation between the acoustic basement and the overlying beds, (Figure 3). The acoustic basement is affected by the numerous normal faults of the ridge flanks, both by the major ones that determine the ridge shape and by numerous small ones with random displacements.

The acoustic section at the site is quite typical for the entire Carnegie Ridge, and shows little lateral variation except for minor thickening and thinning. In Table 1, the acoustic profile is compared with the results of drilling. The data support the correlation of acoustic basement with the top of the chert zone.

In view of the regional uniformity of the topography of the terrace and of the sedimentary section on this part of the Carnegie Ridge, no extensive site survey was carried out. The site was originally selected from seismic reflection profile record 1633 of R/V *Conrad*, Cruise 11, and lies on a flank terrace approximately 20 km wide (north-south). The final site was established after completing a short double pass in an east-west direction to insure that no local anomalies of small size were present. After completion of drilling, a profile across the beacon confirmed that the drilled site is typical for the area.

## OPERATIONS

The beacon was dropped at 1015 hours on February 12 and the hole spudded using a Smith 10 1/8", 3-cone shaped insert bit which performed very well and was still in usable condition after completion of the hole. The hole was cored continuously, using a regular core barrel for Cores 1 through 7, and 13 through 49. Cores 8 through 12 were taken with an extended core barrel. A summary of coring at DSDP 157 is given in Table 2. Core recovery in the chert was not good, probably because of alternating hard and soft

**TABLE 1**
**Comparison of Acoustic Section and Drill Data, DSDP 157**

| Reflectors | Depth[a] (sec) | Drilling Results[a] | Interval (sec) | Velocity[a] (m/sec) | Calculated[b] Depth (m) |
|---|---|---|---|---|---|
| Top upper stratified zone | 0.15 | | | | 116 |
| Top lower stratified zone | 0.32 = | (345 m top chert) | 0-0.32 | (2160) | |
| | 0.32 = | 240 m top chalk | 0-0.32 | 1500 | 248 |
| | 0.32 = | (265 m reduced drilling rate) | 0-0.32 | (1660) | |
| Top acoustic basement | 0.45 = | 345 m top chert | 0-0.45 | 1530 | 345 |
| | 0.45 = | (431 m top basalt) | 0-0.45 | (1930) | |

[a]Underlined – accepted correlation; parenthesis ( ) – correlation not accepted.

[b]Calculated assuming velocity of 1530 m/sec.

layers. A single sidewall core was attempted but the barrel sheared off, probably because the formation was too hard.

Upon completion of the first hole, DSDP 157A was drilled using the extended core barrel in the hope of reducing core disturbance. The first core showed significantly reduced disturbance, but the others were of the same quality as those of DSDP 157 and the attempt was abandoned after three cores.

## LITHOLOGY

Lithologically, the sediments of DSDP 157 and DSDP 157A are uniform. From the surface to the basement contact at 431 meters, they consist of nannofossil chalk ooze and chalk which gradually become more indurated with depth. The upper part of the section, above 342 meters, is rich in biogenous silica in the form of radiolarians and diatoms; below 324 meters, the state of preservation of the siliceous organisms deteriorates and below 342 meters all silica is in the form of chert stringers and nodules. At 431 meters, the sediment rest on basalt.

The chalk oozes and chalks vary in color. Alternating zones are greenish gray, pale olive, light to moderate olive brown, and pale greenish yellow. Mottling and burrowing occur but not excessively; mottles and diffuse laminations are commonly marked by concentrations of fine-grained pyrite and pyrite nodules. Gray, pyrite-rich intervals are common from 250 to 342 meters; above 250 meters, much pyrite occurs in large burrows up to 1 cm wide and 10 cm long. $H_2S$ odor was noticeable throughout.

Near the surface, foraminifers are abundant. They decrease below 50 meters, but remain common to abundant to 250 meters, and common to 342 meters. The dominant components are nannofossils, followed in abundance by diatoms, which decrease markedly in abundance below 333 meters, perhaps as a result of solution. Radiolarians are common throughout the section to 324 meters, below 345 meters they disappear. Subsidiary components are silicoflagellates, pyrite nodules, volcanic glass, glauconite, and sponge spicules, all of which are somewhat more common in the upper part of the section. The relatively rare occurrence of volcanic glass is noteworthy at this site, which is quite close to (albeit upwind from) the Galapagos volcanic complex.

**TABLE 2**
**Coring Summary, DSDP 157 and 157A**

| Core | Depth Below Sea Level (m) | Depth Below Sea Floor (m) | Cored (cm) | Recovered (cm) | Recovered (%) |
|---|---|---|---|---|---|
| 1 | 2601-2610 | 10-19 | 900 | 850 | 94.4 |
| 2 | 2610-2619 | 19-28 | 900 | 900 | 100.0 |
| 3 | 2619-2628 | 28-37 | 900 | 893 | 99.2 |
| 4 | 2628-2637 | 37-46 | 900 | 900 | 100.0 |
| 5 | 2637-2646 | 46-55 | 900 | 900 | 100.0 |
| 6 | 2646-2655 | 55-64 | 900 | 900 | 100.0 |
| 7 | 2655-2664 | 64-73 | 900 | 828 | 92.0 |
| 8 | 2664-2673 | 73-82 | 900 | 593 | 65.9 |
| 9 | 2673-2682 | 82-91 | 900 | 822 | 91.3 |
| 10 | 2682-2690 | 91-98 | 800 | 600 | 75.0 |
| 11 | 2690-2699 | 99-108 | 900 | 534 | 59.3 |
| 12 | 2699-2708 | 108-117 | 900 | 900 | 100.0 |
| 13 | 2708-2717 | 117-126 | 900 | 555 | 61.7 |
| 14 | 2717-2726 | 126-135 | 900 | 830 | 92.2 |
| 15 | 2726-2735 | 135-144 | 900 | 890 | 98.9 |
| 16 | 2735-2744 | 144-153 | 900 | 862 | 95.8 |
| 17 | 2744-2753 | 153-162 | 900 | 900 | 100.0 |
| 18 | 2753-2762 | 162-171 | 900 | 877 | 97.4 |
| 19 | 2762-2771 | 171-180 | 900 | 900 | 100.0 |
| 20 | 2771-2780 | 180-189 | 900 | 170 | 18.9 |
| 21 | 2780-2789 | 189-198 | 900 | 890 | 98.9 |
| 22 | 2789-2798 | 198-207 | 900 | 895 | 99.4 |
| 23 | 2798-2807 | 207-216 | 900 | 900 | 100.0 |
| 24 | 2807-2816 | 216-225 | 900 | 480 | 53.3 |
| 25 | 2816-2825 | 225-234 | 900 | 750 | 83.3 |
| 26 | 2825-2834 | 234-243 | 900 | 895 | 88.3 |
| 27 | 2834-2843 | 243-252 | 900 | 896 | 99.6 |
| 28 | 2843-2852 | 252-261 | 900 | 860 | 95.6 |
| 29 | 2852-2861 | 261-270 | 900 | 356 | 39.6 |
| 30 | 2861-2870 | 270-279 | 900 | 900 | 100.0 |
| 31 | 2870-2879 | 279-288 | 900 | 885 | 98.3 |
| 32 | 2879-2888 | 288-297 | 900 | 900 | 100.0 |
| 33 | 2888-2897 | 297-306 | 900 | 900 | 100.0 |
| 34 | 2897-2906 | 306-315 | 900 | 0 | 0.0 |
| 35 | 3906-2915 | 315-324 | 900 | 150 | 16.7 |
| 36 | 2915-2924 | 324-333 | 900 | 362 | 40.2 |
| 37 | 2924-2933 | 333-342 | 900 | 18 | 2.0 |
| 38 | 2933-2936 | 342-345 | 300 | 73 | 24.3 |
| 39 | 2936-2941 | 345-350 | 500 | 100 | 20.0 |
| 40 | 2941-2950 | 350-359 | 900 | 0 | 0.0 |
| 41 | 2950-2959 | 359-368 | 900 | 51 | 5.7 |
| 42 | 2959-2968 | 368-377 | 900 | 150 | 16.7 |
| 43 | 2968-2977 | 377-386 | 900 | 45 | 5.0 |
| 44 | 2977-2986 | 386-395 | 900 | 0 | 0.0 |
| 45 | 2986-2995 | 395-404 | 900 | 0 | 0.0 |
| 46 | 2995-3004 | 404-413 | 900 | 38 | 4.2 |
| 47 | 3004-3013 | 413-422 | 900 | 40 | 4.4 |
| 48 | 3013-3022 | 422-431 | 900 | 34 | 3.8 |
| 49 | 3022-3028 | 431-437 | 600 | 188 | 31.3 |
| 1A | 2591-2600 | 0-9 | 900 | 900 | 100.0 |
| 2A | 2600-2609 | 9-18 | 900 | 130 | 14.4 |
| 3A | 2609-2618 | 18-27 | 900 | 900 | 100.0 |

Severe disturbance of the sediments by the coring process partly masks the increase in consolidation with depth. However, steadily increasing induration is clearly indicated by reduced coring rates. From approximately 2.1 m/minute at the surface, the rate decreased to 1.6 m/minute at 110 meters. Between 110 and 260 meters, the rate remained approximately constant. From there to 342 meters, the rate again decreased from approximately 1 m/minute to 0.5 m/minute. Below 285 meters, the formation is arbitrarily logged as chalk rather than as chalk ooze, although the transition is very gradual.

At 342 meters, a sharp decrease in the drilling rate marked the highest occurrence of chert and below this depth the formation consists of chert alternating with nannofossil chalk and chalk limestone. The highest chalk limestone appears near 350 meters. The chalk and chalk limestone are similar to the deposits higher in the section except for the absence of unaltered diatoms, radiolarians, or silicoflagellates. Thin sections contain very rare chalcedony and pyrite pseudomorphs after radiolarians. The beds show the same color range as the upper, non-chert-bearing section (yellowish gray, very light gray, pale olive and light olive gray, with yellowish gray predominating). Mottles and burrows are common; the burrows are generally compressed perpendicular to bedding. Fine-grained pyrite is common as darker gray laminae and streaks and as grayish purple to black concentrations.

The chert is commonly calcareous, particularly near the top of the chert section. Mottled bedding and bioturbation are well preserved. The chert is generally darker than the associated chalk and chalk limestone. Moderate to light olive brown and olive black colors predominate, but lighter colors such as pale greenish yellow, pale olive, yellowish gray, light olive gray, and olive gray are also present. The chert occurs as nodules, stringers and irregular crosscutting masses up to 10 mm thick. In thin section, it is seen to have replaced the limestone; microfossil tests are marked by coarser-grained aggregates of chalcedonic quartz. In limestone adjacent to a chert body, foraminiferal chambers are often filled with chalcedony.

Basalt was reached at 431 meters, based on a change in coring rate from 0.45 m/minute to 0.1 m/minute. Between 431 and 437 meters, 1.9 meters of basalt core was recovered. The top 20 cm consists of silicified crust-like masses of medium to light gray basalt with smeared vesicles and amygdules and associated gray fine-grained material which may be altered glass. Below, the rock is medium to dark gray massive basalt, very fine-grained with 0.2 to 1.0 mm labradorite laths and interstitial augite and 1 to 5 mm phenocryst clusters of oscillatory-zoned plagioclase showing synneusis. The groundmass contains plagioclase microlites, magnetite, chlorophaeite, and devitrified glass. The basalt is cut by thin, irregularly trending, mostly steeply dipping veins of calcite and serpentine with concentrations of pyrite and possibly chalcopyrite and pyrrhotite. The basalt-sediment contact is depositional, based on the absence of evidence of metamorphism in overlying sediments and the presence at the top of the basalt of altered, crust-like masses and smeared amygdules which may be part of a basalt pillow.

## GEOCHEMISTRY

Interstitial water samples and shipboard observations for DSDP 157 are listed in Table 3.

**TABLE 3**
**Interstitial Water Samples and Shipboard Observations, DSDP 157**

| Core | Section | Sampled Interval (cm) | pH | Eh (mv) | Lab. Temp. (°C) | Salinity (%) | Squeeze Pressure (psi) |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 0-10 | 7.50 | -36 | 24.0 | 34.7 | 1240 |
| 1 | 2 | 0-10 | 7.73 | -16 | 24.0 | 35.2 | 2436 |
| 2 | 4 | 0-10 | 7.46 | -180 | 23.9 | 35.2 | 2436 |
| 3 | 1 | 0-10 | 7.38 | -189 | 24.0 | 35.2 | 1523 |
| 4 | 2 | 140-150 | 7.38 | -272 | 23.9 | 35.8 | 1015 |
| 5 | 3 | 0-9 | 7.31 | -270 | 24.1 | 35.2 | 1523 |
| 6 | 1 | 142-150 | 6.40 | -208 | 24.2 | 35.2 | 1523 |
| 7 | 4 | 0-9 | 7.36 | -262 | 24.1 | 35.2 | 1015 |
| 8 | 1 | 0-3 | 7.36 | -224 | 24.0 | 35.2 | 1015 |
| 9 | 6 | 0-8 | 7.43 | -305 | 24.0 | 35.2 | 1523 |
| 10 | 1 | 0-9 | 7.34 | -348 | 24.7 | 35.2 | 1015 |
| 12 | 5 | 0-10 | 7.25 | -285 | 24.1 | 35.2 | 1015 |
| 14 | 3 | 0-8 | 7.37 | -311 | 25.5 | 35.2 | 1015 |
| 15 | 5 | 0-9 | 7.31 | -323 | 25.2 | 35.2 | 1523 |
| 16 | 6 | 0-7 | 7.23 | -194 | 25.3 | 35.2 | 1015 |
| 17 | 6 | 0-6 | 7.27 | -155 | 25.5 | 35.2 | 1015 |
| 18 | 4 | 0-6 | 7.20 | -258 | 25.6 | 34.7 | 1015 |
| 19 | 6 | 0-8 | 7.24 | -150 | 25.8 | 34.7 | 1015 |
| 21 | 5 | 0-5 | 7.13 | -335 | 25.8 | 34.7 | 188 |
| 23 | 5 | 0-5 | 7.18 | -301 | 25.0 | 35.2 | – |
| 27 | 3 | 0-6 | 7.22 | -186 | 25.3 | 34.7 | 2436 |
| 28 | 5 | 0-6 | 7.19 | -98 | 25.4 | 34.7 | 2436 |
| 29 | 2 | 0-7 | 7.48 | -130 | 25.5 | 34.7 | 1015 |
| 30 | 6 | 0-6 | 7.27 | 8 | 25.1 | 34.7 | 1523 |
| 31 | 6 | 0-5 | 7.20 | -124 | 25.3 | 34.7 | 1523 |
| 32 | 6 | 0-6 | 7.04 | -240 | 25.4 | 34.7 | 2030 |
| 33 | 6 | 0-8 | 7.26 | -88 | 25.0 | 34.7 | 1015 |
| 35 | 1 | 135-140 | 7.33 | 27 | 25.0 | 34.1 | 2436 |
| 36 | 3 | 0-6 | 7.11 | -229 | 25.4 | 34.7 | 2436 |
| 39 | 1 | 145-150 | 7.08 | -27 | 25.5 | 34.1 | 3000 |
| 1A | 6 | 0-8 | 7.36 | -175 | 24.5 | 34.7 | 1015 |
| 2A | 1 | 145-150 | 7.38 | -218 | 24.5 | 34.7 | 1523 |
| 3A | 5 | 0-9 | 7.43 | -256 | 24.5 | 35.2 | 1015 |

## BIOSTRATIGRAPHY

At Site DSDP 157 a thick, apparently complete upper Miocene to upper Pleistocene sequence was cored. Except for the cherty interval from 345 meters to 437 meters TD in which radiolarians are not preserved, foraminifera, coccoliths, and radiolarians occur jointly throughout. Foraminifera are moderately well to well-preserved in all samples examined, but increasing induration of the sediment from Core 39 downward made the obtaining of representative faunas difficult or impossible. Coccoliths are abundant in all 48 sediment cores, but preservation is generally poor and deteriorates downward. Upper Miocene discoasters are characterized by heavy secondary calcite overgrowth. For both calcareous fossil groups–foraminifera and coccoliths–species diversity is low, and many of the common guide fossils for the upper Miocene and Pliocene are scarce or absent.

Coccoliths indicate that the sediment immediately above basalt is late Miocene in age (*Discoaster neohamatus* Zone). Foraminifera indicate a level within the *Globorotalia plesiotumida* Zone; however, compared to DSDP 158 this level should be already in the underlying *Globorotalia acostaensis* Zone. The discrepancey at DSDP 157 (because of a slightly more diverse foraminiferal fauna of its more tropical character, DSDP 158 is tentatively regarded as biostratigraphically more reliable). can be attributed to downhole displacement of *G. plesiotumida*, which would lower the zonal boundary; but because of the spotty occurrence of *G. plesiotumida* in the Panama Basin sequences, it is not unlikely that the lower occurrences of this species at DSDP 157 may be autochthonous and may have been missed at DSDP 158 because this species occurs rather sporadically.

Radiolarians are diverse and well-preserved down to 324 meters, but their preservation deteriorates downward to 345 meters below which depth they are absent.

In addition to the above fossil groups, silicoflagellates are conspicuous in nannofossil assemblages of Cores 1 through 38. They are discussed in detail by Bukry and Foster (Chapter 29, this volume).

Foraminifera, coccoliths, and radiolarians indicate that, except for the uppermost Pleistocene, the section at DSDP 157 is complete. Both coccoliths and radiolarians indicate that the uppermost Pleistocene is missing, even in Hole 157A, which cored the uppermost part of the section missed in Hole 157. Lack of resolution in this interval did not allow this assessment to be made on the basis of foraminiferal biostratigraphy.

## PHYSICAL PROPERTIES

Drilling in the upper 200 meters of DSDP 157 resulted in a relatively high degree of sediment core disturbance, rendering the GRAPE bulk density and porosity unreliable for this part of the section. Likewise, natural gamma measurements are reported only for the cores with the least apparent disturbance. During analysis of Core 25 and all subsequent cores, the GRAPE system developed technical problems reflected in unstable outputs from the calibration standards (water and aluminum). Bulk density and porosity data have been adjusted accordingly. However, GRAPE and natural gamma data should be regarded with some suspicion.

A relatively small number of sediment samples was collected for laboratory analysis. Consequently, the density of coverage is low, especially in the upper 230 meters of sediment. Likewise, below 340 meters, sediment disturbance and poor core recovery prohibited sampling, which was restricted to areas of least disturbance.

### Bulk Density

On the basis of data generated by the GRAPE system, large variations in the bulk density occur throughout the lithologic section. Values (average per section) range from 1.42 g/cc in the high-porosity upper Pliocene nannofossil chalk ooze to 1.94 g/cc in the low-porosity upper Miocene interbedded chert and chalk limestone which occurs just above the basalt. Laboratory bulk densities range from 1.28 g/cc at 61.5 meters in the nannofossil chalk ooze to 1.67 g/cc at 288 meters and 324 meters in the nannofossil chalk. A value of 1.67 g/cc also occurs in the chalk ooze at 258 meters. A low value of 1.34 g/cc at a depth of 251 meters in the nannofossil chalk ooze is due to the anomalous low grain density and high water content at this depth.

GRAPE and laboratory bulk densities generally decrease with depth, although variations occur throughout the sedimentary sequence. The lowest values occur predominantly in the chalk ooze. The highest bulk densities are common in the chalk limestone below a depth of 342 meters and increase sharply to a depth of about 370 meters where measurements terminated.

### Porosity

GRAPE porosity (average value per section) ranges from 74 per cent at 200 to 220 meters in the nannofossil chalk ooze to 47 per cent at 370 meters in the chalk limestone. A pronounced overall decrease in porosity occurs with depth. Porosities in the chalk ooze range from 54 per cent to 74 per cent and decrease sharply with depth. Although porosities in the chalk range from 54 to 70 per cent, the general decrease with depth is not as clear as in the chalk ooze, and numerous variations are observed. The lowest values occur in the nannofossil chalk limestone where they range from 47 to 57 per cent and decrease sharply with depth within the sedimentary sequence.

A high of 84 per cent porosity at a depth of 61.5 meters contrasts with a low of 59 per cent at depths of 259 meters and 289 meters for laboratory measurements. The highest laboratory porosities with greatest relative variation occur in the chalk ooze. More consistent, lower values are common in the nannofossil chalk. Within the intervals sampled for laboratory measurements, porosities decrease slightly with depth. Unfortunately, the highest sampling densities occur in the interval where GRAPE porosities indicate the least decrease with depth.

### Water Content

Water content (per cent total weight) ranges from 64 per cent in the chalk ooze to 35 per cent in the nannofossil chalk. A value of 25 per cent is found in the lower chalk ooze but higher values are more common. A relatively high water content at 251 meters corresponds to the sample of low bulk density and low grain density. Low and fairly uniform water content in the nannofossil chalk contrasts with the overlying chalk ooze.

### Grain Density

Average grain densities range from 2.38 g/cc to 2.69 g/cc and vary less in the nannofossil chalk than in the overlying chalk ooze. A sharp decrease in grain density, from 2.74 g/cc to 2.40 g/cc, is observed in the upper 230 meters of the chalk ooze. A value of 2.38 g/cc, the lowest density observed, is found at 251.5 meters. Below this depth, the average grain density increases in the lower chalk ooze. The basal nannofossil chalk has grain densities of 2.62 g/cc to 2.66 g/cc.

### Sonic Velocity

Sonic velocities in the upper 330 meters were measured in split core sections confined to the core liner. Samples from greater depths were removed from the core liner and in several cases velocities were measured parallel as well as normal to bedding. In some instances, such as in the interval 345-385 meters, velocities were higher parallel to bedding. Velocities measured normal to bedding were generally higher than parallel measurements in the interval 400 to 430 meters. Differences in sonic velocity perpendicular and parallel to bedding ranged from as little as 0.01 km/sec to as much as 0.53 km/sec. The larger differences are probably due less to the anisotropic characteristics of the sediment than to inconsistencies in technique during testing. Extremely low values are almost certainly due to technique and are not representative of the overall sonic velocity characteristics of the sediment.

Sonic velocities are relatively constant in the upper 330 meters averaging 1.53 km/sec with extremes of 1.34 km/sec and 1.84 km/sec in the depth interval of 215 to 243 meters. A significant increase in velocity (to an average of 2.90 km/sec) is encountered in the interbedded chert and nannofossil chalk limestone between 345 meters and the basalt at a depth of 432 meters. Velocities of 1.85 km/sec to 2.44 km/sec occur at depths of approximately 359 meters, 422 meters, and 431 meters in chalk limestone with essentially no interbedded chert. Five measurements of sonic velocity on one sample of basalt recovered from DSDP 157 averaged 4.54 km/sec with a range of 4.46 km/sec to 4.62 km/sec.

### Natural Gamma Radiation

Relatively few core sections were suitable for natural gamma measurements. Since most of the data are limited to a small depth interval, no trends can be recognized in the sediment except that gamma activity is higher in the lower chalk ooze (260-270 m) than in the underlying nannofossil chalk. Within the short interval tested (260-340 m), the gamma activity is quite variable.

### Shear Strength

A few vane shear measurements were possible in selected intervals of DSDP 157 and 157A. The lowest values of 9.8 and 31.6 g/cm$^2$ are characteristic of the foraminiferal nannofossil chalk ooze in Cores 1 and 2 of DSDP 157A. High water contents and porosities and low bulk densities are typical of this sediment. Shear strenghts of 215.1 to 620.1 g/cm$^2$ occur in the lower chalk ooze from 225 meters to 265 meters. This deeper chalk ooze has lower water contents and porosities and higher bulk densities than the overlying sediment. Although a value of 620.1 g/cm$^2$ occurs at 252 meters, values of 200 to 400 g/cm$^2$ are most common. Shear strengths of 150.5 to 1474.4 g/cm$^2$ occur in the nannofossil chalk from the interval 288 to 333 meters, with the highest values most common in the deepest cores. Low values of 150.5 to 243.3 g/cm$^2$ characterize the upper chalk. Vane shear testing in the chert and chalk limestone was not possible for obvious reasons.

## DISCUSSION AND SUMMARY

The most striking feature of the section sampled by DSDP 157 is its great uniformity, disturbed only by diagenetic changes. This must indicate very stable depositional conditions in the area, thereby strongly supporting a stable latitude for the Carnegie Ridge.

The sediment is siliceous-calcareous ooze to about 240 meters, then changes gradually over the interval 240 to 284 meters to a semi-indurated chalk. The transitional zone, probably consisting of alternating chalk and ooze beds but obscured by coring disturbance, corresponds to a prominent acoustic reflector. The sediment is dominated by nannofossils with abundant foraminifers in the Pleistocene deposits and diatoms abundant throughout. The diversity of the calcareous microfossils is low and the nannofossils are generally poorly preserved. Radiolaria are ubiquitous and of great diversity but become poorly preserved below 324 meters, and disappear altogether with all other siliceous fossils below 345 meters, and disappear altogether with all other siliceous fossils below 345 meters. All freshly opened cores gave off $H_2S$, and pyrite is a ubiquitous component of the sediments. The only other nonbiogenous components are glauconite (generally rare and filling foraminiferal chambers) and rare, mostly light-colored, volcanic glass. The minor lithologic variation between 0 and 345 meters results from subtle changes in the dominant colors from greenish grays to olives to olive browns.

The paleontologic data suggest a sedimentation rate of 60 m/$10^6$ yrs from the surface to about 300 meters. Below 330 meters, the rate is somewhat uncertain but may exceed 29 m/$10^6$ yrs. Between 300 and 330 meters, an interval straddling the Mio-Pliocene boundary, the rate is either markedly reduced or a hiatus of about 1 m.y. is present. Neither the lithologic nor the physical properties of the sediments give a clue to the change in sedimentation regime which this implies.

The average measured acoustic velocity above 345 meters is 1.63 km/sec, a value somewhat, and perhaps significantly higher than the surprisingly low value of 1.53 km/sec calculated from the profiler records. Since the number of reliable sonic measurements is small due to the disturbed condition of the cores, it is difficult to evaluate the meaning of this discrepancy. The porosity of the upper unit decreases irregularly from more than 75 per cent in the disturbed sediment above 200 meters to less than 50 per cent near the base of the section.

At 345 meters, the drilling rate decreased abruptly and the first of a series of cherts that continue to the base of the section at 434 meters was cored. The top of the chert chalk sequence can be confidently correlated with the smooth acoustic basement of the profiler records.

The chert in the calcareous deposits forms nodules, stringers, and irregular masses, rarely as much as 1 cm across. Volumetrically, at least 90 per cent of this unit is chalk or chalk limestone. The chert is mostly olive brown in color, has a conchoidal fracture and is largely chalcedonic quartz with up to 50 per cent relict calcite inclusions. Siliceous tests either near or in the chert masses are extremely rare.

The chalk enclosing and separating cherty beds is similar to the overlying unit except for the lack of siliceous microfossils and the absence of $H_2S$ odor. The increased circulation and torque required to penetrate the chert resulted in poor recovery of the softer intervening calcareous sediment.

Sonic velocities in the 345 to 434 meters interval were generally measured on the more indurated carbonate fragments which tended to contain chert masses. The large range of values, from 1.9 to 4.2 km/sec, reflects the variation in proportion of the two rock types, and is certainly too high for the interval as a whole.

Basement at DSDP 157 is basalt. The upper few centimeters are vesicular, have flow structures, and consist of strongly devitrified silicified glass. Below this, the basalt is fairly massive with plagioclase laths and interstitial augite in an altered groundmass. The basalt is cut by joints and fractures filled with calcite, serpentine, pyrite, and a few other minerals. The gradation from chilled margin to crystalline interior and the absence of metamorphism or metasomatism of the overlying sediments show that the basalt is a flow rather than an intrusion.

As regards the hypothesis for the origin of the Panama Basin (van Andel et al., 1971), the data of DSDP 157 confirm that the Carnegie Ridge has remained within the depositional regime of the equatorial current system now prevailing at the site since the inception of deposition there. The lower sedimentary sequences at this site is very nearly identical with the lowermost deposits at DSDP 155 and 158. Magnetic anomaly data (van Andel et al., 1971; Heinrichs, in press) indicate that the Galapagos Rift north of DSDP 157 and west of the fracture zone at 85°W was activated somewhat before anomaly 3 time or around 4 to 5 m.y. ago. It is at this point that the hiatus or highly reduced sedimentation rate is observed at DSDP 157. Thus, this break may be at least partly the result of the tectonic disturbance produced by the onset of rifting.

In view of the middle Miocene age of the basement at DSDP 155 and 158, the much younger age of DSDP 157 is surprising and might be construed as an argument against the validity of the ancestral Carnegie Ridge concept. However, the approximate age of basement will be determined only if the oldest sediment in the area has been sampled. Since the acoustic basement here is chert, it effectively obscures the relief of the underlying volcanic basement. It is entirely possible, in fact even probable, that this volcanic basement. It is entirely possible, in fact even probable, that this volcanic basement possesses significant relief. Unless by coincidence the site is located in a position where the volcanic basement is deep and therefore was covered early by deposition, the chances are that the oldest sediment recovered was deposited significantly later than the time of formation of the basement. Alternatively, if the age of the basalt corresponds with that of the oldest sediment, late volcanism, either related to the Galapagos volcanic complex or to the process of rifting, may have produced an anomalously young basement. In the absence of an absolute age determination of the basalt itself,—which is probably not obtainable because of the alteration of the rock—the choice between these alternatives remains open. Furthermore, since the relief of the volcanic basement is not observable with ordinary geophysical techniques, there is no means of establishing whether the oldest and thickest sedimentary section in the area has been sampled.

The seismic reflection records of the site area show several internal unconformities in the upper portion of the sedimentary section to a depth of approximately 110 to 125 meters. This includes the entire Pleistocene portion of the sedimentary sequence. Since it is reasonable to assume that these unconformities are related to the processes causing erosion of the crest of the Carnegie Ridge and the formation of the canyons and gullies on its south flank, these erosion processes appear to be due to Pleistocene current conditions rather than to tectonic processes such as uplift of the ridge, which probably occurred considerably earlier during the onset of rifting.

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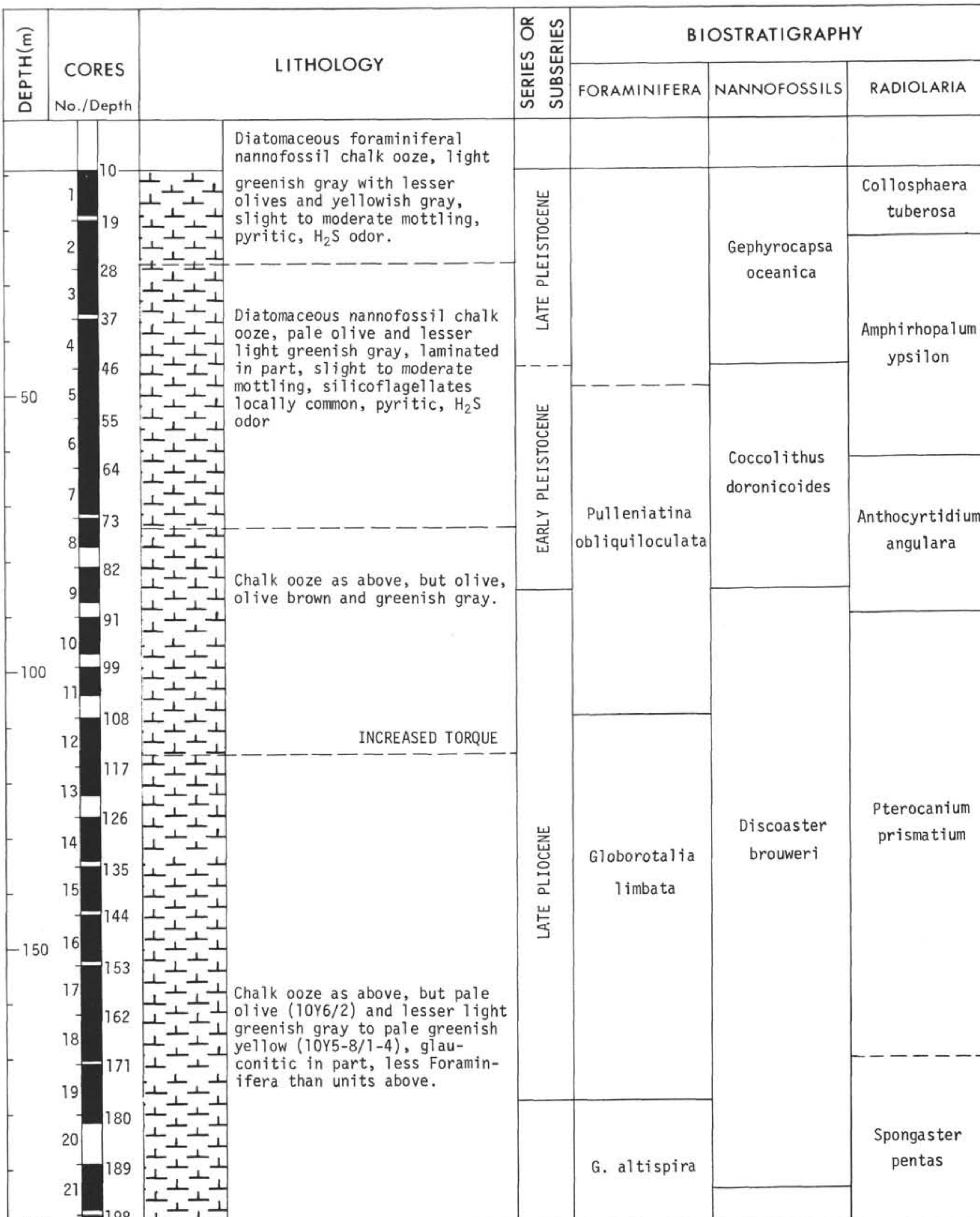
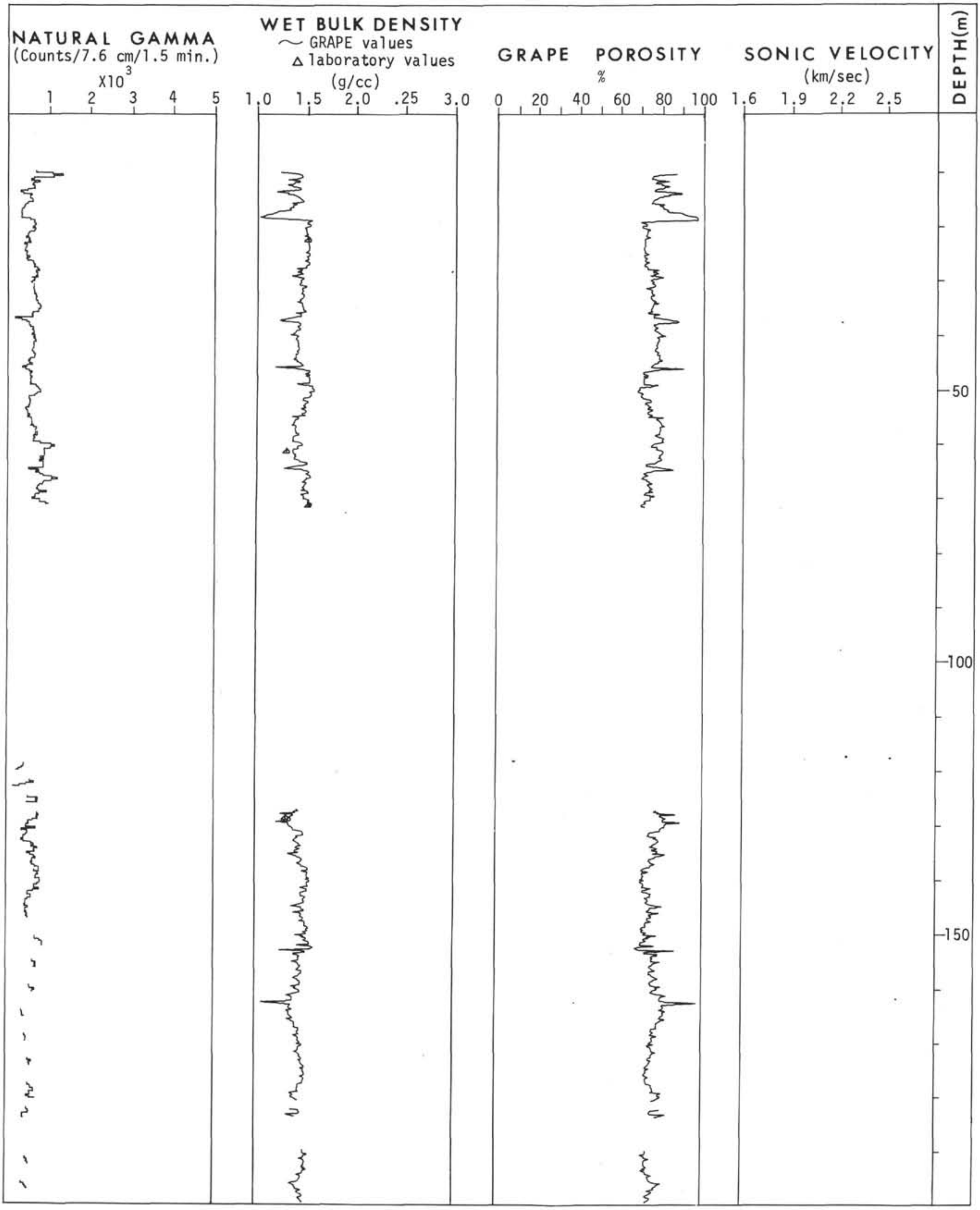



Figure 4. *DSDP 157, graphic hole summary. Vertical scale 1 cm = 10 m (1:1000).*

PHYSICAL PROPERTIES



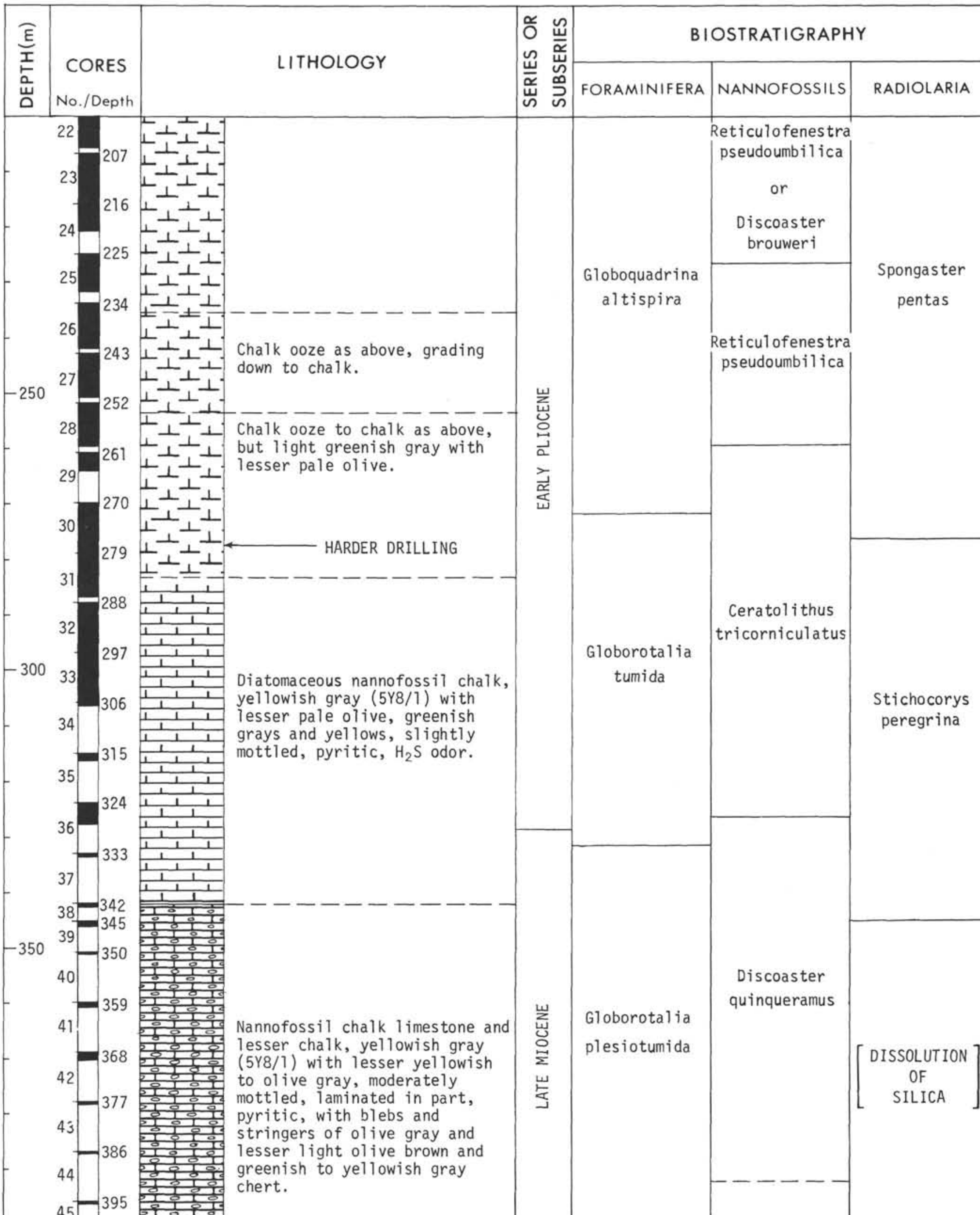



Figure 4. *(Continued).*

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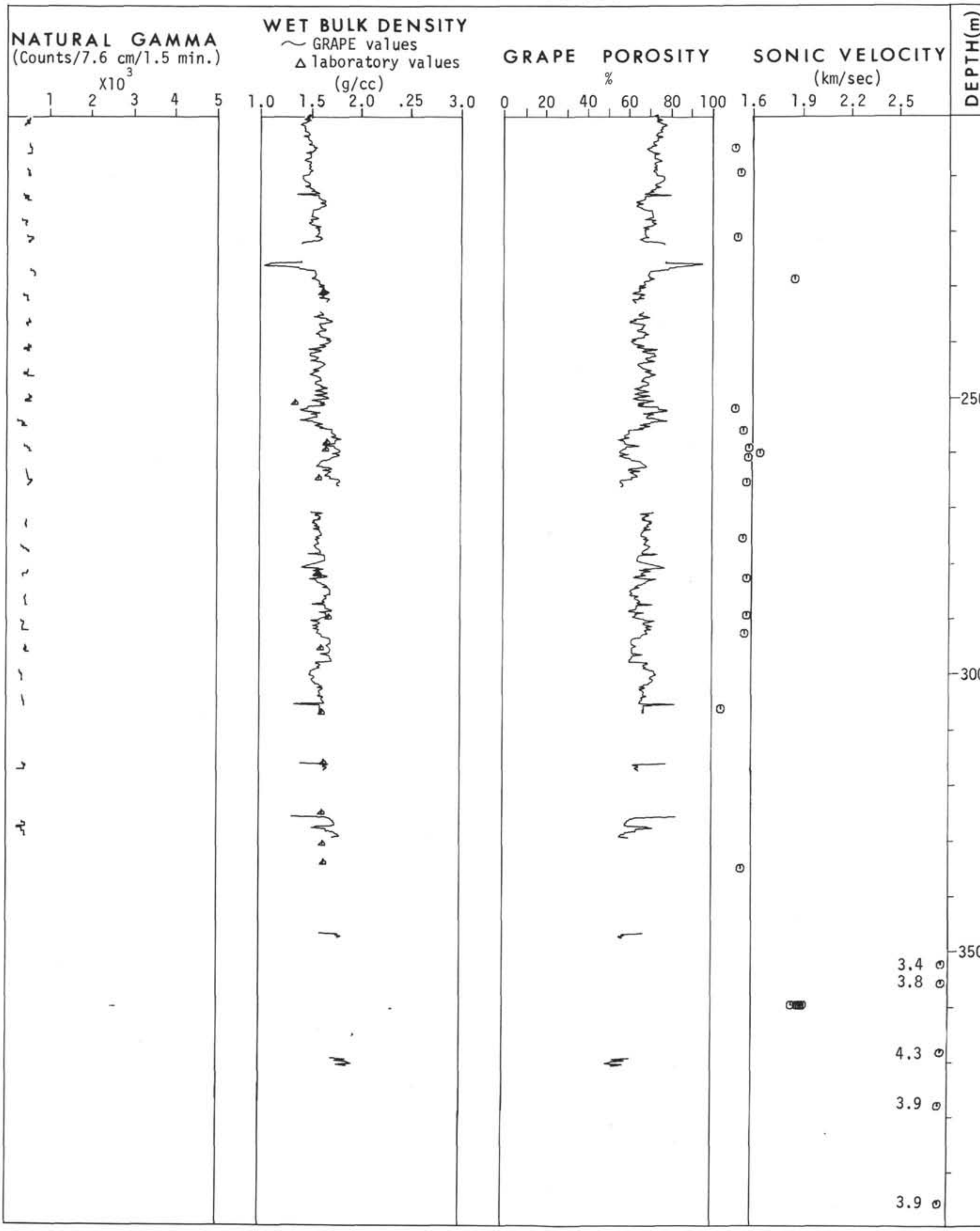

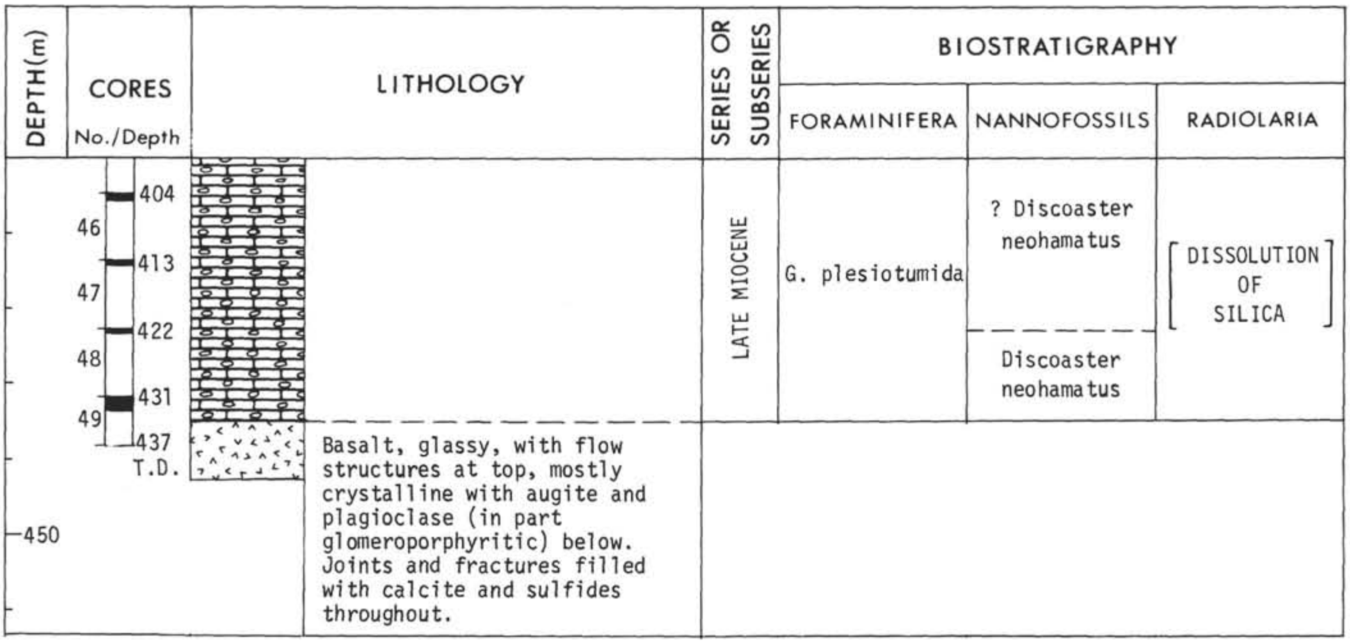


Figure 4. *(Continued)*.

