3. SITE 219

The Shipboard Scientific Party[1]
With Additional Reports From
Norman Hamilton, University of Southampton, United Kingdom
Johannes Hunziker, Mineralogisch-petrographisches Institut der Universität, Bern, Switzerland
and
Paleontological Laboratories of the Geological Survey of India

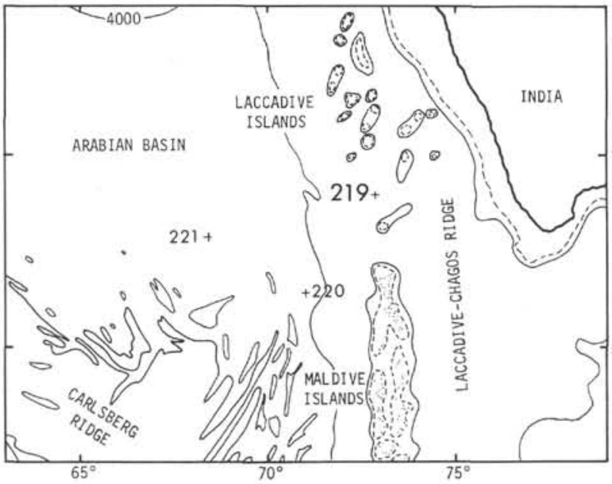


Figure 1. *Position of Site 219 and adjacent Leg 23 sites (shown by +). Contours at 200, 1000, and 4000 meters, from Laughton et al. (1971).*

SITE DATA

Dates: 1315 10 Mar-1945 13 Mar 72

Time: 78 hours **Holes Drilled:** 2

Position (Figure 1): 9°01.75′N, 72°52.67′E

Water Depth by Echo Sounder: 1764 corr. meters

Total Penetration: 411 meters

Total Core Recovered: 223.1 meters from 42 cores

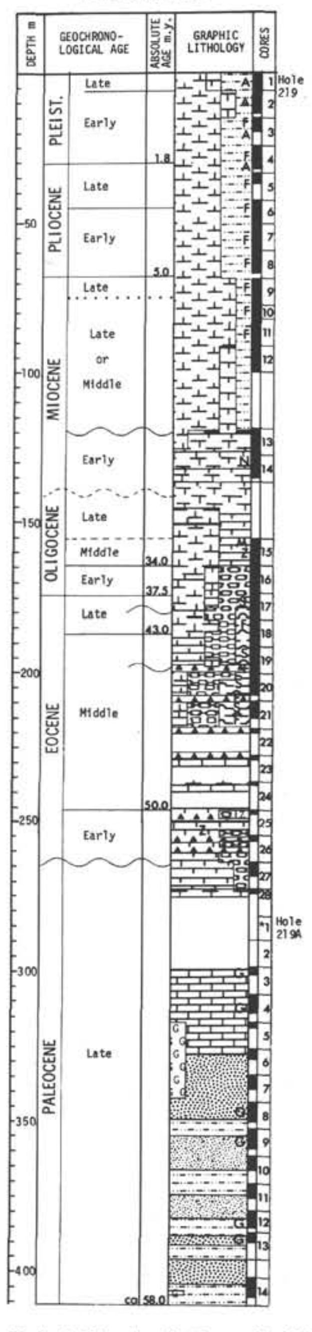
Age of Oldest Sediment: Late Paleocene

Basement: Unknown

ABSTRACT

Shallow-water Upper Paleocene limestones, sandstones, and siltstones are succeeded by Eocene chalk and ooze. The sea bed began to sink about 2000 meters in Early Eocene times. Biogenic silica, sometimes as chert, is common in the Eocene. Sedimentation was at a minimum in the Oligocene. Mainly detrital silty clay nanno ooze was laid down in post-Early Miocene times. Upwelling began in the Middle Miocene and continues today. Volcanic glass is found in the Pleistocene.

SITE SUMMARY



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[1] Robert B. Whitmarsh, National Institute of Oceanography, Wormley, Godalming, Surrey, United Kingdom; Oscar E. Weser, Scripps Institution of Oceanography, La Jolla, California: Syed Ali, State University of New York, Stony Brook, New York; Joseph E. Boudreaux, Texaco, Inc., New Orleans, Louisiana; Robert L. Fleisher, University of Southern California, Los Angeles, California; Dan Jipa, M.I.M.G. Institutul Geologic, Bucharest, Romania; Robert B. Kidd, Southampton University, Southampton, United Kingdom (Present address: National Institute of Oceanography, Wormley, Godalming, Surrey, United Kingdom); Tapas K. Mallik, Geological Survey of India, Calcutta, India; Albert Matter, Geologisches Institut, Universität Bern, Bern, Switzerland; Catherine Nigrini, Lexington, Massachusetts; Hassan N. Siddiquie, Geological Survey of India, Calcutta India (Present address: National Institute of Oceanography, Goa, India); Peter Stoffers, Laboratorium für Sedimentforschung, Universität Heidelberg, Heidelberg, Germany.

BACKGROUND AND OBJECTIVES

Site 219 is located on the crest of the Laccadive-Chagos Ridge (Figure 1). This ridge is a major linear feature of the floor of the Indian Ocean. Its origin has been said, even recently, to be both oceanic and continental by different authors. The almost complete lack of samples from the ridge, other than surficial sediments, has prevented detailed study of its history and nature. Thus a drill hole was clearly desirable but, although the ridge is a feature probably deserving half a dozen holes, time was only allotted for one reconnaissance hole on the northern part of the ridge. During Leg 24, a second hole was drilled near the Chagos Islands. The Laccadive-Chagos Ridge extends a distance of 2200 km in a north-south direction, from the Chagos Islands at 6°S to the Laccadive Islands at 14°N. The ridge is slightly arcuate, being concave to the west. A considerable length of the crest of the ridge is composed of shoals, banks, and coral reefs at depths less than 1500 meters, and, broadly, these shoal areas are grouped as the Laccadive, Maldive, and Chagos islands. Between the shoals, the water depth is commonly around 2000 meters and, exceptionally, reaches 4000 meters between the Maldive and Chagos islands. To the west of the ridge, the sea floor everywhere is relatively steep at first and then flattens out at around 4000 meters. The east flank is modified by the proximity of the Indian continental slope and abutting abyssal plain sediments at 2500 meters depth north of 3°N, but south of the equator a scarp is developed, which drops down to at least 4500 meters, with a parallel ridge and trough (the Chagos Trench) flanking the Chagos mass (information from unpublished charts prepared for the International Indian Ocean Expedition [IIOE] Atlas by R. L. Fisher and A. S. Laughton).

Before the drilling by *Glomar Challenger,* no sedimentary rock, other than coral rock and associated detritus, was known to have been obtained from anywhere along the whole length of the Laccadive-Chagos Ridge (Wilson, 1963). A single sample of a glassy basalt from the west flank of the Laccadive Islands (11°18′N, 71°00′E) has been reported by Vinogradov et al. (1969).

Probably the earliest geophysical measurements made on the ridge were the pendulum gravity observations of Glennie (1936) in the Maldive Islands. He found large negative isostatic anomalies (about -75 mgal) which he interpreted in two ways. First, if the anomalies are due to local superficial anomalies of density, such as a considerable thickness of coral rock, then the Maldive Islands "mark the original site of an oceanic ridge, not a continental block, which has since sunk down under isostatic adjustment." A second hypothesis proposed that the Maldives could lie over "an area where a block of sial has subsided as a result of the downwarping of the lower crustal layers." Glennie calculated coral thicknesses on the basis of these hypotheses, but his figures must be tempered by the fact that he used the Helmert gravity formula of 1901, not the 1930 formula which yields larger negative anomalies. On the other hand, the former gives a gravity value at this latitude which differs little from the newly adopted 1967 gravity formula (Woollard, 1969). In addition, however, account should be taken of the large regional negative free-air anomaly in this part of the Indian Ocean, recently discovered from satellite observations (Gaposchkin and Lambeck, 1971). This anomaly is about -60 mgal in the Maldive area, suggesting that the isostatic anomaly, if any, attributable to the sinking of the Maldive Islands is far less than Glennie supposed.

Magnetic observations by ships during the IIOE have shown that substantial magnetic anomalies (Figure 2), several hundred gammas in amplitude and with wavelengths of tens of kilometers, exist along tracks passing through the Laccadive and Maldive islands (D. H. Matthews, unpublished IIOE Atlas charts; Admiralty Hydrographic Office, 1963 and 1966). These observations led to wide acceptance by oceanographers that the Laccadive-Chagos Ridge has a basaltic and, therefore, probably oceanic foundation.

This conclusion has been borne out by the crustal velocities of 4.8 to 6.1 km/sec and 6.7 to 7.1 km/sec found by seismic refraction studies over the Ridge at latitudes 9°N, 2°S, and 5½°S (Francis and Shor, 1966). However, only at the northernmost station, situated very close to Site 219, was an upper mantle velocity detected, and this unreversed line indicated a crustal thickness of 17.5 km. At 2°S, the Moho is probably at least 20 km deep. Thus, Francis and Shor indicate that the depth at which a normal upper mantle velocity is reached beneath the Laccadive-Chagos Ridge is comparable with that close to Eniwetok Atoll, the inference being that the Maldive Islands rest on a subsided volcanic foundation. Before Leg 23, only five seismic reflection profiles which crossed the northern part of the ridge were available (Ewing et al., 1969; Harbison

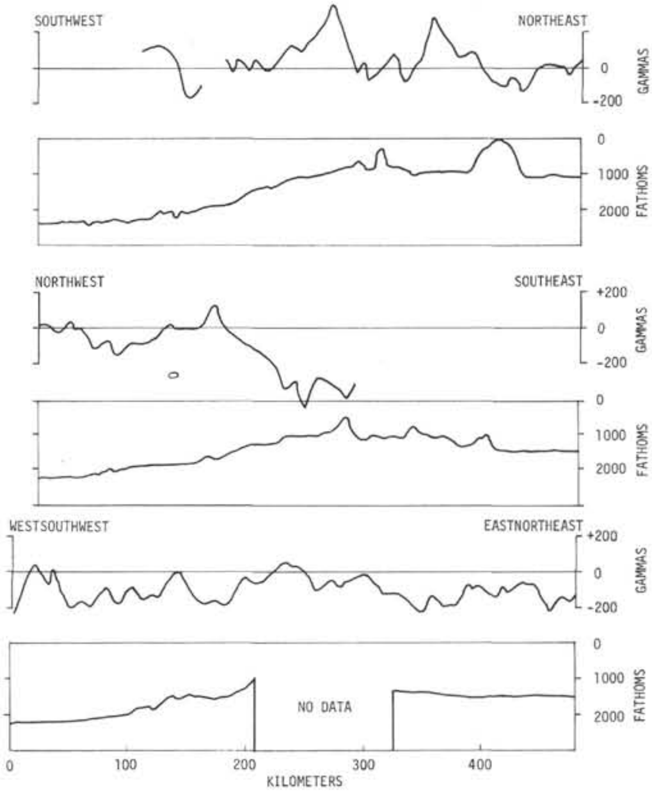

Figure 2. *Bathymetric and magnetic profiles across the northern part of the Laccadive-Chagos Ridge obtained by H.M.S.* Owen *(Admiralty Hydrographic Office 1963). The profiles are arranged in order of decreasing latitude from top to bottom. Site 219 is situated between the two topmost profiles.*

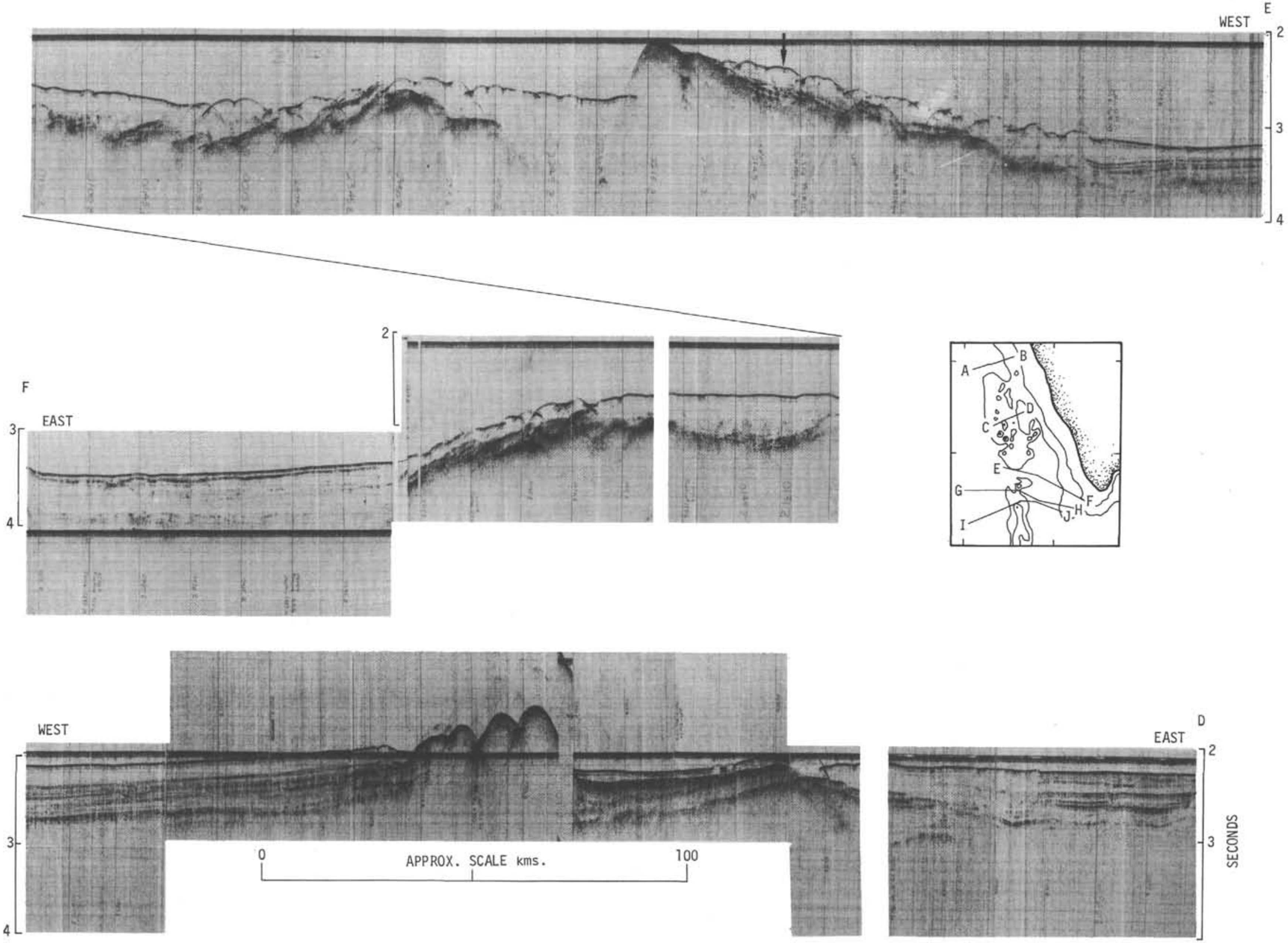

Figure 3. *Two seismic reflection profiles* (CD *and* EF) *across the northern end of the Laccadive-Chagos Ridge (courtesy of N.O.A.A. Atlantic Oceanographic and Meteorlogical Laboratories, Miami). The arrow on profile* EF *marks the proposed site. For tracks of these and other available profiles see inset; profiles* AB, CD, EF *from* Oceanographer, *1967; profile* GH *from* Vema-*19, 1963; profile* IJ *from* Conrad-*9, 1965.*

and Bassinger, 1973), and three of these were close together within the channel between the Laccadive and Maldive islands (Figure 3 inset). Due to the absence of any presite survey, these profiles, therefore, were the sole data from which a proposed site could be chosen. In general, all the profiles, except the northernmost one (profile AB, Figure 3 inset), show a sea bed over the ridge which varies from smooth to hummocky. It has a layer of transparent sediment usually at least 0.4 sec thick, overlying an irregular and probably faulted acoustic basement. In places, the basement crops out. Profile AB apparently has even thicker sediments which include turbidites, and the basement does not crop out but is only clearly seen at one point. The JOIDES Indian Ocean Panel had made a preliminary suggestion for a site in the general area of profile AB. In view of the above comments, however, and the possible complication of being rather close to the Indian continental margin, a site farther south was sought. The proposed site was located on the sediment covered west slope of a basement outcrop forming the crest of the ridge which is bounded by a 1100-meter scarp to the east (profile EF). A similar outcrop exists on profile CD, and it has been suggested by Harbison and Bassinger (1973) that together they form part of a basement ridge extending from 9°N to 20°N. The proposed site seemed to offer the best chance of sampling the acoustic basement in a region near the crest of the northern part of the Laccadive-Chagos Ridge and had the additional advantage of control from a nearby seismic refraction station (Francis and Shor, 1966).

The objectives of drilling the site were thus to:

1) Determine the nature of the true igneous foundation of the ridge and date it if possible.

2) Determine the history of the site from the sediments, and

3) Obtain samples for paleomagnetic measurements ashore.

The JOIDES Advisory Panel on Pollution Prevention and Safety set the operational constraint that minimum coring requirements should be alternate coring and drilling.

OPERATIONS

Site 219 was approached from the east at 10 knots. At a distance of about 20 km from the proposed site, speed was reduced to 8 knots in order to improve the clarity of the airgun records during the presite survey. *Glomar Challenger*'s track passed up to 7 km to the south of the profile EF (Figure 3) obtained by *Oceanographer* and showed the same transparent layer overlying an irregular diffuse reflector. An east-facing fault scarp was initially crossed at 1505 hours. After a further 55 minutes, the ship turned north and then east to obtain an additional crossing of the fault scarp so as to determine its trend. Immediately after the second crossing of the scarp, *Glomar Challenger* turned to starboard onto a westerly course and reduced speed to 5 knots. A 13.5 kHz beacon was dropped under way at 1819 hours, 4½ hours after the ship had reduced speed to 8 knots for the site approach. Immediately after the towed gear had been brought onboard, the ship returned to the beacon to take up station.

A program of nearly continuous coring was planned. This resulted in the taking of 42 cores and the drilling of only 44 meters of sediment in two holes (Table 1).

The soft pelagic sediments on the sea floor were easily penetrated and the first 13 cores, spanning the interval 8 to 127 meters, were continuously cored. A punch core was taken at the surface to minimize sediment deformation. The somewhat more indurated chalks occurring between 127 and 210 meters were not as easily penetrated, and circulation was broken several times.

At Hole 219, some difficulties were encountered between 210 and 273 meters. Hard layers consisting mostly of chert alternated with softer material, including sands. Recovery of the softer material was poor as circulation had to be broken frequently. The inner barrel of the final core (Core 28) became stuck and the drillers were unable to effect circulation suggesting that the water jets in the bit were plugged. The drill string then had to be tripped back to the surface, terminating operations at this hole. The inner barrel was found to be stuck and the jets filled with a foraminifera sand, which apparently came from farther up the hole.

An offset of 200 feet to the east was made for Hole 219A and, to hopefully avoid the running sand found at the previous hole, it was drilled down to 290 meters or 17 meters below the bottom of the previous hole. One hundred barrels of mud were also spotted in the hole. The drill string was run with the inner core barrel in place during this operation, resulting in the recovery of 5.1 meters of sediment of unknown stratigraphic position in Core 1. Core 2 recovered no sediments and the drill string became temporarily stuck again, probably due to the running sands from farther up the hole.

Cores 3 to 14 encountered well-indurated sediments and bit weight had to be increased considerably. Also, the water pump was operated continuously throughout the coring operation. Fortunately, however, there were few, if any, soft sediment streaks, and core recovery was good. The penetration rate decreased as the sediments became progressively harder, and it was finally decided to abandon Hole 219A at a depth of 411 meters. When the bit was brought on deck the teeth showed practically no wear and the bearings were only slightly worn.

Glomar Challenger departed from Hole 219A at 0009 hours on March 14 in a northerly direction at 5 knots while the airguns and hydrophones were streamed. At a distance of about 2 km from the beacon the ship turned to port to take up a southerly course so as to pass over the beacon. The beacon was passed at a range of about 200 meters. Five minutes later the ship came up to full speed and began its passage track to Site 220 via a point at 8°15'N, 72°56'E. The purpose of this slight deviation from the direct track was to obtain a north-south profile across part of the Nine Degree Channel and thus obtain a continuous seismic section from an atoll into the deep water to the west and also to twice cross the projected trend of the NNE fault scarp seen 9 km to the east of Site 219.

A bathymetric chart was constructed of the area around Site 219 from the above site survey and from the collected soundings of other ships (Figure 4).

LITHOLOGY

Two holes (219 and 219A) were drilled at Site 219. The first hole was drilled down to 273 meters. A second hole,

TABLE 1
Coring Summary, Site 219

Core	Date/Time Core on Deck (Time Zone-5)	Depth Below Sea Floor (m)	Cored (m)	Recovered (m)
Hole 219				
	11 Mar:			
1[a]	0030	0-6	6.0	5.6
2	0250	6-15	9.0	7.3
3	0330	15-24	9.0	5.5
4	0415	24-33	9.0	8.2
5	0500	33-42	9.0	4.4
6	0545	42-51	9.0	9.0
7	0630	51-60	9.0	8.0
8	0715	60-69	9.0	7.8
9	0800	69-78	9.0	8.8
10	0845	78-82	4.0	9.3
11	0930	82-91	9.0	8.8
12[b]	1035	91-100	9.0	8.6
13[c]	1150	119-128	9.0	9.0
14[d]	1250	128-137	9.0	8.4
15	1350	156-165	9.0	9.4
16	1450	165-174	9.0	9.0
17	1550	174-183	9.0	7.5
18	1620	183-192	9.0	9.3
19	1715	192-201	9.0	9.4
20	1810	201-210	9.0	8.0
21[e]	1930	210-219	9.0	5.3
22	2040	219-228	9.0	CC
23	2220	228-237	9.0	CC
24[f]	2330	237-246	9.0	CC
	12 Mar:			
25	0015	246-255	9.0	0.5
26	0130	255-264	9.0	1.5
27	0220	264-273	9.0	3.9
28[g]	1000	273-273	0.0	cc
		Totals	235.0	172.5
Hole 219A				
	12 Mar:			
1[h]	2105	0-290	–	5.1
2[i]	2210	290-299	9.0	0.0
3	2320	299-308	9.0	2.2
	13 Mar:			
4	0040	308-317	9.0	4.7
5	0130	317-326	9.0	2.0
6	0225	326-335	9.0	2.4
7	0345	335-344	9.0	3.6
8	0500	344-353	9.0	6.8
9	0610	353-362	9.0	6.2
10[j]	0900	362-371	9.0	3.9
11	1055	371-380	9.0	4.3
12	1345	380-387	7.0	6.3
13	1600	387-396	9.0	2.2
14[k]	1900	402-411	9.0	6.0
		Totals	115.0	50.6

[a] Punch core, 2 inch liner.

[b] Rotating at 20 r.p.m. (at least) from here on.

[c] Drilled 19m with core barrel in place.

[d] Broke circulation for first time.

[e] Cut in 30 mins, previously 4 to 12 mins.

[f] Spotted mud before coring.

TABLE 1 *footnotes continued*

[g] Bit and core barrel stuck.

[h] Core collected while drilling 290m, spotted mud before retrieving core.

[i] Pipe and core barrel stuck temporarily.

[j] Coring time 1-2 hours from here on.

[k] Spotted mud before coring.

219A, was drilled to a depth of 411 meters. The first hole, excepting for several small intervals, was continuously cored down to 273 meters. Hole 219A was washed down to 290 meters and then cored continuously from 290 to 411 meters.

Five lithologic units were recognized. These are shown in Table 2.

Unit I

The entire upper part of this unit consists of detrital silty clay nanno ooze which, with decreasing detrital content, becomes a detrital silty clay-rich nanno ooze in the lower part. The detrital percentage varies from 20 to 35 while nannofossils are more than 55 percent and calcium carbonate ranges from 52 to 76 percent. The upper 15 meters, and the lower 30 meters, are foraminifera rich (about 15%). Volcanic glass, apparently fresh, is common as disseminated grains in the upper 35 meters but does not exceed 5 percent. The sediments are varied shades of gray except for a thin olive-brown bed in Core 1, Section 3, 130 to 150 cm. The percentage of organic carbon (0.2% to 0.3%) is relatively high in this unit.

Unit II

This unit is characterized by nanno-rich foram chalk and ooze in the upper part and foram chalk and ooze in the lower part, all of which are white in color. In the upper part, the percentage of nannofossils varies from 5 to 40 while that of foraminifera is from 60 to 95, and in the lower part, the foraminifera vary from 90 to 98 percent. The calcium carbonate varies from 86 to 98 percent. The alternating ooze and chalk layers are a few decimeters thick. The change in lithology from unit I to unit II is marked by a fairly abrupt color change from gray to white, by the almost complete absence of detrital minerals, as well as by a sudden increase in foraminifera. Chalk was first cored in this unit.

Unit III

This 73-meter unit consists of white oozes and chalk which contain some thin chert beds. The upper part is characterized by about 92 percent calcium carbonate, the middle part by 84 to 87 percent and the lower part by 71 to 72 percent. Lithologically, the unit can be subdivided into four subunits.

Subunit IIIa is characterized by foram nanno ooze and chalk which is locally zeolite bearing. Nannofossils constitute up to 65 percent and forams to about 13 to 35 percent of the sediments. Minor amounts of micarb first occur in this subunit.

Subunit IIIb is a foram-rich nanno micarb ooze and chalk. As the sediment name indicates, micarb particles are the dominant constituent.

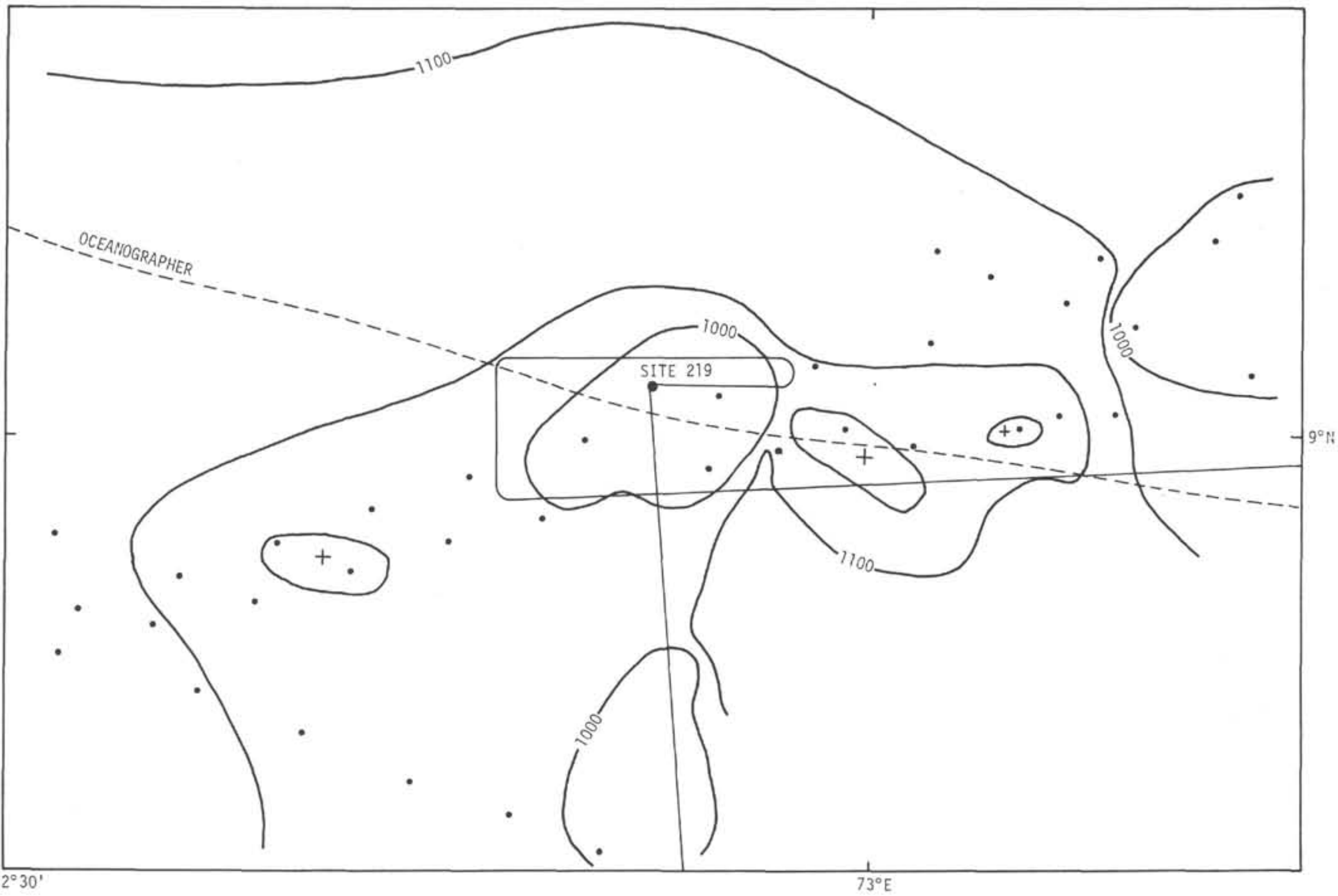

Figure 4. *Bathymetric chart of the area around Site 219 with the tracks of* Glomar Challenger *and* Oceanographer. *Contour interval 100 fms, depths in corrected fathoms, dots represent soundings by other vessels.*

Subunit IIIc consists of rad-rich micarb nanno ooze and chalk. Minor glauconite-bearing intervals also occur. In the upper portion of this subunit, the composition is as follows: foraminifera (5% to 25%), micarb (20% to 65%), nannofossils (15% to 60%), zeolite (trace to 10%), Radiolaria (5% to 20%), and sponge spicules (2% to 8%). Both the radiolarians and sponge spicules increase towards the lower portion of the subunit. A decrease in siliceous organisms from 15 to 5 percent between Core 19, Section 5 and Core 19, Section 6 is accompanied by chert formation and development of up to 8 percent zeolites. The chert intervals are thin and only occur sporadically.

Subunit IIId consists of nanno-rich rad micarb ooze and chalk and also chert. Cherts appear at the bottom of Core 19; below this there are many thin layers of chert. These coupled with the presence of abundant radiolarians give the entire interval a highly siliceous aspect. Nannofossils range from 15 to 20 percent, Radiolaria, 20 to 25 percent, micarb, 40 to 55 percent, and sponge spicules and forams, about 5 percent each.

The chalk and ooze intervals occur in roughly equal amounts in alternating intervals a few centimeters to a meter thick.

Unit IV

The recovery in the unit was poor, but both hard and soft intervals were recovered. The hard streaks consist of thin yellowish-green chert and limestone. The softer sediments, which are more prevalent, consist of nanno ooze, foram chalk, micarb foram ooze and chalk, and zeolite micarb-rich foram chalk, Larger foraminifera are particularly abundant, and they, having the properties of a "running sand," were probably responsible for the drill pipe sticking and subsequent abandonment of Hole 219. No doubt the largely unrecovered sediment from this unit consists of the softer sediment washed away during drilling of the hard streaks. Some phosphorite concretions were found in Core 26 of this unit. Electron microscope studies of a sample from 24, CC reveal the presence of cristobalite spherules.

Hole 219A, Core 1 represents material which accumulated in an open core barrel as the bit was washed down to 290 meters. Consequently, this mélange of nondiagnostic material is not part of the unit description nor is it represented on the Site Summary.

Unit V

Subunit Va (the top 27 m) consists of grayish-yellow to grayish-green limestone. Much of the sequence is glauconite rich or glauconite bearing. The calcium carbonate content varies from 73 to 86 percent. The limestone contains foraminiferal and molluscan shell fragments. Some intervals show burrow structure and parallel and cross-laminations.

TABLE 2
Lithologic Summary, Site 219

Lithology		Thickness (m)	Subbottom Depth (m)	Cores
Units	Subunits			
I Light gray, greenish-gray DETRITAL SILTY CLAY NANNO OOZE. The upper and lower portions are foram-rich.		120	0-120	1-13
II White FORAM OOZE and CHALK, nanno-rich in upper part.		Ca. 26	120-146	13-14
III White OOZES and CHALKS containing nannos, forams, rads and micarb in varying proportions.		73	146-219	15-21
	a White FORAM NANNO OOZE and CHALK.	19		
	b White FORAM-RICH NANNO MICARB OOZE and CHALK.	13		
	c White RAD-RICH MICARB NANNO OOZE and CHALK.	26		
	d White NANNO-RICH RAD MICARB OOZE and CHALK. Also CHERT layers.	15		
IV Grayish-yellow to yellow-brown MICARB CHALK and OOZE, LIMESTONE and CHERT.		81	219-300	22-27 1A-2A
V Green and black LIMESTONE, SANDSTONE and SILTSTONE.		111	300-411	3A-14A
	a Grayish-green LIMESTONE, GLAUCONITE-BEARING or GLAUCONITE-RICH.	27		
	b Yellowish-green to grayish-green and dark gray CALCAREOUS CEMENTED SANDSTONE, SILTSTONE and CLAYEY SILTSTONE. Gray to greenish-black CLAYEY SILTSTONE and SILTY SANDSTONE.	84		

Note: Only sediment names are capitalized.

Subunit Vb is dominated by terrigenous sediments consisting of yellowish-green to grayish-green and dark gray siltstone, clayey siltstone, grayish- to greenish-black clayey siltstone, and silty sandstone. Near the top is a 17-meter interval of calcareous cemented glauconitic sandstone which appears to be transitional between subunits Va and Vb. Some sediment layers are rich in shell fragments including pelecypods, foraminifera, ostracods, red algae, and bryozoans, which gives the interval a calcareous aspect in places. The calcium carbonate in this subunit ranges from 1 to 58 percent. The sequence is mostly well indurated or cemented, locally laced by calcite veins (0.2 to 0.5 m thick) and in places strongly bioturbated. Some beds are well laminated, and sandstone beds near the base of this subunit show graded bedding as well as load casts and convolute bedding. Glauconite occurs in some of the intervals.

Due to limited space, the tables of grain size, carbon-carbonate, X-ray data, *ph*, and salinity are presented with the data of other sites in Appendices I, II, III, and IV, respectively, at the end of the volume.

BIOSTRATIGRAPHY

Foraminifera

Sediments throughout most of the section drilled at Site 219 contain rich populations of planktonic foraminifera representative of tropical or subtropical environments. The downhole distribution of planktonic foraminiferal zones is shown on Figure 5. Benthic foraminifera in the recovered samples suggest as well that during post-Early Eocene time, water depths at this site have been approximately 2500 meters or greater (lower bathyal or abyssal).

Planktonic faunas indicative of Zone N. 23 (notably, *Globigerinella adamsi*) were observed only in the top sample (Core 1, Section 1, 110-112 cm) but may represent contamination from unrecovered overlying sediments. The basal occurrence of *Globorotalia truncatulinoides*, here taken as the base of the Pleistocene, is in Core 4, Section 4, 70-72 cm.

The Pliocene foraminiferal zones are very poorly developed. *Globorotalia tosaensis* is very rare or absent

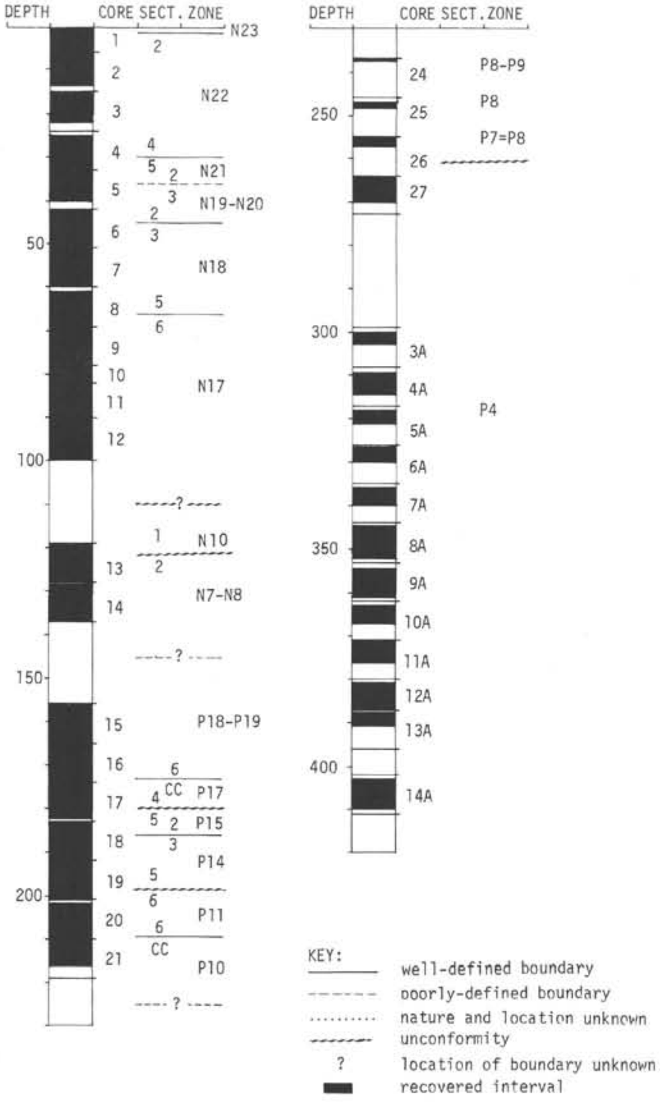

Figure 5. *Foraminiferal zonation, Site 219, depth in meters.*

below the base of the Pleistocene, and the N. 21/N. 20 boundary is placed at Core 5, Section 2, 73-75 cm, the lowest occurrence of *G. tosaensis* and the highest of *Sphaeroidinellopsis sphaeroides.* Zones N. 20 and N. 19 could not be differentiated in this hole.

The basal appearance of *Sphaeroidinella dehiscens immatura*, recognized in Core 6, Section 2, 73-75 cm, marks the base of Zone N. 19, although because this horizon coincides with the extinction of *Globorotalia margaritae*, it appears this event may be somewhat younger here than elsewhere. The Miocene-Pliocene boundary, defined by the initial appearance of *G. tumida tumida,* is located in Core 8, Section 5, 70-72 cm.

Cores 9 through 12 are of Late Miocene (N. 17) age. *Turborotalia acostaensis* is common throughout this interval; *Candeina* spp. and *Globorotalia tumida plesiotumida* are rare but generally present. Significant reworking from lower Middle Miocene sediments is indicated by the presence of common *Turborotalia siakensis* and sporadic occurrences of *Globigerinoides subquadratus* and *Globorotalia* cf. *praefohsi.*

Faunas representative of early Middle Miocene Zone N. 10 are present in Sample 13-1, 68-70 cm. Sample 13-1, 130-132 cm, however, contains a late Early Miocene (N. 8) fauna, including *Globorotalia archeomenardii* and *Globigerinoides sicanus,* indicating a minor unconformity between these two samples corresponding to a pronounced lithologic change at this horizon. The remainder of Cores 13 and 14 represent Early Miocene Zones N. 8 and N. 7. Planktonic foraminifera are particularly abundant in the sediments of these cores, which may indicate winnowing of the nannofossils. Alternatively, the generally diminished fragmentation of foraminiferal tests in these samples suggests that low levels of calcite solution may have been a factor as well. It is difficult to visualize changes in productivity which would increase the foraminiferal populations at the expense of the nannoplankton, particularly in view of the relatively slow sedimentation rate over this interval.

By contrast, test solution is high in sediments from Cores 15 and 16, which contain small and relatively nondiagnostic faunas of Middle to Early Oligocene (P. 18 to P. 19) age. Sample 16, CC and Core 17, Sections 1 through 4, contain Late Eocene (P. 17) faunas. *Globigerinatheka semiinvoluta* appears in Sample 17-5, 51-53 cm, indicating a P. 15 age assignment and suggesting a minor unconformity (representing Zone P. 16) above this sample. The highest occurrence of *Truncorotaloides pseudodubius*, which marks the top of Middle Eocene Zone P. 14, is present in Sample 18-3, 53-55 cm; faunas of this age persist as low as Sample 19-5, 51-53 cm. Below this horizon is located another minor unconformity; in Core 19, Section 6 through Core 20, Section 6, the presence of *Morozovella aragonensis aragonensis* indicates assignment to Zone P. 11. Samples 20, CC through 21, CC are of P. 10 age, based on the presence of *Hantkenina mexicana aragonensis.* No foraminifera were recovered from Cores 22 and 23.

Considerable difficulty was encountered at this and other sites in adequately differentiating early Middle and Early Eocene zones; this was largely due to the absence of several diagnostic zonal taxa and confusion about the ranges of others. As a result, while the samples recovered from Cores 24, 25, and 26 could be recognized as Lower Eocene (as generally defined by planktonic foraminifera), no definite zonal determinations could be made.

A major faunal discontinuity occurs between Cores 26 and 27. All cores above this horizon contain faunas composed largely of planktonic species; roughly 90 percent of the specimens in Sample 26, CC are planktonic, although the ratio is somewhat lower in some Oligocene and Upper Eocene samples because of selective solution of planktonic tests. In samples from Core 27 and from most cores in Hole 219A, planktonic foraminifera are relatively rare, and where foraminifera are present, benthic species predominate. Core 27 and Core 3A to Core 8A, Section 1 commonly contain significant numbers of benthic and larger foraminifera, bryozoans, ostracods, and echinoid spines, a tropical assemblage indicative of inner neritic water depth. The relative abundance of benthic foraminiferal species decreases somewhat in Cores 5A through 14A, suggesting slightly deeper (but probably still neritic) water. In any case, sediments in and below Core 27 were deposited in water much shallower than the sediments above. The shallow-water sediments are entirely of Late Paleocene (P. 4) age; *Globanomalina pseudomenardii* is present in Samples 27-1, 100-102 cm and 219A-12-3, 82-84 cm, along with other, generally rare, Paleocene species. The paleoecology of these Paleocene sediments is discussed in greater detail by the Paleontological Laboratory of the Geological Survey of India (this chapter).

Nannofossils

Hole 219 was drilled in sediments ranging in age from Pleistocene to Early Eocene. Abundant nannofossils were encountered throughout most of the section in sediments deposited in a bathyal environment.

The Late Pleistocene is present in Samples 1-1, 107-108 cm; 1-2, 75-76 cm; and 1-4, 76-77 cm. *Gephyrocapsa oceanica, Gephyrocapsa caribbeanica, Gephyrocapsa protohuxleyi, Helicopontosphaera kamptneri, Emiliania huxleyi, Cyclococcolithus leptoporus,* and *Umbilicosphaera mirabilis* are the most common nannofossils noted in Core 1, Section 1 through Core 1, Section 4. The Early Pleistocene is present in Sample 1, CC and ranges down to Core 4, Section 4, 76-77 cm. The most common nannofossils of the Early Pleistocene interval are *Pseudoemiliania lacunosa, Coccolithus doronicoides,* and *Scyphosphaera campanula.*

The Late Pliocene is present in Sample 4-5, 80-81 cm, and extends down to Sample 6-2, 79-80 cm. *Discoaster brouweri, Discoaster pentaradiatus,* and *Discoaster surculus* are common nannofossils present in the Late Pliocene interval. The Plio-Pleistocene boundary is present between 4-4, 76-77 cm and 4-5, 80-81 cm. The interval between 6-3, 79-80 cm and 8-5, 75-76 cm represents the Early Pliocene, and significant nannofossils within this interval include *Sphenolithus abies, Reticulofenestra pseudoumbilica, Discoaster variabilis, Discoaster challengeri, Discoaster asymmetricus, Ceratolithus rugosus, Ceratolithus tricorniculatus, Discoaster neohamatus,* and *Umbilicosphaera cricota.*

The Miocene-Pliocene boundary, as defined by nannofossils, occurs between 8-5, 75-76 cm and 8-6, 75-76 cm and is based on the extinction level of *Discoaster quinqueramus* in 8-6, 75-76 cm. *Discoaster calcaris, Discoaster quinqueramus,* and *Triquetrorhabdulus rugosus* are commonly present in the Late Miocene interval. The middle Miocene-Late Miocene boundary occurs between 9-4, 75-76 cm and 9-5, 75-76 cm and is based on the extinction level of *Discoaster hamatus.* The Middle Miocene interval ranges from 9-5, 75-76 cm down through 13, CC. Middle Miocene nannofossils present within this interval are *Discoaster hamatus, Scyphosphaera amphora, Catinaster coalitus, Discoaster dilatus, Discoaster perclarus, Coccolithus neogammation, Discoaster kugleri, Discoaster exilis, Sphenolithus moriformis,* and *Sphenolithus heteromorphus.* The Early Miocene ranges from 14-1, 79-80 cm to 14, CC, and nannofossils common to this interval are *Discoaster molengraafi, Coccolithus* aff. *C. bisectus, Sphenolithus belemnos, Sphenolithus conicus, Helicopontosphaera ampliaperta* and *Discoaster nephados.* The early Early Miocene and Late Oligocene were not cored in this hole.

The Middle Oligocene ranges from 15-1, 79-80 cm to 15, CC. *Coccolithus eopelagicus, Coccolithus bisectus, Sphenolithus distentus, Sphenolithus predistentus, Helicopontosphaera compacta, Discoaster woodringi,* and *Discoaster deflandrei* are present in the Middle Oligocene interval. The Early Oligocene ranges from 16-1, 78-79 cm to 16, CC and common nannofossils present in this interval include *Braarudosphaera rosa, Micrantholithus flos, Reticulofenestra umbilica, Cyclococcolithus lusitanicus, Discoaster tani tani, Discoaster plebeius, Discoaster germanicus,* and *Ismolithus* cf. *recurvus.*

The Eocene ranges from 17-1, 127-128 cm down to 27-1, 123-124 cm. The Oligocene-Eocene boundary is present between 16, CC and 17-1, 127-128 cm, and Late Eocene sediments are present down to 18-3, 79-80 cm. *Cyclococcolithus formosus, Discoaster saipanensis, Discoaster barbadiensis,* and *Syracosphaera bisecta* are commonly seen in the Late Eocene interval. The Middle Eocene interval extends from 18-4, 82-83 cm to 24, CC. Common Middle Eocene nannofossils seen in this hole include *Chiasmolithus grandis, Sphenolithus obtusus, Sphenolithus spiniger, Sphenolithus radians,* and *Discoaster sublodoensis.* The Early Eocene is present in Core 25, and *Discoaster lodoensis* is present within this interval. Nannofossils are not present in 27-2, 75-76 cm and 27, CC. The sediment in the bottom of Core 27 is largely composed of recrystallized calcite laths. A bit sample from Core 28 reveals a total absence of nannofossils.

