11. SITE 53

Shipboard Scientific Party[1]

SITE DATA

Occupied: July 13-16, 1969.

Position: Sediment apron on flank of Iwo Jima Ridge:
Latitude: 18° 02.0'N.
Longitude: 141° 11.5'E.

Water Depth: 4629 meters.

Hole 53.0: Eight cores.

Hole 53.1: Three cores.

Hole 53.2: One core.

Total Depth: 201 meters in Oligocene or Lower Miocene basalt and limestone.

MAIN RESULTS

A sequence of Miocene pumice ash beds of mixed andesitic and basaltic composition laps onto an Oligo-Miocene volcanic complex of basalt flows and interbedded baked pink and brown limestones of pelagic origin.

The history of basaltic lava flows, followed by Miocene explosive vulcanism, is similar to that recorded in Guam (Tracey, 1964) except that some sediments and volcanics there extend back to the Eocene. These findings suggest that the crust of the eastern Philippine Sea may have originated in Tertiary time, long after the crust of the adjacent western Pacific which is at least as old as Early Cretaceous.

BACKGROUND

The Mariana Trench and the associated island arc separate the Philippine Sea from the Pacific Ocean. The Philippine Sea consists of a number of subsidiary basins separated by ridges, trending mainly north-south (Figures 1, 2). From east to west are recognized (1) the Mariana Ridge proper, with its many emergent islands; (2) the Iwo Jima Ridge (Hess 1949) (also known as West Mariana Ridge by Karig (in press); and South Honshu Ridge by Menard, 1964). Farther west lies a less well-defined ridge which is the northward extension of the Yap Arc. Still farther west lies the well defined Palau Ridge, forming the eastern boundary of the western Philippine Sea (Chapter 20, Figure 1).

The general crustal structure as revealed by refraction seismology is discussed by Murauchi *et al.* (1968). The structure of the Philippine Sea is in general much like that of the Pacific: The Mohorovicic discontinuity lies at depths of 10 to 16 kilometers. A layer 3 (6.4 to 7.2 km/sec) is generally 4 to 6 kilometers thick, but locally thinner. A layer 2 (4.0 to 6.0 km/sec) varies in thickness, but its base is generally 6 to 8 kilometers below sea level; it outcrops widely in the western Philippine Basin.

Almost all of the eastern and some of the western parts of the Philippine Basin are underlain by rocks showing velocities of 3 to 4 km/sec, and this layer is generally in excess of 1 kilometer thick. Much of the rough topography of the basin, including the ridges proper, is developed in this material, which was interpreted as volcanic by Murauchi *et al.*

The sedimentary cover in the Philippine Sea is normally less than 100 meters thick; exceptions to this are found on the western side of the Iwo Jima Ridge, and locally in the western side of the Parece Vela Ridge, as well as in close proximity to the Philippines. This lack of sedimentary cover left most of the Philippine Sea hazardous for the drilling techniques available.

Two theoretical approaches could be taken to the origin of the Philippine Sea. On the one hand, it may have been a part of the Pacific Ocean cut off from the rest by the development of the island arc system, in the Eocene or earlier. In this case, the floor of the Philippine Sea must be of Mesozoic or greater age, and a time gap at the trenches, between the age of the Pacific floor to the east and the older Philippine Sea floor to the west, should be a clue to the amount of crust swallowed in the trench.

The alternative view is that the floor of the Philippine Sea developed independently of the Pacific, either by accretion at some now vanished ridge, or by some other process, perhaps by the oceanization of a former continental area as proposed by Belousov (1969) for the Sea of Japan. In this case, the floor of the Philippine Sea could be younger, perhaps much younger, than that of the adjacent parts of the Pacific.

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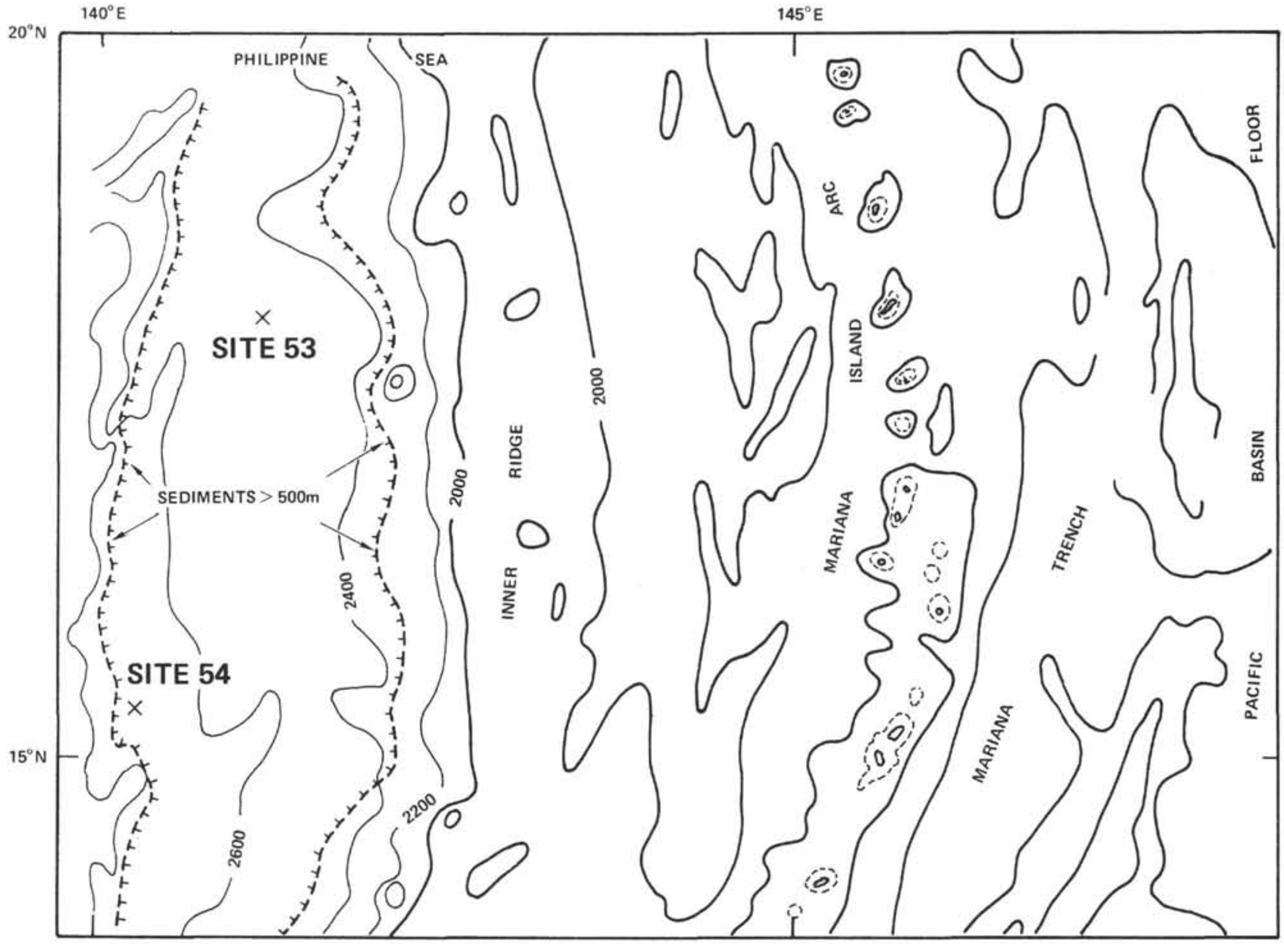

Figure 1. *Bathymetric contour map at Sites 53 and 54.*

In any case, the Philippine Sea clearly had a history somewhat different from that of the adjacent Pacific, as expressed in (1) the 3.0 to 4.0 km/sec layer thickly and widely developed in it, and (2) the rough topography, largely associated with this layer.

Intimately associated with this problem is the origin and history of the intervening island arcs; further, the relationship which ancient geosynclines and the associated sedimentary basins bear to modern island arc settings. Drilling in the Philippine Sea was, therefore, an important program.

The *Challenger* bathymetric and magnetic profile at Site 53 is given as Figure 3.

Objectives

The specific objectives of drilling in the Philippine Sea were to determine the age of the crust, and stratigraphy of the sediment and the history revealed thereby.

Strategy

The general lack of sediment, but existence of some sedimentary belts more than 100 meters thick, had been brought out by the Lamont-Doherty seismic reflection profiles from the area (Ewing *et al.*, 1968). The earlier work was supplemented by a site survey carried out by D. E. Karig on the *Argo*, and transmitted to the scientists by voice and facsimile (Figure 4). The basin between the Mariana and Iwo Jima Ridges was found to be mainly bare of sediment, but a notable apron of sediments against the flanks of basements highs, the basin floors and the underlying stratification show more relief than is typical of true abyssal plains and sites of turbidity current sedimentation.

Bottom soundings around Site 53 are given as Figure 5.

OPERATIONS

The beacon was dropped at Site 53 at 1100 hours on July 13. The hole was spudded at 1930 hours and carried to 99 meters in order to bury the bottom hole

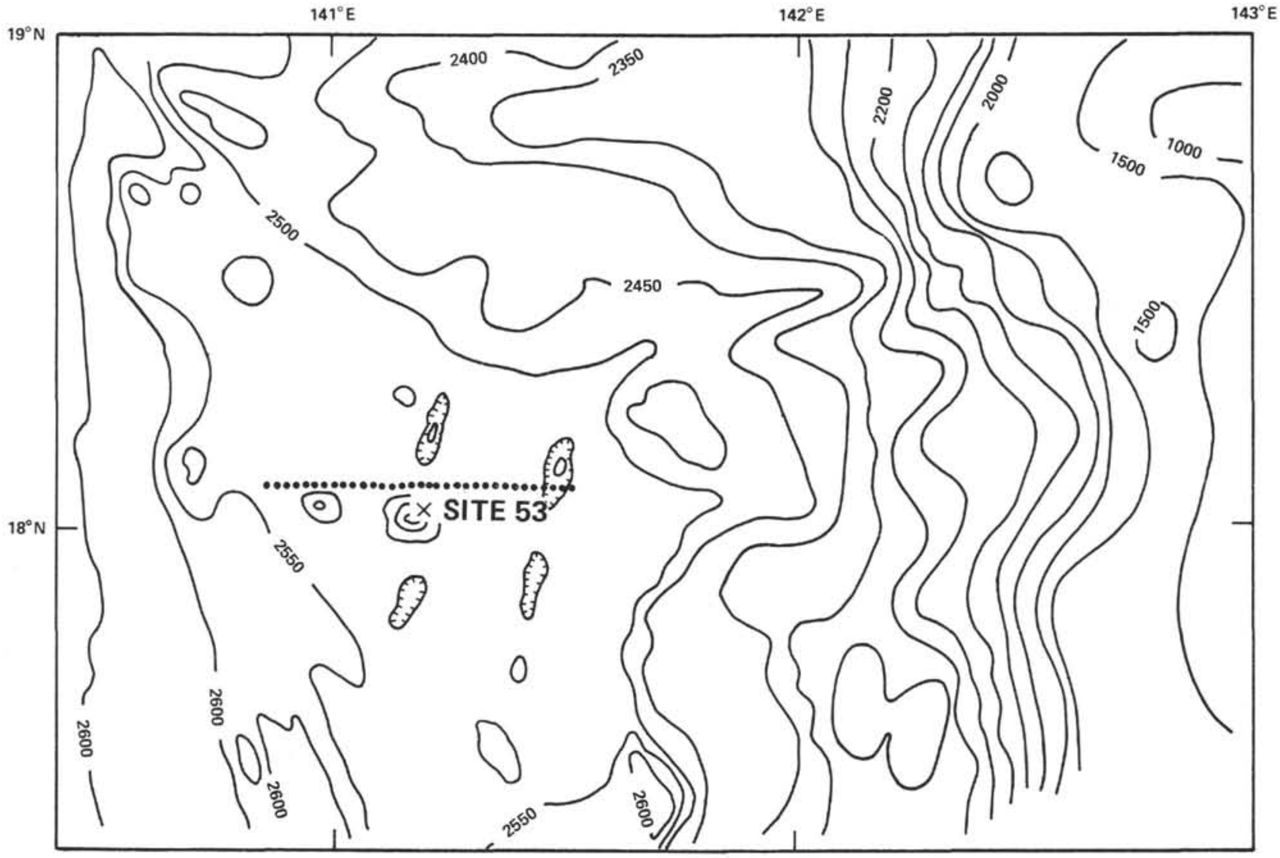

Figure 2. *Bathymetric contour map at Site 53.*

assembly. Drilling was soft despite the reflective nature of the acoustic profiles. Four cores were taken in a Miocene volcanic ash sequence, before hard drilling was encountered in the last four cores to a total depth in interbedded flows, pyroclastics and baked limestones at 201 meters subbottom, at which depth the bit ceased to penetrate further. Liners collapsed in Cores 1 and 3.

The open hole was then logged (electric logs, gamma ray log, neutron log, caliper log, and acoustic velocity log).

Tools were retrieved to mudline and Hole 53.1 was drilled for 3 cores, in the upper section. Tools were again brought to mudline for an additional core (Hole 53.2).

The light diamond bit was retrieved essentially intact, a surprise in view of the slow drilling rate on the deepest core.

The site was abandoned at 1730 hours on July 16.

NATURE OF THE SEDIMENTS

Twelve cores were recovered at this site in three holes (53.0, 53.1, and 53.2) between mudline and 200 meters subbottom depth. Cores from all three holes are described together because in composite they allow recognition of five general lithologic units, as follows:

Unit	Lithology	Estimated Thickness
A	Yellow brown clay and zeolitic clay	13 meters
B	Brown to gray silty radiolarian ooze with volcanic glass	8 meters
C	Gray to gray brown volcanic ash	approximately 153 meters
D	Red to brown chalk ooze and nannoplankton chalk ooze, apparently interlayered with lithified limestone	approximately 21 meters
E	Volcanic rocks interbedded with limestone	unknown

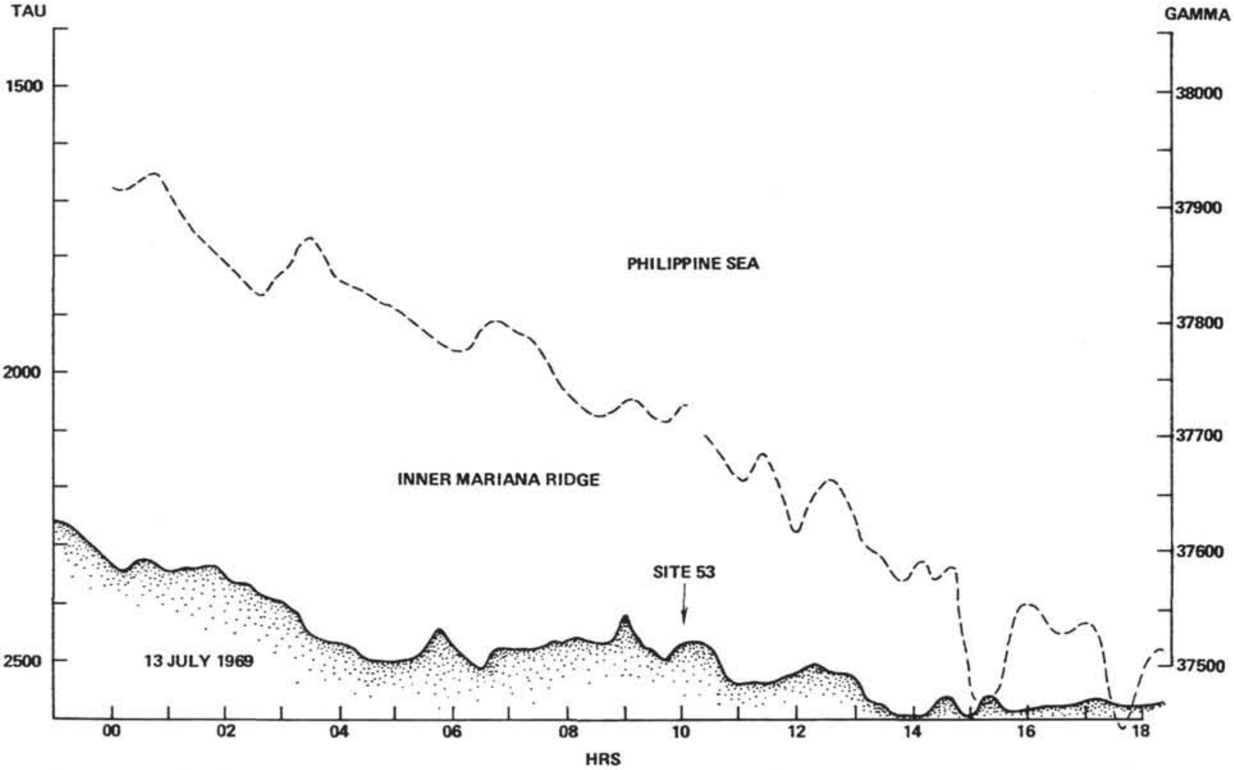

Figure 3. Challenger *bathymetric and magnetic profile at Site 53.*

Unit A extends from mudline to a depth of about 13 meters (Core 1, 53.1; upper 130 centimeters of Core 1, 53.2). It consists of dark yellow-brown zeolitic clay containing abundant clay minerals, zeolites, and limonitic grains, and generally lesser amounts of quartz, feldspar, and volcanic glass. Zeolites tend to become less abundant toward the base of the unit, while the amount of volcanic glass tends to increase.

Unit B, which is transitional in color and composition between units A and C, lies between 13 and 21 meters subbottom depth (lower 8 meters of Core 1, 53.2). The sediment is brown to gray-brown silty radiolarian ooze with abundant clay minerals, well-preserved radiolarian tests, and volcanic glass, rare to abundant sponge spicules, and variable amounts of quartz, plagioclase and mica. Nannofossils and zeolites are occasionally present in very small amounts. Within this unit are scattered pebbles of pumice and several layers of sandy volcanic ash with up to 75 per cent clear glass shards.

Unit C is gray to gray-brown volcanic ash, in layers that are decimeters thick, and lies between 21 and 174 meters below mudline (Cores 2 and 3, 53.1; Cores 1 to 4, 53.0), although this interval was not continuously cored. Most of this ash is firm and coherent, and some layers in the upper part appear to be moderately lithified. The ash is predominantly in the sand and silt size range, but there are scattered layers of clayey and pebbly ash. Grain size in general appears to decrease downward in the unit; pumice pebbles are common near the top, less abundant lower. Compositionally, volcanic glass dominates, clay minerals, quartz, plagioclase, amphiboles, and opaque minerals are common, and calcareous nannofossils and Radiolaria are usually rare to absent. Nannofossils are most common in the upper part of the unit (Cores 2 and 3, 53.1) where in places they form up to 25 per cent of some calcareous ash layers. Radiolaria are likewise most common near the top of the unit and decrease downward.