SITE 157A

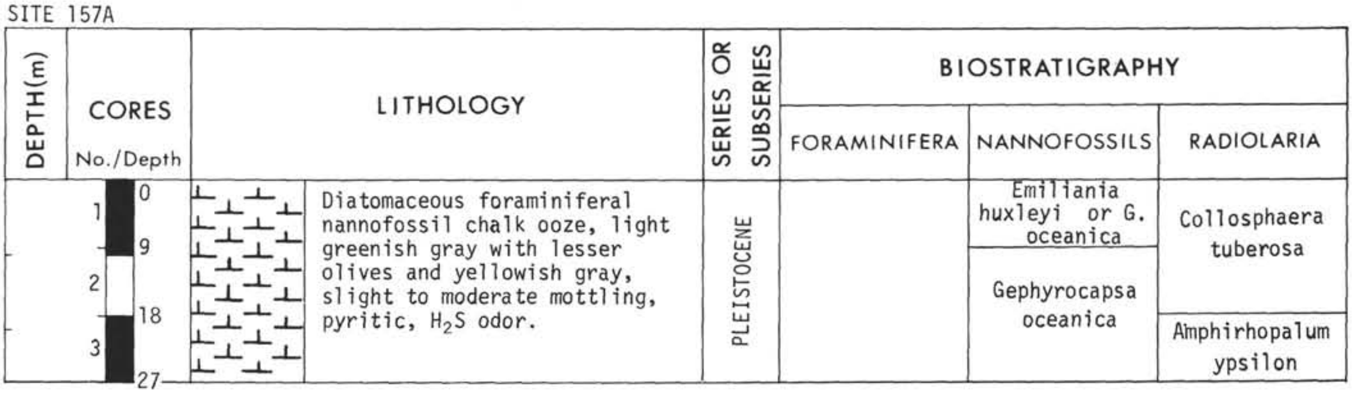


Figure 4. *(Continued)*.

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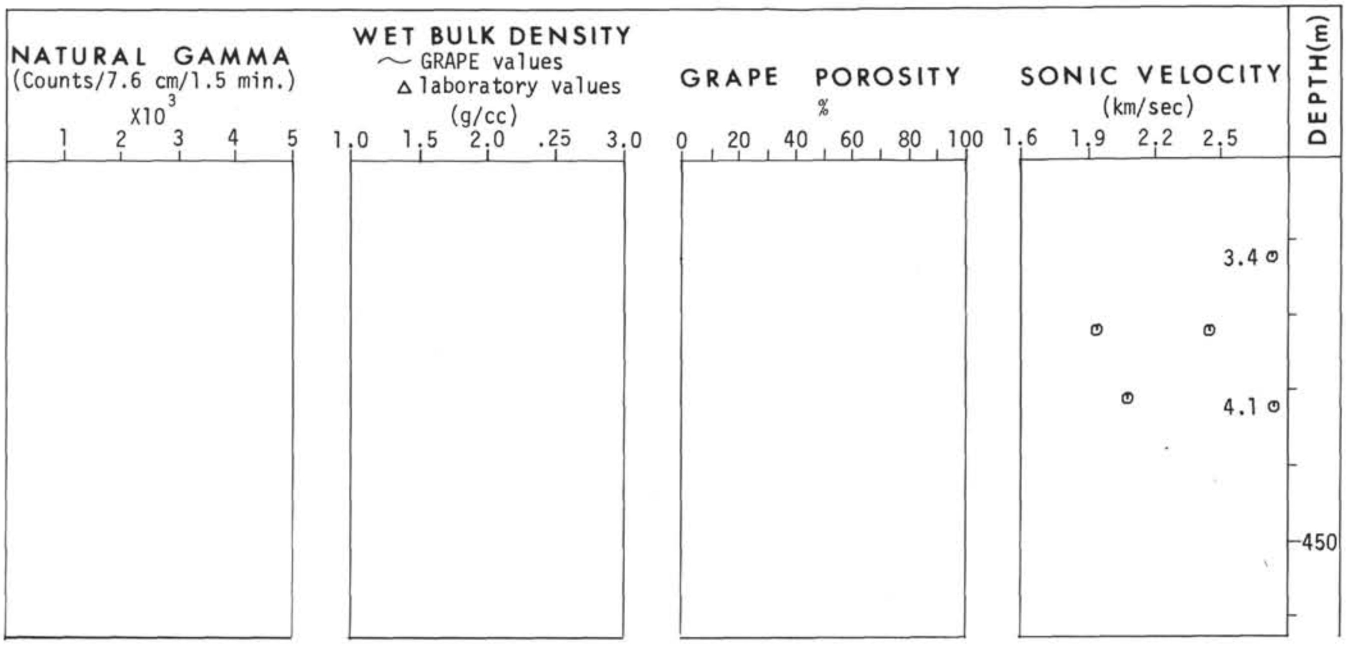


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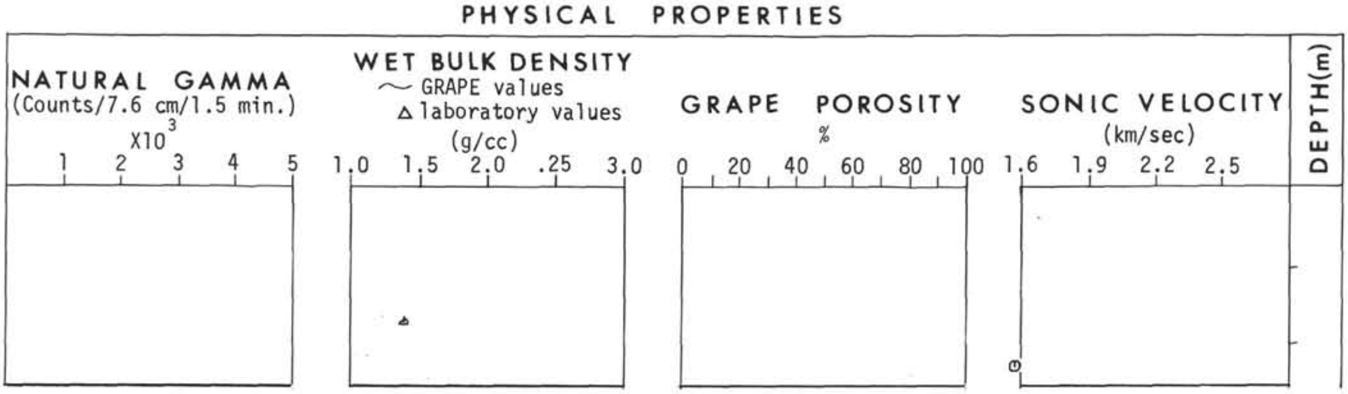
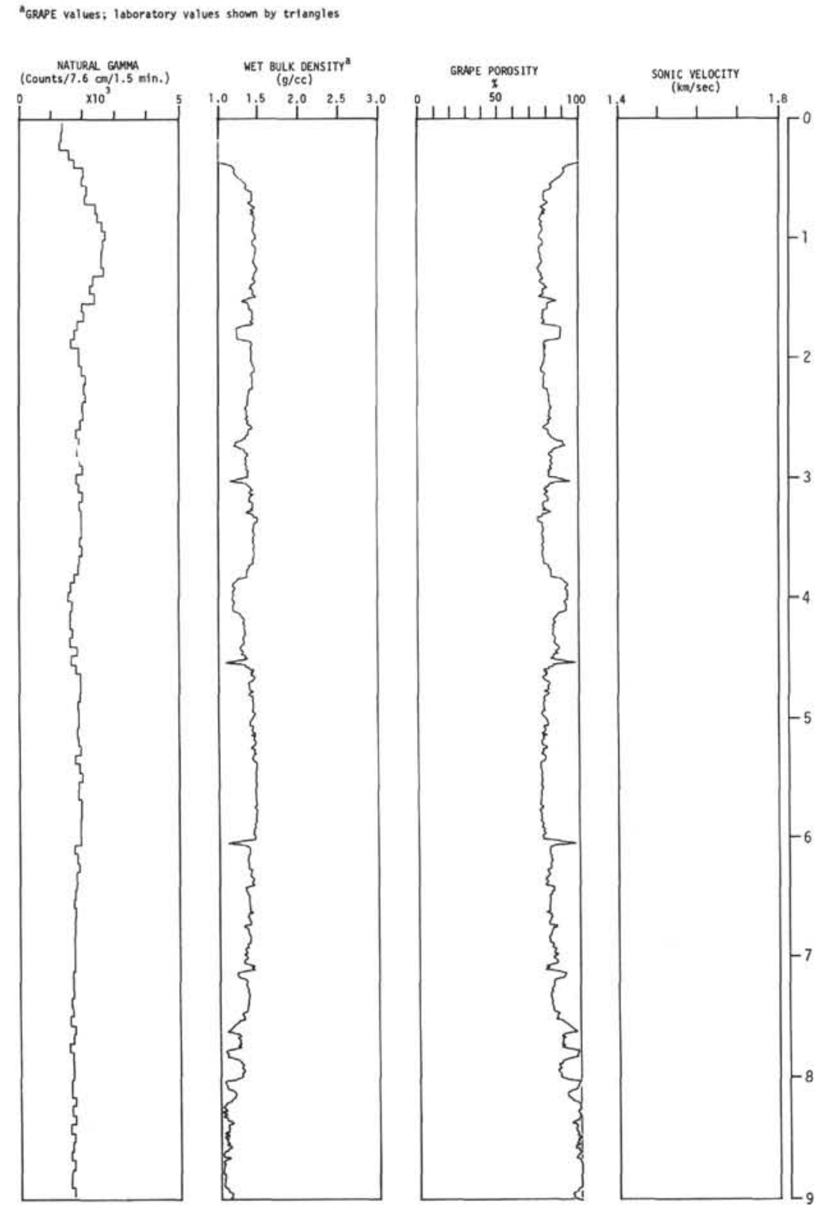


SITE: 157 HOLE: CORE: 1 Cored Interval: 10-19 m

| AGE: SERIES | ZONE: Foram | ZONE: Nanno | ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres (Foram, Nanno, Rad); % $CaCO_3$ 0–50–100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| UPPER PLEISTOCENE | Not Named | *Gephyrocapsa oceanica* | *Collosphaera tuberosa* | 0–1.5 | 1 | VOID | | * | * | Nannofossil - foram chalk ooze, greenish gray, diatoms and rads common, spicules and silico-flagellates present | A G |
| | | | | 1.5–3 | 2 | | | | | | |
| | | | | 3–4.5 | 3 | NOT OPENED | | | | | |
| | | | | 4.5–6 | 4 | | | | | | |
| | | | | 6–7.5 | 5 | | | * | | Nannofossil - foram chalk ooze, mottled, light olive gray to yellowish gray | |
| | | | | | | | | * | | Same, light greenish gray | |
| | | | | 7.5–9 | 6 | NOT OPENED | | | | | |
| | | | | | CC | | | * | * | Same, massive, yellowish gray glauconite present | A G A G |

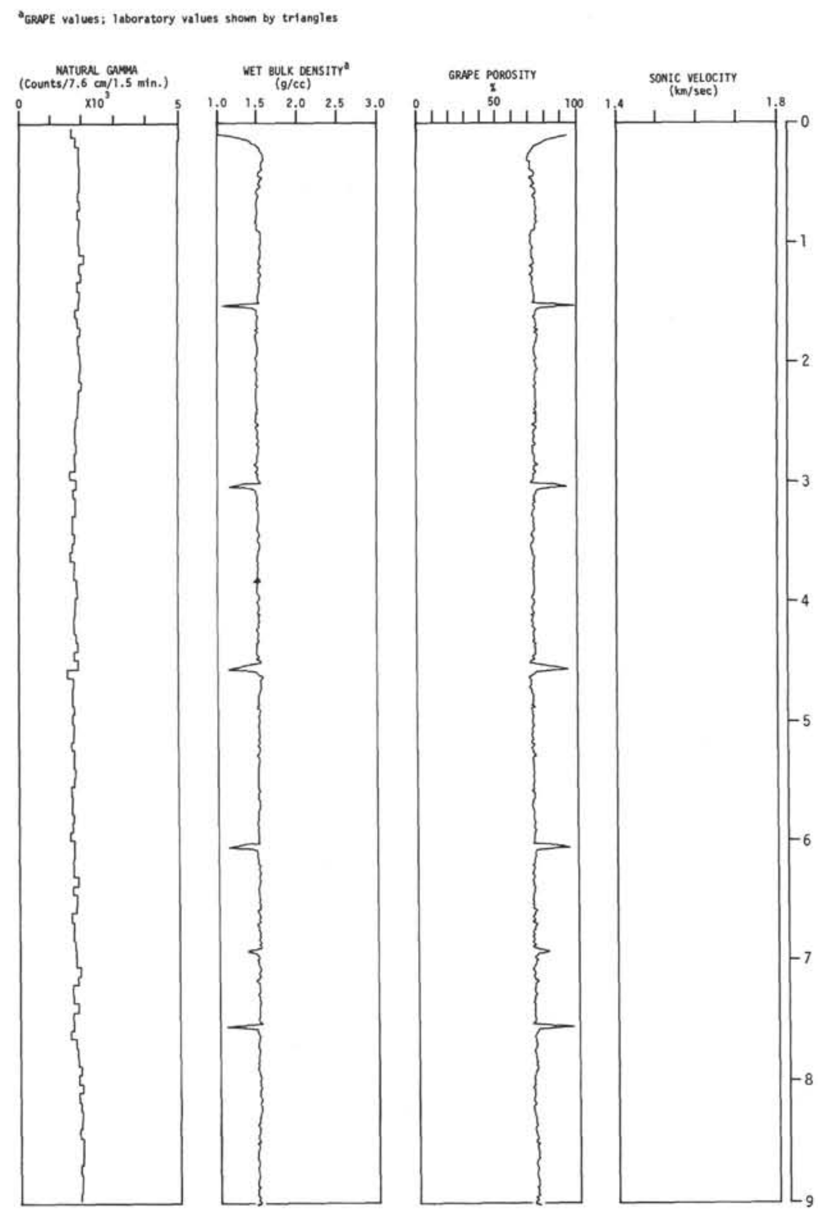
PHYSICAL PROPERTIES



SITE: 157 HOLE: CORE: 2 Cored Interval: 19-28 m

| SERIES | AGE ZONE: Foram | AGE ZONE: Nanno | AGE ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres: Foram | Nanno | Rad | % $CaCO_3$ (0–50–100) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPPER PLEISTOCENE | Not Named | *Gephyrocapsa oceanica* | *C. tuberosa* | 0–1.5 | 1 | | | * * | | Nannofossil chalk ooze, slightly mottled, yellowish gray to light olive gray, diatoms and forams common | | | | |
| | | | *Amphirhopalum ypsilon* | 1.5–3 | 2 | | | | | | | | | |
| | | | | 3–4.5 | 3 | | | * * | | Same, light greenish gray, rare gray streaks with pyrite, strong $H_2S$ odor | | | | |
| | | | | 4.5–6 | 4 | | | * | | | | | | |
| | | | | 6–7.5 | 5 | | | * | | Abundant diatoms | | | | |
| | | | | 7.5–9 | 6 | | | * | | | | | | |
| | | | | | CC | | | * | * | | A G | A G | | |

PHYSICAL PROPERTIES



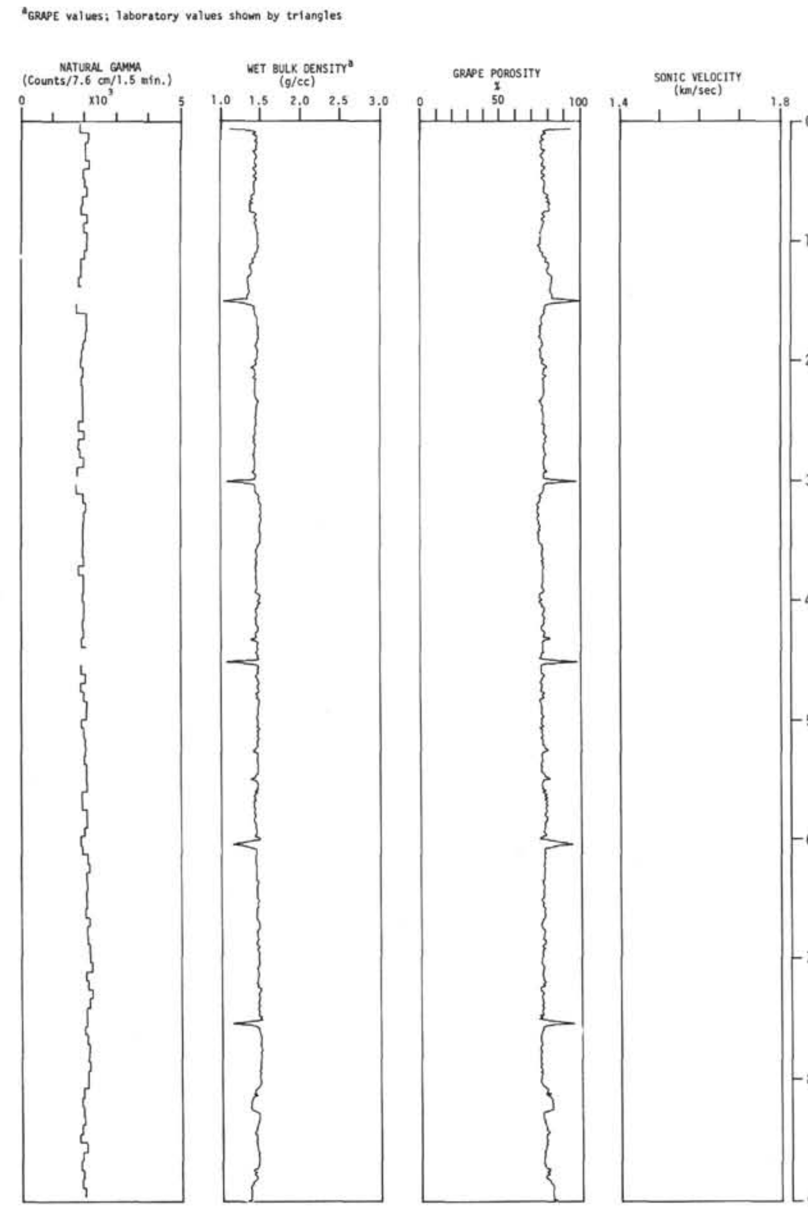
SITE: 157 HOLE: CORE: 3 Cored Interval: 28-37 m

| SERIES | AGE ZONE: Foram | AGE ZONE: Nanno | AGE ZONE: Rad | SECTION | DESCRIPTION |
|---|---|---|---|---|---|
| UPPER PLEISTOCENE | Not Named | *Gephyrocapsa oceanica* | *Amphirhopalum ypsilon* | 1 | Nannofossil chalk ooze, light olive to light greenish gray, 2-4 mm laminae of medium light gray pyrite rich, forams abundant, diatoms and rads common, silicoflagellates and glass present |
| | | | | 2 | Same, pale olive |
| | | | | | Same, local light olive brown layers |
| | | | | 3 | $H_2S$ odor |
| | | | | 4 | Pyritic medium gray layers, forams abundant |
| | | | | 5 | Local light greenish gray layer |
| | | | | | Clay present |
| | | | | 6 | |
| | | | | CC | |

MICROFOSSIL Abund/Pres (CC): Foram C M; Nanno A G; Rad A G

DEPTH (Meters): 1, 2, 3, 4, 5, 6, 7, 8 — LITHOLOGY, Disturbance, Smear Slide, Paleo. sample, % $CaCO_3$ (0, 50, 100)

PHYSICAL PROPERTIES

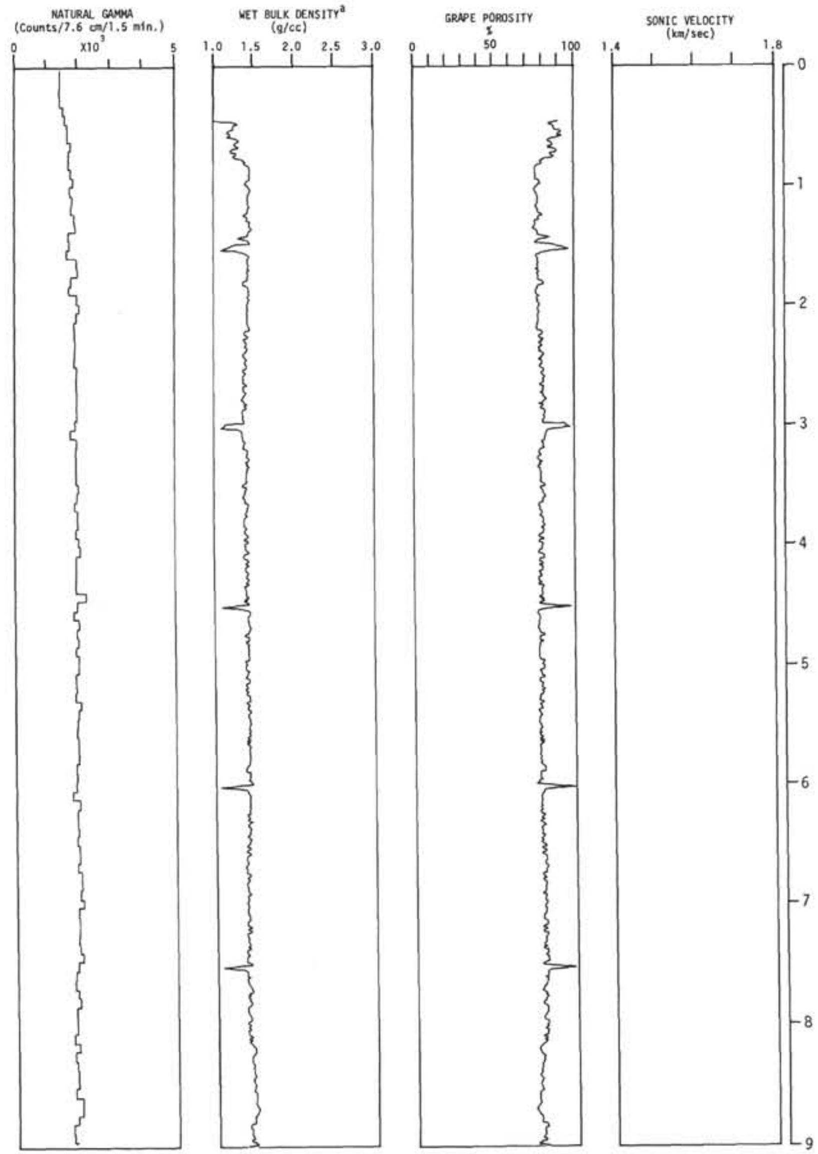


SITE: 157 HOLE: CORE: 4 Cored Interval: 37-46 m

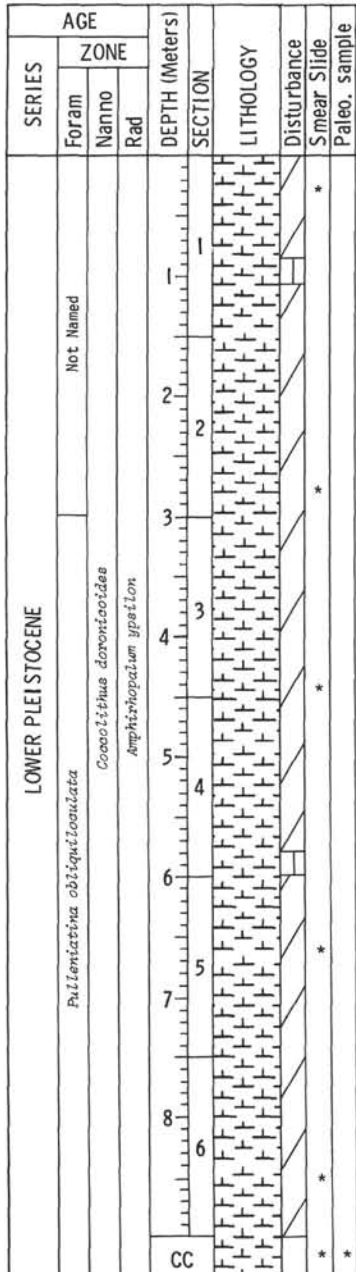
| SERIES | AGE ZONE: Foram | AGE ZONE: Nanno | AGE ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres: Foram, Nanno, Rad; % $CaCO_3$ (0, 50, 100) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| UPPER PLEISTOCENE | Not Named | *Gephyrocapsa oceanica* | *Amphirhopalum ypsilon* | 0–1 | 1 | | | * | | Nannofossil chalk ooze, pale olive, few gray pyritic streaks, diatomaceous, forams abundant, rads and silicoflagellates present | |
| | | | | 2 | 2 | | | * | | Same, few light olive brown streaks | |
| | | | | 3–4 | 3 | | | | | | |
| | | | | 5 | 4 | | | * | | Same, few light greenish gray and dusky yellow layers | |
| | | | | 6–7 | 5 | | | * | | | |
| | | | | 8 | 6 | | | * | | | |
| | | | | | CC | | | * | * | | A M A G A G |

PHYSICAL PROPERTIES

[a]GRAPE values; laboratory values shown by triangles



SITE: 157 HOLE: CORE: 5 Cored Interval: 46-55 m




DESCRIPTION

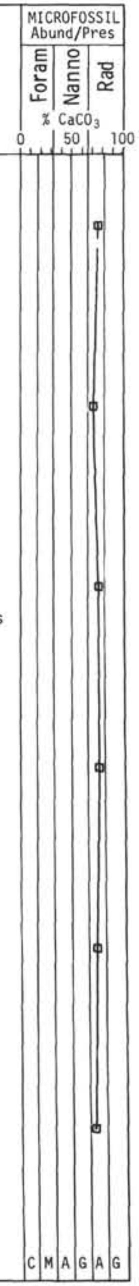
Nannofossil chalk ooze, pale olive, local gray pyritic layers, abundant forams and diatoms, silicoflagellates and rads present

---Color change (325 cm)

Same, light greenish gray with medium light gray laminations, pyrite abundant, including fromboids

Same, pale olive, locally light olive

Same, light greenish gray, locally light olive

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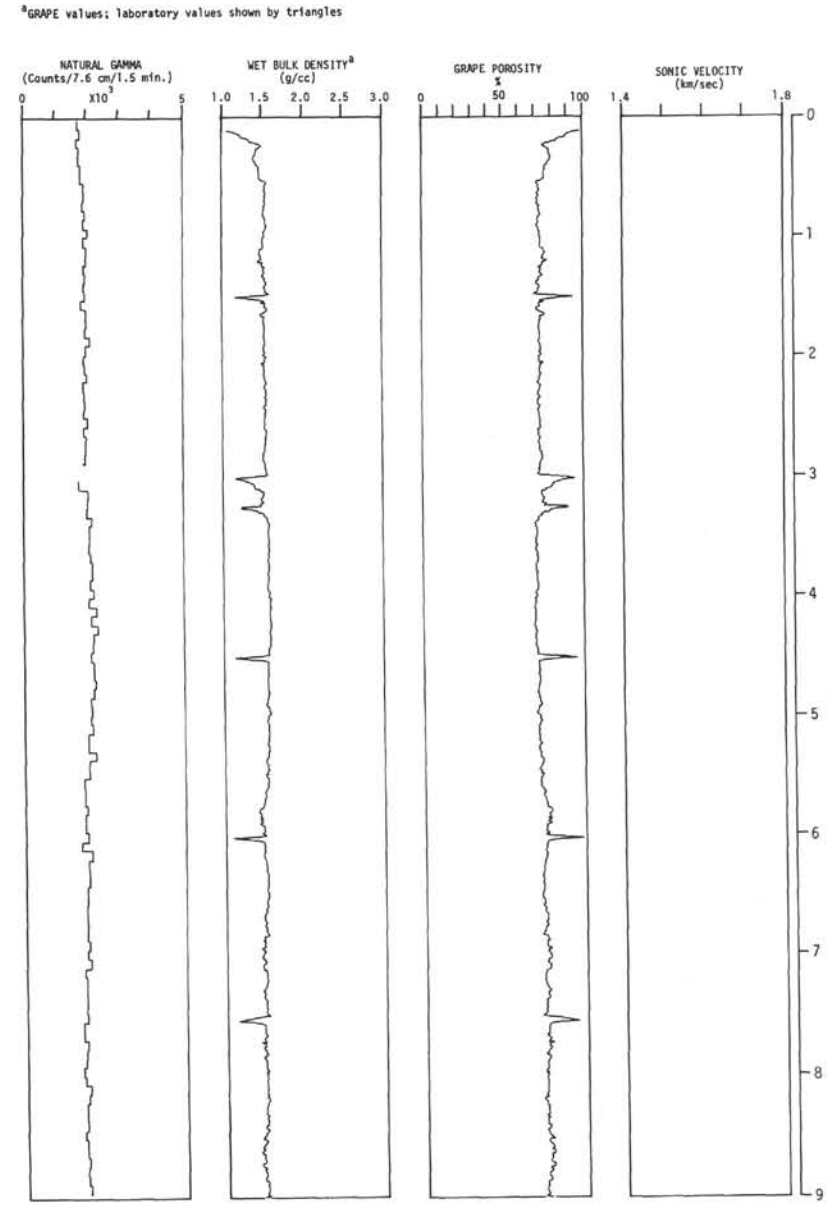
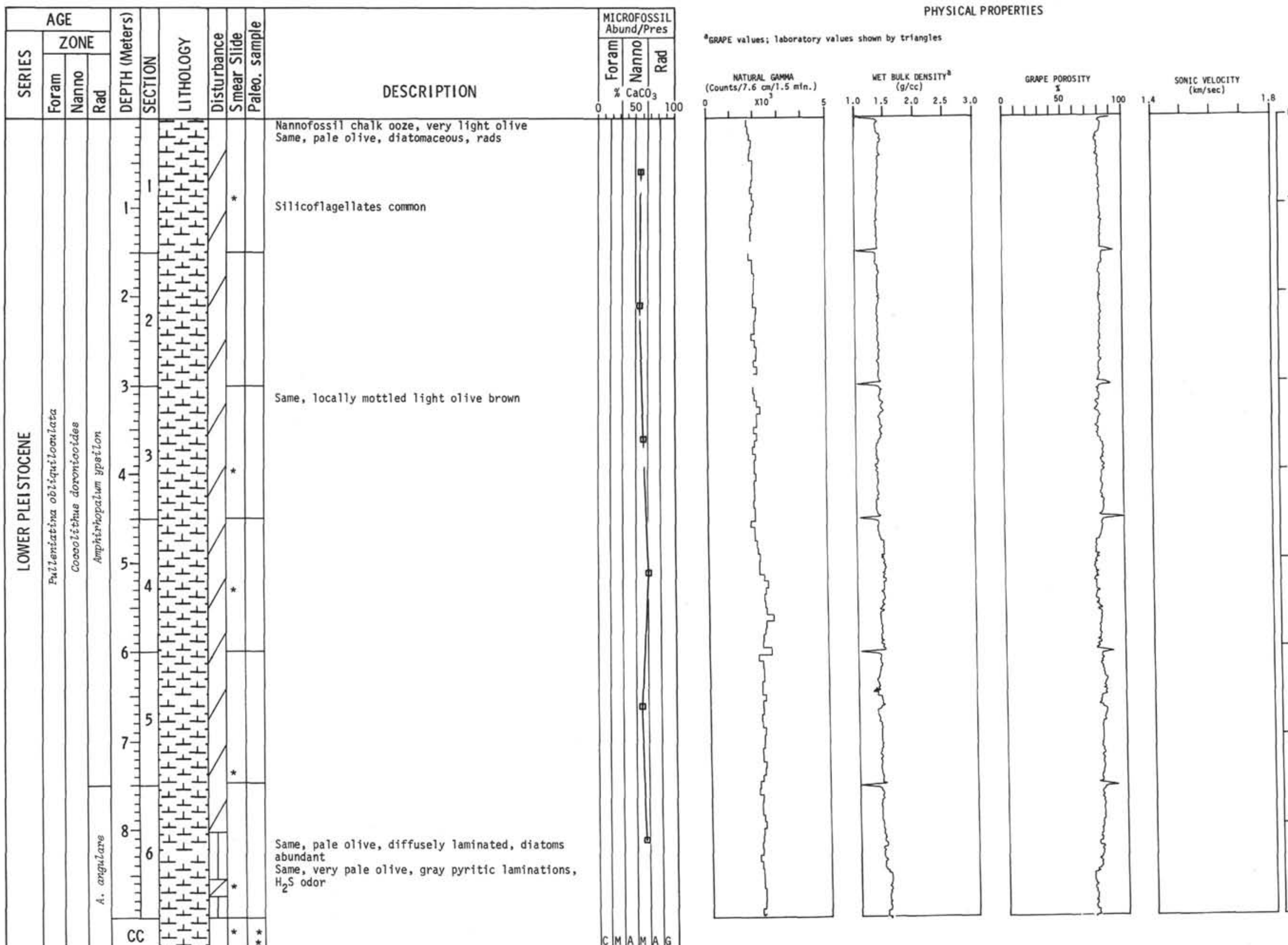


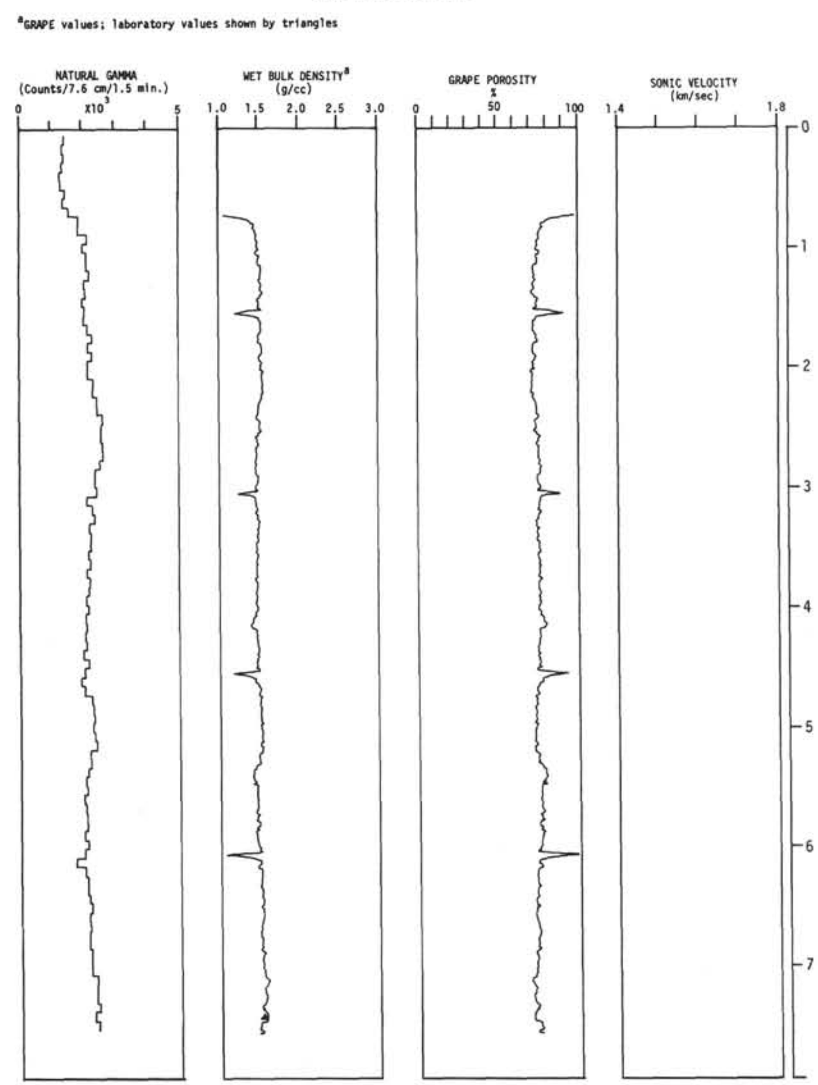
SITE: 157 HOLE: CORE: 6 Cored Interval: 55-64 m



SITE: 157 HOLE: CORE: 7 Cored Interval: 64-73 m

| SERIES | AGE ZONE: Foram | AGE ZONE: Nanno | AGE ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres: Foram / Nanno / Rad; % $CaCO_3$ (0, 50, 100) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LOWER PLEISTOCENE | *Pulleniatina obliquiloculata* | *Coccolithus doronicoides* | *Anthocyrtidium angulare* | 0–1 | | EMPTY | | | | | |
| | | | | 1 | 1 | | | | * | Nannofossil chalk ooze, pale olive diatomaceous, forams and rads common, silicoflagellates present | |
| | | | | 2 | 2 | | | | | Same, mottled to pale greenish yellow and light olive brown | |
| | | | | 3–4 | 3 | | | | | | |
| | | | | 5 | 4 | | | | * | | |
| | | | | 6–7 | 5 | | | | | | |
| | | | | | CC | | | * | ** | | A M A G |

PHYSICAL PROPERTIES



SITE: 157 HOLE: CORE: 8 Cored Interval: 73-82 m

| SERIES (AGE) | ZONE: Foram | ZONE: Nanno | ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION |
|---|---|---|---|---|---|---|---|---|---|---|
| LOWER PLEISTOCENE | *Pulleniatina obliquiloculata* | *Coccolithus doronicoides* | *Anthocyrtidium angulare* | 0–1.5 | 1 | | | * | | Nannofossil chalk ooze, pale olive, slightly mottled, forams abundant, diatoms common, rads silicoflagellates present |
| | | | | | | | | * | | Same, light greenish gray |
| | | | | 1.5–3 | 2 | | | | | Same, mottled with medium gray |
| | | | | | | | | | | Pyritic streaks |
| | | | | | | | | * | | Laminated pale olive |
| | | | | | | | | | | Laminated greenish gray |
| | | | | 3–4.5 | 3 | | | * | | Same, laminated pale olive and light greenish gray, mottled |
| | | | | 4.5–6 | 4 | | | * | | Medium gray streaks |
| | | | | | | | | | | Glauconite (?) present, as are silicoflagellates |
| | | | | CC | CC | | | * | * * | |

| MICROFOSSIL Abund/Pres | Foram | Nanno | Rad |
|---|---|---|---|
| | C M | A M | A G |

% $CaCO_3$: 0 — 50 — 100

SITE: 157 HOLE: CORE: 9 Cored Interval: 82-91 m

| AGE: SERIES | ZONE: Foram | ZONE: Nanno | ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| LOWER PLEISTOCENE | *Pulleniatina obliquiloculata* | *Coccolithus doronicoides* | *Anthocyrtidium angulare* | 0–1 | 1 | EMPTY | |
| | | | | 1 | 1 | | Nannofossil chalk ooze, light olive with laminations of light greenish gray and moderate olive brown, forams and diatoms abundant |
| | | | | 1–2 | 1 | | Same, moderate olive brown mottled pale greenish yellow, pale olive, and light olive brown, silicoflagellates present |
| UPPER PLIOCENE | | *Discoaster brouweri* | | 2–4 | 2, 3 | | |
| | | | | 5 | 4 | | Same, light olive, mottled laminations 2-10 mm across of moderate olive brown, pale olive, pale greenish yellow |
| | | | | 6 | 5 | | Same, olive brown mottled to moderate olive brown |
| | | | | 7 | 5 | | ---Color change<br>Same, light olive gray; |
| | | | *Pterocanium prismatium* | 8 | 6 | | Same, light olive brown, local mottles of yellowish gray |
| | | | | | CC | | |

