7. SITE 524[1]

Shipboard Scientific Party[2]

HOLE 524

Date occupied: 2048, 21 May 1980

Date departed: 0000, 27 May 1980

Time on hole: 123 hr.

Position: 29°29.055′S; 3°30.74′E

Water depth (sea level; corrected m; echo-sounding): 4796

Water depth (rig floor; corrected m; echo-sounding): 4806

Bottom felt (m, drill pipe): 4805

Penetration (m): 348.5

Number of cores: 35

Total length of cored section (m): 306.5

Total core recovery (m): 199.4

Core recovery (%): 65

Oldest sediment cored:
Depth sub-bottom (m): 348.5
Nature: Sandstone
Age: Late Cretaceous

Basement: Not reached (basalt sills and/or flows above oldest sediment)

Principal results: See discussion following Hole 524B data.

HOLE 524A

Date occupied: 0001, 27 May 1980

Date departed: 0340, 27 May 1980

Time on hole: 4 hr.

Position: 29°29.055′S; 3°30.74′E

Water depth (sea level; corrected m; echo-sounding): 4796

Water depth (rig floor; corrected m; echo-sounding): 4806

Bottom felt (m, drill pipe): 4805

Penetration (m): 47.5

Number of cores: 2

Total length of cored section (m): 19.0

Total core recovery (m): 9.9

Core recovery (%): 52

Oldest sediment cored:
Depth sub-bottom (m): 47.5
Nature: Sandstone and ooze
Age: Paleocene

Basement: Not reached (basalt sills and/or flows above oldest sediment)

Principal results: See discussion following Hole 524B data.

HOLE 524B

Date occupied: 0843, 27 May 1980

Date departed: 0315, 28 May 1980

Time on hole: 18 hr.

Position (latitude; longitude): 29°29.07′S; 03°30.74′E

Water depth (sea level; corrected m; echo-sounding): 4796

Water depth (rig floor; corrected m; echo-sounding): 4806

Bottom felt (m, drill pipe): 4805

Penetration (m): 29.3

Number of cores: 7

Total length of cored section (m): 29.5

Total core recovery (m): 20.7

Core recovery (%): 70

Oldest sediment cored:
Depth sub-bottom (m): 29.3
Nature: Nannofossil ooze
Age: Paleocene

Basement:
Depth sub-bottom (m): Not reached (basalt sills and/or flow above oldest sediment)

Principal results: Holes 524, 524A, 524B—

1. Obtained a nearly continuous sequence of Paleocene and Maestrichtian sediments, deposited at rates from 11 to 34 m/m.y., for stratigraphic and paleoceanographic investigations.
2. Obtained a magnetostratigraphy from Chron C-23 to C-31-R.
3. Established a magnetostratigraphic calibration of nannofossil zones from NP3 down to *Nephrolithus frequens* and of foraminifer zones from *Morozovella uncinata* down to *Globotruncana gansseri*.
4. Made tentative correlations between biostratigraphy, magnetostratigraphy, and seafloor anomalies from Chrons C-23 (NP23) down to Chron C-26-R (NP4 and *M. pusilla* Zone).
5. Established the sudden nature of the terminal Cretaceous environmental changes, which led to the mass extinction of marine plankton within less than 50,000 yr.

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[1] Hsü, K. J., LaBrecque, J. L., et al., *Init. Repts. DSDP*, 73: Washington (U.S. Govt. Printing Office).

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6. Obtained basalt samples for studies of the petrology and chemistry of midplate volcanism.

7. Obtained a radiometric date for a basalt sample that dates the emplacement of the Central Walvis Ridge between 64 and 74 Ma.

8. Obtained data that permitted a comparison of magnetostratigraphically and radiometrically derived ages of Paleocene datums. Discrepancies are significant (several million years) if the Cenozoic is assumed to have begun 66.5 Ma, but the discrepancies are smaller if it is assumed to have begun 63.5 Ma.

BACKGROUND AND OBJECTIVES

The Leg 73, 74, and 75 cruises were undertaken to obtain data from a series of holes transecting certain regions in the southeastern Atlantic Ocean to permit the reconstruction of paleoceanographic gradients. The holes on the Walvis Ridge (Leg 74) were to be drilled to different paleodepths in a narrowly confined area to investigate the vertical gradients of ancient oceans; the holes on the Mid-Atlantic Ridge (Leg 73), on the other hand, were intended to provide information about horizontal gradients. Originally seven drill sites were planned for Leg 73; three additional sites were also scheduled, one of which might be drilled if circumstances should permit. One of the three additional sites was in the Angola Basin, one was in the Cape Basin, and one was on the Walvis Ridge. We also decided to consider a fourth site, SA II-6, a location in the Cape Basin that was at the end of the planned northwest–southeast transect across the Walvis Ridge. The crust at this site lay within the magnetic quiet zone, and its Paleocene sediments had been sampled by piston coring by R/V *Jean Charcot* during a 1979 site survey.

Lack of ship time ruled out the Angola Basin and the first of the Cape Basin sites, which were too far away from the Santos–Capetown track. Asked to decide between the Walvis Ridge site and Site SA II-6, the shipboard staff chose the latter. The Walvis Ridge site was an integral part of Leg 74 and was best left to its scientists. Site SA II-6, on the other hand, was alien to a program that emphasized vertical gradients; it was originally chosen to provide data in the Cape Basin for the reconstruction of horizontal gradients in the southeastern Atlantic, the principal goal of our leg. Second, Site SA II-6 might permit us to attain the goals we had set for both the Angola Basin and the first of the Cape Basin sites. The last, and perhaps most important, considerations were weather and scheduling. Weather reports were not favorable, and under adverse weather conditions it is easier to drill a site in deep water than in shallow water (Site SA II-6 was at a water depth of ~5000 m; the Walvis Ridge site, at ~1300 m). The question of scheduling was also important. We had too much time to drill a shallow site but enough time, with some flexibility, to drill Site SA II-6.

Thus, Site SA II-6 became Site 524 (Fig. 1). The primary objectives of drilling at the site were paleoceanographic. Through the siliceous fossils, we hoped to gain information on the past activity of the Benguela Current. The location of the site at the foot of a submarine canyon originating from a low saddle (~3000 m water depth) on the Walvis Ridge might also yield information concerning bottom water circulation, particularly communication between the Angola and Cape basins.

