4. SITE 328

The Shipboard Party[1]
With Additional Reports From
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SITE DATA

Date Occupied: 24-30 April, 1974

Time on Site: 137 hours, 15 minutes.

Position (satellite): 49°48.67'S, 36°39.53'W

Number of Holes: 3

Water Depth: 5095 corrected meters (echo sounding)

Bottom Felt at: 5103 meters (drill pipe)

Penetration:
Hole 328: 397 meters
Hole 328A: 17 meters
Hole 328B: 471 meters.

Number of Cores:
Hole 328: 12
Hole 328A: 2
Hole 328B 8[2]

Total Core Recovered:
Hole 328: 62.1 meters (55%)
Hole 328A: 7.4 meters (44%)
Hole 328B: 62.5 meters (94%)

Age of Oldest Sediment: Upper Cretaceous

Acoustic Basement: Not penetrated, but estimated to lie at about 574 meters below sea bed.

Summary: Site 328 in 5103 meters of water in the Malvinas Outer Basin immediately to the east of the Falkland Plateau and to the south of the Falkland Fracture Zone, was chosen to examine correlatives of Argentine Basin acoustic reflectors, to obtain a deep-water southerly biostratigraphic section, and if possible, to date the underlying oceanic basement. Three holes were drilled at the site. The deepest penetrated 471 meters and bottomed in Upper Cretaceous gray zeolitic claystone.

The top 13.5 meters consist of late Miocene-Quaternary diatomaceous ooze with abundant manganese nodules, sand, and large clasts. The lithology of these presumably ice-rafted clasts does not identify a specific source area. All are found around the Weddell Sea margin and the Antarctic Peninsula. The underlying 34 meters of silty, biogenic siliceous clay is of late Eocene-late Miocene age. Below this sediment Upper Cretaceous or Paleocene-upper Eocene siliceous clay and claystone extends to about 300 meters subbottom. The remainder of the section consists of Upper Cretaceous zeolitic claystone.

The reflector correlated with Horizon A of the Argentine Basin appears to represent a gradual diagenetic change from clay to claystone rather than a distinctive lithic layer. Extrapolation of sedimentation rates suggests that the uncored acoustic basement is of Albian age. The relatively high rate of sedimentation represented by the Upper Cretaceous-upper Eocene clay and claystone is believed to have been related to the mid-Cretaceous uplift of the Andean cordillera. A substantial reduction in sedimentation rate, decrease in clay content, and major breaks in the stratigraphic record indicate increase in bottom current velocity in the late Eocene continuing through the Miocene. Cold water microfossils become dominant in the middle Miocene, and certain ice-rafted material appears in the upper Miocene.

BACKGROUND AND OBJECTIVES

Site 328 is situated in the Malvinas Outer Basin (Ewing and Lonardi, 1971), which lies directly north of South Georgia and east of the Falkland Plateau. The northern boundary of the basin is the Falkland Fracture Zone, a narrow east-west basement ridge; Site 328 lies 90 km southwest of the single prominent gap in that ridge, through which the main northward flow of Antarctic Bottom Water is considered to take place (Figure 1).

The site lies in 5095 meters of water and sediment thickness is estimated to be about 574 meters. Nearby reflection profiles (*Robert Conrad* 16-09; see Figure 2) indicate the presence of a thin (<0.1 sec) stratified layer above a seemingly homogeneous layer extending to a smooth acoustic basement at about 0.7 sec, and with only one very weak and diffuse intermediate reflector at about 0.5 sec. Further to the southwest, northwest of South Georgia, the upper stratified layer thickens to more than 1.5 sec, and was considered by Ewing and Lonardi (1971) to be a distal turbidite, although acoustic penetration was anomalously good. The underlying homogeneous layer, with its weak, diffuse intermediate reflector (Horizon A) and smooth, acoustically opaque base (Horizon B) has been seen through much of the Argentine Basin. There, Horizon A was tentatively correlated by Ewing et al. (1971) with an Eocene chert horizon found in the North Atlantic,

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[2] Core 8 of Hole 328B was recovered when the bottom-hole assembly came on deck and probably comes from 471 meters, the greatest depth drilled.

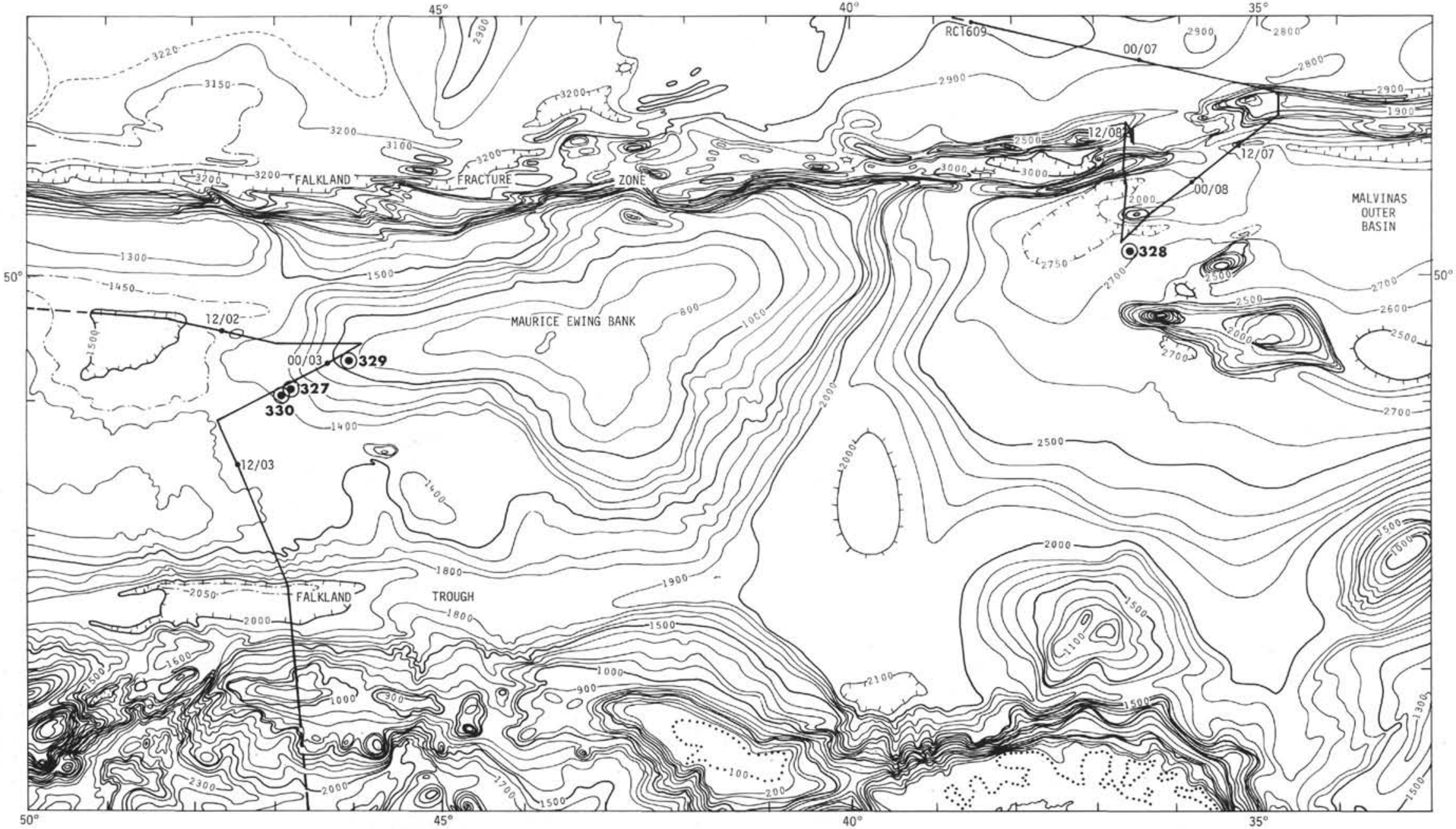


Figure 1. *Bathymetry of the Malvinas Outer Basin in the vicinity of Site 328 (after Lonardi and Ewing, 1971), with* Robert D. Conrad *16-06 track.*

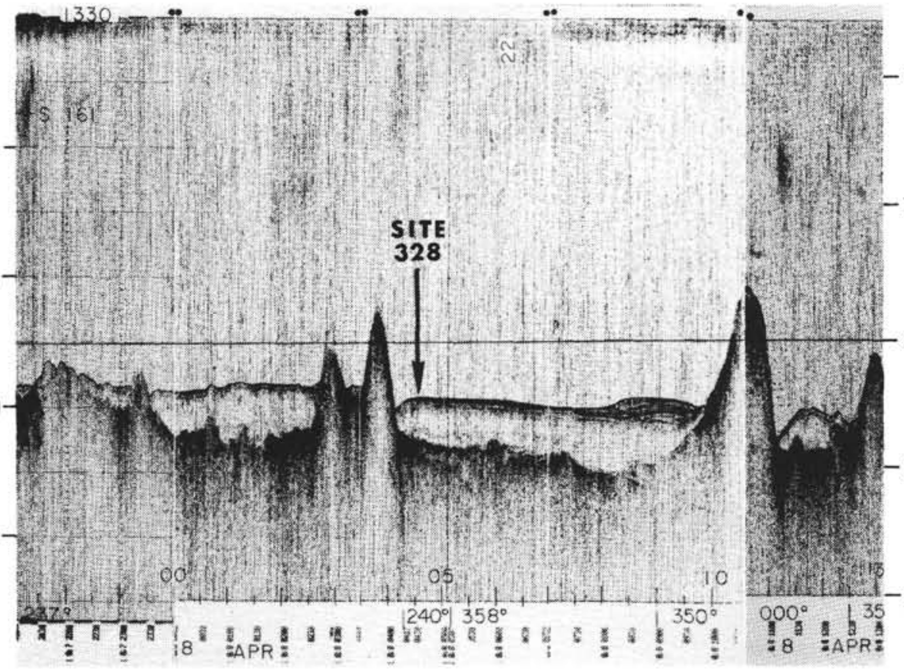


Figure 2. Robert D. Conrad *16-06 reflection profile in the vicinity of Site 328 (see Figure 1 for track).*

and Horizon B, which obscures all but the highest oceanic basaltic basement peaks, with an earlier turbidite deposit.

The objectives at Site 328 were thus:

1) To determine the age of oceanic basement in the Malvinas Outer Basin.

2) To establish the nature and age of Horizons A and B and the upper stratified horizon.

3) To sample a high-latitude, deep-water stratigraphic column for comparison with the shallow-water Falkland Plateau sites (327, 329) and an Argentine Basin site further north (331).

4) To provide information on the glacial history of the region, Antarctic Bottom Water movement, initiation of the circum-polar current (Drake Passage opening), and possibly the separation of South America and Africa.

SURVEY AND OPERATIONS

The original locations of the three options for Site 328 had to be abandoned, being closer than 200 miles to South Georgia and hence in waters claimed by Argentina. A revised position was chosen on the basis of an RC 16-09 reflection profile (Figure 2) so as to permit the same basic objectives to be attained. The main sedimentary section showed 0.8 sec subbottom reflection time to Horizon B, a smooth reflector, overlying and usually masking the normal oceanic basaltic basement. At a point on the flank of the basin, however, this time was reduced to 0.65 sec, making Horizon B accessible. Further site survey was necessary to see if this flank province was more extensive off the preexisting tracks and could be considered representative of the basin as a whole.

Glomar Challenger approached along 334°T, slowing to 5.5 knots at 0132 on 24 April (Figure 3). A more extensive area with Horizon B at 0.65 sec was indeed visible on this profile (Figure 4), and a faint, diffuse Horizon A could be seen at 0.45 to 0.5 sec subbottom. Apart from this, and a trace of multiple reflections in the uppermost 0.05 sec, the sediments were transparent.

A check line was steamed at 110°T through the original position on track RC 16-09 and extended to guard against a southwest extension of the basement outcrop seen on that profile. The beacon was dropped at 0700 on 24 April, in 5095 meters of water in the middle of the newly surveyed flank province. Horizon B lay at 0.68 sec subbottom (see Figure 4).

The ship commenced lowering pipe at 0800 but because of positioning problems and the close approach (within 3 km) of an iceberg, the drill string was not spudded in until 0600Z (Table 1) on 25 April. The first core came on deck at 0950Z, and 11 others were cut in the next 28 hr, continuously to 26.5 meters and then intermittently to 397 meters subbottom. The wind speed then increased to the point at which, because of a 1 to 2 knot current, the ship could not keep station without withdrawing power from the Bowen unit. The pipe was pulled and the drill bit came on deck at 0300Z on 27 April. Meanwhile a sonobuoy line had been fired, between 1300 and 1500Z on 26 April, but without success because of rising seas. The bit was changed and the string lowered again, pausing at 1780 meters for successful tests of the Schlumberger unit. The pipe was spudded in at 0015Z on 28 April and the first (surface) core of Hole 328A came onboard at 0140Z, the plan being to core continuously the first seven intervals, so as to sample fully the interesting Neogene section found in Hole 328, and then to drill to below the last core of that hole before coring again. However, the second core gave very poor recovery and the bit was pulled out of the sea bed and respudded to repeat that interval,

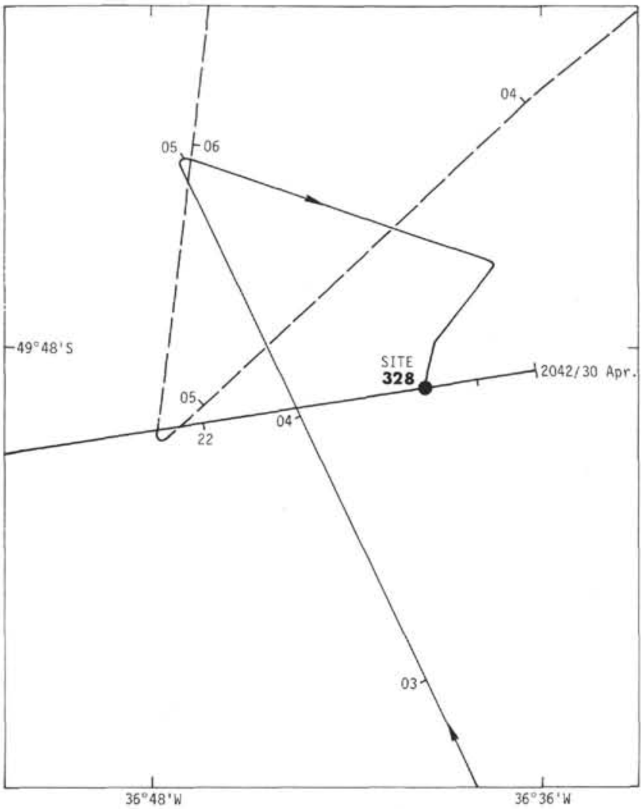


Figure 3. Glomar Challenger *track approaching Site 328.*

thereby terminating Hole 328A and starting 328B. Recovery this time was good, and the remaining shallow intervals were quickly cored. A center bit then replaced the core tube for 13 hr before Core 7 was acquired at 435 to 444.5 meters subbotton. Before the next coring interval was reached, the nearness of an iceberg caused the pipe to be lifted to 5250 meters, so that about 150 meters of pipe remained in the hole. It appears that when the pipe was again lowered, after the iceberg had passed, the bit started to sidetrack rather than run easily back into the hole; the drillers noted some loss in string weight, which was regained after rotation but lost again upon lowering further. This time the pipe would not rotate, and it was feared that the bottom-hole assembly had been lost. The string weight increased again as pipe was pulled, however, and it seems fairly certain that some of the extra pipe lowered had been laid on the ocean floor. The string was recovered, coming on deck at 0015 on 30 April, and three joints of pipe were found to have been bent. A short core section found in the core tube was unlike anything found higher in the hole and is thought to have come from 471 meters, the depth reached before the approach of the iceberg.

Signals from the 13.5-kHz beacon were diminishing, so a 16-kHz beacon was dropped, some 0.25 km to the southwest. Because of high winds the pipe was not started down until 1400 on 30 April and was raised at 1700 on receipt of a forecast of further bad weather. The site was abandoned, and by 2115 the ship was passing over the new beacon position headed along 261° at 5-6 knots, bound for Site 329 on the Falkland Plateau.

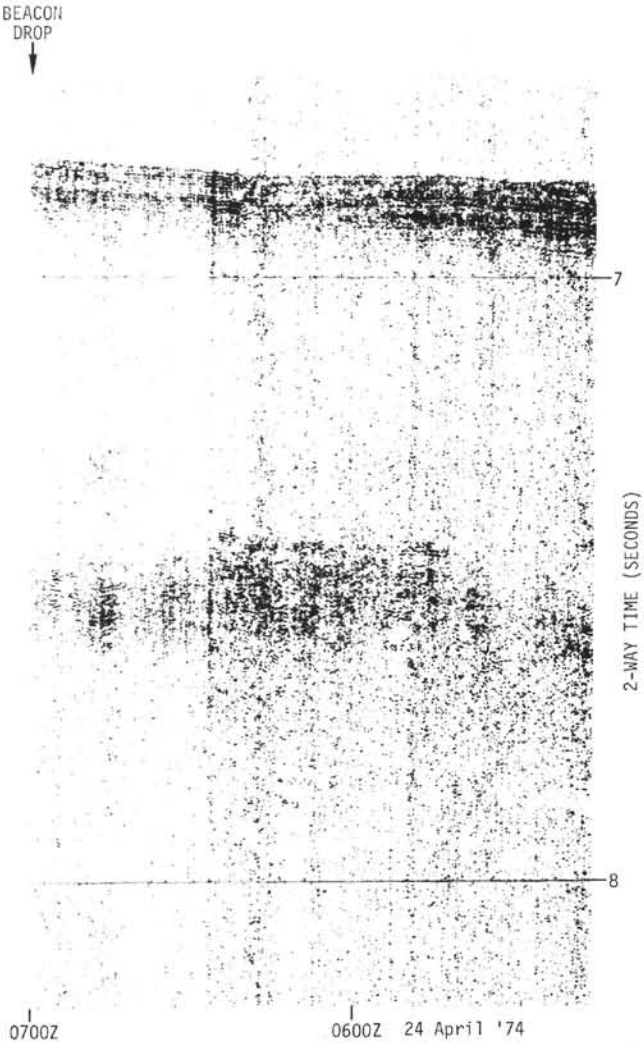


Figure 4. Glomar Challenger *reflection profile in the vicinity of Site 328 (see Figure 3 for track).*

LITHOLOGICAL SUMMARY

General Statement

Site 328 was spudded in the Malvinas Outer Basin east of the Falkland (Malvinas) Plateau in a water depth of 5103 meters. Three holes were drilled that, combined, amounted to continuous coring to 65 meters with overlap and intermittent coring thence to 471 meters subbottom. The lithology of a-l three holes is considered as a continuous section. The sedimentary column is described in terms of four lithologic units (Figure 5). However, the boundary between the third and fourth units is approximate as it occurs in an uncored interval.

Unit 1 (0-13.5 m, Cores 1-2 of Holes 328 and 328A, Core 1 of Hole 328B)

The upper unit consists of 13.5 meters of predominantly diatom ooze and clayey diatom ooze that is distinguished by a subordinate component of silt- to pebble-size detritus. The ooze is soft and slightly sticky. Yellow, gray, green, and olive-gray colors

TABLE 1
Coring Summary, Site 328

Core	Date (April 1974)	Time (GMT) Z	Depth From Drill Floor (m)	Depth Below Sea Floor (m)	Length Cored (m)	Length Recovered (m)	Recovery (%)
Hole 328							
1	25	0950	5103.0-5110.5	0-7.5	7.5	7.4	99
2	25	1125	5110.5-5120.0	7.5-17.0	9.5	8.0	84
3	25	1255	5120.0-5129.5	17.0-26.5	9.5	9.0	95
4	25	1430	5148.5-5158.0	45.5-55.0	9.5	6.9	73
5	25	1615	5196.0-5205.5	93.0-102.5	9.5	3.3	35
6	25	1825	5243.5-5253.0	140.5-150.0	9.5	4.5	47
7	25	2140	5291.0-5300.5	188.0-197.5	9.5	1.4	15
8	26	0010	5338.5-5348.0	235.5-245.0	9.5	2.9	31
9	26	0240	5386.0-5395.5	283.0-292.5	9.5	7.1	74
10	26	0600	5433.5-5443.0	330.5-340.0	9.5	2.6	27
11	26	0900	5462.0-5471.5	359.0-368.5	9.5	6.7	70
12	26	1330	5490.5-5500.0	387.5-397.0	9.5	2.3	24
Total					112.0	62.1	55
Hole 328A							
1	28	0140	5103.0-5110.5	0-7.5	7.5	6.0	80
2	28	0320	5110.5-5120.0	7.5-17.0	9.5	1.4	15
					17.0	7.4	44
Hole 328B							
1	28	0500	5110.5-5120.0	7.5-17.0	9.5	8.5	89
2	28	0640	5120.0-5129.5	17.0-26.5	9.5	9.4	99
3	28	0805	5129.5-5139.0	26.5-36.0	9.5	9.5	100
4	28	0920	5139.0-5148.5	36.0-45.5	9.5	7.4	78
5	28	1040	5148.5-5158.0	45.5-55.0	9.5	9.5	100
6	28	1210	5158.0-5167.5	55.0-64.5	9.5	8.8	93
7	29	0125	5538.0-5547.5	435.0-444.5	9.5	9.5	100
8[a]	30	0030	-5574.0	-471		0.5	
					66.5	62.6	94

[a]In core barrel when brought on deck – probably from lowest drilled interval.

predominate, with the grays occurring in zones rich in clay and silt. Well-preserved diatoms are by far the dominant biogenic component of the ooze with from a few percent to about 15% radiolarians, sponge spicules, and other siliceous organisms. The coarser detrital component, which is predominantly ice rafted, occurs both disseminated throughout the ooze and also as discrete thin beds of sand, silty sand, or pebbly sand to 5 cm thick. It is composed of a wide variety of lithologic types of continental affinities. Typically, the clasts are angular to subangular and a few pebbles clearly show faceting and striations characteristic of abrasions by glacial transport. Table 2 summarizes the lithology and texture of the gravel-size fraction from core-catcher samples of Holes 328 and 328A. Pelletal glauconite is a minor constituent of the thin sand beds and large ferromanganese nodules, many of which are nucleated on pebbles, occur through the unit.

The lower contact of Unit 1 is picked at the lowest stratigraphic occurrence of granule-size detritus which is essentially at the same depth both in Holes 328 and 328B. This contact also coincides closely with a striking downward decrease in the abundance of detrital sand. Except for the disappearance of coarser detritus, the contact is gradational into Unit 2.

Unit 2 (13.5-49 m, Cores 2-4 of Hole 328, Cores 1-5 of Hole 328B)

Unit 2 consists of about 35.5 meters of slightly sticky to sticky siliceous ooze, clay, and silt in varying proportions. Colors are dominantly yellow-gray to yellow-brown in zones rich in biogenous material grading into grayish-orange, dark yellowish-orange, or grayish-yellow in clay-rich parts of the unit. As in Unit 1, the biogenic component is largely diatoms with sparse to common amounts of other siliceous organisms. Silt and sand occur mainly in the upper part of the unit and the clay content tends to increase progressively towards the base. Sand content is generally less than a few percent, although there is as much as 11% within the top meter of the unit.

Approximately 1 meter of diatom-bearing zeolite-rich clay occurs at the bottom of Core 3 in Hole 328, and at the base of the unit in Hole 328B there is a transitional zone 4.5 meters thick in which the clay contains abundant authigenic zeolites. The zeolite minerals are mainly clinoptilolite with minor phillipsite. In general, the content of siliceous organisms is highly variable in Unit 2 and there is a pronounced increase in the amount of dissolution of the tests towards the base of

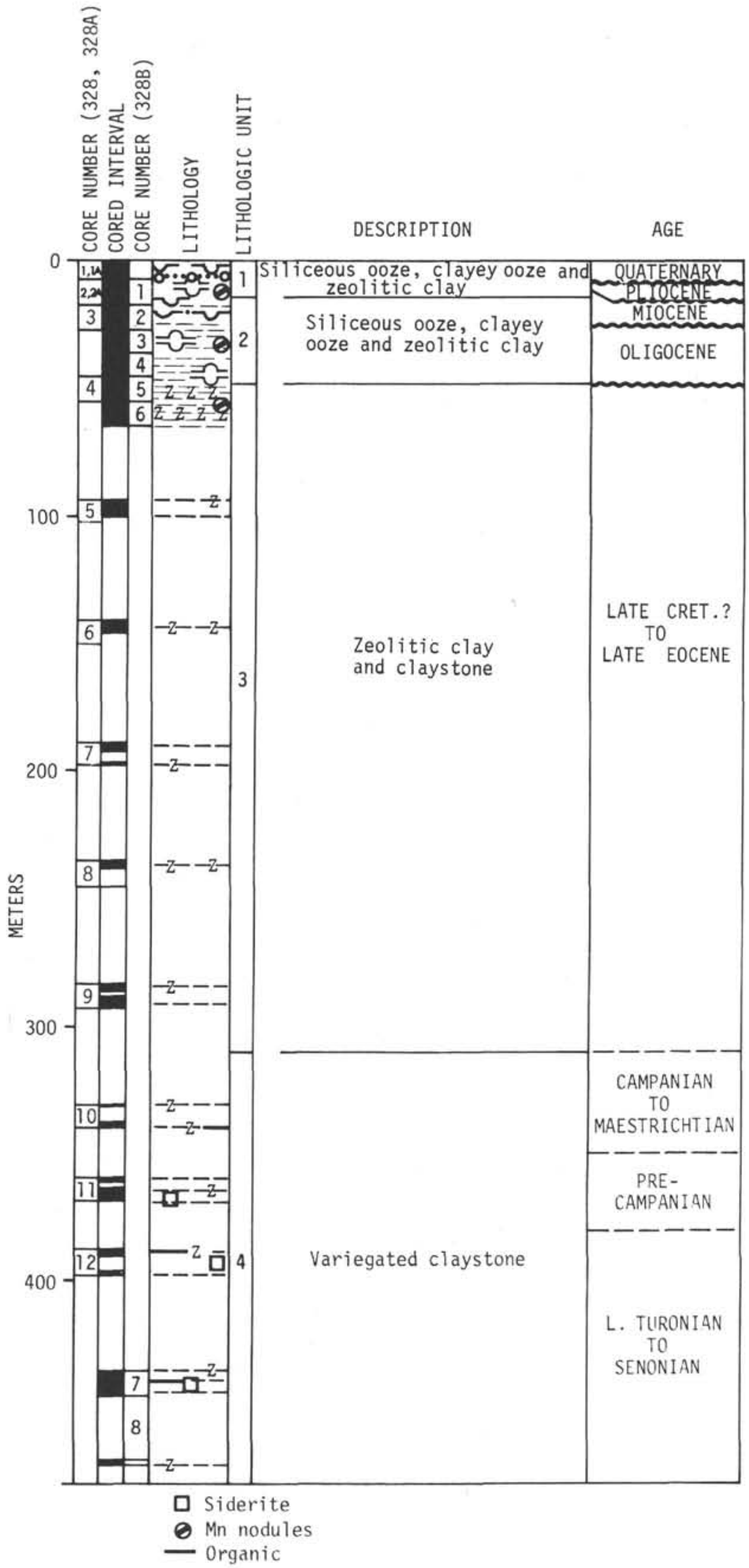


Figure 5. *Columnar section of Site 328 showing basic lithology recovered.*

TABLE 2
Pebble-Size Clasts in Core-Catcher Samples. 328-1 and 328A-1

	328-1			328A-1		
Clast Lithology	No. of Clasts	Volume (%)	Max. Size (cm)	No. of Clasts	Volume (%)	Max. Size (cm)
Manganese nodules and fragments	0	–	–	Many	42	3.8
Rhyolite, dacite, pumice, felsic-porphyry (1 faceted)	6	15	2.7	10	29	3.8
Shale, siltstone, argillite (faceted and striated in part)	14	20	3.6	13	17	4.0
Granite porphyry (possible faceted)	1	25	5.3	–	–	–
Granodiorite, quartz monzonite, diorite	11	10	1.7	7	1.5	2.0
Basalt, andesite	3	10	2.7	1	1	1.4
Gabbro	1	Tr	1.8	1	Tr	1.2
Quartz (1 possible faceted)				4	2	1.7
Sandstone, quartzite	14	15	2.5	6	2	1.4
Gneiss, schist, phyllite	3	5	1.9	6	2	2.3
Sandy mudstone	1	Tr	0.5			

the unit. Deterioration of siliceous tests is especially apparent in the zeolite-rich zones, and the transition from diatomaceous clay to the nonfossiliferous zeolitic clay of Unit 3 occurs abruptly within a stratigraphic interval of 3 meters in Hole 328B.

Minor biogenic constituents noted in Unit 2 are fish debris, pyritized siliceous remains, and displaced Cretaceous radiolarians. Large ferromanganese nodules are common in all but the lower 9 meters of the unit with abundant micronodules throughout.

Chemical analyses of sediment samples bracketing the transition from biogenous ooze to zeolitic clay are presented in Table 3. They were made to test whether the essentially simultaneous appearance of zeolite and loss of siliceous organisms is isochemical, which would be expected if diagenetic alteration of biogenic silica were the source of silica in the zeolite. However, the drop in silica content from over 61% to about 52% across this interval as shown by the analytical data indicates that the system was not isochemical, and thus the zeolites are probably not directly related to the disappearance of the siliceous microorganisms.

Unit 3 (49-130 m, Cores 4-9 of Hole 328, Cores 5 and 6 of Hole 328B)

Unit 3 consists of 261 meters of rather monotonously homogeneous zeolitic clay and claystone. On the basis of color, the unit is subdivided into an upper part roughly 80 meters thick (3A), which is predominantly grayish-orange with yellow-brown mottling, and a lower part (3B) in which greenish-gray to olive-gray colors predominate. The upper half of the unit is a stiff, sticky clay grading through interbedded clay and moderately well indurated claystone in Core 7 of Hole 328 to claystone in the lower part of the unit. Clay minerals consisting of about equal amounts of illite, montmorillonite, and mixed-layer montmorillonite and illite typically comprise 80%-90% of the sediment. The remainder consists largely of authigenic zeolites (mainly clinoptilolite) and apatite with traces of glauconite,

TABLE 3
Chemical and Semiquantitative Spectrographic Analyses of 14 Siliceous Ooze and Clay Samples from Cores 4 and 5, Hole 328B (Analyses by U.S. Geological Survey)

A. X-ray fluorescence analyses (weight percent)[a]

	Unit 2. Biosiliceous ooze			Unit 2. Interbedded siliceous ooze, clayey ooze, and zeolitic clay						Unit 3. Zeolitic clay				
Sample Number	36-328B-4-5 10-12	36-328B-4-5 144-146	36-328B-5-1 5-7	36-328B-5-1 50-52	36-328B-5-1 89-91	36-328B-5-1 140-142	36-328B-5-2 50-52	36-328B-5-2 100-102	36-328B-5-2 140-142	36-328B-5-3 45-47	36-328B-5-3 100-102	36-328B-5-3 145-147	36-328B-5-4 139-141	36-328B-5-5 115-117
SiO_2	60.59	61.45	53.51	53.51	54.57	58.50	55.87	53.35	54.30	55.47	55.73	55.80	53.35	52.35
Al_2O_3	14.07	13.67	15.23	15.38	15.84	13.68	14.90	15.37	15.65	14.90	16.12	16.29	15.47	15.51
Fe_2O_3	6.50	6.07	7.38	6.97	6.93	6.45	6.92	7.14	7.96	6.73	6.80	7.10	7.45	7.36
FeO	0.07	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	2.08	1.89	2.45	2.56	2.50	2.17	2.24	2.45	2.46	2.38	2.74	2.63	2.51	2.89
CaO	0.82	0.61	0.77	0.75	0.56	0.75	0.81	0.76	0.68	0.75	0.65	0.64	0.85	0.75
Na_2O	3.30	3.46	3.27	3.45	3.12	3.11	3.06	3.36	3.42	3.88	3.98	3.88	3.62	3.49
K_2O	2.73	2.18	2.54	2.53	2.59	2.29	2.54	2.54	2.49	2.47	2.39	2.44	2.41	2.26
H_2O^+	4.01	4.82	5.62	6.14	6.02	4.94	5.00	5.33	7.16	5.17	5.27	5.44	6.03	6.25
H_2O^-	4.97	4.84	6.78	5.77	6.48	5.51	6.27	6.22	6.69	6.12	6.68	6.28	7.18	7.41
TiO_2	0.72	0.65	0.79	0.78	0.76	0.73	0.76	0.79	0.81	0.75	0.76	0.78	0.82	0.80
P_2O_5	0.08	0.06	0.11	0.10	0.11	0.10	0.12	0.14	0.14	0.12	0.12	0.13	0.15	0.18
MnO	0.52	0.26	0.77	1.03	0.47	0.88	0.98	0.81	0.77	0.59	0.33	0.31	0.23	0.38
CO_2	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
TOTAL	100.46	99.96	99.22	98.97	100.09	99.11	99.47	98.26	102.53	99.33	101.57	101.72	100.07	99.63

B. Semiquantitative spectrographic analyses (weight percent)[b]

Fe %	5.	5.	5.	5.	5.	5.	5.	5.	7.	5.	5.	5.	5.	5.
Mg %	1.	2.	1.	1.	1.	1.	1.	1.5	1.5	1.5	1.5	1.5	1.	1.5
Ca %	0.5	0.5	0.5	0.7	0.5	0.7	0.7	0.7	0.7	0.7	0.7	0.5	0.7	0.7
Ti %	0.3	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Si %	G	G	G	G	G	G	G	G	G	G	G	G	G	G
Al %	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.	10.	7.	7.	7.
Na %	1.5	1.5	2.	2.	3.	2.	3.	2.	2.	3.	3.	2.	3.	2.
K %	1.5	1.5	2.	2.	3.	2.	3.	2.	2.	2.	2.	2.	2.	1.5
P %	N	N	N	N	N	N	N	N	N	N	N	N	N	N

C. Semiquantitative spectrographic analyses (parts per million)[b]

Mn	2000	1500	3000	3000	2000	5000	3000	3000	3000	2000	1500	1500	1500	2000
Ag	N	N	N	N	N	N	N	N	N	N	N	N	N	N
As	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Au	N	N	N	N	N	N	N	N	N	N	N	N	N	N
B	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Ba	300	200	200	300	300	300	500	500	300	300	200	200	200	300
Be	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2	1.5	2
Bi	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Cd	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Co	20	10	30	30	30	20	30	30	30	20	30	30	15	20
Cr	30	30	30	30	50	50	50	30	50	50	30	30	30	30
Cu	70	70	70	70	70	70	70	70	70	70	100	70	50	70
La	N	N	N	N	N	N	N	N	N	50	50	30	N	N
Mo	10	N	10	15	7	10	15	10	10	7	N	N	N	N
Nb	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ni	70	70	150	100	100	150	100	150	150	100	70	70	50	70
Pb	20	10	20	20	50	20	15	50	30	15	20	30	10	20
Pd	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Pt	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Sb	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Sc	15	15	20	20	20	15	20	20	20	15	20	20	20	20
Sn	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Sr	150	100	150	200	200	200	300	200	200	200	200	150	200	150

Te	N	N	N	N	N	N	N	N	N	N	N	N	N	N
U	N	N	N	N	N	N	N	N	N	N	N	N	N	N
V	100	70	100	100	100	100	100	100	150	100	100	100	70	100
W	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Y	20	20	30	30	30	20	30	30	30	30	30	30	30	30
Zn	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Zr	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Ce	N	N	N	N	150	N	N	N	N	150	200	N	N	N
Ga	20	20	30	20	30	20	30	30	30	20	20	30	30	20
Ge	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Hf	N	N	N	N	N	N	N	N	N	N	N	N	N	N
In	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Li	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Re	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Ta	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Th	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Tl	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Yb	2	2	3	2	3	2	3	3	3	3	3	3	3	3
Looked for only when La or Ce found														
Pr	N				N					N	N	N		
Nd					N					N	N	N		
Sm					N					N	N	N		
Eu		N	N	N	N	N	N	N	N	N	N	N	N	N

[a] H. N. Elsheimer and B. P. Fabbi, Analysts. The as received samples were dried and ground prior to X-ray analysis.