Column headings also printed: Disturbance, Smear Slide, Paleo. sample

MICROFOSSIL Abund/Pres: Foram, Nanno, Rad

% $CaCO_3$: 0, 50, 100

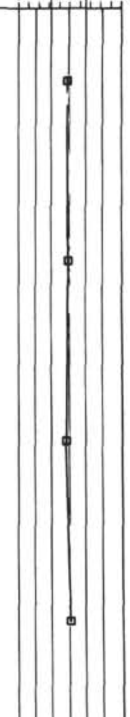
C Pd A ?M A G

SITE: 157 HOLE: CORE: 10 Cored Interval: 91-99 m

| SERIES | AGE ZONE Foram | AGE ZONE Nanno | AGE ZONE Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION |
|---|---|---|---|---|---|---|---|---|---|---|
| UPPER PLIOCENE | *Pulleniatina obliquiloculata* | *Discoaster broweri* | *Pterocanium prismatium* | 0–1.5 | 1 | | | * <br> * | | Nannofossil chalk ooze, yellowish olive brown mottled to moderate olive brown<br>---Color change<br>Same, pale olive, rads, diatoms, forams common, silicoflagellates and discoasters present<br>Pyrite framboids |
| | | | | 1.5–3 | 2 | | | | | |
| | | | | 3–4.5 | 3 | | | * | | |
| | | | | 4.5–6 | 4 | | | | | Same, pale grayish olive |
| | | | | CC | | | | | * <br> * | |

MICROFOSSIL Abund/Pres: Foram, Nanno, Rad

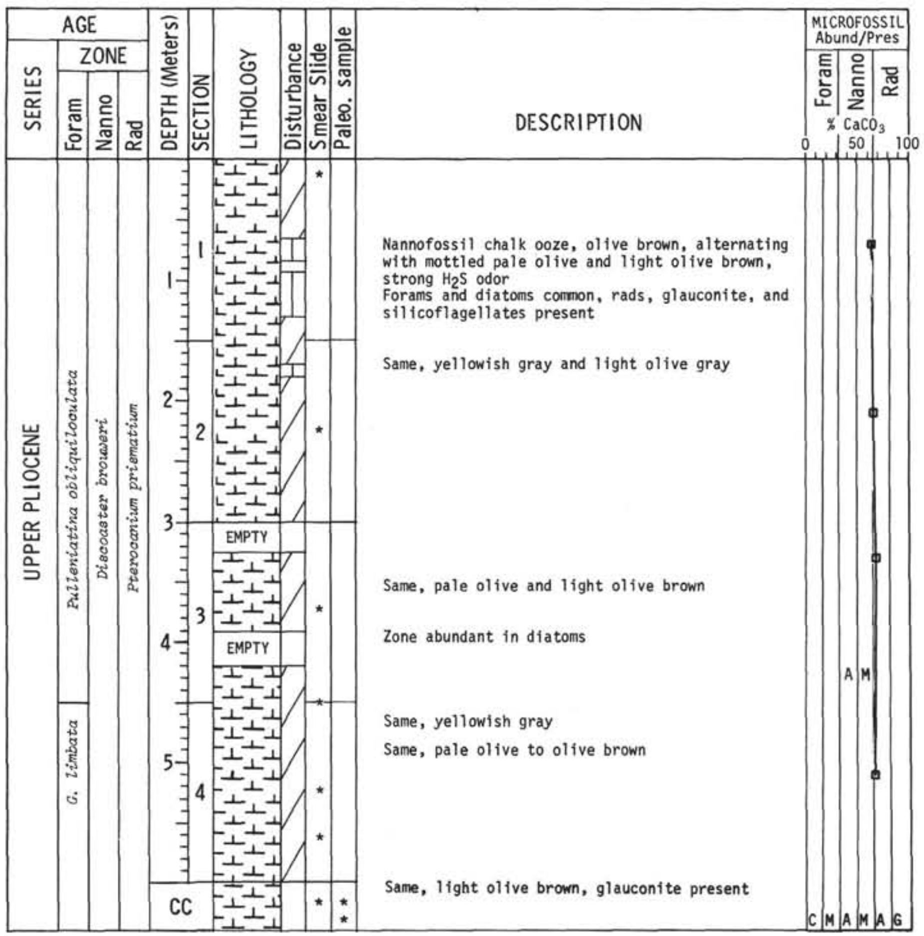
% $CaCO_3$ 0 50 100



A Pd A G

R Pd A M A G

SITE: 157 HOLE: CORE: 11 Cored Interval: 99-108 m



SITE: 157 HOLE: CORE: 12 Cored Interval: 108-117 m

| AGE: SERIES | ZONE: Foram | ZONE: Nanno | ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres: Foram | Nanno | Rad |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPPER PLIOCENE | *Globorotalia limbata* | *Discoaster brouweri* | *Pterocanium prismatium* | 0–1 | 1 | NOT OPENED | | | | | | | |
| | | | | 1–3 | 2 | | | | | | | | |
| | | | | 3–4.5 | 3 | | | | | | | | |
| | | | | 4.5–6 | 4 | | | | | | | | |
| | | | | 6–7.5 | 5 | | | | | | | | |
| | | | | 7.5–9 | 6 | | | | | | | | |
| | | | | | CC | | | | * * | | C M | A G | C G |

% $CaCO_3$: 0 50 100

SITE: 157 HOLE: CORE: 13 Cored Interval: 117-126 m

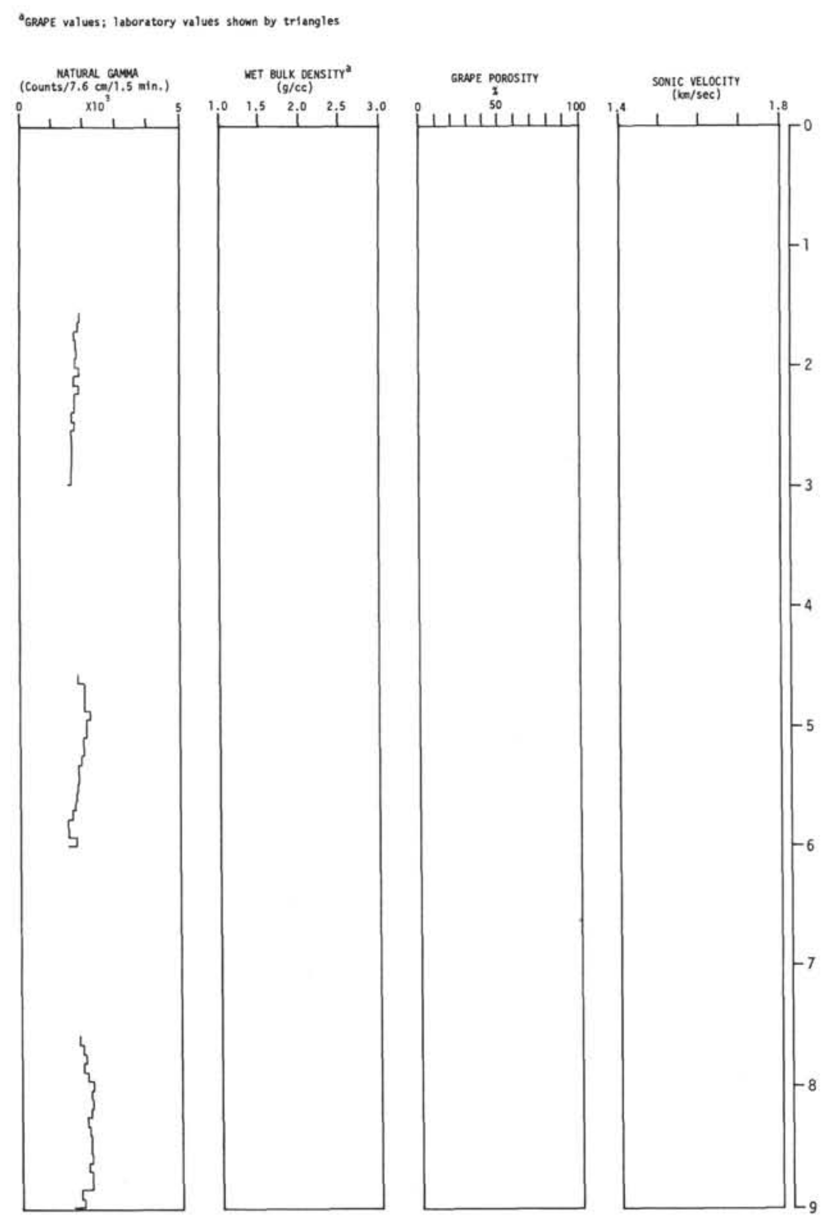
AGE: UPPER PLIOCENE

ZONE: Foram: *Globorotalia limbata*; Nanno: *Discoaster brouweri*; Rad: *Pterocanium prismatium*

| SECTION | DEPTH (Meters) | Smear Slide | Paleo. sample | DESCRIPTION |
|---|---|---|---|---|
| 1 | 0–1.5 | | | Nannofossil chalk ooze, pale olive |
| 2 | 1.5–3 | | | Same, pale greenish yellow |
| | | * | | Forams abundant, diatoms common to abundant, silicoflagellates present |
| 3 | 3–4.5 | | | Same, very pale olive |
| 4 | 4.5–6 | * | | Same, pale olive mottled to moderate olive brown |
| | | * | | Same, pale greenish yellow, $H_2S$ odor |
| 5 | 6–7.5 | | | |
| 6 | 7.5–9 | * | | Same, light olive brown mottled pale greenish yellow |
| CC | | * | * | |

MICROFOSSIL Abund/Pres: Foram, Nanno, Rad; % $CaCO_3$ (0, 50, 100); C M A M C M

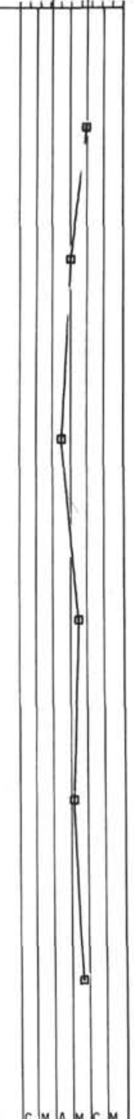
PHYSICAL PROPERTIES



SITE: 157 HOLE: CORE: 14 Cored Interval: 126-135 m

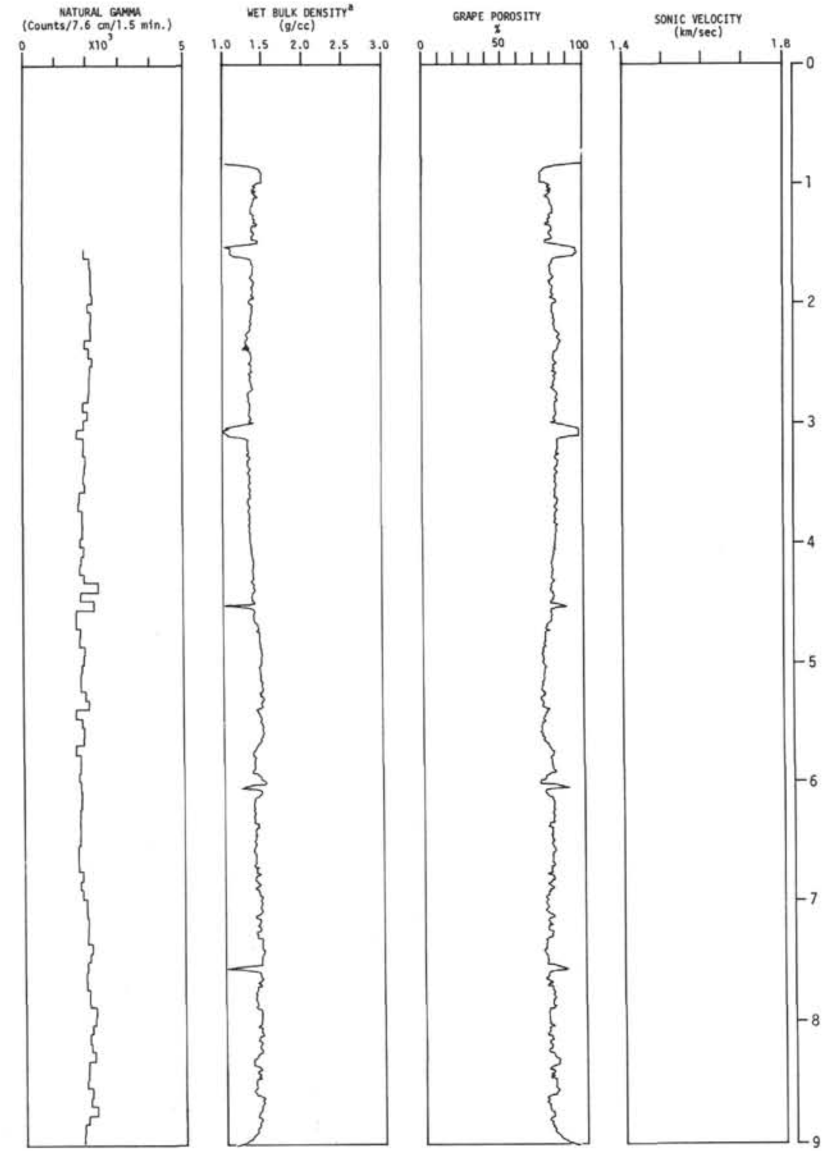
| SERIES | AGE ZONE: Foram | Nanno | Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION |
|---|---|---|---|---|---|---|---|---|---|---|
| UPPER PLIOCENE | *Globorotalia limbata* | *Discoaster brouweri* | *Pterocanium prismatium* | 0–1 | 1 | EMPTY | | * | | Nannofossil chalk ooze, pale greenish yellow<br>---Color change<br>Same, light olive brown, laminae of pale greenish yellow |
| | | | | 2 | 2 | | | | | Forams and diatoms abundant, silicoflagellates common |
| | | | | 3–4 | 3 | | | * | | ---Color change<br>Same, pale olive |
| | | | | 5 | 4 | | | * | | ---Color change<br>Same, pale greenish yellow |
| | | | | 6–7 | 5 | | | * | | Same, pale olive, mottles and burrows of light olive and medium gray |
| | | | | 8 | 6 | | | * | | Same, light olive, mottled<br>---Color change<br>Same, pale olive, mottled and burrowed |
| | | | | | CC | | | | * | |

MICROFOSSIL Abund/Pres: Foram, Nanno, Rad; % $CaCO_3$ 0 50 100




PHYSICAL PROPERTIES

[a]GRAPE values; laboratory values shown by triangles



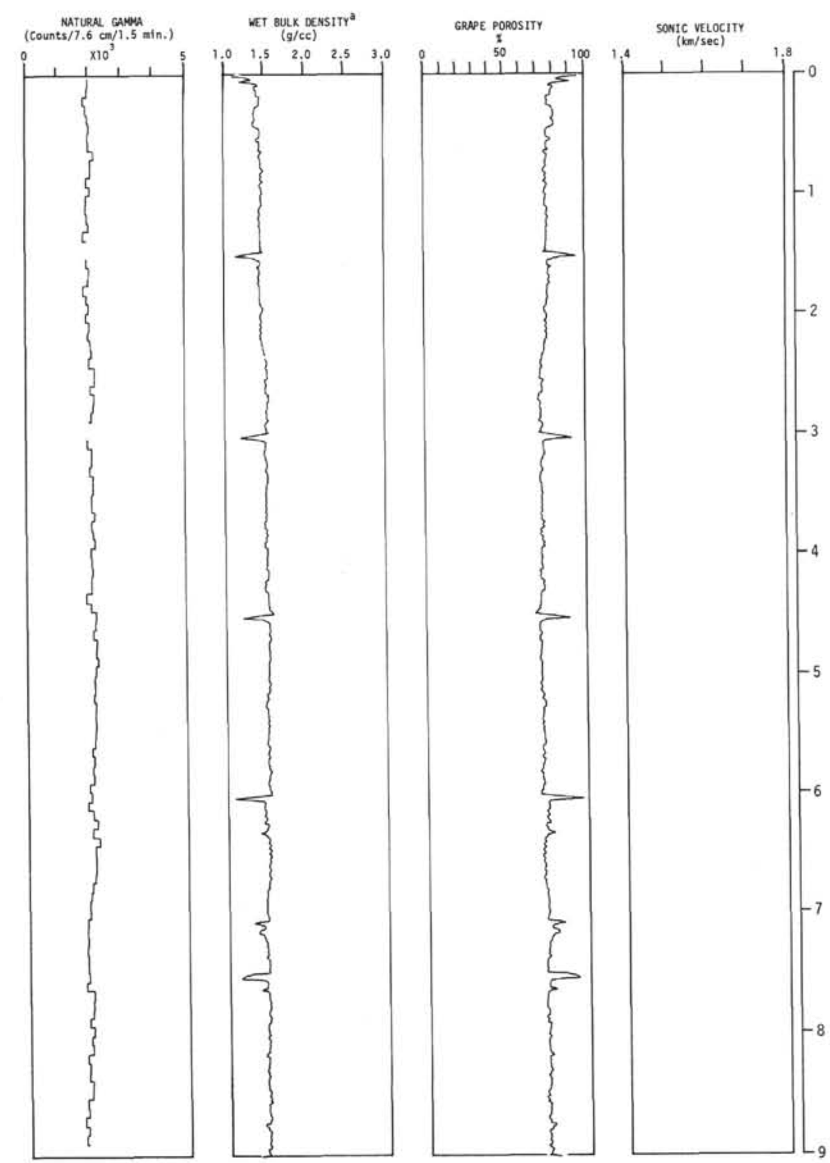
SITE: 157 HOLE: CORE: 15 Cored Interval: 135-144 m

| SERIES | Foram Zone | Nanno Zone | Rad Zone | SECTION | DESCRIPTION |
|---|---|---|---|---|---|
| UPPER PLIOCENE | *Globorotalia limbata* | *Discoaster brouweri* | *Pterocanium prismatium* | 1 | Nannofossil chalk ooze, pale olive mottled with light olive brown<br>Forams gradually decrease in abundance. Diatoms abundant, rads and silicoflagellates present |
| | | | | 2 | Same with pyritic gray streaks |
| | | | | 3 | |
| | | | | 4 | ---Color change<br>Same, very pale olive mottled with pale olive |
| | | | | 5 | |
| | | | | 6 | Strong $H_2S$ odor |
| | | | | CC | |

MICROFOSSIL Abund/Pres (Foram, Nanno, Rad); % $CaCO_3$ (0, 50, 100); CC: A Pd A G

PHYSICAL PROPERTIES

[a]GRAPE values; laboratory values shown by triangles



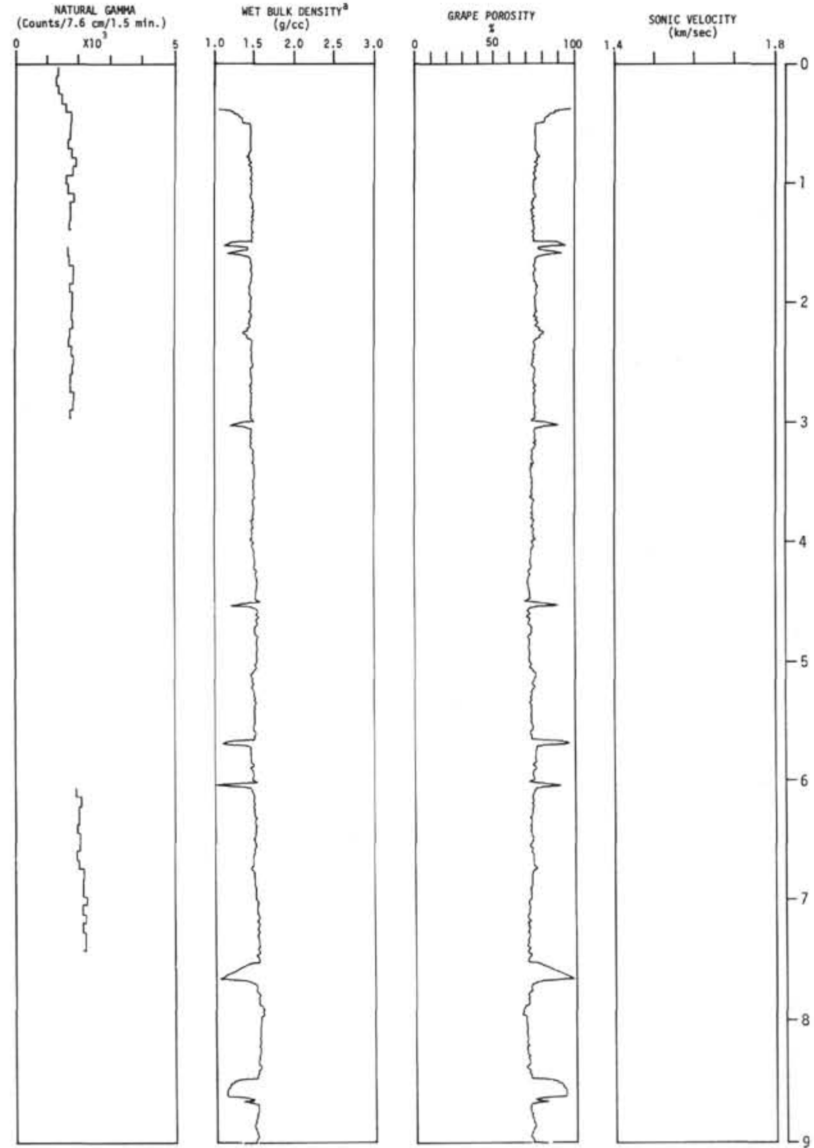
SITE: 157 HOLE: CORE: 16 Cored Interval: 144-153 m

| AGE: SERIES | ZONE: Foram | ZONE: Nanno | ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | DESCRIPTION | MICROFOSSIL Abund/Pres: Foram | Nanno | Rad |
|---|---|---|---|---|---|---|---|---|---|---|
| UPPER PLIOCENE | *Globorotalia limbata* | *Discoaster brouweri* | *Pterocanium prismatium* | 0–1.5 | 1 | EMPTY | Nannofossil chalk ooze, pale olive, mottled, $H_2S$ odor | | | |
| | | | | 1.5–3 | 2 | | Diatoms abundant, forams common, rads, silicoflagellates, discoasters present; pyrite framboids<br>Same with gray pyritic streaks | | | |
| | | | | 3–4.5 | 3 | | | | | |
| | | | | 4.5–6 | 4 | | | | | |
| | | | | 6–7.5 | 5 | | | | | |
| | | | | 7.5–9 | 6 | | Same, very pale olive, common pyritic streaks | | | |
| | | | | | CC | | Strong $H_2S$ odor | C M | A M | A M |

% $CaCO_3$: 0, 50, 100

PHYSICAL PROPERTIES

[a]GRAPE values; laboratory values shown by triangles



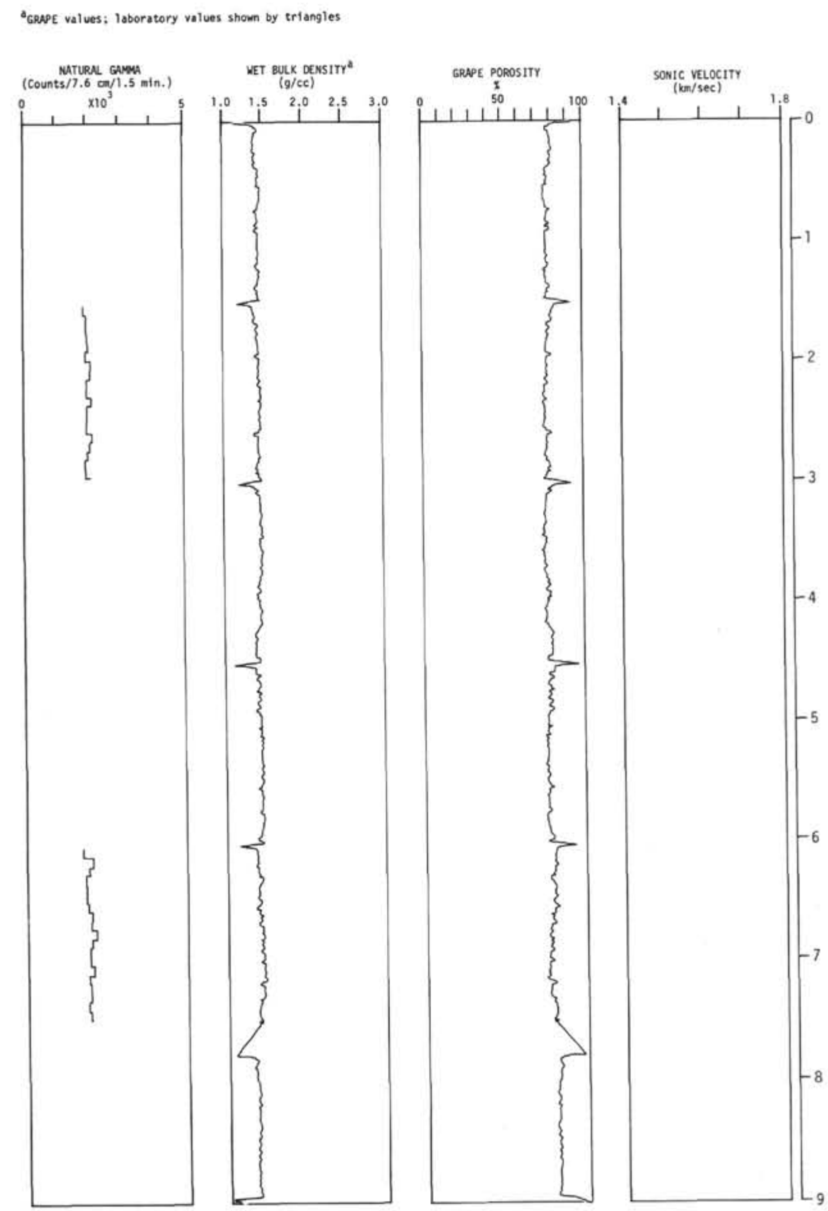
SITE: 157 HOLE: CORE: 17 Cored Interval: 153-162 m

| SERIES | AGE / ZONE: Foram | Nanno | Rad | DEPTH (Meters) | SECTION | Smear Slide | Paleo. sample | DESCRIPTION |
|---|---|---|---|---|---|---|---|---|
| UPPER PLIOCENE | *Globorotalia limbata* | *Discoaster brouweri* | *Pterocanium prismatium* | 0–1.5 | 1 | * | | Nannofossil chalk ooze, pale olive mottled to light olive brown diatomaceous, rads, forams, and silicoflagellates common |
| | | | | 1.5–3 | 2 | | | |
| | | | | 3–4.5 | 3 | * | | Increase in abundance of forams |
| | | | | 4.5–6 | 4 | | | |
| | | | | 6–7.5 | 5 | * | | Same, olive, mottled light olive |
| | | | | 7.5–9 | 6 | | | ---Color change<br>Same, light olive, some pale olive mottling, strong $H_2S$ odor |
| | | | | | CC | * | * | Glauconite present |

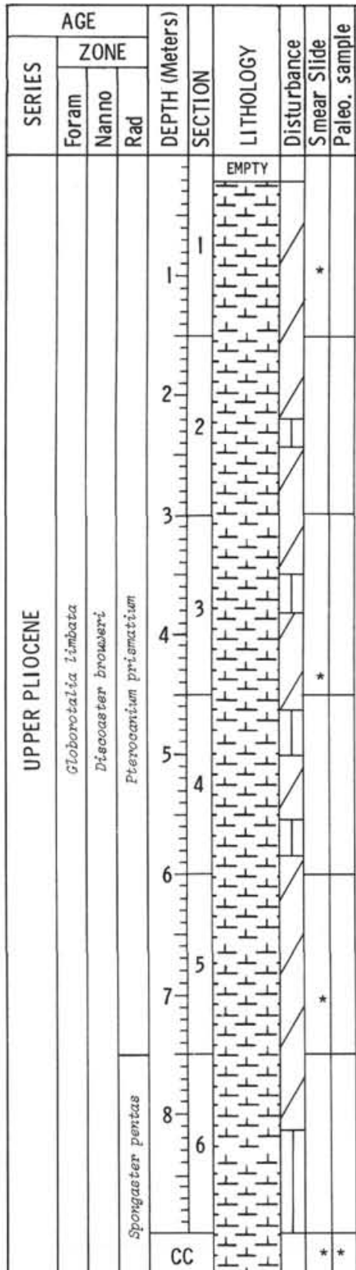
MICROFOSSIL Abund/Pres: Foram C M; Nanno A M; Rad A G

% $CaCO_3$ 0 50 100

PHYSICAL PROPERTIES



SITE: 157 HOLE: CORE: 18 Cored Interval: 162-171 m

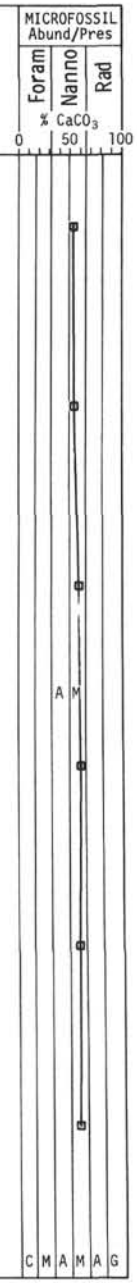



DESCRIPTION

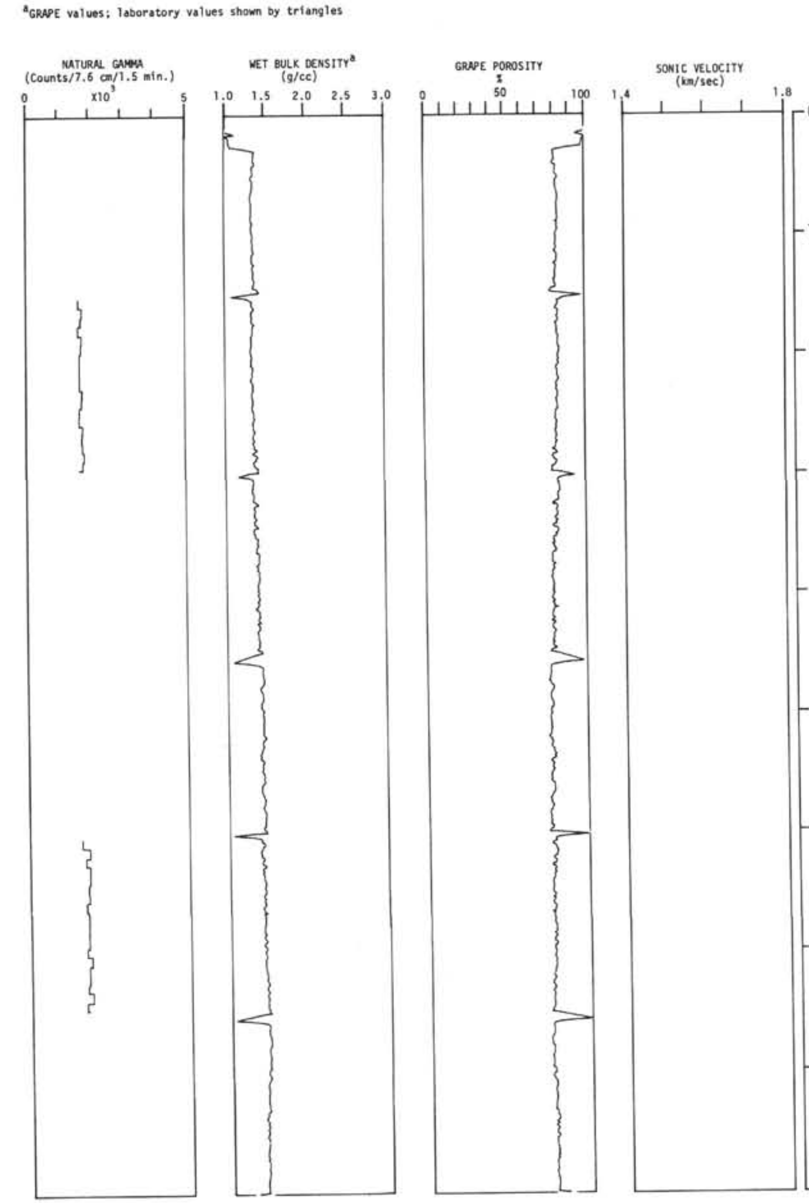
Nannofossil chalk ooze, pale greenish olive, mottled, gray pyritic streaks, H S odor, diatomaceous, forams and rads common, silicoflagellates present

Same, pale olive, gray pyrite layer

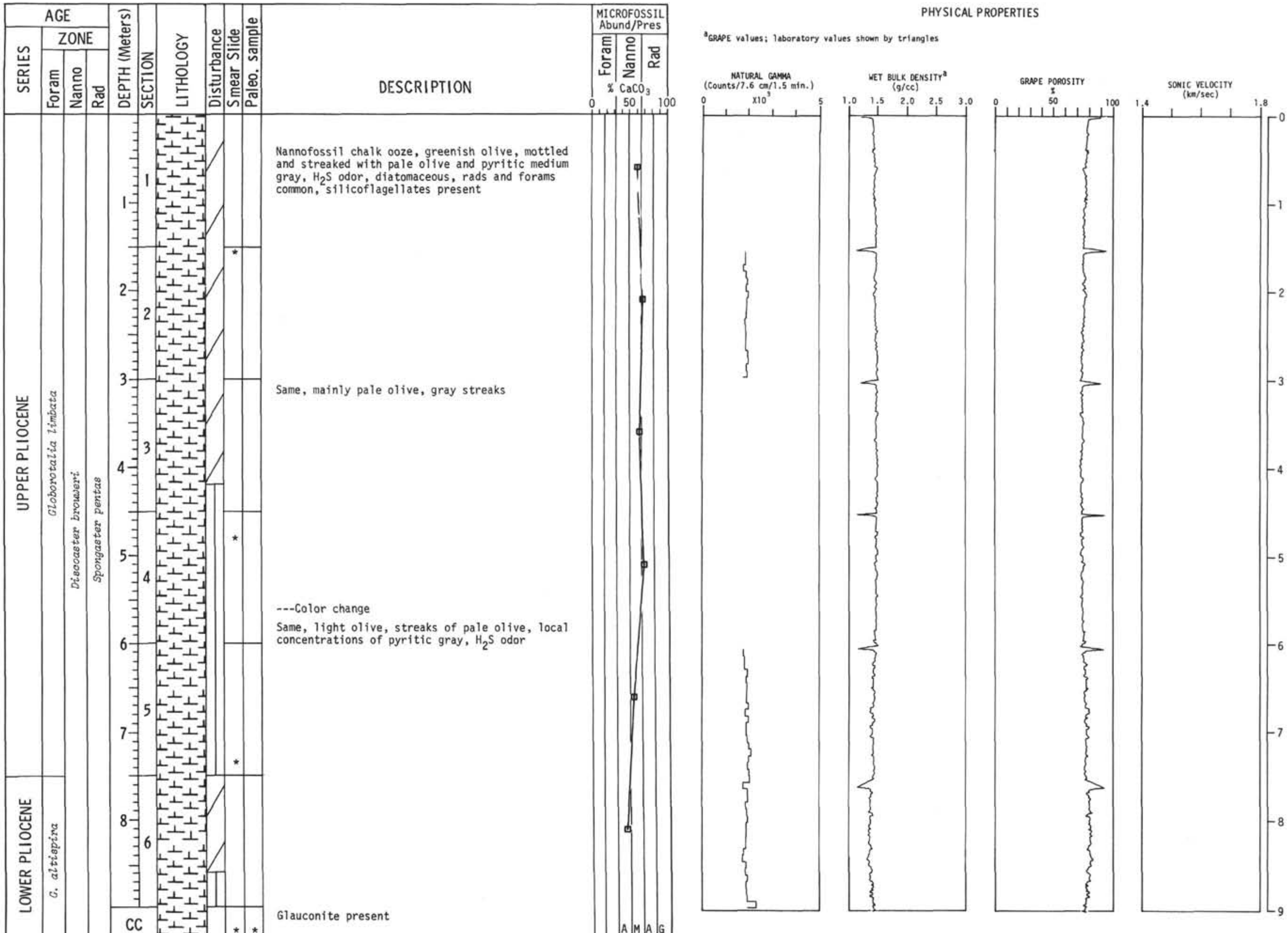
$H_2S$ odor




PHYSICAL PROPERTIES



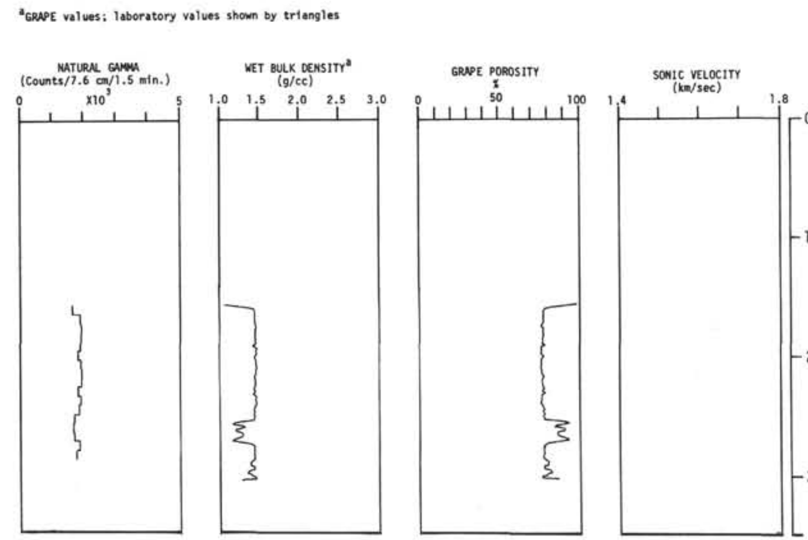
SITE: 157 HOLE: CORE: 19 Cored Interval: 171-180 m



SITE: 157 HOLE: CORE: 20 Cored Interval: 180-189 m

| SERIES | AGE ZONE: Foram | AGE ZONE: Nanno | AGE ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres: Foram / Nanno / Rad; % $CaCO_3$ 0 50 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LOWER PLIOCENE | *Globoquadrina altispira* | *Discoaster brouweri* | *Spongaster pentas* | 1 | 1 | EMPTY | | * | | Nannofossil chalk ooze, pale olive, slightly mottled, streaks of dark gray, diatomaceous, rads and forams common, silicoflagellates present | |
| | | | | 2 | 2 | EMPTY | | | | ---Color change<br>Same, darker pale olive | |
| | | | | CC | | | | * | * | Same, yellowish olive gray; rich in forams, glauconite present | |

PHYSICAL PROPERTIES

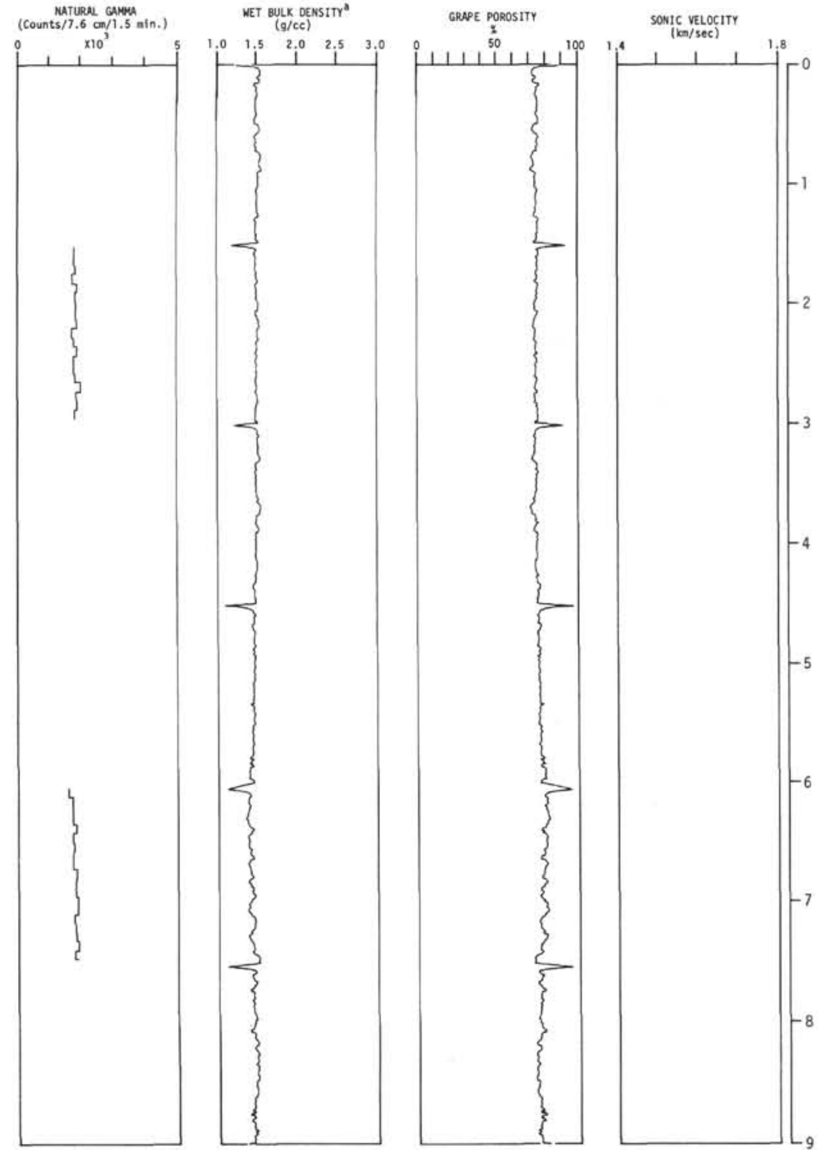


SITE: 157 HOLE: CORE: 21 Cored Interval: 189-198 m

| AGE: SERIES | ZONE: Foram | ZONE: Nanno | ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres: Foram / Nanno / Rad; % $CaCO_3$ 0 50 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LOWER PLIOCENE | *Globoquadrina altispira* | *Discoaster brouweri* (upper); *Reticulofenestra pseudoumbilica* or *Discoaster brouweri* (lower) | *Spongaster pentas* | 0–1 | 1 | | | * | | Nannofossil chalk ooze, pale olive mottled darker pale olive; $H_2S$ odor, diatomaceous, forams and silicoflagellates common | |
| | | | | 2 | 2 | | | | | | |
| | | | | 3–4 | 3 | | | * | | | |
| | | | | 5 | 4 | | | | | | |
| | | | | 6–7 | 5 | | | * | | | |
| | | | | 8 | 6 | | | | | Same, mottled pale greenish yellow and olive gray; $H_2S$ odor | |
| | | | | | CC | | | * | * | | A M C G |

