7. SITE 28

The Shipboard Scientific Party[1]

SETTING AND PURPOSE

The Outer Ridge, which lies between the north wall of the Puerto Rican Trench and the Nares Basin to the north, is covered for the most part with thick, acoustically "transparent" sediments, diminishing in thickness northward where they dip beneath turbidites of the Nares Abyssal Plain (Ewing and Ewing, 1962; Ewing *et al.*, 1965).

Along the southern portion of the Outer Ridge, reflection profiles reveal that the basement layer reaches a maximum elevation, while the sediment cover diminishes to less than 0.2 second acoustical thickness near the north wall of the Puerto Rican Trench. Seismic refraction measurements show that the Outer Ridge crustal layers are unusually thin and that the 8.2 km/sec mantle reaches within less than 5 kilometers of the ocean bottom in this area. This thinning of the crust has been cited by Worzel (1965) as evidence of extensional forces on the seaward side of island arc trenches. The same effect is shown by Ludwig *et al.* (1966) for the Japan Trench. Isaacs *et al.* (1968) show that extensional stresses are predicted on the convex side of the bend of the downmoving lithosphere beneath island arcs, even though the principal stress, deeper in the lithosphere, may be compressional.

Hersey (1966) described the typical Outer Ridge sedimentary section (from seismic refraction and reflection measurements) as having an upper zone of unconsolidated, acoustically "transparent" sediments separated from basement rock by a semi-transparent layer having a considerably higher compressional wave velocity (4.2 km/sec), assumed to be layered rock or sediment.

Figure 1 shows the topography of the Outer Ridge, the position of Site 28, and the location of a reflection profiler transect which is presented in Figure 2. Figure 3, from Ewing and Ewing (1962), shows a section drawn from reflection profiler data from the Caribbean northward across the Puerto Rican Trench and the Outer Ridge. Bunce and Hersey (1966) speculate that the transparent layer which projects below the floor of the Puerto Rican Trench may be of an age which predates the formation of the Trench.

The drilling objectives at this site were to sample and date the layered structures and prominent reflectors described above, and to determine whether any relationships exist between them and the Horizons A and B in the North American Basin (Ewing *et al.*, 1966; Windisch *et al.*, 1968). It was hoped that comparison could be made between the core material and calcareous samples which have been dredged from the walls of the Puerto Rican Trench (Todd and Low, 1964), well below the present carbonate compensation depth, in order to examine the hypothesis of subsidence in this area.

SITE SURVEY

Using profiler records taken by the *R/V Conrad* in 1965, on a north-south transect across the Outer Ridge (Figure 2), the *Glomar Challenger* approached the site area on a northerly course at 0826 hours on March 3, 1969. After a run to the south, a second northward track was made from the north wall of the Puerto Rican Trench, arriving at the final site location at 1205 hours. A PPM acoustic beacon was dropped at 1235 hours at a position later determined by satellite navigation fixes as 20° 35.19′N latitude, 65° 37.33′W longitude.

The underway profiler record made on the final approach shows a transparent layer (Figure 4A) about 0.15 second reflection time, underlain by a semi-transparent layer with a maximum thickness of 0.25 second. In spite of the broad banding on the record, which is an artifact caused by the air-gun signal, a fine banding or layering is observed in the lower section. Subsequent drilling found this to be due to alternating thin-bedded cherty layers interbedded with soft sediment below about 175 meters (575 feet) in the section. The same section is revealed in Figure 4B from an on-site profiler record. The two-way travel time thickness of the transparent and semi-transparent layers measures about 0.4 second. It was estimated that the depth of the transparent layer (assuming a sonic velocity of 2.0 to 2.3 km/sec) approximated 150 to 175 meters (492 to 575 feet). This estimate was verified by the drilling, which encountered a banded cherty formation (Eocene) at 176

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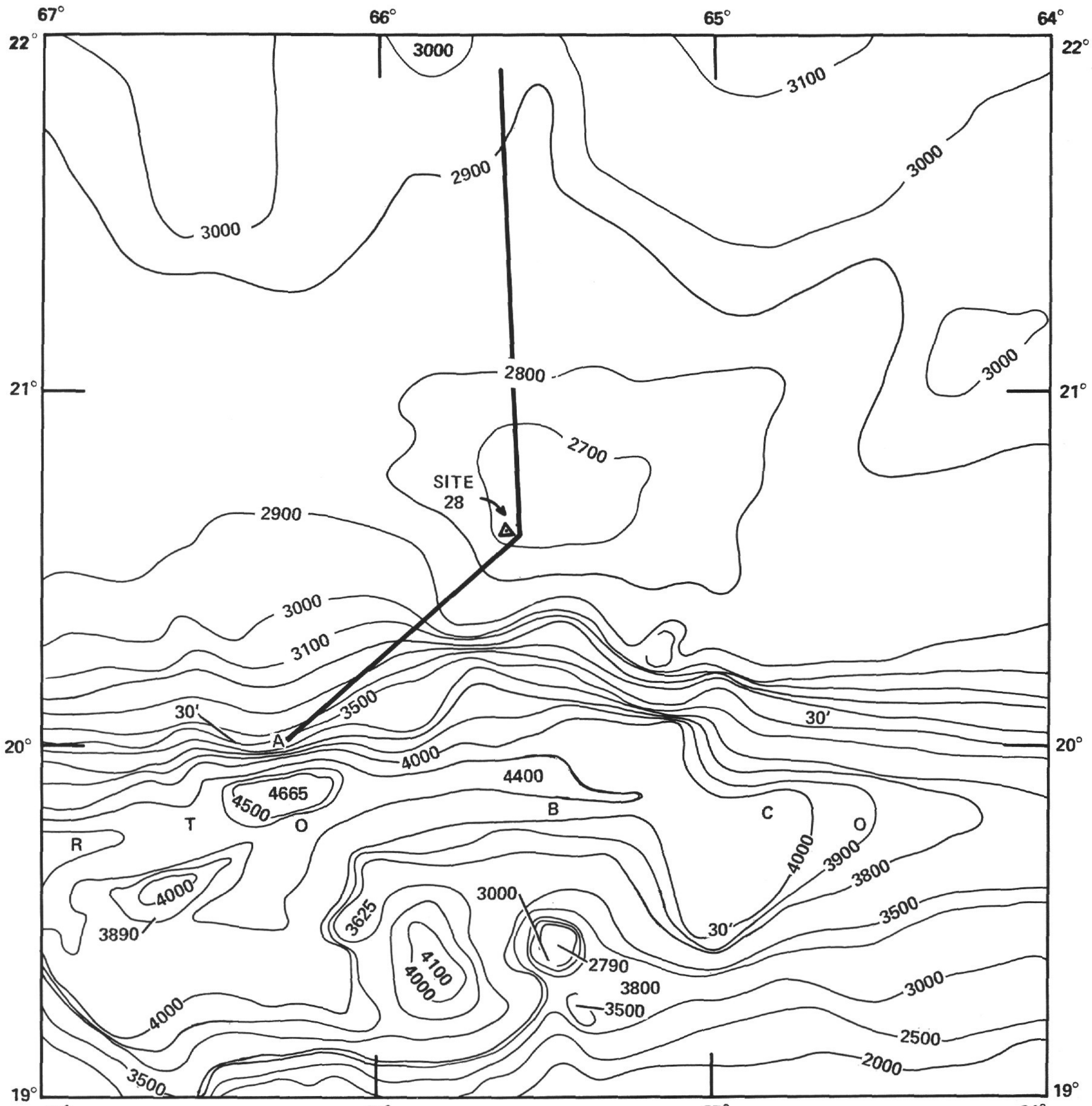

Figure 1. *Topography of the Outer Ridge area showing the location of Site 28 and reflection profiler section A-B (see Figure 2 for profiler record). Topography from U. S. Navy Hydrographic Office Chart BC-0704N.*