Hole 219A was drilled in sediments of Paleocene age. Environments encountered throughout the cored section indicate marine continental shelf-type deposition with conditions favorable for the formation of glauconite. Nannofossils are rare and corroded in Cores 4, 5, 6, 7, 8, 9, 10, 12, and 14. The presence of *Cruciplacolithus tenuis* in 10-3, 124-125 cm was established. Poor preservation of nannofossils in this interval is detrimental to proper identification of individual species and an accurate age determination was not obtained in the bottom of this hole from nannofossil data.

Radiolaria

Rare, often fragmented, specimens of Radiolaria are present in the core catcher samples of Cores 1 through 10. No age assignment based on Radiolaria was possible in this interval. Radiolaria are absent from Core 11 through Sample 16-5, 12-14 cm. At 16-5, 28-30 cm, a rich radiolarian fauna appears that belongs to the *Thyrsocyrtis bromia* Zone, which spans the Eocene-Oligocene boundary. There is no obvious megascopic change in lithology between the radiolarian and nonradiolarian parts of the core. The base of the *T. bromia* Zone lies between Core 18, Sections 4 and 5.

Between Core 18, Section 5 and Core 19, Section 5 the radiolarian fauna is characteristic of the *Podocyrtis mitra* Zone (Middle Eocene). Both *Podocyrtis chalara* and *Podocyrtis goetheana* are absent from Site 219 and so it is not possible to recognize the *P. chalara* and *P. goetheana* zones, as described by Riedel and Sanfilippo (1970) and by Moore (1971).

Below the *P. mitra* Zone lies a new zone, the *Podocyrtis ampla fasciolata* Zone (Middle Eocene) which seems to parallel stratigraphically the *Podocyrtis ampla ampla* Zone of Riedel and Sanfilippo (1970). *P. ampla ampla* is absent from the present material. For discussion of this new zone see Nigrini (this volume*). Between the *P. mitra* and *P. ampla fasciolata* zones there is an apparent faunal gap owing to the formation of chert in Core 19, Section 6. Radiolaria are common and well-preserved in Core 19, Section 5 and Core 19, CC, but are almost absent from Core 19, Section 6.

The *Thyrsocyrtis triacantha* Zone (Middle Eocene) extends from Core 20, Section 6 to Core 21, CC. Core 21 bottomed in chert.

Below the chert layer, in the core catcher sample of Core 24, a sparse and poorly preserved assemblage appears to belong to the *Theocampe mongolfieri* Zone (lower Middle Eocene). Radiolaria were not found in subsequent Site 219 cores.

Benthonic Foraminifera[2]

A total of 33 samples has been studied out of which four samples, i.e., 219A-13-2, 60-63 cm; 219A-11-2, 82-83 cm; 219A-10-3, 130-131 cm; and 219A-10-2, 127-128 cm from the Lower Paleocene are devoid of any benthonic foraminifera. However, the overlying and underlying samples have yielded a fairly continuous assemblage. Absence of benthonics in these samples may be ascribed to local unfavorable ecological factors.

Sixty-six genera have been identified, the majority of them ranging from Cretaceous to Recent with wide geographical distribution.

The larger foraminifera are represented by *Discocyclina ramaraoi* Samanta, *Discocyclina* sp., *Operculina canalifera,* and *Operculina* sp.

It may be noted that *Cibicidina* sp. has been reported only from Eocene strata in North American (Loeblich and Tappan, 1964, p. 686), but in the present assemblage *Cibicidina* sp. has been found dating back even to Early Paleocene.

The fauna is predominantly calcareous, only seven genera of arenaceous foraminifera, representing 10 percent of the total fauna, are present, suggesting an open-sea depositional environment.

The total benthonic foraminiferal percentage by dry weight is less than one percent in Lower Paleocene sediments, but it rises to three percent in the Middle Paleocene and then again declines in the Upper Paleocene. It suddenly jumps to 12 percent towards the top of the Paleocene and declines again towards the Lower Eocene, reaching less than one percent from the top of the Lower Eocene to the Lower Oligocene.

The distribution of benthonic foraminiferal genera in different samples and their state of preservation with foraminiferal percentage curve are depicted in Table 3.

The benthonic foraminiferal assemblage is similar to the Indo-Pacific foraminiferal fauna recorded from the east coast of India and from the Saipan Islands.

The characteristic foraminiferal species *Discocyclina ramaraoi* Samanta (Samanta, 1967), with variation from flat to triagonal shape of its test, is represented in the present assemblage. This species is known from the Pondicherry Formation (Middle Paleocene to basal Eocene) of the east coast of India and has not been recorded, so far, from any other localities in India. Its presence, therefore, suggests the possibilities of intermingling of the fauna of the east coast of India with the fauna from this site.

The general pattern of the benthonic foraminiferal assemblage and the abundance of larger foraminiferal genera towards the close of the Paleocene suggests an open-sea shallow-water neritic environment of less than 100 meter water depth for Site 219 during most of Paleocene and Eocene times.

Ostracods[3]

A study of the ostracod fauna was made from the same samples as those examined for benthonic foraminifera. Out of the 33 samples studied for foraminifera between the Samples 219-15-1, 100-102 cm to 219A-14-3, 138-140 cm only 14 samples yielded ostracods. The amount of ostracod fauna by dry weight percentage is negligible, and they are present in traces only. Their state of preservation is poor between Samples 219A-14-3, 138-140 cm and 219A-4-3, 60-62 cm. The rest show fair to good preservation.

Sixteen genera belonging to nine families are present in the assemblage with the genera *Bairdia, Cytherella, Krithe,* and *Loxoconcha* being the most common. The presence of *Cytherelloidea* in Samples 219-14-3, 138-140 cm and 219A-7-3, 48-49 cm suggest shallow, warm sea conditions. The interval between 219A-3-2, 119-120 cm, to 219-27-1, 60-61 cm suggests an epineritic environment of deposition with maximum development of ostracod fauna. From Sample 219-25-1, 138-140 cm and above, deep water genera such as *Paracypris, Bythocypris,* and *Macrocypris* are also present in the assemblage suggesting a gradual deepening of the site.

The general faunal pattern supports the evidence from benthonic foraminifera of a shallow epineritic to neritic environment throughout the Paleocene and up to the basal Eocene with a gradual deepening during the latter part of Early Eocene and later times. The distribution of the genera is shown in Table 4.

Biostratigraphic Summary

Nannofossils and planktonic foraminifera are common to abundant throughout most of the sediments collected in Hole 219, although both become rare to absent in Hole 219A. Faunal assemblages in this latter interval are dominated by such benthonic fossils as benthic and larger foraminifera, bryozoans, and ostracods. Radiolaria are rare or absent in post-Eocene sediments, well-developed in the Upper and Middle Eocene, again rare to absent in post-Eocene sediments, well-developed in the Upper and Middle Eocene, and again rare to absent at lower horizons.

Pleistocene sediments are present as low as Core 4, Section 4 (0 to 30 m), and contain abundant and well-developed nannofossil and foraminiferal assemblages. The Miocene/Pliocene boundary, as recognized here (top of *Discoaster quinqueramus* Zone), occurs in Core 8, Section 6 (69 m). The interval between Core 8, Section 6 and Core 9,

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[2] V. D. Mamgain, B. P. Chatterjee, M. K. Sen, and R. S. Misra of the Paleontology Division, Geological Survey of India under the guidance of M.V.A. Sastry.

*"This chapter will now be published in Volume 24 of the Initial Reports series."

[3] Paleontological Laboratories of the Geological Survey of India.

Section 4 contains sediments of Late Miocene (N. 17, *D. quinqueramus* Zone) age.

The interpretations of the sediment ages from Core 9, Section 5 through Core 12, CC are at variance, and it has not been possible to reconcile them. Nannofossil floras indicate a Middle Miocene, *D. hamatus* Zone, age, while the planktonic foraminifera suggest that this interval should be assigned to Zone N. 17, with considerable Middle Miocene reworking. The reader is advised to examine the nannofossil and foraminifera reports in this chapter, as well as the special chapters involving these groups (Boudreaux, Bukry, Fleisher*, and Akers*, all this volume).

Middle and Lower Miocene sediments were recovered from Cores 13 and 14 (119 to 137 m), although there is some disagreement between nannofossil and foraminiferal determinations as to where the boundary between them should be placed. Planktonic foraminifera are particularly abundant in samples from these cores, which may be the result of winnowing of the nannofossils or, in part, of decreased solution of foraminiferal tests.

Middle and Lower Oligocene sediments are present in Cores 15 and 16 (156 to 174 m). Radiolarians become abundant in Core 16, Section 5 (173 m), although they are absent in overlying strata. Late Eocene assemblages were recovered between Sample 16, CC and Core 18, Section 2 (174-186 m); this interval appears to contain a minor unconformity at 180 meters. A second Eocene unconformity at 200 meters is present within the Middle Eocene sequence.

Fossil assemblages recovered from Cores 24 through 26 (237-264 m), below the chert, contain common foraminifera, while radiolarians and nannofossils are rare to absent. These assemblages represent Lower Eocene deep-sea sediments. Core 27, however, is dominated by shallow-water (neritic) benthonic organisms; the rare planktonic foraminifera in this core and in samples from Hole 219A indicate that the shallow-water sediments in which this site was drilled (264 to 411 m) are entirely of Late Paleocene (foraminiferal Zone P. 4) age.

Sedimentation Rates

The fluctuations in the sedimentation rate at Site 219 probably reflect the fact that the site lies on the crest of a ridge. Shallow-water sediments of Paleocene age (264 to 405 m) accumulated at a rate of at least 70 m/m.y. (see Figure 6). In portions of this sequence, the sediments consist largely of the fossils of benthonic organisms. Lower and Middle Eocene sediments of deep-sea origin, separated from the Paleocene sediments by a significant unconformity (at approximately 260 m), accumulated less rapidly (18 m/m.y.).

A second unconformity at 200 meters is overlain by a continuous sequence of Middle and Upper Eocene sediments; the sedimentation rate of these deposits is not clearly established, but was at least 9 m/m.y. The Late Eocene to Middle Oligocene sequence (156-177 m) above the third unconformity (between Sections 4 and 5, Core 17, at approximately 178 m) was deposited at the lowest sedimentation rate observed at this site (2 to 5 m/m.y.). Above this interval, Lower Miocene sediments were deposited somewhat more rapidly (5 to 11 m/m.y.); whether an unconformity separates the Miocene and Oligocene cannot be determined due to nonrecovery (drilling) of the appropriate horizons. Another unconformity between Middle and Lower Miocene deposits within Core 13 (at 121 m) probably represents no more than 1 m.y.

The age of sediments between 77 and 100 meter has not been clearly established; alternative interpretations are shown on the accompanying chart. Minimal rates of 12 and 31 m/m.y. have been calculated for this interval, on the basis of nannofossil and foraminiferal determinations, respectively, but paleontological control is inadequate for a more precise calculation. The nannofossil ages for these sediments indicate the presence of an unconformity (at 76 m) above this interval; if the foraminiferal ages are correct, one may instead be present within the drilled interval separating Cores 12 and 13. The Upper Miocene to Pleistocene sediments (0 to 64 m) accumulated at the rate of 14 m/m.y.

GEOCHEMISTRY

The nanno ooze recovered from the upper 100 meters at Site 219 is apparently enriched in magnesium, titanium, chromium, copper, nickel, iron, and vanadium, compared to the sediments recovered from the basal 130 meters (Figure 7).

There is also a high correlation between concentrations of titanium, copper, chromium, nickel, iron, and vanadium. This suggests that these elements are contributed by a single mechanism, and that they have suffered little post-depositional migration. A preliminary examination of smear slides of sediments from Site 219 shows the presence of detrital material only in these upper 100 meters of sediments.

It is conceivable that during deposition of the upper 100 meters of the section, Site 219 was in a position to receive more detrital material than during the interval from 100 to 230 meters.

Another interesting feature of the section examined is an apparent correlation between the barium concentration and the relative abundance of nannofossils in the sediments as determined by smear slide examination. This association of barium with the biogenic aspects of oceanic sediments has been noted by various authors. Goldberg and Arrhenius (1958) have shown that in the areas of high productivity in the equatorial Pacific, the barium concentrations of the sediments are high. Turekian and Tausch (1964) also noted a similar relationship of barium to high productivity in the sediments of the Atlantic Ocean. Thus, the distribution of barium in the sediments of Site 219 could be related to productivity.

MINERALOGY AND K-Ar DATING OF GLAUCONITE[4]

At Holes 219 and 219A, 265 meters of Recent to Eocene deep-water pelagic oozes and chalks, containing mostly nannofossils and planktonic foraminifera, were found to overlie shallow-water sediments. The latter consist of chalks and limestones (60 m) with larger foraminifera. They are underlain by 90 meters of glauconitic limestones and glauconitic siltstones (see Lithology Section).

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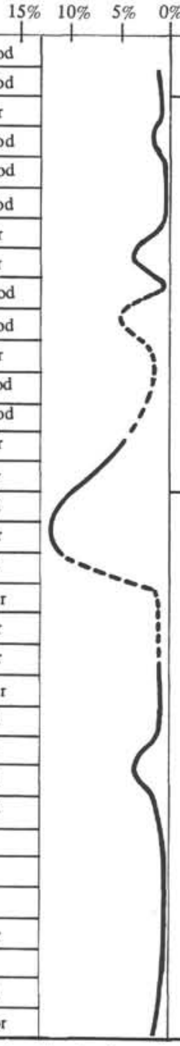
*"This chapter will now be published in Volume 24 of the Initial Reports series."

[4] J. Hunziker and A. Matter.

TABLE 3
Distribution of Benthonic Foraminiferal Genera, Site 219

					Lituolidae	*Textulariidae*			*Ataxophragmiidae*			*Fischerinidae*	*Miliolidae*		*Nodosariidae*								*Polymorphinidae*	*Glandulinidae*				*Turrilinidae*		*Bolivinitidae*
State of Presservation	Benthonic Foraminiferal Percentage Curve	Horizon		Sample (Interval in cm)	*?Haplophragmoides*	*Semivulvulina*	*Textularia*	*Vulvulina*	*Gaudryina*	*Tritaxia*	*Verneuilina*	*Fischerina*	*Quinqueloculina*	*Triloculina*	*Dentalina*	*Lagena*	*Lenticulina*	*?Marginulina*	*Nodosaria*	*Pseudonodosaria*	*Saracenaria*	*Vaginulina*	*Polymorphina*	*Glandulina*	*Fissurina*	*Oolina*	*Tristix*	*Buliminella*	*Turrilina*	*Bolivina*
																														
Good		Oligocene	Early	219-15-5, 100-102		x	x									x	x		x	x	x			x	x	x		x		x
Good				16-6, 70-72			x								x	x	x		x	x	x									
Fair		Eocene	Late	18-4, 40-42			x								x				x	x					x					
Good				19-6, 100-102			x	x							x		x		x					x						
Good			Middle	20-2, 120-122																				x						
Good				21-2, 120-122													x							x	x					
Fair			Early	25-1, 108-110			x	x		x				x		x	x		x							x			x	x
Fair				25-1, 138-140		x		x	x						x	x	x		x	x	x			x	x					
Good				25, CC																										
Good				26-1, 17-19		x	x		x	x			x		x	x	x		x		x					x	x			x
Fair				26-1, 135-137			x						x				x													
Good				27-1, 60-61						x				x		x	x	x												
Good				27-1, 95-96						x				x		x	x													x
Fair				27-1, 148-150			x				x				x	x	x										x			
Fair				27-3, 90-92			x			x					x	x	x													x
Bad		Paleocene	Late	219A-3-1, 139-140			x									x	x									x				
Fair				3-2, 27-28	x	x	x		x					x	x	x	x			x	x	x	x	x			x			x
Bad				3-2, 119-120		x	x		x					x		x	x		x						x					
Poor				4-2, 124-125			x										x													
Fair				4-3, 60-62													x													
Fair				5-2, 117-120													x													x
Poor				6-2, 34-35								x			x	x	x								x		x			
Bad			Middle	7-3, 48-49			x		x				x	x	x		x										x			
Bad				8-2, 35-40			x									x	x		x								x			
Bad				8-3, 56-57			x							x			x													
Bad				8-5, 22-23		x	x							x			x													
			Early	[a]10-2, 127-128																										
				[a]10-3, 130-131																										
				[a]11-2, 82-83																										
Fair				12-3, 115-116			x		x						x	x			x		x			x	x		x	x		x
				[a]13-2, 60-63																										
Bad				14-3, 32-33		x	x							x			x													
Poor				14-3, 138-140			x		x					x			x									x		x		x

[a] No benthonic foraminifera.

TABLE 3 – *Continued*

Eouvigerinidae		*Buliminidae*		*Uvigerinidae*	*Discorbidae*			*Siphonininidae*	*Epistomariidae*	*Spirillinidae*			*Rotaliidae*	*Nummulitidae*		*Eponididae*		*Cibicididae*				*Discocyclinidae*		*Pleurostomellidae*	*Caucasinidae*	*Loxostomidae*	*Nonionidae*					*Alabaminidae*			*Osangulariidae*	*Anomalinidae*			*Ceratobuliminidae*		
?Eouvigerina	*Stilostomella*	*Bulimina*	*Reusella*	*Uvigerina*	*Discorbis*	*Epistominella*	*Valvulineria*	*Siphoninella*	*Nuttalides*	*Conicospirillina*	*Patellina*	*Spirillina*	*Rotalia*	*Operculina* Sp *A*	*Operculina* Sp *B*	*Cibicorbis*	*Eponides*	*Cibicides*	*Cibicidella*	*Cibicidina*	*Planulina*	*Discocyclina Ramaraoi*	*Discocyclina* Sp	*Pleurostomella*	*?Caucasina*	*Loxostomum*	*Astrononion*	*Florilus*	*Nonion*	*Nonionella*	*Pullenia*	*Alabamina*	*Gyroidina*	*Svratkina*	*Osangularia*	*Anomalina*	*Gavelinella*	*Heterolepa*	*Epistomina*	*Hoeglundina*	*Lamarackina*
	x	x		x												x		x					x						x		x	x		x	x						
				x													x	x										x	x		x	x	x		x	x		x			
	x								x								x	x													x	x			x	x		x			
		x															x	x										x	x		x	x	x		x			x			
	x																x	x															x								
																	x	x													x		x		x						
					x			x	x				x	x			x	x					x	x					x		x				x			x			
				x	x												x	x										x							x	x		x			
														x	x							x	x						x							x		x			
	x	x	x		x				x	x		x		x			x	x				x	x		x			x	x		x		x		x	x		x		x	
	x									x		x										x	x					x								x					
					x									x				x					x						x			x	x								
					x					x				x			x	x					x						x			x	x			x	x				
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TABLE 4
Distribution of Ostracod Fauna, Site 219

Horizon		Sample (Interval in cm)	Genera															
			Bairdia	*Bythocypris*	*Macrocypris*	*Paraypris*	*Brachycythere*	*?Alatacythere*	*Krithe*	*Loxoconcha*	*Schizocythere*	*Trachyleberis*	*Hermanites*	*Occultocythereis*	*Quadracythere*	*Trachyleberidea*	*Cytherella*	*Cytherelloidea*
Oligocene		219-15-5, 100-102	x		x	x			x									
		219-16-6, 70-72				x		x	x									
Eocene	Late	219-18-4, 40-42							x			x						
		219-19-6, 100-102			x				x									
	Middle	219-20-2, 120-122	x				x											
		219-21-2, 120-122	x															
	Early	219-25-1, 108-110	x	x		x												
		219-25-1, 138-140			x				x									
		219-26-1, 17-19	x														x	
		219-27-1, 60-61	x						x	x				x	x			
		219-27-1, 95-96	x															
		219-27-1, 148-150				x				x							x	
		219-27-3, 90-92	x	x					x	x					x			
Paleocene	Late	219A-3-1, 139-140								x					x		x	
		219A-3-2, 27-28								x			x	x				
		219A-3-2, 119-120	x	x					x	x	x		x		x		x	
	Middle	219A-4-2, 124-125	x				x											
		219A-4-3, 60-62								x							x	
		219A-5-2, 117-120	x															
	Early	219A-7-3, 48-49	x				x											x
		219A-8-3															x	
		219A-8-5, 22-23	x									x		x			x	
		219A-14-3, 32-33	x												x			
		219A-14-3, 138-140	x							x				x		x	x	x

In contrast to the pelagic section where paleontologic control was excellent, only a general Paleocene age could be assigned to the shallow-water sediments because of their poorly developed microfossil assemblages. Therefore, it was decided to attempt glauconite dating with the potassium-argon method.

Two samples were studied, one, 219A-9-5, 5-40 cm, where paleontologic control was still available (Paleocene) and the other, 219A-14-4, 0-25 cm, from the bottom of the borehole and of unknown age.

Under the petrological microscope, the upper sample is a sandy, zeolite- and glauconite-rich biomicrite. Light to dark green "glauconite" occupies the cells and chambers of bryozoans, echinoderms, coralline algae, and larger foraminifera and replaces parts of pelecypod shells and, especially, the glassy matrix of sand- to silt-sized volcanic rock particles. The lower sample, though similar, is finer grained, much more recrystallized, and contains less "glauconite" (<15%). There the "glauconite" is a brownish green color.

The samples were first disaggregated using 5 percent acetic acid to get rid of the carbonate and then sieved and passed through a magnetic separator.

The fraction 0.175 to 0.150 mm was crushed and X-rayed after various treatments to identify the nature of the "glauconite." The green mineral from Core 9 is identical to what Porrenga (1967) named "proto" glauconite (see loc. cit, fig. 38) and which is actually

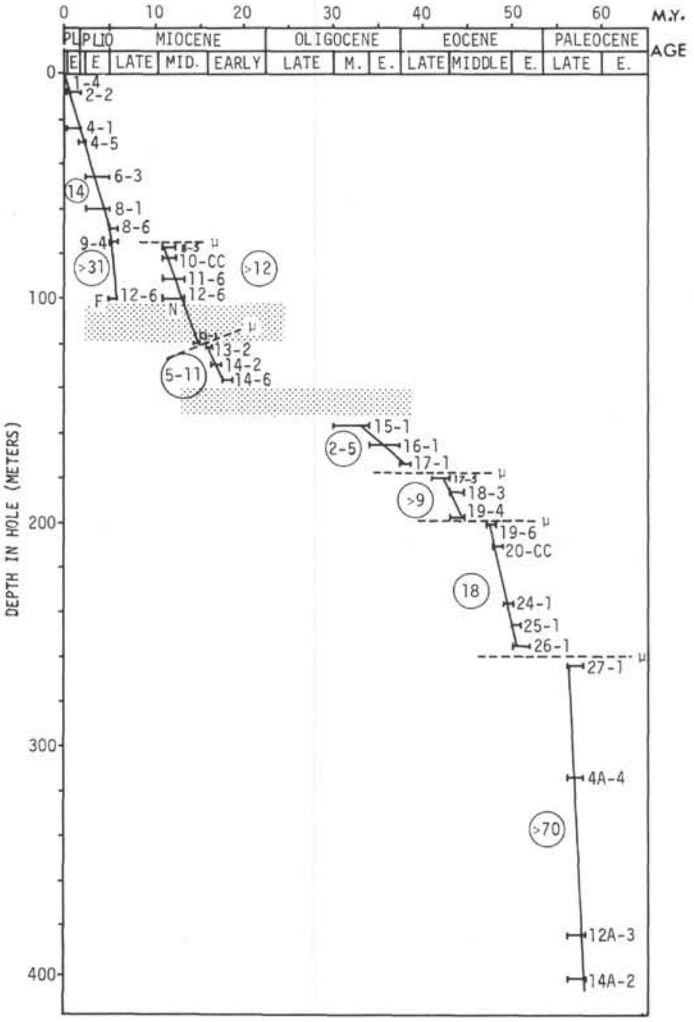

Figure 6. *Sedimentation rate curve, Site 219. Plotted bars are those sufficient to control slopes of lines. Stippled pattern represents some uncored intervals. See Chapter 2, Explanatory Notes, for explanation of age ranges and other symbols.*

montmorillonite. The brownish-green "glauconite" from the bottom of the borehole is also a montmorillonite mineral but probably a nontronite-like variety. This is suggested by its behavior after heating to 550°C, where all reflections disappear. A similar montmorillonite was noted in the Red Sea. A more detailed account of the nature and mineralogy of the "glauconites" from Site 219 will be published later.

Potassium was determined by flame photometry. Argon was extracted from the minerals with a high frequency furnace and measured by isotopic dilution using an Ar^{38} spike.

Isotope ratios were obtained on a GD 150, 180°mass spectrometer of Varian MAT Bremen (Germany), which is operated statistically. On the basis of interlaboratory standards, the accuracy of this technique for K plus Ar is estimated to be ± 4 percent. Line and techniques have been described by Purdy (1972).

The samples yielded the ages given in the following table, (Table 5).

TABLE 5
Radiogenic Ages of Site 219 Samples

	$cm^3 10^{-6} Ar^{40}{}_{rad}/gSTP$	Rad (%)	K (%)	Age (m.y.)
219A-9-5, 05-40 cm	3.89	56.2	2.32	41.6 ± 3.0
219A-14-4, 0-25 cm	4.31	56.1	2.43	43.9 ± 3.1

Both ages are Eocene and not Paleocene as shown by the paleontological evidence. Statistically, the two ages are not significantly different.

The X-ray analysis shows that the green mineral is not a glauconite *sensu stricto*. Obradovitch (1965) and Odin (in press) have already cautioned against using glauconites of this type for age determinations because readings may be up to 30 percent too low. Apparently, the lattice of montmorillonitic glauconites is not a closed system. The erroneous ages are, therefore, either due to argon loss or absorption of potassium or both.

PHYSICAL PROPERTIES

Sediment Density, Porosity, and Water Content

No major variation in density is evident over the upper 100 meters at this site. The first 12 cores recovered display a steady, but slight, gradient from 1.56 to 1.70 g/cc, presumably related to increasing sediment compaction. This interval corresponds to lithological unit I which shows only gradual lithological variations with depth. Water content varies little from a mean at about 37 percent.

A general drop in density occurs in Cores 13 and 14 together with water content values which increased to around 47 percent. These features can be related to the unit II lithology of foram ooze and chalk since the hollow foram tests would be expected to cause such effects.

Between 150 and 220 meters, over the interval of Cores 15 to 21, a greater fluctuation in density is evident. Water content also fluctuates between 28 and 42 percent. The GRAPE density plots on the core summary logs show a series of rapid changes. The unit III lithology, an alternation of oozes with harder chalk layers, accounts for these fluctuations.

Plotted data are sparse below this level, but Core 26 displays a major density increase to 2.0 g/cc, and in Hole 219A, downward from 300 meters, density fluctuates markedly around a mean of about 1.8 g/cc.

Compressional Wave Velocity

Over the upper 100 meters, velocity can be expected, due to the homogeneous nature of the lithology, to remain at around 1.54 km/sec as measured in Core 4.

A slight rise is evident in unit II (foram ooze and chalk) with values of up to 1.70 km/sec for the chalks in Core 14. Chalks in unit III (alternating ooze and chalk) have values of up to 1.84 km/sec.

A major peak in the velocity plot occurs at the base of Core 21, where values reach 4.0 km/sec. This reflects a chert layer, and other such layers in the interval of unit IV give values approaching this, as peaks above a general level of about 2.0 km/sec.

Below 326 meters, marked fluctuations in velocity are displayed, rising to just over 4.1 km/sec. These appear to

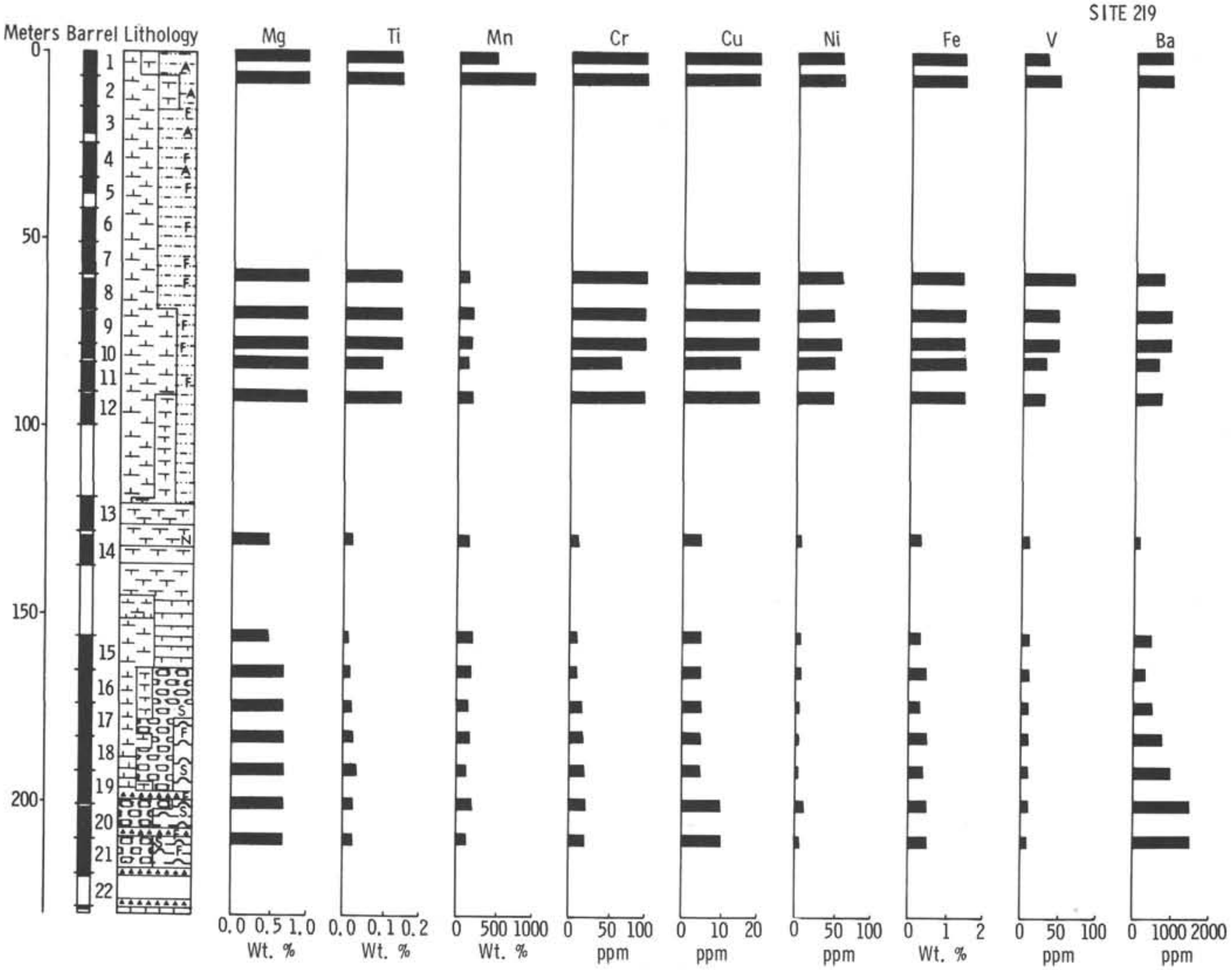

Figure 7. *Chemistry of the sediments from Site 219.*

correlate with glauconite-rich limestones and glauconite-bearing siltstones. A value of over 5.3 km/sec was recorded from a limestone in 219A-10-2.

Specific Acoustic Impedance

This parameter bears an inherent relationship to the reflection coefficient and so should identify the major reflectors. Its plot almost parallels the sonic velocity graph and thus shows the major physical boundaries to be at depths of 219 and 308 meters.

When a comparison is made with Francis and Shor's (1966) nearby seismic refraction station at 9°N, their belief that the upper refracting horizon, with a measured velocity of 3.85 km/sec, was volcanic rock appears unfounded since velocities approaching this value are shown to be present in the glauconite calcareous sandstone sequence and reach 4.0 km/sec in the cherts and limestones above this.

CORRELATION OF REFLECTION PROFILES AND LITHOLOGIES

Two reflectors can be consistently identified in the region around Site 219 (Figure 8). The upper reflector is weak and lies in the lower half of an acoustically transparent layer. At the base of this layer, a strong but diffuse reflector, typically spread over 0.3 seconds, is ubiquitous. A careful study of this reflector reveals that it probably consists of two sets of merged reflections. Rare hyperbolic echoes near the base of the diffuse reflector suggest the presence of an irregular, even deeper, surface.

The observed reflections at this site occurred at 0.17, 0.28, 0.42, and at about 0.55 (hyperbolic echo) seconds of two-way travel time below the sea bed. These times are indicated on Figure 9. Also indicated on this figure are the depths of various lithologies which showed an appreciable increase in hardness compared with the immediately overlying rocks.

The first such lithology is the foram chalk, first cored in Core 13 (119-128 m). It occurs as hard bands between beds of ooze, and after Core 13, circulation was required to cut the cores. The chalk undoubtedly gives rise to the weak upper reflector in the transparent layer. This is also suggested by the greater density of the chalk, compared to that of the ooze.

The next deepest reflection, which appears on the records as the top of the strong diffuse reflector, was discovered to be due to Early and Middle Eocene chert stringers. The first chert was encountered in Core 19 at 200 meters; other cherts occurred sporadically in the underlying 57 meters. The chert has a density of 2.0 g/cc and a velocity of 4.0 km/sec and hence provides a high acoustic contrast with the overlying chalk and ooze.

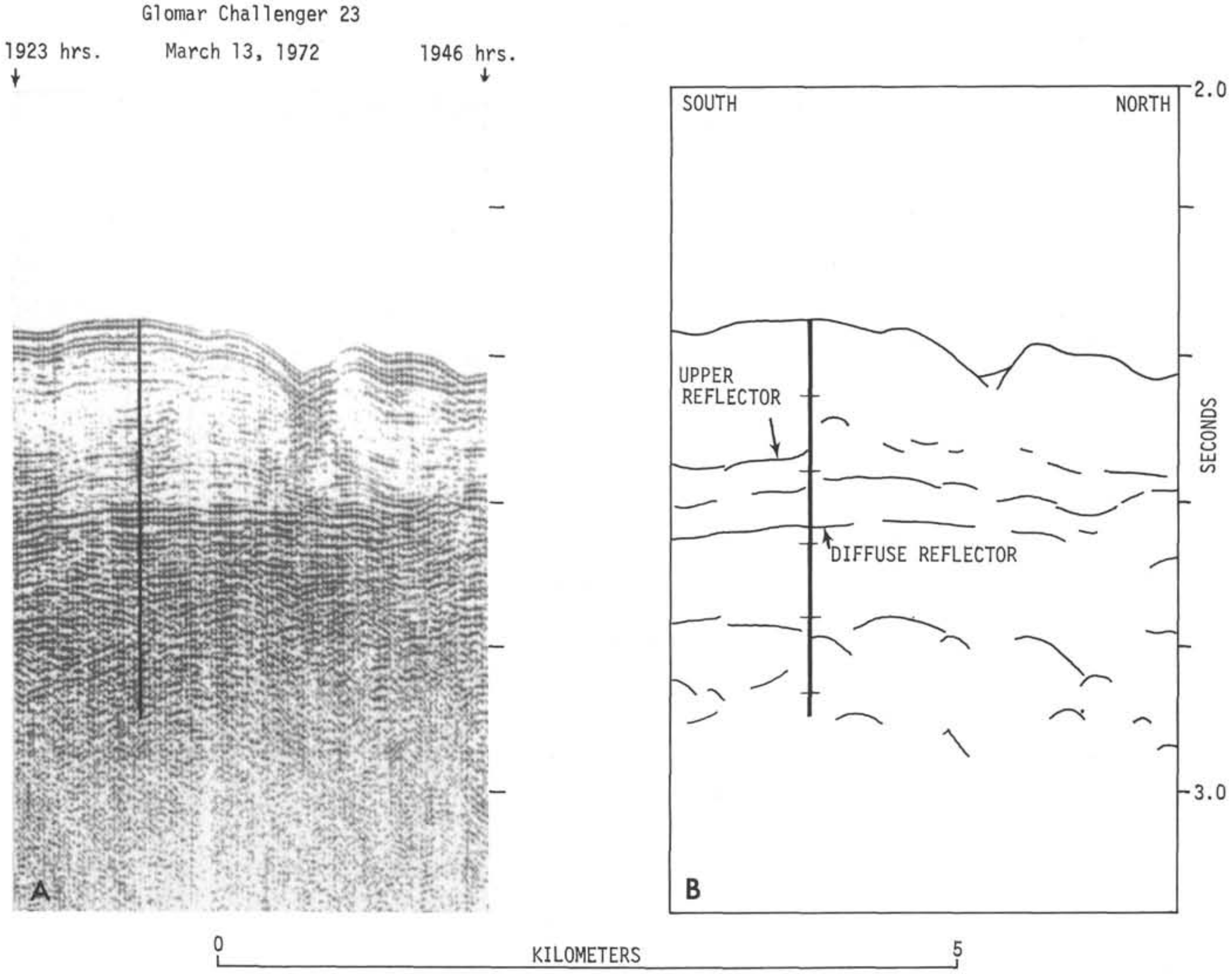

Figure 8. (a). *Seismic reflection record obtained on departure from the site along a north-south track. The ship passed within 200 meters of the beacon. The vertical line represents the approximate extent of penetration of the drill string.* (b). *A line drawing showing the interpretation of Figure 8*a *used to construct Figure 9. The vertical line has tenth second divisions.*

No core was recovered between 273 and 299 meters. Above and below this gap, the main lithologies are chalk and limestone, respectively. Consequently, the 0.42-sec reflector may be assigned to the boundary separating the above contrasting lithologies, but in view of the unrealistic interval velocity which results, the reflector is correlated with the top of the sandstone at 327 meters.

From the above conclusions regarding the correlation of reflections with lithological boundaries, it is only possible to precisely calculate the mean velocity to the chert, which is 1.54 km/sec. If the rare hyperbolic echoes represent true igneous basement, then this lies at a depth of at least 425 meters.

PALEOMAGNETIC MEASUREMENTS

All 11 samples taken for preliminary paleomagnetic study at this site were from lithological unit V. The sampled interval covers a time span of about 4.5 m.y. within the Paleocene sequence.

An essential magnetic characteristic of these samples, apart from Samples 219A-7-3, 77 cm and 10-1, 99 cm, is the low intensity of the natural remanent magnetism (NRM) (mean value $2.1 \pm 0.5 \times 10^{-7}$ G/cm^3). All measurements were completed using a long-spin time constant (528 revolutions) in order that an improved signal to noise ratio could be achieved. However, despite this precaution the scatter of repeated measurements remained high and the reliability of the results, presented in Table 6, is questionable.

On the basis of repeat measurements after 6 months storage and partial alternating field (Af) demagnetization at a peak field of 50 oersteds, it is evident that, on the whole, the group of samples has low stability. Two samples, 219A-7-3, 77 cm and 14-2, 118 cm, were subjected to progressive partial Af demagnetization to peak fields of 200 oersted. The results of this procedure are presented in Table 7. Figure 10 shows the plot of relative intensity (J/J_o) against demagnetization field for both samples. Sample 219A-14-2, 118 cm shows some indication of stability in that 50 percent of the original NRM remains after demagnetization in peak fields in excess of 100 oersted. The increase in intensity observed on demagnetization at a peak field of 200 oersted is thought to be an instrumental effect. While it is difficult to be certain from the migration pattern of the remanent vector during demagnetization as

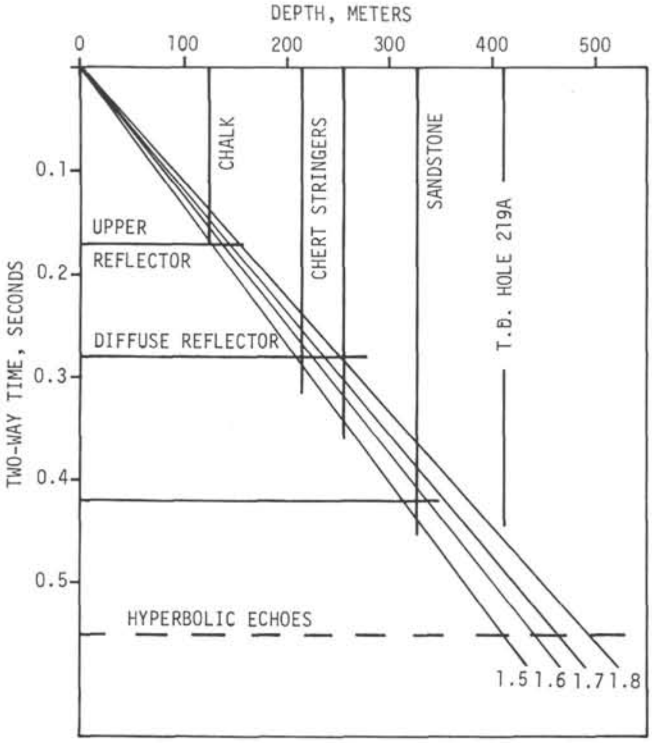

Figure 9. *Plot of reflection times beneath Site 219 against the depths of significant changes in lithology found in the cores. Lines are drawn corresponding to mean velocities of 1.5, 1.6, 1.7, and 1.8 km/sec.*

to the stable direction of any underlying hard magnetization component, there is some suggestion that this may be associated with an inclination around 50°.

The mean inclination calculated for all samples after demagnetization is 29.1 ± 5.6 degrees. Such an inclination would correspond, accepting an axial dipole approximation, to a paleolatitude for the site in Paleocene times of 15.5°S. This result appears to be widely discrepant from that of 40°S given from the Deccan Trap data by McElhinny (1968). The presence of appreciable viscous magnetization components may account to some extent for the anomalously low value of absolute inclination that is observed when the samples are considered as a group. Those samples, such as 219A-10-1, 99 cm, 14-2, 118 cm, and possibly, 219A-14-4, 54 cm, which appear to have better stability, have significantly higher inclination values in the range 35° to 50° (after demagnetization) and thus indicate paleolatitudes within the range 20 to 30°S. Such a range is in broad agreement with the expected position of the Indian plate based on the reconstructions of McKenzie and Sclater (1971).

DISCUSSION AND CONCLUSIONS

Subsidence of the Site

The Paleocene sediments exhibit conclusive evidence that they were deposited in shallow water. On the evidence of the benthonic foraminifera and the abundance of larger foraminifera, the depth is estimated to have been about 100 meters. Additional indicators of shallow water are glauconite, cross laminations, fragments of pelecypods, coarsely ornamented ostracods, red algae, bryozoans, and echinoids. At present, the site lies in 1764 meters of water. Since the depth of deposition of the oldest sediments recovered from this site was 100 meters, and because these sediments are now found 411 meters below the sea floor, the sea floor at this site has sunk 2075 meters since early Late Paleocene time (ca. 58 m.y. ago), indicating a mean subsidence rate of 36 m/m.y. Sinking had probably begun by Late Paleocene time simply because there are at least 150 meters of shallow-water sediments, but the sedimentation rate of at least 70 m/m.y. was clearly adequate to approximately keep pace with the sinking. However, around the Paleocene/Eocene boundary there appears to have been a period of nondeposition lasting about 5 m.y.; after this, the sedimentation rate was only 18 m/m.y. In addition, the Lower Eocene benthic foraminifera indicate a bathyal environment. This indication of a relatively sudden increase in water depth can probably be explained by a combination of nondeposition for about 5 m.y. and continuing steady sinking at around 70 m/m.y. The sinking history of the site since the Early Eocene is not known except that it probably did not exceed the rate which allows coral growth upwards to keep pace with sinking since the coral atoll of Minikoi lies 45 miles to the south. In fact, figures quoted by Seibold (1972) indicate that vertical reef growth can reach 20mm/yr. This rate is unlikely to have been exceeded by the sinking. Pacific atolls

TABLE 6
Summary of Magnetic Data, Hole 219A

	NRM			Af Demagnetization			
Sample (Interval in cm)	Intensity (G/cm^3)	Relative Declination (degrees)	Inclination (degrees)	Peak Field (oersted)	Intensity (G/cm^3)	Relative Declination (degrees)	Inclination (degrees)
4-2, 56	1.3×10^{-7}	23.6	-27.4	50	1.5×10^{-8}	339.0	20.3
4-2, 34	1.2×10^{-7}	293.2	16.6	50	1.3×10^{-7}	279.3	50.9
4-4, 101	3.8×10^{-8}	352.9	22.4	50	1.6×10^{-7}	27.3	13.8
6-1, 71	2.0×10^{-7}	58.5	-13.0	50	1.8×10^{-7}	55.6	4.0
6-2, 68	1.8×10^{-7}	302.3	40.1	50	1.3×10^{-7}	28.1	35.3
7-3, 77	2.1×10^{-6}	348.0	9.7	50	7.4×10^{-7}	345.7	21.1
9-5, 47	1.3×10^{-7}	91.5	-52.8	50	1.2×10^{-7}	285.0	13.7
10-1, 99	4.5×10^{-7}	264.3	42.7	50	1.8×10^{-7}	234.6	35.5
10-2, 129	4.3×10^{-7}	8.2	-11.3	50	4.4×10^{-7}	5.8	-18.7
14-2, 118	1.1 x 10-5	54.0	35.7	50	7.9×10^{-6}	68.5	65.8
14-4, 55	2.2×10^{-7}	159.5	31.2	50	1.6×10^{-7}	166.2	40.9

TABLE 7
Af Demagnetization Results, Hole 219A

Sample	Peak Field (oersteds)	Intensity (G/cm^3)	Relative Declination (degrees)	Inclination (degrees)
7-3,77 cm	NRM	2.1×10^{-6}	348.0	9.7
	25	1.3×10^{-6}	358.3	19.7
	50	7.4×10^{-7}	345.7	21.6
	75	4.1×10^{-7}	0.0	0.0
	100	2.8×10^{-7}	3.8	- 33.3
	150	2.4×10^{-7}	7.8	- 31.0
	200	5.7×10^{-7}	315.0	- 33.9
14-2,118 cm	NRM	1.1×10^{-5}	54.0	35.7
	25	9.4×10^{-6}	52.9	51.3
	50	7.9×10^{-6}	68.5	65.8
	75	6.7×10^{-6}	122.9	78.9
	100	5.7×10^{-6}	129.6	64.8
	150	6.0×10^{-6}	47.0	52.6
	200	7.1×10^{-6}	19.5	40.1

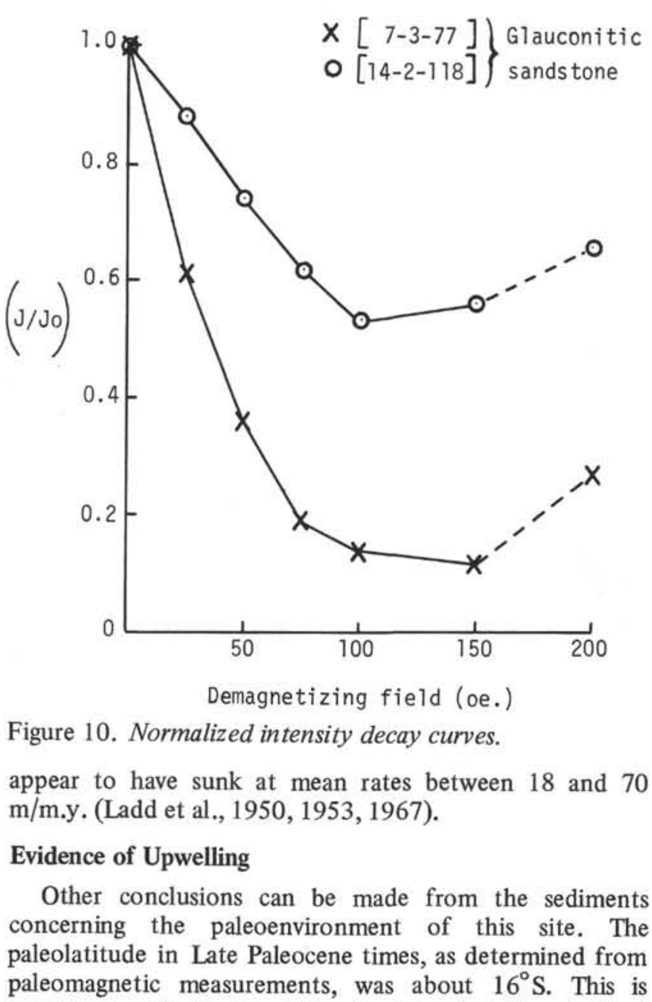

Figure 10. *Normalized intensity decay curves.*

appear to have sunk at mean rates between 18 and 70 m/m.y. (Ladd et al., 1950, 1953, 1967).

