18. SITE 228

The Shipboard Scientific Party[1]
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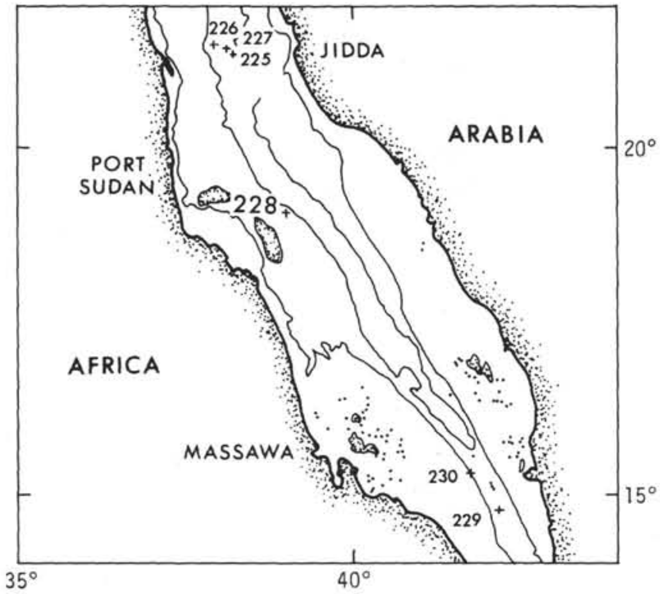


Figure 1. *Bathymetric chart showing the position of Site 228 and other Leg 23 sites in the Red Sea. Contours at 200 and 1000 meters, from Laughton (1970).*

SITE DATA

Dates: 1300 22 Apr–2200 24 Apr 72

Time: 57 hours

Position (Figure 1): 19°05.16′N, 39°00.20′E

Holes Drilled: 1

Water Depth by Echo-Sounder: 1038 corr. meters

Total Penetration: 325 meters

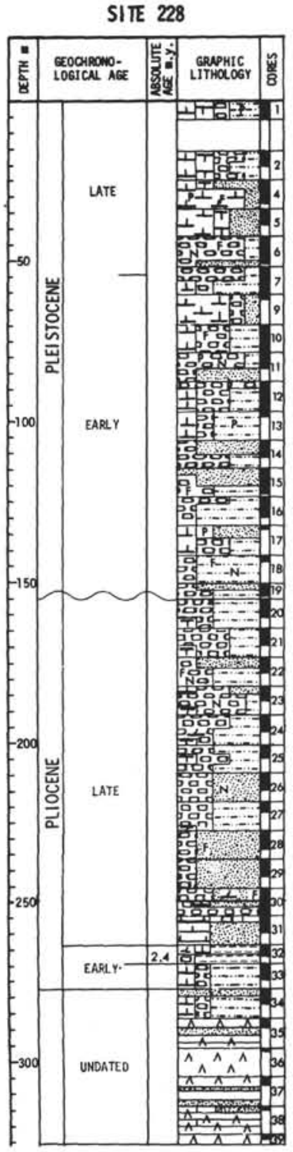
Total Core Recovered: 184.7 meters from 40 cores

Age of Oldest Sediment: Early Pliocene

Basement: Not reached

ABSTRACT

A sequence of Plio-Pleistocene siltstones and oozes overlies presumed Late Miocene anhydrite and siltstones. The latter siltstones are enriched in boron, zinc, lead, and copper. The postevaporite sequence is thicker than at Sites 225 and 227 due to an influx of detrital material from a delta forming off the Sudanese coast. The lithology grades upward from carbonaceous silty claystone to micarb siltstone to micarb nanno ooze or micarb-rich siltstone with carbonaceous beds rich in molybdenum and vanadium. The site is probably on the flank of a salt diapir, and deformation structures seen in the cores may reflect diapirism (see Site Summary).



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BACKGROUND AND OBJECTIVES

In 1964 the first seismic reflection profiles were obtained across the axial trough of the Red Sea (Knott et al., 1966). Later, during succeeding cruises of R. V. *Chain*, further seismic profiles were obtained (Phillips and Ross, 1970; Ross and Schlee, in press). All these profiles showed that a strong reflector was present over much of the Red Sea at depths of some hundreds of meters beneath the sea bed, but was always absent in the axial trough. This reflector, named the S reflector by Phillips and Ross, was cored by *Glomar Challenger* at Sites 225 and 227 close to Atlantis II Deep and was found to mark the top of an evaporite sequence of halite and anhydrite. The relatively high compressional wave velocity of anhydrite is sufficient to explain the strength of the S reflection.

In general terms, the discovery that the S reflector represents the top of an evaporite sequence is consistent with the detailed seismic refraction survey of Tramontini and Davies (1969). These authors, working in the main trough around 22°30′N, 38°E, found a 4.3-km/sec layer about 4 km thick overlying a 6.6-km/sec layer outside the axial trough. Although the upper layer might include appreciable volcanics in its lower part, the indications are that the evaporites are of the order of several kilometers thick. Comparable thicknesses have been found in deep boreholes on the margins of the Red Sea and nearer its center beneath the Dahlak and Farisan islands (Girdler, 1970; Ahmed, 1972). Seismic refraction data are not available for the immediate vicinity of Site 228, but the closest station of Drake and Girdler (1964), which lay some 150 km to the south, shows over 4 km of material (evaporites?) with velocities in the range 4.06-4.41 km/sec. The nearest land borehole, named Durwara 2, encountered evaporites over a 1400-meter interval (Baldassarri, 1967).

Magnetic control was available for Site 228, due to a pair of unpublished Conoco aeromagnetic profiles flown from the Sudanese coast to the axial trough.

The site was chosen on the basis of a sparker/airgun reflection profile obtained in 1971 during *Chain*-100 (Figure 2). The profile shows a well-developed reflector S about 0.35 sec below the sea bed. Although the first two sites in the Red Sea had already confirmed that the S reflector represented the top of the evaporites, Site 228 was situated 270 km to the south and on the opposite side of the Red Sea and so represented a very different situation from the holes drilled near Atlantis II Deep. The objectives of drilling at the site were, therefore,

1) To discover the nature of the S reflector.

2) To obtain as complete a stratigraphic section as possible to learn about past connections of the Red Sea with the Mediterranean Sea or Gulf of Aden.

3) To determine the nature of the 4.06-4.41 km/sec layer and if this were composed of evaporites to obtain further information about the evaporites for comparison with other sites.

The JOIDES Advisory Panel on Pollution Prevention and Safety made a number of general recommendations for all the Red Sea sites among which were the constraints to continuously core and to monitor downhole temperatures.

OPERATIONS

The site was approached from the axial trough along a southwesterly course on 22 Apr 72 (see Figure 3 for track). The proposed position of the site had been moved about 2.8 km to the east-southeast so that it lay beneath one of the Conoco aeromagnetic profiles. The S reflector was located near the margin of the axial trough but here the sea floor and the reflector had an irregular topography. After turning north, *Glomar Challenger* followed a south-southeast track parallel to the strike of the axial valley, and it was along this course that a suitable site was eventually found at which the S reflector could be clearly seen and where the water depth exceeded the operational minimum of 900 meters. After slowing to 5 knots and turning to a reciprocal course, a 16-kHz beacon was dropped at 1530 hours in a water depth of 1038 meters.

No major drilling problems were encountered at this site. At the request of the JOIDES Advisory Panel on Pollution Prevention and Safety, cores were taken continuously, except for a 10-meter section near the top of the hole. We took 40 cores from the 325-meter hole and recovered 184.7 meters of core (Table 1). The coring time was 22.1 hours. Six heat flow attempts were made, but only the first three were successful. Bit weight was generally 5-8 Klb or less for the first 11 cores, increasing to about 10-15 Klb by Core 22, and about 15-20 Klb for the remainder. Drilling time was generally less than 30 minutes for the first 28 cores, but then increased, reaching about 80 or more minutes by Core 35 when we encountered the anhydrite. Drilling was stopped after Core 39 because the bumper subs had seized up with anhydrite chippings and were not absorbing the heave of the ship. Core 40 (only a core-catcher sample) was obtained when the pipe was lowered to the bottom to confirm the jamming of the bumper subs after the pumps had been left on for an hour. Drilling was terminated at 2030 hours on 24 April 72.

At 0100 hours on 25 Apr 72 the ship departed to the west to stream gear, returned over the beacon at 8 knots, and continued on a course of 060° for 1 hour before heading south at full speed to reach Site 229. An intervening second priority site had originally been proposed, but because of its proximity to boreholes in which hydrocarbons had been met, the Pollution Prevention and Safety Panel had recommended that the site be moved at least 55 km further north. However, in view of the S reflector having been shown to mark the top of an evaporite sequence on both sides of the Red Sea at points 270 km apart, it appeared that little was to be gained from drilling this second priority site where the S reflector was almost certainly the top of the evaporites.

LITHOLOGY

The stratigraphic sequence at Site 228 was continuously cored to a depth of 325 meters below the sea bed. A rather thick Plio-Pleistocene section was encountered over anhydrite. Four lithologic units, similar to those of Sites 225 and 227, are recognized (Table 2).

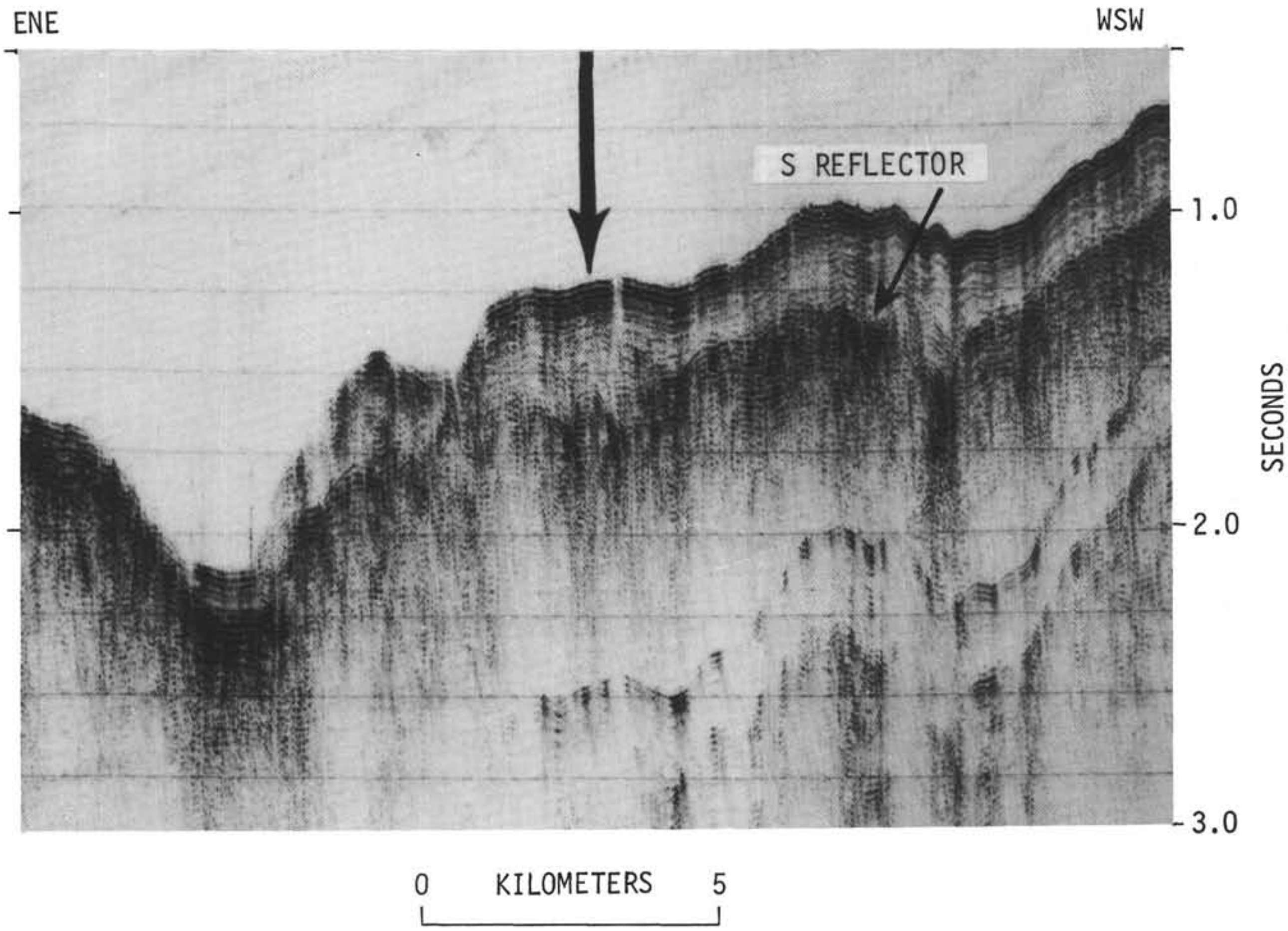

Figure 2. *Seismic reflection profile across the proposed position of Site 228, shown by an arrow. The deepest water lies in the axial trough. Beneath the shallower part, multiples of the bottom and the S reflector can be seen.*

Unit I

This unit comprises the entire Pleistocene and uppermost Pliocene. It consists of greenish to olive-gray detrital silty micarb oozes and micarb-rich silts which are semilithified below a depth of about 100 meters. Tests of nannofossils (5%-75%) and foraminifera (5%-20%), micarb particles (5%-65%), and sand- to clay-sized clastic detritus (10%-70%) are the major components. The observed spectrum of sandy silty to clayey oozes, as well as micarb-rich silty clays, etc., is due to minor variations of the proportions and/or grain size of these major components. Color changes also reflect these variations.

A high content of heavy minerals ranging up to 15% is typical for many beds within this facies. The total carbonate content, due to the presence of calcite, magnesian calcite, and aragonite varies greatly within this unit (Figure 4). Down to about 120 meters it ranges from 10% to 70% (average 40%), from 120 to 150 meters it is low (average ~20%), rising again to higher values (average ~40%) in the lowermost part of the unit. The organic carbon content is low throughout (0.1%-0.5%), except for a few dark gray to black beds which show values as high as 8% (Figure 4).

Pieces of lithified pteropod-rich layers occur in Cores 1 to 4, 11, 12, 15, and 17; however, it is likely that the fragments found below Core 4 have fallen down the hole during drilling operations because they are found only in the most disturbed parts of the cores.

Thin layers and irregular streaks of reddish-brown clay and silt are found throughout this unit. The color is due to a high content of ferric iron as shown by chemical analysis.

The sediments of unit I are generally massive. Bioturbation is slight to moderate, with those burrows present being very small. In the uppermost 30 meters of the section some distinctly graded beds are seen.

Unit II

A semilithified gray micarb siltstone, occasionally nanno- or foram-rich, is the characteristic sediment of this unit (micarb 10%-30%, detrital material 60%-80%, nannos 5%-15%, forams 5%-15%). The carbonate content stays fairly constant around 30%. Figure 4 clearly shows that calcite and calcian dolomite are the only carbonate minerals present. The organic carbon content is low (0.1%-0.4%).

The siltstones of this unit are homogeneous, only rarely is bedding observed.

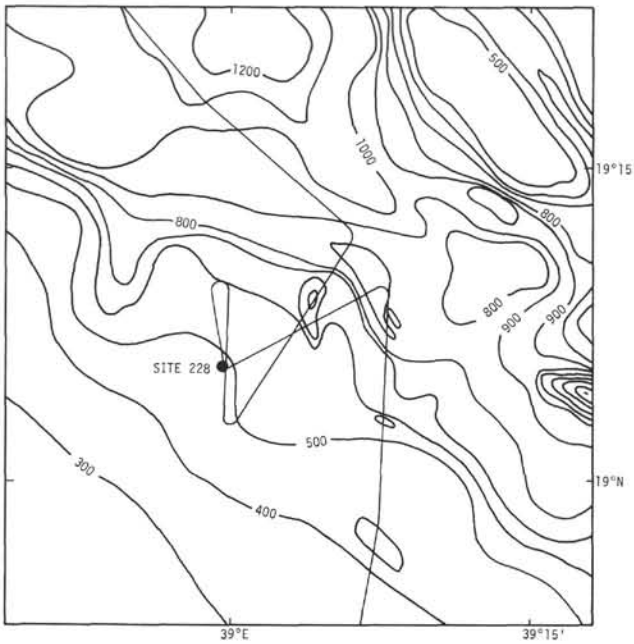

Figure 3. *Bathymetric chart of the area around Site 228 with the tracks of* Glomar Challenger. *Contour interval 100 fathoms depths in corrected fathoms. Contours based on collected soundings too numerous to show clearly (after Laughton, unpublished).*

TABLE 1
Coring Summary, Site 228

Core	Date/Time Core on Deck (Time Zone-3)	Subbottom Depth (m)	Cored (m)	Recovered (m)
	22 Apr.			
1	1940	0-5	5.0	4.8
2	2035	15-24	9.0	4.5
3[a]	2115	24	0.0	1.5
4	2200	24-33	9.0	7.3
5	2240	33-42	9.0	5.8
6	2325	42-51	9.0	7.9
	23 Apr.			
7	0025	51-60	9.0	8.8
8[a]	0100	60	0.0	4.5
9	0150	60-69	9.0	CC
10	0250	69-78	9.0	8.5
11	0355	78-87	9.0	5.6
12	0510	87-96	9.0	9.5
HF[a]		96	0.0	0.0
13	0645	96-105	9.0	1.9
14	0755	105-114	9.0	6.0
15	0840	114-123	9.0	8.3
16	0940	123-132	9.0	6.3
HF[a]	1015	132	0.0	0.0
17	1115	132-141	9.0	0.2
18	1225	141-150	9.0	2.3
19	1315	150-155	5.0	3.7
20	1415	155-164	9.0	5.7
21	1515	164-173	9.0	5.5
HF[a]		173	0.0	0.0
22	1650	173-182	9.0	4.9
23	1815	182-191	9.0	4.2
24	1910	191-200	9.0	5.0
25	1955	200-209	9.0	4.6
KT[b]	2040	209	0.0	0.0
26	2150	209-218	9.0	5.8
27	2250	218-227	9.0	3.9
HF[a]	2335	227	0.0	0.0
	24 Apr.			
28	0040	227-236	9.0	6.0
29	0200	236-245	9.0	5.7
30	0330	245-254	9.0	8.9
31	0955	254-263	9.0	5.6
32	0600	263-268	5.0	3.6
33	0715	268-277	9.0	6.0
34	0820	277-286	9.0	4.3
35	1030	286-295	9.0	2.4
36	1245	295-304	9.0	0.8
37	1450	304-313	9.0	2.6
38	1710	313-322	9.0	0.6
39	1850	322-325	3.0	1.2
40	2030	325	0.0	CC
Total			315.0	184.7

[a] Von Herzen heat flow probe used.

[b] Kuster recording thermometer.

TABLE 2
Lithologic Summary, Site 228

	Lithologic Units	Thickness (m)	Subbottom Depth (m)	Core
I.	Gray DETRITAL SILT-RICH MICARB NANNO OOZE and MICARB-RICH SILTSTONE	195	0-195	1-24
II.	Gray MICARB SILTSTONE	55	195-250	24-30
III.	Gray/Black DOLOMITIC DETRITAL SILTY CLAYSTONE	37	250-287	30-35
IV.	EVAPORITES	⩾38	287-325	35-39

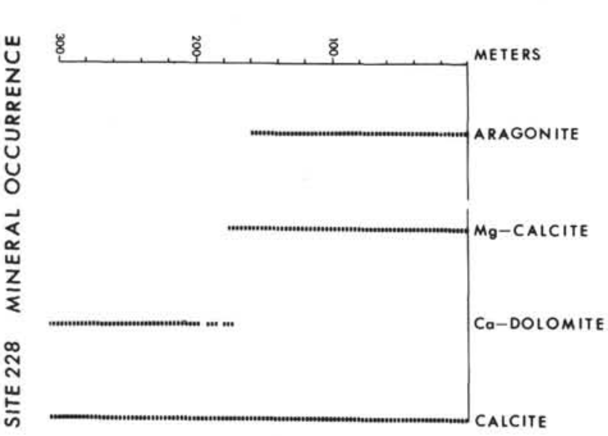

Figure 4. *Total carbonate, organic carbon content, and occurrence of carbonate minerals..*

Unit III

This unit is made up of a semilithified gray to black dolomitic silty claystone (dolomite trace to 40%, total detrital 35%-90%, pyrite 1%-10%) with admixtures of nannofossils (5%-30%) and micarb particles (5%-20%). A high organic carbon content (maximum 2.9%) is typical of the black beds. The carbonate content varies from 5%-40% within this unit. Analcite, which is a common component of the black claystones of Site 227, was recorded by shore-based X-ray studies only in Cores 31 and 33 of Site 228.

Bedding is generally horizontal, but dips increasing from 20° to 70° were observed from Core 27 to Core 34. These steeply dipping layers are interbedded with horizontal strata.

The contact between units II and III is gradational; scattered black siltstones with high organic carbon contents do occur already in the lower part of unit II and rarely also in unit I, as noted above (see also Figure 4).

Unit IV

Unit IV is the lithified evaporite sequence already encountered at Sites 225 and 227. At Site 228 it consists of anhydrite beds interbedded with gray to black siltstones. Most of the anhydrite is brecciated, with a matrix of siltstone. Some is nodular with pyrite and dolomite in between the nodules. The black siltstones contain stringers of anhydrite and euhedral sphalerite crystals. No rock salt was encountered, but pore water salinities suggest the presence of halite about 25 meters below the bottom of the hole (see Geochemistry section). For a detailed description and discussion of the origin of the evaporites, see Stoffers and Kühn (this volume).

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

Provenance of Detrital Minerals[2]

The assemblage and relative abundance of detrital minerals in core-catcher samples from 20 separate cores were determined (Table 3). The size range of these detrital minerals varies from 0.01-1.5 mm with the average about 0.04-0.5 mm. Individual grains are angular to subangular with many showing effects of solution etching and pitting. This unaltered and angular nature of the grains indicates first-generation sedimentation. Quartz and feldspar are the dominant minerals and plagioclase exceeds K-feldspar in nearly all the samples. Brown to green biotite is present in all samples and is remarkably fresh. Hornblende having a green to bluish-green pleochroism is most abundant followed by brown hornblendes. A few rare fragments of riebeckite were identified, and these signify the presence of alkali granites in the source area. Iron-rich epidote is common to abundant in nearly all samples and is accompanied occasionally by clinozoisite. Muscovite is a persistent mineral throughout the section, and its similarity to quartz in the slide mounts may have resulted in underestimating its abundance. The other less abundant minerals such as garnet, sillimanite, staurolite, sphene, and rutile are indicative of a metamorphic source terrain. Zircon and tourmaline are more likely derived from granitic rocks.

The consistency of the detrital mineral assemblage from the Pliocene-Pleistocene sections at Site 228 indicates derivation from a single source area during the period of deposition. The mineral assemblages suggest that the source area was probably a metamorphic and granitic terrain. The appearance of recognizable gneissic fragments (up to 3 mm) in the core further reinforces this supposition. The geologic map of Sudan shows widespread areas of Precambrian metamorphic and granitic rocks adjacent to the Red Sea coastline (Whiteman, 1971). Furthermore, the present-day drainage pattern of eastern Sudan reveals an ~478,000 sq km drainage basin within the Precambrian shield whose mouth is centered along the coast from Trinkitat to Aqiq and is related to an extensive shallow area extending eastward towards the central Red Sea rift (Figure 5).

Increased rainfall during the pluvial period accompanied by uplift must have effectively moved considerable alluvial material from the Precambrian interior of the Sudan and deposited it along the western shoreline outward into the Red Sea trough. The shallow banks extending eastward from Trinkitat and Aqiq (Figure 5) may represent the top surface of a "Sudanese Delta" formed during Plio-Pleistocene times due to the accelerated rainfall of this period. These observations provide a reasonable geologic explanation for the much thicker Plio-Pleistocene cover at Site 228 where the sedimentation rate is at least twice that at Site 227.

BIOSTRATIGRAPHY

Foraminifera

Planktonic foraminifera are almost always present in samples from Cores 1 through 33. Faunal associations are generally similar to those observed at Sites 225 and 227. The *Globigerinoides sacculifer* Biofacies (cf. Foraminifera section, Site 225) dominates the planktonic assemblages from Core 1 through Sample 16-3, 60-62 cm. Below this horizon, faunas representative of the *G. ruber* Biofacies are present as low as Sample 29-1, 104-105 cm; the highest occurrence of *G. obliquus* is located in Sample 16-5, 55-57 cm. The boundary between Pleistocene and Pliocene

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[2] R. G. Coleman.

TABLE 3
Insoluble Minerals, Site 228

Core / Material	Pleistocene											Upper Pliocene								
	4,CC	5,CC	6,CC	10,CC	12,CC	13,CC	14,CC	15,CC	16,CC	17,CC	18,CC	20,CC	21,CC	22,CC	23,CC	24,CC	25,CC	31,CC	32,CC	34,CC
Quartz	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Feldspar	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	C	C	A
Biotite	A	C	C	C	C	C	C	C	C	C	C	C	S	C	C	C	C	C	C	C
Hornblende	C	A	C	A	A	A	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Epidote	C	C		C	C	C	C		A		C	C	C	C	A	C	C	C	S	C
Muscovite		C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	A	A	A
Sphene	C	C	C	C	C	C		C			C	C		C	C	C	C	S	C	C
Zircon	S	S	S	S	S	S				S		S	S	S	S			S		S
Pyrite							C	C		C			A	S	C	A				
Magnetite										S				S	S					
Tourmaline		S							R		S			R						
Garnet		S	S						S	S			S							
Sillimanite									R			R								
Staurolite																	R			
Rutile									R											
Apatite									S											S
Others										X					X	X[a]			X	X
Size (mm)	.1-.2	.1-.2	.05-.1	.05-.1	.05-.1	.03-.05	.03-.05	.03-.05	.03-.1	.03-.1	.03-.1	.03-.1	.01-.05	.03-.1	.05-.1	.05-.1		.05-.1	.07-1.5	.05-.2

Note: All from core catcher samples. Dissolved in 15% HCL Fines elutriated and mounted on slides.

A = Abundant, C = Common, S = Very scarce, R = Rare.

[a] Includes gneiss fragments.

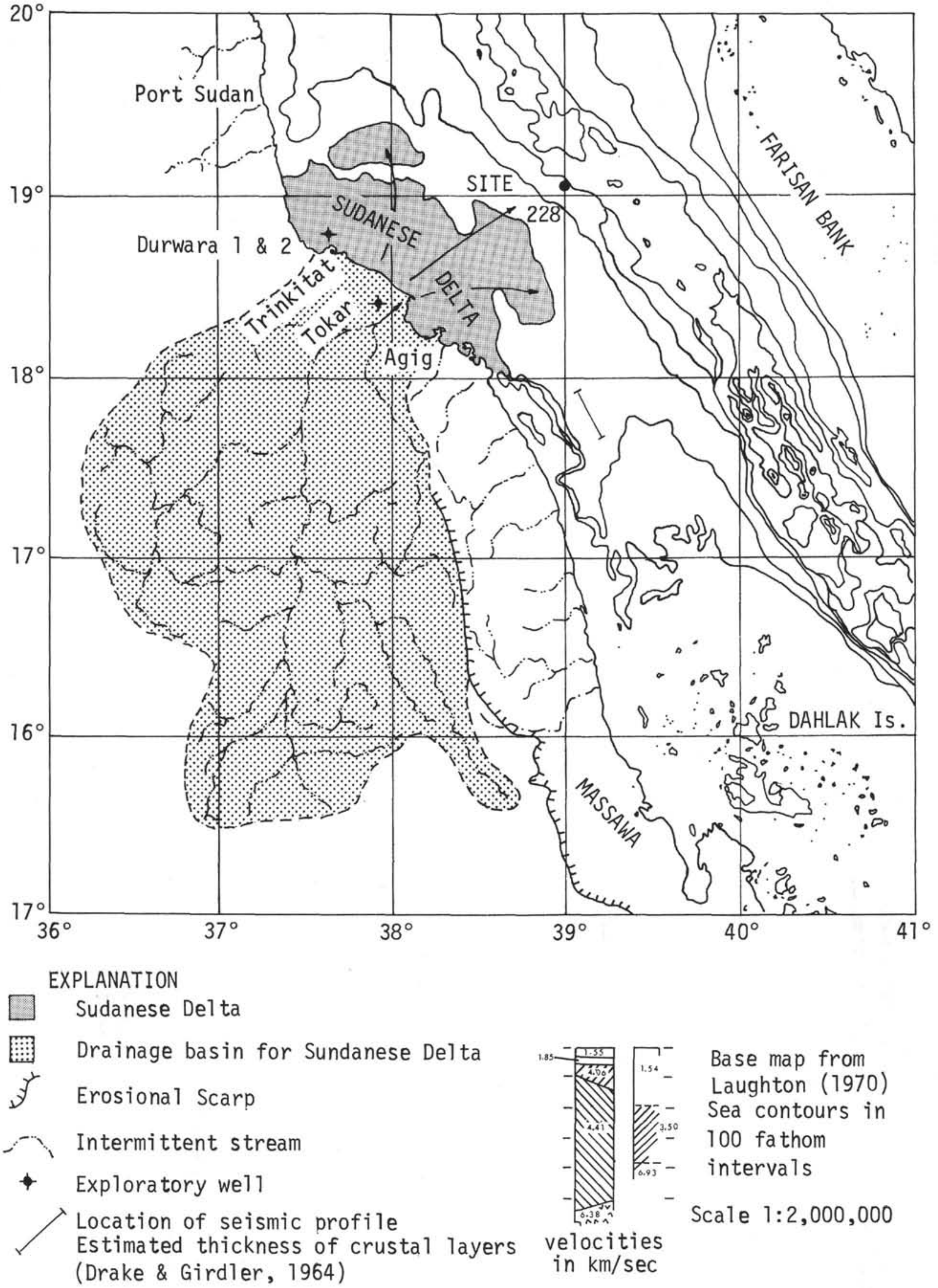

Figure 5. *Drainage pattern of eastern Sudan, showing the provenance of sediments contributing to the extensive offshore shoal area ("Sudanese Delta") and to Site 228.*

benthic faunas is somewhat more gradational at Site 228 than at Sites 225 and 227, but is tentatively located within Core 26.

Core 29, Section 2 through Sample 30, CC contain faunas indicative of the *Globigerinita glutinata* Biofacies. *G. ruber* dominates Core 31, Section 1, but planktonic species are absent in the remainder of this core. *Turborotalita quinqueloba* is common in isolated samples from Cores 32 and 33, although no other planktonic species is present; it is, however, absent from all samples below Sample 33-4, 48-50 cm.

Benthic foraminifera are present in most samples above Core 34, Section 2, but are absent below. As at Site 227 the lowest observed faunas are very poorly preserved, and it seems likely that secondary destruction is at least partially responsible for their absence in sediments just above, and intercalated within, the evaporites.

Nannofossils

Site 228 was drilled in sediments ranging in age from Late Pleistocene to late Early Pliocene. A minor unconformity may be present in the Late Pliocene, and a possible major unconformity exists between late Early Pliocene sediments and presumed Late Miocene evaporites.

Abundant *Gephyrocapsa caribbeanica* (Boudreaux and Hay, 1969) of Late Pleistocene age are found in Cores 1, 2, 3, 4, and 5 and *Coccolithus doronicoides* is abundant in the same interval. The extinction level of *Pseudoemiliania lacunosa* in Sample 7, CC marks the top of the Early Pleistocene. The *Pseudoemiliania lacunosa* Zone extends from Sample 7, CC through Core 19.

The Late Pliocene zone of *Discoaster brouweri* is not noted in this hole as at Site 227. *Discoaster pentaradiatus* occurs in Cores 20, 21, 22, and 23. The *Discoaster surculus* Zone ranges from Sample 24, CC through Core 29 and the *Sphenolithus abies* Zone, also of Late Pliocene, is present in Cores 30 and 31. *Reticulofenestra pseudoumbilica* of late Early Pliocene age is present in Core 32 and abundant in Core 33, Sections 2 and 4. Cores 34 through 39 are completely barren of nannofossils and anhydrite of presumably Late Miocene age is present below Core 33.

Radiolaria

Radiolaria were not found in any of the cores recovered at Site 228.

Palynology

Sample 35-2, 72-75 cm from within the evaporite sequence was examined for spores and pollen by Dr. David Wall of the Woods Hole Oceanographic Institution, but none were found.

Biostratigraphic Summary

Sediments ranging in age from Late Pleistocene to late Early Pliocene, as well as possibly Late Miocene evaporites, are present at Site 228. The absence of at least the *Discoaster brouweri* Zone of Late Pliocene suggests the presence of a minor hiatus. A major hiatus of local extent may exist in the lower portion of this hole above the evaporite section where late Early Pliocene sediments rest unconformably on presumably Late Miocene anhydrite.

Nannofossils are very abundant throughout the post-evaporite stratigraphic section, and practically all zones are present within the sedimentary sequence from Late Pleistocene to late Early Pliocene. Nannofossils are completely absent from the evaporites. Unfortunately, radiolarians were not found at this site probably as a result of poor preservation.

Planktonic and benthonic foraminifera are common to abundant. Tentative correlations based on faunal changes appear to coincide with nannofossil zones. Detailed studies of foraminiferal assemblages should contribute information lending to the reconstruction of the environmental history of the Red Sea.

Stratigraphic and seismic evidence obtained at Site 228 suggests the existence of salt diapirism. Salt domes and salt ridges are apparently common structural features over the entire Red Sea except in the axial trough. Site 228 may have been drilled on or near the apex of a salt diapiric structure.

An absolute age of about 2.4 million years is assigned to the top of the last recognizable nannofossil zone of *Reticulofenestra pseudoumbilica* in the late Early Pliocene sediments found in Core 33. Most of the Early Pliocene section is missing in this hole, and a hiatus of at least 1 million years may be present between the presumed Late Miocene evaporites and the last reliable paleontological zone. The missing Early Pliocene sediments were truncated by salt uplift and probably exist in the form of stratigraphic pinchouts on the flanks of the structure. Therefore, the hiatus is a local feature of a type rather commonly found on all piercement-type salt structures.

Sedimentation Rates

Pliocene sedimentation (159-272 m) occurred at the rate of 230 m/m.y. (Figure 6). A minor unconformity near the Pliocene/Pleistocene boundary is indicated by the absence of the *Discoaster brouweri* Zone. The Quaternary sedimentation rate, 150 m/m.y., is somewhat lower, a trend similar to that observed at Site 225.

GEOCHEMISTRY

Solids

Beginning with Core 13, around 98 meters depth, black claystones containing abnormal concentrations of vanadium and molybdenum were found. These rocks were still in the Lower Pleistocene. Dark shales and also some reddish carbonate-rich sediments contained greater concentrations of these metals deeper in the section, and at Core 21, 169 meters, 1500 ppm V and 300 ppm Mo were noted in the spectrographic analyses (Manheim and Siems, Chapter 29). Lead was still low. Thus, the metalliferous black shale suite noted earlier at Sites 225 and 227 also occurs here.

Iron, titanium, and silicates are more prominent in the sediments here than at Sites 225 and 227, but a bromoform separation of heavy minerals in the uppermost layers did not show the basaltic character inferred for earlier sites. For example, the minerals were not markedly magnesium rich. Strontium was again found to be enriched in lithified rocks and in a pteropod ooze at 115 meters, suggesting that these phases contain inorganically precipitated aragonite.

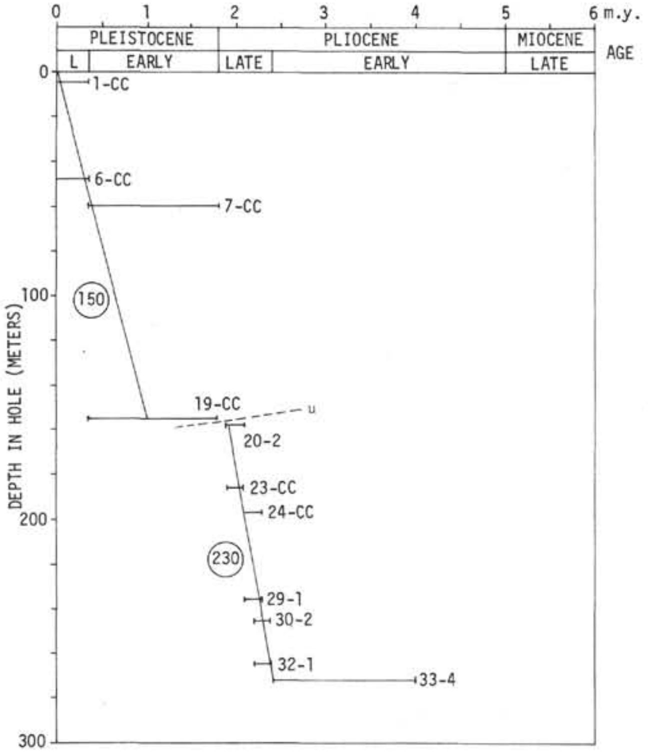

Figure 6. *Sedimentation rates, Site 228. Plotted bars are those sufficient to control slopes of lines.*

The big heavy metal concentrations, however, were at the bottom of the hole in a much fractured and brecciated shale-anhydrite sequence. Here the petrologists found layers of discrete sphalerite crystals with pyrite. The black shale in this section was studied in detail by Stoffers and Kühn (this volume), and spectrographic analyses found all of Core 39 enriched with zinc (not, however, with vanadium or molybdenum, and with only minor copper enrichment). One sample reached 5% Zn, a range hitherto only found among marine sediments in the hot brine deeps of the central Red Sea. Evidently, the shattering and fracturing of rocks in this section has promoted fluid movements and mineralization, with dark shales a very likely source of metals. Although the stuck bumper subs prevented further penetration, the evidence further confirms the idea that upper Tertiary sediments in the Red Sea strata are promising primary sources of the metals enriched in the known brine deeps. Metals characteristic of the brine deeps are most enriched in dark shales within the evaporite unit, whereas the vanadium-molybdenum suite prominent in shales of Plio-Pleistocene age appears to be another geochemical facies. The lowermost metal-rich shales in the evaporite sequence also have as their signature (like previous sites) an extraordinarily high boron content and manganese on the order of 1% Mn.

Although one separated fraction of pyrite contained 3000 ppm As, the black shales of neither the V-Mo facies nor the Zn facies contained detectable As (less than 10 ppm).

Interstitial Waters

Near-surface sediments started off almost immediately with appreciable interstitial salinity anomalies (S>50 °/oo) (Table 4). However, the salinity increased only gradually with depth until the anhydrite was reached at about 278 meters (Figure 7). At this point the salinity, though more than 150°/oo, was still not close to saturation with NaCl. This indicated that halite (which had earlier been associated with and should give rise to brines saturated with NaCl) was still some distance away. By the bottom of the hole, salinity had reached 210 °/oo, and extrapolation of the curve to NaCl saturation suggested that halite might be some 25 meters deeper. However, bumper sub difficulties forced abandonment of the hole at this point. Whatever the distance to the rock salt, there is little doubt that it could not be far away, for some concentrated source of NaCl had to provide the diffusing salt.

The evaporite suite and inferred rock salt suggest that the deepest rocks are Miocene, in spite of lack of fossils. Moreover, the observed association with the interstitial brines and the widespread character of the seismic reflector, which we now assume to represent salt throughout the central-southern parts of the Red Sea, lead one to conclude that brine deposits can be formed almost anywhere in the Red Sea where tectonic action exposes the evaporite sequence close to the sediment-water interface. Whitmarsh has noted the similarity in depth between the evaporite reflector and the top of the Atlantis II Deep, leading to the idea that brines can be formed just by leaching of rock salt, without brine aquifers being breached. Whereas this could explain some of the "cold" brine pools discovered by the R/V *Valdivia* and communicated to us during a rendezvous in the Red Sea, it cannot explain the hot brine deeps, which evidently require not only a source of heat, but also injection of hot fluid (Brewer et al., 1971; Ross, 1972). Thus, the probability that some deeper permeable horizons are tapped through faults or other channels remains good.

It has been implied that the evaporite section is poorly permeable. Direct evidence on the general diffusion permeability of strata encountered in the Red Sea has been obtained by a "diffusimeter" technique described and documented in Chapter 2.

