10. SITE 31

The Shipboard Scientific Party[1]

SETTING AND PURPOSE

The sedimentary beds underlying the Caribbean basins, as seen by the reflection profiler, are typically flat-lying and exhibit two prominent reflecting horizons, A″ and B″, within and at the base of the Carib beds. Horizon A″ commonly lies within 200 to 300 meters (656 to 984 feet) below bottom, and B″ Horizon lies at about the same distance below A″. In most areas the B″ layer, believed to be an ancient turbidite marking the Paleozoic-Mesozoic boundary, is the deepest reflector observable, but occasionally a deeper "basement" reflector with rougher topography is observed (Ewing, Talwani and Ewing, 1965).

Horizon A″ had been sampled at Site 29 at 229 meters (751 feet) depth and was found to be of Eocene age. The chert-like nature of this layer made it unlikely that it could be penetrated with present methods. It was, therefore, important to locate a site where Horizon A″ was missing, so that the older sedimentary section might be sampled in order to resolve outstanding problems of the geological history of the Caribbean.

Since 1963, four Lamont cruises have surveyed an area of the Venezuelan Basin called the Beata Scarp, where outcrops of Horizon A″, exposed by faulting, have been found (Talwani *et al.*, 1966). The Beata Ridge is believed to have had two periods of uplift, one following the deposit of Horizon B″ in Mesozoic time and a second relatively recent uplift in late Tertiary or Pleistocene, possibly contemporaneous with the Jamaica uplift (Ewing *et al.*, 1967). Recent piston coring on the ridge suggests the existence of Eocene carbonate material having a shallow water origin (Fox *et al.*, 1970). Dredge samples from the escarpment between 4100 and 2500 meters (13,451 and 8202 feet) reveal basaltic rocks, one porphyritic basalt sample containing unbaked upper Cretaceous pelagic fauna.

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Upon completion of survey operations at Site 29, the *R/V Vema* made a profiler transect across the Beata Ridge. J. L. Worzel, Chief Scientist aboard *Vema*, reported a prospective site location along the fault scarp where Horizon A″ was apparently missing and B″ was within a few hundred meters of the surface. After completion of work at Site 30 the shipboard party elected to drill the final site of Leg 4 at the suggested Beata Ridge location.

The objectives at this site were to sample Horizon B″ and to obtain a stratigraphic sequence, sampling the oldest layered rocks in the Caribbean. It was hoped that samples of the upper layers would contain a record of the Pleistocene-Pliocene boundary.

SITE SURVEY

The approach to the site (Figure 1) was made on course 280° in order to cross normal to the ridge and its western faulted limb just eastward of the site. The air gun profiler record (Figure 2) made along this track by the *R/V Vema* reveals two prominent reflecting horizons on the east flank of the Ridge at 0.3 and 0.65 second subbottom, respectively, and suggest the absence of Horizon A″ on the flat ledge westward of the scarp. Faulting along the west flank shows these reflectors displaced vertically about 0.25 second on the downthrow side.

The *D/V Glomar Challenger* profile is inconclusive due to the unfortunate depth scale of the bottom features with respect to the recorder scale; the deeper reflections are lost in the noise of the outgoing air gun pulse. A poor quality on-site reflection record taken at Site 31 is not helpful in resolving the problem. It shows a possible reflecting horizon at 0.34 to 0.38 second subbottom. However, the drilling showed a dense chalk beginning at 200 meters (656 feet) depth and extending to near the maximum depth drilled (325 meters, 1066 feet). The top of this formation should be observable on the profiler.

DRILLING AND CORING OPERATIONS

Upon reaching the site position at 14° 56.6′N, 72° 01.63′W, a PPM beacon was dropped at 1845 hours on March 19. The drill bit spudded in at 0230 hours on March 20 in 1842 fathoms (3369 meters, 11,053 feet) depth, and a surface core was taken.

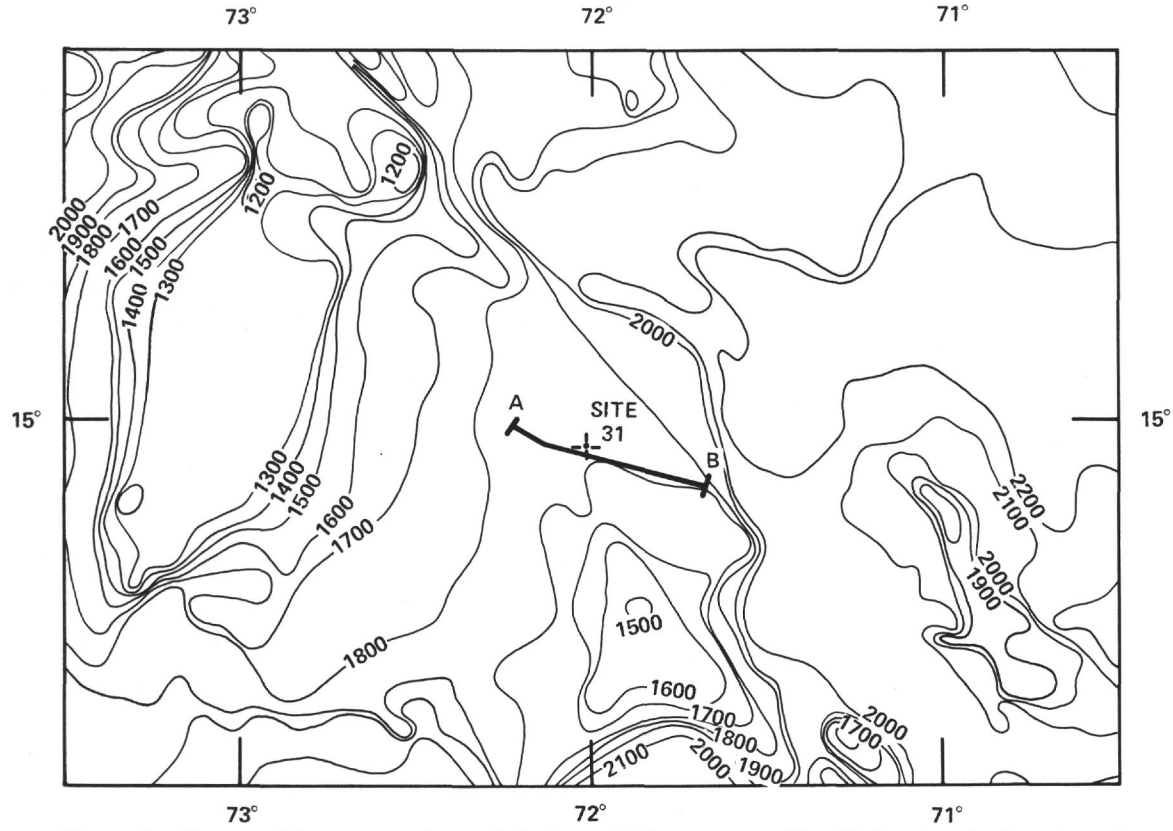

Figure 1. *Topographic contour chart of the Beata Ridge area near Site 31 showing the location of the* R/V Vema *reflection profiler record (see Figure 2) across the site. Topography from U. S. Navy Hydrographic Office Chart BC-0803N.*

Table 1 lists the cored intervals at this site. Except for two drilled intervals of 19 and 23 meters (63 and 75 feet) in the upper section, continuous coring was accomplished down to 106 meters (348 feet). Thereafter, intermittent drilling and coring proceeded down to 325 meters (1066 feet). At this depth at 2400 hours on March 21, the center bit became stuck, and attempts to retrieve it were unsuccessful. During the last attempt, the wire line broke at the drilling floor level, leaving the core barrel and a quantity of broken wire rope inside the drill stem. This curtailed a hoped-for logging measurement at this site.

The drill string was raised above bottom at 0530 hours and tripped to the surface. At 1600 hours, with the drill tools laid down, tests were performed with the receiving transducers mounted in the hull to determine the causes of recent beacon signal failures. Following these tests, an experiment was performed using the ES log lowered in the ocean, the results of which are discussed in the section on logging. At 1900 hours on March 21, the *D/V Glomar Challenger* was under way for Panama, thus concluding the scientific work of Leg 4.

TABLE 1
Cores Recovered from Hole 31
(Using a Diamond Bit)

Core	Drill String (m)	Penetration (m)	Core Recovered (m)
1	3395-3404	0-9	9.1
2	3427-3436	32-41	0.3
3	3456-3465	60-69	9.1
4	3465-3474	69-79	2.7
5	3474-3483	79-88	1.5
6	3483-3492	88-97	3.0
7	3492-3501	97-106	1.5
8	3550-3559	155-164	2.7
9	3607-3616	212-221	3.4
10	3665-3674	270-279	7.6
		Total	40.9