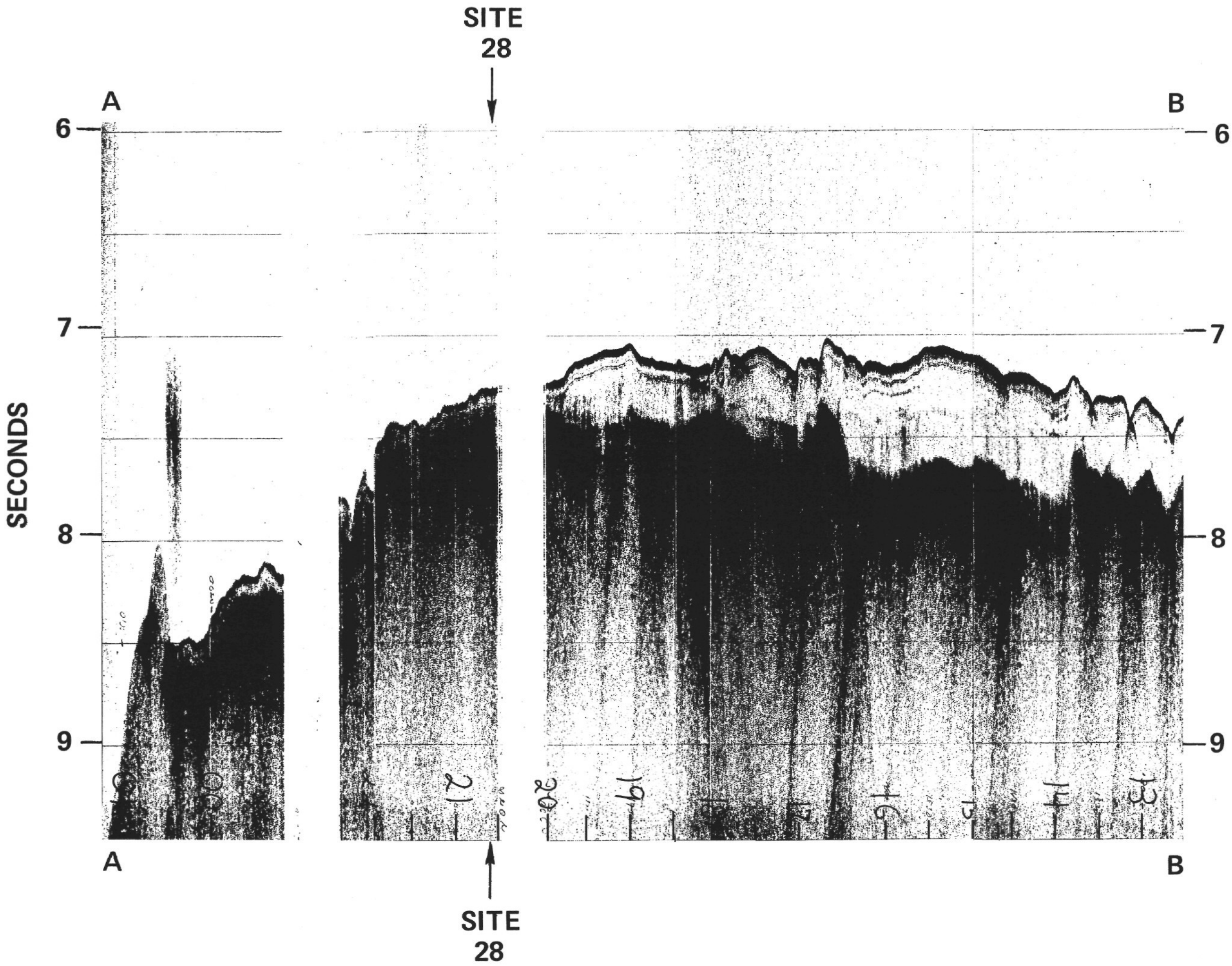

Figure 2. *Reflection profiler record across the Outer Ridge (see Figure 1 for location) obtained on cruise of the* R/V ROBERT D. CONRAD *19, December, 1965. Note the thick mantle of "transparent" sediment above a rough basement over the ridge.*

meters (578 feet). The semi-transparent layer was penetrated to a depth of 404 meters (1326 feet) without sampling "basement", so it is impossible to check the lower portion of the profiler record against the coring results. If the semi-transparent layer does indeed have the relatively high (4.2 km/sec) sonic velocity assigned by Hersey (1966), then its thickness would be about 400 meters (1312 feet). The deepest penetration at this site would, therefore, be about 172 meters (357 feet) above the basement reflector.

DRILLING AND CORING OPERATIONS

The *Glomar Challenger* began operations at Site 28 at 1245 hours on March 3, 1969, when the position-keeping gear was put on automatic and the tools were lowered. The diamond drill bit was spudded in with a water depth of 3018 fathoms (5519 meters; 18,107 feet) at 0300 hours on March 4; and, the bottom hole assembly was drilled down to 59 meters (194 feet) before attempting to core.

Table 1 shows the drilling intervals and results at this site. The upper "transparent" layer ended with Core 3, which bottomed in a chert-like thin bed. Core recovery in this upper section was variable, from 0 to 100 per cent in plastic clay. A flapper-type core catcher was used on the first attempted core, but it stuck open and no core was recovered. Five cores were attempted in the section below Core 3 (176 to 404 meters; 578 to 1326 feet) with very marginal results. The first of these, directly below the cherty layer (Core 4, 176 to 185 meters; 578 to 608 feet), was a mere 0.5 meter (1.5 feet), while all the rest were only core-catcher samples, some recovering only a few cubic centimeters. The beds

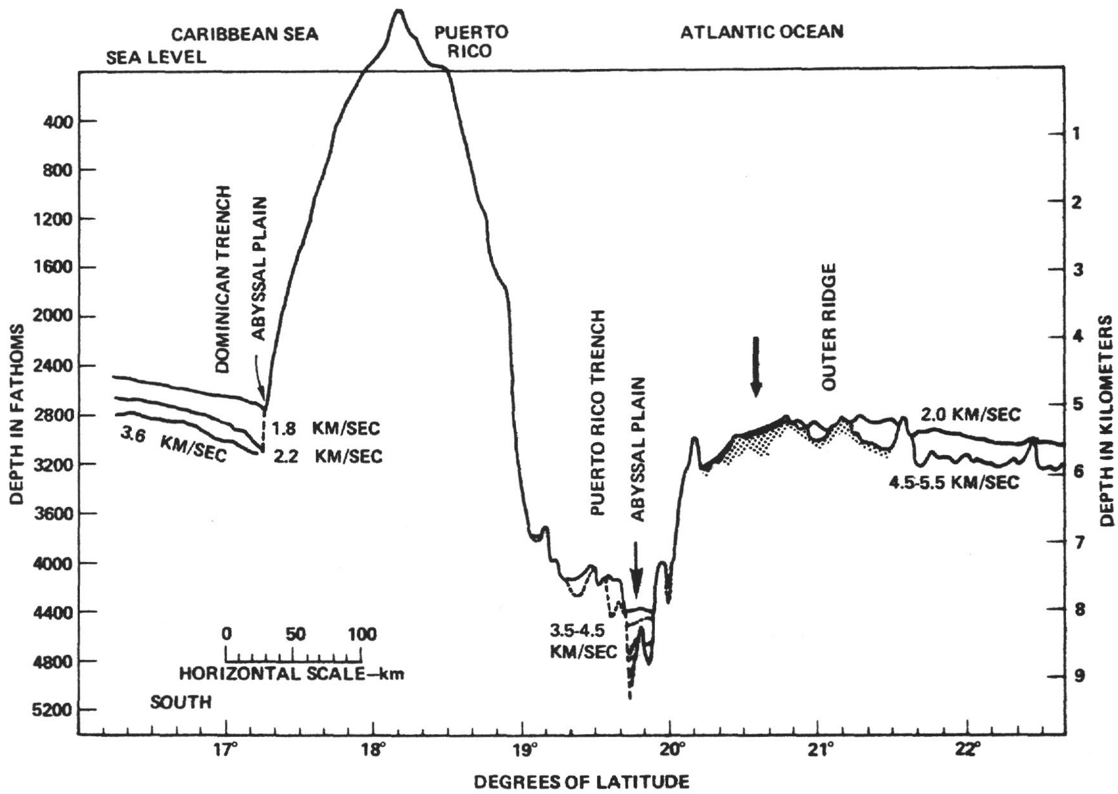

Figure 3. *Reflection profiler section from the Caribbean northward, across the Outer Ridge drawn from Lamont-Doherty seismic profiler records. Indicated seismic velocities are from nearby refraction stations (from Ewing and Ewing, 1962.*

TABLE 1
Cores Recovered from Hole 28
(Using a Diamond Bit)

Core	Drill String (m)	Penetration (m)	Core Recovered (m)
1	5593-5603	59-68	0.0
2	5603-5612	68-77	4.6
3	5703-5710	169-176	7.6
4	5710-5720	176-185	0.5
5	5770-5779	236-245	0.3
6	5810-5814	276-280	0.0
7	5814-5817	280-283	0.3
8	5879-5888	345-354	0.3
9	5934-5938	400-404	0.3
		Total	13.9

below the so-called "transparent" layer were found to be interbedded clays and harder layers, which made for numerous drilling breaks and changes. The lack of core recovery within the interbedded "semi-transparent" layers is thought to be due to damage to the bit at the initial contact with the "cherty" layer at 176 meters (578 feet). When the diamond bit was brought on deck on March 7 at 1030 hours, it was found to have been badly torn apart and, no doubt, had been rotating in an eccentric manner, which prevented core recovery.