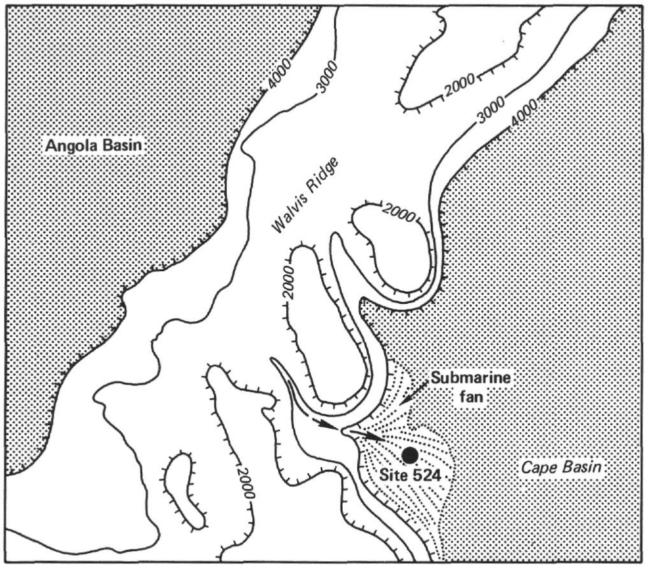

Figure 1. Location of Site 524 on a submarine fan at the mouth of a submarine canyon. Bathymetric contours are in m.

The water depth of the site is over 4800 m, near or below the calcite compensation depth (CCD) of the Cape Basin during much of the Neogene. We expected at most a thin veneer of Pliocene–Quaternary sediments. The earlier acquisition by means of piston coring of Paleocene calcareous sediments led us to expect to reach the Cretaceous/Tertiary contact. Because of experience at Site 520 we knew that the preservation of calcareous fossils could be very good locally at depths below the regional CCD, and so we expected to find a calcareous Paleogene sequence if the site was frequented by turbidity currents then. The possibility existed of finding easily accessible Eocene and Paleocene sediments; if found, these sediments would permit us to extend our already highly successful program of magnetostratigraphic–biostratigraphic correlation beyond the middle Eocene sediments obtained at Hole 523 into the Upper Cretaceous.

A preliminary examination of seafloor magnetic stripes suggested that the site was within the magnetic quiet zone and that the crust was Santonian or Turonian in age. Thus, if we drilled to the basement we should penetrate Campanian sediments, which were found to be anoxic at the Angola Basin and not anoxic at the sites in the Cape Basin drilled during Leg 40. Information on the Campanian paleoenvironments at Site 524 might thus clarify the role of the Walvis Ridge in controlling the bottom circulation patterns of the Angola and Cape basins. Certainly we should be able to view the paleoenvironmental effect of the formation of the central portion of the Walvis Ridge, which has been ascertained (on the basis of magnetic anomaly lineations) to be of Maestrichtian age.

Finally, as far as we know, no deep sea cruises had ever sampled the ocean crust from magnetic quiet zones. We hoped to sample the basalt basement, which would enable us to investigate the magnetic properties of ocean crust in a quiet zone and the petrology and geochemistry of the seafloor basalts. Further, a determination of the age of basement would add to our knowledge of the seafloor spreading history of the South Atlantic.

Therefore, all the members of our interdisciplinary team looked forward to drilling Site 524. One of the paleontologists was hoping for diatoms. All the paleontologists were looking for Paleogene sections and the Cretaceous/Tertiary boundary. The geophysicists and magnetostratigraphers were hoping to further the correlation between the magnetic epochs and the biostratigraphy as well as to gain knowledge concerning the composition and formation of the Walvis Ridge. The petrologists were waiting for basalt samples. One of us was dreaming of finding the sterile bed deposited when the oceanic plankton was practically wiped out by a fallen comet. Perhaps all of us had derived some satisfaction by the end of the drilling!

OPERATIONS

Site 524 was located by using the position given for Site SA II-6, 29°29.06′S and 03°30.74′E. We wanted to find a location remote from submarine channels that would supply sand capable of plugging the drilling hole. The technique we used to locate the site was to join an existing seismic profile at 29°30′S and 3°29′E and to steam at 54° along the profile line until we observed a suitable site. A course of 54° was set at 1812Z on 21 May. At 1845Z we noted a submarine channel on the seismic record (Fig. 2). We decided that the point at 1830Z on our profile was appropriate for the site. The order was given to return to the 1830Z location to drop the beacon and retrieve gear. This was done and vessel positioning began (Fig. 3).

At 2048Z on 21 May, the vessel was in auto on Site 524. At 2054Z, the crew started to run the pipes down. Toward the morning of 22 May, winds reached 40 mph; they increased to 45 mph 10 min. later, and the vessel started to roll 6°. At 0600Z, operations on the rig floor were suspended to wait for the weather to improve. At 1015Z the weather improved, and the drilling crew resumed running pipe down.

At 1200Z on 22 May the pipes were down and the crew was ready to spud in. However, an attempt was made to conduct an engineering test to monitor the heave of the ship, and the engineering package, when pumped down, became tightly embraced by the drill bit. The package could not be freed, and it became necessary to pull out of the hole. Coring operations at the site were delayed 24 hr. by the incident.

At 1147Z on 23 May, the drill bit again felt bottom and was ready to spud in. The first core was empty. The original schedule called for using the rotary drill to obtain random cores down to the basement and then using the hydraulic piston corer (HPC) to drill the upper section. However, when Core 3 was cut open by eager sedimentologists, a layer of chert was found, which was bound to obstruct the progress of the HPC. It was therefore decided to start continuous rotary coring.

Meanwhile, the weather worsened again. The arrival of a storm front was forecast for 0600Z on 24 May; however, after making a threatening gesture, the storm turned right and passed 60 mi. south of the vessel.

With the return of sunshine and a calm sea, coring resumed, with good recovery. Throughout the day of 24 May, cores came up regularly (Table 1) to be dated regularly as NP3. We knew we were close to the Cretaceous/Tertiary boundary, and tension mounted. Recovery was good, but the treasured contact might nevertheless occur where there was a gap in recovery.

The contact was finally found in Core 20. All traces of fallen comet were gone, but the presence of nearly sterile sediments caused great excitement.

A prominent reflector encountered at about 280 m sub-bottom (as predicted successfully for the first time during this cruise) was found to be the highest sill of a volcanic complex. After 24 hr. of basalt drilling, the drill bit conveniently wore out. Hole 524 was terminated at 348.5 m sub-bottom, 68.5 m below the prominent reflector and some 5000 m(?) above the Moho. The last

Table 1. Coring summary, Holes 524, 524A, and 524B.