Evidence of Upwelling

Other conclusions can be made from the sediments concerning the paleoenvironment of this site. The paleolatitude in Late Paleocene times, as determined from paleomagnetic measurements, was about 16°S. This is consistent with the tropical and subtropical foraminiferal faunas found at the site. Upwelling occurs today in the Minikoi region during the northeast monsoon (Rao and Jayaraman, 1966), and it is interesting to see whether traces of earlier upwelling can be found in the sediments. Phosphorite concretions were found in a core of Early Eocene age. Rich radiolarian faunas, sponge spicules, and chert (below Core 219-19) were found in Middle Eocene to Lower Oligocene sediments (Cores 219-21 to 219-16), and chert was found in older sediments down to the beginning of the Early Eocene; however, such concentrations of biogenic silica in the Eocene may partly reflect a much more widespread, or even global, change in seawater chemistry (see other Leg 23 Arabian Sea sites; also Heath and Moberly, 1971). Samples from the uniform chalks and oozes of the top 230 meters of the site were analyzed for trace elements and the upper 100 meters, post-Lower Miocene sediments, were found to be enriched between three and tenfold in vanadium and nickel. These trace elements together with zinc and molybdenum (not sought for) are believed to indicate an oxygen-poor benthic environment consistent with deposition in an upwelling region (McKelvey and Chase, 1966). In accord with this interpretation is the relatively high organic carbon content in the top 100 meters, compared with most of the underlying sediments, and the presence of pyritic layers and burrows in this interval. Thus, the above rather scant evidence could be interpreted to suggest upwelling near the site in Tertiary times, especially since the Early Miocene, although evidence is lacking for the entire Middle Oligocene to Early Miocene period. The latter period was a time of very slow sedimentation at the site, possibly due to strong near bottom currents. Additionally, from a study of cores and oceanographic data from the western continental margin of India, von Stackelberg (1972) detected a markedly oxygen-poor layer in the sea lying between 150 and 700 meters depth off Cochin. Where this layer impinges on the sea bed, biogenic silica has undergone solution and bioturbation is lacking except for rare pyritized burrows. The data of Rao and Jayaraman (1966) also suggest the top of such an oxygen-poor layer off Minikoi occurs at depths around 200 meters, due to upwelling. The cores from Site 219 indicate that the base of this layer has extended to a depth of at least 1860 meters, assuming no Neogene subsidence of the site, since the Middle Miocene. Wyrtki (1971, ch. 2) shows a mean dissolved oxygen level of about 2 ml/l for the sea bed at this site today.

Comparisons with India and the Ninetyeast Ridge

Comparisons may also be made with the geology of India and an adjacent DSDP site. The Paleocene shallow benthonic foraminiferal fauna of Site 219 is similar to that of the east coast of India, and one species, *Discocyclina ramaraoi* Samanta, is otherwise known only from the Pondicherry formation. This suggests a marine link with the east coast of India in Paleocene times. The Eocene sediments of peninsula India are in part marine, but in contrast to Site 219, chert is unknown in these rocks (Wadia, 1968).

It is also interesting to compare the history of Site 219 on the Laccadive-Maldive Ridge with that of Site 217 on the Ninetyeast Ridge, which is at the same latitude and on the same plate (von der Borch et al., 1972). Site 217 has sunk since Late Campanian times, and today the whole ridge is free of living coral reefs, whereas, coral atolls exist within 200 kilometers to the north and south of Site 219, where the sea bed started to sink in the Late Paleocene or Early Eocene at latitude 16°S. Colonial corals are temperature dependent, and it would seem that (provided the Ninety East Ridge did not sink too fast for coral growth) as the Indian plate moved northwards, it crossed the critical 20°C isotherm for coral growth between Late Campanian and Late Paleocene times. The 75 m.y. reconstruction of McKenzie and Sclater (1971) shows Site 217 to have been at latitude 40°S.

Chert Reflector and Depth to Igneous Basement

The strong diffuse reflector at this site has been demonstrated to be Early and Middle Eocene chert while a deeper less distinct reflection is attributable to the shallow-water Paleocene sandstone. No deeper reflections were discernible on the airgun records so that the true depth to igneous basement is still unknown. However, an estimate may be made from the results of Francis and Shor (1966). Their Station 1 detected a 3.85 and a 5.00 km/sec refractor. They attributed the 3.85 km/sec velocity to volcanic rock, but from our results it seems certain that this is incorrect and this refractor is chert or shallow-water limestones and sandstones. The 5.00 km/sec refractor probably does represent volcanic rock, however, and lies over 1500 meters below the bottom of Hole 219A; this does not necessarily exclude the possibility of igneous basement lying at a shallower depth.

The main feature of the reflection profiles across the site (Figures 3, 11) is that the strong Eocene chert reflector has an irregular surface, often with a sawtooth profile. The steeper parts of the sawtooth have a varying vertical offset which is generally greater than the present-day sea floor relief. For instance, just east of the site the chert reflector is depressed some 1.1 sec (about 1000 m) whereas, the sea bed only shows relief of 250 meters. The profile of the chert reflector suggests that post-Middle Eocene faulting has occurred, but the lack of any evidence of consistent dip, micro-faulting, or slump structures in the cores does not support this, although, admittedly, all the Neogene cores were disturbed by drilling and such structures may have been destroyed. An alternative explanation is that the chert beds were draped over preexisting rough topography, the greater relief of which was attributable to the vertical offset across fracture zones. From the site survey and by combining reflection profiles and soundings, mainly in the region south of the site, it seems that several of the sea bed scarps have a NNE trend (Figure 12) consistent with a fracture zone origin. A further feature of the reflection profiles is the way in which the post-chert sediments have filled in the irregularities in the chert reflector. The uneven thickness of sediment overlying the chert reflector suggests the influence of bottom currents on their deposition. This suggestion is strengthened by the wavy almost dune-like profile of parts of the sea bed.

Depositional History

The sedimentary history of Site 219 can, therefore, be summarized as follows. In Late Paleocene time, shallow-water limestones, sandstones, and siltstones were deposited (at least 70 m/m.y.) on a subsiding foundation in water depths of less than 100 meters. Fresh unaltered detrital feldspar, zeolite, and montmorillonite in these sediments suggest a volcanic provenance, perhaps the Deccan Traps. Toward the end of the Late Paleocene, the detrital component decreased and a glauconitic limestone was laid down. Then in Early Eocene time, the sea bed began to sink concurrently with other tectonic events in India (formation of Cambay graben, first Himalayan uplift), and mainly chalk and ooze were deposited at a slower rate (18 m/m.y.). Phosphorite concretions in one core suggest local upwelling and nondeposition at this time. Biogenic silica, later to become chert, began to accumulate. Fairly constant conditions seem to have been maintained, except for an ever decreasing sedimentation rate, until Early Oligocene time when biogenic silica became scarce in the sediments. The decrease in biogenic silica seems to have been reflected by an increase in carbonate. From Early Oligocene to Early Miocene time, sedimentation was minimal (about 1 m/m.y.) and probably reflects a time when the site was subject to strong bottom currents. The cause of such currents is uncertain but may be related to the postulated vigorous Oligocene circulation due to global climatic cooling which led to the essential absence of Oligocene sediments at drilling sites between Australia and New Zealand (Kennett et al., 1972). A similar regional Paleogene unconformity appears to exist to the north, east, and south of Madagascar

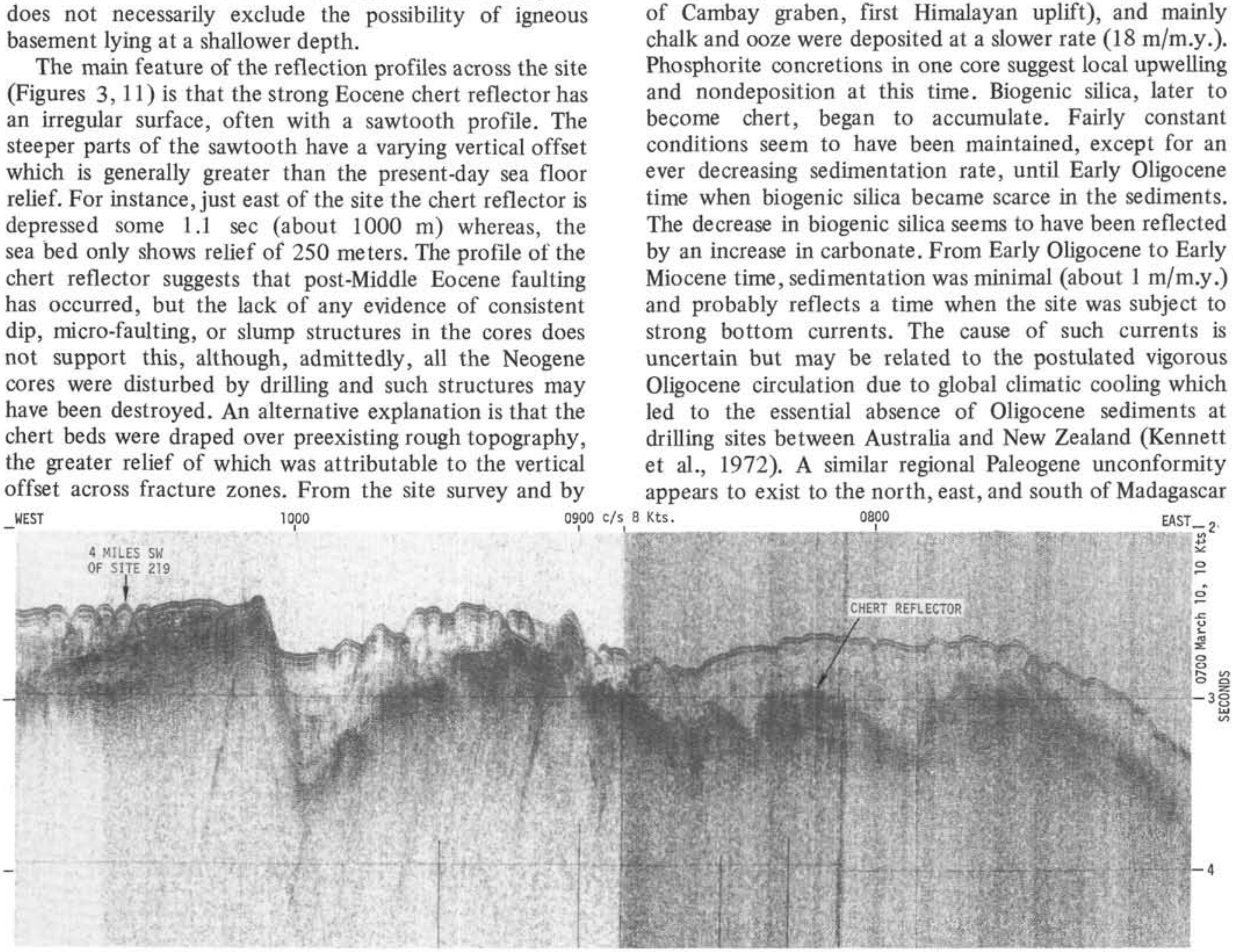

Figure 11. *Seismic reflection profile obtained by* Glomar Challenger *during the approach to Site 219 showing the irregular sawtooth shape of the chert reflector and the wavy dune-like nature of the sea bed.*

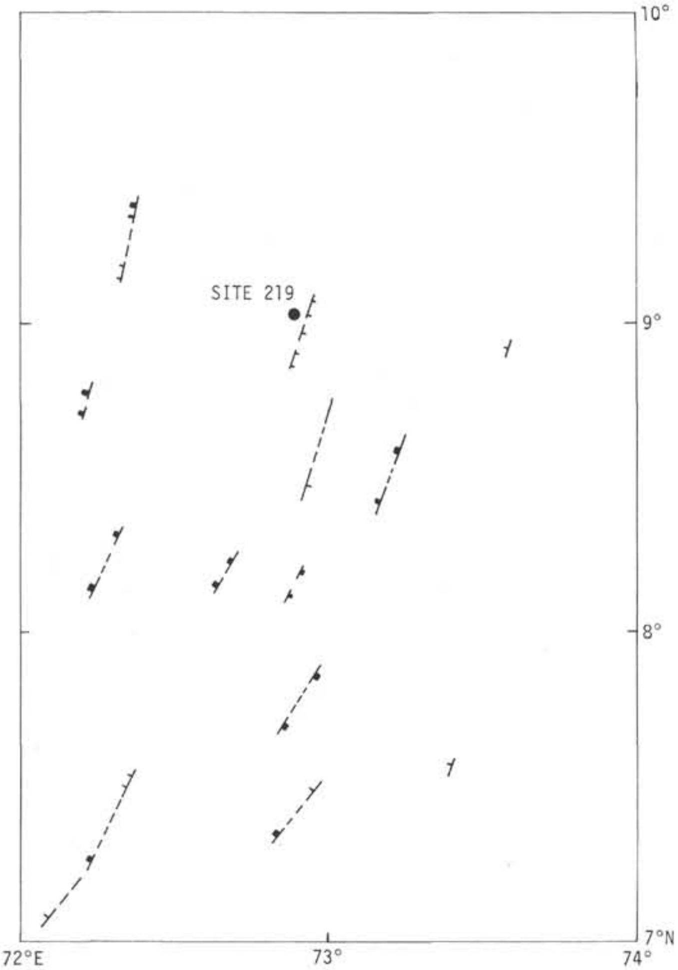

Figure 12. *Sea floor scarps deduced from collected soundings and from seismic reflection profiles obtained by* Glomar Challenger, Conrad *and* Oceanographer. *Each long dash denotes one observation of a scarp with the square on line (soundings or reflection profile, respectively) denoting the side on which the scarp face lies. Short dashes represent interpolations between observations.* Oceanographer *data courtesy of N.O.A.A. Atlantic Oceanographic and Meteorological Laboratory, Miami;* Conrad *data from cruise* Conrad-9 *courtesy of the Lamont-Doherty Geological Observatory.*

(Simpson et al., 1972). In post-Early Miocene time, a nanno ooze, supplemented by a 20 to 35 percent detrital component, was deposited at a mean rate of around 15 m/m.y. At first the ooze contained abundant foraminifera but with the onset of upwelling they became rarer in the sediments due to solution, probably because the carbonate compensation depth rose as a consequence of the upwelling (La Fond, 1966). The detrital material may have been carried to the site in suspension by near bottom currents and may have originated from the erosion of the Deccan Traps. Upwelling, which appears to have begun in Middle Miocene time, continues to the present day. Fresh volcanic glass is found throughout the Pleistocene sediments as has been reported by von Stackelberg (1972), who believed it to be of eolian origin probably from the southeast. Today the closest active volcanoes are northwest of Karachi and near the Andaman islands.

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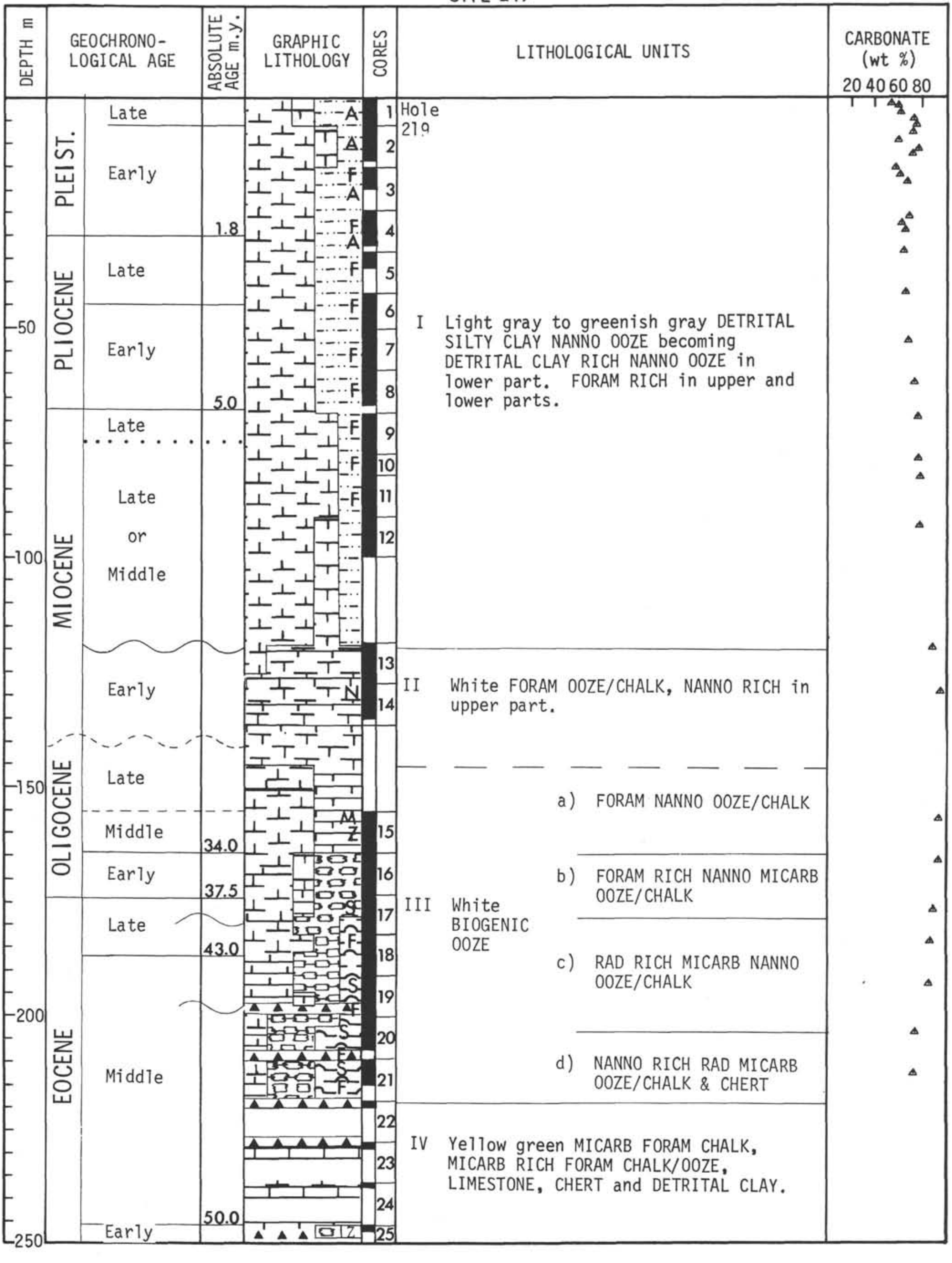
SITE 219



I Light gray to greenish gray DETRITAL SILTY CLAY NANNO OOZE becoming DETRITAL CLAY RICH NANNO OOZE in lower part. FORAM RICH in upper and lower parts.

II White FORAM OOZE/CHALK, NANNO RICH in upper part.

III White BIOGENIC OOZE

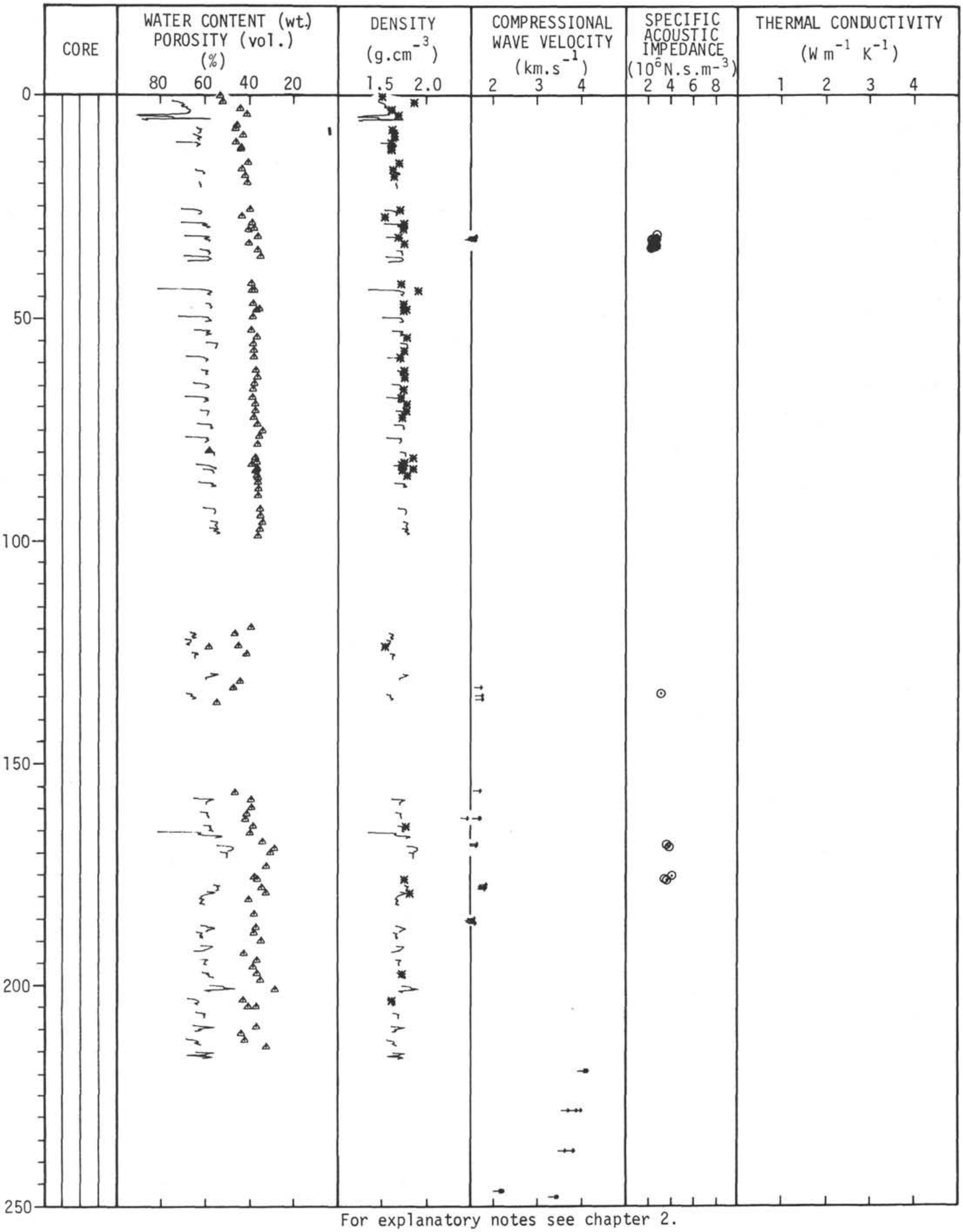
a) FORAM NANNO OOZE/CHALK

b) FORAM RICH NANNO MICARB OOZE/CHALK

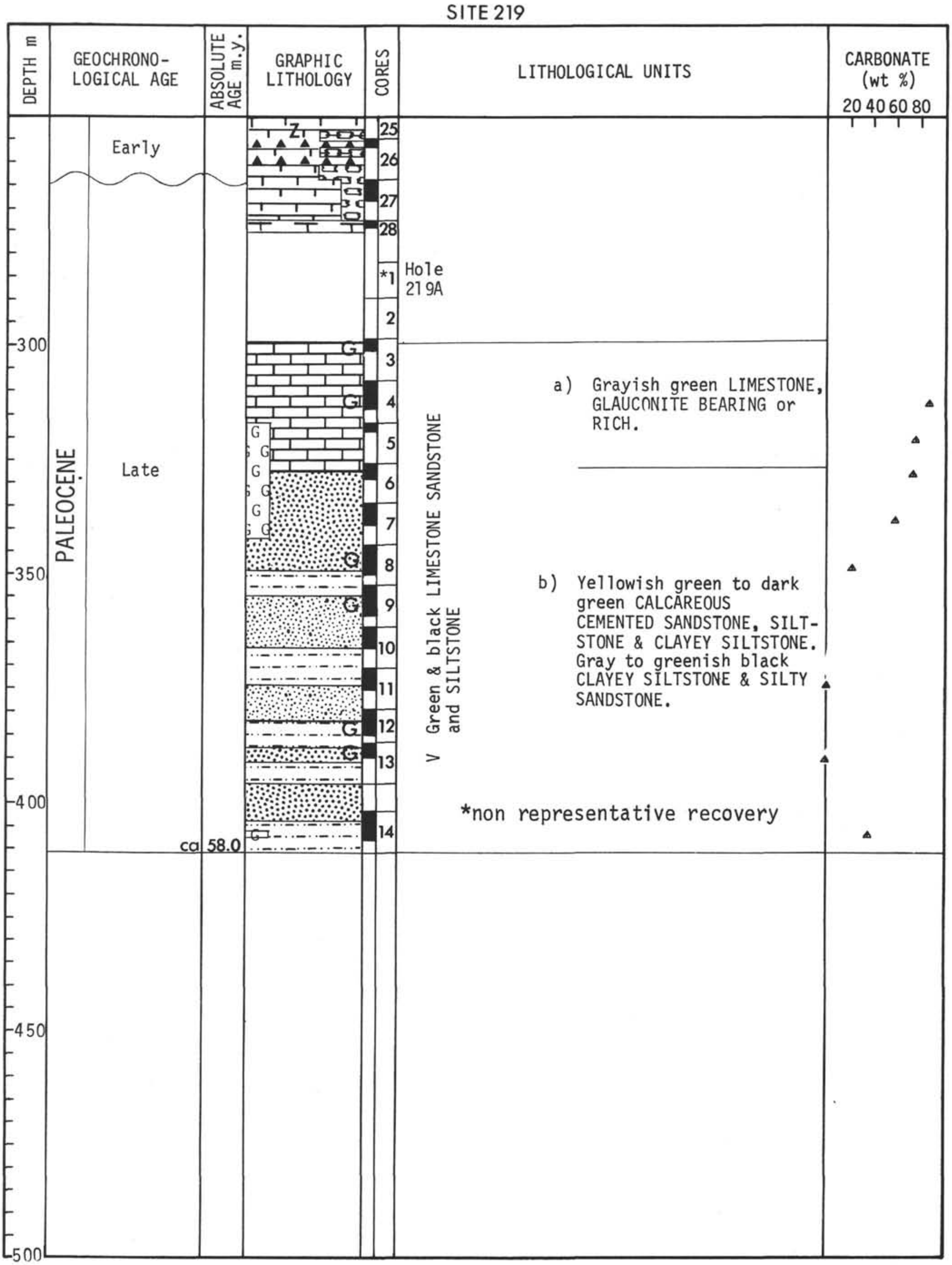
c) RAD RICH MICARB NANNO OOZE/CHALK

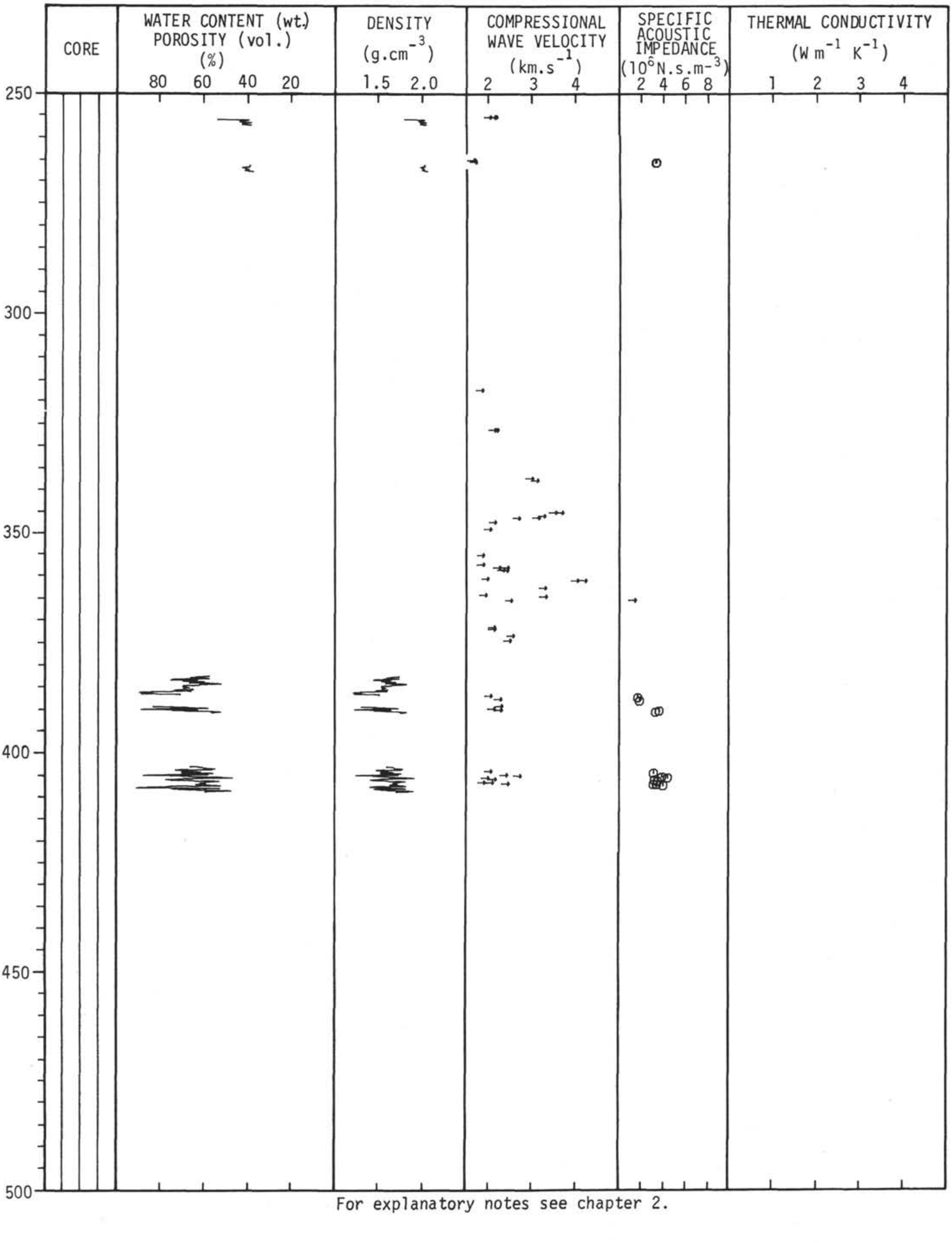
d) NANNO RICH RAD MICARB OOZE/CHALK & CHERT

IV Yellow green MICARB FORAM CHALK, MICARB RICH FORAM CHALK/OOZE, LIMESTONE, CHERT and DETRITAL CLAY.



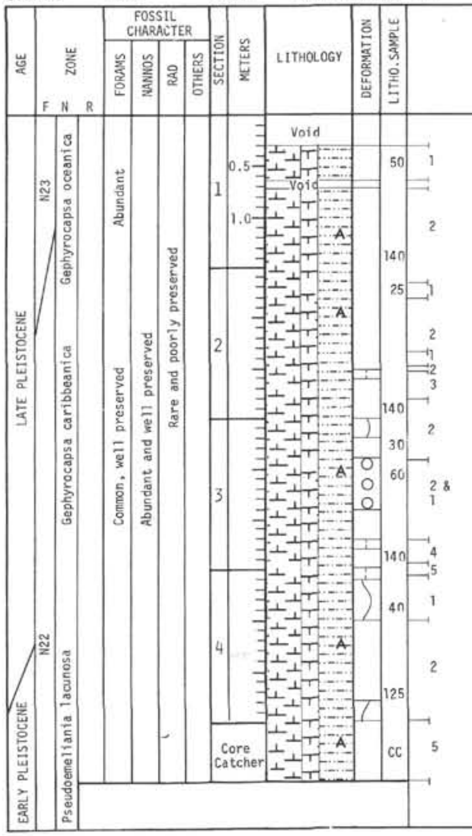
For explanatory notes see chapter 2.


SITE 219
DEPTH m
GEOCHRONO-LOGICAL AGE
ABSOLUTE AGE m.y.
GRAPHIC LITHOLOGY
CORES
LITHOLOGICAL UNITS
CARBONATE (wt %)
20 40 60 80
Early
Late
PALEOCENE
ca 58.0
25
26
27
28
*1
2
3
4
5
6
7
8
9
10
11
12
13
14
Hole 219A
-300
-350
-400
-450
-500
V Green & black LIMESTONE SANDSTONE and SILTSTONE
a) Grayish green LIMESTONE, GLAUCONITE BEARING or RICH.
b) Yellowish green to dark green CALCAREOUS CEMENTED SANDSTONE, SILT-STONE & CLAYEY SILTSTONE. Gray to greenish black CLAYEY SILTSTONE & SILTY SANDSTONE.
*non representative recovery
G
Z



For explanatory notes see chapter 2.

Site 219 Hole Core 1 Cored Interval: 0-6



LITHOLOGIC DESCRIPTION

Gray FORAM RICH DETRITAL SILTY CLAY NANNO OOZE

Dominant lithology SS: Section 2-25 cm
FORAM RICH DETRITAL SILTY CLAY NANNO OOZE
Composition:

Nannos	55%
Detrital grains	30%
Forams	12%
Volcanic glass	3%
Carbonate needles	Trace

Color legend:

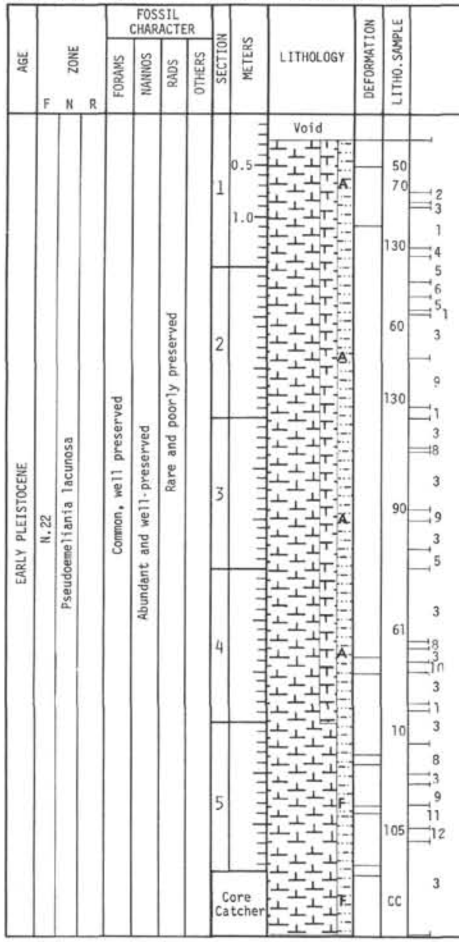
1 = yellowish gray 5Y 7/2
2 = light olive gray 5Y 5/2
3 = pale olive 10Y 6/2
4 = moderate olive brown 5Y 4/4
5 = grayish olive 10Y 4/2

Shore-based laboratory results

Carbonate
Section 1-38 cm = 68%
Section 1-139 cm = 52%
Section 2-38 cm = 58%
Section 3-40 cm = 60%
Section 4-30 cm = 71%

Explanatory notes in chapter 2

Site 219 Hole Core 2 Cored Interval: 6-15



LITHOLOGIC DESCRIPTION

Gray FORAM DETRITAL SILTY CLAY RICH NANNO OOZE

Some pyrite streaks occur in the lower part of the core.

Dominant lithology SS: Section 3-90 cm
FORAM DETRITAL SILTY CLAY RICH NANNO OOZE
Composition:

Nannos	60%
Detrital grains	20%
Forams	15%
Volcanic glass	5%

Color legend:

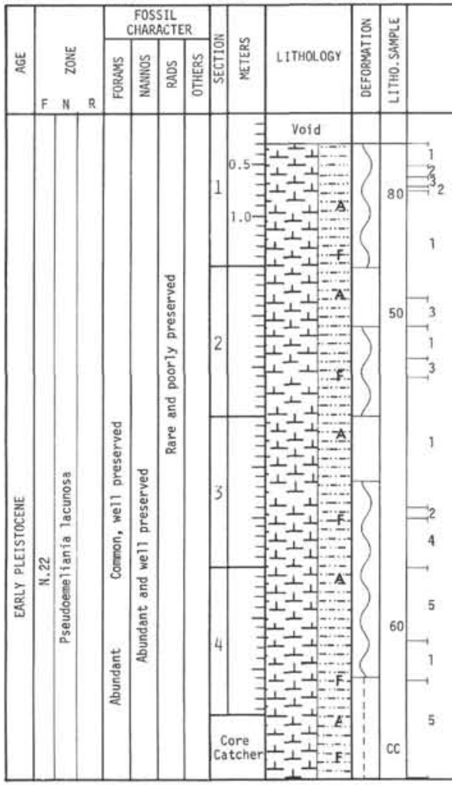
1 = grayish olive 10Y 4/2
2 = greenish yellow 10Y 7/2
3 = light olive gray 5Y 5/2
4 = greenish black 5GY 2/1
5 = moderate olive brown 5Y 4/4
6 = dusky yellow 5Y 6/4
7 = greenish gray 5Y 6/1
8 = yellowish gray 5Y 7/2
9 = pale olive 10Y 6/2
10 = pale greenish yellow 10Y 8/2
11 = greenish gray 5GY 6/1
12 = moderate greenish yellow 10Y 7/4

Shore-based laboratory results

Carbonate
Section 1-10 cm = 73%
Section 2-20 cm = 70%
Section 3-40 cm = 58%
Section 4-90 cm = 75%
Section 5-40 cm = 70%

Explanatory notes in chapter 2

Site 219 Hole Core 3 Cored Interval: 15-24



LITHOLOGIC DESCRIPTION

Gray DETRITAL SILTY CLAY NANNO OOZE

Lower sections contain some pyrite streaks and there is a general coarsening of the detrital fraction.

Dominant lithology SS: Section 4-60 cm
DETRITAL SILTY CLAY NANNO OOZE
Composition:

Nannos	50%
Detrital grains	35%
Forams	10%
Volcanic glass	5%

Color legend:

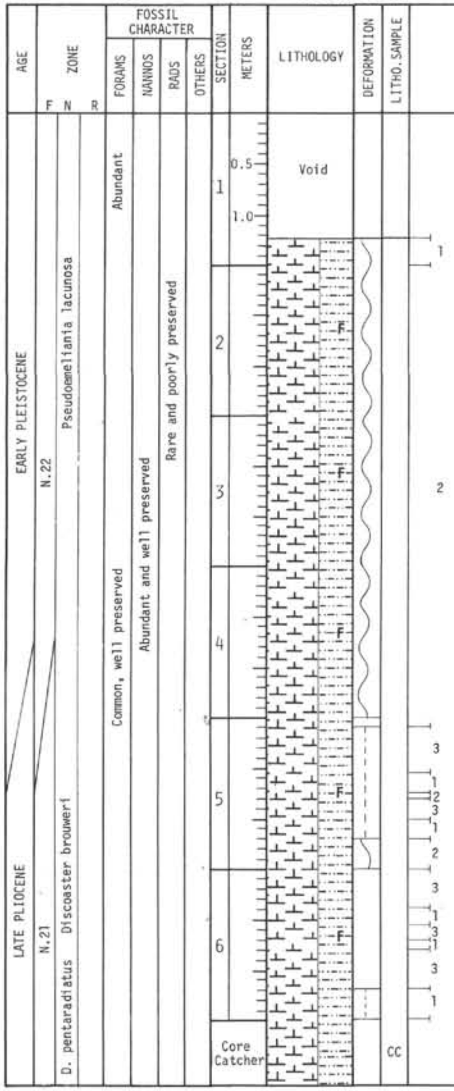
1 = greenish gray 5GY 6/1
2 = light greenish gray 5G 8/1
3 = pale olive 10Y 6/2
4 = grayish olive 10Y 4/2
5 = light olive gray 5Y 5/2

Shore-based laboratory results

Carbonate
Section 1-40 cm = 56%
Section 2-40 cm = 59%
Section 3-40 cm = 65%

Explanatory notes in chapter 2

Site 219 Hole Core 4 Cored Interval: 24-33



LITHOLOGIC DESCRIPTION

Gray DETRITAL SILTY CLAY NANNO OOZE

Dominant lithology SS: Section 5-90 cm
DETRITAL SILTY CLAY NANNO OOZE
Composition:

Nannos	55%
Detrital grains	35%
Forams	10%

Color legend:

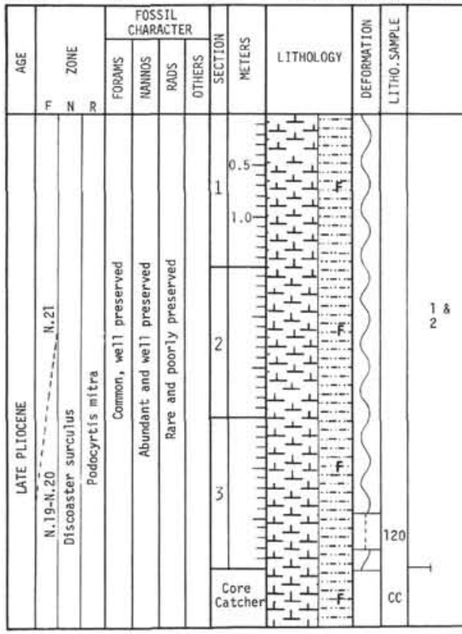
1 = greenish gray 5GY 6/1
2 = light olive gray 5Y 5/2
3 = pale olive 10Y 6/2

Shore-based laboratory results

Carbonate
Section 2-40 cm = 67%
Section 3-40 cm = 61%
Section 4-40 cm = 64%

Explanatory notes in chapter 2

Site 219 Hole Core 5 Cored Interval: 33-42



LITHOLOGIC DESCRIPTION

Gray DETRITAL SILTY CLAY NANNO OOZE

Most of core badly disturbed.