The glass in the volcanic ash of Unit C is chiefly colorless, unaltered vesicular glass, commonly in the form of elongate shards with tubular vesicles. Measurements of the refractive index of glass in the catcher sample of Core 1, 53.0 (depth of 92 meters) have n = 1.520, indicating an andesitic composition (62 per cent SiO_2, d = 2.80). In addition to this colorless glass, smaller amounts of pale brown, unaltered glass and varying amounts of apparently altered and devitrified glass are also present. The latter consists of sand to silt size grains of fine-grained, very weakly birefringent material that appears to be a mixture of clay minerals, microcrystalline quartz, and opaque iron oxides. The proportion of altered glass seems to increase downward in Unit C, and most of the grains in the basal part appear

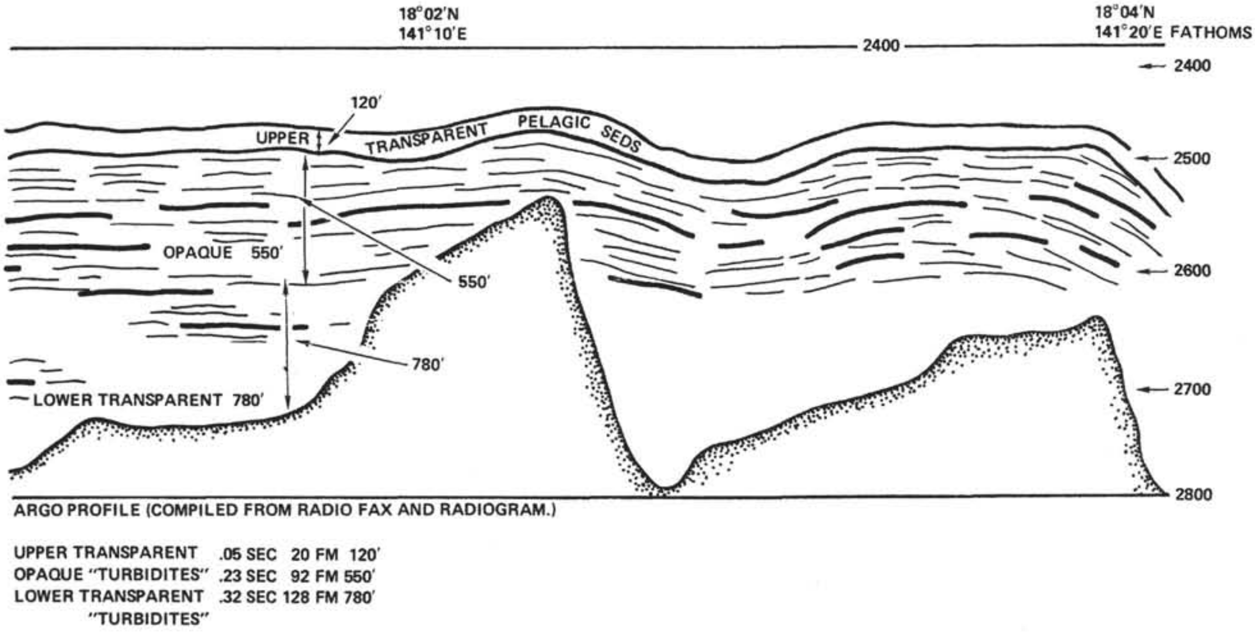

Figure 4. *Sketch of* Argo *profile at Site 53.*

to be of this type, as seen in Core 4, 53.0. Core 4, 53.0, also records a color change from the predominantly gray colors above to shades of red, brown and green; in addition, it has thinner bedding, on the centimeter rather than the decimeter scale.

Unit D is poorly defined at this site due to a lack of recovery. It appears to consist of interlayered soft chalk ooze, slightly lithified brown marl, friable white limestone, and hard red limestone, possible with thin interlayers of lithified volcanic tuff. These types of materials were recovered sporadically, mainly as core catcher and center bit samples, between 174 and 195 meters below mudline (core catcher sample of Core 4, center bit sample between Cores 4 and 5, catcher sample of Core 5, Core 6; all from Hole 53.0).

At the top of Unit D (catcher sample, Core 4, 53.0) the sediment is unlithified but firm, reddish brown nannoplankton chalk ooze consisting of approximately equal amounts of clay minerals, nannofossils, and small anhedral calcite grains. Lower in the unit (Core 5 and 6, 53.0) the proportion of recognizable nannofossils decreases to 5 per cent or less, while anhedral calcite grains become the dominant constituent. This anhedral calcite is very fine-grained (Chapter 38), most of it being in the 2 to 5 micron size range, with occasional larger crystals up to 15 microns across. Nannofossils, particularly discoasters, commonly show peripheral overgrowths of secondary calcite and other forms of alteration (Chapter 38). The possibility exists that what appeared in the cores as soft chalk ooze may have been produced during coring through disintegration of the lithified marls and oozes described below.

Lithified carbonates are first present in small amounts as angular fragments in the catcher samples for Cores 4 and 5, and in the center bit sample between Cores 4 and 5. They become more abundant in Cores 5 and 6, and three main types are present:

(1) Small pieces of friable white limestone that are about 30 per cent nannofossils, 60 per cent fine-grained anhedral calcite.

(2) Rounded pieces, up to 10 centimeters across, of punky brown nannoplankton marl that is heavily burrowed and slightly cemented. Clay minerals form about half of this material, and nannofossils and anhedral calcite are present in approximately equal amounts.

(3) Hard pale red to brown to yellowish-brown limestone with veins of white sparry calcite (see Chapter 38). Most of this limestone is a breccia, with angular and irregular clasts of limestone cemented by fine-grained pinkish limestone; in some cases the clasts are partially or completely rimmed by white sparry calcite, with the remainder of inter-clast space filled by pinkish limestone. Some veins are entirely sparry calcite-filled, others are composite and have alternating bands of sparry calcite and fine-grained pinkish limestone, the latter representing internal resedimentation of carbonate ooze. Both the breccias and veins appear to have been generated by fracturing of lithified limestone, followed by precipitation of sparry calcite and infiltration of carbonate sediment into open spaces. In thin

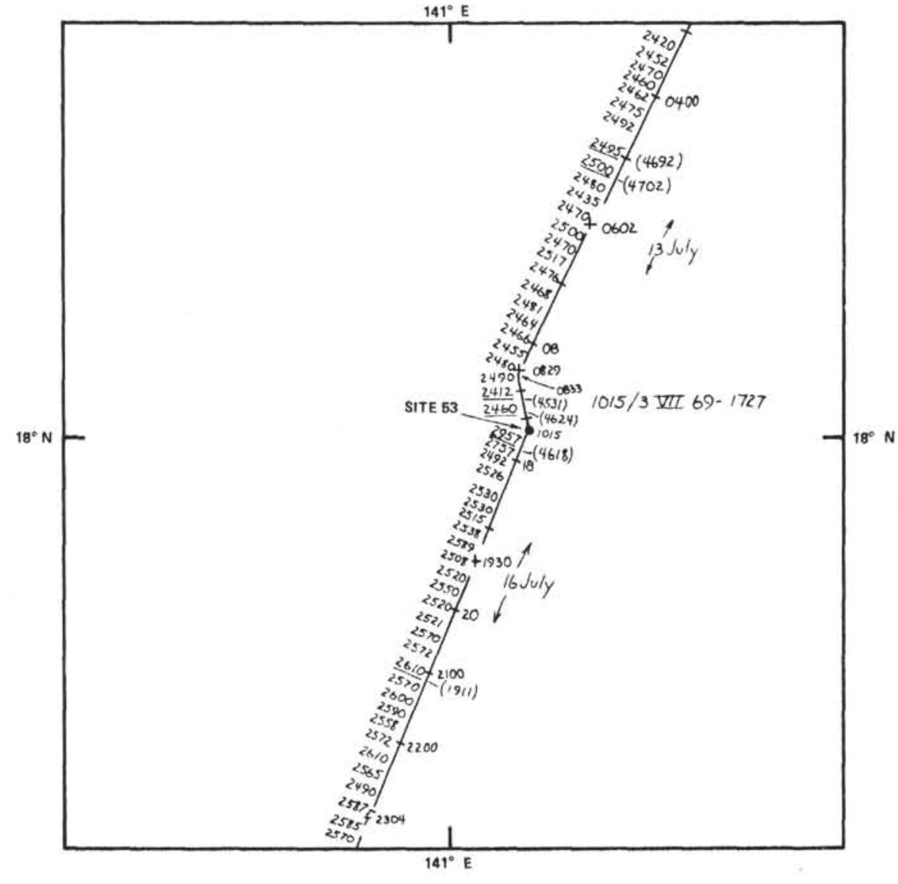

Figure 5. *Bottom soundings in area of Site 53.*

section the limestone consists of a matrix of fine anhedral calcite and argillaceous matter in which are embedded scattered aggregates of sparry calcite that are probably highly altered microfossils. Also present are scattered grains of feldspar, chlorite, devitrified volcanic glass, and reddish brown iron oxides that occur as discrete aggregations and as coatings around other grains, particularly remnants of fossils. The internally resedimented pinkish limestone is likewise very fine-grained, but is very even grained and lacks remains of microfossils or other types of grains. Both types of limestone appear to have been thoroughly recrystallized.

The only significant continuous recovery from Unit D is in Core 6, 53.0. This contains about 150 centimeters of: (1) hard, pale red limestone like that described above, and (2) alternating friable limestone and unlithified chalk ooze, which may be in part or wholly a "drilling breccia".

In addition to the carbonate rocks and sediments in Unit D, the center bit sample between Cores 4 and 5 contained small pieces of varicolored lithified tuff, but these may be cavings from Unit C above. The catcher sample for Core 5 contained larger chunks, up to 3 centimeters across, of hard, dark brown lithified tuff that appears more likely to be a part of Unit D, perhaps as thin interlayers.

Unit E, encountered in Cores 7 and 8 of Hole 53.0 at subbottom depths between 196 and 200 meters, is also poorly defined, but seems to consist of interbedded dark volcanic rocks and pale red to brown limestone. A variety of volcanic rocks are present. Some seem to be altered amygdaloidal flow rocks of basaltic or andesitic composition. These have a variolitic texture with spherulite-like masses of acicular plagioclase laths and reddish-brown iron oxide aggregations in a fine-grained and highly altered matrix of weakly birefringent clay minerals, iron oxides and possibly chlorophaeite or a chloritic (?) material. Other volcanic rocks are clearly fragmental tuffs and tuff breccias. Refractive index measurements of unaltered glass in one of these tuffs (from the catcher sample, Core 7) gave n = 1.56 to 1.57, indicating an andesitic composition. R. I. measurements of plagioclase in the same tuff gave values of 1.565 (labradorite) and 1.55 (andesine). The original

TABLE 1
Summary of Coring at Site 53

Core No.	Interval Cored (below mudline) (ft)	(m)	Recovery (ft)	(m)
53.0-1	326-341	99.4-103.9	15	4.6
53.0-2	341-371	103.9-113.1	5	1.5
53.0-3	448-463	136.6-141.1	5	1.5
53.0-4	541-571	164.9-174.0	6	1.8
53.0-5	633-638	192.9-194.5	1	0.3
53.0-6	638-641	194.5-195.4	3	0.9
53.0-7	641-646	195.4-196.9	3	0.9
53.0-8	646-658	196.9-200.6	2	0.6
53.1-1	0-30	0.0-9.1	30	9.6
53.1-2	71-101	21.6-30.8	28	8.5
53.1-3	175-205	53.3-62.5	25	7.6
53.2-1	41-71	12.5-21.6	30	9.1

Water depth: 4629.3 meters (15,188 feet)

character of other specimens is indeterminate pending more detail study; among these is a highly altered, chloritic "greenstone".

Limestones in Unit E are similar to those in Unit D. They are chiefly light brown to pale red, fine-grained, hard, and appear to be recrystallized. They contain numerous veins of sparry calcite, as well as small aggregations of sparry calcite that resemble highly altered microfossils (Chapter 38). Some veins are composite, containing zeolites (harmotome) and other minerals as well as sparry calcite (Chapter 38). Like Unit D, most of these limestones are breccias consisting of angular limestone clasts cemented in places by fine-grained limestone, in other places by sparry calcite composite.

Relations between limestones and volcanic rocks are illustrated by a number of specimens from Cores 7 and 8. The limestone breccias mentioned above also contain a few large clasts of altered volcanic rock; in addition some specimens have limestone clasts that in turn contain angular clasts of altered volcanic rock (i.e. a fragment of a breccia within a breccia). In some specimens thin layers of limestone are sandwiched between volcanic layers; in one instance of this kind the top of a limestone layer is irregularly eroded by a tuff breccia. One specimen has a limestone-filled vein within volcanic rock, and this vein can be traced to its probable source in an interlayered limestone band. In another specimen, limestone is cut by a sparry calcite vein that contains an angular chunk of altered volcanic rock.

Interpretation of Units D and E: The intimate association of limestone and volcanic rocks in Unit E seems best interpreted as the result of alternating episodes of submarine volcanism and volcanic quiescence, with carbonate sediments accumulating, probably as nannoplankton chalk ooze, during the latter intervals. Such carbonate layers would tend to be disrupted, locally intruded and eroded, and perhaps lithified and recrystallized during igneous activity subsequent to their deposition.

Less clear is the origin of the oozes and limestones with abundant anhedral calcite in Unit D. These first appear at 174 meters below mudline, some 22 meters above the first volcanic rock encountered. Two origins seem possible for the fine-grained, anhedral calcite in these materials: (1) inorganic precipitation, to which a small amount of nannoplankton were added by normal depositional processes, or (2) recrystallization of an original nannoplankton chalk ooze, either due to low temperature diagenetic reactions or to thermal metamorphism associated with igneous activity. Evidence favoring the latter alternative is more fully discussed in Chapter 38. And it should be noted at this point that since thermal metamorphism appears likely here, the possibility exists that dikes or localized sills may intrude Unit D in areas immediately adjacent to Site 53, or that the basaltic rocks of Unit E may have been a shallow intrusive body (rather than a flow on the sea floor) that thermally metamorphosed early Oligocene chalk oozes.

PHYSICAL PROPERTIES

These cores were slightly disturbed during coring operations, therefore, the physical property measurements do not accurately represent *in situ* conditions.

Natural Gamma Radiation

Holes 53.0, 53.1, and 53.2

Natural gamma radiation emitted from the Miocene-Oligocene (?) brown clays, siliceous oozes, and ash retrieved at Site 53 (0 to 197 meters), ranged from 100 to 900 counts/7.6 cm core segment/1.25 minutes. The differing lithologies of the Miocene red zeolite clay, radiolarian silt, volcanic ash and chalk oozes had typical counts of 500 counts/7.6-cm core segment/1.25 minutes. The highest count of 900 was emitted from Miocene volcanic sand in Core 53.0/1. The lowest emissions, averaging about 200, were from the Oligocene limestones and volcanic rocks recovered in Cores 53.0/6, 7, and 8 at depths within 195 to 197 meters. The general good condition of the cores indicated that these radiation counts were probably representative of *in situ* conditions with a few exceptions. See the well log taken at this site (Appendix IV).

It was interesting to note that the radiation did not increase with depth as the porosity decreased in the upper 100 meters. This suggests at least two possibilities. First, the siliceous oozes and brown clays may have emitted higher radiation per weight of solid material, but the total radiation was reduced by high porosities so that it was equivalent to the radiation emitted from the volcanic ash and ooze which had lower porosities. Secondly, it may also be possible that the source was in the interstitial water as the relative percentage change of its volume was much less than the relative percentage change of the matrix minerals.

Porosity, Wet-Bulk Density, and Water Content

Holes 53.0, 53.1, and 53.2

Miocene-Oligocene (?) brown clay, siliceous ooze, ash, and hard tuff cored at Site 53 had porosities, wet-bulk densities, and water contents ranging from 10 to 85 per cent, 1.20 to 2.28 g/cc, and 20 to 73 per cent, respectively, averaging about 67 per cent, 1.49 g/cc, and 45 per cent. Porosities decreased from 80 per cent to about 60 per cent with increasing depth from 0 to 100 meters. As the sediment was cored without plastic liners below this depth, GRAPE porosities could not be measured. The 10 per cent minimum porosity occurred in lithified volcanic tuff at depths of 197 meters. Of course, the wet-bulk densities irregularly increased with increasing depth being directly similar to sound velocity averages. These variations were in part related to increasing particle size with depth.

The lithologic variations at Site 53 were reflected by their porosities and wet-bulk densities. The Miocene "red" zeolite clay (Unit A: 0 to 13 meters) had distinctly higher porosities (68 to 84 per cent) and lower wet-bulk densities (1.24 to 1.44 g/cc) than the other lithologic units.

Miocene ashey radiolarian ooze with silty clay and radiolarian clayey silt with ash forms Unit B (13 to 21 meters). The silty clay had higher porosities of 79 per cent (1.25 g/cc) wet-bulk density and the radiolarian clayey silt had intermediate porosities of 68 per cent (1.42 g/cc). The ashey radiolarian ooze had porosities of about 65 per cent (1.50 g/cc), with many porosity highs depending on the ash content and coring disturbance.

Unit C (21 to 174 meters) was a Miocene-Oligocene volcanic ash with porosities ranging from 40 to 78 per cent with an average of 63 per cent, a wet-bulk density of 1.52 g/cc between 21 and 110 meters being typical. The wide range of values is attributed to pebbles in the sediment in addition to drilling deformation. Below 110 meters the GRAPE measurements were not taken in Unit C. But water content measurements decreased from 50 per cent at 102 meters to 42 per cent at 138 and 166 meters.

Unit D was Oligocene (?) chalk ooze which contained limestone cobbles (artificial?) and volcanic tuff fragments, which had porosities as low as 10 per cent measured by the GRAPE, (2.3 g/cc) wet-bulk density where the cobbles were present in the ooze. These are not true minimum porosities as the rocks occur in a matrix of calcareous ooze and the GRAPE measurement averages the porosity of all constituents.

A neutron well log was taken at this site, but as porosity measurements were made only down to 110 meters the log could not be calibrated below this depth. The neutron log was in API units of radiation and thus without proper log analysis absolute porosities of these deeper sediments could not be calculated with confidence.

Sound Velocity

Holes 53.0, 53.1, and 53.2

Miocene unlithified clays, siliceous ooze, and ashes cored at Site 53 had sound velocities ranging from 1.50 to 2.23 km/sec, which averaged 1.65 km/sec. Sound traveled through Miocene-Oligocene (?) limestone and tuff at a rate of 3.19 to 4.27 km/sec with an average of 3.62 km/sec. Sound velocity core averages increased from 1.55 to 1.95 km/sec from 0 to 90 meters. Velocity variations with depth were directly similar to the wet-bulk density depth variations, but higher velocities were a function of the coarser grain size distribution, low porosity, and increased the rigidity of the sediment.

The differing lithologies at the site appeared to have semicharacteristic sound velocity ranges or averages. Unit A, a Miocene brown zeolite clay (0 to 13 meters), had low velocities of 1.52 to 1.60 km/sec. Sound velocities through Unit B of radiolarian silt and ooze were 1.54 to 1.65 km/sec. Unit C, a Miocene volcanic ash (21 to 174 meters), had a wide velocity range of 1.50 to 2.23 km/sec with core averages from 1.57 to 1.93 km/sec.

Sound traveled through the lithified Oligocene (?) brown limestone (with white sparry calcite veins) in Unit D at 3.19 km/sec (53.0/6/1; 175 to 195 meters) and at 3.40 km/sec in the black tuff (7.5-centimeter fragment; 53.0/7/1). Sound velocities were 3.95 and 4.07 km/sec in the red limestone and green brecciated limestone, respectively, of a 13-centimeter core segment from 53.0-8-CC in Unit E (200 meters). A 2.5-centimeter core segment of black tuff from 53.0-8-CC (200 meters) had a velocity of 3.25 km/sec.

The sound velocity well logs were good but were taken below areas of coring in which sound velocities were measured and thus were not directly comparable to the laboratory values. However, well log sound velocities compare well to the overlying ash (Unit C) velocity of 1.5 to 2.2 km/sec. The well log velocities decreased from 2.2 to 1.5 km/sec at the bottom of the hole, averaging about 2.0 km/sec. The highest well log velocities, however, were about 2.9 km/sec.

Heat Conductivity

Holes 53.0, 53.1, and 53.2

Heat conductivity of unconsolidated Miocene-Oligocene (?) clays, radiolarian silt, and ashes cored at Site 53 (0 to 200 meters) ranged from 2.0 to 2.7×10^{-3} cal°C^{-1} cm^{-1} sec^{-1} averaging 2.26×10^{-3}. Conductivity variations were inversely similar to porosity and questionably similar to the penetrometer averages plotted against depth. A systematic variation did not seem to exist between the lithologies.

Penetrometer

Holes 53.0, 53.1, and 53.2

Penetrometer readings at Site 53 ranged from nil to complete penetration to the core liner. Miocene red clay and radiolarian silt from 0 to 21 meters has average penetrometer values of 90 and 110×10^{-1} millimeters. These values irregularly decrease with depth and at 200 meters they average 10×10^{-1} millimeters in Miocene-Oligocene (?) ash.

CONCLUSIONS

The sediment apron west of the West Mariana Ridge is a sequence of Miocene volcanic ashes, mainly pumice ash of andesitic composition, with an admixture of the most solution-resistant nannofossils (discoasters).

Restriction of thick sediments to one side of the Iwo Jima Ridge suggests that this feature was the source of the ash, and was volcanically active mainly during the Miocene.

The sediments are underlain by basaltic flows and pyroclastics with interbedded altered limestones, of Oligocene or Lower Miocene age. Velocity measurements on these rocks in the laboratory confirm the view that this represents the 3 to 4 km/sec layer of the refraction profiles in the Philippine Sea.