Core	Date (May 1980)	Time (hr.)	Depth from drill floor (m)	Depth below seafloor (m)	Length cored (m)	Length recovered (m)	Recovery (%)
Hole 524							
1	23	1302	4805.0–4806.5	0–1.5	1.5	tr	0
2	23	1455	4814.5–4824.0	9.5–19.0	9.5	2.3	24
3	23	1702	4813.5–4843.0	28.5–38.0	9.5	4.9	83
4	23	1910	4852.5–4862.0	47.5–57.0	9.5	5.1	53
5	23	2100	4862.0–4871.5	57.0–66.5	9.5	7.3	77
6	23	2252	4871.5–4881.0	66.5–76.0	9.5	4.5	47
7	24	0050	4881.0–4890.5	76.0–85.5	9.5	2.7	28
8	24	0245	4890.5–4900.0	85.5–95.0	9.5	8.2	86
9	24	0440	4900.0–4909.5	95.0–104.5	9.5	7.7	81
10	24	0630	4909.5–4919.0	104.5–114.0	9.5	7.0	74
11	24	0825	4919.0–4928.5	114.0–123.5	9.5	8.3	87
12	24	1020	4928.5–4938.0	123.5–133.0	9.5	9.1	96
13	24	1220	4938.0–4947.5	133.0–142.5	9.5	6.7	71
14	24	1450	4947.5–4957.0	142.5–152.0	9.5	4.4	46
15	24	1650	4957.0–4966.5	152.0–161.5	9.5	6.7	71
16	24	1905	4966.5–4976.0	161.5–171.0	9.5	8.0	84
17	24	2105	4976.0–4985.5	171.0–180.5	9.5	7.4	78
18	24	2305	4985.5–4995.0	180.5–190.5	9.5	8.0	84
19	25	0105	4995.0–5004.5	190.0–199.5	9.5	5.4	57
20	25	0322	5004.5–5014.0	199.5–209.0	9.5	5.1	54
21	25	0525	5014.0–5023.5	209.0–218.5	9.5	7.5	79
22	25	0732	5023.5–5033.0	218.5–228.0	9.5	7.3	77
23	25	0920	5033.0–5042.5	228.0–237.5	9.5	7.5	79
24	25	1115	5042.5–5052.0	237.5–247.5	9.5	8.3	87
25	25	1315	5052.0–5061.5	247.5–256.5	9.5	9.3	98
26	25	1530	5061.5–5071.0	256.5–266.0	9.5	9.7	102
27	25	1735	5071.0–5080.5	266.0–275.5	9.5	6.2	65
28	25	1958	5080.5–5090.0	275.5–285.0	9.5	7.1	75
29	25	2244	5090.0–5094.0	285.0–289.0	4.0	2.2	55
30	26	0212	5094.0–5099.5	289.0–294.5	5.5	2.1	38
31	26	0537	5099.5–5108.5	294.5–303.5	9.0	1.8	2
32	26	0930	5108.5–5117.5	303.5–312.5	9.0	3.2	36
33	26	1305	5132.5–5137.5	327.5–332.5	5.0	4.7	94
34	26	1738	5137.5–5144.5	332.5–339.5	7.0	1.7	24
35	26	2119	5144.5–5153.5	339.5–348.5	9.0	2.0	22
Total					306.5	199.4	64.3
Hole 524A							
1	27	0135	4832.5–4842.0	28.5–38.0	9.5	7.5	79
2	27	0340	4842.0–4851.5	38.0–47.5	9.5	2.4	25
Total					19.0	9.9	
Hole 524B							
1	27	0915	4804.5–4807.5	0–3.0	3.0	3.0	100
2		1051	4807.5–4812.0	3.0–7.5	4.5	4.0	89
3	27	1218	4812.0–4816.5	7.5–12.0	4.5	4.4	98
4	27	1345	4816.5–4820.5	12.0–16.0	4.0	0.5	13
5	27	1530	4820.5–4825.0	16.0–20.5	4.5	4.5	100
6	27	1630	4825.0–4929.5	20.5–25.0	4.5	tr	0
7	27	1831	4829.5–4933.8	25.0–29.3	4.3	4.3	100
Total					29.3	20.7	71

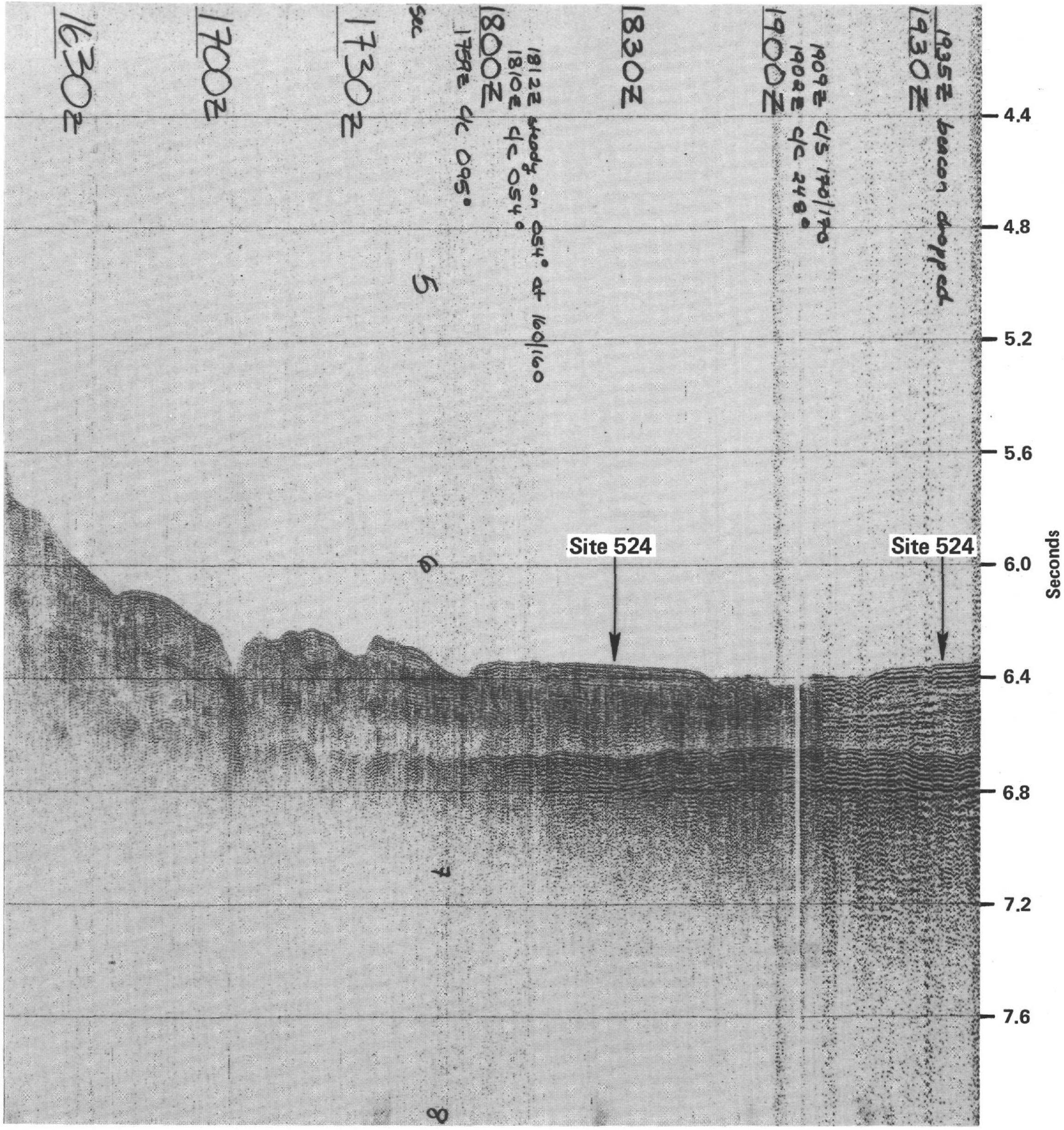

Figure 2. *Glomar Challenger* seismic record over Site 524.

barrel brought up sediments described as "dirty green sands."