Dominant lithology SS: Section 3-120 cm
DETRITAL SILTY CLAY NANNO OOZE
Composition:

Nannos	55%
Detrital grains	35%
Forams	10%

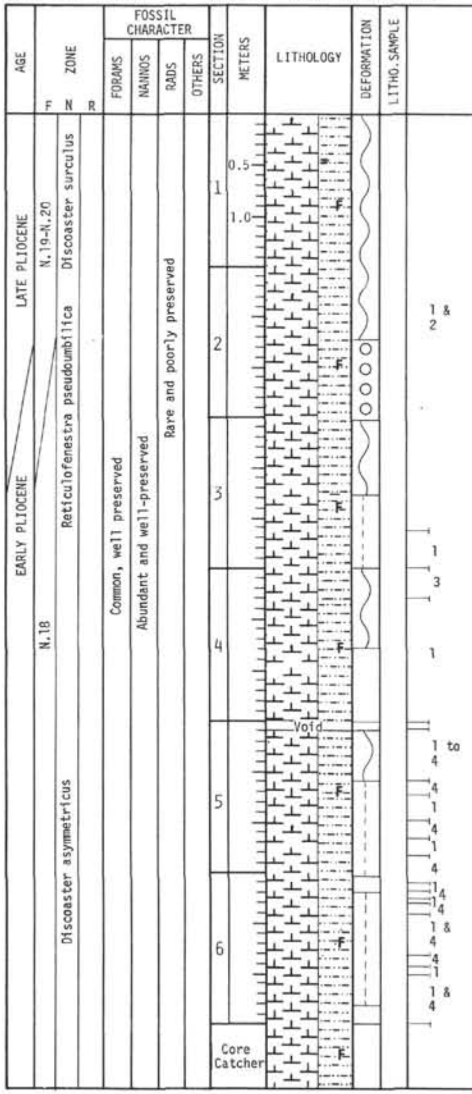
Color legend:
1 = greenish gray 5GY 6/1
2 = light gray 5Y 5/2

Shore-based laboratory results

	Carbonate
Section 1-40 cm =	62%

Explanatory notes in chapter 2

Site 219 Hole Core 6 Cored Interval: 42-51



LITHOLOGIC DESCRIPTION

Gray DETRITAL SILTY CLAY NANNO OOZE

Dominant lithology SS: Section 3-130 cm
DETRITAL SILTY CLAY NANNO OOZE
Composition:

Nannos	55%
Detrital grains	35%
Forams	10%

Color legend:
1 = greenish gray 5GY 6/1
2 = olive gray 5Y 5/2
3 = light gray 5Y 6/1
4 = very light gray N8

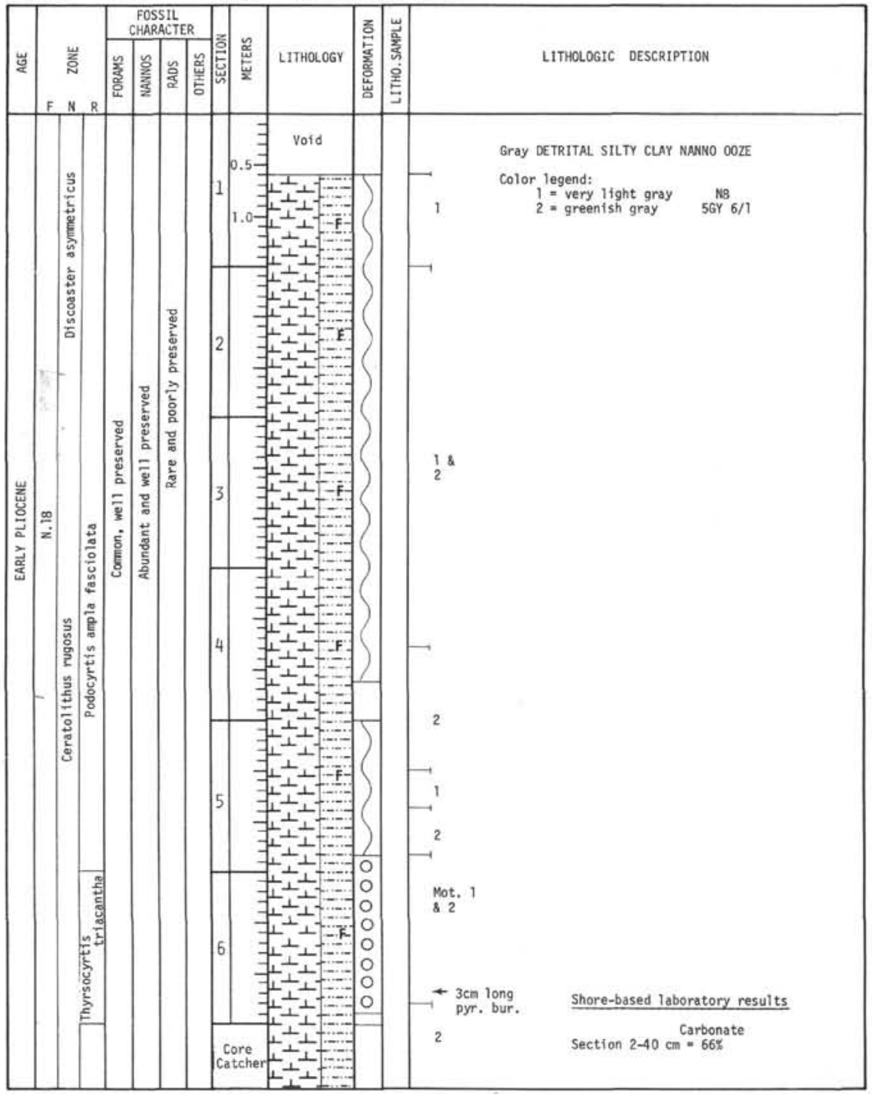
Shore-based laboratory results

	Carbonate
Section 1-40 cm =	64%

Explanatory notes in chapter 2

Podocyrtis ampla fasciolata

Site 219 Hole Core 7 Cored Interval: 51-60



Gray DETRITAL SILTY CLAY NANNO OOZE

Color legend:
1 = very light gray N8
2 = greenish gray 5GY 6/1

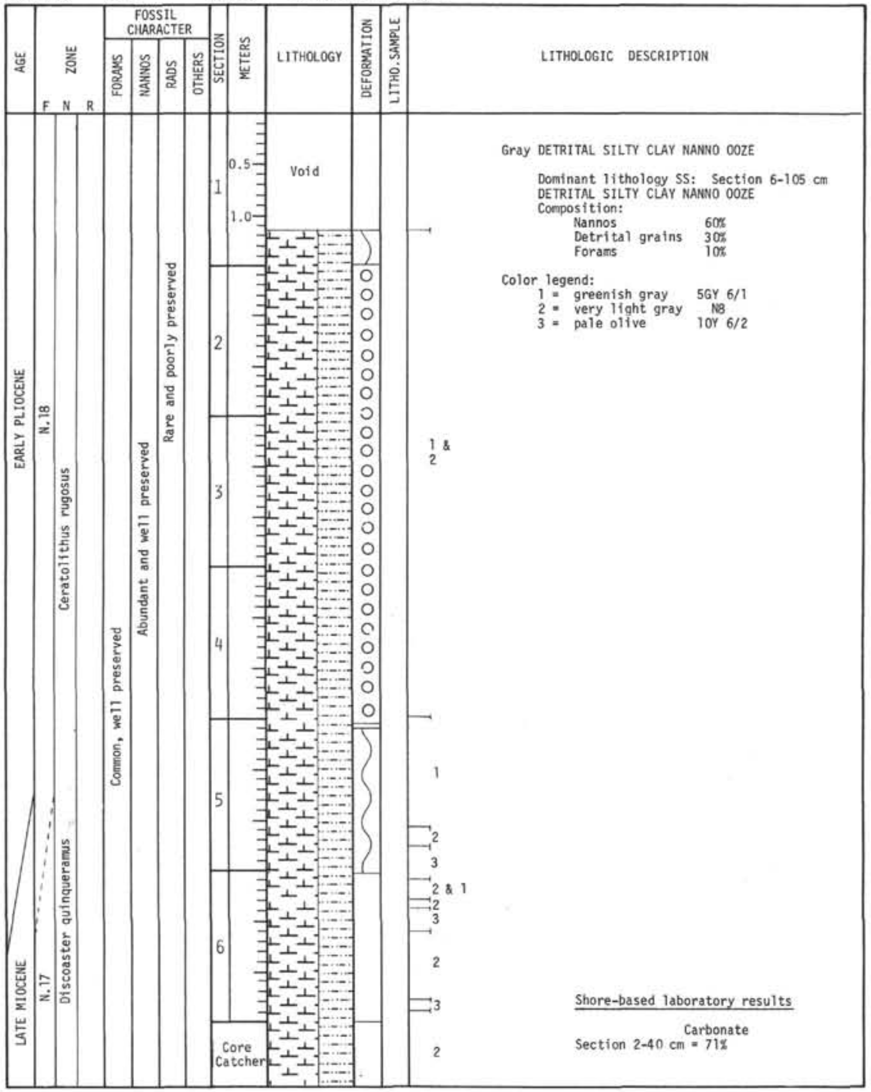
← 3cm long pyr. bur.

Shore-based laboratory results

Carbonate
Section 2-40 cm = 66%

Explanatory notes in chapter 2

Site 219 Hole Core 8 Cored Interval: 60-69



Gray DETRITAL SILTY CLAY NANNO OOZE

Dominant lithology SS: Section 6-105 cm
DETRITAL SILTY CLAY NANNO OOZE
Composition:

Nannos	60%
Detrital grains	30%
Forams	10%

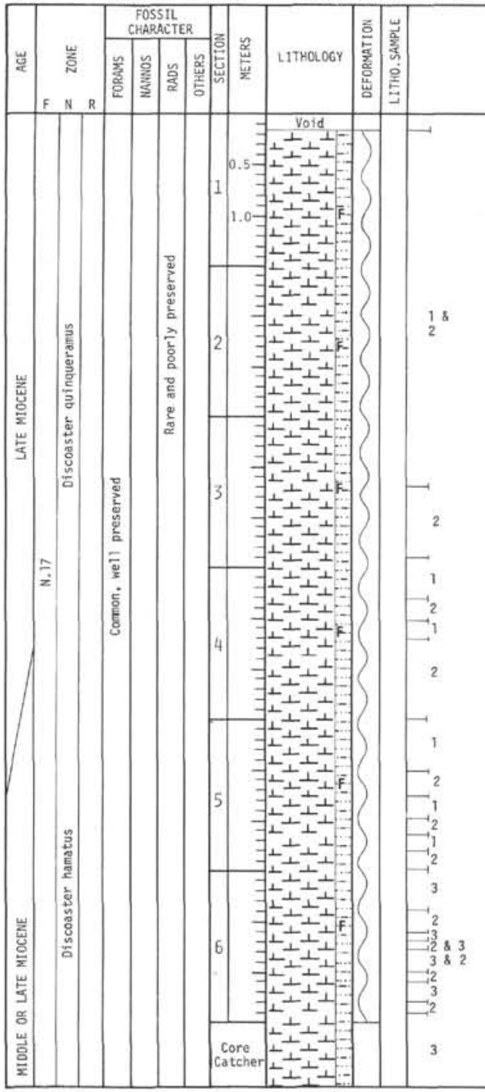
Color legend:
1 = greenish gray 5GY 6/1
2 = very light gray N8
3 = pale olive 10Y 6/2

Shore-based laboratory results

Carbonate
Section 2-40 cm = 71%

Explanatory notes in chapter 2

Site 219 Hole Core 9 Cored Interval: 69-78



LITHOLOGIC DESCRIPTION

Gray DETRITAL SILTY CLAY RICH NANNO OOZE

Many color bands have mottles which are the color of the adjoining bands.

Color legend:
1 = light olive gray 5Y 5/2
2 = very light gray N8
3 = green gray 5GY 6/1

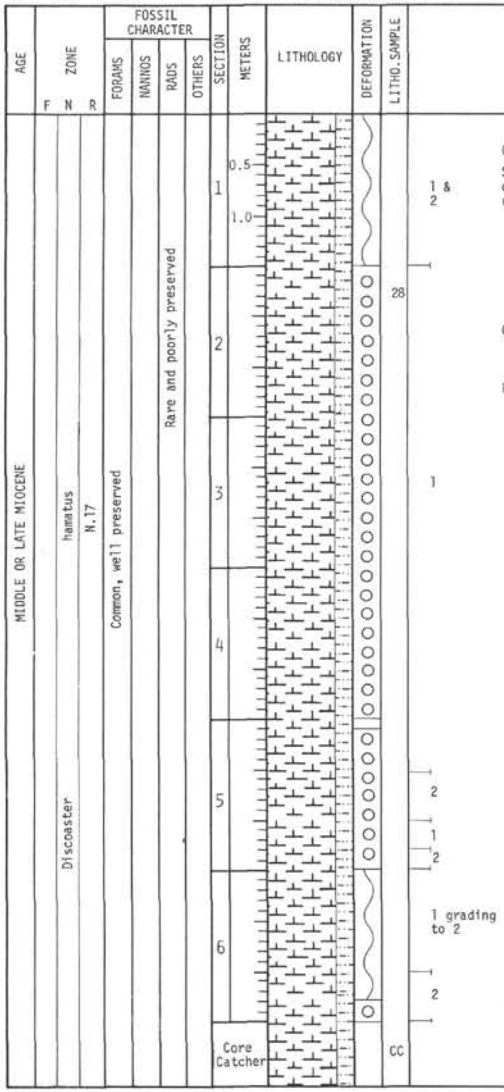
Shore-based laboratory results

Carbonate
Section 1-40 cm = 74%

X-ray mineralogy:	Section 1-45 cm
Calcite	90%
Dolomite	1%
Quartz	4%
Plagioclase	1%
Mica	3%
Chlorite	1%

Explanatory notes in chapter 2

Site 219 Hole Core 10 Cored Interval: 78-82



LITHOLOGIC DESCRIPTION

Gray DETRITAL SILTY CLAY RICH NANNO OOZE.

Section 2 contains some pyrite streaks. Many color bands have mottles which are the color of the adjoining bands.

Minor lithology SS: Section 2-28 cm
PYRITIC NANNO OOZE
Composition:

Nannos	50%
Pyrite	38%
Forams	12%

Color legend:
1 = green gray 5GY 6/1
2 = very light gray N8

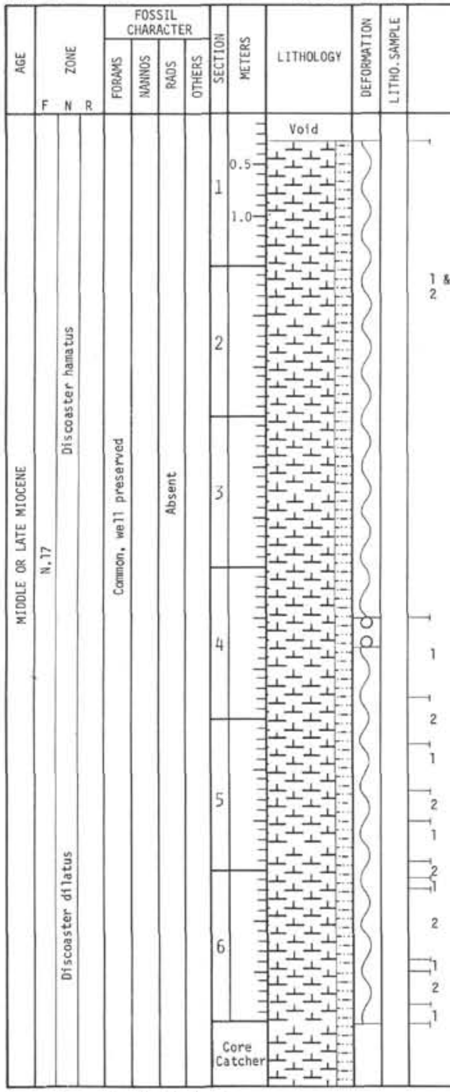
Remarks:
A depth of 4 meters was only cored, thus the extra core length recovered indicates that sections 3-6 represent duplication of sediment already cored.

Shore-based laboratory results

Carbonate
Section 1-40 cm = 74%

Explanatory notes in chapter 2

Site 219 Hole Core 11 Cored Interval: 82-91



LITHOLOGIC DESCRIPTION

Gray DETRITAL SILTY CLAY RICH NANNO OOZE

Many color bands have mottles which are the color of the adjoining bands.

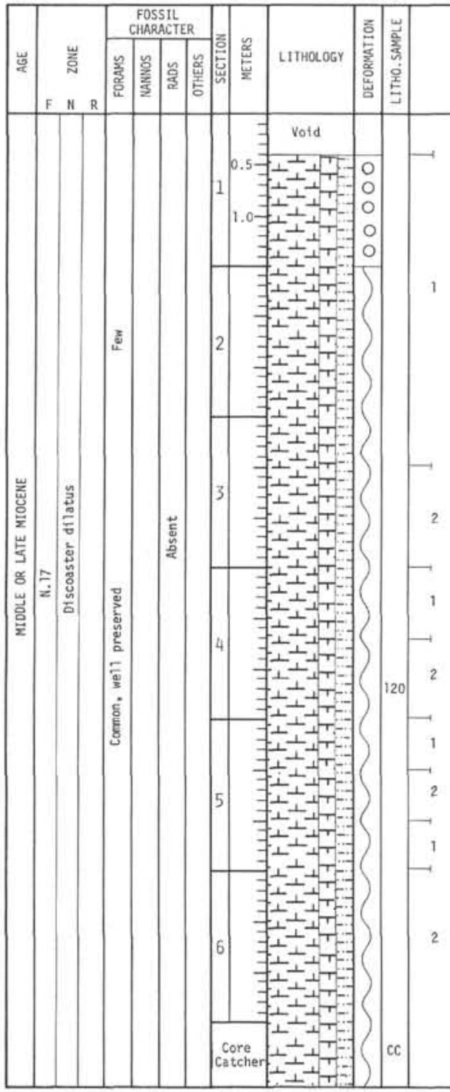
Color legend:
1 = green gray 5GY 6/1
2 = very light gray N8

Shore-based laboratory results

Carbonate
Section 1-40 cm = 76%

Explanatory notes in chapter 2

Site 219 Hole Core 12 Cored Interval: 91-100



LITHOLOGIC DESCRIPTION

Gray FORAM DETRITAL CLAY RICH NANNO OOZE

Pyrite streaks occur in sections 1, 3, 4, 5 and 6. Most color bands have mottles which are the color of the adjoining bands.

Dominant lithology SS: Section 4-120 cm
FORAM DETRITAL CLAY RICH NANNO OOZE
Composition:

Nannos	60%
Detrital grains	25%
Forams	15%

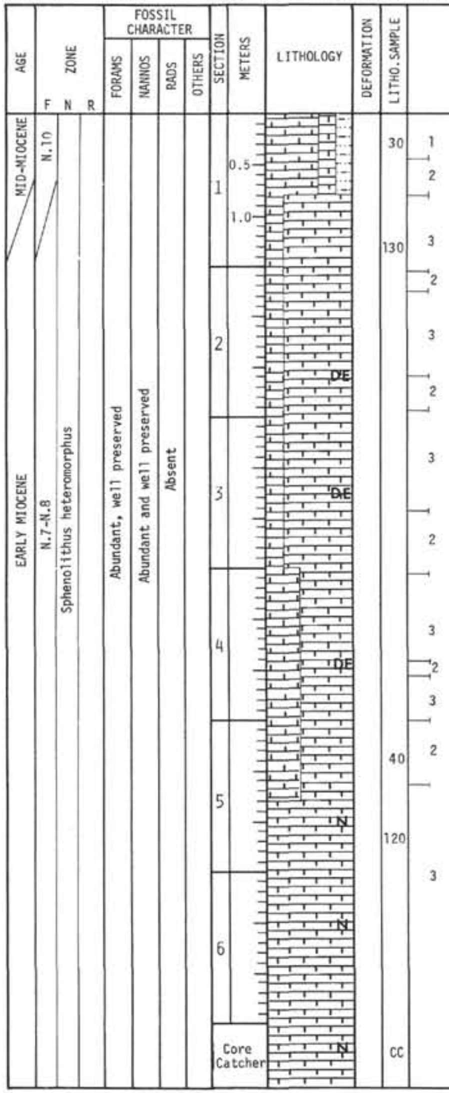
Color legend:
1 = green gray 5GY 6/1
2 = very light gray N8

Shore-based laboratory results

Carbonate
Section 2-40 cm = 75%

Explanatory notes in chapter 2

Site 219 Hole Core 13 Cored Interval: 119-128



LITHOLOGIC DESCRIPTION

White and gray NANNO RICH FORAM CHALK

Locally varying to FORAM NANNO CHALK and FORAM CHALK/OOZE.

Dominant lithology SS: Section 1-130 cm
NANNO RICH FORAM CHALK
Composition:

Forams	70%
Nannos	20%
Detrital grains	10%

Color legend:

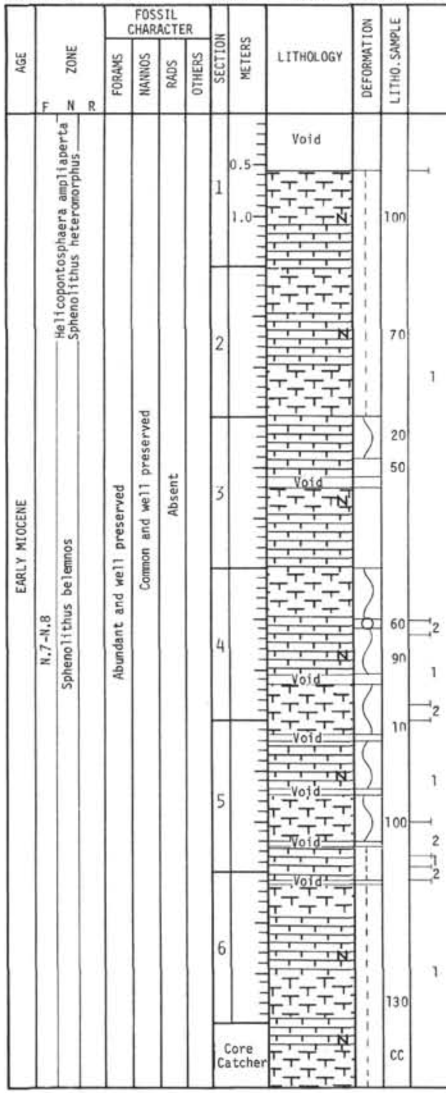
1 =	light blue gray	5Y 7/1
2 =	yellow gray	5Y 8/1
3 =	white	N9

Shore-based laboratory results

Carbonate
Section 1-40 cm = 86%

Explanatory notes in chapter 2

Site 219 Hole Core 14 Cored Interval: 128-137



LITHOLOGIC DESCRIPTION

White FORAM OOZE/CHALK

Alternating ooze and chalk layers (few decimeters thick) chiefly in sections 3-6.

Dominant lithology SS: Section 4-90 cm
FORAM OOZE
Composition:

Forams	92%
Detrital grains	5%
Nannos	3%

Color legend:

1 =	white	N9
2 =	yellowish gray	5Y 8/1

Shore-based laboratory results

Carbonate
Section 1-100 cm = 93%

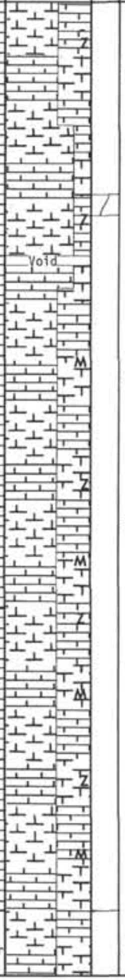
X-ray mineralogy: Section 5-110 cm

Calcite	98%
Quartz	1%
Mica	1%

Explanatory notes in chapter 2

Site 219 Hole Core 15 Cored Interval: 156-165

AGE	ZONE (F N R)	FOSSIL CHARACTER: FORAMS	FOSSIL CHARACTER: NANNOS	FOSSIL CHARACTER: RADS	FOSSIL CHARACTER: OTHERS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
MIDDLE OLIGOCENE	P.18-P.19 Sphenolithus predistentus	Common, well preserved, non-diverse	Common and well preserved	Absent		1 2 3 4 5 6 Core Catcher	0.5 1.0			70 20 80 70 60 75 CC	



1

1

White FORAM NANNO OO7E/CHALK.

Alternating hard chalk (few centimeters thick) and soft ooze bands (few decimeters thick) in sections 2-6.

In sections 3-4 the hard chalk bands are regularly spaced ~15-20 centimeters.

Dominant lithology SS: Section 4-70 cm
FORAM NANNO OOZE/CHALK
Composition:

Nannos	57%
Forams	30%
Zeolites	6%
Micarb	5%
Detrital grains	2%

Color legend:
1 = white N9

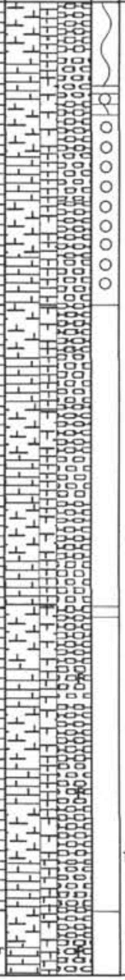
Shore-based laboratory results

Carbonate
Section 1-60 cm = 92%

Explanatory notes in chapter 2

Site 219 Hole Core 16 Cored Interval: 165-174

AGE	ZONE (F N R)	FOSSIL CHARACTER: FORAMS	FOSSIL CHARACTER: NANNOS	FOSSIL CHARACTER: RADS	FOSSIL CHARACTER: OTHERS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
EARLY OLIGOCENE	Helicopontosphaera reticulata P17 Thyrsocyrtis bromia	Few, well preserved	Common and well preserved	Absent Common and well preserved		1 2 3 4 5 6 Core Catcher	0.5 1.0			70 75 45 80 80 80 100 CC	



1

White FORAM RICH NANNO MICARB OOZE/CHALK and NANNO MICARB OOZE/CHALK.

Alternating hard chalk bands (maximum a decimeter) and soft ooze layers (few decimeters) occur. These are regularly spaced.

Dominant lithology SS: Section 4-80 cm
FORAM RICH NANNO MICARB OOZE/CHALK
Composition:

Micarb	45%
Nannos	40%
Forams	15%
Detrital grains	5%

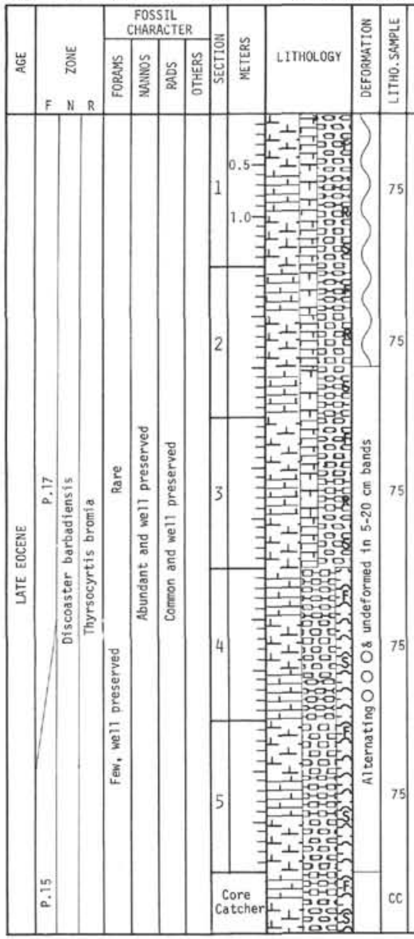
Color legend:
1 = white N9

Shore-based laboratory results

Carbonate
Section 1-60 cm = 92%

Explanatory notes in chapter 2

Site 219 Hole Core 17 Cored Interval: 174-183



LITHOLOGIC DESCRIPTION

1

White FORAM RICH MICARB NANNO OOZE/CHALK

Lower part of sections 2, 3, 4 and upper part of 5 contain alternate hard chalk and soft ooze layers.

Dominant lithology SS: Section 1-75 cm
FORAM RICH MICARB NANNO OOZE/CHALK
Composition:

Nannos	43%
Micarb	30%
Foram	12%
Sponge spicules	8%
Radiolarians	7%

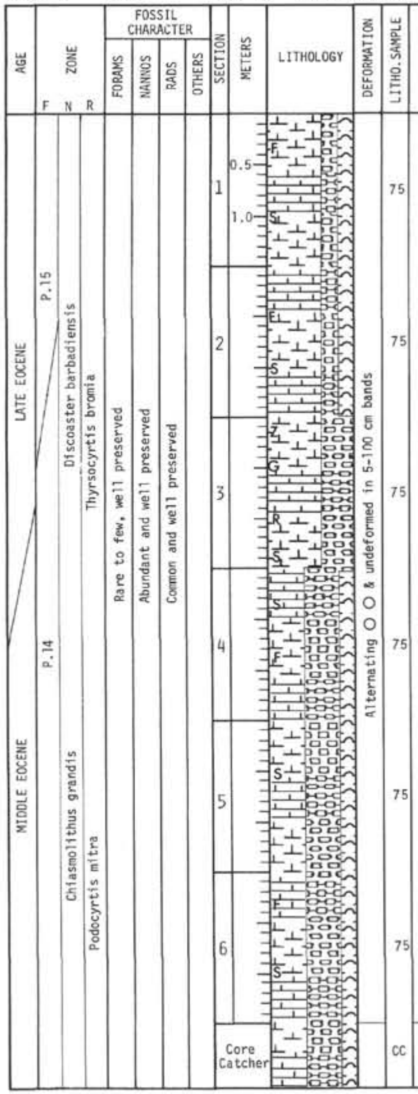
Color legend:
1 = white N9

Shore-based laboratory results

Carbonate
Section 2-75 cm = 87%

Explanatory notes in chapter 2

Site 219 Hole Core 18 Cored Interval: 183-192



LITHOLOGIC DESCRIPTION

← *
← *
← *
← *

1

White RAD RICH MICARB NANNO OO7E/CHALK

Alternate hard chalk (up to a meter). Soft ooze (up to a few decimeters) layers. The broken layers shown in deformation column are mainly of chalk. GLAUCONITE BEARING interval near middle of core.

Dominant lithology SS: Section 5-75 cm
RAD RICH MICARB NANNO OOZE
Composition:

Nannos	50%
Micarb	30%
Radiolarians	12%
Forams	5%
Sponge spicules	3%

Color legend:
1 = white N9

* glauconitic bearing layers.

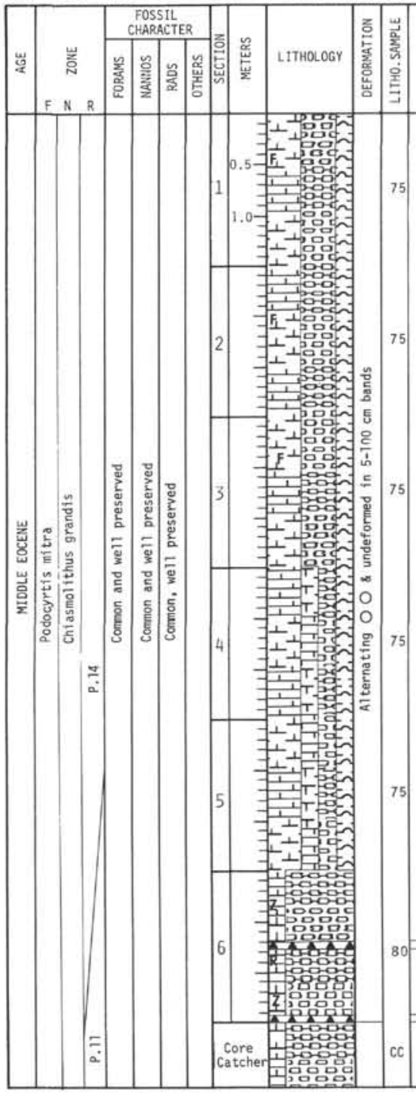
Shore-based laboratory results

Carbonate
Section 1-45 cm = 85%

X-ray mineralogy: Section 1-40 cm
Calcite 100%

Explanatory notes in chapter 2

Site 219 Hole Core 19 Cored Interval: 192-201



LITHOLOGIC DESCRIPTION

White RAD RICH MICARB NANNO CHALK/OOZE. Thin CHERT bands.

Alternating soft ooze (few centimeters) and hard chalk layers (maximum to 1 meter thick) layers. The broken intervals are hard chalk layers. Chert near bottom.

Dominant lithology SS: Section 3-75 cm
RAD RICH MICARB NANNO CHALK
Composition:

Nannos	45%
Micarb	30%
Radiolarians	13%
Forams	10%
Sponge spicules	2%

Color legend:

1 =	white	N9
2 =	yellowish gray	5Y 7/2

1

2 ← (CHERT)

1

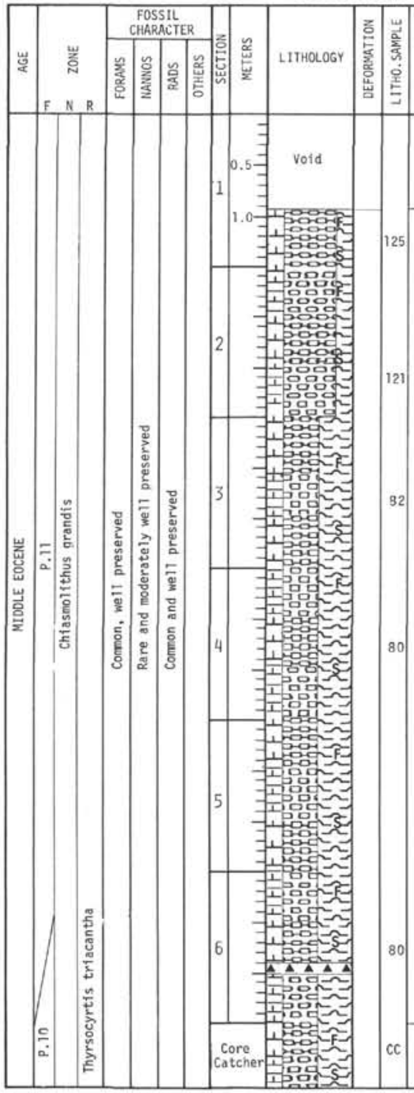
2 ← (CHERT)

Shore-based laboratory results

Carbonate
Section 1-35 cm = 84%

Explanatory notes in chapter 2

Site 219 Hole Core 20 Cored Interval: 201-210



LITHOLOGIC DESCRIPTION

White NANNO RICH RAD MICARB OOZE/CHALK

Alternate hard chalk (few centimeters to meters) and soft ooze (few centimeters to meters). Ooze and chalk occur in approximately equal proportions.

Dominant lithology SS: Section 3-80 cm
NANNO RICH RAD MICARB OOZE
Composition:

Micarb	40%
Radiolarians	26%
Nannos	20%
Forams	10%
Sponge spicules	4%

Color legend:

1 =	white	N9

1

← (CHERT)

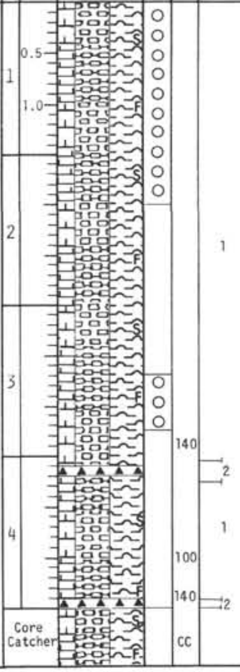
Shore-based laboratory results

Carbonate
Section 2-40 cm = 72%

Explanatory notes in chapter 2

Site 219 Hole Core 21 Cored Interval: 210-219

AGE	ZONE F	ZONE N	ZONE R	FORAMS	NANNOS	RADS	OTHERS
MIDDLE EOCENE	P.10	Chiasmolithus grandis	Thyrosocyrtis triacantha	Common, well preserved	Rare and moderately well preserved	Common and well preserved	



LITHOLOGIC DESCRIPTION

White NANNO RICH RAD MICARB OOZE/CHALK with CHERT.

Sections 1, 2, 3 consist of soupy or massive ooze. White chalk predominates in section 4. Several CHERTY intervals near bottom of core.

Dominant lithology SS: Section 2-130 cm
NANNO RICH RAD MICARB OOZE
Composition:

Micarb	45%
Radiolarians	30%
Nannos	15%
Forams	5%
Sponge spicules	5%

Color legend:
1 = white N9
2 = yellowish gray 5Y 8/1

Shore-based laboratory results

Carbonate
Section 2-40 cm = 71%

Site 219 Hole Core 22 Cored Interval: 219-228

AGE	ZONE	FORAMS	NANNOS	RADS	OTHERS
MIDDLE EOCENE					

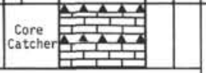
LITHOLOGIC DESCRIPTION

Green CHERT fragments in core catcher.

Color legend:
1 = grayish yellow green 5GY 7/2

Site 219 Hole Core 23 Cored Interval: 228-237

AGE	ZONE	FORAMS	NANNOS	RADS	OTHERS
MIDDLE EOCENE					



LITHOLOGIC DESCRIPTION

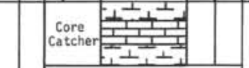
Yellow to green LIMESTONE and CHERT

Color legend:
1 = yellowish green 5Y 7/2
2 = greenish yellow 5GY 7/2

Explanatory notes in chapter 2

Site 219 Hole Core 24 Cored Interval: 237-246

AGE	ZONE F	ZONE N	ZONE R	FORAMS	NANNOS	RADS	OTHERS
MIDDLE EOCENE	P.8-P.9	Discoaster sublodoensis		Few to common, preservation fair to good	Common and well preserved	Rare and poorly preserved	



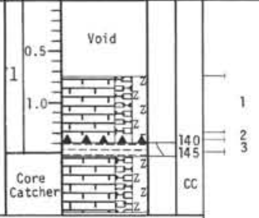
LITHOLOGIC DESCRIPTION

Orange LIMESTONE and NANNO OOZE

Color legend:
1 = very pale orange 10YR 8/2

Site 219 Hole Core 25 Cored Interval: 246-255

AGE	ZONE F	ZONE N	ZONE R	FORAMS	NANNOS	RADS	OTHERS
EARLY EOCENE	P.8	Discoaster lodoensis		Common, well preserved	Rare and poorly preserved	Absent	



LITHOLOGIC DESCRIPTION

White ZEOLITE MICARB RICH FORAM CHALK

Dominant lithology SS: Section 1-140 cm
ZEOLITE MICARB RICH FORAM CHALK
Composition:

Forams	60%
Micarb	15%
Zeolites	15%
Nannos	10%

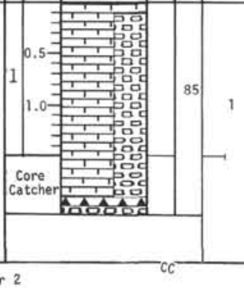
Minor lithology SS: Section 1-145 cm
RAD RICH DETRITAL CLAY
Composition:

Detrital grains	70%
Radiolarians	20%
Forams	10%

Color legend:
1 = white N9
2 = yellowish gray 5Y 8/1
3 = moderate yellow brown 10YR 5/4

Site 219 Hole Core 26 Cored Interval: 255-264

AGE	ZONE F	ZONE N	ZONE R	FORAMS	NANNOS	RADS	OTHERS
EARLY EOCENE		P.7-P.8		Few to common, good preservation	Absent	Absent	



LITHOLOGIC DESCRIPTION

Brown MICARB FORAM CHALK

Chalk contains pieces of LIMESTONE (0-30 cm) and PHOSPHATE concretions. Sediments are semi-lithified to lithified.

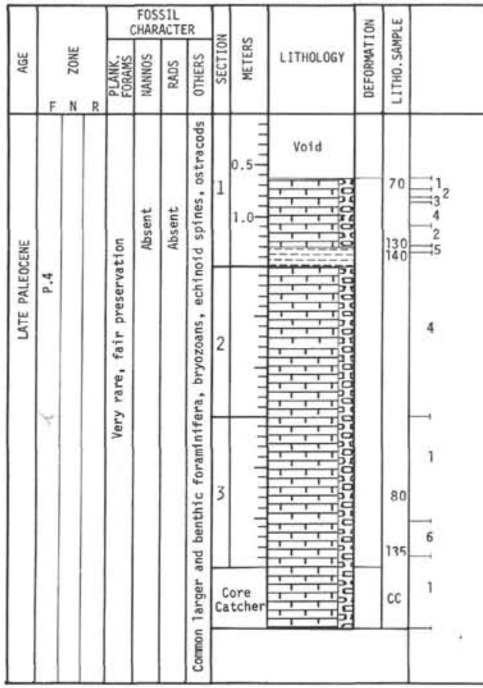
Dominant lithology SS: Section 1-85 cm
MICARB FORAM CHALK
Composition:

Forams	55%
Micarb	30%
Detrital minerals	10%
Zeolites	5%

Color legend:
1 = dark yellow brown 10YR 4/2

Explanatory notes in chapter 2

Site 219 Hole Core 27 Cored Interval: 264-273



LITHOLOGIC DESCRIPTION

Orange to yellow MICARB RICH FORAM OOZE/CHALK

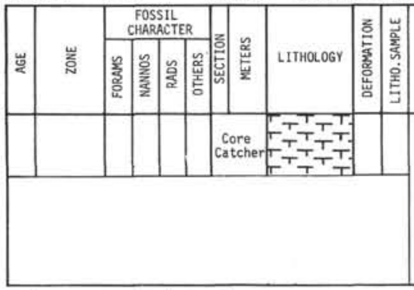
Many of the sand grains are foraminifera, some of the smaller grains are probably also of foraminiferal origin.

Dominant lithology SS: Section 3-80 cm
MICARB RICH FORAM OOZE
Composition:

Forams	85%
Micarb	15%

Color legend:
1 = pale yellow orange 10YR 8/4
2 = pale yellow brown 10YR 6/2
3 = pale yellow orange 10YR 8/6
4 = white N9
5 = green yellow 10Y 7/4
6 = red brown 10YR 5/4

Site 219 Hole Core 28 Cored Interval: 273-



LITHOLOGIC DESCRIPTION

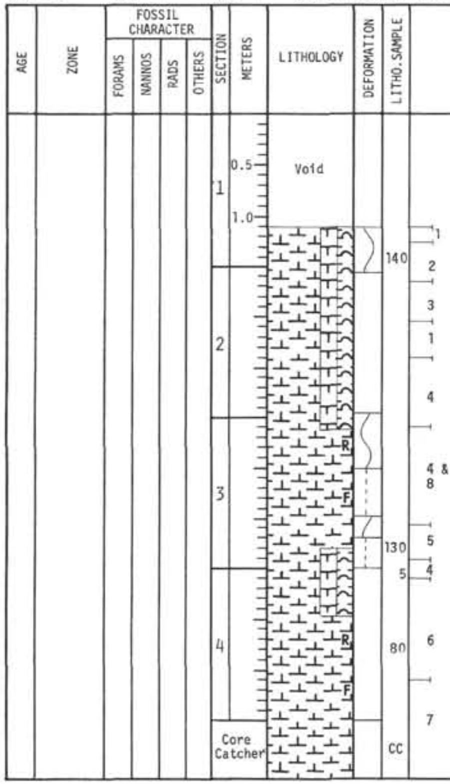
Orange FORAM OOZE

Color is yellowish orange.

Remarks:
The core barrel became stuck in the hole and the sediment probably represents the interval just above 273 meters. Many of the foraminifera are benthonic and larger forms.

Explanatory notes in chapter 2

Site 219 Hole A Core 1 Cored Interval: 0-290



LITHOLOGIC DESCRIPTION

Green to gray FORAM RAD RICH NANNO OOZE, locally NANNO OOZE.

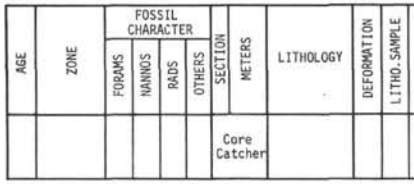
Core taken by washing down to 290 meters with core barrel in place. Core material probably represents the composite of this entire interval and is therefore not representative of the lithology at 290 meters.

Dominant lithology SS: Section 1-140 cm
FORAM RAD RICH NANNO OOZE
Composition:

Nannos	70%
Forams	15%
Radiolarians	15%
Diatoms	Trace

Color legend:
1 = grayish olive green 5GY 3/2
2 = dusky yellow 5Y 6/4
3 = moderate olive brown 5Y 4/4
4 = grayish olive 10Y 4/2
5 = pale greenish yellow 10Y 8/2
6 = white N9
7 = light greenish gray 5Y 8/1
8 = pale olive 10Y 6/2

Site 219 Hole A Core 2 Cored Interval: 290-299



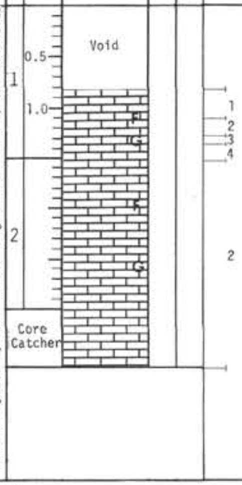
LITHOLOGIC DESCRIPTION

There was no core recovery.

Explanatory notes in chapter 2

Site 219 Hole A Core 3 Cored Interval: 299-308

AGE	ZONE			FOSSIL CHARACTER			
	F	N	R	FORAMS	NANNOS	RADS	OTHERS
LATE PALEOCENE	P.4			Rare to few, fair preservation	Rare and moderately well preserved	Absent	Common bryozoans, benthic and larger foraminifera, rare echinoids



LITHOLOGIC DESCRIPTION

Yellow and gray LIMESTONE

Grayish yellow and greenish gray LIMESTONE containing forams, molluscan shell fragments. Layers glauconite rich and bearing. Shallow-water benthics and larger forams abundant.

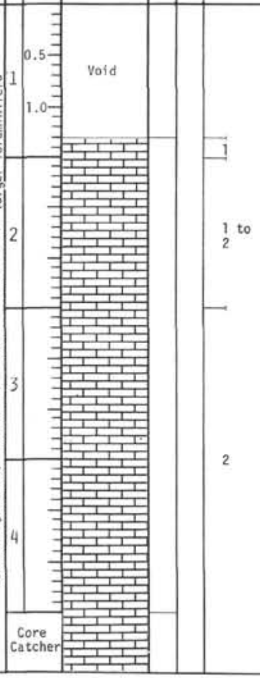
Color legend:

1 =	grayish yellow	5Y 8/4
2 =	grayish yellow green—	5GY 7/2
3 =	dark yellowish orange	10YR 6/6
4 =	greenish gray	5G 6/1

Explanatory notes in chapter 2

Site 219 Hole A Core 4 Cored Interval: 308-317

AGE	ZONE			FOSSIL CHARACTER			
	F	N	R	FORAMS	NANNOS	RADS	OTHERS
LATE PALEOCENE	P.4			Rare, fair to poor preservation	Rare and moderately well preserved		Common bryozoans, echinoids, benthic foraminifera; rare ostracods; larger foraminifera



LITHOLOGIC DESCRIPTION

Green and gray LIMESTONE

Yellowish green and gray LIMESTONE contains medium to coarse sand size calcareous material bound by calcareous cement.

Parallel and cross-lamination common, burrow structures present. Large mollusk fragments noted.

Color legend:

1 =	grayish yellow green	5GY 7/2
2 =	yellowish gray	5Y 7/2

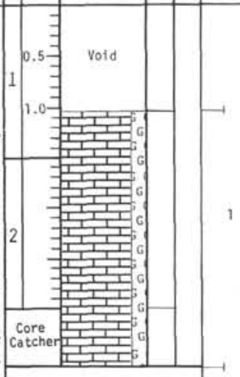
Shore-based laboratory results

	Carbonate
Section 3-34 cm =	86%

Explanatory notes in chapter 2

Site 219 Hole A Core 5 Cored Interval: 317-326

AGE	ZONE (F N R)	PLANK. FORAMS	NANNOS	RADS	OTHERS
LATE PALEOCENE	P.4	Rare to absent, poorly preserved	Rare and moderately well preserved	Absent	Common benthic foraminifera, bryozoans; rare ostracods, larger foraminifera



LITHOLOGIC DESCRIPTION

Green GLAUCONITE RICH LIMESTONE

Abundant benthic foraminifera, ostracods, bryozoans.

Grains range from coarse to very coarse sand size. Fragments of shells and shallow-water mollusks were noted.

Color legend:
1 = pale blue green 5BG 7/2

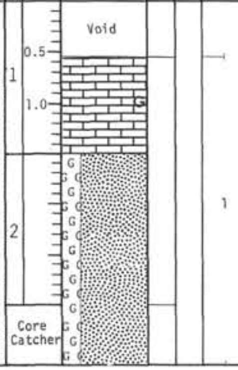
Shore-based laboratory results

Carbonate
Section 2-75 cm = 75%

X-ray mineralogy:	Section 2-80 cm
Calcite	89%
Plagioclase	8%
Clinoptilolite	3%

Site 219 Hole A Core 6 Cored Interval: 326-335

AGE	ZONE (F N R)	FORAMS	NANNOS	RADS	OTHERS
LATE PALEOCENE	P.4	Rare, poor preservation	Very rare and poorly preserved	Absent	Common benthic foraminifera; few bryozoans



LITHOLOGIC DESCRIPTION

Green CALCAREOUS CEMENTED GLAUCONITE RICH SANDSTONE overlain by LIMESTONE.

Grains of very coarse sand size. Parallel and oblique lamination noted. Shell fragments present also abundant benthic foraminifera.