Whereas these data are strictly applicable only to diffusional permeability, they also provide insight into bulk flow as well. Generally speaking, reductions in fluid permeability will be far more stringent than the limitations described for ionic diffusion. In the upper, carbonate-rich parts of all sections the diffusional permeability is about 3 to 4 times poorer than in free water,[3] increasing to 10 to 30 times in the denser shales, siltstones, and carbonates. Relatively pure anhydrites are several hundred times less permeable to diffusion than an immobile free water column (i.e., no eddy diffusion or tubulence), whereas rock salt shows no diffusional permeability whatsoever (off scale on our apparatus at more than 6000-fold permeability decrease and probably much more than this).

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[3] Excluding mixing or eddy diffusion and neglecting temperature effect.

TABLE 4
Interstitial Water Data, Site 228

Core, Section, Interval (cm)	Depth (m)	H_2O Recovered (ml)	Punch-in pH (mv)	Pore Fluid pH	Lab. Temp. (°C)	Salinity (Corr.) (o/oo)	Alkalinity (mg/kg)	Sp.G.
1,CC	9	16	–	–	26.5	52.3	–	–
3,CC	24	12	–	7.11	26.9	58.7	1.8	–
5-3,0-10	38	25	–	7.26	27.0	65.5	2.18	1.057
7-6,0-10	58.5	–	+ 9.8	7.14	25.8	81.9	2.33	1.068
10-6,0-10	76	15	+12.2	7.09	26.8	74.3	2.14	–
11-4,145-150	85	8	–	–	26.6	97.4	2.07	–
13,CC	105	9	–	6.85	26.9	110.7	1.83	–
15-6,0-10[a]				6.88		86.5[b] 91.5[c] 94.2[d]		–
16-5,0-10	130	–	–	6.92	27.0	122.8	1.43	–
18	~145	7	–	7.16 (6.9)	26.9	129.7	0.51	–
19-2,140-150	154	5	–	–	26.9	129.0	–	1.090
21-2,140-150	167	10.5	–	6.60	26.9	136.9	<1.0	–
24-3,140-150	198	9	–	6.25	24.0	147	0.934	–
26-3,140-150	215	7	–	6.25	24.0	150	0.678	–
28-2,0-6	230	6	–	–	25.0	153.5	0.805	–
30-4,140-150	251	6	–	–	23.5	170.0	1.72	–
33-1,0	269	4	–	–	25.0	158	1.08	–
35-1,140-150	~290	7	–	7.52	23.8	170	1.65	–
37-2,11	~310	5.5	–	7.01	27.2	197	1.41	1.152
39	~324	2	–	–	27.2	210	–	–

Note: Salinity refers to salinity derived from refractivity measurements and calibrated with salt water. Alkalinity is total alkalinity. Sp.G. refers to interstitial water.

[a] This sample appeared contaminated with drill slurry.

[b] First aliquot.

[c] Second aliquot.

[d] Third aliquot.

In translating these data to bulk flow in a qualitative way, one has to conclude that unless fracturing or similar processes create permeability channels, the evaporite strata hitherto penetrated cannot be expected to transmit any appreciable amounts of fluid either vertically or horizontally.

The other measurements made in the shipboard laboratory indicate that *p*H values and alkalinities both decrease with depth in the section and that most (but not all) deeper brines approach a NaCl composition. For discussion of the brine composition, see Manheim et al. (Chapter 35).

Water Content

Unlike Site 227, Site 228 does demonstrate a progressive, though fluctuating, decrease in water content with depth (Table 5). Mean water contents range around 35% in surficial muds, to on the order of 15% at 250 meters depth (Figure 8). It is interesting to note that there is no decrease in observed water content in shales below or interbedded between anhydrites, as before. This may be explained by the very poor permeability of the evaporite strata, not permitting appreciable loss of fluid in the vertical direction.

Again, as usual, the anhydrites themselves have very low water content, estimated at around 1% or less. They seem to contain water (brine) chiefly to the extent that they are admixed with shale or clay matter.

The trends noted above are generally reflected in other physical properties (e.g., GRAPE density) but detailed comparisons are not made here.

One may also note that Red Sea sediments start out with a good deal less water than many oceanic or geosynclinal deposits, even though they may seem quite fluid near the sediment-water interface. This may be partially due to the large detrital or macro carbonate detritus component; i.e., very porous phases such as highly dispersed clays, amorphous silica, etc., are present in minor or subordinate amounts.

Diffusimetry-Resistivity Measurements on Cores

Table 6 contains the resistivity and formation factor results for this site. For a detailed description see Chapter 2.

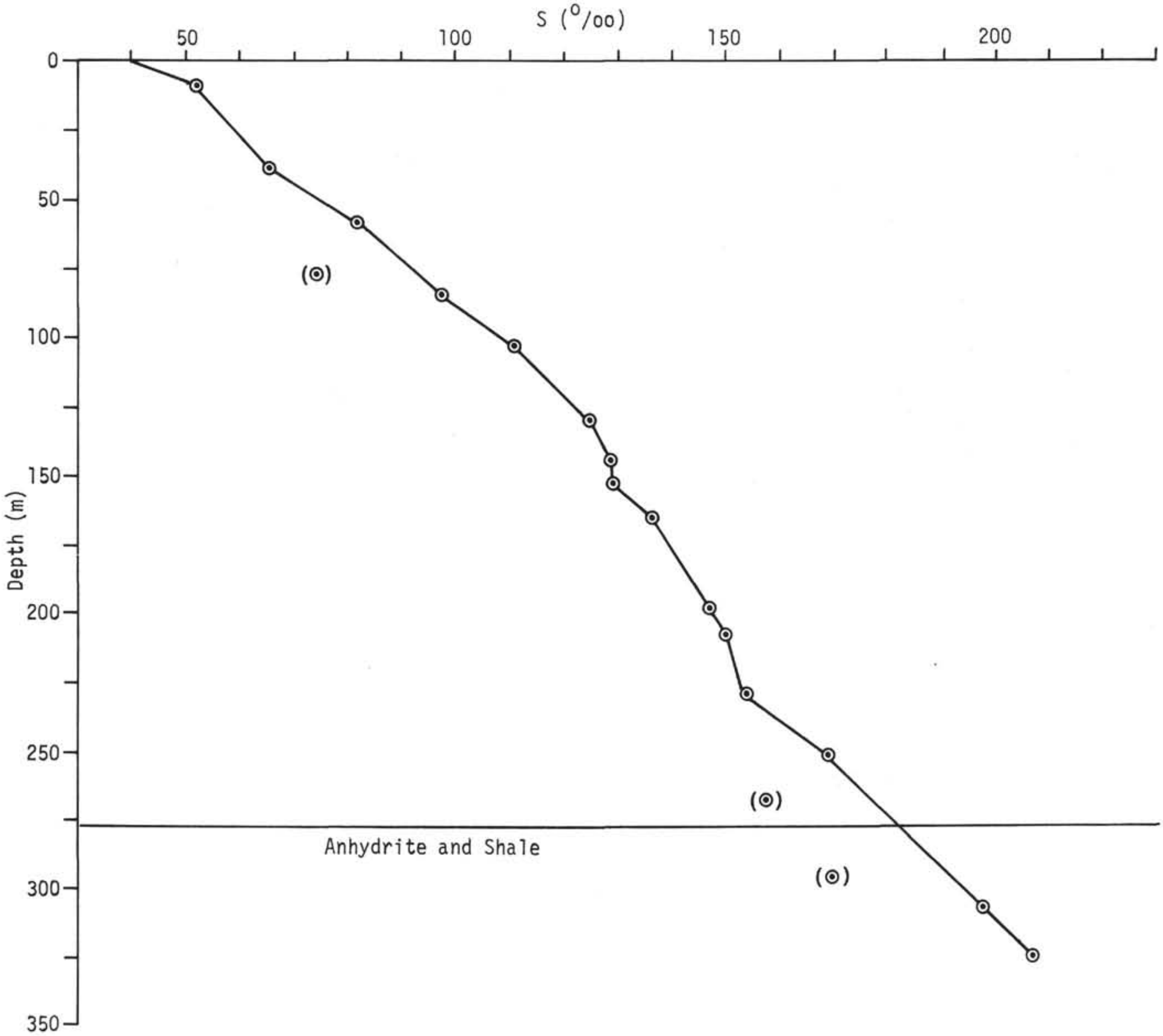

Figure 7. *Interstitial water salinities, Site 228.*

Oxygen and Carbon Isotope Analyses[4]

The objective of these analyses was to determine the feasibility of a detailed stable-isotope study of fossils in order to obtain paleoclimatologic and paleooceanographic information.

Seven sediment samples (wet weight between 40 and 100 g) from widely spaced core sections of Site 228 were selected. Portions of the samples were washed through standard sieves to recover their fossil content. Clean and well-preserved Globigerinas (no species separation was made for the limited purposes of this study) were individually selected from the 250-500μ size fraction and subjected to isotopic analysis according to standard procedures. The results are listed in Table 7.

Conclusions drawn from this pilot study are: (1) All samples obtained contain ample fossil material for isotope analyses of planktonic foraminifera. If the present set of samples is approximately representative of the bulk of the cores, 10-g (wet) sediment samples should suffice for this type of study. Larger samples would be required where foraminifera are rare. (2) Significant isotopic variations appear to exist throughout the cored strata. (Reproducibility of measurements is better than ±0.1 °/₀₀.)

It is thus apparent that the cores are amenable to detailed isotopic studies of their fossil content and that such studies promise revealing results.

Other Isotope Studies

Variations of the stable oxygen and carbon isotopes of the pore water and carbonates were measured by Lawrence (this volume). The deuterium/hydrogen ratio of interstitial

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[4] W. G. Deuser.

TABLE 5
Water Content, Site 228

Core, Section, Interval (cm)	Estimated Depth (m)	Water Content (%)	Porosity (%)	Density (g/cm^3)
1-2,82	2.32	28.2	54.8	1.94
1-4,57	5.07	37.9		
2-1,68	15.6	24.8		
2-2,50	17.0	25.3		
2-3,40	18.4	26.1		
3-1,45	24.4	25.9		
4-1,40	24.4	37.4		
4-2,40	25.9	26.1		
4-3,100	28.0	31.8	61.7	1.94
4-4,103	29.5	37.2		
4-5,80	30.8	29.8		
5-3,95	36.9	30.3	58.7	1.94
5-4,123	38.7	24.0	53.3	2.22
6-2,80	44.3	27.1		
6-3,140	46.4	36.2	73.4	2.03
6-4,70	47.2	30.4	65.6	2.16
6-5,110	49.1	24.4	49.7	2.04
6-6,50	50.0	22.6	47.6	2.10
7-1,40	51.4	24.7	56.3	2.28
7-2,58	53.0	35.9		
7-4,74	56.2	29.8		
7-5,100	58.0	26.4		
7-6,40	58.9	22.3	48.9	2.20
8-3,75	63.7	20.9		
10-6,67	77.1	23.4	45.6	1.95
11-4,85	83.3	20.6	44.6	2.16
12-4,135	92.8	19.8		
13-2,108	98.5	18.6		
14-1,24	105.2	16.6		
14-2,46	106.9	18.1		
14-4,81	110.3	19.9		
15-1,122	115.2	25.7		
15-2,80	116.3	21.9		
15-4,77	119.2	20.5		
16-2,12	124.6	14.4		
16-3,22	125.2	20.1		
16-5,78	129.7	18.2		
18-1,136	142.36	14.8		
19-3,51	153.5	19.3		
20-1,35	155.3	18.7		
20-2,60	156.5	21.0		
20-3,52	158.5	16.9		
21-1,50	164.5	14.8		
21-2,60	166.1	23.7		
21-3,20	167.2	16.3		
21-4,01	168.5	16.8		
23-1,50	182.5	11.9		
23-2,	183.5	21.8		
23-3,16	185.1	14.7		
24-2,102	193.5	21.1		
24-3,28	194.2	14.2		
25-1,60	200.6	13.7		
25-2,04	201.5	16.0		
25-4,60	205.1	20.6		
26-1,130	210.3	17.1		
26-1,130-133	210.3	16.2		
26-2,16	210.6	13.5		
26-4,48	213.9	25.4		
27-1,70	218.7	13.5		
27-2,55	220.0	13.8		
27-3,110	222.1	18.1		
28-1,20	227.2	16.2		
28-2,101	229.5	14.3		
28-4,104	232.5	15.6		
29-1,39	236.3	13.4		
29-2,35	237.8	14.5		
30-1,120	246.2	14.6		
30-1,120	246.2	13.5		
30-4,57	250.0	14.1		
30-4,140	250.9	11.4		
30-6,28	252.7	12.6		
31-1,110	255.10	12.5		
31-4,10	258.6	15.5		
32-2,8	264.5	22.0		
33-2,35	269.8	22.4		
33-3,100	272.0	3.9		
34-1,70	277.7	10.5		
34-3,50	280.5	15.1		
35-1,140-150	287.4	(0.2)		
35-1,140-150		1.4		
35-1,140-150		<2		

Note: Data based on water loss on heating at 110-120°C. Porosity and density are based on syringe volume measurements.

waters was measured by Friedman and Hardcastle (this volume). The uranium and thorium isotope contents of sediment samples were measured by Ku (this volume). Sulfur isotope measurements were made by Shanks et al. (this volume) on sulfates and sulfides from anhydrites and shales.

Lead Isotope Analyses[5]

The lead isotopic composition of the lead-enriched shaly fraction from an evaporite sequence Core 39-1 is within the range of the samples from the Atlantis II and Discovery deeps reported by Cooper and Richards (1969) and Delevaux et al. (1967) in which the lead is apparently of mantle derivation or leached from rocks of mantle derivation, such as basalt, rather than of pelagic sediment derivation.

PHYSICAL PROPERTIES

Water Content, Porosity, and Density

The top 263 meters consisting of silty nanno-foram carbonate oozes and chalk and calcareous siltstones show gentle variations of these physical properties with depth similar to those observed at Site 227. The GRAPE porosities decrease from about 45% at 20 meters to about 38% at 250 meters and the densities increase from about

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[5] M. H. Delevaux and B. R. Doe.

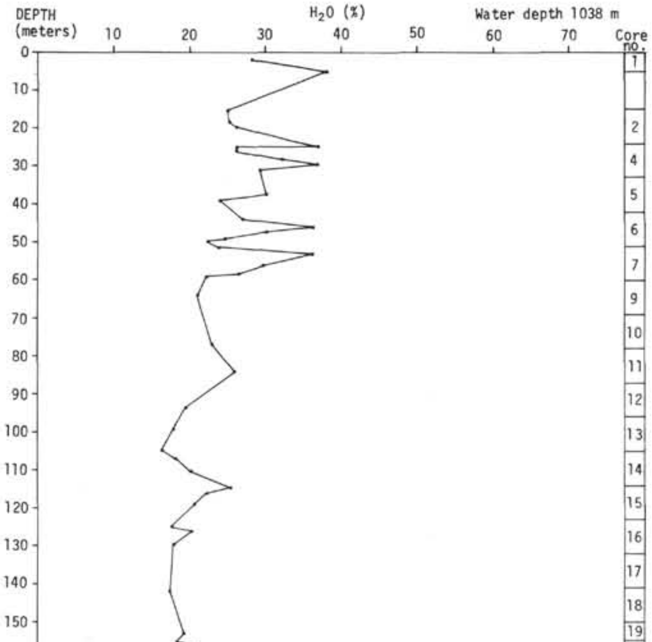

Figure 8. *Water content versus depth, Site 228.*

1.9 g/cm^3 at 20 meters to 2.1 g/cm^3 at 250 meters (see Site Summary). Also shown in the Site Summary are eight syringe densities obtained from the water content; these are up to 12% higher than the GRAPE densities and are probably suspect, as at the core level there is good agreement among the section weight (□), water content (*), and GRAPE densities.

At this site the evaporite sequence was reached at 290 meters and consisted mainly of anhydrite with interbedded siltstones. As much of the anhydrite is nodular and brecciated, it was not possible to obtain reliable GRAPE densities and it would be reasonable to assume the mean density of 2.86 g/cm^3 obtained by Wheildon et al. (this volume).

For the individual cores, good GRAPE plots are obtained up to and including Core 15 (i.e., to a depth of 120 m). After this, the plots are seen to be somewhat erratic with many spurious values probably due to breaks in the cores which become semilithified below a depth of about 100 meters. The good agreement among the three methods of obtaining the densities is particularly well seen in nearly all the core plots. Smaller features of interest include:

Core 4 – maxima and minima occur in the lower part of the core correlating with dark and light bands.

Core 10 – maximum reaching 2.1 g/cm^3 at 7.9 meters correlating with much finer grained material.

Cores 14, 16, 20, 21 – many irregular oscillations correlating with dark and light bands in the sediments.

Core 23 – minima in lower part of core is due to fragmentation and presence of voids.

Deeper cores – many are broken and fragmented giving rise to oscillations in the GRAPE plots.

Compressional Wave Velocity

The compressional wave velocities through the silty nanno oozes show a corresponding increase with depth from about 1.6 km/sec at 20 meters to about 2.3 km/sec at 250 meters. The increase is very smooth, scattered values not appearing until after 260 meters, i.e., where the carbonaceous siltstone (263-290m) is reached.

In the evaporite series, three measurements on samples of anhydrite gave 5.58, 5.65, and 5.91 km/sec, cf. a mean of 4.8 ± 0.58 km/sec (N=6) obtained for Sites 225 and 227 by Wheildon et al. (this volume). In addition, one measurement on the interbedded shales gave 3.37 km/sec and one measurement on the interbedded silt gave 4.92 km/sec.

Specific Acoustic Impedance

The specific acoustic impedance increases from about 3 $\times 10^6$ Nsm^{-3} at 20 meters depth to about 4.5 $\times 10^6$ Nsm^{-3} at 250 meters depth reflecting the gentle increase with depth of the densities and seismic velocities. At a depth of 290 meters the acoustic impedance jumps to nearly 17 Nsm^{-3} where the anhydrites appear.

Thermal Conductivity

The values of thermal conductivities for the top 260 meters of sediment are listed in Table 4 of Girdler et al. (this volume). The values range from 1.089 to 1.925 Wm^{-1} K^{-1} and have a mean of 1.522 ± 0.219 Wm^{-1} K^{-1} (N=23). The thermal conductivities as a function of depth are shown in Figure 4 (Girdler et al., this volume) and an appreciable trend can be seen, the conductivities increasing with depth in a similar way to the porosities, densities, and sonic velocities.

No measurements were made on the anhydrite from this site.

TABLE 6
Resistivity Measurements, Site 228

Core, Section, Interval (cm)	Depth (m)	R_s (app)	T (°C)	R_w (app)	T (°C)	R_{pw}	T (°C)	S (o/oo)	R_s	C	F
1-3	4	0.0655	(25)	0.0335	(25)	0.162	(25)	45.5	0.38	5.8	2.3
1-4	5	0.0785	(25)	0.0335	(25)	0.153	(25)	47.0	0.45	5.8	2.9
2-2	17	0.0718	(25)	0.0335	(25)	0.131	(25)	55.5	0.42	5.8	3.2
2-3	19	0.0715	(25)	0.0335	(25)	0.129	(25)	56.4	0.42	5.8	3.3
4-1	25	0.0649	(25)	0.0320	(25)	0.125	(25)	59.1	0.40	6.1	3.2
4-2	26	0.0563	(25)	0.0320	(25)	0.123	(25)	59.6	0.35	6.1	2.8
4-4,103	30	0.0499	(25)	0.0320	(25)	0.120	(25)	61.5	0.31	6.1	2.6
4-5	31	0.0556	(25)	0.0335	(25)	0.119	(25)	62.2	0.33	5.8	2.8
5-3	38	0.0579	(25)	0.0320	(25)	0.104	(25)	65.8	0.36	6.1	3.5
7-6,0	59	0.0574	(25)	0.0320	(25)	0.0846	(25)	81.7	0.35	6.1	4.1
10-6,0	78	0.0657	(25)	0.0320	(25)	0.0922	(25)	92.8	0.40	6.1	4.1
11-3	84	0.0613	(25)	0.0335	24	0.076	(25)	97.0	0.36	5.8	4.7
12-6	95	0.0709	24.1	0.0335	(25)	0.072	(25)	104.1	0.41	5.8	5.7
14-1,134	106	0.0865	(25)	0.0335	(25)	0.067	(25)	111.4	0.50	5.8	7.4[a]
16-3,105	128	0.0849	25.8	0.0335	(25)	0.063	(25)	121.3	0.49	5.8	7.9
16-5,0	131	0.0623	25.5	0.0335	(25)	0.063	(25)	122.5	0.38	6.1	6.4
18-1,110	142	0.0685	25.0	0.0335	25	0.061	(25)	127.0	0.40	5.8	6.5
18-2,140-50	144	(0.0499)[b]	25	0.0291	25.3	0.061	(25)	127.6	0.33	6.7	(5.5)[b]
18,CC	149	0.0790	25.5	0.0385	25.5	0.060	(25)	129.4	0.40	5.1	6.6
19-2,140-50	152	0.0848	27.2	0.0290	27.3	0.060	(25)	130.3	0.57	6.7	10.6
21-2,140-50	167	0.0616	29.9	0.0290	(25)	0.055	25.7	136.7	0.41	6.7	8.4[c]
24-3,140	193	0.0858	(25)	0.0290	(25)	0.053	(25)	145.4	0.58	6.7	10.8
26-3,140-50	213	0.107	(25)	0.0290	(25)	0.053	(25)	149.2	0.72	6.7	13.5
28-2,0	229	0.105	26	0.0290	(25)	0.052	(25)	152.5	0.71	6.7	13.4[d]
35-1,40	286	0.108	26	0.0360	(25)	0.048	(25)	174.5	0.58	5.4	12.1[e]
35-1,60	287	4.55	25	0.0450	(25)	0.048	(25)	175.0	19.6	4.3	408[f]
37-2,110	306	0.0795	26	0.0420	(25)	0.0445	(25)	196.8	0.37	4.7	8.4[g]
39-1,105	323	0.236	27	0.0360	(25)	0.0437	(25)	211.0	1.29	5.4	31[h]

Note: All measurements in ohm-m. Reference fluid has $S = 35.4\ ^\circ/_{\circ\circ}$. $R_w = 0.196$ at 25°C. R_s is resistivity of sediments, R_{pw} is resistivity of pore water, and R_w is resistivity of reference fluid. C is cell constant and F is formation factor as defined in text.

[a] Hard carbonate mud.

[b] Probably disturbed or contaminated.

[c] Crack joining electrodes in sediment.

[d] Dark green shale.

[e] Black shale.

[f] Anhydrite, shaley.

[g] Shale.

[h] Shale-anhydrite breccia.

HEAT FLOW MEASUREMENTS

Downhole temperatures were obtained at 25 meters, 61 meters, and 97 meters subbottom. Three further attempts at measuring temperatures at this site (subbottom depths of 133, 174, and 228 meters) failed due to malfunctioning of the apparatus. This was most unfortunate as it is seen from the temperature-depth plot (see Girdler et al., this volume) that unlike for the previous sites the points do not lie on a line. The best that can be done is to accept the maximum temperature gradient (186 K km^{-1}) obtained by taking the bottom water temperature and the maximum temperature of 40.33°C obtained at 97 meters subbottom depth. It is

TABLE 7
Oxygen and Carbon Isotope Measurements[a] on Globigerinas from Selected Depths of Site 228

Core, Section, Interval (cm)	Depth in Sediment (m)	Age	$\delta 0^{18}$	δC^{13}
5-3,0-10	36.0	U. Pleist.	+0.20	+1.27
7-6,0-10	58.5	L. Pleist.	-0.45	+1.29
10-6,0-10	76.5	L. Pleist.	-0.68	+1.24
16-5,0-10	129.0	L. Pleist.	-0.84	+1.56
19-2,140-150	152.9	L. Pleist.	-1.98	+0.88
26-3,140-150	213.5	U. Plio.	-1.48	+1.30
28-2,0-6	228.5	U. Plio.	-0.77	+1.13

[a] Expressed as δ (°/oo) relative to PDB standard.

noted that the gradient is the highest recorded for all the sites.

The thermal conductivity over the depth range of the measurements is taken as 1.348 ± 0.108 $Wm^{-1} K^{-1}$. These values give a somewhat questionable heat flow of 251 mWm^{-1}. It is not realistic to quote an experimental error on this value because of the difficulty with the temperature gradient.

CORRELATION OF REFLECTION PROFILES AND LITHOLOGIES

Although the originally proposed site lay on a seismic reflection profile giving no suggestion of flowage of the evaporite sequence, the 2.8-km shift of the final site position brought it into an area of irregular sea floor in which the S reflection was not always clearly visible. The dome-like cross-section of the sea floor mounds and of the underlying S reflector seemed to indicate vertical flowage of the evaporites. In an attempt to avoid these complications the beacon was dropped over a flat sea bed (Figure 9), but in retrospect this was just a sediment pond in a depression between diapiric-like features.

The profile over the site can be divided into three layers separated by two poorly determined reflectors (Figure 9). The top layer is well stratified. This is due to graded beds which were found in the top 30 meters of the hole. The middle and lowest layers are structureless and the S reflector between them is indistinct. This reflector lies at about 0.3 sec below the sea bed. Anhydrite was first cored from 287 meters so that the inferred mean velocity to reflector S is about 1.9 km/sec, which is in fairly good agreement with compressional wave velocity measurements made onboard ship.

DISCUSSION AND CONCLUSIONS

Stratigraphy

The results from Site 228 are in many ways similar to those from Sites 225 and 227. Essentially the same lithologies were met down the hole, although for technical reasons the halite beds beneath the anhydrite were not reached. The Late Pliocene to Pleistocene sediments differ, however, in having been laid down at rates in excess of 150 m/m.y. whereas at the other two sites the sedimentation rate, although variable, probably never exceeded 100 m/m.y. This is emphasized by the fact that the total Late Pliocene to Pleistocene section is 110 and 50 meters thick at Sites 225 and 227, respectively, but 290 meters thick at Site 228. The proportion and type of clastic constituents in the Site 228 sediments, as well as the form of shallow banks along the coast, suggest that the greater thickness of sediments at this site is due to its position relative to a former delta off Sudan which has a metamorphic and granitic source area such as the Precambrian rocks of that country.

Diapirism

The sediments in the 75-meter interval above the anhydrite sometimes exhibit dips between 20° and 70° although horizontal beds also occur. At higher levels in the hole only horizontal bedding is seen. The cores from the anhydrite-siltstone sequence show recumbent folds and steep dips in the siltstone and brecciation of the anhydrite. Seismic reflection profiles obtained across the site revealed that it was situated in a region where the S reflector was irregular with many dome-shaped features on the sea bed. All this information together suggests that the site was drilled on the flanks of a salt diapir although some of the steep dips could also be attributed to collapse structures brought about by solution of underlying halite beds. Although halite was not cored, its presence is strongly suggested by the interstitial water salinity gradient down the hole, the bottommost sediments having a salinity of 200°/₀₀.

Depositional History

Only the top of the evaporites was sampled at this site. These beds consist of about 40 meters of nodular and laminated anhydrite, black siltstone, and fragments of anhydrite in siltstone. The lowermost siltstones contain sulfides and have an extraordinarily high boron content and about 1% manganese. These sediments are also enriched in zinc and lead and in copper in one instance. The lead appears to be of mantle origin or else derived from rocks of mantle origin.

The evaporitic sequence was followed by about 40 meters of dark dolomitic silty claystone in which Pliocene nannofossils can be identified. The organic carbon content of these sediments is relatively high. A delta forming off the Sudanese coast began to contribute an appreciable amount of detrital material to the site at this time.

In the Late Pliocene the sediments changed gradually to a homogeneous fossiliferous gray micarb siltstone with a low organic carbon content, and then to a micarb nanno ooze or micarb-rich siltstone. The latter sediment types continued to the present day. A notable feature of these sediments is the presence of dark colored beds with very high organic carbon contents as at Sites 225 and 227. These layers are characterized by unusually large amounts of molybdenum (100-300 ppm) and vanadium (300-1500 ppm) and occurred up to the middle Early Pleistocene. They clearly suggest periods when reducing conditions prevailed on the Red Sea floor, but at other times the bottom waters were able to support a benthic fauna as indicated by slight to moderate bioturbation of the sediments. A high content of heavy minerals in many beds of the ooze and siltstone may reflect the advance of the delta off Sudan at this time.

Salt tectonics, probably in the form of diapirism, was active at this time. It is possible that the short Plio-Pleistocene unconformity can be indirectly attributed to such movements (e.g., local slumping, slight uplift causing nondeposition, etc.). Signs of sediment deformation are visible in the cores right up to, but not later than, the Early Pleistocene. This may indicate that salt flowage at this site ceased at that time. It may also be significant that one of the highest heat flow values of the Red Sea was measured at this site. Since the thermal conductivity of salt is four times that of the overlying sediments, a salt diapir may tend to focus the flow of heat.

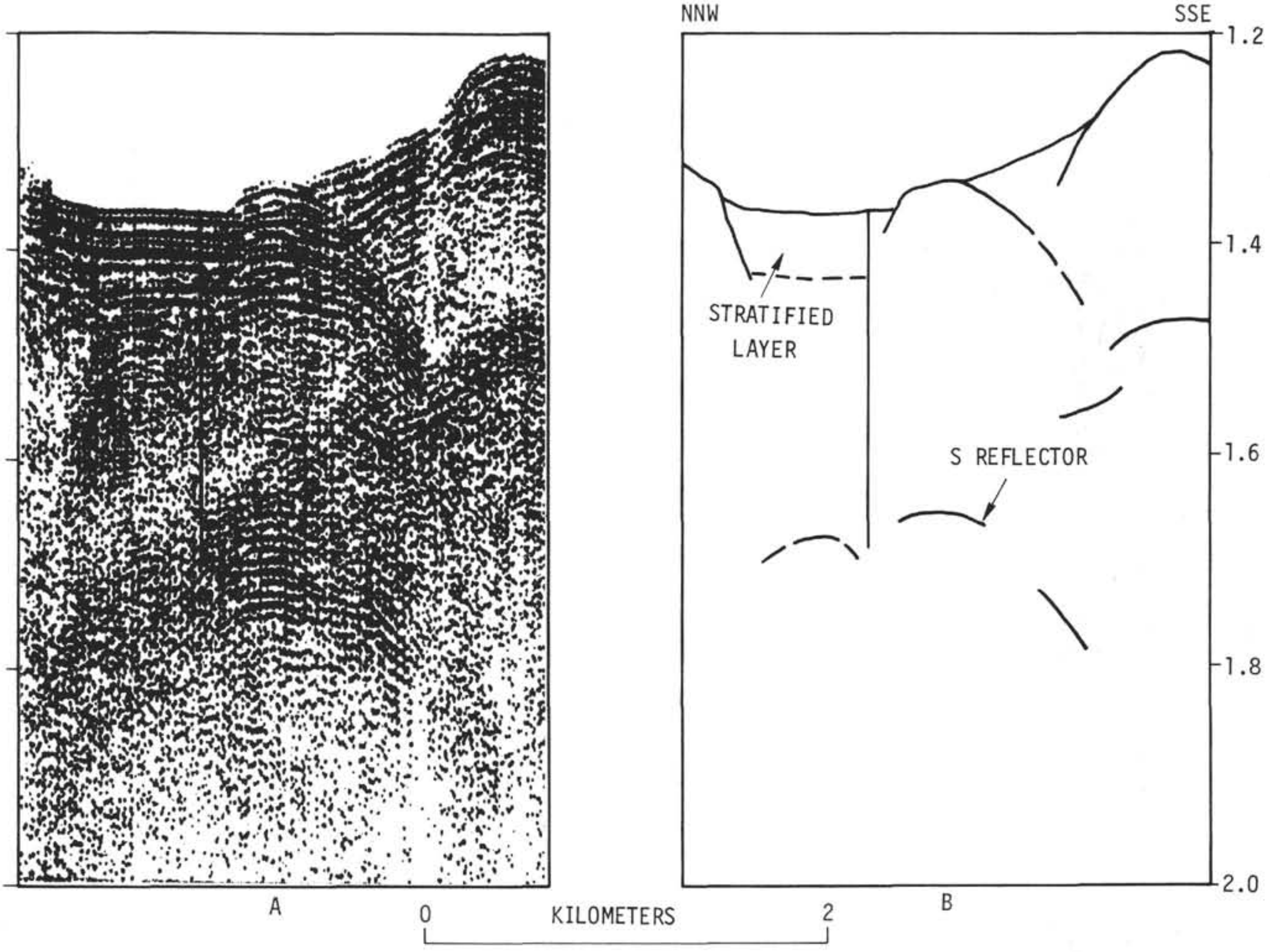

Figure 9. (a) *Seismic reflection profile obtained on the approach to Site 228. The vertical line marks the position of the drilled hole.* (b) *Line drawing interpretation of (a). The dashed reflector marks the approximate base of the sediment pond containing graded beds. The vertical line has tenth second divisions.*

During the Late Pleistocene turbidity currents deposited several graded beds. These now appear as the uppermost reflector on our reflection profiles across the site.

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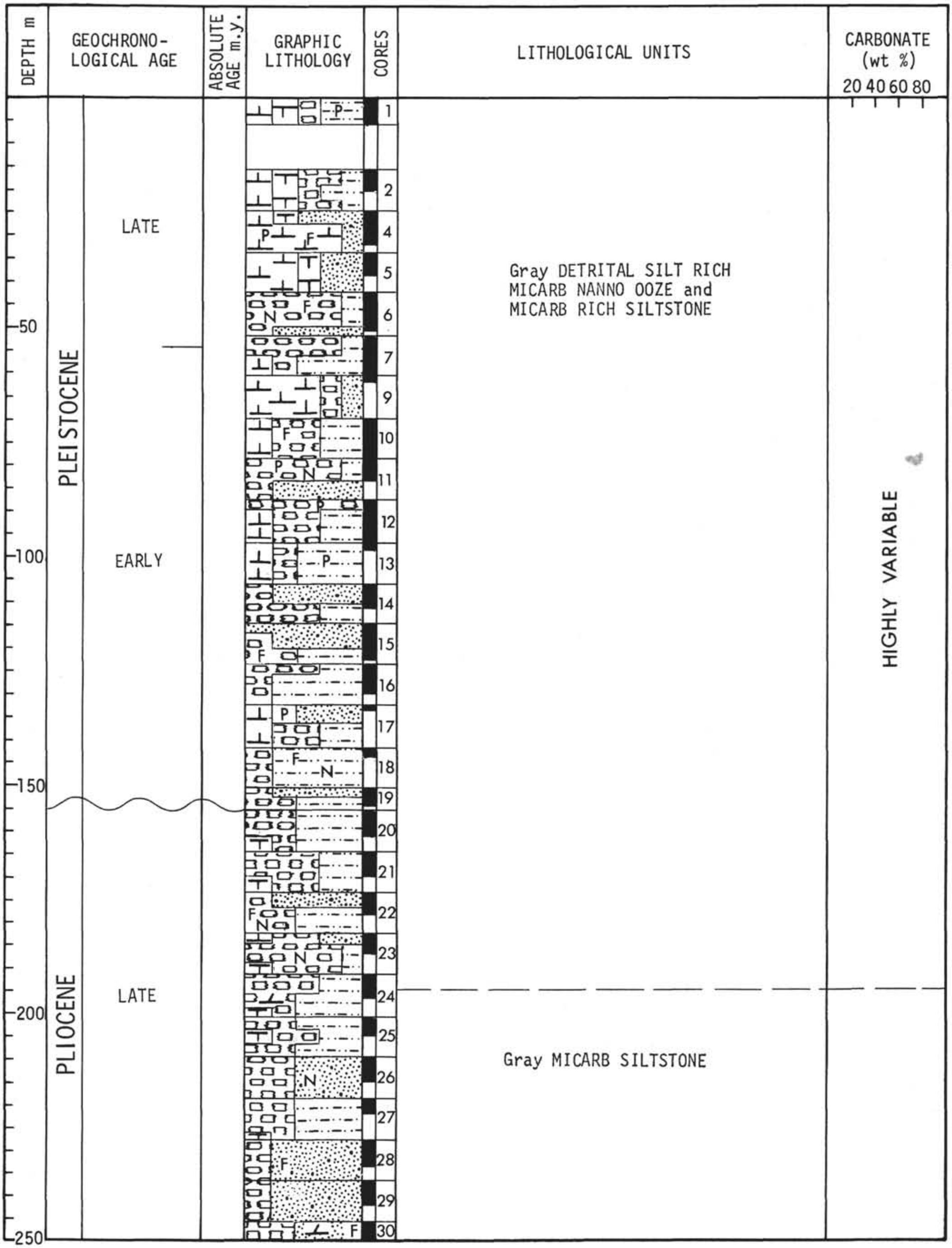
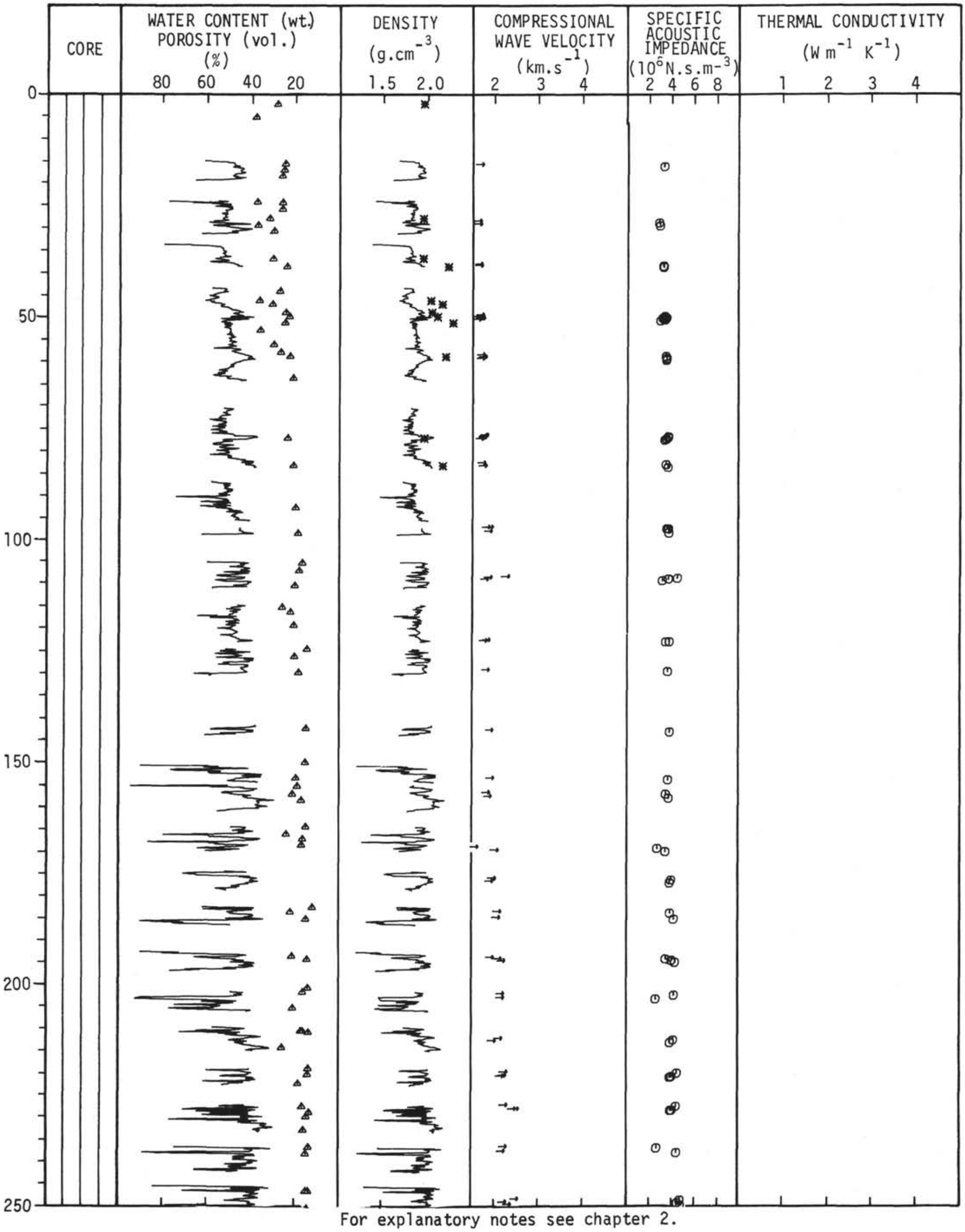
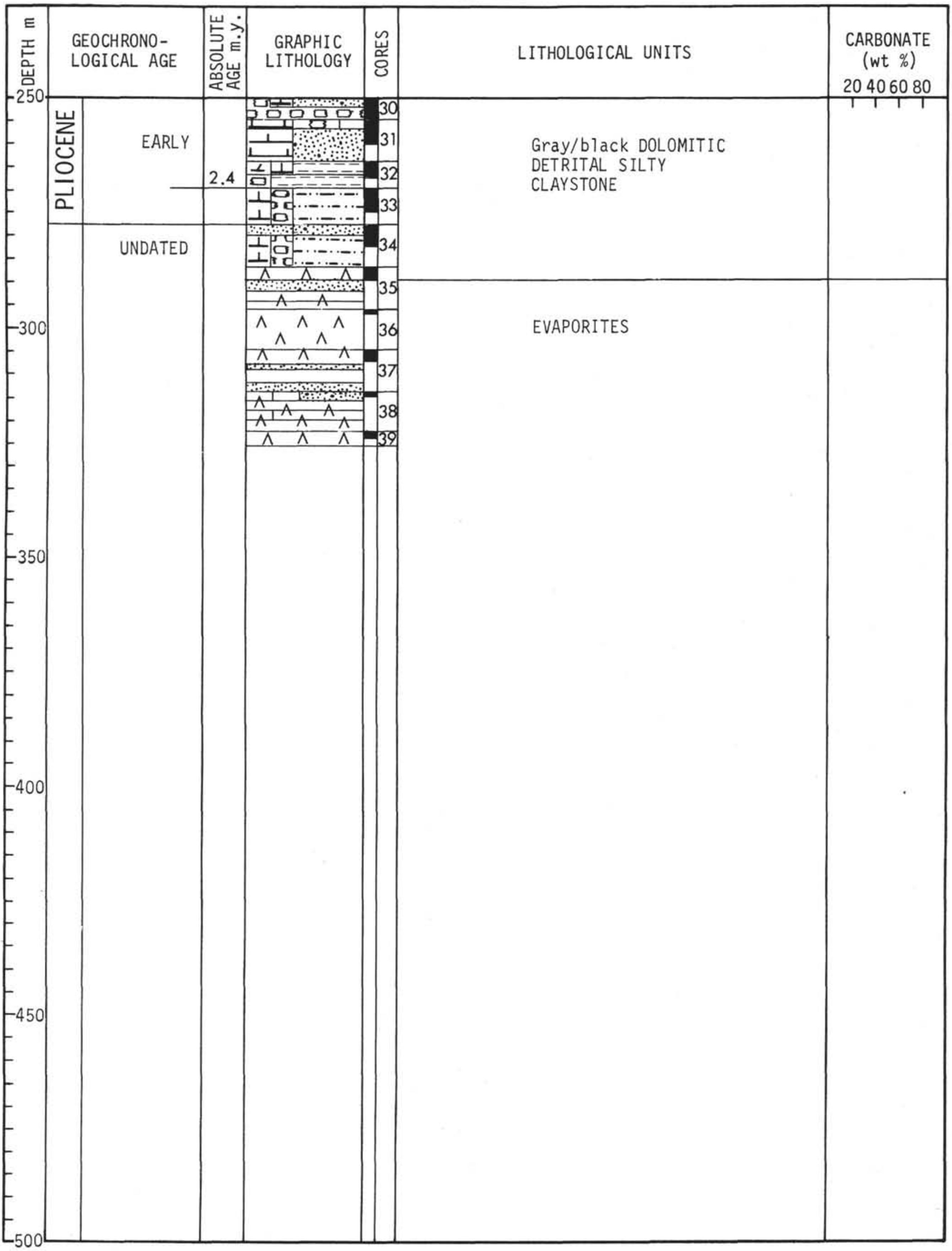
SITE 228