This (?) basement seems to correspond to the Eocene-Oligocene Alutom Formation, and the Lower Miocene Umatac Formation of Guam. These are the oldest rocks exposed on Guam, and are volcanic-sedimentary complexes some thousands of feet thick, with no base exposed. The Guam section was formed at shallower depths to judge from fossils in interbedded limestones.

The similarity of the sequence to that on Guam and the wide distribution of the 3 to 4 km/sec layer in the Philippine Sea, suggest that this volcanism was not a localized phenomena of the island arc, but was regionally widespread.

Still unsolved is the question whether the ultramafic basement presumably present beneath these volcanic complexes is ancient Pacific sea floor, or whether it also dates from Eocene-Oligocene time. If it is young, then the question arises as to its site and manner of emplacement.

Preservation of the early Miocene fossils, and the abundance of anhedral authigenic calcite in the early Miocene beds, suggests peculiar diagenetic conditions, perhaps a lingering touch of hydrothermal activity.

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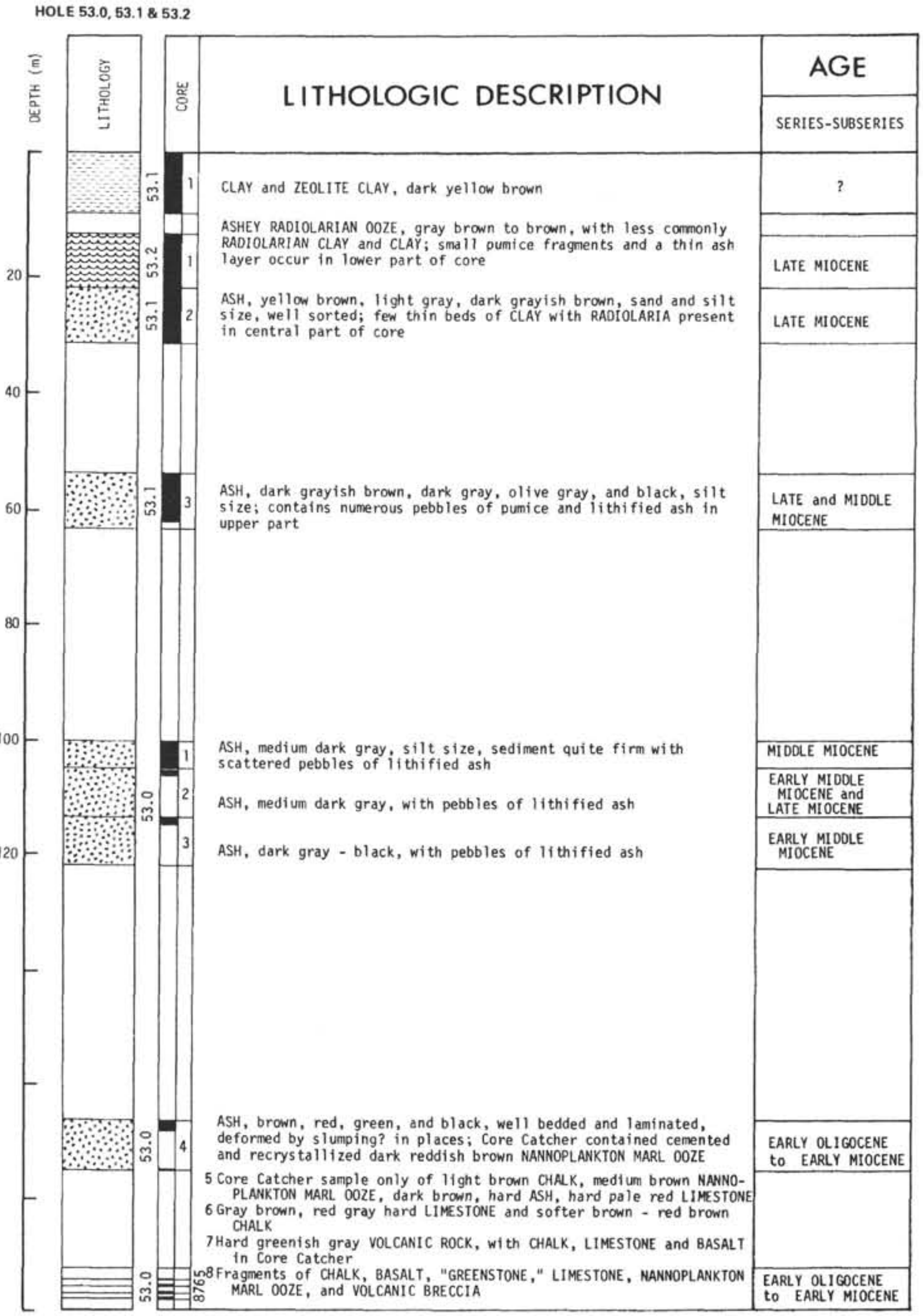


Figure 6. *Summary of lithology in Holes 53.0, 53.1 and 53.2.*

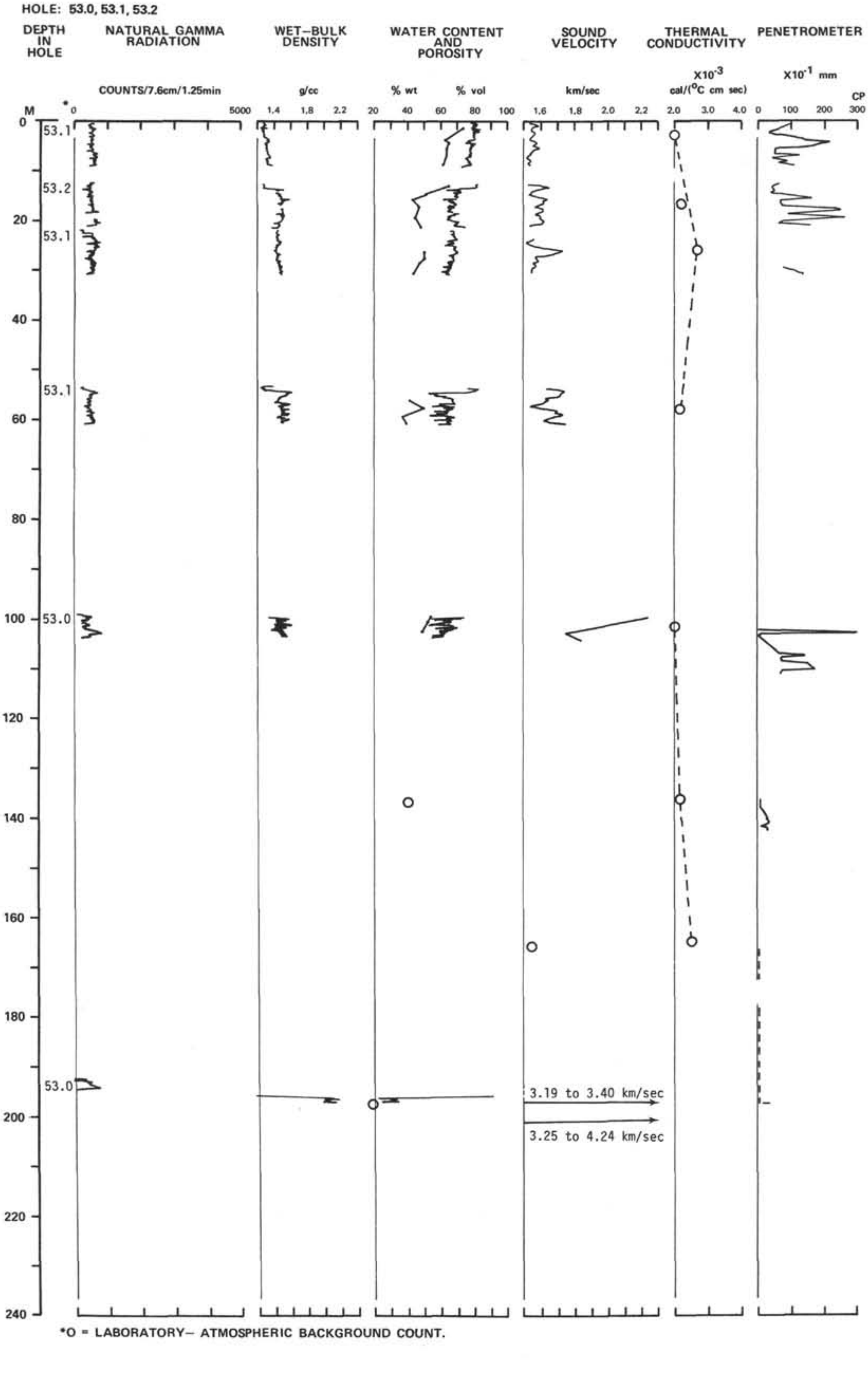


Figure 7. *Summary of physical properties in Holes 53.0, 53.1 and 53.2.*

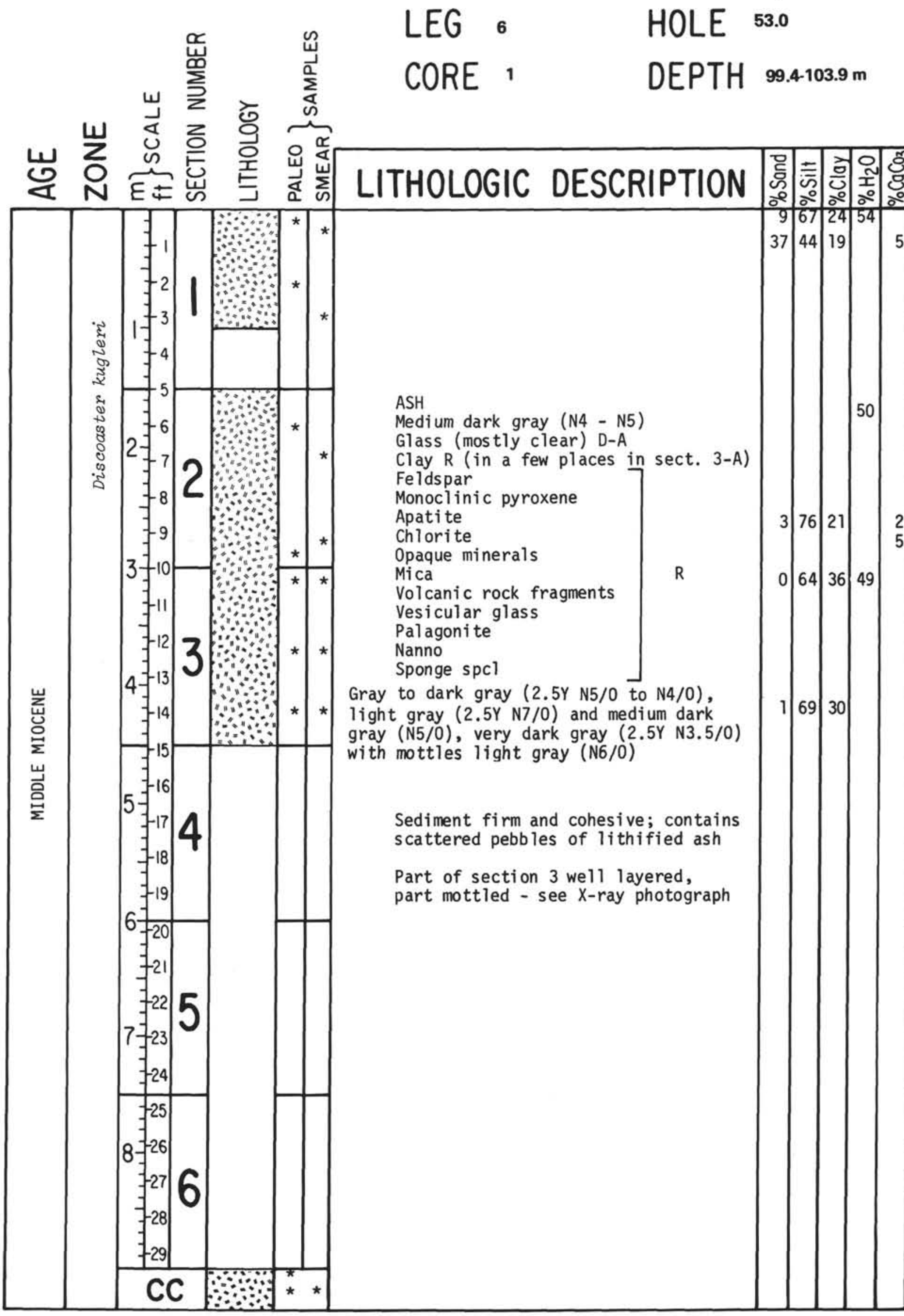


Figure 8. *Summary of lithology in Hole 53.0 Core 1.*

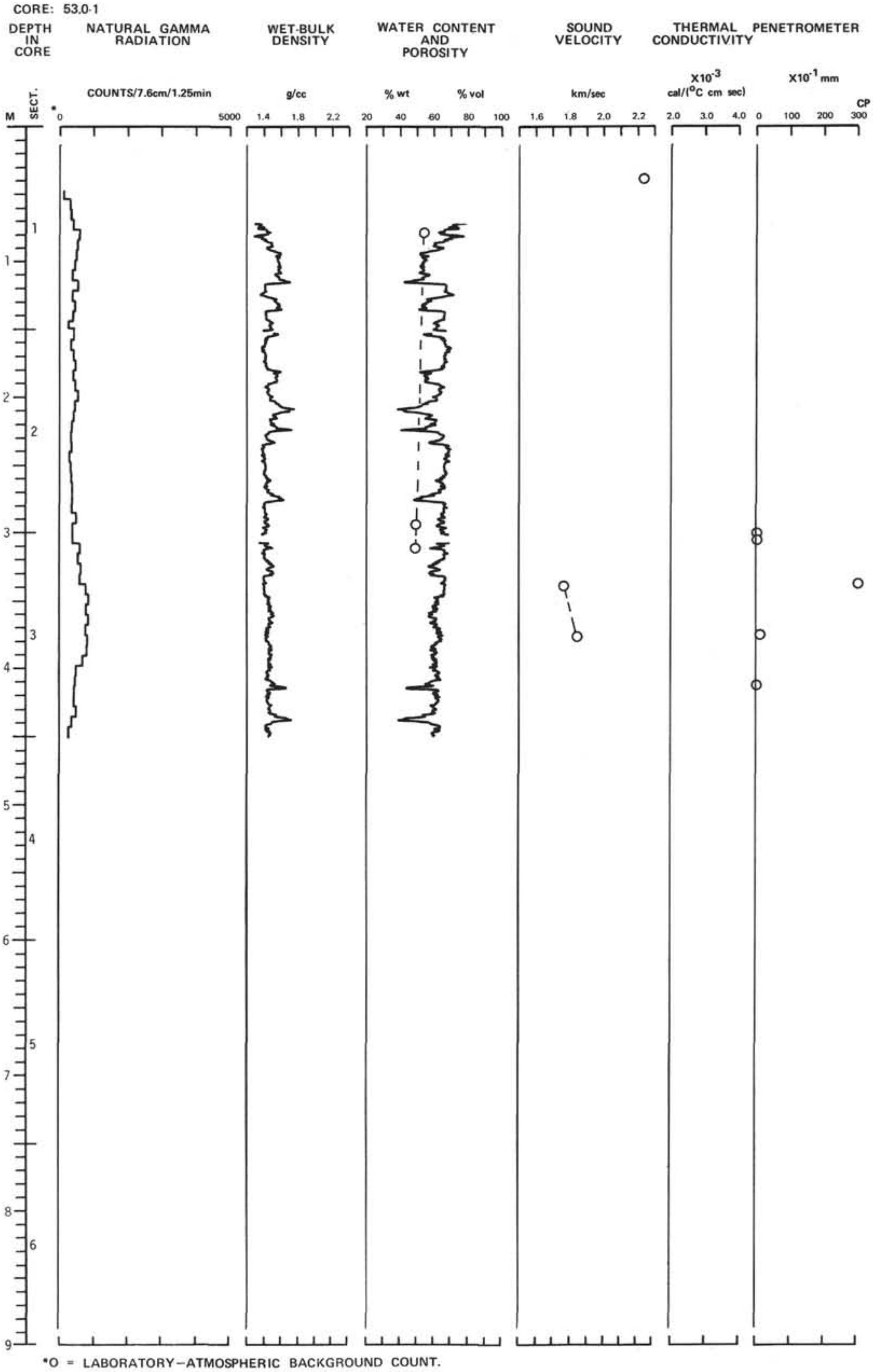


Figure 9. *Summary of physical properties in Hole 53.0 Core 1.*

LEG 6 HOLE 53.0

CORE 2 DEPTH 103.9-113.1 m

AGE	ZONE	SCALE (m / ft)	SECTION NUMBER	LITHOLOGY	SAMPLES: PALEO	SAMPLES: SMEAR	LITHOLOGIC DESCRIPTION	%Sand	%Silt	%Clay	%H_2O	%$CaCO_3$
EARLY MIDDLE MIOCENE	*Sphenolithus heteromorphus*	0–1.5 m / 0–5 ft	1		*	*	ASH Medium dark gray (N5/0) Glass D Clay C Nanno R Others (same as core 1) R	0	74	26		
		1.5–3 m / 5–10 ft	2				Pebble size fragments of lithified ash also occur					
		3–4.5 m / 10–15 ft	3									
		4.5–6 m / 15–20 ft	4									
		6–7.5 m / 20–25 ft	5									
		7.5–9 m / 25–30 ft	6									
			CC		* *	*						