Drilling and coring for Hole 524 terminated at 2119Z on 26 May. The drill string was pulled clear of the mudline at 0000Z on 27 May. At 0001Z on 27 May, Hole 524A was spudded in at 4805 m of water depth, with no offset. Two rotary cores were taken to complete the sedimentary section recovered at Site 524. The hole was terminated at 47.5 m sub-bottom after Core 2 came up at 0340Z on 27 May. The drill string cleared the mudline again at 0430 on 27 May, and the vessel was offset 100 ft. to the south to avoid the drilling debris around the opening of Hole 524. Rigging for bit conversion consumed some time, but at 0843Z, Hole 524B was spudded in. Seven hydraulic piston cores were obtained. Hard objects were encountered in Cores 4 and 6, and recovery in those cores was poor, but persistence and a calm mirrorlike sea permitted the full recovery of Core 7, which was brought on deck at sunset. Hole 524B was terminated at 29.3 m sub-bottom. At 1845Z the drill string was pulled clear of the mudline for the third time that day. All the pipes were on deck at 0315Z on 28 May. Rig work, involving the spooling of new sand lines, was carried out. The vessel was under way and homeward bound at 0712Z on 28 May, 3 min. ahead of schedule.

LITHOLOGY

Sediments and Sedimentary Rocks

The sediments and sedimentary rocks recovered from the three holes drilled at Site 524 in the Cape Basin, southeast of the Walvis Ridge, include a sequence of

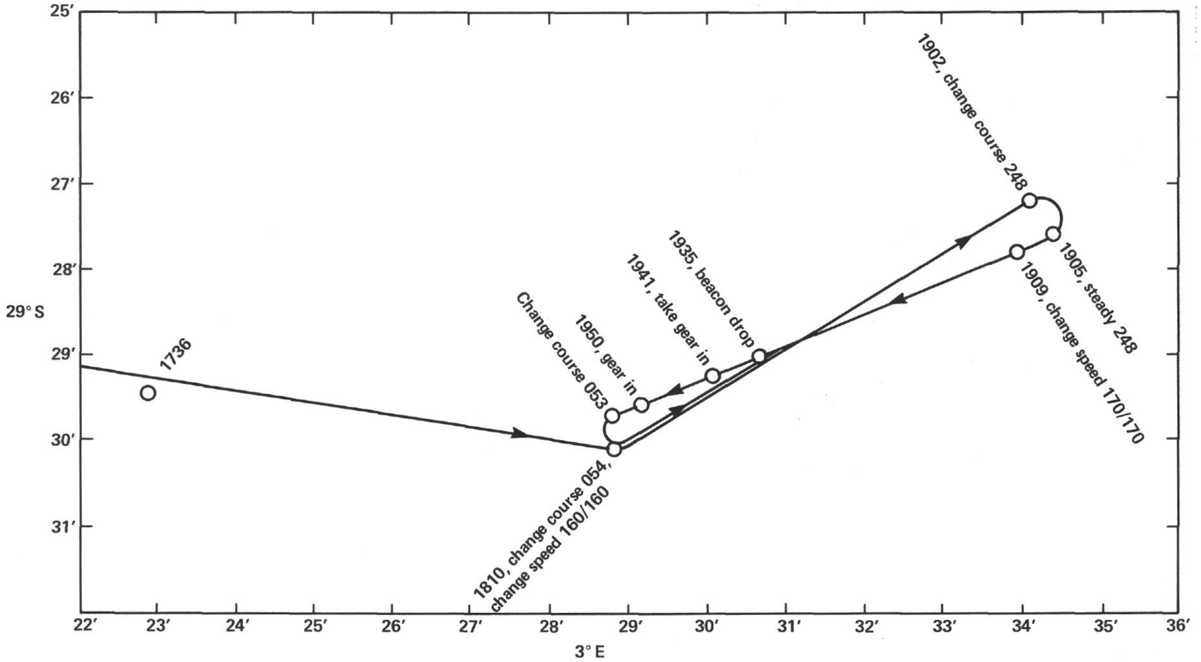

Figure 3. *Glomar Challenger* approach track, Site 524.

lower Eocene through upper Paleocene nannofossil ooze, chalk, and claystone that is underlain by a thick Paleocene through Maestrichtian section of interbedded marl, claystone, and sandstone. Interbedded basalt and sandstone occur at the base of this section. We distinguished four lithologic units on the basis of color, composition, and carbonate content (Fig. 4).

Nannofossil ooze and chalk are the principal sediment types that make up Unit 1 (Hole 524, Cores 1-7, 0-77.5 m sub-bottom; Hole 524A, Cores 1-2; Hole 524B, Cores 1-6). The ooze is generally very pale brown and contains abundant scattered patches of white ooze (burrows), some of which are surrounded by grayish haloes. Several intensely burrowed, yellowish brown marly intervals occur within the ooze. Also present is one layer of foraminifer ooze with sharp top and bottom contacts (Core 5, Hole 524B). A patch of volcaniclastic sand associated with scattered volcanic rock fragments (Core 3, Hole 524B; Core 4, Hole 524) and several fragments and nodules of chert and cherty limestone also occur in this unit (Cores 3-5, Hole 524; Core 2, Hole 524A). The chert is dark brown and burrowed and composed of opal-CT and quartz; diatoms, radiolaria, and sponge spicules occur nearby (Core 4, Hole 524) in the nannofossil ooze. The limestone is light brownish gray, burrowed, and sometimes laminated. Silica occurs as nodules in the sediment and in the matrix of the limestone. Lithification of ooze to pinkish white chalk begins at about 48 m sub-bottom. Thin layers of dark grayish brown volcanic ash and glauconitic-foraminifer sand and scattered chert fragments and nodules occur in the chalk.

Volcaniclastic carbonate sandstone, nannofossil marl, and claystone characterize Unit 2 (Hole 524, Cores 7-16, 76-171 m sub-bottom). The shallowest sandstone layer and a dramatic decrease in bulk carbonate content (Fig. 4) mark the top of this unit. Moderately well sorted sandstones occur as thin layers with sharp basal contacts. These sandstone layers fine upward to a dark, intensely burrowed claystone, then to an overlying lighter, homogeneous claystone. The frequency of the sandstone layers increases slightly from two to three per meter to four to five per meter with increasing depth. Many sandstones have parallel laminations and are graded or fine upward; load casts, scours, reverse grading, and cross laminations are less common. Clay-filled burrows from the overlying claystone penetrate the tops of many sandstone layers; burrows reach the bases of some layers. Sand-filled burrows often occur at the contact between the claystone or marl and the overlying layer of sandstone. The principal components of these sandstones are rounded grains of bioclastic carbonate and bryozoan fragments, foraminifers, volcanic rock fragments, and glauconite. The fine fraction is composed of clay and carbonate. Total carbonate content varies between 45 and 78%. Most sandstones are greenish gray, although some have yellowish alteration zones.