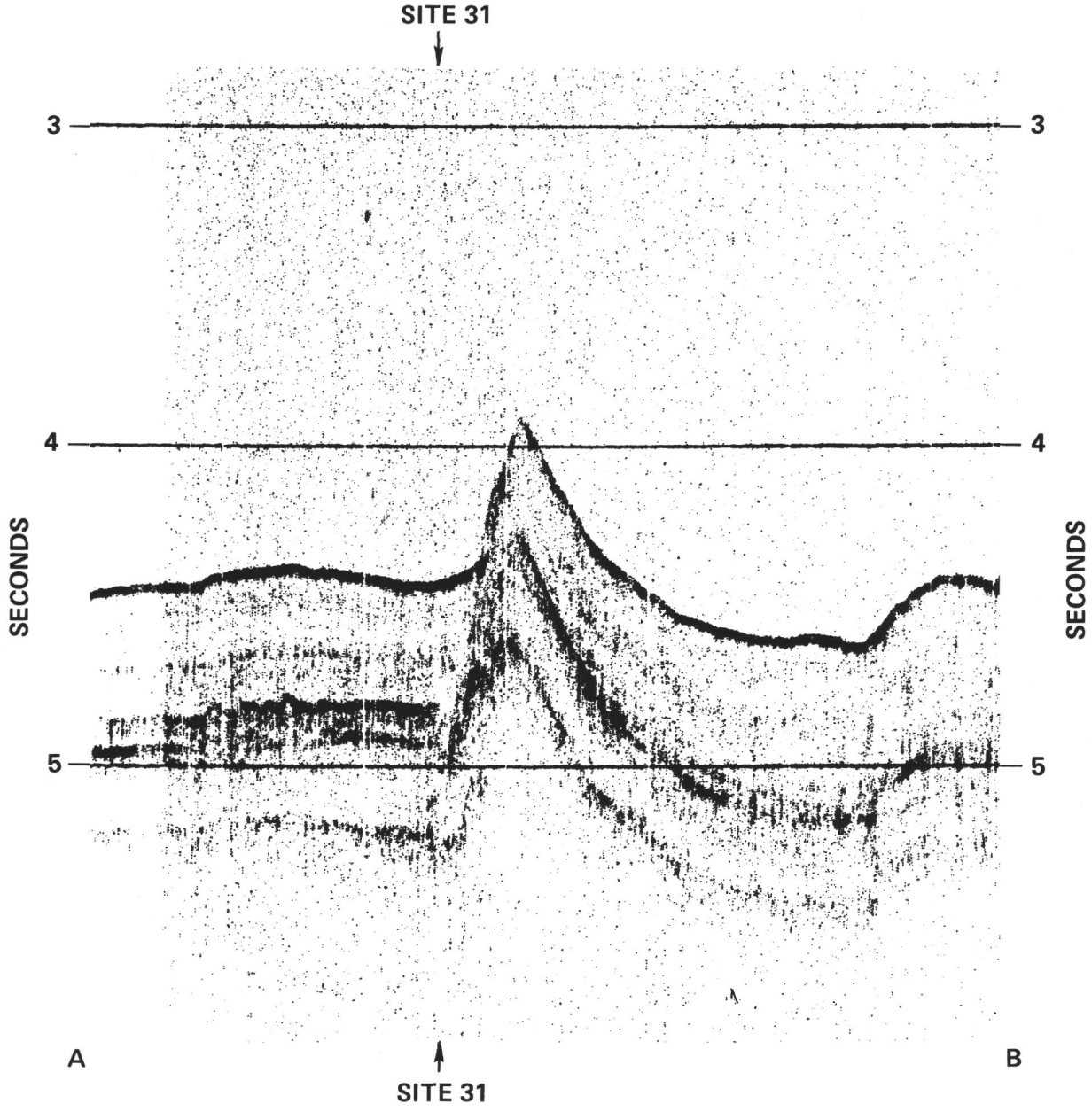

Figure 2. R/V Vema *reflection profiler record across a faulted feature of the Beata Ridge. Site 31 is located near the base of the downthrow side of the fault.*

LITHOLOGIC SUMMARY

For detailed lithology and paleontology see Hole Summaries. (See pages 254-264).

Core 1, a core of the surficial sediment, recovered a sequence of 30 feet (9.1 meters) of beige to yellow-brown calcareous plankton ooze. Smear slides indicate a strong increase in clay content with depth; there is a corresponding decrease in the abundance of planktonic foraminifera which constitute about 60 per cent of the sediment at the surface, but only about 20 per cent at a depth of 30 feet (9.1 meters). In the lower parts of the core there are some stringers of nearly pure fine planktonic foraminiferal sand. Minerals in the sediment include altered glass shards (about 10 per cent), micas, quartz, non-skeletal carbonate and clay minerals. Traces of diatoms, unidentified spicules and a few benthonic foraminifera were also observed. Calcareous plankton indicate a Late Pleistocene age.

Core 2, taken between 105 and 135 feet (32.0 and 41.2 meters) recovered only one foot of sediment, similar to that described above, which was also Pleistocene in age.

Cores 3 through 6 sampled the interval between 198 and 318 feet (60.4 and 96.9 meters) beneath the sea floor, and the sediments are gray to beige mottled plastic foraminiferal marls. Planktonic foraminifera constitute the bulk (60 per cent) of the sediment; calcareous nannoplankton form only about 10 per cent of the sediment. Pyritized "worm tubes" are embedded in the soft sediment matrix. The calcareous plankton date these strata as Late and Middle Pliocene.

A distinct lithologic break occurs in the immediately subjacent strata sampled by Core 7 between 318 and 348 feet (96.9 and 106.1 meters) beneath the sea floor. The upper soft, light gray marl ooze is underlain by a moderately hard, dark-gray silty clay containing minor amounts of mica, zeolites and non-skeletal carbonate. The contact between the two units is very sharp, but is irregular due to disturbance during the drilling of the core. A high radiation peak is noted in the gamma ray record at the contact. The lower clayey sediment contains a one-centimeter thick layer of angular to subrounded, fine to medium quartz sand, with 20 per cent feldspar, some mica, non-skeletal carbonates, and a few ferruginous minerals. The clay sediment is significantly more consolidated than the overlying marl ooze. Calcareous plankton date the clayey sediment as Pliocene.

Core 8, taken between 508 and 538 feet (154.8 and 164.0 meters) beneath the sea floor contains a firm, light to dark gray, or beige to green calcareous nannofossil chalk, with up to 80 per cent calcareous nannoplankton fossils, the rest of the sediment being planktonic foraminifera and clay. This is interbedded with a nannoplankton marl, having about 40 per cent non-skeletal carbonate. The sediment is mottled, and often irregularly spotted with fine ferruginous sandy material. Calcareous plankton indicate a Middle Miocene age.

The 36 feet (11.0 meters) of sediment in Cores 9, from 696 to 726 feet (212.1 to 221.3 meters) and 10, from 886 to 916 feet (270.1 to 279.2 meters), including a small plug bit sample from the drilled interval between them, is a white to light gray, indurated, compact calcareous nannoplankton chalk. This material is indurated, and the sections were split with difficulty. Only a few sections of this harder material were split on board ship, and they show no distinct bedding or structures other than burrows which give the chalk a streaky and mottled character. Calcareous plankton date this material as Early Miocene.

The drill bit, on its removal from the base of the hole at 1066 feet (324.9 meters) beneath the sea floor, provided a sample of pink-to-reddish firm clay, containing about 10 per cent non-skeletal carbonate. This material was not encountered at higher levels in the hole, and probably represents a sediment drilled between 916 and 1066 feet (279.2 and 324.9 meters). It is barren of fossils, and cannot be dated.

PHYSICAL AND CHEMICAL PROPERTIES

The natural gamma radiation intensities from cores recovered from above the interval 97 to 106 meters fall in the range 1000-1300 counts/1.25 min. These values reflect the roughly equal proportions of clay (50 to 60 per cent) and biogenic material. A distinct lithologic break is found in the 97 to 106 meter interval (see Figure 3, especially natural gamma data). The increase in natural gamma radiation (to 2500 counts) reflects a lithologic change from marl (carbonate equals 45 to 50 per cent) to a silty clay (carbonate $<$ 20 per cent). The sediment from Core 8 (155 to 164 meters) is similar to Cores 1 through 6 but is more consolidated. The greater degree of consolidation may account for the slightly higher gamma-ray intensities (1500 counts). Gamma radiation from the indurated chalks of Cores 9 and 10 (212 meters, 221 meters, and 270 to 279 meters) are only 200 to 300 counts. The clay content of the latter is very low and the gamma radiation level is typical of that usually associated with nearly pure biogenic deposits.

Data on water content and density are presented in Figure 3. Sonic velocities in the unconsolidated sediments (Cores 1 through 6) are usual for clays (on the order of 1550 m/sec). The increased consolidation and cementation of Core 8 are reflected in sonic velocities up to 1775 m/sec. The velocity of sound in the hard chalks of Cores 9 and 10 reaches 2150 m/sec.

With the exception of the non-biogenic clays of Core 7, carbonate contents are 45 to 55 per cent with Cores 9