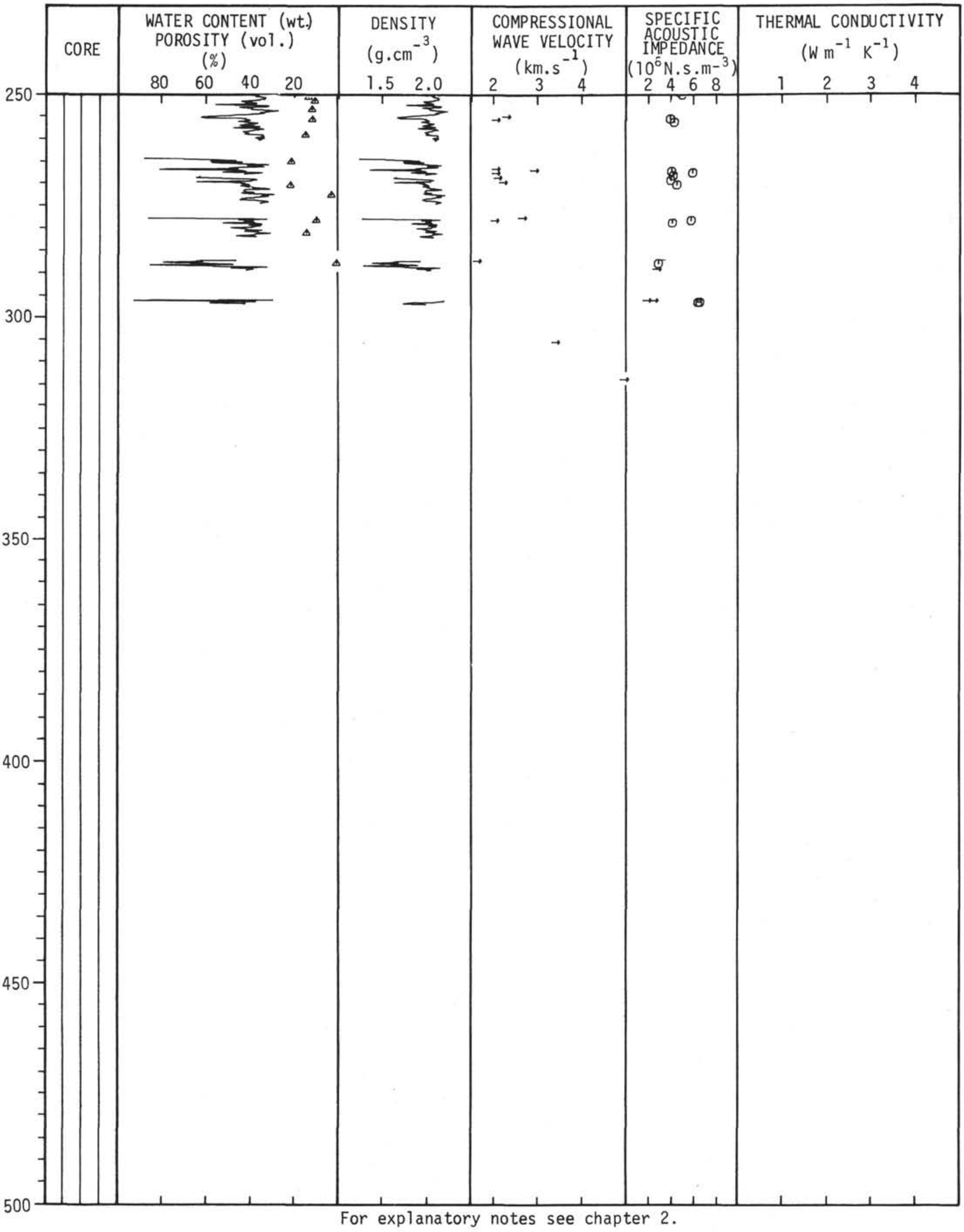

DEPTH m
GEOCHRONO-LOGICAL AGE
ABSOLUTE AGE m.y.
GRAPHIC LITHOLOGY
CORES
LITHOLOGICAL UNITS
CARBONATE (wt %)
20 40 60 80
50
100
150
200
250
PLEISTOCENE
LATE
EARLY
PLIOCENE
LATE
P
F
N
1
2
4
5
6
7
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
Gray DETRITAL SILT RICH MICARB NANNO OOZE and MICARB RICH SILTSTONE
Gray MICARB SILTSTONE
HIGHLY VARIABLE



For explanatory notes see chapter 2.

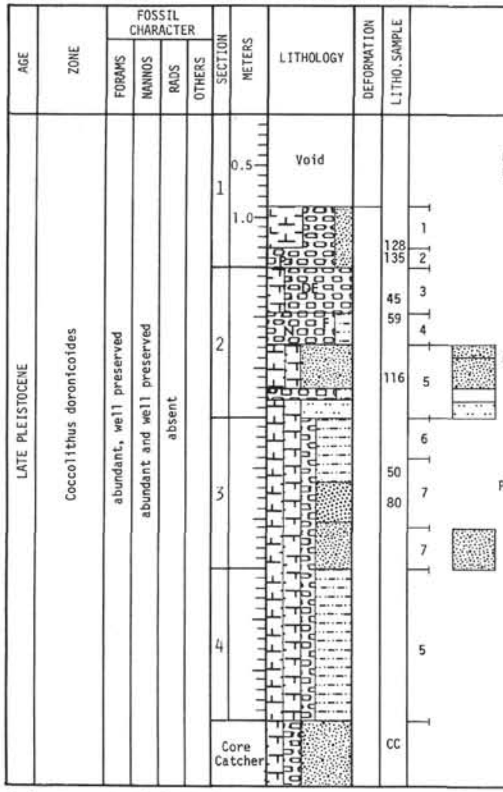
SITE 228


DEPTH m
GEOCHRONO-LOGICAL AGE
ABSOLUTE AGE m.y.
GRAPHIC LITHOLOGY
CORES
LITHOLOGICAL UNITS
CARBONATE (wt %)
20 40 60 80
250
300
350
400
450
500
PLIOCENE
EARLY
2.4
UNDATED
30
31
32
33
34
35
36
37
38
39
Gray/black DOLOMITIC DETRITAL SILTY CLAYSTONE
EVAPORITES



For explanatory notes see chapter 2.

Site 228 Hole Core 1 Cored Interval: 0-5



LITHOLOGIC DESCRIPTION

Gray MICARB NANNO FORAM RICH - DETRITAL CLAYEY SILT.

Pieces of lithified Pteropod crusts at 1-117 to 150 cm. Some graded intervals. Homogeneous, soft.

Dominant lithology SS: Section 3-50 cm.
Composition:

Detrital	50%
Nannos	20%
Forams	20%
Micarb	10%

Color legend:
1 = moderate yellowish brown 10YR 5/4
2 = light olive gray 5Y 5/2
3 = grayish olive 10Y 4/2
4 = yellowish gray 5Y 7/2
5 = greenish gray 5GY 6/1
6 = light greenish gray 5GY 8/1
7 = yellowish gray 5Y 8/1

P = Pteropod

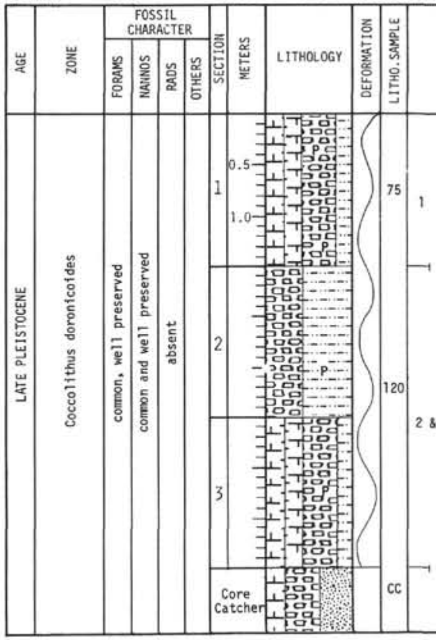
Shore-based laboratory results

	Organic Carbon	Carbonate
Section 1-95 cm =		19%
Section 2-45 cm =		3%
Section 3-46 cm =	.1%	8%
Section 3-85 cm =		58%

X-ray mineralogy:	Section 3-50 cm
Calcite	59%
Aragonite	2%
Quartz	9%
K-feldspar	4%
Plagioclase	14%
Kaolinite	8%
Mica	2%
Montmorillonite	2%

Explanatory notes in chapter 2

Site 228 Hole Core 2 Cored Interval: 15-24 m



LITHOLOGIC DESCRIPTION

Greenish NANNO FORAM - DETRITAL CLAYEY SILT RICH MICARB OOZE alternating with MICARB - DETRITAL SAND-SILT-CLAY.

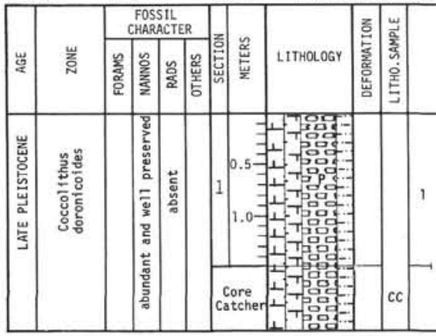
Layers richer in carbonate contain fragments of lithified Pteropod crusts. Sediments thin bedded, soft. Entire core intensely disturbed by drilling.

Dominant lithology SS: Section 2-120 cm.
Composition:

Total detrital	60%
Micarb	35%
Forams	5%

Color legend:
1 = greenish gray 5GY 6/1
2 = dusky yellow green 5GY 5/2
3 = pale olive 10Y 6/2

Site 228 Hole Core 3 Cored Interval: 24-24 m



LITHOLOGIC DESCRIPTION

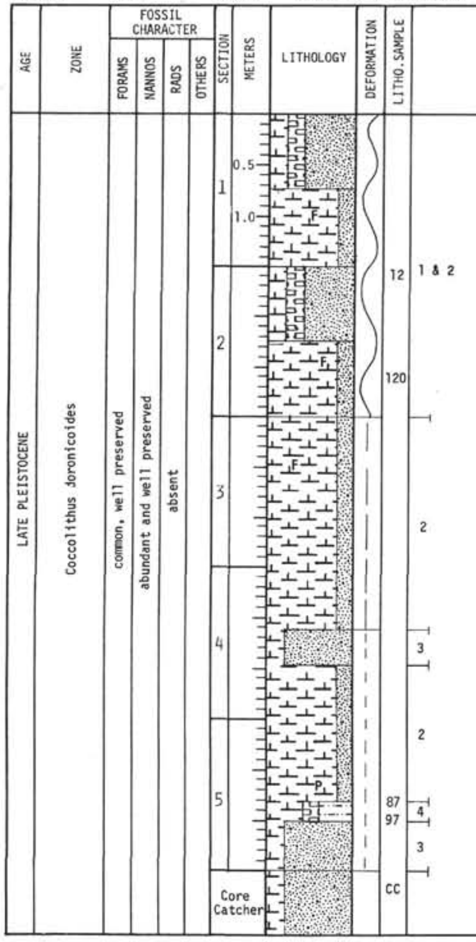
Gray NANNO FORAM - DETRITAL CLAYEY SILT RICH - MICARB OOZE with fragments of Pteropod rich lithified layers.

Core soupy. Heat probe core.

Color legend:
1 = greenish gray 5GY 6/1

Explanatory notes in chapter 2

Site 228 Hole Core 4 Cored Interval: 24-33 m



LITHOLOGIC DESCRIPTION

Greenish gray DETRITAL SANDY SILT NANNO OOZE. In 1 and 2 alternating with NANNO MICARB RICH - DETRITAL SILTY SAND.

Homogeneous, soft. Intensely to moderately disturbed by drilling. Pteropod bearing lithified fragments at 5-65 cm.

Dominant lithology SS: Section 2-120 cm.
Composition:

Nannos	75%
Total detrital	15%
Forams	5%
Micarb	5%

Minor lithology SS: Section 2-12 cm.
Composition:

Total detrital	60%
Nannos	25%
Micarb	10%
Pyrite	5%

Color legend:
1 = dark greenish gray 5GY 4/1
2 = greenish gray 5GY 6/1
3 = dusky yellow green 5GY 5/2
4 = moderate yellowish brown 10YR 5/4

Shore-based laboratory results

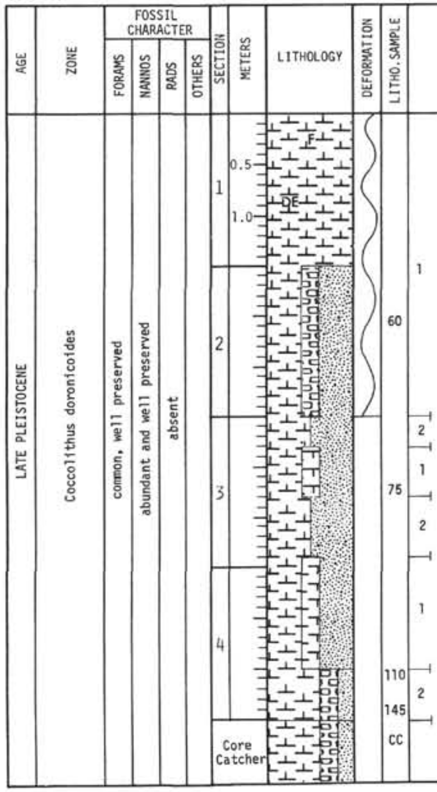
	Organic Carbon	Carbonate
Section 5-62 cm =	.2%	24%

Grain size: Sections

	5-21 cm,	5-39 cm,	5-49 cm
Sand	9%	16%	14%
Silt	50%	58%	62%
Clay	41%	26%	24%

Explanatory notes in chapter 2

Site 228 Hole Core 5 Cored Interval: 33-42 m



LITHOLOGIC DESCRIPTION

Greenish FORAM or MICARB RICH - NANNO DETRITAL SANDY SILT.

Mostly homogeneous, Sections 1 and 2 mottled with moderate yellow brown (10YR 5/4). Soft. Upper half of core intensely disturbed.

Dominant lithology SS: Section 3-75 cm.
Composition:

Total detrital	40%
Nannos	35%
Forams	15%
Micarb	10%

Color legend:
1 = greenish gray 5GY 6/1
2 = dusky yellow green 5GY 5/2

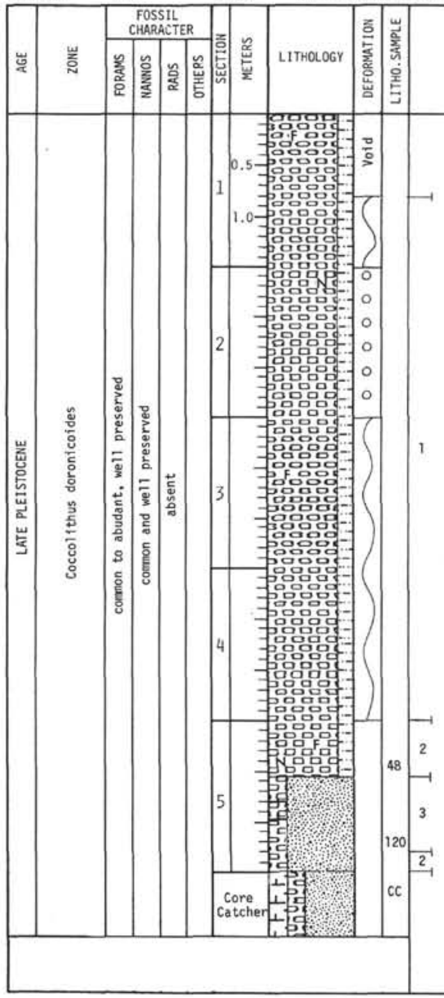
Shore-based laboratory results

	Organic Carbon	Carbonate
Section 3- 50 cm =	.1%	34%
Section 3-110 cm =	.2%	48%
Section 4-143 cm =	.1%	20%
Section 4-145 cm =		11%

X-ray mineralogy:	Section 3-110 cm
Calcite	40%
Aragonite	2%
Mg-Calcite	6%
Quartz	11%
K-feldspar	11%
Plagioclase	14%
Kaolinite	9%
Mica	2%
Chlorite	4%
Montmorillonite	2%

Explanatory notes in chapter 2

Site 228 Hole Core 6 Cored Interval: 42-51 m



LITHOLOGIC DESCRIPTION

Greenish gray DETRITAL SILTY CLAY RICH - MICARB OOZE.

Soft. Most of core intensely distrubed by drilling.

Lithology SS; Section 5-48 cm.
Composition:

Micarb	65%
Total detrital	25%
Nannos	5%
Forams	5%

Color legend:
1 = greenish gray 5GY 6/1
2 = dusky yellow green 5GY 5/2
3 = gray olive green 5GY 3/2

Shore-based laboratory results

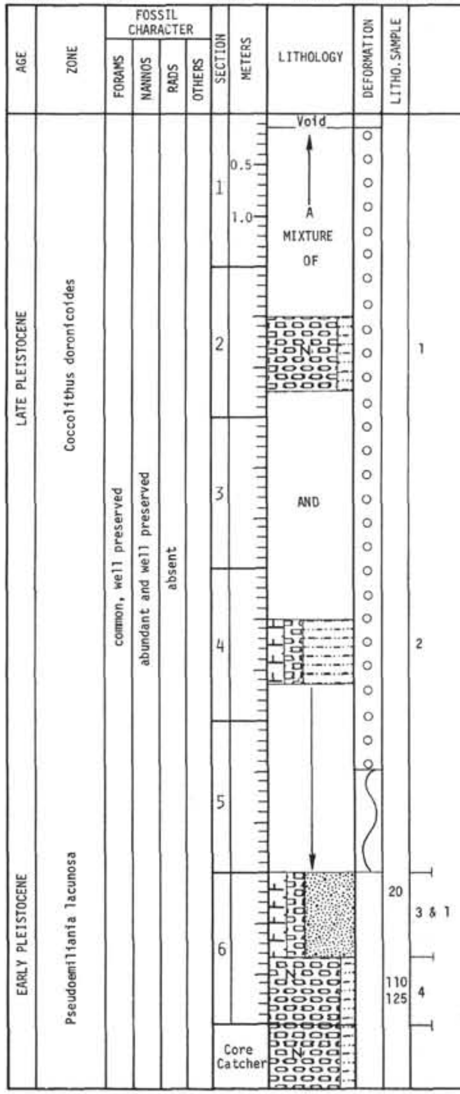
	Organic Carbon	Carbonate
Section 4-10 cm =		70%
Section 5-90 cm =	.5%	12%
Section 6-20 cm =	.2%	37%

Grain size: Sections

	5-83 cm,	5-115 cm,	5-125 cm
Sand	5%	3%	3%
Silt	73%	71%	72%
Clay	22%	26%	25%

Explanatory notes in chapter 2

Site 228 Hole Core 7 Cored Interval: 51-60 m



LITHOLOGIC DESCRIPTION

Most of core brecciated by drilling. Mainly consisting of greenish gray DETRITAL CLAYEY SILT RICH - MICARB OOZE and dark greenish gray NANNO MICARB RICH DETRITAL CLAYEY SILT.

Color legend:
1 = greenish gray 5GY 6/1
2 = dark greenish gray 5GY 4/1
3 = gray olive green 5GY 3/2
4 = dusky yellow green 5GY 5/2

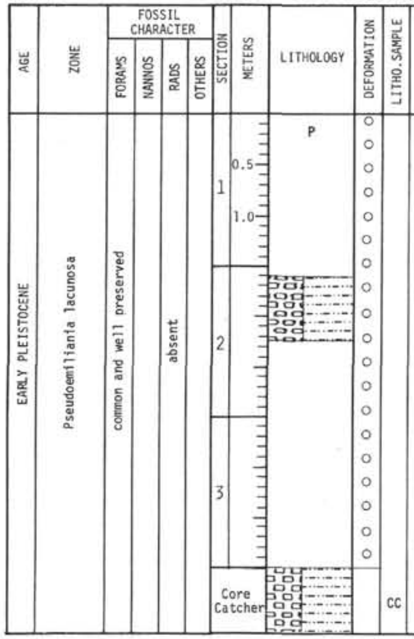
Shore-based laboratory results

Grain size: Sections

	6-64 cm,	6-78 cm
Sand	6%	10%
Silt	59%	67%
Clay	35%	23%

Explanatory notes in chapter 2

Site 228 Hole Core 8 Cored Interval: 60-60 m

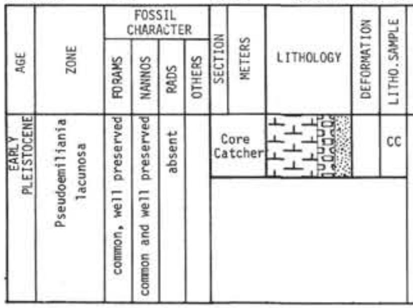


LITHOLOGIC DESCRIPTION

Drilling breccia (heat probe core). Dominantly olive gray (5Y 5/2). MICARB - DETRITAL CLAYEY SILT.

In uppermost 15 cm Pteropod rich lithified fragments. Soft.

Site 228 Hole Core 9 Cored Interval: 60-69 m



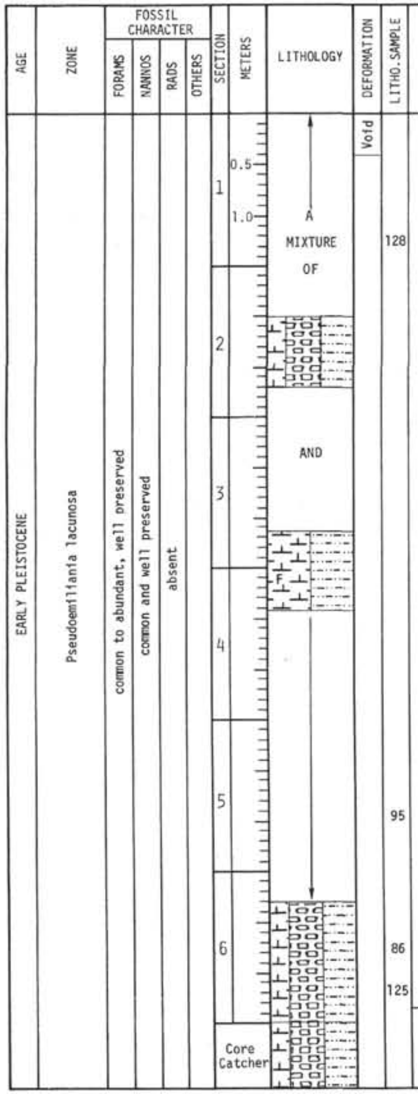
LITHOLOGIC DESCRIPTION

Greenish gray (5GY 6/1) MICARB - DETRITAL SANDY SILT RICH - NANNO OOZE.

Soft.

Explanatory notes in chapter 2

Site 228 Hole Core 10 Cored Interval: 69-78 m



LITHOLOGIC DESCRIPTION

Drilling breccia. Dominantly greenish gray (5GY 4/1) NANNO RICH MICARB - DETRITAL CLAYEY SILT and greenish black (5G 2/1) - DETRITAL SILTY CLAY - NANNO OOZE. Stiff.

Lithology SS: Section 6-125 cm.
Composition:

Micarb	40%
Total detrital	30%
Nannos	20%
Forams	<10%

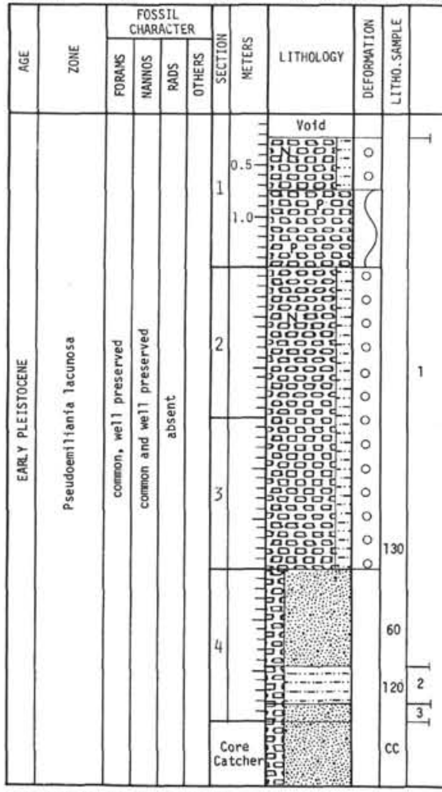
Shore-based laboratory results

	Organic Carbon	Carbonate
Section 6-84 cm =	.1%	54%

X-ray mineralogy:	Section 6-60 cm
Calcite	47%
Aragonite	1%
Quartz	14%
K-feldspar	4%
Plagioclase	17%
Kaolinite	12%
Mica	2%
Montmorillonite	3%

Explanatory notes in chapter 2

Site 228 Hole Core 11 Cored Interval: 78-87 m



LITHOLOGIC DESCRIPTION

Olive gray DETRITAL SILTY CLAY RICH - MICARB OOZE. Locally detrital fraction sandy silt.

Section 1 rich in broken up fragments of Pteropod rich lithified layers. Stiff, locally chalky bands. Homogeneous. Most of core intensely disturbed by drilling.

Dominant lithology SS: Section 3-130 cm.
Composition:

Micarb	85%
Total detrital	15%

Color legend:

1 =	olive gray	5Y 5/2
2 =	brown	10YR 5/3
3 =	olive gray	5Y 4/2

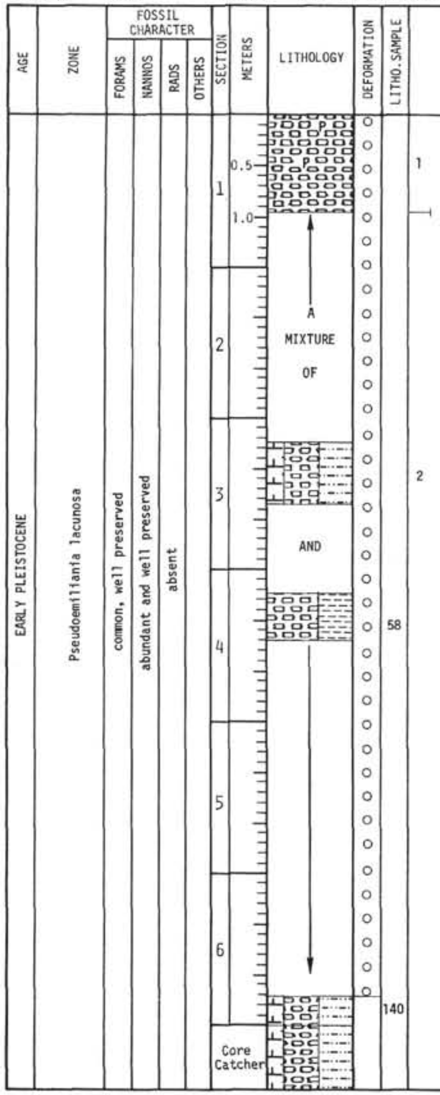
Shore-based laboratory results

X-ray mineralogy: Sect.un 4-120 cm

Calcite	13%
Aragonite	2%
Mg-Calcite	9%
Quartz	17%
K-feldspar	7%
Plagioclase	25%
Kaolinite	19%
Mica	2%
Montmorillonite	7%

Explanatory notes in chapter 2

Site 228 Hole Core 12 Cored Interval: 87-96 m



LITHOLOGIC DESCRIPTION

Dark gray NANNO RICH - MICARB DETRITAL SILT with fragments of moderate reddish brown (10R 4/6) DETRITAL CLAY - MICARB OOZE.

At top broken up fragments of Pteropod lithified layers. Stiff. Completely disturbed by drilling.

Dominant lithology SS: Section 6-140 cm.
Composition:

Total detrital	45%
Micarb	40%
Nannos	15%

Color legend:

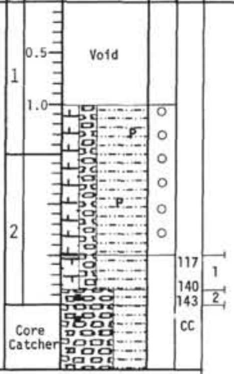
1 =	olive gray	5Y 5/2
2 =	dark gray	5Y 4/1

Explanatory notes in chapter 2

Site 228 Hole Core 13 Cored Interval: 96-105 m

AGE	ZONE	FOSSIL CHARACTER FORAMS	FOSSIL CHARACTER NANNOS	FOSSIL CHARACTER RADS	FOSSIL CHARACTER OTHERS
EARLY PLEISTOCENE	Pseudoemiliania lacunosa	common, well preserved	abundant and well preserved	absent	

SECTION · METERS · LITHOLOGY · DEFORMATION · LITHO. SAMPLE



LITHOLOGIC DESCRIPTION

Green FORAM MICARB RICH - DETRITAL SAND-SILT-CLAY.

Rich in broken up fragments of lithified Pteropod layers. Alternation of 2-5 cm bands of stiff and semilithified sediment at bottom. Most of core is a drilling breccia.

Lithology SS: Section 2-111 cm.

Composition:

Total detrital	65%
Micarb	15%
Forams	10%
Nannos	5%
Opaques	5%

Color legend:

1 = dusky olive green 5GY 5/2

2 = gray 5Y 5/1

<u>Shore-based laboratory results</u>

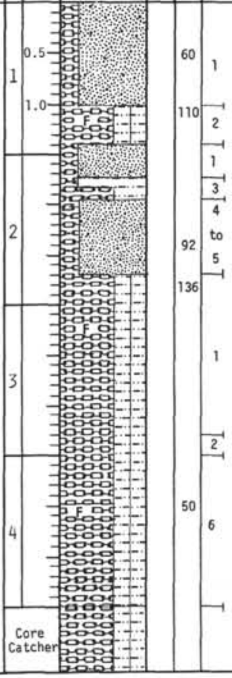
	Organic Carbon	Carbonate
Section 2-140 cm =	2.3%	62%

Explanatory notes in chapter 2

Site 228 Hole Core 14 Cored Interval: 105-114 m

AGE	ZONE	FOSSIL CHARACTER FORAMS	FOSSIL CHARACTER NANNOS	FOSSIL CHARACTER RADS	FOSSIL CHARACTER OTHERS
EARLY PLEISTOCENE	Pseudoemiliania lacunosa	abundant, well preserved	abundant and well preserved	absent	

SECTION · METERS · LITHOLOGY · DEFORMATION · LITHO. SAMPLE



LITHOLOGIC DESCRIPTION

Olive gray DETRITAL SILTY CLAY RICH - MICARB CHALK. At top 0.5 to 2 cm interbeds with moderate reddish brown (10R 4/6) MICARB RICH - DETRITAL CLAY.

More sandy in upper part, locally 15% heavy minerals. Mottled. Semilithified.

Dominant lithology SS: Section 4-50 cm.

Composition:

Micarb	50%
Total detrital	36%
Forams	9%
Nannos	5%

Color legend:

1 = olive gray 5Y 5/2

2 = light olive gray 5Y 6/1

3 = light olive gray 5Y 6/2

4 = olive gray 5Y 4/2

5 = very dark gray 5Y 3/1

6 = gray 5Y 5/1

<u>Shore-based laboratory results</u>

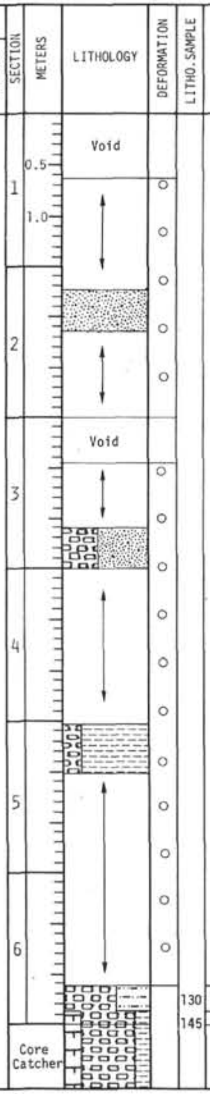
	Organic Carbon	Carbonate
Section 1-28 cm =	.2%	22%
Section 1-30 cm =		15%
Section 2-41 cm =	.1%	55%

X-ray mineralogy:	Section 2-40 cm
Calcite	16%
Dolomite	1%
Mg-Calcite	22%
Quartz	14%
K-feldspar	6%
Plagioclase	19%
Kaolinite	16%
Mica	2%
Montmorillonite	3%

Explanatory notes in chapter 2

Site 228 Hole Core 15 Cored Interval: 114-123 m

AGE	ZONE	FOSSIL CHARACTER			
		FORAMS	NANNOS	RADS	OTHERS
EARLY PLEISTOCENE	Pseudoemiliania lacunosa	common, well preserved	abundant and well preserved	absent	



LITHOLOGIC DESCRIPTION

Drilling breccia composed of dark gray (5 4/1) DETRITAL SANDY SILT olive gray (5Y 5/2) MICARB - DETRITAL SANDY SILT and moderate reddish brown (10R 4/6) MICARB DETRITAL CLAY.

At various levels fragments of Pteropod rich lithified crust.

Color legend:
1 = dusky yellow green 5GY 5/2
2 = black N1

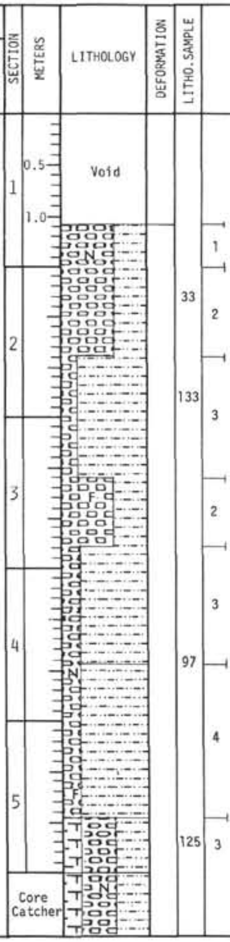
Shore-based laboratory results

	Organic Carbon	Carbonate
Section 6-115 cm =	3.2%	60%

Explanatory notes in chapter 2

Site 228 Hole Core 16 Cored Interval: 123-132 m

AGE	ZONE	FOSSIL CHARACTER			
		FORAMS	NANNOS	RADS	OTHERS
EARLY PLEISTOCENE	Pseudoemiliania lacunosa	common, well preserved	common and well preserved	absent	



LITHOLOGIC DESCRIPTION

Gray MICARB RICH - DETRITAL CLAYEY SILTSTONE. Some scattered reddish MICARB - DETRITAL CLAYSTONE layers and irregular streaks.

Few very fine burrows. Semilithified.

Dominant lithology SS: Section 2-133 cm.
Composition:

Total detrital	76%
Micarb	14%
Nannos	<5%
Forams	<5%

Color legend:
1 = greenish gray 5GY 6/1
2 = olive gray 5Y 5/2
3 = dark gray 5Y 4/1
4 = dusky yellow green 5GY 5/2

Shore-based laboratory results

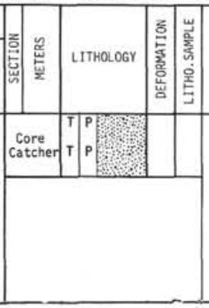
	Organic Carbon	Carbonate
Section 1-125 cm =	.2%	51%
Section 3- 20 cm =	.3%	20%
Section 5- 72 cm =		15%
Section 5- 75 cm =	.3%	20%

Grain size: Section 1-124 cm

Sand	1%
Silt	51%
Clay	48%

Site 228 Hole Core 17 Cored Interval: 132-141 m

AGE	ZONE	FOSSIL CHARACTER			
		FORAMS	NANNOS	RADS	OTHERS
EARLY PLEISTOCENE	Pseudoemiliania lacunosa	few to common, well preserved	rare and moderately well preserved	absent	

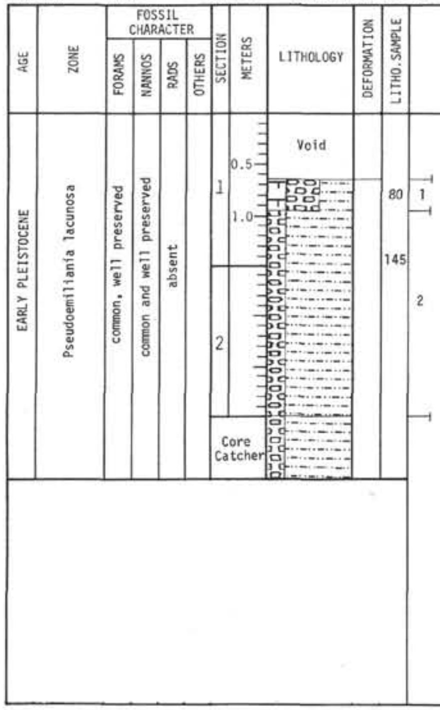


LITHOLOGIC DESCRIPTION

Greenish gray (5GY 6/1) FORAM PTEROPOD RICH - DETRITAL SANDY SILT with small fragments of broken up lithified layers.