PHYSICAL PROPERTIES

aGRAPE values; laboratory values shown by triangles



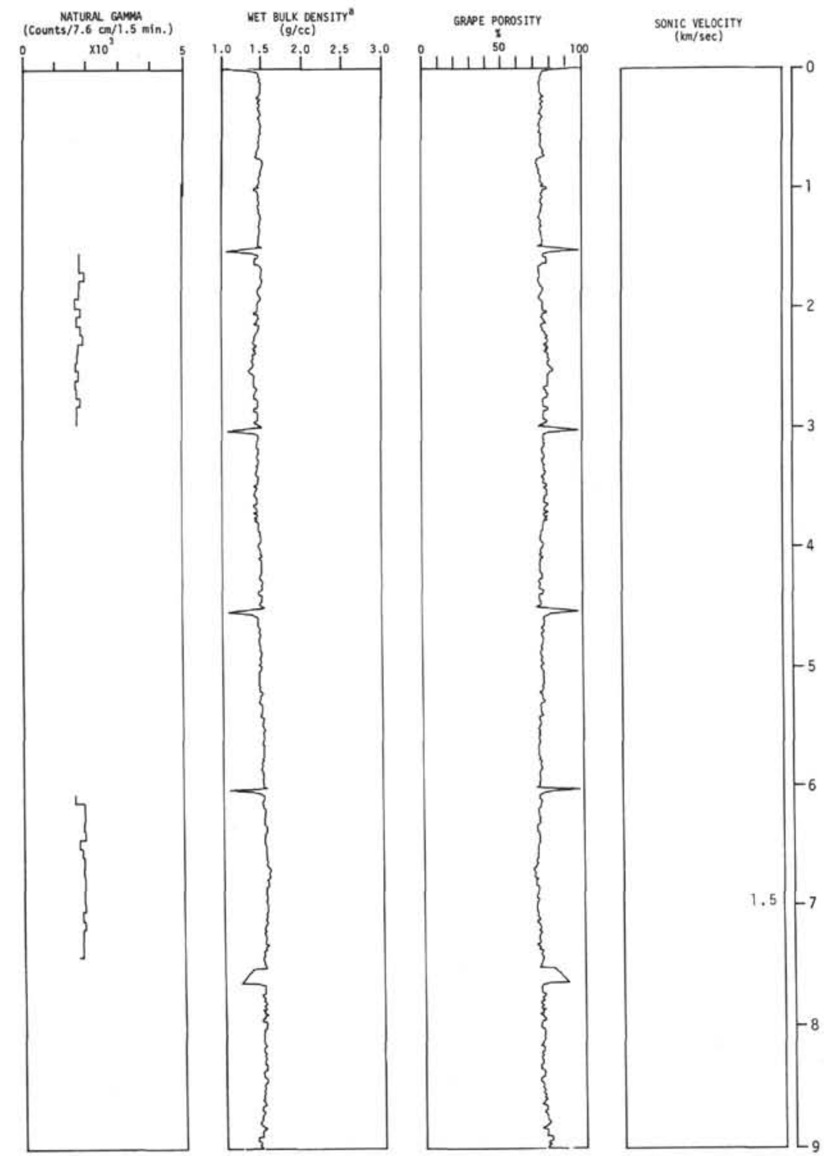
SITE: 157 HOLE: CORE: 22 Cored Interval: 198-207 m

| SERIES | AGE: ZONE Foram | AGE: ZONE Nanno | AGE: ZONE Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION |
|---|---|---|---|---|---|---|---|---|---|---|
| LOWER PLIOCENE | *Globoquadrina altispira* | *Reticulofenestra pseudoumbilica* or *Discoaster brouweri* | *Spongaster pentas* | 0–1.5 | 1 | | | | | Nannofossil chalk ooze, pale olive, mottled, diatomaceous, rads and forams common, silico-flagellates present |
| | | | | 1.5–3 | 2 | | | * | | Same, streaks of dark to medium gray |
| | | | | 3–4.5 | 3 | | | * | | Same, very pale olive |
| | | | | 4.5–6 | 4 | | | | | Same, pale olive, mottled light olive and medium gray |
| | | | | 6–7.5 | 5 | | | * | | |
| | | | | 7.5–9 | 6 | | | | | |
| | | | | | CC | | | * | * | |

MICROFOSSIL Abund/Pres: Foram, Nanno, Rad; % $CaCO_3$ 0, 50, 100; A M C G

PHYSICAL PROPERTIES

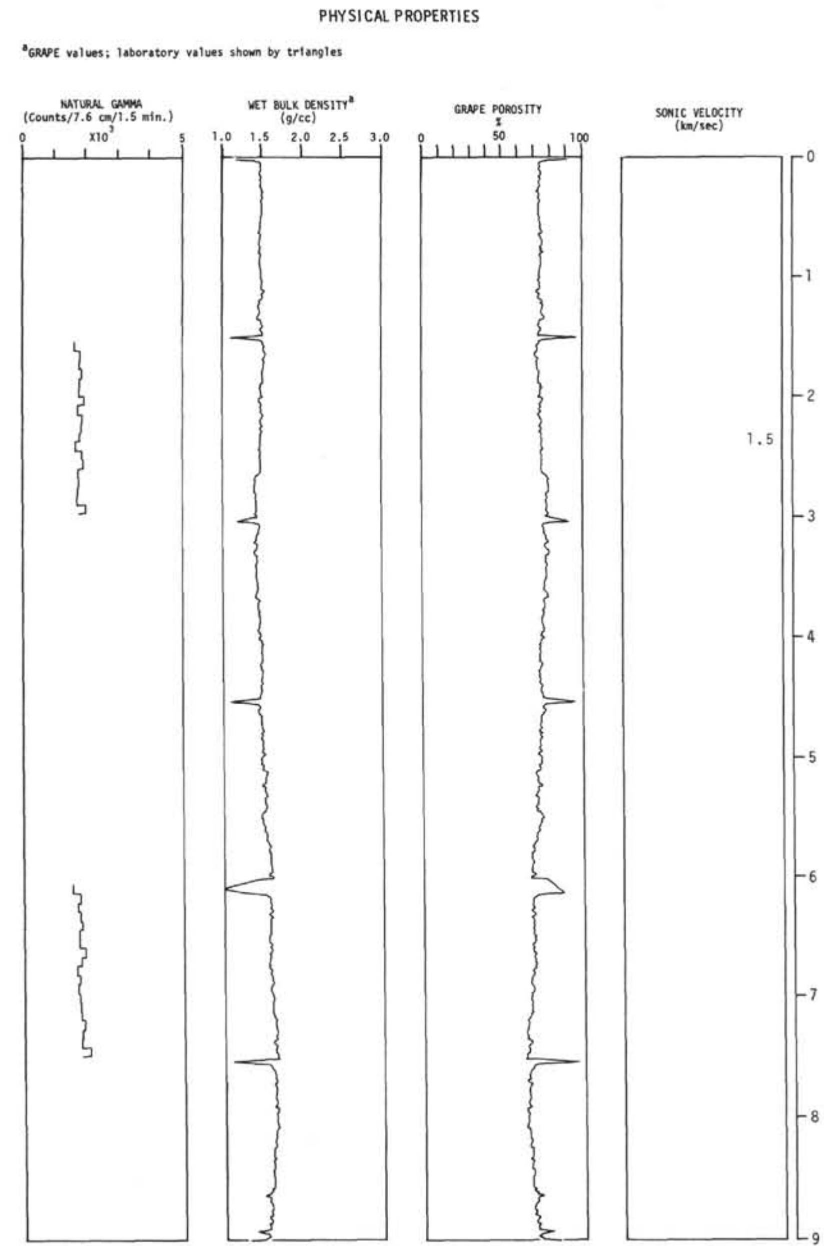
[a]GRAPE values; laboratory values shown by triangles



SITE: 157 HOLE: CORE: 23 Cored Interval: 207-216 m

| SERIES | Foram zone | Nanno zone | Rad zone | DEPTH (Meters) | SECTION | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres (Foram, Nanno, Rad) |
|---|---|---|---|---|---|---|---|---|---|
| LOWER PLIOCENE | *Globoquadrina altispira* | *Reticulofenestra pseudoumbilica* or *Discoaster brouweri* | *Spongaster pentas* | 0–1.5 | 1 | * | | Nannofossil-foraminiferal chalk ooze, pale olive, mottled light olive gray to medium gray, $H_2S$ odor, diatomaceous, forams common, rads and silico-flagellates present | |
| | | | | 1.5–3 | 2 | | | | |
| | | | | 3–4.5 | 3 | * | | Nannofossil chalk ooze, pale greenish yellow, mottled and locally burrowed | |
| | | | | 4.5–6 | 4 | | | Same, alternating very pale to pale olive, mottled, burrowed | |
| | | | | 6–7.5 | 5 | | | Local gray pyritic streaks | |
| | | | | 7.5–9 | 6 | | | | |
| | | | | | CC | * | * | | A M A G |

% $CaCO_3$: 0, 50, 100



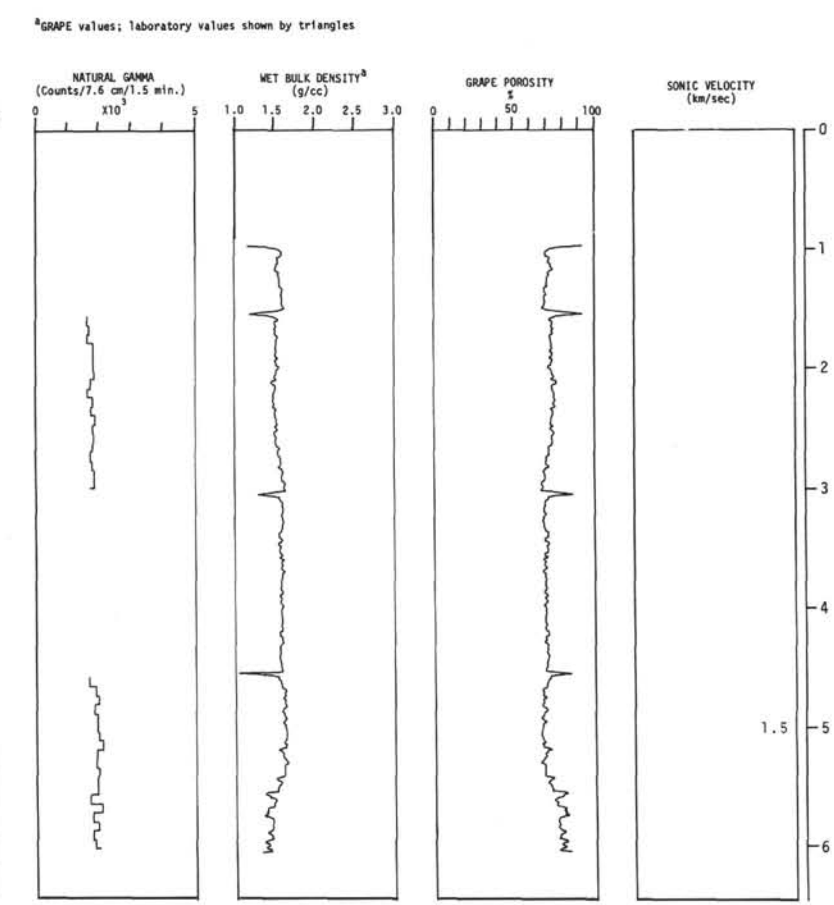
SITE: 157 HOLE: CORE: 24 Cored Interval: 216-225 m

| SERIES | Foram zone | Nanno zone | Rad zone | SECTION | LITHOLOGY | Smear Slide | Paleo. sample | DESCRIPTION |
|---|---|---|---|---|---|---|---|---|
| LOWER PLIOCENE | *Globoquadrina altispira* | *Reticulofenestra pseudoumbilica* or *Discoaster brouweri* | *Spongaster pentas* | 1 | EMPTY | | | |
| | | | | 1 | | * | | Nannofossil chalk ooze, pale olive, $H_2S$ odor, diatomaceous, forams common |
| | | | | 2 | | | | Same, slightly mottled grayish olive, gray pyritic streaks |
| | | | | 2 | | | | Same, very pale olive |
| | | | | 3 | | * | | Vertical burrows 3-10 mm across, 10 cm deep |
| | | | | 4 | EMPTY | | | |
| | | | | 4 | | * | | Same, light olive, vertical burrows 5 mm across, upto 2 cm deep |
| | | | | CC | | * | * | |

MICROFOSSIL Abund/Pres (CC): Foram A, Nanno M A, Rad G

Depth (Meters): 1, 2, 3, 4, 5

PHYSICAL PROPERTIES

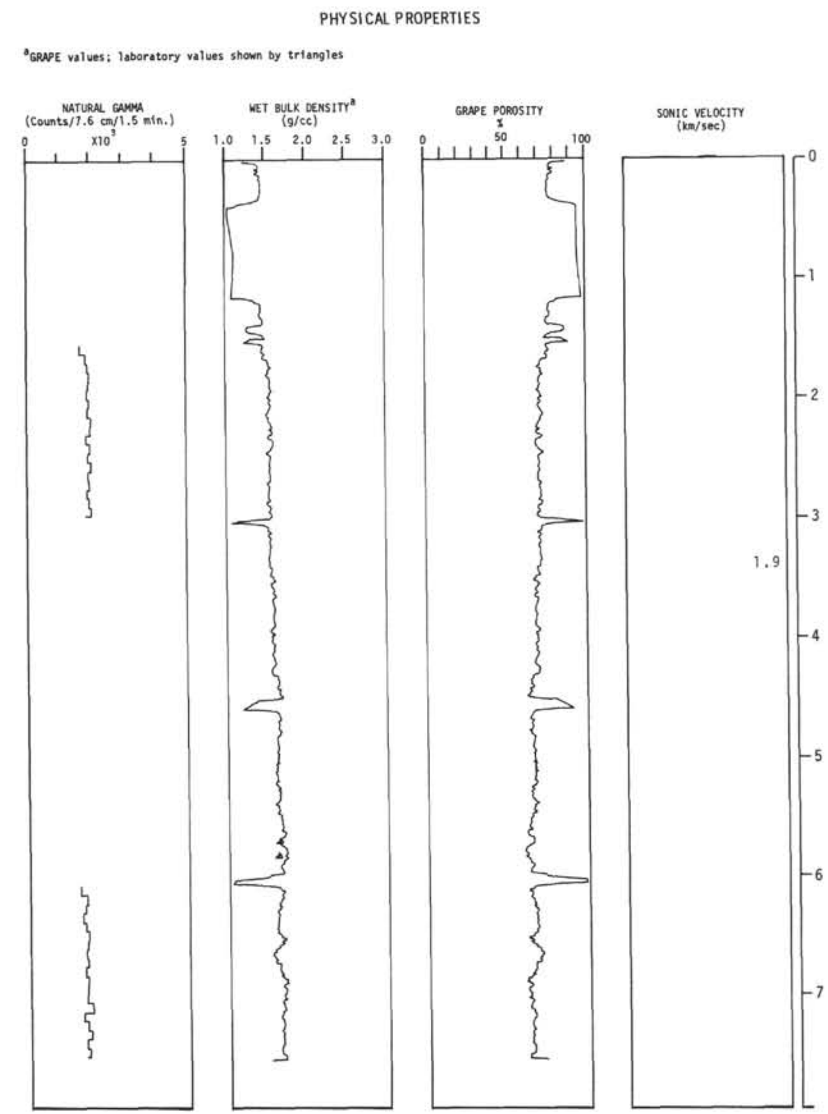


SITE: 157 HOLE: CORE: 25 Cored Interval: 225-234 m

| SERIES | AGE / ZONE: Foram | Nanno | Rad | DEPTH (Meters) | SECTION | LITHOLOGY | DESCRIPTION |
|---|---|---|---|---|---|---|---|
| LOWER PLIOCENE | *Globoquadrina altispira* | *Reticulofenestra pseudoumbilica* | *Spongaster pentas* | 0–1.5 | 1 | NOT OPENED | |
| | | | | 1.5–3 | 2 | | Nannofossil chalk ooze, pale olive, mottled and burrowed, local gray pyrite streaks, diatomaceous, forams and silicoflagellates common, rads present |
| | | | | 3–4.5 | 3 | | ---Color change<br>Same, very pale olive, mottled, horizontal and vertical burrows 5-20 mm in diameter, spots of gray |
| | | | | 4.5–6 | 4 | | Vertical burrow 12 cm long, 1 cm diameter, pyritic concentrations 1-3 mm across, and in thin streaks |
| | | | | 6–7.5 | 5 | | Same, pale olive |
| | | | | | CC | | |

MICROFOSSIL Abund/Pres: Foram, Nanno, Rad; % $CaCO_3$ (0, 50, 100); A M C G

PHYSICAL PROPERTIES



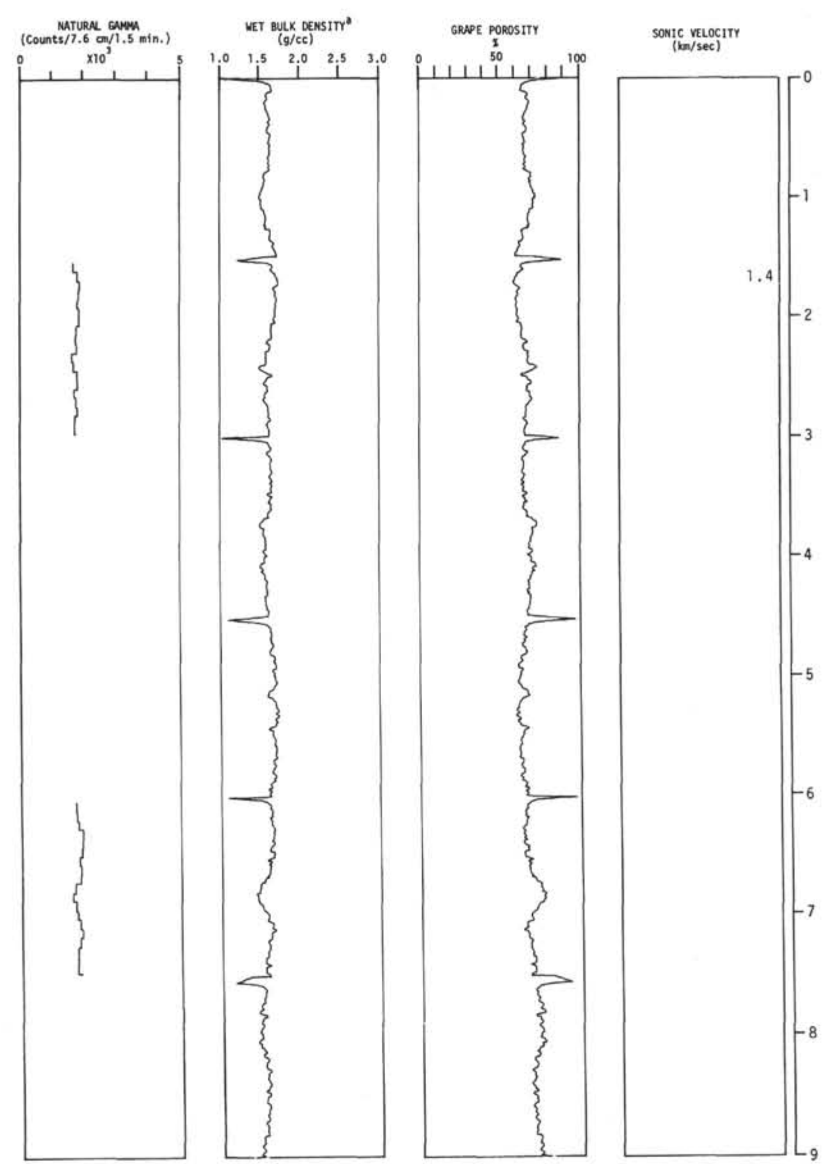
SITE: 157 HOLE: CORE: 26 Cored Interval: 234-243 m

| SERIES | AGE ZONE: Foram | AGE ZONE: Nanno | AGE ZONE: Rad | DEPTH (Meters) | SECTION | DESCRIPTION |
|---|---|---|---|---|---|---|
| LOWER PLIOCENE | *Globoquadrina altispira* | *Reticulofenestra pseudoumbilica* | *Spongaster pentas* | 0-1.5 | 1 | Nannofossil chalk ooze, stiff, pale olive, slightly mottled, few gray streaks, forams and diatoms common, rads and silicoflagellates present |
| | | | | 1.5-3 | 2 | Same, very pale olive<br>---Color change<br>Same, pale olive mottled light olive, burrows up to 1 cm diameter, not stiff |
| | | | | 3-4.5 | 3 | Same, stiff<br>Same, burrowed, one burrow 10 cm long |
| | | | | 4.5-6 | 4 | Same, very pale olive, burrows 5 mm diameter filled with grayish olive<br>---Color change<br>Same, greenish gray<br>Same, mottled very pale olive, stiff |
| | | | | 6-7.5 | 5 | Broadly layered. Diatoms abundant |
| | | | | 7.5-9 | 6 | $H_2S$ odor |
| | | | | | CC | |

MICROFOSSIL Abund/Pres (Foram, Nanno, Rad); % $CaCO_3$ (0, 50, 100): CC: C G A M A G

PHYSICAL PROPERTIES

[a]GRAPE values; laboratory values shown by triangles

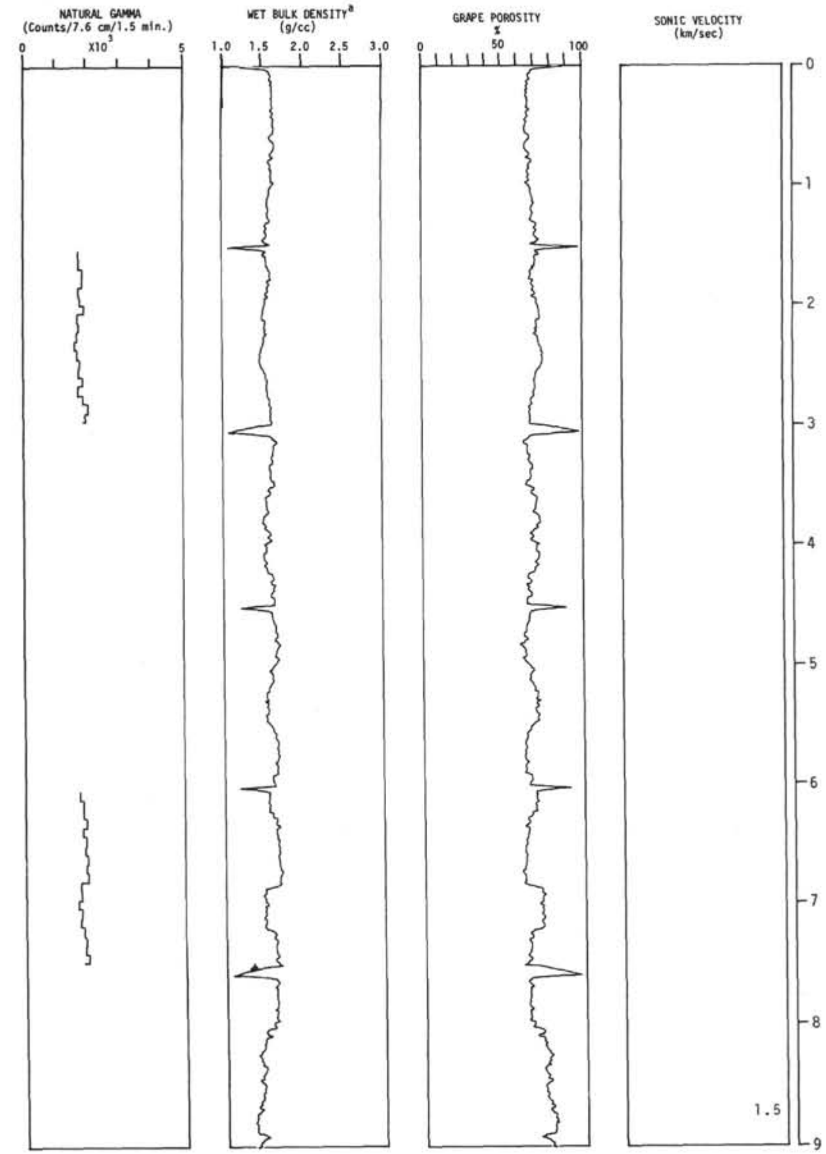


SITE: 157 HOLE: CORE: 27 Cored Interval: 243-252 m

| SERIES | AGE ZONE: Foram | AGE ZONE: Nanno | AGE ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres (Foram / Nanno / Rad); % $CaCO_3$ (0, 50, 100) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LOWER PLIOCENE | *Globoquadrina altispira* | *Reticulofenestra pseudoumbilica* | *Spongaster pentas* | 0–1.5 | 1 | | | * | | Nannofossil chalk ooze, soft, pale olive, slightly mottled<br>Diatomaceous, rads and forams common, silicoflagellates present | |
| | | | | 1.5–3 | 2 | | | | | | |
| | | | | 3–4.5 | 3 | | | * | | Diatoms abundant | |
| | | | | 4.5–6 | 4 | | | | | | |
| | | | | 6–7.5 | 5 | | | * | | Same, very pale olive | |
| | | | | 7.5–9 | 6 | | | | | Same, pale olive, diffusely bedded, mottled; some pyritic streaks, $H_2S$ odor | |
| | | | | | CC | | | * | * | | A M A G |

PHYSICAL PROPERTIES

[a]GRAPE values; laboratory values shown by triangles

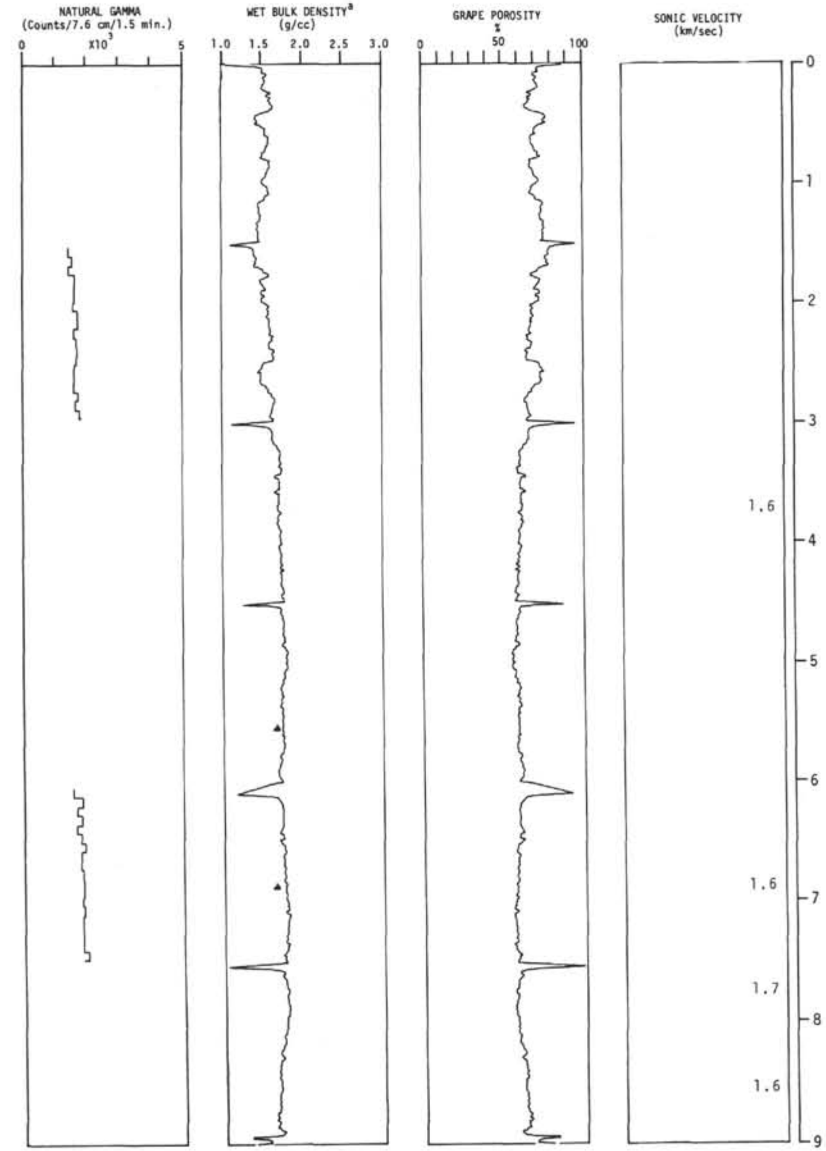


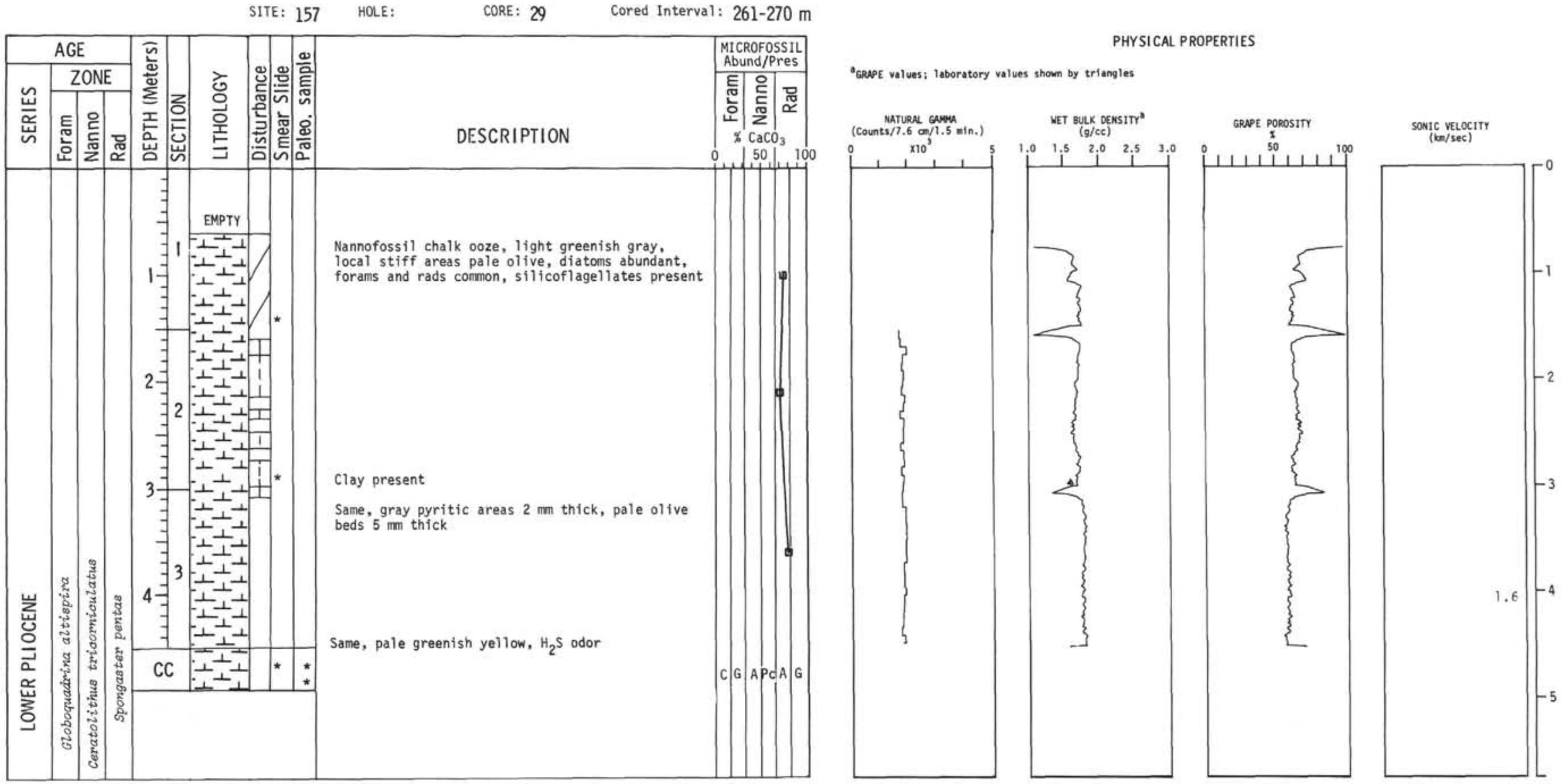
SITE: 157 HOLE: CORE: 28 Cored Interval: 252-261 m

| SERIES | AGE / ZONE: Foram | Nanno | Rad | DEPTH (Meters) | SECTION | LITHOLOGY | DESCRIPTION | MICROFOSSIL Abund/Pres (Foram, Nanno, Rad); % $CaCO_3$ |
|---|---|---|---|---|---|---|---|---|
| LOWER PLIOCENE | *Globoquadrina altispira* | *Reticulofenestra pseudoumbilica* | *Spongaster pentas* | 0–1.5 | 1 | EMPTY; EMPTY | Nannofossil chalk ooze, pale olive, slightly mottled, diatomaceous, forams common but reduced in abundance, rads and silicoflagellates present | |
| | | | | 1.5–3 | 2 | | Same, light greenish gray | |
| | | | | 3–4.5 | 3 | | Same, stiff where least disturbed, strong $H_2S$ odor | A P |
| | | | | 4.5–6 | 4 | | Mottled gray pyritic areas | A M |
| | | | | 6–7.5 | 5 | | | A P |
| | | *C. tricorniculatus* | | 7.5–9 | 6 | | | |
| | | | | | CC | | | A M A G |

## PHYSICAL PROPERTIES

[a]GRAPE values; laboratory values shown by triangles




SITE: 157 HOLE: CORE: 29 Cored Interval: 261-270 m
AGE
SERIES
ZONE
Foram
Nanno
Rad
DEPTH (Meters)
SECTION
LITHOLOGY
Disturbance
Smear Slide
Paleo. sample
DESCRIPTION
MICROFOSSIL Abund/Pres
Foram Nanno Rad
% CaCO3
0 50 100
LOWER PLIOCENE
Globoquadrina altispira
Ceratolithus tricorniculatus
Spongaster pentas
EMPTY
1 2 3 4
1 2 3 CC
Nannofossil chalk ooze, light greenish gray, local stiff areas pale olive, diatoms abundant, forams and rads common, silicoflagellates present
Clay present
Same, gray pyritic areas 2 mm thick, pale olive beds 5 mm thick
Same, pale greenish yellow, H2S odor
C G A P C A G
PHYSICAL PROPERTIES
aGRAPE values; laboratory values shown by triangles
NATURAL GAMMA (Counts/7.6 cm/1.5 min.) x10^3
0 5
WET BULK DENSITYa (g/cc)
1.0 1.5 2.0 2.5 3.0
GRAPE POROSITY %
0 50 100
SONIC VELOCITY (km/sec)
1.6
0 1 2 3 4 5

SITE: 157 HOLE: CORE: 30 Cored Interval: 270-279 m

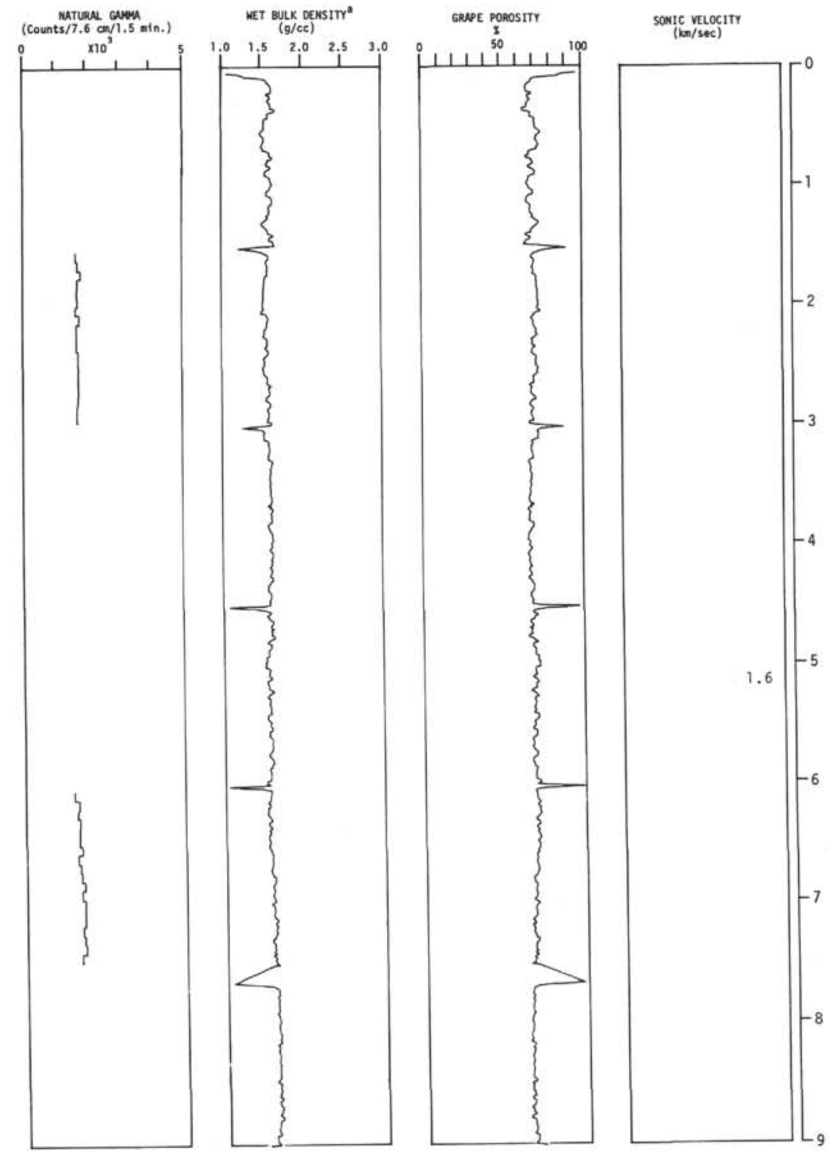
| SERIES | Foram zone | Nanno zone | Rad zone | Section | DESCRIPTION |
|---|---|---|---|---|---|
| LOWER PLIOCENE | *G. altispira* | *Ceratolithus tricorniculatus* | *Spongaster pentas* | 1 | Nannofossil chalk ooze, light greenish gray to pale olive, diatomaceous, forams and rads common, silicoflagellates present |
| | *Globorotalia tumida* | | | 2 | Same, light greenish gray |
| | | | | 2 | Same, very pale olive |
| | | | | 3 | |
| | | | *Stichocorys peregrina* | 4 | Light olive burrows |
| | | | | 4–5 | Same, light greenish gray, $H_2S$ odor, stiff in undisturbed areas, local mottles to light olive |
| | | | | 6 | |
| | | | | CC | |

MICROFOSSIL Abund/Pres (% $CaCO_3$: 0, 50, 100) — CC: Foram A, Nanno M, Rad A G

Depth (Meters): 1, 2, 3, 4, 5, 6, 7, 8

PHYSICAL PROPERTIES

[a]GRAPE values; laboratory values shown by triangles

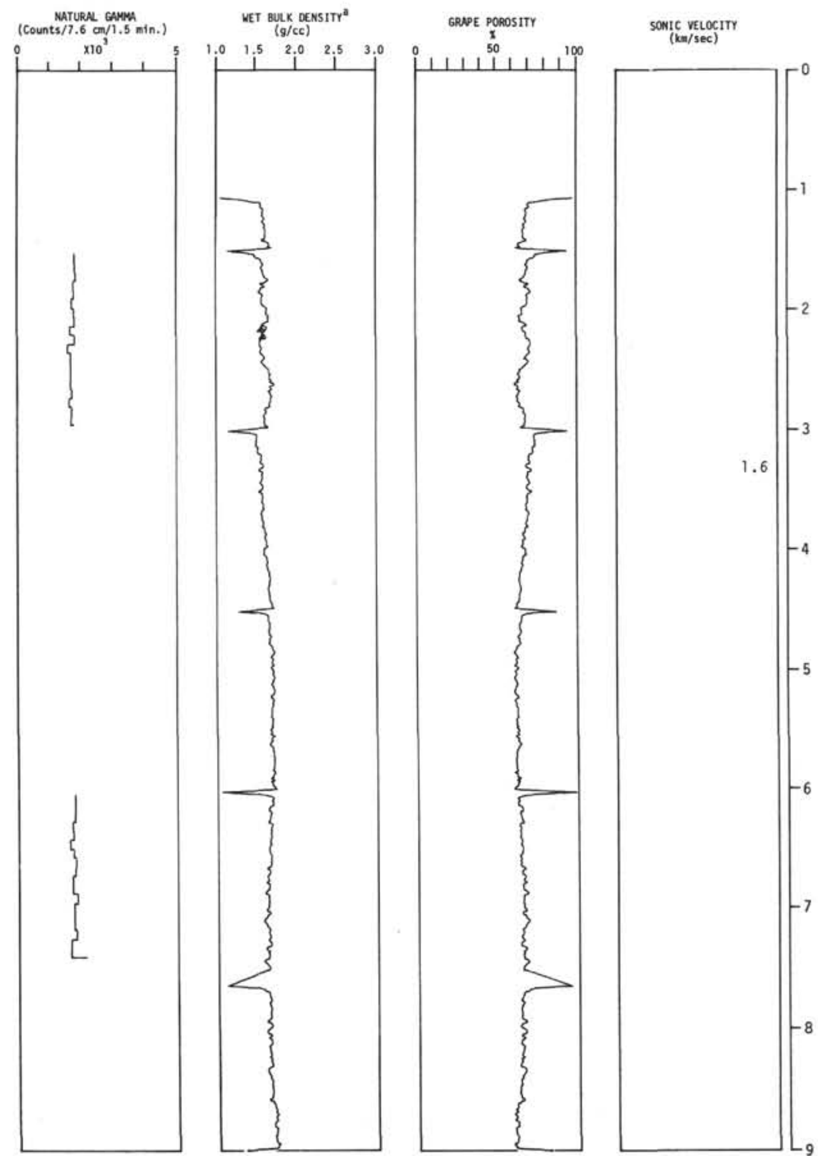


SITE: 157 HOLE: CORE: 31 Cored Interval: 279-288 m

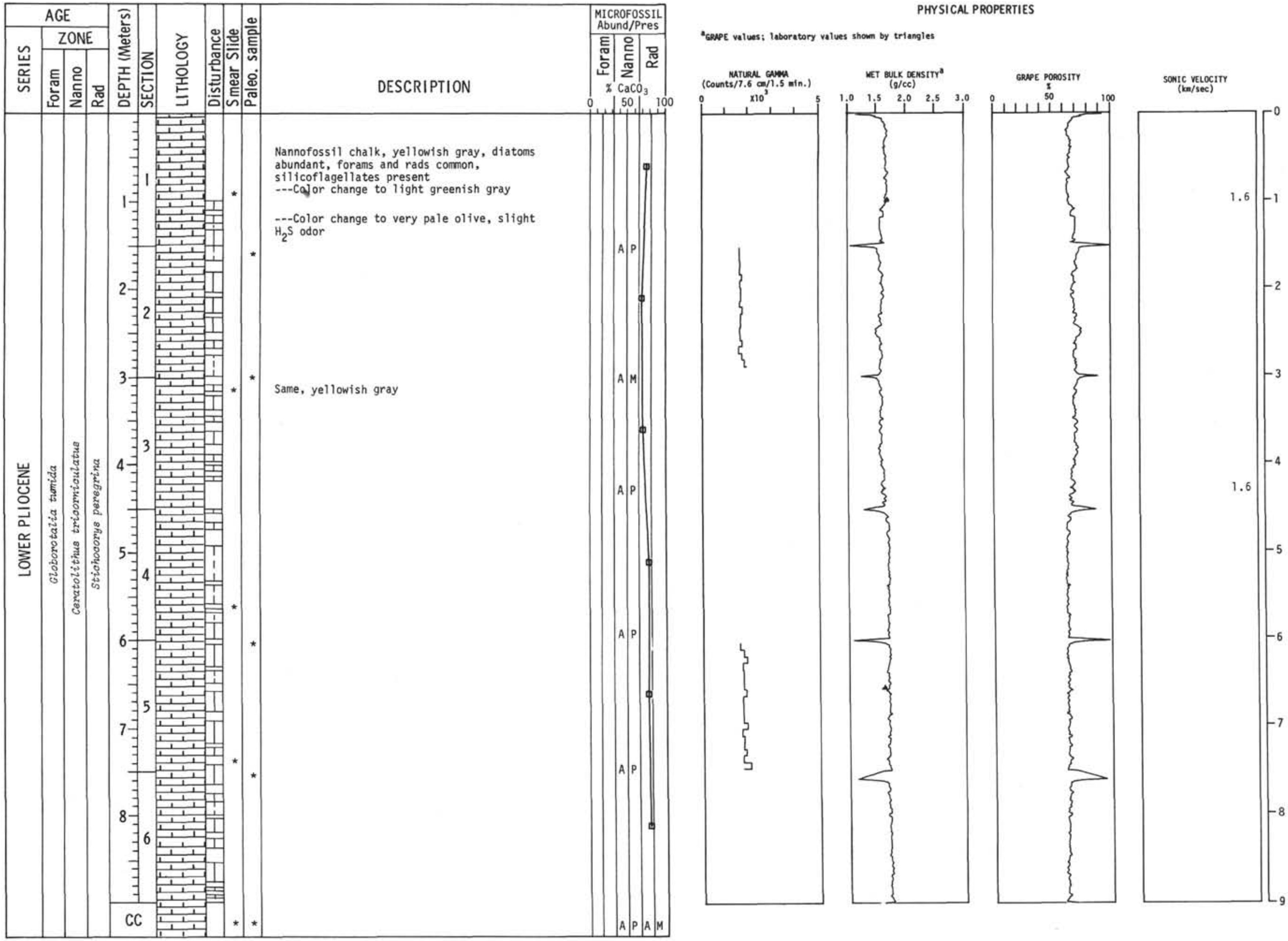
| SERIES | Foram | Nanno | Rad | DEPTH (Meters) | SECTION | LITHOLOGY | DESCRIPTION | MICROFOSSIL Abund/Pres |
|---|---|---|---|---|---|---|---|---|
| LOWER PLIOCENE | *Globorotalia tumida* | *Ceratolithus tricorniculatus* | *Stichocorys peregrina* | 0–1.5 | 1 | EMPTY | Nannofossil chalk ooze, stiff, very pale olive, few gray streaks, diatoms fairly abundant, forams and rads common, silicoflagellates and sponge spicules present | A P |
| | | | | 1.5–3 | 2 | | Same, pale olive | A P |
| | | | | | | | ---Gradational color change to pale greenish yellow; gray burrows 2-5 mm across | |
| | | | | 3–4.5 | 3 | | Same, pale olive mottled very pale olive | A P |
| | | | | 4.5–6 | 4 | | Nannofossil chalk ooze, stiff; where least deformed, nanno chalk, light greenish gray mottled to very pale olive, local gray burrow fillings | A P |
| | | | | | | | Diatoms abundant, rads and forams common, silicoflagellates present | |
| | | | | 6–7.5 | 5 | | Volcanic glass present | |
| | | | | 7.5–9 | 6 | | | |
| | | | | | CC | | $H_2S$ odor | A P A G |