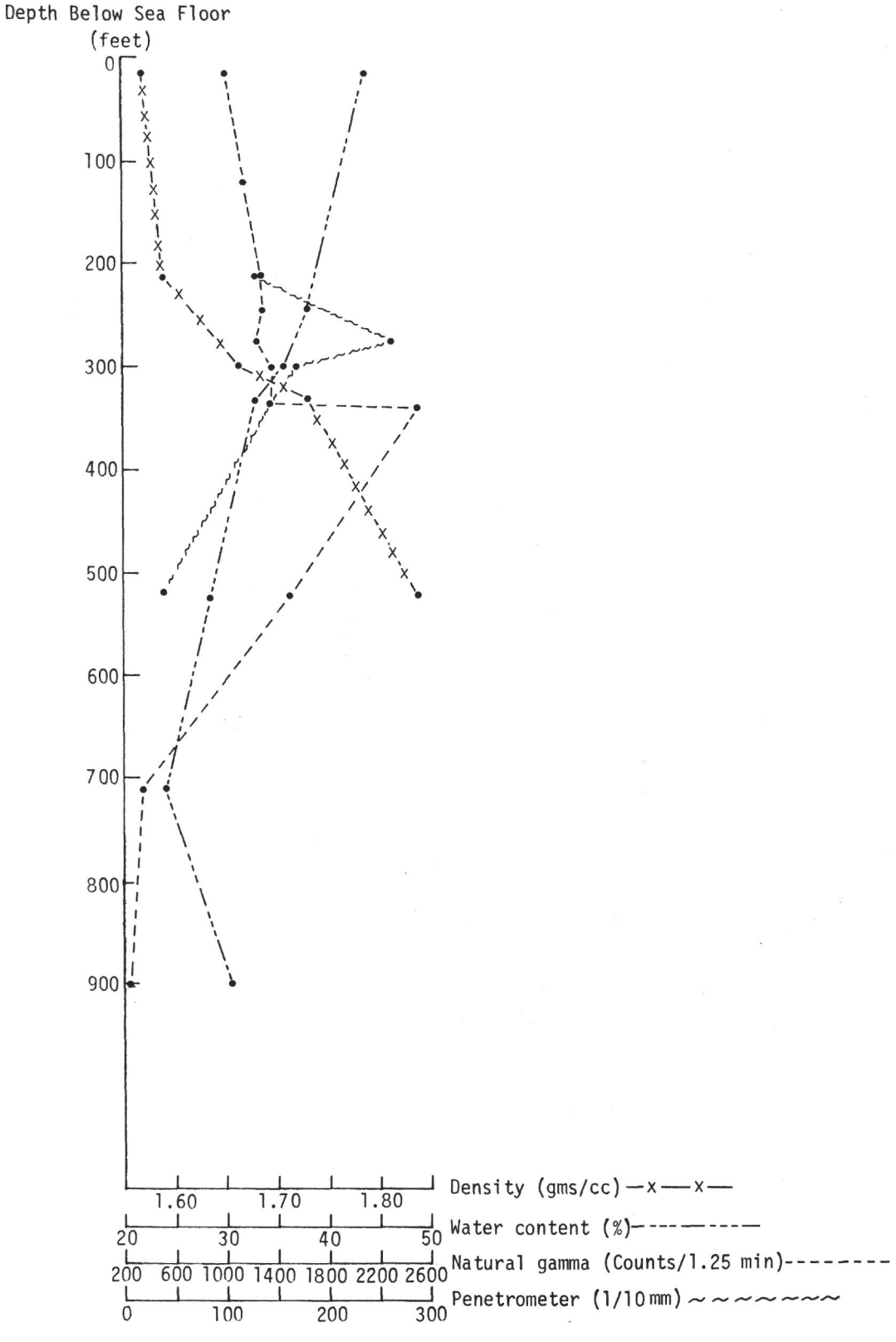

Figure 3. *Summary of physical properties, Site 31.*

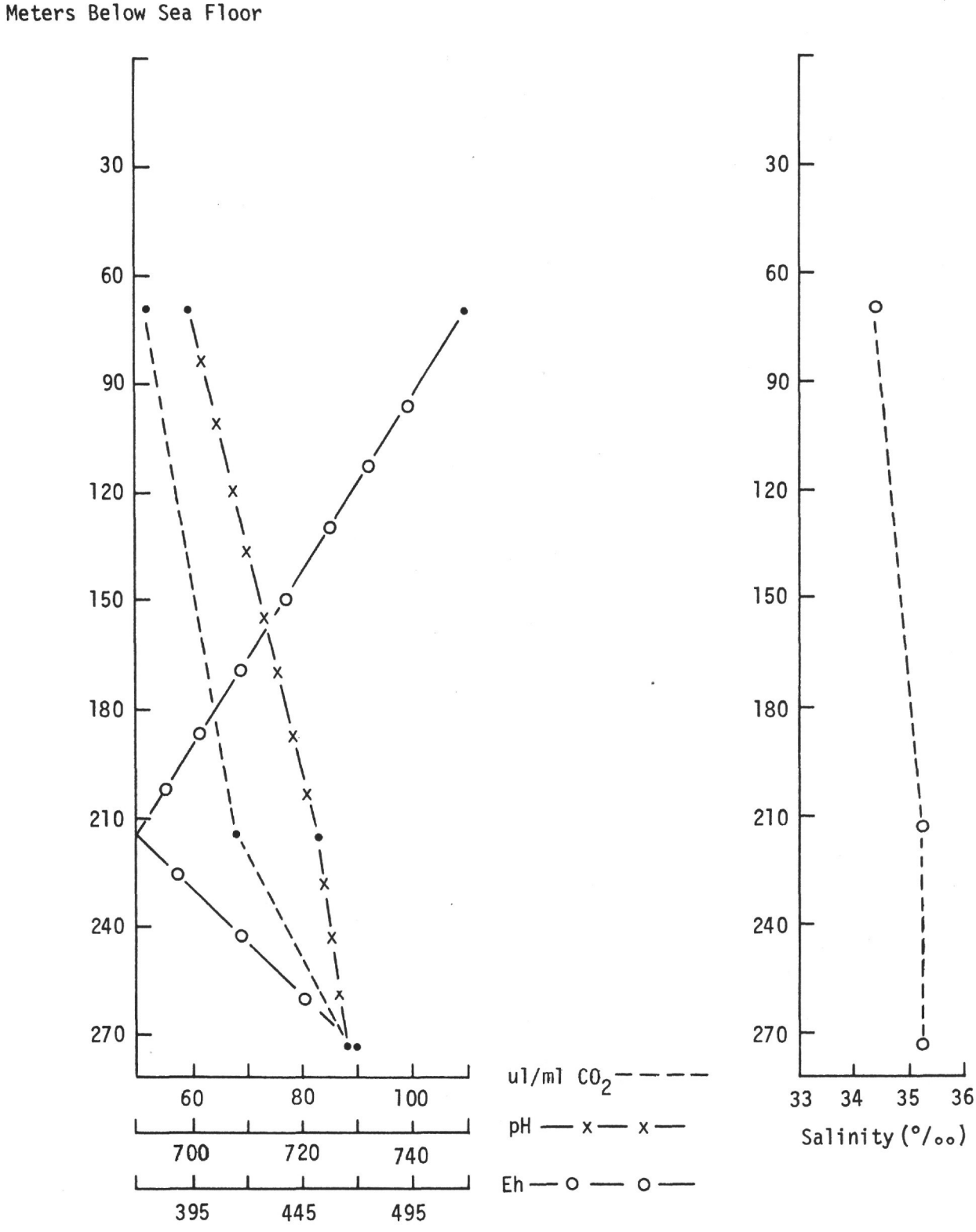

Figure 4. *Summary of chemical properties, Site 31.*

TABLE 2
Thermal Conductivity Data

Hole	Core	Section	Sample Depth Below Bottom (feet)	Sample Depth Below Bottom (meters)	Lithology	Thermal Conductivity $\times 10^{-3}$ cal/°C/cm/sec
31	1	2	0-30	0-9.1	Gray-brown ooze.	2.52
31	3	1	198-228	60.4-69.5	Light brown-gray foraminiferal ooze.	2.38
31	4	2	228-258	69.5-78.6	———	2.39
31	5	1	258-288	78.6-87.8	Light olive-gray foraminiferal ooze.	2.50
31	6	2	288-318	87.8-96.9	———	2.52
31	9	3	696-726	212.1-221.3	Dense white nannoplankton chalk.	3.00

and 10 being somewhat higher (65 to 75 per cent). Organic carbon is low (nil to 0.1 per cent) except in the clays of Core 7 where a single sample with 0.3 per cent organic carbon was taken.

Only three samples of interstitial water were collected. The chemical parameters are summarized in Figure 4. The most noteworthy aspect is the *p*H of solution presumably in equilibrium with the calcium carbonate of the chalks; *p*H values of 7.00 to 7.28 are low and the carbon dioxide content is not particularly high (90 µl/ml). If an equilibrium model is utilized, then relatively high Ca^{++} activities must be present to suppress calcium carbonate ($CaCO_3$) solution. Salinities deviate only slightly from sea water (34.4 to 35.2).

Six thermal conductivity measurements were made at this site. Values range from 2.38 to 3.0 $\times$ 10^{-3} cal/°C/cm/sec (Table 2). Four measurements between 61 and 122 meters (200 and 400 feet) show a modest downward increase along with density. The thermal conductivity of the deepest sample (Core 9) in chalk is noticeably higher than that in the clays above, correlating directly with increased sound velocity and density and inversely with water content toward the bottom of the hole.

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Fox, P. J., Ruddiman, W. F., Ryan, W. B. F. and Heezen, B. C. (in press). The geology of the Caribbean Crust, Part I: Beata Ridge. *Techtonophysics.* 1970.

Talwani, M., Ewing, J., Ewing, M. and Saito, T., 1966. Geological and geophysical studies of the Caribbean submarine escarpment (Abstract). *Geol. Soc. Am.* (Annual Meeting Trans.) 217.