Explanatory notes in chapter 2

Site 228 Hole Core 18 Cored Interval: 141-150 m



LITHOLOGIC DESCRIPTION

Olive MICARB RICH - DETRITAL CLAYEY SILTSTONE. Diffuse streaks of reddish MICARB - DETRITAL CLAYSTONE and white MICARB blebs in upper part.

Rich in heavy minerals. Homogeneous, slightly bioturbated. Semilithified.

Dominant lithology SS: Section 1-145 cm.
Composition:

Total detrital	80%
Micarb	20%
(Heavies 15%)	

Color legend:
1 = greenish gray 5GY 6/1
2 = olive 5Y 5/3

<u>*Shore-based laboratory results*</u>

	Organic Carbon	Carbonate
Section 1-119 cm =	.1%	16%

Grain size: Section 1-145 cm

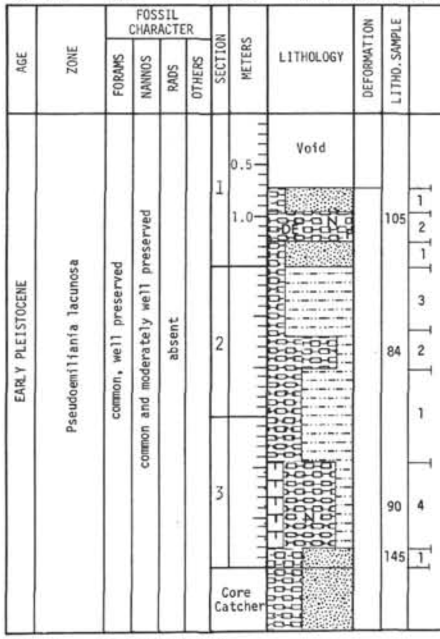
Sand	6%
Silt	67%
Clay	27%

X-ray mineralogy: Section 1-140 cm

Calcite	11%
Mg-Calcite	2%
Quartz	22%
K-feldspar	7%
Plagioclase	32%
Mica	20%
Chlorite	2%
Amphibole	6%

Explanatory notes in chapter 2

Site 228 Hole Core 19 Cored Interval: 150-155 m



LITHOLOGIC DESCRIPTION

Gray MICARB - DETRITAL CLAYEY SILTSTONE and DETRITAL CLAYEY SILT RICH - MICARB CHALK. Locally Pyrite streaks.

Sandy siltstones contain up to 15% heavy minerals. Homogeneous, occasionally faintly laminated. Slightly bioturbated.

Lithology SS: Section 3-90 cm.
Composition:

Micarb	65%
Total detrital	15%
Forams	10%
Nannos	<10%

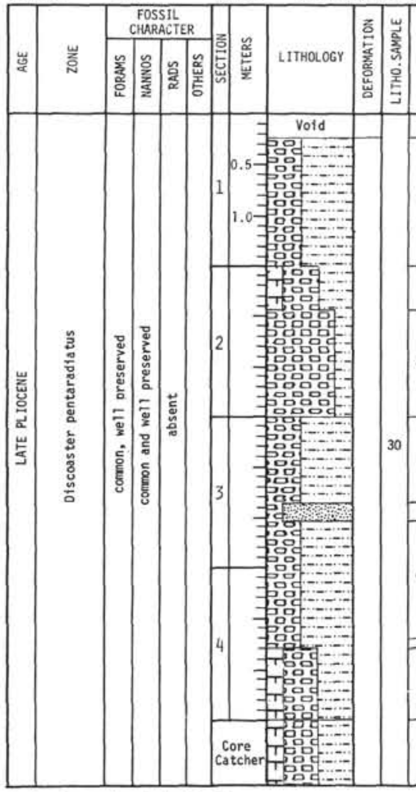
Color legend:
1 = gray olive green 5GY 3/2
2 = light olive gray 5Y 6/2
3 = gray 5GY 5/1
4 = gray 5Y 5/1

<u>Shore-based laboratory results</u>

	Organic Carbon	Carbonate
Section 2-72 cm =		38%

Explanatory notes in chapter 2

Site 228 Hole Core 20 Cored Interval: 155-164 m



LITHOLOGIC DESCRIPTION

Olive MICARB - DETRITAL CLAYEY SILTSTONE. Locally Foram rich. Thin irregular layers and streaks of reddish MICARB - DETRITAL CLAYSTONE.

Mottled. Slightly biosturbated. Semilithified.

Dominant lithology SS: Section 3-30 cm.
Composition:

Total detrital	53%
Micarb	45%
Opaques	2%

Color legend:
1 = dusky olive green 5GY 5/2
2 = gray 5Y 5/1
3 = olive gray 5Y 5/2
4 = gray olive 10Y 4/2
5 = dark greenish gray 5GY 4/1
6 = medium reddish brown 10R 4/6

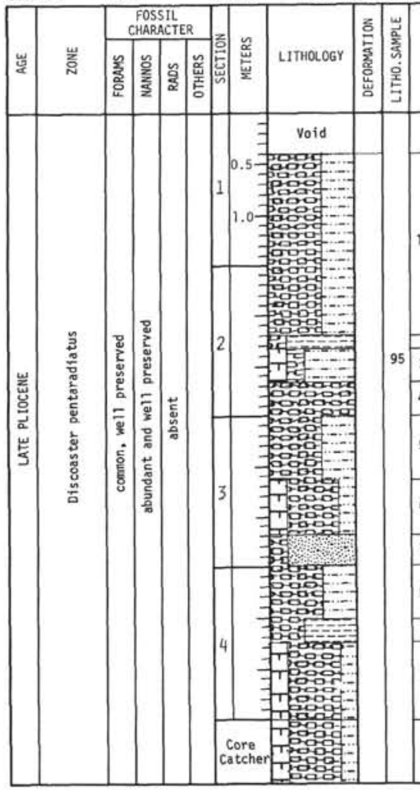
Shore-based laboratory results

	Organic Carbon	Carbonate
Section 4-127 cm =	.5%	44%

X-ray mineralogy:	Section 4-130 cm
Calcite	41%
Aragonite	6%
Mg-Calcite	7%
Quartz	8%
K-feldspar	3%
Plagioclase	9%
Kaolinite	2%
Mica	14%
Chlorite	2%
Montmorillonite	6%
Palygorskite	3%

Explanatory notes in chapter 2

Site 228 Hole Core 21 Cored Interval: 164-173 m



LITHOLOGIC DESCRIPTION

Grayish olive DETRITAL CLAYEY SILT - MICARB CHALK alternating with beds with varying proportions of detrital admixtures, MICARB and forams. Scattered irregular thin layer and streaks of reddish brown MICARB - DETRITAL CLAYSTONE. High organic carbon content in black layers.

Slightly bioturbated. Homogeneous. Semilithified.

Color legend:
1 = gray olive 10YR 4/2
2 = moderate reddish brown 10R 4/6
3 = black N1
4 = olive gray 5Y 5/2
5 = gray olive 10Y 4/2
6 = gray 5Y 5/1
7 = dark greenish gray 5GY 4/1

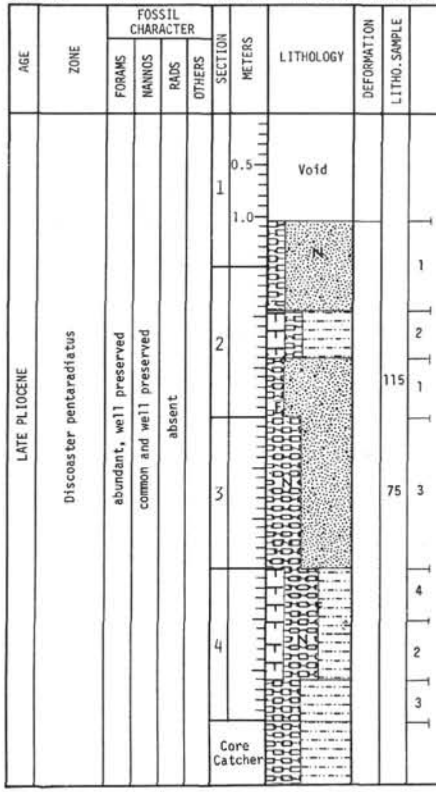
Shore-based laboratory results

	Organic Carbon	Carbonate
Section 4-61 cm =	7.2%	46%

X-ray mineralogy:	Section 4-61 cm (WHOI)
Calcite	50%
Quartz	8%
Plagioclase	15%
Pyrite	9%
Layered Silicates	18%

Explanatory notes in chapter 2

Site 228 Hole Core 22 Cored Interval:173-182 m



LITHOLOGIC DESCRIPTION

Gray to olive DETRITAL SILT MICARB CHALK to MICARB DETRITAL SILTSTONE. Diffuse streaks of reddish brown MICARB - DETRITAL CLAYSTONE.

Homogeneous. Locally highly bioturbated. Semilithified.

Lithology SS: Section 3-75 cm.
Composition:

Total detrital	60%
Micarb	30%
Forams	5%
Nannos	5%

Color legend:

1 = dark greenish gray 5GY 4/1
2 = black N1
3 = gray olive 10Y 4/2
4 = gray 5Y 5/1

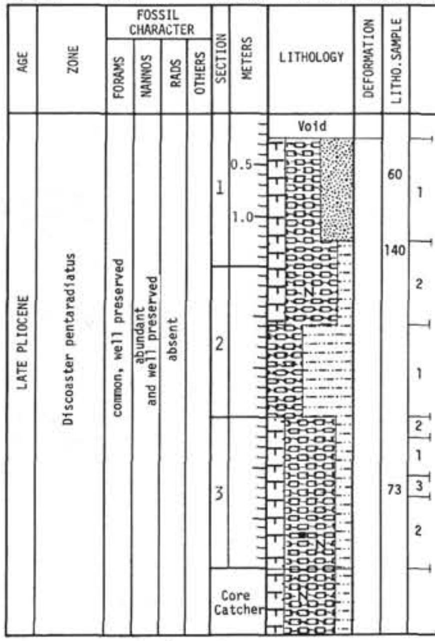
<u>Shore-based laboratory results</u>

	Organic Carbon	Carbonate
Section 3-75 cm =	.3%	32%
Section 4-75 cm =	2.8%	57%

X-ray mineralogy:	Section 3-60 cm
Calcite	21%
Mg-Calcite	2%
Quartz	17%
K-feldspar	7%
Plagioclase	23%
Mica	25%
Chlorite	3%
Amphibole	3%

Explanatory notes in chapter 2

Site 228 Hole Core 23 Cored Interval:182-191 m



LITHOLOGIC DESCRIPTION

Gray FORAM or NANNO RICH - DETRITAL SILTY CLAY - MICARB CHALK. Scattered irregular streaks of reddish brown MICARB - DETRITAL CLAYSTONE.

Locally slightly bioturbated. Top rich in heavy minerals. Semilithified.

Dominant lithology SS: Section 2-140 cm.
Composition:

Micarb	60%
Forams	15%
Total detrital	15%
Nannos	15%

Color legend:

1 - dark greenish gray 5G 4/1
2 - gray 5Y 5/1
3 - black N1

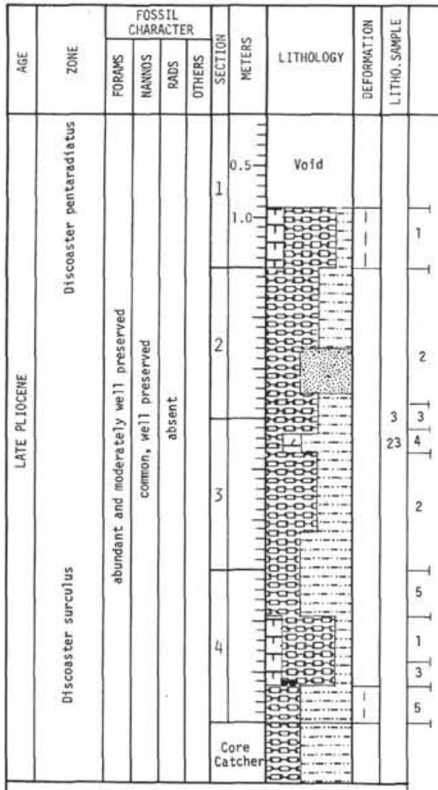
<u>Shore-based laboratory results</u>

	Organic Carbon	Carbonate
Section 2-3 cm =	.5%	44%

Grain size:	Section 2-94 cm
Sand	5%
Silt	69%
Clay	26%

Explanatory notes in chapter 2

Site 228 Hole Core 24 Cored Interval: 191-200 m



LITHOLOGIC DESCRIPTION

Greenish gray MICARB - DETRITAL SILTY CLAYSTONE alternating with beds of FORAM - DETRITAL CLAYEY SILT RICH - MICARB CHALK and MICARB DETRITAL SILTSTONE.

High organic carbon content in black layers. Some irregular streaks of reddish clay. Gneiss fragments in core catcher. Locally slightly bioturbated. Semilithified.

Color legend:

1 =	gray	5Y 5/1
2 =	gray olive	10Y 4/2
3 =	black	N1
4 =	medium black gray	5B 5/1
5 =	dark greenish gray	5G 4/1

Shore-based laboratory results

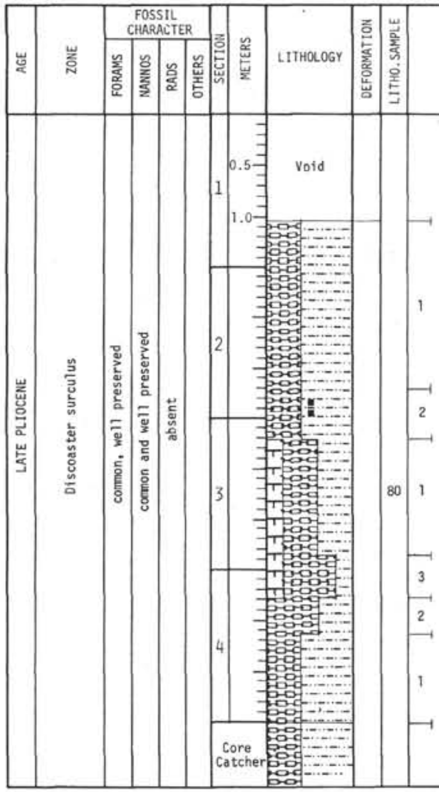
	Organic Carbon	Carbonate
Section 2-140 cm =	8.3%	57%
Section 3- 28 cm =		31%

X-ray mineralogy:	Section 3-28 cm (WHOI)
Calcite	10%
Ca-Dolomite	25%
Quartz	9%
Plagioclase	10%
Layered Silicates	46%

	Section 3-30 cm
Calcite	9%
Dolomite	26%
Quartz	15%
K-feldspar	4%
Plagioclase	20%
Mica	18%
Chlorite	3%
Pyrite	3%
Amphibole	1%

Explanatory notes in chapter 2

Site 228 Hole Core 25 Cored Interval: 200-209 m



LITHOLOGIC DESCRIPTION

Greenish gray MICARB - DETRITAL CLAYEY SILTSTONE, locally foram rich or pyrite bearing. Slump folds at 4-40 cm. Locally reddish CLAYSTONE layers and streaks.

Slightly bioturbated.

Lithology SS: Section 3-80 cm.
Composition:

Total detrital	50%
Micarb	30%
Forams	10%
Nannos	<10%

Color legend:

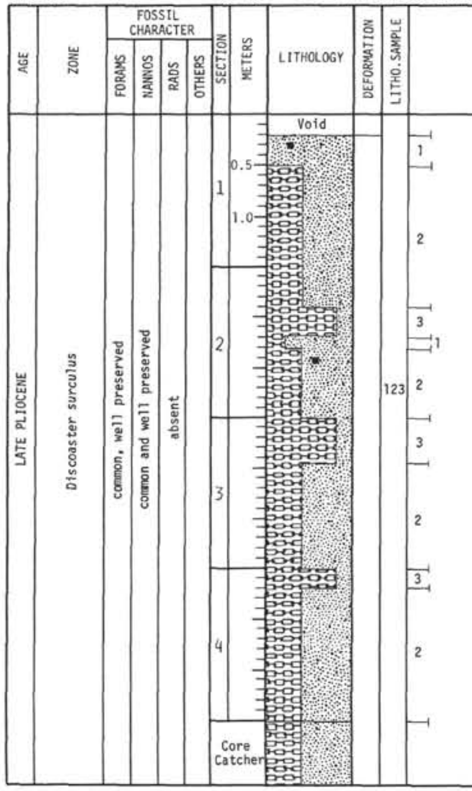
1 =	dark greenish gray	5GY 4/1
2 =	black	N1
3 =	gray	5Y 5/1

Shore-based laboratory results

X-ray mineralogy:	Section 3-4 cm (WHOI)
Calcite	44%
Quartz	8%
Plagioclase	14%
Layered Silicates	25%
Pyrite	8%
Sphalerite	2%

Explanatory notes in chapter 2

Site 228 Hole Core 26 Cored Interval: 209-218 m



LITHOLOGIC DESCRIPTION

Dominantly greenish gray MICARB - DETRITAL SANDY SILTSTONE. Moderately mottled with reddish MICARB DETRITAL CLAYSTONE.

Slightly to moderately bioturbated. Homogeneous. Semilithified.

Dominant lithology SS: Section 2-123 cm.
Composition:

Total detrital	58%
Micarb	25%
Nannos	5%
Opaques	2%

Color legend:

1 =	black	N1
2 =	dark greenish gray	5GY 4/1
3 =	gray	5Y 5/1

Shore-based laboratory results

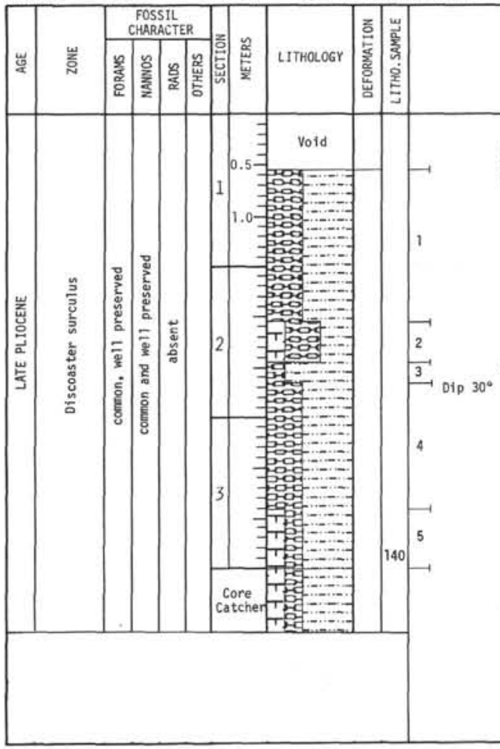
	Organic Carbon	Carbonate
Section 1-130 cm =	.1%	29%

Grain size:	Section 1-130 cm
Sand	19%
Silt	64%
Clay	17%

X-ray mineralogy:	Section 1-130 cm
Calcite	24%
Quartz	19%
K-feldspar	6%
Plagioclase	25%
Mica	21%
Chlorite	2%
Amphibole	3%

Explanatory notes in chapter 2

Site 228 Hole Core 27 Cored Interval: 218-227 m



LITHOLOGIC DESCRIPTION

Greenish gray MICARB - DETRITAL CLAYEY SILTSTONE. Locally foram rich and nanno bearing.

Generally homogeneous, but at 2-95 to 115 cm - bedded and steeply dipping. Semi-lithified.

Lithology SS: Section 3-140 cm.
Composition:

Total detrital	65%
Forams	10%
Micarb	10%
Nannos	5%

Color legend:

1 =	dark greenish gray	5GY 4/1
2 =	gray	5Y 5/1
3 =	black	N1
4 =	dark greenish gray	5G 4/1
5 =	olive gray	5Y 3/2

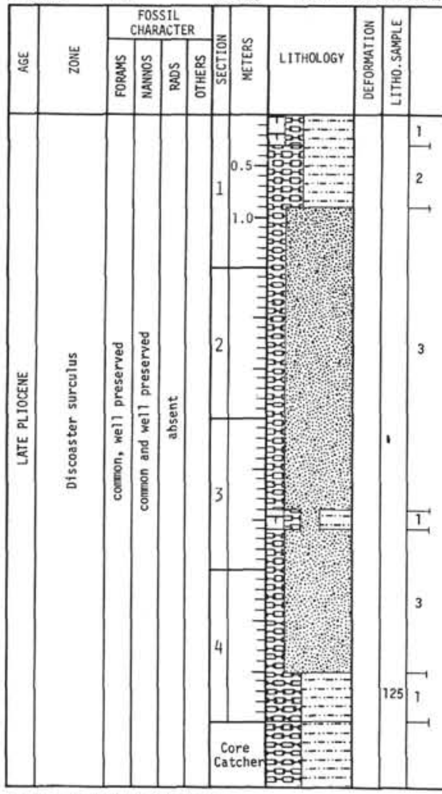
Shore-based laboratory results

	Organic Carbon	Carbonate
Section 3-110 cm =	.4%	30%

X-ray mineralogy:	Section 3-110 cm
Calcite	36%
Dolomite	6%
Quartz	11%
Plagioclase	14%
Kaolinite	2%
Mica	17%
Chlorite	2%
Montmorillonite	3%
Palygorskite	7%
Pyrite	1%

Explanatory notes in chapter 2

Site 228 Hole Core 28 Cored Interval: 227-236 m



LITHOLOGIC DESCRIPTION

Greenish gray to olive gray MICARB RICH DETRITAL SANDY SILTSTONE.

Homogeneous. Slightly to moderately bioturbated. Burrows oxidized. Semilithified. At 2-110 cm layers dipping with 20 to 30°.

Color legend:

1 =	gray	5Y 5/1
2 =	olive gray	5Y 5/2
3 =	dark olive gray	5GY 4/1

Shore-based laboratory results

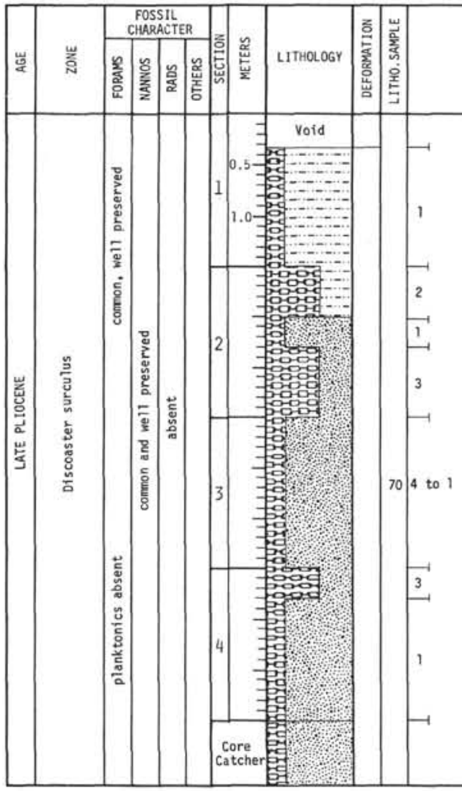
	Organic Carbon	Carbonate
Section 2-101 cm =	.2%	17%
Section 4-104 cm =	.3%	33%

Grain size: Sections	2-101 cm,	4-104 cm
Sand	23%	7%
Silt	63%	50%
Clay	14%	43%

X-ray mineralogy:	Section 2-100 cm
Calcite	16%
Dolomite	3%
Quartz	22%
K-feldspar	6%
Plagioclase	28%
Mica	19%
Chlorite	1%
Amphibole	4%

Explanatory notes in chapter 2

Site 228 Hole Core 29 Cored Interval: 236-245 m



LITHOLOGIC DESCRIPTION

Gray MICARB RICH DETRITAL SILTSTONE.

Homogeneous. Moderate burrow mottling. At 3-80 to 100 cm joint filled with palygorskite (smear 3-70). Semilithified.

Color legend:

1 =	dark greenish gray	5GY 4/1
2 =	black	N1
3 =	dark gray	5Y 3/1
4 =	olive gray	5Y 4/2

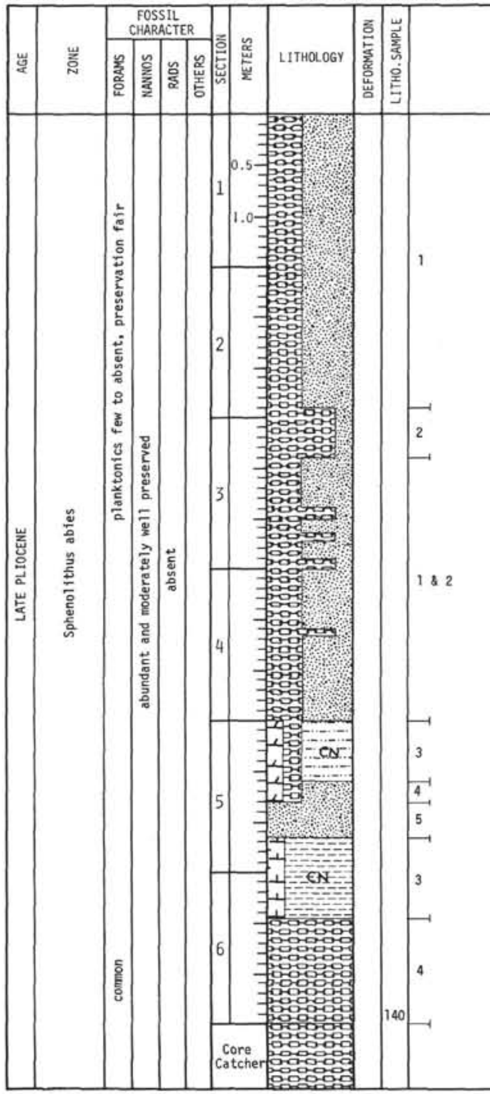
Shore-based laboratory results

	Organic Carbon	Carbonate
Section 3-70 cm =		5%

X-ray mineralogy:	Section 3-70 cm (vein mineralization)
Palygorskite	88%
Plagioclase	10%
Calcite	2%

Explanatory notes in chapter 2

Site 229 Hole Core 30 Cored Interval: 245-254 m



LITHOLOGIC DESCRIPTION

Greenish gray MICARB - DETRITAL SILTSTONE interbedded with gray DETRITAL SILT RICH - MICARB CHALK, black MICARB DOLOMITE RICH CLAYSTONE with high organic carbon content and MICARB SILTSTONES.

Slightly bioturbated. Generally homogeneous. At 6-45 cm dip of 20°. Semilithified.

Color legend:

1 =	dark greenish gray	5GY 4/1
2 =	gray	5Y 5/1
3 =	black	N1
4 =	dark greenish gray	5G 4/1
5 =	greenish black	5GY 2/1

Shore-based laboratory results

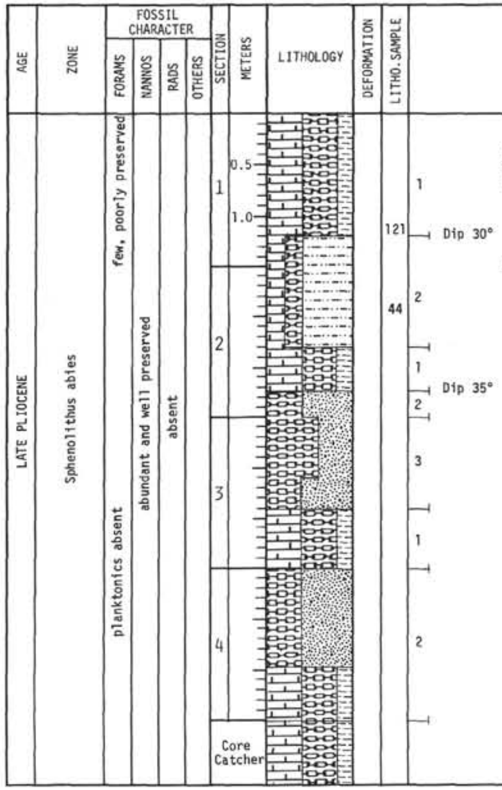
	Organic Carbon	Carbonate
Section 1-120 cm =	.3%	42%
Section 5- 37 cm =	2.9%	37%

X-ray mineralogy:	Section 1-120 cm
Calcite	30%
Dolomite	8%
Quartz	11%
K-feldspar	7%
Plagioclase	21%
Mica	20%
Chlorite	2%
Montmorillonite	1%
Amphibole	2%

	Section 5-37 cm (WHOI)
Calcite	23%
Ca-Dolomite	22%
Quartz	8%
Plagioclase	9%
Layered Silicates	38%

Explanatory notes in chapter 2

Site 228 Hole Core 31 Cored Interval: 254-263 m



LITHOLOGIC DESCRIPTION

Dark and greenish gray MICARB - DETRITAL SILTSTONE and DETRITAL CLAY RICH - NANNO MICARB CHALK.

Rich in heavy minerals. Slightly to moderately bioturbated. Homogeneous. At 1-125, 2-120 dip of 35°. Semilithfied.

Color legend:

1 =	very dark gray	5Y 3/1
2 =	dark greenish gray	5G 4/1
3 =	greenish gray	5GY 6/1

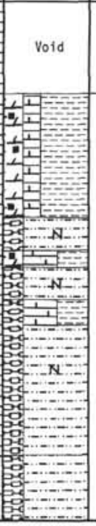
Shore-based laboratory results

	Organic Carbon	Carbonate
Section 1-110 cm =	1.2%	38%

X-ray mineralogy:	Section 1-110 cm (WHOI)
Calcite	35%
Quartz	8%
Plagioclase	10%
Layered Silicates	42%
Analcite	5%

Explanatory notes in chapter 2

Site 228 Hole Core 32 Cored Interval: 263-268 m

AGE	ZONE	FOSSIL CHARACTER				SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE
		FORAMS	NANNOS	RADS	OTHERS					
EARLY PLIOCENE	Reticulofenestra pseudoumbilica	planktonics few to absent, preservation fair to poor	abundant and moderately well preserved	absent		1 2 3 Core Catcher	0.5 1.0	Void 		5 130

LITHOLOGIC DESCRIPTION

1
2
3
2
3
2
3

Greenish gray MICARB RICH - DETRITAL CLAYEY SILTSTONE interbedded with greenish black DOLOMITE NANNO RICH - DETRITAL CLAYSTONE with high organic carbon content.

Dominant lithology SS: Section 2-5 cm.
Composition:

Total detrital	63%
Nannos	15%
Dolomite	10%
Micarb	5%
Pyrite	5%
Organic matter	2%

Minor lithology SS; Section 3-130 cm.
Composition:

Total detrital	78%
Nannos	10%
Micarb	10%
Opaques (10% heavies)	2%

Color legend:

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

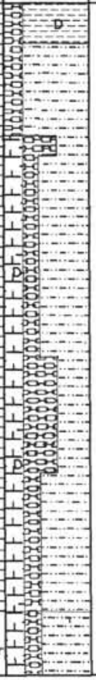
Shore-based laboratory results

	Organic Carbon	Carbonate
Section 2- 8 cm =	1.9%	29%
Section 2-120 cm =	.2%	6%

X-ray mineralogy:	Section 2-8 cm (WHOI)
Calcite	23%
Ca-Dolomite	10%
Quartz	10%
Plagioclase	15%
Layered Silicates	37%
Pyrite	5%
	Section 2-120 cm
Quartz	26%
K-feldspar	10%
Plagioclase	29%
Mica	26%
Chlorite	3%
Montmorillonite	5%
Amphibole	1%

Explanatory notes in chapter 2

Site 228 Hole Core 33 Cored Interval: 268-277 m

AGE	ZONE	FOSSIL CHARACTER				SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE
		FORAMS	NANNOS	RADS	OTHERS					
EARLY PLIOCENE	Reticulofenestra pseudoumbilica	planktonics rare to absent, preservation fair	abundant and moderately well preserved	absent		1 2 3 4 Core Catcher	0.5 1.0			95

LITHOLOGIC DESCRIPTION

1
2
1
3 Dip 40°
4 Dip 50°
3 Dip 30-50°

Greenish gray and black SILTSTONE, some beds NANNO and/or MICARB RICH. Light gray LIMESTONE at 1-10 cm, 120 cm.

Bedding dipping 40° to 80°.

Dominant lithology SS: Section 2-95 cm.
Composition:

Total detrital	55%
Nannos	20%
Micarb	20%
Opaques	<5%

Color legend:

1 =	greenish black	5G 2/1
2 =	dark greenish gray	5G 4/1
3 =	black	N1
4 =	dark greenish gray	5GY 4/1

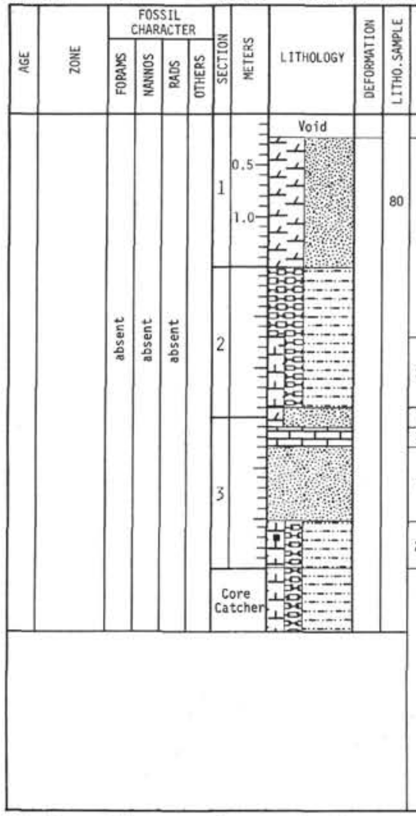
Shore-based laboratory results

	Organic Carbon	Carbonate
Section 1-100 cm =		7%
Section 3-100 cm =	.2%	67%

X-ray mineralogy:	Section 4-30 cm
Calcite	65%
Dolomite	7%
Quartz	7%
K-feldspar	2%
Plagioclase	9%
Mica	8%
Chlorite	2%

Explanatory notes in chapter 2

Site 228 Hole Core 34 Cored Interval: 277-286 m



LITHOLOGIC DESCRIPTION

Greenish gray DOLOMITE - DETRITAL SANDY SILTSTONE and beds of black NANNO and/or MICARB RICH - CLAYEY SILTSTONE. Rich in heavy minerals.

Homogeneous. Semilithified. At 3-60 cm dip of 70°.

Lithology SS: Section 1-30 cm.
Composition:

Total detrital	53%
Dolomite rhombs	40%
Micarb	<5%
Opaques	2%

Color legend:

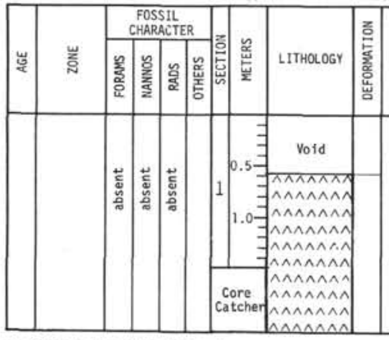
1 =	dark green gray	5G 4/1
2 =	black	N1
3 =	light green	5G 7/4

Shore-based laboratory results

	Organic Carbon	Carbonate
Section 1-69 cm =	.2%	34%
Section 3-50 cm =	.7%	0%

X-ray mineralogy:	Section 1-70 cm
Dolomite	37%
Quartz	17%
K-feldspar	6%
Plagioclase	21%
Kaolinite	2%
Mica	14%
Chlorite	3%
Pyrite	1%
	Section 1-80 cm (WHOI)
Dolomite	40%
Quartz	10%
Plagioclase	18%
Layered Silicates	32%

Site 228 Hole Core 36 Cored Interval: 295-304 m

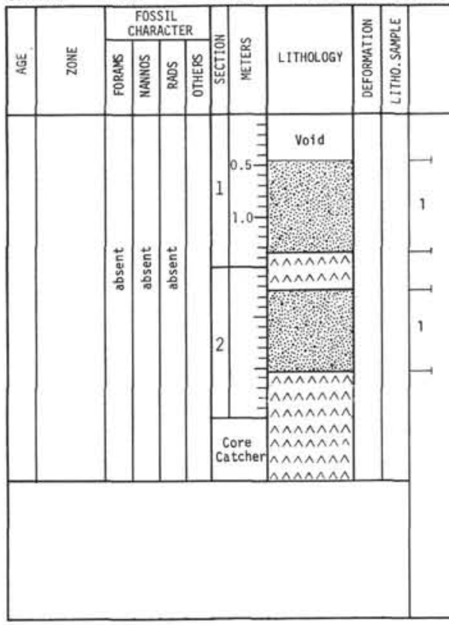


LITHOLOGIC DESCRIPTION

ANHYDRITE, nodular, brecciated at 110 to 120 cm.

Explanatory notes in chapter 2

Site 228 Hole Core 35 Cored Interval: 286-295 m



LITHOLOGIC DESCRIPTION

Black SILTSTONE and white ANHYDRITE.

Top of anhydrite is fractured and these are lined with serpentine and black siltstone. Anhydrite is laminated.

Color legend:

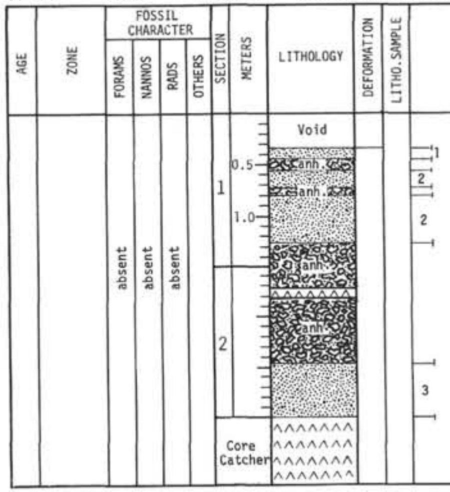
1 =	black	N1

Shore-based laboratory results

	Organic Carbon	Carbonate
Section 1-110 cm =	1.1%	1%
Section 1-120 cm =		<5%
Section 1-122 cm =	.3%	0%
Section 2- 81 cm =	.3%	0%

X-ray mineralogy:	Section 2-81 cm (WHOI)
Quartz	23%
Plagioclase	27%
Layered Silicates	50%

Site 228 Hole Core 37 Cored Interval: 304-313 m



LITHOLOGIC DESCRIPTION

Brecciated ANHYDRITE with SILTSTONE matrix interbedded with black to gray SILTSTONE with high organic carbon content. Lowermost SILTSTONE locally laminated.

Color legend:

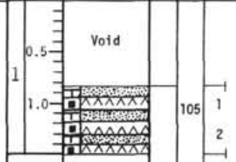
1 =	greenish black	5G 2/1
2 =	medium bluish gray	5B 5/1
3 =	greenish black	5GY 2/1

Shore-based laboratory results

	Organic Carbon	Carbonate
Section 1-125 cm =	2.1%	1%
Section 1-124 cm =		<5%
Section 2-114 cm =	.2%	4%
Section 2-122 cm =		45%

X-ray mineralogy:	Section 2-114 cm (WHOI)
Ca-dolomite	6%
Quartz	15%
Plagioclase	20%
Layered Silicates	59%

Site 228 Hole Core 38 Cored Interval:313-322 m

AGE	ZONE	FOSSIL CHARACTER				SECTION	METERS / LITHOLOGY / DEFORMATION / LITHO. SAMPLE
		FORAMS	NANNOS	RADS	OTHERS		
		absent	absent	absent		1	
						Core Catcher	

LITHOLOGIC DESCRIPTION

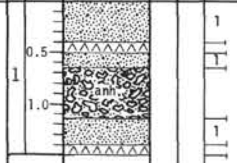
FORAM MICARB RICH SILTSTONE with interbeds of PYRITE RICH ANHYDRITE.

Color legend:
1 = dark greenish gray 5GY 4/1
2 = dark brown 7.5YR 4/4

Shore-based laboratory results

	Organic Carbon	Carbonate
Section 1-95 cm =		<5%

Site 228 Hole Core 39 Cored Interval:322-325 m

AGE	ZONE	FOSSIL CHARACTER				SECTION	METERS / LITHOLOGY / DEFORMATION / LITHO. SAMPLE
		FORAMS	NANNOS	RADS	OTHERS		
		absent	absent	absent		1	
						Core Catcher	

LITHOLOGIC DESCRIPTION

ANHYDRITE, mostly brecciated with matrix of SILTSTONE alternating with beds of greenish black SILTSTONE with high organic carbon content.