[b] Chris Heropoulos, Analyst. The reported values were made on the ashed material. "G" indicates greater than 10%. "N" indicates element not detected.

fish debris, opaque minerals, radiolarian tests, goethite, and possibly some finely crystalline sphalerite. The opaque minerals are dominantly pyrite. Radiolarian tests commonly show the effects of dissolution and replacement by pyrite. Although the unit shows abundant color banding and mottling, these changes do not reflect detectable compositional or textural variations. A few local black color bands and patches are probably the trails of burrowing organisms. There are scattered small, soft patches of ferromanganese near the top of the unit and manganiferous micronodules are abundant throughout.

Unit 4 (310-471 m, Cores 10-12 of Hole 328, Cores 7 and 8 of Hole 328B)

The lowest unit consists of 161 meters of variegated slightly zeolitic claystone that is only slightly more variable in lithology than Unit 3. Color banding occurs on a scale of centimeters to meters. Commonly, there is a cyclical gradation from reds and browns at the bottom through green or olive to gray and black at the top. The dark-colored bands tend to be relatively richer in finely divided plant-derived carbonaceous material. Bioturbation is evident at several horizons and *Zoophycos* and *Chondrites*, the feeding trails of burrowing organisms, are locally recognizable. The clay-size fraction is dominantly illite-montmorillonite mixed-layer clays with minor chlorite and kaolinite. Cristobalite in significant amounts occurs in X-ray analyses of two samples from Core 10 near the top of this unit, and 8% tridymite occurs in one of these samples. The presence of these minerals is probably related to diagenetic changes although there is no obvious megascopic lithologic change in this interval. Authigenic siderite, in aggregates having distinctive dumbell shapes, is a characteristic accessory constituent that is locally highly concentrated in thin zones a few meters thick. Other constituents present in minor amounts include pyrite, oxides and hydroxides of iron, fish debris, pyritized radiolarians, agglutinated benthonic foraminifera, and glauconite. The fish debris is in part altered to both apatite and collophane. The only coarse clastic unit is a 1-1/2-cm-thick microturbidite of very fine- to medium-grained size-graded sandstone in Core 7, Hole 328B. The sandstone, which is composed entirely of authigenic and biogenic material, includes a probable pre-Campanian displaced coccolith flora that represents the only calcareous microfossils recovered from Site 328.

PHYSICAL PROPERTIES

Wet bulk densities, porosities, and water content were determined underway using gravimetric and GRAPE methods. Sonic velocities were measured using the Hamilton frame system. These values are shown in the site summary graphic logs and core summaries.

With the exception of Core 8 (Hole 328) and Cores 1 and 2 (Hole 328A) which were highly disturbed, all the remaining 19 cores (Holes 328 and 328B) were sampled, and physical properties determined in all four lithological units.

A special effort was made to sample in detail the uppermost 60 meters (0.08 sec two-way travel time), a thinly stratified sequence which extends over a large area of this physiographic province and reaches a thickness corresponding to 2.0 sec to the southwest of the site. Sixty-four sonic velocity measurements were made in the top 65 meters of the hole, consisting of diatom ooze and silty siliceous zeolitic clay, and a similar number of wet bulk density, porosity, and water content determinations were performed.

Most of the undisturbed core sections down to 471 meters were also sampled for physical properties, across zeolitic clay and claystone (65-310 m) and zeolite-bearing claystone (310-471 m).

Down to about 100 meters sonic velocities decrease slightly from about 1.55 km/sec to 1.51 km/sec. Across this section (which includes the acoustically finely stratified upper sequence mentioned above) all other physical parameters are also relatively uniform. Porosities range typically from 50% to 65%, wet bulk densities from 1.25 g/cm^3 to 1.50 g/cm^3, and water content from 50% to 65%.

Between 100 and 310 meters there is a moderate increase in the degree of compaction of the clays, which become claystones at about 250 meters depth; this increase is mirrored in the velocity and density values.

Between 320 meters (top of the zeolite-bearing claystones of Lithological Unit 4) and 380 meters, sonic velocities gradually increase from about 1.58 km/sec to range between 1.75 km/sec and 1.94 km/sec in well-indurated claystones of similar composition. The average velocity between 380 meters and the base of the hole is close to 1.83 km/sec.

A similar rate of change is observed in average values of other mass physical properties. Porosities decrease from 72% (310 m) to 49% (400 m) to 52% (445 m). Average wet bulk densities increase correspondingly from 1.52 g/cm^3 (310 m) to 1.89 g/cm^3 (400 m) and remain practically constant downhole (1.87 g/cm^3 at 445 m). Water content decreases on the average from 48% (310 m) to 28% (400 m to 445 m).

Variations of acoustical impedance follow changes observed with depth in compressional velocities, and lie between an average 2.10×10^5 g/cm^2 sec (±0.4) determined for the uppermost 65 meters to a maximum of 3.57×10^5 g/cm^{2}sec at 400 m, decreasing slightly to 3.35×10^5 g/cm^{2}sec near the bottom of the hole.

The plotted values are estimated to be accurate to ±7% syringe porosity, ±6% GRAPE porosity, ±0.1 g/cm^3 syringe bulk density, and ±1% velocity.

PALEONTOLOGY

Biostratigraphic Summary

The 471-meter-thick sedimentary sequence drilled at this site reflects primarily a record of nearly continuous abyssal sedimentation from the early Late Cretaceous to the present. Changes in lithology represent only changes in the contributing sedimentary components at various points in time (see Lithologic Summary). The lack of calcareous microfossils throughout the section indicates deposition below the CCD during the entire documented depositional history. The major lithologic change from a zeolitic clay and claystone in the lower part of the column (55-471 m) to a siliceous ooze and silty siliceous clay above (0-55 m) reflects a major change in surface and near-bottom oceanographic conditions, possibly resulting from the separation of Australia and Antarctica in late Eocene time.

Only siliceous microfossils occur in the sediments of the upper 55 meters. Both diatoms and radiolarians show very similar trends in their respective abundances, degrees of preservation, and diversity throughout this section. From 55 to 295 meters (Cores 5-9) biostratigraphic control is very poor due to the scarcity of microfossils. Small amounts of agglutinated foraminifera are present in Cores 8, 9, 10, and 12. Rare terrestrial palynomorphs occur in Core 9 and marine dinoflagellate cysts are abundant in the deepest part of the hole (Cores 10, 11, 12 of 328 and Core 7 of 328B).

Paleontologic correlation based on diatoms and radiolarians and silicoflagellates is satisfactory for the upper part (26.5 m) of the sedimentary sequence which contains assemblages of Pleistocene, Pliocene, and middle to late Miocene age. Breaks in the stratigraphic record are indicated at the Miocene-Pliocene and Pliocene-Pleistocene boundaries.

There is very little doubt about the sudden change from the middle Miocene age of the sediments in Core 328B-2 (bottom) to those of earliest early Miocene (?) or late Oligocene age in Core 328B-2 (top). The top of Core 3 contains a few specimens of *Cyrtocapsella tetrapera*, whose first appearance occurs at the Oligocene-Miocene boundary, indicating that only the very earliest Miocene may be present at the top of Core 328B-3. At 328B-3-1, 5-7 cm, *Rocella gemma* is very common and indicates a late Oligocene age. A late Oligocene age for Cores 3 and 4 of 328B is supported by the silicoflagellates and radiolarians. Of the last group, common representatives are *Lithomelissa challengerae*, *L. robusta*, *Calocyclas semipolita*, and *Cyclampterium longiventer*.

Cores 328-4, 328B-5, and possibly the bottom of 328B-4 are of late Eocene age, evidence for which are the radiolarians *Lychnocanoma bellum* and *L. amphitrite* as well as the silicoflagellates.

Due to extensive dissolution of the assemblages, both radiolarians and diatoms become useless for dating sediments below 45 meters; the Radiolaria persist a few meters beyond the last occurrence of the diatoms due to their generally more robust skeletons.

No microfossils were found in the sediments from 55 to 200 meters. Below 200 meters palynomorphs are the most common microfossils and indicate ages from the late Paleocene to late Turonian.

The radiolarian, diatom, and silicoflagellate fauna and flora from the top 55 meters of the section indicate general cool surface water conditions throughout the Pleistocene through middle Miocene. The late Pliocene and Pleistocene record reflects the more frigid temperatures which are so characteristic of the circum-Antarctic environment today. Both the diatoms and the radiolarians indicate a possible slight warming trend in the middle Miocene. No estimate of surface oceanographic conditions can be made for the pre-late Oligocene time.

Since the late Turonian the sedimentary history of the site has been characterized by deposition of fine-grained clays and silts transported mainly by bottom currents. The presence of reworked older microfossils throughout the entire sedimentary sequence is mute evidence for this process. Besides the process of transport by bottom currents over some distance, downslope displacement of sediments from nearby topographic highs may have occurred as is suggested by the presence of small amounts of well preserved pre-Maestrichtian nannofossils in the lower part of the section (Lithologic Unit 4, below 300 m), as well as by moderately well preserved Cretaceous and Paleocene radiolarians in the sediments below 50 meters. The most likely source for this material is probably the eastern end of the Falkland (Malvinas) Plateau. The composition of the sedimentary components changed significantly in the late Paleogene and Neogene when siliceous organisms became an important factor of the sedimentary load. This change can be attributed to a rather abrupt increase in surface water productivity related to changing surface oceanographic conditions in late Eocene time. No record of a high Paleocene-early Eocene surface productivity, as observed at Site 327, was found in the sediments at this site suggesting that the period of Paleocene productivity may have been restricted to the waters of the relatively shallow Falkland Plateau, perhaps as a result of a rather unique local oceanographic regime.

Foraminifera

Rare arenaceous benthonic foraminifera were found in the lower part of the section, in Cores 8-10 and 12. At several levels, specimens have undergone fractionation, but relatively well preserved assemblages were recovered from Core 10.

The following species could be identified: *Ammodiscus cretaceous*, *Glomospira charoides*, *Rzehakina epigona*, *Haplophragmoides* sp., *H. excavata*, *Nodellum velascoense*, *Bathysiphon* spp., *Saccamina complanata*, *Hormosina ovulum*, *Uvigerinammina* sp., and *Paratrochamminoides* sp. This assemblage is characteristic for the Late Cretaceous-early Eocene interval from depths below the calcium carbonate compensation level.

A very similar assemblage of approximately the same age (Cretaceous-Paleocene) has been reported from Site 323 in the Bellingshausen Abyssal Plain (Rögl, in press).

Calcareous Nannofossils

Sediments recovered in three holes at Site 328 were deposited in deep water well below the carbonate compensation depth and contain no nannoliths except for rare well preserved Mesozoic forms reworked into the zeolitic claystone in the lower part of the section (Lithologic Unit 4). These coccoliths are *Watznaueria barnesea*, a taxon common only in pre-Maestrichtian sediments of this region.

Silicoflagellates

The siliceous oozes in the top 51 meters at Site 328 contain abundant silicoflagellate assemblages which document the presence of Quaternary, Pliocene, late Miocene, late Oligocene, and Eocene strata. As expected at this high latitude site, the cool-water indicating genus *Distephanus* predominates, particularly in the Neogene section.

Assemblages recovered from the three holes drilled at this site can be zoned according to silicoflagellate biostratigraphic zonations developed from studies of materials recovered by DSDP Cruises 28 and 29 to the Pacific sector of the Southern Ocean and environs (Ciesielski, 1975; Bukry, 1975a, b). Quaternary assemblages may be assigned to the *Dictyocha aculeata* Zone of Bukry and Foster (1974) or to the *Distephanus speculum* A Zone of Ciesielski (1974), depending on which zonation is followed (see Busen and Wise and Bukry, both this volume). Similarly, both Ciesielski's *Distephanus speculum* B Zone or Bukry's *Distephanus boliviensis boliviensis* Zone may be distinguished in the somewhat sparse Pliocene floras (Hole 328, Cores 2 and 3 and Hole 328B, interval 1-3, 5 cm to 2-1, 144 cm). Sparse floras in Sections 328-3-2 to 328-3-4 are assigned to the Miocene *Mesocena circulus*/*Mesocena-diodon* Zones (of Busen and Wise, this volume) whereas Sections 328B-3-1 to 328B-4-5 belong to the late Oligocene *Naviculopsis biapiculata* Zone. Late Eocene assemblages assigned to the *Dictyocha deflandrei* Zone are present in Cores 328B-5 and 328-4 to 328-5.

Diatoms

Diatoms are common to abundant through the Neogene interval in Hole 328. Preservation of frustules is poor to moderate. Diatoms in the Paleogene interval in Core 4 are generally abundant and well preserved.

The following Neogene diatom zones of McCollum (1975) are represented in Hole 328: *Coscinodiscus lentiginosus* Partial-Range Zone (1-1, 1-3 cm to 1-3, 5-7 cm); *Coscinodiscus elliptopora*/*Actinocyclus ingens* Concurrent Range Zone (1-3, 81-83 cm to 1-5, 138-140 cm); *Cosmiodiscus insignis* Partial-Range Zone (2-1, 148-150 cm to 2-2, 5-7 cm); *Nitzschia interfrigidaria* Partial-Range Zone (2-2, 80-82 cm to 2-3, 5-7 cm); *Denticula hustedtii* Partial-Range Zone (2-3, 78-80 cm to 2-5, 5-7 cm); *Denticula hustedtii*/*Denticula lauta* Partial-Range Zone (2-5, 81-83 cm to 3-1, 5-7 cm); *Denticula lauta*/*Denticula antarctica* Partial-Range Zone (3-1, 81-83 cm to 3-2, 140-142 cm). The interval from Samples 3-3, 5-7 cm to 3-4, 81-83 cm was not zoned, but is included in the middle Miocene.

The *Coscinodiscus lentiginosus* and *Coscinodiscus elliptopora*/*Actinocyclus ingens* zones are Quaternary in age. The *Cosmiodiscus insignis* and *Nitzschia interfrigidaria* zones are middle to early Pliocene in age. The *Denticula hustedtii* Zone is late Miocene. The *Denticula hustedtii*/*Denticula lauta* Zone straddles the middle-late Miocene boundary. The *Denticula lauta*/*Denticula antarctica* Zone and the interval below it to Sample 3-4, 81-83 cm are middle Miocene.

The absence of the *Rhizosolenia barboi*/*Nitzschia kerguelensis* Partial-Range Zone and the *Coscinodiscus kolbei*/*Rhizosolenia barboi* Range Zone between the *Coscinodiscus elliptopora*/*Actinocyclus ingens* Concurrent Range Zone and the *Cosmiodiscus insignis* Partial Range Zone suggests the existence of a hiatus at this level (i.e., between Samples 1-5, 138-140 cm and 2-1, 148-150 cm). Alternatively, the absence of these two zones may be explained fully or in part by a drilling gap of about 1 meter between Cores 1 and 2.

The *Nitzschia praeinterfrigidaria* Partial-Range Zone is missing from between the *Nitzschia interfrigidaria* Partial-Range Zone and the *Denticula hustedtii* Partial-Range Zone within Core 2 (i.e., between Samples 2-3, 5-7 cm and 2-3, 78-80 cm). This interval corresponds to the occurrence of deformed, centimeter scale laminae of sandstone at 3.7 meters in Core 2.

Samples 3-5, 10-12 cm to 3-6, 48-50 cm are barren of diatoms. Sample 3-6, 81-83 cm contains a trace of diatoms.

Core 4 is late Eocene in age. The *Pyrgupyxis eocena/Pterotheca aculeifera* Zone is represented in Samples 4-1, 147-149 cm through 4-3, 5-7 cm.

Diatoms are abundant and are moderately well to well preserved in the samples examined from Hole 328A. The *Coscinodiscus lentiginosus* Partial-Range Zone of McCollum (1975) is represented in Samples 1-1, 35-37 cm through 1-4, 70-72 cm. Samples 1-4, 146-148 cm through 2-1, 145-147 cm are assigned to the *Coscinodiscus elliptopora/Actinocyclus ingens* Concurrent Range Zone.

These zones are Pleistocene to Recent in age and have been correlated to the paleomagnetic time scale by McCollum. The Bruhnes-Matuyama boundary is nearly coincident with the boundary of the *Coscinodiscus lentiginosus* Zone with the *Coscinodiscus elliptopora/Actinocyclus ingens* Zone.

In Hole 328B, diatoms are of Neogene age from the top of Core 1 through Sample 2-4, 70-72 cm. In this interval the diatoms are common to abundant from the top of Core 1 through Core 2, Section 2. Preservation in this interval is moderate. Diatoms are rare and poorly preserved in the interval Core 2, Section 3 through Core 2, Section 4.

Samples 1-1, 89-91 cm through 1-2, 5-7 cm are placed within the *Nitzschia interfrigidaria* Zone based on the highest occurrence of *Nitzschia praeinterfrigidaria* in Sample 1-2, 70-72 cm. This indicates a Pliocene age for this interval. The remainder of the Neogene section is disturbed to the extent that it was not possible to assign zones. However, correlation with Hole 328 suggests a late Miocene age for Samples 1-2, 70-72 cm through 1-6, 70-72 cm, and a middle Miocene age for Samples 1-6, 140-142 cm through 2-4, 70-72 cm.

Samples 2-5, 5-7 cm and 2-5, 70-72 cm are barren of diatoms. Sample 2-6, 5-7 cm contains a trace of diatom fragments. Sample 2-6, 123-125 cm is barren of diatoms.

Diatoms are common to abundant and poorly to moderately well preserved in Cores 3 through 5. This interval is Paleogene and includes late Eocene through late Oligocene age sediments.

The late Eocene *Pyrgupyxis eocena/Pterotheca aculeifera* Zone is represented in Samples 5-1, 147-149 cm through 5-3, 84-86 cm. The late Eocene-late Oligocene *Hemiaulus incisus* Zone is represented in Samples 4-4, 5-7 cm through 5-1, 9-11 cm. The late Oligocene *Cyclotella hannae* and *Pyrgupyxis prolongata* zones are represented in Samples 4-1, 45-47 cm through 4-3, 145-147 cm and 3-2, 70-72 cm through 3-6, 126-128 cm, respectively.

Radiolaria

Radiolaria occur in various abundances, degrees of preservation, and diversity throughout the Neogene and late Paleogene sections of all three holes drilled at this site, i.e., in Cores 1 through 4 of Hole 328, Cores 1 and 2 of Hole 328A, and in Cores 1 through 6 of Hole 328B.

Small amounts of reworked older fossils were observed in many of the samples examined and point to a nearly continuous record of eroding bottom currents in this area throughout the Tertiary.

Pleistocene assemblages are present in Core 328-1 and in both cores of Hole 328A. The co-occurrence of *Prunopyle antarctica* with *Stylatractus universus* in the first three sections of 328-1 indicate a late Pleistocene age. Specimens of *Antarctissa ewingi* occurring below Section 328-3-5 indicate an early Pleistocene age for the lower part of the core. Small numbers of upper Miocene and Pliocene radiolarians indicate admixing of older sediments into those of Quaternary age, and compound the problem of detecting zone boundaries in the core. The top two sections of Core 328-1 are assigned to the upper Pleistocene *Antarctissa denticulata* Zone, and Section 3 seems to belong to the *Stylatractus universus* Zone. Scattered throughout the core are specimens of *Saturnalis circularis*. Considerable intraspecific variations in *Antarctissa denticulata* and *A. ewingi*, in addition to the admixing problems, make it difficult to recognize the boundary between the *S. universus* and *S. circularis* zones. It is rather arbitrarily placed between Sections 3 and 4.

The Pliocene record appears to be much shortened. The top of Cores 328-2 and 328B-1 contain rare *Desmospyris spongiosa*. This, plus admixed Oligocene and Miocene Radiolaria could indicate, albeit tentatively, the *Eucyrtidium calvertense* Zone, although it can also be interpreted that this zone is altogether absent. The *Helotholus vema* Zone is represented in Core 328-2, Sections 1, 2, and 3, 39-41 cm.

Assemblages of Miocene age are encountered in the remainder of Core 328-2 and in Core 3. The presence of *Actinomma tanyacantha, Antarctissa conradae, Eucyrtidium cienkowskii, Dendrospyris haysi, Prunopyle spiropyrinus, Cyrtocapsella tetrapera, Ommatartus antepenultimus, Ommatartus* sp. cf. *O. hughesi, Amphistylus angelinus, Theocalyptra bicornis spongothoriax, Stichocorys peregrina*, and *Stichocorys delmontenses* indicate the late Miocene *Theocalyptra bicornis spongothorax* Zone throughout most of this interval. Elements of Oligocene faunal assemblages, *Cyclampterium longiventa, Calocycles semipolita* ?, and *Lithocyclia* sp., point to reworking with older sediments. Core 328-3 does not appear to reach into any other Miocene radiolarian zones. The strongly disturbed nature of the sediments recovered in Cores 1 and 2 of Hole 328B makes it difficult to establish any kind of zonation for the Miocene.

Cyclampterium longiventer, *Calocyclas semipolita* ?, *Lithomelissa sphaerocephalis*, *Lithomelissa challengerae*, *Lithomelissa robusta*, *Prunopyle spongopyrinus*, *Eucyrtidium* sp., *Artophormis* sp. cf. *A. gracilis*, *Lychnocanoma elongata*, *Dorcardospyris* sp. aff. *D. ateuchus*, and *Calocycletta* sp. occur at the top of Core 328B-3. Associated with this assemblages are a few specimens of *Cyrtocapsella tetrapera*, which indicates a thin veneer of lower Miocene sediment at the top of this core. The above-mentioned assemblage, minus *C. tetrapera*, is of Oligocene age.

No radiolarian zones exist yet for the fossil Oligocene assemblages from high latitudes, and thus it is not possible, from the radiolarian data, to establish if the sediment recovered is of a late or early Oligocene age. However, the silicoflagellates suggest late Oligocene. No change in the radiolarian assemblages was observed throughout Cores 328B-3 and 4. In both Cores 328-4 and 328B-5, late Eocene faunas are present, indicated by *Lychnocanoma amphitrite*, *L. bellum*, *Lophocyrtis* sp. cf. *L. jacchia*, *Theocampe urceolus*, and *Amphisophaera minor*.

The number of radiolarians rapidly declines and preservation and diversity deteriorate sharply below Core 5, Section 5 in Hole 328 and below Section 4 in Core 5 in Hole 328B. This general decline of the fauna coincides with the sharp change in lithology from an essentially silty siliceous clay above to a zeolitic clay below. Core 6 of Hole 328B contains only a few poorly preserved radiolarians of Eocene age. Similar occurrences exist in Core 5 of Hole 328. In these intervals in Hole 328, a large part of the radiolarian fauna is composed of species typical for the Upper Cretaceous, Paleocene, and possibly lowermost Eocene. The presence of these older fossils again points to strong reworking processes operating at the site.

Cores 7, 8, and 9 of Hole 328, a zeolitic clay and claystone, are essentially barren of microfossils. Only a few nondiagnostic pyritized radiolarians were observed in the core-catcher sample of Core 9. The HCl-treated coarse fraction ($>63\mu m$) from a sample taken from Core 10, Section 5, consisted nearly entirely of radiolarians. All specimens are poorly preserved, with most diagnostic characteristics obliterated, and many specimens are present only as zeolitic casts and inner molds. From the general shape of the forms, it is concluded that the fauna represents an assemblage of at most Maestrichtian to Paleocene age. No radiolarians were observed in the core-catcher samples of Cores 7 and 8 from Hole 328B.

The general appearance of the radiolarian assemblages is quite unlike those encountered at low latitudes and reflects their cool-water environment. Representatives of the warm-water Collosphaerids are generally absent. An exception is the middle Miocene interval. A few collosphaerids are consistently present in the samples examined as well as occurrences, admittedly rare, of such species as *Calocycletta costata*, *Cyrtocapsella cornuta*, *Cannartus* sp. cf. *C. mammiferus*, and *Dorcadospyris* sp., which are typical for tropical assemblages of the same age. Thus, although the evidence is far from conclusive, it seems possible to conclude that during that interval warmer water penetrated farther to the south than in subsequent times. This may have been the result of a regional change in current regimes, or it may represent an event of larger scale.

PALYNOMORPHS

Palynomorphs are present in Cores 9 to 12 of Hole 328 and in Core 7, Hole 328B.

There is in the core-catcher sample from Core 9 a small assemblage of spores and pollen and few dinoflagellate cysts. Abundant tracheid and cuticular material is also present. *Haloragacidites harrisii* and *Milfordia homeopunctata* suggest a Tertiary age, probably no older than late Paleocene. There is some doubt, however, that the sample is in situ. In Cores 10 to 12, and 7 of Hole 328 B marine dinoflagellates constitute 95% of the assemblage. Cores 10 and 11 contain *Gillinia hymenophora*, *Zenikoon australis*, and *Nelsoniella aceras* and are of Campanian to early Maestrichtian age. *Dinopterygium cladoides* and *Trichodinium castaneum* appear in Core 12 suggesting an age older than Campanian. Core 7 of Hole 328B contains *Aiora fenestrata*, *Conosphaeridium stiatoconus*, and *Cribroperidinium orthoceras* and is late Turonian to early Senonian in age.

CORRELATION OF REFLECTION PROFILES WITH LITHOLOGY

Figure 6 shows the correlation of core lithology with the reflection profile obtained on leaving the site, and the quality of the fit between shipboard-measured acoustic velocities and the velocity-depth model used in the correlation.

The model is intended as an unbiased fit to the measured velocities, since there was no certain way to estimate and correct for differences between in situ and shipboard values. Sampling was good down to 65 meters but poor beneath. Acoustic impedance varies with velocity, so that reflections may be expected mainly at depths where velocity varies abruptly; a more precise correlation is precluded by relatively larger uncertainties in density measurements.

The uppermost 0.06 sec TW (two-way) of the reflection profile, containing many fine reflections, corresponds to the Eocene and younger biogenic siliceous ooze of Units 1 and 2. The fine structure of the measured velocities within this depth interval is probably real, but can be matched neither to particular reflectors nor to lithologic variations within the oozes. The amplitude of these fine variations decreases towards the base of Unit 2, but the poor sampling below 65 meters prevents our seeing whether they occur within Unit 3 where, between 0.06 and 0.42 sec, no reflections are seen. The faint and diffuse correlative of Horizon A of the Argentine Basin (Ewing and Lonardi, 1971) is seen at 0.42 sec TW (two-way), equivalent to a depth of 325 meters which is close to the boundary between Units 3 and 4. Thus, we may propose that, in the Malvinas Outer Basin, this diffuse reflector results from compaction with secondary diagenesis within a uniform sequence of siliceous clays and claystones. At

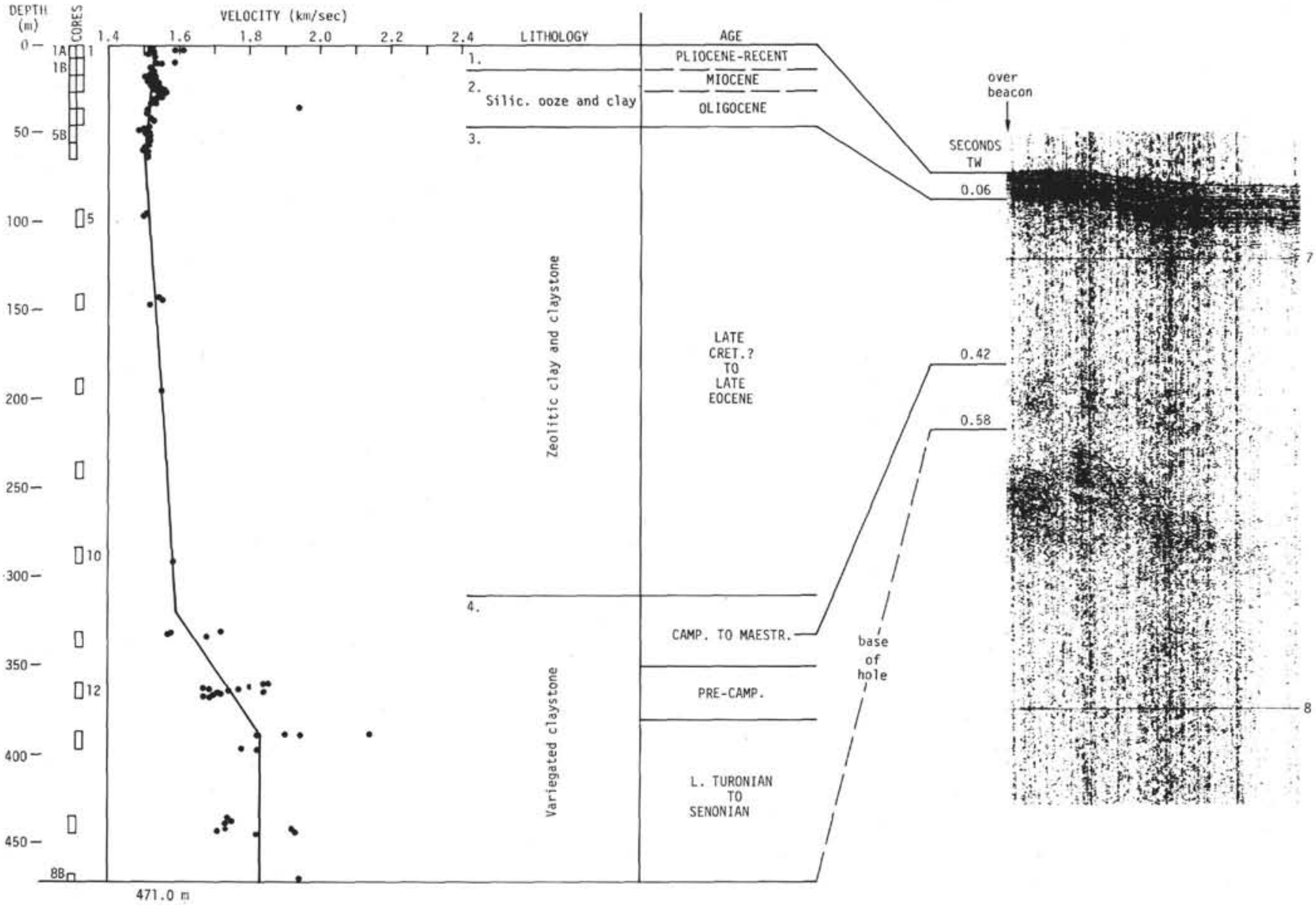


Figure 6. *Correlation between* Glomar Challenger *reflection profile leaving Site 328 and lithology.*

Site 328 the clays are of between Eocene and early Senonian to Turonian age and the reflector (Horizon A) lies directly below the Cretaceous-Tertiary boundary.

Acoustic basement near the site is rough and probably represents the oceanic basaltic layer. If the velocity-depth model can be extrapolated, the time of 0.68 sec TW to this reflector represents a depth of 574 meters, or about 100 meters below the base of the hole.

The upper, finely stratified layer identified with the biogenic ooze of Units 1 and 2 thickens westward from the site, as Figure 6 shows, and exceeds 1.5 sec TW in thickness farther to the southwest, directly east of the end of the Falkland Trough (Birmingham University, unpublished data). This variation in thickness argues against a model for sedimentation at Site 328 consisting of steady deposition of biogenic oozes through the Late Cretaceous and Cenozoic, with steady diagenetic dissolution of microfossils below a given depth to form the clays; a distinct change in either sediment sources or bottom currents or both in Eocene times is required.

SUMMARY AND CONCLUSIONS

Site 328 is located in the Malvinas Outer Basin immediately to the east of the Falkland Plateau and to the south of the Falkland Fracture Zone at 49°48.67'S, 36°39.53'W in 5103 meters of water. Of three holes drilled at the site the deepest one, Hole 328B, penetrated 471 meters and bottomed in Upper Cretaceous gray zeolitic claystone.

Hole 328 was cored continuously to 26.5 meters and intermittently below that level to 397 meters. Hole 328A was abandoned at 17 meters after recovery of two consecutive shallow cores. Hole 328B was cored continuously to 64.5 meters and then drilled to 435 meters where one additional core was cut. Finally 0.5 meters of core was recovered from the deepest interval before the hole had to be abandoned at 471 meters.

Objectives at Site 328 were to determine the age of basement in the South Atlantic Ocean south of the Falkland Fracture Zone, to obtain a deep-water biostratigraphic section for comparison with that of the proposed Site 331 to the north in the Argentine Basin and with the shallow-water sites on the Falkland Plateau (Sites 327, 329, and 330), and to determine the nature and age of an upper finely stratified unit and of other acoustic reflectors tentatively correlated with Horizon A and Horizon B of the Argentine Basin by Ewing and Lonardi (1971). All these primary objectives bear on problems associated with the separation of South America and Africa and the development of circulation patterns in the Southern Ocean, including the history of Antarctic Bottom Water and the circumpolar current. The site is located 90 km southwest of the opening in the Falkland Fracture Zone through which

Antarctic Bottom Water at present flows northwards into the Argentine Basin (Le Pichon et al., 1971).

Four lithologic units are distinguished in the cores recovered at Site 328. Unit 1 was penetrated by all three holes, and Units 2, 3, and 4 by Holes 328 and 328B. While general lithologic correlation between the holes is satisfactory, individual layers of manganese nodules, ice-rafted clasts, and glauconitic sand cannot be identified in more than one hole.

Unit 1, which extends to about 13.5 meters subbottom in Holes 328 and 328B and includes both the cores recovered from Hole 328A, consists of diatomaceous ooze with abundant manganese nodules, sand, and large clasts. Many of the nodules have formed around large terrigenous clasts. The lower limit of pebbles and abundant sand is taken as the base of the unit which contains late Miocene to Quaternary siliceous microfossils. The composition of the coarse clasts does not identify a specific source area for most of this presumably ice-rafted detritus, although the Beacon Supergroup of Antarctica is the likely source for some distinctive quartz sandstone and red bed components. Clasts include granodiorite, granite, rhyolite, andesite, basalt, pegmatite, schist, gneiss, graywacke, arkose, quartzite, sandstone, and siltstone. All are found either around the Weddell Sea margin, the present source of icebergs in the southern Atlantic Ocean, or else on the Pacific margin of the Antarctic Peninsula.

Unit 2 consists of upper Eocene-upper Miocene silty, biogenic siliceous clay, extending from 13.5 meters subbottom to 46 meters in Hole 328B and to 48 meters in Hole 328. Sand in amounts generally less than a few percent occurs throughout the upper part of the unit. The diatoms present show extensive dissolution in the lower part. The underlying Unit 3 extends to about 300 meters in Hole 328 (only the topmost part was cored in Hole 328B). This unit consists of Upper Cretaceous or Paleocene to upper Eocene siliceous clay and (towards the base) claystone containing abundant phillipsite and clinoptilolite. Unit 4 is wholly made up of Upper Cretaceous zeolitic claystone except for a thin (1-1.5 cm) graded silty sandstone containing reworked Cretaceous (pre-Maestrichtian) nannofossils. The claystone, unlike the clay of Unit 3 is variegated.