Figure 10. *Summary of lithology in Hole 53.0 Core 2.*

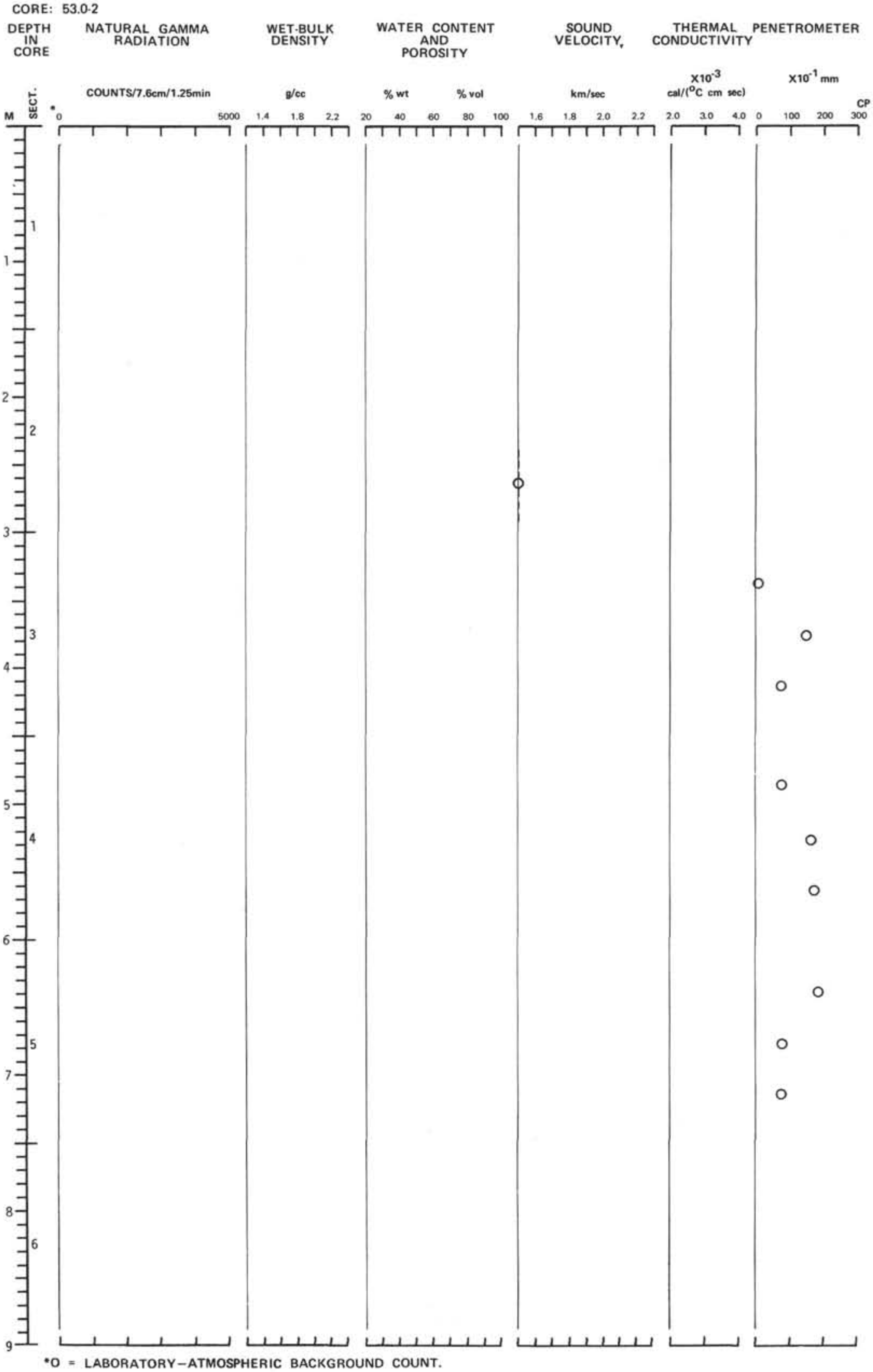


Figure 11. *Summary of physical properties in Hole 53.0 Core 2.*

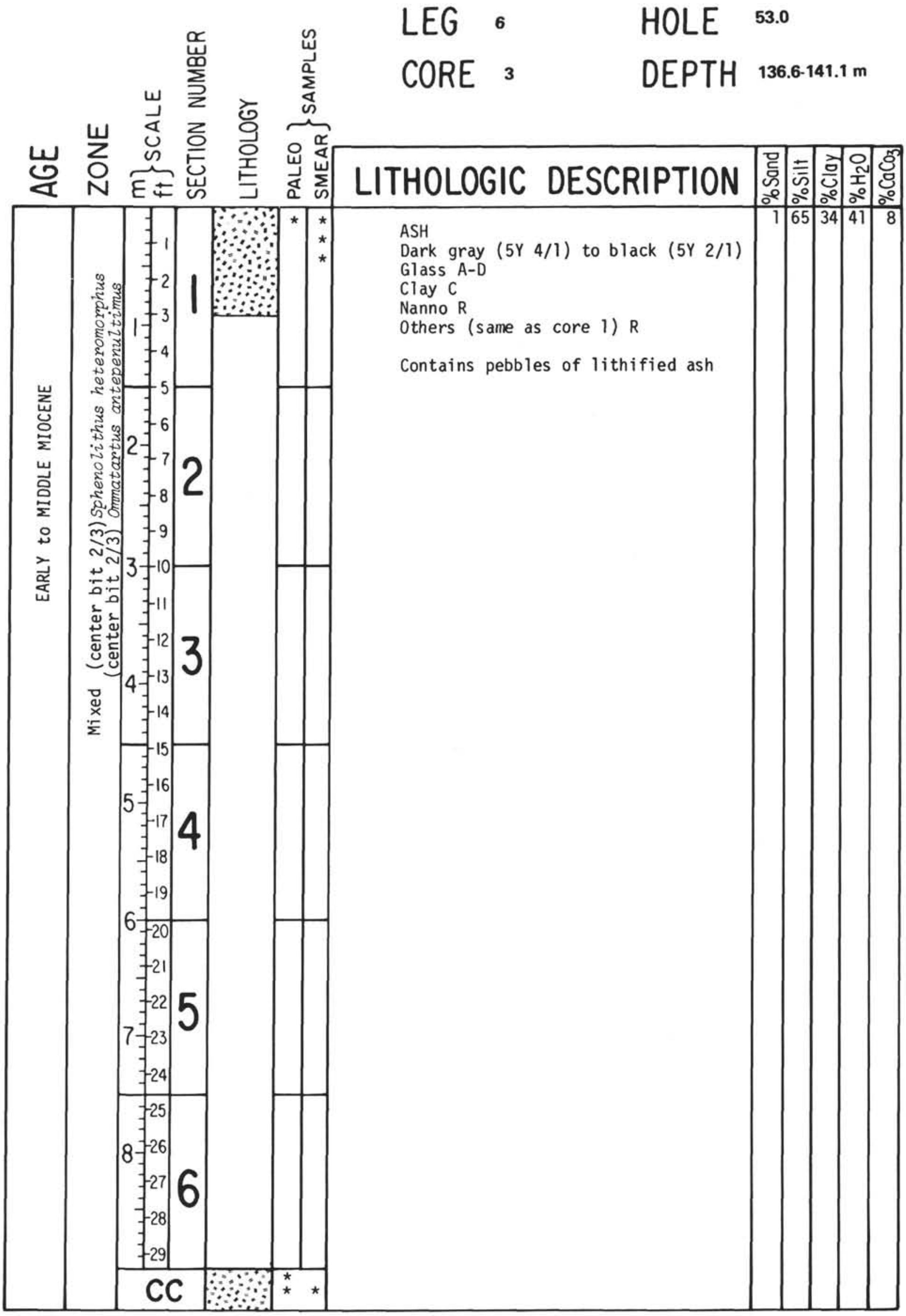


Figure 12. *Summary of lithology in Hole 53.0 Core 3.*

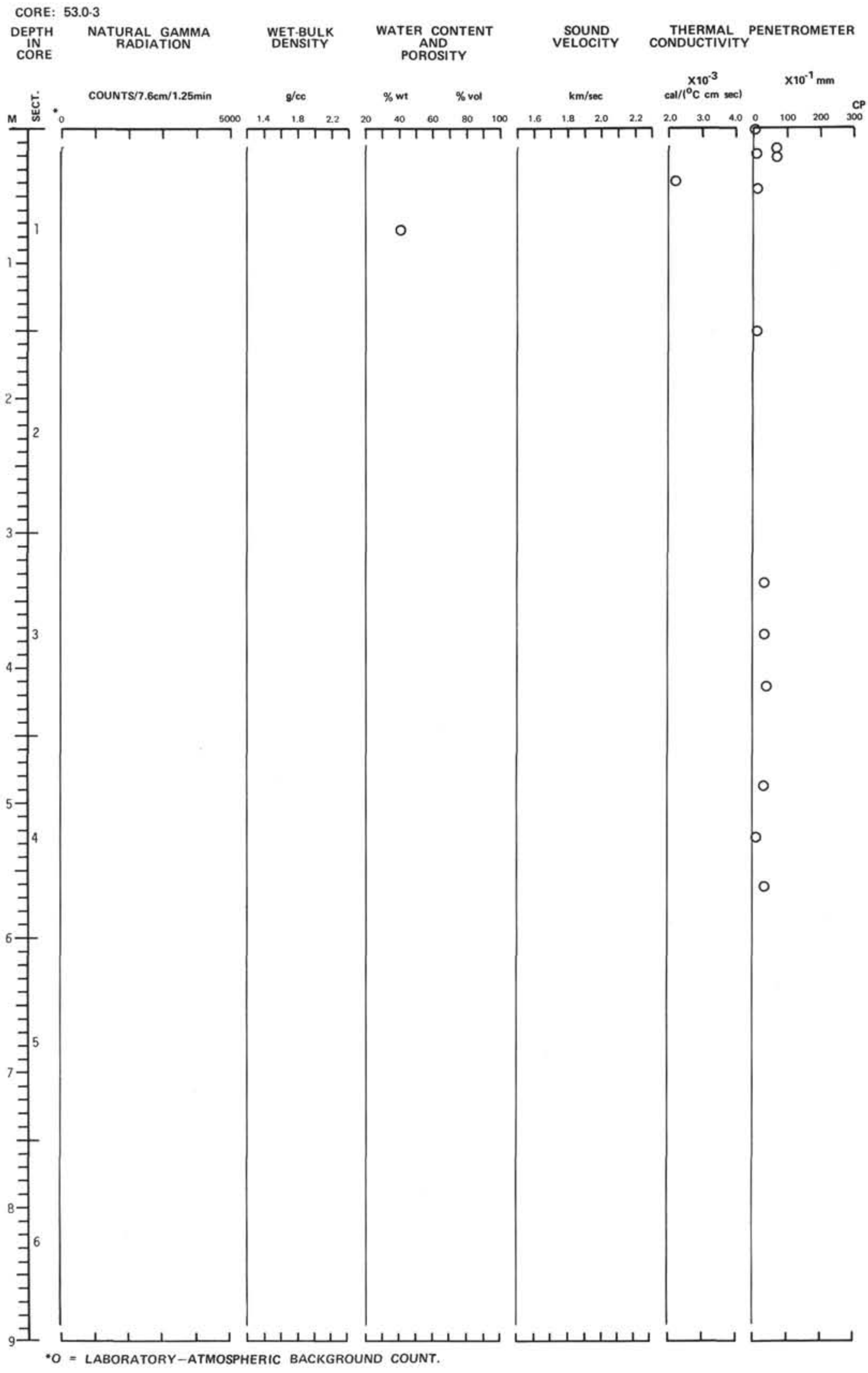


Figure 13. *Summary of physical properties in Hole 53.0 Core 3.*

LEG 6 HOLE 53.0

CORE 4 DEPTH 164.9-174.0 m

AGE	ZONE	SECTION NUMBER	LITHOLOGIC DESCRIPTION	%Sand	%Silt	%Clay	%H_2O	%$CaCO_3$
EARLY OLIGOCENE to EARLY MIOCENE		1	ASH	0	10	90	43	
			Brownish black (5YR 2/1), grayish	11	49	40		
			red (10R 4/2), dark greenish gray	4	25	71		
			(5GY 4/1) to greenish black (5GY 2/1)					
			Glass (altered) A					
			Clay C-A	1	9	90		
			Feldspar, Opaques C-A					
								0
			See section description					
		2	0-80 cm - beds 5 to 10 cm thick	2	11	87	41	0
			80-150 cm - beds 2 to 3 mm thick					
		3						
		4						
		5						
		6	NANNO MARL OOZE					
			Dark reddish brown (5YR 3/2)					
			Partially cemented and recrystallized					
			Nanno A					
			Clay A					
			Calcite and/or Dolomite A					
			Chert, cosmic particles, limonite, opaques C					
		CC	Also contains sand size limestone grains					