Color legend:
1 = grayish yellow green 5GY 7/2

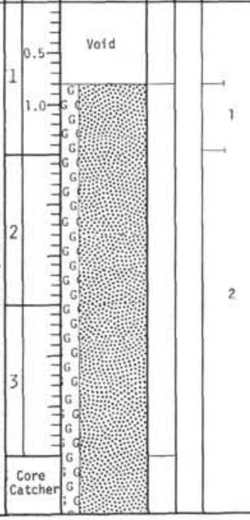
Shore-based laboratory results

Carbonate
Section 1-80 cm = 73%

Explanatory notes in chapter 2

Site 219 Hole A Core 7 Cored Interval: 335-344

AGE	ZONE (F N R)	FORAMS	NANNOS	RADS	OTHERS
LATE PALEOCENE	P.4	Absent	Very rare and poorly preserved	Absent	Common benthic foraminifera, bryozoans, echinoids



LITHOLOGIC DESCRIPTION

Green CALCAREOUS CEMENTED GLAUCONITE RICH SANDSTONE

Grain size varies from medium to coarse. Rare horizontal lamination and possibly cross-lamination is present in section 3. Burrow type structures and thick walled mollusk fragments are in evidence. Varies significantly in induration from soft to very hard.

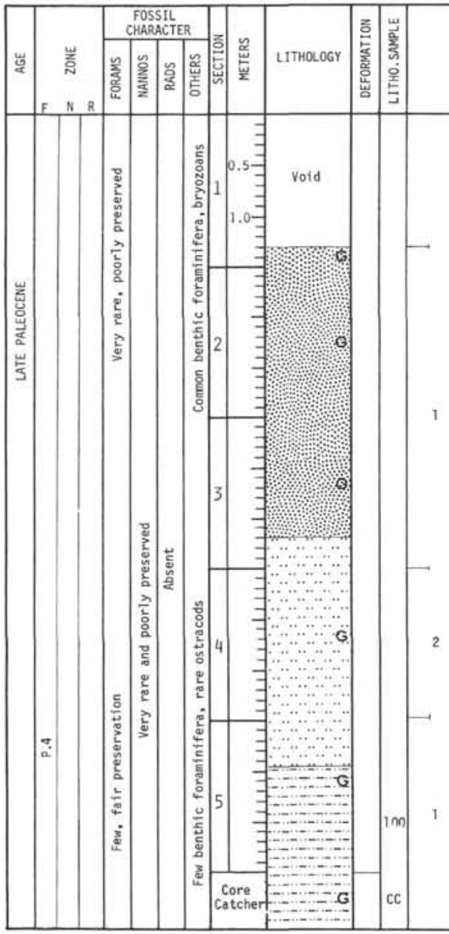
Color legend:
1 = grayish green 5G 5/2
2 = pale blue green 5BG 7/2

Shore-based laboratory results

Carbonate
Section 2-40 cm = 58%

Explanatory notes in chapter 2

Site 219 Hole A Core 8 Cored Interval: 344-353



LITHOLOGIC DESCRIPTION

Green SANDSTONE, SILTY SANDSTONE, SILTSTONE and SILTY CLAY

The sandstone varies from semi-lithified to lithified. In addition to a dominance of detrital grains, pelecypod, foraminifera, ostracods, red algae, bryozoan and belemnite fragments are present.

Minor lithology SS: Section 5-100 cm
CALCAREOUS CEMENTED SILTY CLAYSTONE
Composition:

Detrital minerals	95%
Sponge spicules	5%
Glauconite	Trace
Radiolarians	Trace

Color legend:

1 =	grayish green	5G 5/2
2 =	pale green	10G 9/2

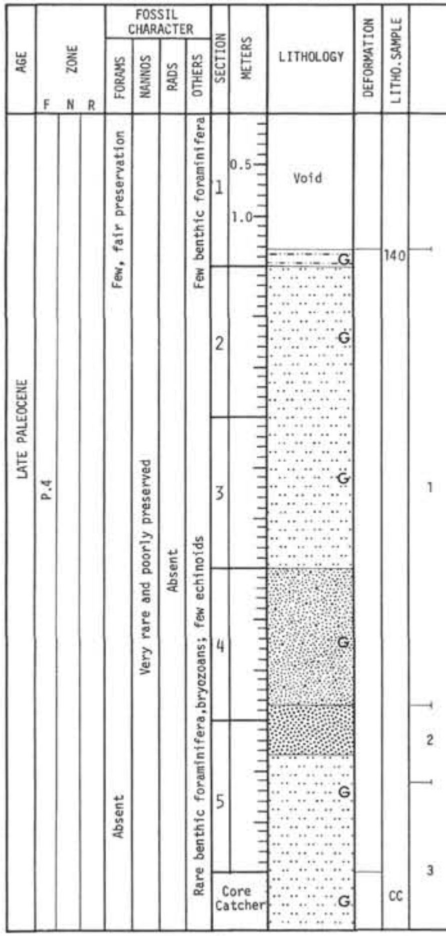
Remarks:
20% of detrital grains are calcareous particles.

Shore-based laboratory results

	Carbonate
Section 3-43 cm =	22%

Explanatory notes in chapter 2

Site 219 Hole A Core 9 Cored Interval: 353-362



LITHOLOGIC DESCRIPTION

Green GLAUCONITE BEARING SILTSTONE and SANDSTONE.

The siltstone is laminated and locally biogenous. The sandstone is biogenous and contains large pelecypod and red algae fragments, etc. Some of these are glauconitized.

Minor lithology SS: Section 1-140 cm
SILTY CLAY
Composition:

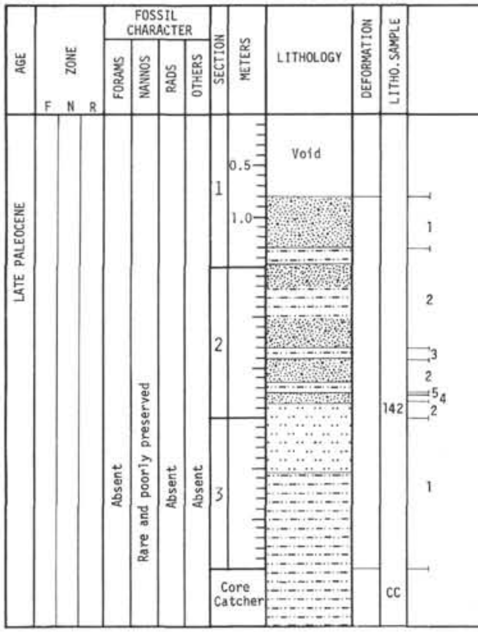
Detrital grains	90%
Sponge Spicules	10%

Color legend:

1 =	grayish green	5G 5/2
2 =	pale yellowish green	10GY 7/2
3 =	light bluish gray	5B 7/1

Explanatory notes in chapter 2

Site 219 Hole A Core 10 Cored Interval: 362-371



LITHOLOGIC DESCRIPTION

Gray SANDY SILTSTONE, SILTSTONE and SILTY CLAYSTONE.

Strata are horizontally laminated.

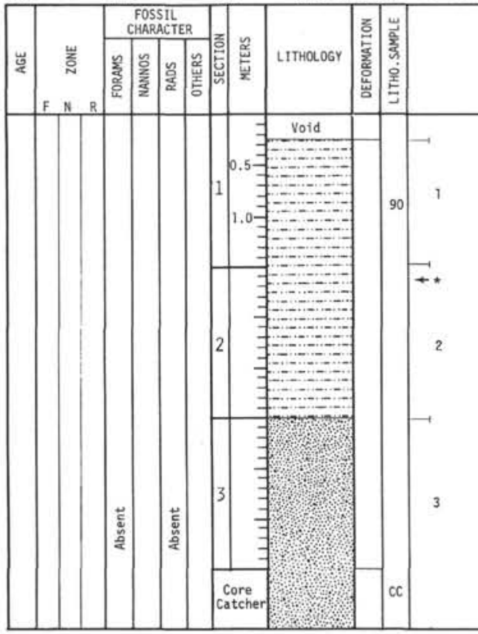
Minor lithology SS: Section 2-142 cm
SANDY SILTSTONE
Composition:

Quartz	70%
Feldspars	30%

Color legend:

1 = greenish gray 5G 6/1
2 = dark green gray 5G 4/1
3 = bluish white 5B 9/1
4 = greenish black 5G 2/1
5 = white N9

Site 219 Hole A Core 11 Cored Interval: 371-380



LITHOLOGIC DESCRIPTION

Gray CLAYEY SILTSTONE and greenish black SANDY SILTSTONE.

Sections 2 and 3 are traversed by calcite veins.

Dominant lithology SS: Section 1-90 cm
CLAYEY SILTSTONE
Composition:

Detrital grains	99%
Nannos and Zeolites	Trace

Color legend:

1 = greenish gray 5G 6/1
2 = dark greenish gray 5G 4/1
3 = greenish black 5G 2/1

* calcite vein

Shore-based laboratory results

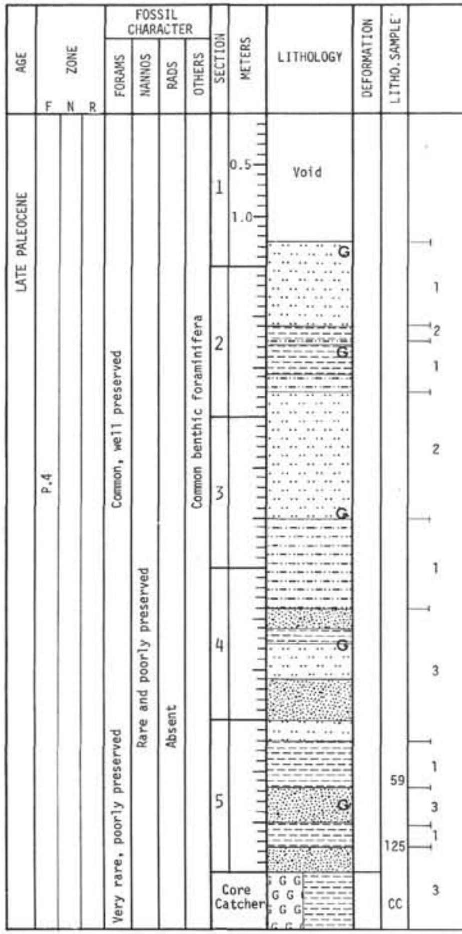
	Carbonate
Section 2-47 cm =	2%

X-ray mineralogy: Section 2-45 cm

Calcite	3%
Plagioclase	33%
Montmorillonite	49%
Phillipsite	15%

Explanatory notes in chapter 2

Site 219 Hole A Core 12 Cored Interval: 380-387



LITHOLOGIC DESCRIPTION

Gray SILTSTONE, SANDY SILTSTONE, SILTY SANDSTONE and dark gray CLAYEY SILTSTONE and CLAYSTONE.

Burrow structures and pelecypod shell fragments are common.

Minor lithology SS: Section 5-59 cm
SILTY CLAYSTONE
Composition:

Detrital minerals	100%

Minor lithology SS: core catcher
GLAUCONITIC SILTY CLAYSTONE
Composition:

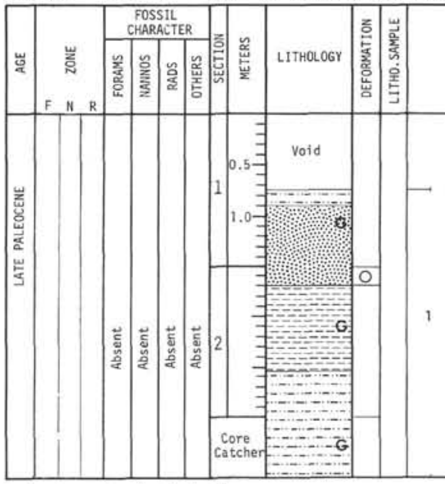
Detrital minerals	70%
Glauconite	30%

Color legend:

1 = dark gray N2
2 = greenish gray 5GY 6/1
3 = dark greenish gray 5GY 4/1

Explanatory notes in chapter 2

Site 219 Hole A Core 13 Cored Interval: 387-396



LITHOLOGIC DESCRIPTION

Green CLAYEY SILTSTONE, CLAYSTONE, SILTY SANDSTONE and SANDSTONE.

Horizontal and cross-lamination.

Color legend:
1 = grayish green 5G 5/2

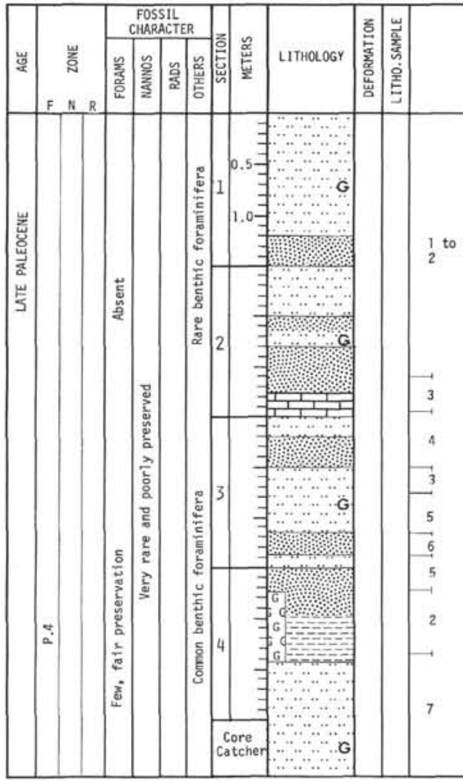
Shore-based laboratory results

Carbonate
Section 2-60 cm = 1%

X-ray mineralogy:	Section 2-60 cm
Calcite	9%
Plagioclase	12%
Montmorillonite	64%
Phillipsite	13%
Analcite	1%
Anatase	1%

Explanatory notes in chapter 2

Site 219 Hole A Core 14 Cored Interval: 402-411



LITHOLOGIC DESCRIPTION

Black and gray SANDSTONE, SILTSTONE and SILTY SANDSTONE

Lamination, cross-bedding, graded bedding, load casts, convolute bedding and burrows are common. Calcite veins are present in Sections 1 and 5.

Large molluscan shells and shell fragments are common in many beds.

Color legend:

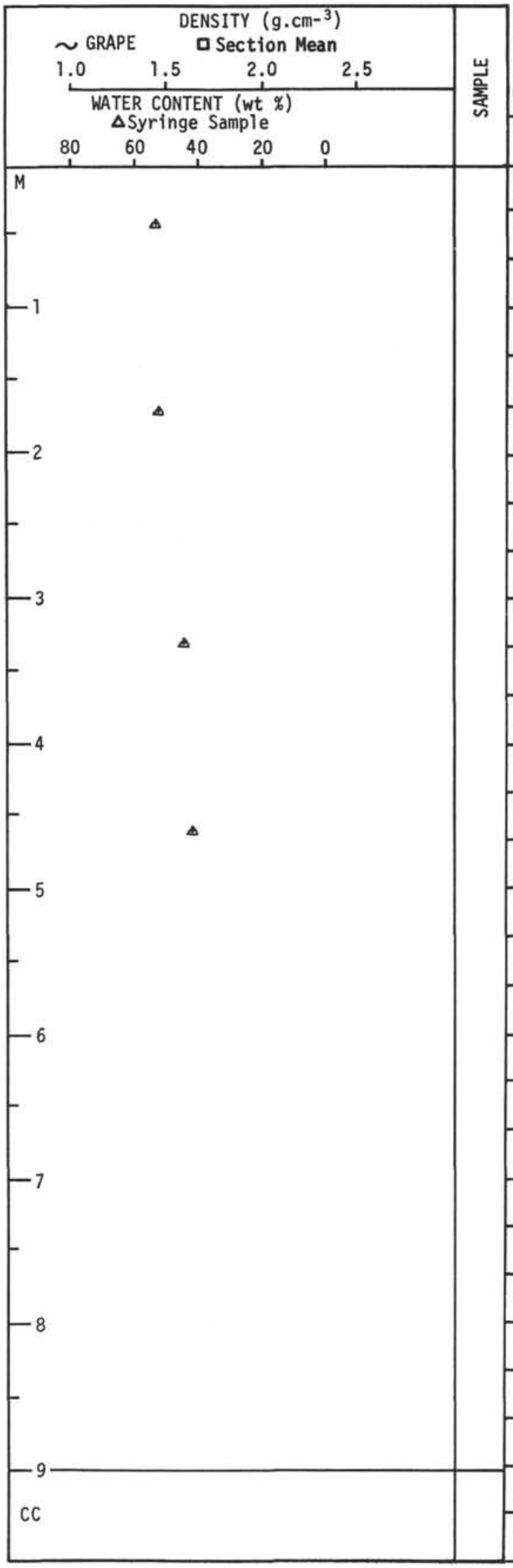
1 =	olive black	5GY 2/1
2 =	greenish black	5G 2/1
3 =	greenish gray	5GY 6/1
4 =	dark greenish gray	5GY 4/1
5 =	olive gray	5Y 4/1
6 =	very dusky purple red	5RP 2/2
7 =	light greenish gray	5G 8/1

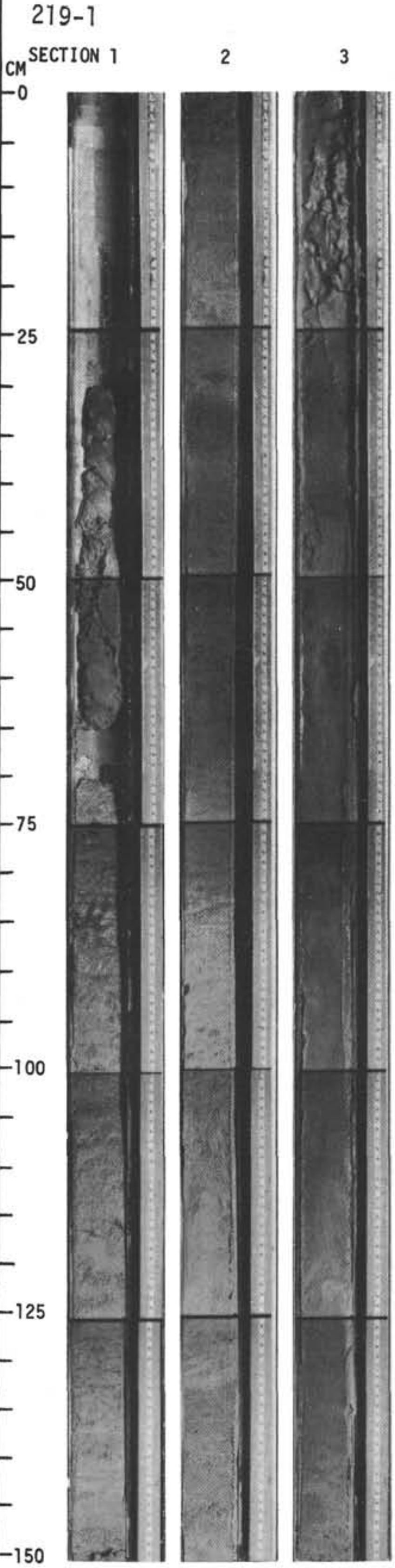
Shore-based laboratory results

Carbonate
Section 3-60 cm = 37%

Grain size:	Section 3-60 cm
Sand	22%
Silt	33%
Clay	45%

Explanatory notes in chapter 2





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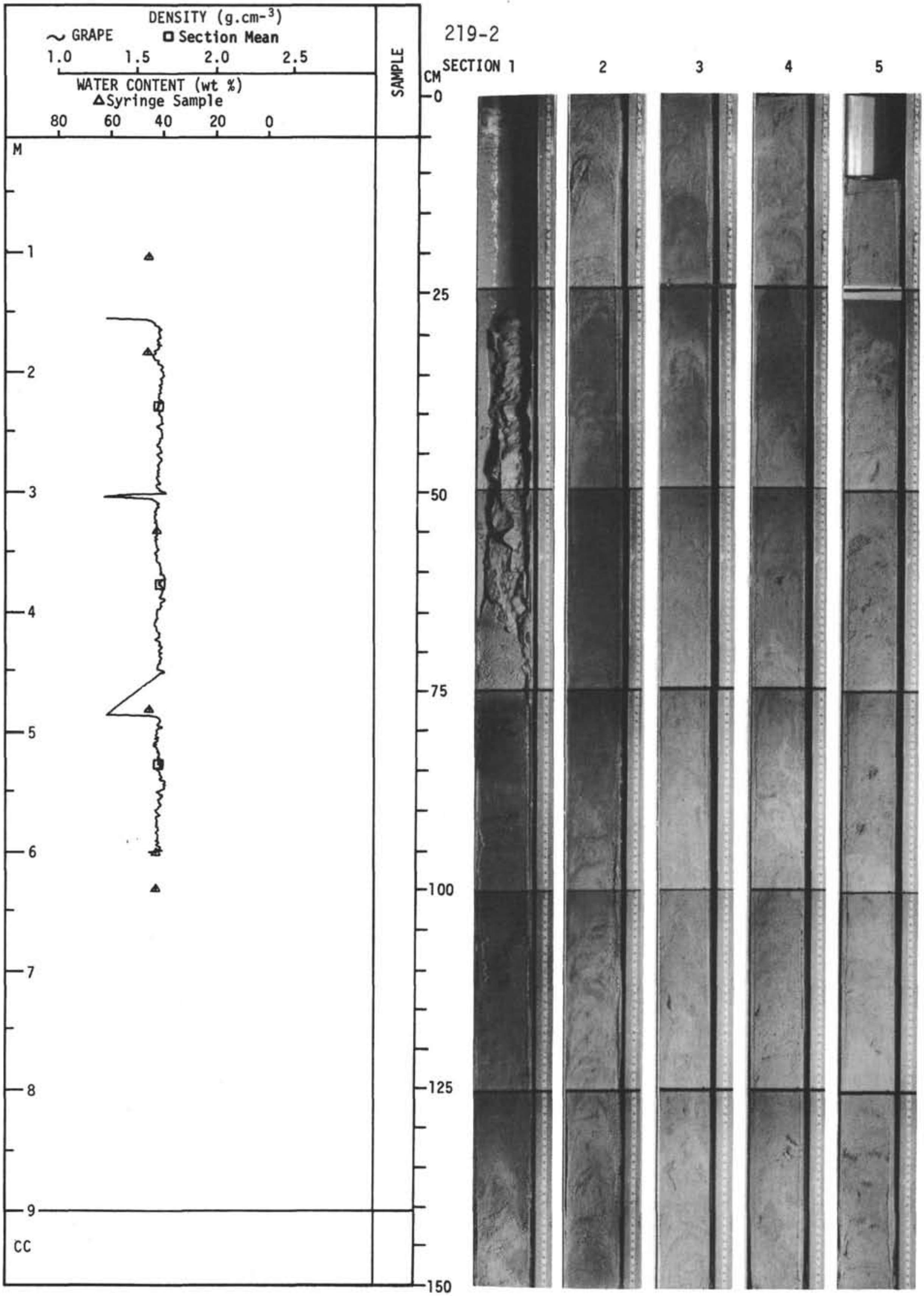
For Explanatory Notes, see Chapter 2



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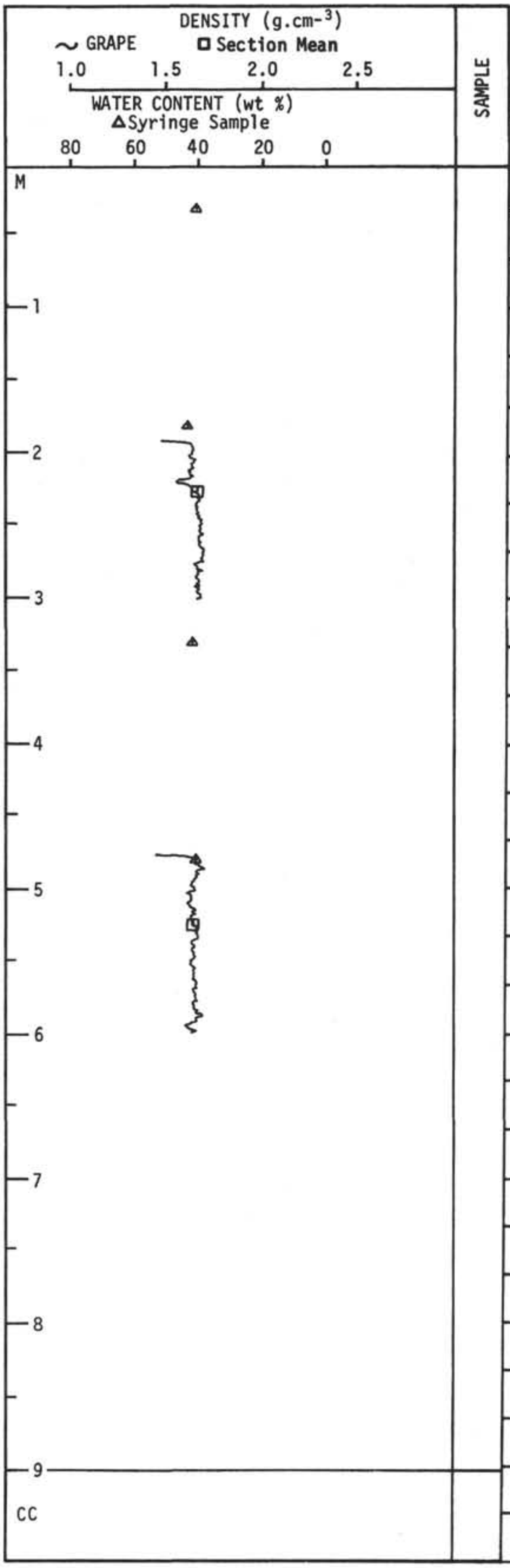

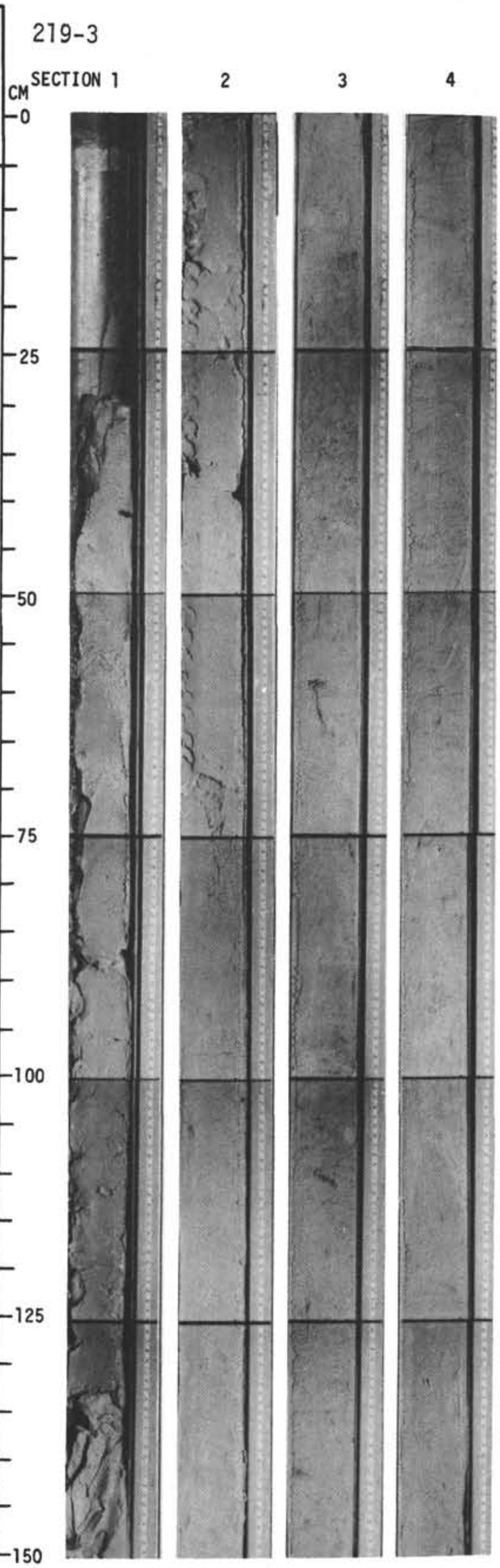

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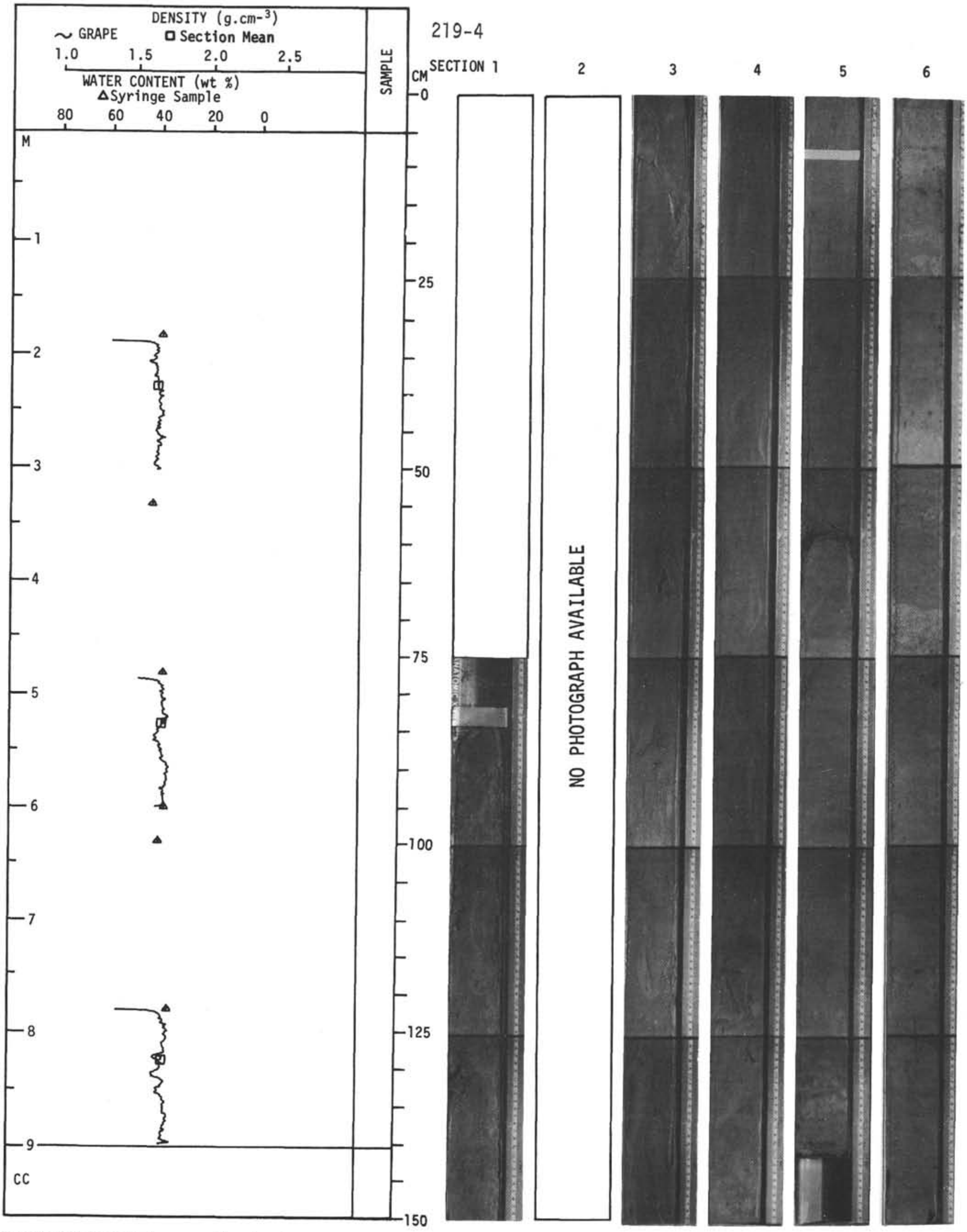

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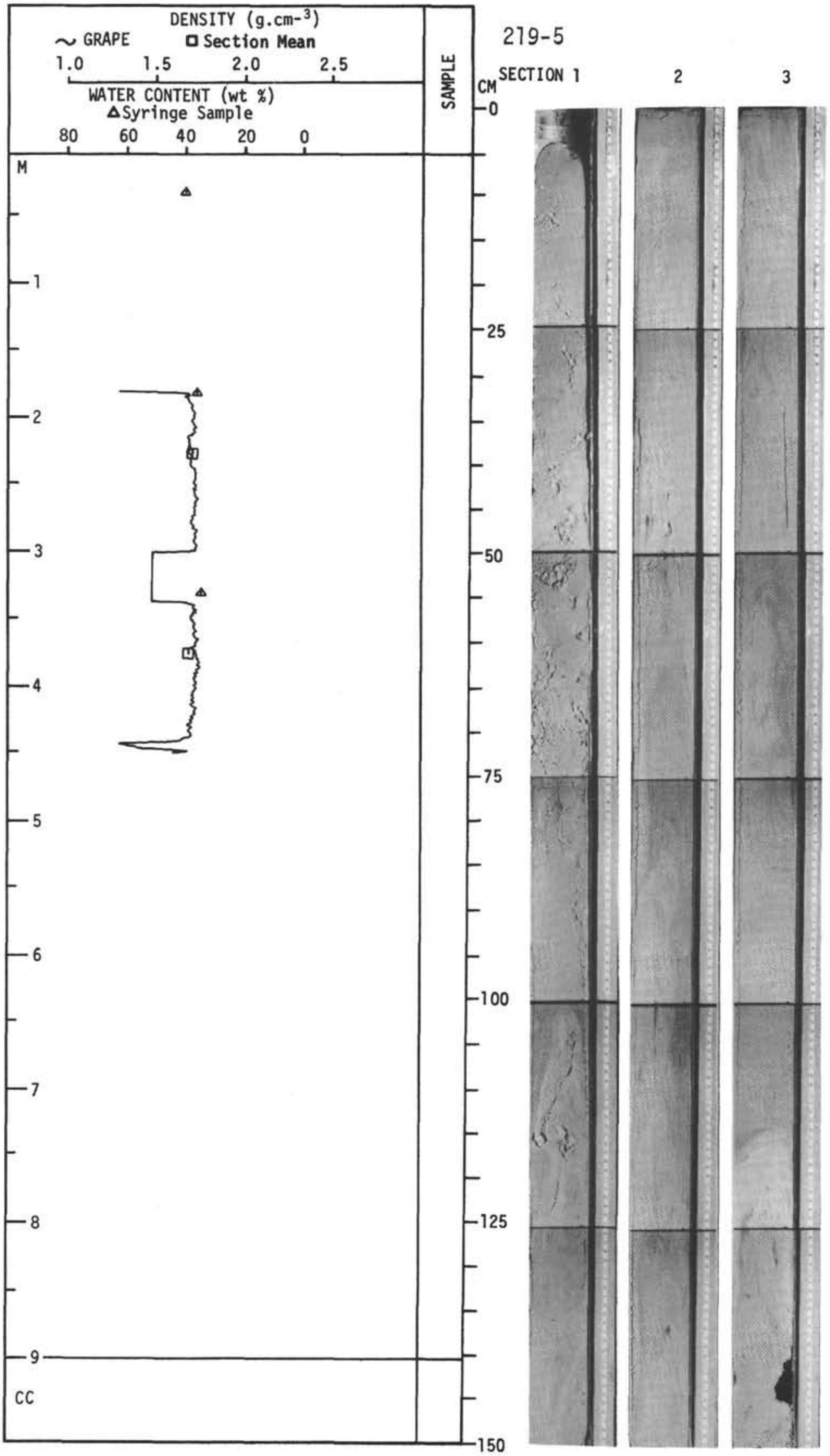

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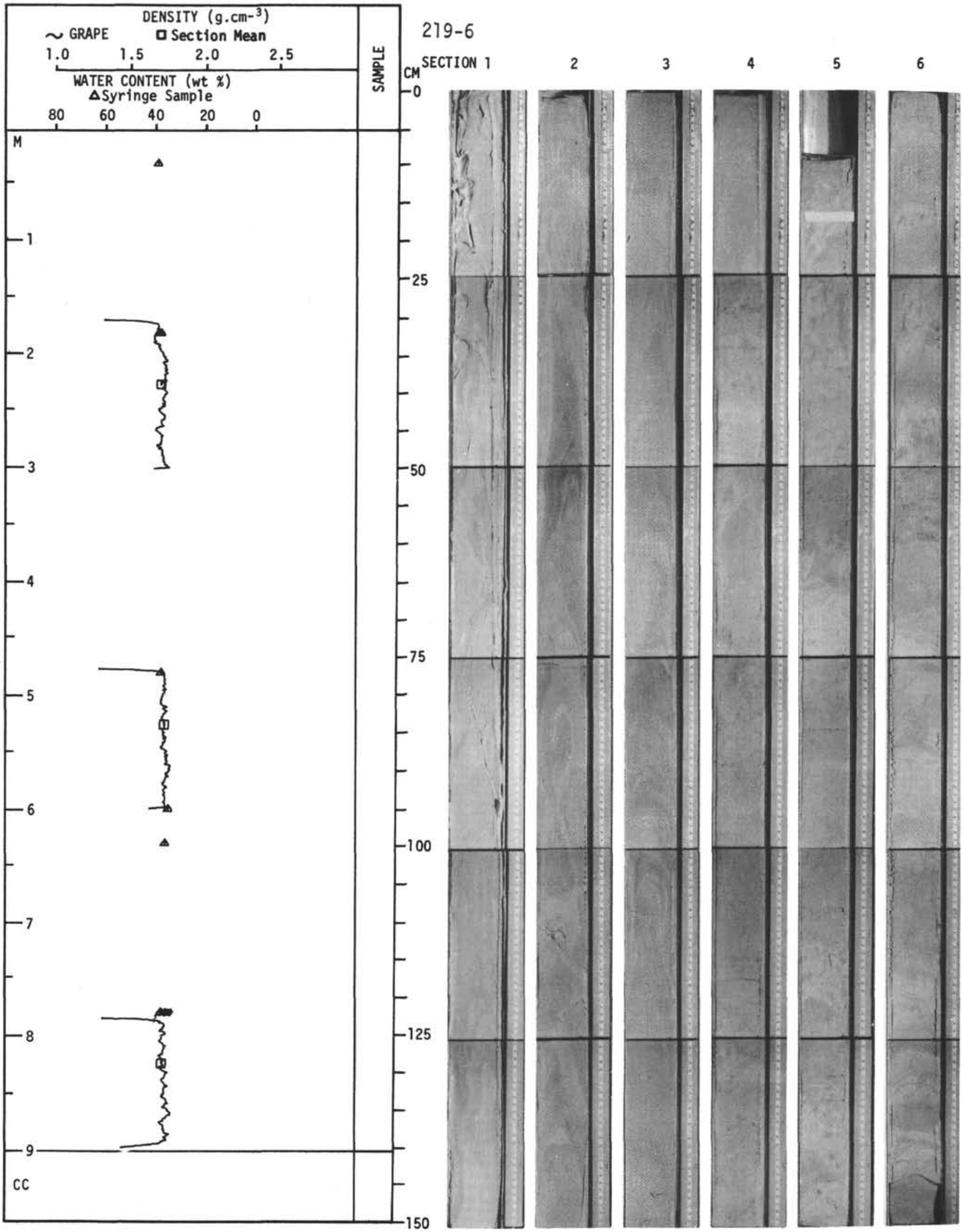

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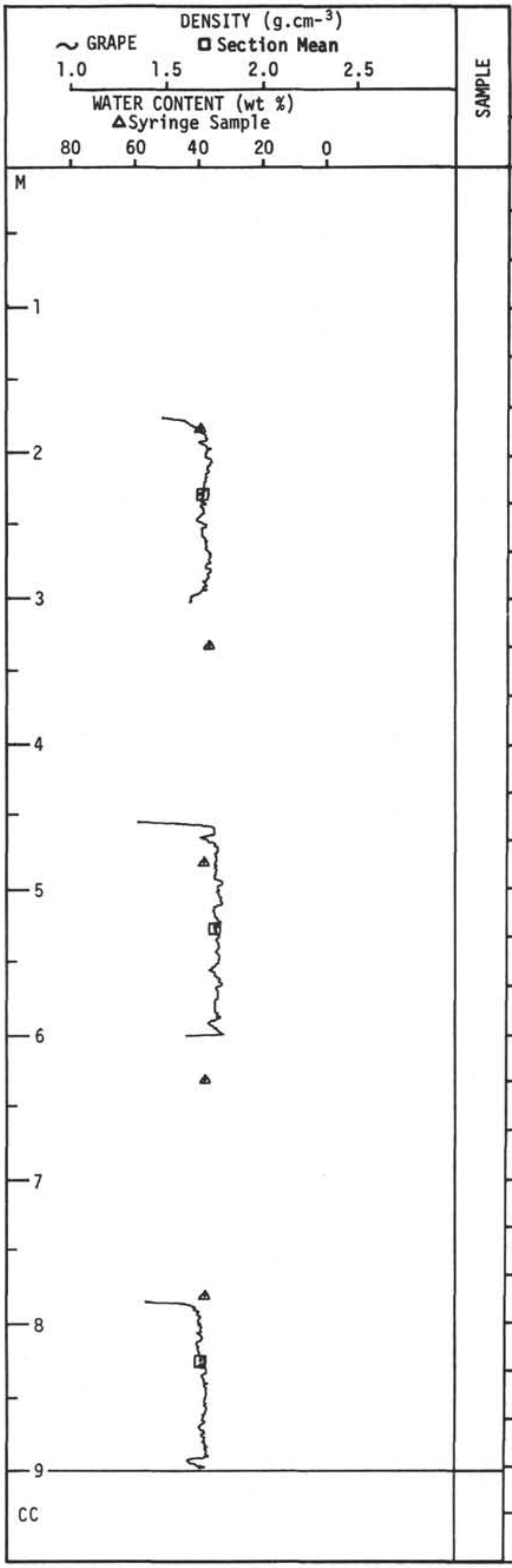

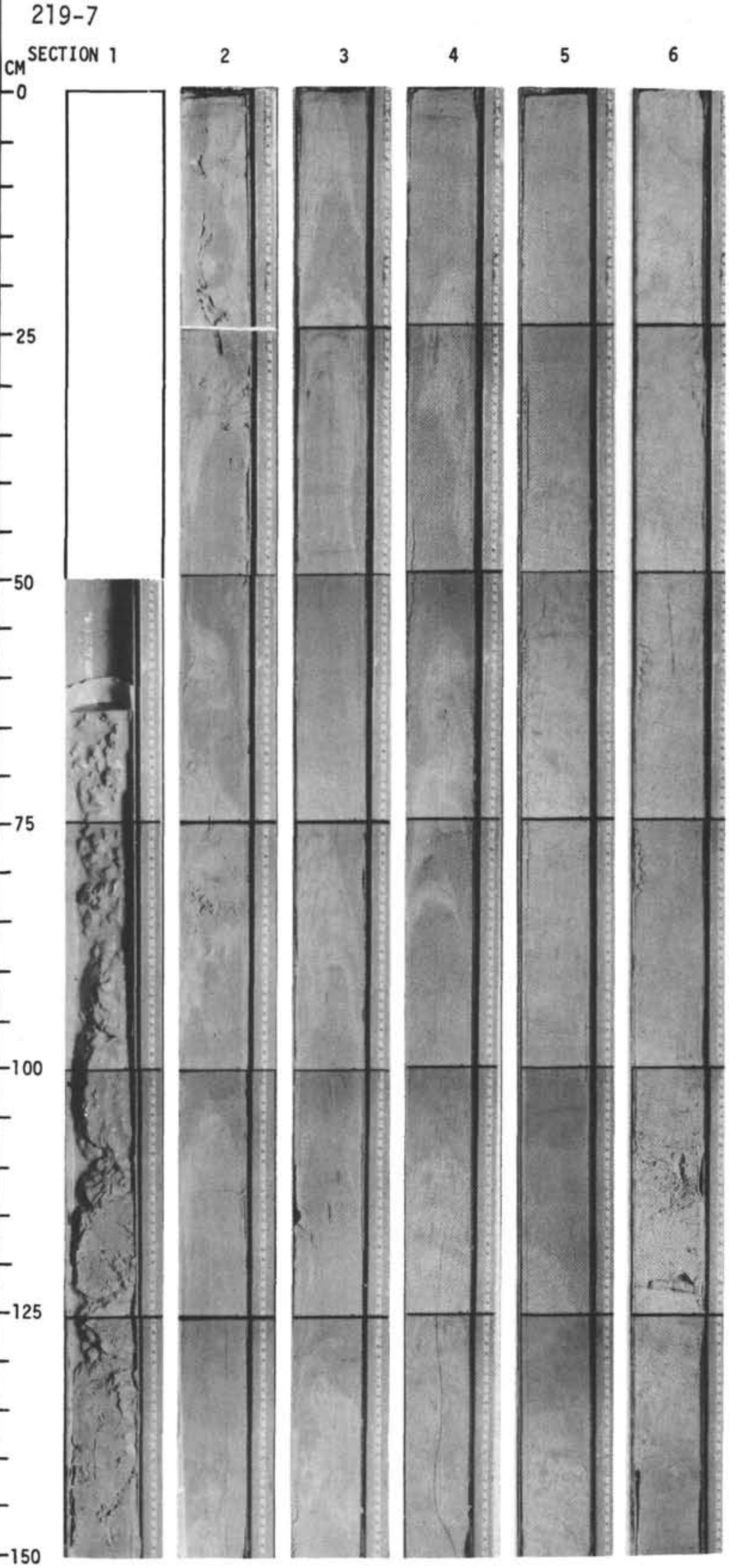

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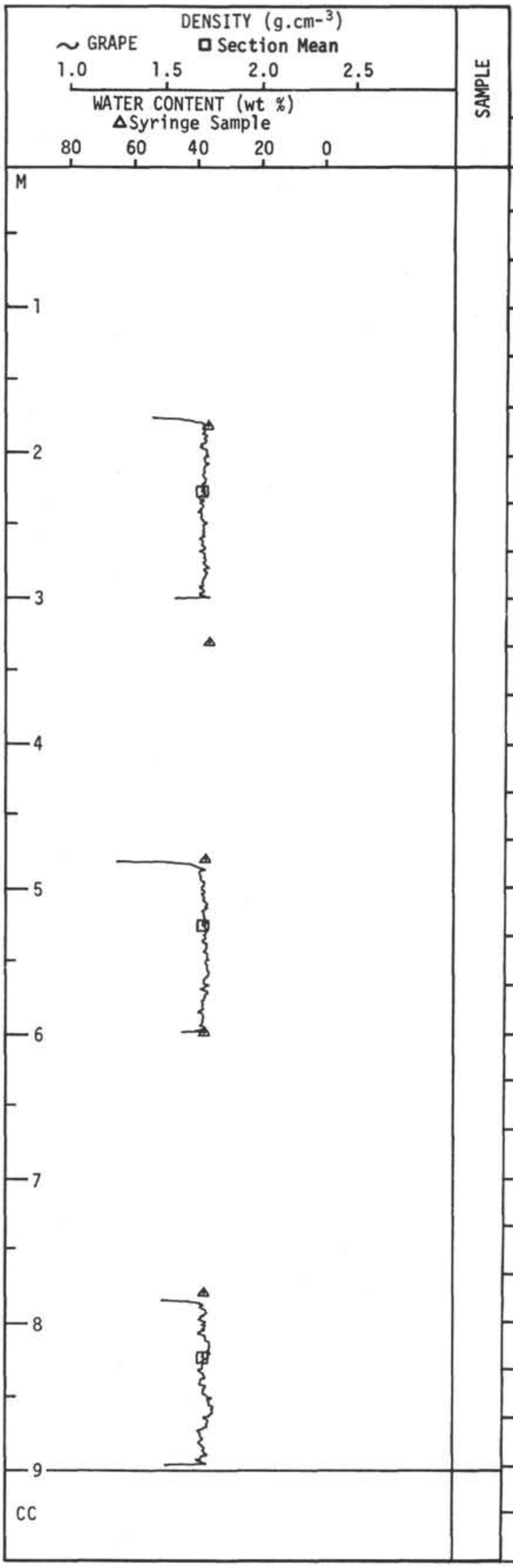