The reflector correlated with Horizon A of the Argentine Basin occurs within the upper part of this unit and at this site appears to represent a gradual diagenetic change to claystone rather than a particularly distinctive lithologic layer. The smooth acoustic basement at 0.68 sec TW reflection time subbottom, tentatively correlated with Horizon B of the Argentine Basin by Ewing and Lonardi (1971), is estimated to lie at 574 meters subbottom. If Unit 4 sedimentation rates are assumed to apply down to this interface, its age will be about 12 m.y. older than the base of Core 7 of Hole 328B or about Albian. The South American source postulated below for the thick pelagic clay deposits in the Upper Cretaceous section at Site 328 existed since the Albian or Cenomanian (see below), hence extrapolation of the sedimentation rate appears to be justifiable.

The upper Turonian or Senonian to upper Eocene clays and claystones of Units 3 and 4 were deposited below the carbonate compensation depth (CCD) in an environment essentially isolated from coarse-grained terrigenous sediments and sufficiently quiescent to allow the settling of fine clays. A notable scarcity of siliceous microorganisms suggests low productivity during this interval. The sedimentation rate averages about 10 m/m.y. with some indication from subtle lithologic changes and the sparse microfauna of a hiatus of about 5-10 m.y. near the Cretaceous-Tertiary boundary. This abnormally high rate of clay accumulation at Site 328, roughly an order of magnitude higher than rates reported for clays elsewhere in deep ocean basins, must be a consequence of an unusual supply of argillaceous material and efficient trapping of sediment in the partially enclosed Malvinas Outer Basin.

By the time the Upper Cretaceous claystone cored at the base of Holes 328 and 328B was being deposited, the Falkland Plateau had entirely separated from Africa, opening a deep seaway into the Atlantic Ocean basin from the south. An African source for the sediment is unlikely in view of the efficient sedimentary barriers along the Falkland-Agulhas Fracture Zone (Le Pichon et al., 1971) and because the sedimentation continued at essentially the same rate for over 40 m.y. without any major change while Africa was moving away from the Falkland Plateau. A more likely source for the argillaceous material deposited in the Malvinas Outer Basin during the Late Cretaceous is the Andean cordillera and possibly the West Antarctic cordillera with which it was joined (Dalziel and Elliot, 1973).

The initial tectonic uplift of the Andean cordillera occurred in the late Albian-Cenomanian (Dalziel, 1974). At that time detritus eroded from the rising cordillera along the Pacific margin of southern South America was deposited as relatively fine grained flysch in the deepening Magallanes Basin on the continental side of the cordillera. Excellent and consistent paleocurrent data indicate that sedimentary transport in this basin was southward and parallel to the cordillera (Scott, 1966). As the Magallanes Basin merges with the deeper submarine Falkland Trough between the Falkland Plateau and the submerged continuation of the cordillera (the North Scotia Ridge), transport of material by turbidity currents eastwards down the Falkland Trough is likely to have occurred. The thick Upper Cretaceous clay and claystone sequence in the Malvinas Outer Basin indicates that the fine-grained component of the turbidity currents was transported into the basin and redistributed there by bottom currents, presumably as a nepheloid layer.

Material being eroded from the rising cordillera included silicic, intermediate, and mafic igneous rocks and volcaniclastic sedimentary rocks; hence, the cordillera would have been a suitable source for the clays and claystones of the Malvinas Outer Basin which are rich in montmorillonite, have a high amorphous content, and commonly contain zeolite.

At the present time bottom currents are flowing northwards over Site 328 and through the gap in the Falkland Fracture Zone into the Argentine Basin. They are believed to be carrying clay-sized material into that basin (Ewing and Lonardi, 1971; Le Pichon et al., 1971). However, the currents consist of cold Antarctic

Bottom Water and there is no reason to believe that significant cooling of surface waters around the Antarctic continent took place before the Oligocene (Hayes, Frakes, et al., 1975; Shackleton and Kennett, 1975). Hence there are no compelling arguments for the presence of Antarctic Bottom Water during the Late Cretaceous and early Paleogene. Moreover, earlier suggestions that the present current regime in the Malvinas Outer Basin and in the Argentine Basin date back at least as far as the late Mesozoic (Ewing and Lonardi, 1971) were based on assumptions concerning the age of reflecting Horizon A in the Argentine Basin that are now known to be incorrect. Hence the bottom current regime in the Malvinas Outer Basin during the Late Cretaceous and early Paleogene is not known. However, the fast deposition of fine clays in the basin at that time clearly indicates relatively slow bottom current activity.

The variegated color of the claystone in Unit 4 is likely to be related to alternations of oxidizing and reducing conditions that may reflect climatic deterioration near the Cretaceous-Tertiary boundary as seen on the Falkland Plateau at Site 327. An upward increase in oxidation of the sediments is evidenced in the Paleogene part of the sequence (Unit 3) by a color change, the loss of palynomorphs, and the occurrence at the top of the unit of manganese micronodules. Influx of a limited amount of silty terrigenous material towards the top of Unit 3 may reflect an increase in bottom current velocity possibly related to the onset of Antarctic glaciation.

A major change in the conditions at Site 328 occurred at the close of the Eocene. The sedimentation rate dropped substantially to about 1.8 m/m.y. during the Oligocene (Figure 7), and there was a significant increase in the quantity of siliceous organisms in the sediments accompanied by a spectacular decrease in clay content (lower part of Unit 2). Major breaks occur in the stratigraphic record at the site from the late Eocene to the late early Oligocene (approximately 5 m.y.) and from the latest Oligocene to the middle Miocene (approximately 10 m.y.). There is a slight decrease in the sedimentation rate to 1.6 m/m.y. during the middle and

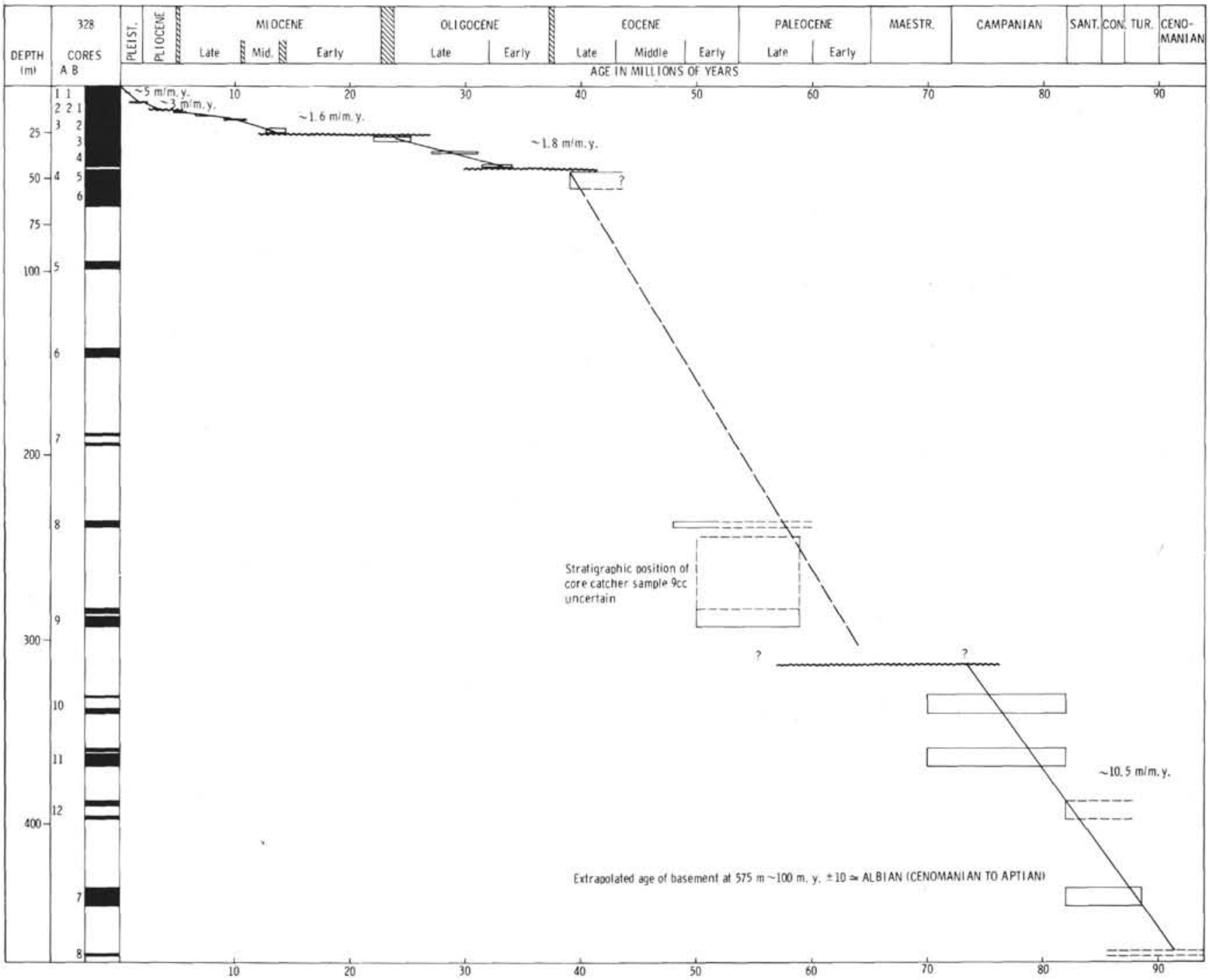
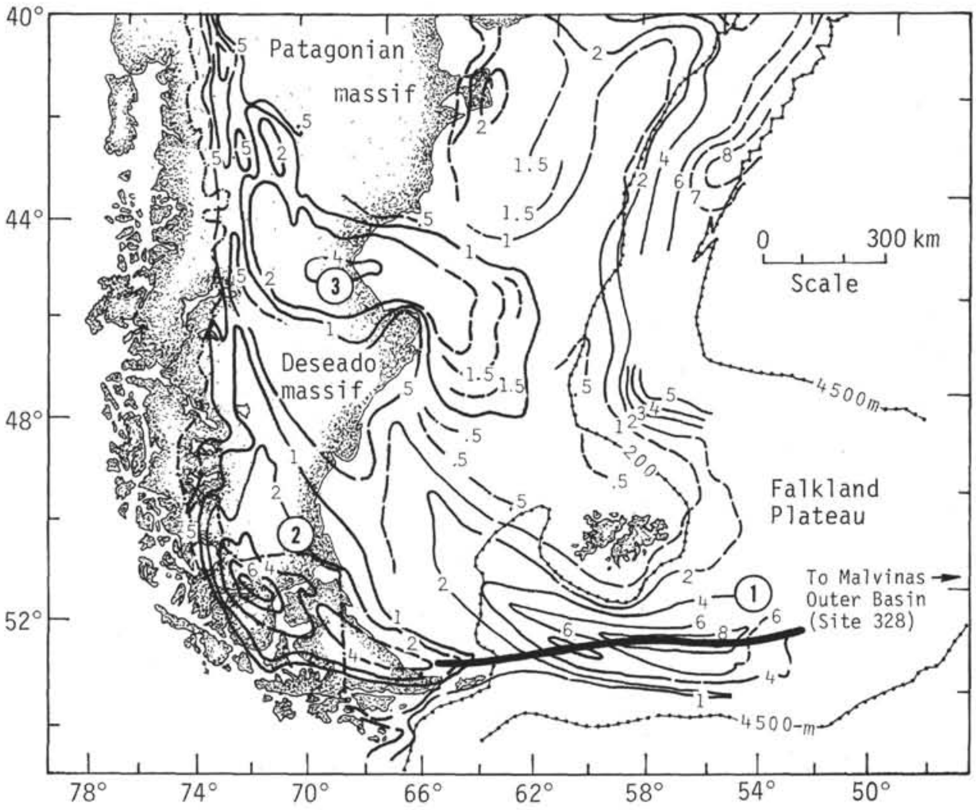


Figure 7. *Sedimentation rates at Site 328.*

late Miocene (upper part of Unit 2) with evidence of winnowing and increase in the quantity of manganese nodules and coarse clastic detritus during this time interval. Hence an increase in the bottom current velocity is indicated beginning probably in the late Eocene and continuing through the Miocene. Cold-water microfossils become dominant in the middle Miocene, and although there is no certain ice-rafted material below the uppermost Miocene (5-7 m.y.), the sand-sized fraction could represent glacially derived material at least in part.

At present the exact cause of increased bottom current activity in the Malvinas Outer Basin in post-late Eocene time must remain speculative. Establishment of continental glaciation in Antarctica and hence the likely generation of Antarctic Bottom Water, continued opening of a seaway between Antarctica and Australia, and initial opening of the Drake Passage to allow a complete circumpolar current are all thought to have occurred at or about this time (Barker, 1970, in press; Hayes, Frakes, et al., 1975). All three events contributed to vastly improved circulation in the Southern Ocean.

The presence of icebergs in the region is apparent from dropstones throughout the upper Miocene, Pliocene, and Quaternary when the sedimentation rate varied between 1.6 and 5.0 m/m.y. Small breaks in the late Neogene record occur at the Miocene-Pliocene and Plio-Pleistocene boundaries; the latter could, however, result from a coring gap. Increased productivity in the Neogene would result from the upwelling of cold nutrient-rich water around the Antarctic and its transportation into the Malvinas Outer Basin by the circumpolar current. Unpublished seismic reflection profiles (University of Birmingham, England) show that the Eocene and younger siliceous ooze above the clays of Units 3 and 4 thickens to at least 1.5 km in the southwestern part of the basin. (See Figure 8.) This suggests that the condensed section at Site 328 is a local effect due to its location at the extreme distal end of the deep sea fan built eastward from the eastern end of the Falkland Trough. Terrigenous sediment supply from the Andean cordillera probably slowed after the mid-Cretaceous Andean orogeny. Nevertheless, the fact that the sedimentation rate did not exceed 5 m/m.y. in the Neogene suggests that much of the fine-grained



1 Falkland Trough (Malvinas Basin)
2 Magallanes Basin
3 San Jorge Basin

Figure 8. *Relation between the Falkland Trough and the Magallanes Basin. Isopachs represent kilometers of late Mesozoic and Cenozoic sedimentary cover on top of Middle-Upper Jurassic volcanic or Paleozoic-early Mesozoic metamorphic-plutonic basement (after Urien and Zambrano, 1973). Axis of gravity minimum from unpublished data of the University of Birmingham.*

was transported away as a nepheloid layer into the Argentine Basin as is happening at the present time (Le Pichon et al., 1971). The location of Site 328 directly southwest of the gap in the Falkland Fracture Zone (Figure 1) through which the bottom current flows into the Argentine Basin is probably significant. Elsewhere in the Malvinas Outer Basin deposition of argillaceous material may take place in current eddies and backwaters.

REFERENCES

Barker, P.F., 1970. Plate tectonics of the Scotia Sea region: Nature, Lond., v. 228, p. 1293-1297.

———, in press. The tectonic framework of Cenozoic volcanism in the Scotia Sea region—a review: Bull. Volc.

Bukry, D., 1975a. Coccolith and silicoflagellate stratigraphy near Antarctica, Deep Sea Drilling Project, Leg 28. *In* Hayes, D.E., Frakes, L.A., et al., Initial Reports of the Deep SeaDrilling Project, Volume 28: Washington (U.S. Government Printing Office), p. 709-723.

———, 1975b. Silicoflagellate and coccolith stratigraphy, Deep Sea Drilling Project, Leg 29. *In* Kennett, J.P., Houtz, R.E., et al., Initial Reports of the Deep Sea Drilling Project, Volume 29: Washington (U.S. Government Printing Office), p. 845-872.

Bukry, D. and Foster, J.H., 1974. Silicoflagellate zonation of Upper Cretaceous to lower Miocene deep-sea sediment: U.S. Geol. Surv. J. Res., v. 2, p. 303-310.

Ciesielski, P.F., 1974. Neogene and Oligocene silicoflagellate biostratigraphic zonation for the Southern Ocean: Antarctic J. U.S., v. 9, p. 271-272.

———, 1975. Biostratigraphy and paleoecology of Neogene and Oligocene silicoflagellates from cores recovered during Antarctic Leg 28, Deep Sea Drilling Project. *In* Initial Reports of the Deep Sea Drilling Project, Hayes, D.E., Frakes, L.A., et al., Volume 28: Washington (U.S. Government Printing Office), p. 625-691.

Dalziel, I.W.D., 1974. The margins of the Scotia Sea. *In* Burk, C.A. and Drake, C.L. (Eds.), The geology of continental margins: New York (Springer-Verlag), p. 567-579.

Dalziel, I.W.D. and Elliot, D.H., 1973. The Scotia Arc and Antarctic Margin. *In* Nairn, A.E.M. and Stehli, F.H. (Eds.), The ocean basins and margins: 1. The South Atlantic: New York (Plenum Press), p. 171-245.

Ewing, M. and Lonardi, A.G., 1971. Sediment transport and distribution of the Argentine Basin. *In* Physics and chemistry of the earth: Exeter (Pergamon Press), v. VIII, p. 123-151.

Ewing, J.I., Ludwig, W.J., Ewing, J., and Eittrium, S.L., 1971. Structure of the Scotia Sea and Falkland Plateau: J. Geophys. Res., v. 76, p. 7118-7137.

Hayes, D.E., Frakes, L.A., et al., 1975. Initial Reports of the Deep Sea Drilling Project, Volume 28: Washington (U.S. Government Printing Office).

Le Pichon, X., Eittreim, S.L., and Ludwig, W.L., 1971. Sediment transport and distribution in the Argentine Basin. 1. Antarctic Bottom Current passage through the Falkland Fracture Zone. *In* Physics and chemistry of the earth: Exeter (Pergamon Press), v. VIII, p. 1-28.

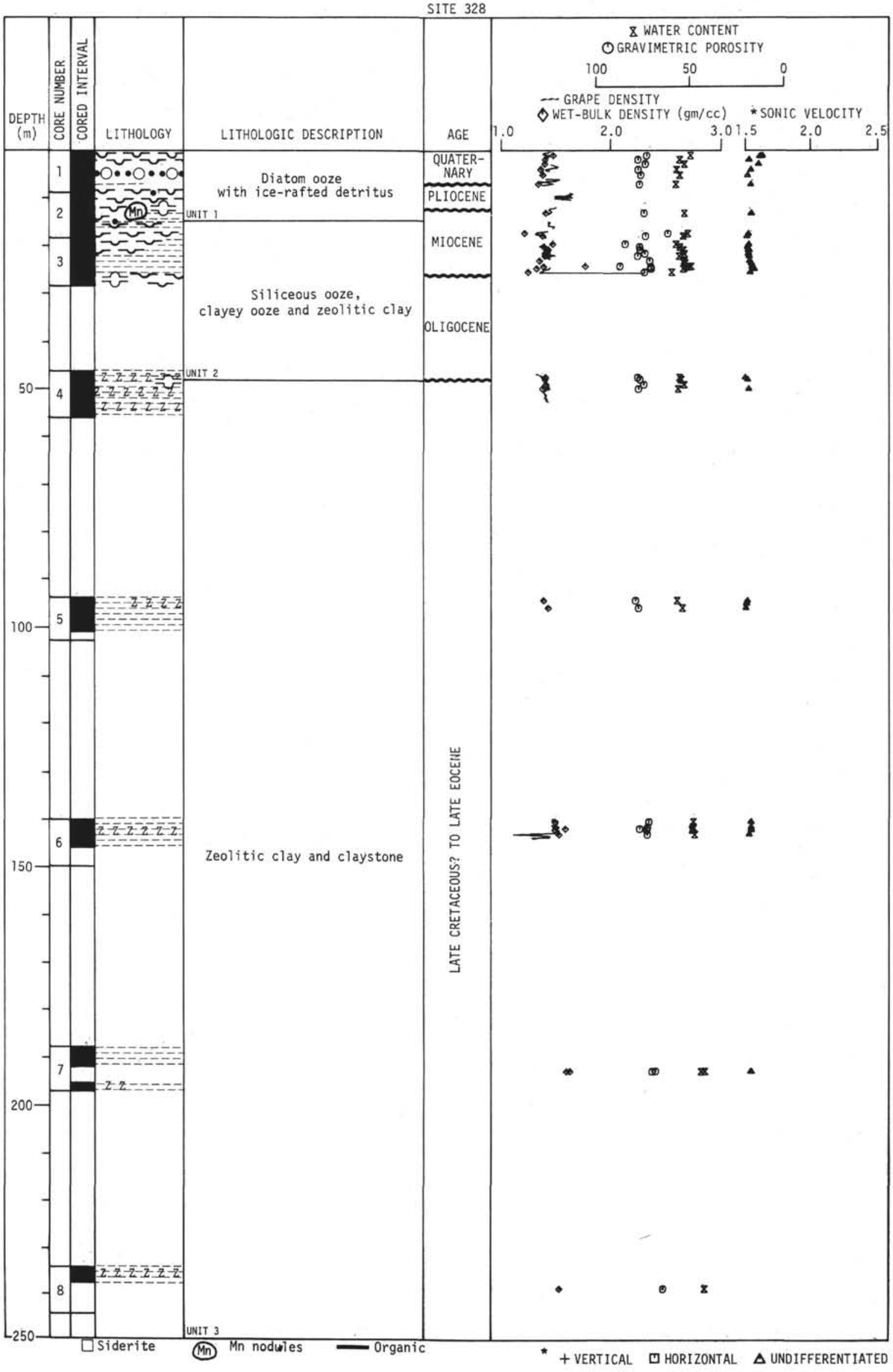
Lonardi, A. and Ewing, M., 1971. Bathymetry chart of the Argentine Basin (Map, no scale). *In* Physics and chemistry of the earth, v. 8: London (Pergamon Press).

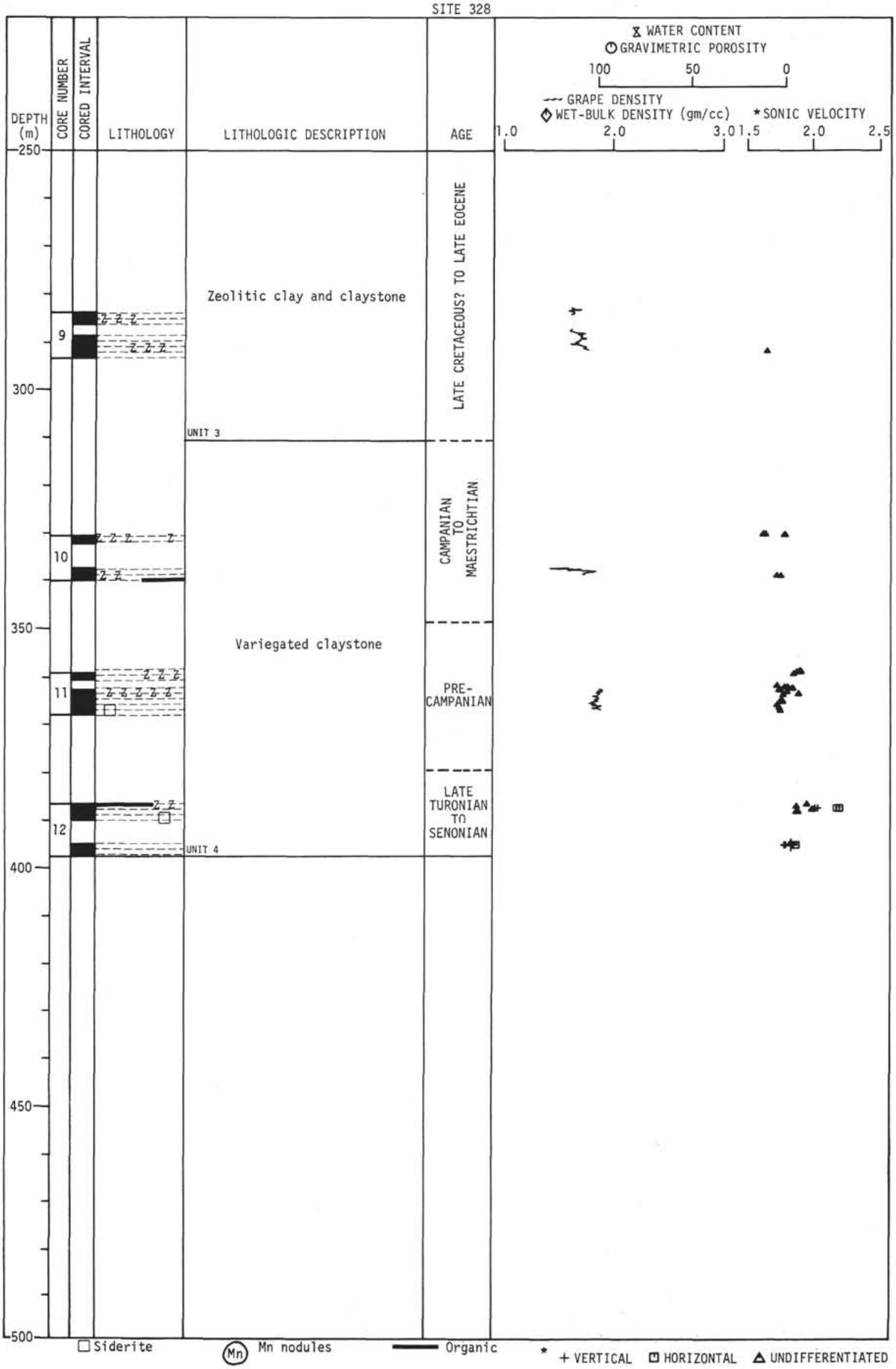
McCollum, D.W., 1975. Diatom stratigraphy of the Southern Ocean. *In* Hayes, D.E., Frakes, L.A., et al., Initial Reports of the Deep Sea Drilling Project, Volume 28: Washington (U.S. Government Printing Office), p. 515-571.

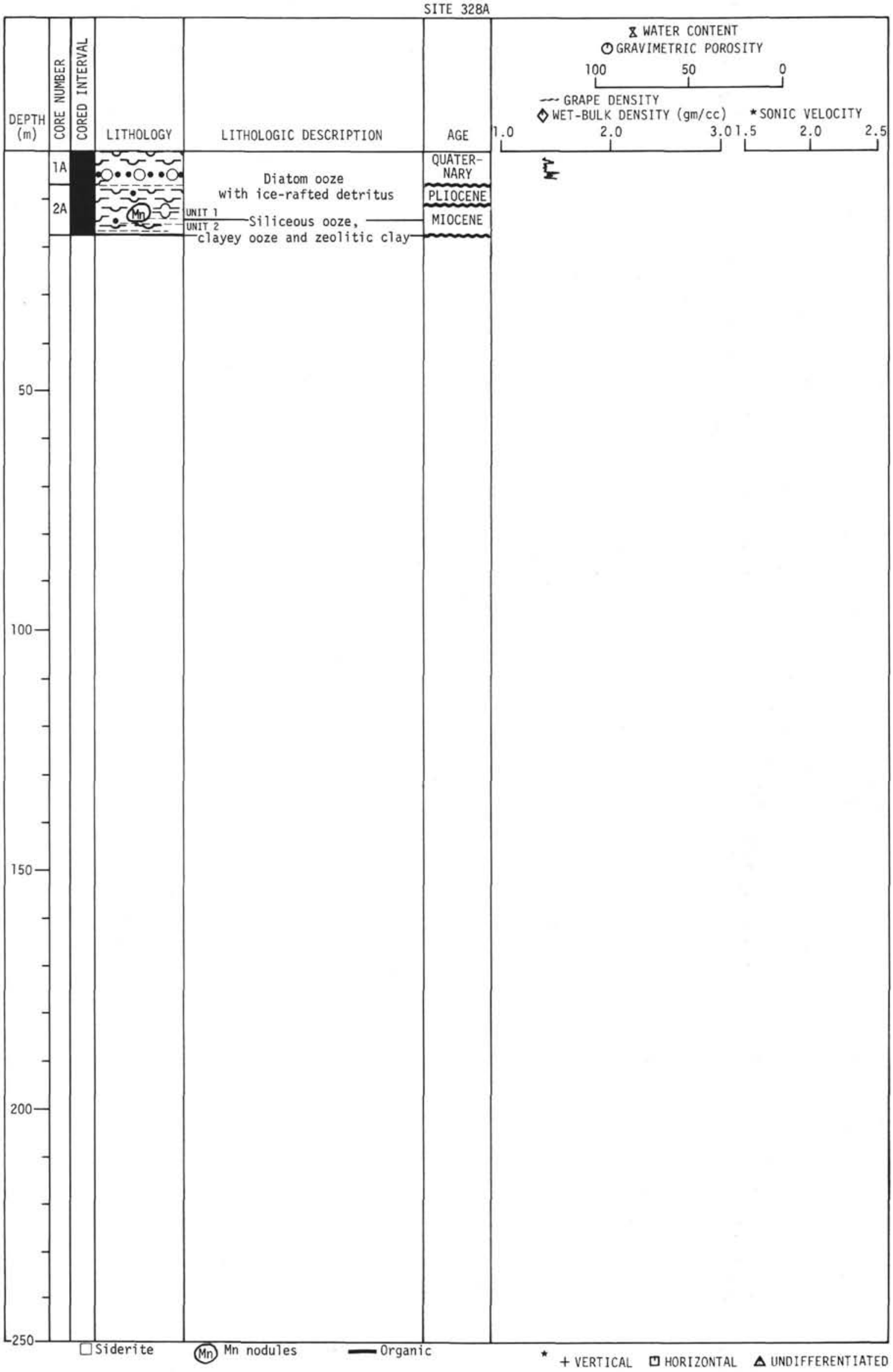
Scott, K., 1966. Sedimentology and dispersal patterns of a Cretaceous flysch sequence, Patagonian Andes, Southern Chile: Am. Assoc. Petrol. Geol. Bull., v. 50, p. 72-107.

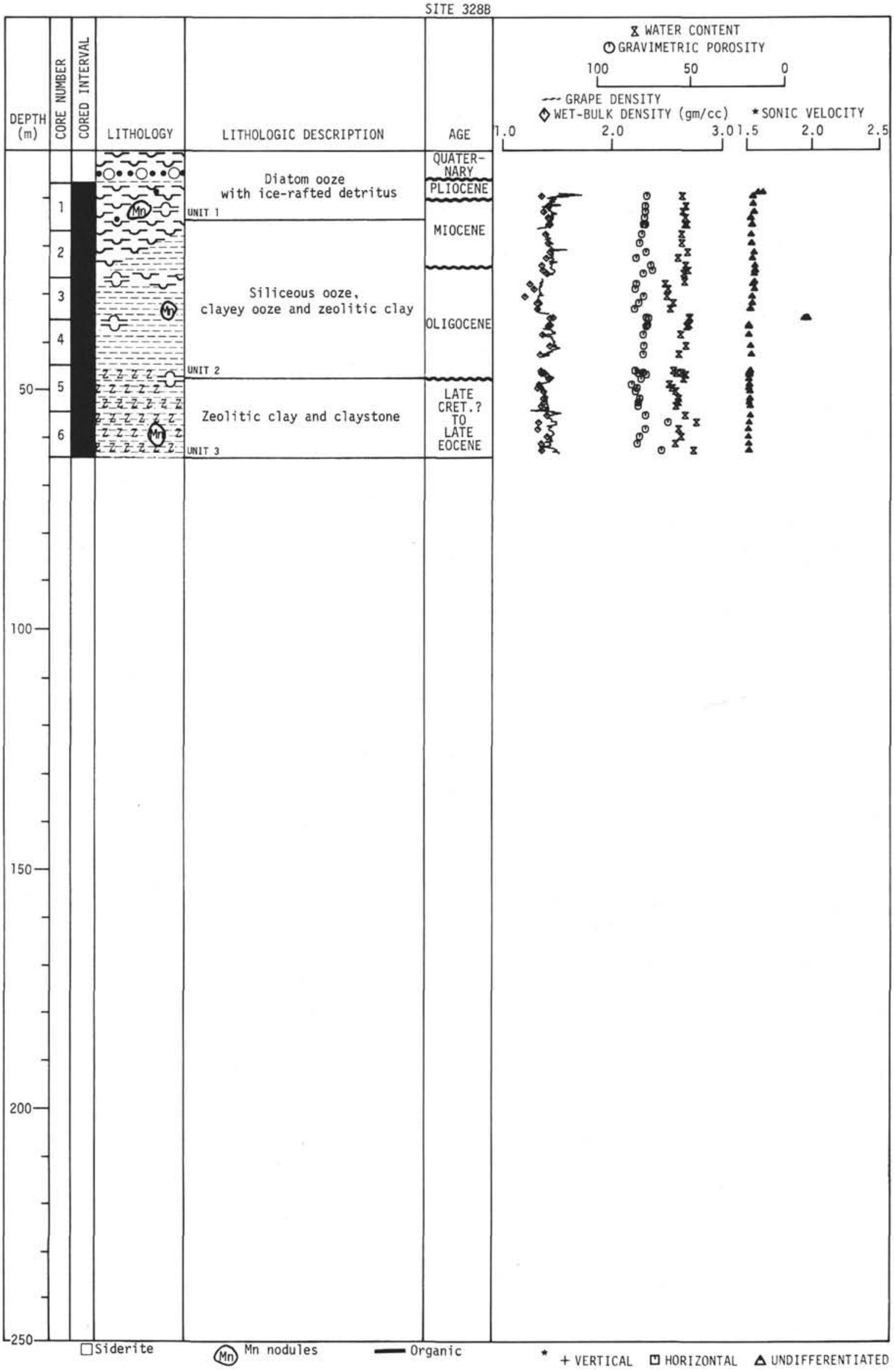
Shackleton, N.J. and Kennett, J.P., 1975. Late Cenozoic Oxygen and carbon isotopic changes at DSDP Site 284: Implications for glacial history of the northern hemisphere and Antarctic. *In* Kennett, J.P., Houtz, R.E., et al., Initial Reports of the Deep Sea Drilling Project, Volume 29: Washington (U.S. Government Printing Office), p. 801-808.