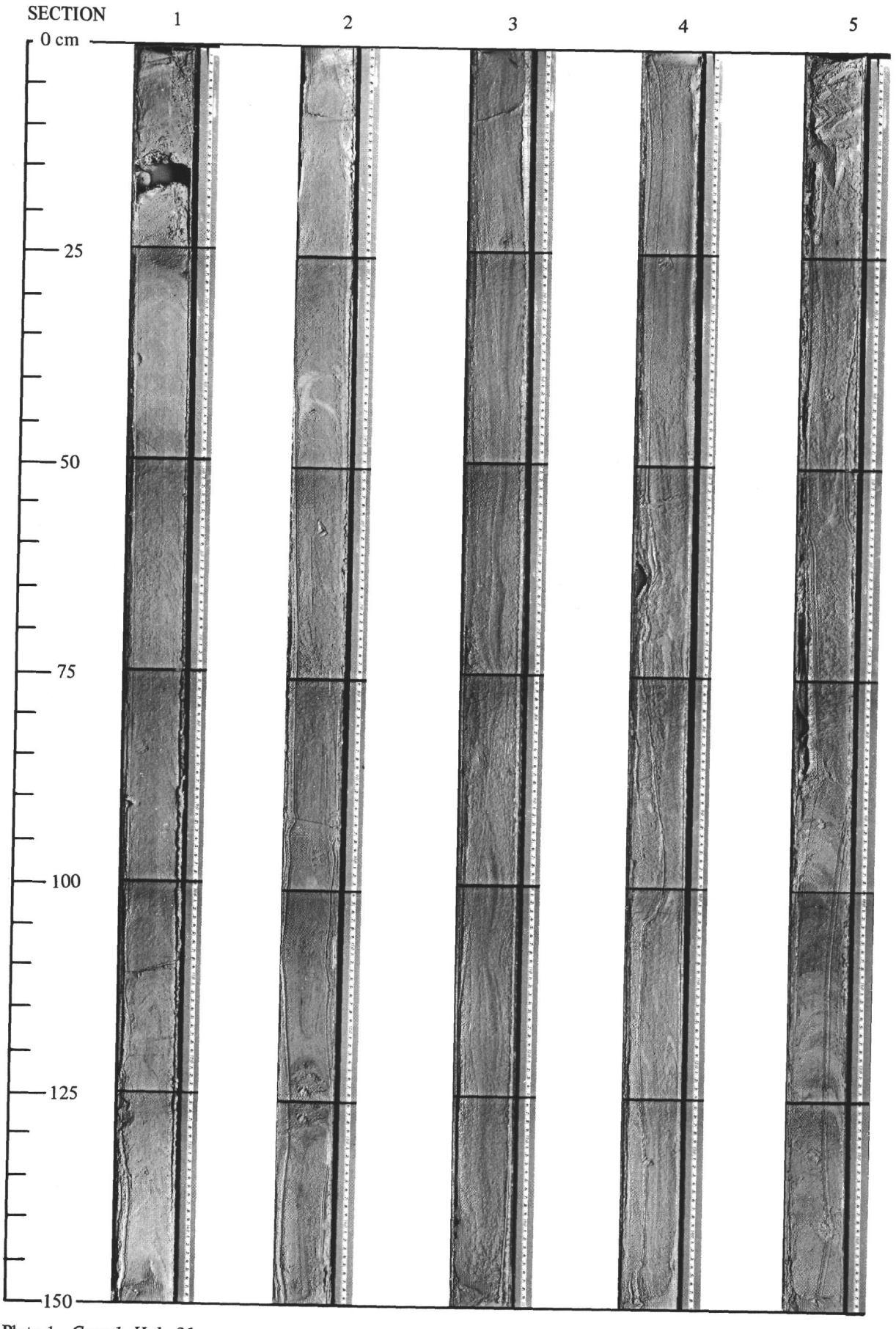

Plate 1. *Core 1, Hole 31.*

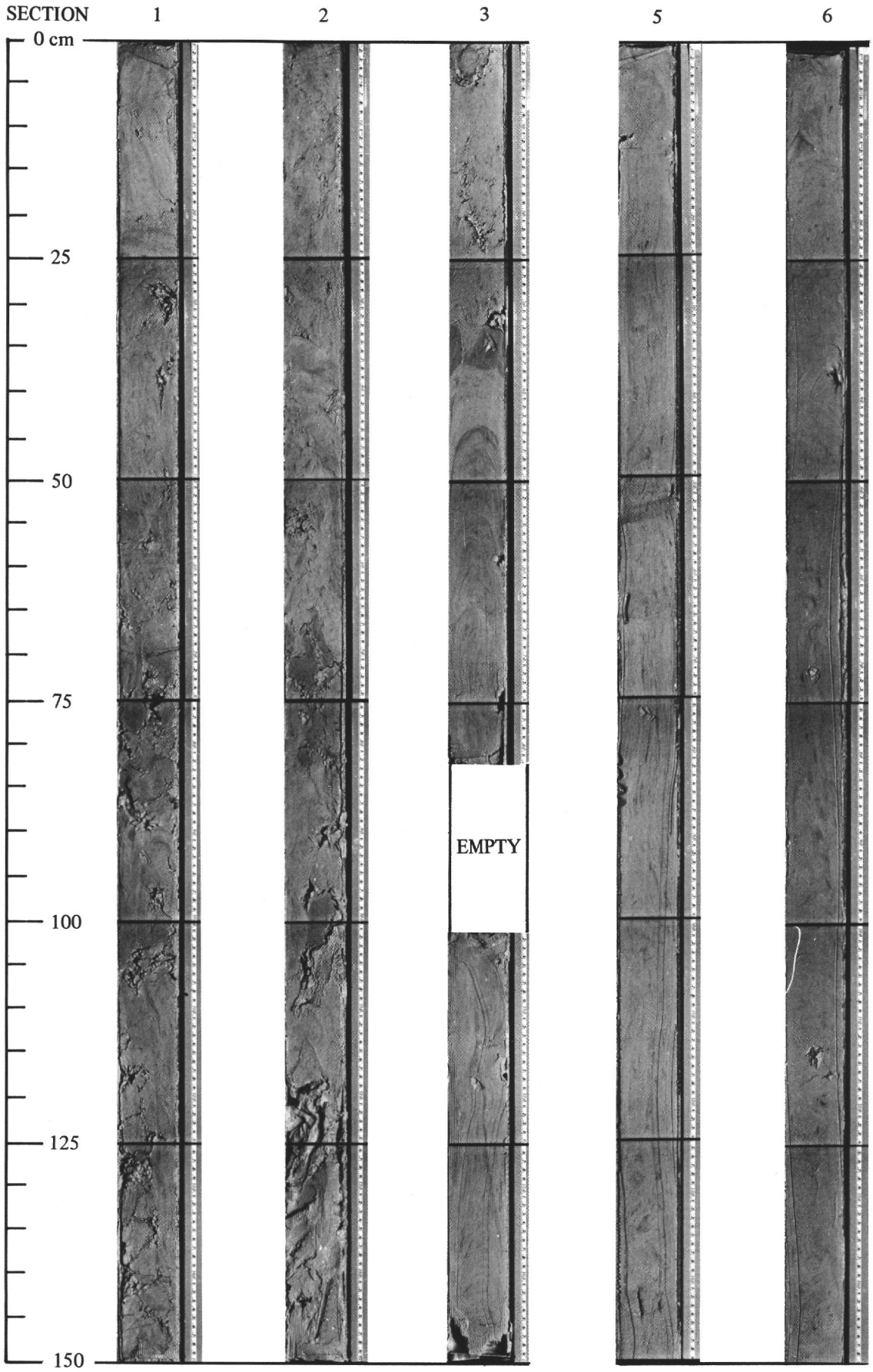

Plate 2. *Core 3, Hole 31.*

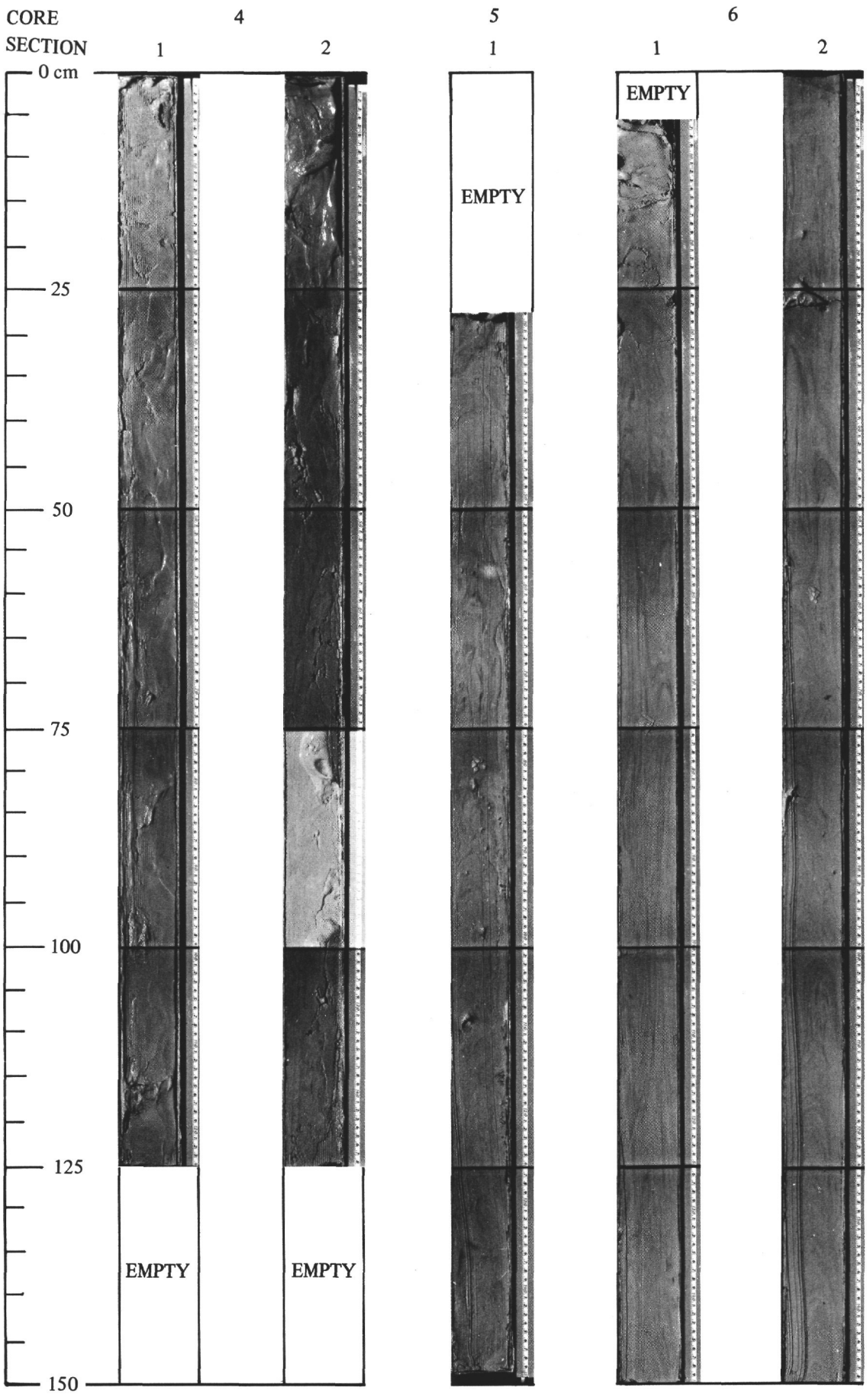

Plate 3. *Cores 4, 5 and 6, Hole 31.*