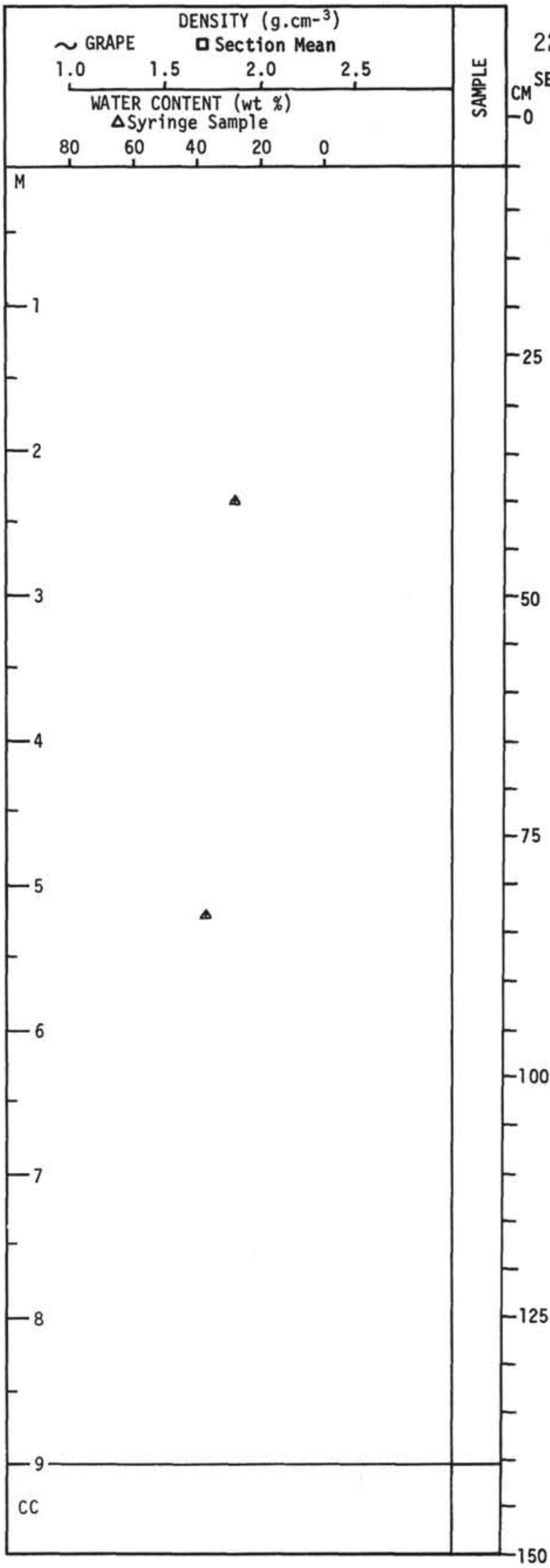
Color legend:
1 = greenish black 5GY 2/1

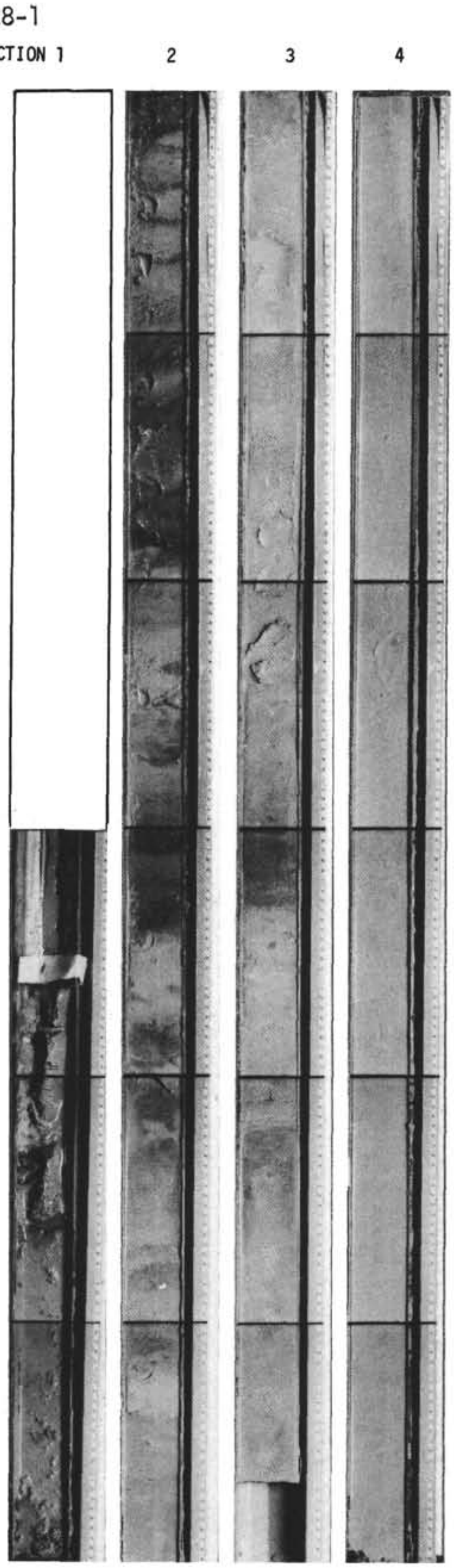
Shore-based laboratory results

	Organic Carbon	Carbonate
Section 1-114 cm =	1.8%	16%

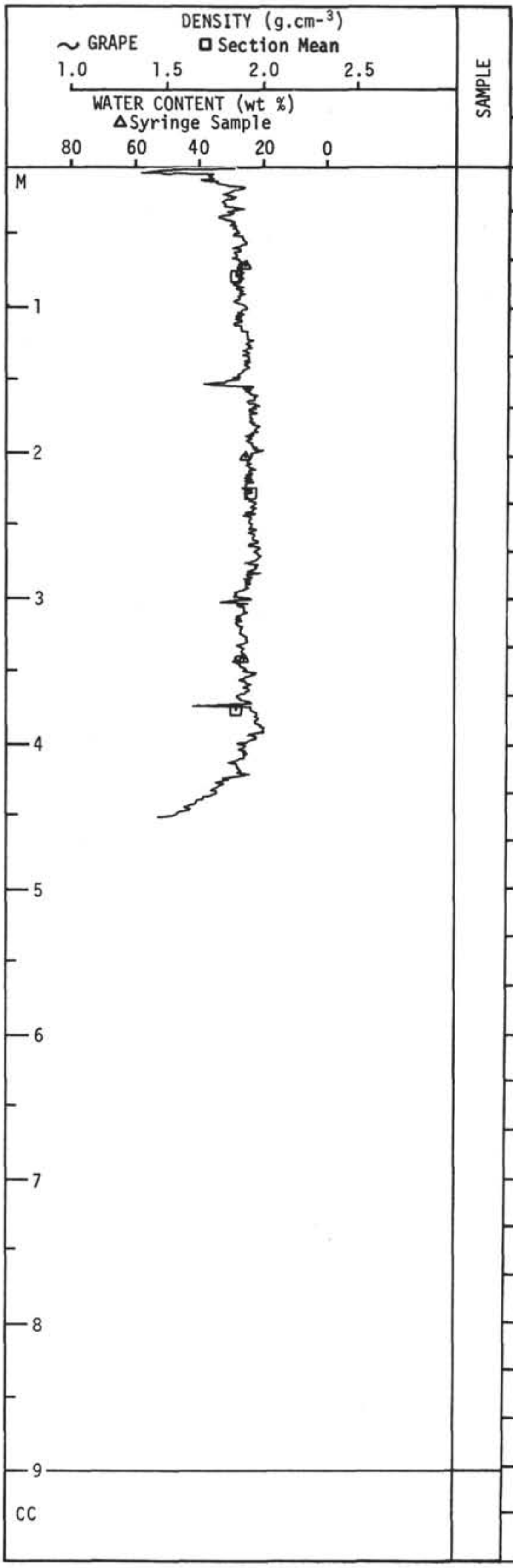
X-ray mineralogy:	Section 1 (WHOI)
Quartz	10%
Layered Silicates	50%
Pyrite	5%
Anhydrite	30%
Gypsum	5%
	Section CC (WHOI)
Quartz	24%
K-feldspar	8%
Plagioclase	7%
Layered Silicates	32%
Anhydrite	27%
Gypsum	2%

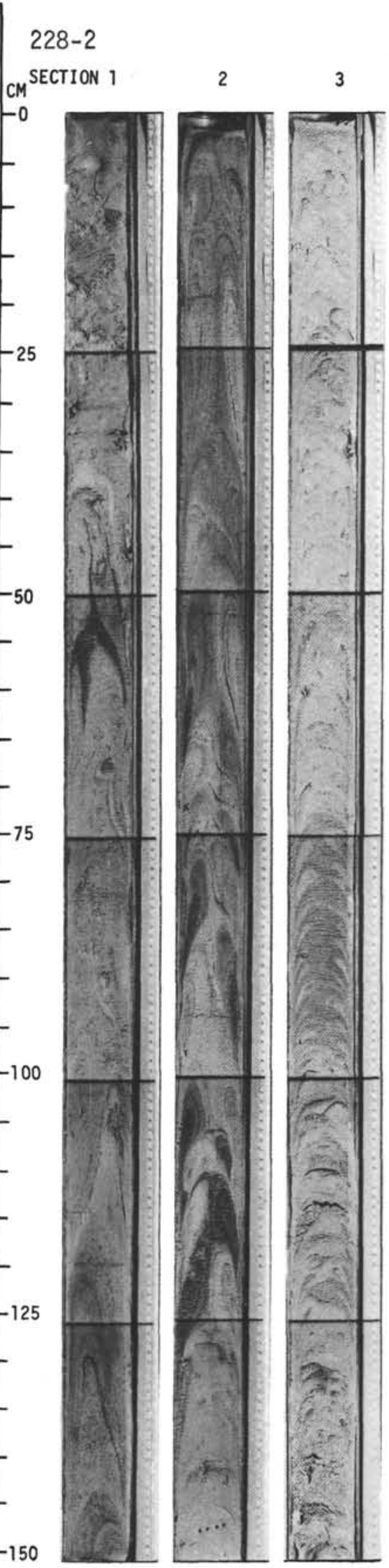
Explanatory notes in chapter 2





For Explanatory Notes, see Chapter 2





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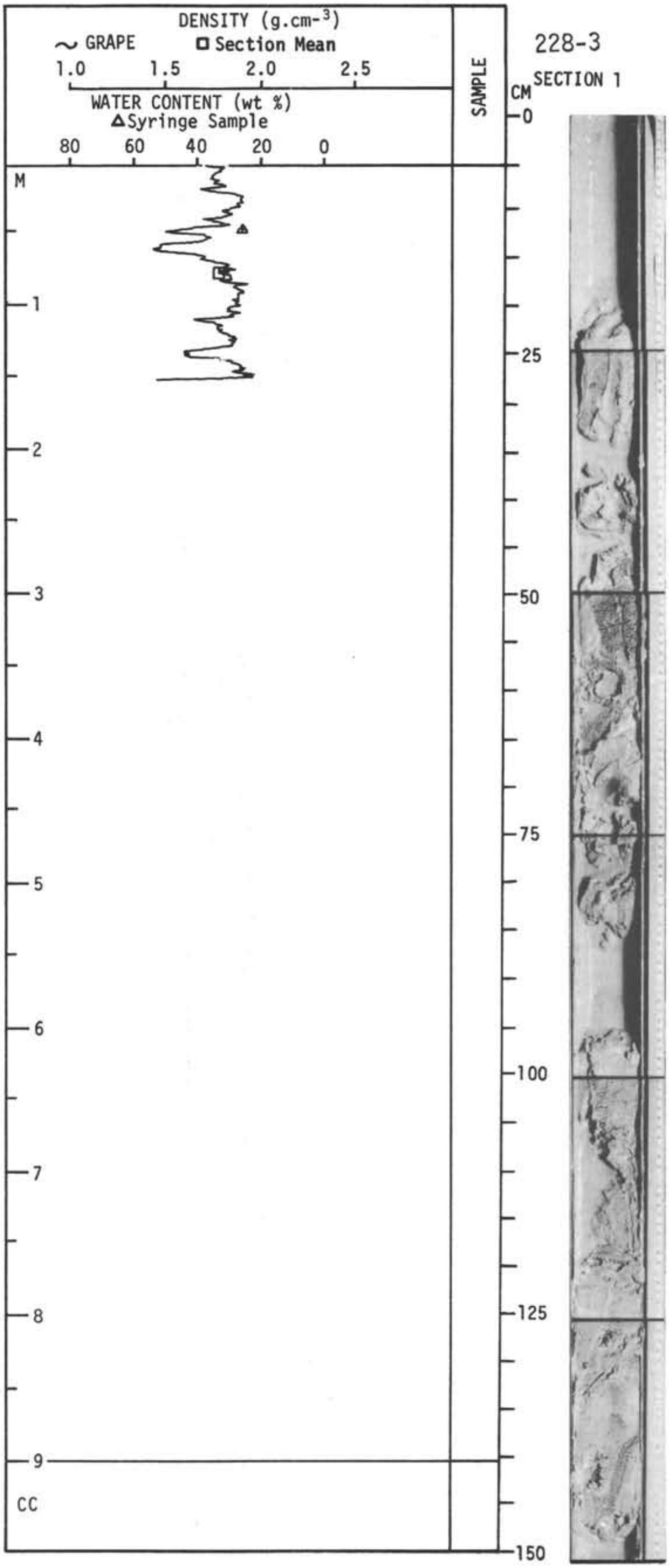

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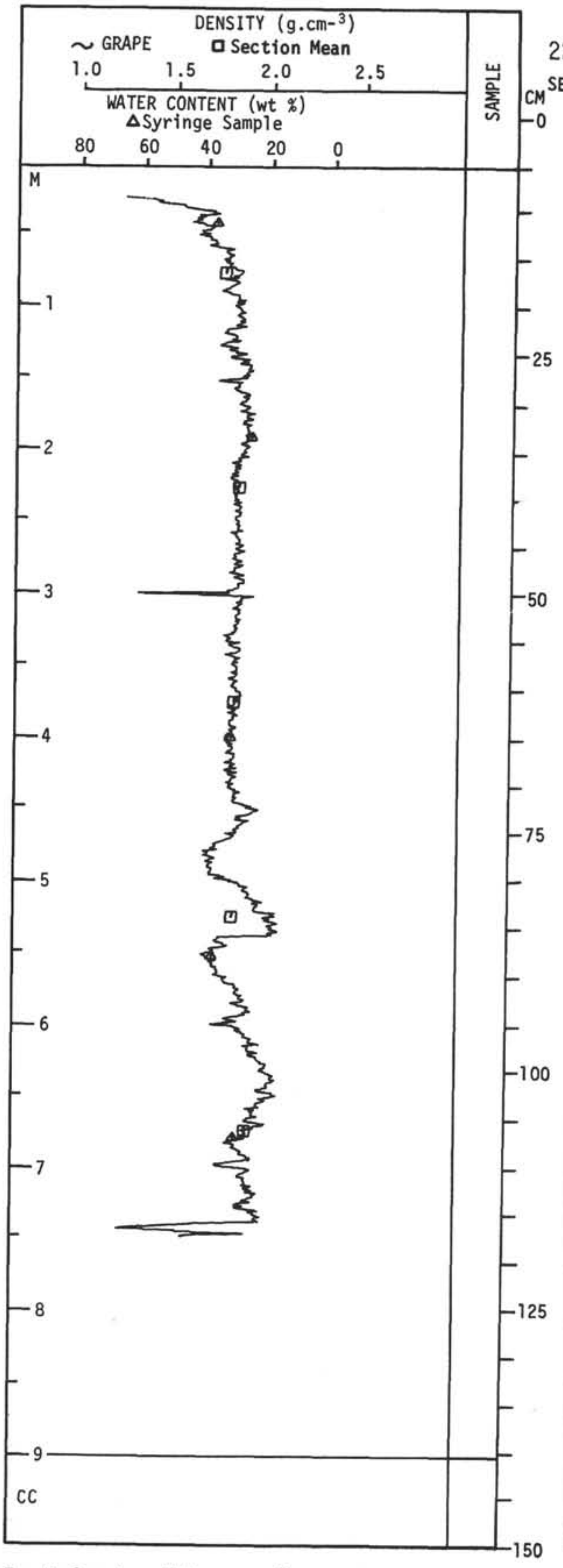

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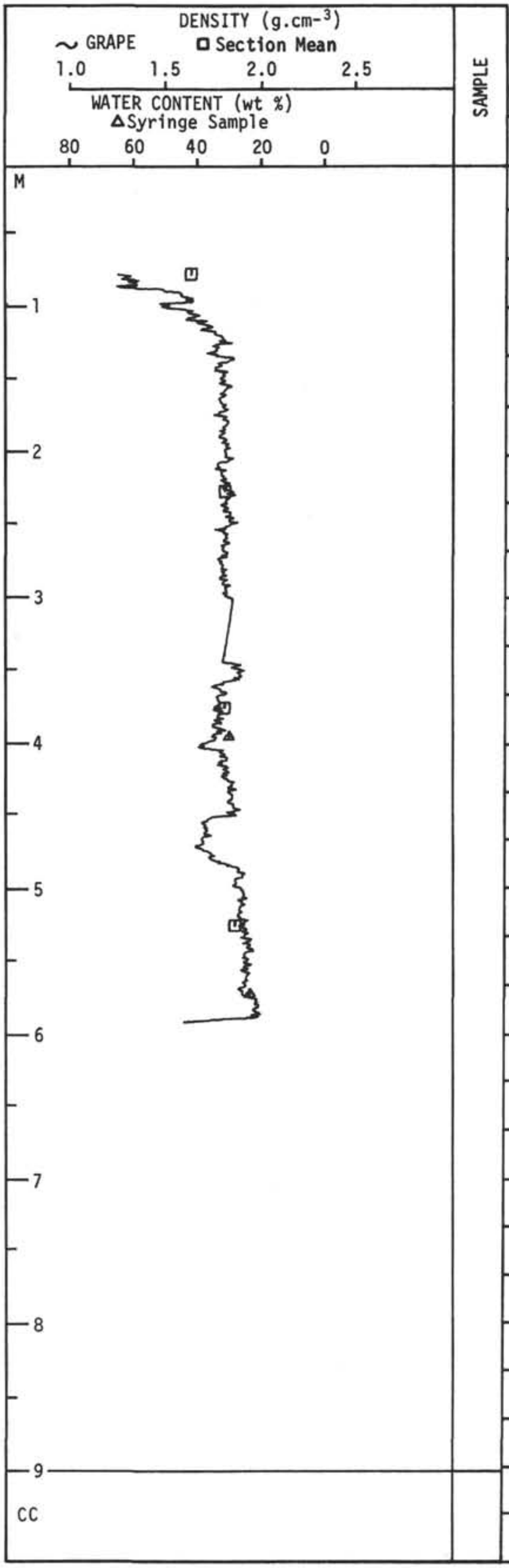

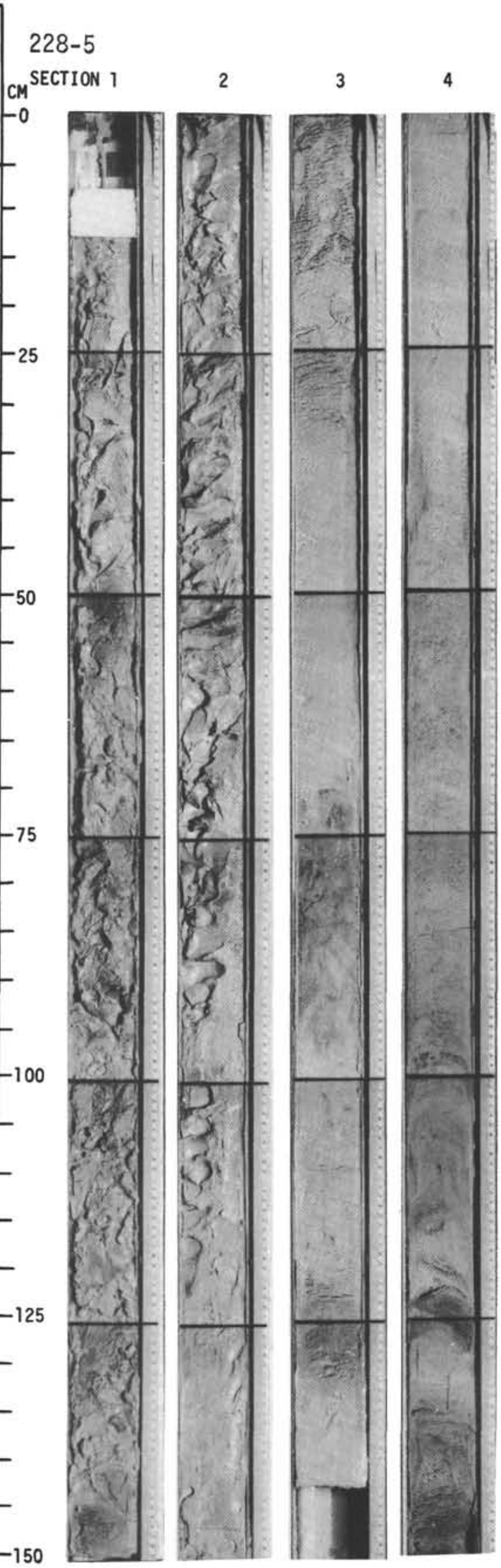

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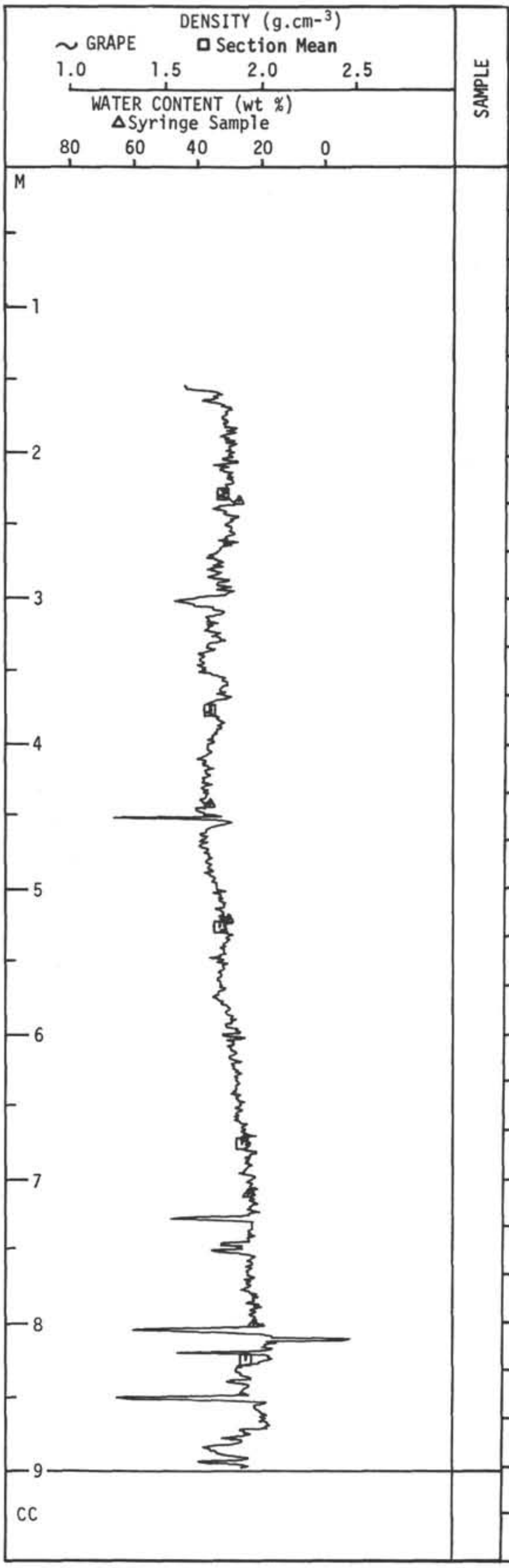

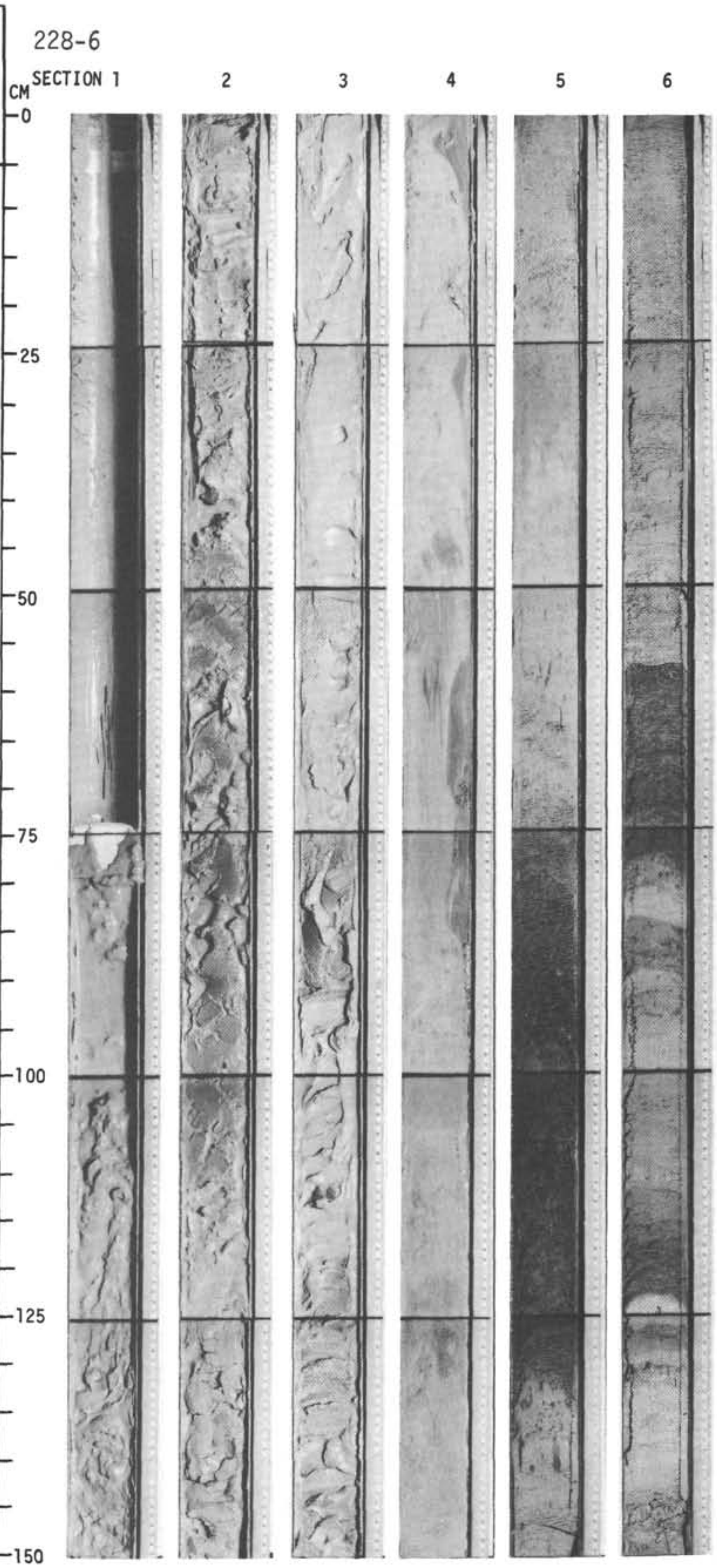

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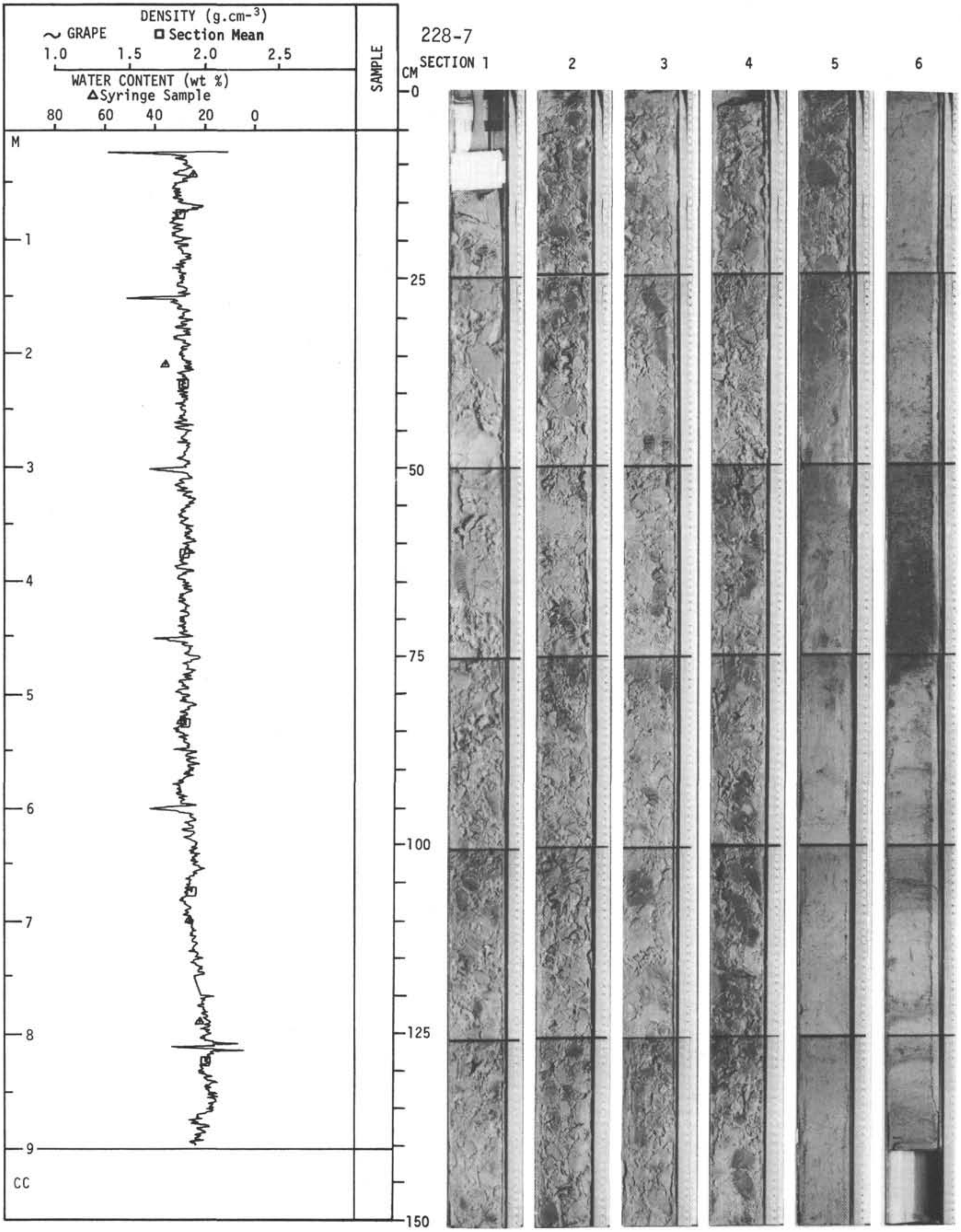

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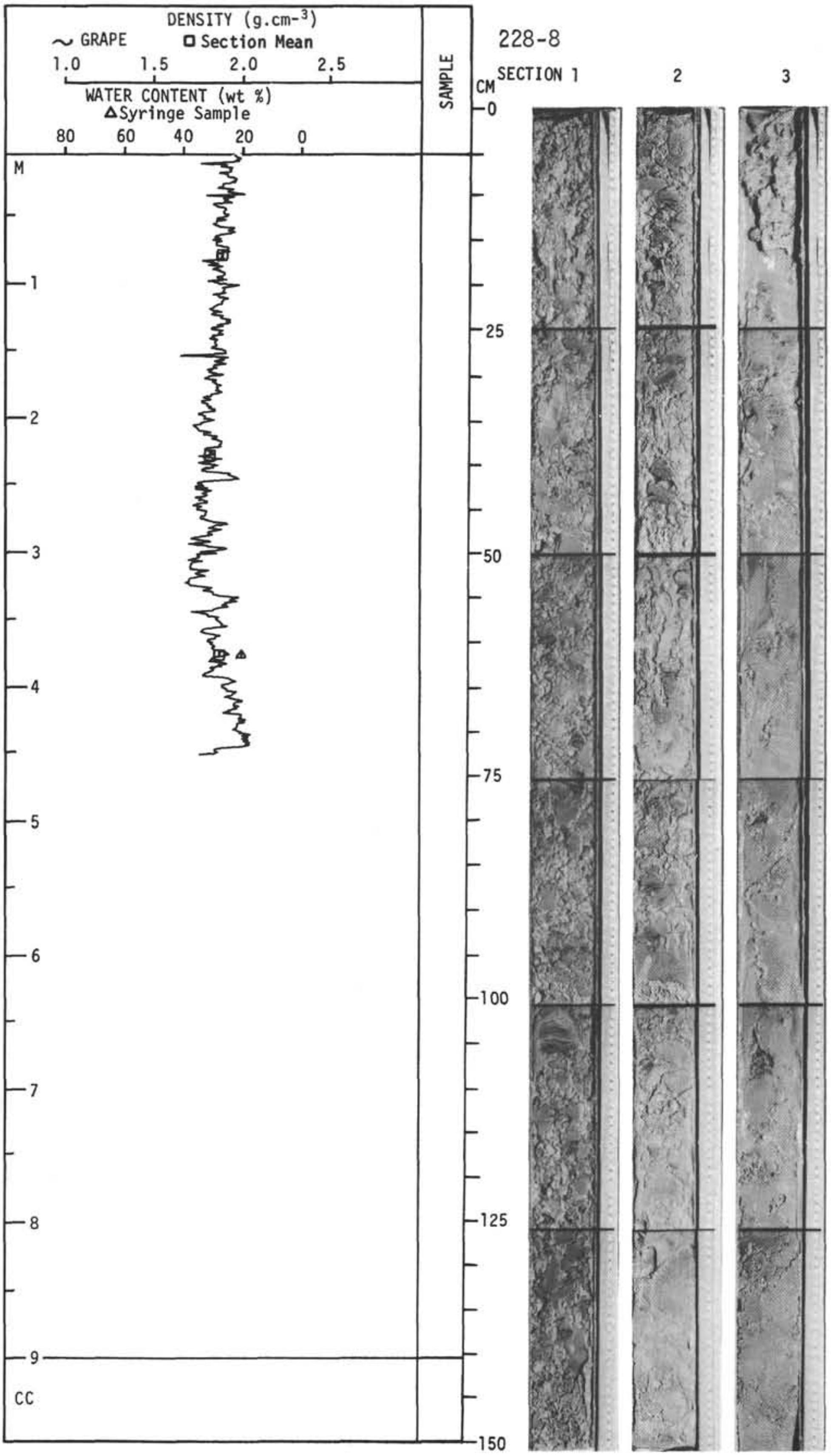

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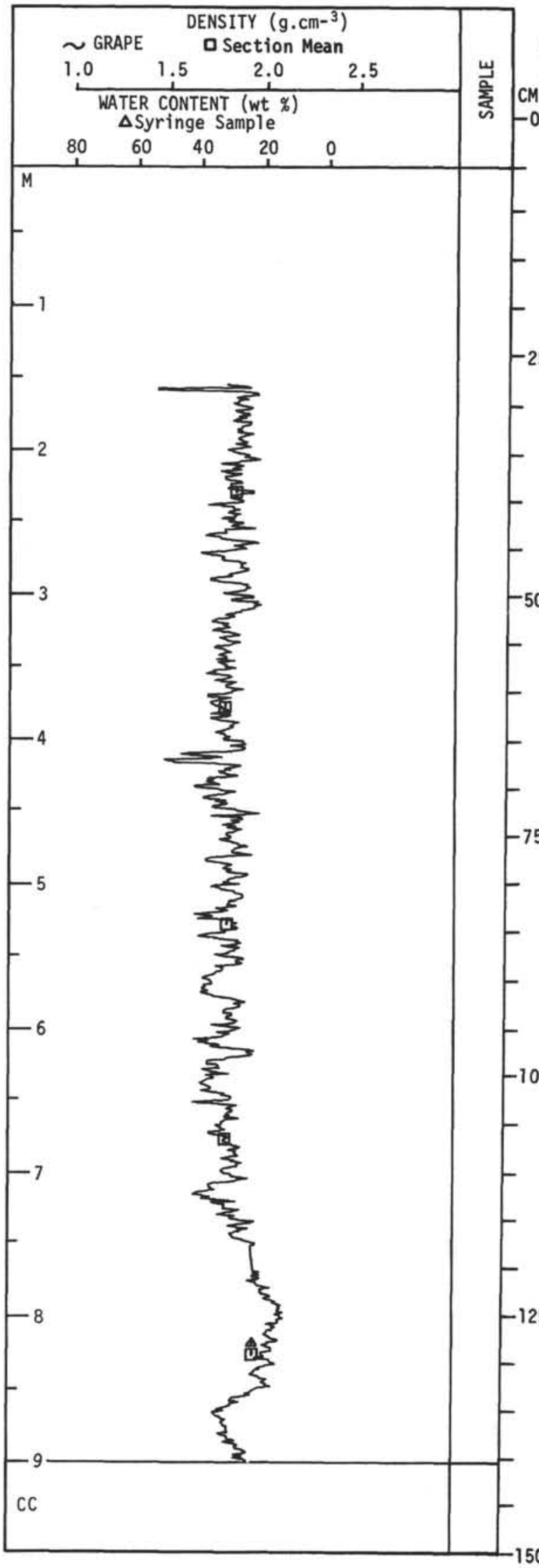