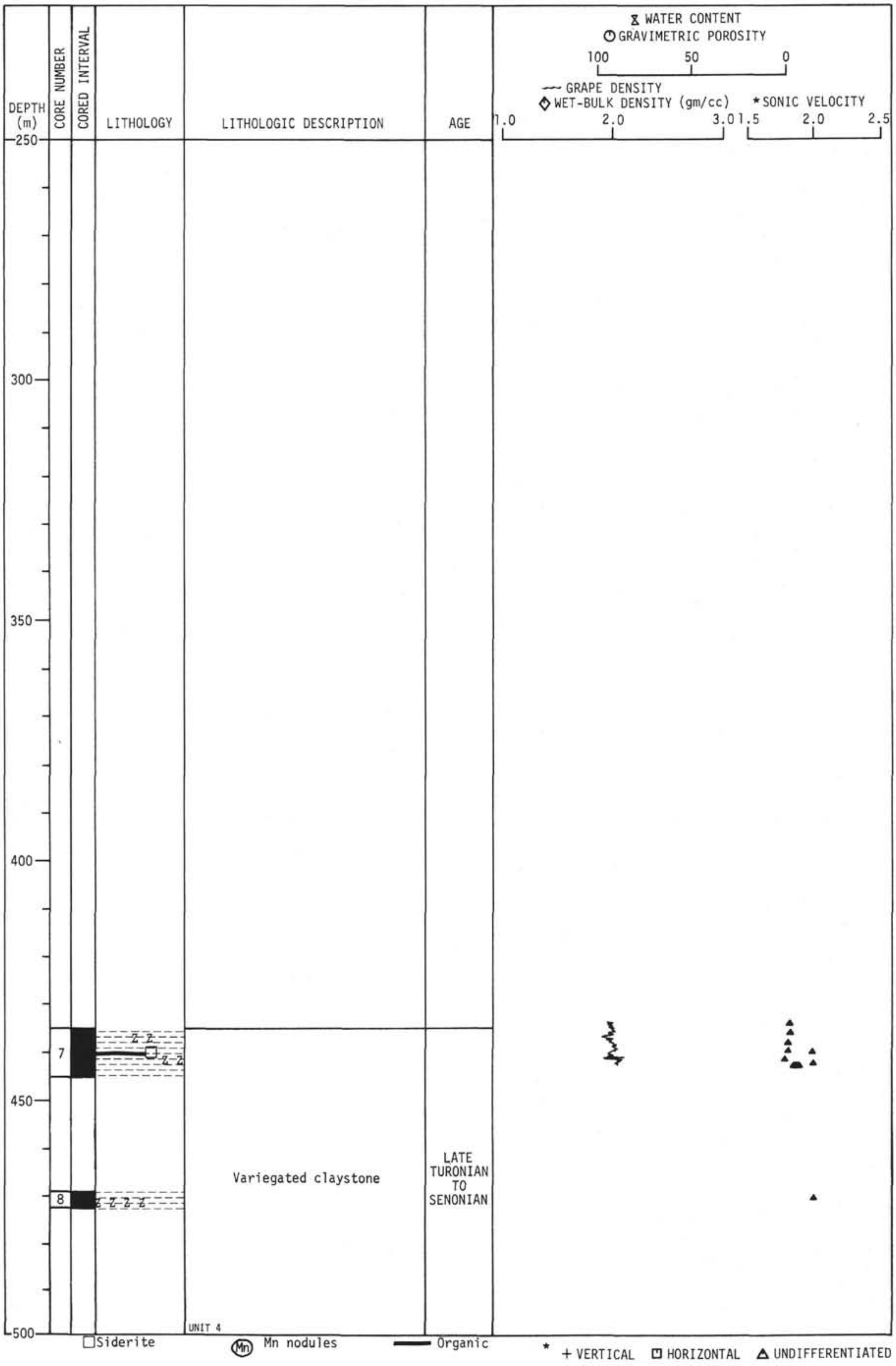
Urien, C.M. and Zambrano, J.J., 1973. The geology of the basins of the Argentine continental margin and Malvinas Plateau. *In* Nairn, A.E.M. and Stehli, F.G. (Eds.), The Ocean basins and margins I, the South Atlantic: New York (Plenum), p. 135-169.


SITE 328
DEPTH (m)
CORE NUMBER
CORED INTERVAL
LITHOLOGY
LITHOLOGIC DESCRIPTION
AGE
WATER CONTENT
GRAVIMETRIC POROSITY
100
50
0
GRAPE DENSITY
WET-BULK DENSITY (gm/cc)
SONIC VELOCITY
1.0
2.0
3.0
1.5
2.0
2.5
1
2
3
4
5
6
7
8
50
100
150
200
250
Mn
UNIT 1
UNIT 2
UNIT 3
Diatom ooze with ice-rafted detritus
Siliceous ooze, clayey ooze and zeolitic clay
Zeolitic clay and claystone
QUATER-NARY
PLIOCENE
MIOCENE
OLIGOCENE
LATE CRETACEOUS? TO LATE EOCENE
Siderite
Mn nodules
Organic
+ VERTICAL
HORIZONTAL
UNDIFFERENTIATED

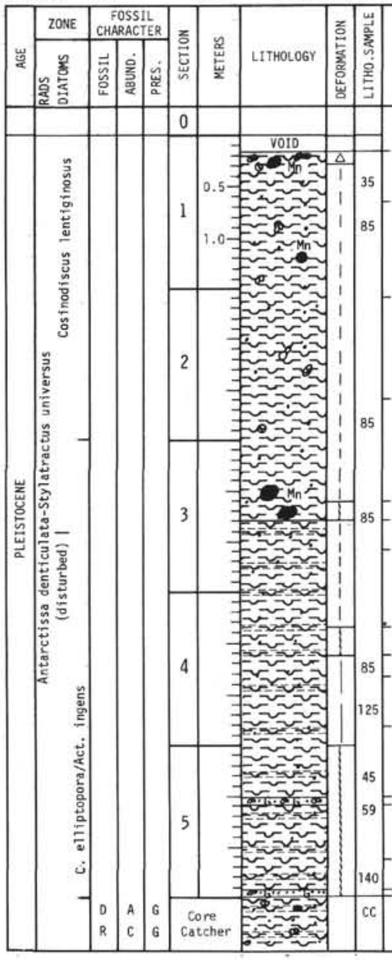

SITE 328
DEPTH (m)
CORE NUMBER
CORED INTERVAL
LITHOLOGY
LITHOLOGIC DESCRIPTION
AGE
WATER CONTENT
GRAVIMETRIC POROSITY
100
50
0
GRAPE DENSITY
WET-BULK DENSITY (gm/cc)
SONIC VELOCITY
1.0
2.0
3.0
1.5
2.0
2.5
250
300
350
400
450
500
9
10
11
12
Zeolitic clay and claystone
UNIT 3
Variegated claystone
UNIT 4
LATE CRETACEOUS? TO LATE EOCENE
CAMPANIAN TO MAESTRICHTIAN
PRE-CAMPANIAN
LATE TURONIAN TO SENONIAN
☐ Siderite
Mn Mn nodules
Organic
* + VERTICAL
HORIZONTAL
UNDIFFERENTIATED


SITE 328A
DEPTH (m)
CORE NUMBER
CORED INTERVAL
LITHOLOGY
LITHOLOGIC DESCRIPTION
AGE
WATER CONTENT
GRAVIMETRIC POROSITY
100
50
0
GRAPE DENSITY
WET-BULK DENSITY (gm/cc)
1.0
2.0
3.0
SONIC VELOCITY
1.5
2.0
2.5
1A
2A
Mn
Diatom ooze with ice-rafted detritus
UNIT 1
UNIT 2
Siliceous ooze, clayey ooze and zeolitic clay
QUATERNARY
PLIOCENE
MIOCENE
50
100
150
200
250
Siderite
Mn nodules
Organic
* + VERTICAL
HORIZONTAL
UNDIFFERENTIATED


SITE 328B
DEPTH (m)
CORE NUMBER
CORED INTERVAL
LITHOLOGY
LITHOLOGIC DESCRIPTION
AGE
WATER CONTENT
GRAVIMETRIC POROSITY
100
50
0
GRAPE DENSITY
WET-BULK DENSITY (gm/cc)
SONIC VELOCITY
1.0
2.0
3.0
1.5
2.0
2.5
1
2
3
4
5
6
Diatom ooze with ice-rafted detritus
UNIT 1
Siliceous ooze, clayey ooze and zeolitic clay
UNIT 2
Zeolitic clay and claystone
UNIT 3
QUATERNARY
PLIOCENE
MIOCENE
OLIGOCENE
LATE CRET.? TO LATE EOCENE
Mn
50
100
150
200
250
Siderite
Mn nodules
Organic
+ VERTICAL
HORIZONTAL
UNDIFFERENTIATED


DEPTH (m)
CORE NUMBER
CORED INTERVAL
LITHOLOGY
LITHOLOGIC DESCRIPTION
AGE
⧗ WATER CONTENT
○ GRAVIMETRIC POROSITY
100
50
0
~ GRAPE DENSITY
◇ WET-BULK DENSITY (gm/cc)
1.0
2.0
3.0
* SONIC VELOCITY
1.5
2.0
2.5
250
300
350
400
450
500
7
8
Variegated claystone
LATE TURONIAN TO SENONIAN
UNIT 4
□ Siderite
Ⓜn Mn nodules
Organic
* + VERTICAL
□ HORIZONTAL
△ UNDIFFERENTIATED

Site 328 Hole Core 1 Cored Interval: 0.0-7.5 m



5Y 7/2

5Y 7/2
with patches
10YR 6/2

5Y 7/2
with patches
5YR 4/1

5Y 7/2
5Y 6/1

5Y 7/2

5Y 5/2 with
patch 5B 7/1

5GY 6/1

5G 6/1

5GY 5/2

5G 3/2

5GY 5/2

N6 with
patches 5GY 5/2
5GY 2/1

N3

LITHOLOGIC DESCRIPTION

SILTY BIOSILICEOUS OOZE

Faintly laminated yellow gray to greenish gray and brownish gray mottled with pale yellow brown and dusky yellow green. Slightly sticky contains clay, silt, sand, and pebbles throughout. Coarse clasts are angular to subangular dropstones, some of which are faceted, striated, and coated with manganese crusts. Pebbles are polymictic and up to 8 cm in maximum dimension. Two thin beds of PEBBLY GLAUCONITIC SANDSTONE, dusky green to dark greenish black, friable, very fine-grained, with pyrite spherules and pebbles to 1.9 cm maximum dimension.

Characteristic smear slide

	2-85	4-85	CC
clay	6	5	
diatoms	89	83	
rads	1	2	
qtz., feld.	4	10	
rock frags.	-	-	
glauc.	-	-	
heavy min.	-	-	

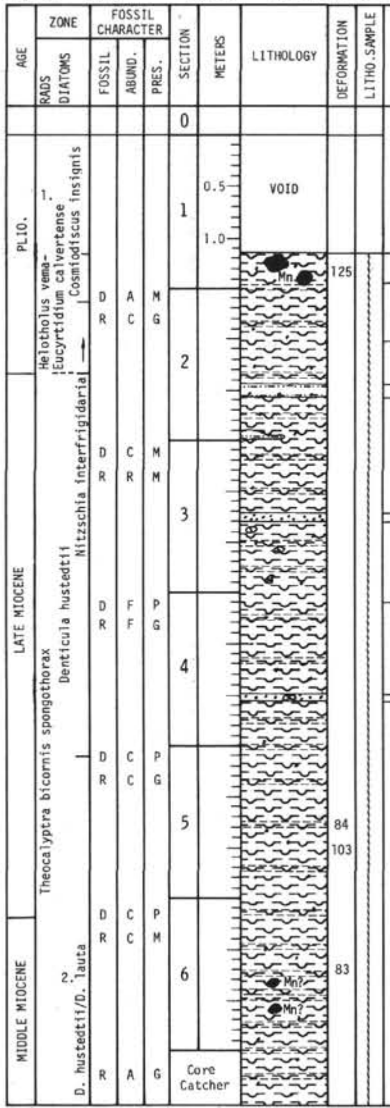
Grain size

	3-111	4-110	5-55	5-110
sand	0.0	8.6	7.5	9.7
silt	99.5	31.2	21.4	28.6
clay	0.4	60.1	71.1	61.7

Bulk X-ray

	2-107	5-107
amor.	65.4	58.6
quar.	37.1	29.0
K-Fe.	11.4	11.9
plag.	19.4	21.1
kaol.	1.1	1.7
mica	14.9	19.5
chlo.	2.1	6.5
mont.	11.1	6.9
clin.	1.5	1.2
amph.	1.5	2.3

Site 328 Hole Core 2 Cored Interval: 7.5-17.0 m



5Y 7/2

10YR 5/4

5Y 7/2 with
patches
10YR 5/4
10YR 4/2

5Y 7/2

10YR 4/2

5Y 7/2 mottled
with 10YR 4/2

5Y 7/2

10YR 2/2

5Y 7/2

LITHOLOGIC DESCRIPTION

CLAYEY BIOSILICEOUS OOZE

Homogeneous, slightly sticky, yellow gray to moderate yellow brown. Contains dispersed silt and sand throughout with pebbles, in part coated with manganese, down to 5.5 m. Deformed cm scale laminae of SANDSTONE at 3.7 and 5.5 m, very fine-grained, pebbly and SANDY SILT at 2.5 and 3.0 m. Minor micronodules throughout.

Grain size

	2-110	3-80	3-110	4-124	5-10
sand	40.2	55.0	26.9	6.9	11.0
silt	29.9	24.2	26.3	29.1	33.1
clay	29.9	20.8	46.8	64.0	56.0

	5-110	6-10	6-110
sand	5.2	1.9	1.8
silt	33.1	35.9	32.8
clay	61.7	62.2	65.3

Characteristic smear slide

	1-125	5-103	5-84
clay	5	10	-
diatoms	90	80	-
rads	-	-	-
qtz., feld.	5	10	79
glauc.	-	-	20
opaques	-	-	-
vol. glass	TR	-	-
heavy min.	1	-	1

Bulk X-ray

	1-145	6-14
amor.	55.1	66.7
quar.	31.3	27.5
K-Fe.	14.3	13.7
plag.	21.6	19.8
kaol.	0.9	0.8
mica	20.8	17.2
chlo.	1.1	0.5
mont.	7.4	13.6
paly.	-	4.7
clin.	1.2	1.1
amph.	1.2	1.1

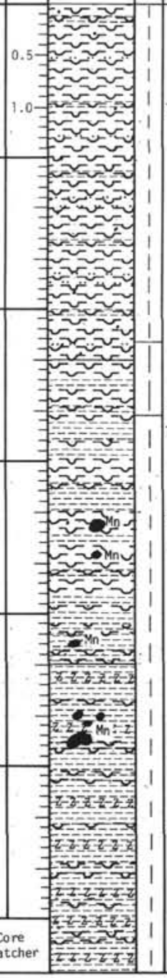
Explanatory notes in Chapter 1

Site 328 Hole Core 3 Cored Interval: 17.0-26.5 m

AGE: MIDDLE MIOCENE

ZONE (RADS / DIATOMS): *Denticula lauta/ Denticula antarctica*; *Theocalptra bicornis spongothorax*

SECTION	FOSSIL	ABUND.	PRES.	LITHO. SAMPLE
0				
1				100
2	D R	C C	M G	
3	D R	C C	P G	92 130
4	D R	R C	P M	11 61
5	D R	R F	P M	
6	D R	R R	P P	69
Core Catcher				



LITHOLOGIC DESCRIPTION

5Y 7/2

10YR 7/4

10YR 5/4
10YR 8/2
mottled with
10YR 7/4

10YR 5/4

10YR 7/4

10YR 5/4 with
patches 10YR 7/4

BIOSILICEOUS OOZE, BIOSILICEOUS CLAY, AND BIOSILICEOUS ZEOLITIC CLAY
Slightly sticky to sticky and lumpy. Moderate yellow brown to grayish orange. Manganese nodules to 8 cm diameter, silt, and rare sand throughout.

Characteristic smear slide

	1-100	3-92	4-11	6-69
qtz., feld.	20	5	2	5
clay	20	65	88	74
diatoms	55	15	-	-
rads	5	5	-	-
micronods.	-	1	-	-
zeol.	-	-	5	15
diatoms, rads	-	-	5	6

Carbon-carbonate

	1-113
t. carb.	0.1
o. carb	0.1
$CaCO_3$	0.0

Grain size

	1-10	1-110	2-114	3-110	4-110
sand	2.1	0.8	0.7	1.3	0.7
silt	40.2	32.7	32.2	24.7	26.1
clay	57.7	66.5	67.2	74.0	73.3

	5-110	6-112
sand	0.5	0.5
silt	22.2	24.2
clay	77.3	75.2

Bulk X-ray

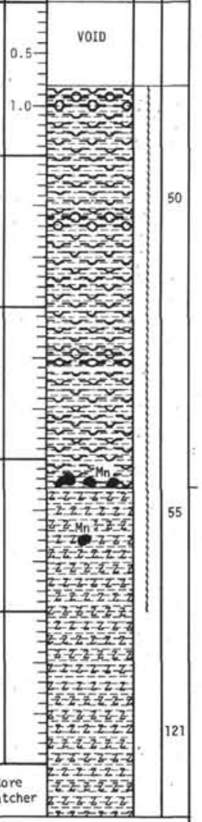
	2-17	3-113	4-113	5-14	5-113
amor.	61.8	58.5	58.5	59.6	57.6
quar.	22.4	20.4	17.4	18.9	16.9
K-Fe.	10.8	6.6	5.6	6.4	3.9
plag.	20.2	19.8	20.7	19.6	21.5
kaol.	0.7	0.6	-	1.2	1.1
mica	17.1	18.6	20.2	20.6	19.8
chlo.	0.9	0.8	-	1.1	0.7
mont.	19.4	25.4	26.9	22.0	28.7
paly.	5.7	5.3	6.2	5.1	4.6
clin.	1.8	1.7	2.2	4.1	2.2
amph.	0.9	0.8	0.7	0.8	0.7

	6-10	6-115
amor.	61.1	58.7
quar.	17.5	20.0
K-Fe.	6.0	4.2
plag.	21.2	19.3
kaol.	0.6	0.6
mica	20.6	17.3
chlo.	1.1	0.8
mont.	25.2	28.1
paly.	4.8	7.1
clin.	2.3	1.7
amph.	0.8	0.9

Site 328 Hole Core 4 Cored Interval: 45.5-55.0 m

AGE: LATE EOCENE

SECTION	FOSSIL	ABUND.	PRES.	LITHO. SAMPLE
0				
1				
2	D R	C C	G G	50
3	D R	F C	P/M M	
4	D R	R F	P M	55
5	D R	VR F	P M	121
Core Catcher	R	R	P	



LITHOLOGIC DESCRIPTION

10YR 7/4

MANGANESE
NODULES
to 2.9 cm
diameter.

10YR 8/2
to
10YR 7/4

BIOSILICEOUS CLAY
Slightly sticky, grayish orange with dark streaks and patches manganese, silty.

Representative smear slide

	2-50
qtz., feld.	5
clay	62
diatoms	30
rads	3

Carbon-carbonate

	3-22
t. carb	0.1
o. carb	0.1
$CaCO_3$	0.0

Bulk X-ray

	2-50	3-20	3-113	4-10	4-60
amor.	67.8	68.1	67.2	63.4	65.1
quar.	21.1	21.1	21.9	21.6	20.0
K-Fe.	3.5	4.8	7.2	7.6	5.6
plag.	15.2	12.7	13.6	14.1	13.4
kaol.	2.0	2.1	2.1	1.4	2.0
mica	23.0	20.1	25.1	23.2	25.1
chlo.	1.7	1.3	1.3	1.7	1.6
mont.	29.9	27.5	22.3	19.3	21.0
paly.	-	5.7	-	3.8	-
clin.	2.7	3.7	5.6	6.4	11.4
amph.	0.9	0.9	0.9	0.9	-

ZEOLITIC CLAY
Sticky, very pale orange to grayish orange with dark streaks and patches manganese. Fish debris in core catcher.

Representative smear slide

	4-55	5-121
qtz., feld.	1	-
clay	58	73
zeol.	41	20
goethite?	-	4
opaques	-	3

Carbon-carbonate

	5-62
t. carb	0.1
o. carb	0.1
$CaCO_3$	0.0

Bulk X-ray

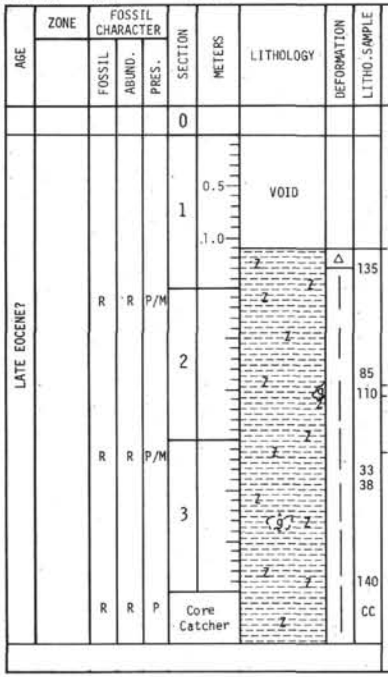
	4-110	5-10	5-50	5-100
amor.	61.0	61.5	62.8	59.6
quar.	15.9	15.2	12.4	15.8
K-Fe.	3.7	4.3	2.1	4.5
plag.	7.8	8.3	14.4	9.1
kaol.	2.1	1.0	1.7	1.6
mica	20.6	24.9	16.7	24.4
chlo.	0.7	0.6	1.1	1.6
mont.	30.1	23.1	30.5	19.6
palg.	-	-	4.8	4.3
clin.	12.9	12.7	12.2	14.5
phil.	4.8	9.1	3.9	4.7
gibb.	-	-	0.2	-
amph.	1.4	0.7	-	-

Grain size

	2-110
sand	0.8
silt	25.4
clay	73.8

Explanatory notes in Chapter 1

Site 328 Hole Core 5 Cored Interval: 93.0-102.5 m



LITHOLOGIC DESCRIPTION

5G 6/1

5G 4/1

5G 6/1

5GY 4/1

ZEOLITIC CLAY
Sticky, faintly banded greenish gray and dark greenish gray with mm-scale greenish black and dark grayish black laminae. Rare to common detrital silt. Fish debris in core catcher.

Carbon-carbon

	3-48
t. carb	0.4
O. carb	0.1
$CaCO_3$	3.0

Characteristic smear slide

	1-135	2-85	3-38	3-140	CC
qtz.	5	-	-	1	-
clay	79	96	97	83	90
zeol.	15	3	2	15	10
opaques	1	-	1	1	-
chalcedony	-	1	-	-	-

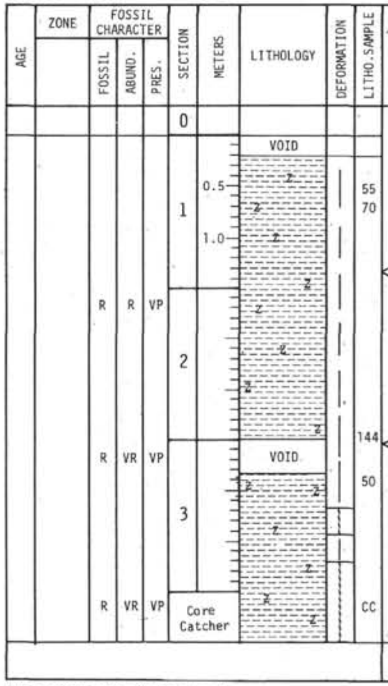
Bulk X-ray

	3-53
amor.	51.3
quar.	15.1
K-Fe.	4.9
plag.	7.7
kaol.	2.0
mica	17.8
chlo.	1.2
mont.	44.5
paly.	5.5
clin.	1.3

Grain size

	3-50
sand	0.1
silt	20.1
clay	79.8

Site 328 Hole Core 6 Cored Interval: 140.5-150.0 m



LITHOLOGIC DESCRIPTION

5GY 4/1

< 5G 6/1 (3 mm)

< 5Y B/1 (3 mm)

ZEOLITIC CLAY
Slightly sticky to sticky, dark greenish gray mottled with dark gray and with mm-scale dark gray laminae. Rare radiolarians. Fish debris in core catcher sample.

Carbon-carbonate

	2-48
t. carb	0.4
o. carb	0.4
$CaCO_3$	0.0

Representative smear slide

	1-55	1-70	2-144	3-50	CC
clay	88	93	98	90	90
zeol.	10	7	-	7	10
opaques	2	-	-	3	-
apatite	-	-	2	-	-
sphalerite(?)	-	-	-	-	TR

Bulk X-ray

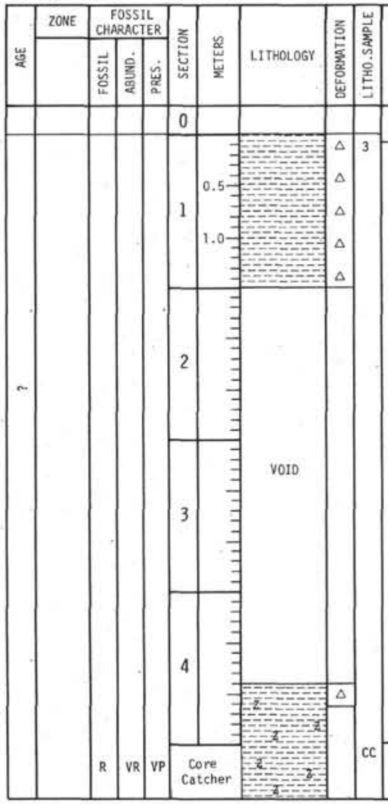
	2-53	2-81
amor.	46.3	52.6
calc.	-	3.9
quar.	15.8	15.4
K-Fe.	4.0	4,4
plag.	5.0	5.0
kaol.	1.0	1.5
mica	14.0	13.9
chlo.	1.0	1.3
mont.	46.6	52.5
paly.	7.2	-
clin.	0.7	0.7
amph.	-	1.4

Grain size

	2-50
sand	0.0
silt	19.8
clay	80.1

Explanatory notes in Chapter 1

Site 328 Hole Core 7 Cored Interval: 188.0-197.5 m



LITHOLOGIC DESCRIPTION

5Y 7/2

5GY 4/1

5Y 4/1

CLAY AND ZEOLITIC CLAY
Sticky, homogeneous, dark greenish gray to olive gray with yellow gray claystone lump 3 cm thick at top. Rare pyritized radiolarians.

Representative smear slide

	1-3	CC
clay	99	90
opaques	1	5
zeol.	-	5

Bulk X-ray

	4-111
amor.	48.1
quar.	15.7
K-Fe.	3.6
plag.	4.0
kaol.	2.1
mica	16.2
chlo.	1.6
mont.	47.3
paly.	4.3
clin.	0.7
phil.	4.6

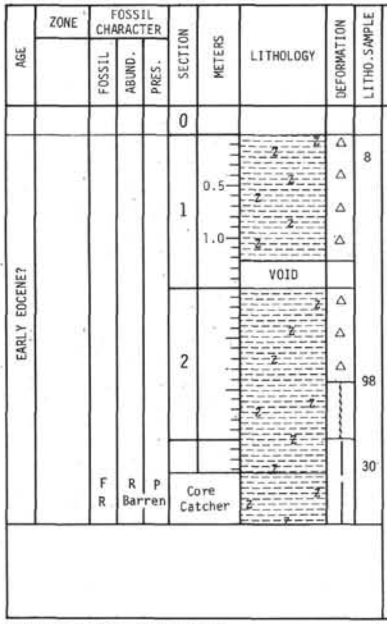
Carbon-carbonate

	4-115
t. carb	0.4
o. carb	0.3
$CaCO_3$	0.0

Grain size

	4-113
sand	0.0
silt	7.5
clay	92.5

Site 328 Hole Core 8 Cored Interval: 235.5-245.0 m



LITHOLOGIC DESCRIPTION

5GY 4/1
to
5Y 4/1

5Y 4/1

ZEOLITIC CLAY AND CLAYSTONE
Breccia of sticky clay containing lumps of harder claystone. Dark greenish gray to olive gray.

Representative smear slides

	1-8	2-98	3-30
clay	89	90	91
zeol.	10	6	6
opaques	1	2	1
goethite?	-	2	2

Bulk X-ray

	2-118
amor.	41.8
quar.	14.5
K-Fe.	3.1
plag.	3.7
kaol.	1.4
mica	13.9
chlo.	0.6
mont.	53.2
paly.	5.3
phil.	4.3

Carbon-carbonate

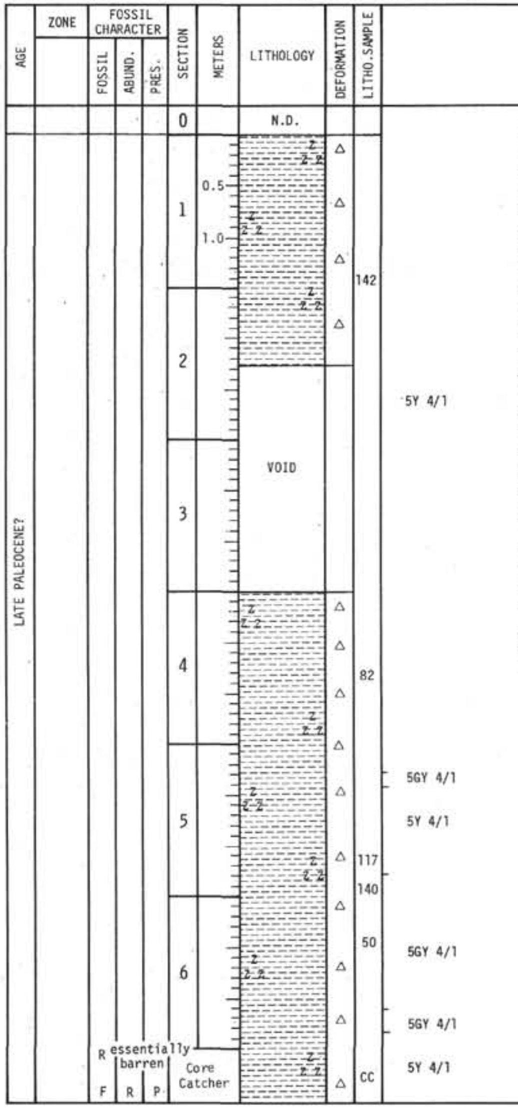
	2-123
t. carb	0.3
o. carb	0.3
$CaCO_3$	0.0

Grain size

	2-120
sand	0.1
silt	19.9
clay	80.0

Explanatory notes in Chapter 1

Site 328 Hole Core 9 Cored Interval: 283.0-292.5 m



ZEOLITIC CLAYSTONE
Breccia of hard claystone lumps in matrix of ground up sticky clay. Olive gray to dark greenish gray, faintly color-banded. Fish debris in core catcher sample.

Representative smear slide

	1-142	4-82	5-140	6-50
clay	88	90	93	90
zeol.	10	8	5	7
opaques	1	1	2	1
goethite?	1	1	-	1
sphalerite?	TR	TR	TR	1
collophane?	-	-	-	1

Bulk X-ray

	5-72	6-142
amor.	44.1	44.4
quar.	15.9	15.5
K-Fe.	5.6	4.3
plag.	4.5	3.4
kaol.	2.5	1.5
mica	17.2	17.1
chlo.	0.9	1.3
mont.	49.9	55.6
paly.	2.8	-
clin.	0.7	0.7
amph.	-	0.7

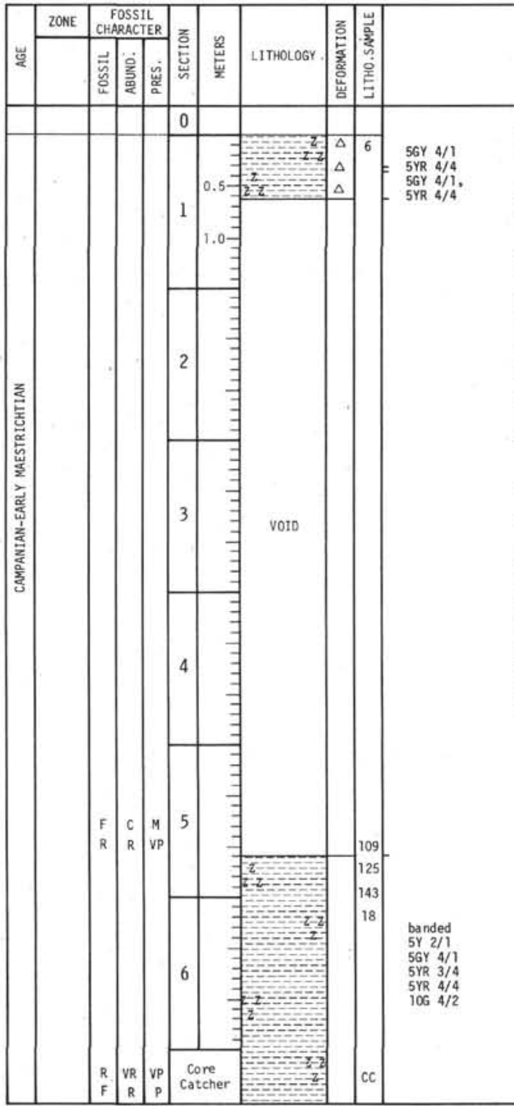
Carbon-carbonate

	5-77
t. carb	0.3
o. carb	0.3
$CaCO_3$	0.0

Grain size

	5-78
sand	0.1
silt	14.4
clay	85.6

Site 328 Hole Core 10 Cored Interval: 330.5-340.0 m



ZEOLITIC CLAYSTONE
Lumps of hard claystone in sheared matrix of sticky clay. Cyclical cm- to decimeter-scale color banding in brown, gray, olive, green, and black. Rare casts and tests of microfossils visible megascopically.

Representative smear slide

	1-6	5-105	5-143	6-18
clay	89	91	95	86
zeol.	7	5	3	10
heavies	3	3	-	-
opaques	-	-	2	3
collophane	1	-	-	-
goethite	-	-	-	-
siderite	-	1	-	-

Grain size

	6-78
sand	0.1
silt	11.2
clay	88.8

Carbon-carbonate

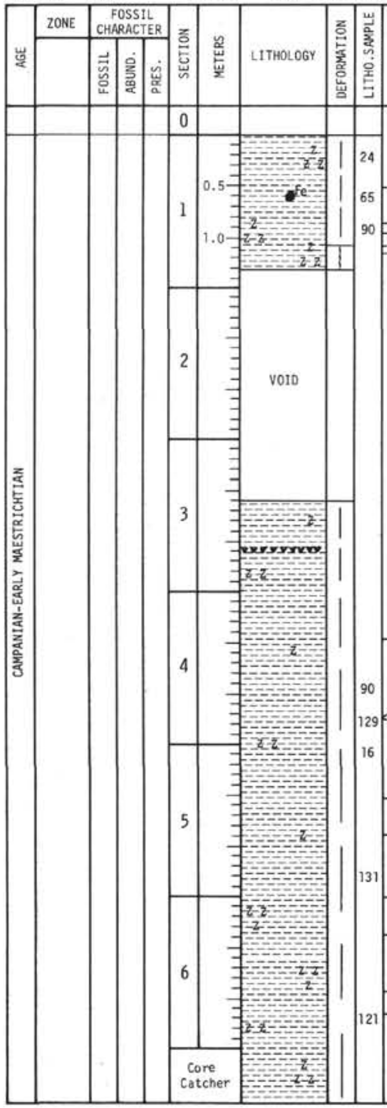
	6-72
t. carb	0.4
o. carb	0.4
$CaCO_3$	0.0

Bulk X-ray

	5-124	5-146	6-81
amor.	47.5	36.5	49.8
quar.	17.1	12.3	23.3
cris.	23.3	29.4	-
K-Fe.	6.5	2.7	5.1
plag.	4.7	3.0	5.0
kaol.	1.6	0.8	1.5
mica	15.8	11.4	16.6
chlo.	0.7	0.7	1.4
mont.	30.2	26.4	47.2
paly.	-	3.2	-
trid.	-	8.4	-
clin.	-	1.0	-

Explanatory notes in Chapter 1

Site 328 Hole Core 11 Cored Interval: 359.0-368.5 m



LITHOLOGIC DESCRIPTION

5G 2/1 mottled with 5G 4/1 siderite nodule
N3
5G 4/1
N3
5YR 3/4
N3 to N4
3 mm gray expansive shale
5YR 3/4
10YR 4/6
10YR 2/2
5YR 3/4
10YR 2/2
5G 2/1
N3 to N2
5Y 2/1
N3 to N2

CLAYSTONE

Indurated, banded and mottled gray to dark gray, moderate brown, dusky yellow brown, olive black and greenish black. Scattered patches and burrows of black carbonaceous material including <u>zoophycus</u> feeding trails. Mm-scale laminae rich in siderite. Minor zeolite.