Figure 14. *Summary of lithology in Hole 53.0 Core 4.*

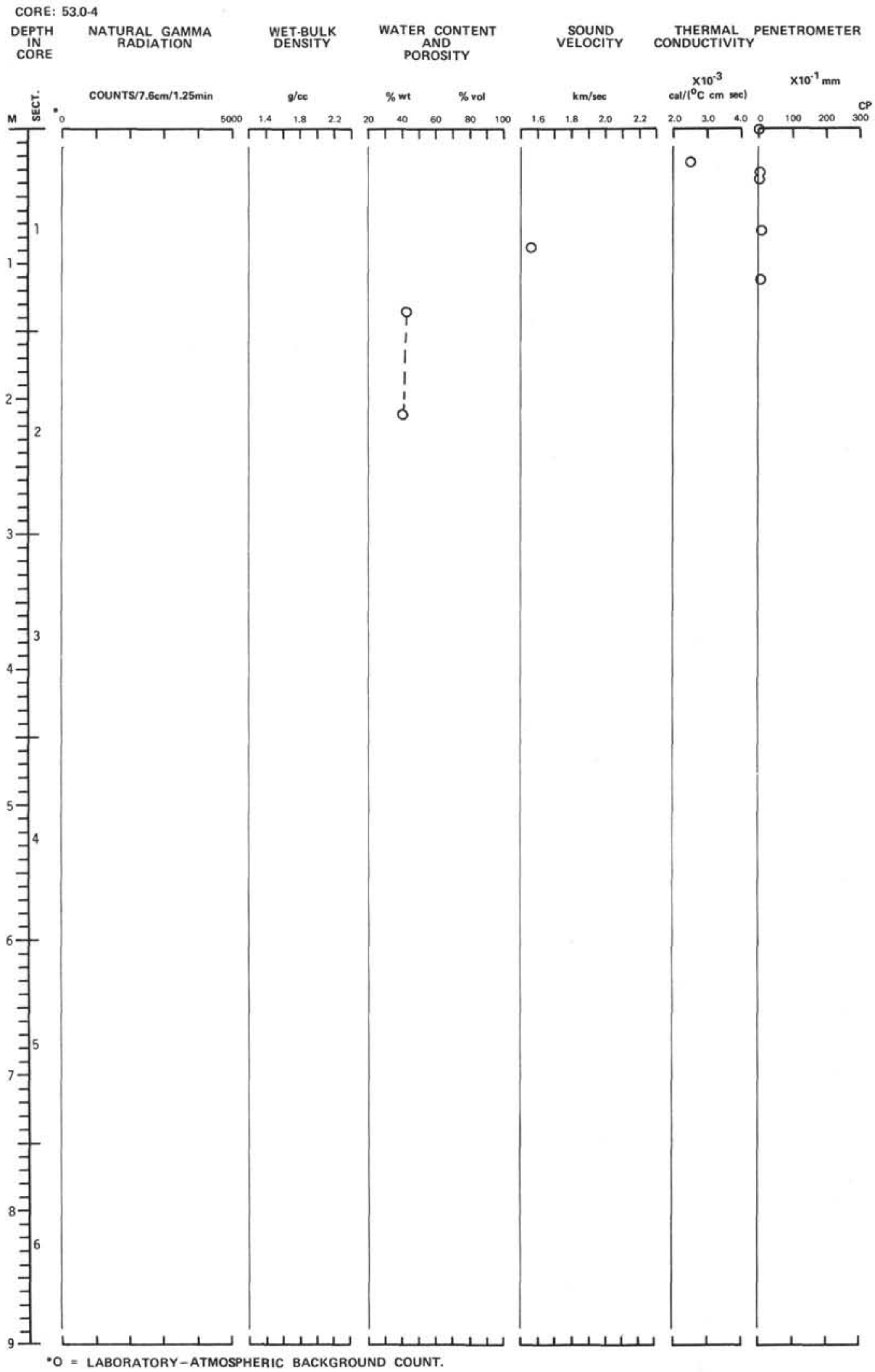


Figure 15. *Summary of physical properties in Hole 53.0 Core 4.*

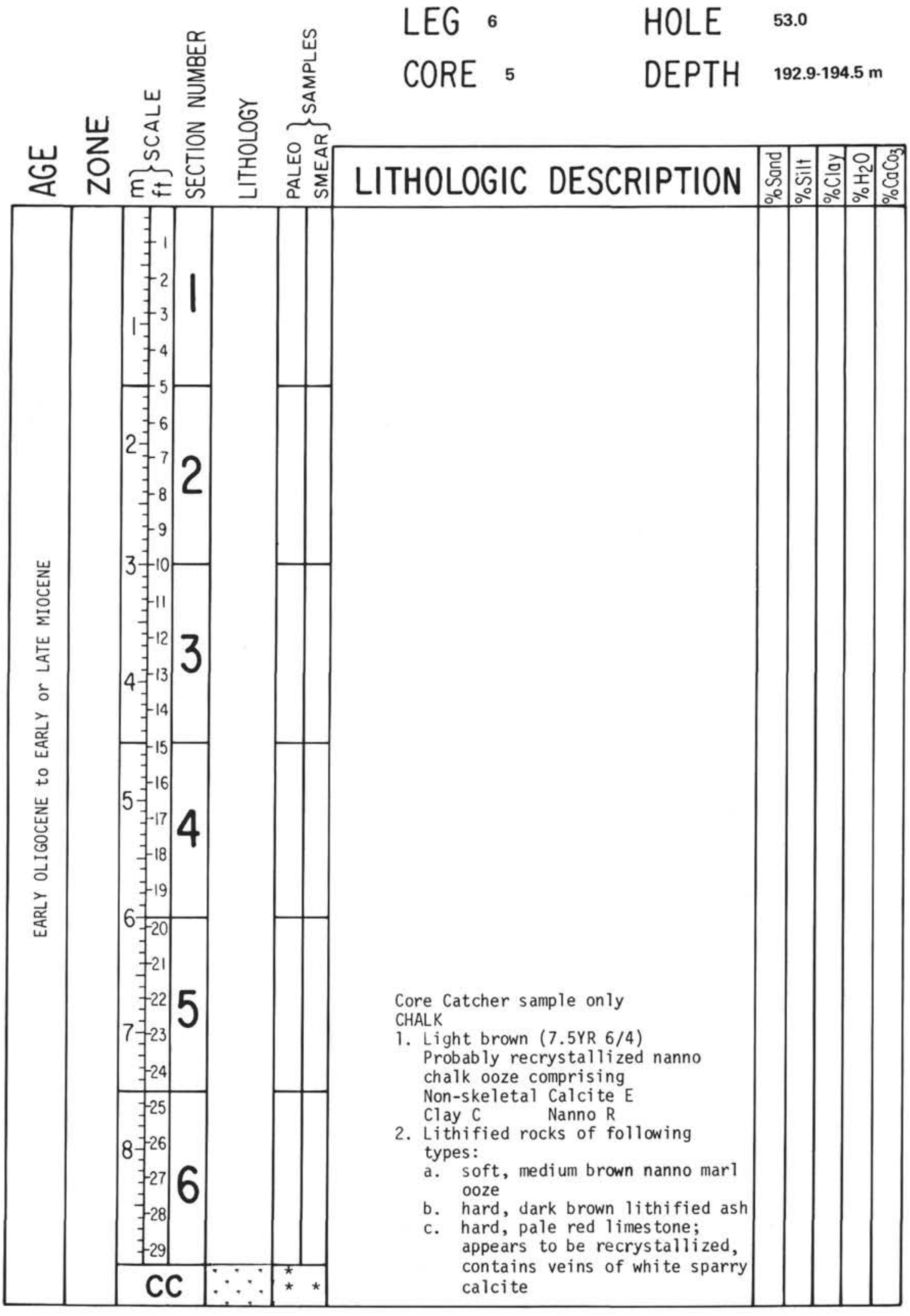


Figure 16. *Summary of lithology in Hole 53.0 Core 5.*

NO PHYSICAL PROPERTIES FOR HOLE 53.0 CORE 5

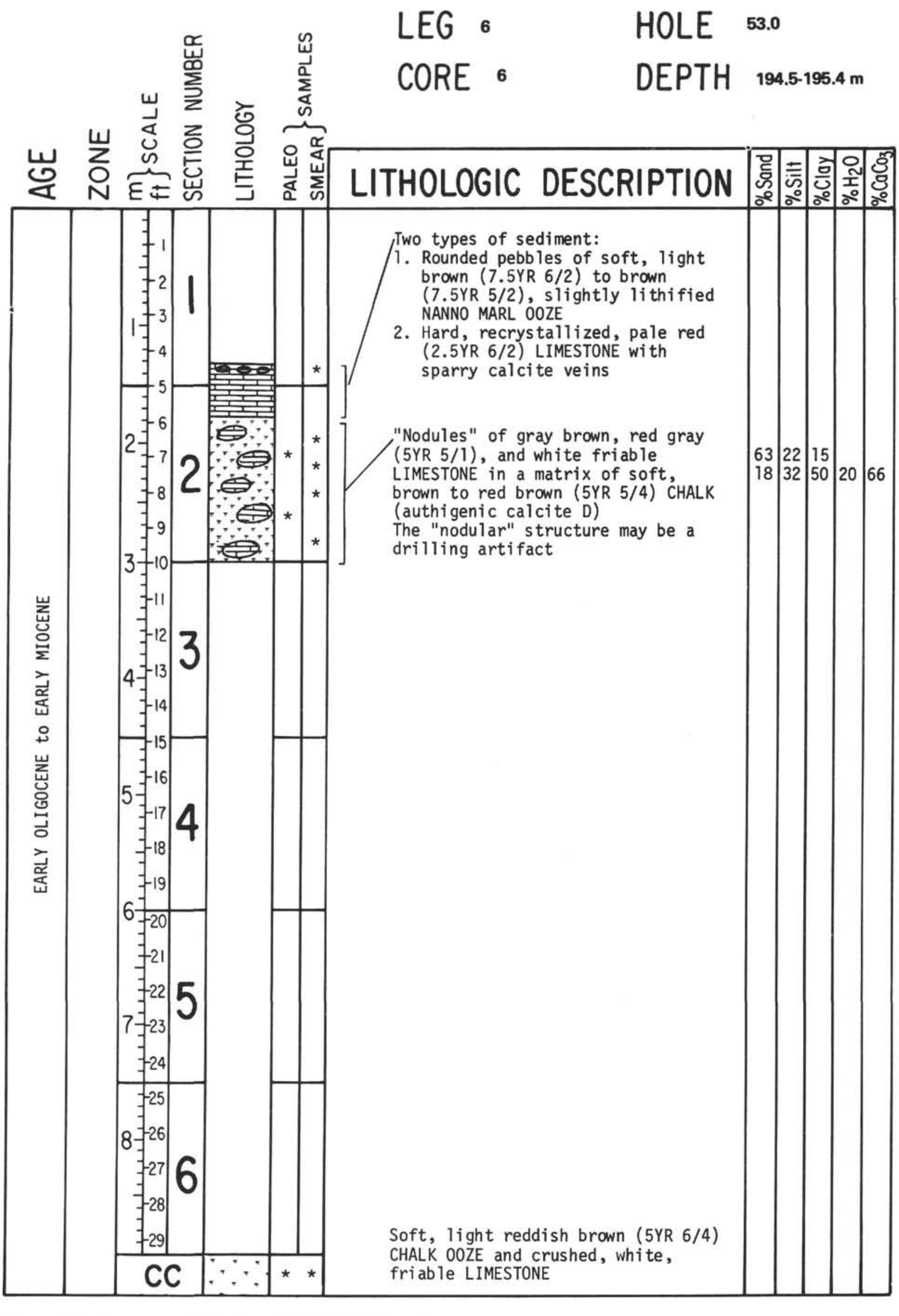


Figure 18. *Summary of lithology in Hole 53.0 Core 6.*

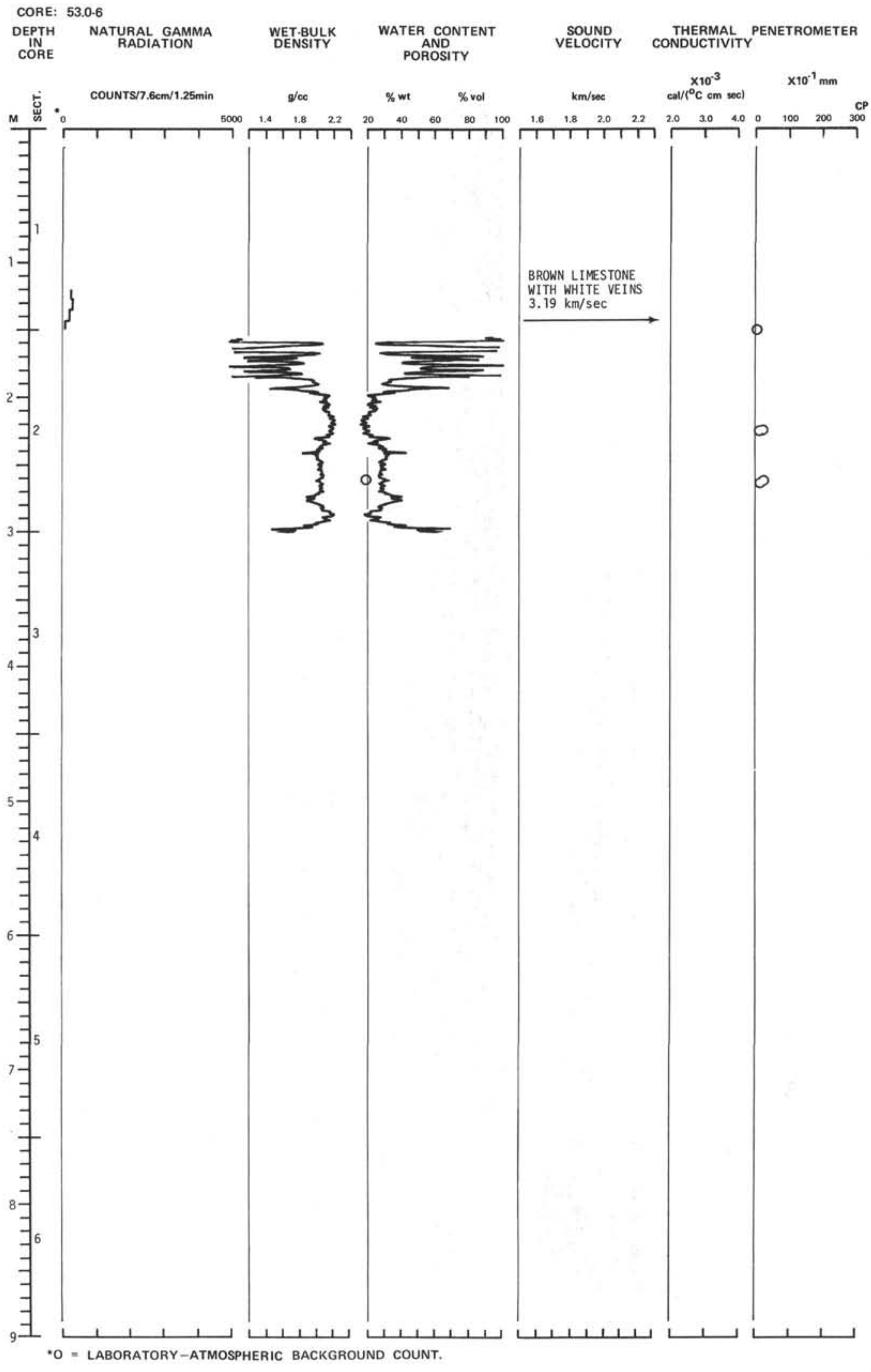


Figure 19. *Summary of physical properties in Hole 53.0 Core 6.*

LEG 6 HOLE 53.0

CORE 7 DEPTH 195.4-196.9 m

AGE	ZONE	SECTION NUMBER	SAMPLES PALEO	SAMPLES SMEAR	LITHOLOGIC DESCRIPTION	%Sand	%Silt	%Clay	%H_2O	%$CaCO_3$
EARLY OLIGOCENE to EARLY MIOCENE		1		*	Hard, greenish gray (10GY 5/2) volcanic rock containing altered volcanic glass and feldspar; tuff or flow rock?	50	23	27		12
		2								
		3								
		4								
		5								
		6								
		CC	* *	*	Core Catcher sample contained: 1. Soft, coherent, dark brown to brown (10YR 4/3 - 5/3) CHALK Authigenic calcite C Clay minerals C Poorly preserved nanno R 2. Hard, dark gray, amygdaloidal to vesicular, highly altered BASALT or ANDESITE, containing veins of white sparry calcite. Abundant rosettes of brown, prismatic, secondary plagioclase (andesine or labradorite) in fine grained matrix. Thin layers of light brown LIMESTONE occur interbedded with volcanic rocks					

Figure 20. *Summary of lithology in Hole 53.0 Core 7.*

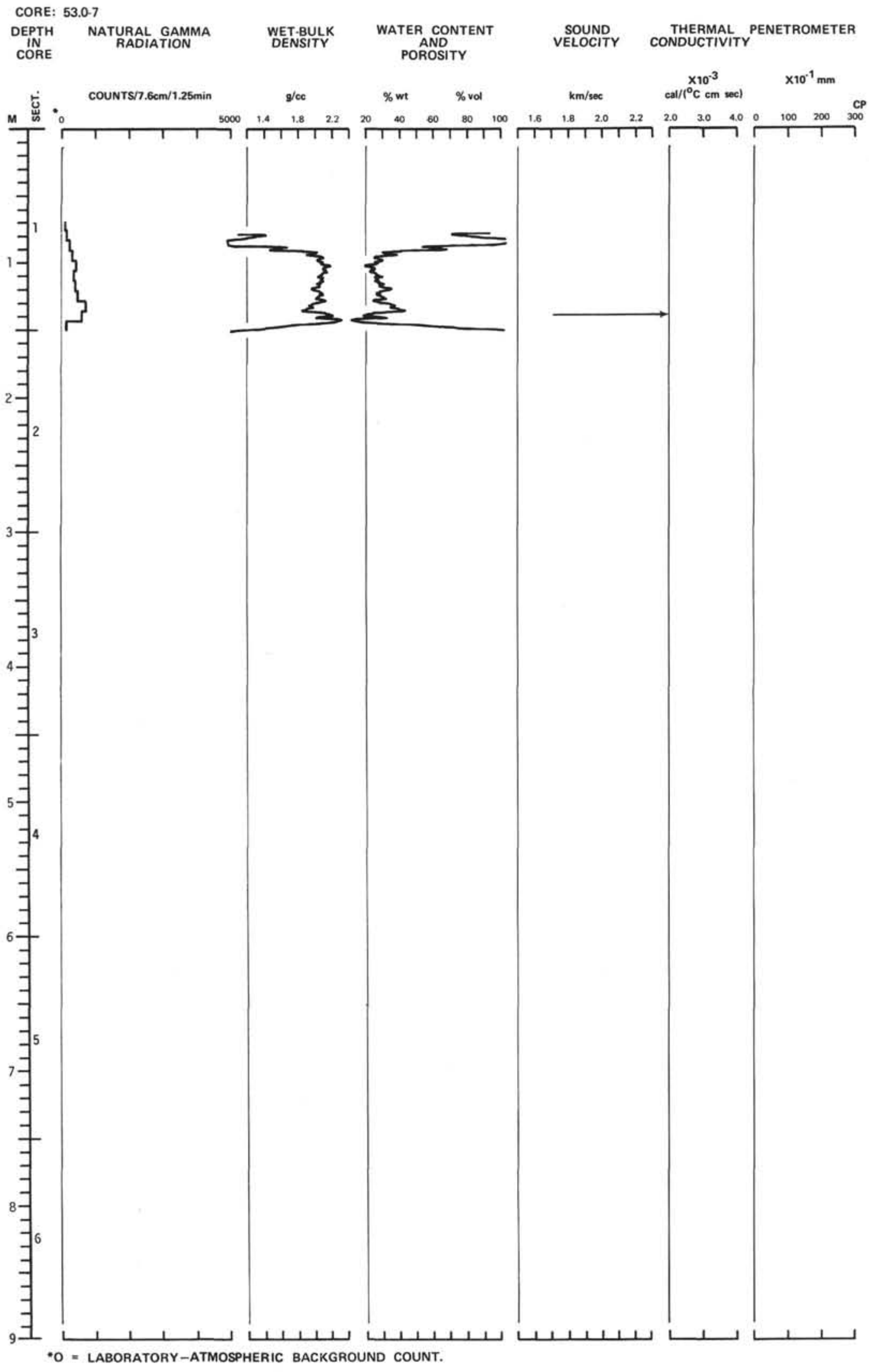
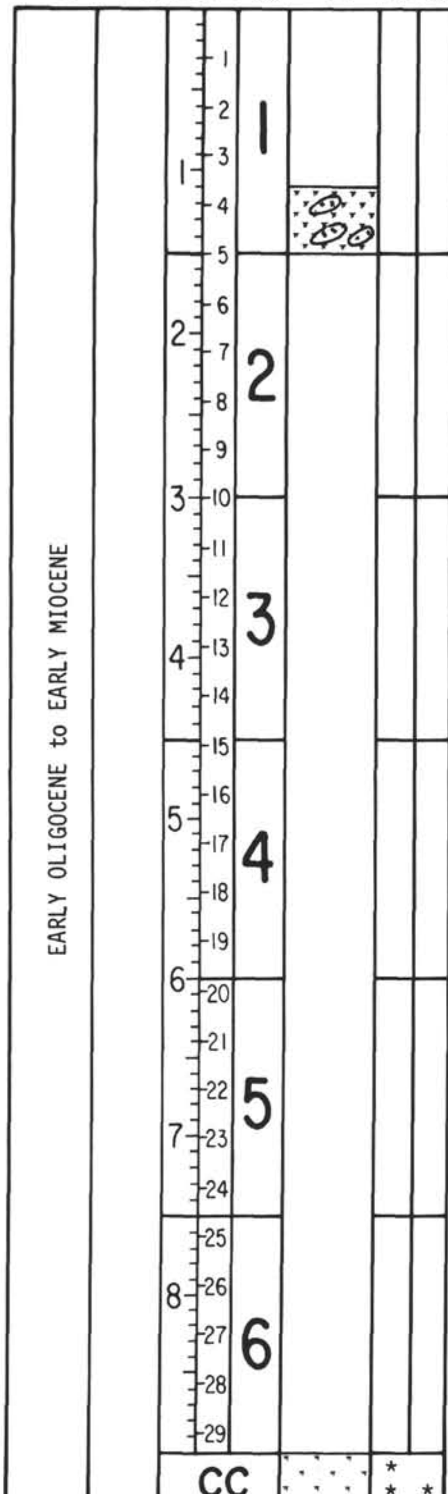


Figure 21. *Summary of physical properties in Hole 53.0 Core 7.*

LEG 6 HOLE 53.0

CORE 8 DEPTH 196.9-200.6 m

AGE	ZONE	m / ft SCALE	SECTION NUMBER	LITHOLOGY	PALEO / SMEAR SAMPLES	LITHOLOGIC DESCRIPTION	%Sand	%Silt	%Clay	%H2O	%CaCO3



Loose rocks recovered from barrel and Core Catcher as follows:

1. CHALK - soft brown to dark gray (10YR 5/3 - 4/2)
2. BASALT or ANDESITE - dark gray, altered, amygdaloidal
3. ("GREENSTONE") - chloritic, highly altered basaltic or andesitic flow rock or tuff
4. NANNO MARL OOZE - light brown, soft, with burrow mottles
5. LIMESTONE - hard, pale red (2.5YR 6/2) to pinkish white (5YR 8/2), recrystallized and cut by numerous sparry calcite veins. In some pieces this rock is interlayered with volcanic rocks
6. VOLCANIC BRECCIA - angular fragments of altered volcanic rock in tuffaceous matrix

Figure 22. *Summary of lithology in Hole 53.0 Core 8.*

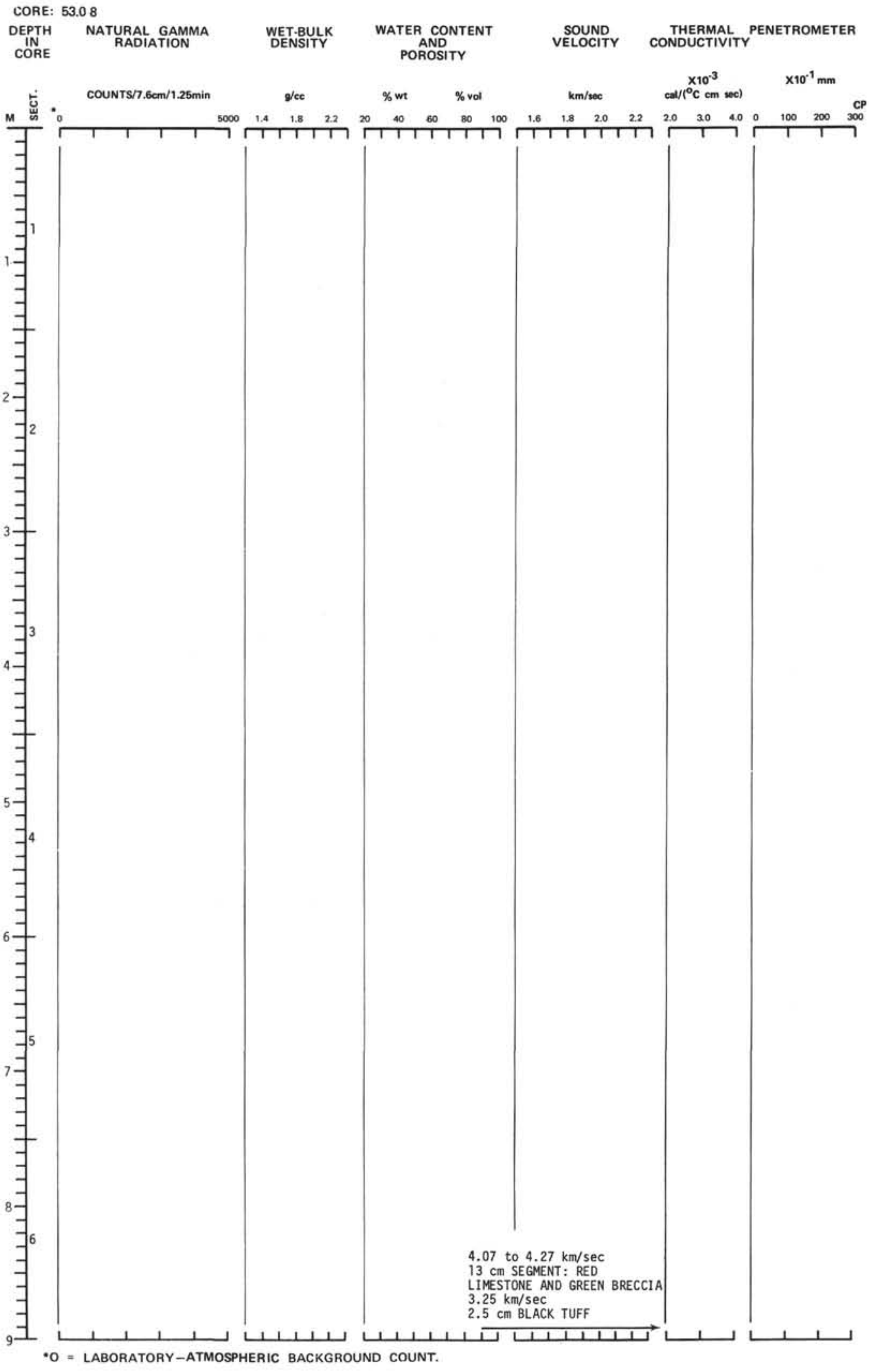


Figure 23. *Summary of physical properties in Hole 53.0 Core 8.*

LEG 6 **HOLE** 53.0

CORE 1 **DEPTH** 99.4-103.9 m

FORAMINIFERA	NANNOPLANKTON	RADIOLARIA
None.	Middle Miocene assemblages composed of *Cyclococcolithina leptoporus, C. neogammation, Discoaster aulakos, D. brouweri* s.l., *D. deflandrei, D. exilis, D. perclarus, D.* sp. aff. *D. variabilis,* and *Reticulofenestra pseudoumbilica* are present throughout the core. At the top of the core *Discoaster kugleri* is present and indicates correlation with the *Discoaster kugleri* Zone.	Radiolaria are very rare in this core. No age diagnostic species were seen.

Figure 24. *Summary of biostratigraphy in Hole 53.0 Core 1.*

LEG 6 HOLE 53.0

CORE 2 DEPTH 103.9-113.1 m

FORAMINIFERA	NANNOPLANKTON	RADIOLARIA
None.	This core was extruded onto the deck of the *Challenger* explosively. Four random samples were gathered and examined to supplement the paleontologic information available from the core-catcher sample. Assemblages from all samples are assigned to the lower middle Miocene *Sphenolithus heteromorphus*. Species present include *Cyclococcolithina neogammation*, *Discoaster brouweri* s. l., *D. challengeri*, *D. deflandrei*, *D. exilis*, *D. variabilis*, *Helicopontosspaera kamptneri*, and *Sphenolithus heteromorphus*.	Radiolaria are very rare in this core. No age diagnostic species were seen.

Figure 25. ***Summary of biostratigraphy in Hole 53.0 Core 2.***

LEG 6 HOLE 53.0

CORE 3 DEPTH 136.6-141.1 m

FORAMINIFERA	NANNOPLANKTON	RADIOLARIA
Rare but diverse planktonic Foraminifera found in the center bit sample between cores 2 and 3 determine the age of sediments as the *Globorotalia menardii* Zone, upper Middle Miocene (Tortonian stage). The assemblage includes *Globorotalia menardii, G. lenguaensis, G. mayeri, Sphaeroidinellopsis grimsdalei, S. rutschi, Orbulina universa, Globigerina nepenthes, G. bulloides, G. bulbosa, Globigerinoides bollii, G. adriatica, G. altiapertura, Biorbulina bilobata, Globoquadrina larmeui, G. altispira G. dehiscens, Globorotaloides variabilis.*	The assemblages appear to be mixed and may be either lower or middle Miocene. Species present include *Cyclococcolithina leptoporus, C. neogammation, Discoaster aulakos, D. brouweri* s.l., *D. deflandrei, D. druggii, exilis, Helicopontosphaera kamptneri* [large], and *Sphenolithus heteromorphus.*	The center bit sample between cores 2 and 3 contains species of the lower upper Miocene *Ommatartus antepenultimus* Zone. The core itself contains too few specimens to make an accurate age determination. CENTER BIT 2/3: *Ommatartus antepenultimus, O. hughesi, Cannartus laticonus, Lithopera bacca, Stichocorys peregrina,* and *S. delmontense.*

Figure 26. ***Summary of biostratigraphy in Hole 53.0 Core 3.***

LEG 6 HOLE 53.0

CORE 4 DEPTH 164.9-174.0 m

FORAMINIFERA	NANNOPLANKTON	RADIOLARIA
None.	Three samples from the core itself proved to be barren. Nannoplankton assemblages are present in the top and core-catcher samples. Species present include *Cyclococcolithina neogammation*, *Discoaster brouweri* s.l., *D. challengeri* s.l., *D. deflandrei*, *Helicopontosphaera kamptneri*, *Sphenolithus heteromorphus*, and *Triquetrorhabdulus* sp. cf. *T. carinatus*. These assemblages are considered to be lower Miocene.	Radiolaria are too rare in this core to permit an accurate age determination. Preservation is poor.