Prior to tripping out the drill pipe, a gamma-ray neutron log was run in the pipe, with the drill bit 13 meters (43 feet) above the bottom of the hole. The results of this operation are summarized in the section on logging.

Work at this site was completed by March 7, and the ship was under way at 1030 hours to the next site in the Caribbean.

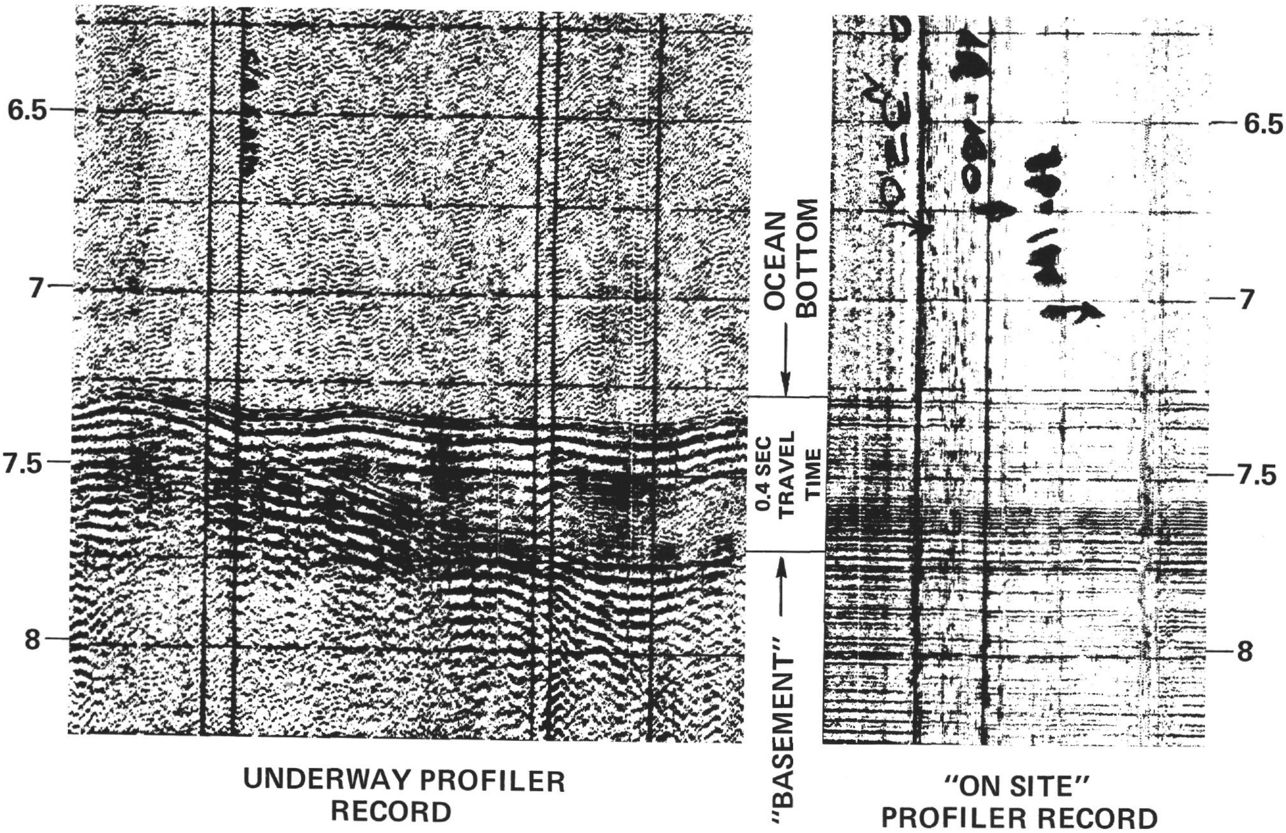

Figure 4A. Glomar Challenger *profiler record on the Outer Ridge made while approaching Site 28.*

Figure 4B. *On-site profiler record made aboard* Glomar Challenger *at Site 28. Note "transparent" and "semitransparent" zones in the upper 0.4 second portion above a possible "basement" reflector.*

LITHOLOGIC SUMMARY

For detailed lithology and paleontology see Hole Summaries. (See pages 135-143).

Coring began at a depth of 194 feet (59.1 meters) below the sea floor, with Cores 1 and 2 taken between this depth and 253 feet (77.1 meters). Only a very small sample, about 1 cubic centimeter, was recovered by Core 1, but 15 feet (4.6 meters) of core was recovered by Core 2. The sediments are deep sea "red clays", actually beige-brown, soft, zeolitic and slightly silty. Occasionally a few dolomite crystals, feldspars, some quartz, altered micas and minor quantities of other minerals were observed; the total amount of all these was usually less than 20 per cent. Several thin, soft layers, up to 5 inches thick, of silty green sediment in the core consist of up to 90 per cent feldspar (usually plagioclase, but with one sample almost 50 per cent orthoclase), fresh to only slightly altered. Mottling, as well as most of the dome-like to diapirical structural disturbances of the core were produced in the plastic sediment during coring. A thin, dark-brown to black film around much of the material in Core 2 seems to be contamination (rust and paint particles) from the core barrel. No calcareous fossils or Radiolaria were found in this sediment.

A small amount of crumbly sediment was recovered from the drill bit, representing some part of the section between 253 and 553 feet (77.1 and 168.6 meters). Three types of sediment could be distinguished: a) non-fossiliferous, brown calcareous clay; b) chips of white, friable, highly calcareous and fossiliferous chalk with a late Eocene nannoflora; and, c) green, plastic, slightly calcareous clays of early Late Eocene age, these constitute most of the sample.

Cores 3 and 4 were cored between 553 and 608 feet (168.6 and 185.3 meters) below the sea floor. Recovery was complete with the first core which contains a sequence of rather uniform gray-green stiff clays. Most of the clay is calcareous, and there are some layers in the upper part of the core which consist almost entirely of siliceous and calcareous skeletal materials, including calcareous nannofossils, diatoms, radiolarians and sponge spicules. The carbonate content of the core seems to decrease with depth, with an increase in the amount of clay and siliceous fossils. The calcareous nannofossils and Radiolaria suggest an age of late Middle Eocene for these strata. At the base of the core recovered by Core 3, at a depth of about 758 feet (176.2 meters) below the sea floor is a thin bed of hard, indurated while siliceous limestone. From the relatively short delay in drilling, this bed appears to have only minor thickness, but it may represent one of the reflectors recorded in the upper, acoustically transparent layers. The lithology of the sediments below Core 3 is obviously different from that of the higher strata. Recovery from Core 4 was only 1.5 feet (0.4 meter) of light greenish-gray hard, calcareous silty clay, also containing a late Middle Eocene nannoflora. Drilling records, however, indicate frequent changes in drilling speed which probably reflect alternating harder and softer layers.

No samples were taken between 608 and 774 feet (185.3 and 235.9 meters), where a hard layer impeded drilling progress.