<u>Representative smear slide</u>

	1-24	1-65	1-90
clay	87	10	88
zeol.	10	-	10
opaques	-	-	1
collophane(?)	1	-	1
siderite	-	90	-

	4-90	5-16	6-121
clay	93	92	85
zeol.	5	8	12
opaques	2	-	3
collophane(?)	-	-	-
siderite	-	-	-

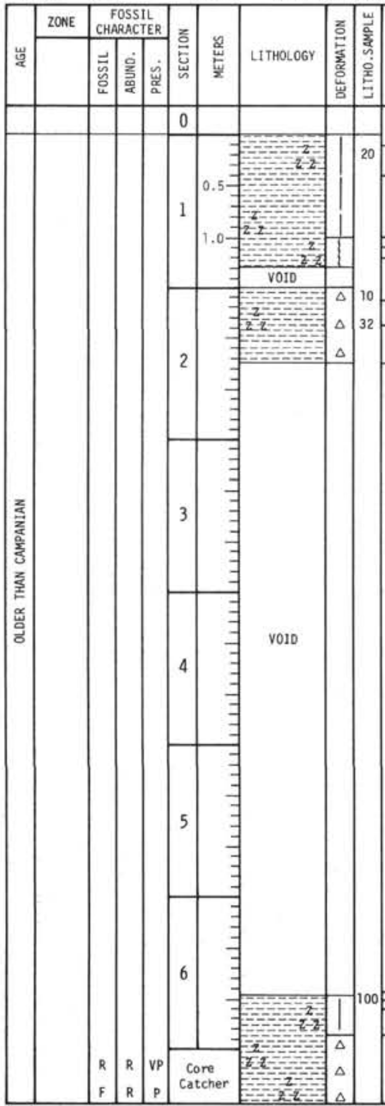
<u>Carbon-carbonate</u>

	1-77	6-70
t. carb	0.4	0.5
o. carb	0.4	0.4
$CaCO_3$	0.0	0.0

<u>Bulk X-ray</u>

	4-119	6-126
amor.	49.6	43.3
quar.	35.4	37.1
K-Fe.	3.7	2.6
plag.	3.2	3.2
mica	14.6	12.3
chlo.	-	1.4
mont.	43.2	37.3
paly.	-	6.1

Site 328 Hole Core 12 Cored Interval: 387.5-397.0 m



LITHOLOGIC DESCRIPTION

5Y 4/1
N3 to N2
5Y 4/1
5YR 4/4
N2
5GY 4/1 to 10R 4/6
N3 to N2
mixed red, green, black
5GY 4/1
5RP 4/2
N2 to N3
5GY 2/1

CLAYSTONE

Well indurated, finely color-laminated, gray, grayish black, greenish black, reddish brown, and grayish red purple. Mn-scale black carbonaceous wisps, patches, and laminations throughout. Abundant authigenic siderite in coarse dumbell-shaped crystals from 84-87 cm and disseminated throughout core. Fish debris in core catcher. Minor zeolite.

<u>Representative smear slide</u>

	1-20	2-10	6-100
clay	90	88	92
zeol.	8	5	5
heavies	2	2	2
siderite	-	5	-
collophane(?)	TR	-	-
hematite	-	-	1

<u>Carbon-carbonate</u>

	1-130	2-7	2-17
t. carb.	0.5	0.2	0.5
o. carb	0.5	0.2	0.5
$CaCO_3$	0.0	0.0	0.0

<u>Bulk X-ray</u>

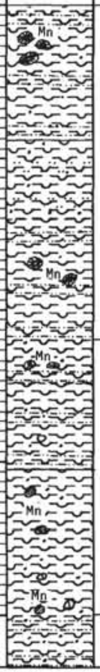
	1-45	2-7	2-17
amor.	45.4	48.5	46.2
quar.	54.9	32.3	22.4
K-Fe.	2.8	5.1	5.2
plag.	1.6	3.8	3.3
kaol.	-	-	3.4
mica	10.8	20.0	16.9
chlo.	1.0	1.2	1.3
mont.	28.9	37.5	43.7
paly.	-	-	3.8

Explanatory notes in Chapter 1

Site 328 Hole A Core 1 Cored Interval: 0.0-7.5 m

AGE	ZONE RADS / DIATOMS	FOSSIL	ABUND.	PRES.	SECTION	METERS	DEFORMATION	LITHO. SAMPLE	
					0				
PLEISTOCENE	Saturnalis circulus-Stylatractus universus -Antarctissa denticulata Coscinodiscus lentiginosus Coscinodiscus elliptopora/: Actinocyclus ingens	D	A	G	1	0.5 1.0		7 75 140	5Y 7/2 10Y 6/2
		D	A	G	2				10Y 6/2 mottled with 5Y 7/2
		D	C	G	3				10Y 6/2
		D	C	G	4			7	5Y 7/2
		R	C	G	Core Catcher				

LITHOLOGY



LITHOLOGIC DESCRIPTION

BIOSILICEOUS OOZE, BIOSILICEOUS CLAY
Slightly sticky to sticky, yellow gray to pale olive. Abundant disseminated silt, sand, and pebbles to 2.2 cm maximum dimension. Coarse clasts are angular to subangular, polymictic, in part faceted. Disseminated manganese nodules and manganese rinds on pebbles.

Representative smear slide

	1-75	1-140	4-7
diatoms	75	30	33
rads	5	-	1
clay	10	40	30
qtz., feld., etc.	10	30	35
silico.	-	-	1

Grain size

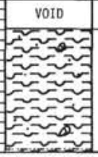
	1-100	2-20	2-100	3-20	3-100
sand	13.9	14.0	20.3	9.2	13.9
silt	39.3	32.5	30.3	32.3	32.3
clay	46.8	53.4	49.4	58.4	53.8

	4-20	4-102
sand	16.0	19.1
silt	28.4	30.3
clay	55.5	50.6

Site 328 Hole A Core 2 Cored Interval: 7.5-17.0 m

AGE	ZONE RADS / DIATOMS	FOSSIL	ABUND.	PRES.	SECTION	METERS	DEFORMATION	LITHO. SAMPLE	
					0				
PLEISTOCENE	Saturnalis circulus-Stylatractus universus Coscinodiscus elliptopora/ Actinocyclus ingens				1	0.5 1.0			10G 6/2 5GY 5/2 5G 6/1

LITHOLOGY

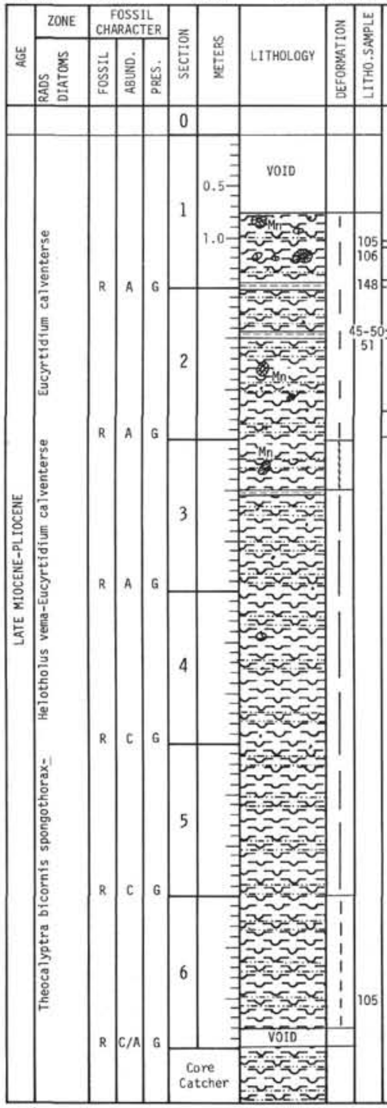


LITHOLOGIC DESCRIPTION

BIOSILICEOUS OOZE
Slightly sticky, greenish gray, pale green, dusky yellow green. Silty, sandy, and pebbly.

Explanatory notes in Chapter 1

Site 328 Hole B Core 1 Cored Interval: 7.5-17.0 m



10YR 7/4

5BG 7/2

10YR 7/4

10YR 5/4

5Y 7/2

5YR 3/4

5YR 7/2

10YR 6/2

lower limit pebbles

10YR 6/2

lower limit granules

LITHOLOGIC DESCRIPTION

SILTY AND CLAYEY BIOSILICEOUS OOZE
Slightly sticky, yellow gray to grayish orange. Disseminated polymictic pebbles to 3.3 cm maximum dimension, some of which are faceted. Interbeds of very fine-grained, incoherent, subangular to rounded, moderately well sorted sand to 5 cm thick. Scattered manganese nodules to 6.7 cm diameter and manganese rinds on pebbles.

Representative smear slide

	1-106	2-45	6-105
qtz., feld., etc.	30	47	30
clay	20	0	10
diatoms	49	-	40
rads	1	-	20
heavies	TR	1	-
rock frags.	-	53	-

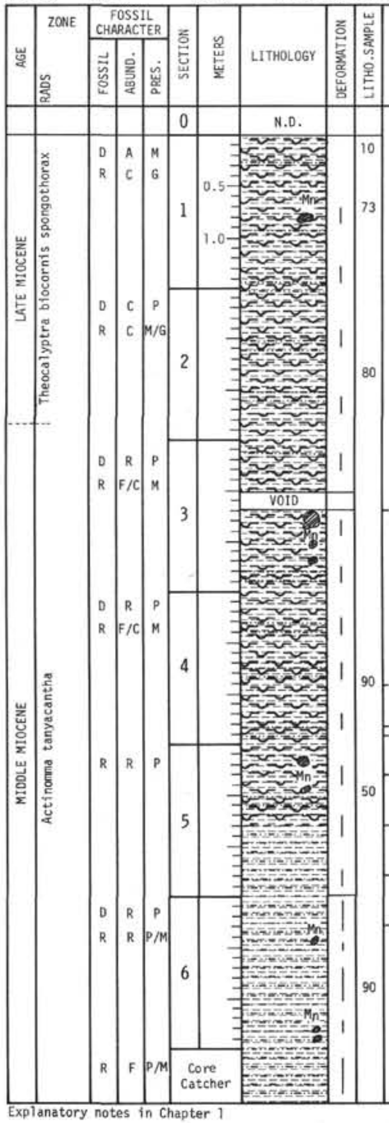
Grain size

	1-85	2-20	2-100	3-20	3-100
sand	27.3	11.9	5.6	7.1	5.7
silt	28.6	39.0	38.2	41.4	32.5
clay	44.1	49.1	56.2	51.5	61.8

	4-20	4-100	5-20
sand	2.0	10.0	4.4
silt	37.1	39.2	35.5
clay	60.8	50.9	60.0

	5-100	6-20	6-100
sand	1.5	2.3	2.4
silt	30.6	33.4	34.7
clay	67.9	64.3	62.9

Site 328 Hole B Core 2 Cored Interval: 17.0-26.5 m



10YR 7/4

10YR 7/4
mottled with
10YR 5/4

10YR 5/4
5YR 8/4
5YR 8/4

10YR 5/4

10YR 7/4

10YR 6/6

10YR 7/4

10YR 6/6

LITHOLOGIC DESCRIPTION

BIOSILICEOUS SILTY CLAY, SILTY CLAY
Slightly sticky to sticky, grayish orange to dark yellow orange with moderate yellow brown mottling. Sand-bearing silt-rich clay lamination 2-3 mm thick at 73 cm. Manganese nodules to 6.4 cm diameter and micronodules throughout.

Representative smear slide

	1-10	1-73	2-80
qtz., feld.	5	10	5
rock frags.	2	-	-
clay	70	83	79
diatoms	15	7	10
rads	5	-	4
heavies	-	-	1

	4-90	5-80	6-90
qtz., feld.	1	3	10
rock frags.	-	-	-
clay	96	88	90
diatoms	3	8	-
rads	1	-	-
heavies	-	1	TR

Grain size

	1-20	1-100	2-20	2-100
sand	1.1	0.6	1.3	2.5
silt	32.8	32.0	31.1	25.1
clay	66.2	67.3	67.6	72.4

	3-20	3-100	4-20	4-100
sand	0.6	0.9	0.4	2.4
silt	26.9	28.5	23.5	26.2
clay	72.5	70.6	76.0	71.4

	5-18	5-100	6-20	6-100
sand	0.4	0.5	0.8	0.8
silt	24.2	24.4	25.1	22.6
clay	75.4	75.0	74.1	76.6

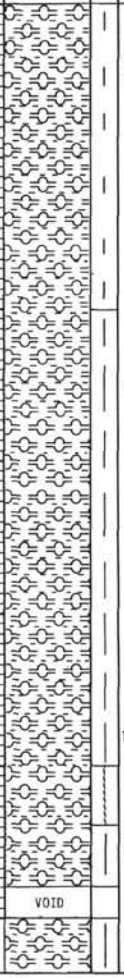
Explanatory notes in Chapter 1

Site 328 Hole B Core 3 Cored Interval: 26.5-36.0 m

AGE: LATE OLIGOCENE

ZONE (SILICOS): *Naviculopsis biapiculata*

SECTION	FOSSIL	ABUND.	PRES.	LITHO. SAMPLE
1	D R	F C	P M	53 56
2	D R	F C	P M	
3	D R	F C	P M	75
4	D R	C C	M M/G	72
5	D R	C C	M M/G	120
6	D R	C C	M M	53 70 87
Core Catcher	R	C	M/G	



5YR 5/6 to 10YR 5/4

10YR 7/4 to 10YR 5/4

5GY 8/1

10YR 7/4

BIOSILICEOUS CLAY, CLAYEY BIOSILICEOUS OOZE

Slightly sticky with scattered lumps moderately hard clay. Grayish orange to moderate yellow brown or light brown. Abundant partially dissolved diatoms.

Representative smear slide

	1-56	3-75	4-72	5-120	6-70
qtz., feld.	3	3	2	2	5
clay	75	87	78	55	40
diatoms	5	7	5	20	40
rads	15	3	15	20	15
sponge spic.	2	-	-	-	-
silico.	-	-	-	2	-
collophane(?)	-	-	-	1	-

Grain size

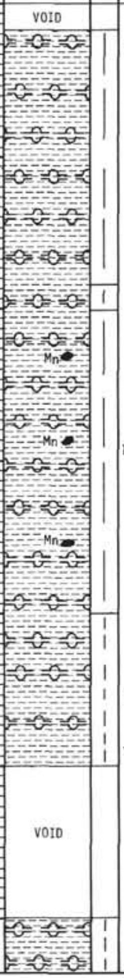
	1-20	1-100	2-20	2-100
sand	1.1	0.5	0.7	0.8
silt	24.3	24.9	24.6	24.8
clay	74.7	74.7	74.7	74.5
	3-20	3-100	4-20	4-100
sand	0.7	0.5	0.6	0.9
silt	25.3	25.7	26.0	33.1
clay	74.0	73.8	73.4	66.0
	5-20	5-100	6-70	6-100
sand	1.0	2.0	0.5	0.8
silt	26.3	33.0	22.2	23.6
clay	72.7	65.0	77.3	75.6

Site 328 Hole B Core 4 Cored Interval: 36.0-45.5 m

AGE: EARLY OLIGOCENE

ZONE (SILICOS): *Naviculopsis biapiculata*

SECTION	FOSSIL	ABUND.	PRES.	LITHO. SAMPLE
1				47
2	D R	C C	P M/G	
3	D R	F C	P G	147
4	D R	C C	P G	
5	D R	C C	M M/G	80 140
6				
Core Catcher	R	C	G	



10YR 6/2 mottled with 5Y 7/2

10YR 7/4

10YR 7/4 with laminae 10YR 6/2

CLAYEY BIOSILICEOUS OOZE TO BIOSILICEOUS CLAY

Slightly sticky, grayish orange to pale yellow brown mottled with yellow gray. Rare soft manganese nodules to 2 cm diameter and abundant micronodules. Rare zeolite.

Representative smear slide

	1-47	3-147	5-80
qtz., feld.	15	1	2
clay	25	69	38
diatoms	40	25	40
rads	20	5	20

Grain size

	1-100	6-20
sand	0.3	0.8
silt	23.2	27.3
clay	76.5	71.9

Carbon-carbonate

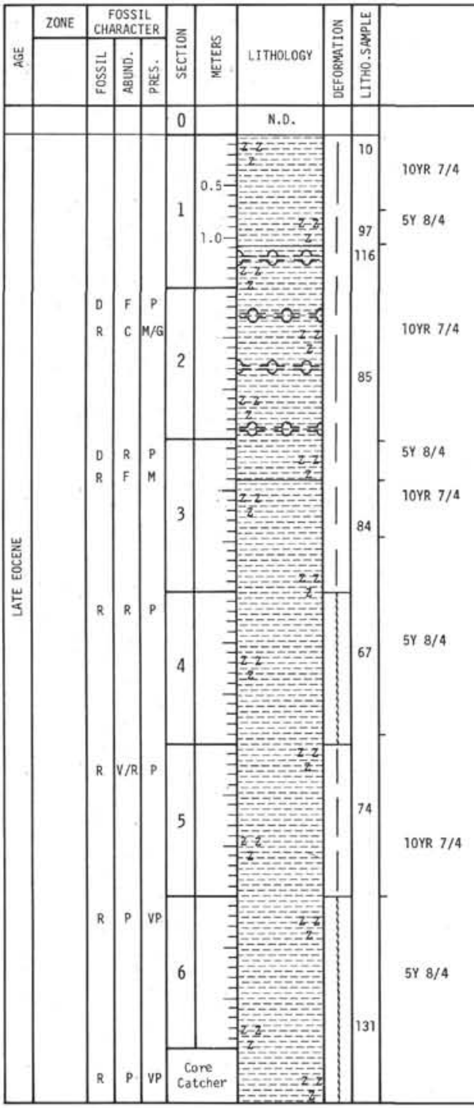
	5-15
t. carb	0.1
o. carb	0.1
$CaCO_3$	0

Bulk X-ray

	5-15
amor.	65.2
quar.	23.5
K-Fe.	7.6
plag.	12.1
kaol.	2.2
mica	29.7
chlo.	1.4
mont.	20.6
clin.	2.9

Explanatory notes in Chapter 1

Site 328 Hole B Core 5 Cored Interval: 45.5-55.0 m



LITHOLOGIC DESCRIPTION

ZEOLITE CLAY AND BIOSILICEOUS ZEOLITE CLAY
Sticky, grayish orange to grayish yellow. Dissolution of diatoms common. Abundant manganiferous streaks and patches throughout. Zeolite is euhedral clinoptilolite.

Representative smear slide

	1-10	1-116	5-74	6-131
clay	55	50	74	79
zeol.	40	30	15	20
opaques	3	1	-	1
diatoms	-	5	TR	-
rads	-	14	TR	-
collophane(?)	2	-	-	-
qtz.	-	-	1	-
micronods.	-	-	10	-

Grain size

	1-98	6-100
sand	0.2	0.1
silt	17.0	2.4
clay	82.8	97.5

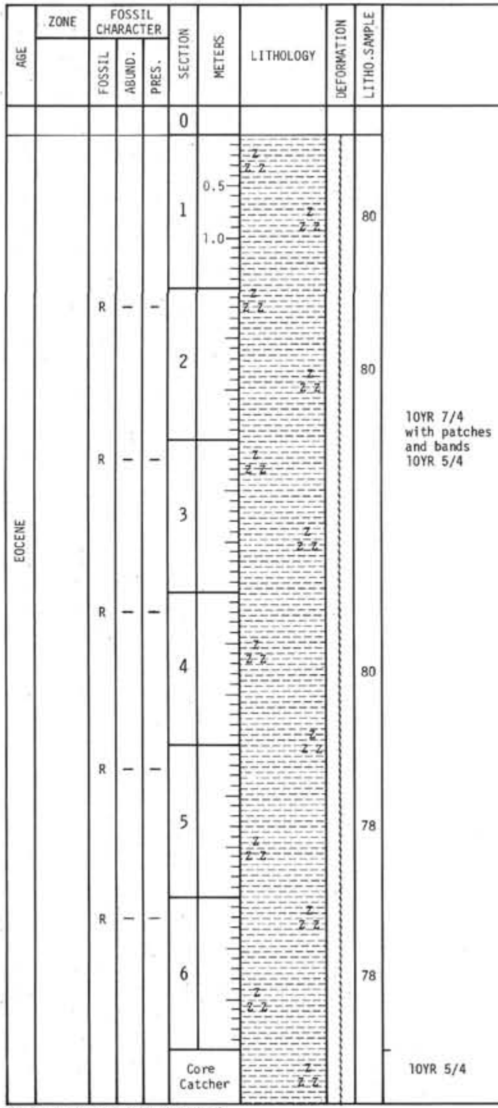
Carbon-carbonate

	3-134
t. carb	0.1
o. carb	0.0
$CaCO_3$	0.1

Bulk X-ray

	3-10	3-134
amor.	67.8	67.8
quar.	17.6	17.7
K-Fe.	2.2	5.1
plag.	12.0	8.7
kaol.	2.4	2.4
mica	26.4	24.3
chlo.	1.8	1.9
mont.	17.6	26.4
paly.	9.8	-
clin.	10.2	13.6

Site 328 Hole B Core 6 Cored Interval: 55.0-64.5 m



LITHOLOGIC DESCRIPTION

ZEOLITIC CLAY
Slightly sticky color banded and mottled in grayish orange and moderate yellow brown. Abundant anhedral to euhedral clinoptilolite. Rare soft manganese nodules.

Representative smear slide

	1-80	2-80	4-80	5-78	6-78
opaques	2	4	6	6	6
clay	88	75	70	56	54
zeol.	10	21	24	40	40
sphalerite(?)	-	TR	-	TR	-
apatite	-	-	-	-	TR

Grain size

	6-55
sand	0.1
silt	13.2
clay	86.8

Carbon-carbonate

	6-63
t. carb	0.1
o. carb	0.1
$CaCO_3$	0.0

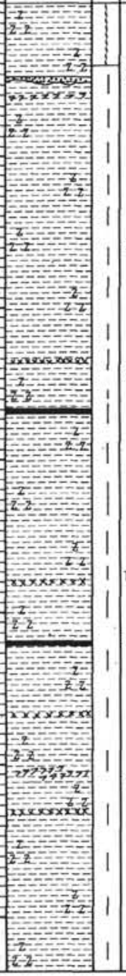
Bulk X-ray

	6-63
amor.	60.9
quar.	18.4
K-Fe.	5.0
plag.	6.3
kaol.	6.5
mica	25.1
chlo.	2.6
mont.	32.9
clin.	3.1

Explanatory notes in Chapter 1

Site 328 Hole B Core 7 Cored Interval: 435.0-444.5 m

AGE	ZONE	FOSSIL CHARACTER FOSSIL	ABUND.	PRES.	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO.SAMPLE
					0		N.D.		
LATE TURONIAN-SENONIAN					1	0.5 1.0			68 74
		R	–	–	2				97
		R	–	–	3				71
		R	–	–	4				119
		R	–	–	5				32
		R	–	–	6				18
		R	–	–	Core Catcher				



LITHOLOGIC DESCRIPTION

5YR 3/4
5GY 4/1 to
10R 4/2
N3 to 5G 4/1
5Y 8/1
N4
5YR 3/4 to
10R 4/6
5Y 4/1 to
5YR 4/1
5YR 3/4
5B 9/1
5YR 3/4 to
10R 4/6
5YR 4/1 to
10R 4/6
5YR 4/4 to
10R 4/6
5B 9/1
N4 to N2
5YR 4/1 to
5B 5/1
5YR 2/1 to
5YR 4/1
10R 4/2 to
10R 4/6
5YR 4/1 to
5YR 2/1
5YR 4/1 to
10R 4/6
5YR 4/1
10R 4/2 to
10R 4/6

CLAYSTONE
Well indurated, varicolored in shades of red, brown, green, gray, and black. Locally finely-laminated and carbonaceous. Thin zones of mm-scale black feeding trails of *Zoophycos*. Cm-scale concentrations of medium-grained siderite aggregates with distinctive dumbell form. Claystone desiccates and cracks markedly on exposure to air. Thin bed 1-1.5 cm thick SILTY SANDSTONE at 70 cm. Graded, channelled base, mainly angular crystals of K-feldspar to 0.4 mm diameter.

Representative smear slide

	1-68	2-97	3-71
clay	77	90	99
zeol.	20	10	1
siderite	-	-	-
opaques	-	-	-
sphalerite(?)	-	-	-
heavies	3	-	-

	4-119	5-32	6-18
clay	10	98	85
zeol.	-	2	10
siderite	50	-	-
opaques	40	TR	-
sphalerite(?)	-	-	5
heavies	-	-	-

Grain size

	6-55
sand	0.0
silt	5.5
clay	94.5

Carbon-carbonate

	1-61	3-102	5-40	6-63
t. carb	0.4	0.4	0.4	0.0
o. carb	0.3	0.3	0.4	0.1
$CaCO_3$	0.0	0:0	0.0	0.0

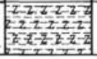
Bulk X-ray

	1-74	5-81	5-135	6-63
amor.	29.4	57.8	48.8	51.1
quar.	2.4	28.3	29.2	28.0
K-Fe.	48.5	3.0	4.5	4.3
plag.	3.7	2.5	2.5	2.4
kaol.	-	2.6	1.7	3.3
mica	1.4	11.7	13.8	16.9
chlo.	-	-	1.1	1.0
mont.	42.8	36.3	47.1	36.8
hema.	-	-	-	7.3
apat.	-	15.6	-	-
anal.	1.3	-	-	-

xxxv siderite-rich zone
▬ carbonaceous zone
>>>> feeding trail

Site 328 Hole B Core 8 Cored Interval: 471.0-471.5 m

AGE	ZONE	FOSSIL CHARACTER FOSSIL	ABUND.	PRES.	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO.SAMPLE
					0				
					Core Catcher				CC CC



LITHOLOGIC DESCRIPTION

1OR 4/6
IOR 4/2
N5

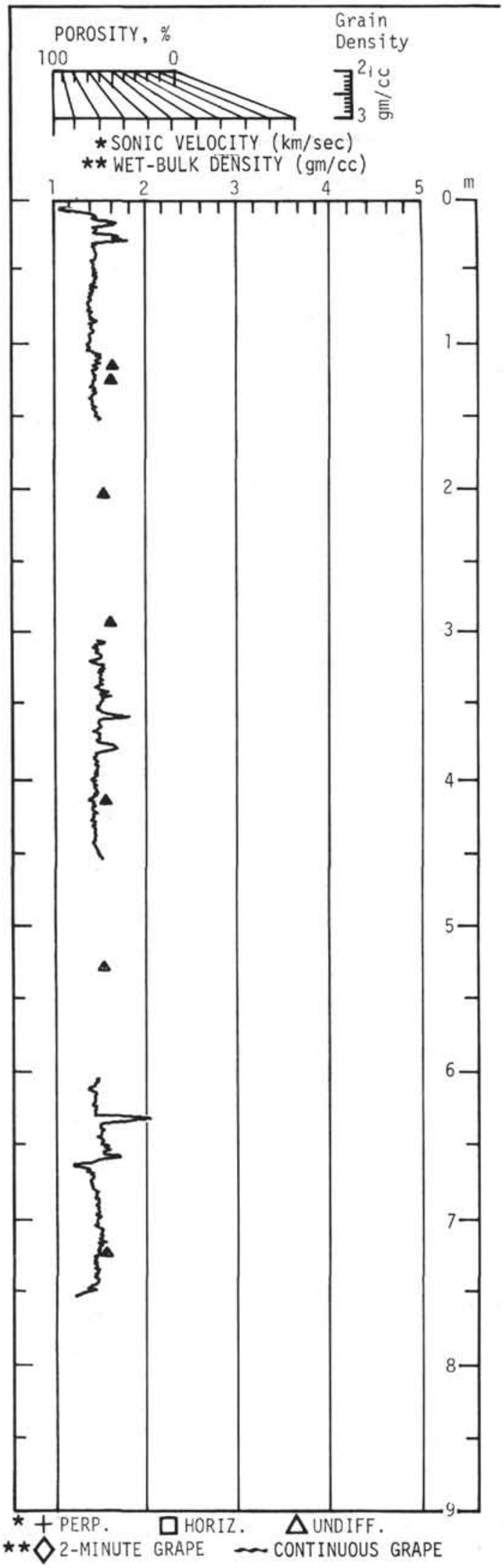
CLAYSTONE
Fragments of rounded drilling breccia from unknown stratigraphic interval. Varicolored in moderate reddish brown, grayish red, and medium gray. Possible local bioturbation. Strong desiccation cracking on exposure to air.

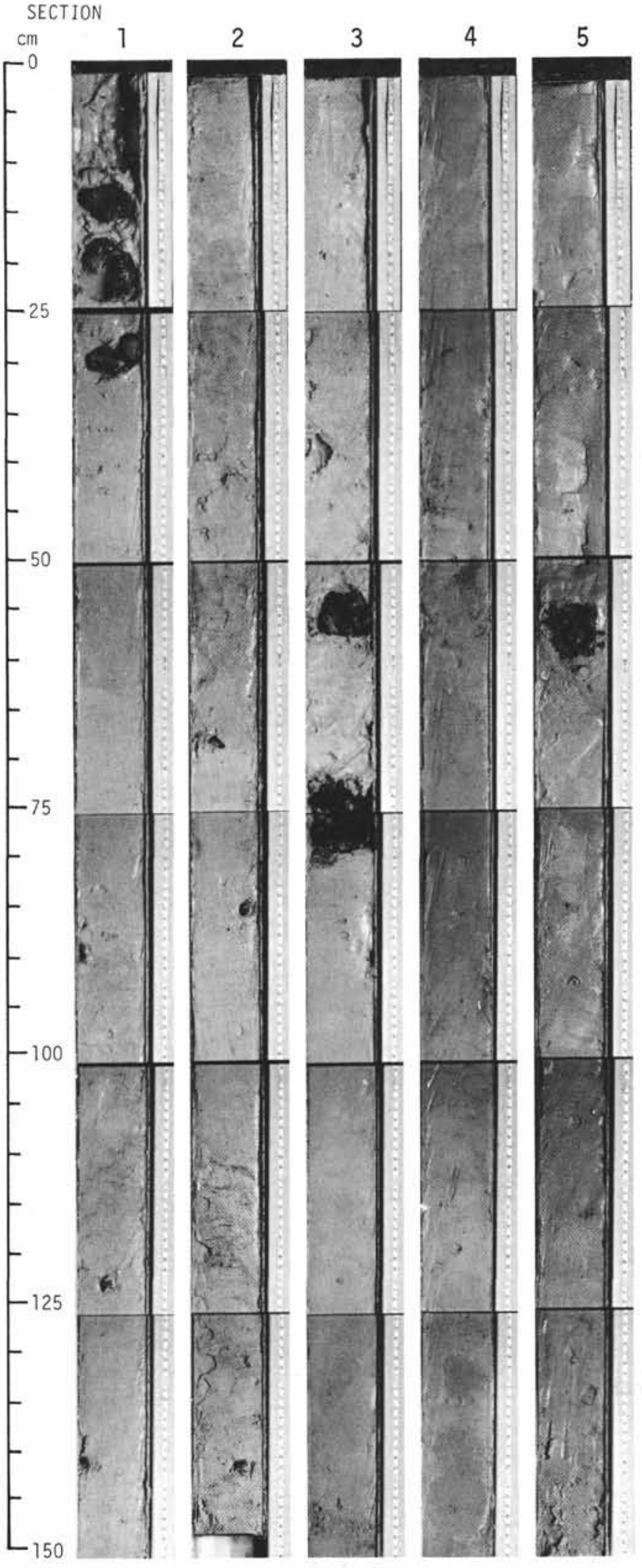
Characteristic smear slide

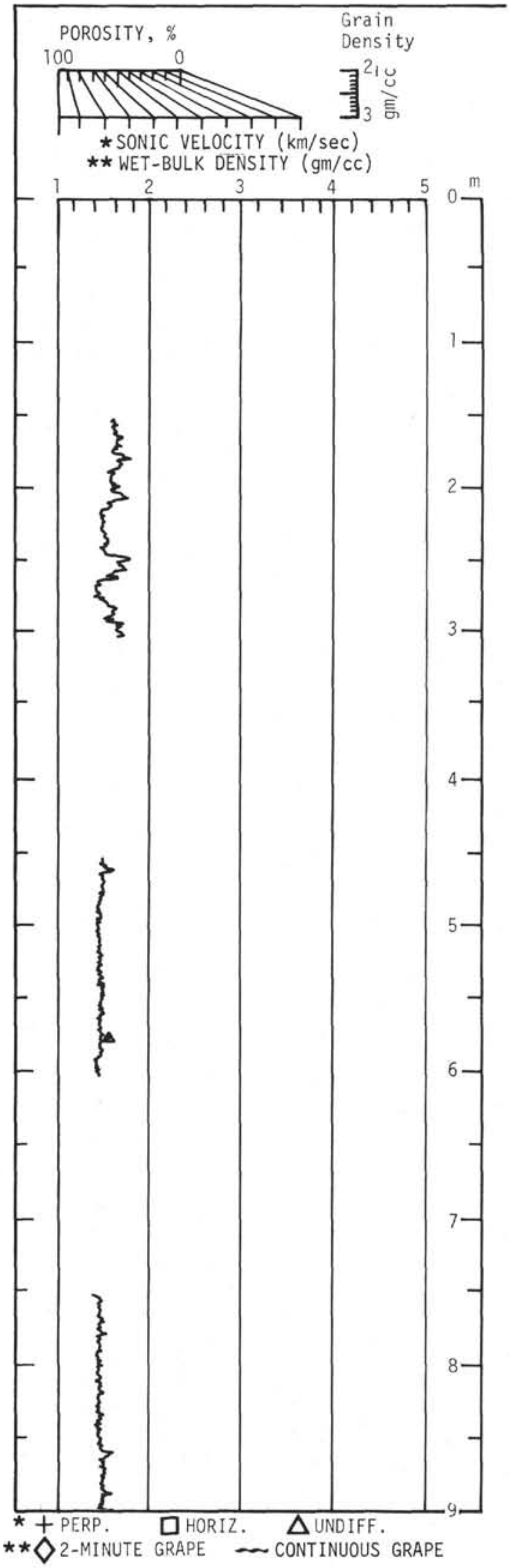
	CC
clay	90
zeol.(?)	8
opaques	2

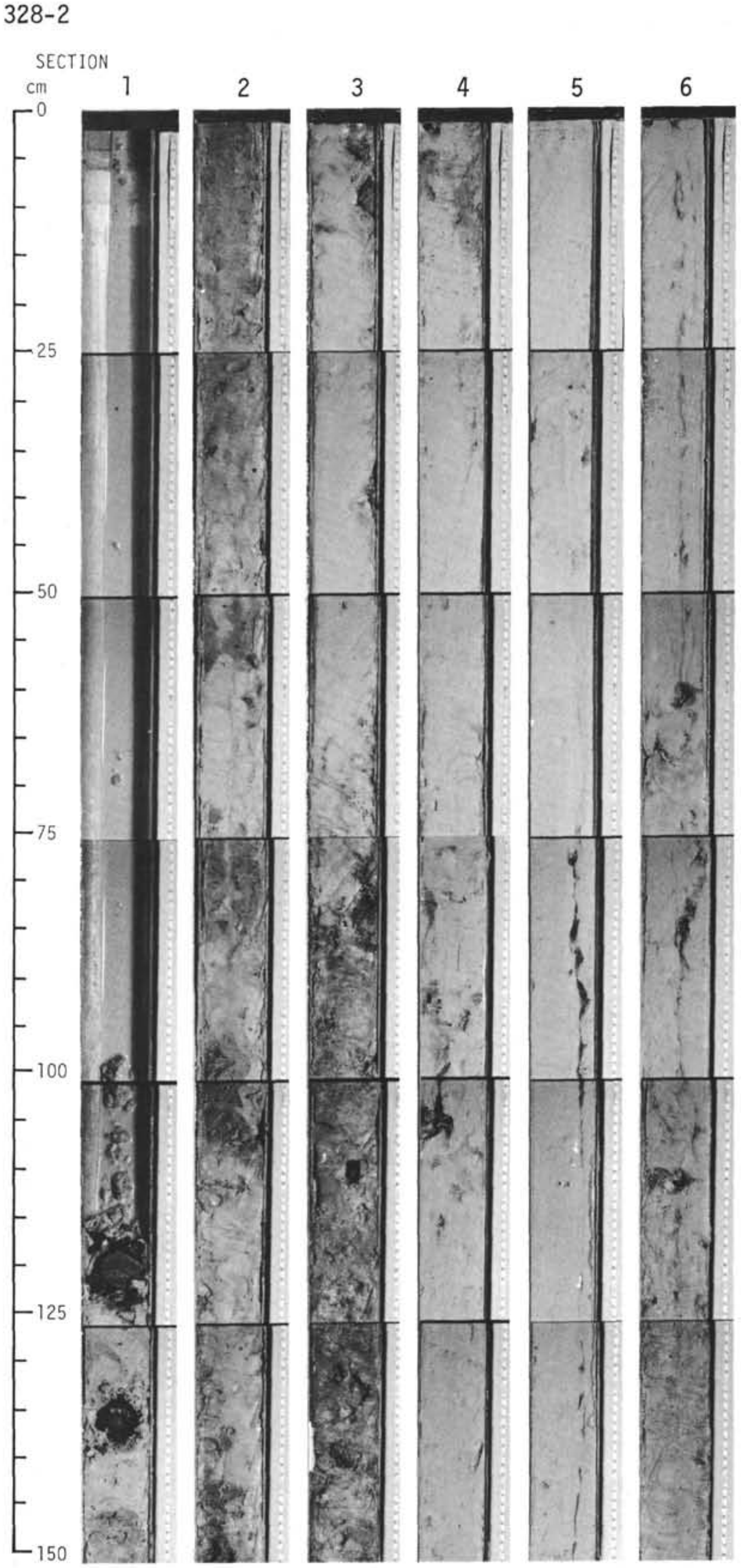
Explanatory notes in Chapter 1

328-1

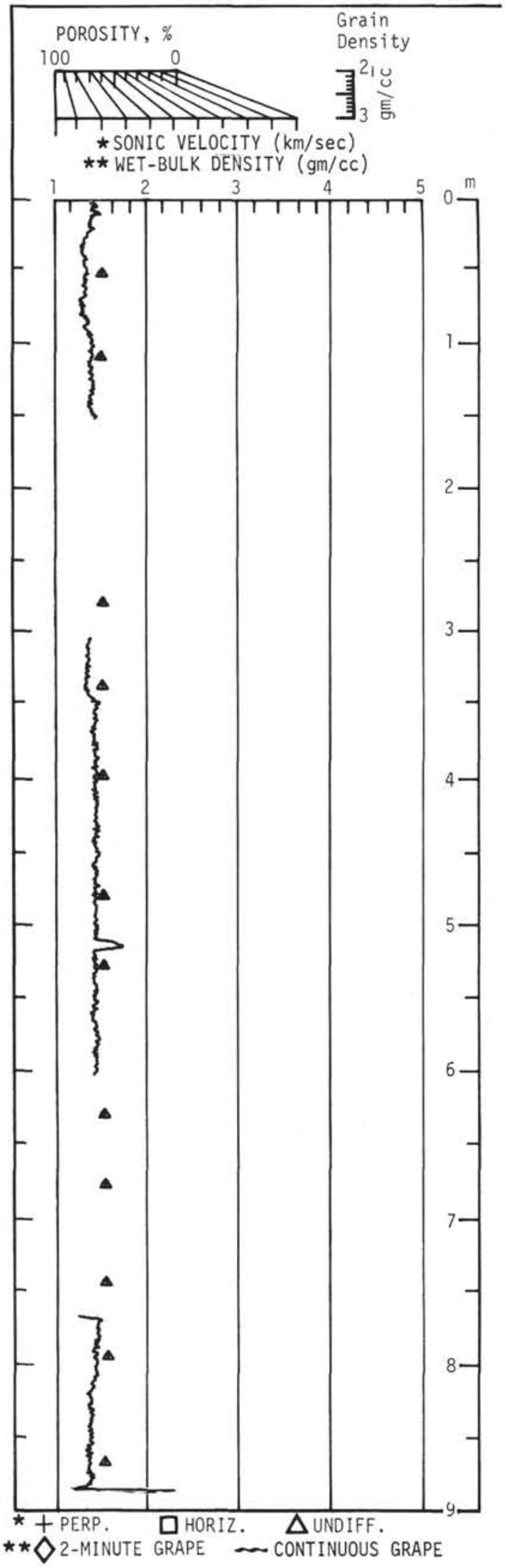

POROSITY, %
100
0
Grain Density
2
3
gm/cc
* SONIC VELOCITY (km/sec)
** WET-BULK DENSITY (gm/cc)
1
2
3
4
5
m
0
1
2
3
4
5
6
7
8
9
* + PERP.
□ HORIZ.
△ UNDIFF.
** ◇ 2-MINUTE GRAPE
〰 CONTINUOUS GRAPE