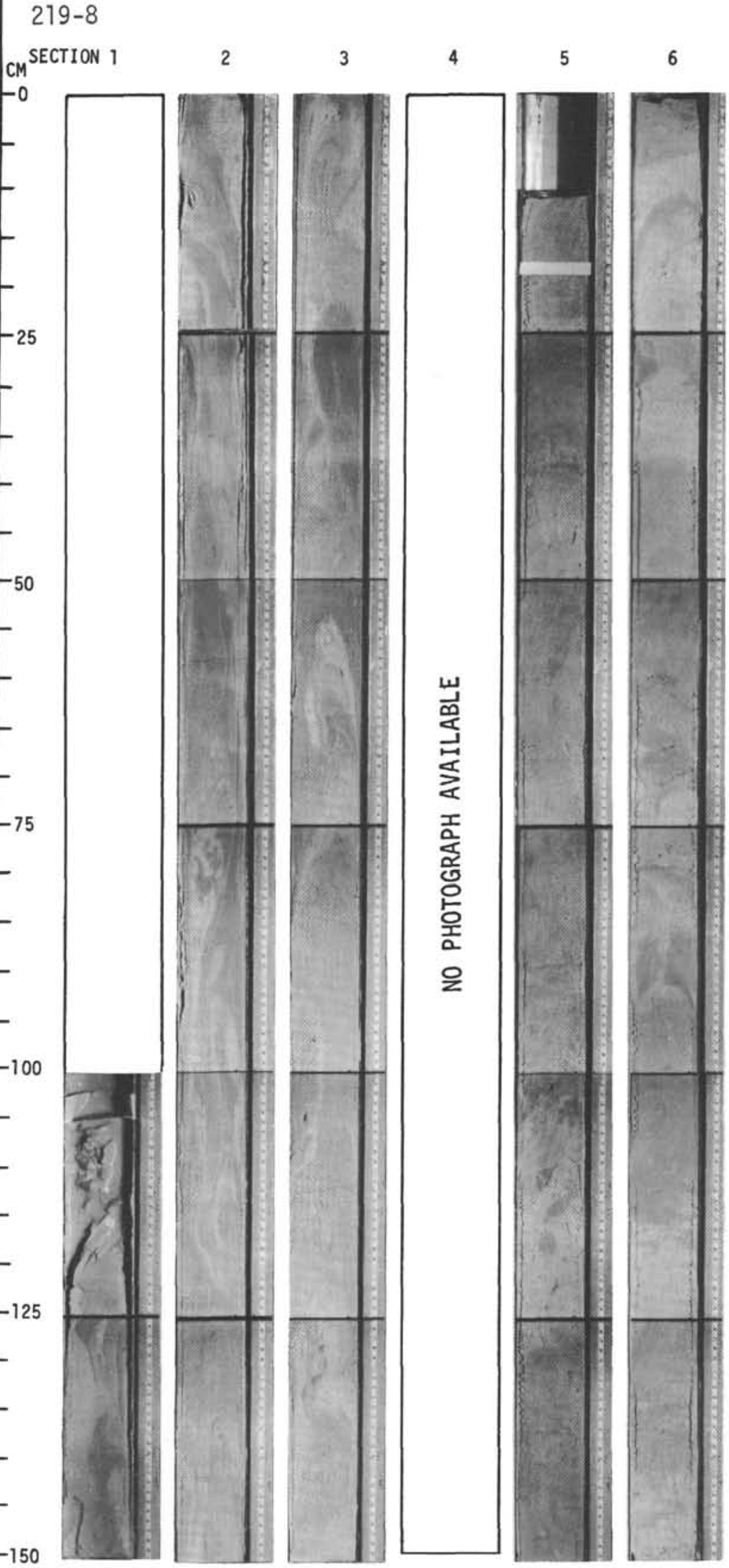

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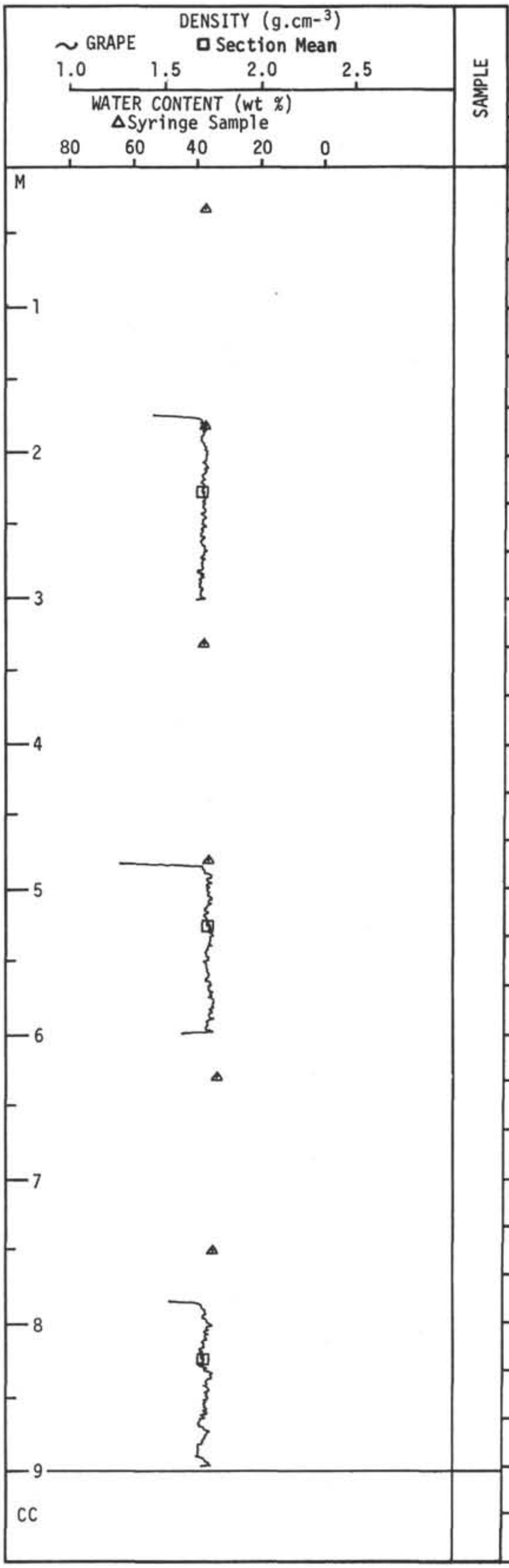

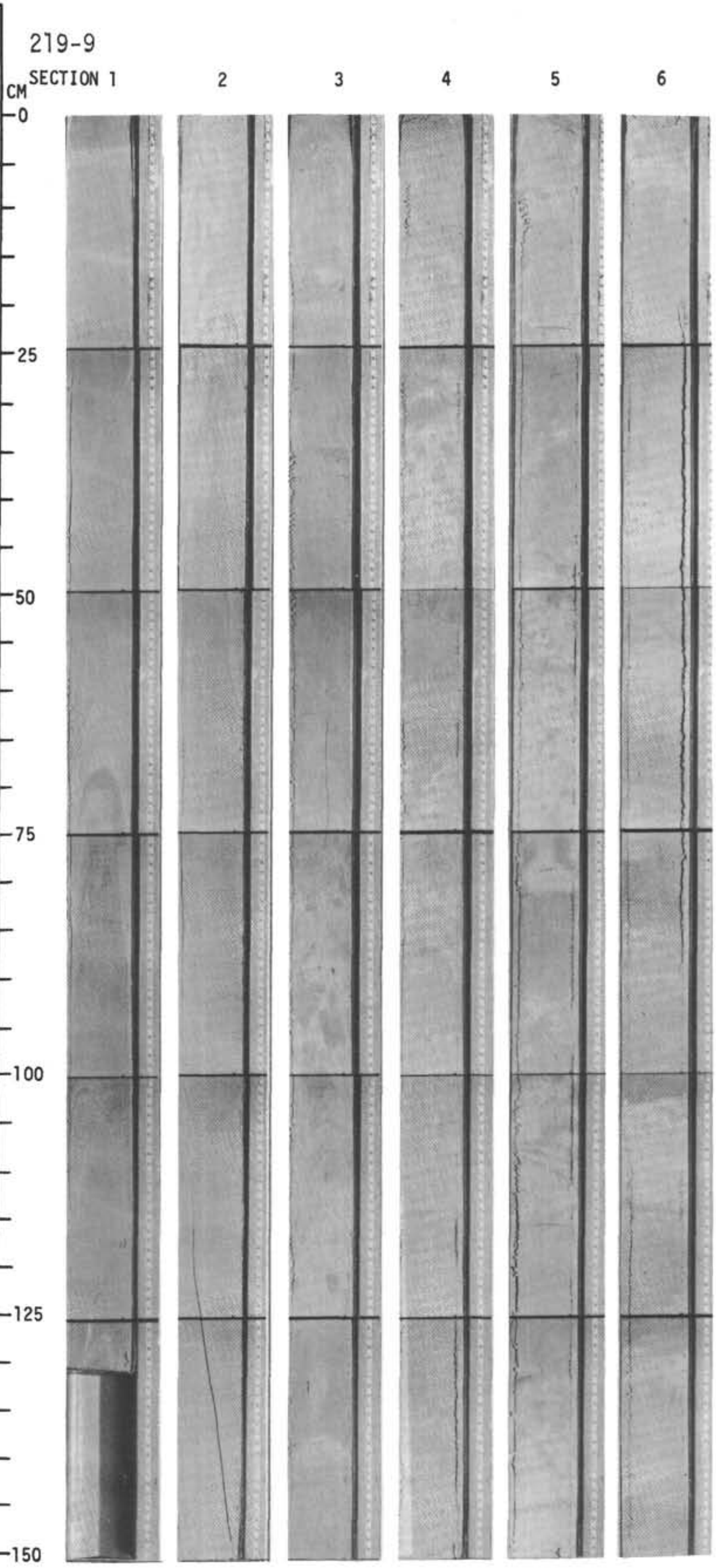

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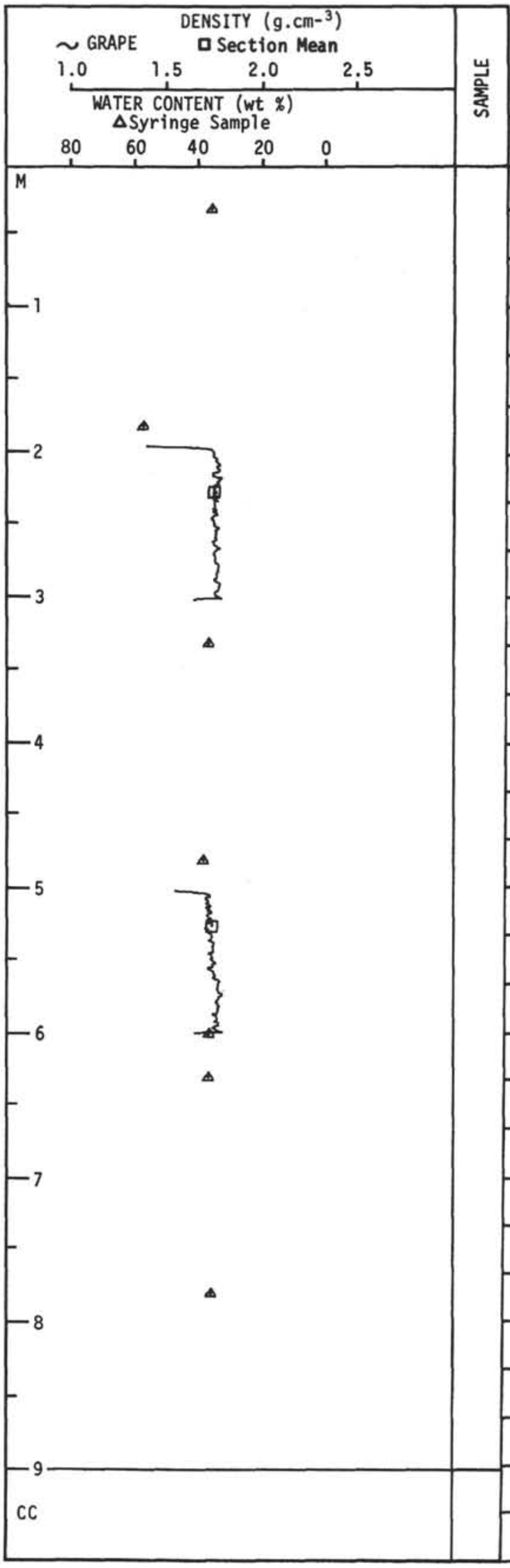

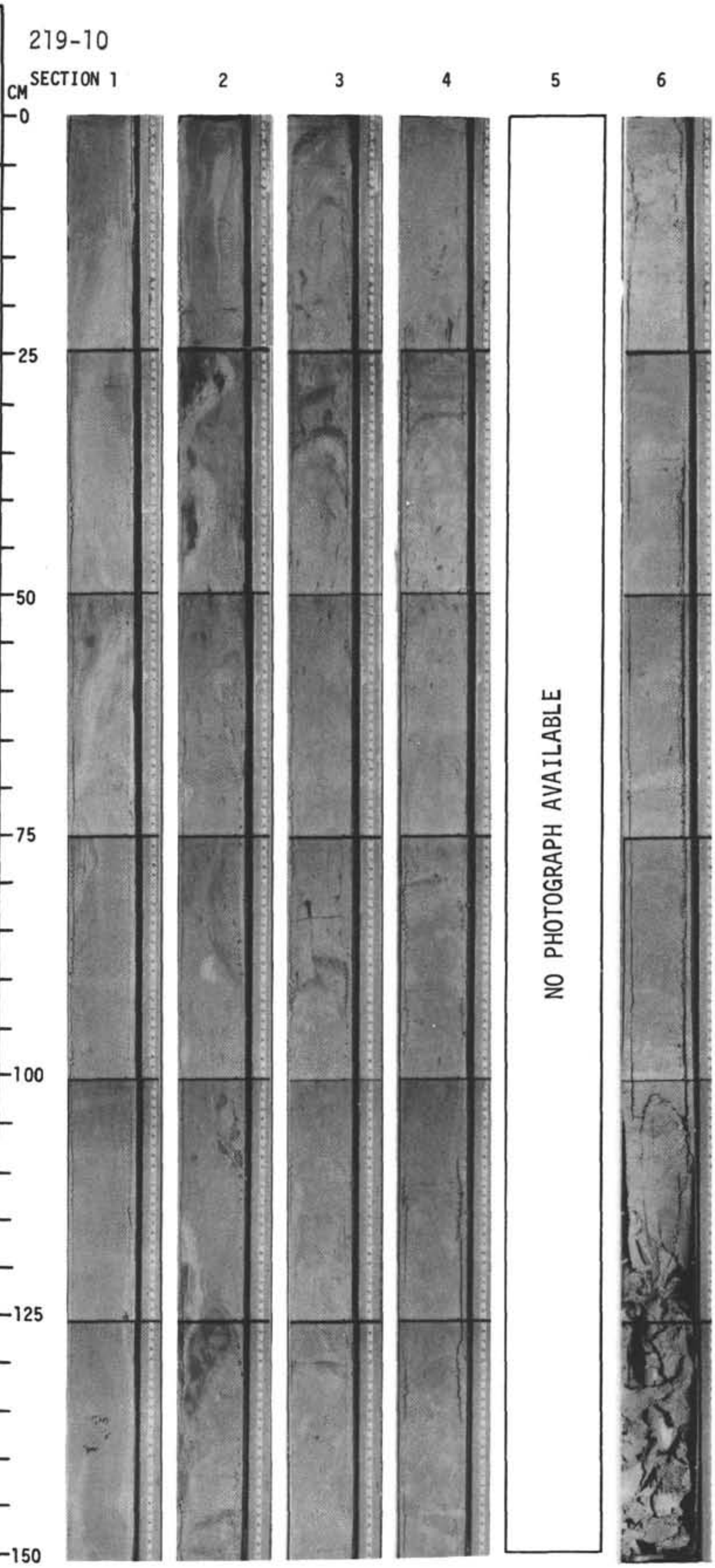

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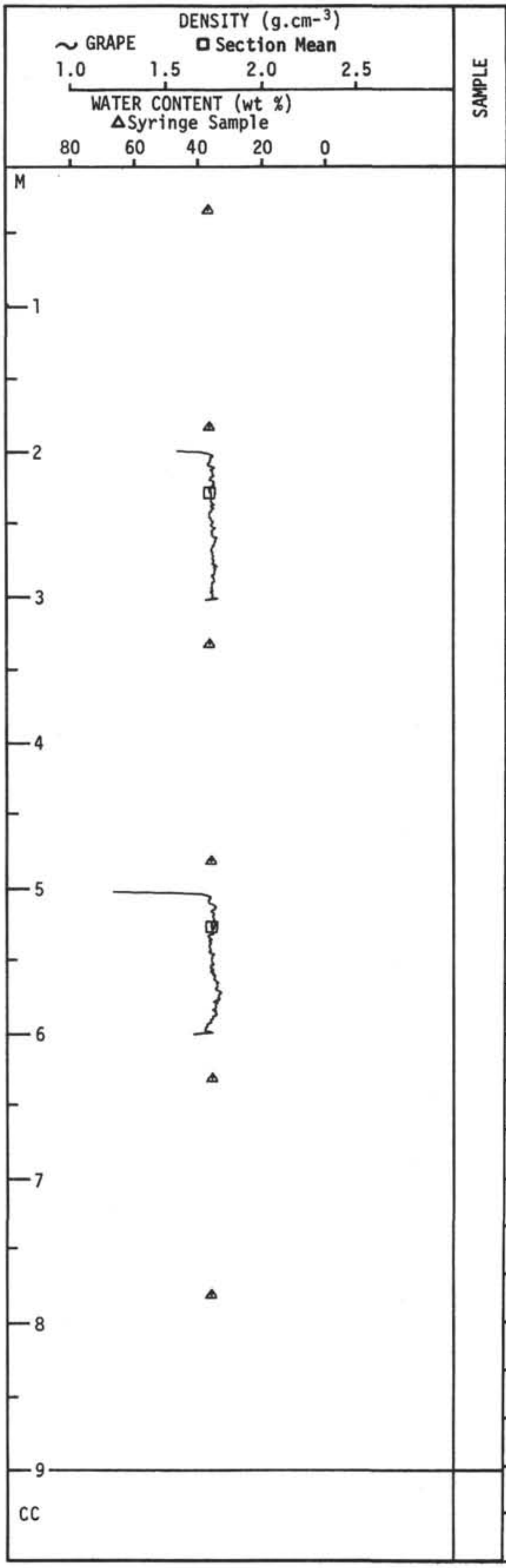

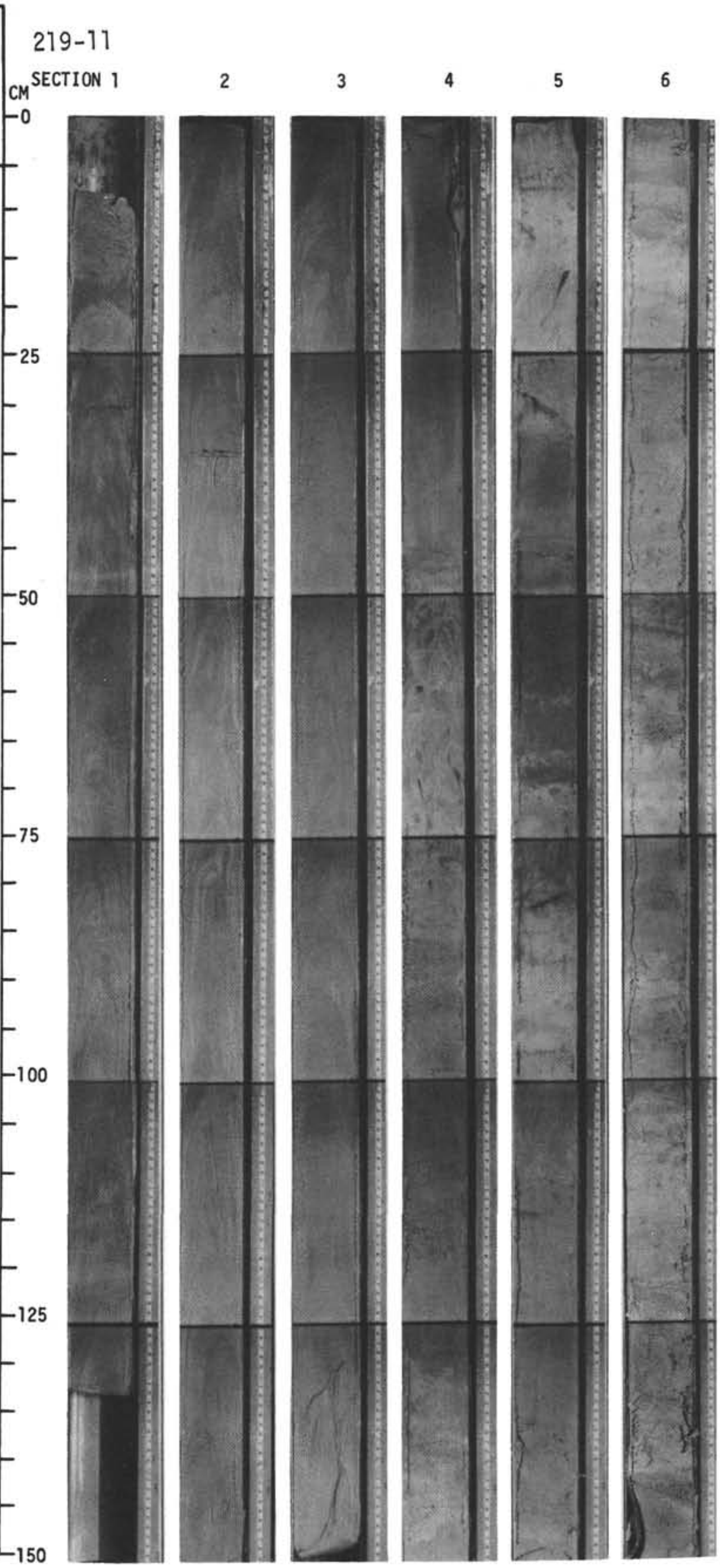

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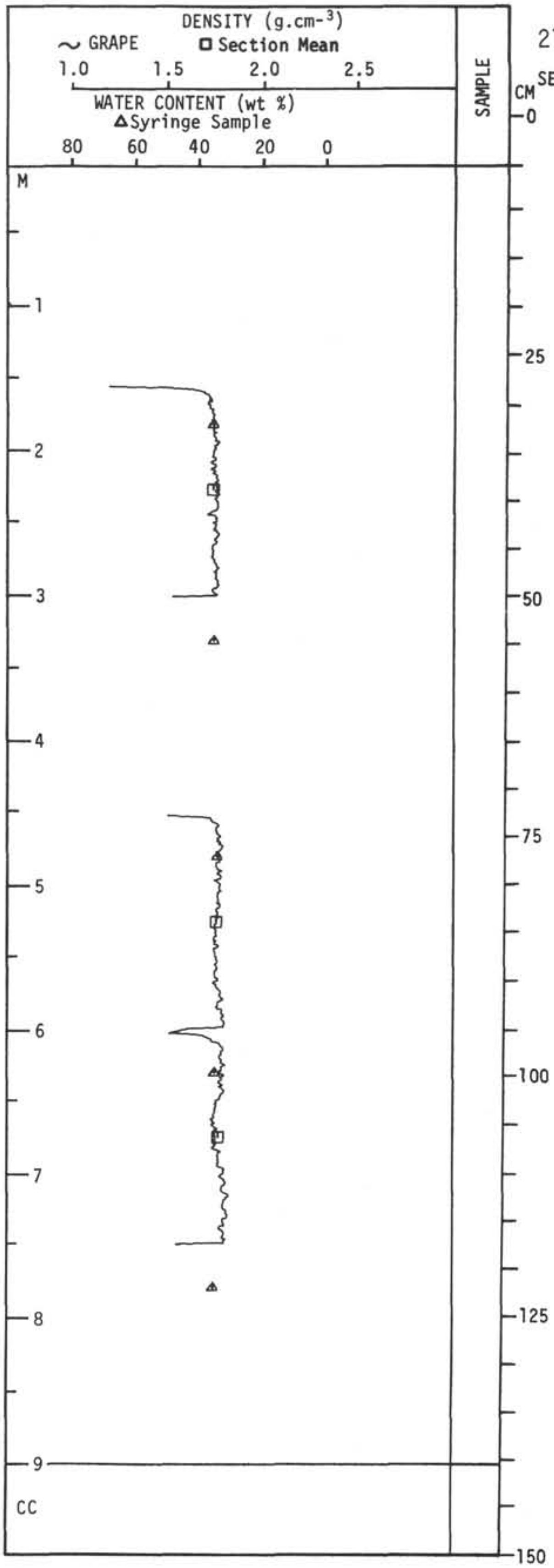

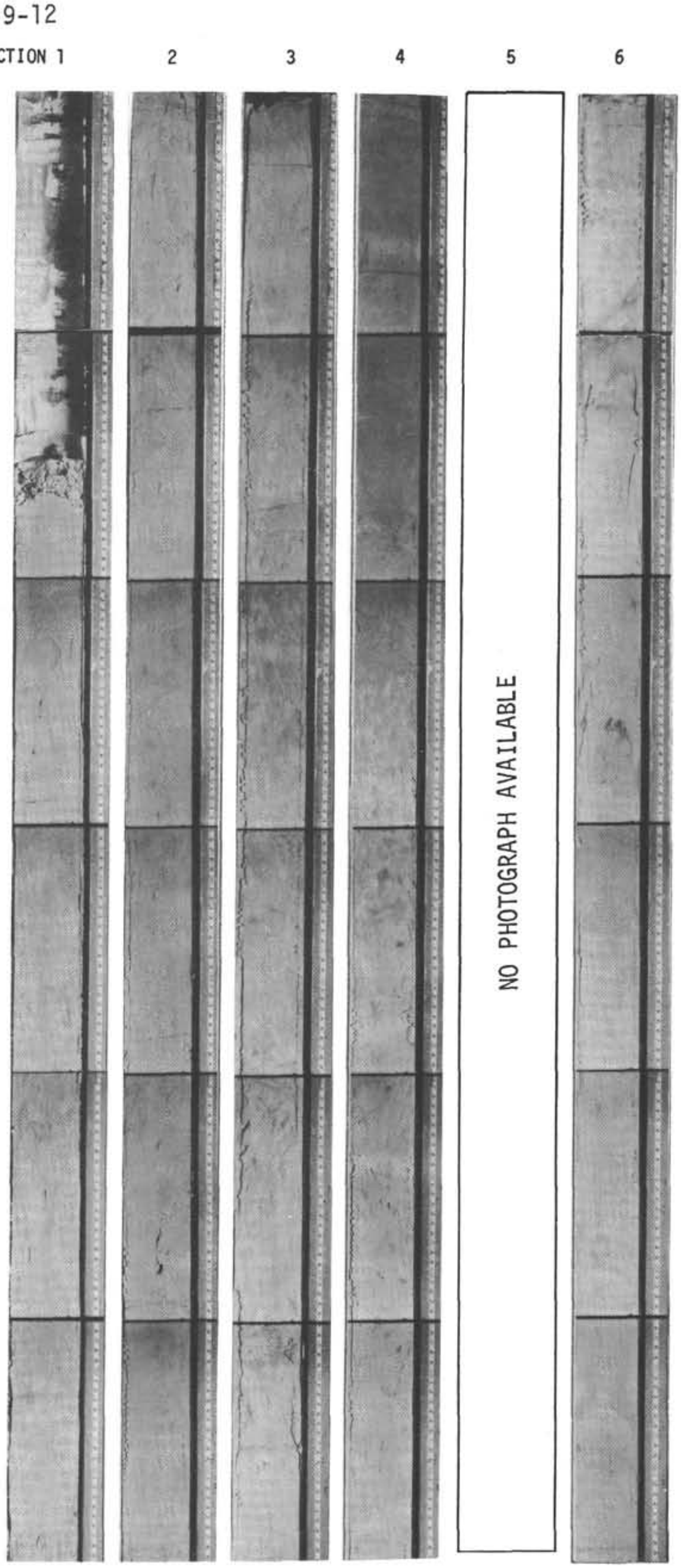

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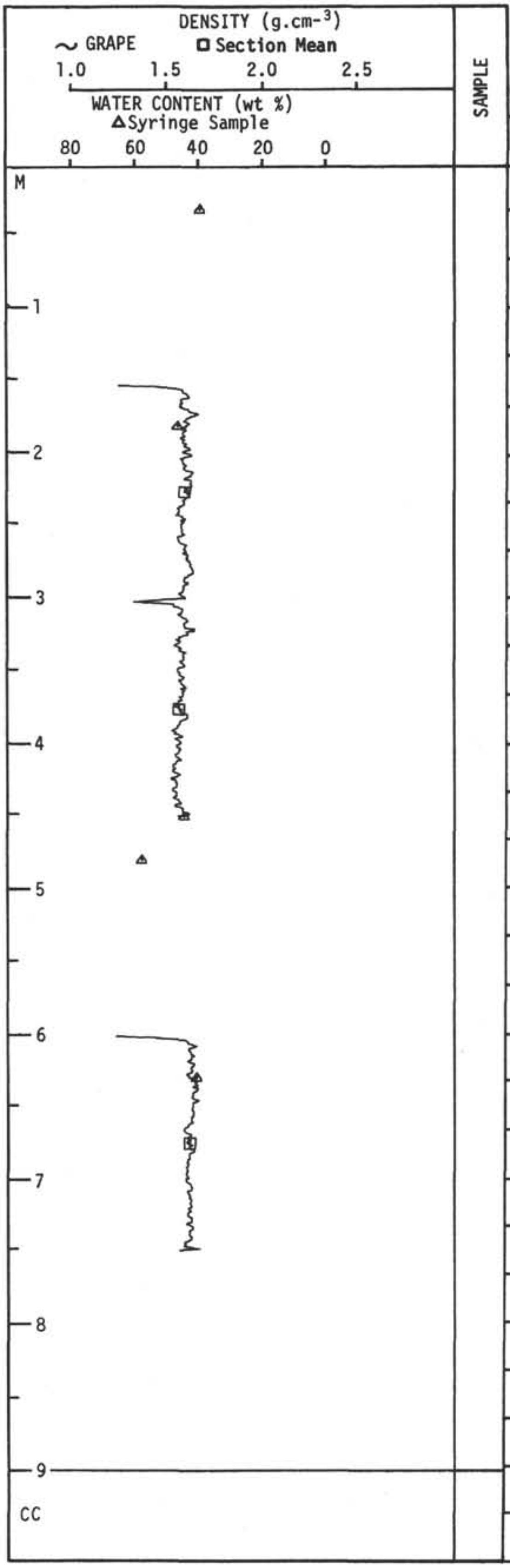

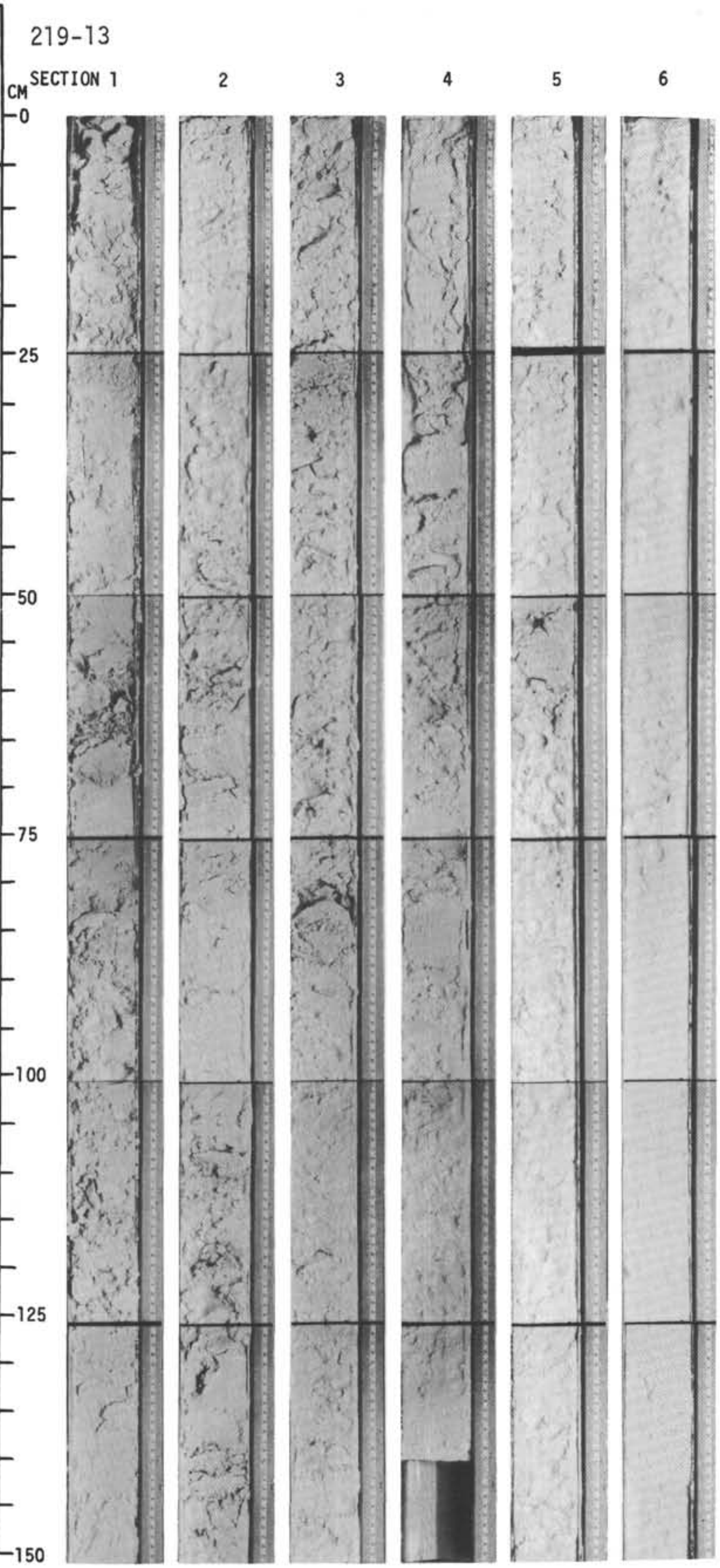

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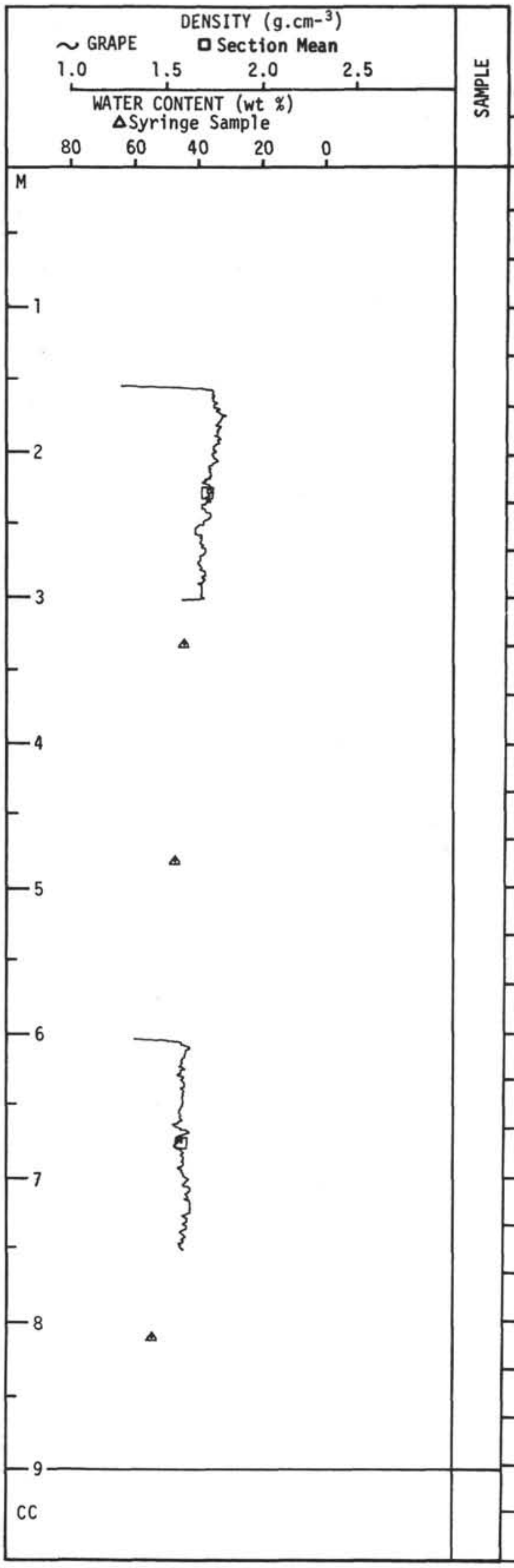

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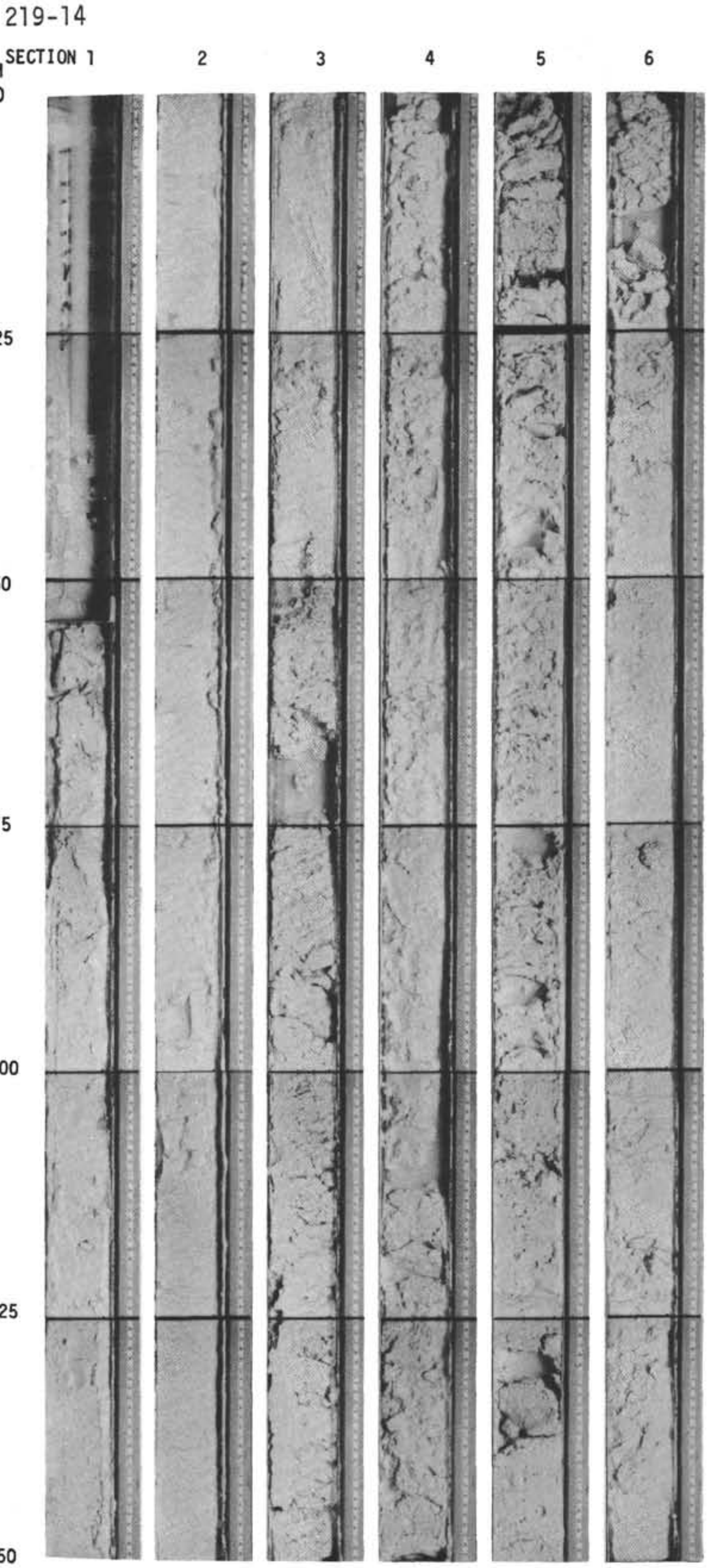

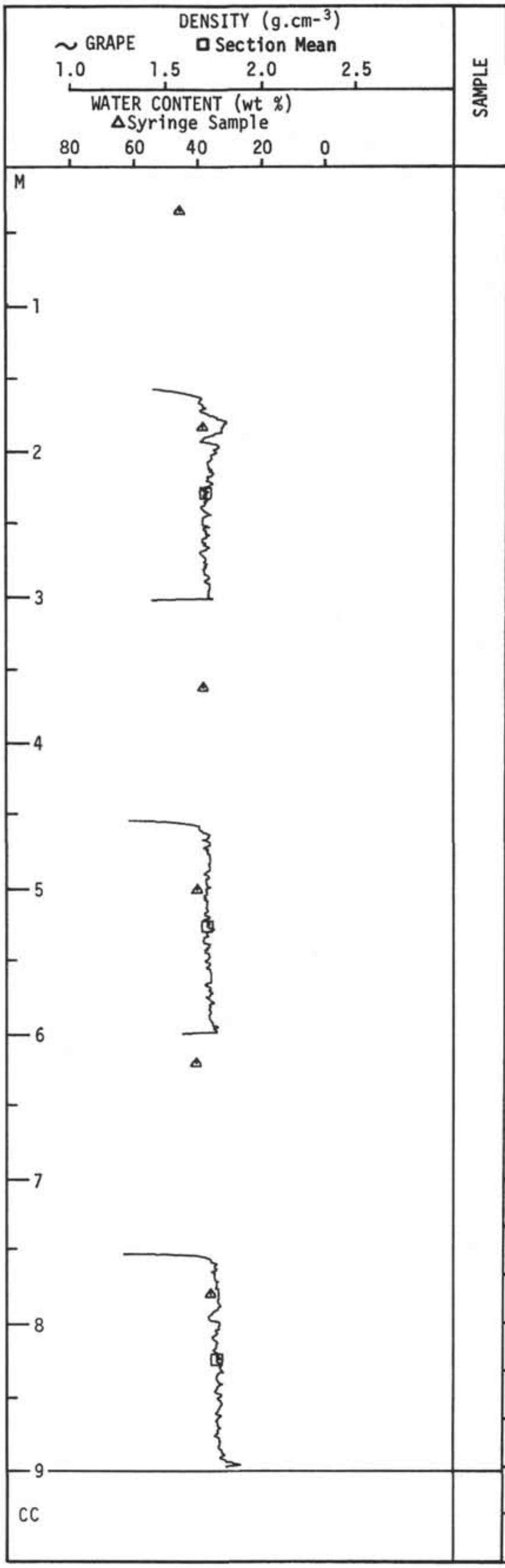

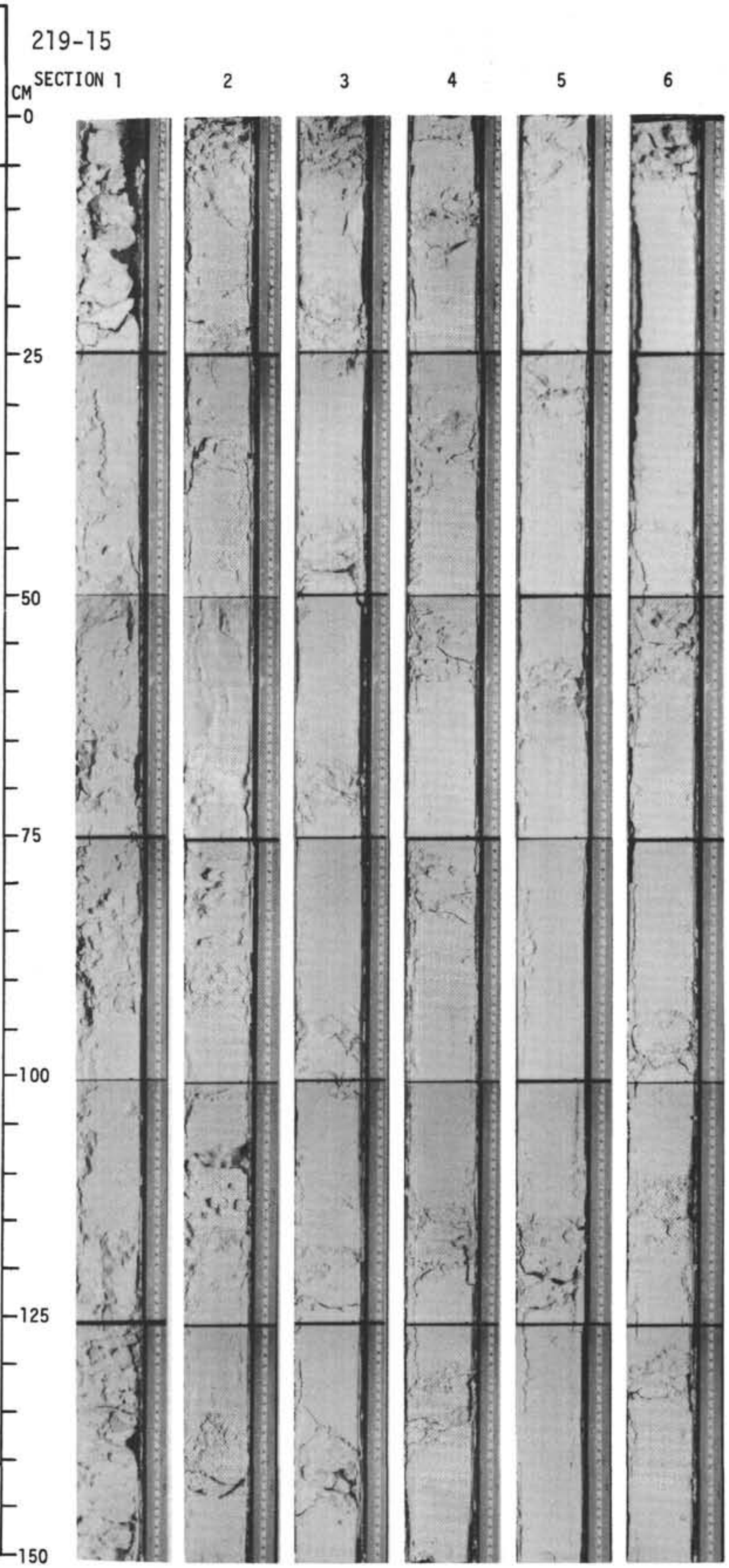

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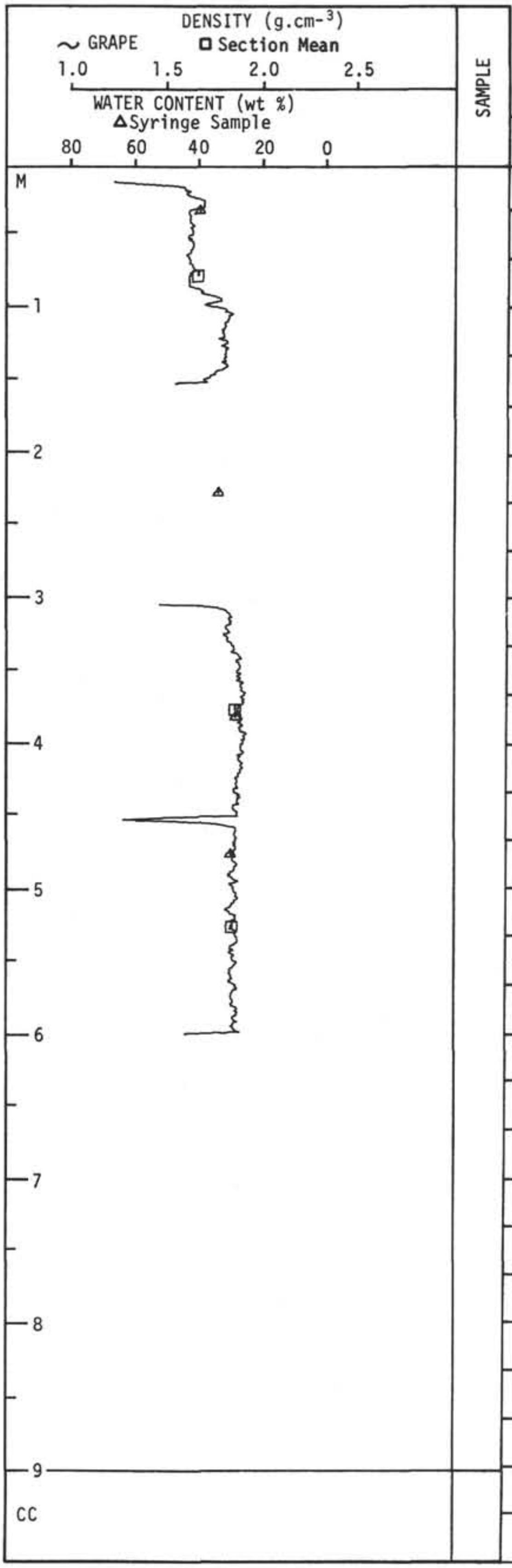