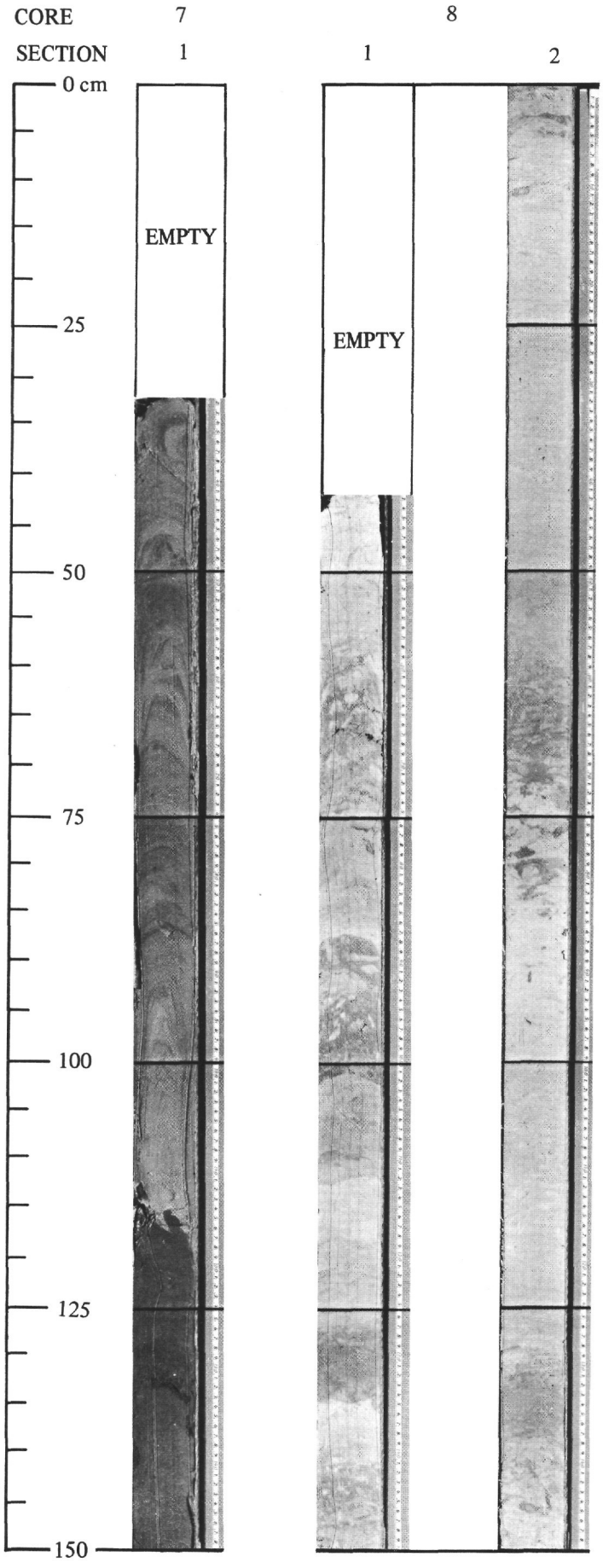

Plate 4. *Cores 7 and 8, Hole 31.*

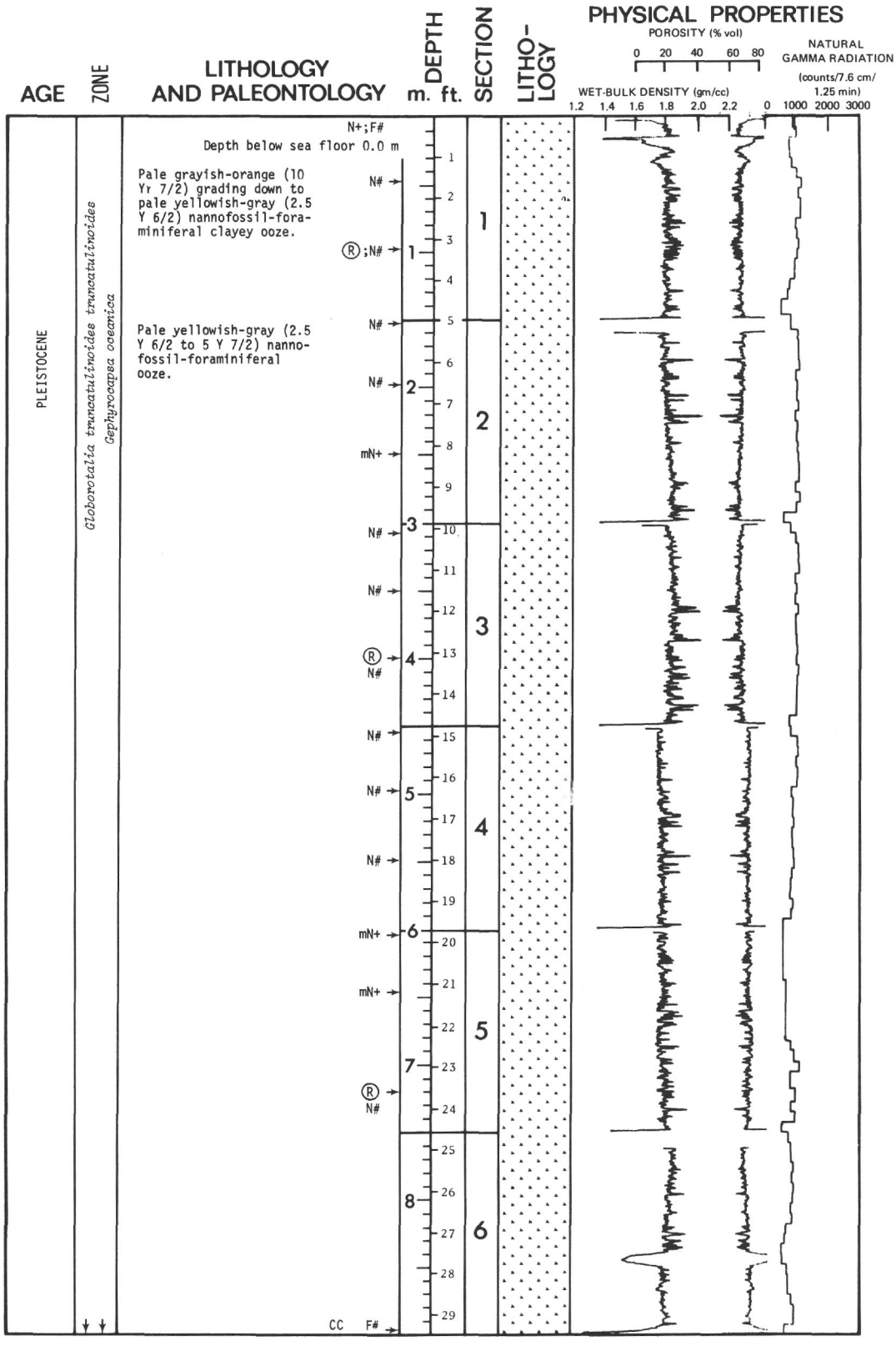

Figure 5. *Core 1, Hole 31.*

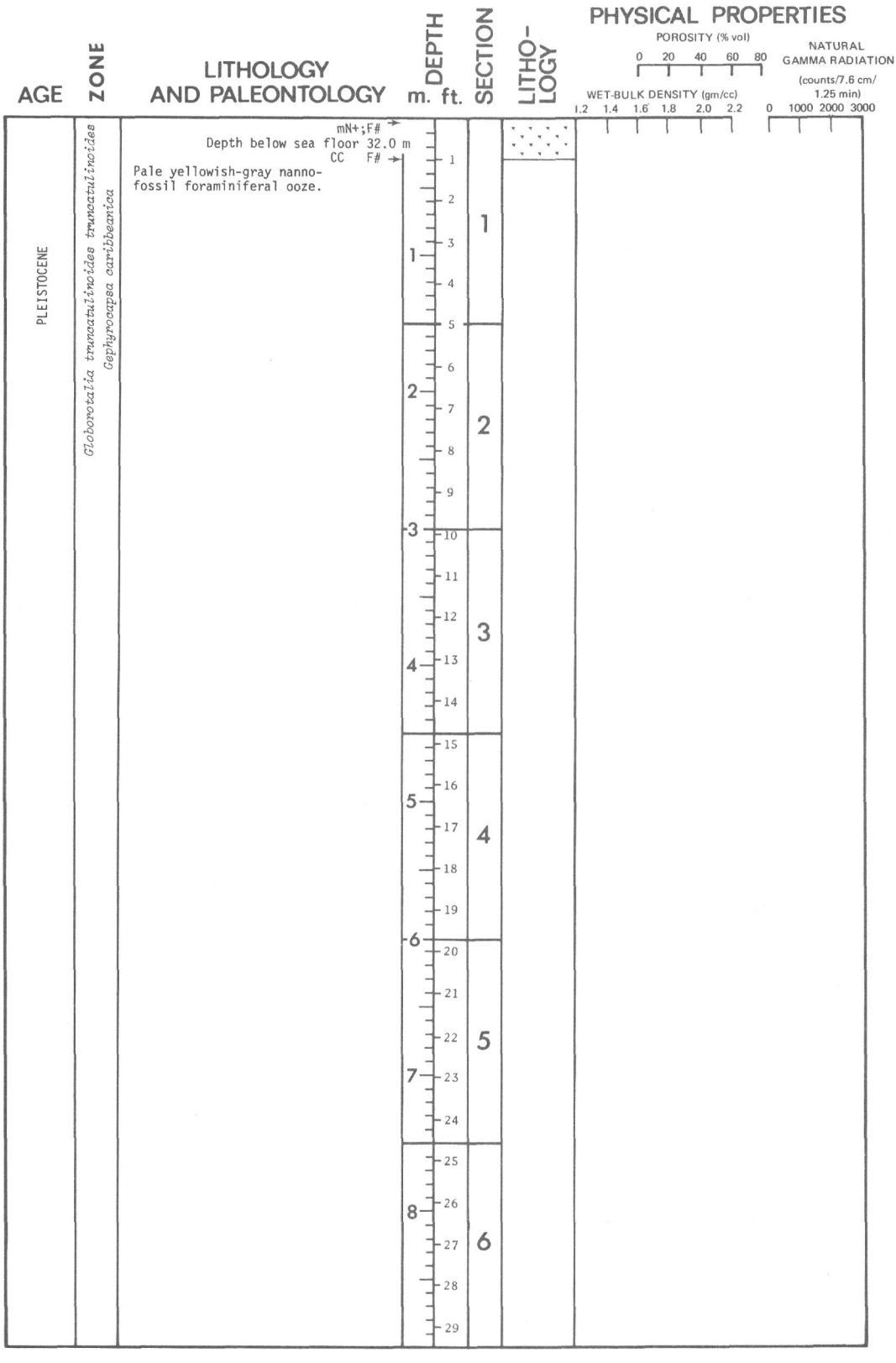