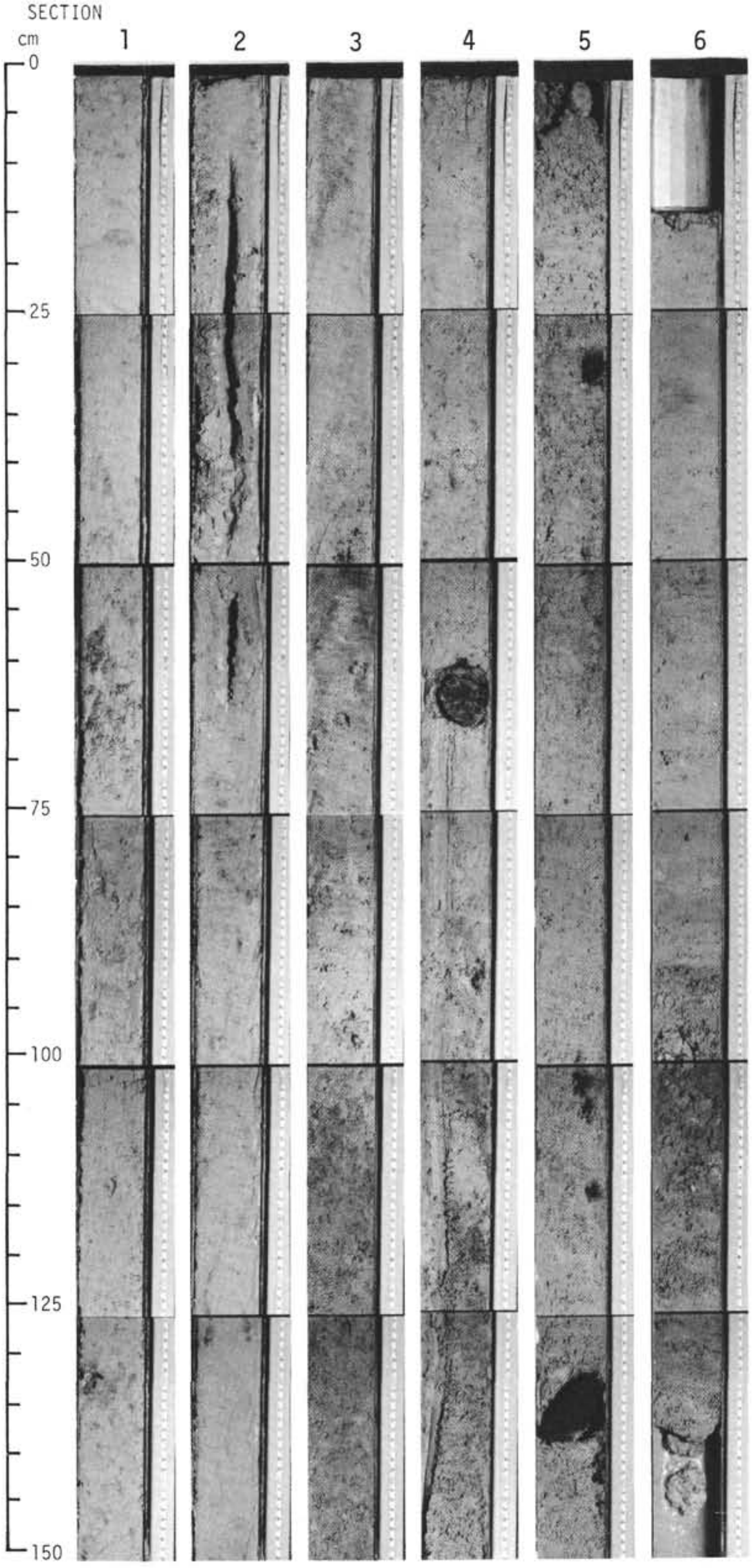

SECTION
cm
1
2
3
4
5
0
25
50
75
100
125
150

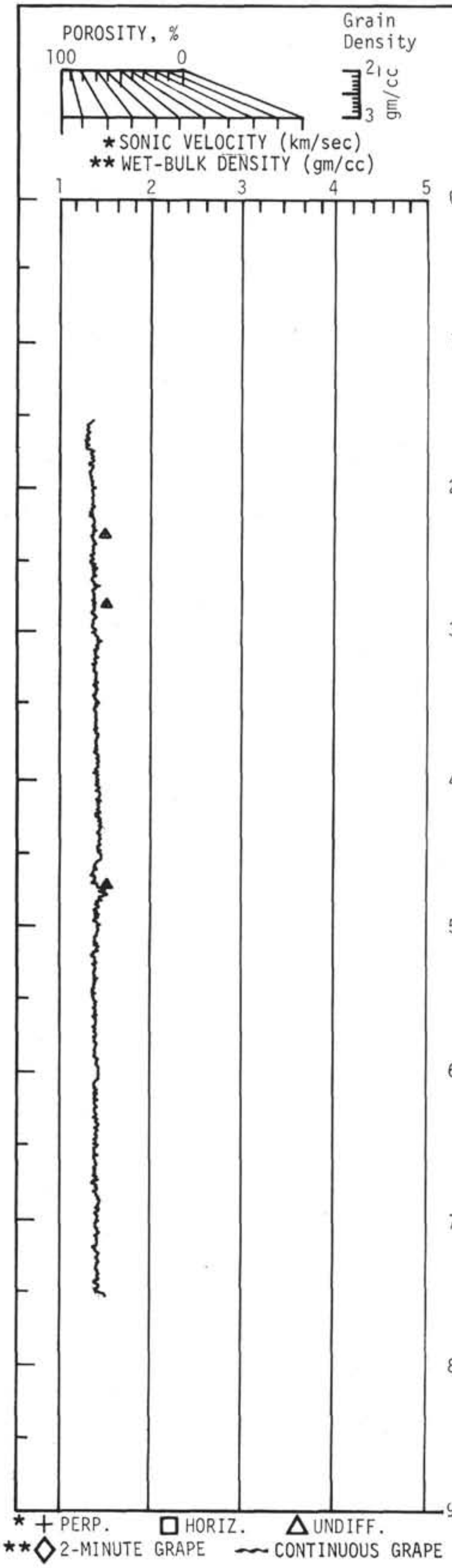

POROSITY, %
100
0
Grain Density
2
3
gm/cc
* SONIC VELOCITY (km/sec)
** WET-BULK DENSITY (gm/cc)
1
2
3
4
5
m
0
1
2
3
4
5
6
7
8
9
* + PERP. □ HORIZ. △ UNDIFF.
** ◇ 2-MINUTE GRAPE ~ CONTINUOUS GRAPE


328-2
SECTION
cm
1
2
3
4
5
6
0
25
50
75
100
125
150

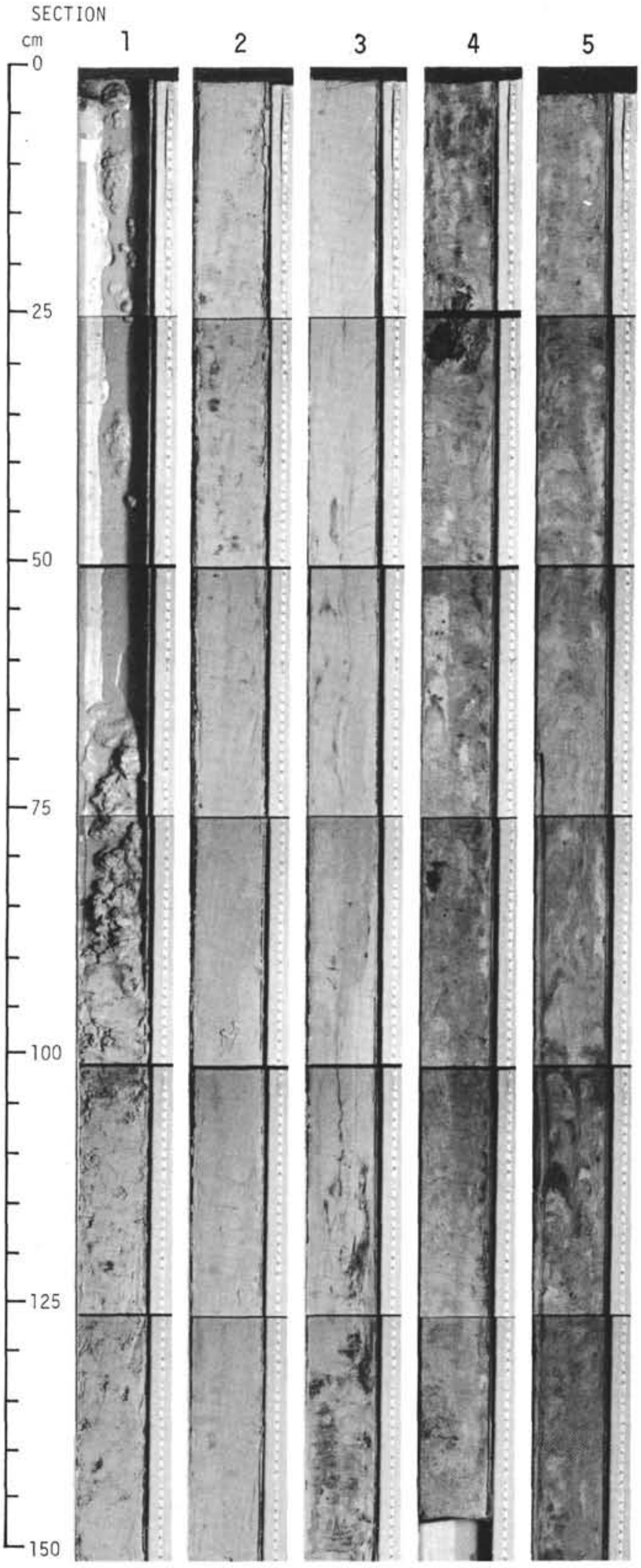
328-3


POROSITY, %
100
0
Grain Density
2
3
gm/cc
* SONIC VELOCITY (km/sec)
** WET-BULK DENSITY (gm/cc)
1
2
3
4
5
m
0
1
2
3
4
5
6
7
8
9
* + PERP.
☐ HORIZ.
△ UNDIFF.
** ◇ 2-MINUTE GRAPE
~ CONTINUOUS GRAPE

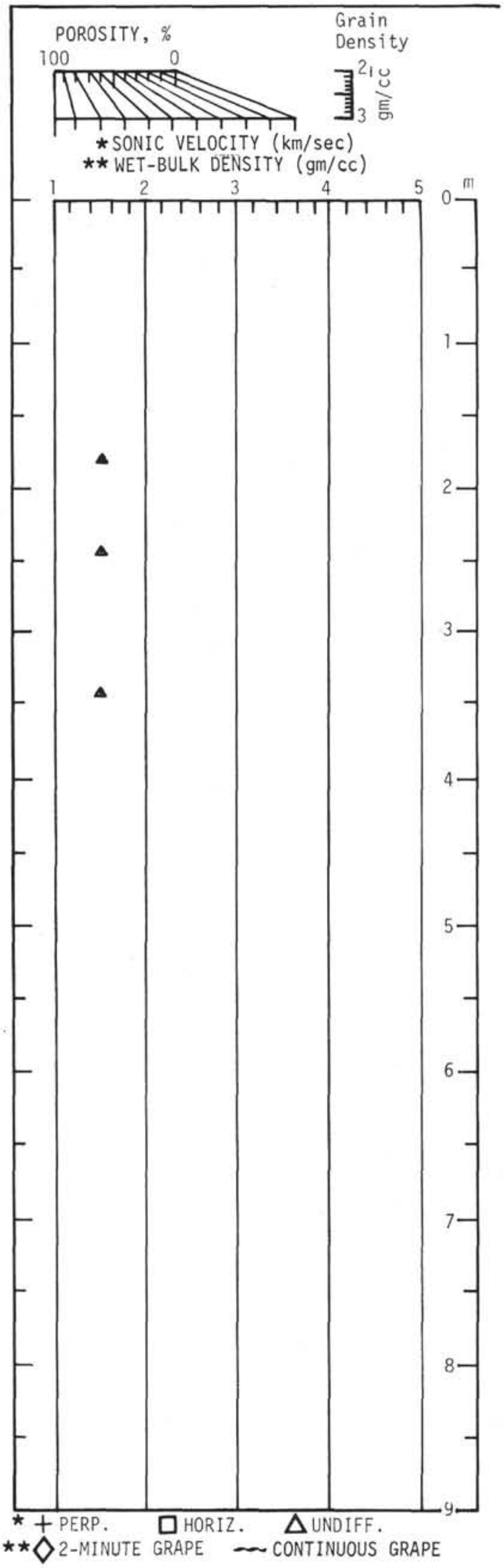

SECTION
cm
1
2
3
4
5
6
0
25
50
75
100
125
150

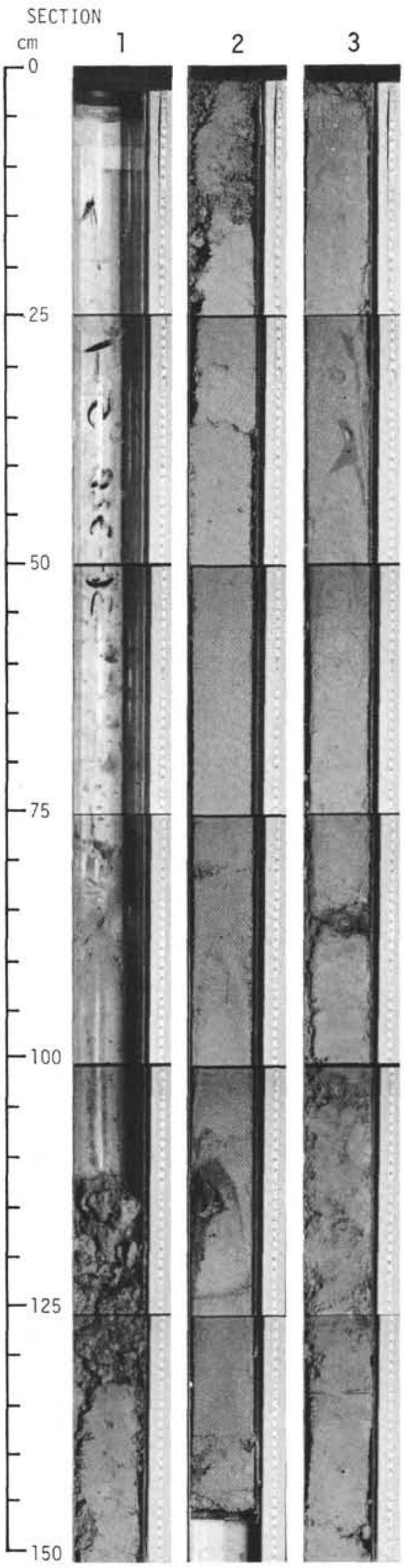

POROSITY, %
100
0
Grain Density
2
3
gm/cc
*SONIC VELOCITY (km/sec)
**WET-BULK DENSITY (gm/cc)
1
2
3
4
5
m
0
1
2
3
4
5
6
7
8
9
* + PERP.
□ HORIZ.
△ UNDIFF.
** ◇ 2-MINUTE GRAPE
~ CONTINUOUS GRAPE

328-4


SECTION
cm
0
25
50
75
100
125
150
1
2
3
4
5

328-5


POROSITY, %
100
0
Grain Density
2
3
gm/cc
*SONIC VELOCITY (km/sec)
**WET-BULK DENSITY (gm/cc)
1
2
3
4
5
m
0
1
2
3
4
5
6
7
8
9
* + PERP.
□ HORIZ.
△ UNDIFF.
** ◇ 2-MINUTE GRAPE
〜 CONTINUOUS GRAPE


SECTION
cm
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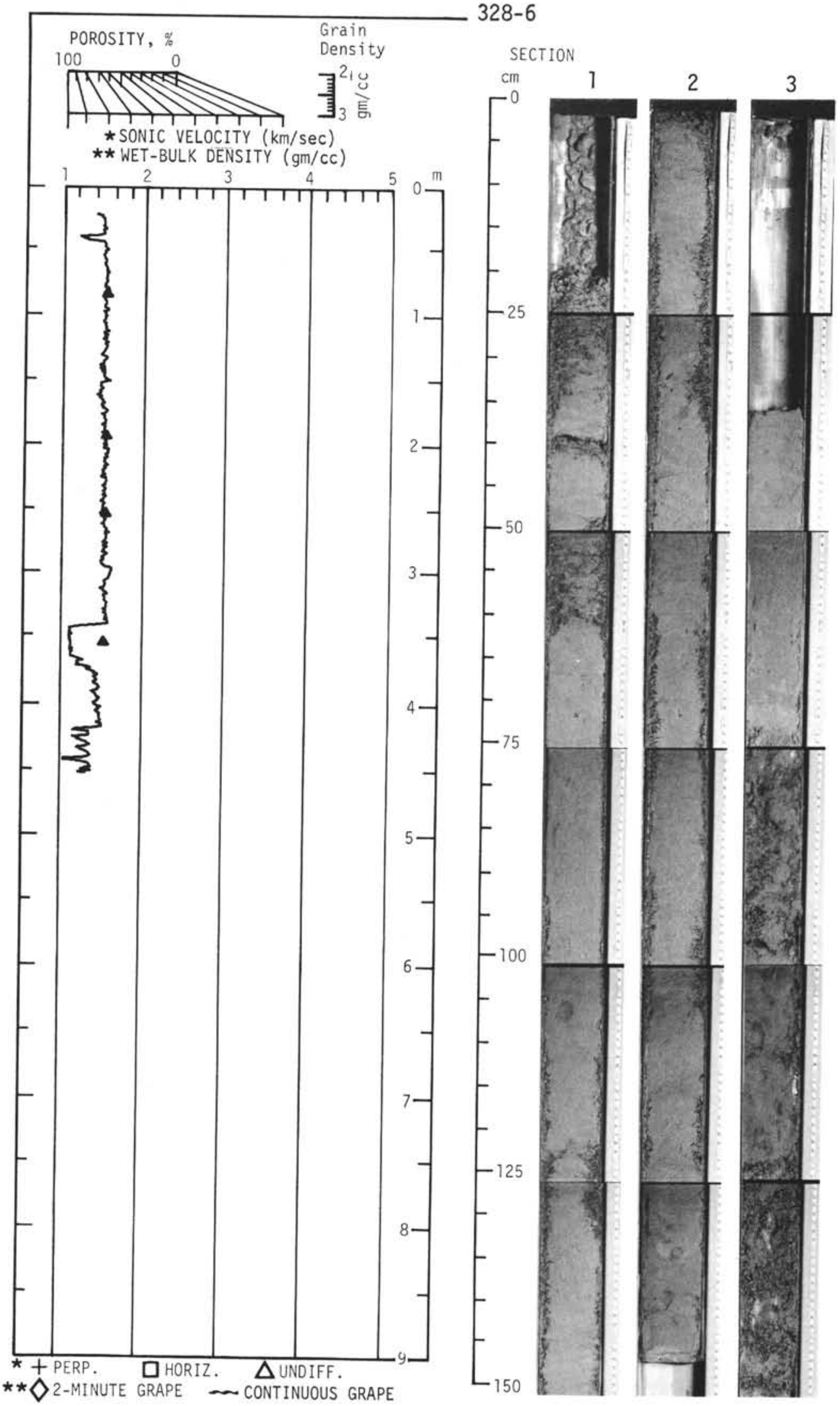
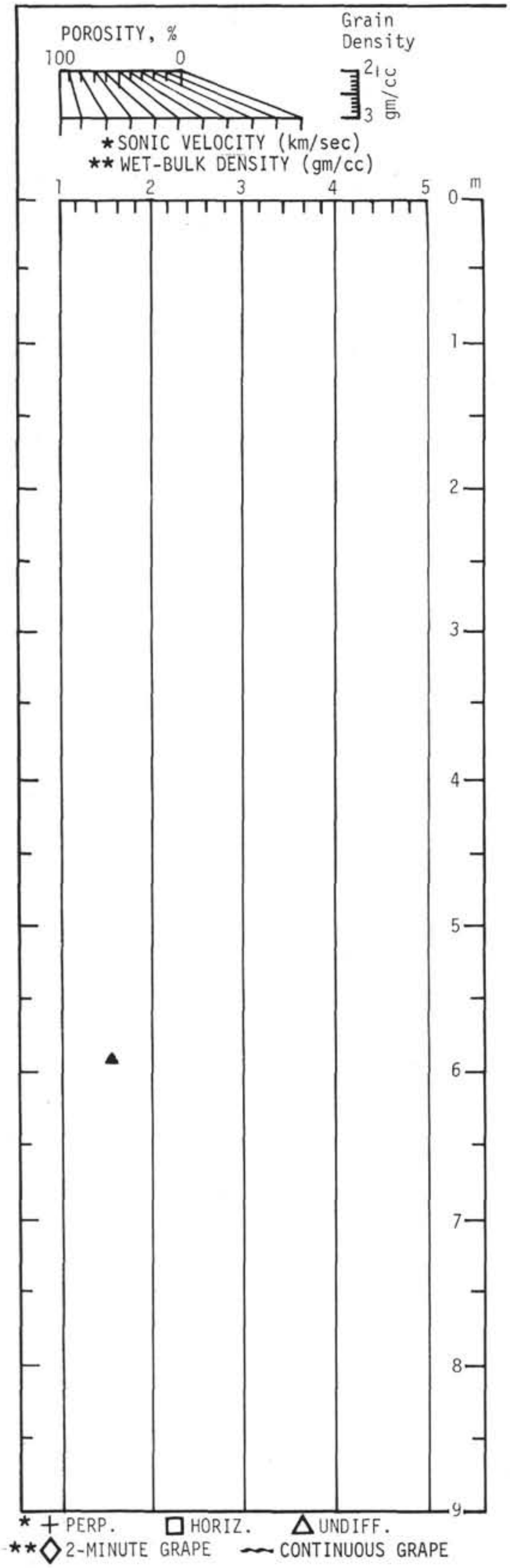
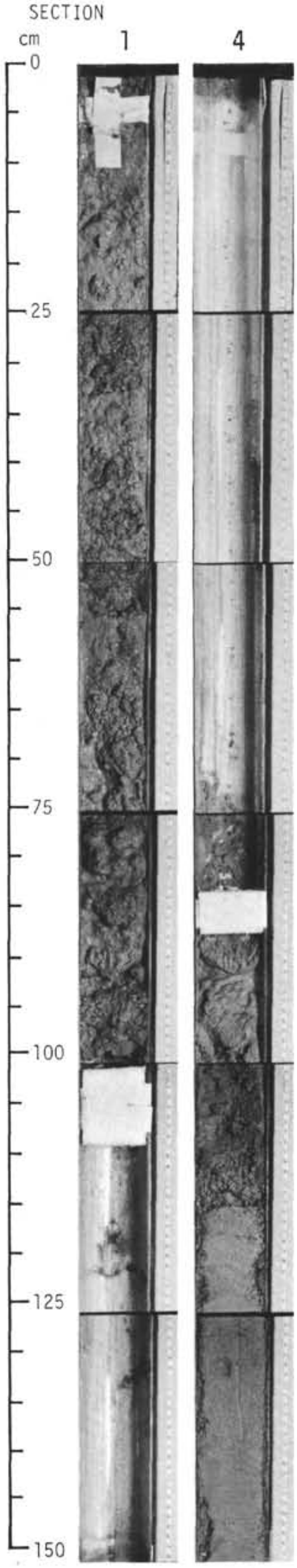
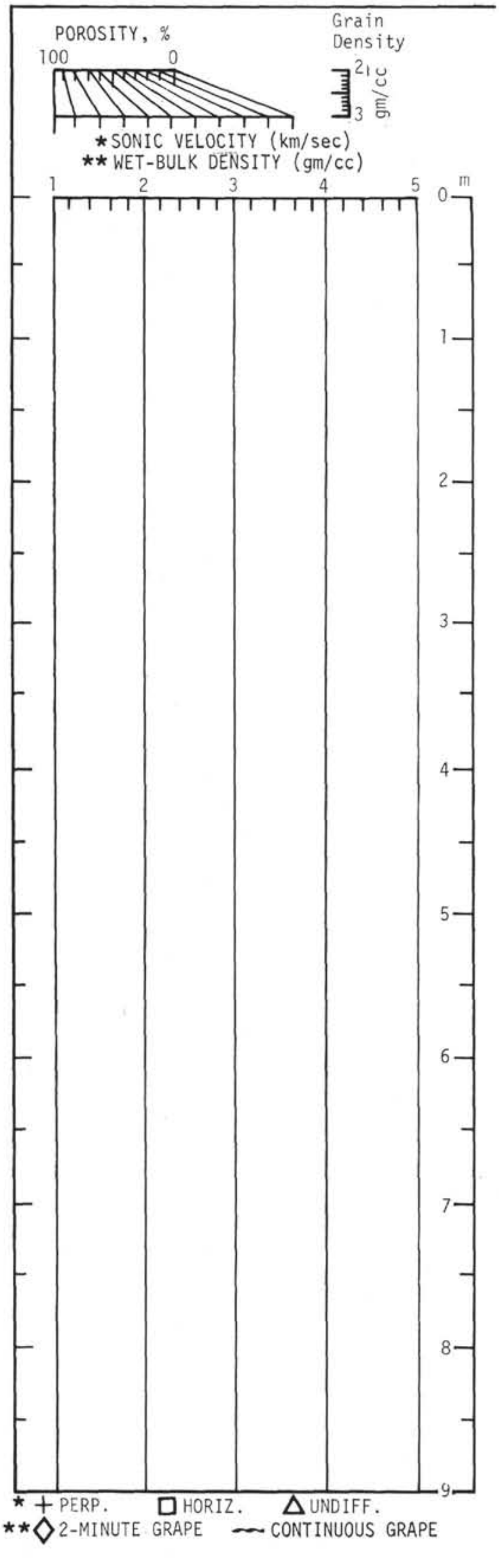
2
3
0
25
50
75
100
125
150

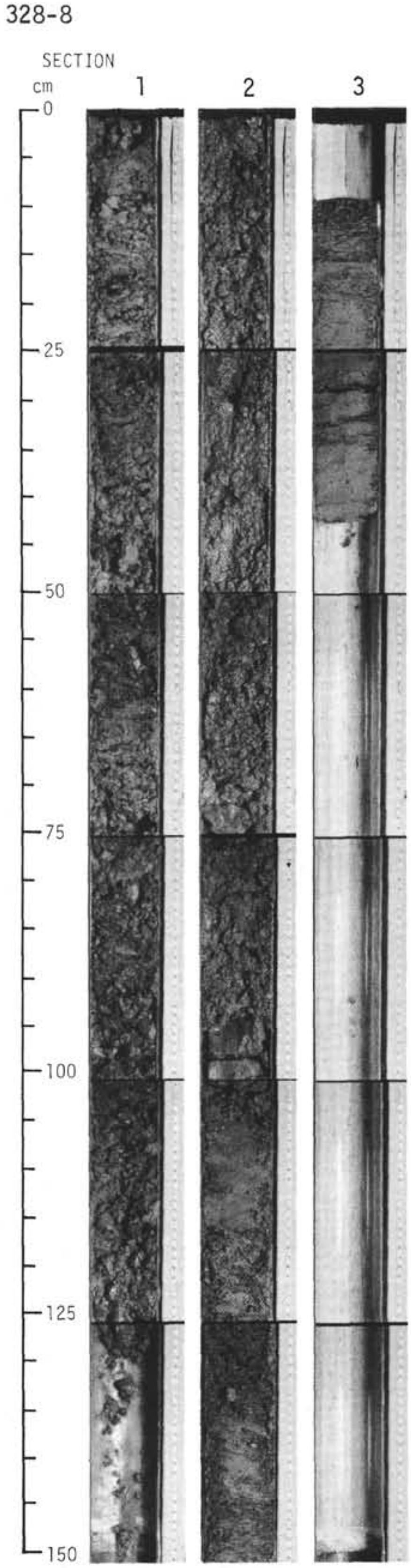

328-6
POROSITY, %
100
0
Grain Density
2
3
gm/cc
* SONIC VELOCITY (km/sec)
** WET-BULK DENSITY (gm/cc)
1
2
3
4
5
m
0
1
2
3
4
5
6
7
8
9
SECTION
cm
1
2
3
0
25
50
75
100
125
150
* + PERP.
□ HORIZ.
△ UNDIFF.
** ◇ 2-MINUTE GRAPE
~ CONTINUOUS GRAPE

328-7

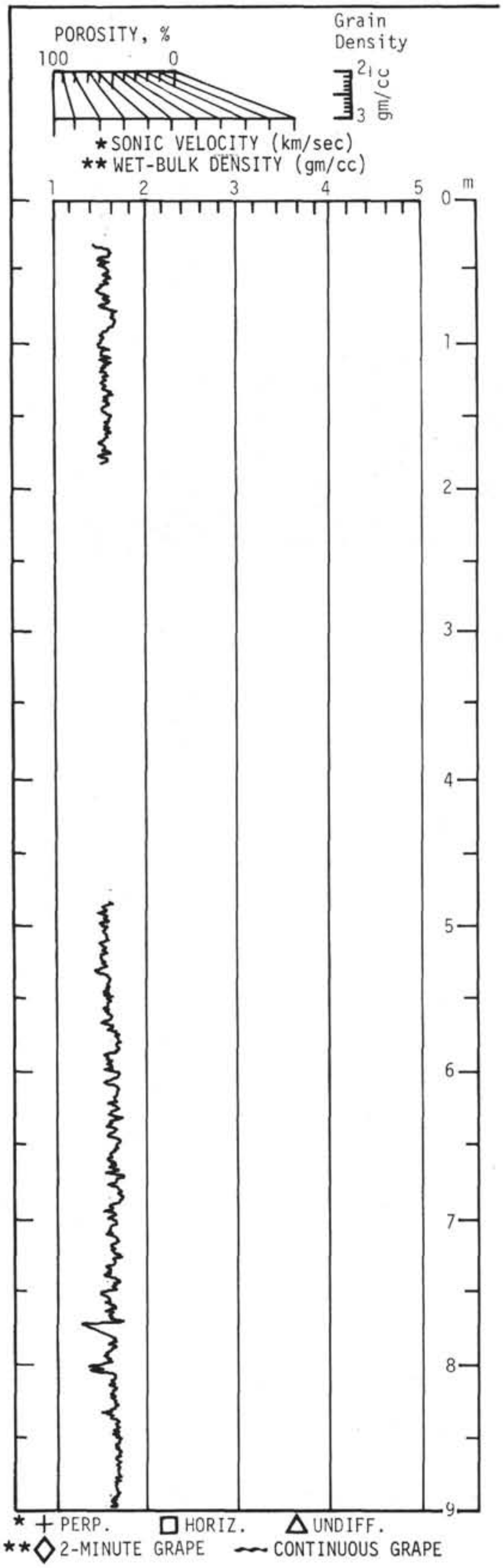

POROSITY, %
100
0
Grain Density
2
3
gm/cc
* SONIC VELOCITY (km/sec)
** WET-BULK DENSITY (gm/cc)
1
2
3
4
5
m
0
1
2
3
4
5
6
7
8
9
* + PERP.
□ HORIZ.
△ UNDIFF.
** ◇ 2-MINUTE GRAPE
〰 CONTINUOUS GRAPE