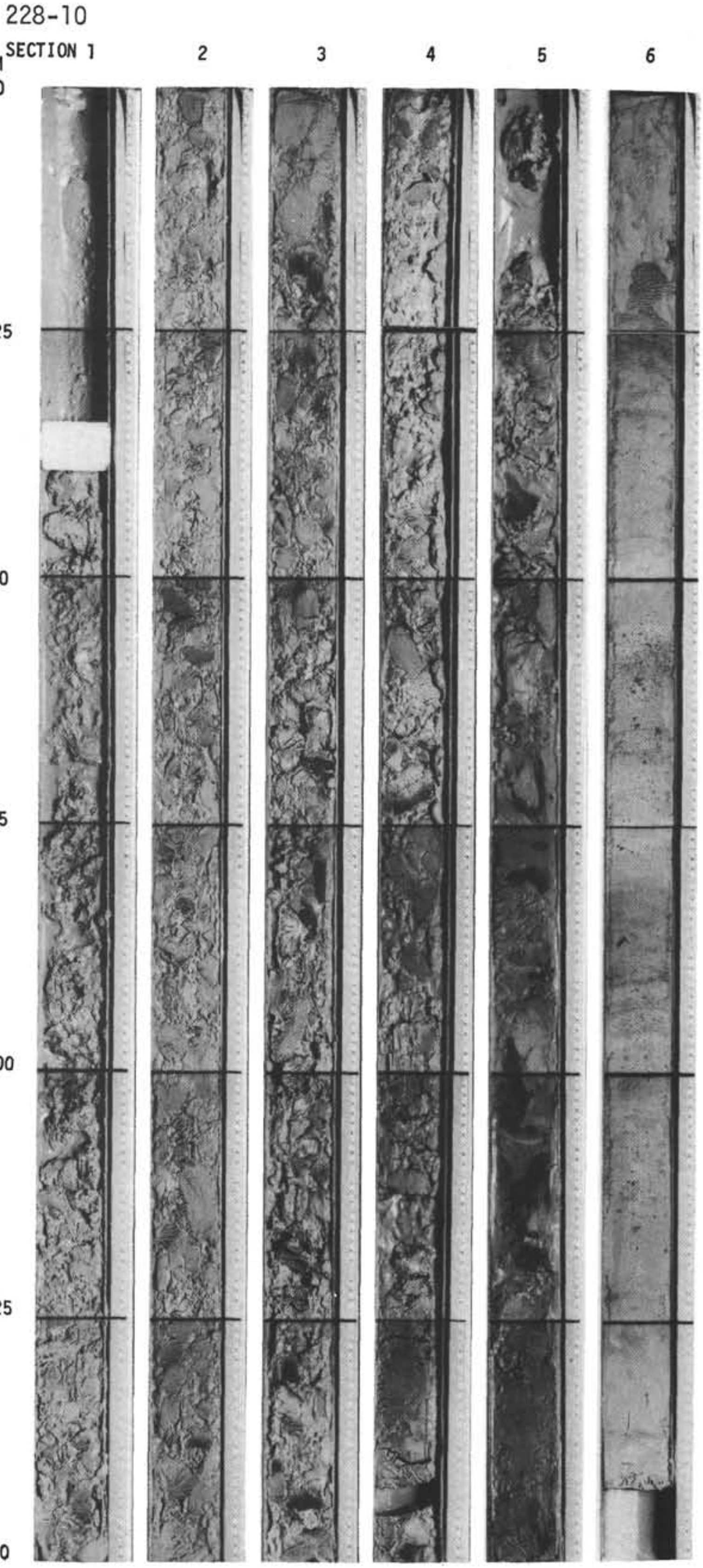

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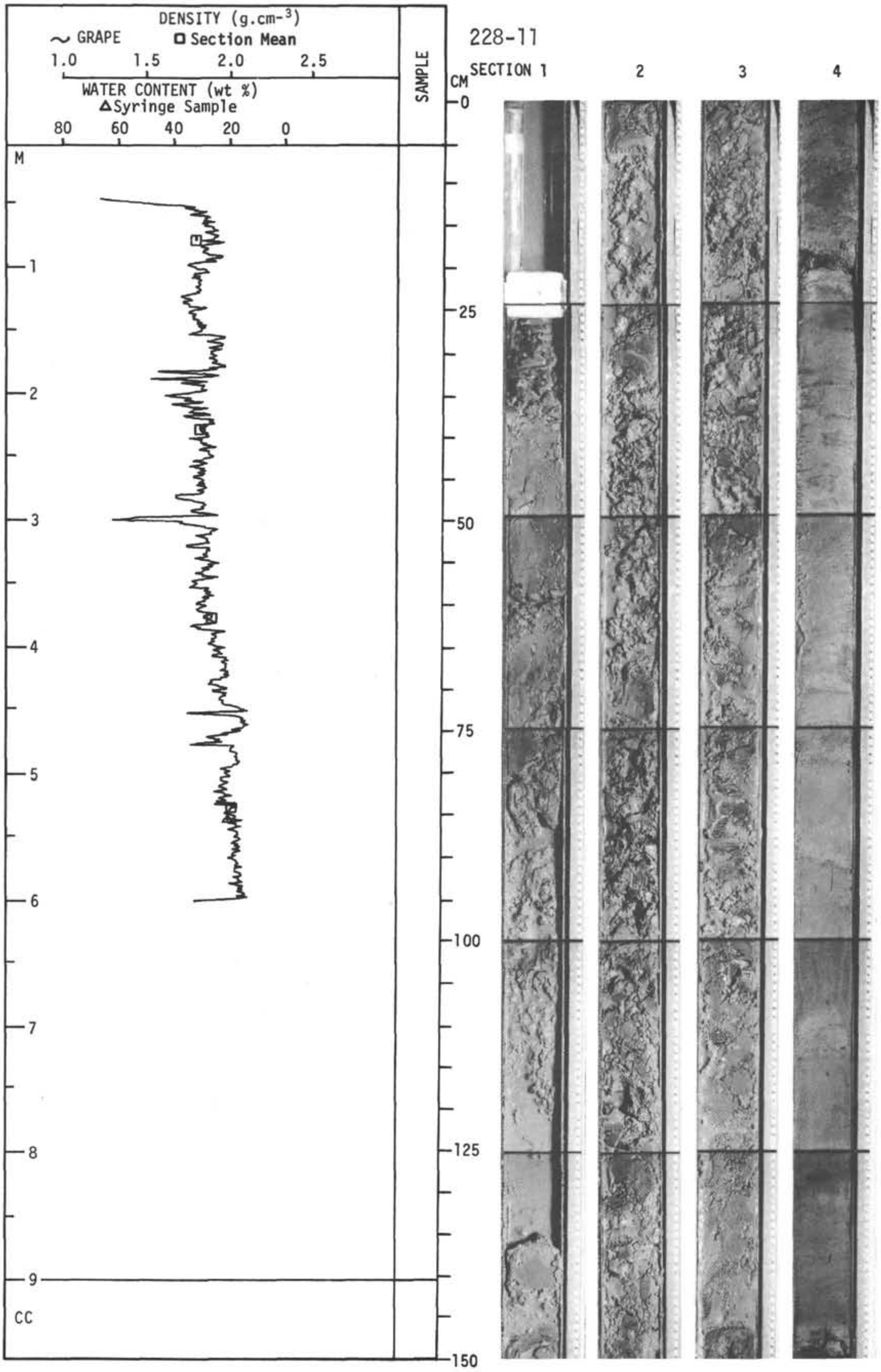

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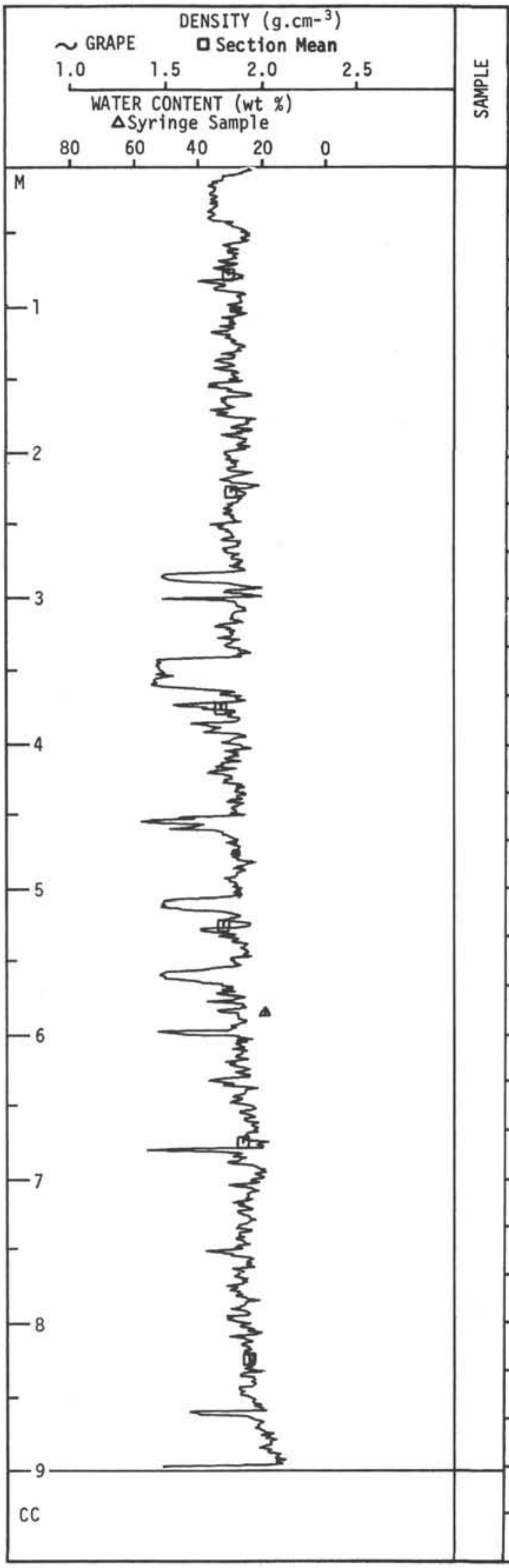

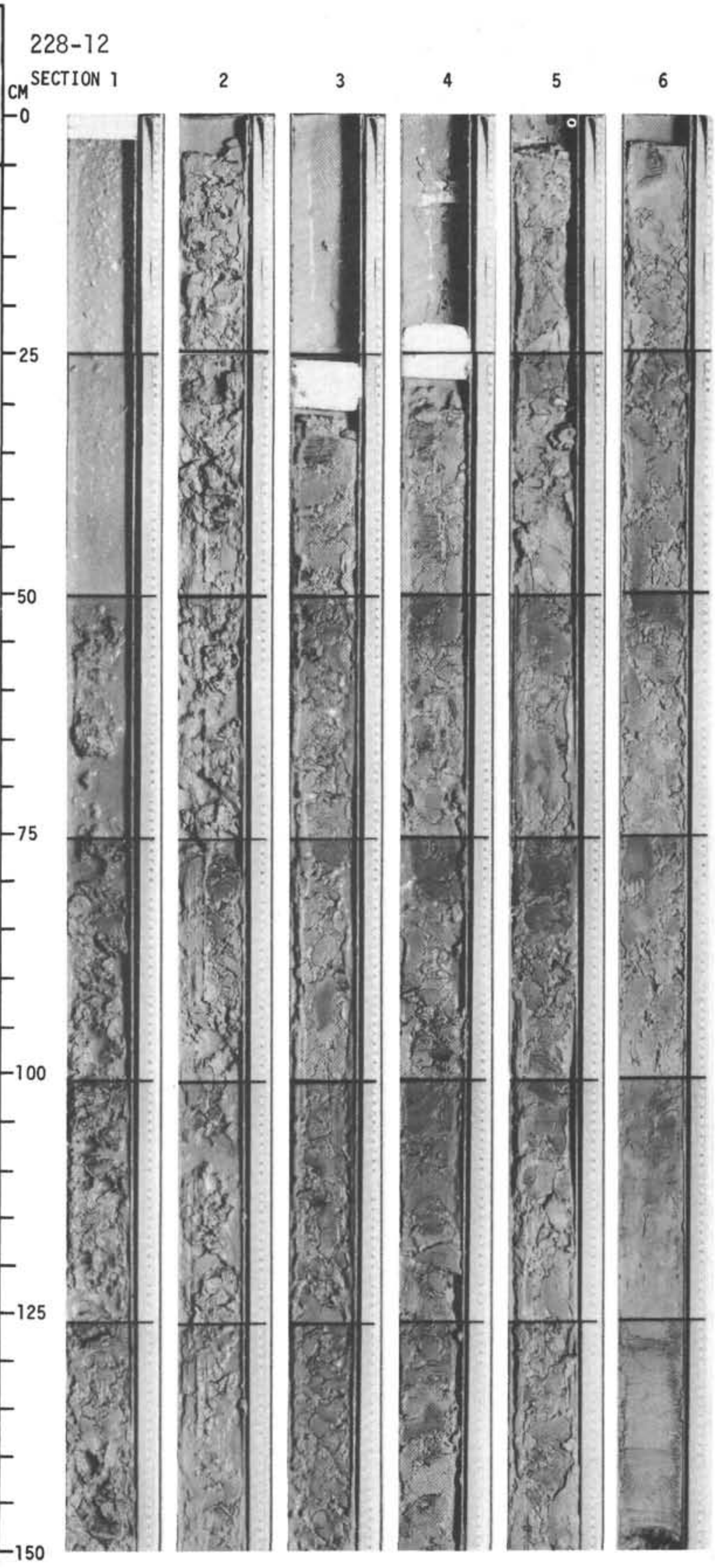

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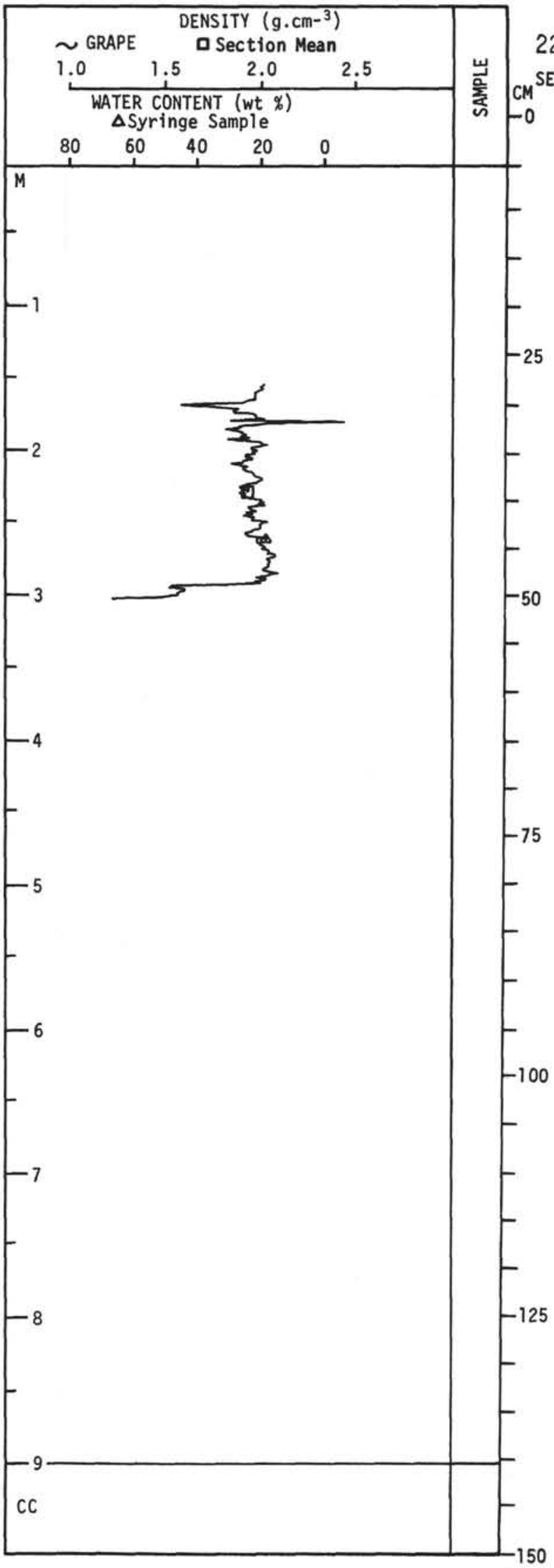

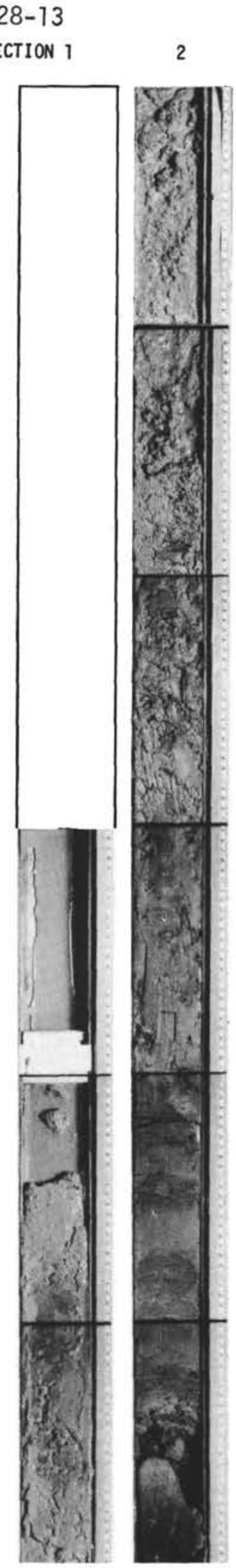

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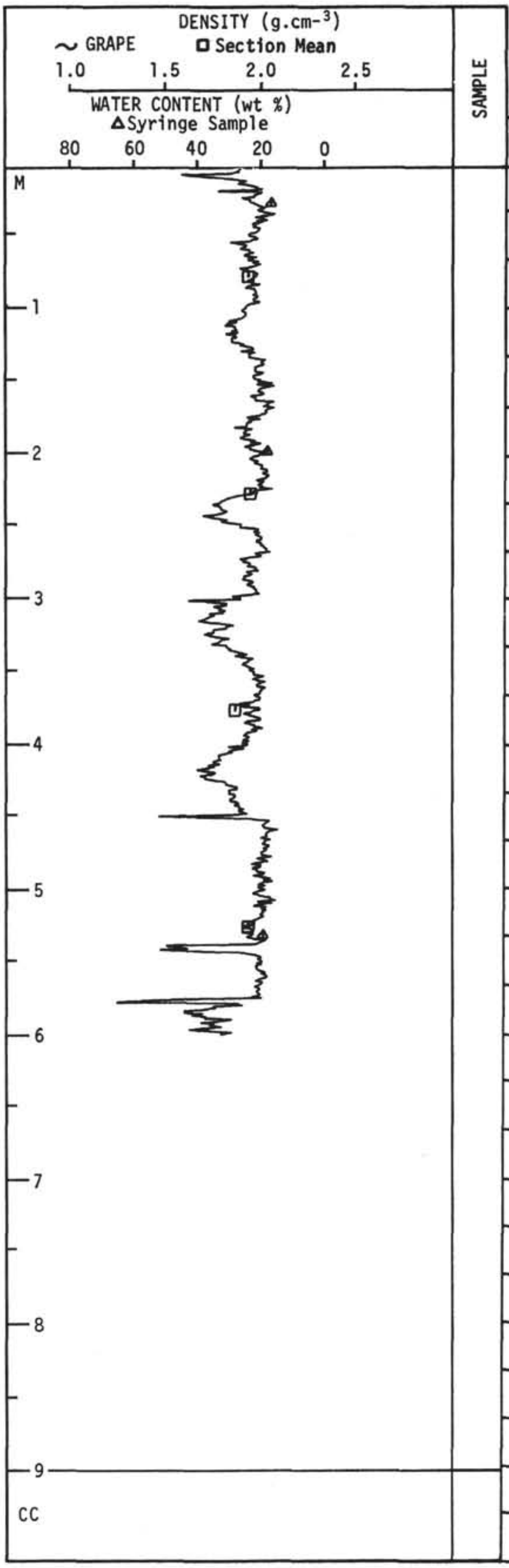

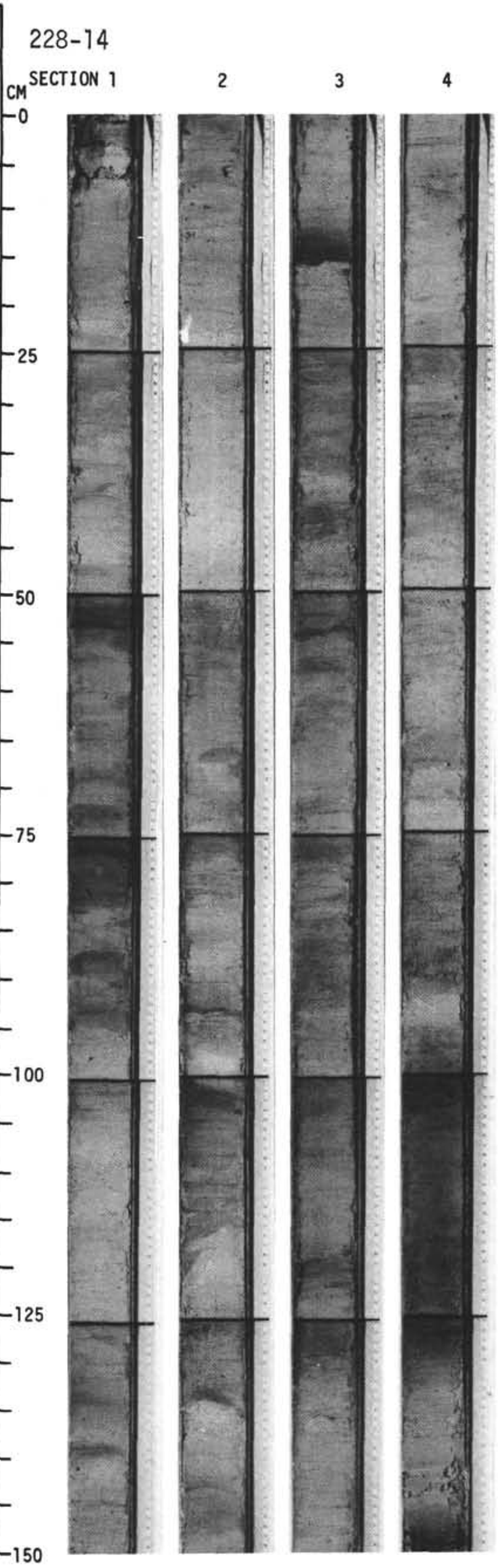

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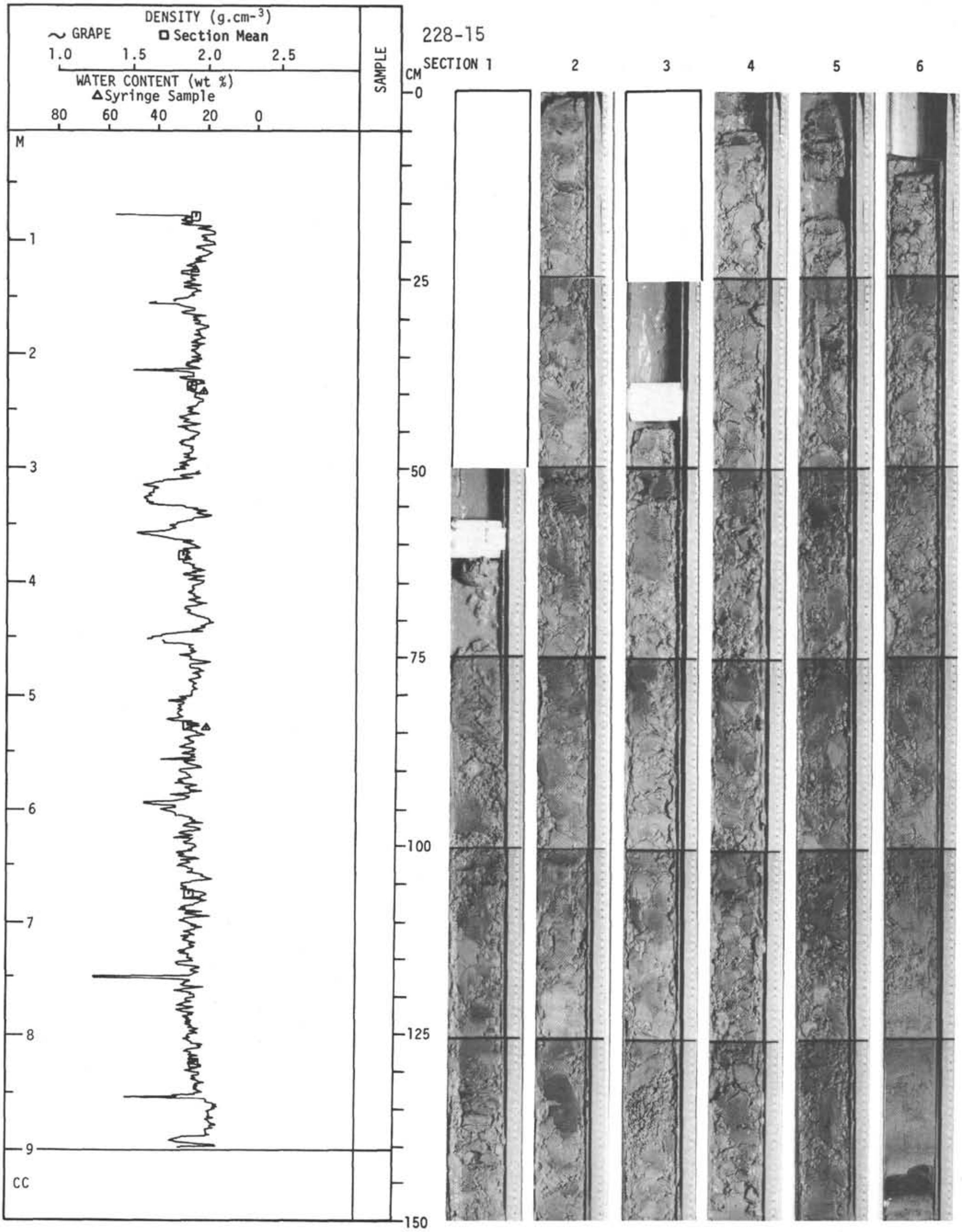

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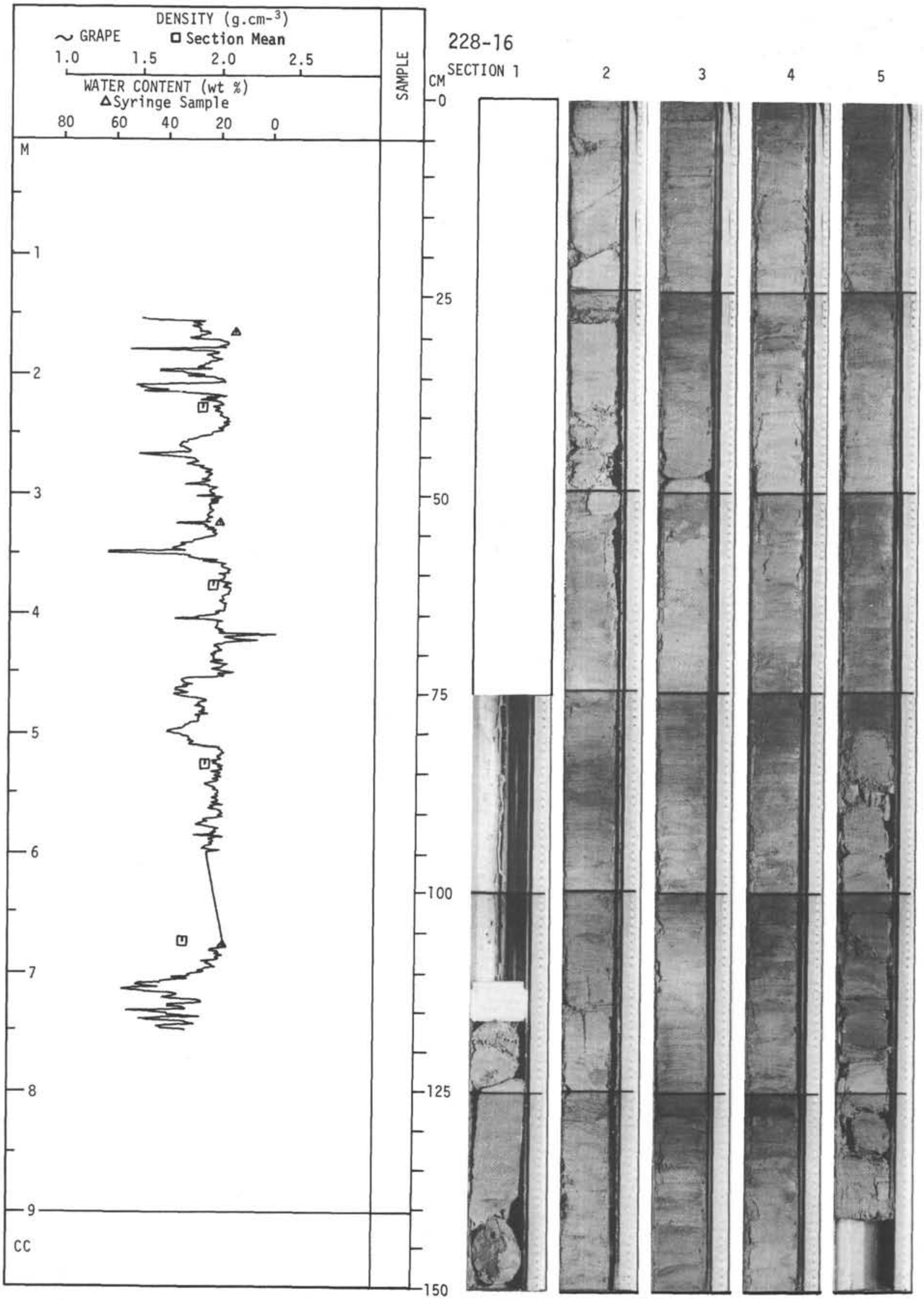

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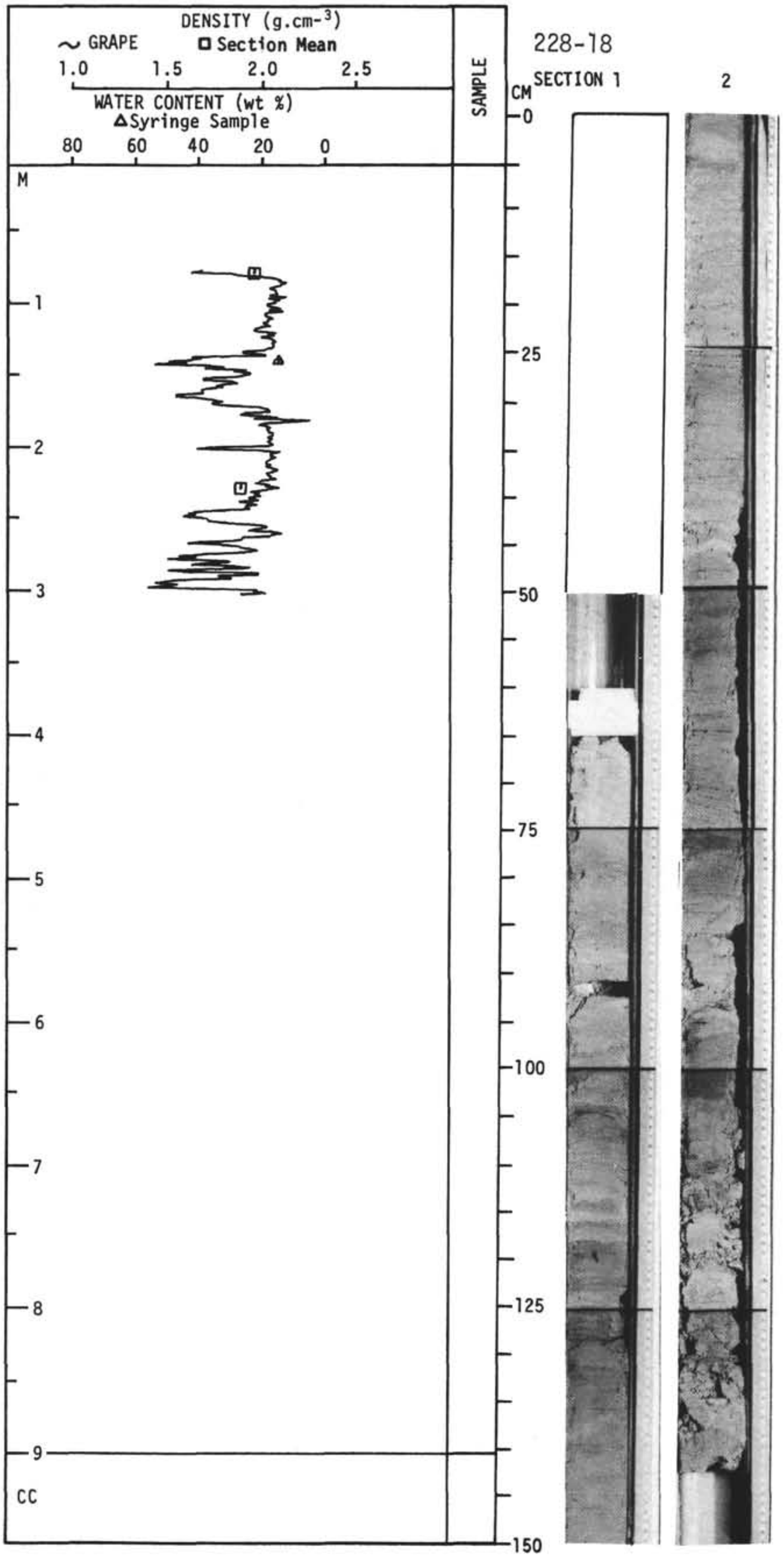

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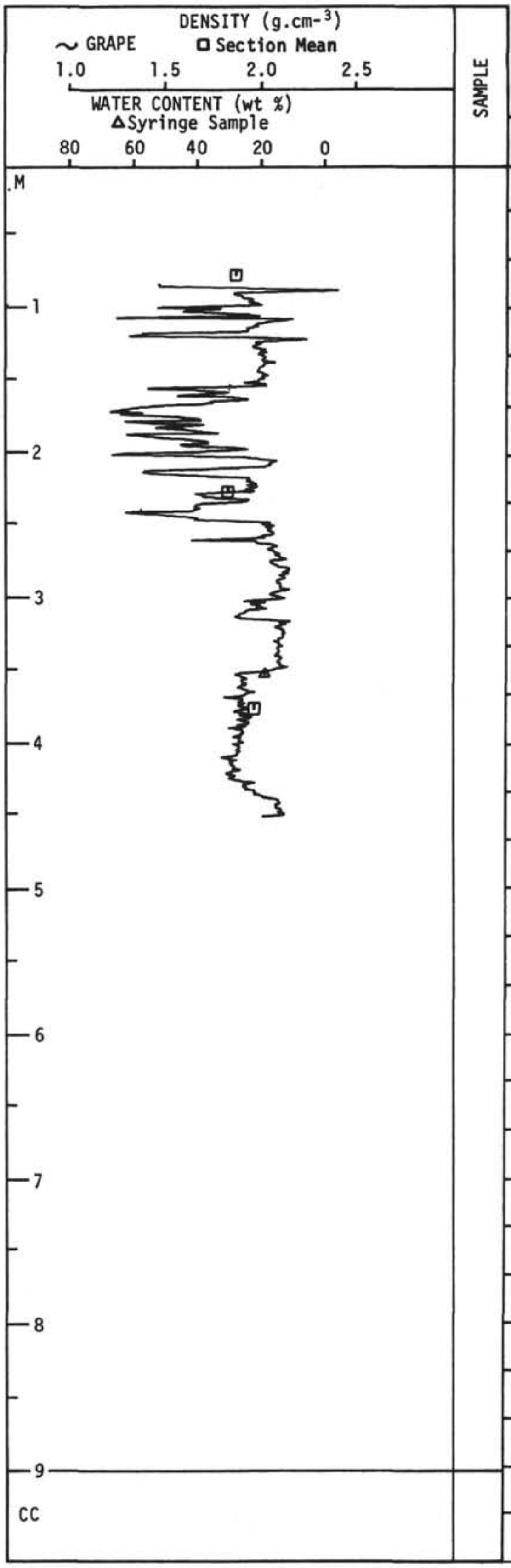

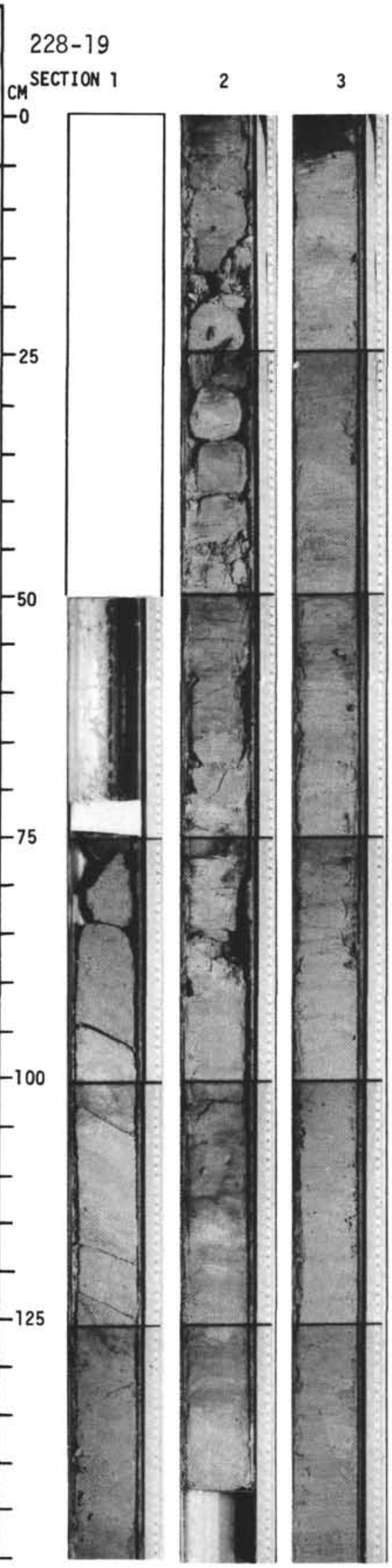

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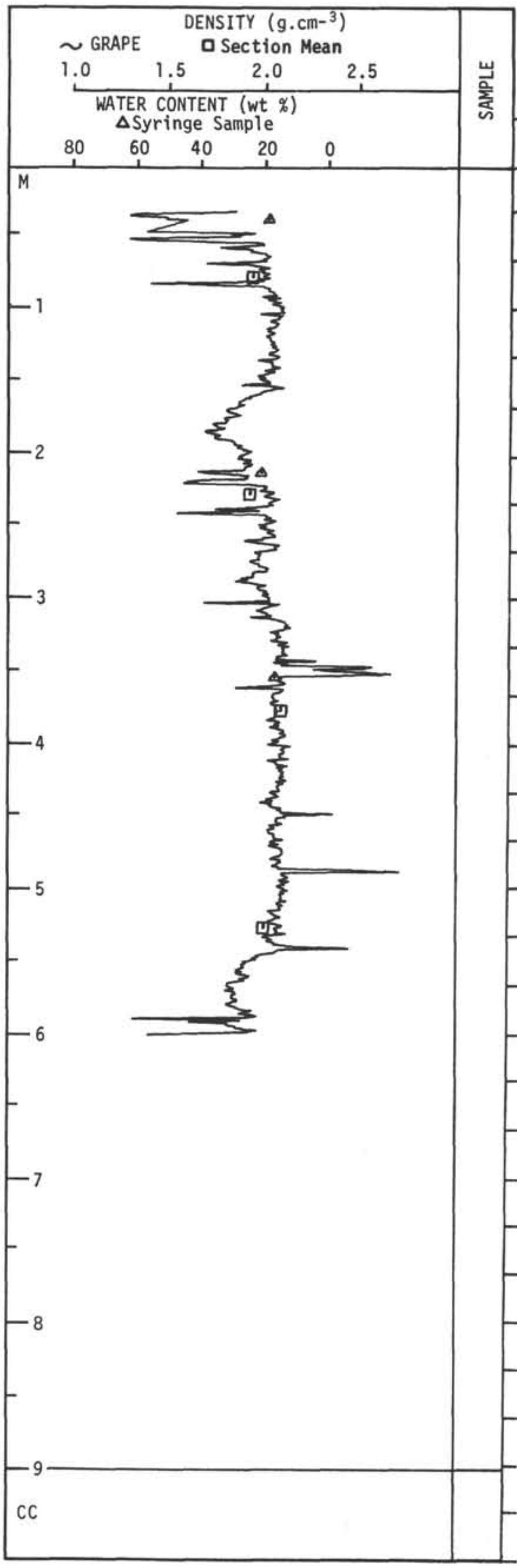