PHYSICAL PROPERTIES

[a]GRAPE values; laboratory values shown by triangles



SITE: 157 HOLE: CORE: 32 Cored Interval: 288-297 m



SITE: 157 HOLE: CORE: 33 Cored Interval: 297-306 m

AGE — SERIES: LOWER PLIOCENE

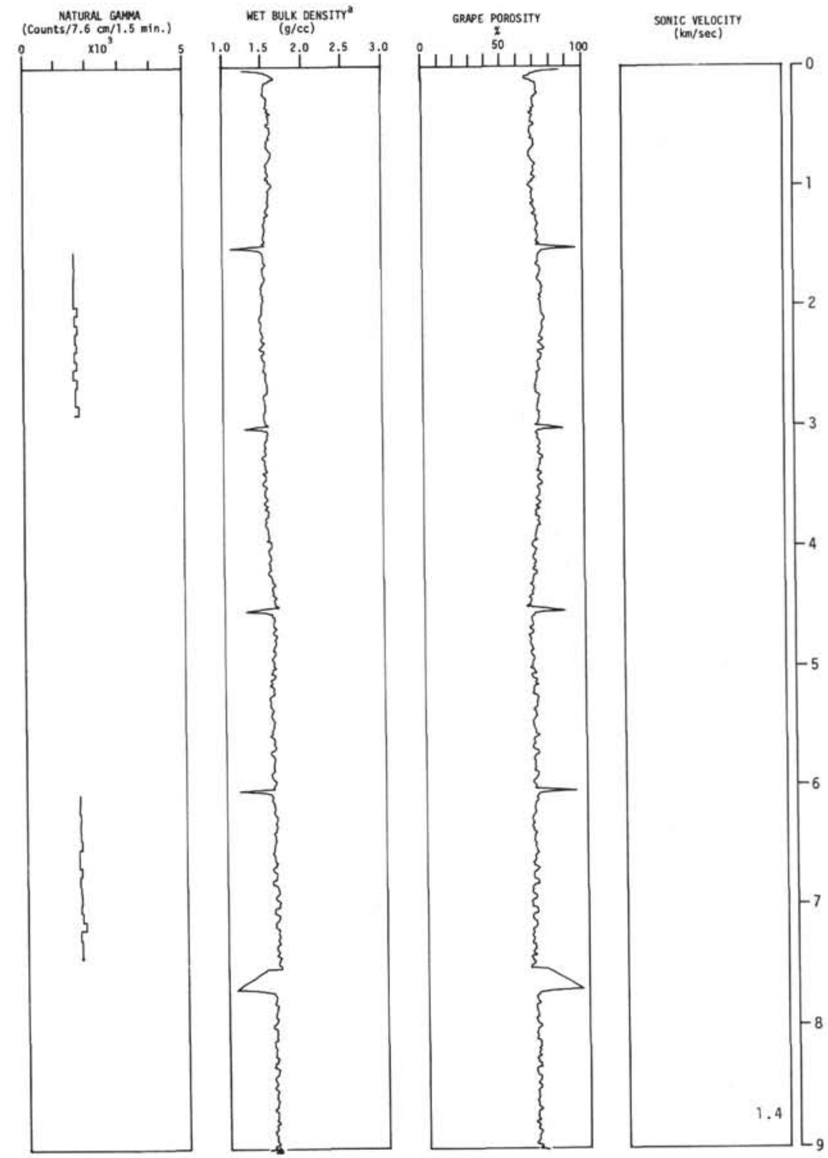
ZONE — Foram: *Globorotalia tumida*; Nanno: *Ceratolithus tricorniculatus*; Rad: *Stichocorys peregrina*

| DEPTH (Meters) | SECTION | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres (Foram, Nanno, Rad) |
|---|---|---|---|---|---|
| 0 | 1 | | * | | A P |
| 0.5 | 1 | * | | Nannofossil chalk, pale olive grading down to light pale olive, $H_2S$ odor, diatomaceous, forams and rads common, silicoflagellates present | |
| 2.6 | 2 | | | | A M |
| 3 | 3 | | * | Same, burrows are dusky yellow | |
| 3.8 | 3 | * | | Same, pale olive mixed with medium light gray in 5-20 mm beds and in burrows. Zone rich in pyrite | |
| 4.4 | 3 | | | Same, pale olive | |
| 4.7 | 3 | | | Same, yellowish gray | |
| 5.6 | 4 | * | | | A P |
| 6 | 4 | | * | Same, light greenish gray | |
| 7.3 | 5 | * | | | |
| 7.5 | 6 | | * | | A P |
| 8 | 6 | | | Same, yellowish gray | |
| | CC | * | * | $H_2S$ odor | A Pc A G |

% $CaCO_3$: 0 50 100

PHYSICAL PROPERTIES

[a]GRAPE values; laboratory values shown by triangles



SITE: 157 HOLE: CORE: 34 Cored Interval: 306-315 m

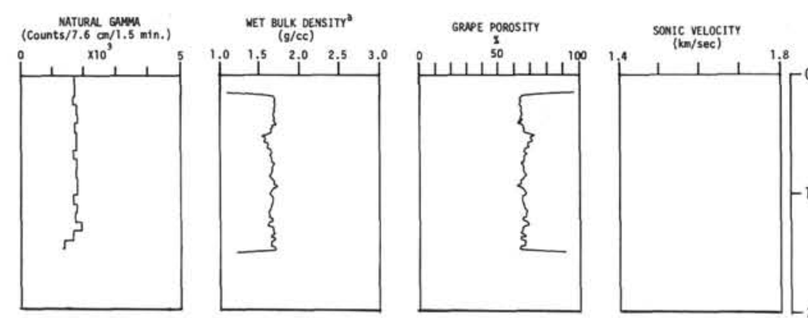
| SERIES | AGE ZONE Foram | AGE ZONE Nanno | AGE ZONE Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres Foram | Nanno | Rad | % $CaCO_3$ 0 50 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LOWER PLIOCENE | *G. tumida* | *C. tricorniculatus* | *S. peregrina* | | CC | | | * | * | CORE CATCHER<br>Nannofossil chalk, pale greenish yellow, $H_2S$ odor, diatoms abundant, rads and forams common, silicoflagellates present | | | C G | |

SITE: 157 HOLE: CORE: 35 Cored Interval: 315-324 m

| SERIES | AGE ZONE Foram | AGE ZONE Nanno | AGE ZONE Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres Foram | Nanno | Rad | % $CaCO_3$ 0 50 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LOWER PLIOCENE | *G. tumida* | *C. tricorniculatus* | *S. peregrina* | 1 | 1 | | | * | * | Nannofossil chalk, yellowish gray, slightly mottled, diatoms, abundant, rads common, forams, silicoflagellates present<br>---Color change<br>Same, pale olive, gray mottles and burrows | | | | |
| | | | | | CC | | | * | * | Same, pale greenish yellow | A P | A G | | |

PHYSICAL PROPERTIES

[a]GRAPE values; laboratory values shown by triangles

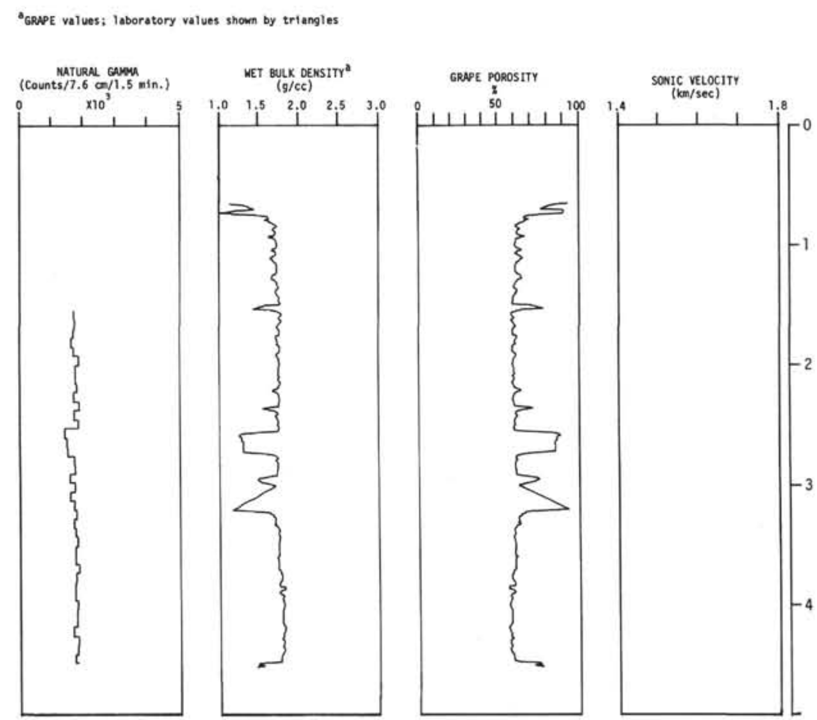


SITE: 157 HOLE: CORE: 36 Cored Interval: 324-333 m

| AGE: SERIES | ZONE: Foram | ZONE: Nanno | ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres: Foram | Nanno | Rad |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LOWER PLIOCENE | *Globorotalia tumida* | *C. tricorniculatus* | *Stichocorys peregrina* | 0–1 | 1 | EMPTY | | * | | Nannofossil chalk, light greenish gray to yellowish gray, diatoms abundant, rads common, forams less common, silicoflagellates present | | | |
| | | | | 2 | 2 | EMPTY | | | | | | | |
| | | | | 3–4 | 3 | | | | | Same, yellowish gray, local gray mottles | | | |
| | | | | | CC | | | * | * | Same, pale greenish gray, $H_2S$ odor | A | M | C M |

% $CaCO_3$: 0, 50, 100

PHYSICAL PROPERTIES

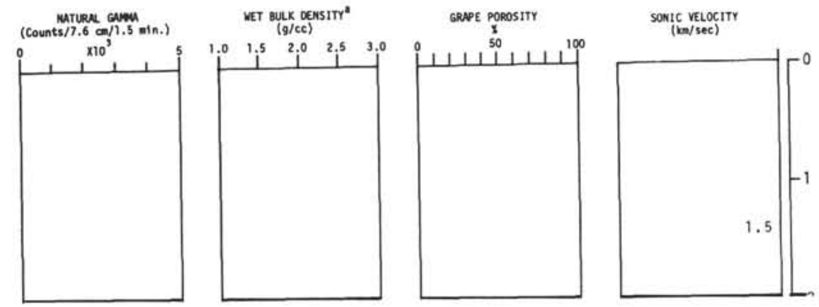


SITE: 157 HOLE: CORE: 37 Cored Interval: 333-342 m

| SERIES | AGE ZONE Foram | AGE ZONE Nanno | AGE ZONE Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres Foram | Nanno | Rad | % $CaCO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPPER MIOCENE | *G. plesiotumida* | *D. quinqueramus* | *S. peregrina* | 1 | 1 | EMPTY | | | | Nannofossil chalk, yellowish gray, mottled, diffuse areas of light gray | | | | |
| | | | | | | | | | | Same, pale greenish yellow, slight $H_2S$ odor | | | | |
| | | | | | CC | | | * | * | Diatoms common, forams, rads, silicoflagellates present | A P | C M | | |

PHYSICAL PROPERTIES

[a]GRAPE values; laboratory values shown by triangles




SITE: 157 HOLE: CORE: 38 Cored Interval: 342-345 m

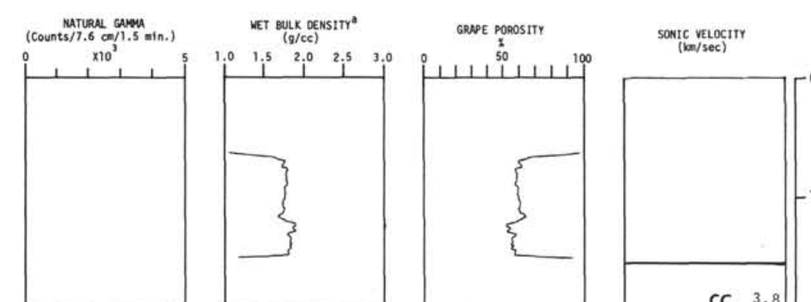
| SERIES | AGE ZONE Foram | AGE ZONE Nanno | AGE ZONE Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres Foram | Nanno | Rad | % $CaCO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPPER MIOCENE | *G. plesiotumida* | *D. quinqueramus* | *S. peregrina* | 1 | 1 | EMPTY | | | | | | | | |
| | | | | | | | | | * | Calcareous chert, hard, conchoidal fracture, mottled bedding, moderate to light olive brown; chalk, pale olive (all fragments) | | A M | | |
| | | | | | CC | | | * | * | Calcareous chert, as above, local bioturbation, abundant microfossils | | A M | | |
| | | | | | | | | * | * | Diatoms absent, rads in trace quantities | | A M | C P | |

SITE: 157 HOLE: CORE: 39 Cored Interval: 345-350 m

| SERIES | AGE ZONE Foram | AGE ZONE Nanno | AGE ZONE Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres Foram | Nanno | Rad | % $CaCO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPPER MIOCENE | *G. plesiotumida* | *D. quinqueramus* | | 1 | 1 | EMPTY | | | | | | A P | | |
| | | | | | | | | | * | Nannofossil chalk, yellowish gray to pale olive, mottled and burrowed | | | | |
| | | | | | | | | | | CORE CATCHER | | | | |
| | | | | | | | | | | Forams present, rads and diatoms virtually absent | | | | |
| | | | | | CC | | | * * | * | Nannofossil chalk, pale greenish yellow, $H_2S$ odor; calcareous chert, hard, mottled, pale greenish yellow, pale olive, yellowish gray, moderate olive brown, local gray streaks, bioturbation, forams | | A P | | |

PHYSICAL PROPERTIES

[a]GRAPE values; laboratory values shown by triangles



SITE: 157 HOLE: CORE: 40 Cored Interval: 350-359 m

| AGE: SERIES | AGE: ZONE: Foram | AGE: ZONE: Nanno | AGE: ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres: Foram | Nanno | Rad |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPPER MIOCENE | *G. plesiotumida* | *D. quinqueramus* | | 1 | 1 | EMPTY | | | | | | | |
| | | | | | CC | | | * | | CORE CATCHER<br>Chalk limestone, yellowish gray; and calcareous chert, yellowish gray to light olive gray, mottled, laminated<br>Forams in limestone, but no rads or diatoms | | | |

% $CaCO_3$: 0, 50, 100

SITE: 157 HOLE: CORE: 41 Cored Interval: 359-368 m

| AGE: SERIES | AGE: ZONE: Foram | AGE: ZONE: Nanno | AGE: ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres: Foram | Nanno | Rad |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPPER MIOCENE | *G. plesiotumida* | *D. quinqueramus* | | 1 | 1 | EMPTY | | | | Chalk limestone, hard, fine grained, cherty, yellowish gray mottled moderate olive brown and yellowish gray; chert mottles moderate olive brown<br>Chalk, yellowish gray and light olive gray<br>Calcareous chert, pale olive<br>Chalk, yellowish gray | | | |
| | | | | | CC | | | | | CORE CATCHER<br>Calcareous chert, light olive gray, interbedded with chalk limestone, yellowish gray | | | |

% $CaCO_3$: 0, 50, 100

SITE: 157 HOLE: CORE: 42 Cored Interval: 368-377 m

| SERIES | AGE ZONE: Foram | AGE ZONE: Nanno | AGE ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres: Foram | Nanno | Rad |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPPER MIOCENE | *G. plesiotumida* | *D. quinqueramus* | | 1 | 1 | | | * * * | * | Nannofossil chalk, yellowish gray mottled to light olive gray, locally cherty limestone, forams present<br>Same, light greenish gray<br>Siliceous limestone, organic mottling, light olive gray to locally moderate olive brown<br>Nannofossil chalk as above<br>Hard limestone, yellowish gray, burrows up to 1-2 mm across, 8 mm long<br>Same, light olive gray mottled with chert; no rads or diatoms; chert replaces limestone, preserving chalcedonic pseudomorphs of forams; forams in limestone commonly filled with chalcedony | | | |
| | | | | | CC | | | * | * | | A | P | |
| | | | | | | | | | | | A | | |

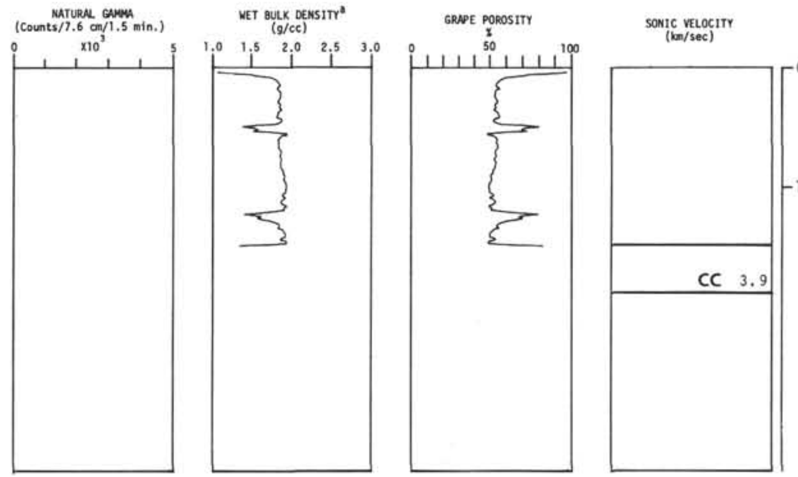
% $CaCO_3$: 0 50 100

CORE CATCHER

Chalk limestone, yellowish gray to pale olive, irregular nodules of olive gray to light olive gray chert; thin mottling parallel to bedding; dip 0°

PHYSICAL PROPERTIES

[a]GRAPE values; laboratory values shown by triangles




Sonic Velocity (km/sec) 4.2

SITE: 157 HOLE: CORE: 43 Cored Interval: 377-386 m

| SERIES | AGE ZONE: Foram | AGE ZONE: Nanno | AGE ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres: Foram | Nanno | Rad |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPPER MIOCENE | *G. plesiotumida* | *D. quinqueramus* | | 1 | 1 | | | | | Nannofossil chalk limestone, laminated to nodular, yellowish gray to very light gray, bioturbation and mottles, stringers of nodular chert, mottled light olive gray to olive gray, 1-5 mm thick | | | |
| | | | | | CC | | | | * | | A | | |

% $CaCO_3$: 0 50 100

SITE: 157 HOLE: CORE: 44 Cored Interval: 386-395 m

| AGE: SERIES | ZONE: Foram | ZONE: Nanno | ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres: Foram | Nanno | Rad |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPPER MIOCENE | *G. plesiotumida* | *?D. quinqueramus* | | | CC | | | * | * | Chalk limestone, yellowish gray, thin streaks light olive gray; irregular lenses of olive gray chert; silic. veins to 2 mm cross bedding | | A P | |

Sonic Velocity (km/sec) 3.9; CC

% $CaCO_3$: 0, 50, 100

SITE: 157 HOLE: CORE: 45 Cored Interval: 395-404 m

| AGE: SERIES | ZONE: Foram | ZONE: Nanno | ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres: Foram | Nanno | Rad |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPPER MIOCENE | *G. plesiotumida* | *?D. neohamatus* | | 1 | 1 | | | | | | | | |
| | | | | | CC | | | * | * * | Chalk limestone, yellowish gray, massive, with nodules of olive gray chert | | P P<br>A P | |

% $CaCO_3$: 0, 50, 100

SITE: 157 HOLE: CORE: 46 Cored Interval: 404-413 m

| AGE: SERIES | ZONE: Foram | ZONE: Nanno | ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres: Foram | Nanno | Rad |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPPER MIOCENE | *G. plesiotumida* | *?D. neohamatus* | | 1 | 1 | EMPTY | | | | Chalk limestone, hard, light greenish gray, mottled to greenish gray, pale olive; irregular concretionary bodies of chert, olive black, abundant bioturbation | | A P | |
| | | | | | CC | | | | | CORE CATCHER<br>Thin section: silica replacing calcite matrix and fossil fragments<br>Chalk limestone, yellowish gray, 1 mm concentrations of chert; irregular contact with massive chert, olive gray mottled to light olive gray | | A P | |

% $CaCO_3$: 0, 50, 100

SITE: 157 HOLE: CORE: 47 Cored Interval: 413-422 m

| AGE: SERIES | ZONE: Foram | ZONE: Nanno | ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres: Foram | Nanno | Rad |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPPER MIOCENE | *G. plesiotumida* | *?D. neohamatus* | | 1 | 1 | EMPTY | | | | Nannofossil chalk limestone, light olive gray with stringers of yellowish gray and olive gray, extensive burrowing, burrows compressed axially. | | | |
| | | | | | CC | | | | * | CORE CATCHER<br>Chalk limestone, pale olive, mottled with light olive to medium gray lenses, local discontinuous 1 mm laminae; pyritic concentrations | A P | | |

% $CaCO_3$: 0, 50, 100

SITE: 157 HOLE: CORE: 48 Cored Interval: 422-431 m

| AGE | | | | | | | | | | MICROFOSSIL Abund/Pres | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SERIES | ZONE: Foram | ZONE: Nanno | ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | Foram | Nanno | Rad |
| UPPER MIOCENE | *G. plesiotumida* | *?D. neohamatus* | | 1 | 1 | EMPTY | | | | Nannofossil chalk limestone, very light gray to dark gray, mottled, streaked and burrowed; burrows axially compressed; pyritic? concentrations are black grading outward to grayish purple to medium light gray; diffuse areas 5-10 mm thick are pale blue and pale blue green | | | |
| | | | | | CC | | | | | CORE CATCHER<br>Chalk limestone, yellowish gray to light greenish gray, thin laminae of dark gray; irregular nodules and bodies of chert, moderate olive brown up to 1 cm across; rads and diatoms absent | A A | M P | |

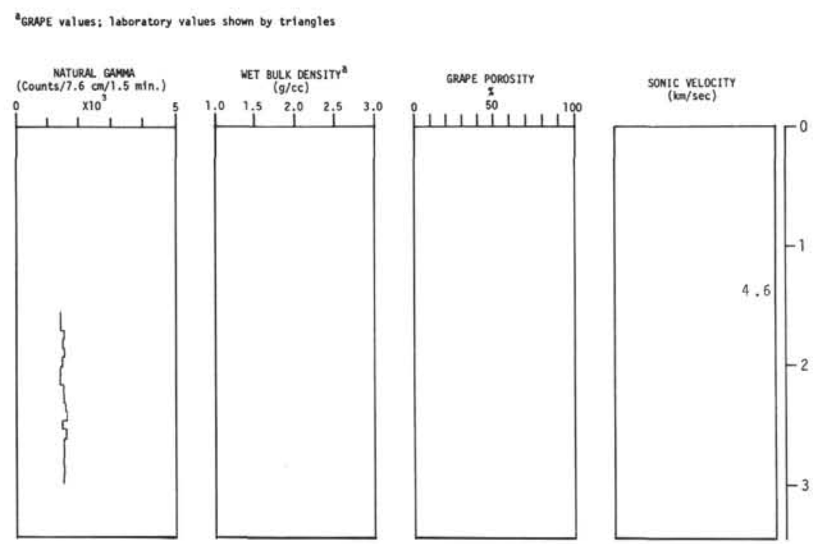
% $CaCO_3$: 0, 50, 100

SITE: 157 HOLE: CORE: 49 Cored Interval: 431-437 m

| AGE | | | | | | | | | | MICROFOSSIL Abund/Pres | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SERIES | ZONE: Foram | ZONE: Nanno | ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | Foram | Nanno | Rad |
| | | | | 1 | 1 | EMPTY | | * * | * | Basalt: convex- upward, curved, crust-like masses, medium to light gray, smeared vesicles and amygdules, associated gray fine grained volcanic sediment or altered glass<br>Medium to dark gray massive basalt, very fine grained with 0.2-1 mm plagioclase laths and interstitial augite; 1-5 mm glomeroporphyritic clots of oscillatory-zoned plagioclase showing synneusis, veins of calcite with pyrite, ?chalcopyrite and ?pyrrhotite | | | |
| | | | | 2 | 2 | | | | | | | | |
| | | | | | CC | | | | | | | | |

% $CaCO_3$: 0, 50, 100

PHYSICAL PROPERTIES



SITE: 157 HOLE: A CORE: 1 Cored Interval: 0-9 m

| SERIES | AGE / ZONE: Foram | Nanno | Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres: Foram / Nanno / Rad; % $CaCO_3$ (0, 50, 100) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| UPPER PLEISTOCENE OR HOLOCENE | Not Named | *Gephyrocapsa oceanica* or *Emiliania huxleyi* | *Collosphaera tuberosa* | 0–9 | 1, 2, 3, 4, 5, 6, CC | EMPTY (top of Section 1) | | | | Nannofossil-foraminiferal chalk ooze, light olive diatoms abundant, rads common<br>Same, mottled pale olive to moderate olive brown, burrowed; silicoflagellates present<br>Same, moderate greenish yellow; burrow 5 mm diameter moderate olive brown<br>Same, light olive<br>Same, pale olive, disturbed mottles and 10 mm burrows of light olive<br>5 mm burrows filled with light olive<br>Same, mottled light olive and pale olive<br>Burrows<br>Massive<br>Slightly mottled<br>Same, light greenish gray mottled pale olive<br>Light olive mottled greenish gray<br>Same, mottled pale olive to very pale olive; light gray burrows and 3-8 mm streaks<br>Same, light greenish gray; light gray 1-2 mm burrows and 3-8 mm discontinuous laminaes<br>Same, pale olive, light olive mottles and burrows<br>5 cm burrow and 5 mm light olive interbedded<br>5 cm light olive interbed; otherwise pale olive<br>Same, very pale olive, darker interbeds, medium light gray streaks<br>Same, pale olive, streaks light gray, burrows up to 5 mm<br>Same, with light greenish gray interbeds<br>Large burrow 2 mm across | A G (top, ~1 m)<br>A G (CC) |

SITE: 157 HOLE: A CORE: 2 Cored Interval: 9-18 m

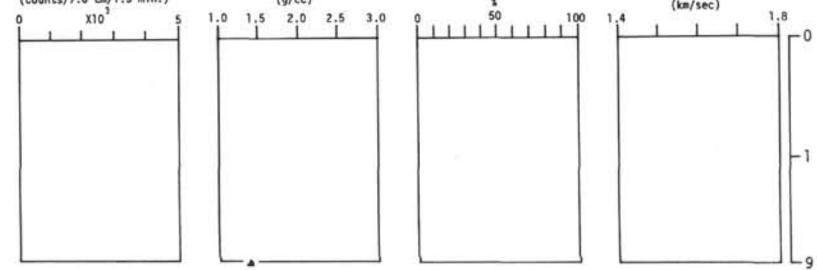
| SERIES | AGE ZONE: Foram | AGE ZONE: Nanno | AGE ZONE: Rad | DEPTH (Meters) | SECTION | LITHOLOGY | Disturbance | Smear Slide | Paleo. sample | DESCRIPTION | MICROFOSSIL Abund/Pres: Foram | Nanno | Rad |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UPPER PLEISTOCENE | Not Named | 1[1] | Collasphaera tuberosa | 1 | 1 | EMPTY | | * * * | | Nannofossil-foraminiferal chalk ooze, $H_2S$ odor, pale olive grading down to very pale olive, burrows to 3 mm<br>Light greenish gray to light olive burrows<br>Medium light gray streaks<br><br>Same, pale olive mottled very pale olive and light gray | | | |
| | | 2[2] | | | CC | | | | * | Forams reduced in abundance, diatoms abundant, rads common, silicoflagellates present | | A G | |

% $CaCO_3$: 0 50 100

[1] *Gephyrocapsa oceanica* or *Emiliania huxleyi* [2] *Gephyrocapsa oceanica*

PHYSICAL PROPERTIES

[a] GRAPE values; laboratory values shown by triangles



SITE: 157 HOLE: A CORE: 3 Cored Interval: 18-27 m

| SERIES | AGE ZONE: Foram | Nanno | Rad | DEPTH (Meters) | SECTION | DESCRIPTION |
|---|---|---|---|---|---|---|
| UPPER PLEISTOCENE | Not Named | *Gephyrocapsa oceanica* | *Amphirhopalum ypsilon* | 0–1.5 | 1 | Nannofossil-foraminiferal chalk ooze, $H_2S$ odor, light greenish gray, local mottling to light olive<br>Diatoms abundant, rads common, silicoflagellates present |
| | | | | 1.5–3 | 2 | Same, pale olive with light olive mottles<br>Same, with light gray di-fuse laminaes<br>5 mm dusky yellow burrow |
| | | | | 3–4.5 | 3 | Same (pale olive) with laminae of light olive and light gray<br>Same, with 1-3 mm diffuse laminae of light gray |
| | | | | 4.5–6 | 4 | Same with mottles and burrows of pale greenish yellow<br>Same, very light olive<br>Gradational change to pale olive<br>Layer of light olive |
| | | | | 6–7.5 | 5 | Same, very pale olive, mottles and streaks of light gray<br>Same, very light olive<br>Same, very pale olive<br>Same, very light olive |
| | | | | 7.5–9 | 6 | Same, very pale olive, streaks of light gray<br>Same, very light olive, slightly mottled |
| | | | | | CC | |

MICROFOSSIL Abund/Pres: Foram, Nanno, Rad; % $CaCO_3$ (0, 50, 100). CC: A G

PHYSICAL PROPERTIES

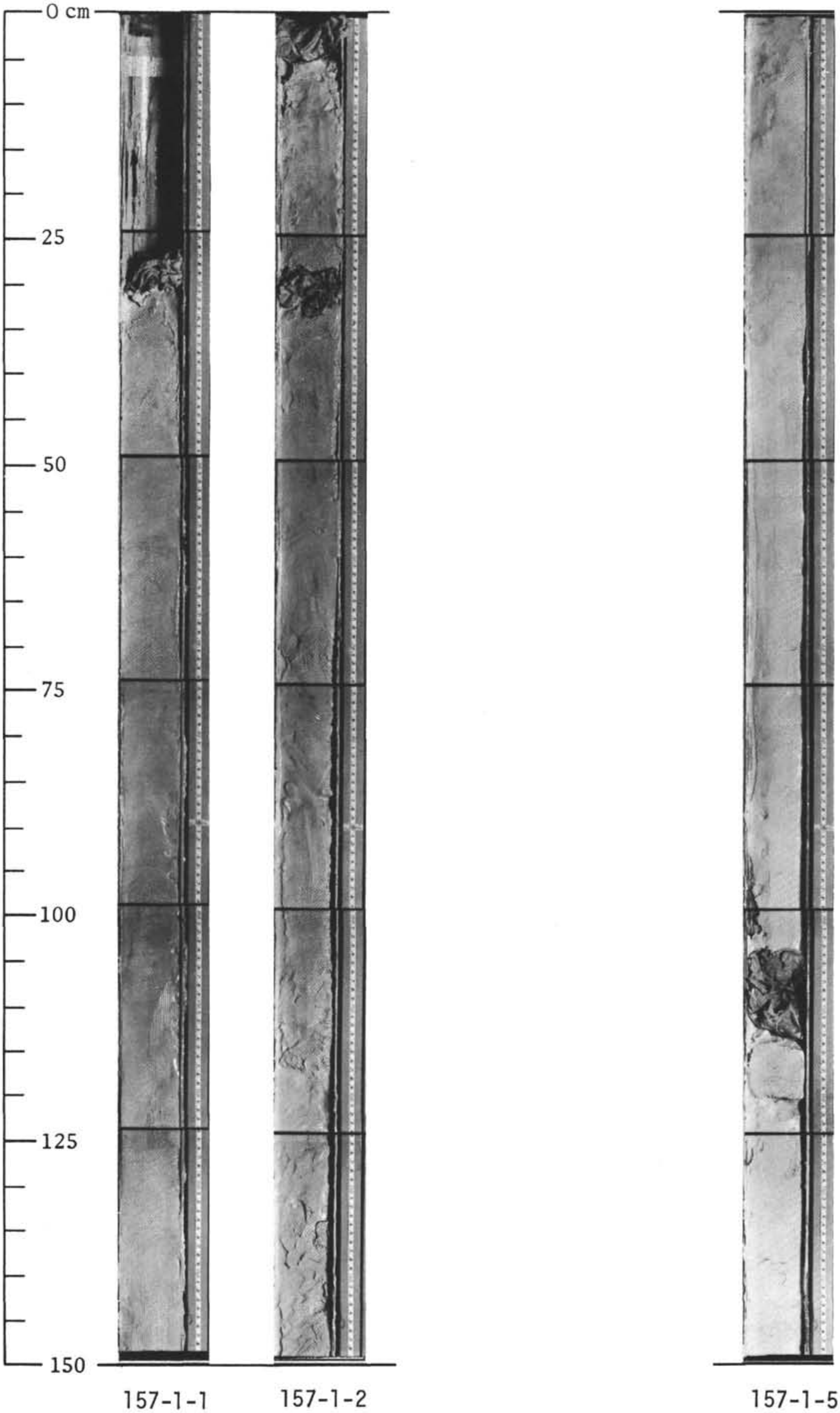
[a]GRAPE values; laboratory values shown by triangles

NATURAL GAMMA (Counts/7.6 cm/1.5 min.) 0 – 5 X10[3]