Core 5 was an attempt to core the harder material between 774 and 805 feet (235.9 and 245.4 meters) below the sea floor. Recovery was slight, with only a few inches of sediment found in the core catcher. The sediment consists of white, friable chalky material, highly calcareous, with up to 50 per cent nonskeletal calcium carbonate, about 30 per cent clay minerals, and the remainder nannoplankton fossils and planktonic foraminiferal tests and test fragments. Associated with this sediment are small granules of grayish calcareous clay which contain a well-preserved assemblage of calcareous nannofossils, diatoms and planktonic foraminifera indicating a Middle Eocene age. Radiolaria from the chalky sediment are scarce, but also suggest a Middle Eocene age.

A variety of sedimentary materials were recovered from the bit plug after drilling from 803 to 904 feet (244.8 to 275.5 meters): a) brownish-gray to gray clay, slightly calcareous, containing calcareous nannofossils like the assemblages encountered above, and constituting about 65 per cent of the sampled recovered: b) "chert-like" hard fragments of argillite, reddish-brown, waxy, noncalcareous, containing abundant diatoms and radiolarians, and comprising about 20 per cent of the sample; and, c) white chalky claystone, friable and highly calcareous, making up the rest of the sample.

Cores 6 and 7 were cored between 904 and 920 feet (275.5 and 280.4 meters) below the sea floor, but only the lower of these, drilled between 917 and 920 feet (279.5 and 280.4 meters) recovered any sediment. Core 7 contained about 0.5 foot of light greenish-gray, very calcareous clay with a slight silt content, mixed with some brown argillaceous material which tends to be chert-like, but may be soft and contains calcareous nannofossils and planktonic foraminifera.

No samples were recovered from the drilled interval between 920 and 1132 feet (2.804 and 345.0 meters) below the sea floor.

Core 8 was cored between 1132 and 1162 feet (345.0 and 354.2 meters) below the sea floor, but recovery was limited to a few fragments of sediment: a) white calcareous soft clay with abundant calcareous nannofossils indicating an early Middle Eocene age, b) white chalk with much sand to silt-size crystalline calcite and containing a few radiolarians; c) reddish, dense, noncalcareous argillite, partly silica cemented and containing radiolarians; and, d) vari-colored claystones, green, gray, bluish, pink, brown and yellow-brown, slightly calcareous to noncalcareous, occasionally silty.

The plug bit, removed after drilling the interval from 1162 to 1311 feet (354.2 to 399.6 meters) yielded a small sample of greenish-gray calcareous clay mixed with nonfossiliferous white, uncemented carbonate, brown clays with some (?) organic detritus, and probable drill pipe contamination as black and rusty flakes. Although only a small sample was obtained, the brown clays are especially important as they contain Late Cretceous pelagic foraminifera and calcareous nannoplankton.

After hitting another hard layer at 1311 feet (399.6 meters) Core 9 attempted to core the sediment between 1311 and 1326 feet (399.6 and 404.2 meters) below the sea floor. Only about 30 cubic centimeters of sediment were recovered, consisting of greenish-gray clay, noncalcareous, with a waxy luster, soft, and slightly silty, containing some fine-grained pyrite and radiolarians. The radiolarians are moderately well-preserved, and include pseudoaulophacids and *Dictyomitra* spp. (some multicostate), indicating a Cretaceous (probably Late Cretaceous age.

About 1000 grams of sediment were recovered from the bumper sub (200 to 240 feet—61.0 to 73.2 meters—above the drill bit). These materials probably represent a cross section of the sediments in the lower part of the hole. Splintery black, reddish-brown, beige, and white to green chert pieces are mixed with chips of green and brown firm clay, partially calcareous, white, friable chalk, and probably fine sandstone with clayey matrix. About 20 per cent of the sample consists of black, hard fragments, resembling partly silicified oil shales; heating them develops dark smoke and a strong bituminous smell; dissolving with trichlorethylene gives a light olive-brown color cut (5Y5/6).

PHYSICAL AND CHEMICAL PROPERTIES

Few data on the physical properties and geochemistry of the pore solutions were collected due to the paucity of recovered core material. Only two cores were lined and could be run through the analog instruments. Poor recovery from Cores 4 through 9 severely limited the information gathered from these samples; most of the material was recovered as small fragments.

Natural gamma radiation was measured on only one core and is low relative to most clay sediment (1400-2000 counts/1.25 min.). Water content for the two cores measured (2 and 3) range from 36 to 40 per cent; porosity ranges from 57 to 60 per cent. These values are relatively high as compared to previously cored sediment of similar lithology from equivalent depths. Densities range from 1.56 to 1.69 gm/cc.

The carbonate in the sediment cored in Core 2 and in the first section of Core 3 is on the order of 1 per cent. In Section 3-2 and subsequent sections the carbonate content increases to greater than 24 per cent. The depths from which the cores were taken (as well as the depth of the bottom) is greater than the carbonate compensation depth; it seems most probable that the calcareous clays were deposited in shallower water at depths above the carbonate compensation depth.

The organic carbon content of the sections from Core 2 and all but Sections 3 and 4 of Core 3 is nil. The organic carbon content of samples from the latter is about 0.5 per cent.

Two interstitial water samples were collected. The salinities of these solutions were 34.7 and 35.2 mil. The *p*H values were more acid than most previous samples (7.00 and 7.15). Total carbon dioxide differed widely, being 186 μl/ml in Section 28-2-3 (71 meters) and only 74 μl/ml in Section 28-3-1 (196 meters). But solutions had Eh values of +460 millivolts.

Only one thermal conductivity measurement was made at this site. A value of 2.39×10^{-3} cal/°C/cm/sec was obtained for Core 3, Section 1.

REFERENCES

Bunce, E. T. and Hersey, J. B., 1966. Continuous seismic profiles of the outer ridge north of Puerto Rico. *Bull. Geol. Soc. Am.* **77**, 803.

Ewing, J. and Ewing, M., 1962. Reflection profiling in and around the Puerto Rico Trench. *J. Geophys. Res.* **67**, 4729.

Ewing, M., Lonardi, A. G. and Ewing, J., 1965. The sediments and topography of the Puerto Rico Trench and Outer Ridge. *4th Caribbean Geol. Conf., Trinidad.* 325.

Ewing, J., Worzel, J. L., Ewing, M. and Windisch, C., 1966. Ages of Horizon A and the Oldest Atlantic sediments. *Science.* **154**, 1125.

Hersey, J. B., 1966. Marine geophysical investigations in the West Indies. *Geol. Sur. Canada, Paper 66-15.* 151.

Isaacs, B., Oliver, J. and Sykes, L. R., 1968. Seismology and the new global tectonics. *J. Geophys. Res.* **73**, 5855.

Ludwig, W. J., Ewing, J., Ewing, M., Murauchi, S., Den, N., Asano, S., Hotta, H., Hayakawa, M., Asanuma, T., Ichikawa, K. and Noguchi, I., 1966. Sediments and structure of the Japan trench. *J. Geophys. Res.* **71**, 2121.

Todd, R. and Low, D., 1964. Cenomanian (Cretaceous) foraminifera from the Puerto Rico Trench. *Deep-Sea Res.* **11**, 395.

Windisch, C., Leyden, R., Worzel, J. L., Saito, T. and Ewing, J., 1968. Investigation of Horizon Beta. *Science.* **162**, 1473.

Worzel, J. L., 1966. Structure of continental margins and development of ocean trenches. *Geol. Sur. Canada, Paper 66-16.* 357.