Nannofossil claystone and marls in Unit 2 are light gray to greenish gray, changing deeper in the sequence to brown and dark grayish brown. Carbonate content is extremely variable (28-82%), but in general, the darker burrowed claystones immediately overlying the sandstones have lower carbonate contents than the lighter claystones above them.

Unit 3 (Hole 524, Core 17-Core 28, Section 3, 171-279 m sub-bottom) consists of interbedded nannofossil and calcareous claystone and volcaniclastic sandstone. A sharp decrease in carbonate content of both claystones and sandstones and a distinct change in color of the claystones (from greenish gray and grayish brown to reddish brown) at about 171 m sub-bottom marks the top of this unit. The thickness, frequency, color, and

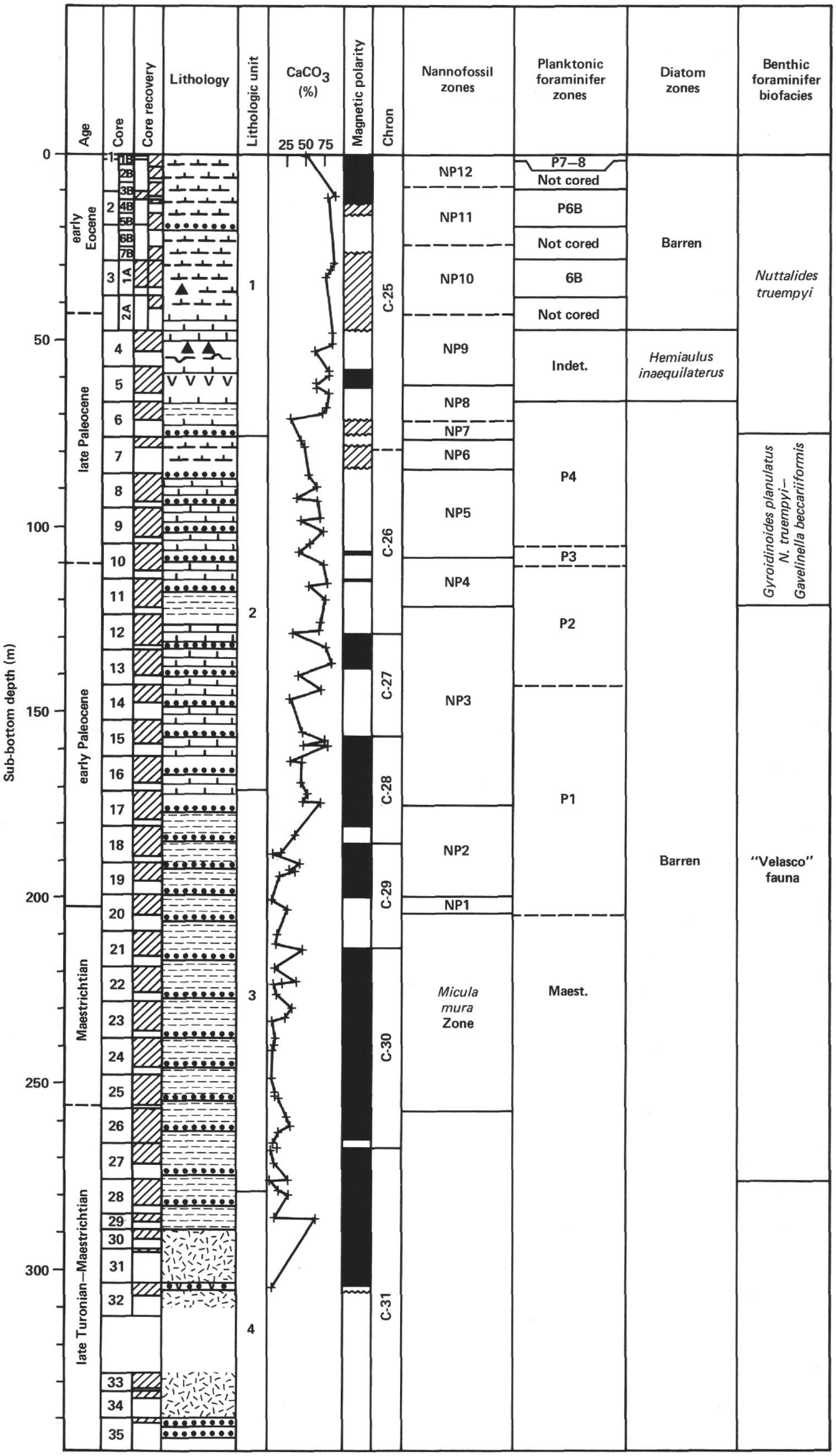

Figure 4. Stratigraphic summary, Site 524. Cores labeled A and B are from Holes 524A and 524B, respectively; cores carrying neither designation are from Hole 524. Lithology and magnetic chronology are defined in Hsü, LaBrecque, et al. (this vol.). Solid blocks denote intervals of normal magnetization; cross-hatched blocks, intervals of unknown polarity.

sedimentary structures of the sandstone and claystone layers are similar to those in the basal part of Unit 2. Although bioclastic carbonate is still a common component of the sandstones, altered, volcanic lithic fragments predominate. The claystones overlying each sandstone layer vary upward from gray, richer in carbonate, and burrowed to reddish brown and poor in carbonate. The reddish brown claystones change gradually to gray and dark gray near the base of the unit. Total carbonate variation in the claystone is 1 to 45%; it is less for the interbedded sandstones (6–30%). This unit also contains scattered thin (1–3 cm) layers of grayish blue and pale blue green claystone. Fragments of this lithology also occur as discrete grains in some of the sandstones.

Interbedded calcareous claystone, volcaniclastic sandstone, volcanic breccia, and basalt comprise Unit 4 (Hole 524, Core 28, Section 3–Core 35, 279–348.5 m sub-bottom). The shallowest occurrence of basalt in Core 28 marks the top of this unit. The claystone is olive gray to dark grayish brown and commonly burrowed throughout. Carbonate content ranges from 5 to 61%. Greenish gray to greenish black sandstone interbeds in this unit are sedimentologically similar to although less common than those in the overlying units (i.e., graded/fining upward sequences, parallel and cross laminations, scours). Many layers fine upward to burrowed claystone. The sandstone in Core 35 is very poorly sorted and contains some large (pebble-sized) fragments of angular basalt in a green clayey zeolithic matrix. A volcanic breccia in Core 32 contains angular basalt and pumice fragments.