WET BULK DENSITY[a] (g/cc) 1.0 1.5 2.0 2.5 3.0

GRAPE POROSITY % 0 50 100

SONIC VELOCITY (km/sec) 1.6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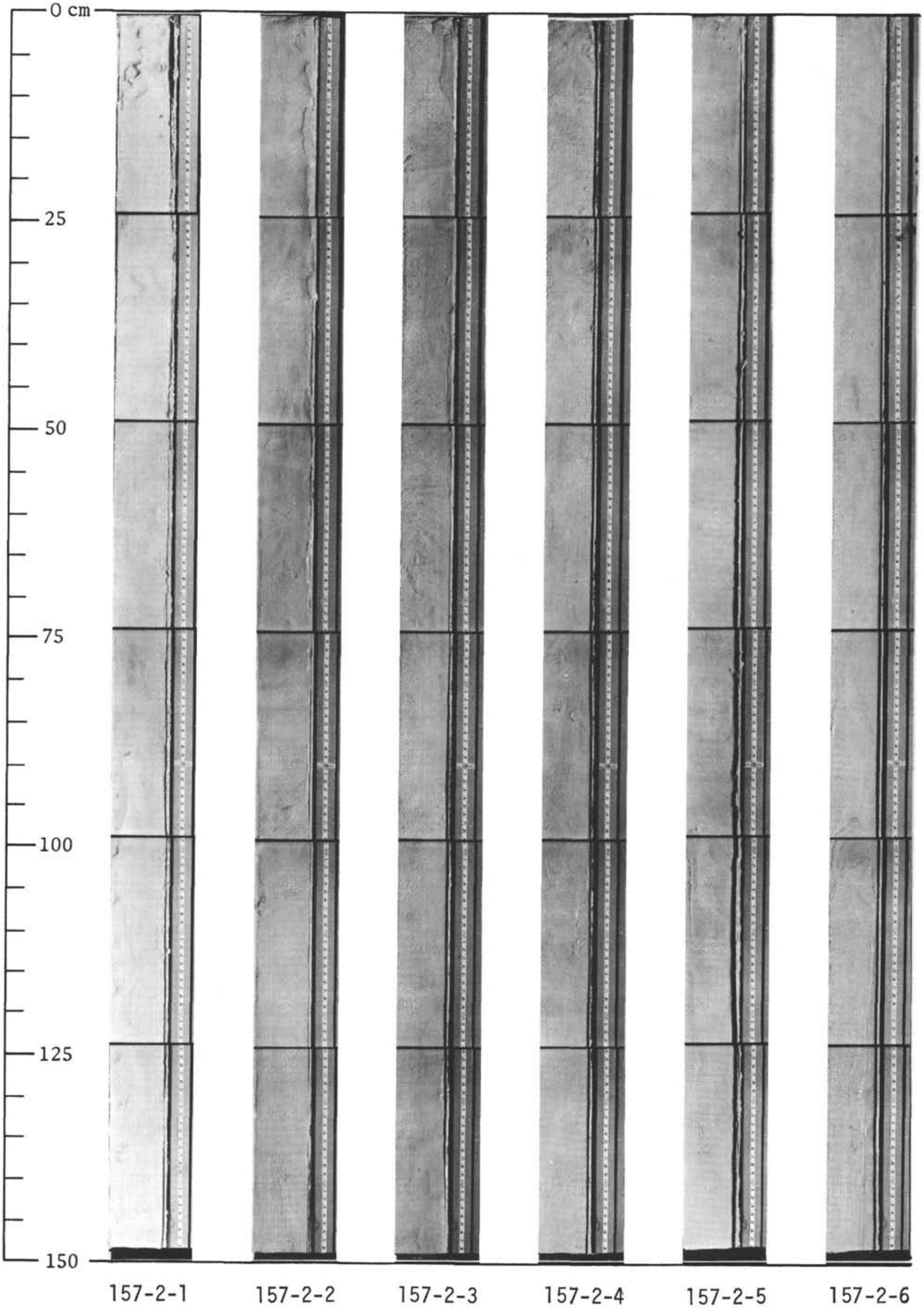
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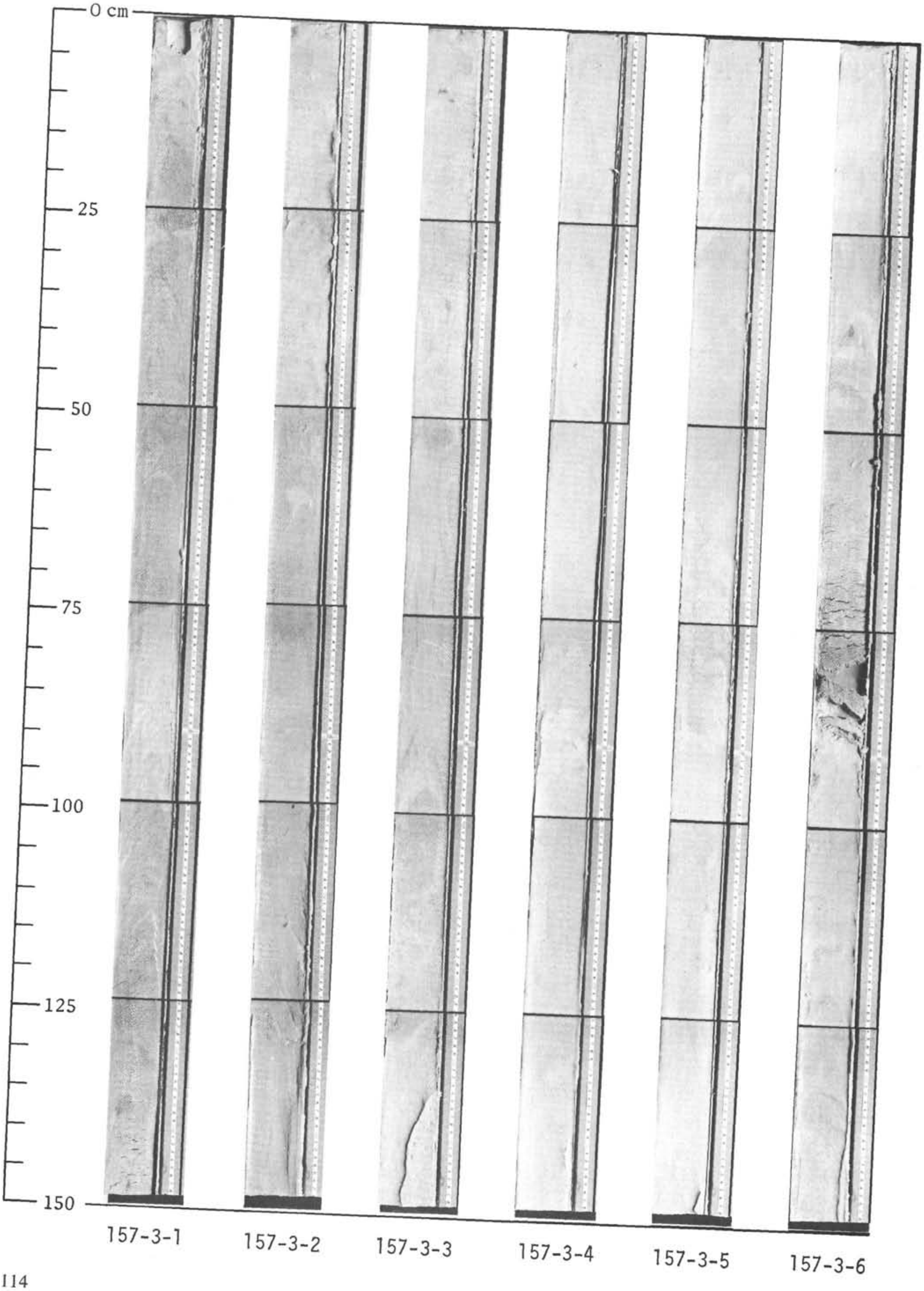
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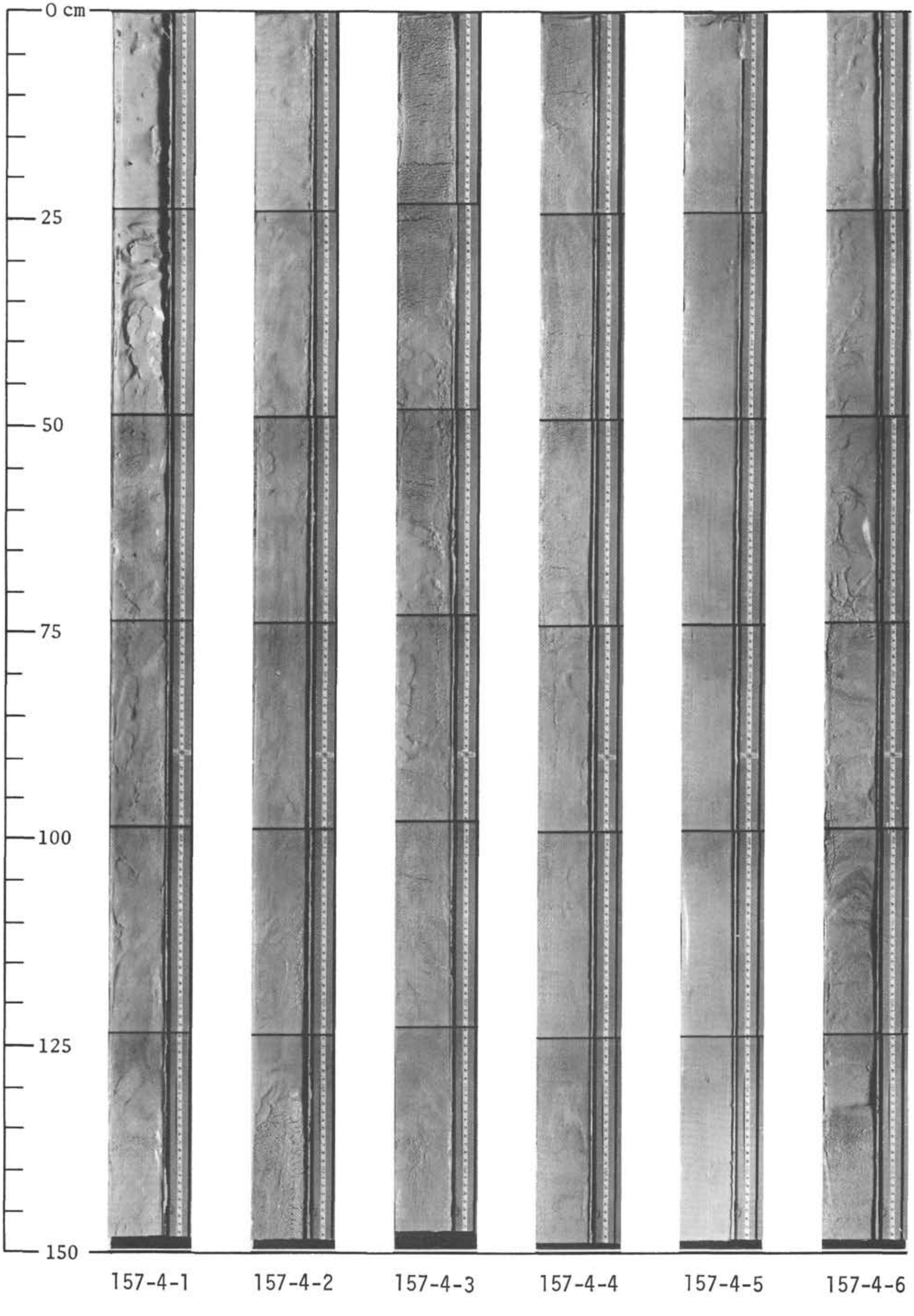
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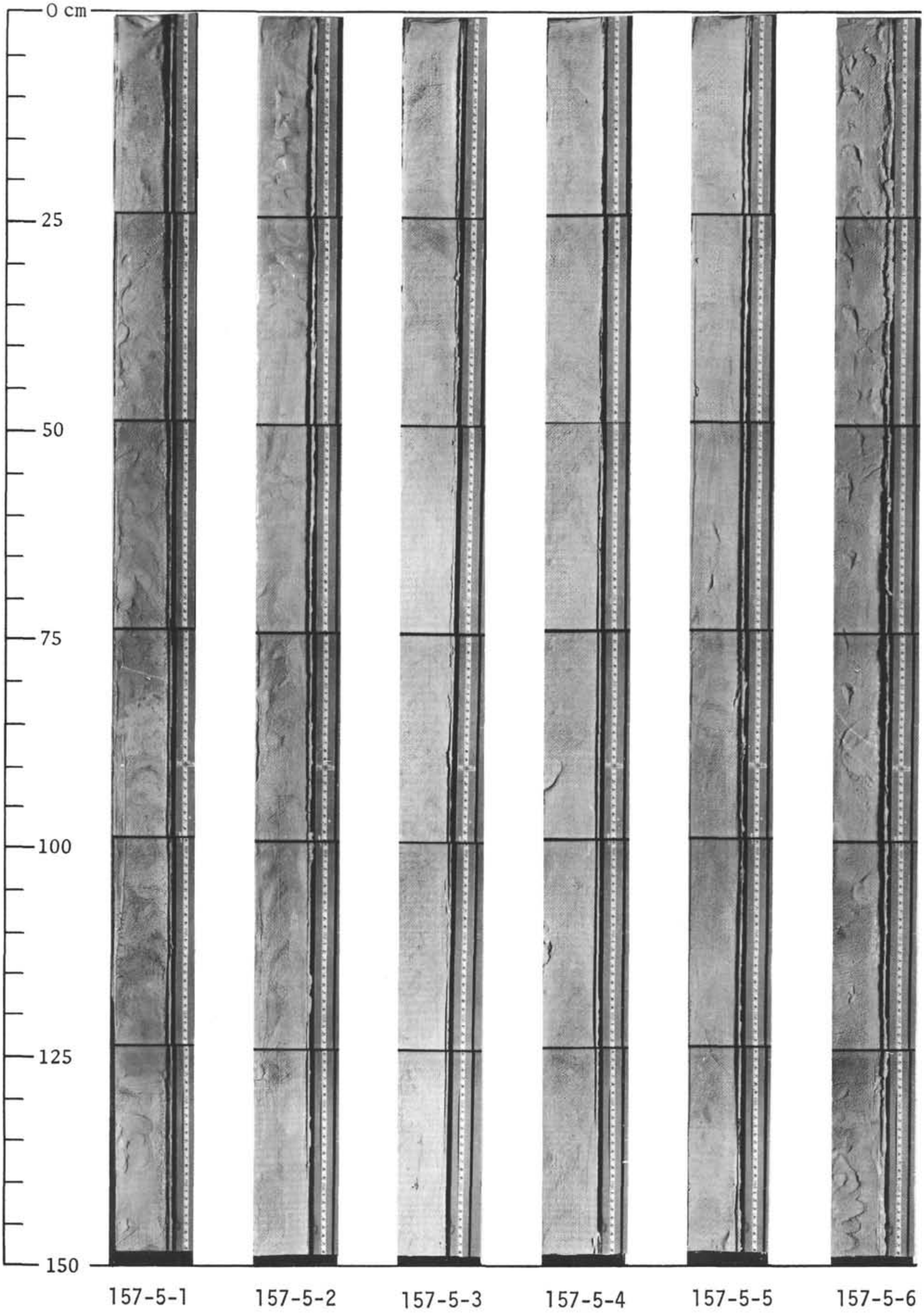
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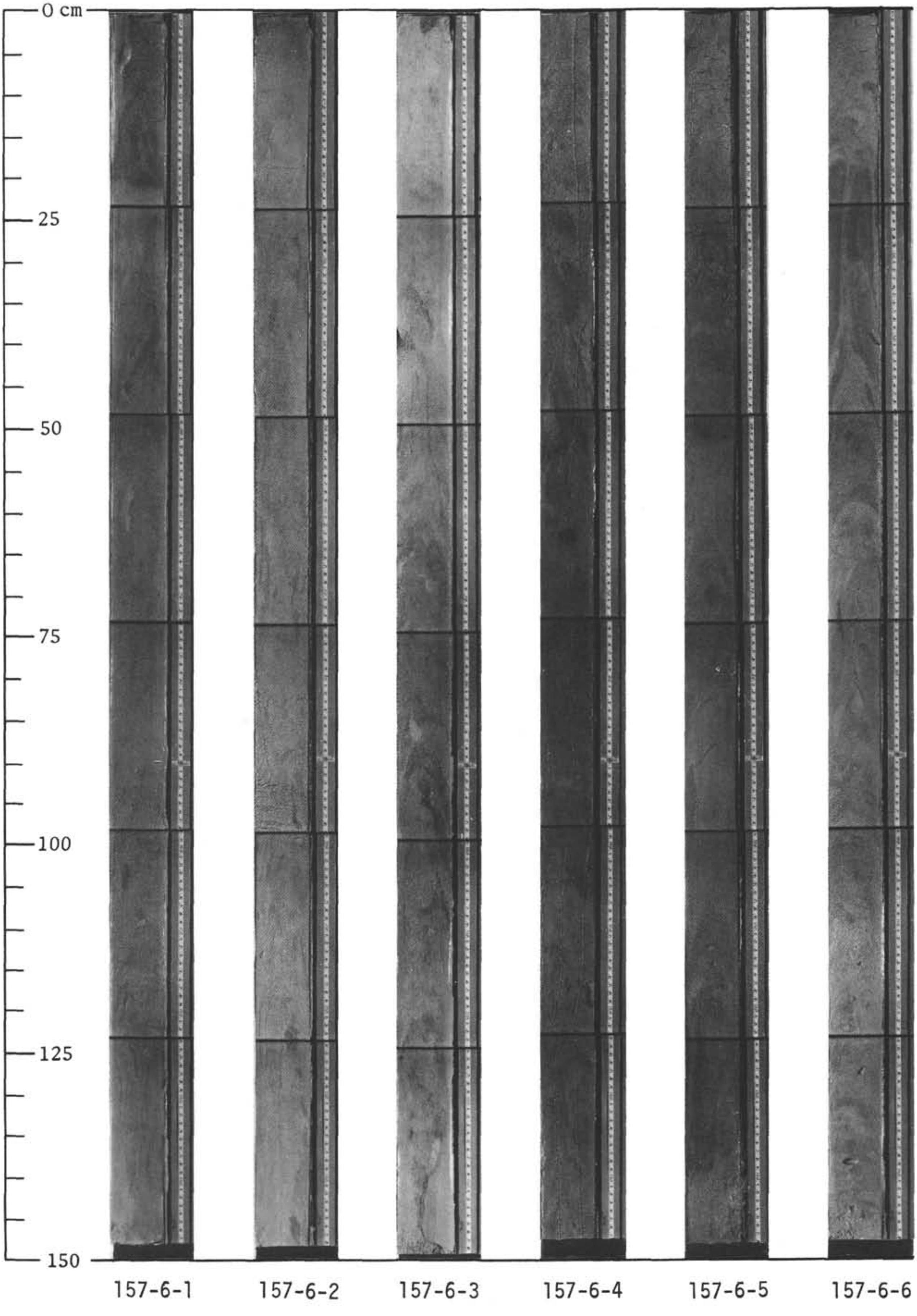
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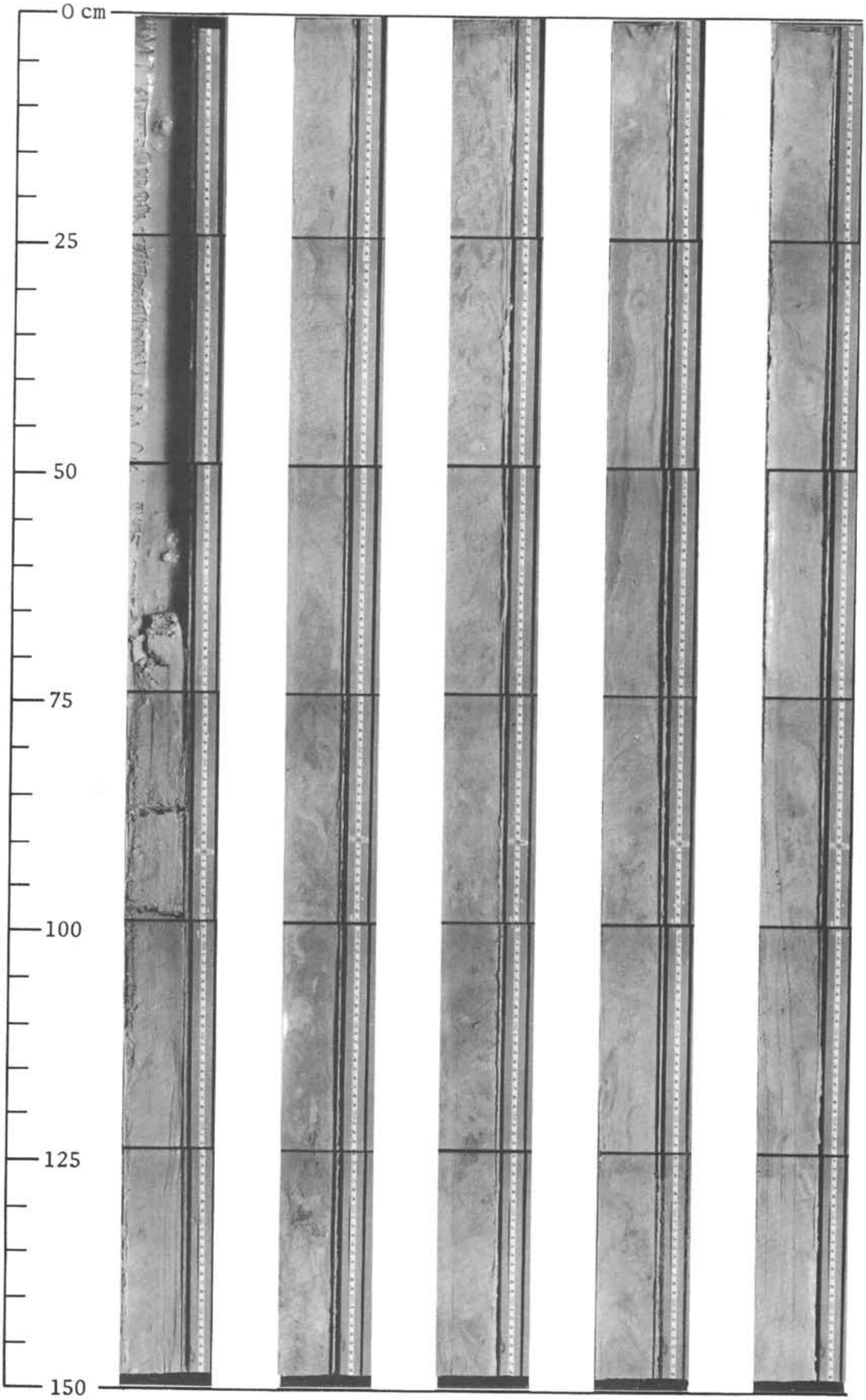