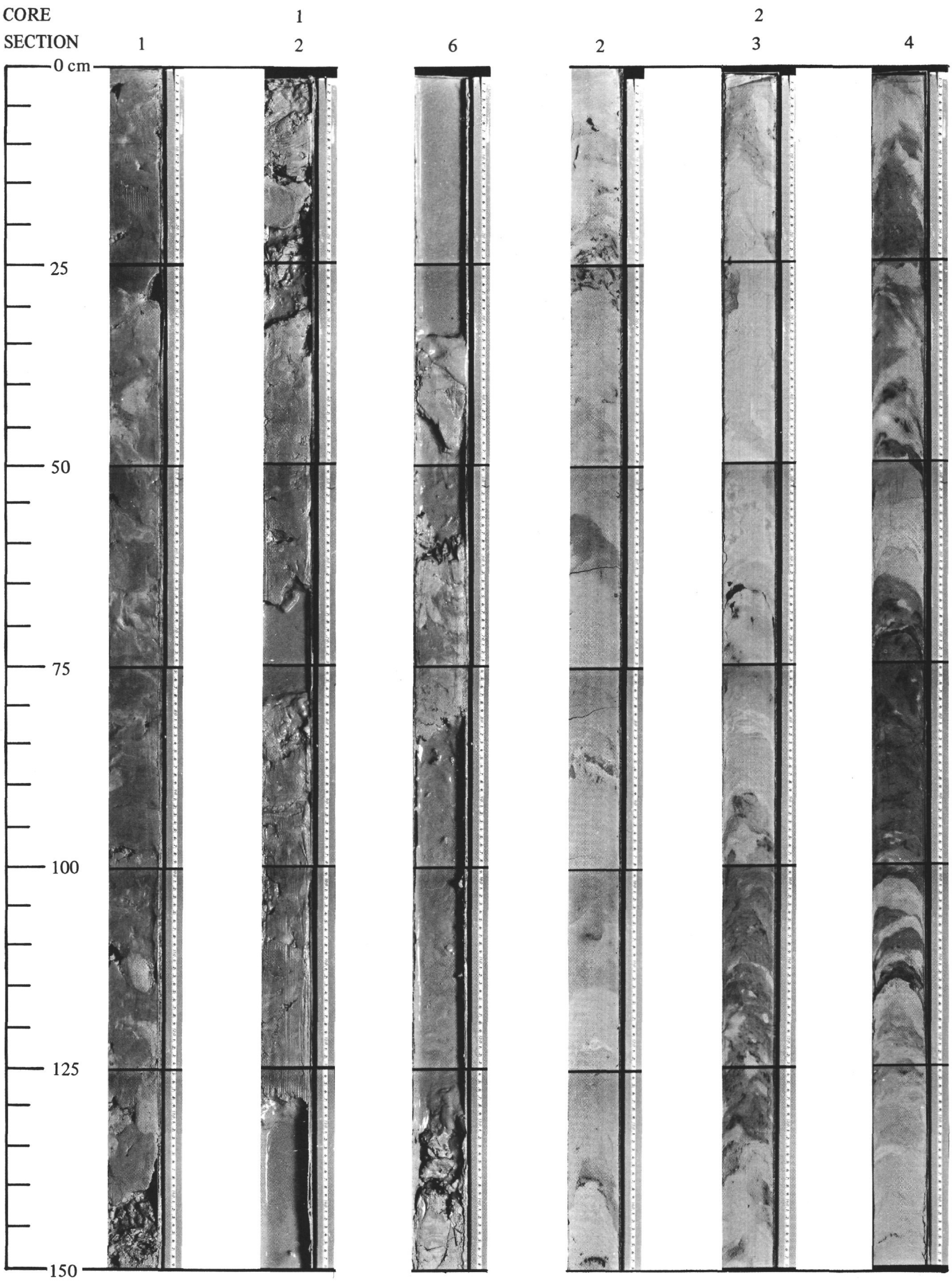

Plate 1. *Cores 1 and 2, Hole 28.*

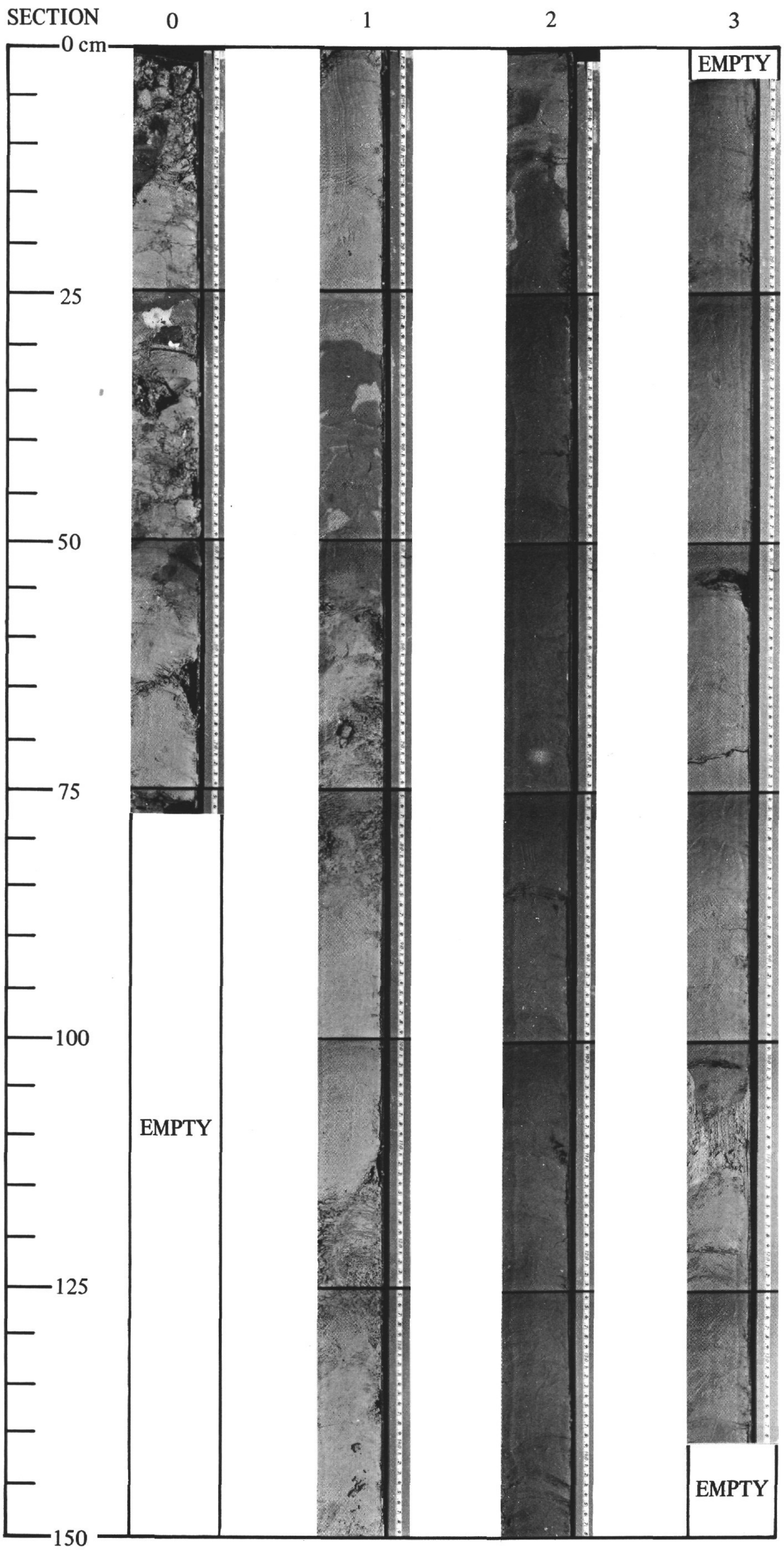

Plate 2. *Core 3, Hole 28.*

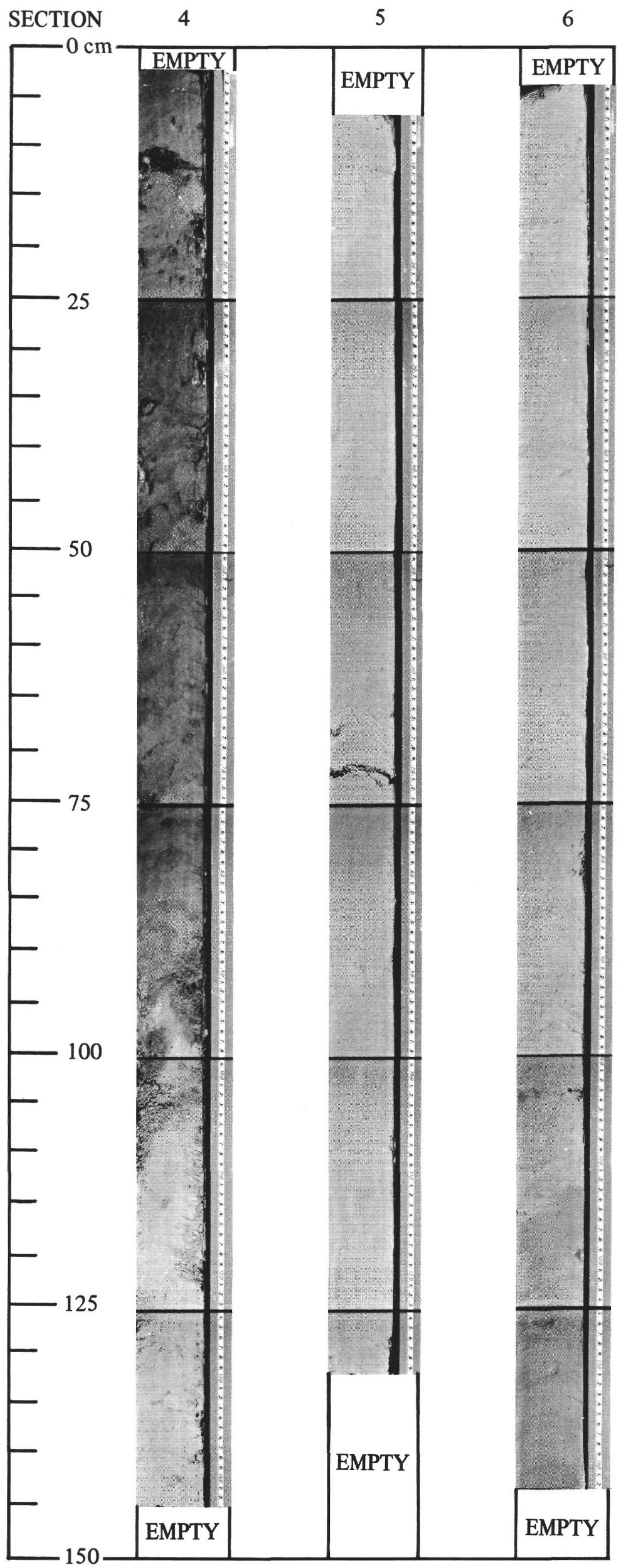

Plate 3. *Core 3, Hole 28 (continued).*

AGE	ZONE	LITHOLOGY AND PALEONTOLOGY	DEPTH m.	DEPTH ft.	SECTION	LITHO-LOGY	PHYSICAL PROPERTIES
?	?	Ⓝ;Ⓕ Depth below sea floor 68.3 m Brown-beige soft zeolitic clay.	1	1, 2, 3, 4	1		
			2, 3	5, 6, 7, 8, 9	2		
			3, 4	10, 11, 12, 13, 14	3		
			5, 6	15, 16, 17, 18, 19	4		
			6, 7	20, 21, 22, 23, 24	5		
			8	25, 26, 27, 28, 29	6		

PHYSICAL PROPERTIES: POROSITY (% vol) 0 20 40 60 80; WET-BULK DENSITY (gm/cc) 1.2 1.4 1.6 1.8 2.0 2.2; NATURAL GAMMA RADIATION (counts/7.6 cm/1.25 min) 0 1000 2000 3000