The dark gray basalt interbedded with the sediments of Unit 4 is aphyric and contains many calcite- and smectite-filled fractures; some pyrite mineralization is also present (see Igneous Rocks section for complete description). Sediment/basalt contacts are sharp (mostly drilling artifacts). The claystone above and below the thin basalt layer in Core 28 differs little from claystone in the rest of the unit. In Core 29, a fragment of brown calcareous claystone is separated from the underlying basalt by a thin (5 cm), baked, light gray limestone.

The sedimentary sequence at Site 524 provides clues to the evolution of the Walvis Ridge and to past oceanographic variations in the northern Cape Basin. The Maestrichtian sequence of interbedded basalt, volcanic breccia, and volcaniclastic sandstone and claystone records a period of volcanism that probably extended from the Walvis Ridge (ridge-derived sandstones and breccias) to the northern Cape Basin (interbedded basalts). A seismic survey conducted after the drilling suggests that this complex of interbedded basalt and sediment may continue below Unit 4 for as much as another kilometer. Volcanic activity in the late Maestrichtian and early Paleocene appears to have been confined to the Walvis Ridge, because Unit 3 contains only volcaniclastic sandstones and claystones (no basalt). The sandstones are ridge-derived turbidites. Many layers display complete (Ta–e) or partial (Ta, b, e, or Tb, e) Bouma sequences and include abundant volcanic rock fragments with only minor bioclastic carbonate. The claystones of Unit 3 are poor in carbonate and become more reddish brown (iron-rich?) near the top of the unit; they reflect an oxidizing depositional environment below the CCD.

Both the turbiditic sandstones and interbedded calcareous claystones of Unit 2 contain more carbonate than those of Unit 3. Bioclastic fragments and foraminifers in three volcaniclastic sandstones indicate neritic conditions on parts of the Walvis Ridge during the early to late Paleocene. Nannofossils become common in the claystone, suggesting a CCD drop in the northern Cape Basin.

The late Paleocene to early Eocene history of the northern Cape Basin includes the cessation of bioclastic and volcaniclastic turbidites from the Walvis Ridge and the onset of sustained calcareous pelagic sedimentation above the CCD. There was a brief period of siliceous plankton activity in the late Paleocene and early Eocene, which accounts for the presence of chert and cherty limestone in these sediments. Post-lower Eocene sediments are absent at Site 524, indicating nondeposition, erosion, and/or pronounced dissolution.

Igneous Rocks

Summary

Basaltic rock, which was interlayered with sedimentary rock at Site 524, was encountered in three different intervals. The first interval, or unit, occurred in Core 28, was 50 to 60 cm thick, and contained three cooling units that were interpreted as pillow-basalt flows (Fig. 5). In chemistry the rocks were alkaline basalts (Dietrich et al., this vol.). The second unit (Cores 29–32) was 16+ m thick; 5.1 m of the unit were recovered. The third unit (Cores 32–34) was 9 m thick; 6.5 m of this unit were recovered. In chemistry the second and third units were alkaline and tholeiitic basalts, respectively (Dietrich et al., this vol.); both units were tentatively interpreted as sills.

Chemically, the pillow unit and upper sill are typical alkaline olivine basalts, with 14 to 24% normative olivine; high TiO_2, Na_2O, K_2O, P_2O_5, incompatible trace element, and LREE contents; and low Cr and Ni contents. The pillows appear to be more fractionated than the sill; they have lower Mg-numbers (0.33–0.39, vs. 0.45–0.46) and higher TiO_2 and trace elements (such as Ba and Sr). The overall trace element contents of the pillows and upper sill are quite different from those of the lower sill (Dietrich et al., this vol.) and suggest that the sources for the alkalic and tholeiitic rocks are altogether different.

The chemistry of the lower sill is distinctly tholeiitic, with a maximum of 11% olivine in the norm and Mg numbers of 0.53 to 0.57. The basalts appear to be more evolved than in Holes 519A and 522B; the basalts in Hole 524 also have higher TiO_2, Zr, Sr, and Ba contents and lower Cr and Ni contents. The overall composition suggests that the Hole 524 rocks crystallized from an olivine tholeiitic magma source.

Mineralogically the alkalic and tholeiitic units differ in that the alkalic rocks are rich in ilmenite, with subordinate magnetite; further, both alkalic units have a notable (1–3%) content of apatite, which is not found in

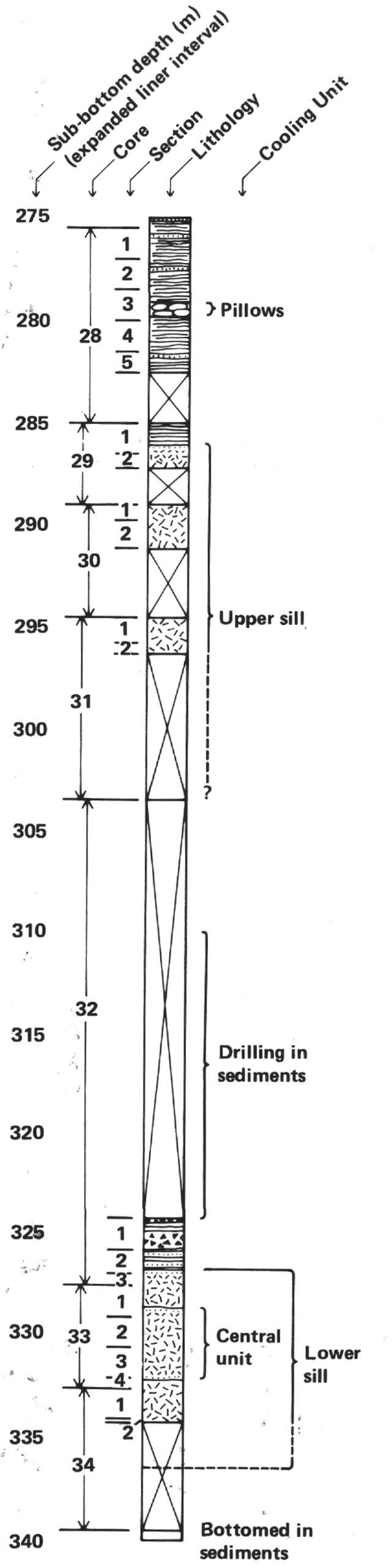

Figure 5. Summary of igneous rocks, Site 524.

the tholeiitic (lower) rocks. The plagioclase in the pillows is more sodic than in the tholeiites, and the upper sill has quite sodic and strongly zoned plagioclase, with mantles of alkali feldspar; the lower sill, on the other hand, has the more calcic plagioclase typical of tholeiitic basalt.

The thin uppermost sequence is considered a series of pillows chiefly because of the lack of contact heating effects in the adjoining sediments and the glassy and other quench textures found in all samples of the units. Each of the three cooling units in the 60-cm interval containing basalt is about 20 cm thick, and each has strongly quenched upper and lower margins.