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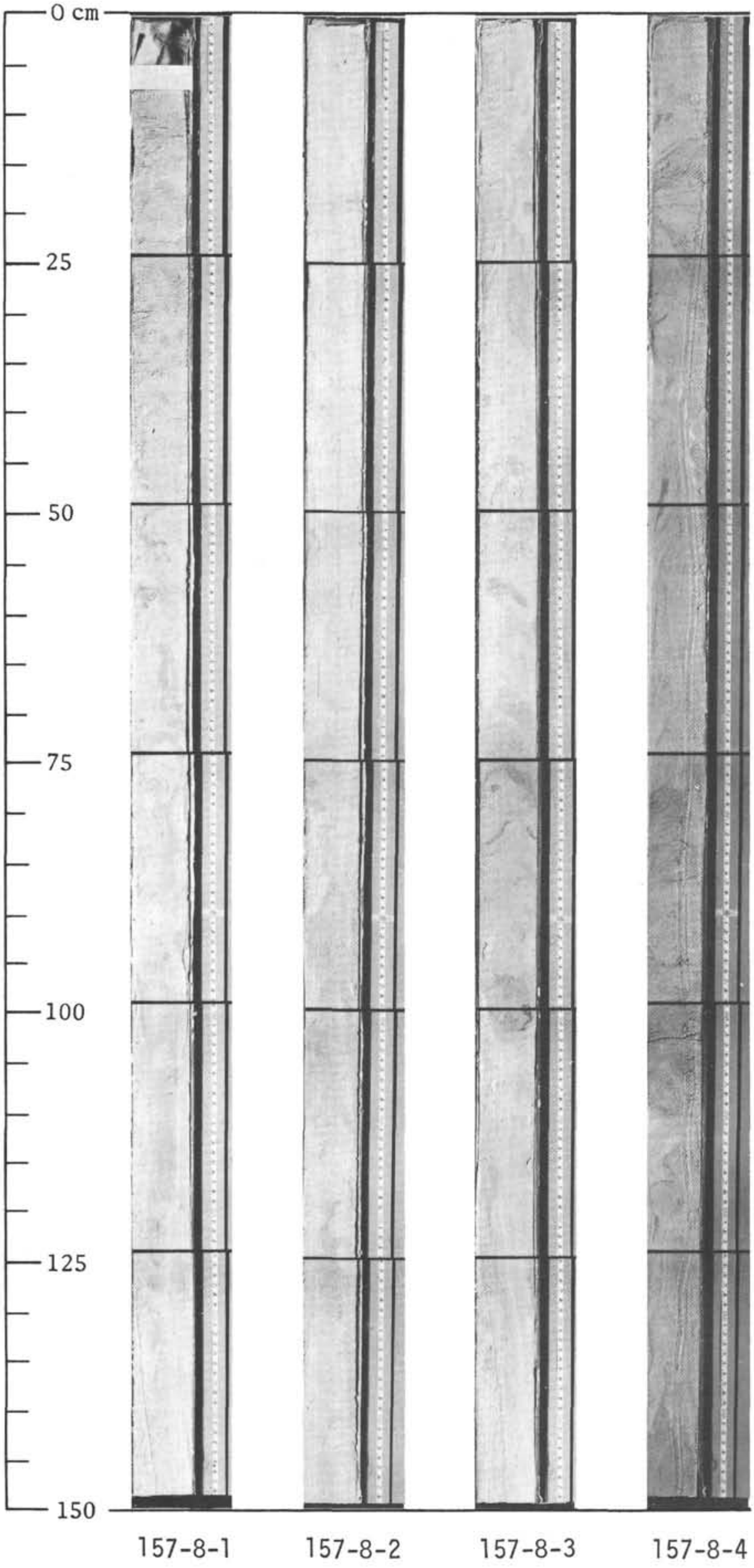
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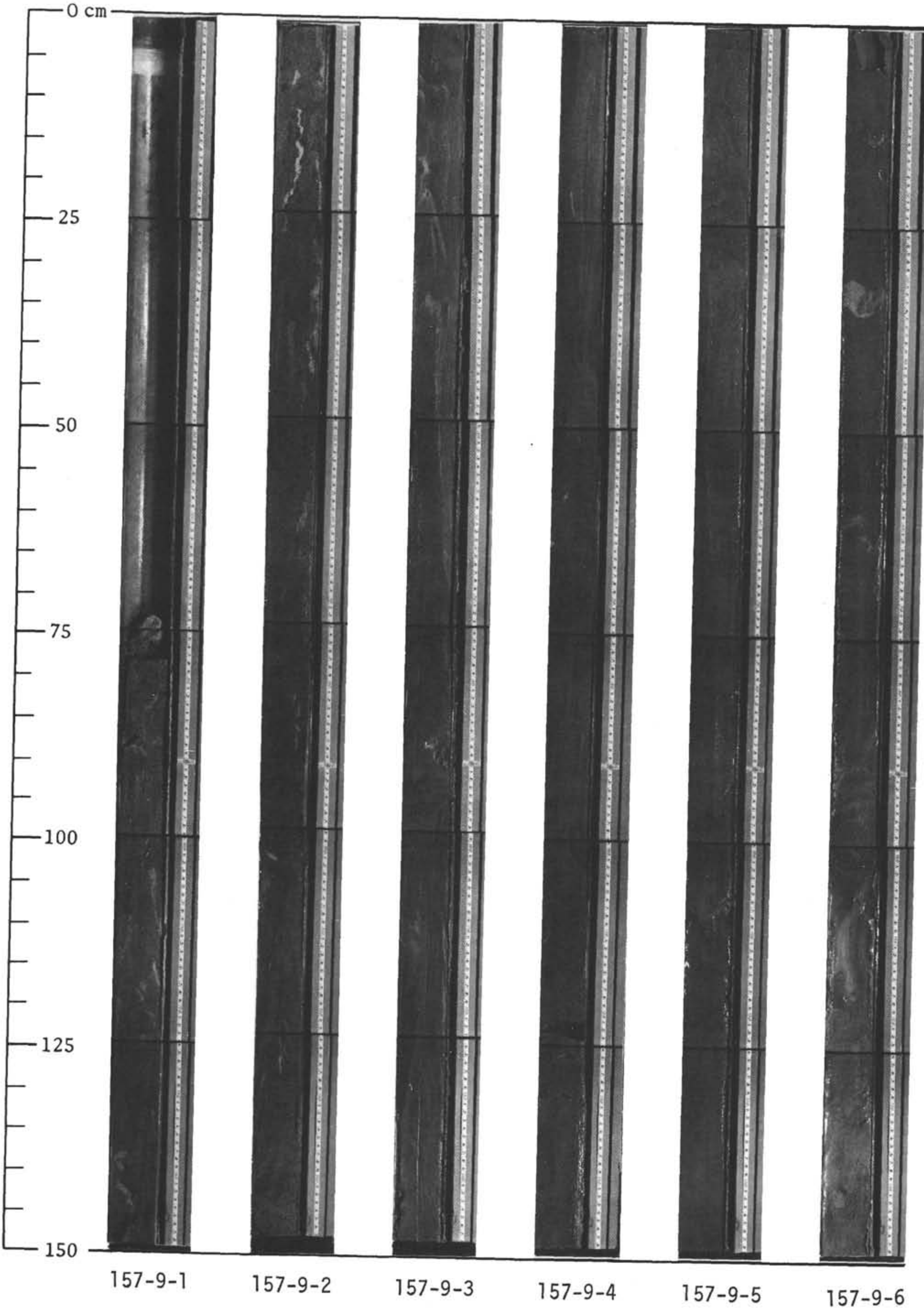
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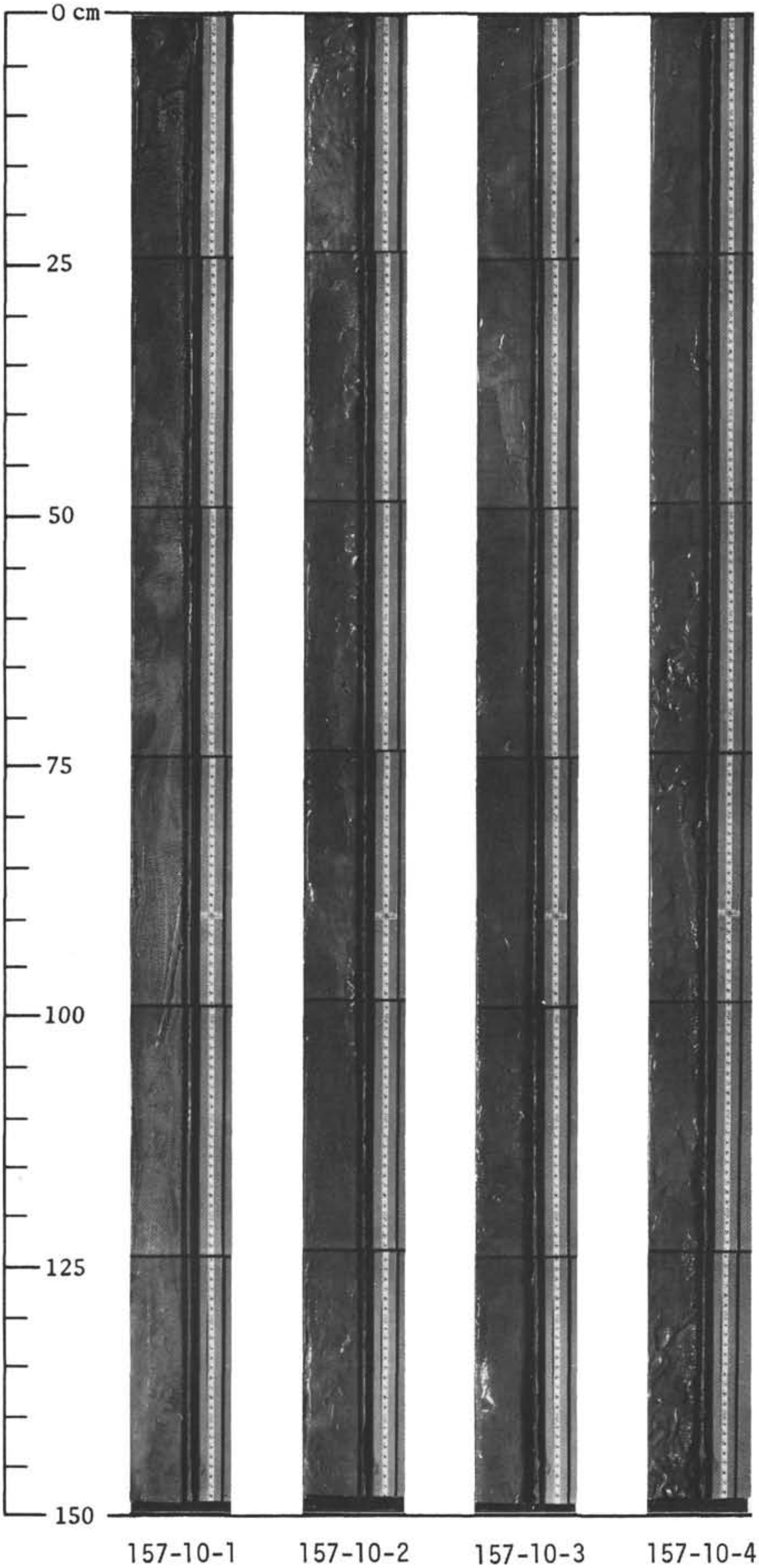
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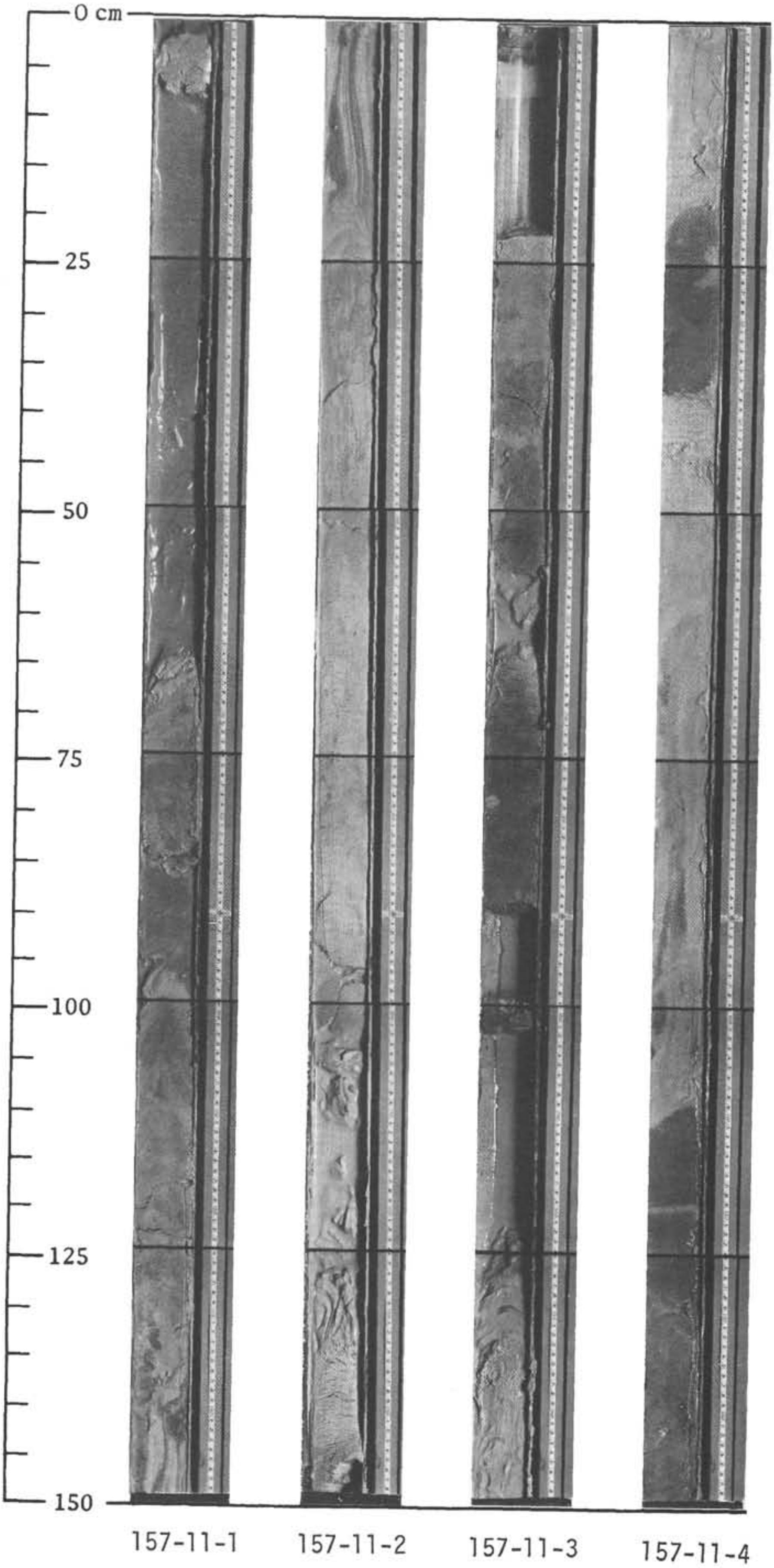
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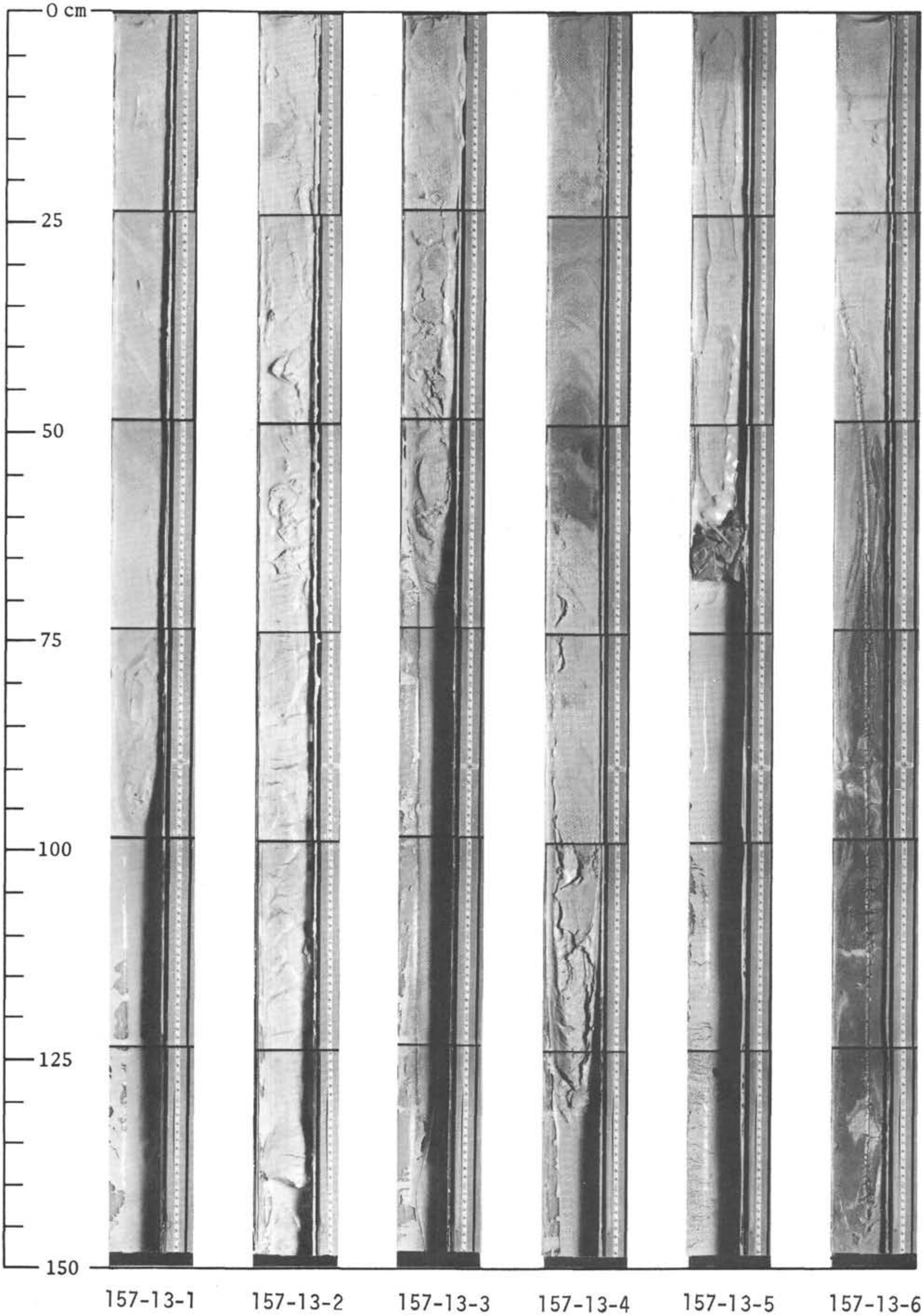
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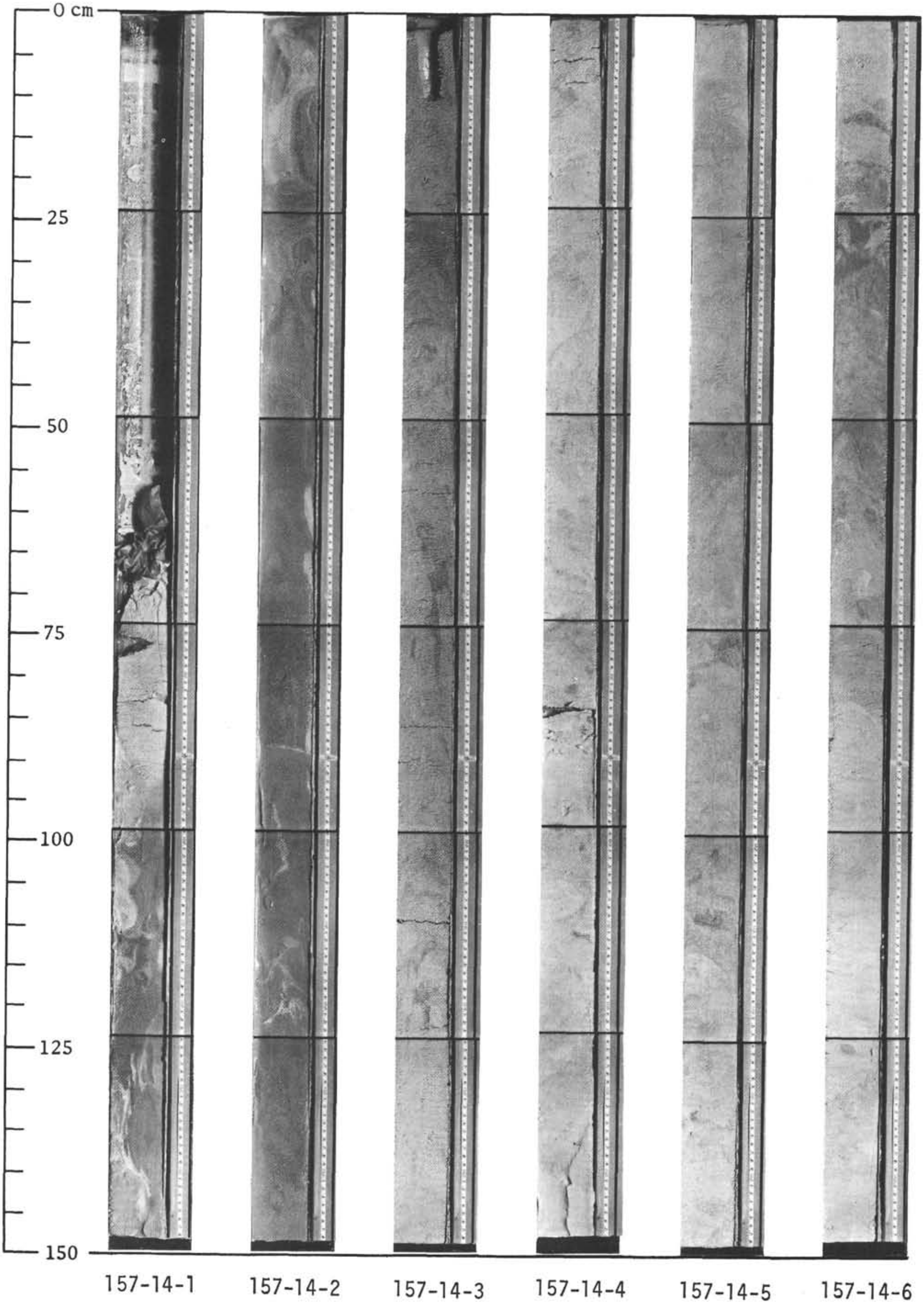
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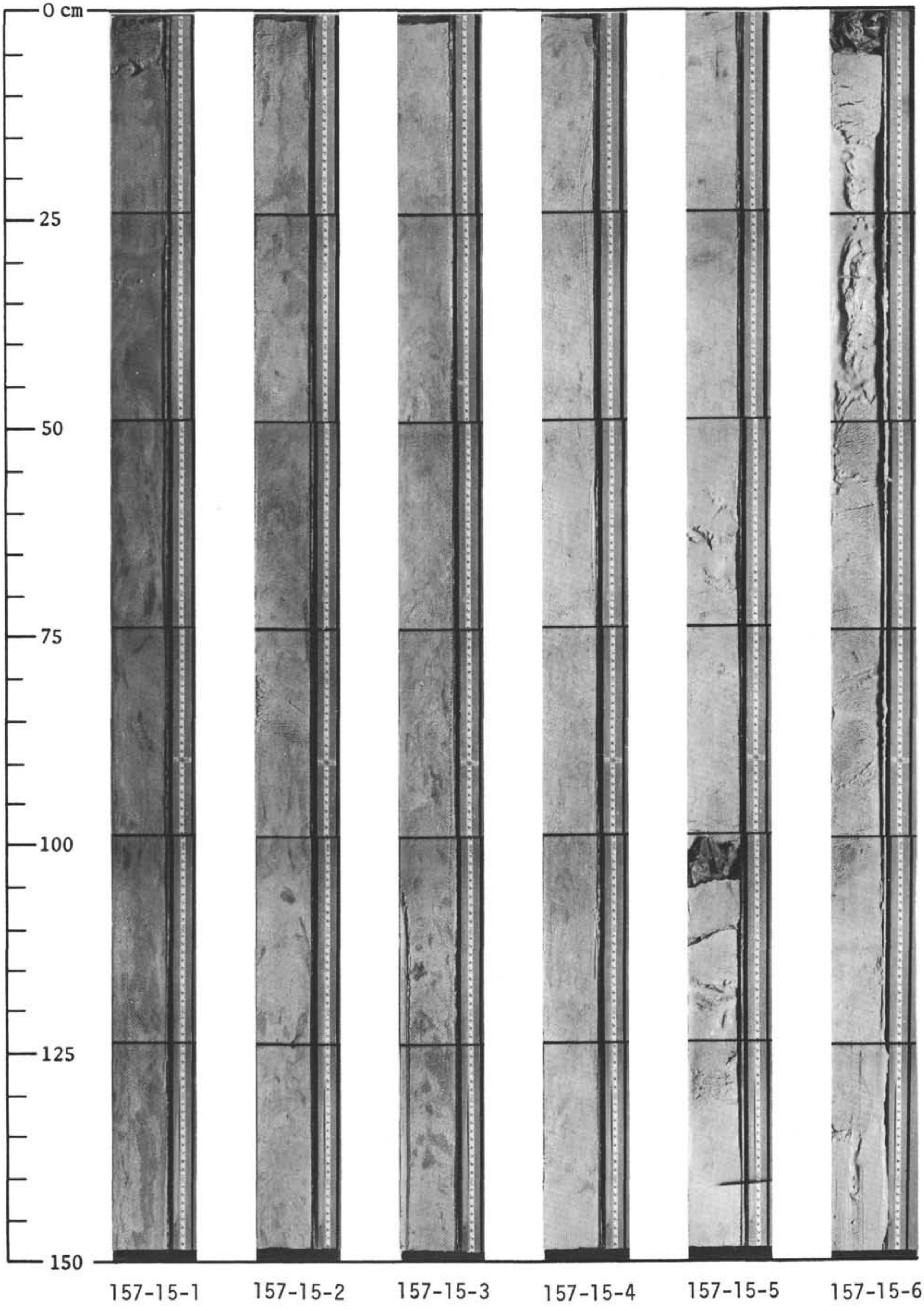
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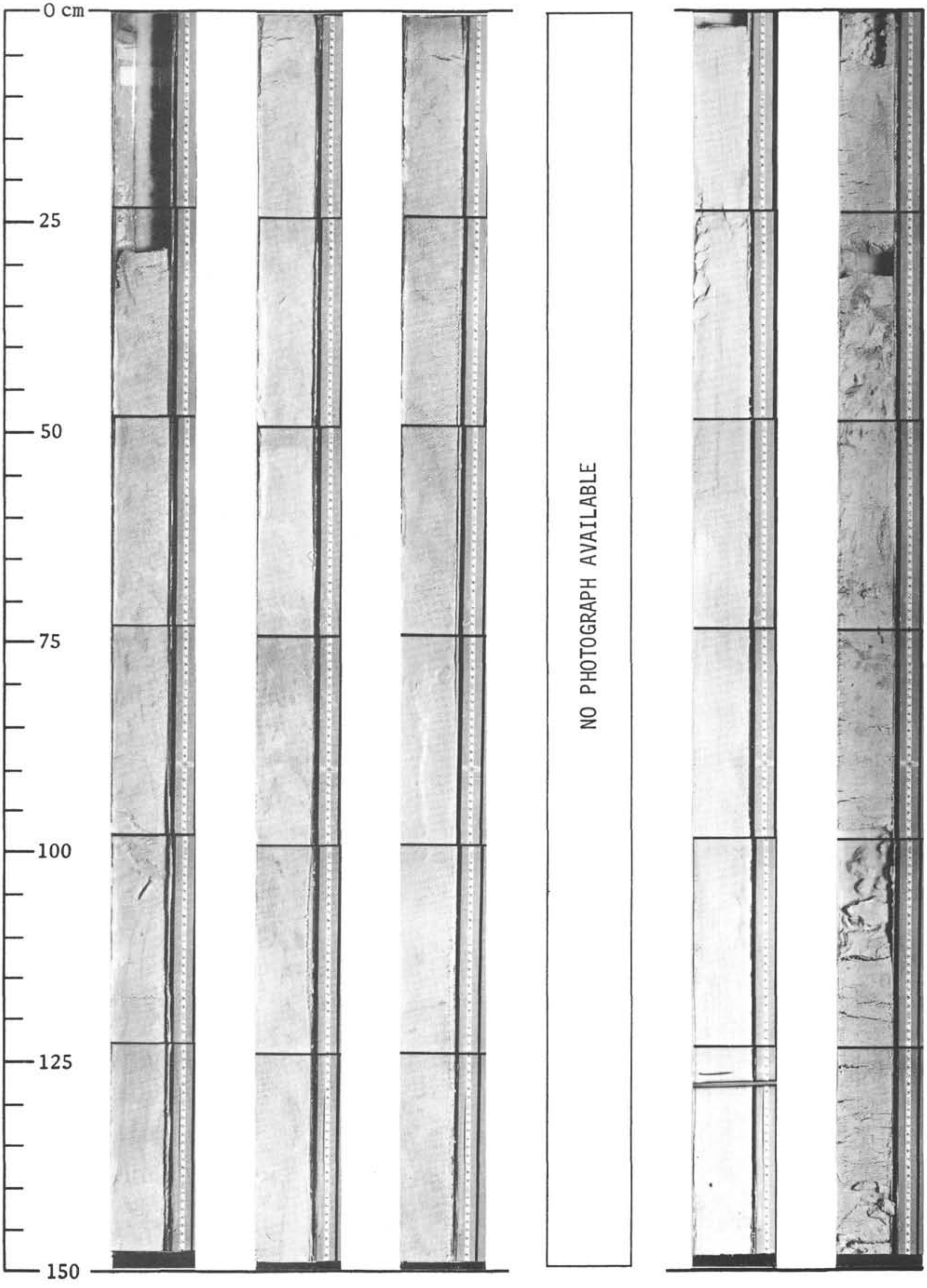
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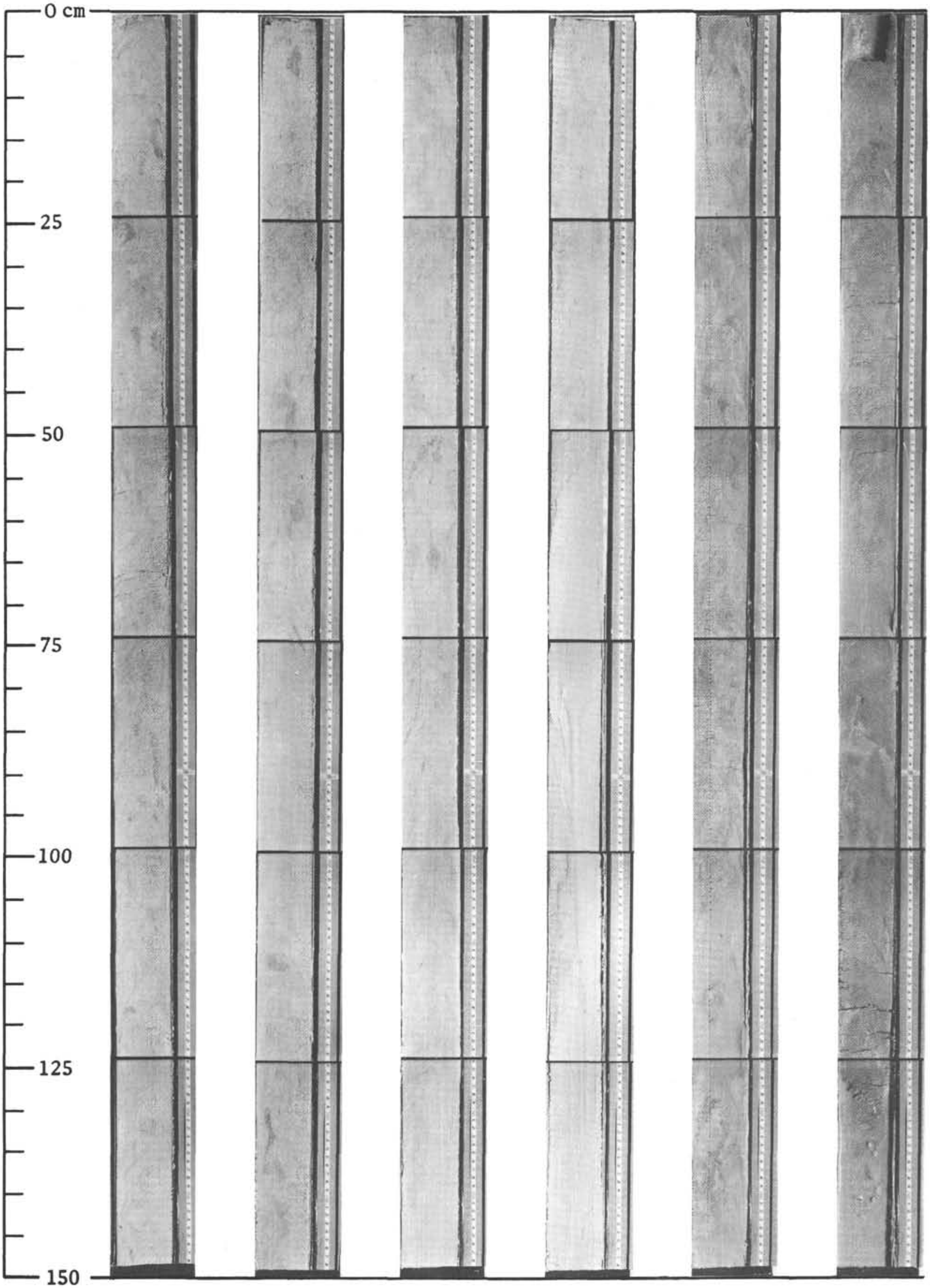
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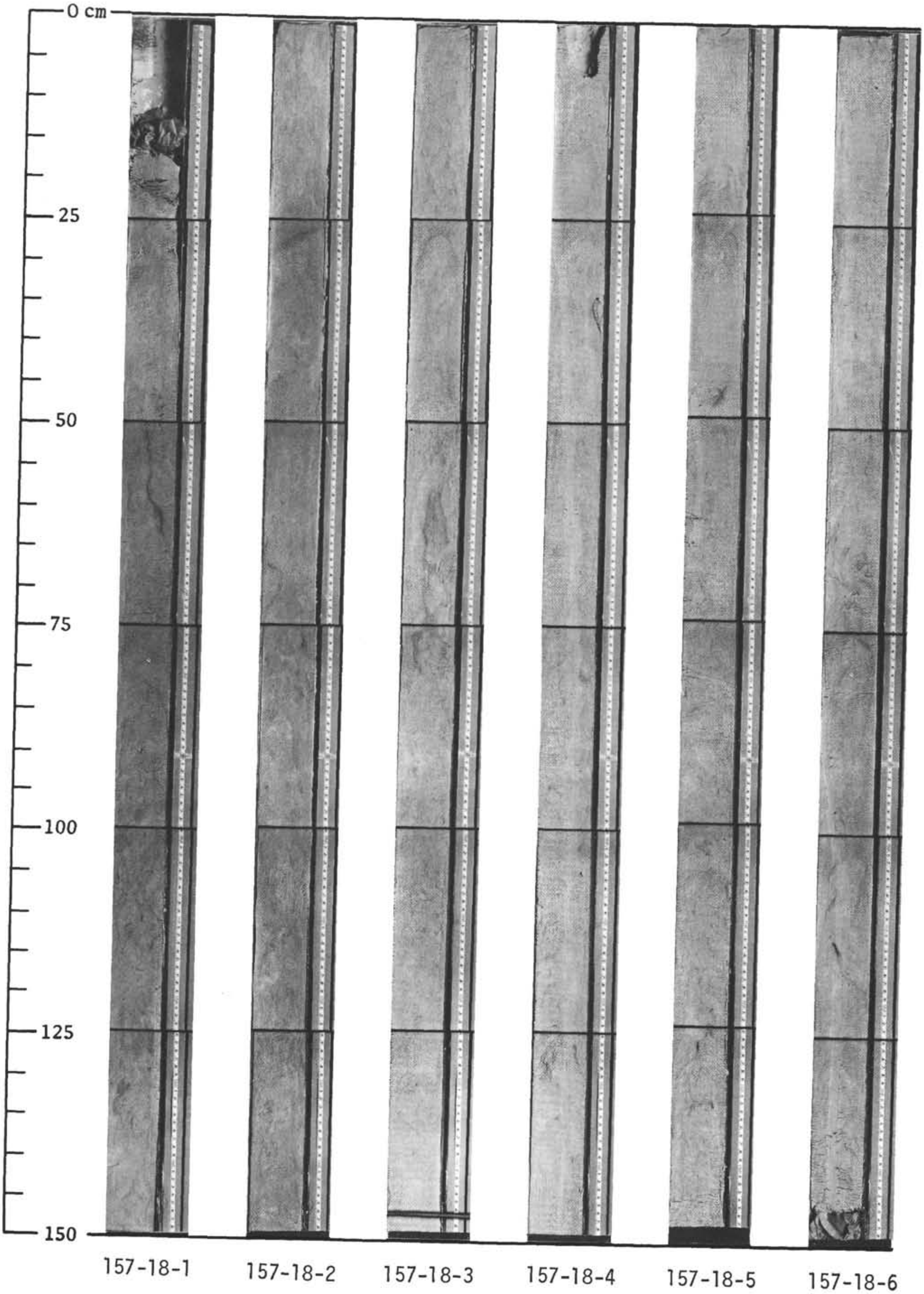
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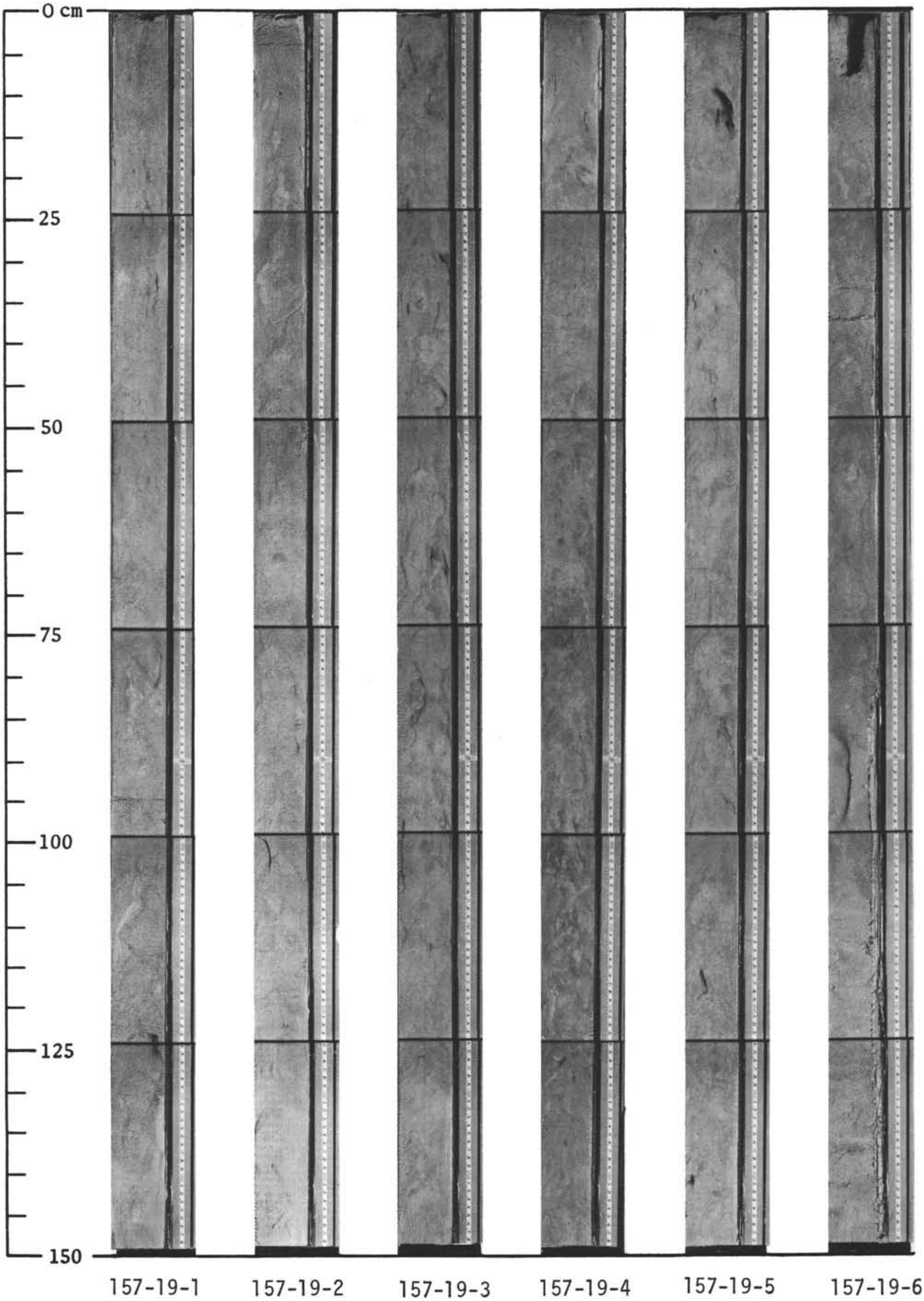
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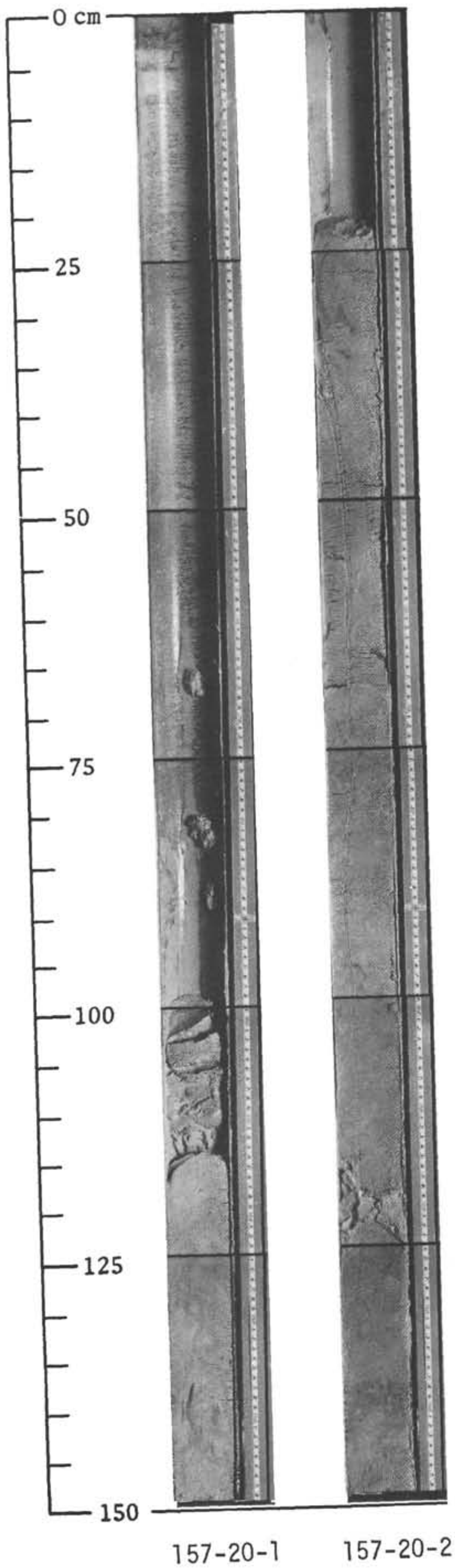
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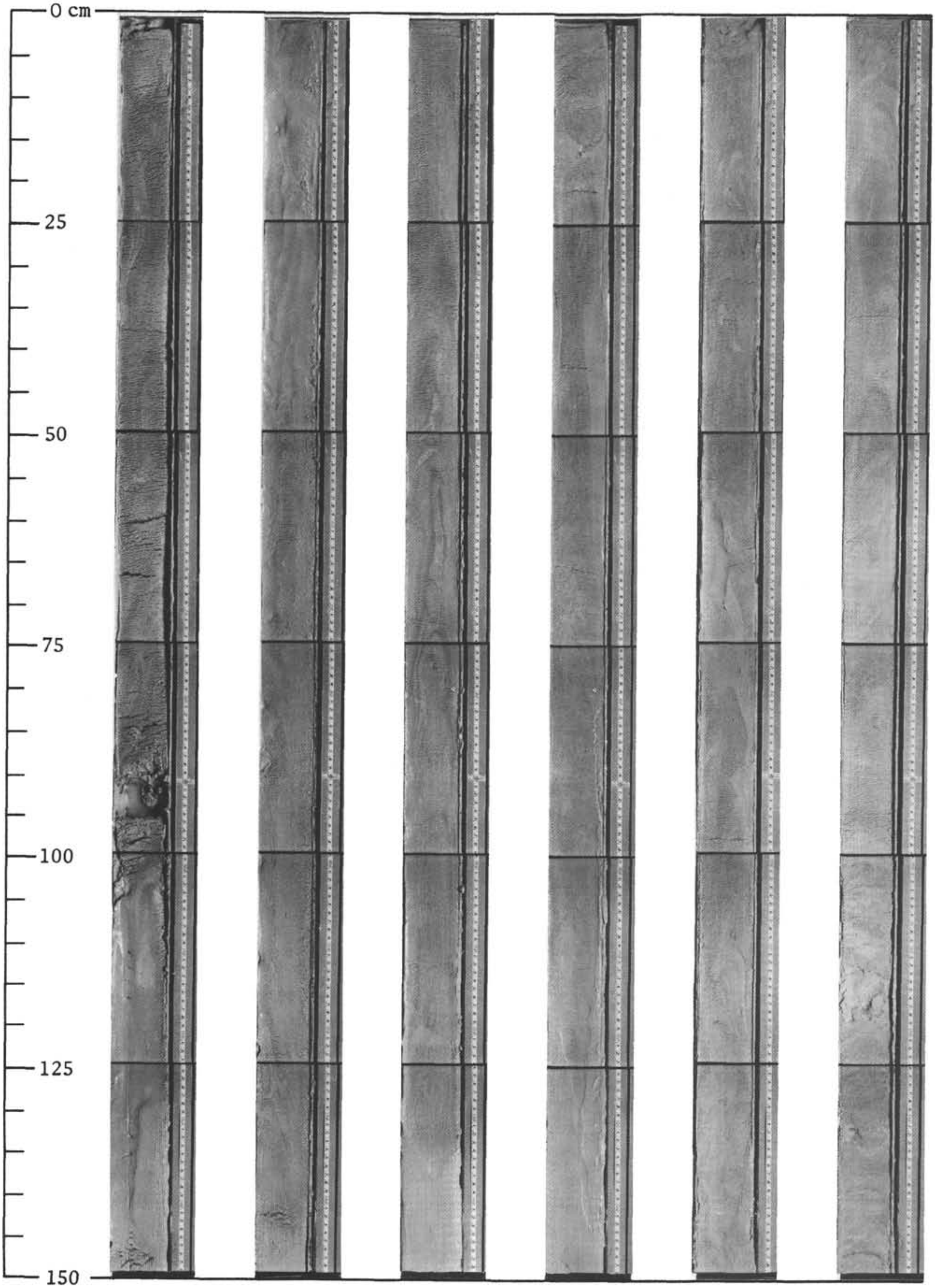
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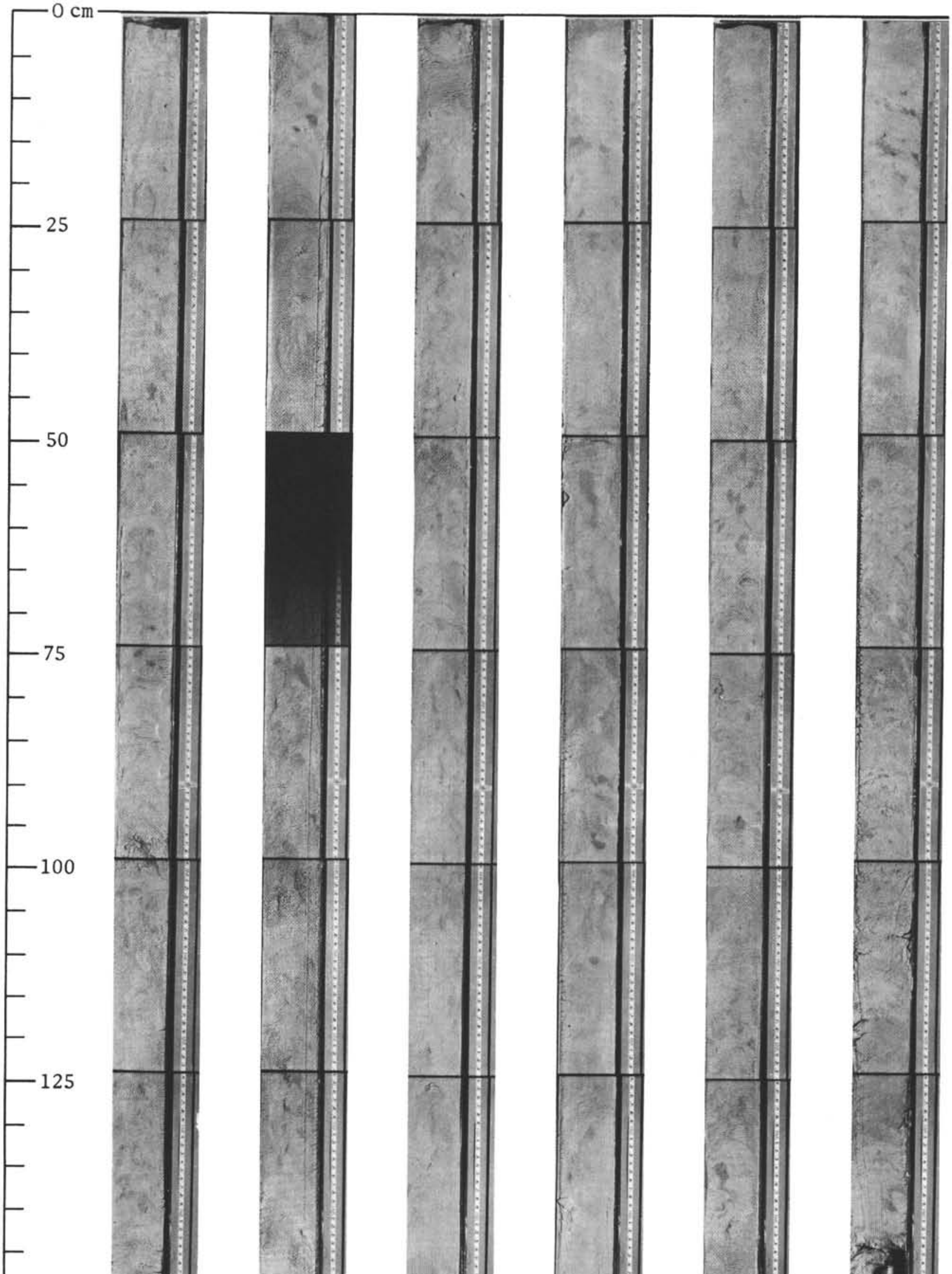
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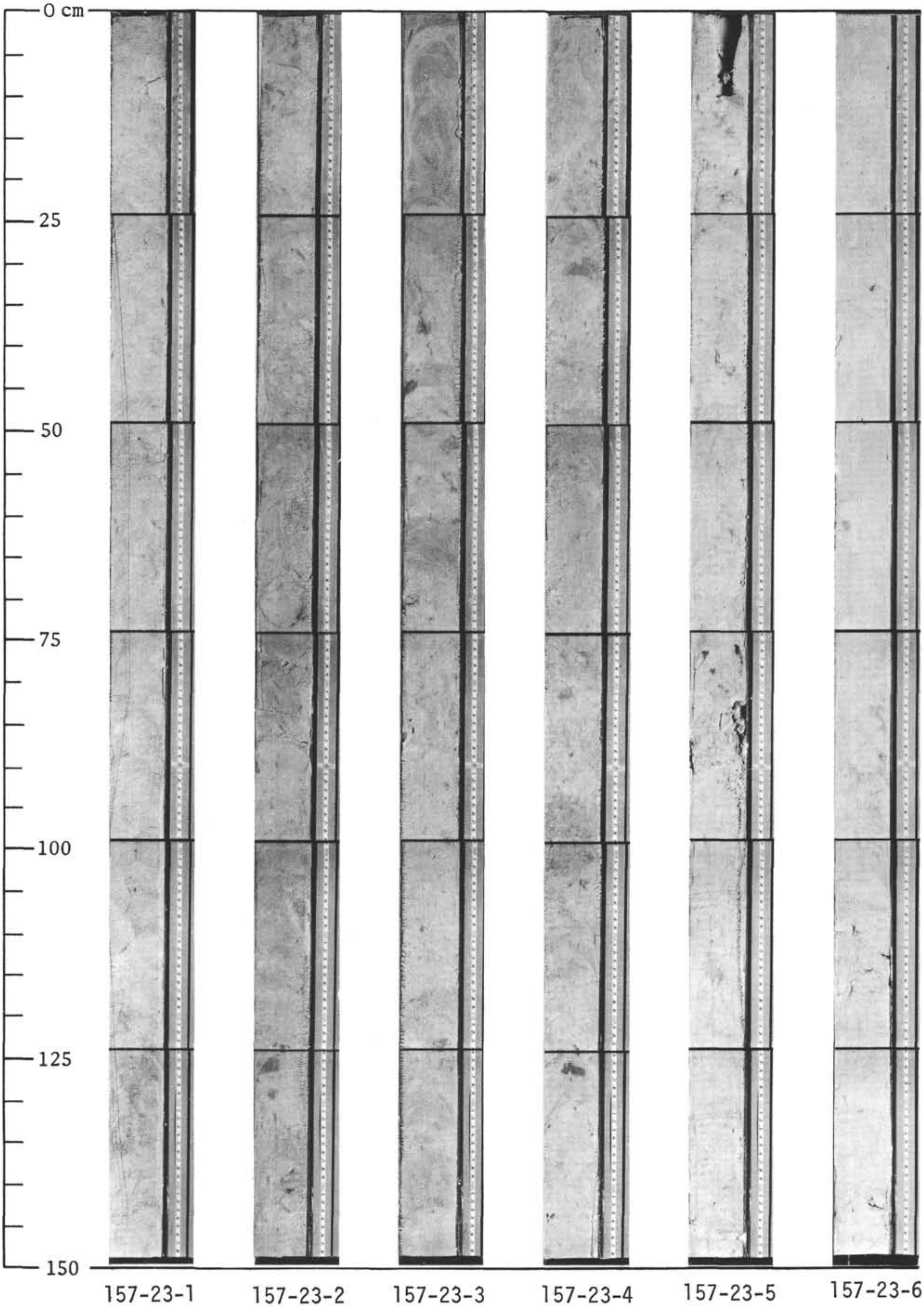
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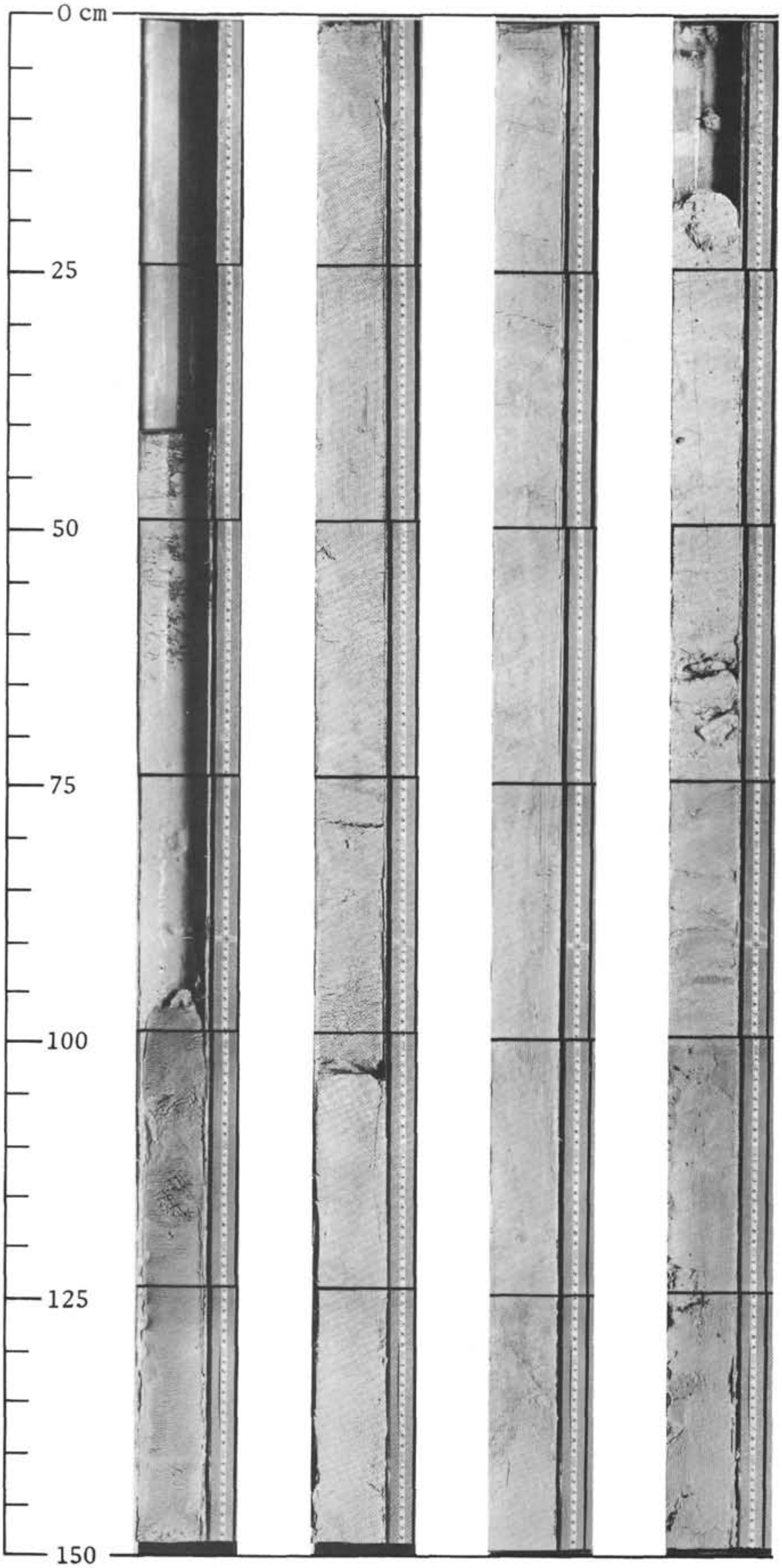


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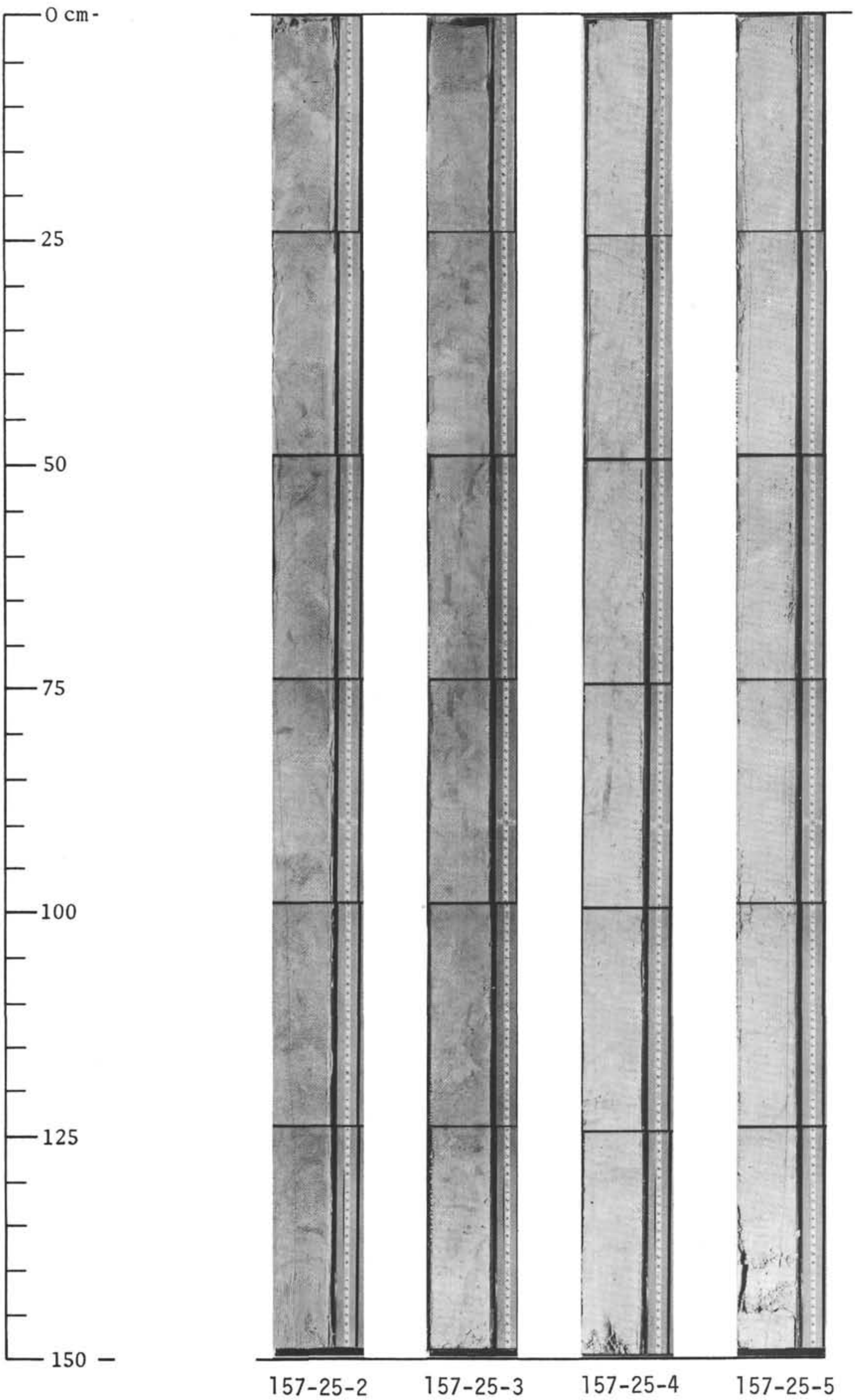
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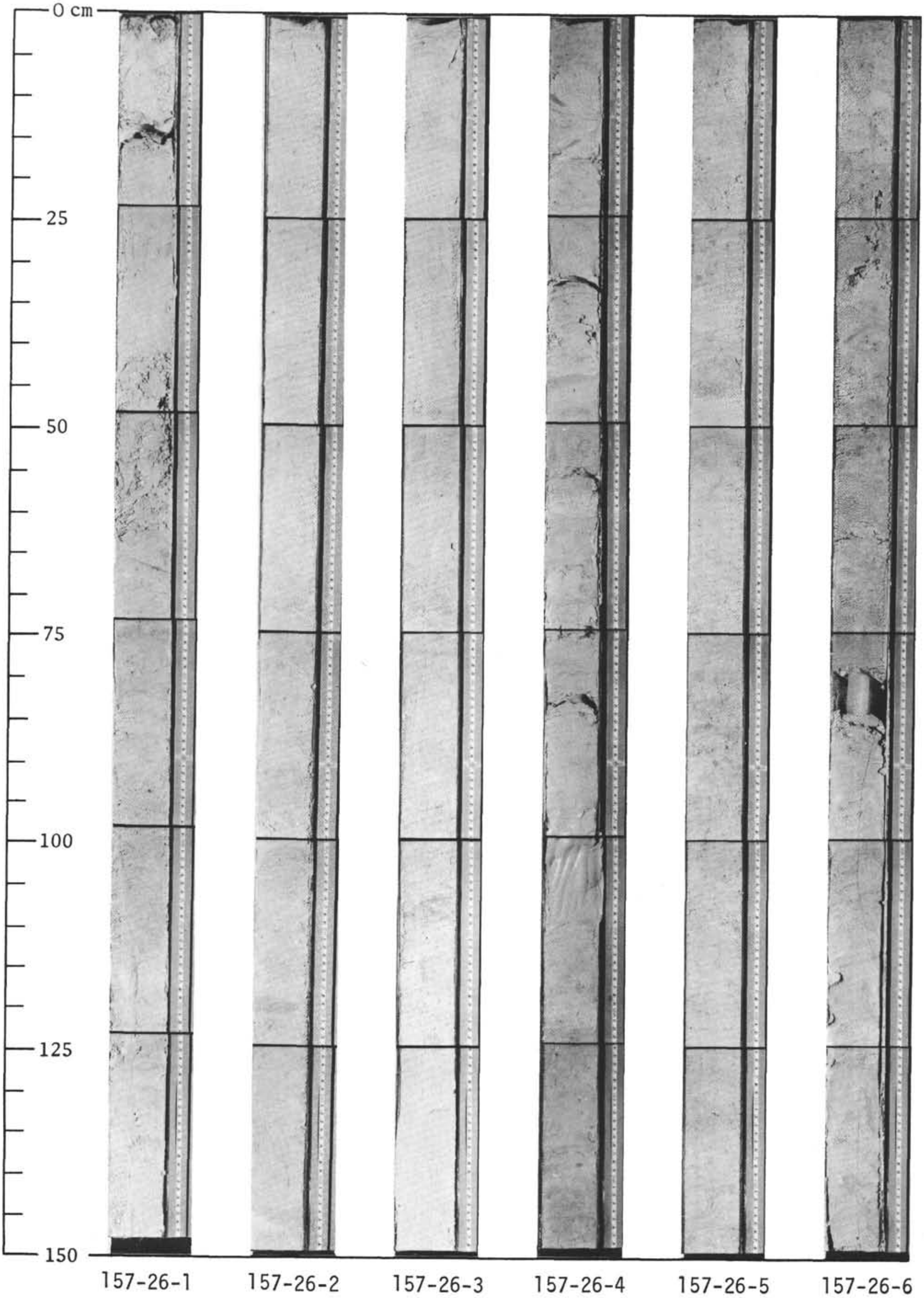
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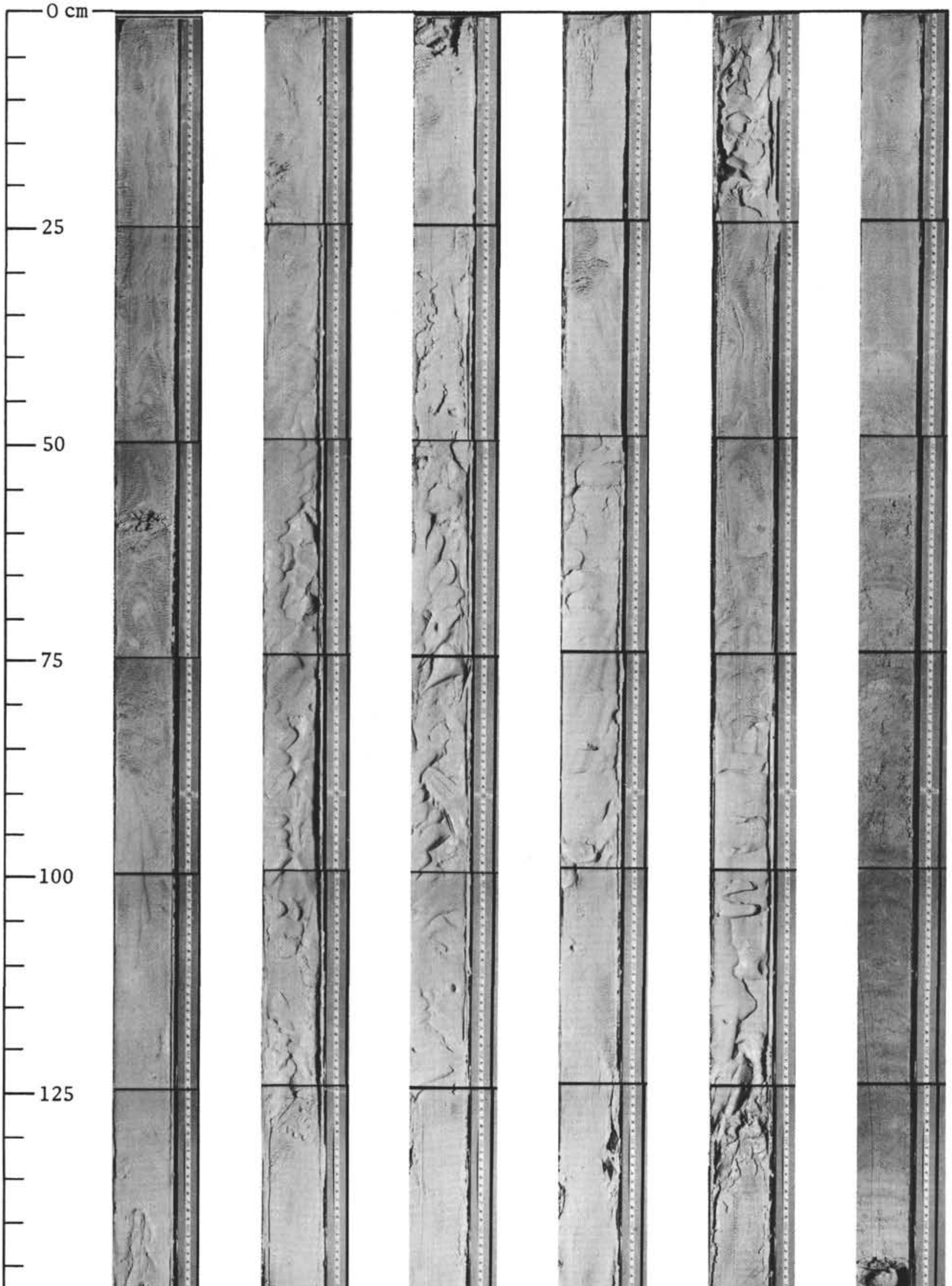
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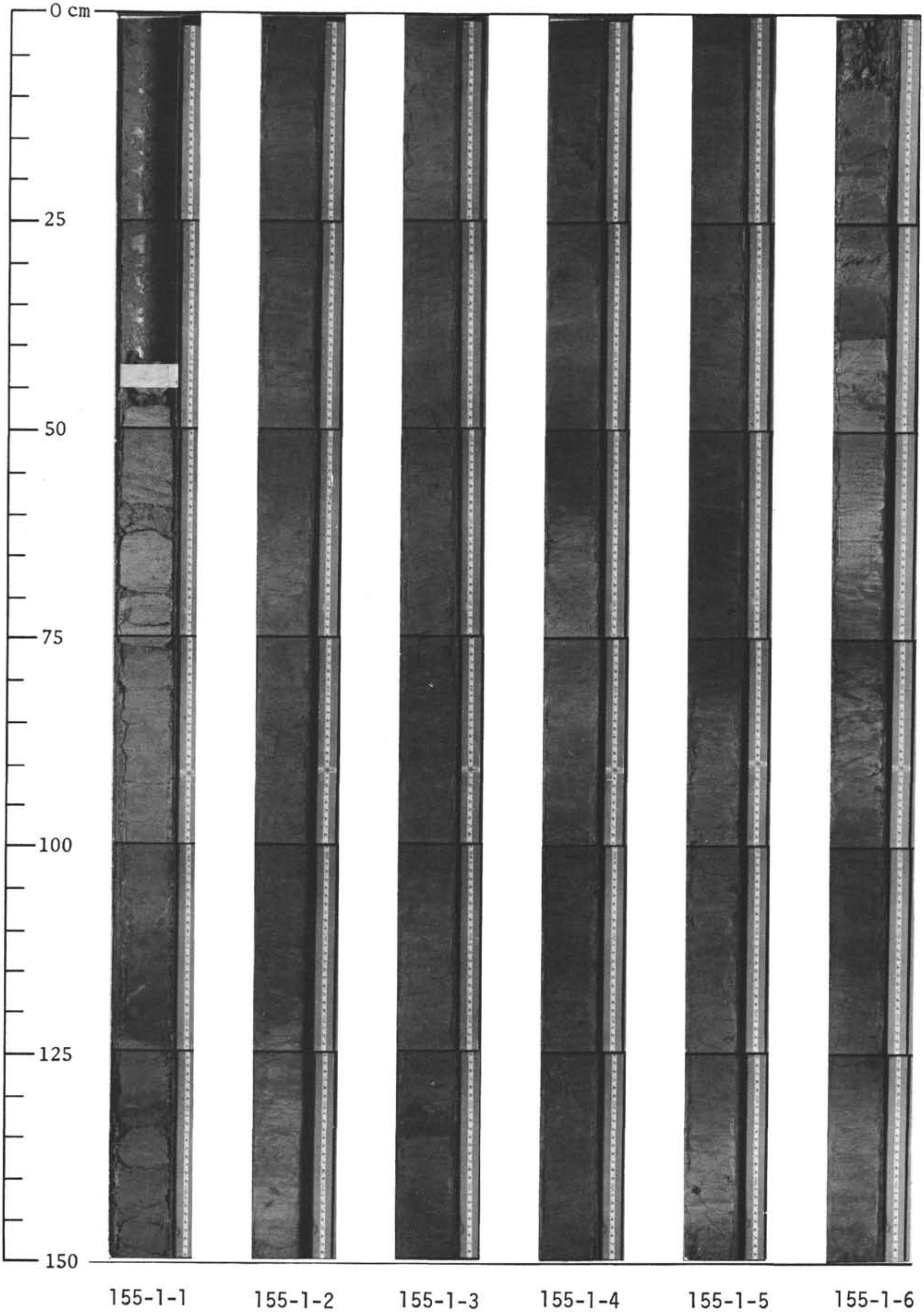
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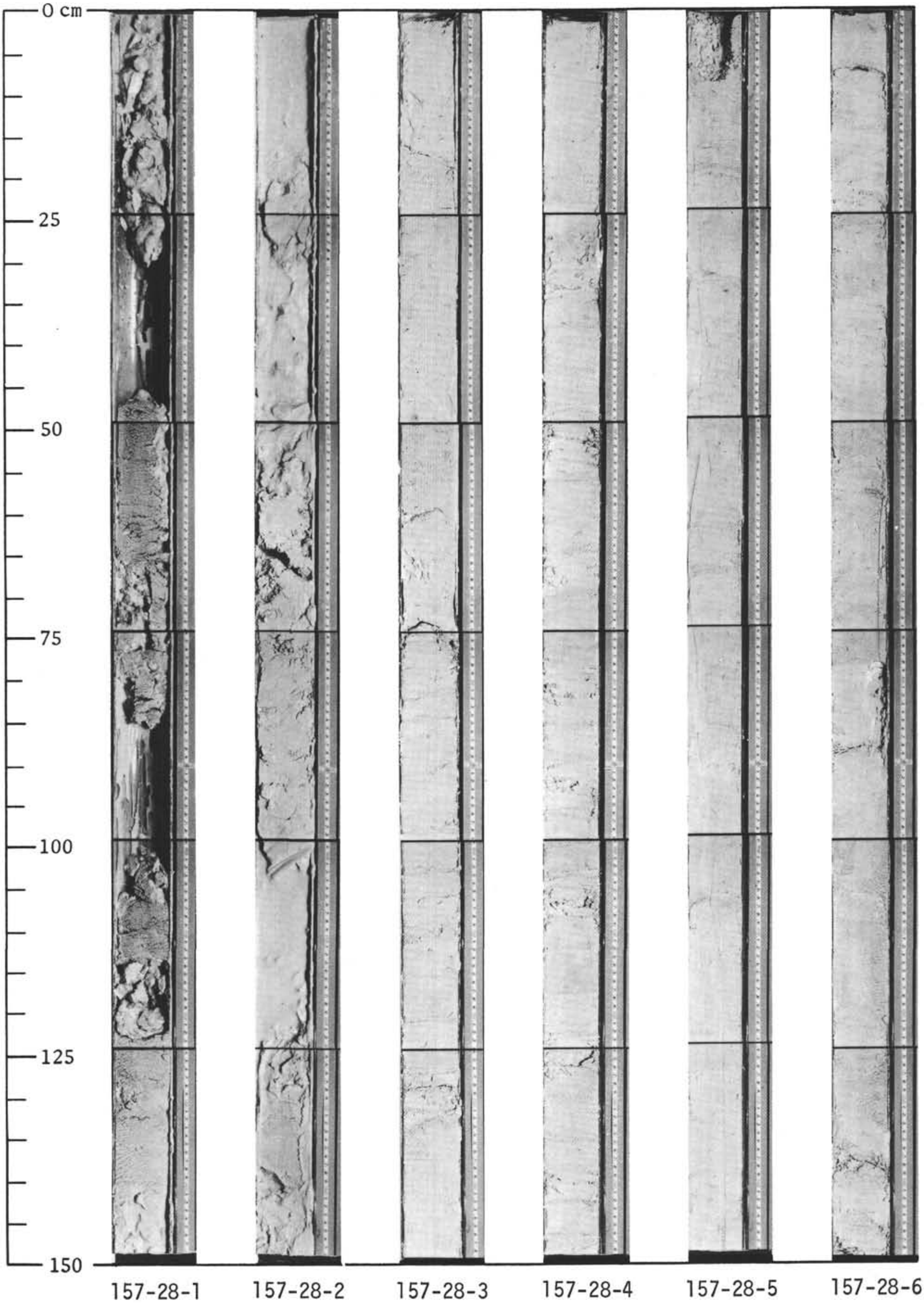
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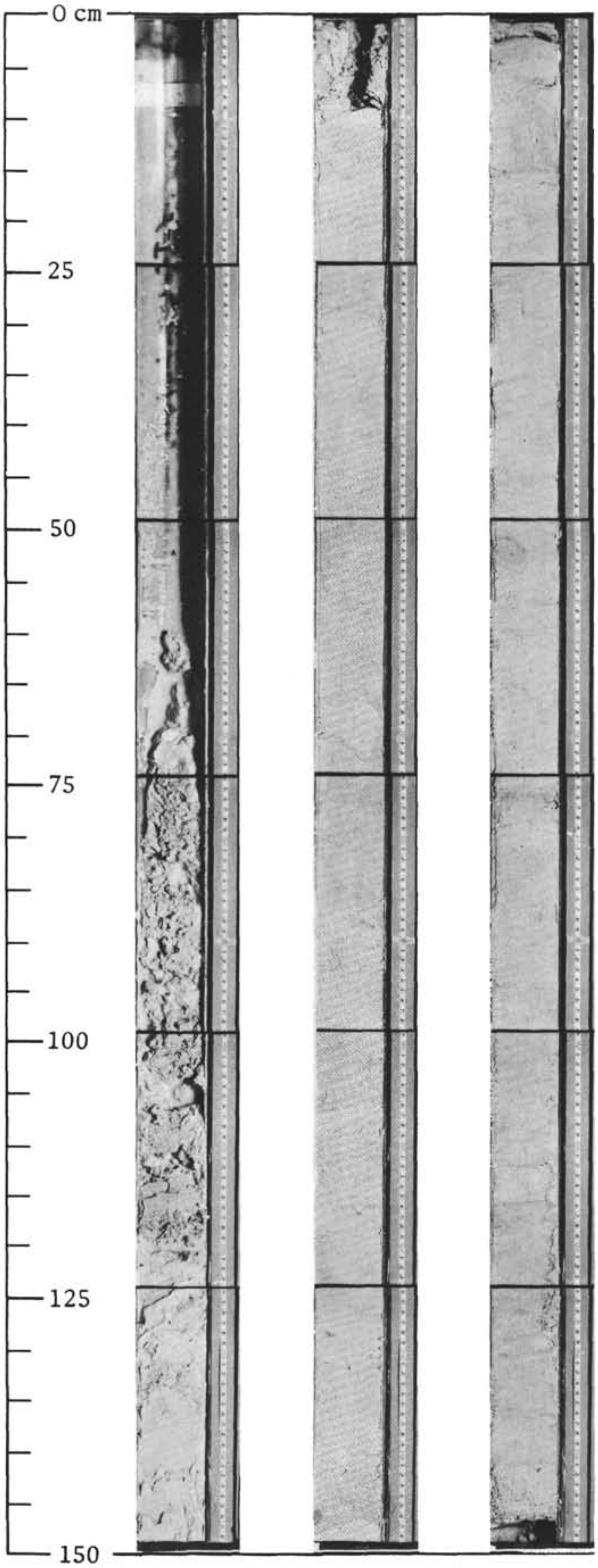