Figure 6. *Core 2, Hole 31.*

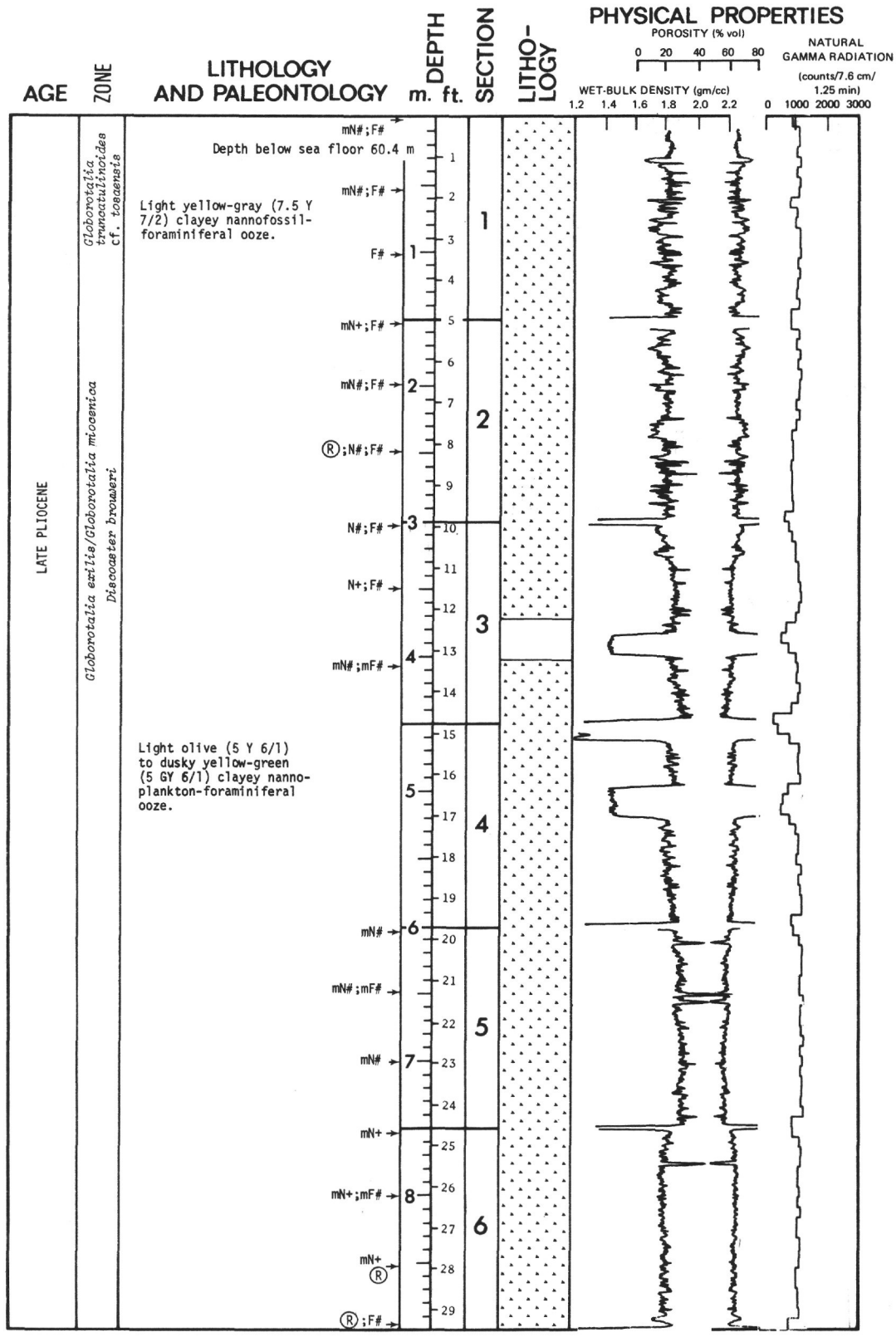

Figure 7. *Core 3, Hole 31.*

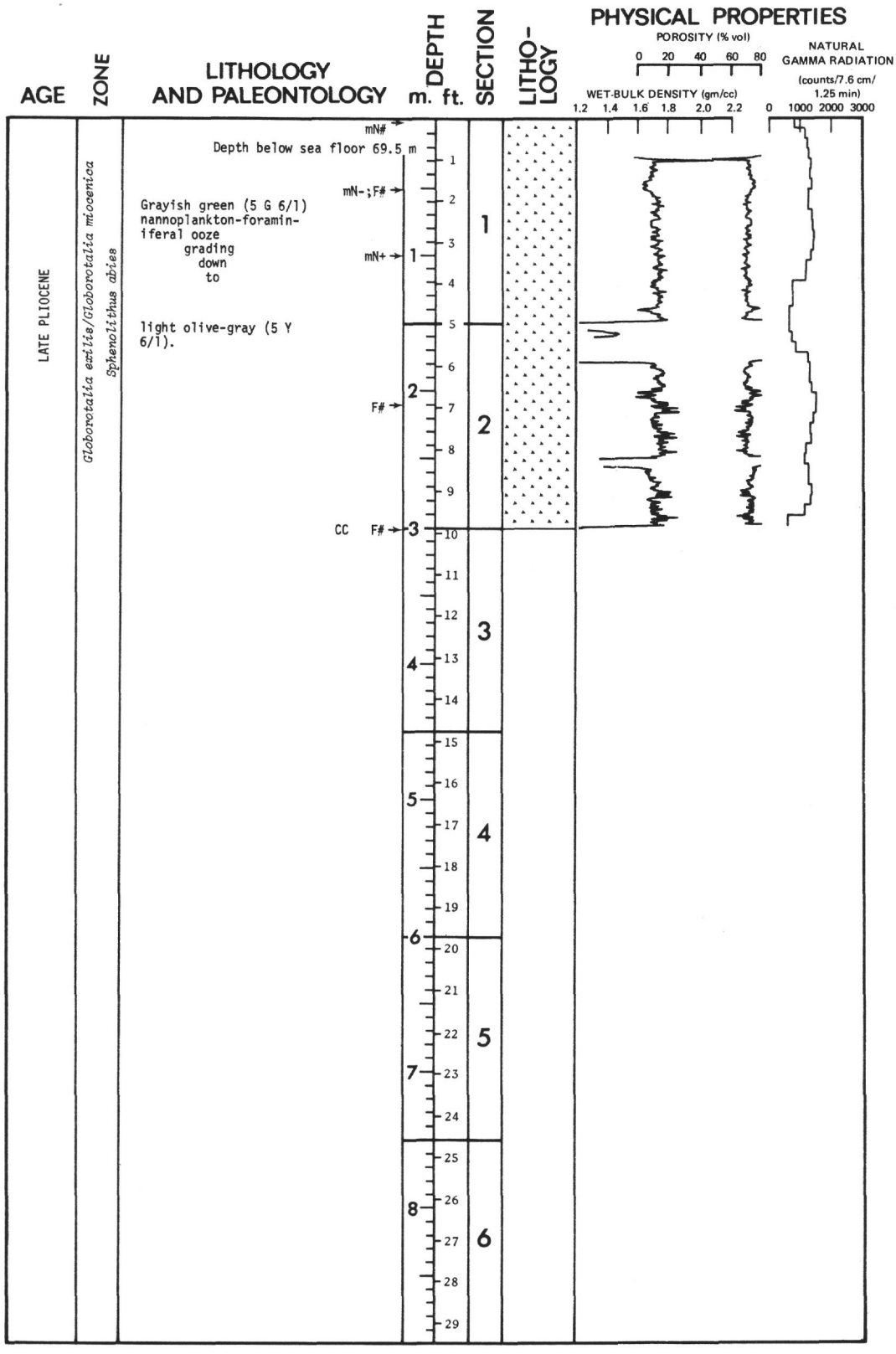

Figure 8. *Core 4, Hole 31.*

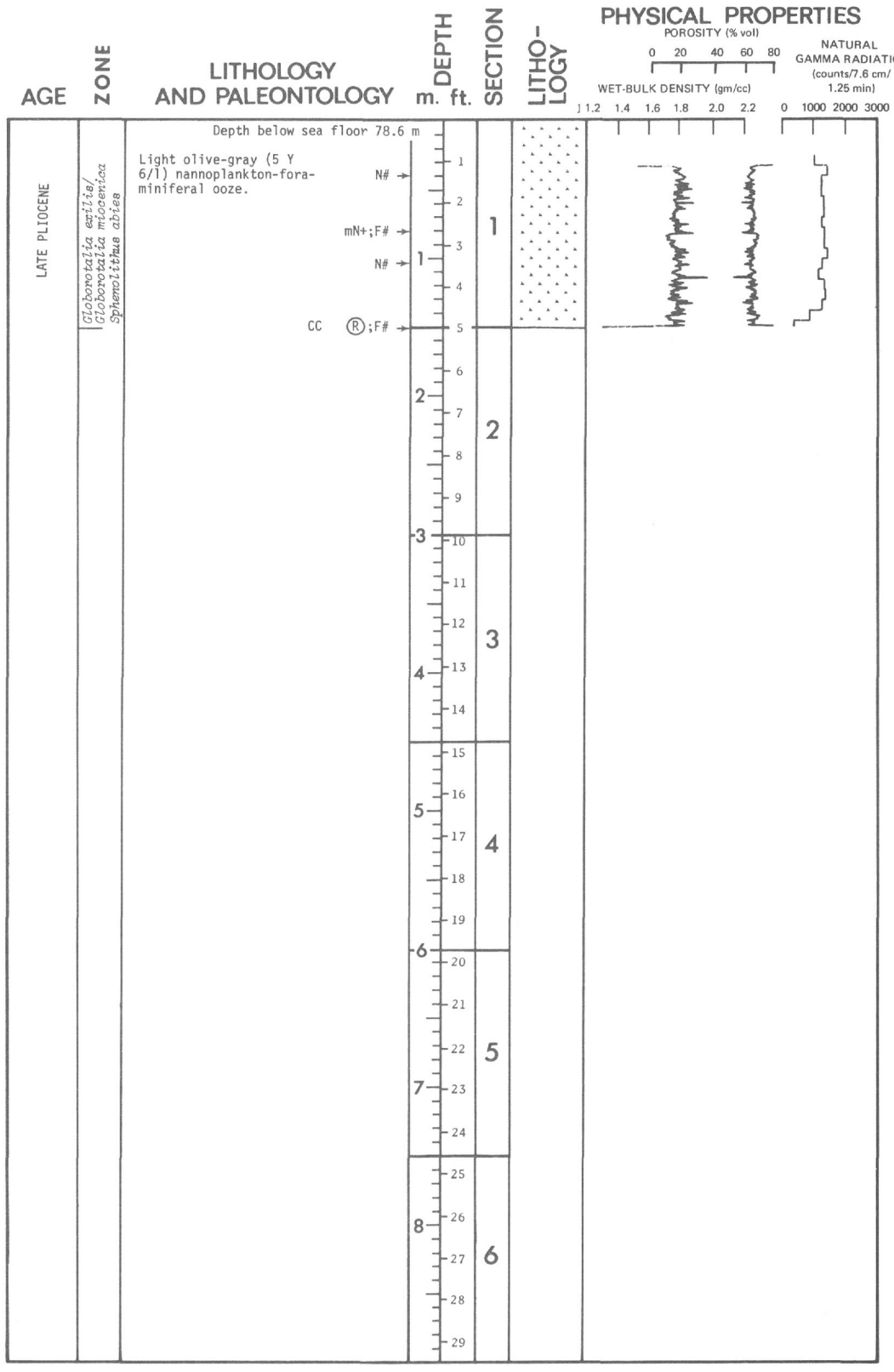