Figure 5. *Core 1, Hole 28.*

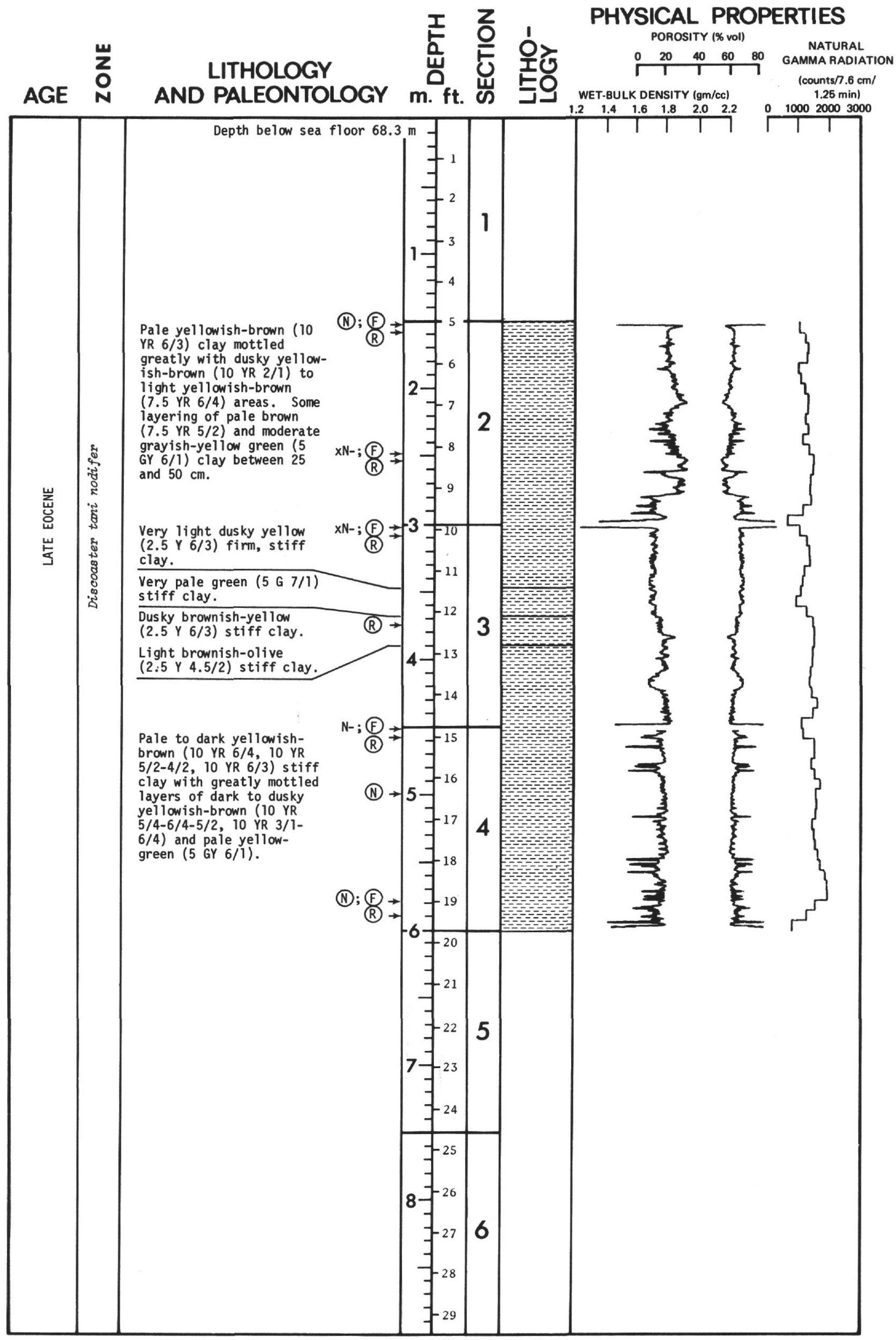

Figure 6. *Core 2, Hole 28*

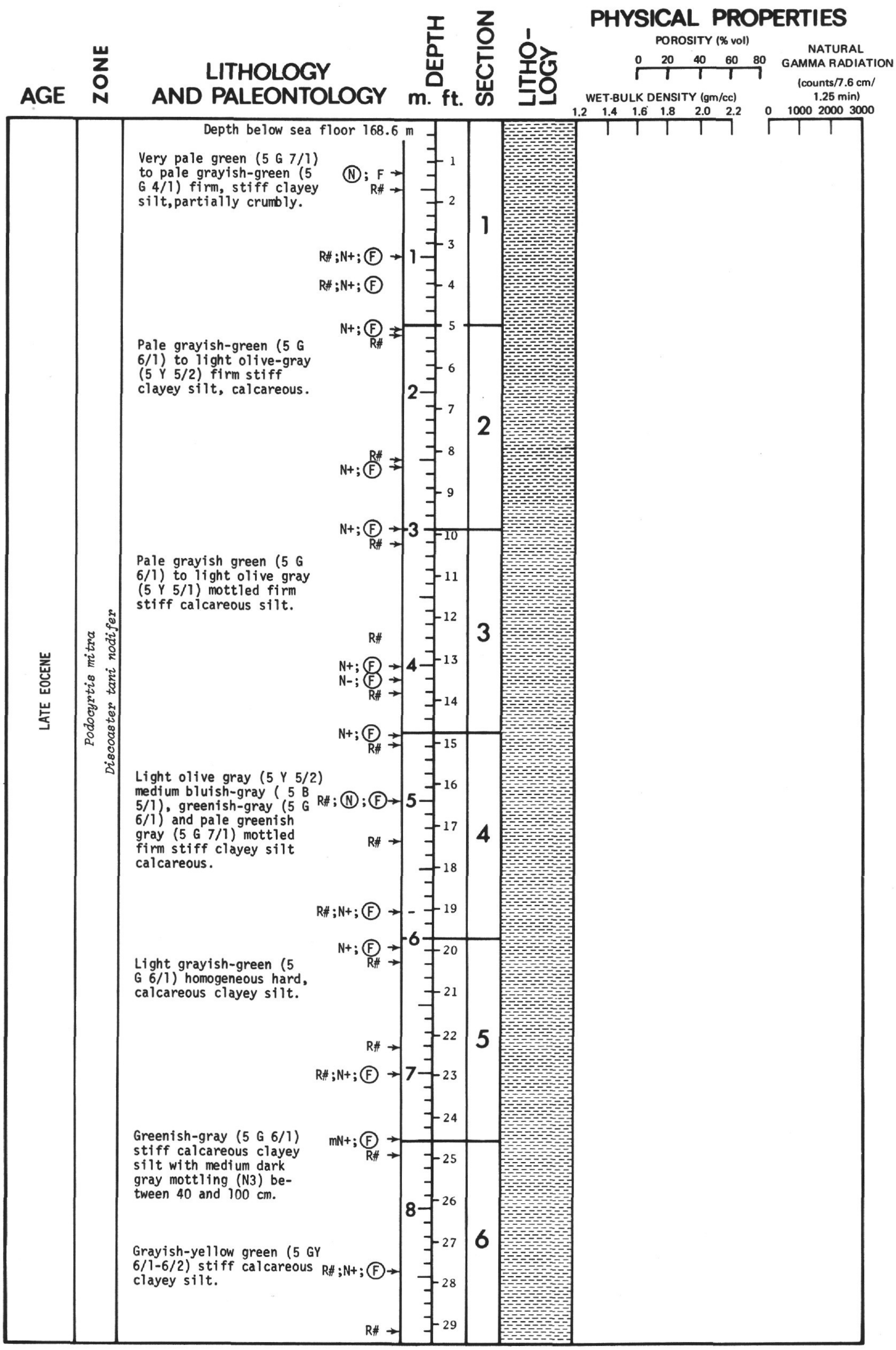

Figure 7. *Core 3, Hole 28.*

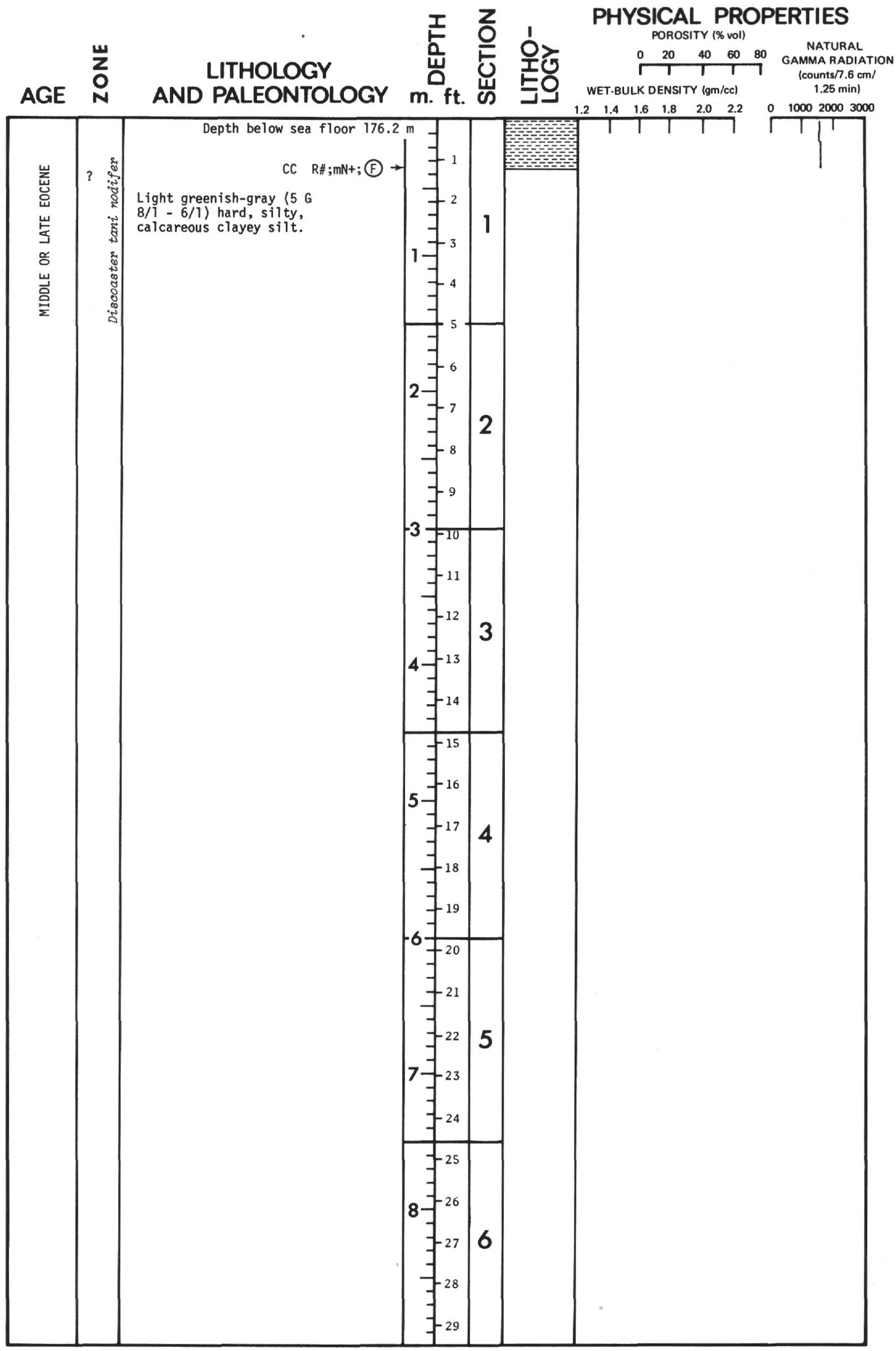

Figure 8 *Core 4, Hole 28.*

AGE	ZONE	LITHOLOGY AND PALEONTOLOGY	DEPTH m. ft.	SECTION	LITHO-LOGY	PHYSICAL PROPERTIES
MIDDLE EOCENE	*Podocyrtis mitra*	R-;mN+;(F) → Depth below sea floor 235.9 m Greenish-gray (5 G 4/1) silty, calcareous clay with chips of white (N9) chalky material.		1		
				2		
				3		
				4		
				5		
				6		

PHYSICAL PROPERTIES: POROSITY (% vol) 0 20 40 60 80; WET-BULK DENSITY (gm/cc) 1.2 1.4 1.6 1.8 2.0 2.2; NATURAL GAMMA RADIATION (counts/7.6 cm/ 1.25 min) 0 1000 2000 3000

DEPTH: m. 1 2 3 4 5 6 7 8; ft. 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29