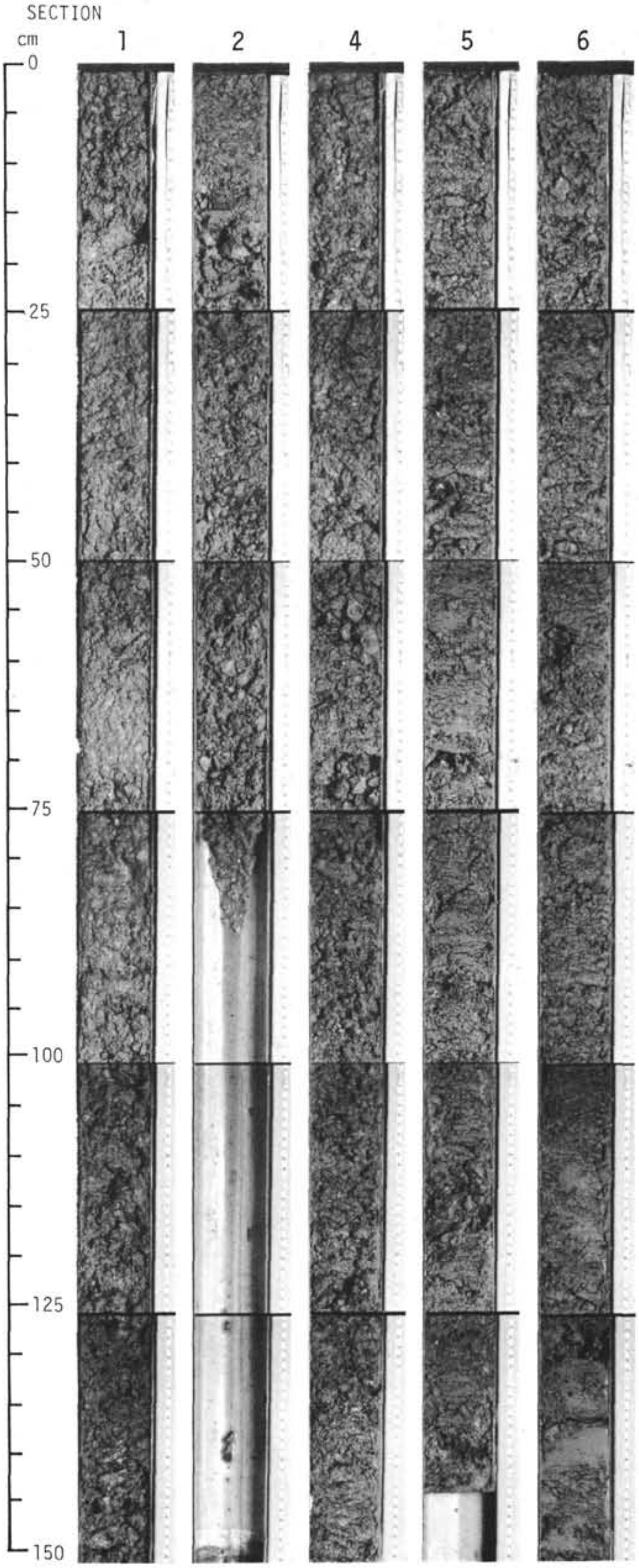

SECTION
cm
1
4
0
25
50
75
100
125
150

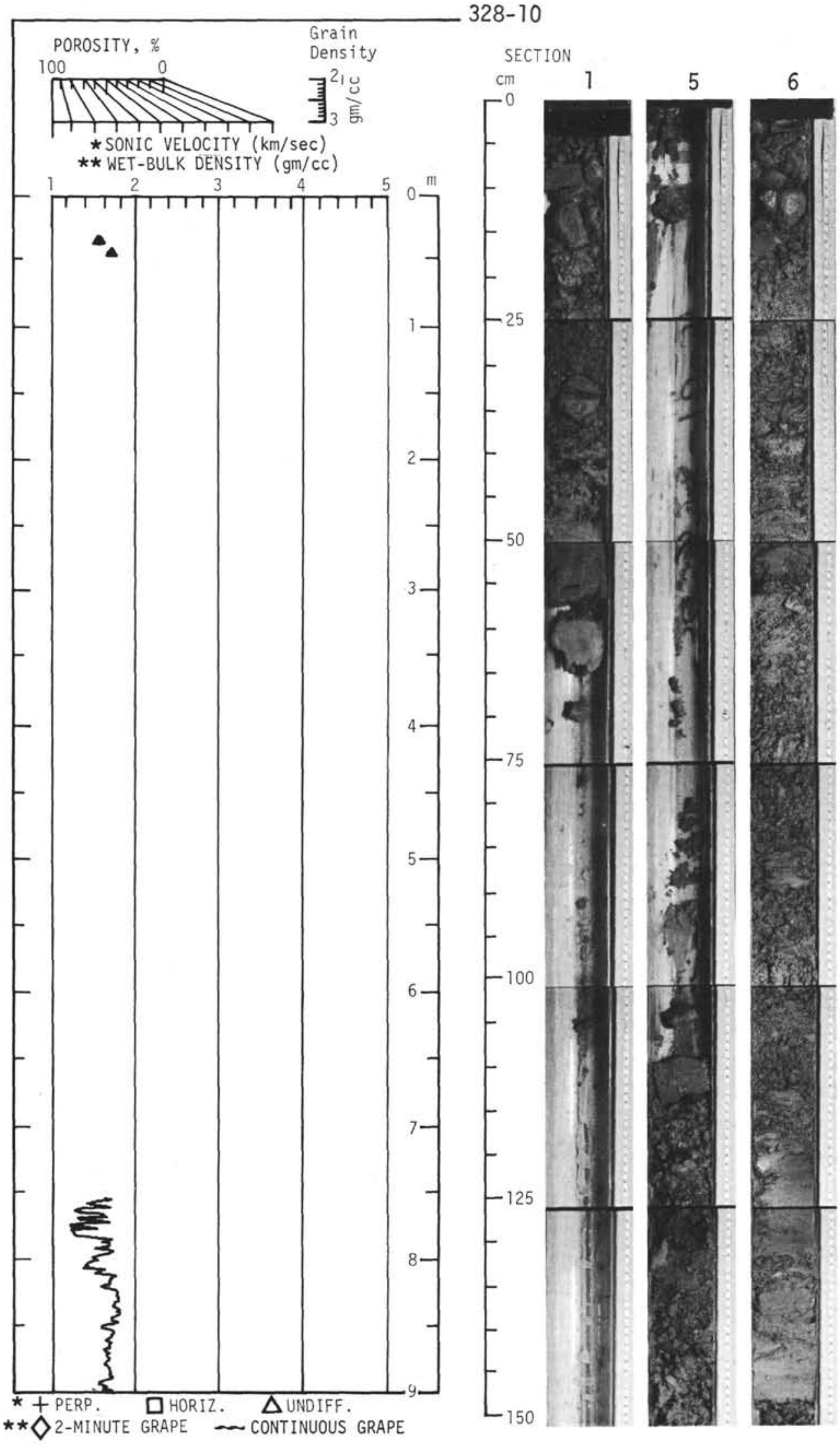

POROSITY, %
100
0
Grain Density
2
3
gm/cc
* SONIC VELOCITY (km/sec)
** WET-BULK DENSITY (gm/cc)
1
2
3
4
5
m
0
1
2
3
4
5
6
7
8
9
* + PERP.
□ HORIZ.
△ UNDIFF.
** ◇ 2-MINUTE GRAPE
~ CONTINUOUS GRAPE

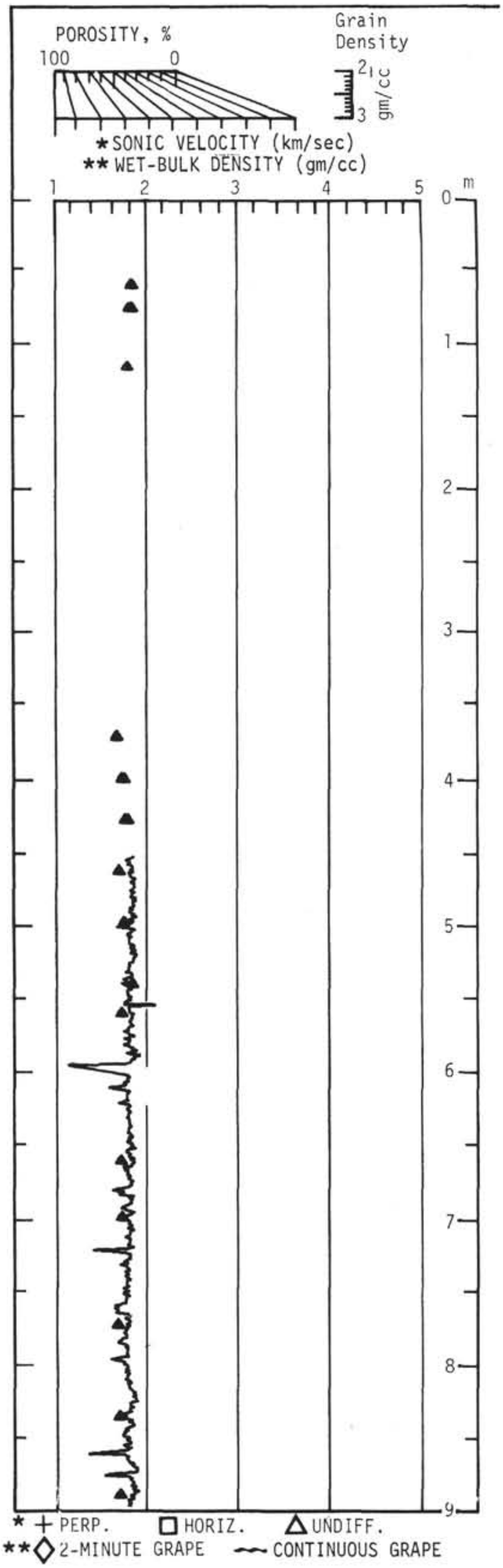

328-8
SECTION
cm
1
2
3
0
25
50
75
100
125
150

328-9

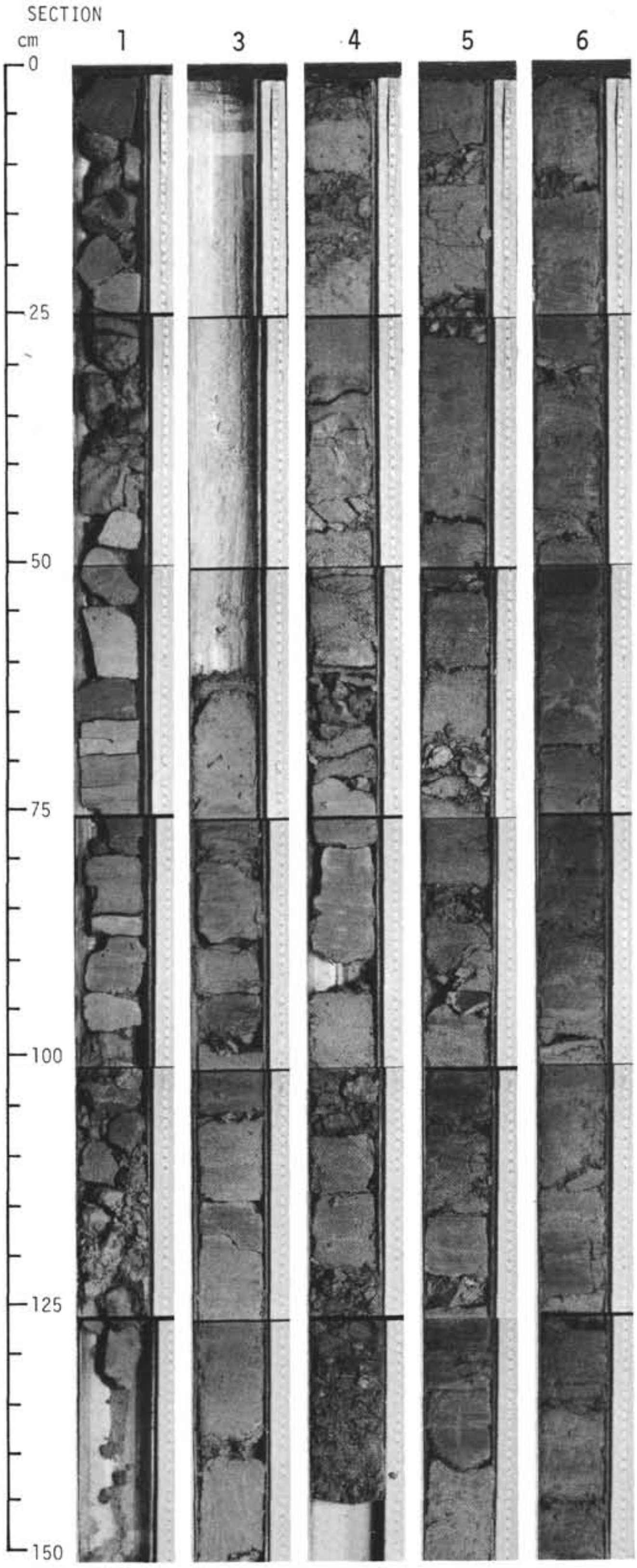

POROSITY, %
100
0
Grain Density
2
3
gm/cc
* SONIC VELOCITY (km/sec)
** WET-BULK DENSITY (gm/cc)
1
2
3
4
5
m
0
1
2
3
4
5
6
7
8
9
* + PERP.
□ HORIZ.
△ UNDIFF.
** ◇ 2-MINUTE GRAPE
CONTINUOUS GRAPE

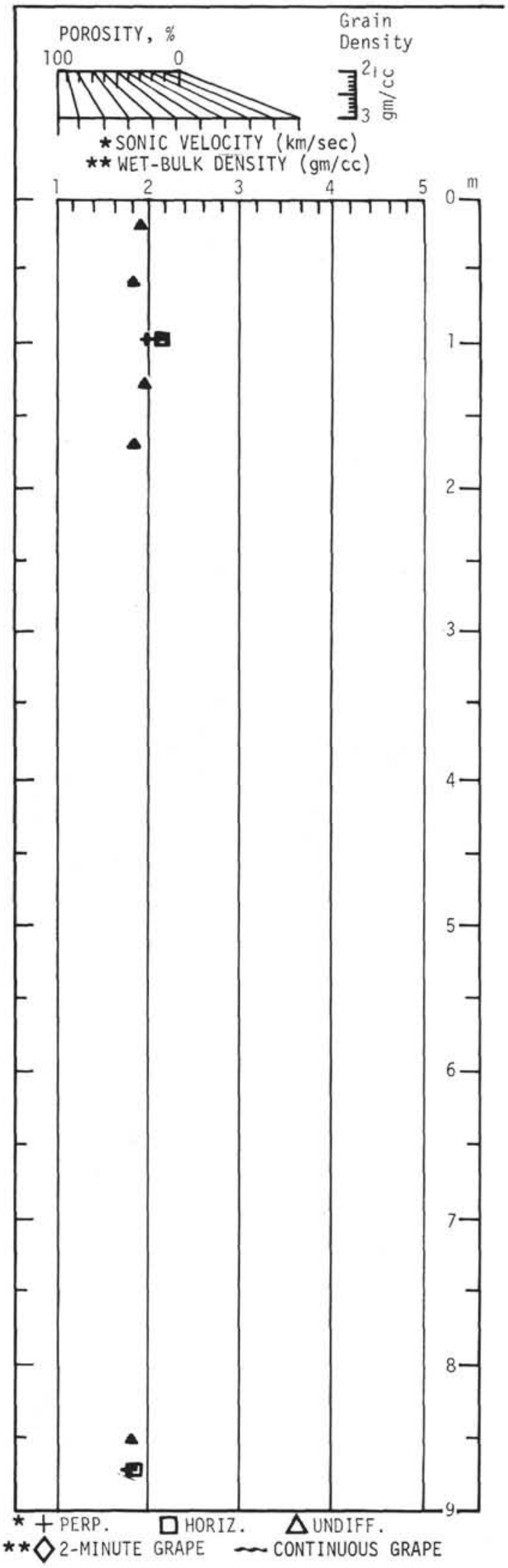

SECTION
cm
1
2
4
5
6
0
25
50
75
100
125
150

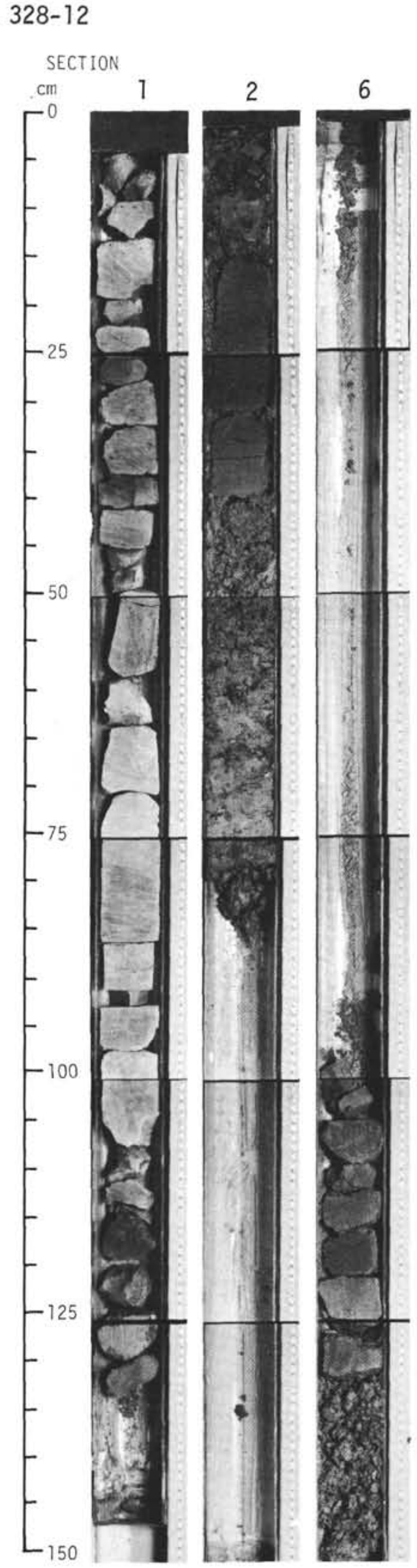

328-10
POROSITY, %
100
0
Grain Density
2
3
gm/cc
* SONIC VELOCITY (km/sec)
** WET-BULK DENSITY (gm/cc)
1
2
3
4
5
m
0
1
2
3
4
5
6
7
8
9
* + PERP.
□ HORIZ.
△ UNDIFF.
** ◇ 2-MINUTE GRAPE
~ CONTINUOUS GRAPE
SECTION
cm
0
25
50
75
100
125
150
1
5
6

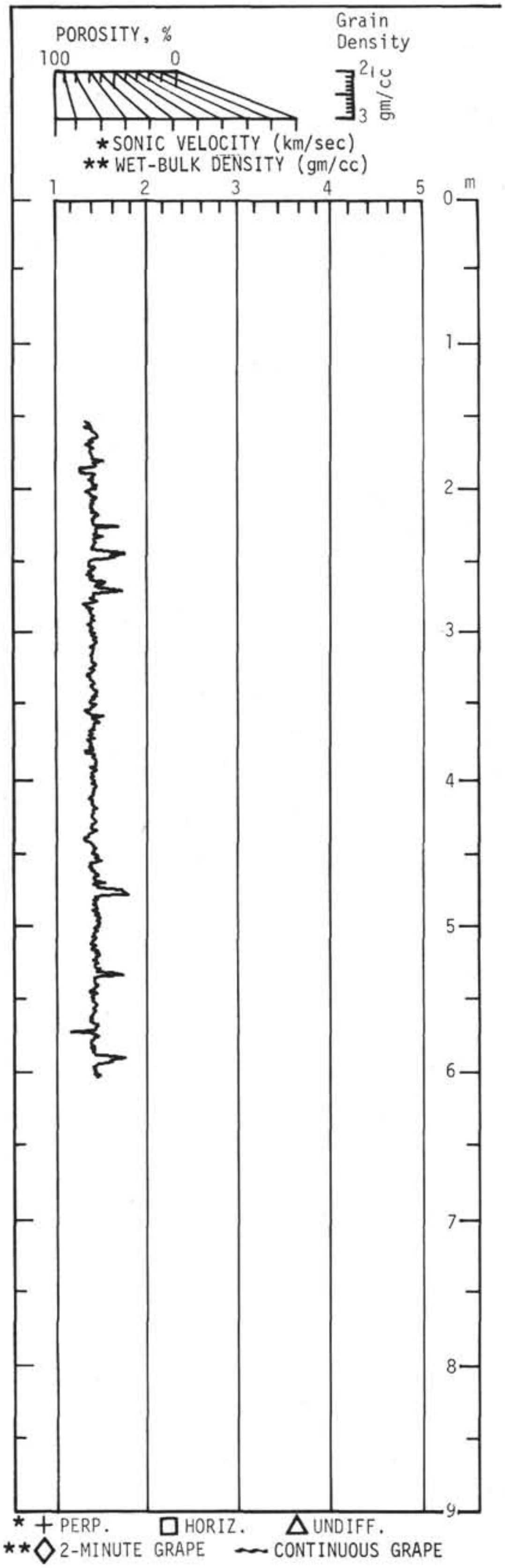

POROSITY, %
100
0
Grain Density
2
3
gm/cc
* SONIC VELOCITY (km/sec)
** WET-BULK DENSITY (gm/cc)
1
2
3
4
5
m
0
1
2
3
4
5
6
7
8
9
* + PERP.
□ HORIZ.
△ UNDIFF.
** ◇ 2-MINUTE GRAPE
~ CONTINUOUS GRAPE

328-11

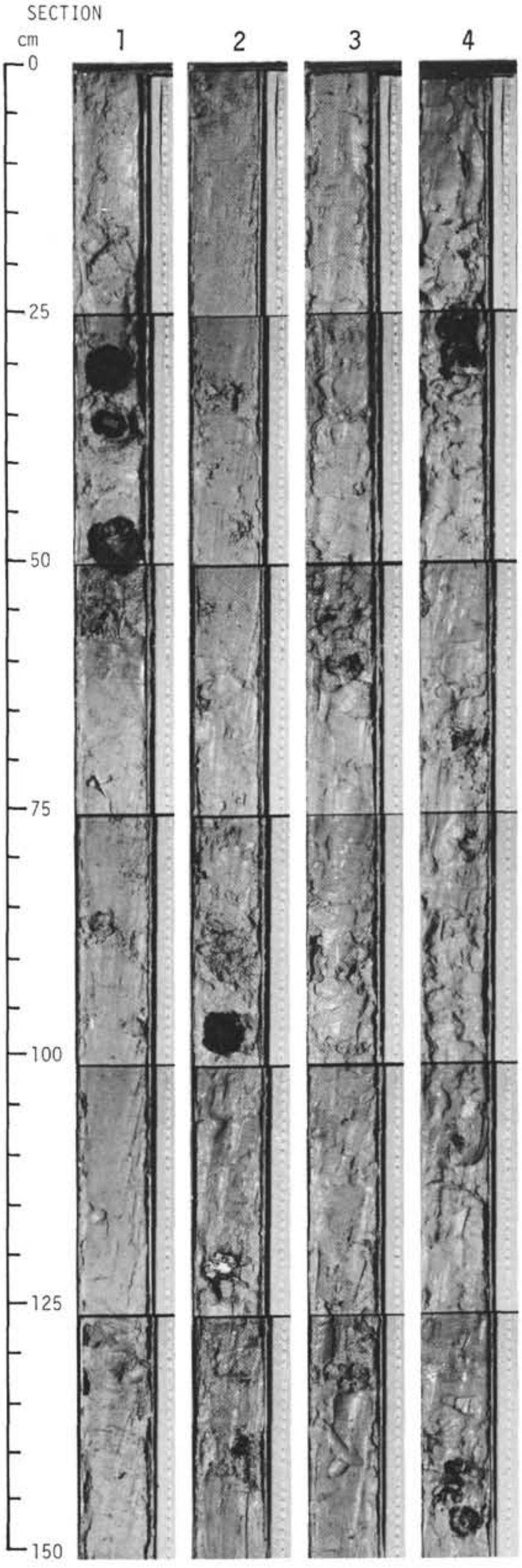

SECTION
cm
1
3
4
5
6
0
25
50
75
100
125
150


POROSITY, %
100
0
Grain Density
2
3
gm/cc
* SONIC VELOCITY (km/sec)
** WET-BULK DENSITY (gm/cc)
1
2
3
4
5
m
0
1
2
3
4
5
6
7
8
9
* + PERP.
☐ HORIZ.
△ UNDIFF.
** ◇ 2-MINUTE GRAPE
~ CONTINUOUS GRAPE

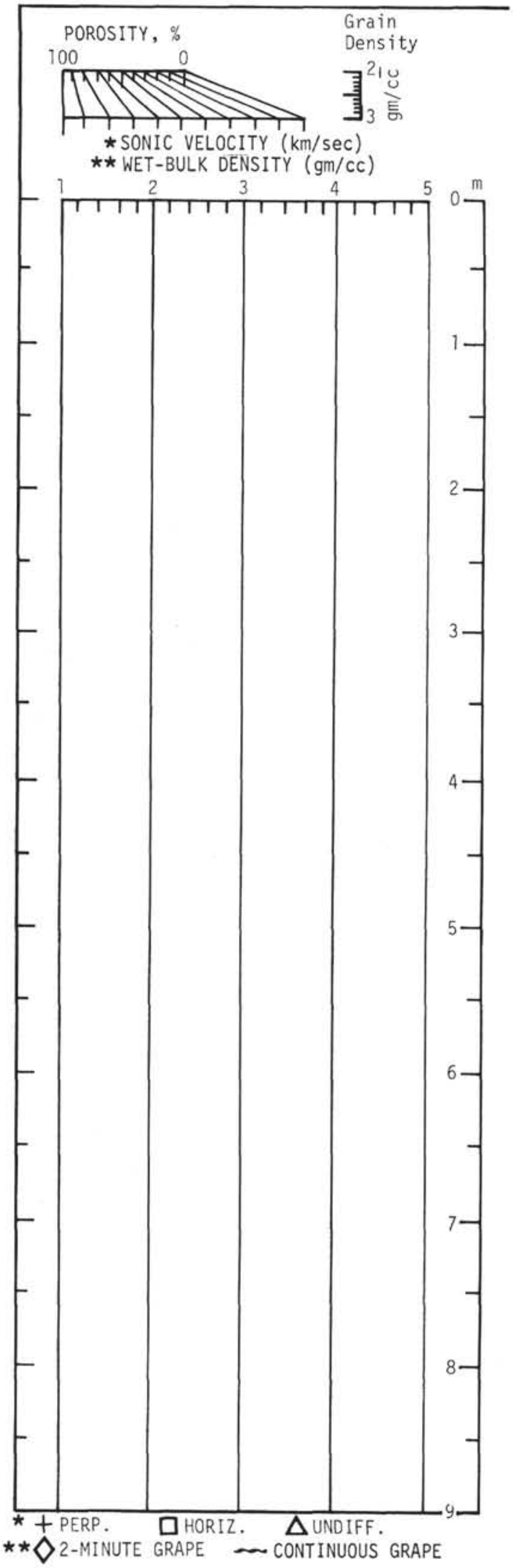

328-12
SECTION
cm
0
25
50
75
100
125
150
1
2
6

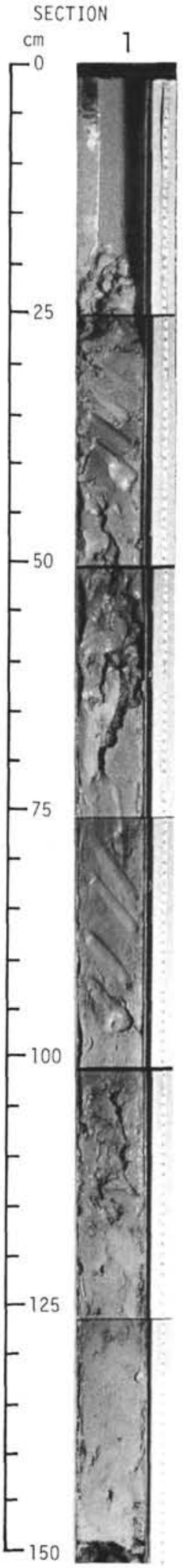

POROSITY, %
100
0
Grain Density
2
3
gm/cc
*SONIC VELOCITY (km/sec)
**WET-BULK DENSITY (gm/cc)
1
2
3
4
5
m
0
1
2
3
4
5
6
7
8
9
* + PERP.
□ HORIZ.
△ UNDIFF.
** ◇ 2-MINUTE GRAPE
~ CONTINUOUS GRAPE

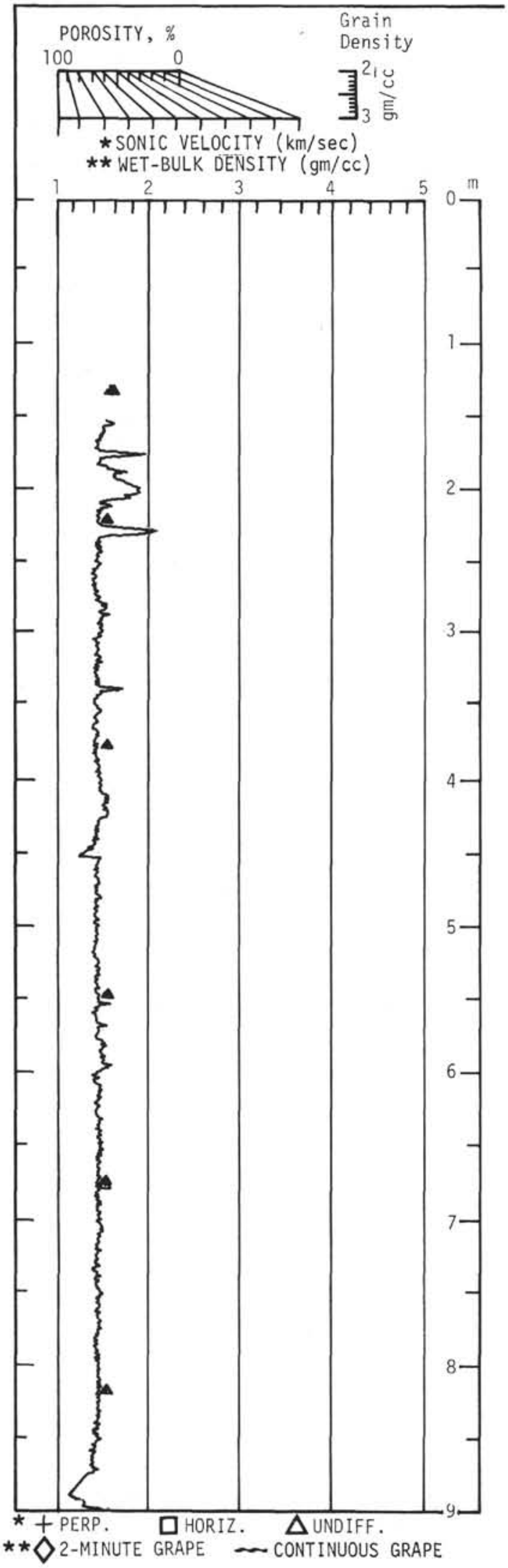
328A-1


SECTION
cm
1
2
3
4
0
25
50
75
100
125
150

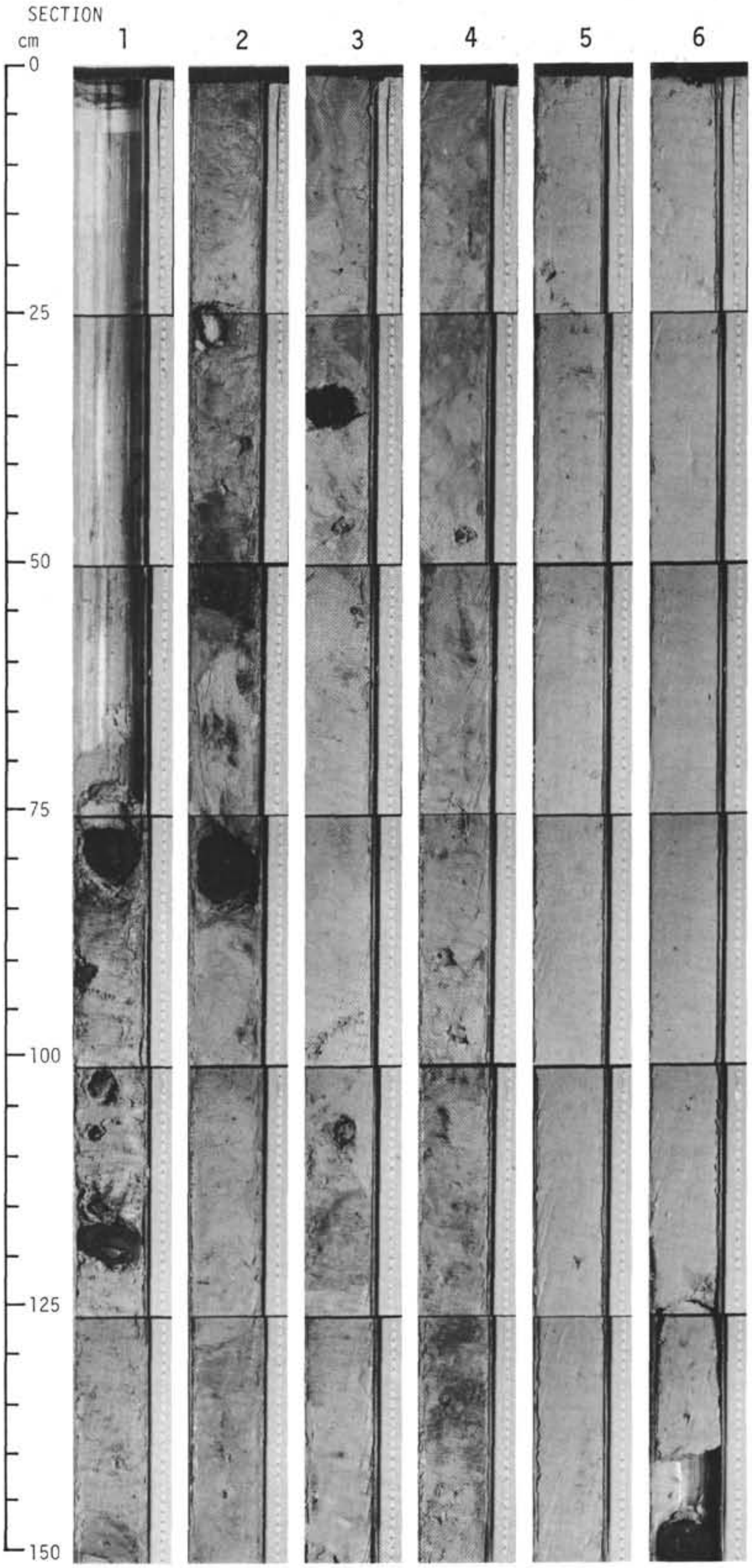
328A-2

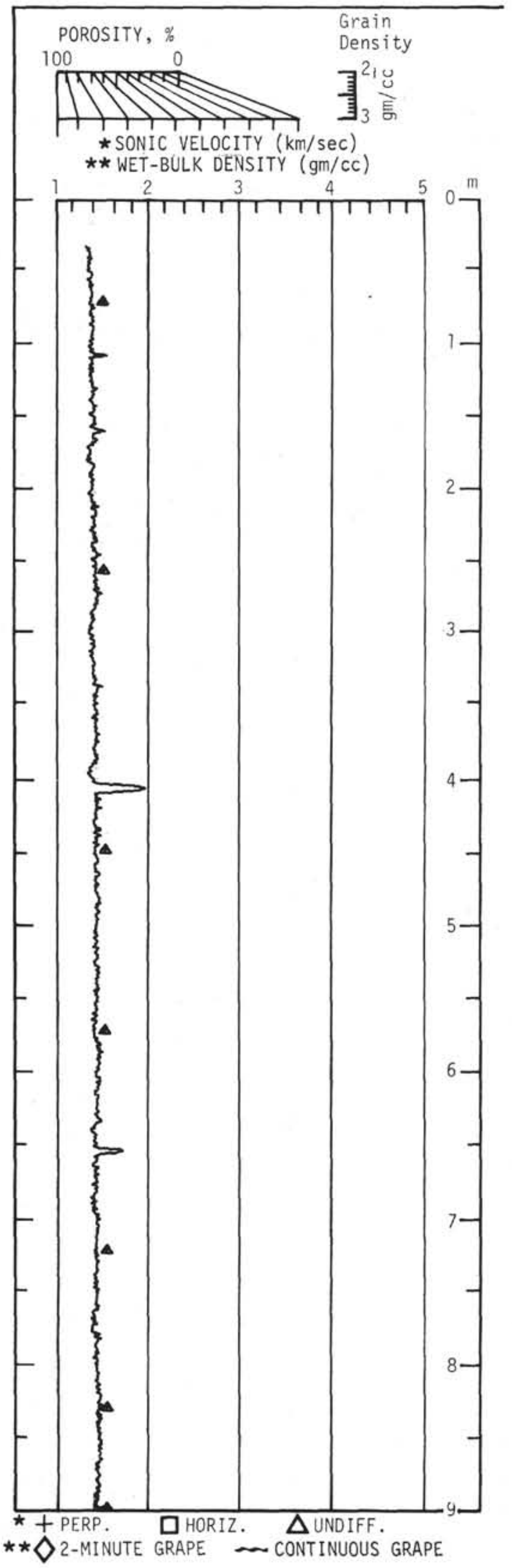

POROSITY, %
100
0
Grain Density
2
3
gm/cc
*SONIC VELOCITY (km/sec)
**WET-BULK DENSITY (gm/cc)
1
2
3
4
5
m
0
1
2
3
4
5
6
7
8
9
* + PERP.
□ HORIZ.
△ UNDIFF.
**◇ 2-MINUTE GRAPE
~ CONTINUOUS GRAPE