Figure 9. *Core 5, Hole 31.*

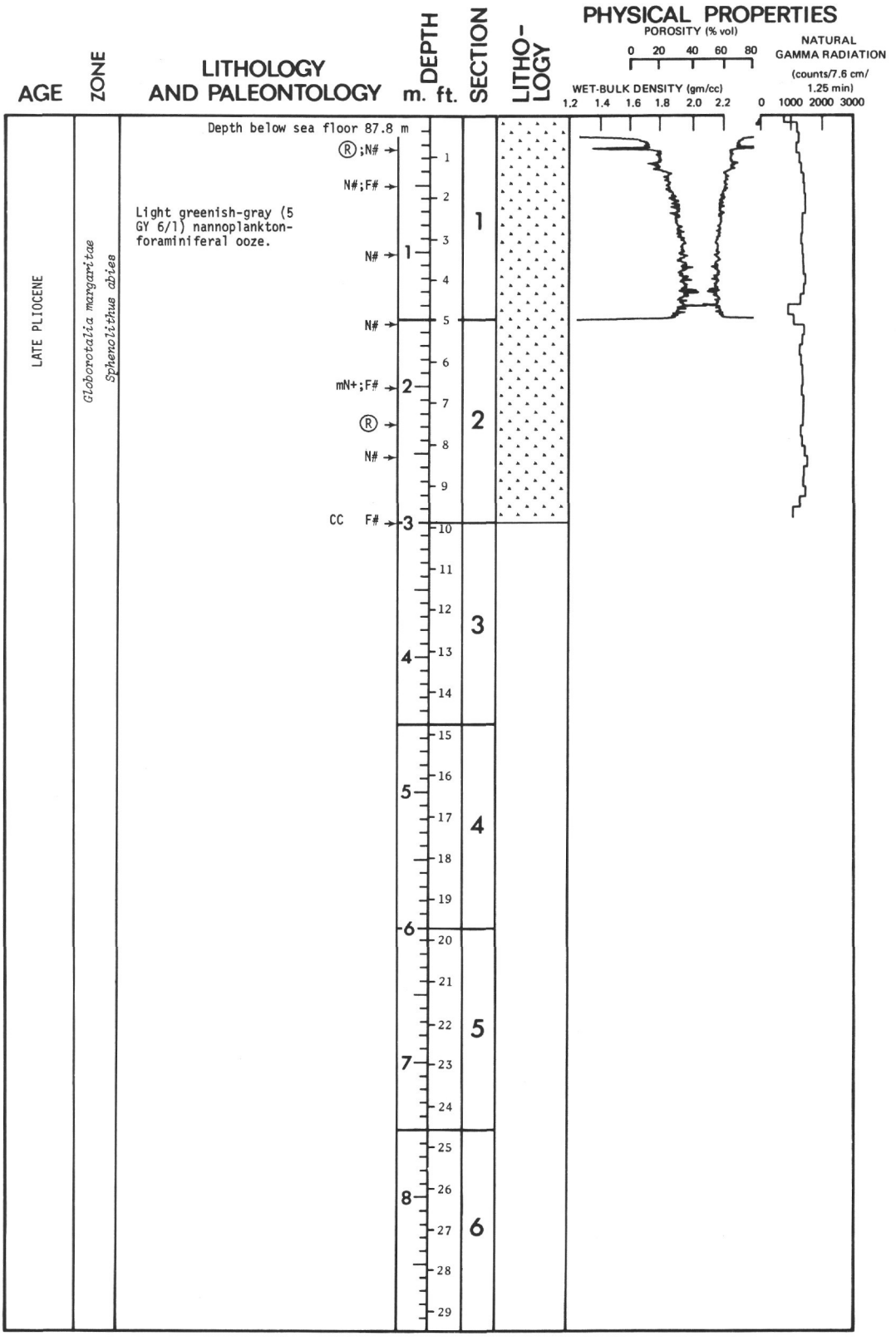

Figure 10. *Core 6, Hole 31.*

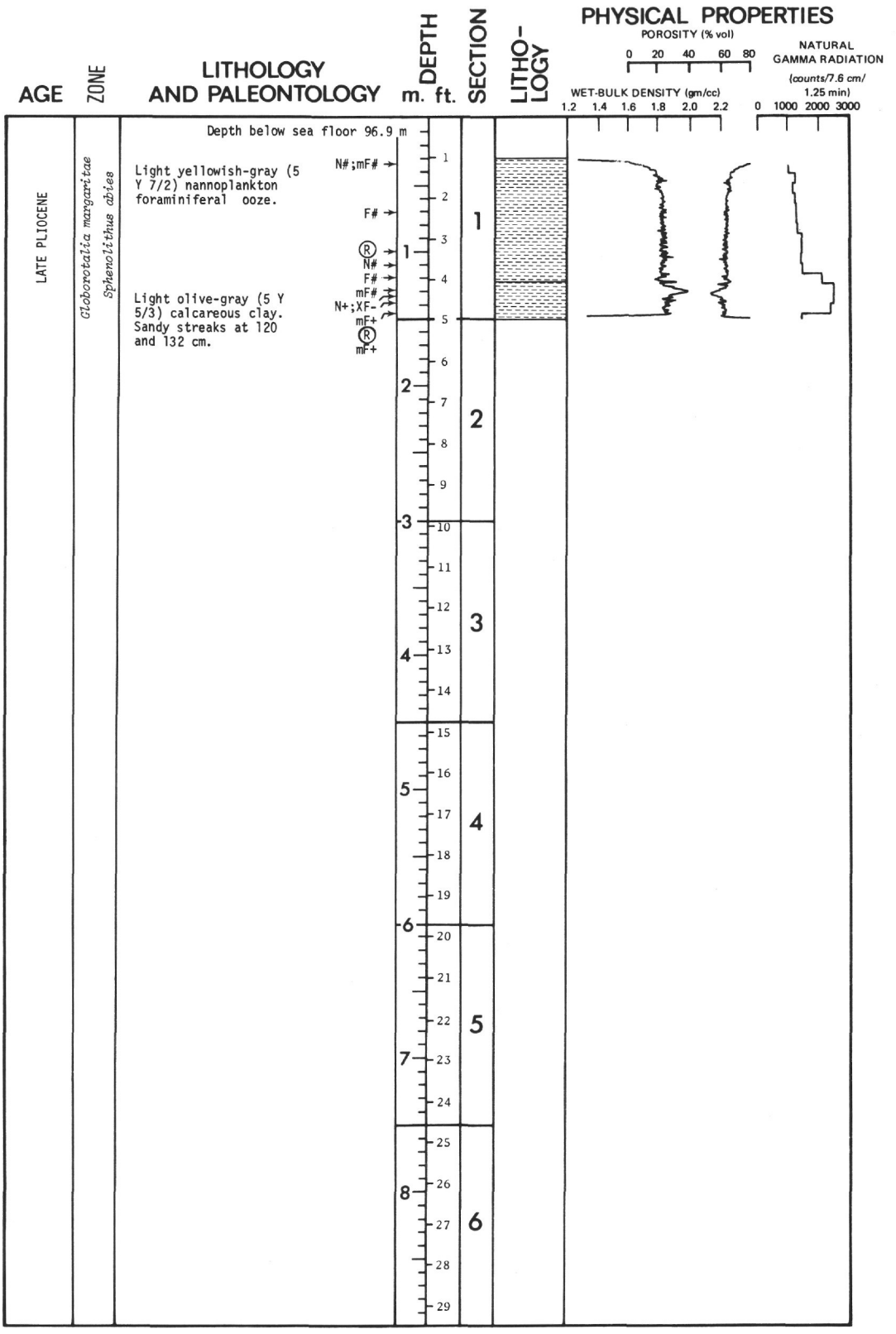

Figure 11. *Core 7, Hole 31.*