Figure 9. *Core 5, Hole 28.*

NO CORE RECOVERED

Figure 10. *Core 6, Hole 28.*

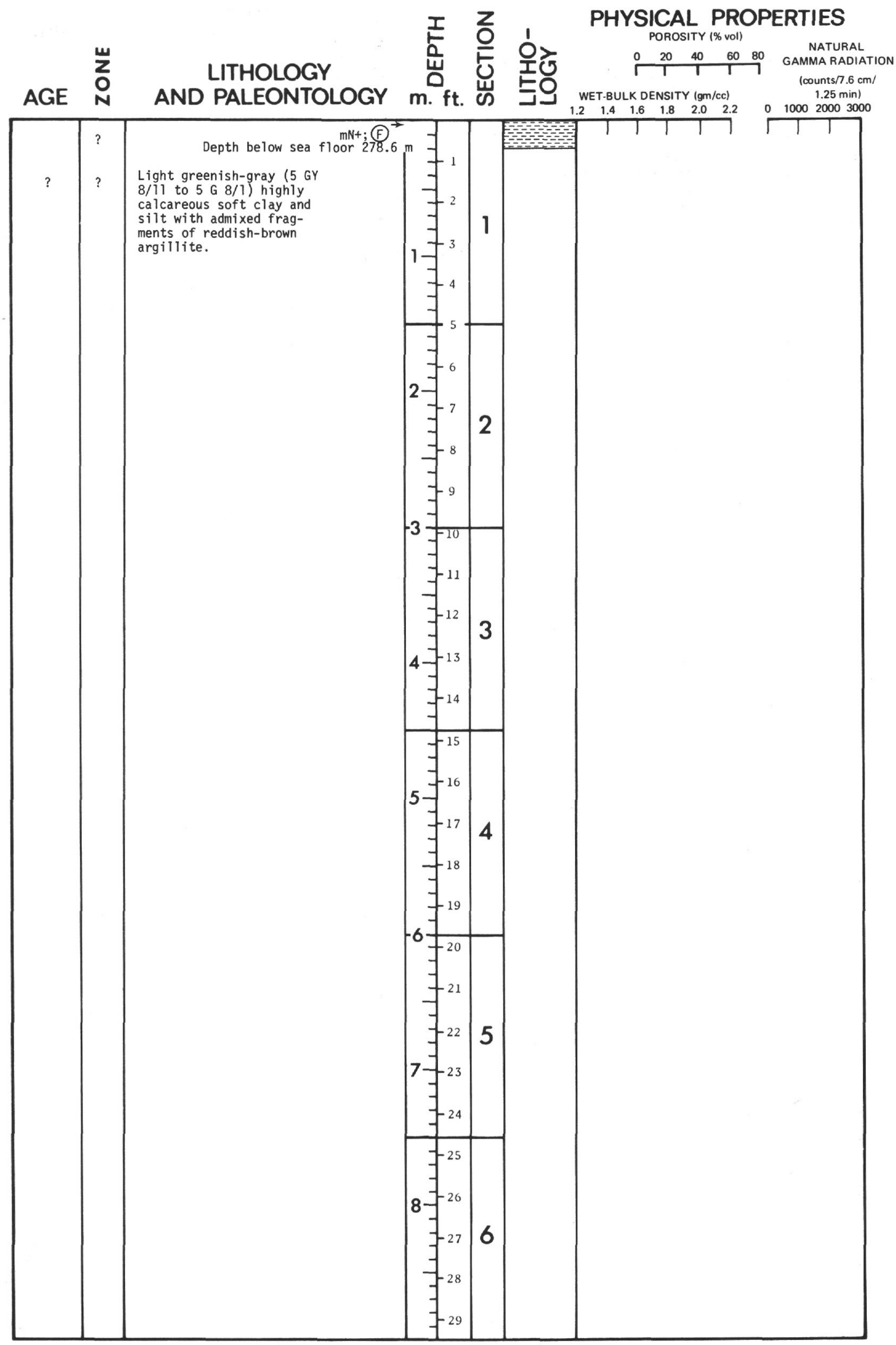

Figure 11. *Core 7, Hole 28.*

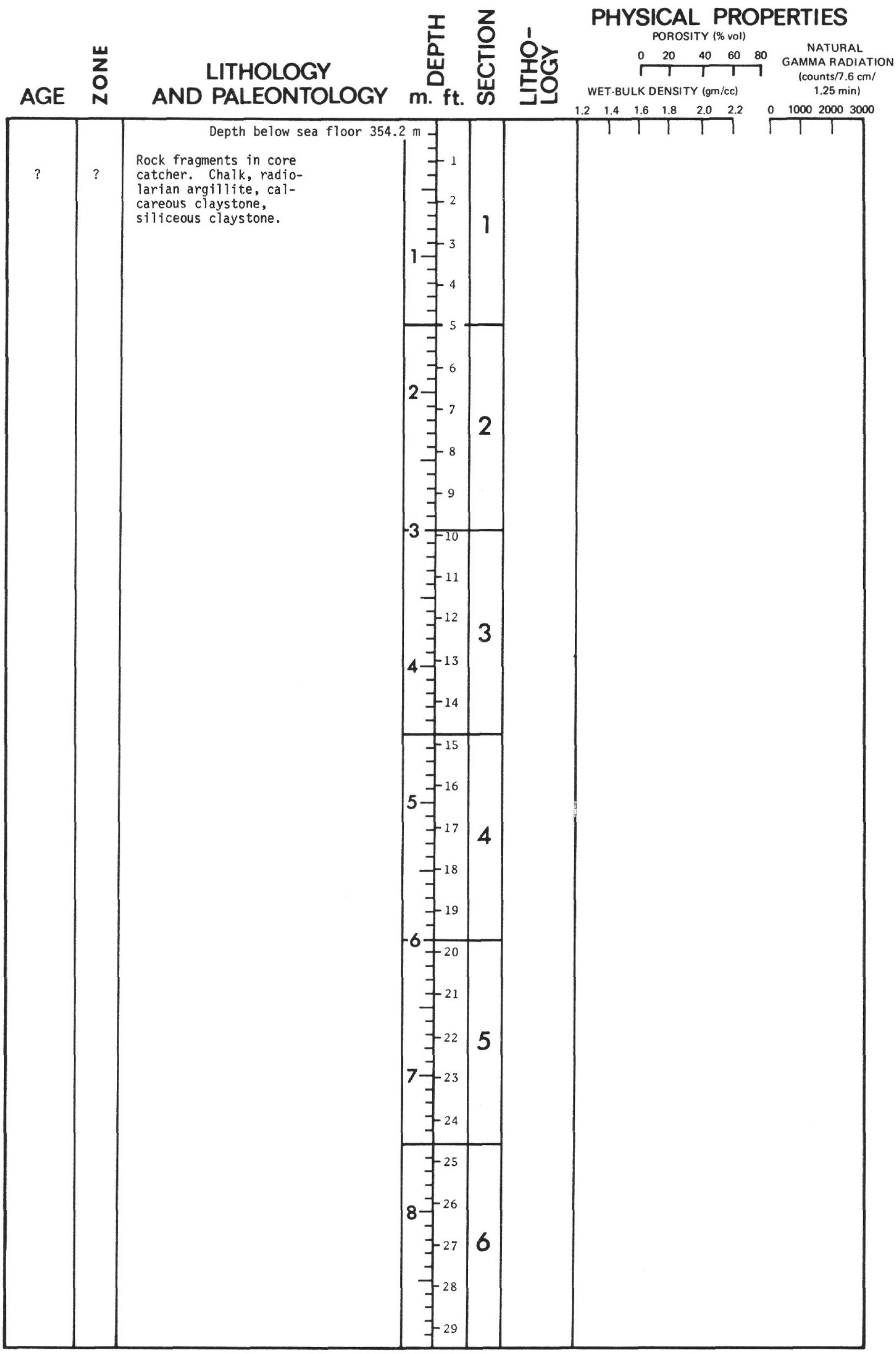

Figure 12. *Core 8, Hole 28.*

AGE	ZONE	LITHOLOGY AND PALEONTOLOGY	DEPTH m. ft.	SECTION	LITHO-LOGY	PHYSICAL PROPERTIES: POROSITY (% vol) 0 20 40 60 80; WET-BULK DENSITY (gm/cc) 1.2 1.4 1.6 1.8 2.0 2.2; NATURAL GAMMA RADIATION (counts/7.6 cm/1.25 min) 0 1000 2000 3000
? LATE CRETACEOUS ?	?	mR+;xN-;F Depth below sea floor 404.2 m Greenish-gray clay (5 G 5/2) to 10 G 6/2) non-calcareous silty clay. Some chert fragments. Approximately 20% of fragments are hard black shale, rich in organic carbon.	m: 1, 2, 3, 4, 5, 6, 7, 8 ft: 1–29	1, 2, 3, 4, 5, 6		

Figure 13. *Core 9, Hole 28.*