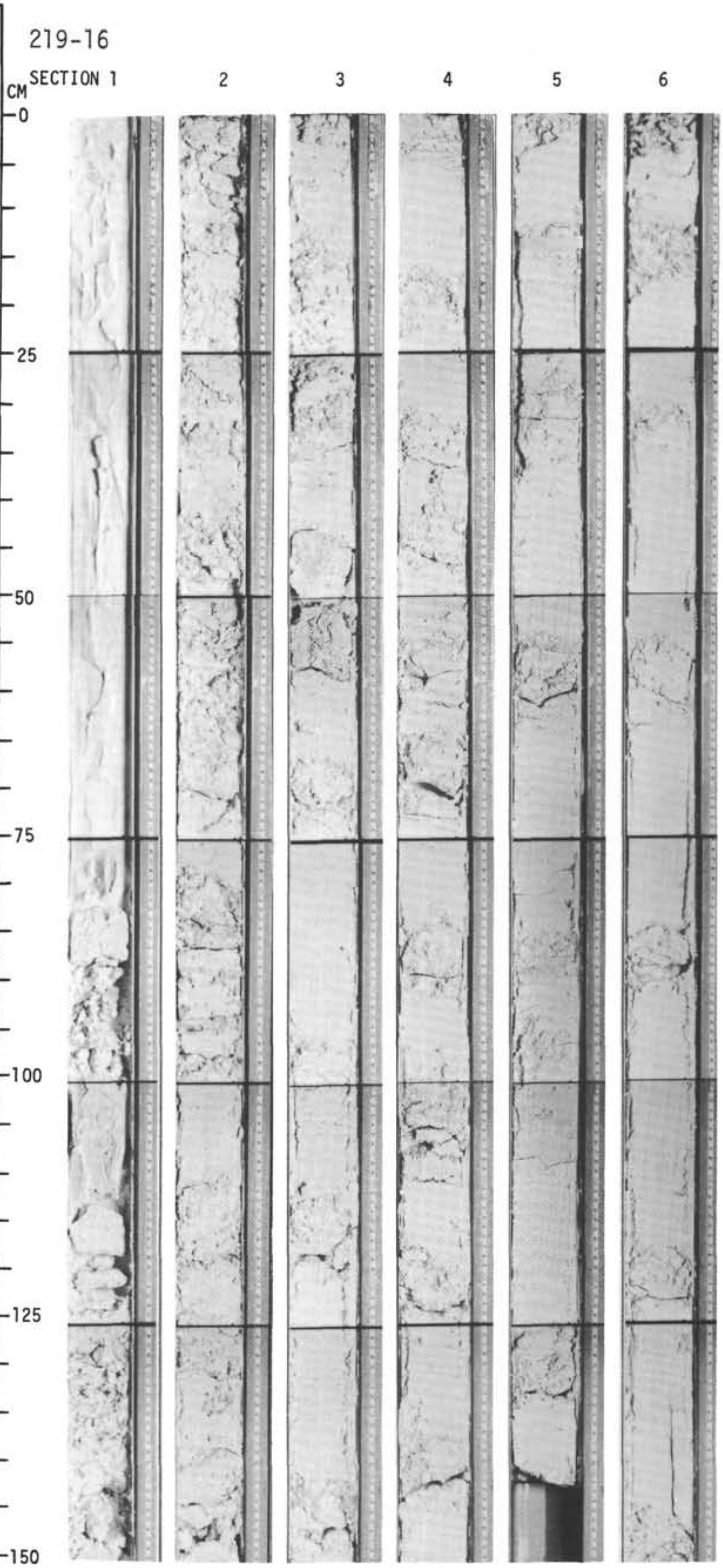

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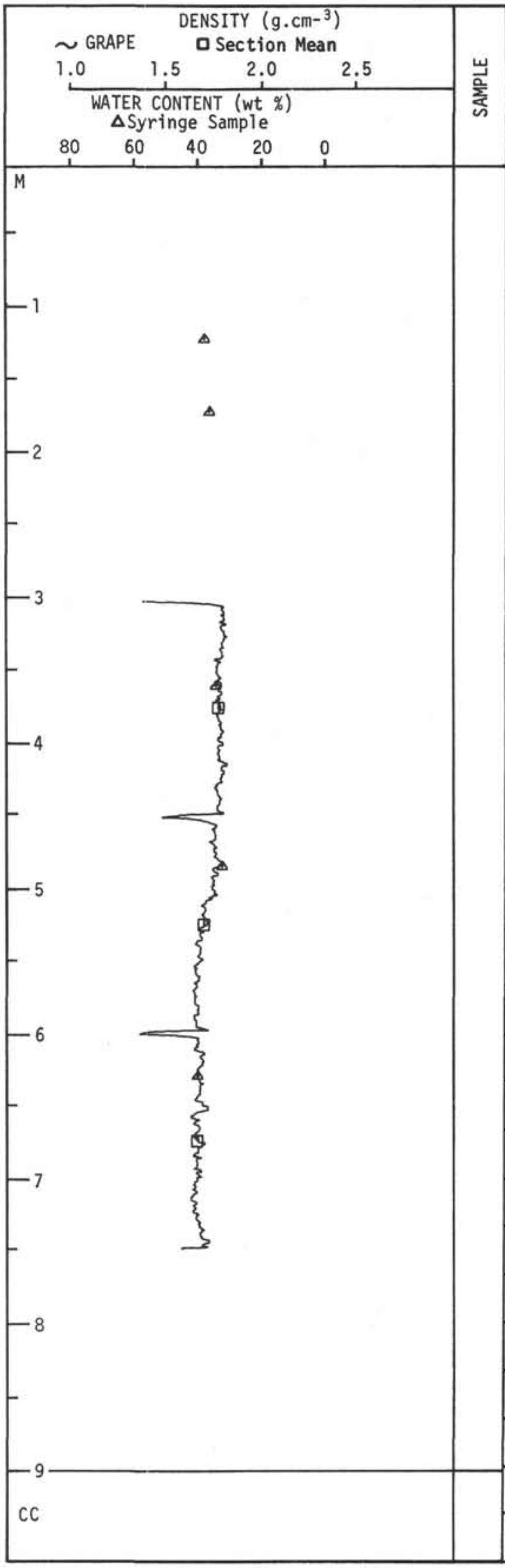

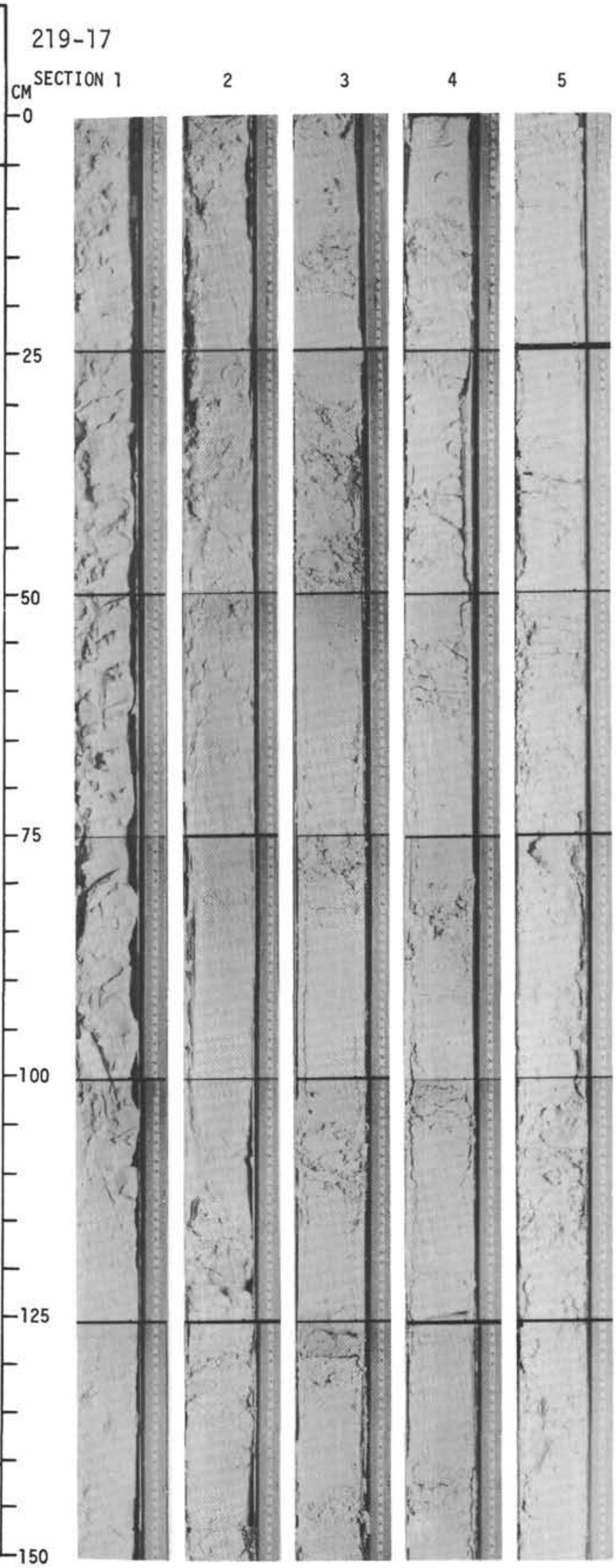

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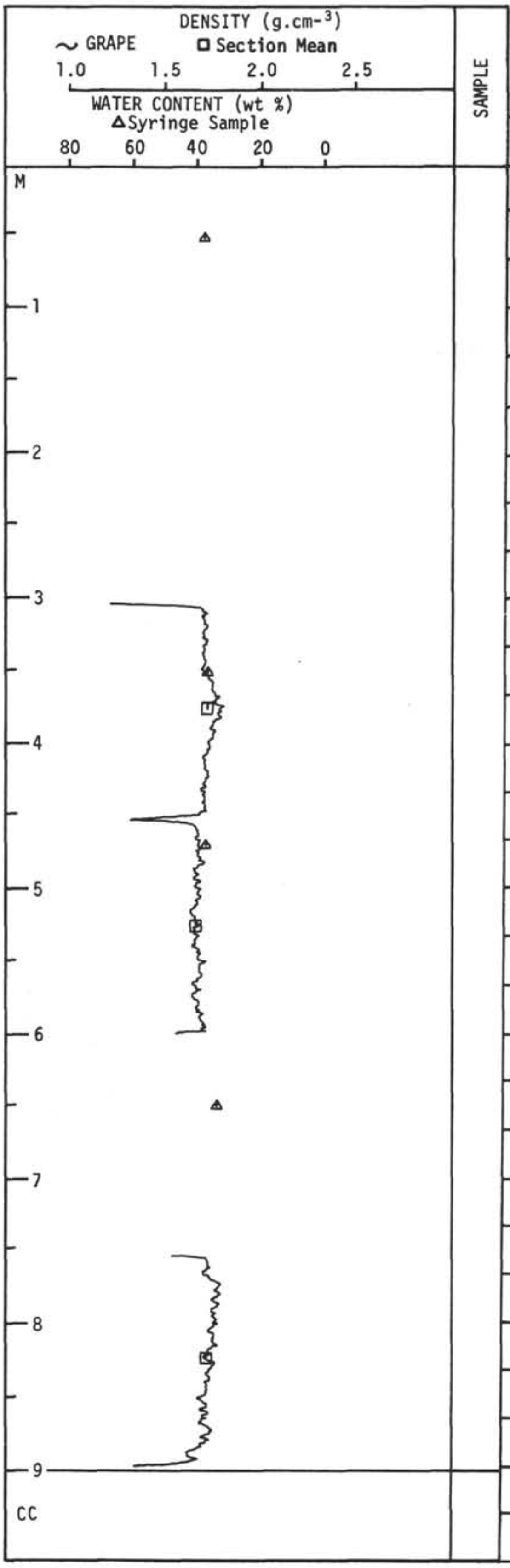

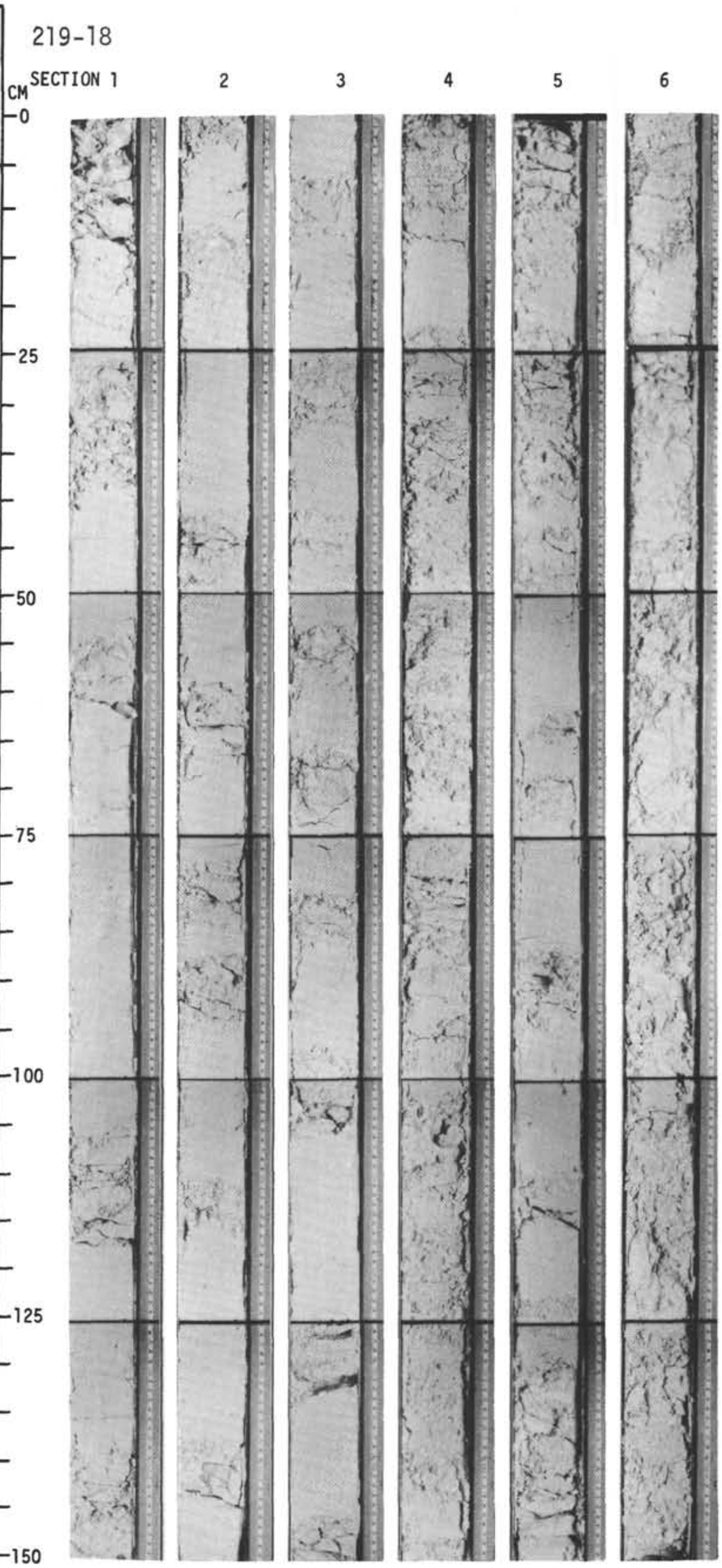

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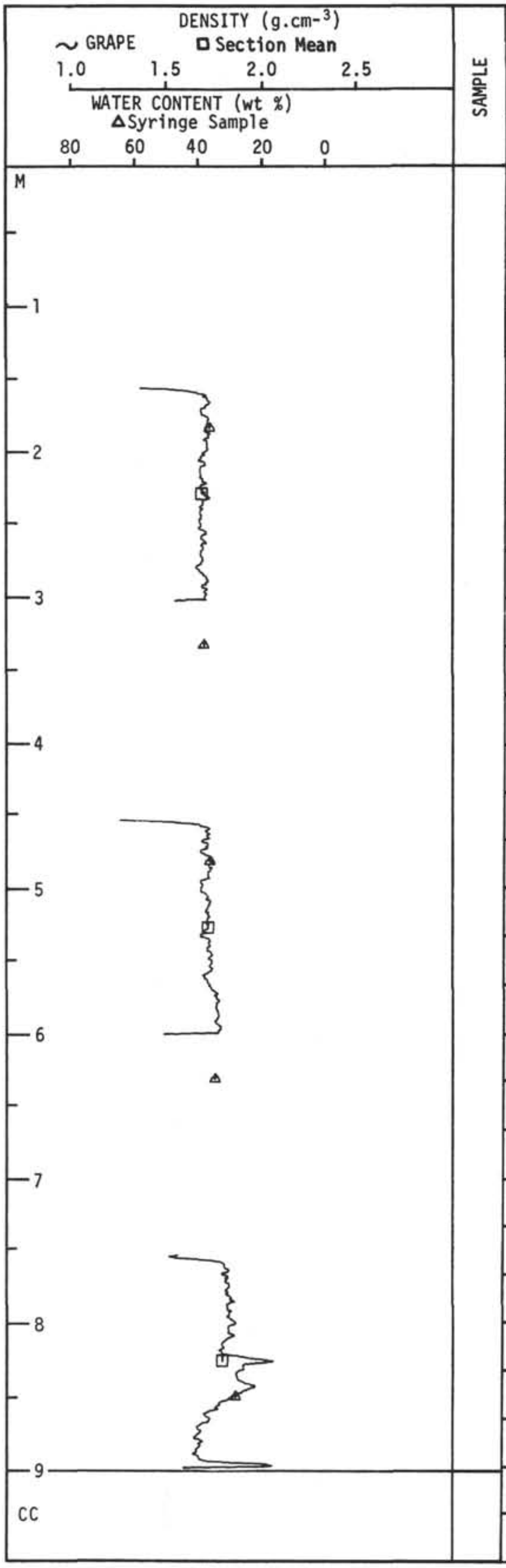

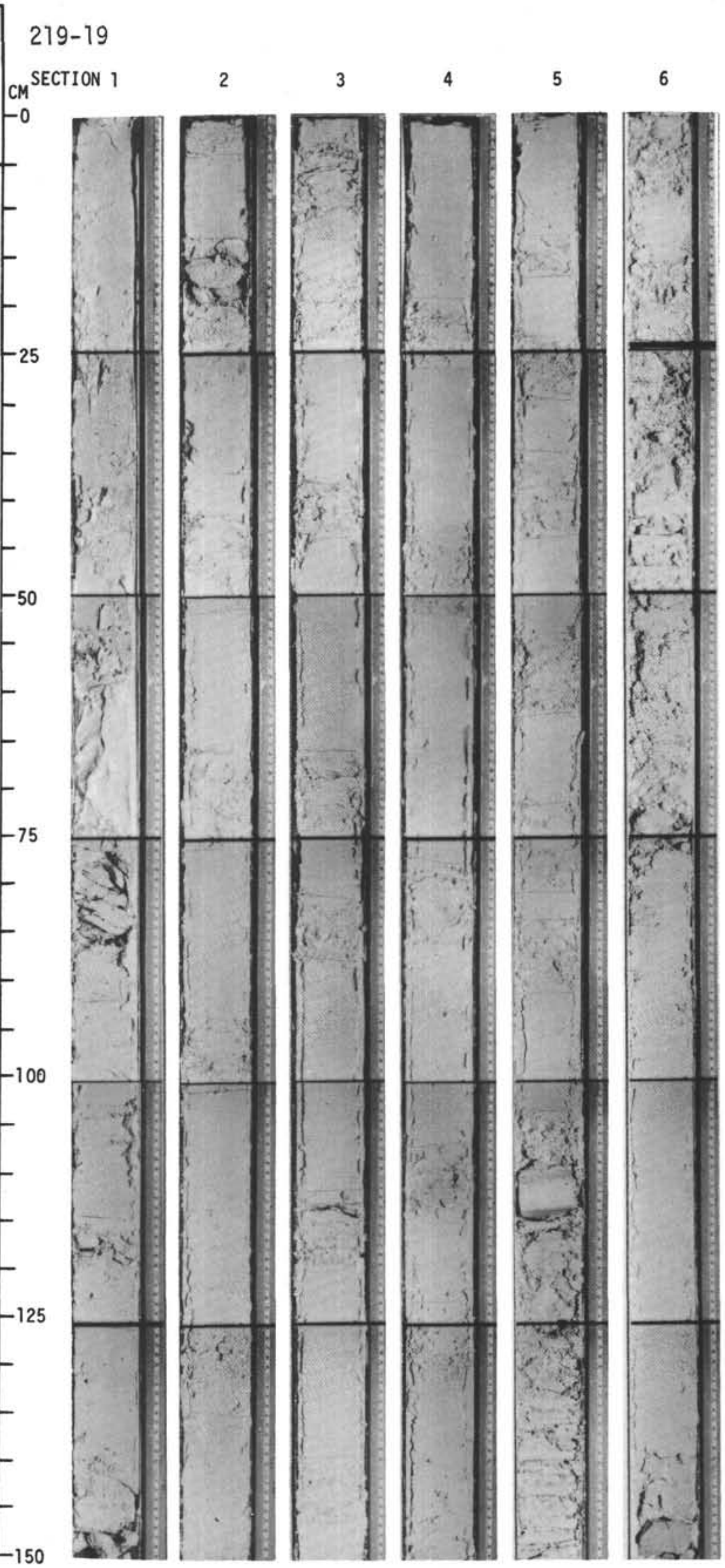

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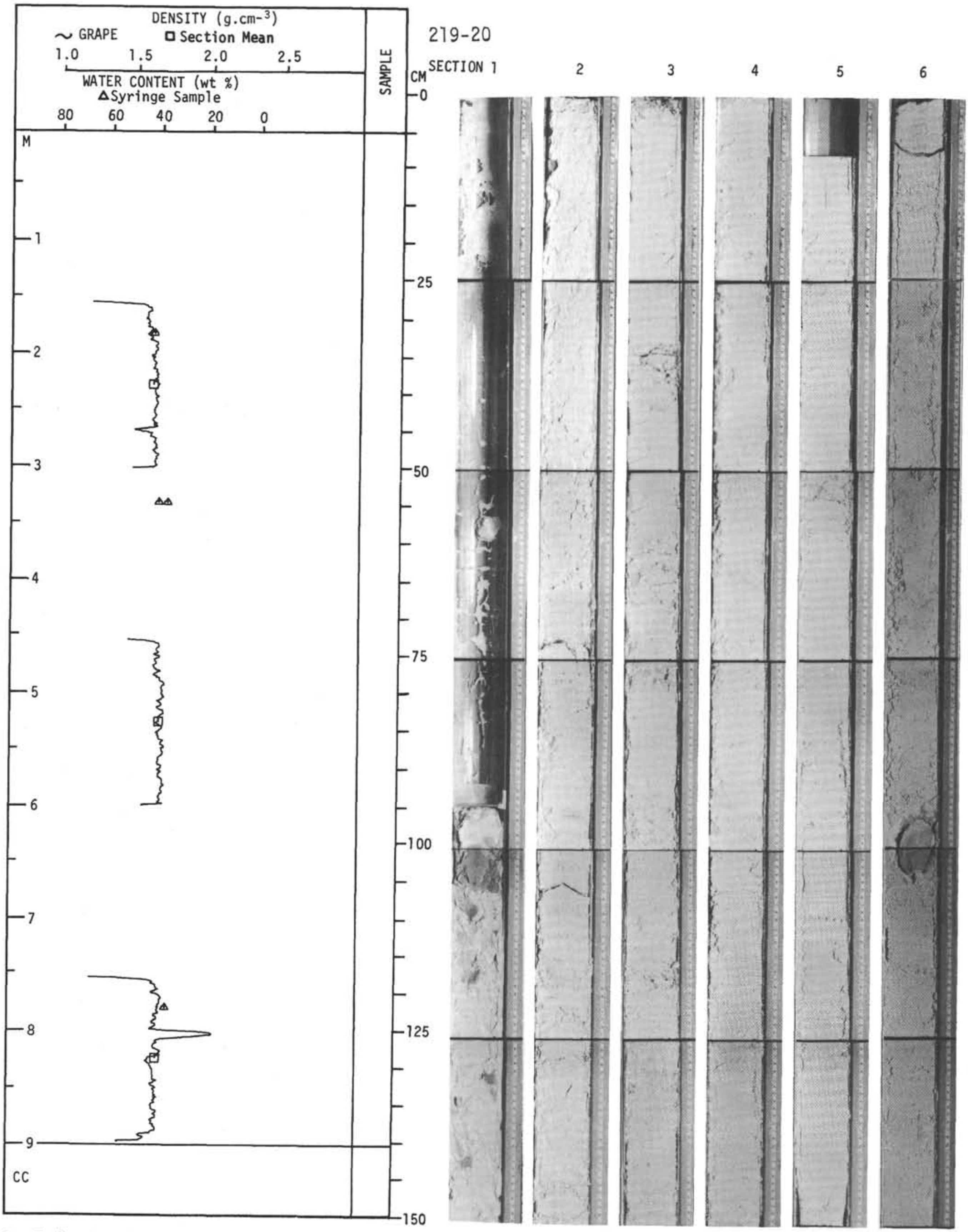

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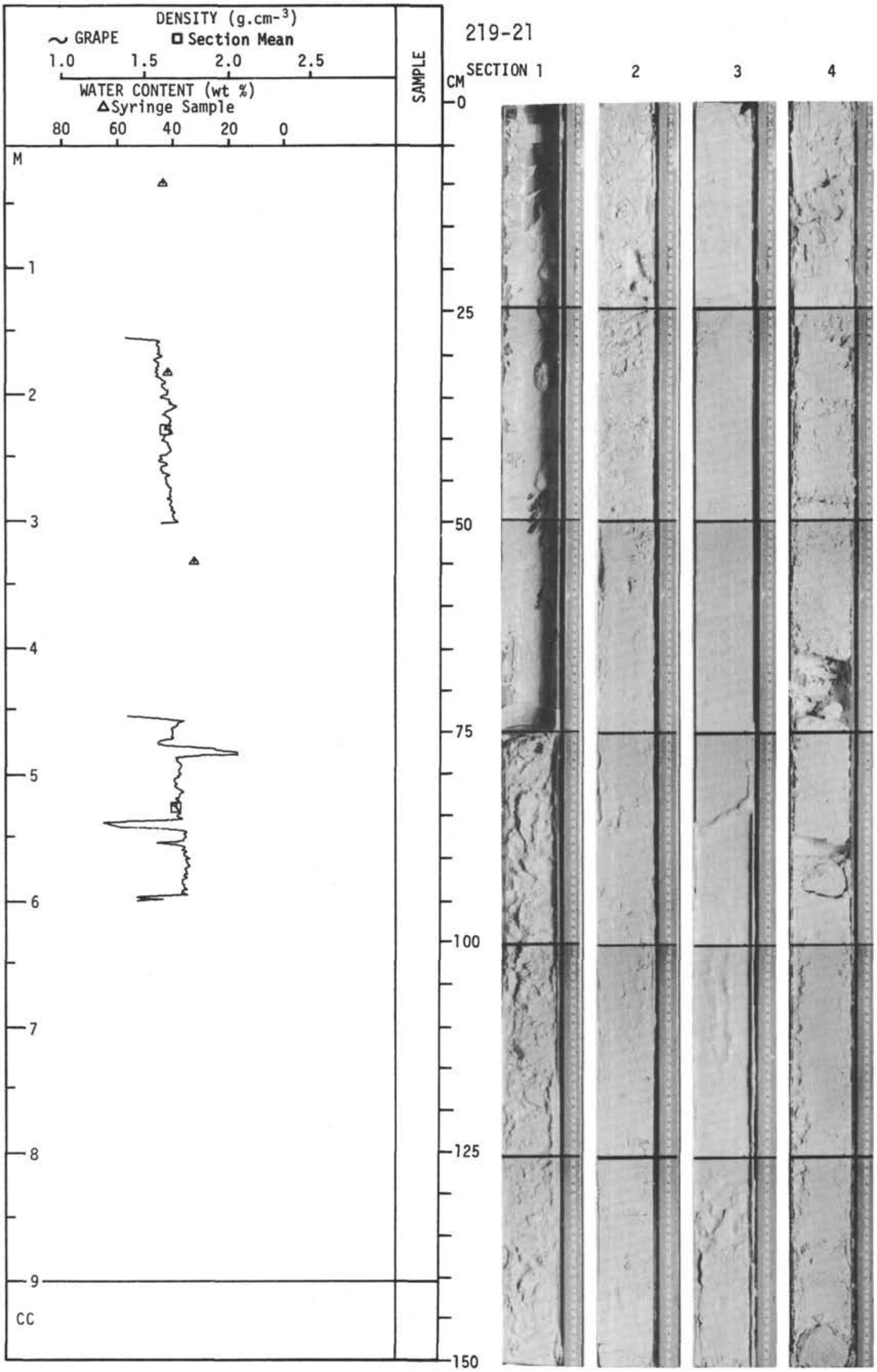

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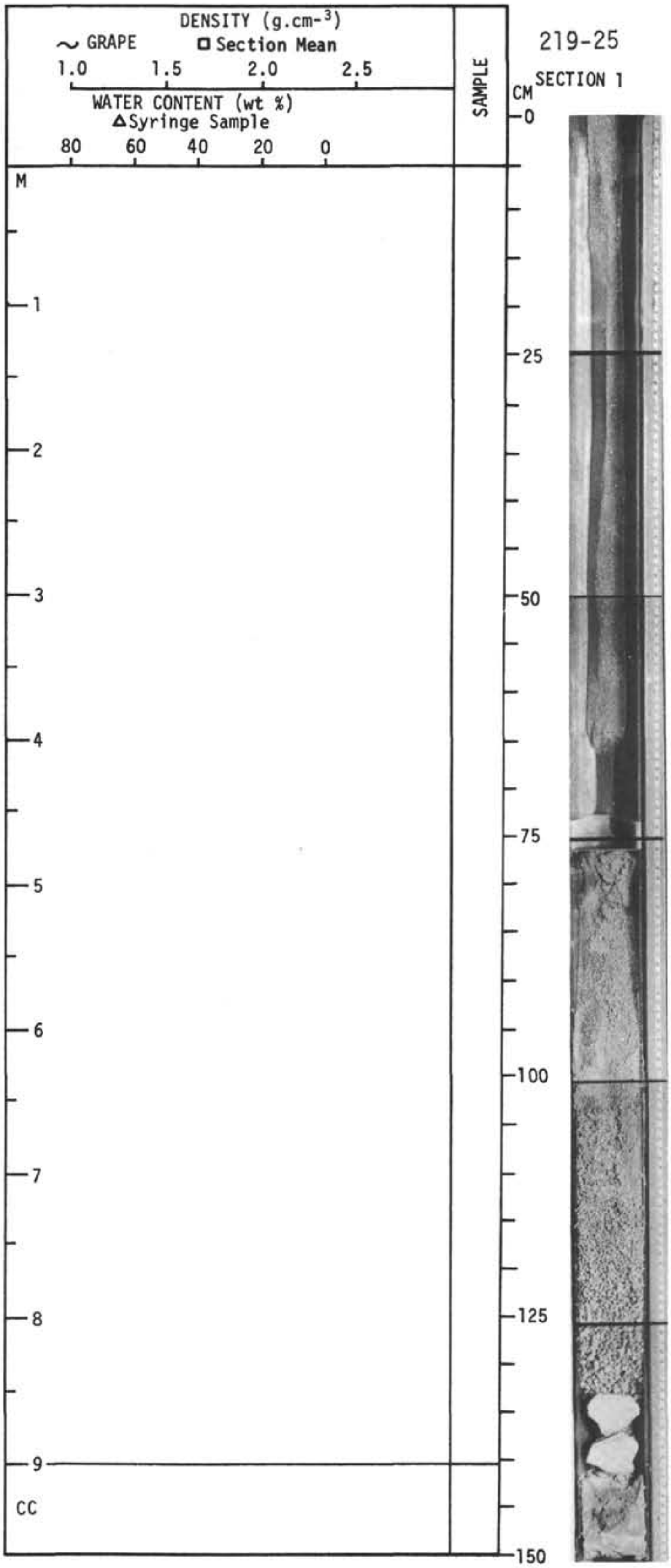

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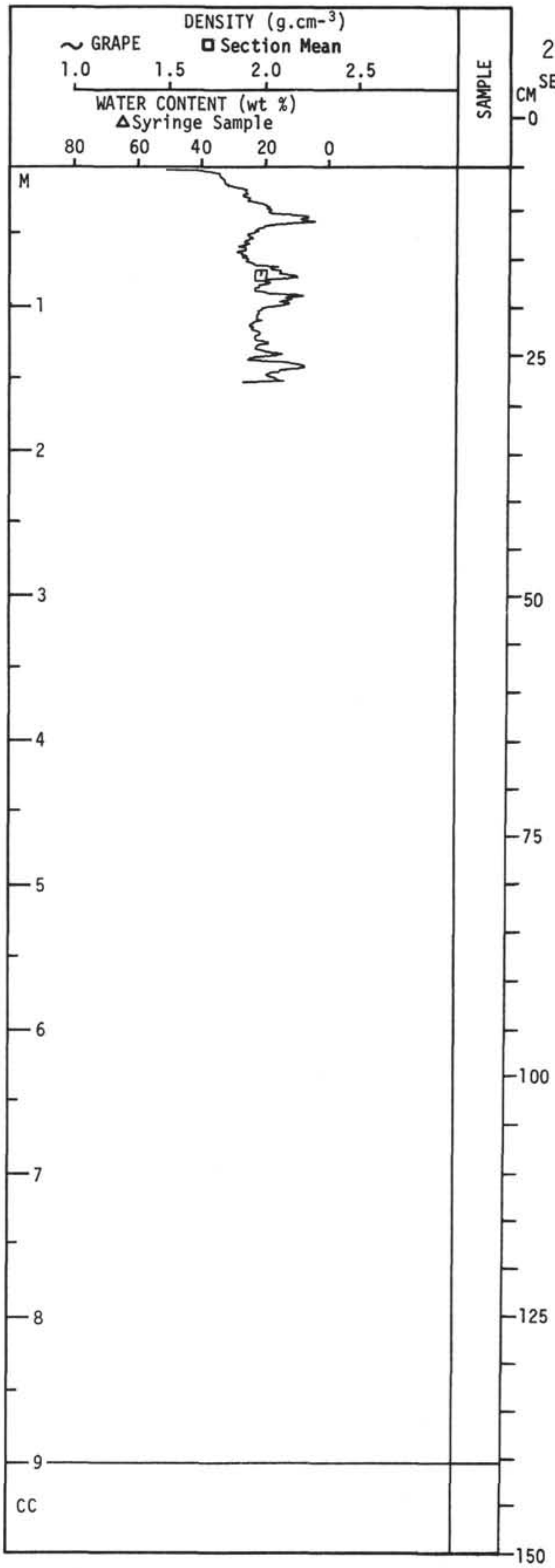

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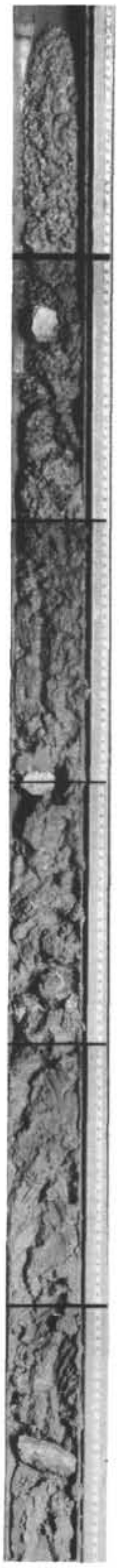
SECTION 1



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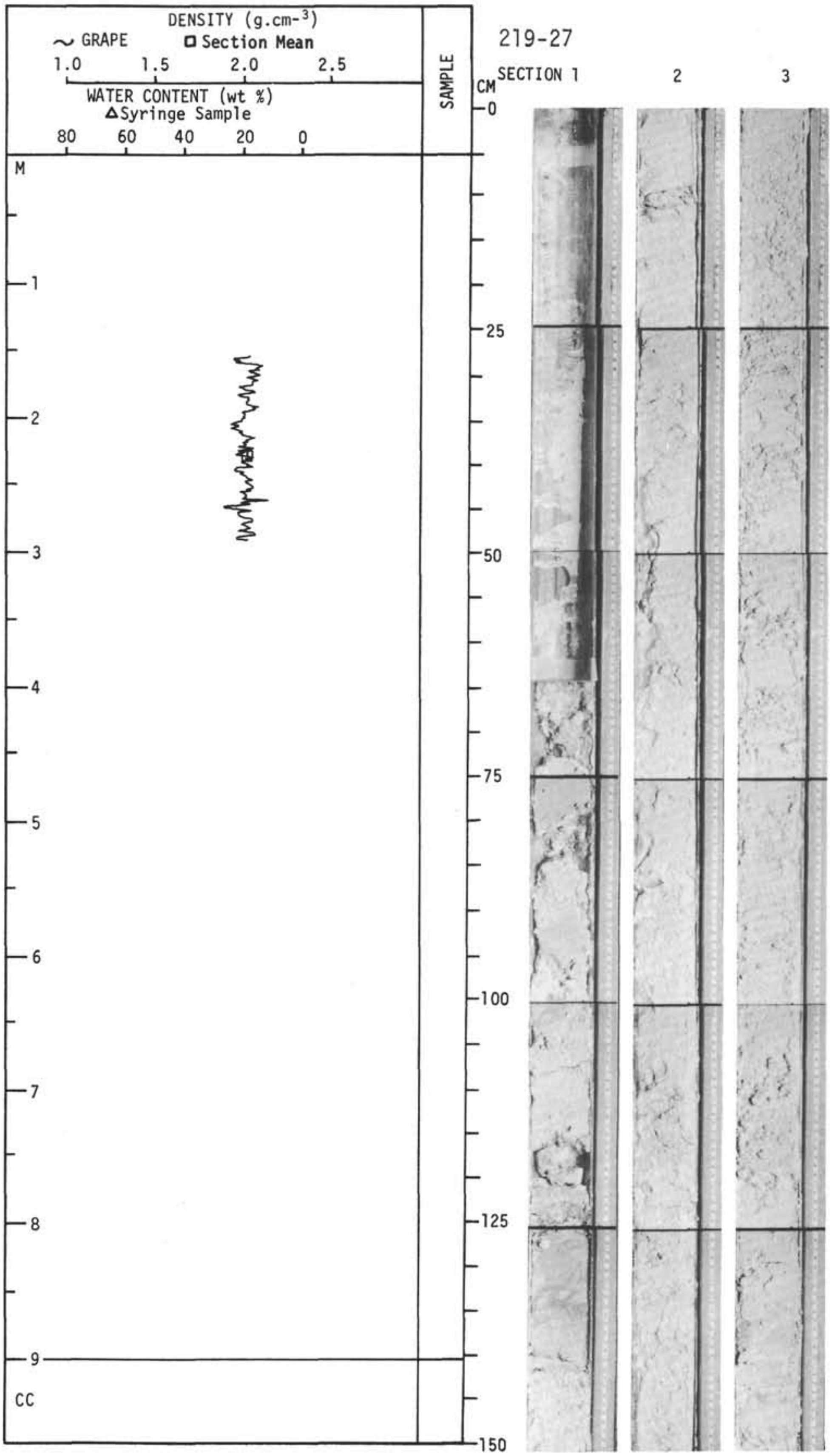

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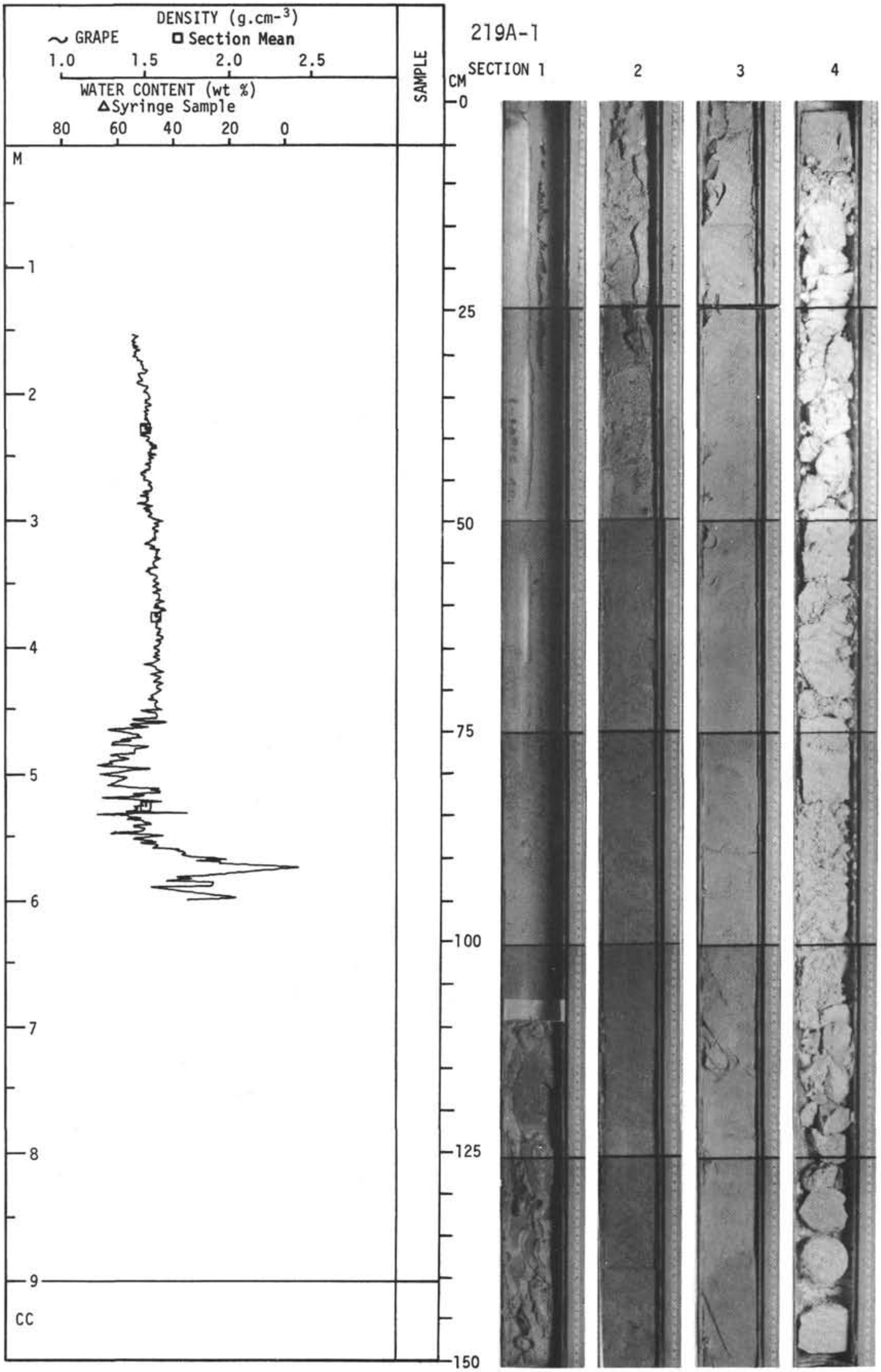