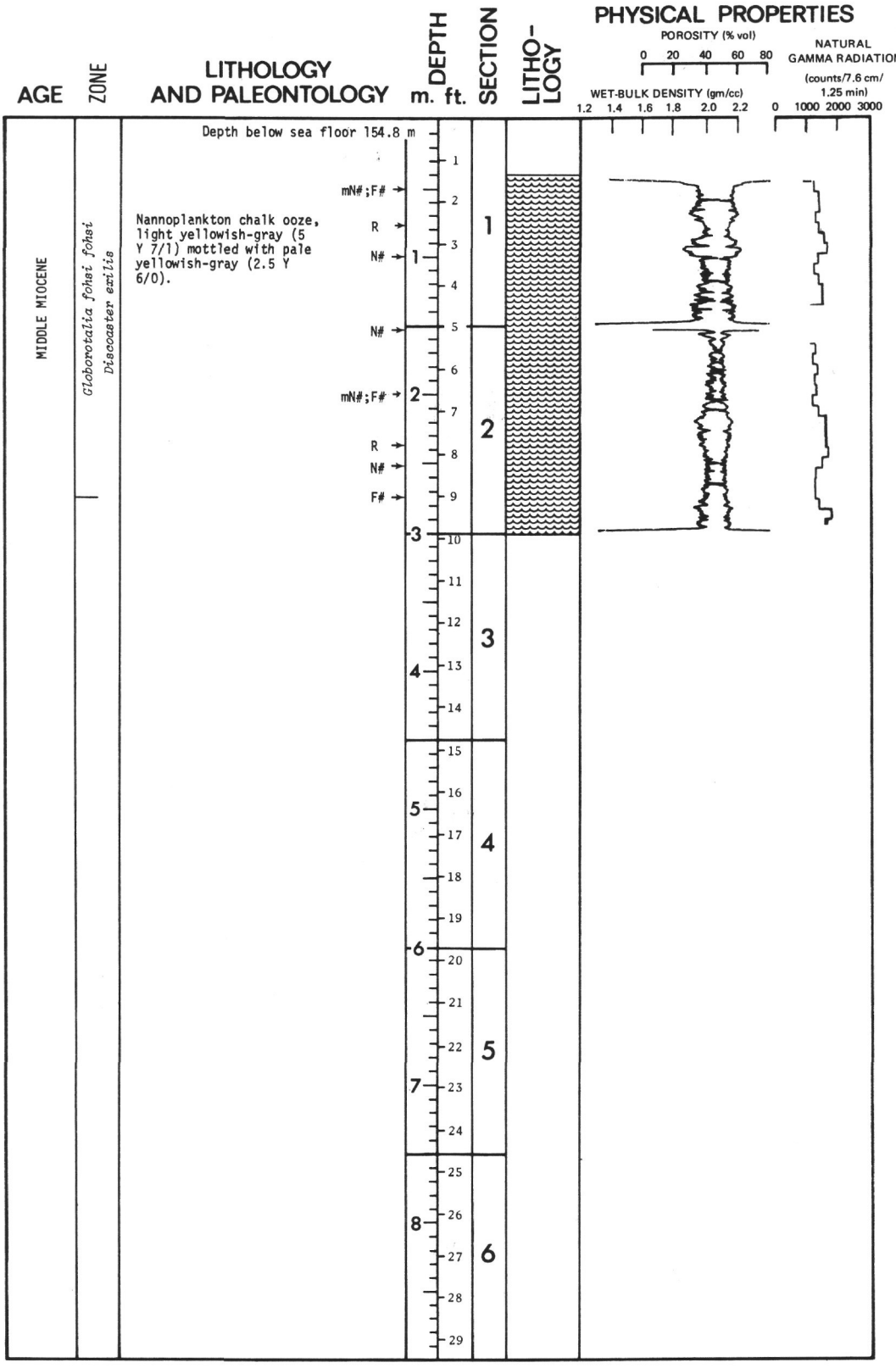

Figure 12. *Core 8, Hole 31.*

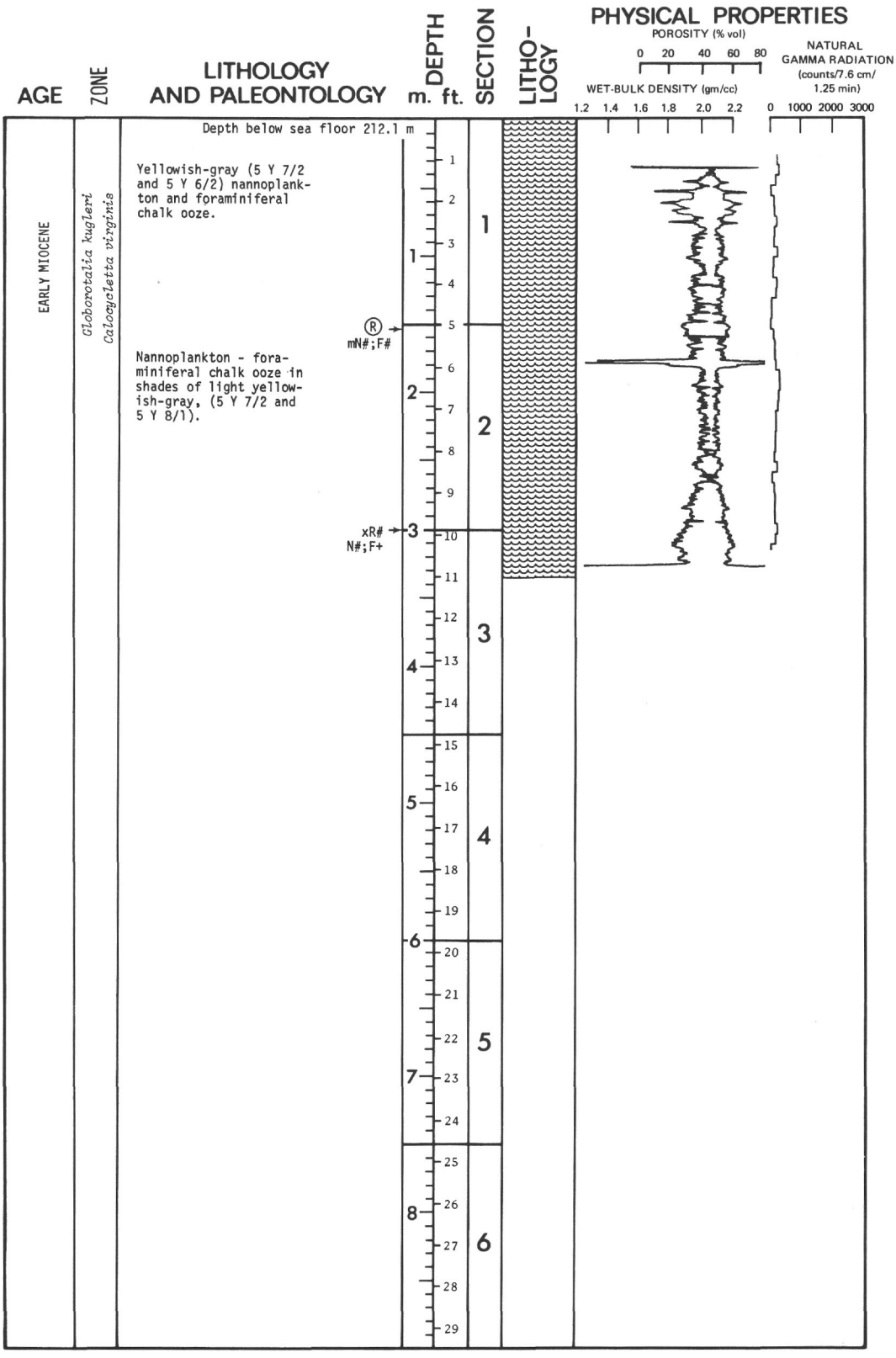

Figure 13. *Core 9, Hole 31.*

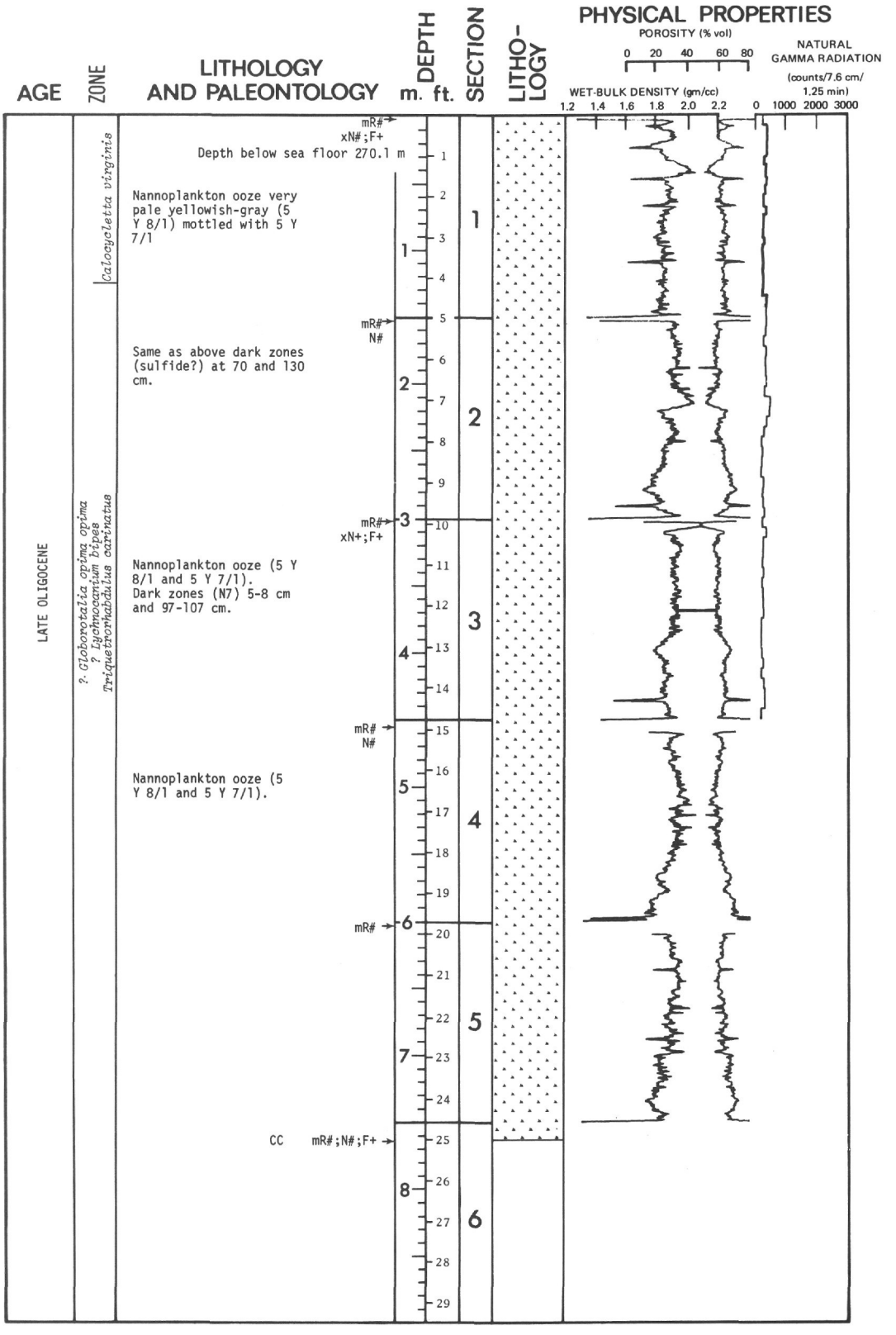

Figure 14. *Core 10, Hole 31.*