Figure 27. *Summary of biostratigraphy in Hole 53.0 Core 4.*

LEG 6 HOLE 53.0

CORE 5 DEPTH 192.9-194.5 m

FORAMINIFERA	NANNOPLANKTON	RADIOLARIA
None.	The identifiable species in this core include only *Coccolithus pelagicus*, *Cyclococcolithina neogammation*, and *Discoaster deflandrei*. Even these are irregular in form owing to overgrowths of calcite. Since these species are the most resistant to deterioration and also the most abundant forms in the lower Oligocene to lower Miocene interval, this range must be assumed in the absence of any other evidence.	Radiolaria are rare in this core. Species present at the bottom suggest a late Miocene age. BOTTOM: *Ommatartus hughesi*, *Stichocorys delmontense*.

Figure 28. *Summary of biostratigraphy in Hole 53.0 Core 5.*

LEG 6 HOLE 53.0

CORE 6 DEPTH 194.5-195.4 m

FORAMINIFERA	NANNOPLANKTON	RADIOLARIA
None.	Only *Cyclococcolithina neogammation* and *Discoaster deflandrei* are identifiable in this core. On this basis the core is considered lower Oligocene to lower Miocene.	No Radiolaria.

Figure 29. ***Summary of biostratigraphy in Hole 53.0 Core 6.***

LEG 6 HOLE 53.0

CORE 7 DEPTH 195.4-196.9 m

FORAMINIFERA	NANNOPLANKTON	RADIOLARIA
None.	Only *Cyclococcolithina neogammation* is identified from this core. The core is tentatively considered lower Oligocene to lower Miocene.	No Radiolaria.

Figure 30. *Summary of biostratigraphy in Hole 53.0 Core 7.*

LEG 6 HOLE 53.0

CORE 8 DEPTH 196.9-200.6 m

FORAMINIFERA	NANNOPLANKTON	RADIOLARIA
None.	*Coccolithus eopelagicus*, *Cyclococcolithina neogammation*, and *Discoaster deflandrei* are present in a poor state of preservation. The core is considered lower Oligocene to lower Miocene.	No Radiolaria.

Figure 31. *Summary of biostratigraphy in Hole 53.0 Core 8.*

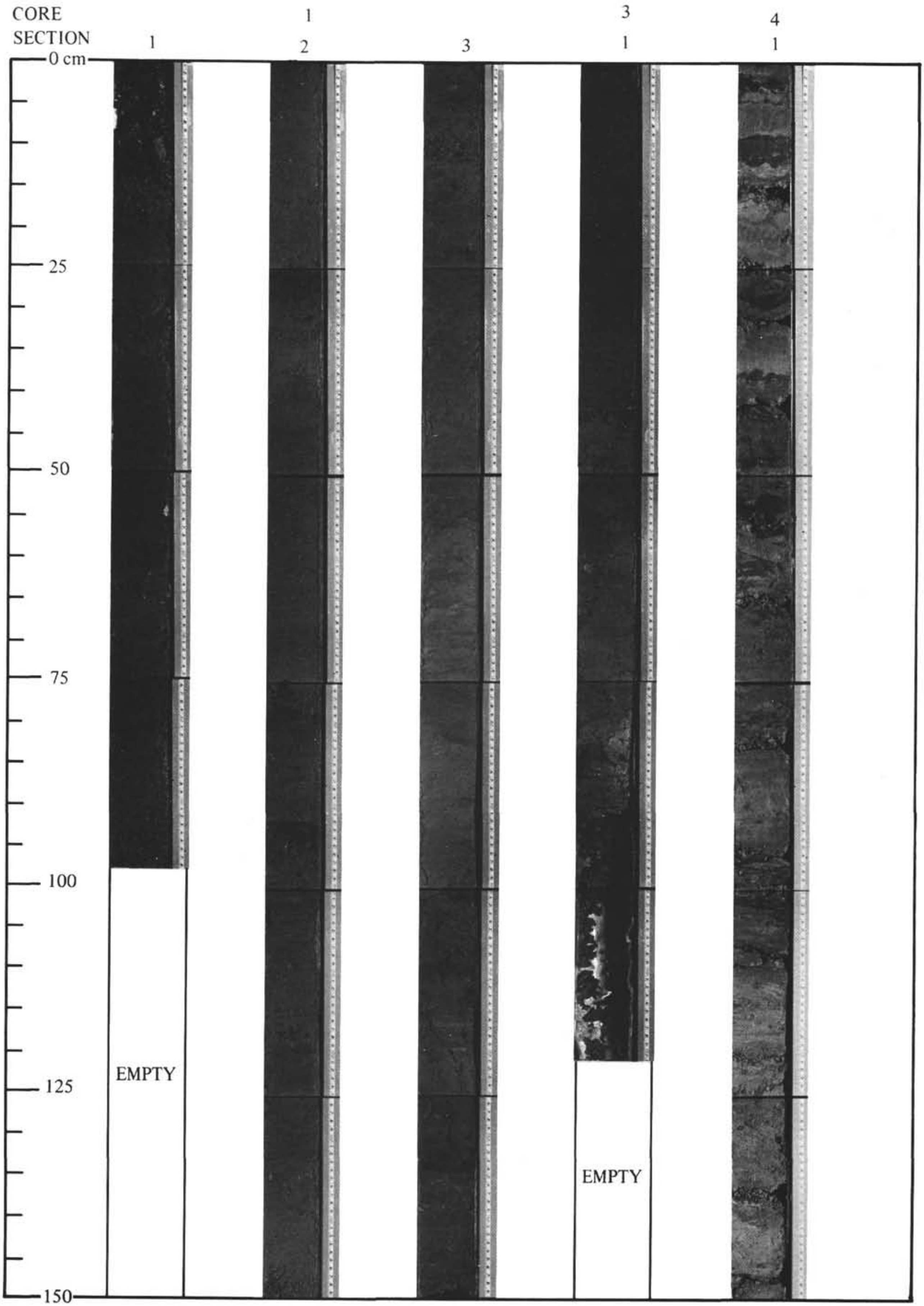


Plate 1. *Photographs of Hole 53.0 Cores 1, 3 and 4.*

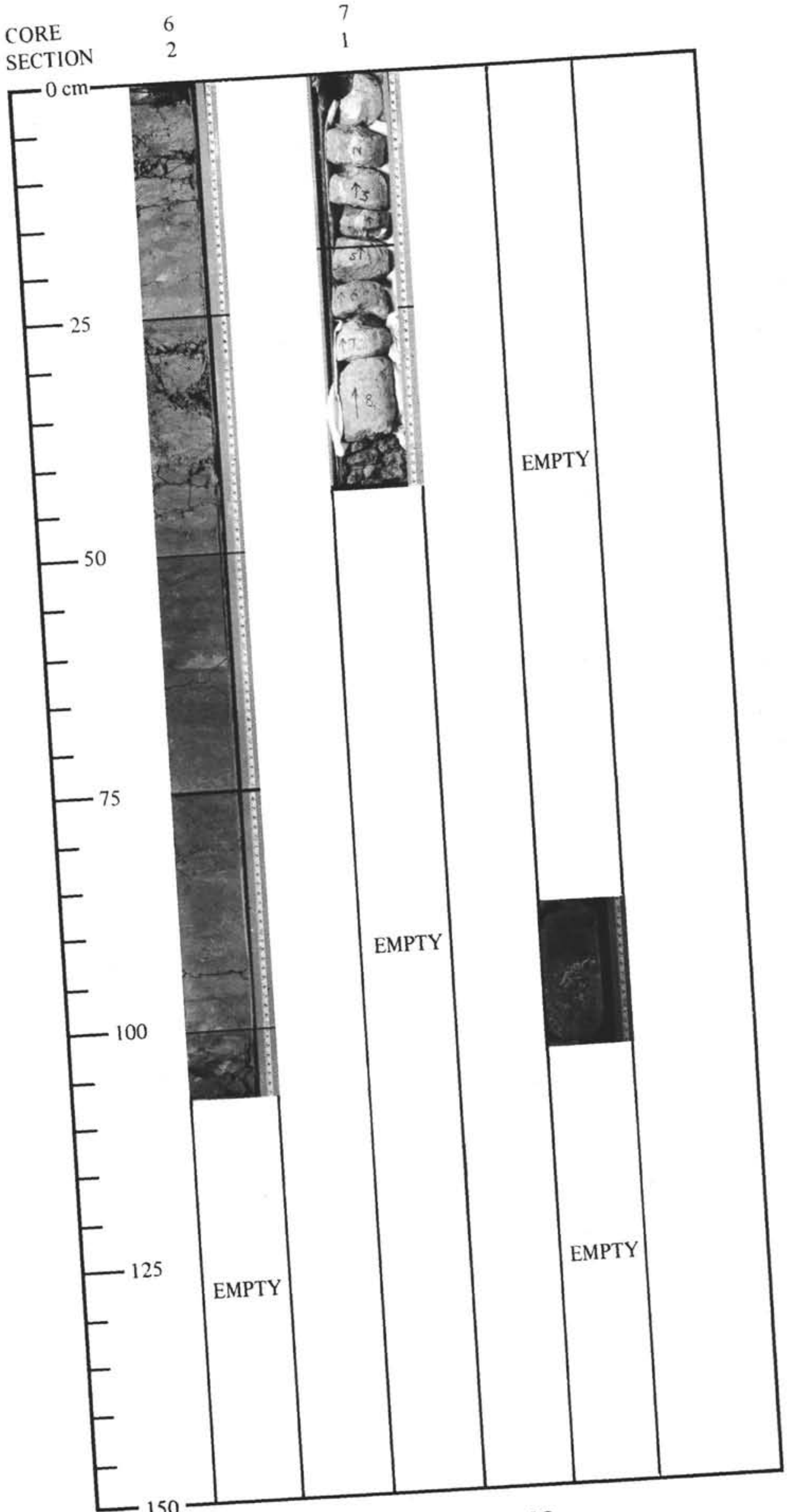
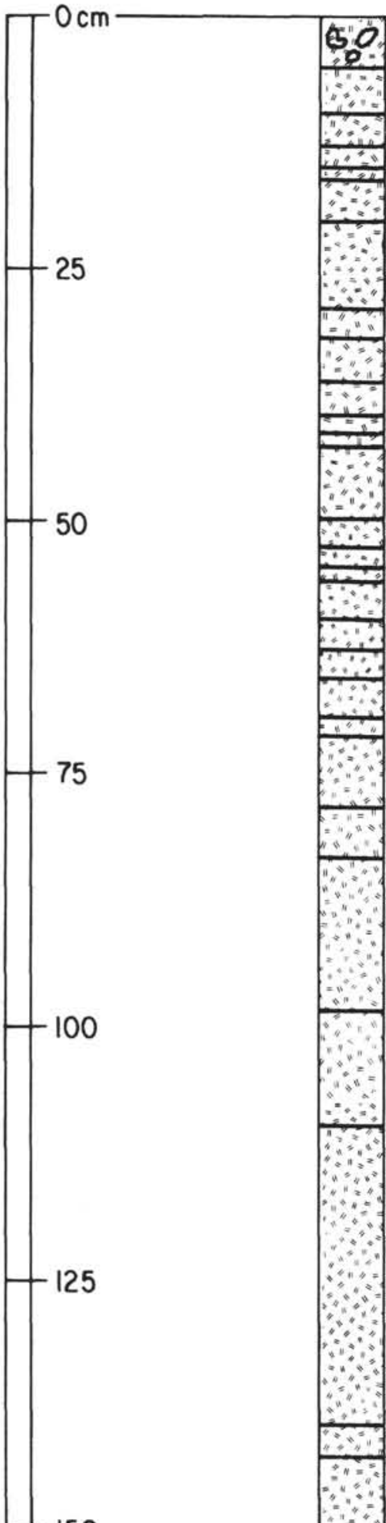


Plate 2. *Photographs of Hole 53.0 Cores 6, 7 and 8.*

HOLE 53.0
CORE 4
SECTION 1



1. ASH: Brownish black
   from 0-70 cm these beds moderate-strongly deformed by slumping?
   Composition: Glass (altered) 65%
   Opaque minerals 20%
   Clay 15%

2. ASH: Grayish red
   Composition: Glass (altered) 50-60%
   Opaque minerals and altered plagioclase 15-30%
   Clay 10%

3. ASH: Dark greenish gray to greenish black
   Composition: Glass (altered) 50%
   Opaque minerals and altered plagioclase 40%
   Clay 10%

All ash is of sand-silt-clay size. From 80-140 cm beds thinly laminated (2-3 mm thick). From 0-80 cm beds are thicker (5-10 cm).

Figure 32. *Summary of lithology in Hole 53.0 Core 4 Section 1.*

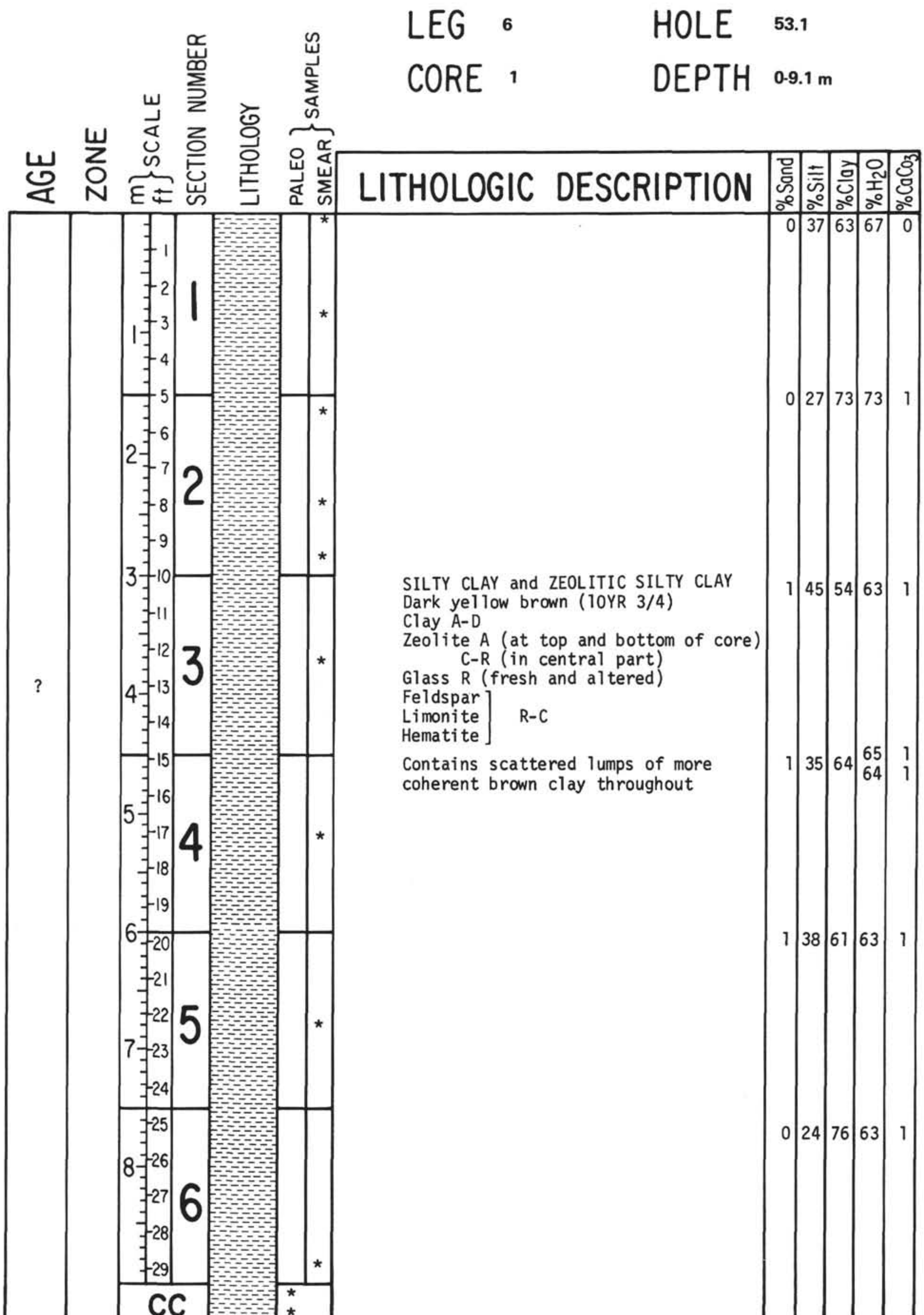


Figure 33. *Summary of lithology in Hole 53.1 Core 1.*

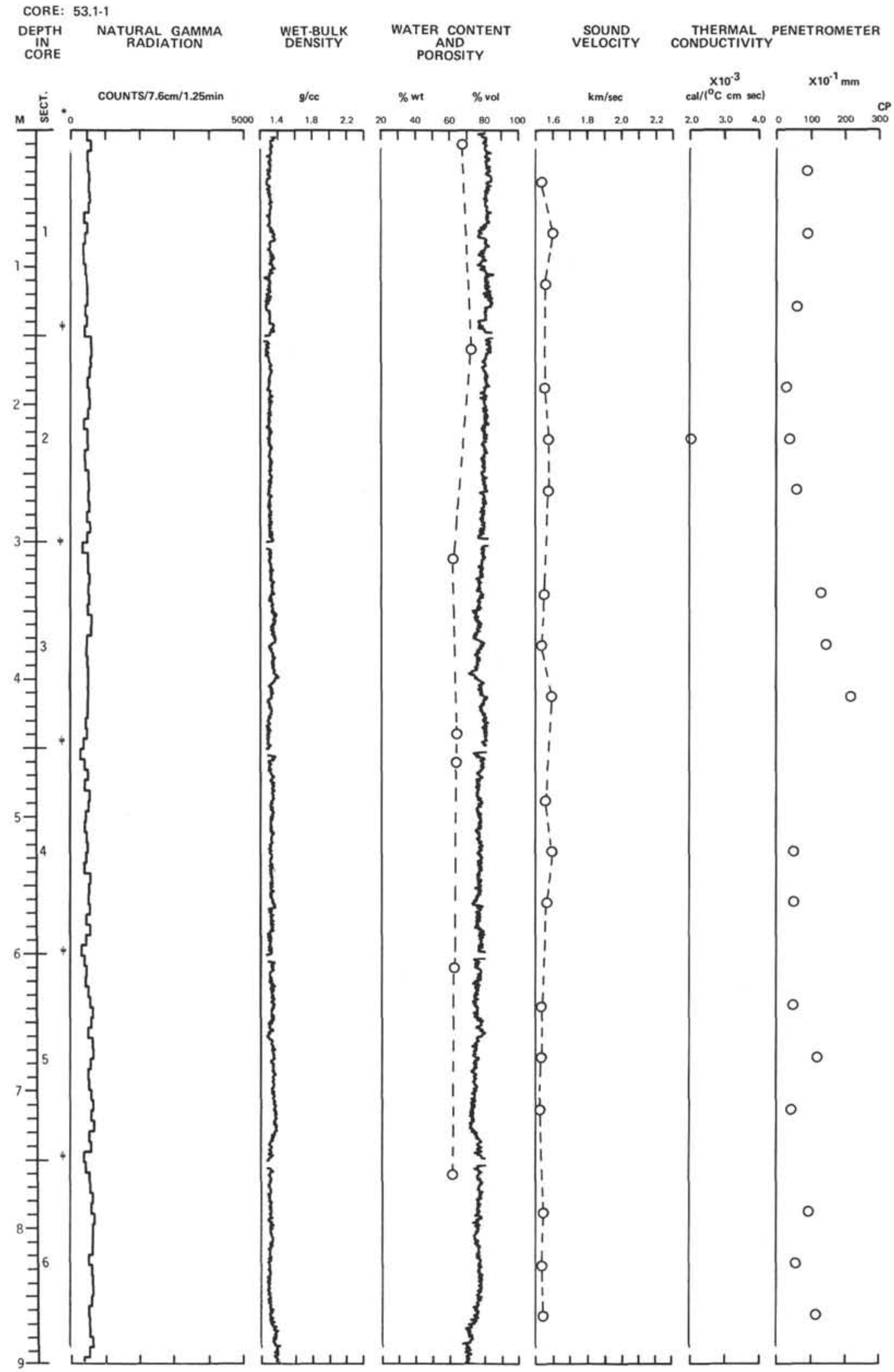


Figure 34. ***Summary of physical properties in Hole 53.1 Core 1.***

LEG 6 HOLE 53.1

CORE 1 DEPTH 0-9.1 m

FORAMINIFERA	NANNOPLANKTON	RADIOLARIA
None.	No nannoplankton are present in samples from this core.	No Radiolaria.