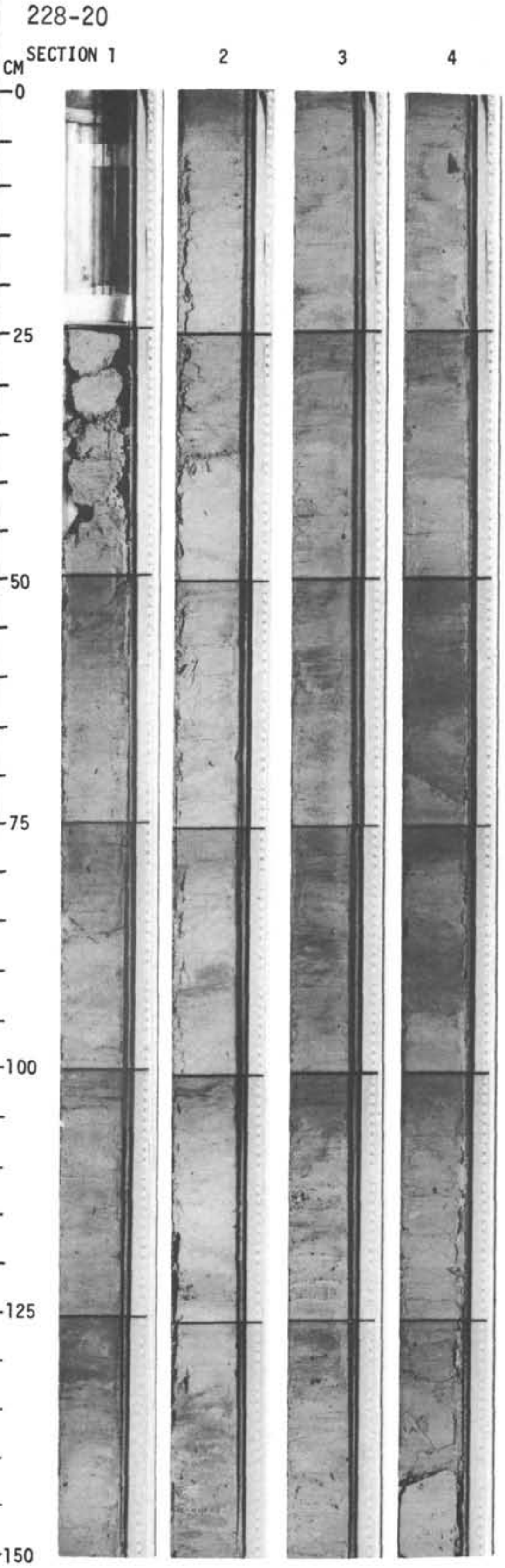

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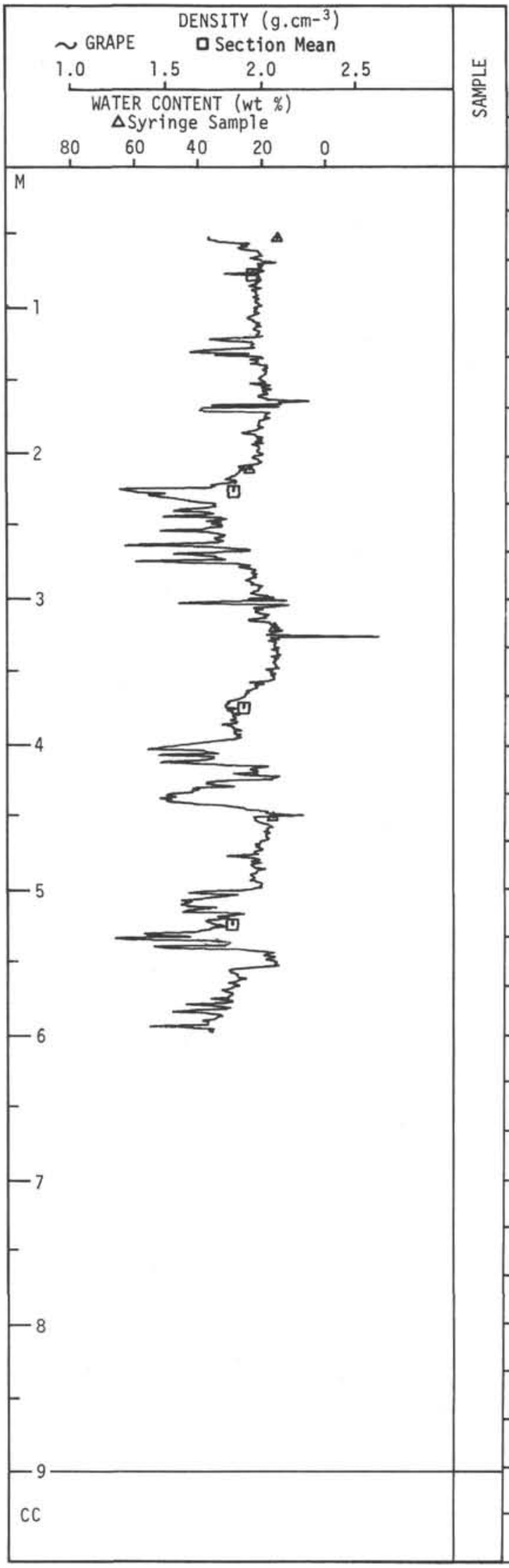

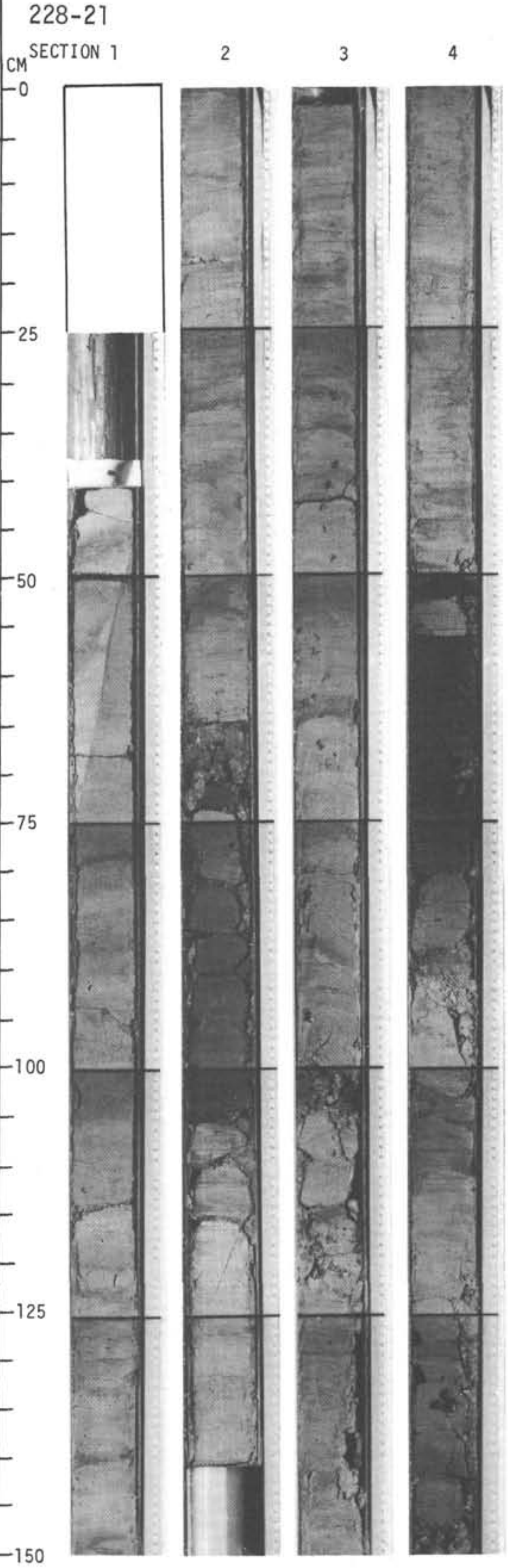

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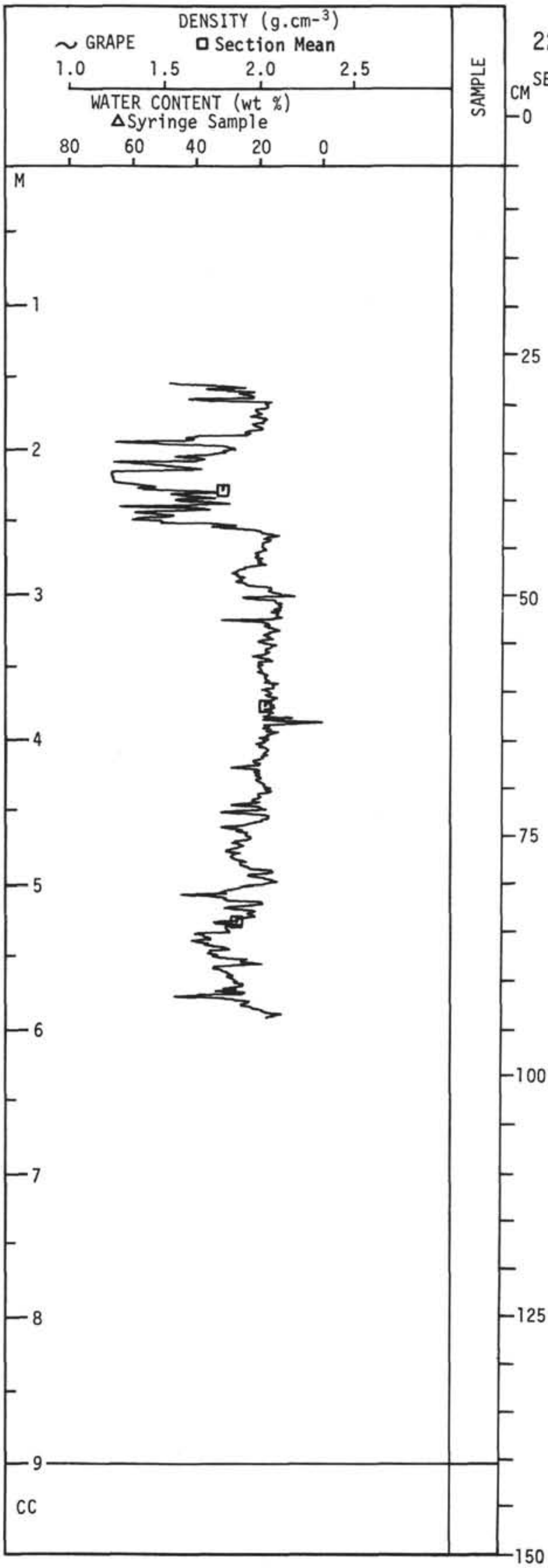

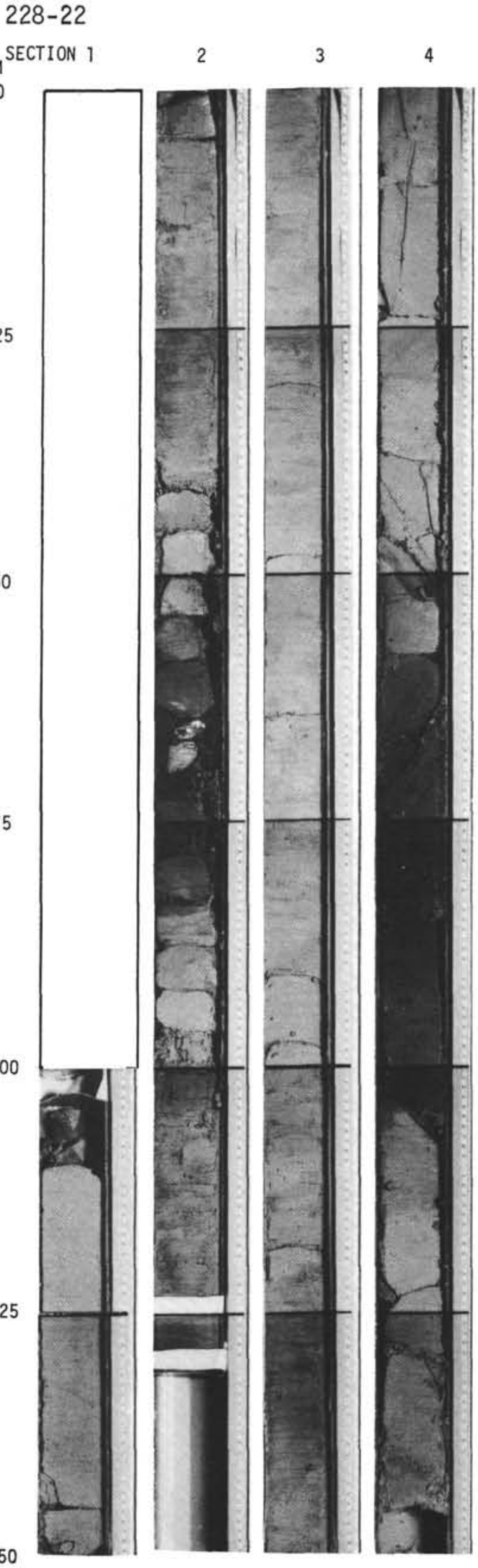

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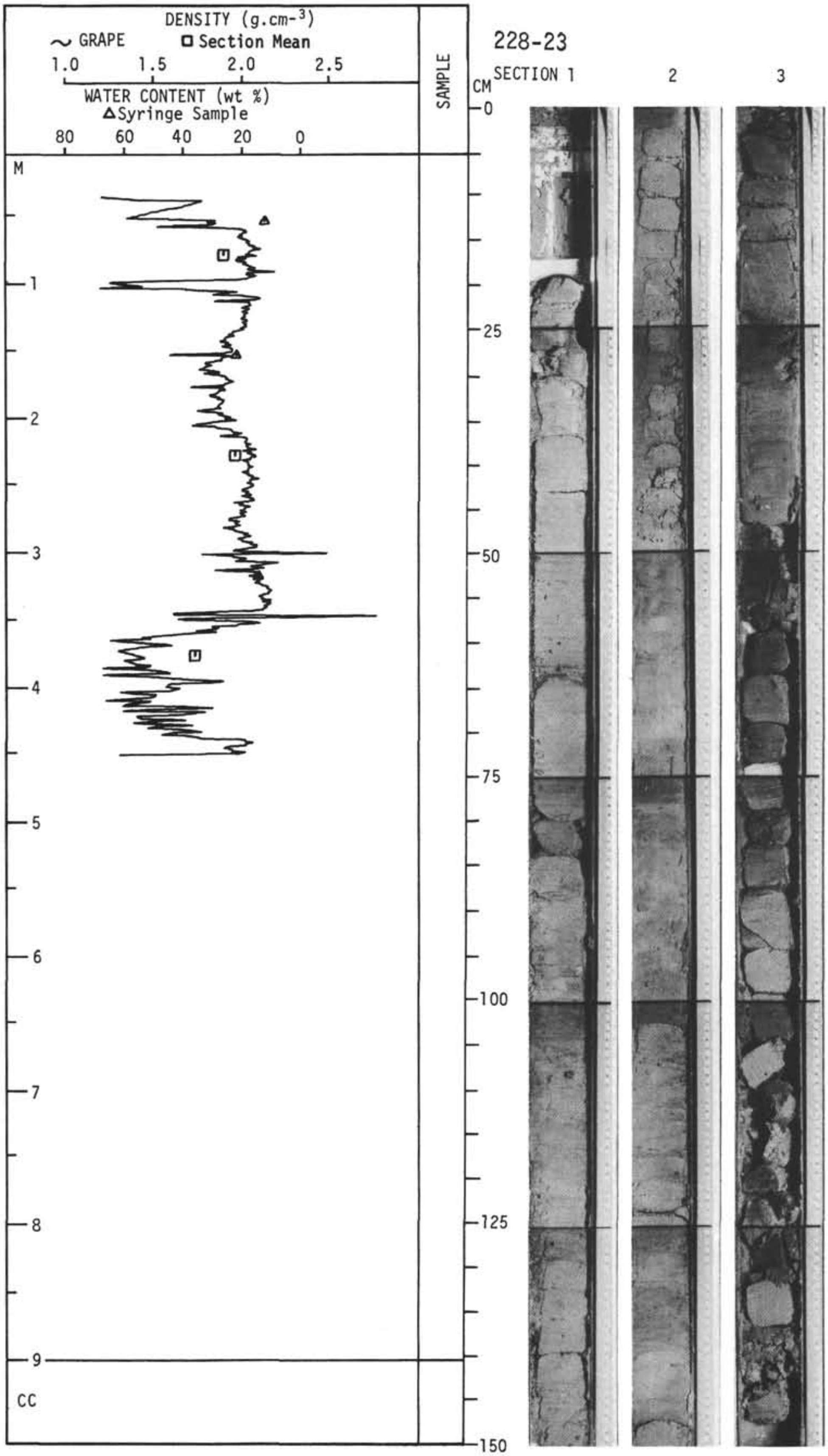

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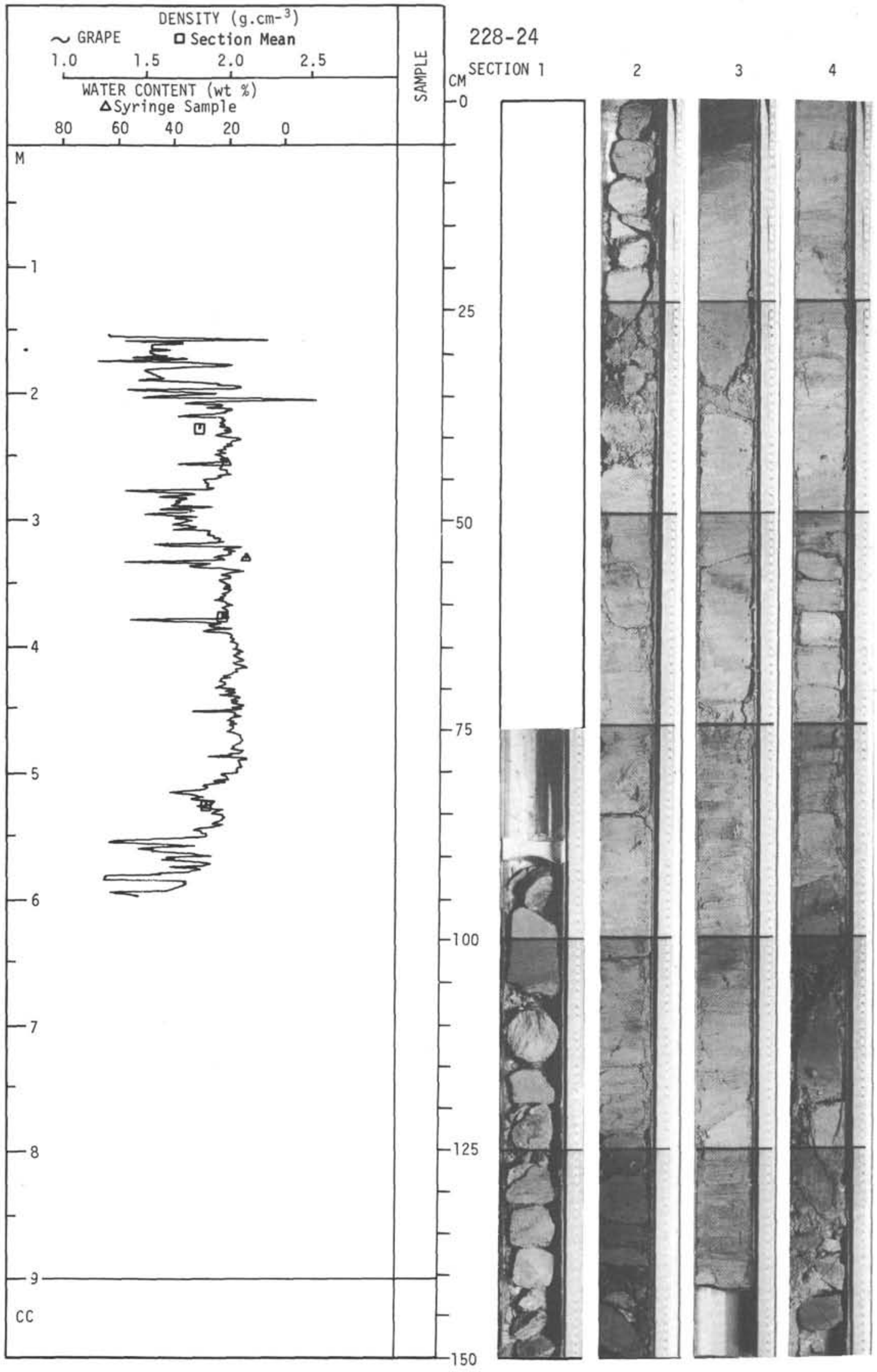

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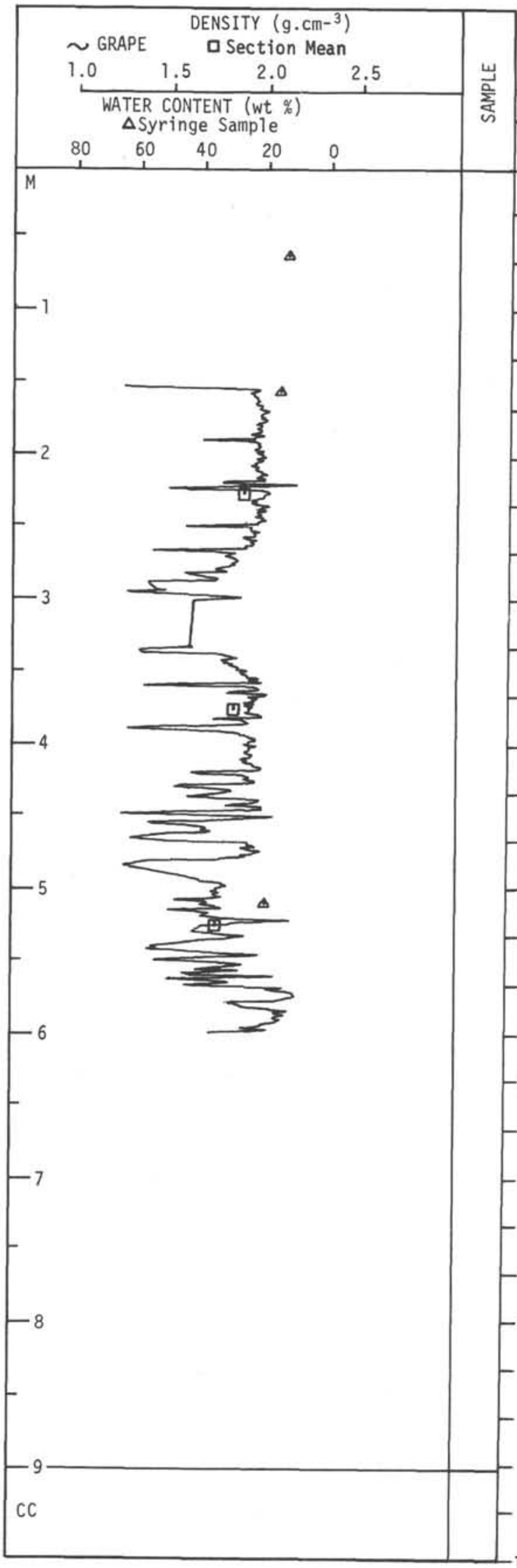

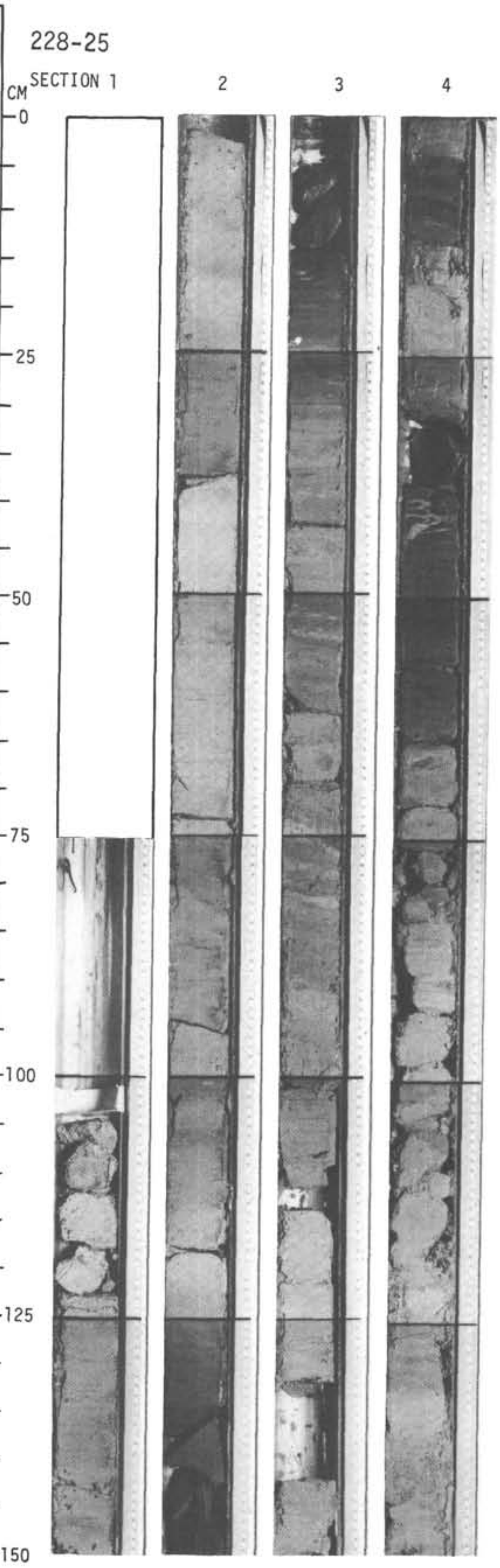

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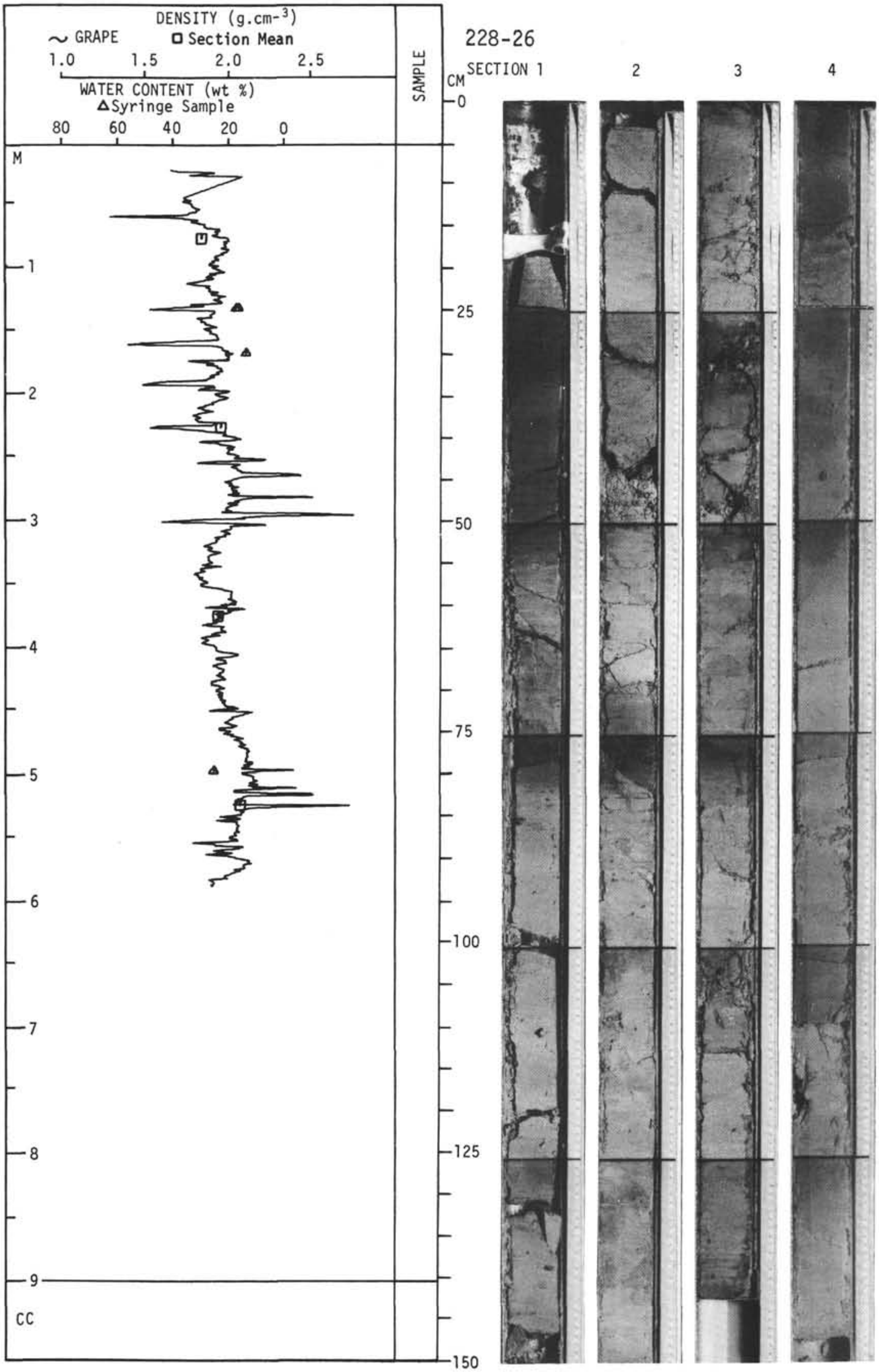

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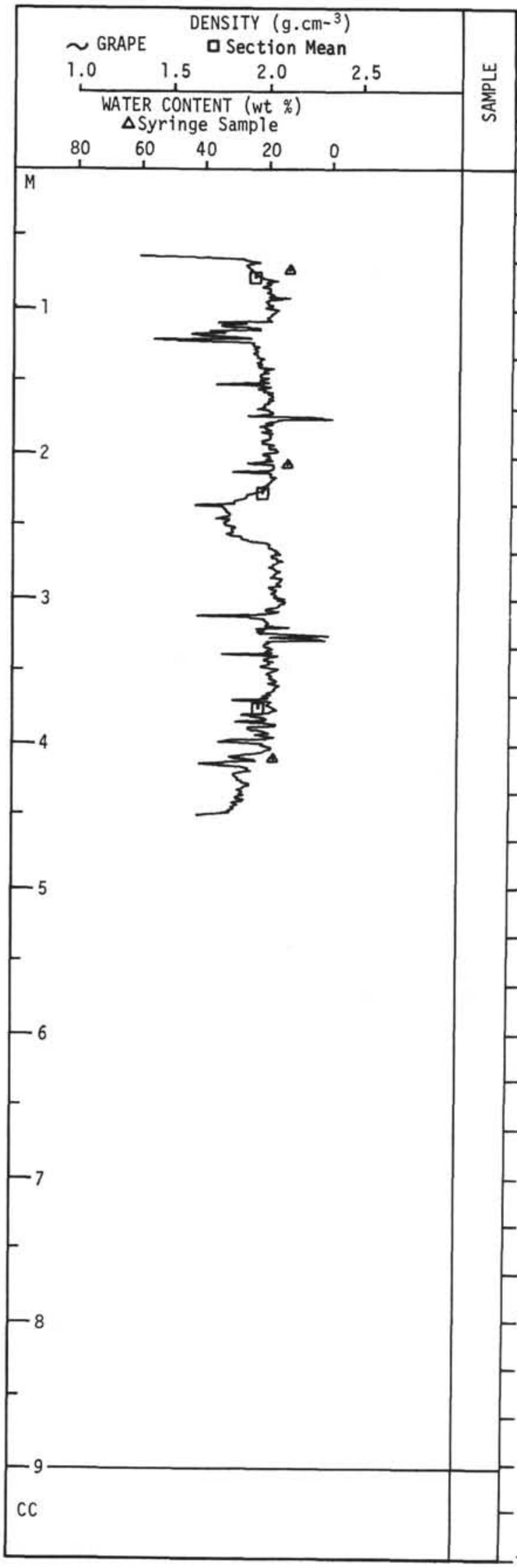

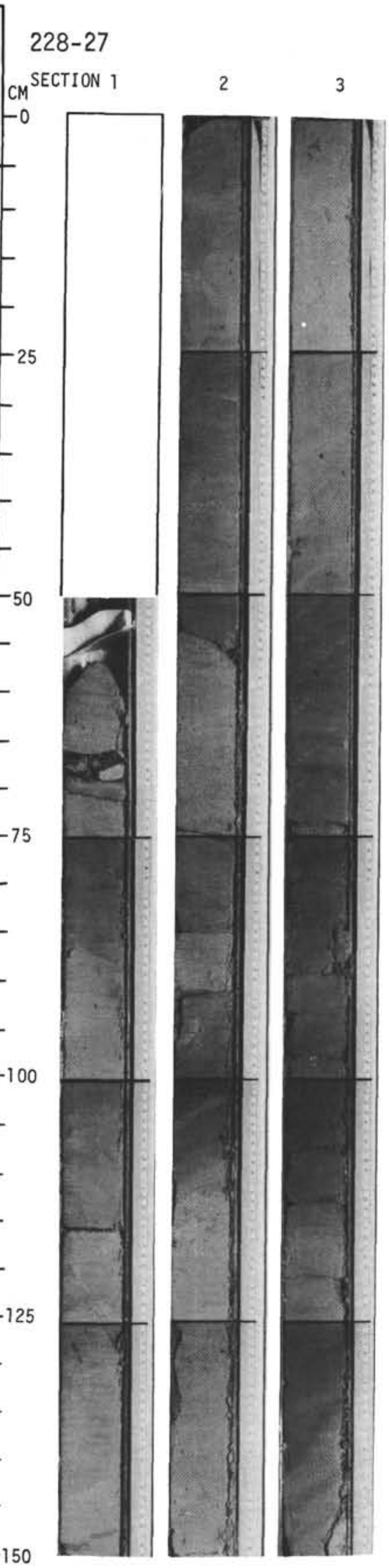

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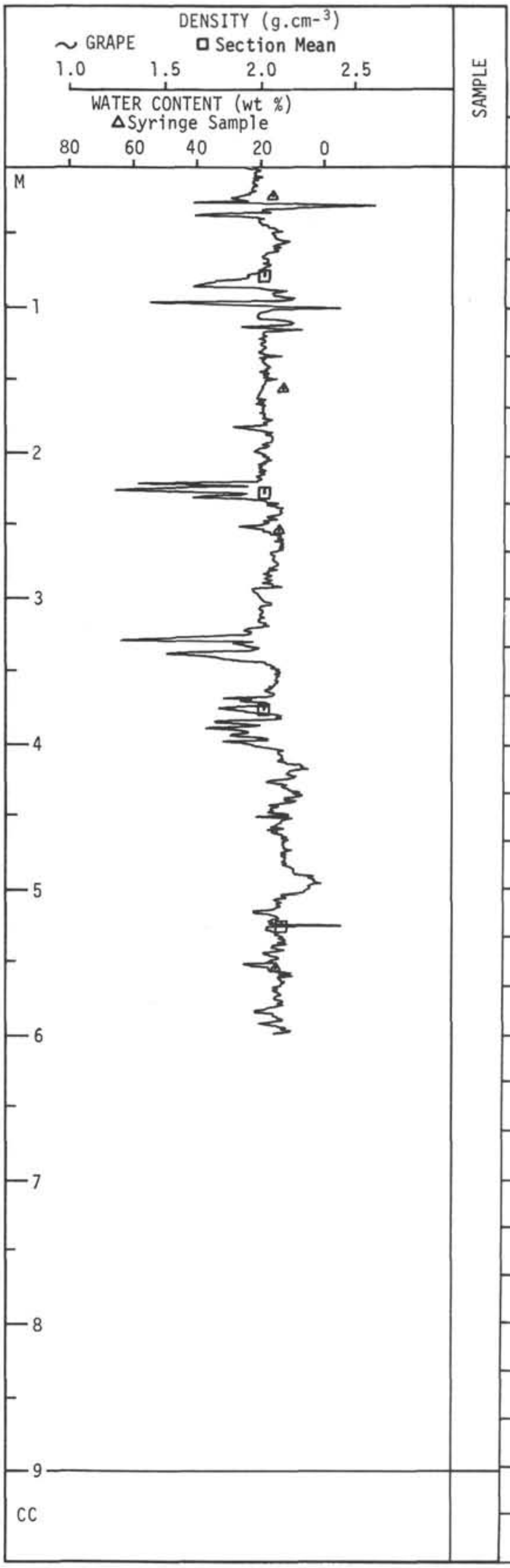

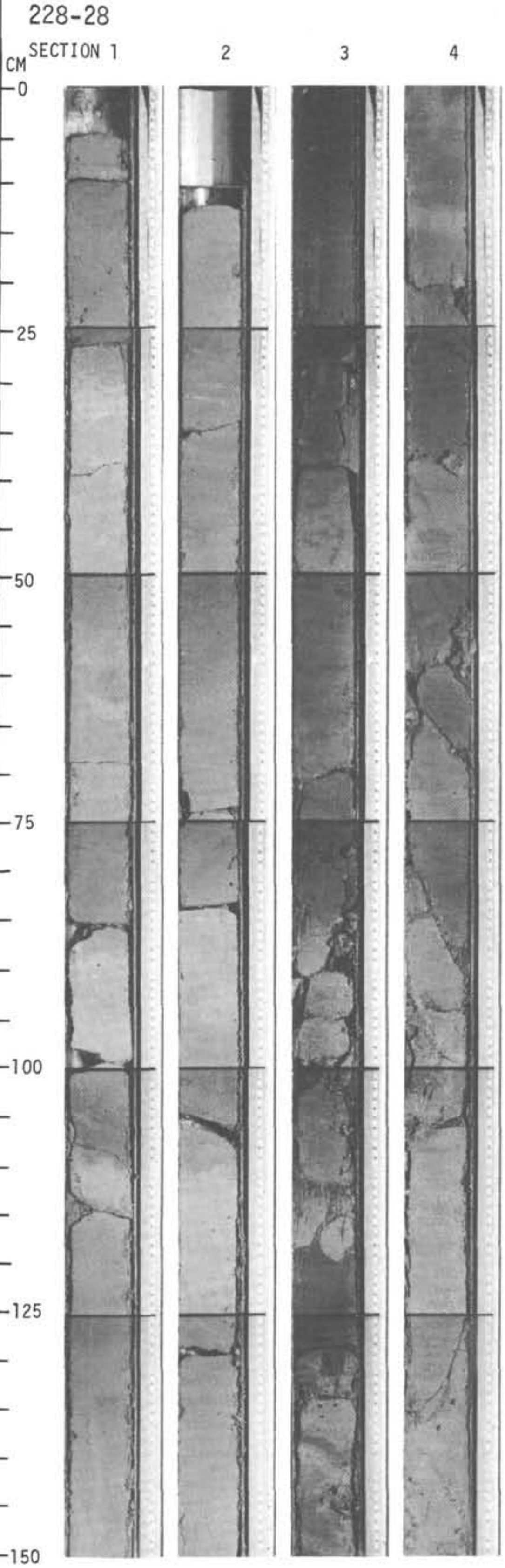

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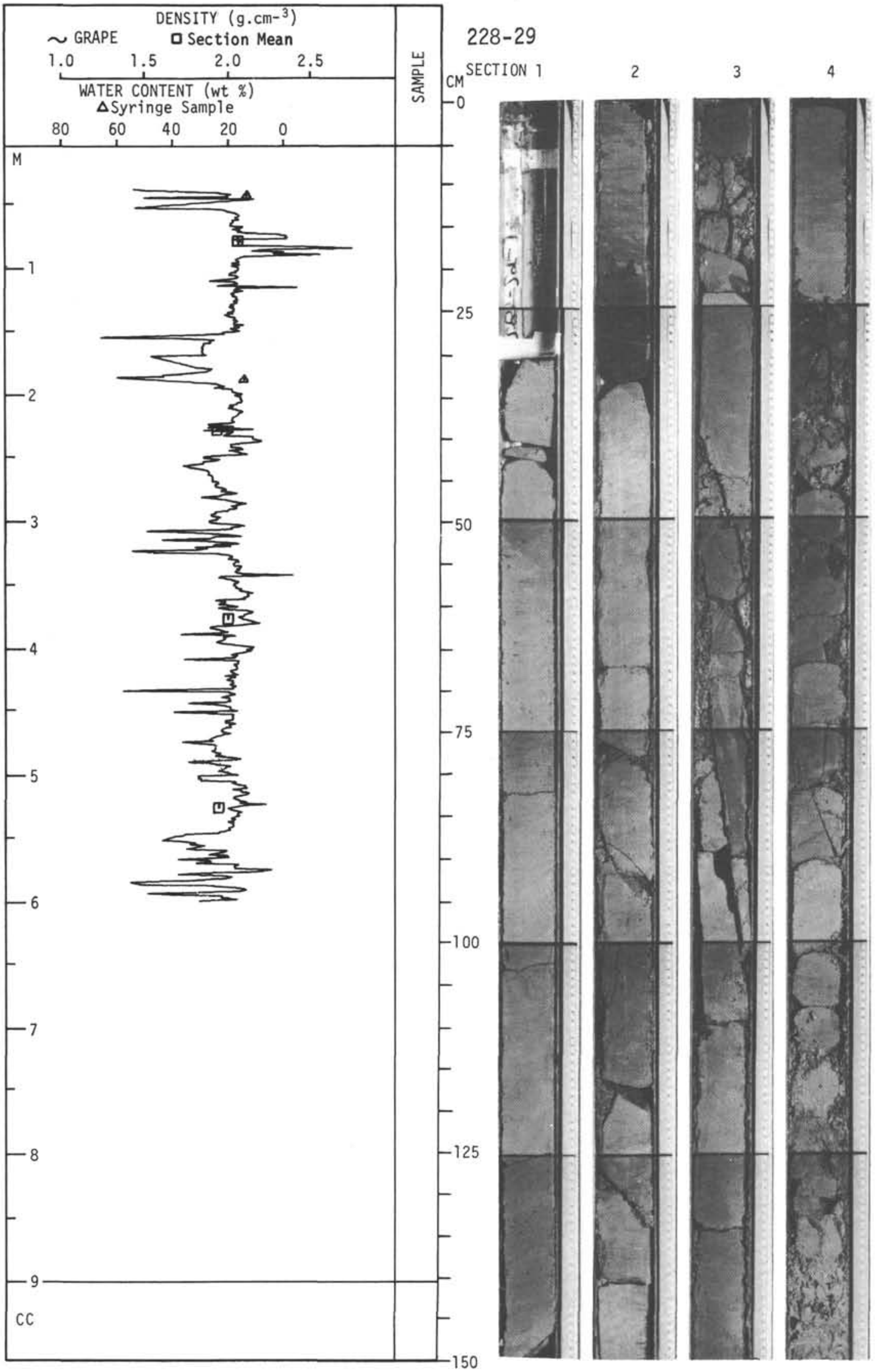