SECTION
1
cm
0
25
50
75
100
125
150

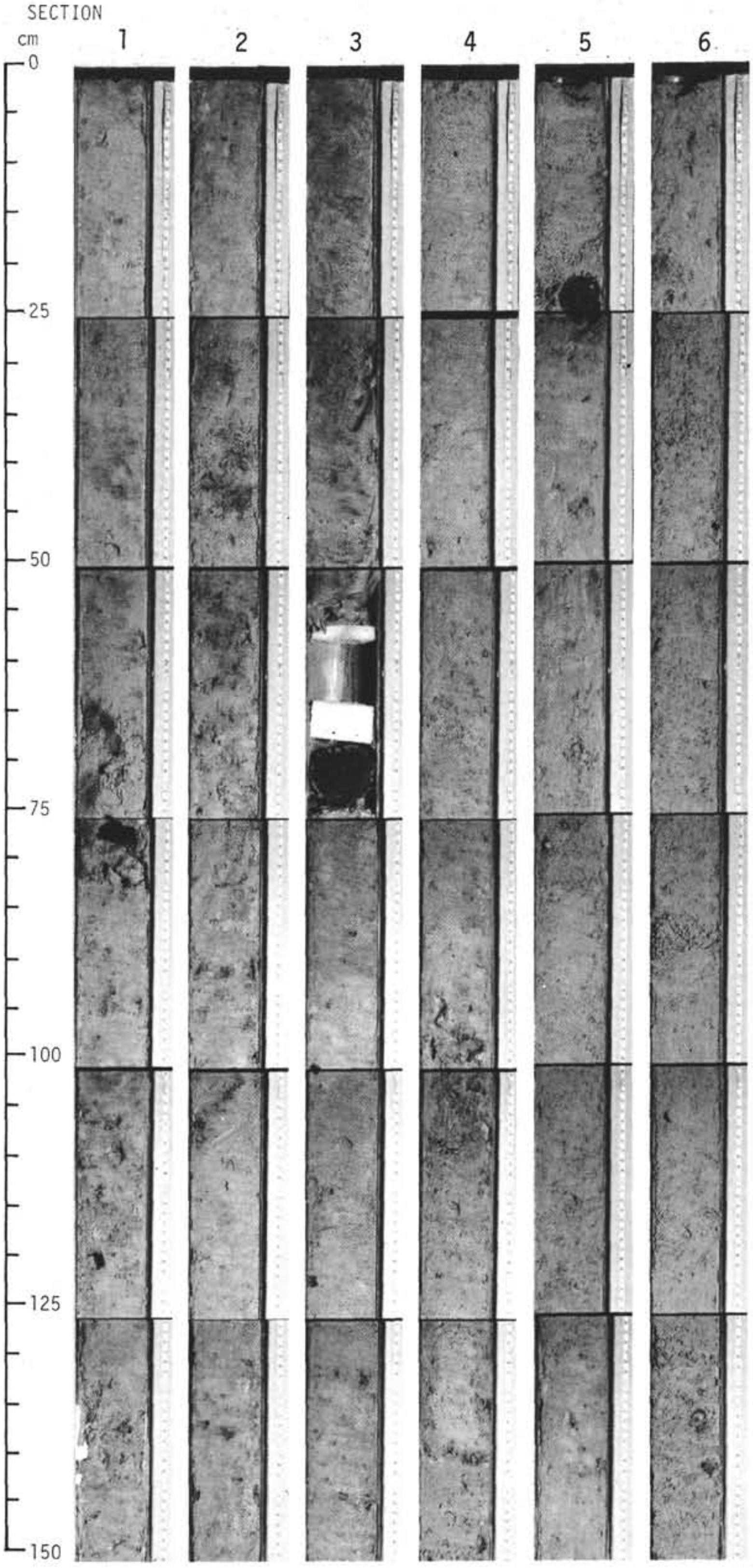

POROSITY, %
100
0
Grain Density
2
3
gm/cc
*SONIC VELOCITY (km/sec)
**WET-BULK DENSITY (gm/cc)
1
2
3
4
5
m
0
1
2
3
4
5
6
7
8
9
* + PERP.
□ HORIZ.
△ UNDIFF.
** ◇ 2-MINUTE GRAPE
~ CONTINUOUS GRAPE

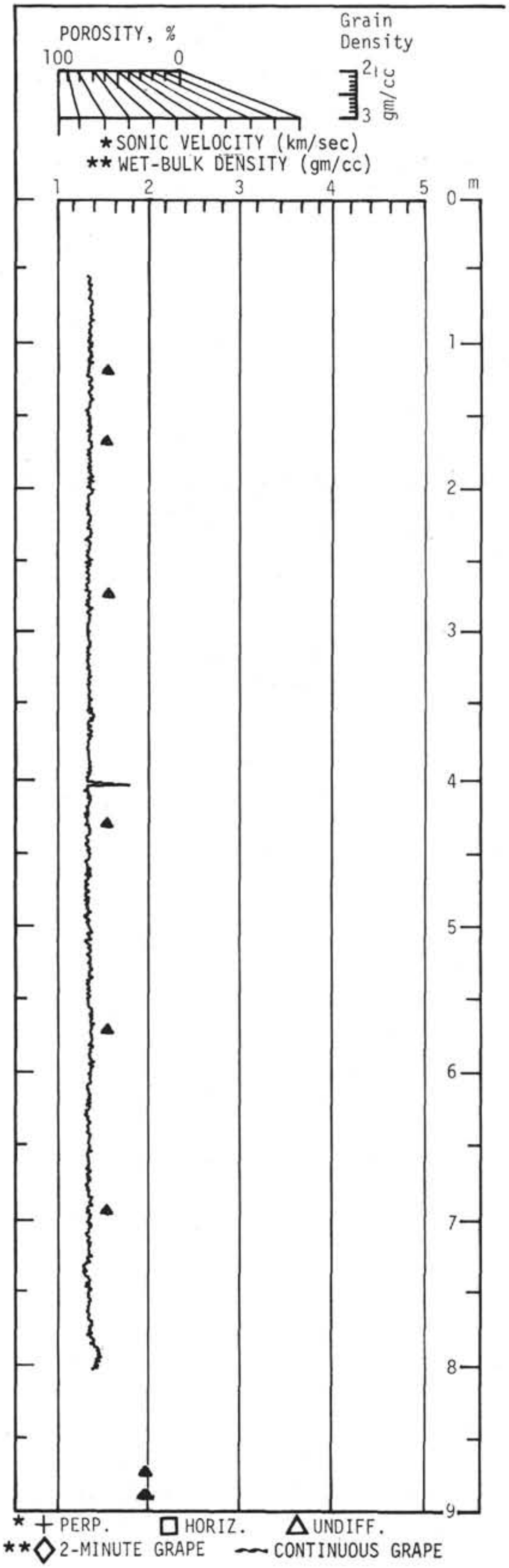
328B-1


SECTION
cm
1
2
3
4
5
6
0
25
50
75
100
125
150

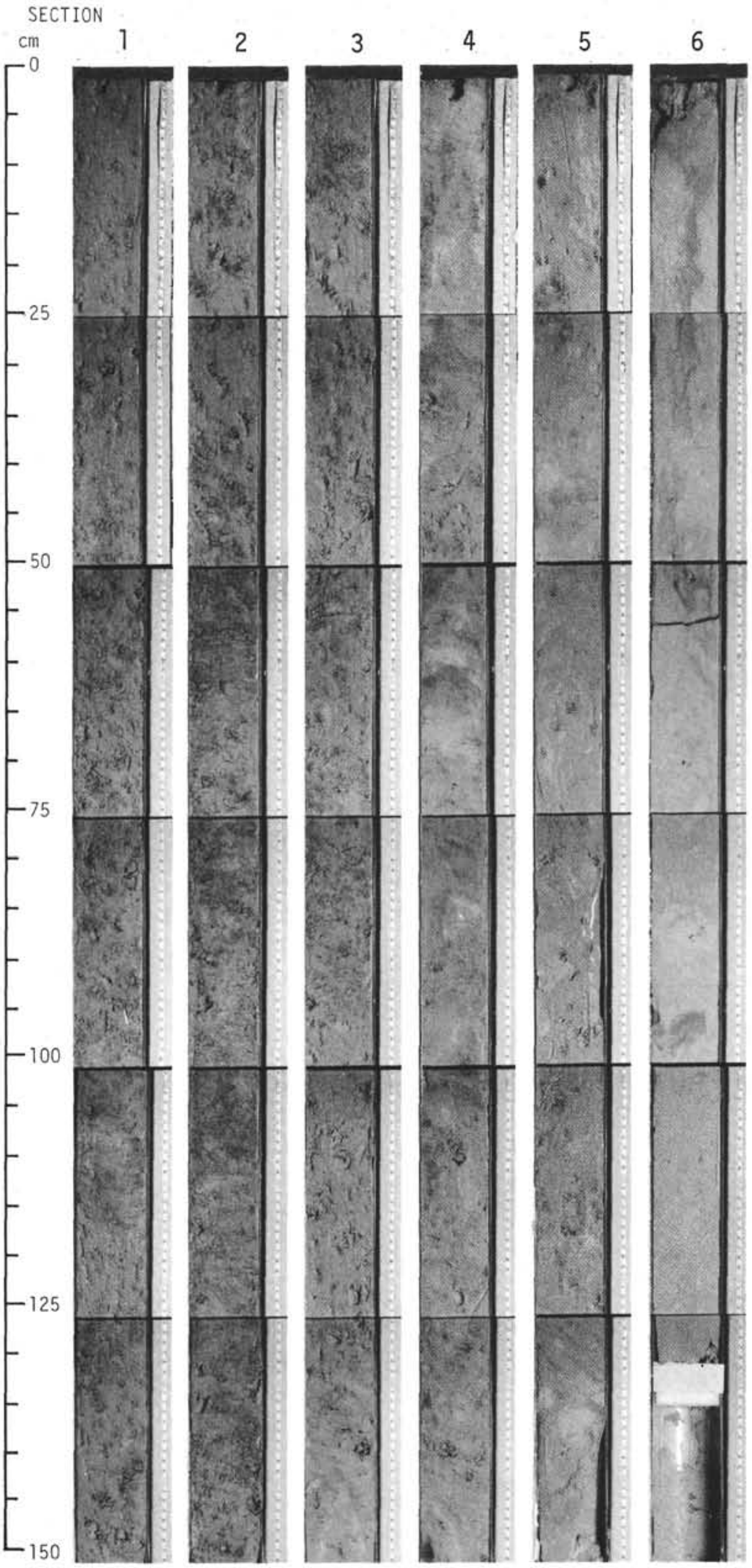

POROSITY, %
100
0
Grain Density
2
3
gm/cc
* SONIC VELOCITY (km/sec)
** WET-BULK DENSITY (gm/cc)
1
2
3
4
5
m
0
1
2
3
4
5
6
7
8
9
* + PERP.
□ HORIZ.
△ UNDIFF.
** ◇ 2-MINUTE GRAPE
〜 CONTINUOUS GRAPE

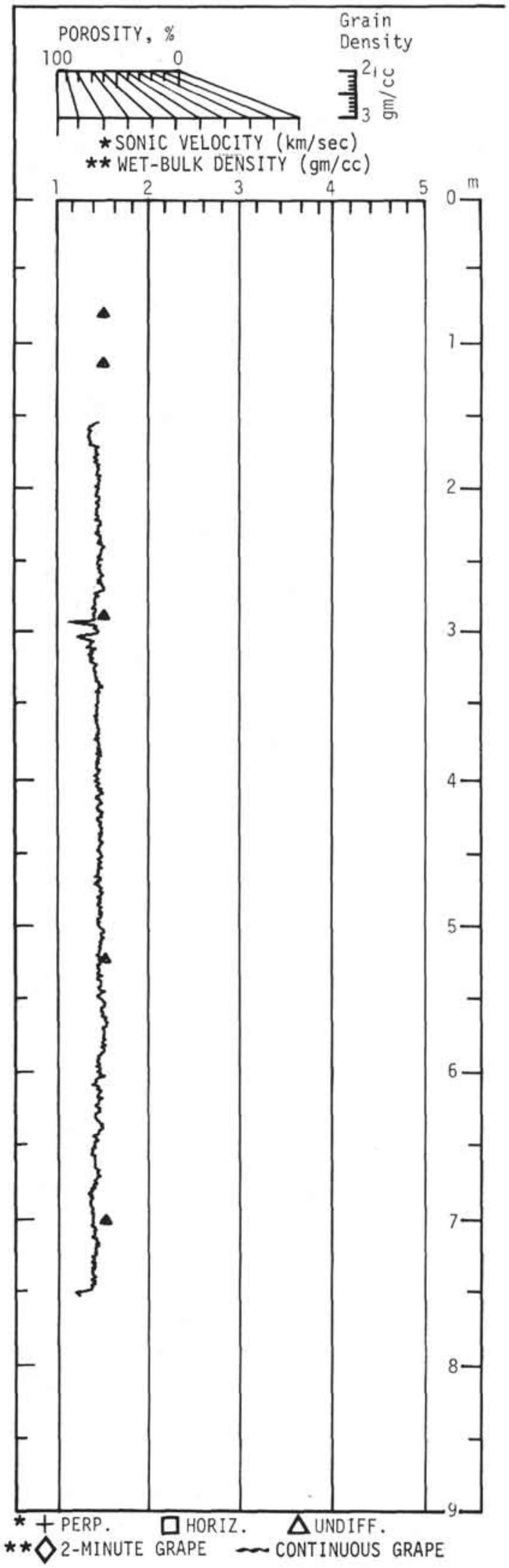
328B-2

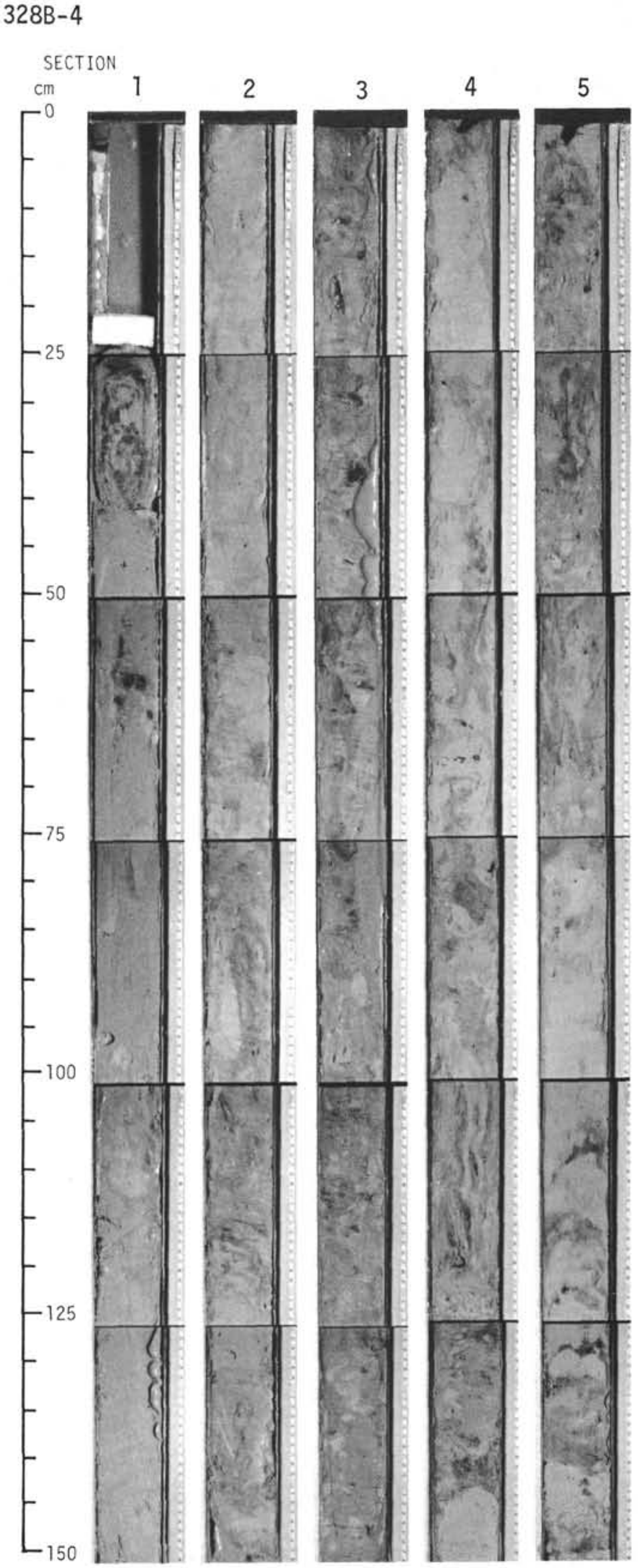

SECTION
cm
1
2
3
4
5
6
0
25
50
75
100
125
150


POROSITY, %
100
0
Grain
Density
2
3
gm/cc
* SONIC VELOCITY (km/sec)
** WET-BULK DENSITY (gm/cc)
1
2
3
4
5
m
0
1
2
3
4
5
6
7
8
9
* + PERP.
☐ HORIZ.
△ UNDIFF.
** ◇ 2-MINUTE GRAPE
~ CONTINUOUS GRAPE

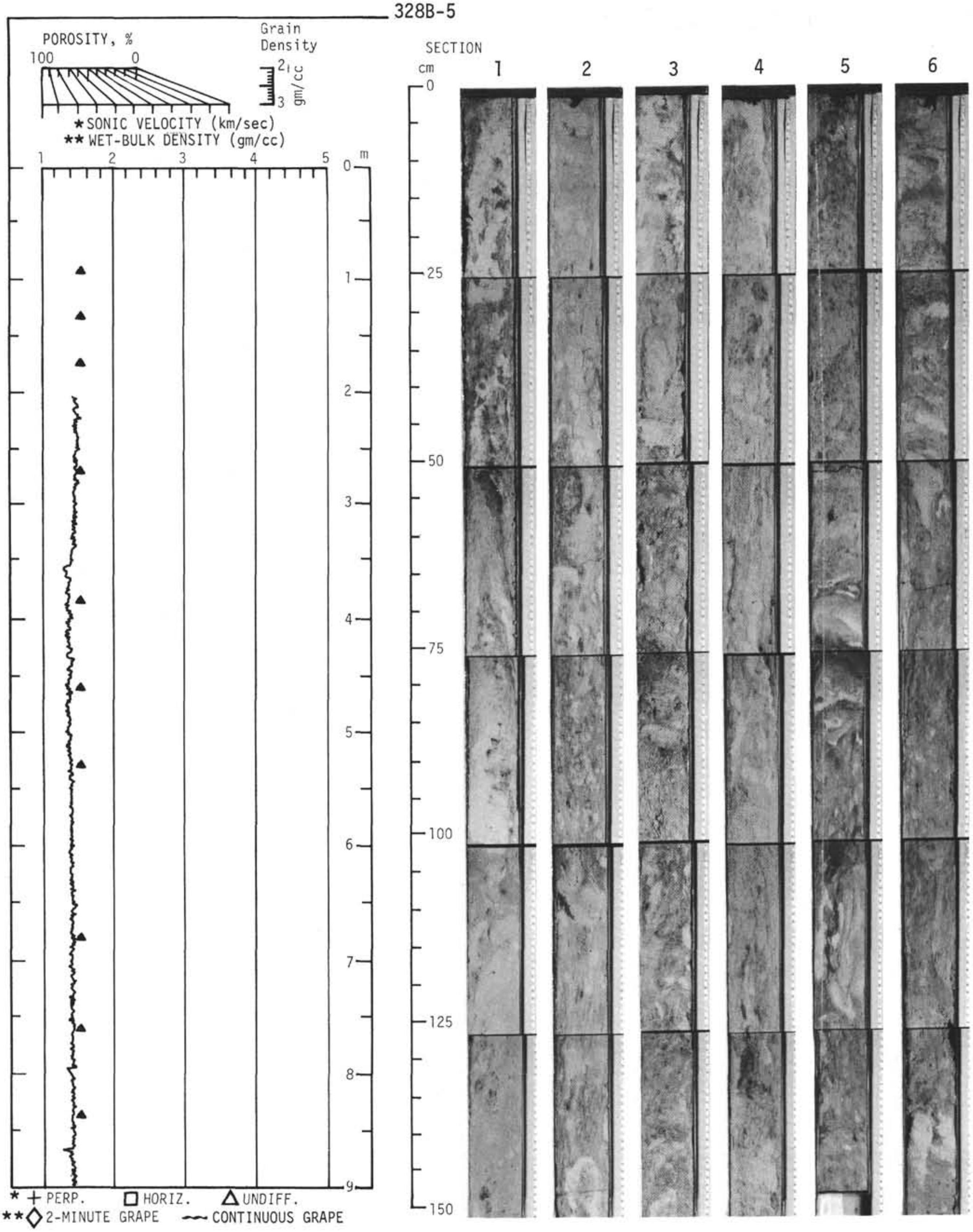
328B-3

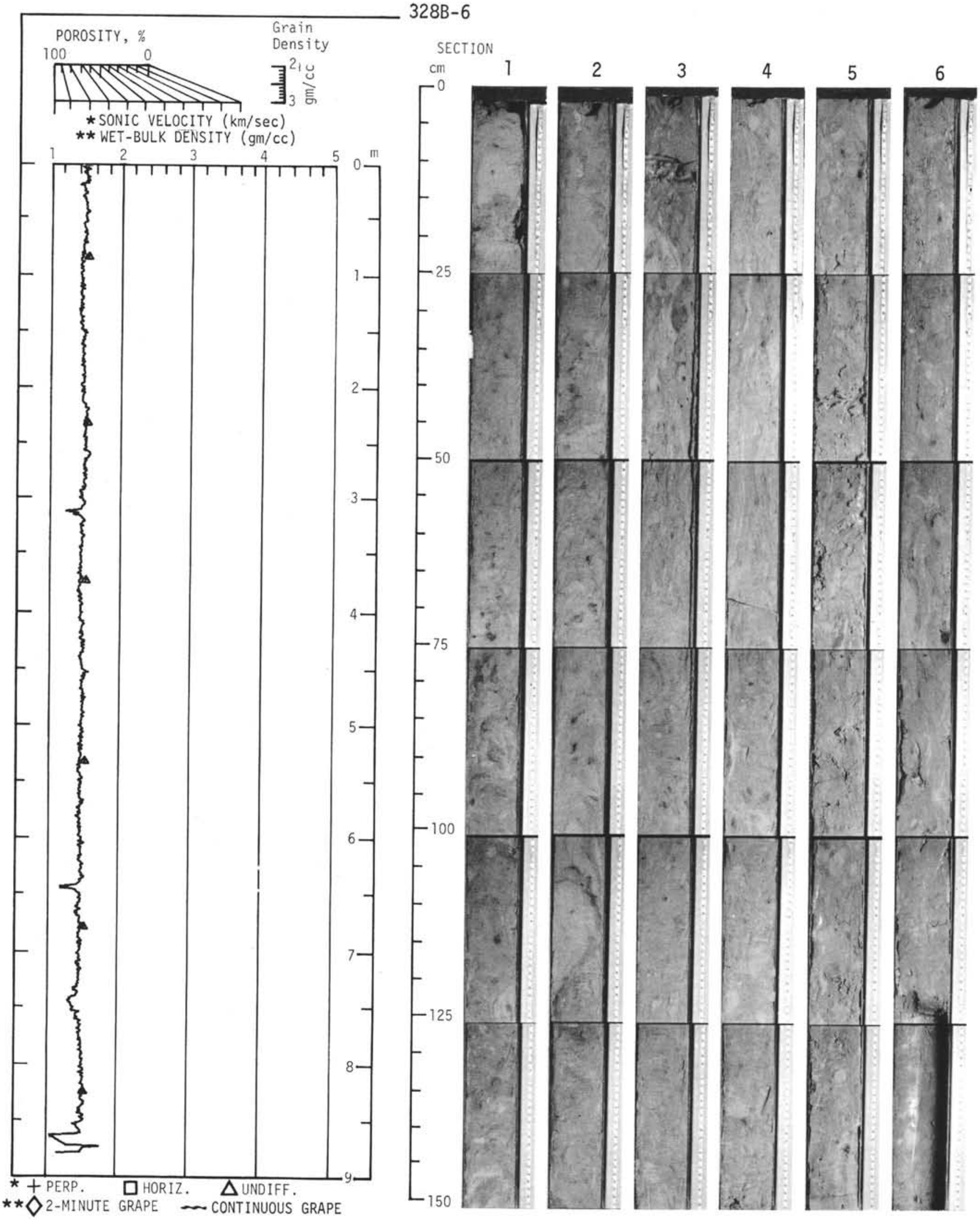

SECTION
1
2
3
4
5
6
cm
0
25
50
75
100
125
150

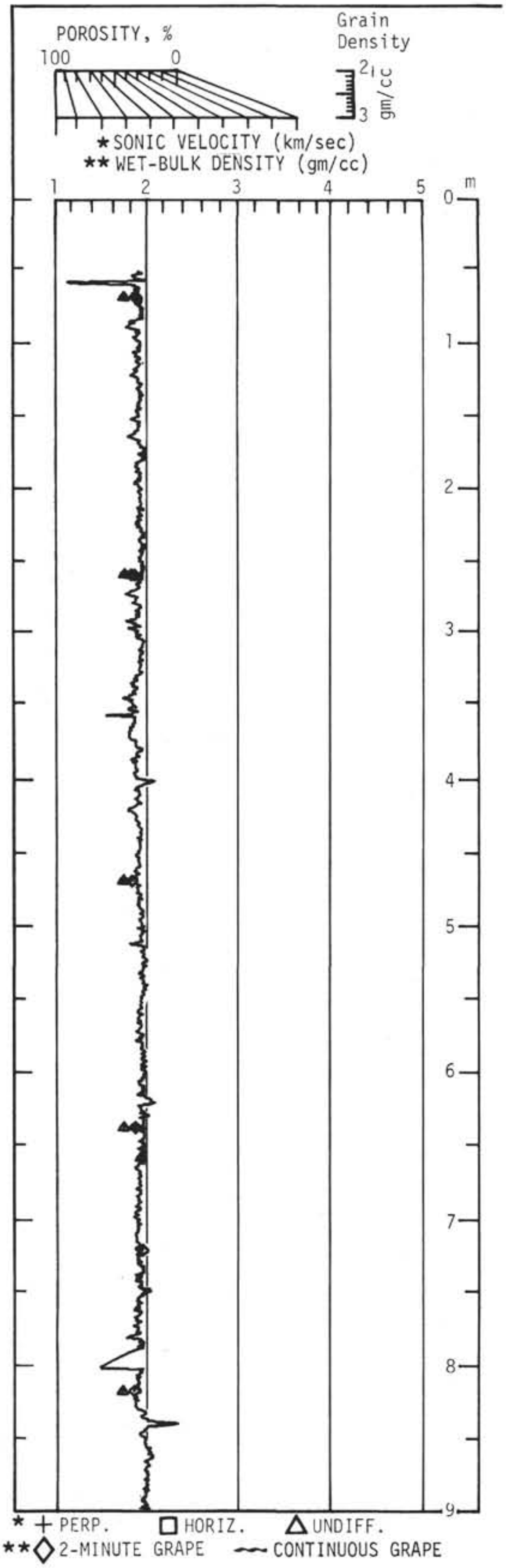

POROSITY, %
100
0
Grain Density
2
3
gm/cc
* SONIC VELOCITY (km/sec)
** WET-BULK DENSITY (gm/cc)
1
2
3
4
5
m
0
1
2
3
4
5
6
7
8
9
* + PERP.
□ HORIZ.
△ UNDIFF.
** ◇ 2-MINUTE GRAPE
~ CONTINUOUS GRAPE


328B-4
SECTION
1
2
3
4
5
cm
0
25
50
75
100
125
150

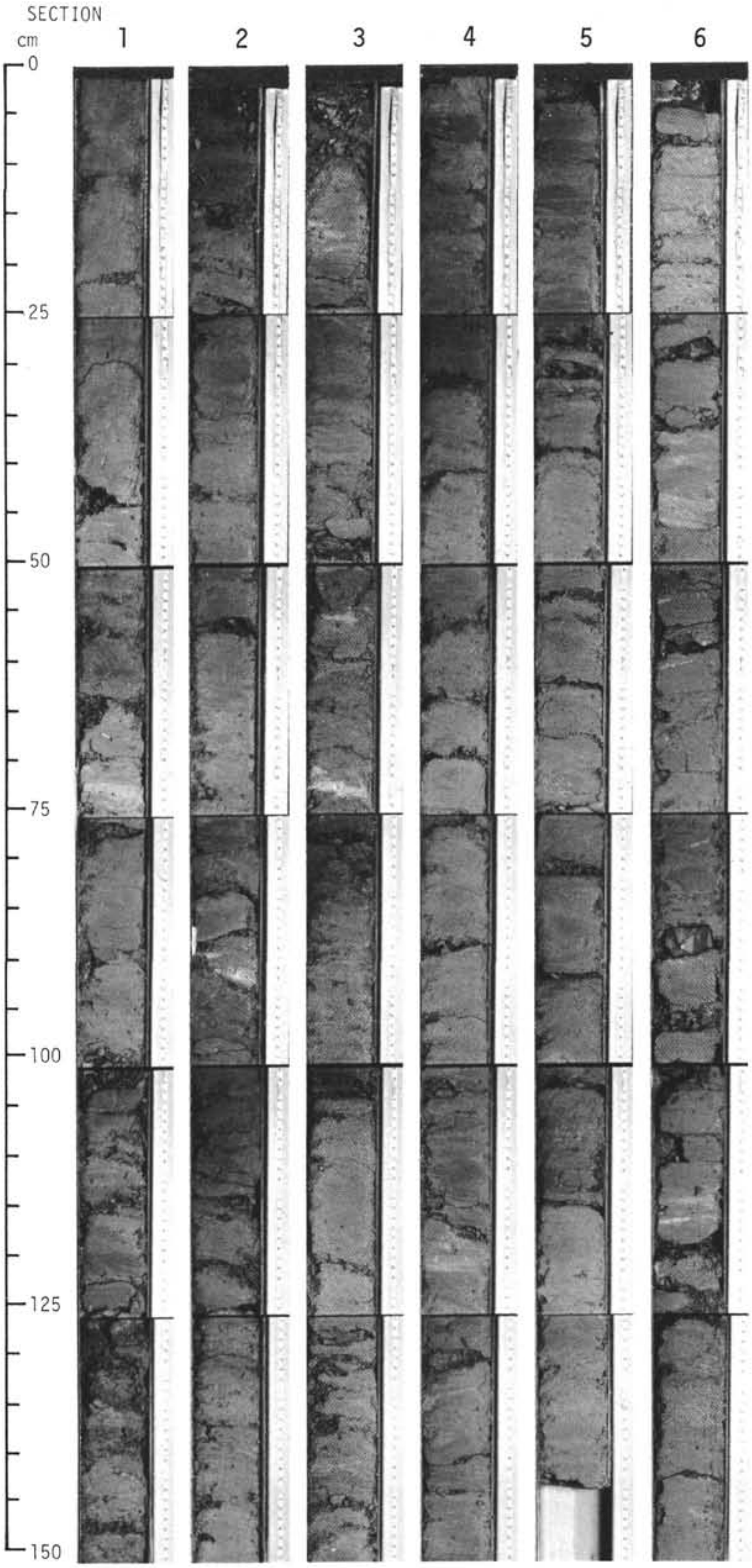
328B-5


POROSITY, %
100
0
Grain Density
2
3
gm/cc
* SONIC VELOCITY (km/sec)
** WET-BULK DENSITY (gm/cc)
1
2
3
4
5
m
0
1
2
3
4
5
6
7
8
9
* + PERP.
□ HORIZ.
△ UNDIFF.
** ◇ 2-MINUTE GRAPE
CONTINUOUS GRAPE
SECTION
cm
0
25
50
75
100
125
150
1
2
3
4
5
6


328B-6
POROSITY, %
100
0
Grain Density
2
3
gm/cc
* SONIC VELOCITY (km/sec)
** WET-BULK DENSITY (gm/cc)
1
2
3
4
5
m
0
1
2
3
4
5
6
7
8
9
* + PERP.
□ HORIZ.
△ UNDIFF.
** ◇ 2-MINUTE GRAPE
CONTINUOUS GRAPE
SECTION
cm
1
2
3
4
5
6
0
25
50
75
100
125
150


POROSITY, %
100
0
Grain Density
2
3
gm/cc
* SONIC VELOCITY (km/sec)
** WET-BULK DENSITY (gm/cc)
1
2
3
4
5
m
0
1
2
3
4
5
6
7
8
9
* + PERP.
□ HORIZ.
△ UNDIFF.
** ◇ 2-MINUTE GRAPE
~ CONTINUOUS GRAPE

328B-7


SECTION
cm
1
2
3
4
5
6
0
25
50
75
100
125
150