Figure 35. *Summary of biostratigraphy in Hole 53.1 Core 1.*

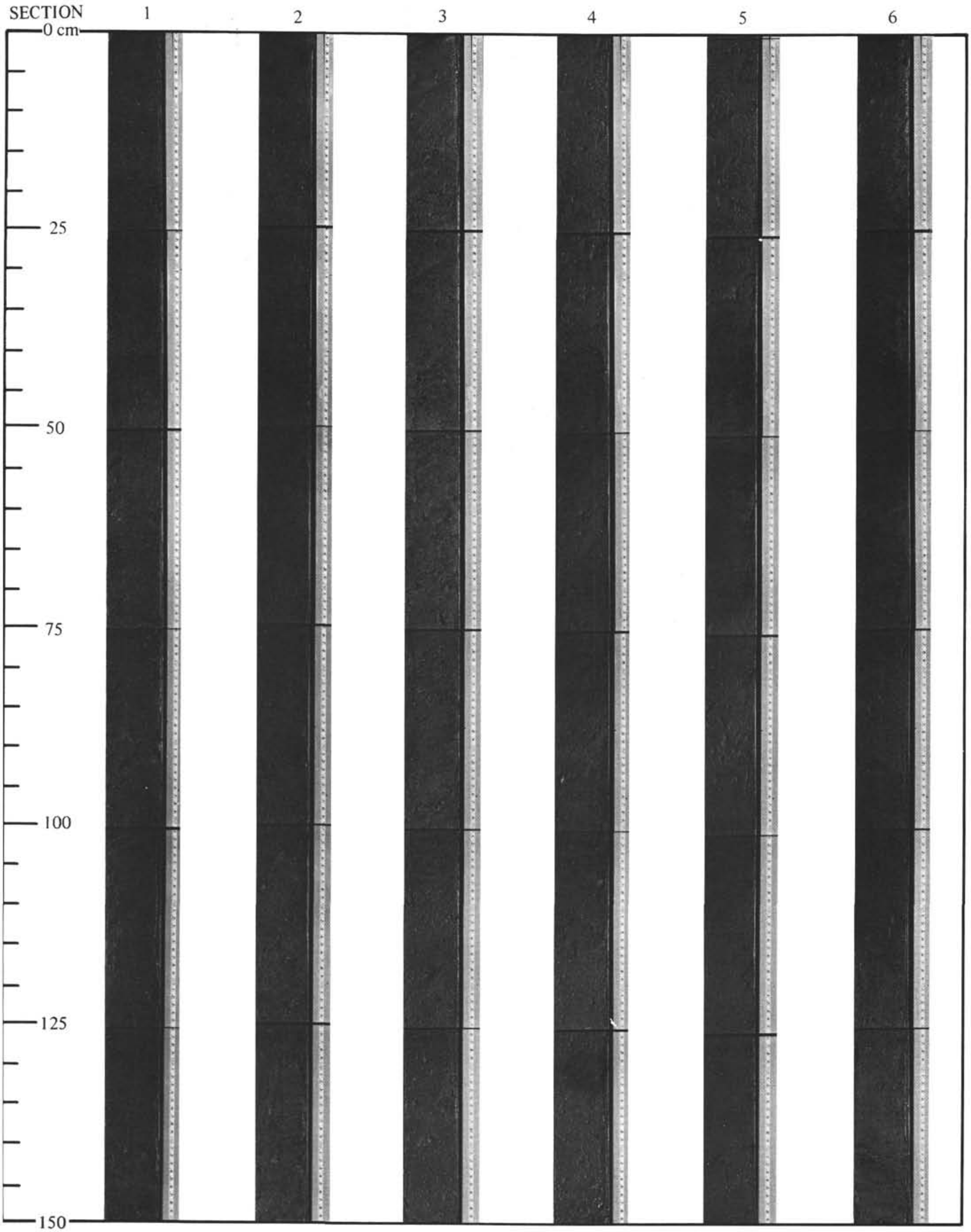


Plate 3. *Photographs of Hole 53.1 Core 1.*

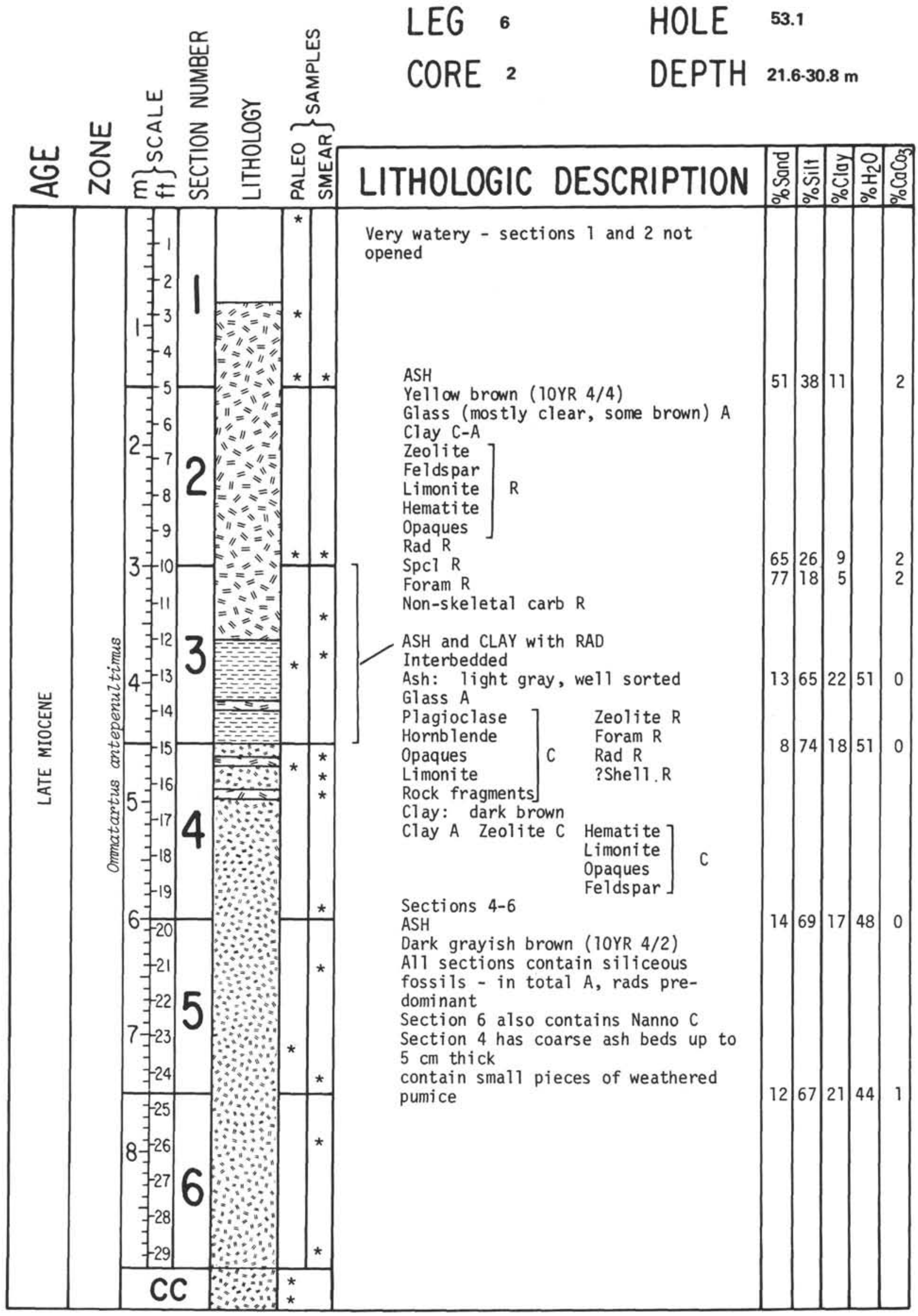


Figure 36. *Summary of lithology in Hole 53.1 Core 2.*

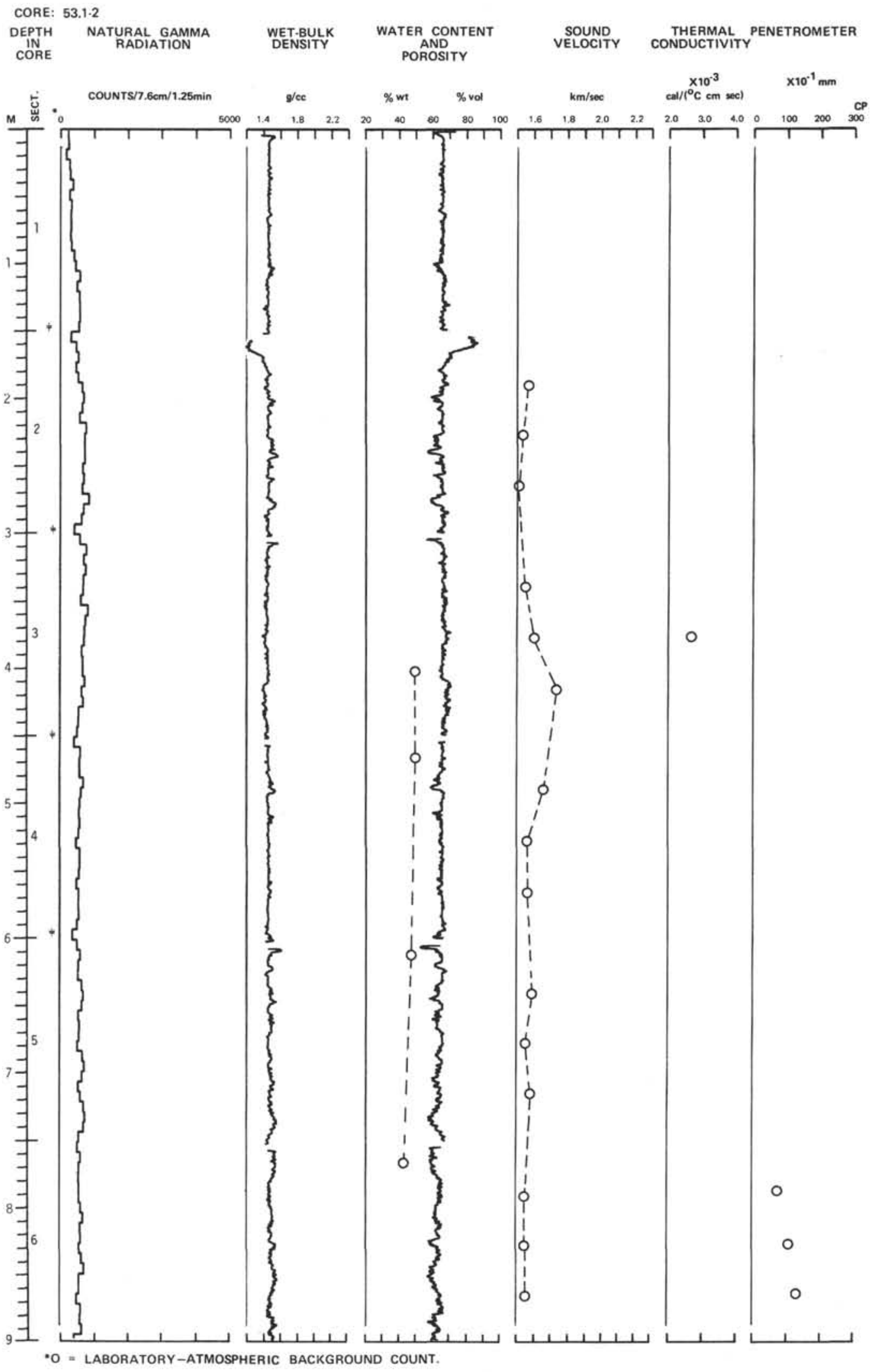


Figure 37. ***Summary of physical properties in Hole 53.1 Core 2.***

LEG 6 HOLE 53.1

CORE 2 DEPTH 21.6-30.8 m

FORAMINIFERA	NANNOPLANKTON	RADIOLARIA
None.	Three samples from this core proved to be barren. Other samples contained assemblages composed only of small discoasters which have a central pore instead of a central knob owing to solution. Questionably identified in these samples are *Discoaster brouweri* s.l., *D. challengeri*, *D. exilis*, *D. quintatus*, and *D. variabilis*. One sample contained, in addition, *Cyclococcolithina leptoporus*, *Discoaster pentaradiatus*, *Helicopontosphaera kamptneri*, and *Reticulofenestra pseudoumbilica*. The presence of *D. pentaradiatus* and *?D. quintatus* suggests an upper Miocene assignment.	This core contains species indicating the lower upper Miocene *Ommatartus antepenultimus* Zone. Radiolaria are abundant and well preserved throughout the core. TOP: *Ommatartus antepenultimus O. hughesi, Cannartus laticonus, C.(?) petterssoni, Stichocorys delmontense, S. peregrina, Lithopera bacca,* and *L. neotera*. BOTTOM: *Ommatartus antepenultimus, O. hughesi, Cannartus laticonus, Stichocorys delmontense,* and *Lithopera bacca*.

Figure 38. ***Summary of biostratigraphy in Hole 53.1 Core 2.***

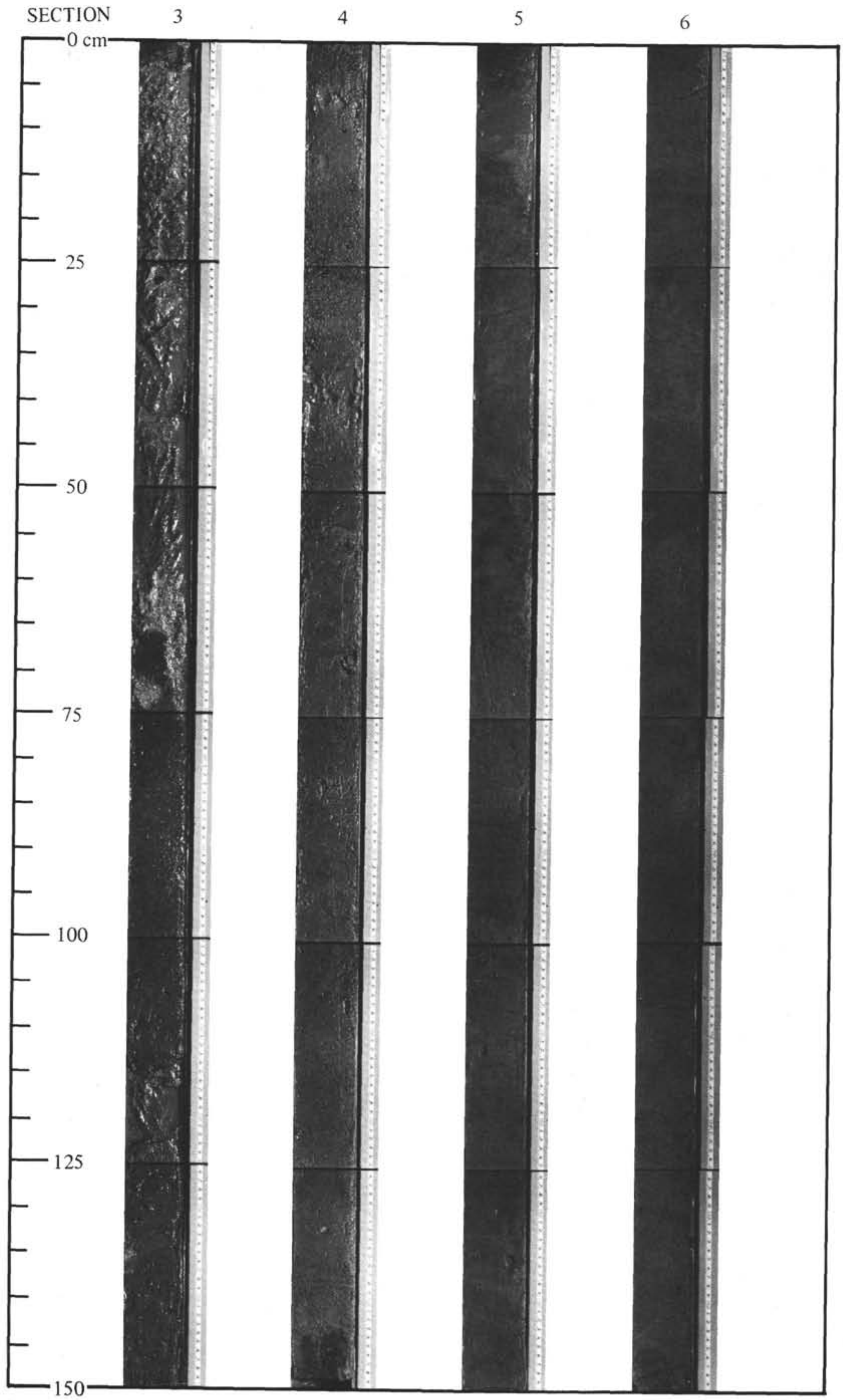


Plate 4. *Photographs of Hole 53.1 Core 2.*

LEG 6 HOLE 53.1

CORE DEPTH 53.3-62.5 m

AGE	ZONE	m / ft SCALE	SECTION NUMBER	LITHOLOGY	PALEO / SMEAR SAMPLES
MIDDLE to LATE MIOCENE	*Ommatartus antepenultimus*; *Cannartus*(?) *petterssoni*	m 1–8; ft 1–29	1, 2, 3, 4, 5, 6, CC		*

LITHOLOGIC DESCRIPTION

Section watery - not split: abundant pebbles visible in X-ray

ASH
Very dark grayish brown (10YR 3/2)
Glass A Rad C-A Nanno R-C
Clay C Spcl C
Feldspar, Pyroxene, Mica, Opaques A

ASH with PEBBLES
Brown and dark grayish brown (10YR 4/3 and 4/2)
Ash similar to section 1
Pebbles, mostly round, 5-25 mm diameter, two varieties:
black pumice,
dark grayish brown lithified ash with common black specks of magnetite

ASH
Dark grayish brown (2.5YR 4/2) and mottled dark gray (5Y 4/1) and gray (5Y 5/1) with thin (1-3 cm) black ash beds
Nanno A lower part of section 3

Gray (5Y 5/1) with mottles and streaks of black
Dark gray (5Y 4/1) and dark olive gray (5Y 3/2)
Light red (2.5YR 6/6) pumice layer
Gray (5Y 5/1) with layers of light gray (5Y 7/1), very dark gray (5Y 3/1) and black
See X-ray photograph

%Sand	%Silt	%Clay	%H_2O	%$CaCO_3$
27	61	12		0
34	51	15	42	0
11	70	19	50	4
14	68	18	37	3
6	74	20	40	0