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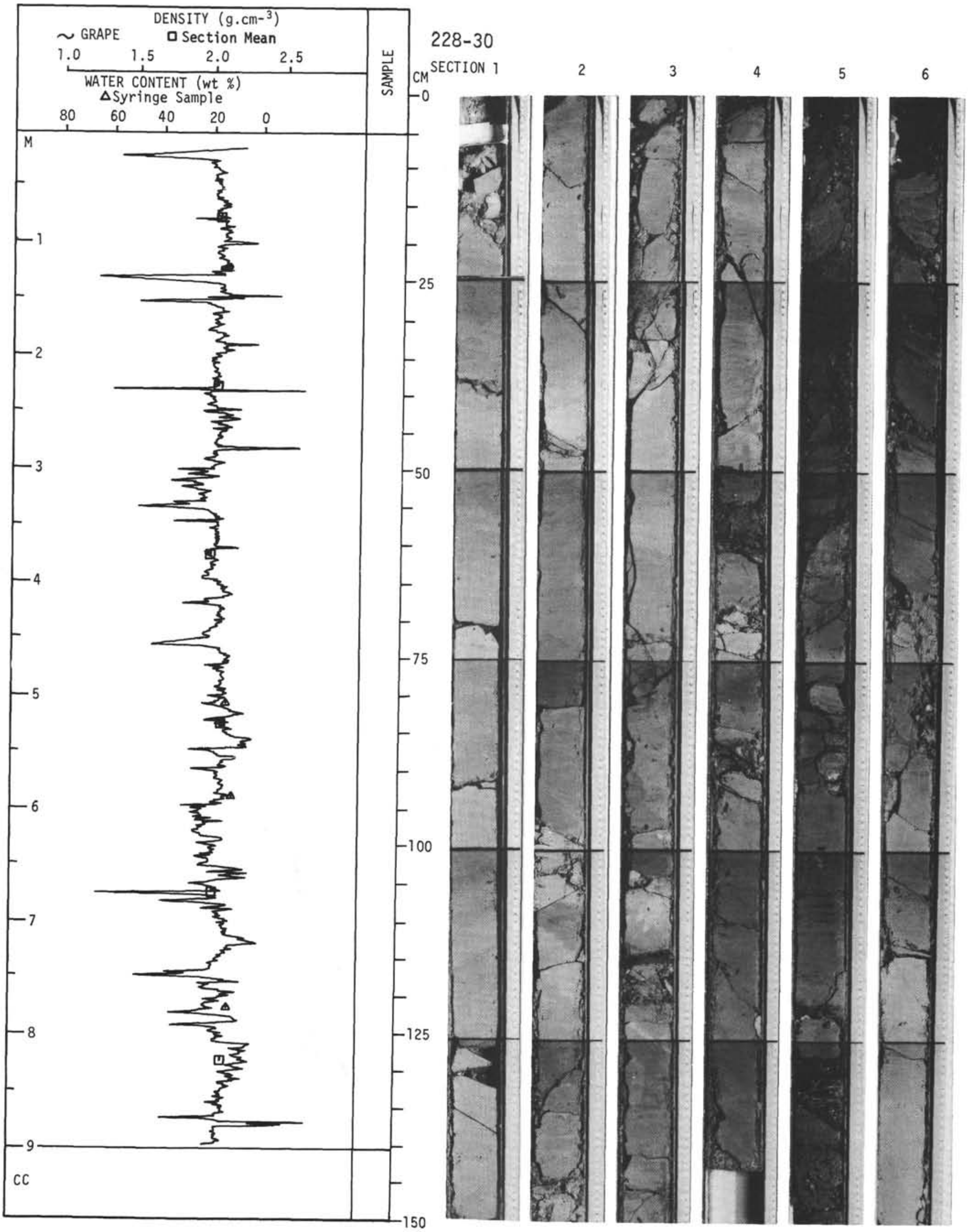

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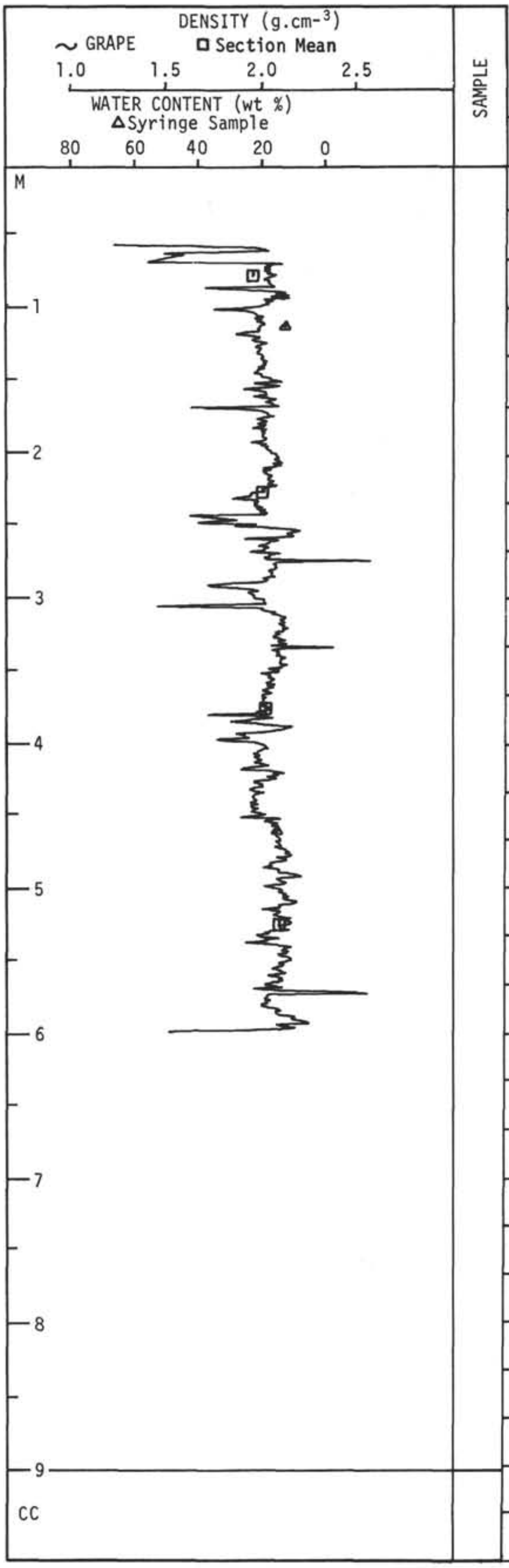

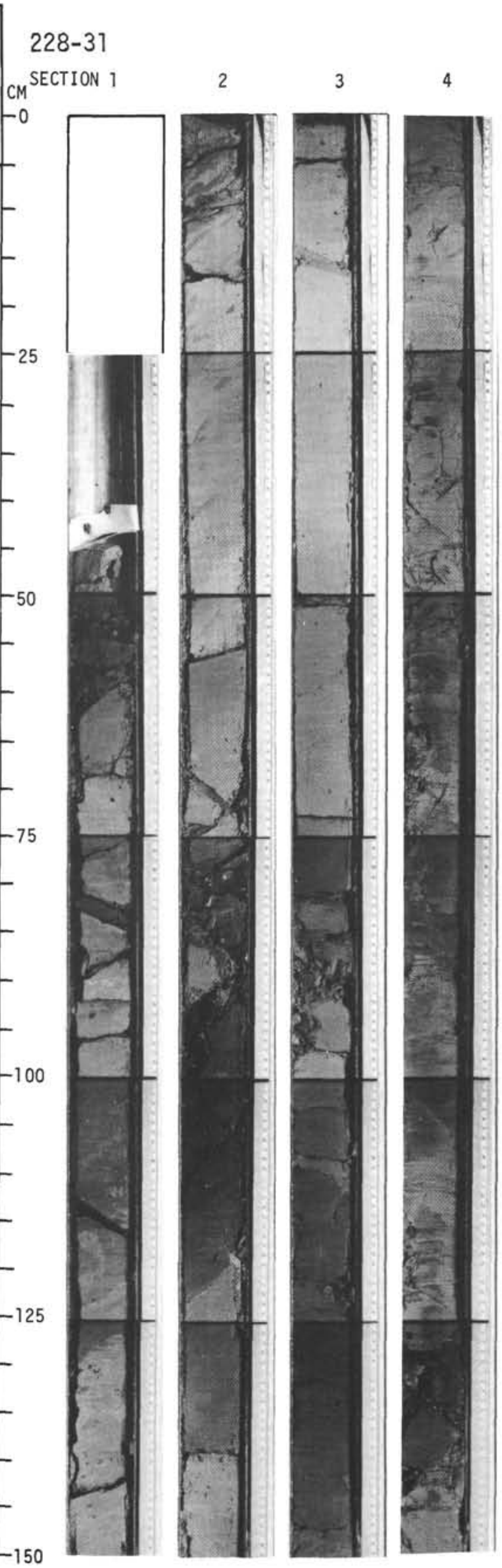

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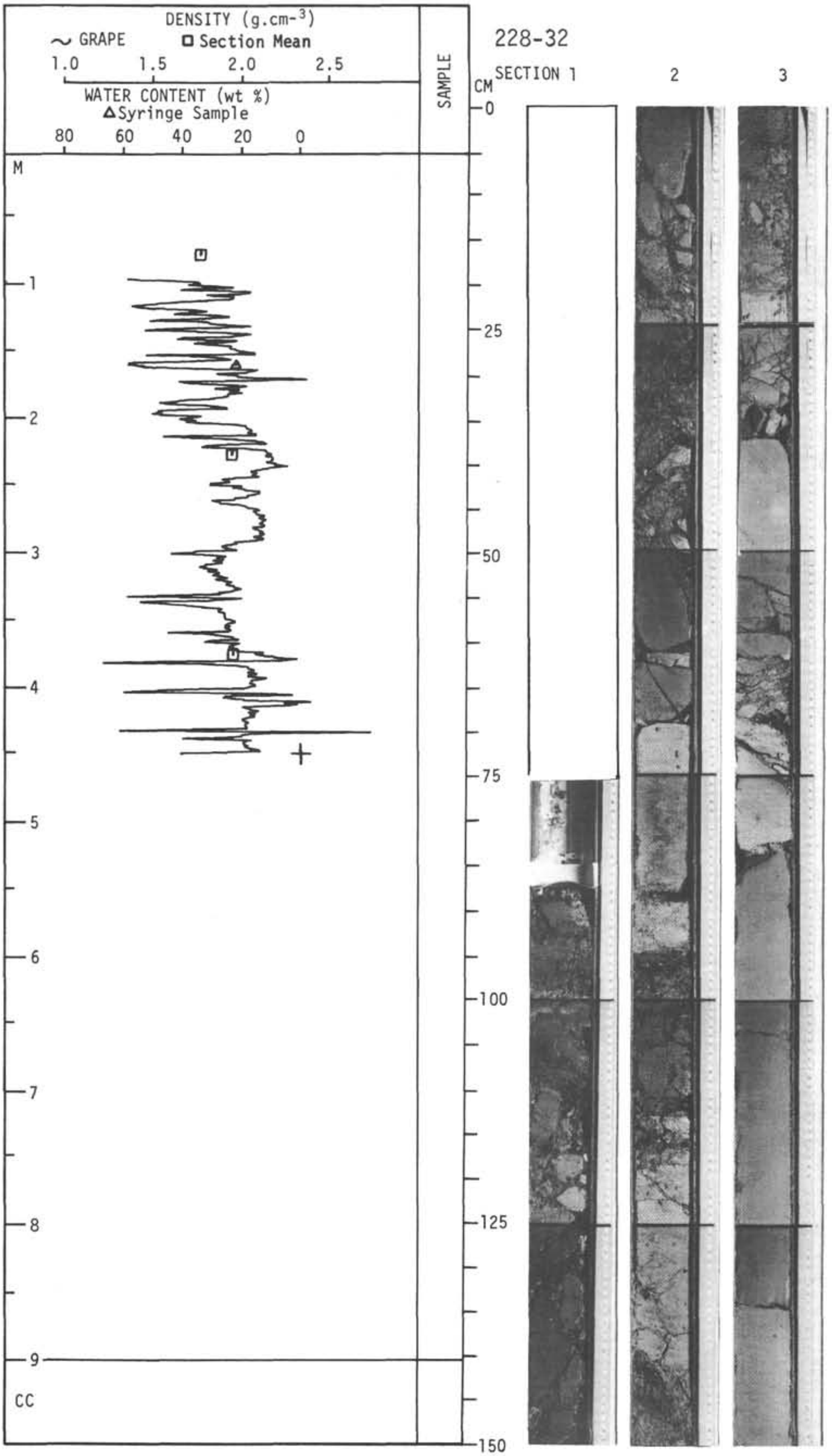

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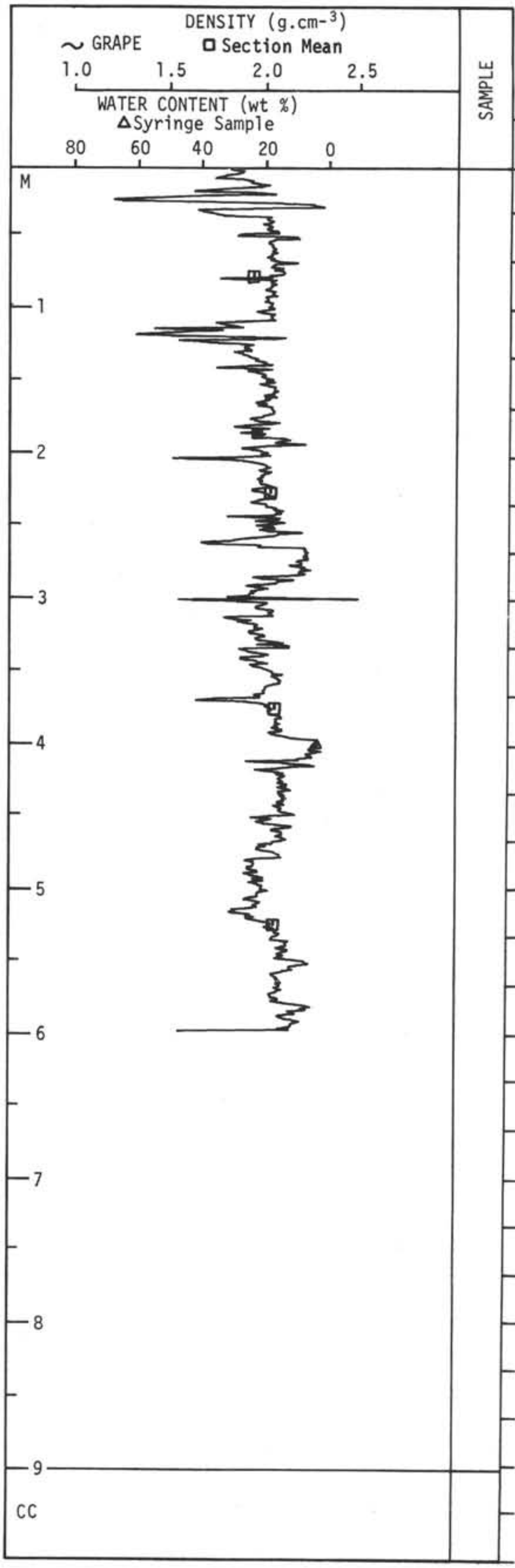

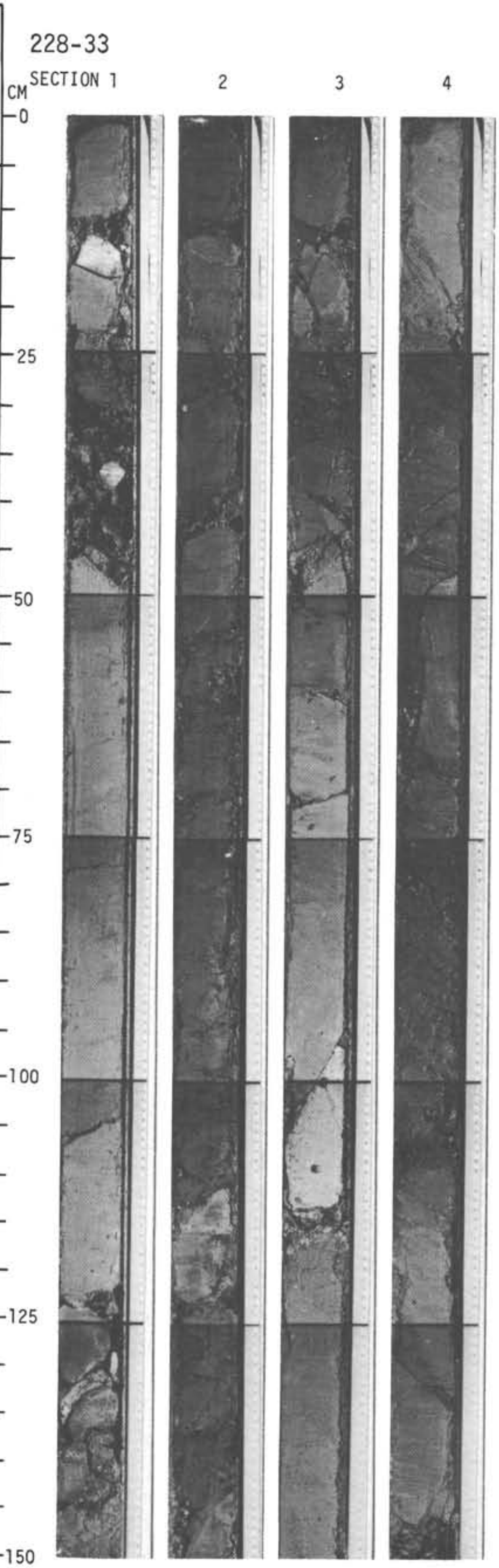

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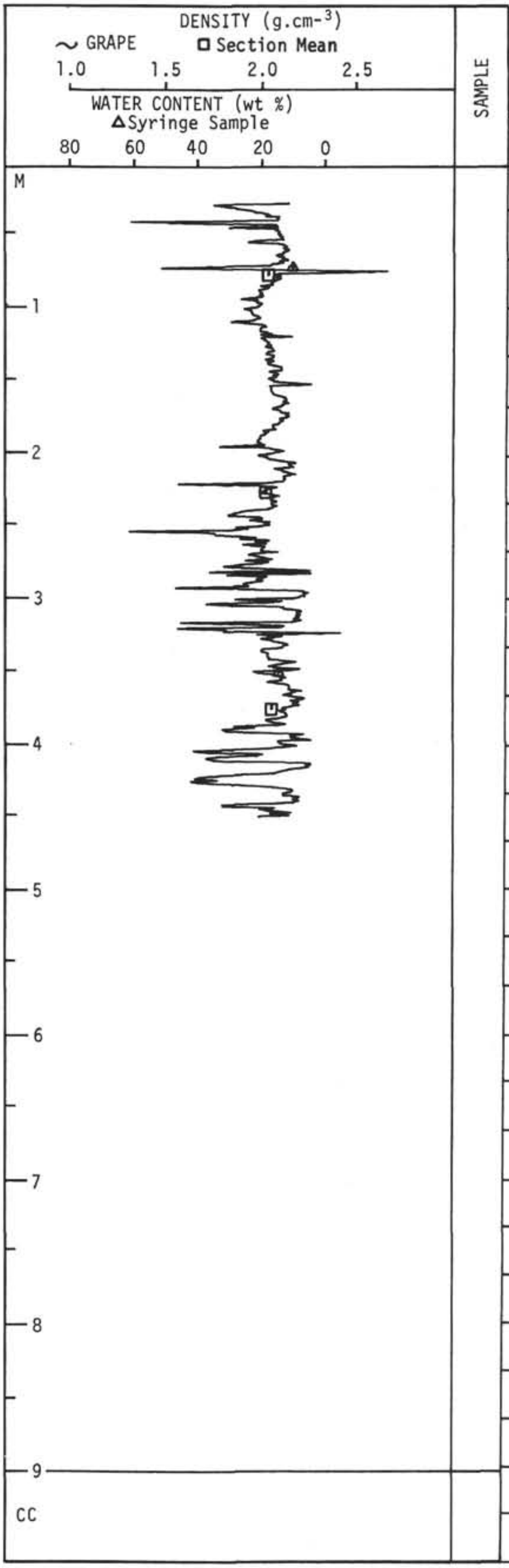

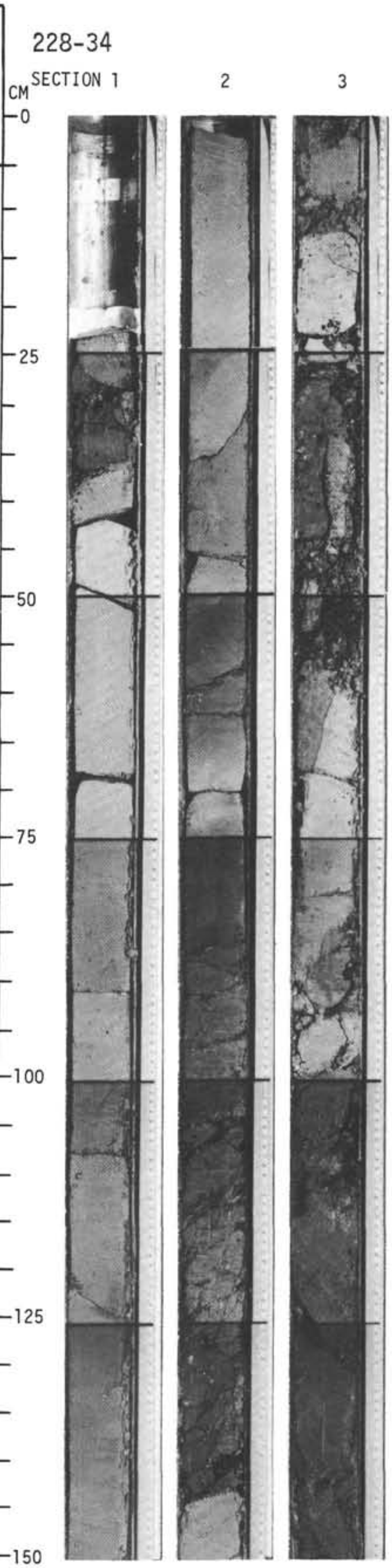

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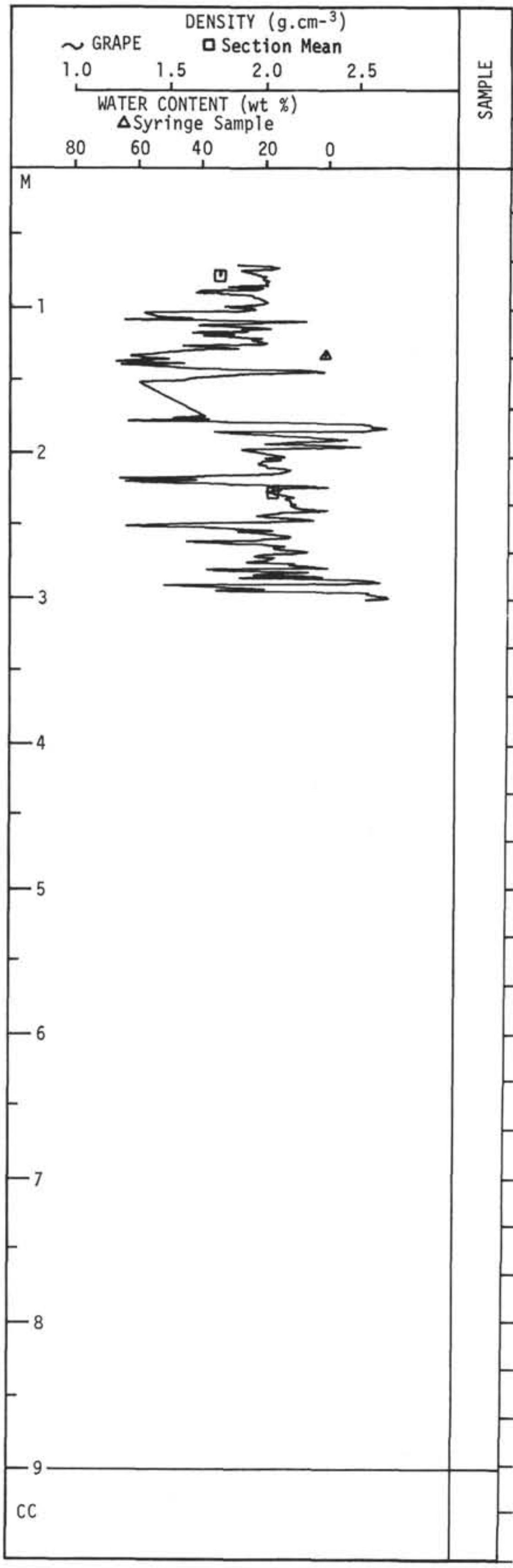

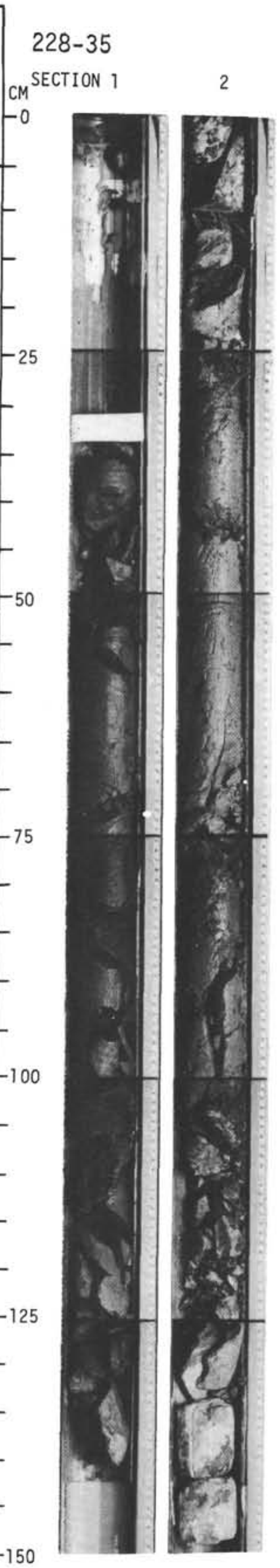

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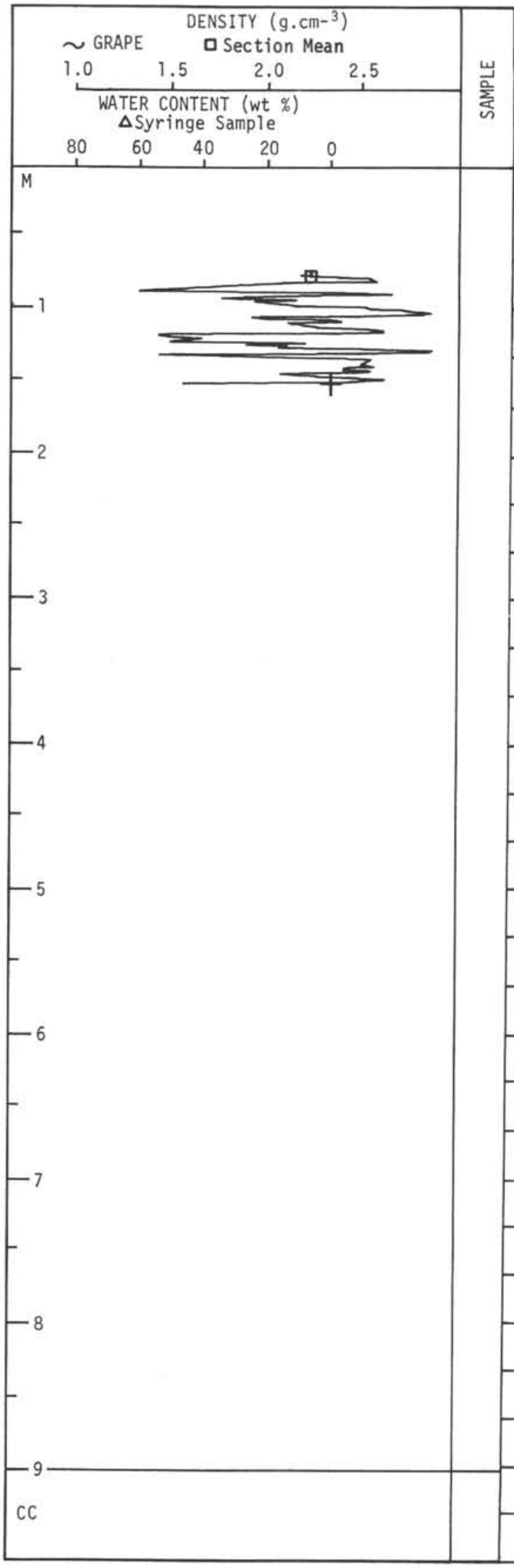

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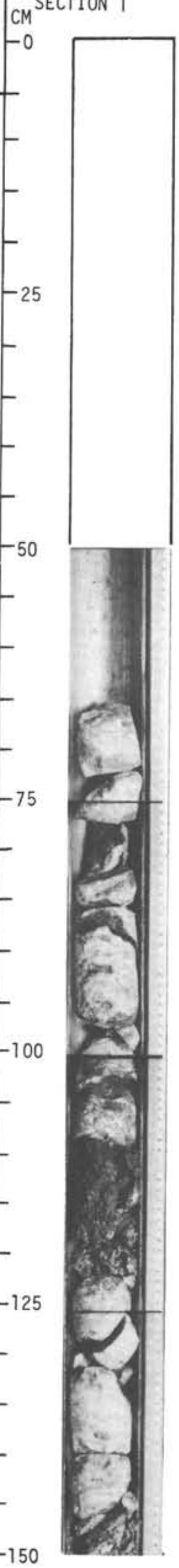
SECTION 1



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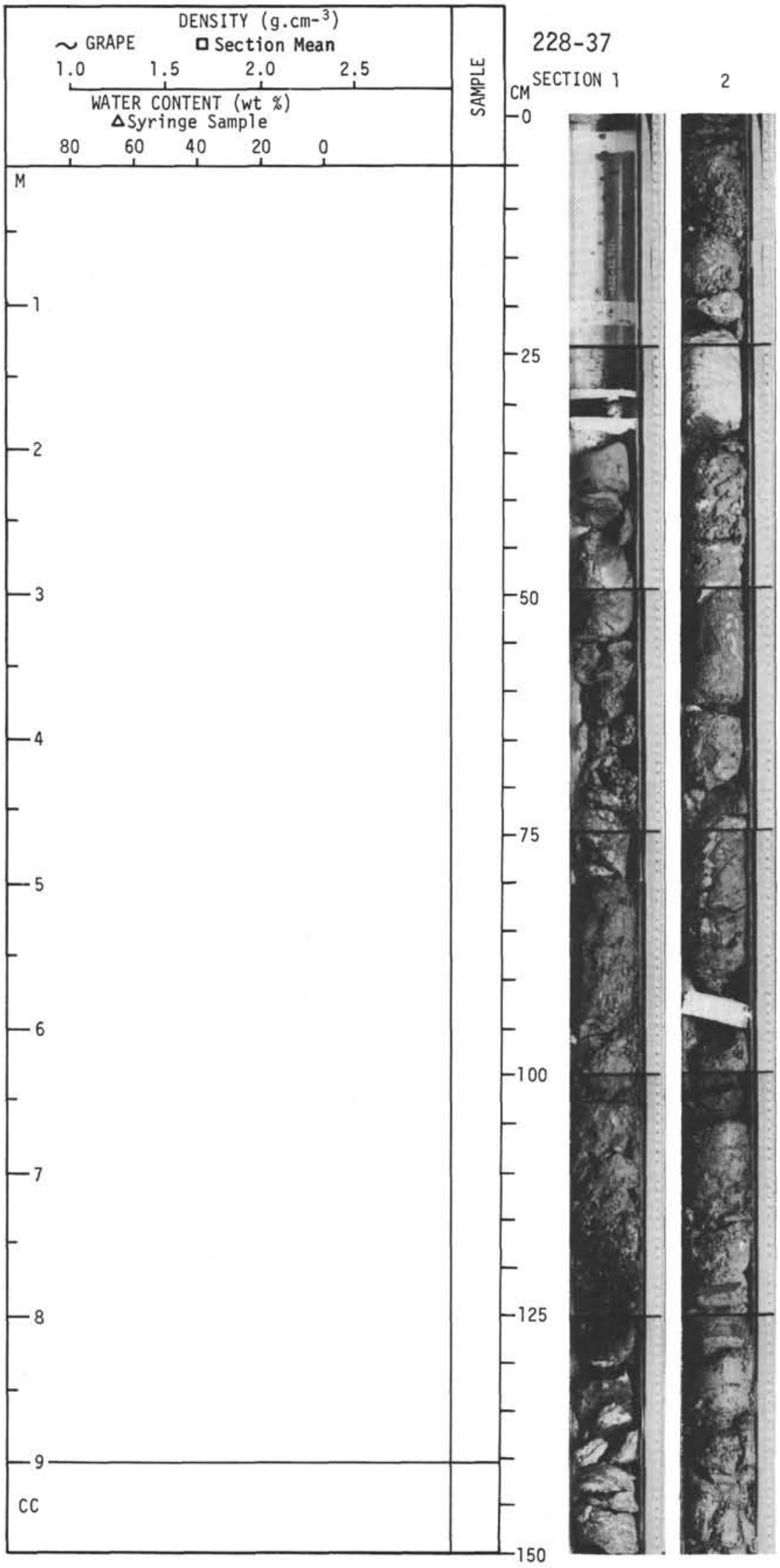

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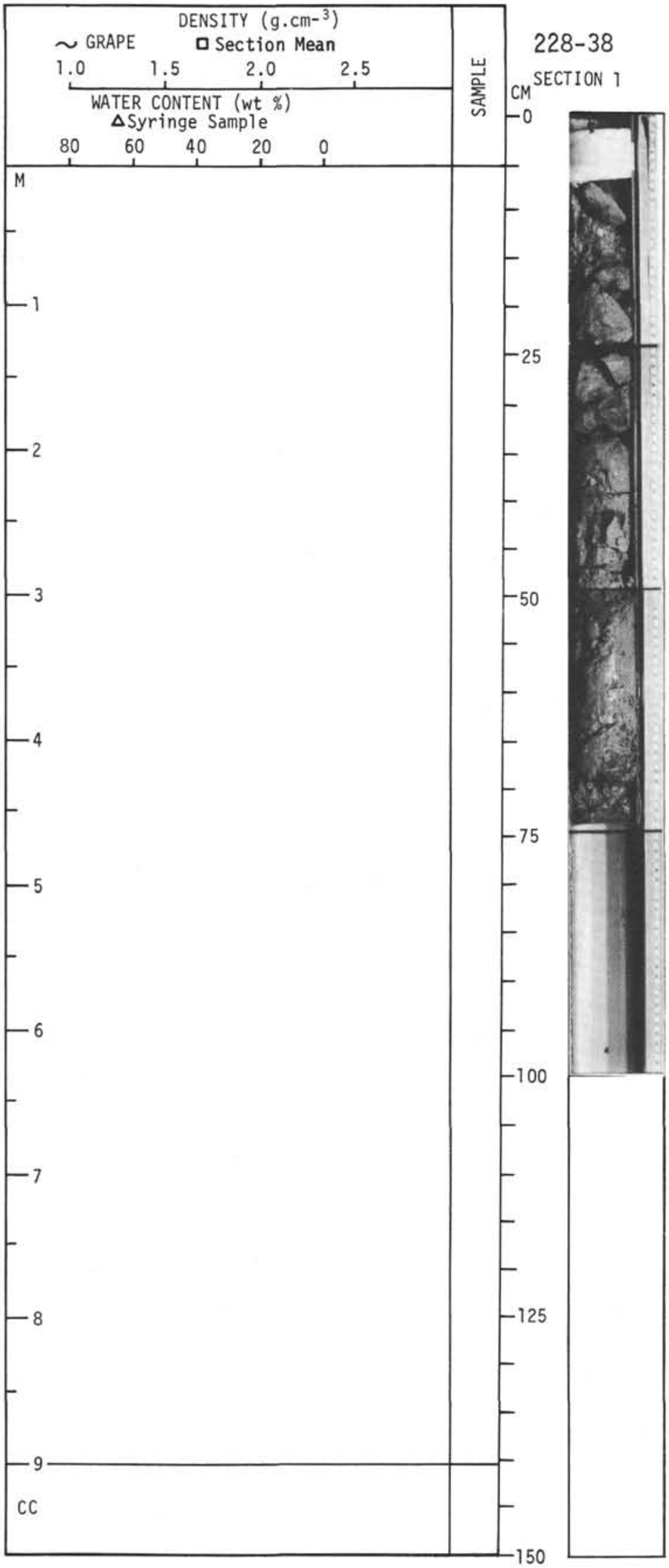

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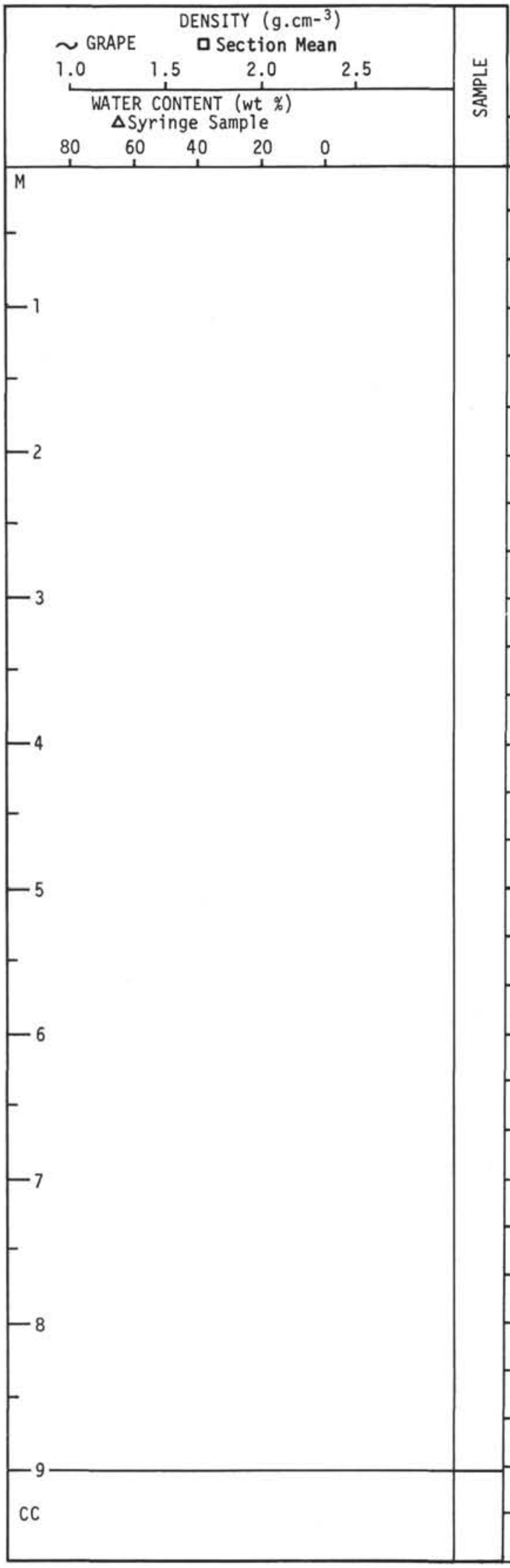

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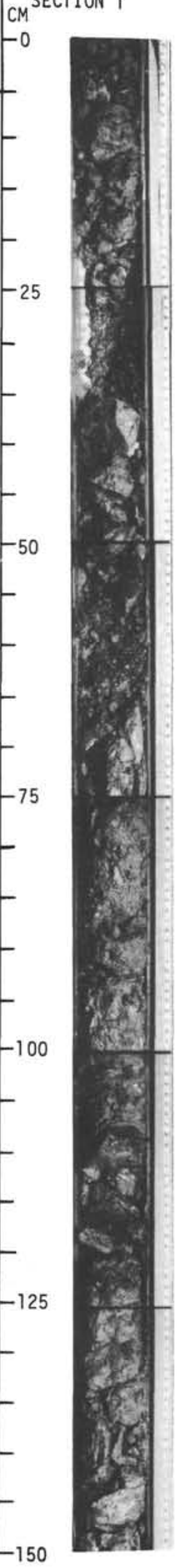
SECTION 1



For Explanatory Notes, see Chapter 2