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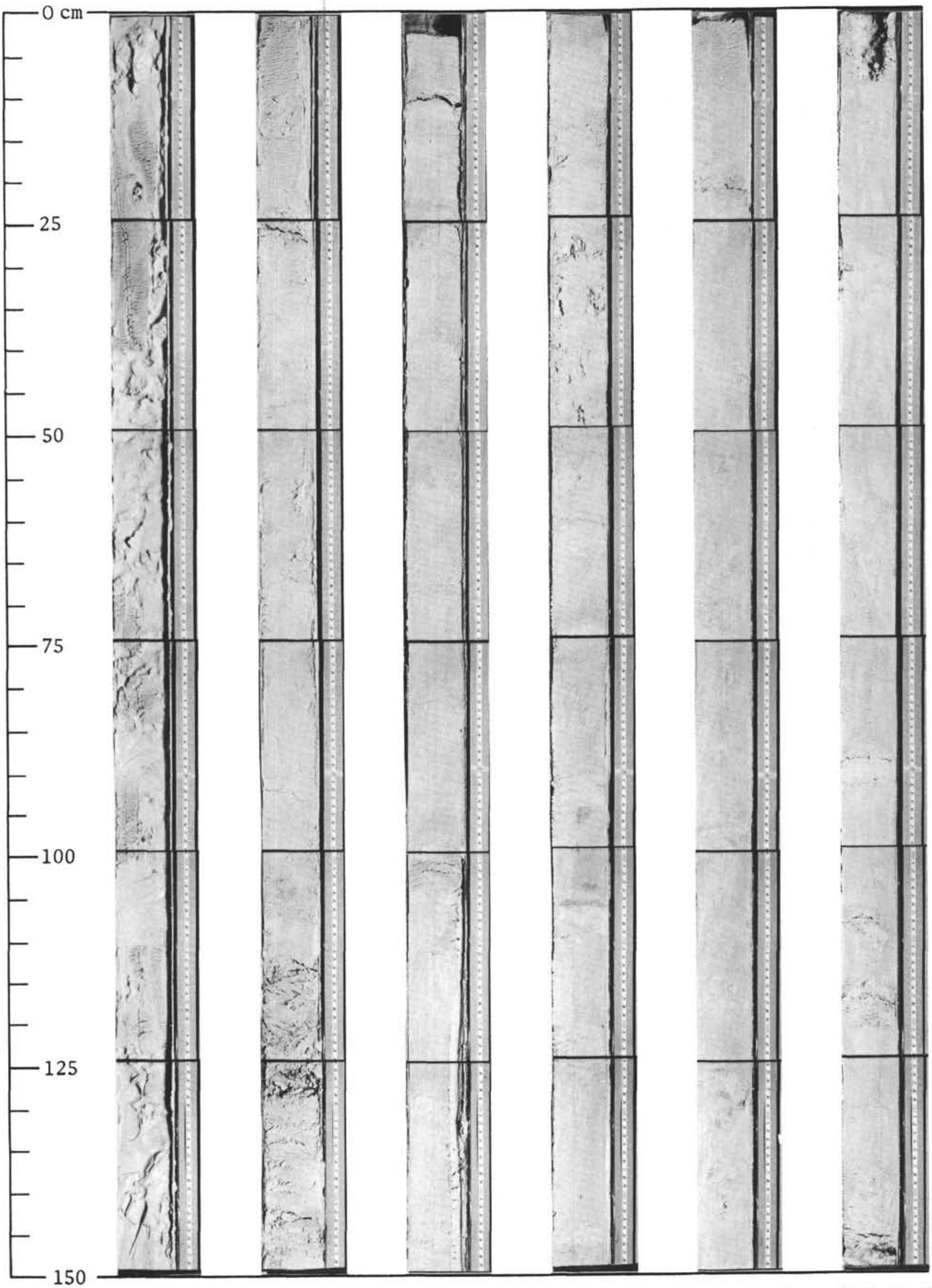
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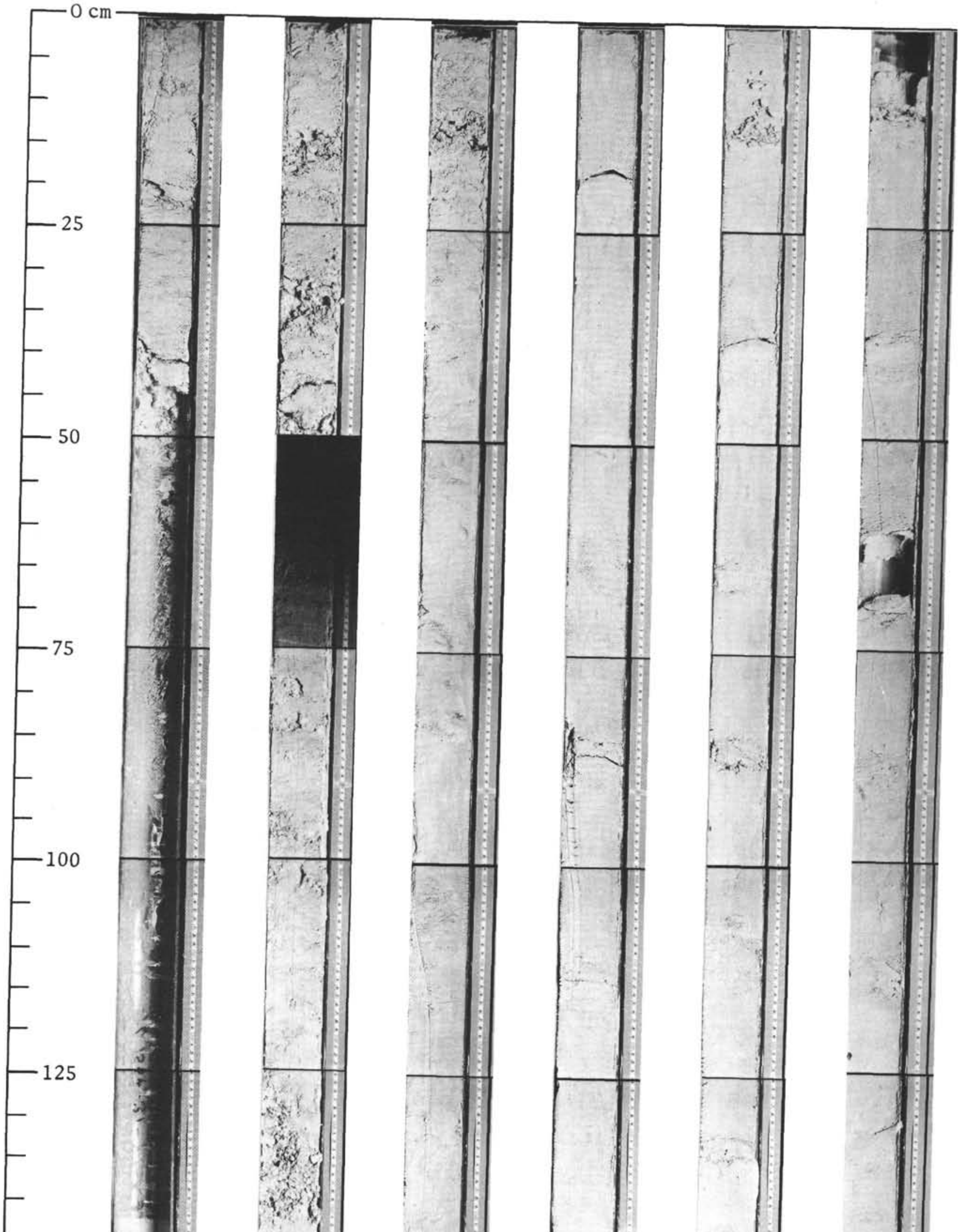
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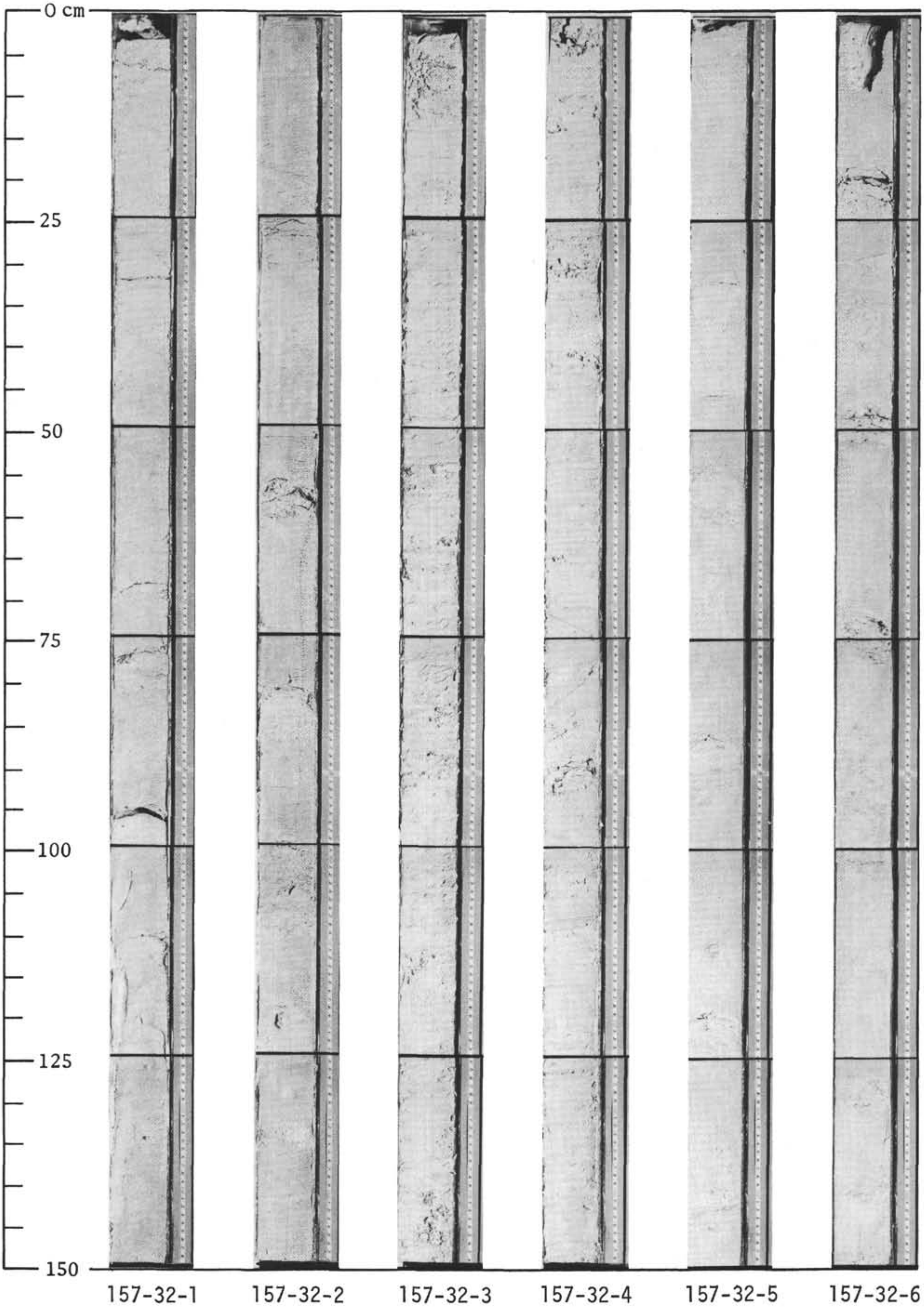
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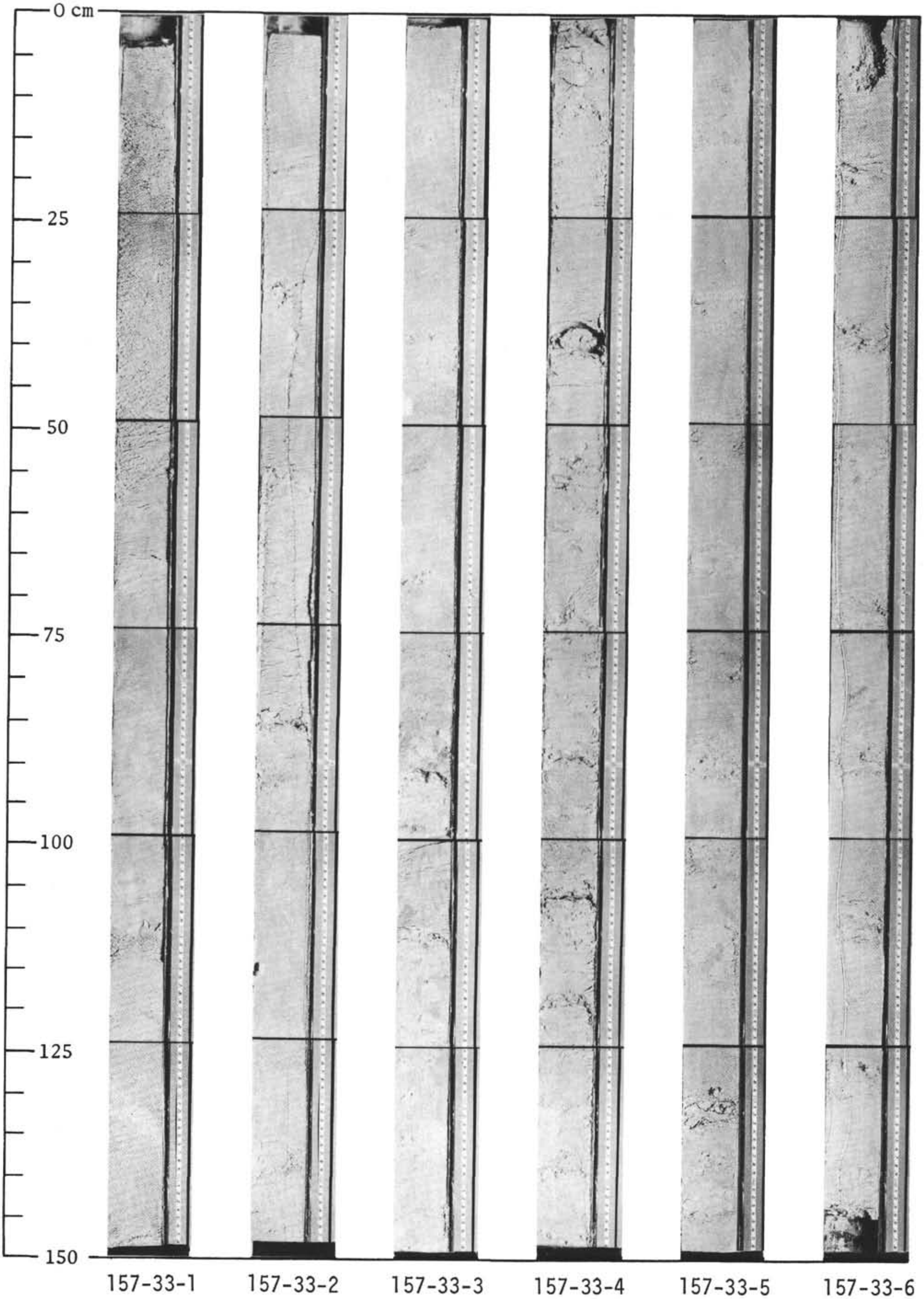
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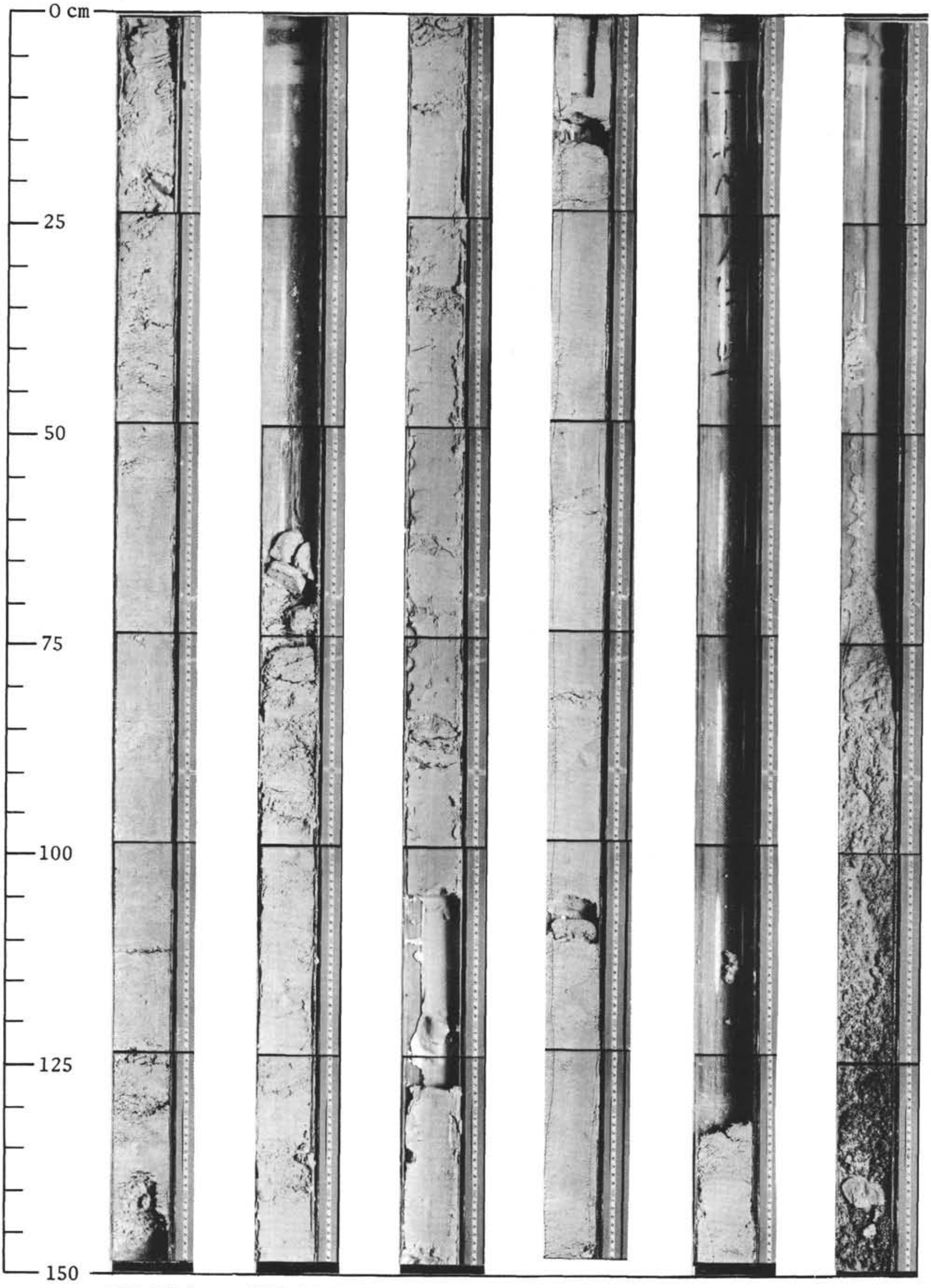
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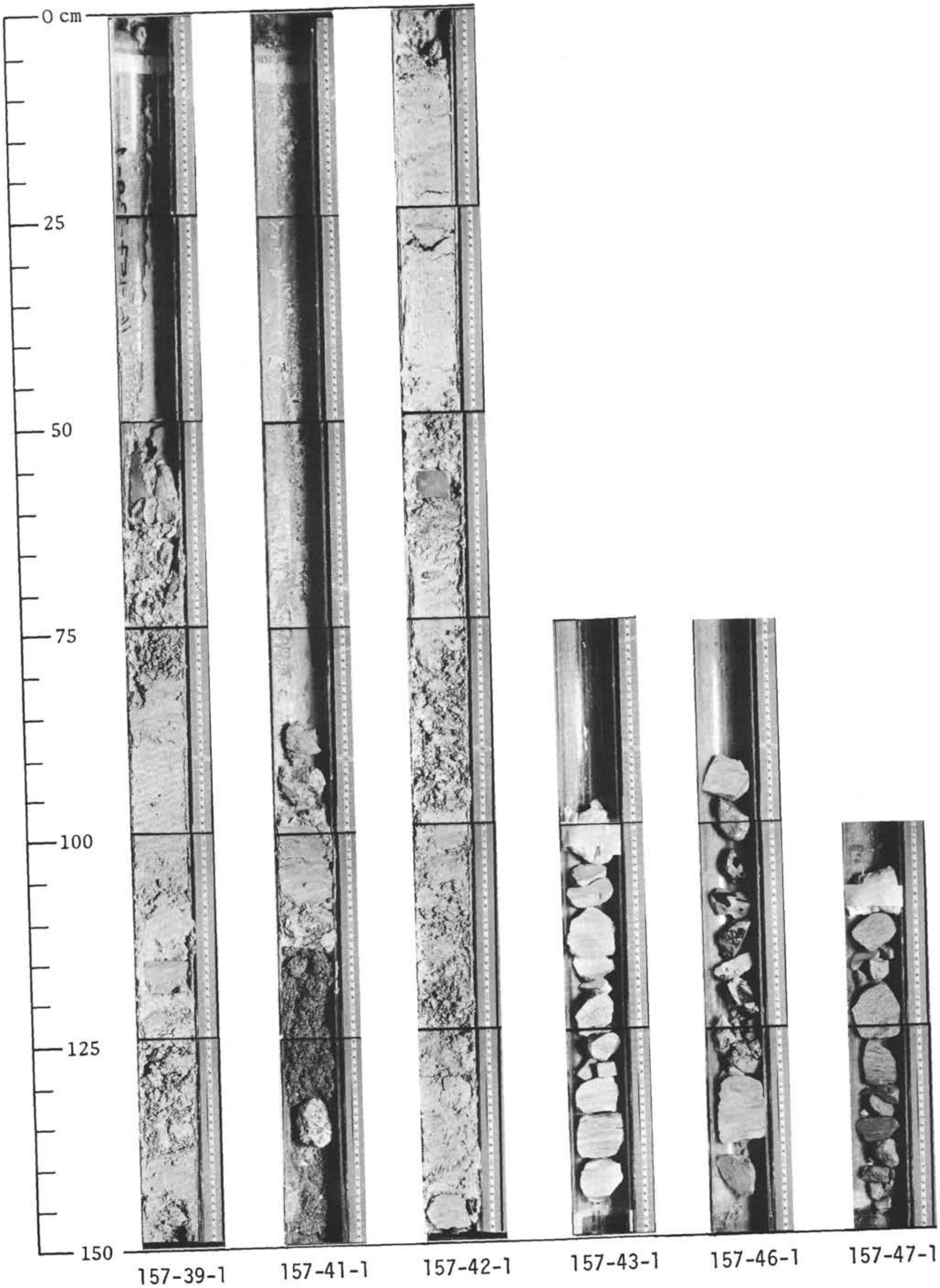
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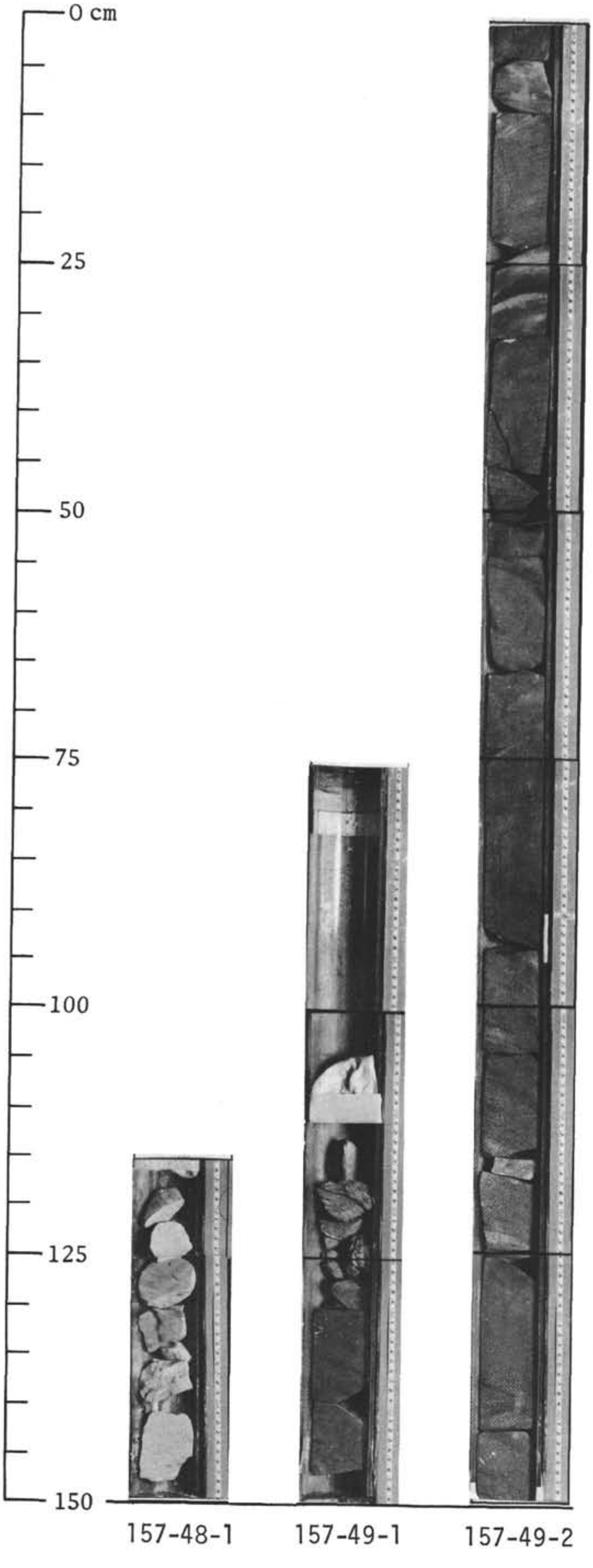
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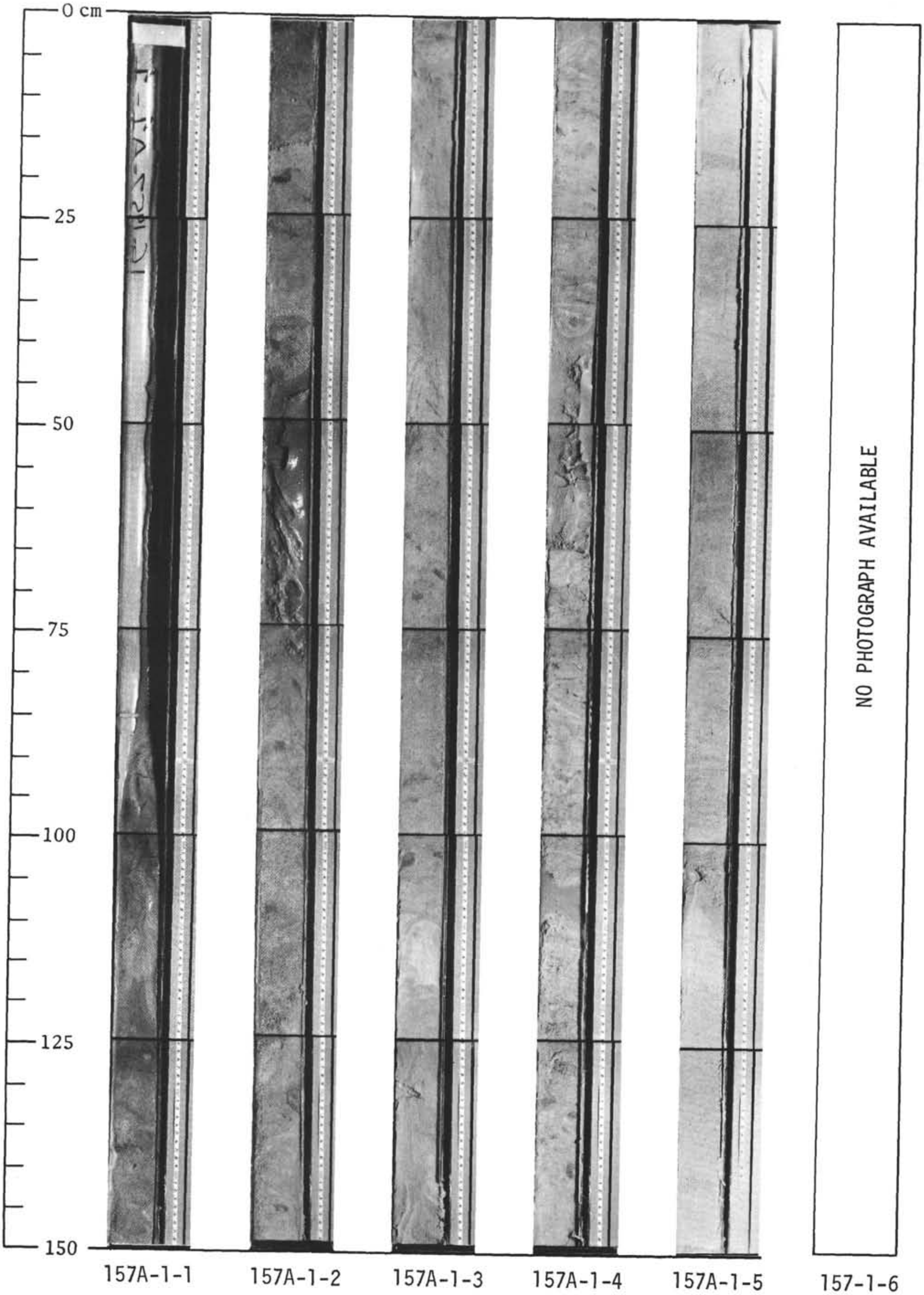
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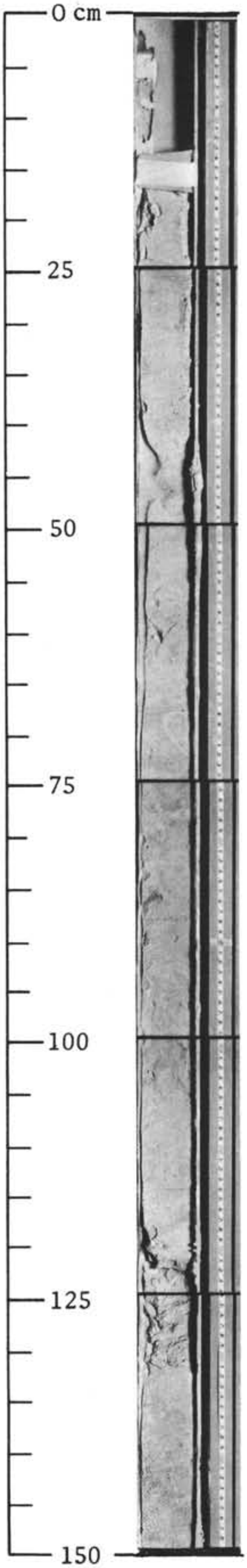


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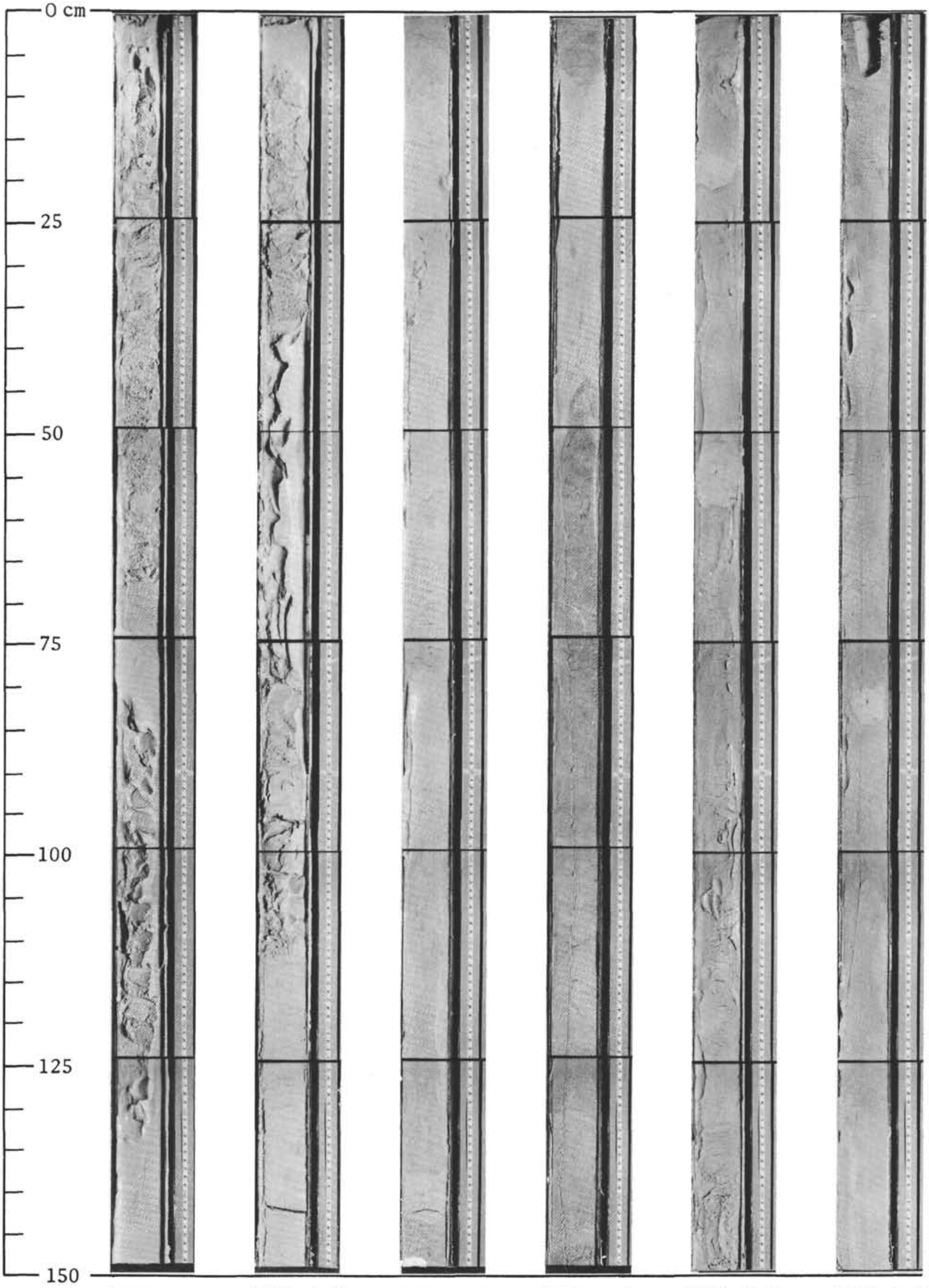
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