Figure 39. *Summary of lithology in Hole 53.1 Core 3.*

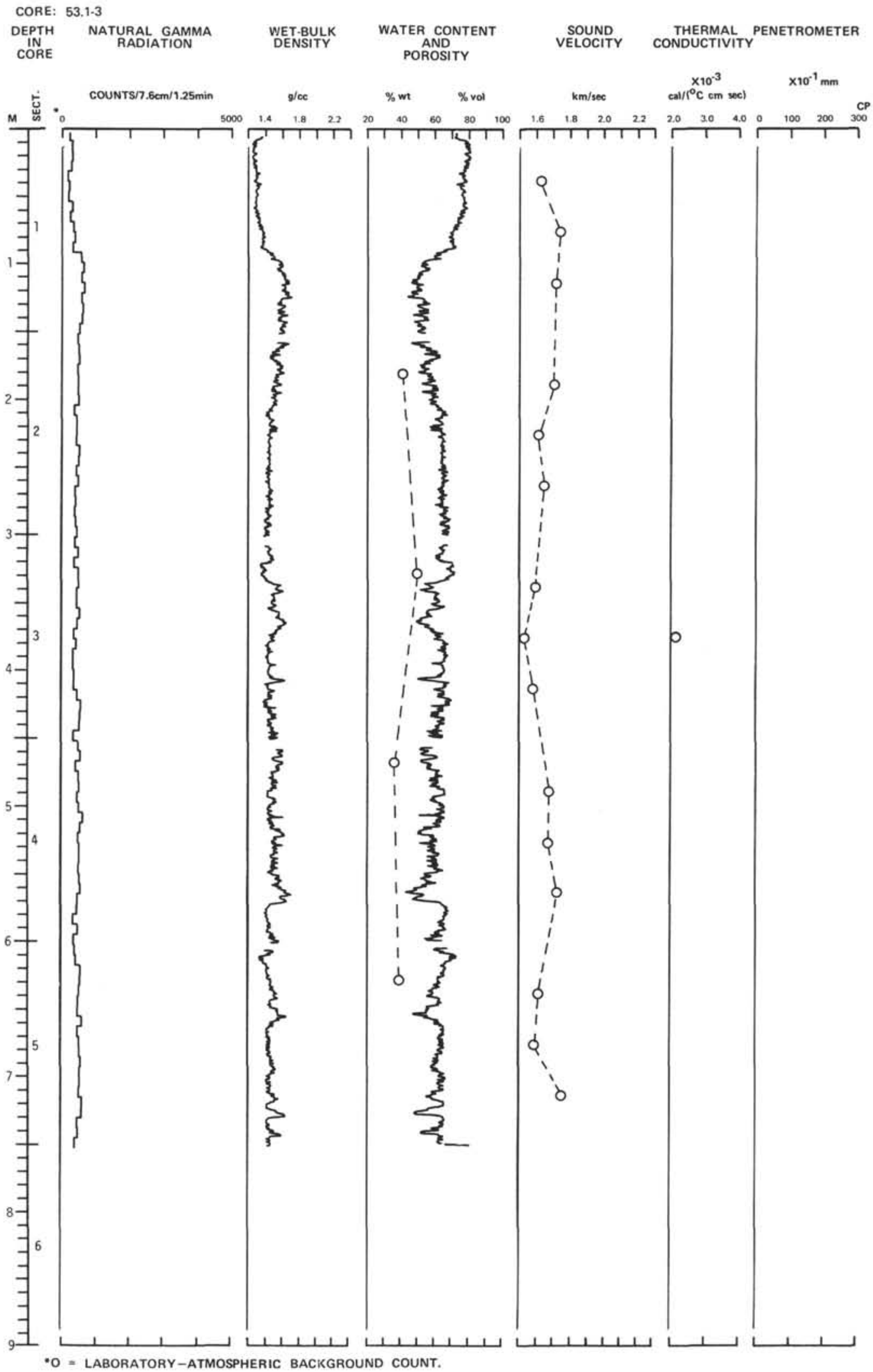


Figure 40. *Summary of physical properties in Hole 53.1 Core 3.*

LEG 6 HOLE 53.1

CORE 3 DEPTH 53.3-62.5 m

FORAMINIFERA	NANNOPLANKTON	RADIOLARIA
None.	Assemblages of long-ranging species in this core indicate a middle or upper Miocene correlation. Species present include *Cyclococcolithina leptoporus*, *Discoaster brouweri*, *D. challengeri*, *D. exilis*, *D. variabilis*, and *Triquetrorhabdulus rugosus*.	Among rare Radiolaria at the top of this core is *Ommatartus antepenultimus* suggesting the presence of the upper Miocene Zone named for that species. Abundant Radiolaria in the middle of the core belong to the middle Miocene *Cannartus (?) petterssoni* Zone. Radiolaria are again rare at the bottom of the core. TOP: *Ommatartus antepenultimus*, *Stichocorys delmontense*, and *Lithopera neotera*. MIDDLE: *Cannartus laticonus*, *Stichocorys delmontense*, *Cyrtocapsella cornuta*, *Lithopera neotera*, and *L. bacca*. BOTTOM: *Stichocorys delmontense* and *Lithopera neotera*.

Figure 41. ***Summary of biostratigraphy in Hole 53.1 Core 3.***

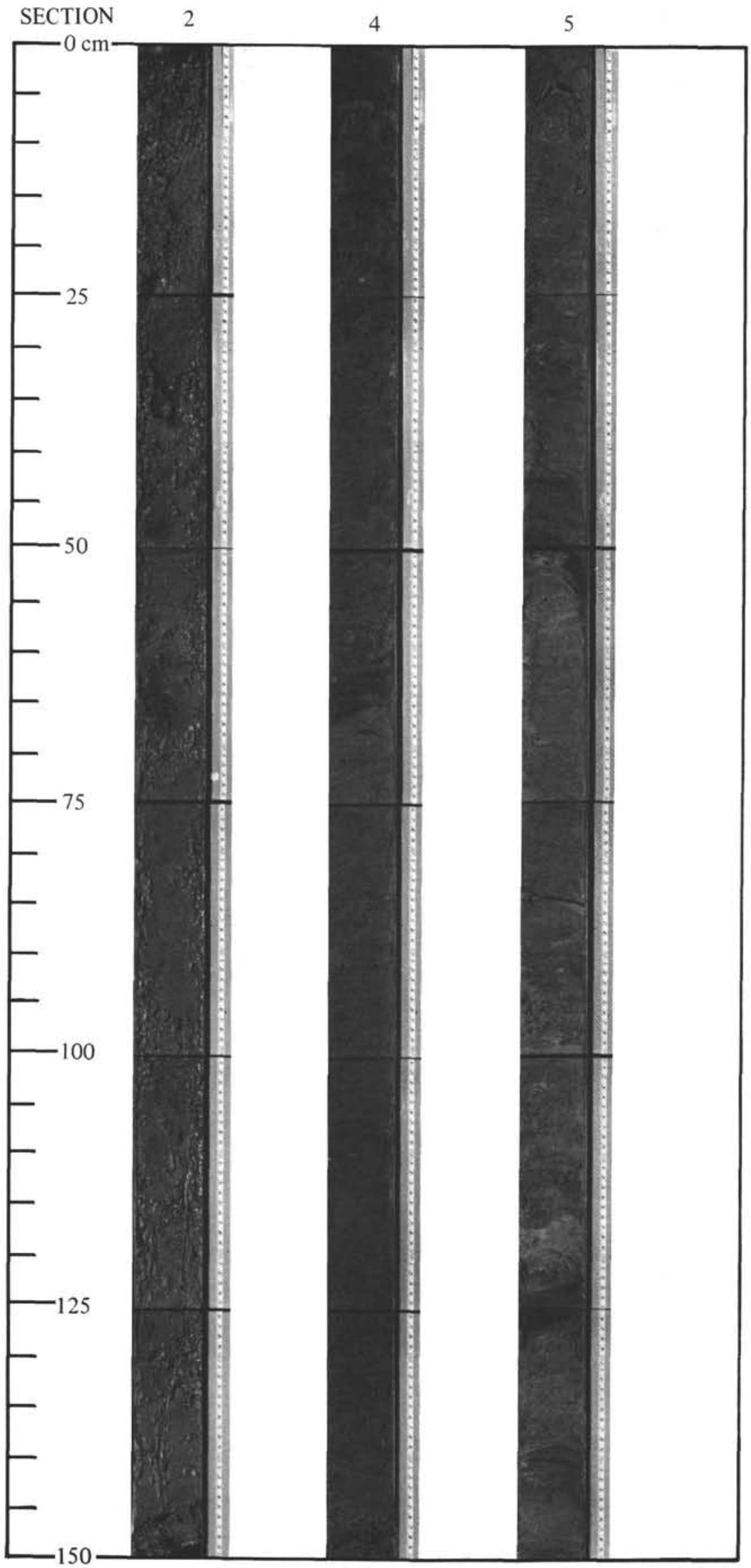


Plate 5. *Photographs of Hole 53.1 Core 3.*

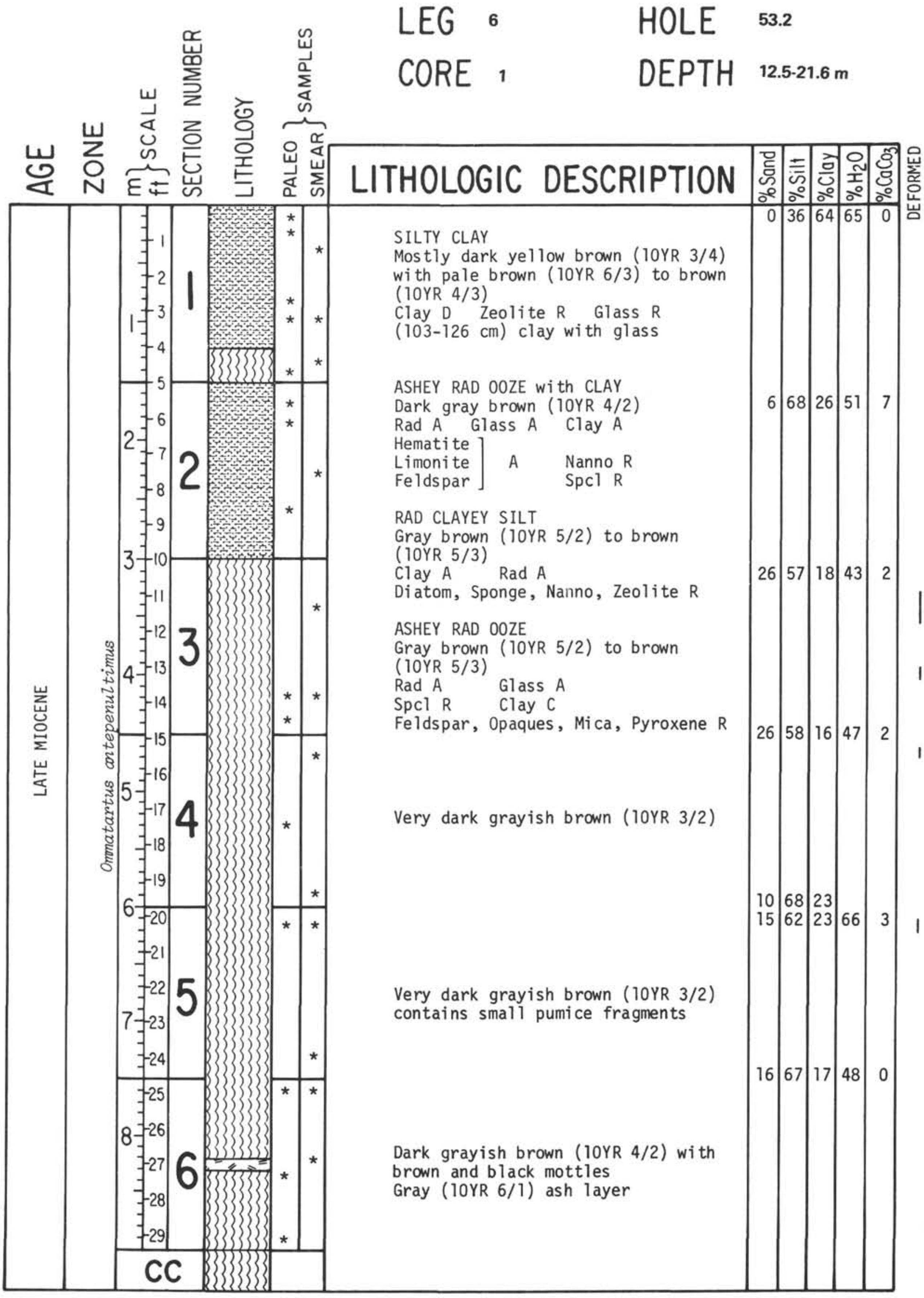


Figure 42. *Summary of lithology in Hole 53.2 Core 1.*

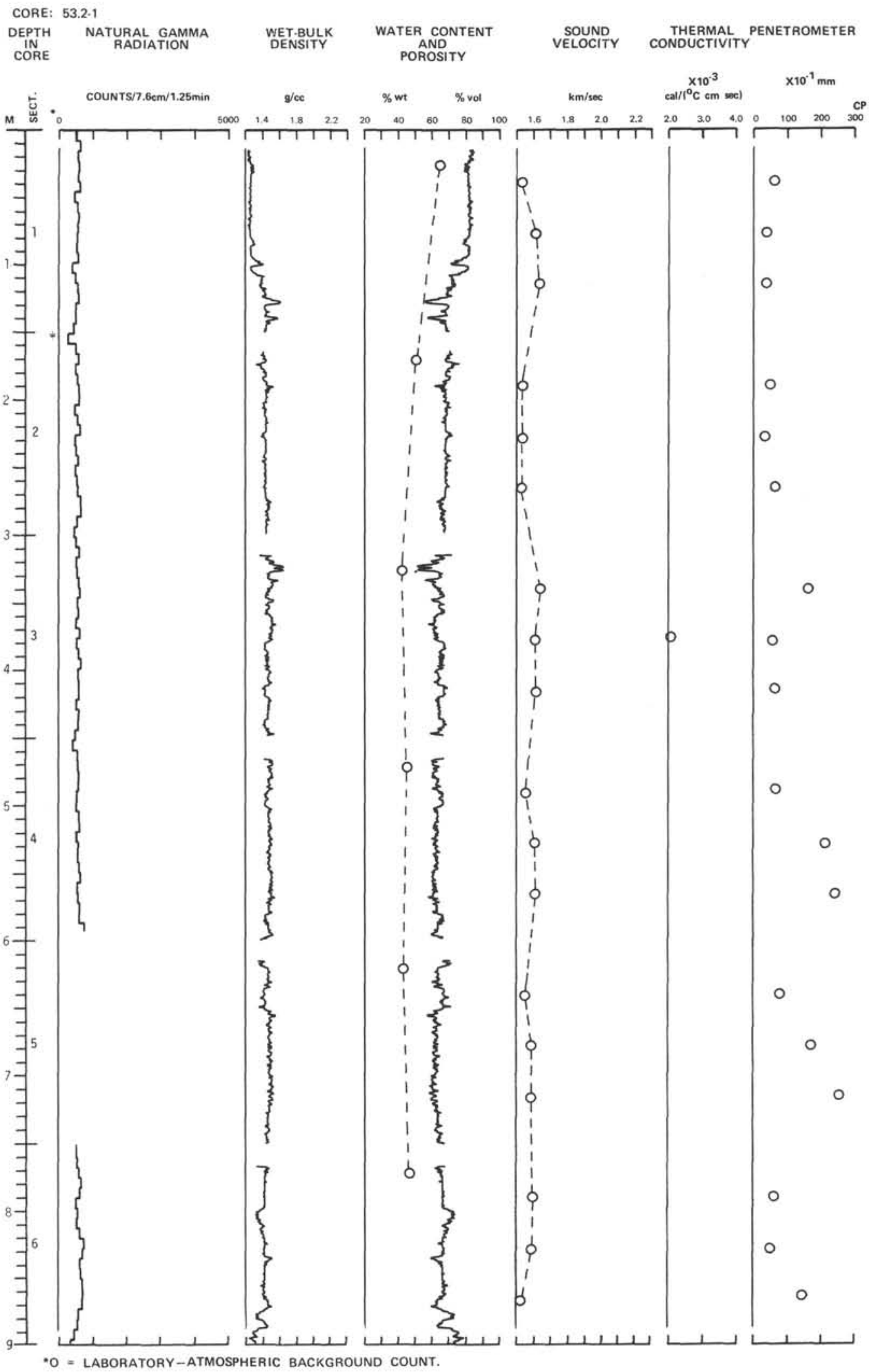


Figure 43. *Summary of physical properties in Hole 53.2 Core 1.*

LEG 6 HOLE 53.2

CORE 1 DEPTH 12.5-21.6 m

FORAMINIFERA	NANNOPLANKTON	RADIOLARIA
None.	Assemblages composed only of discoasters with dissolved centers are present sporadically in this core. Questionably identified species include *Discoaster brouweri* s.l., *D. challengeri*, *D. quintatus*, and *D. variabilis*. An upper Miocene correlation is indicated by this assemblage.	This core contains radiolarian species indicating the lower upper Miocene *Ommatartus penultimus* Zone. TOP: *Ommatartus antepenultimus, O. hughesi, Stichocorys delmontense, S. peregrina, Cannartus laticonus, Acrobotrys tritubus, Lithopera bacca, Cyrtocapsella cornuta, C. japonica.* BOTTOM: *Stichocorys delmontense, Ommatartus hughesi, O. antepenultimus, Cannartus laticonus, C. (?) petterssoni, Stichocorys peregrina, Lithopera bacca.*

Figure 44. *Summary of biostratigraphy in Hole 53.2 Core 1.*

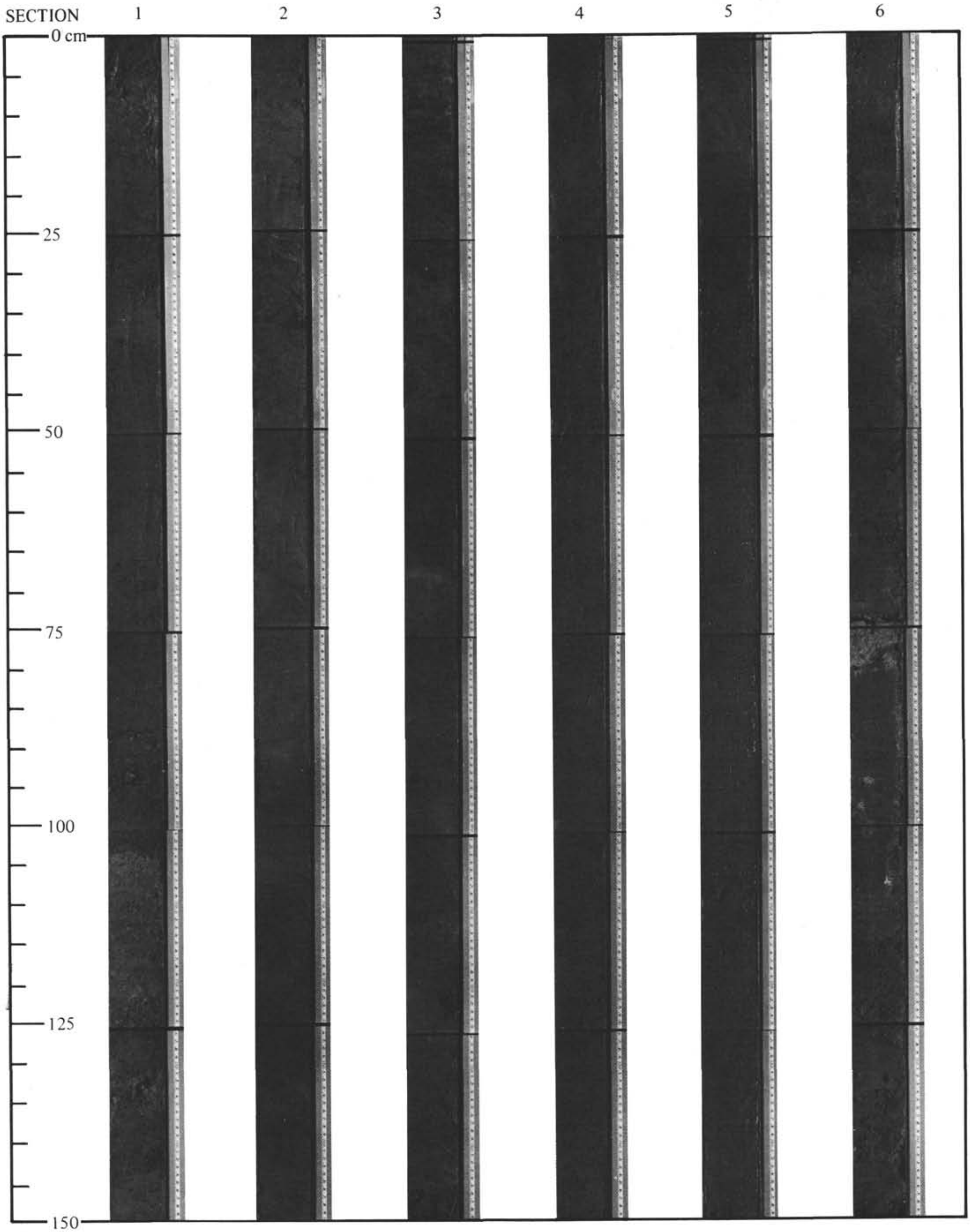


Plate 6. *Photographs of Hole 53.2 Core 1.*