The second unit is considered a sill because of the baking effects in the sediments at the upper contact, the absence of a glassy rind, and the very coarse-grained texture throughout all except the outermost few centimeters of rock. The baking effects appear in Core 29, where calcareous clay and clayey limestone sediments rest on the basalt. The sediments in a zone about 10 cm thick have been bleached white; the calcareous clay immediately above is the reddish brown color typical of this type of sediment. The lower 5 cm of the bleached zone has lithified into solid rock, whereas the material above can be cut rather easily with a knife.

In Core 32 the top of the lower sill is in contact with claystone, most of which is a soft greenish gray. At the contact with basalt, about 3 cm of the claystone is reddish brown and well indurated. This zone is also interpreted as having been baked, and it is in solid contact with finely phyric basalt. Most of the phenocrysts in the basalt are flow aligned parallel to the contact, and in the upper 2 to 3 cm they are set in a finely spherulitic and dendritic groundmass. Within the next 4 cm the flow alignment disappears and the texture grades into fine to medium seriate intergranular; within the next few centimeters, the texture grades into massive coarse- to very coarse-grained basalt (diabase). This basalt continues through Cores 33 and 34. In chemistry all the samples in Cores 32 to 34 are similar to each other and different from samples higher in Hole 524. The samples also differ from those of the other holes drilled on Leg 73 (Dietrich et al., this vol.).

Drilling records show "drilling in sediments" for about 14 m, in addition to the normal interval of 9 m, between the bottom of Core 31 and the top of Core 33. This interval constituted Core 32, of which 3.2 m were recovered.

Because the rock had the characteristics described above, and because the rock in contact with the claystone in Core 32 is like the rock in Cores 33 and 34, all of the rock rocovered in Core 32 is shown at the bottom of the core in Figure 5, instead of at the top (in accordance with standard, although arbitrary, DSDP practice). The thickness of the upper sill is at least 10 m and could be considerably more if it occupies a significant part of the unrecovered portion of Core 32.

The most impressive evidence of intrusion of a lower sill is found in Core 33, where a central unit is chilled upward and downward against very coarse-grained contacts (Pl. 1, Figs. 1 and 2). These bounding rocks retain a very coarse grain right up to the contacts. Thin sections show the bounding rocks to be identical to each other and distinguishable from the central intrusion petrographically on the basis of texture but not on the basis of composition. The conclusion is that this is a multiple sill, formed by successive injections of the same magma, a conclusion confirmed by rock chemistry (Dietrich et al., this vol.).

The outer 1 to 4 cm of the alkaline pillows and upper sill have sets of horizontal discontinuous contraction fractures (Pl. 1, Figs. 3 and 4). These fractures are narrower (≈0.5 mm) nearest the margin and increase in width away from the contact. Some are filled with feldspar and zeolite(?), many are filled with calcite, and a few contain chlorite and green smectite. The interior of the upper sill has sparse horizontal veinlets 1 to 2 mm wide that are composed primarily of feldspar (Pl. 1, Fig. 5). Some of these veinlets contain smectite-filled vugs into which euhedral feldspars project (Pl. 1, Fig. 6). Such veinlets and filled fractures are common in shallow alkaline mafic intrusive sheets and were formed in the late stages of crystallization. The total lack of such features in the tholeiitic lower sill and the tholeiitic lavas of the other Leg 73 sites suggests that the physical nature of alkaline magma near final crystallization is distinctly different from that of tholeiitic magma, the alkaline magma behaving in a somewhat brittle fashion in response to the tensional stress of cooling contraction. Both sills have crude sets of conjugate (30–45° to core axis), horizontal, vertical, and irregular fractures that are coated with green smectite, sooty manganese oxide, and pyrite (usually in that order). The conjugate sets are generally located near the central part of the unit. The sills are finely and only slightly vesicular, with a suggestion of a small concentration of vesicles in the upper 20 to 30 cm of the lower unit.

Petrography

Pillow Unit

As indicated earlier, the uppermost unit is typified by glassy to very fine-grained margins and quench textures throughout.

The outermost rims of the pillows are analogous to Zones 2 and 3 described for the glassy borders in previous holes. Zone 2 consists of pale brown to pinkish brown glass that is set with tiny (0.01 mm and less) quench plagioclase microlites with typical hollow skeletal and swallowtail forms. The microlites are rimmed by spherulitic mantles and interspersed with spherulites that have no visible plagioclase core. This zone grades into Zone 3 (solid spherulites). The dominant feature in these zones is the presence of ultrafine fibrous ilmenite dendrites, which cause the spherulites to form a dense reticulate pattern (Pl. 2, Fig. 1). Interstitial to the spherulites is a brown mesostasis that is largely cryptocrystalline devitrified glass.

The pillow interiors are very sparsely phyric, with relatively large (0.7–1.6 mm) plagioclase phenocrysts set in a hyalopilitic quench matrix. The phenocrysts are more calcic than about An_{45} (refractive index, R.I., > 1.55), but they are about 50% replaced by inclusion-filled sodic plagioclase (R.I.: 1.55) and slightly replaced by smectite or chlorite (Pl. 2, Fig. 2). The matrix of the rock (Pl. 2, Figs. 3 and 4) has the following components: Na-rich (R.I.: 1.55), elongate (0.04–0.5 mm, length-to-width ratio: 1:3–1:35), quench-skeletal plagioclase microlites; abundant ilmenite dendrite needles (0.001–0.004 mm thick and 0.04–0.2 mm long) in a pervasive rectangular network pattern; sparser magnetite cubes and octahedra in two generations (first: 0.02–0.25 mm; second: 0.004–0.01 mm); dendritic, skeletal, and subophitic to faintly prismatic clinopyroxene anhedra (0.001–0.04 mm); hollow skeletal apatite prisms (0.004–0.008 mm); and pleochroic brown (0.002–0.004 mm) biotite flakes. All these are set in a mesostasis of pale green to brown and pinkish brown, platy or fibrous to cryptocrystalline smectite or chlorite. There are local clear pink or green isotropic patches that appear to be remnants of glass. The approximate mode is as follows: plagioclase phenocrysts 1%, plagioclase microlites 30 to 40%, ilmenite 10 to 15%, magnetite 3 to 5%, clinopyroxene 10 to 15%, apatite 1 to 3%, devitrified glass 30 to 35%.