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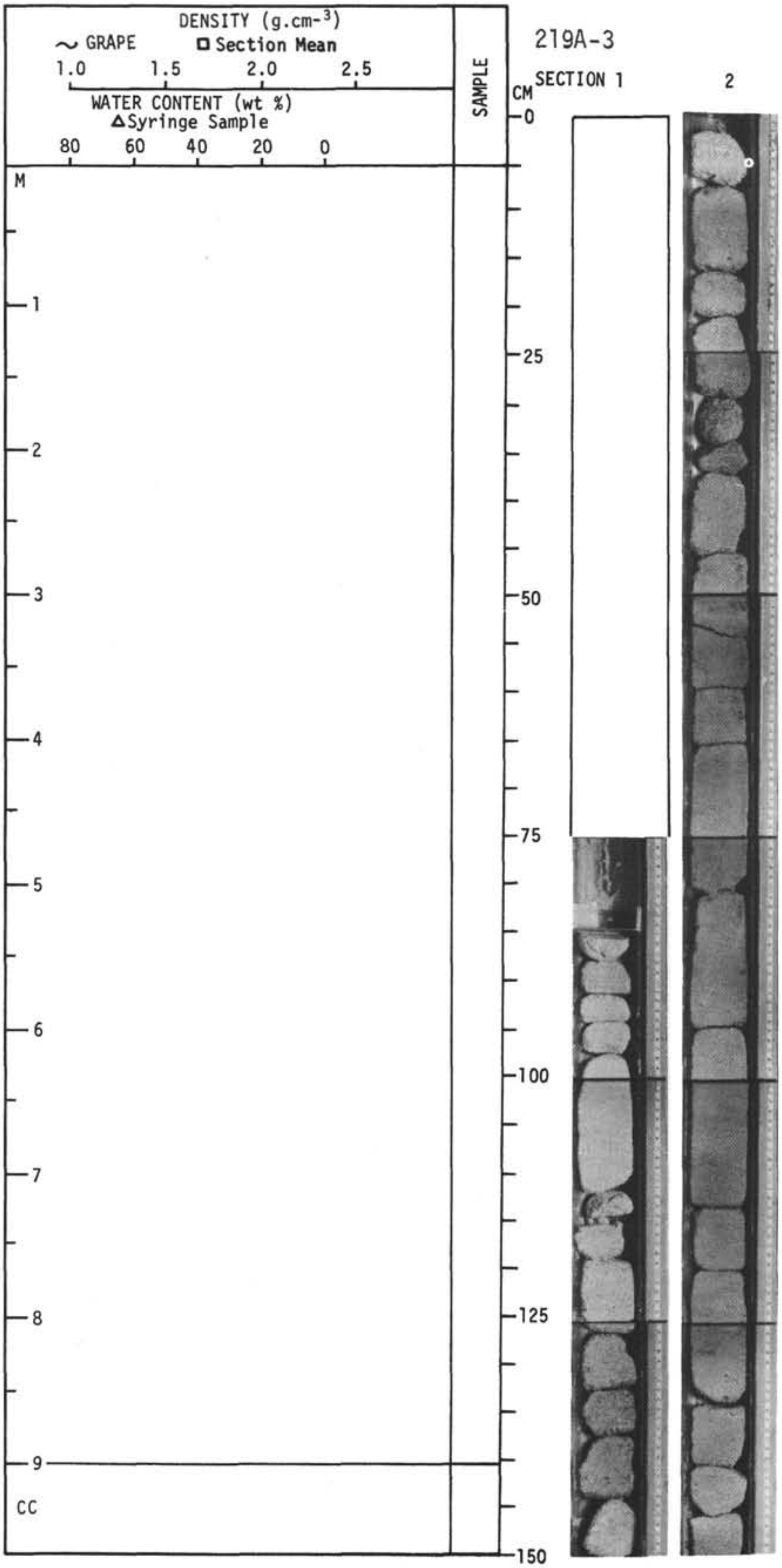

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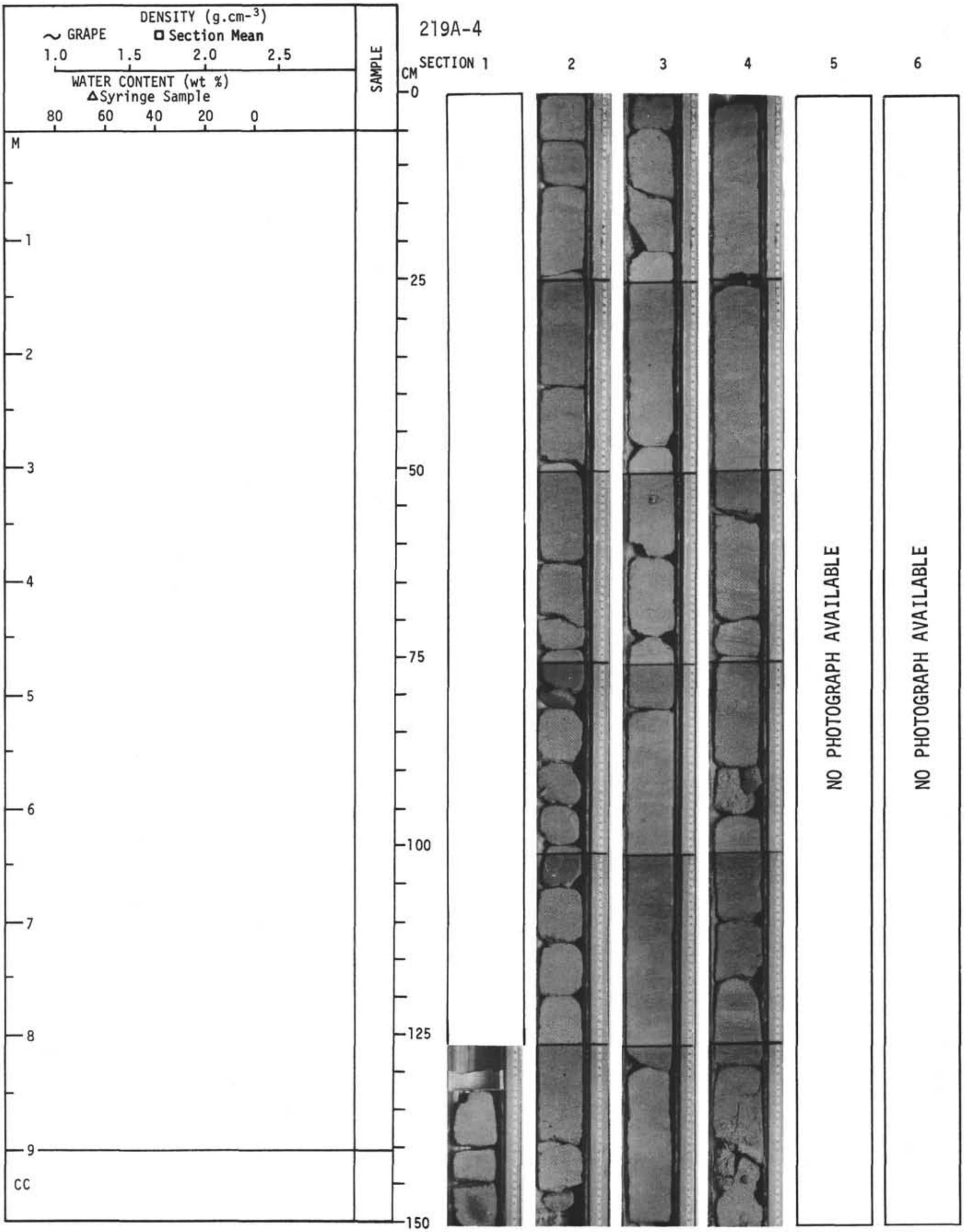

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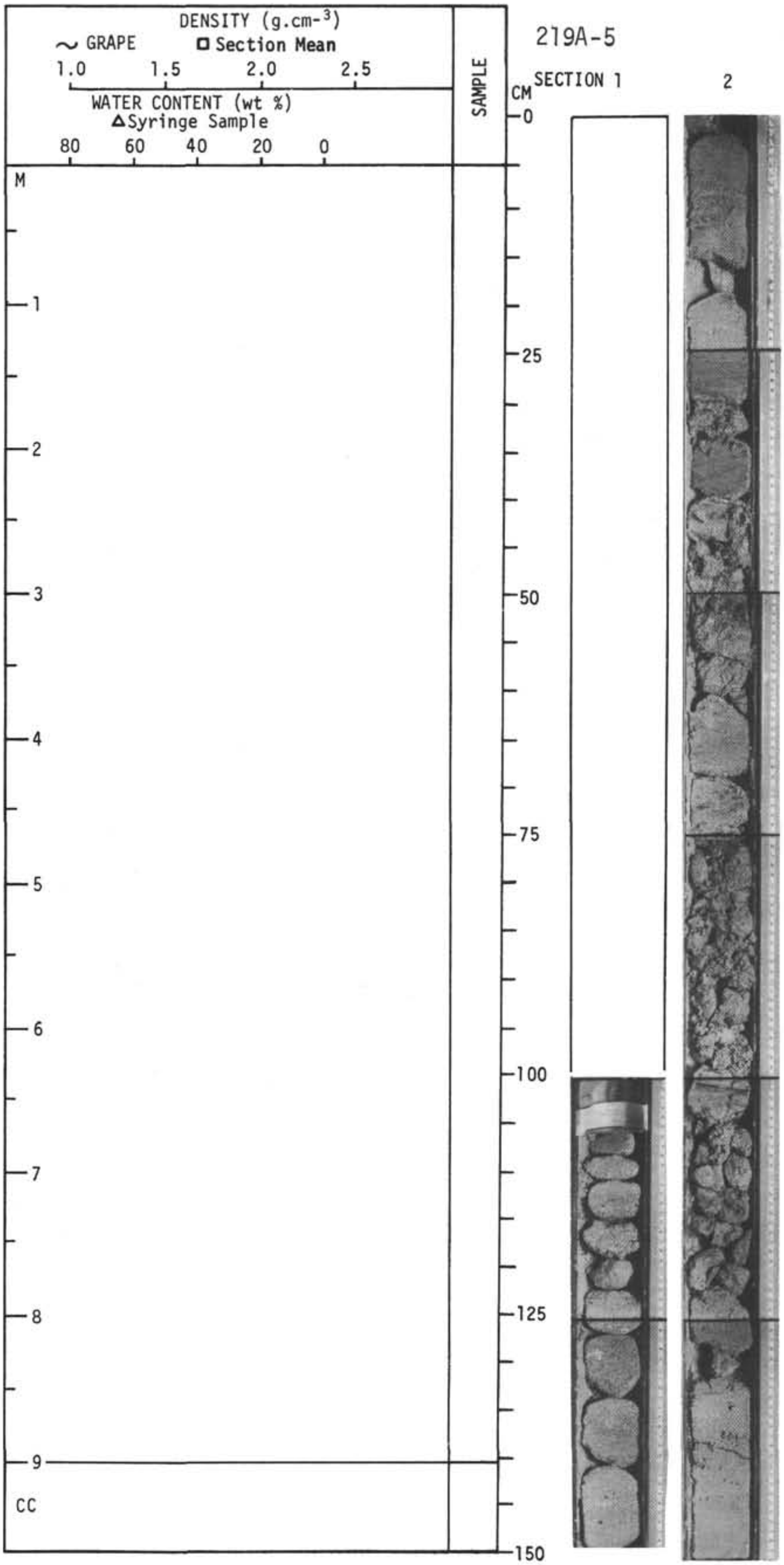

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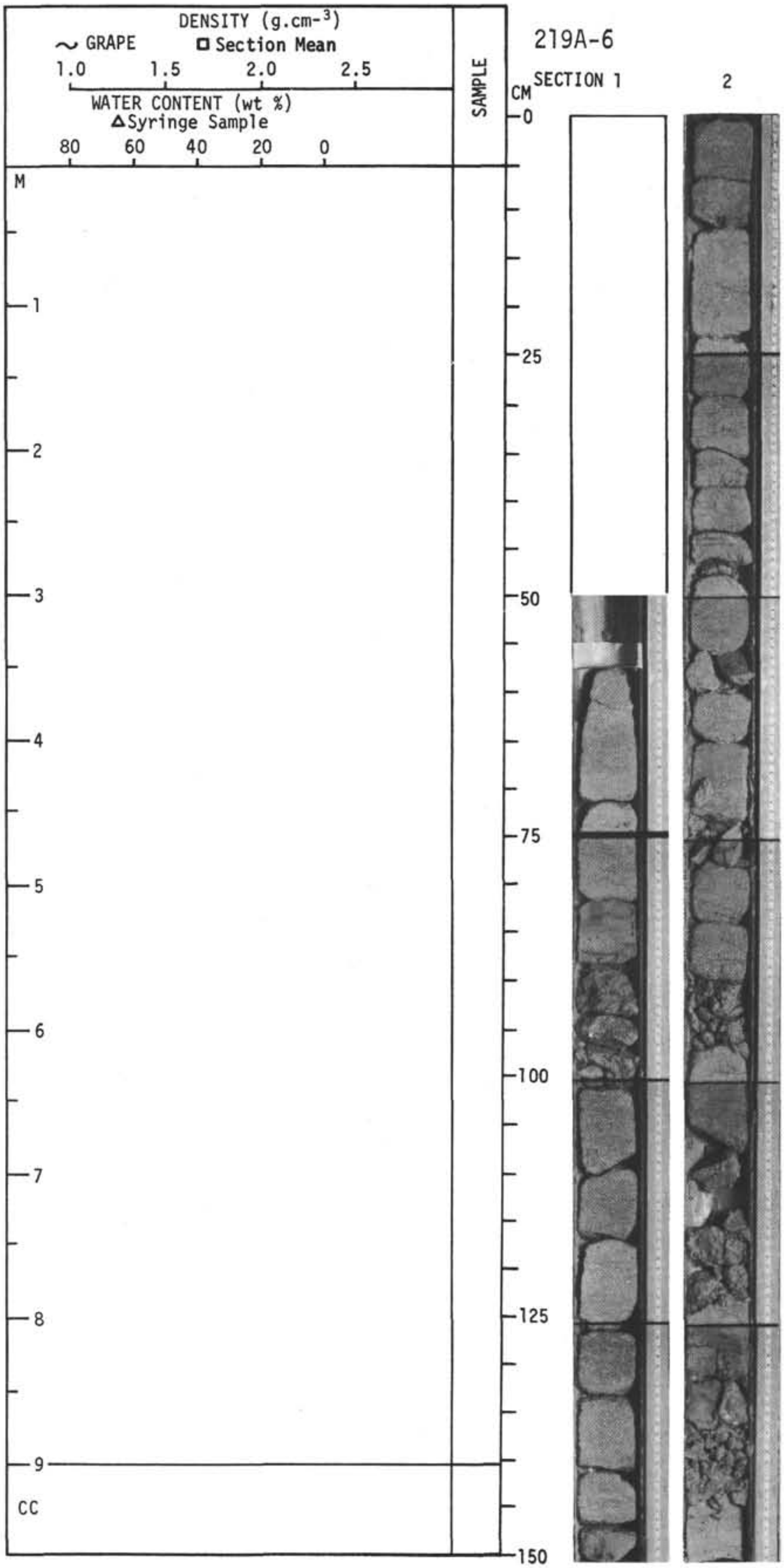

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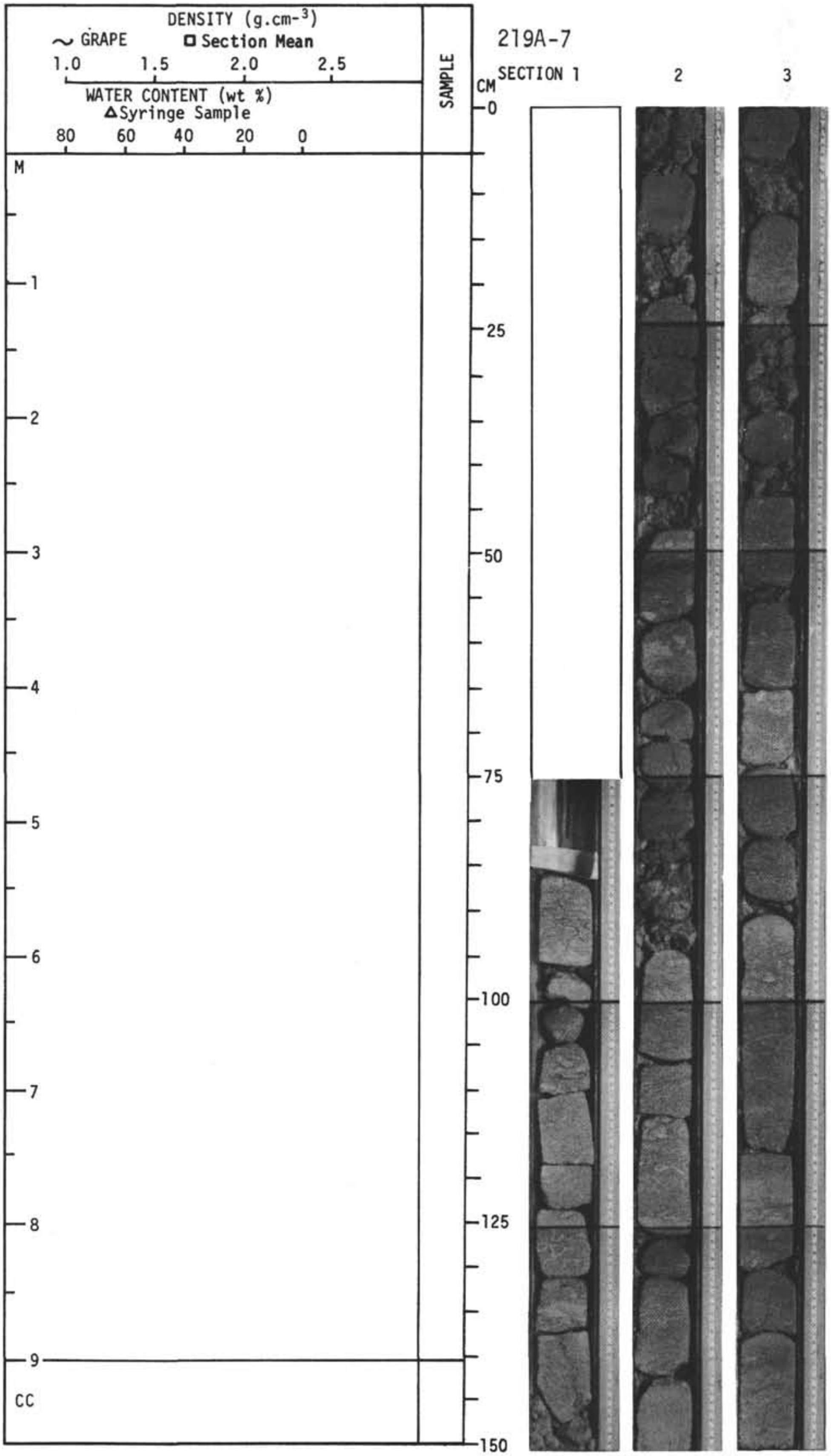

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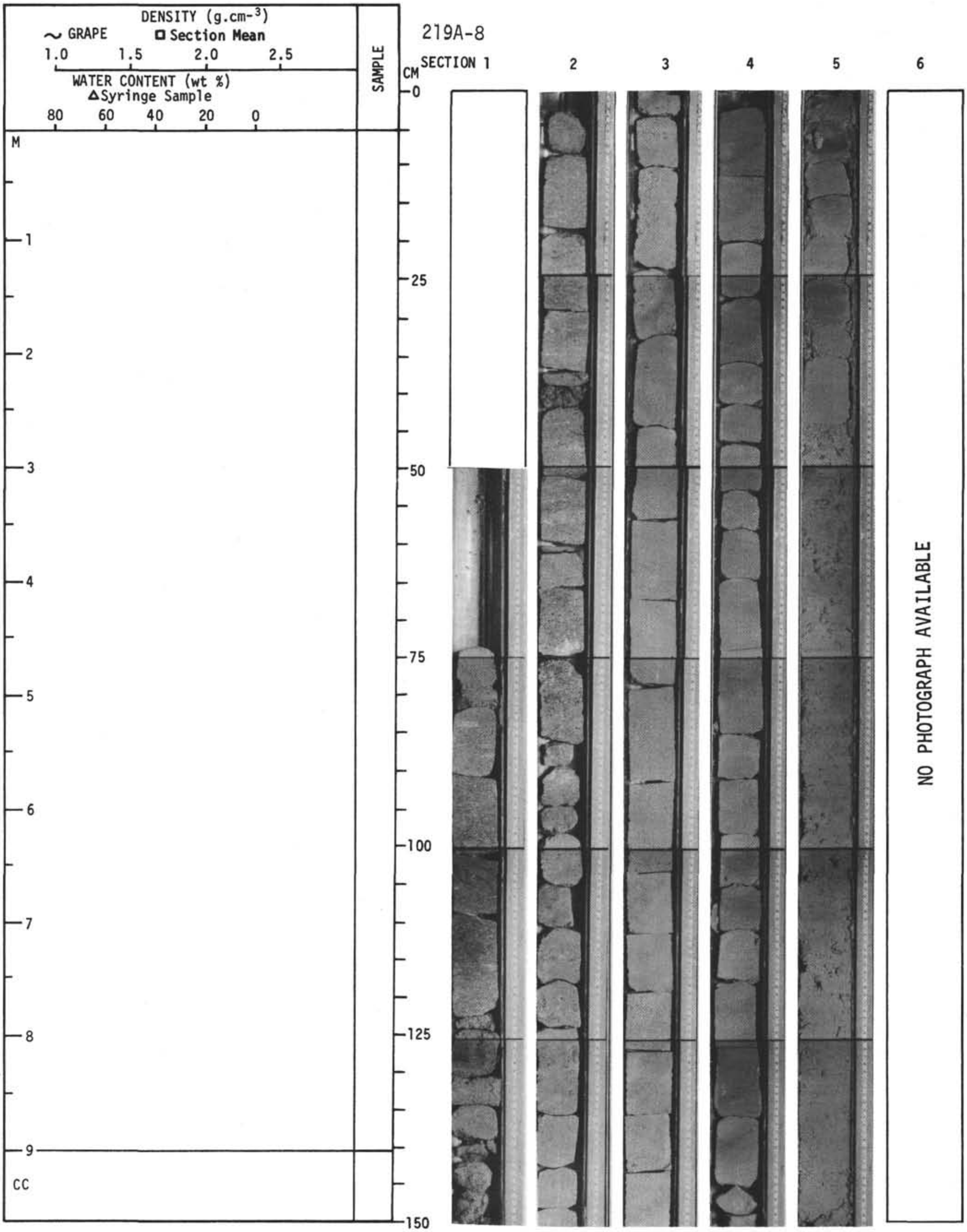

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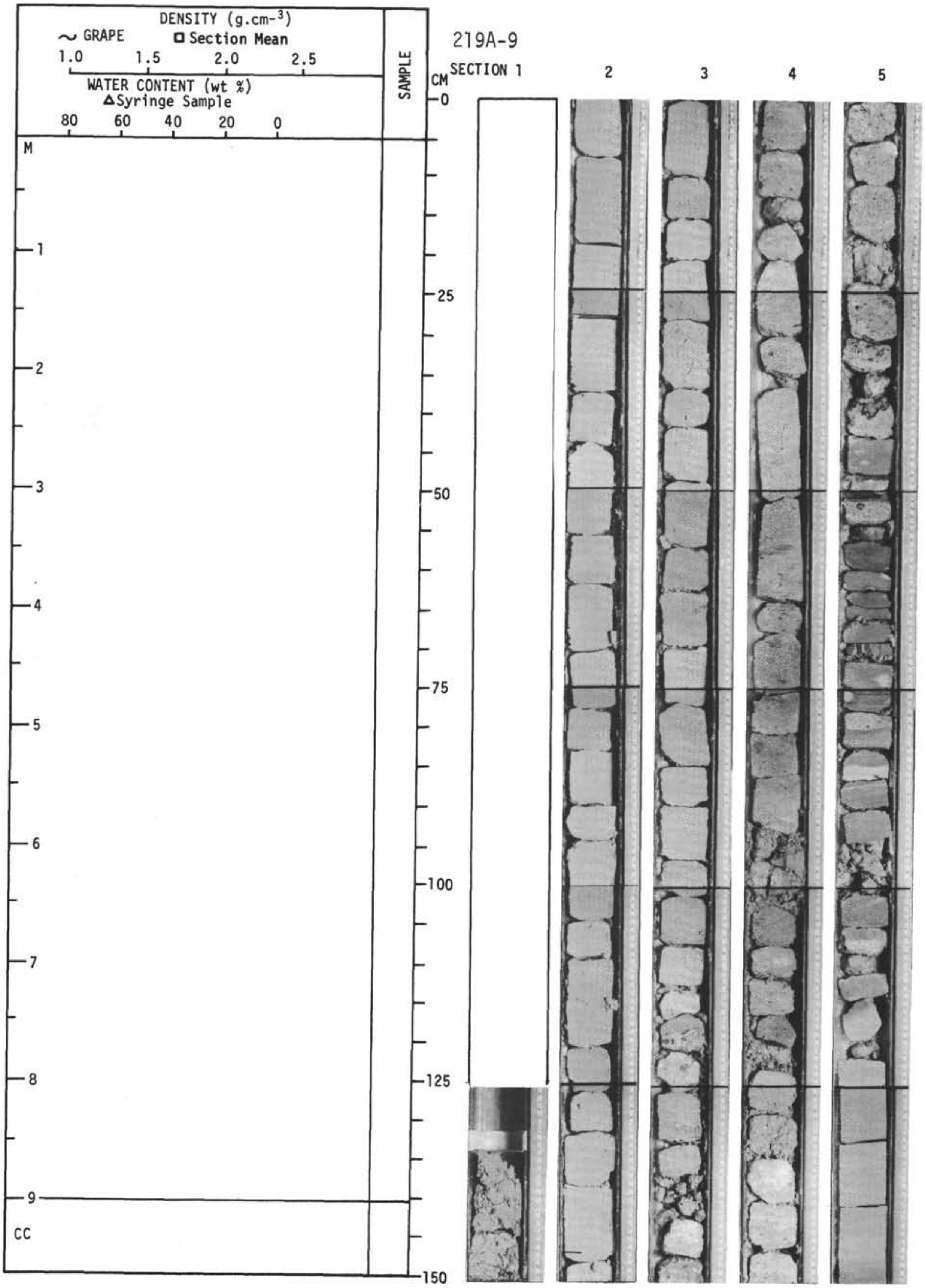

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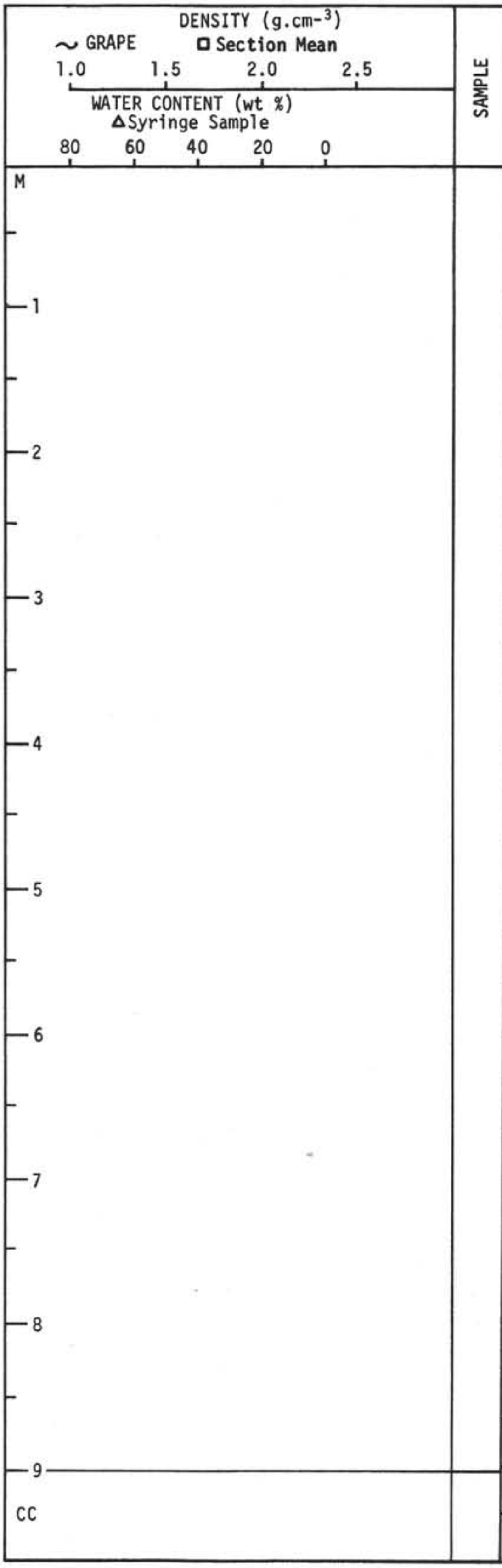

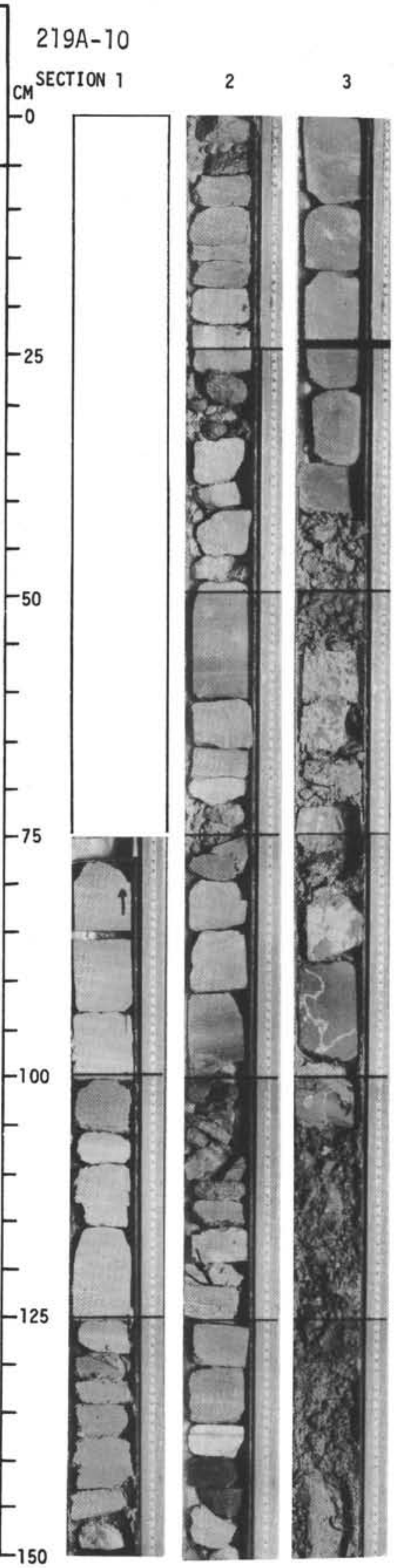

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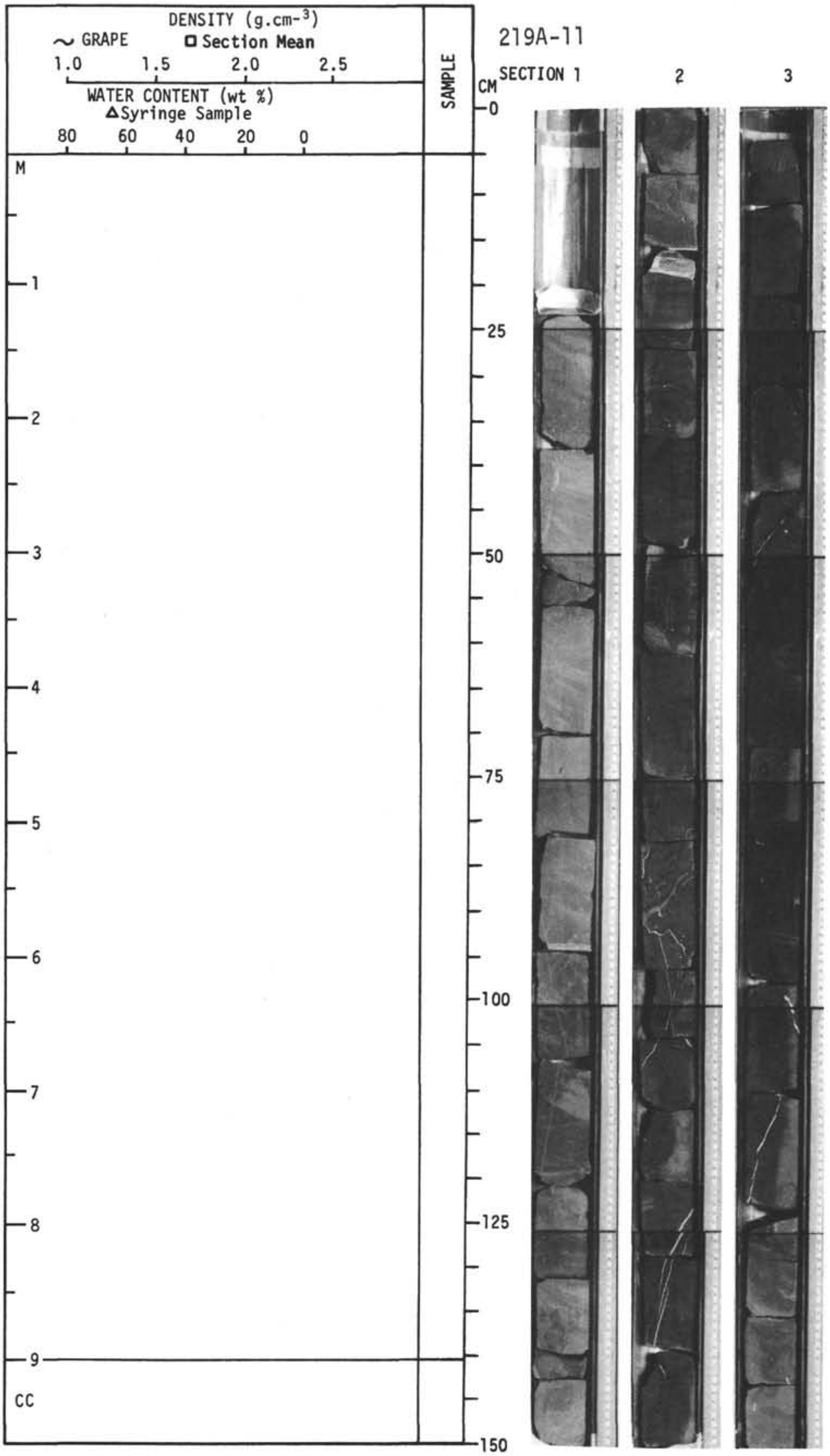

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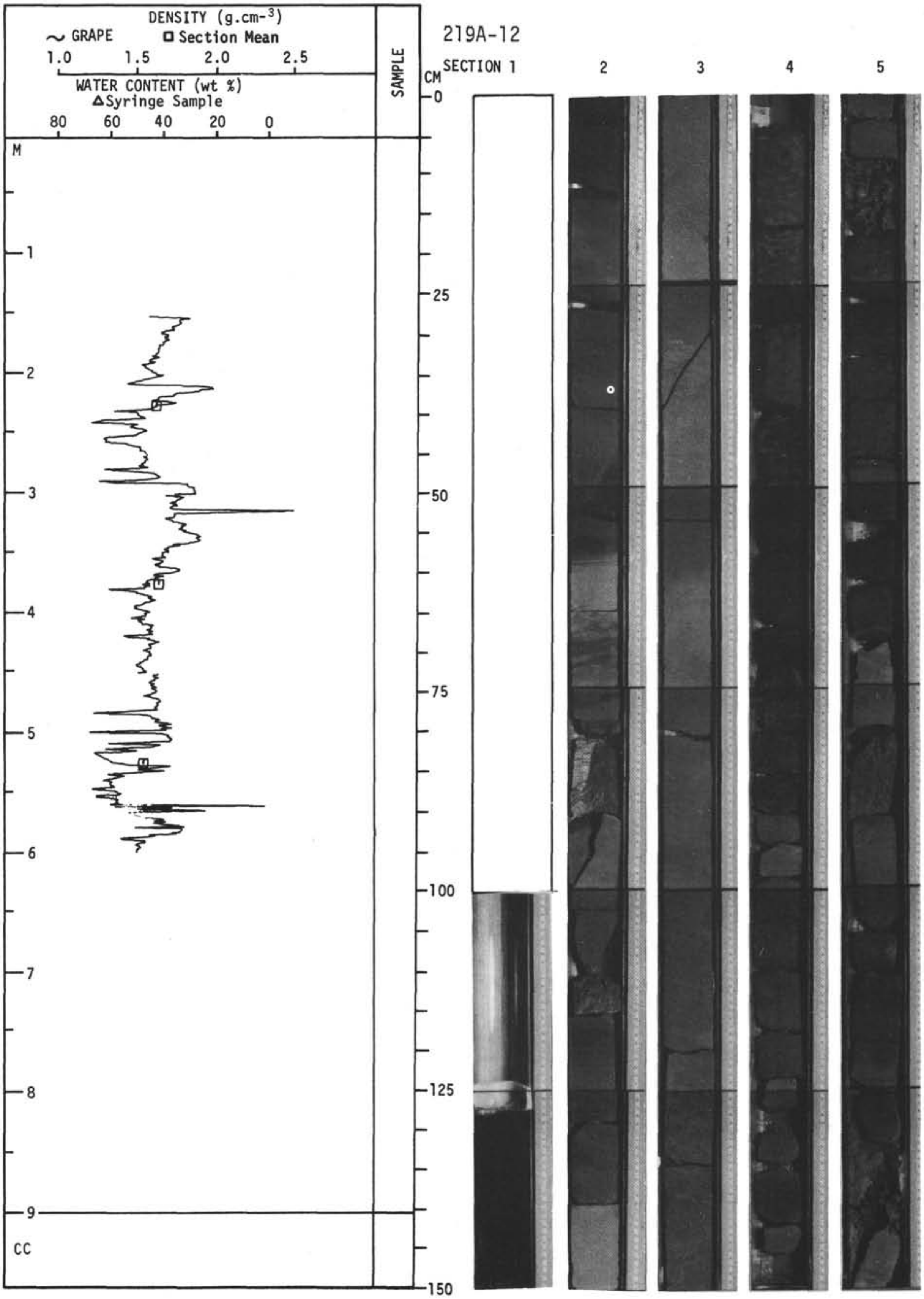

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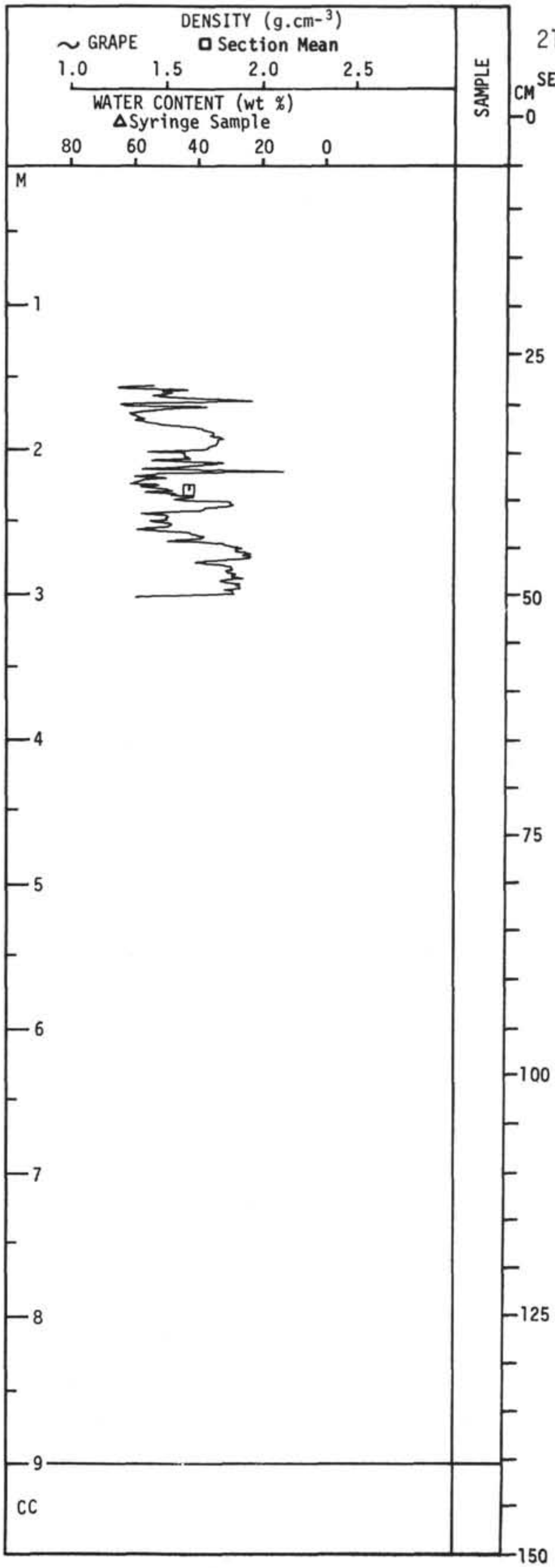

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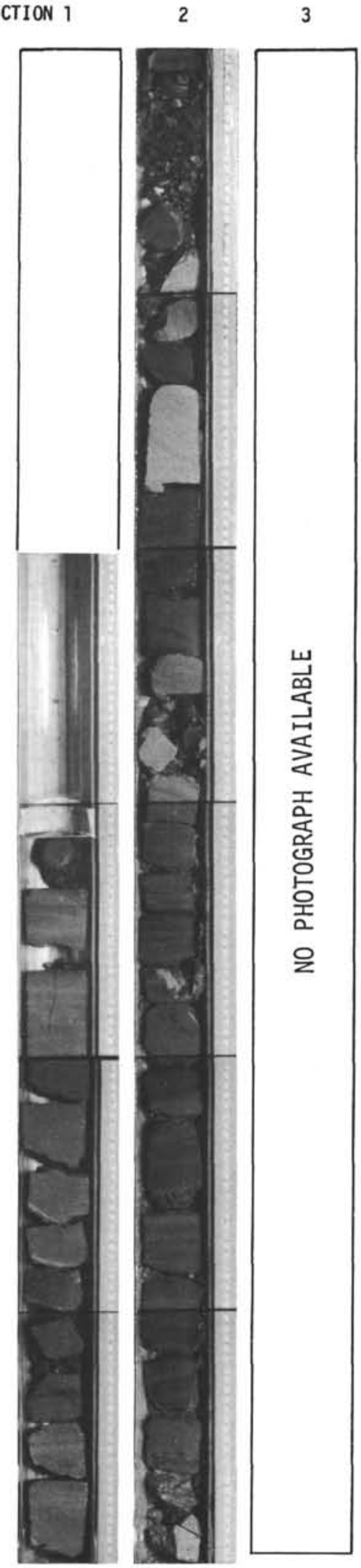

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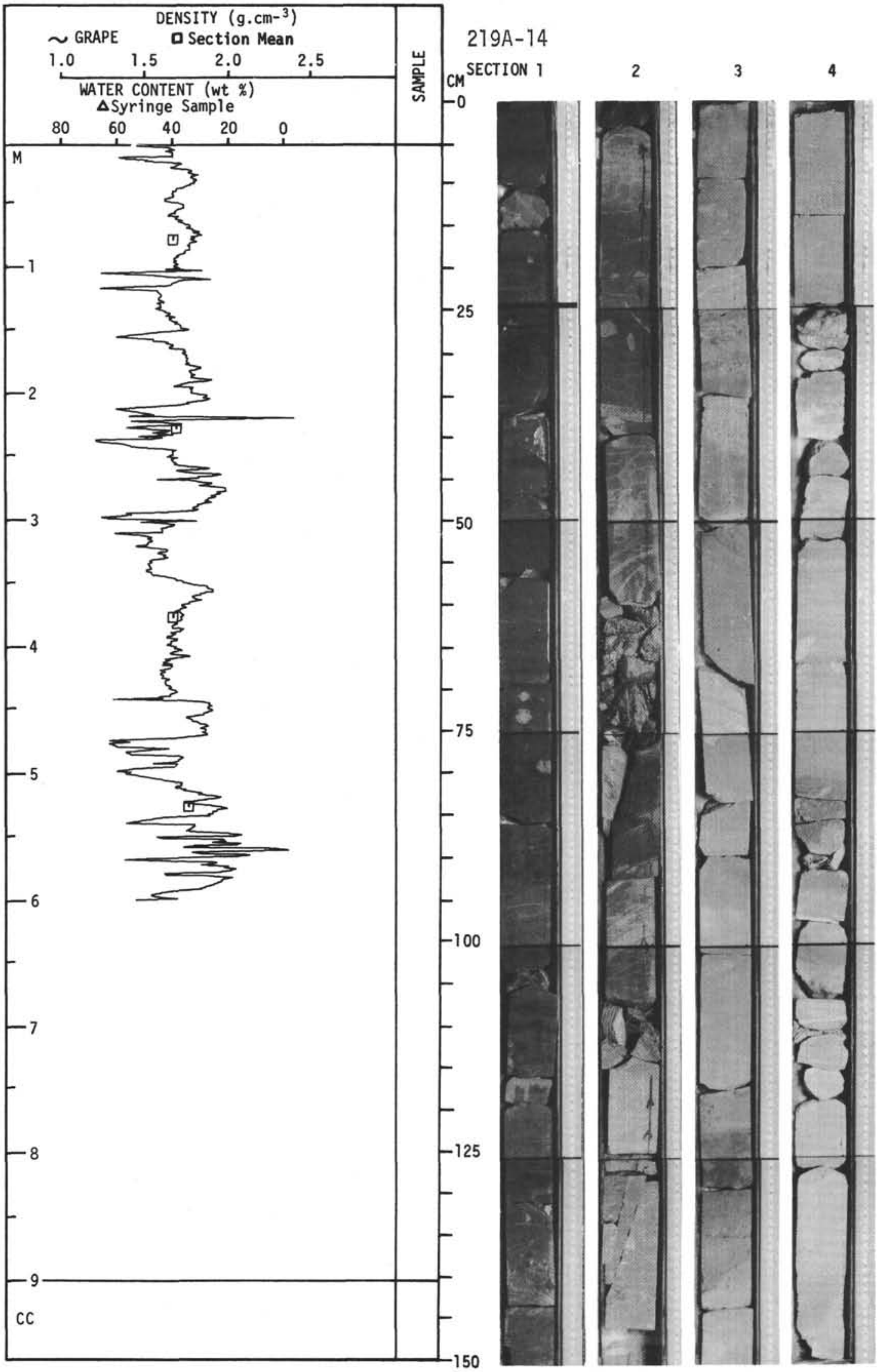

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