Upper Sill

The outer few centimeters of the upper sill are very similar in texture to the pillows above the sill, with abundant ilmenite dendrite needles in the distinctive rectangular network pattern (compare Pl. 2, Figs. 4 and 5). Thin sections taken across the interior of the sill are quite similar in texture and mineralogy. They reveal an essentially aphyric rock ranging from fine grained within a few centimeters of the contacts to very coarse grained throughout most of the extent. The rocks have seriate intergranular intersertal texture and are composed of essential dominant tabular, compositionally zoned plagioclase euhedra (0.05–3 mm, An_{45-17}) with epitaxial alkali feldspar or oligoclase mantles (Pl. 2, Fig. 6). The rocks also have the following components: subordinate intergranular, mostly subhedral grains of clinopyroxene (0.01–0.15 mm, $2V_Z = 60°$, colorless in thin section); ilmenite-magnetite opaque minerals (0.005–0.35 mm); and accessory apatite needles and prisms (0.01–0.35 mm, length-to-width ratio: 1:12), many of which have hollow cores. In addition, there are small subhedral to euhedral plates (0.02–0.2 mm) of reddish brown pleochroic biotite, plus probable olivine now pseudomorphed by greenish brown smectite. Interstitial to all these is a smectite mesostasis believed to be devitrified glass. There are rare (< 1%) clinopyroxene microphenocrysts (0.15–0.25 mm). An approximate mode is as follows: plagioclase 35 to 40%, clinopyroxene 15 to 20%, opaque minerals 15 to 20%, devitrified glass (smectite) 15 to 20%, apatite 2 to 3%, olivine(?) 2 to 3%, biotite < 1%.

In addition to being slightly more coarse grained, a sample from the lower part of the sill (Core 31) shows two significant differences. First, the epitaxial mantles on euhedral plagioclase are thick, more fully developed, and more sharply defined than in the higher rocks. The optics of the mantles (axial plane ⊥ (010), $2V_X < 60°$)

indicate the mantles to have one of three possible compositions: in order of likelihood, (1) anorthoclase or Na-sanidine, (2) oligoclase, or (3) K-rich sanidine. The first choice is considered most likely because the boundary between the mantle and the core plagioclase is sharply defined (oligoclase should give a more gradational transition) and because the refractive index difference between the mantle and core is less than would be expected with K-rich sanidine.

The second difference between the Core 31 and higher rocks is that the ilmenite plates are much more sparse and less well developed than in rocks from Core 29. These differences, in combination with the paleomagnetic records (see section on basalt paleomagnetism), which show the rocks from Core 31 to have lower stable inclinations (average: −60°?) than those of Cores 29 and 30 (average: −75°), suggest that the upper sill may be a multiple sill, like the lower sill.

Lower Sill

The lower sill, although multiple, contains essentially one rock type—a coarse- to very coarse-grained phyric olivine diabase with a seriate intergranular and subophitic texture. The rock has very coarse (0.5-3.8 mm) plagioclase phenocrysts (An_{65-30}), most of which are complexly twinned and have a slightly zoned core, an altered (smectite) border, and an outer clear, strongly zoned rim. These phenocrysts, together with zoned euhedral to subophitic clinopyroxene microphenocrysts (0.75 mm), grade into a groundmass of zoned plagioclase (0.01-0.5 mm, $An_{62-47 \text{ and less}}$), very fine intergranular clinopyroxene (0.005-0.01 mm), and magnetite-ilmenite opaque minerals (0.004-0.12 mm). All the clinopyroxene appears to be normal augite (colorless in thin section, $2V_Z \sim 60°$), although the finer pyroxene should be checked more thoroughly for the presence of pigeonite. These smaller clinopyroxene grains dominate the pyroxene total and occur in peculiar aggregated clusters reminiscent of metamorphic textures. There are sparse smectite pseudomorphs of euhedral olivine (0.09-0.3 mm). Greenish brown smectite is interstitial and replaces some plagioclase. An approximate mode is as follows: plagioclase 30 to 40%, clinopyroxene 30 to 40%, opaque minerals 15 to 20%, smectite 5 to 10%, and olivine 1 to 3%.

The central intrusion of this multiple sill has the same mineralogy as and a texture very similar to the bounding rocks. However, the plagioclase is considerably altered to smectite (15-25%) in the cores of the grains. Minor textural differences also make the rock distinctive. The opaque minerals tend to be aggregated into clots and very elongate stringers, and small (0.01-0.04 mm) clinopyroxene granules occur in tight clusters. The ranges of grain size are also different. They are as follows (in mm):

Textural component	Central intrusion	Bounding rock
Plagioclase phenocrysts	0.5-1.1	0.5-3.8
Clinopyroxene phenocrysts	0.5-1.1	0.5-0.75
Opaque minerals	0.02-0.3	0.004-0.12

Conclusions

Although basaltic basement was not reached in Hole 524, the chemistry of the lower multiple sill shows it to be of typical oceanic olivine tholeiite and very likely to be representative of the ocean floor in this region. The upper two basaltic units are sure to be associated with the Walvis Ridge because of their distinctly different and alkaline chemistry and their intercalation with volcaniclastic sediments clearly derived from the Walvis Ridge.

BIOSTRATIGRAPHY

Summary

The uppermost sediments in Hole 524 belong to the lower Eocene, and the lowermost belong to the Upper Cretaceous (Figs. 4 and 6). The planktonic foraminifers and nannoplankton show the boundary between the late Paleocene and early Eocene to lie between Cores 3 and 4. Diatoms in Cores 4 and 5 confirm the late Paleocene age of this part of the hole. The benthic foraminifers show no change across the boundary.

Throughout the Paleocene, which appears to be complete, the correlation of the planktonic foraminifer and nannoplankton zonations is good. The late/early Paleocene boundary appears to lie in the lower part of Core 12, in the upper part of Zone NP3 and at the base of the *Globorotalia angulata* Zone, the position of which is estimated to lie in an unsampled interval between Samples 524-11,CC and 524-12,CC.

The Cretaceous/Tertiary boundary is indicated by calcareous nannoplankton to occur at Sample 524-20-3, 106 cm. The precise location of the boundary is not as clear in the planktonic foraminifer record. There are some calcareous nannoplankton belonging to the Maestrichtian assemblage (*Micula mura* Zone) in the Danian NP1 Zone. The benthic foraminifers show no change across the boundary. Some slumping or reworking is present at the base of Core 19 (above the boundary). The nannoplankton are late Maestrichtian (*M. mura* Zone); the planktonic foraminifers are a mixture of early Paleocene and late Maestrichtian.

The Cretaceous nannoplankton encountered below the boundary belong to the late Maestrichtian (*M. mura* Zone) from Cores 20 to 26. The planktonic foraminifers and calcareous nannofossils are late Maestrichtian from Cores 20 to 28. The nannoplankton from Cores 29 through 35 can only be dated as late Turonian to Maestrichtian.

Calcareous Nannoplankton

Hole 524

Sample 524-1,CC is early Eocene NP12 in age according to the occurrence of *Tribrachiatus orthostylus* Shamrai and *Discoaster lodoensis* Bramlette and Riedel. In the interval from Sample 524-2-1, 89-90 cm to 524-2,CC, early Eocene NP11 is recognized on the basis of the presence of *T. orthostylus* Shamrai and the absence of *D. lodoensis* Bramlette and Riedel. Samples 524-3-1,

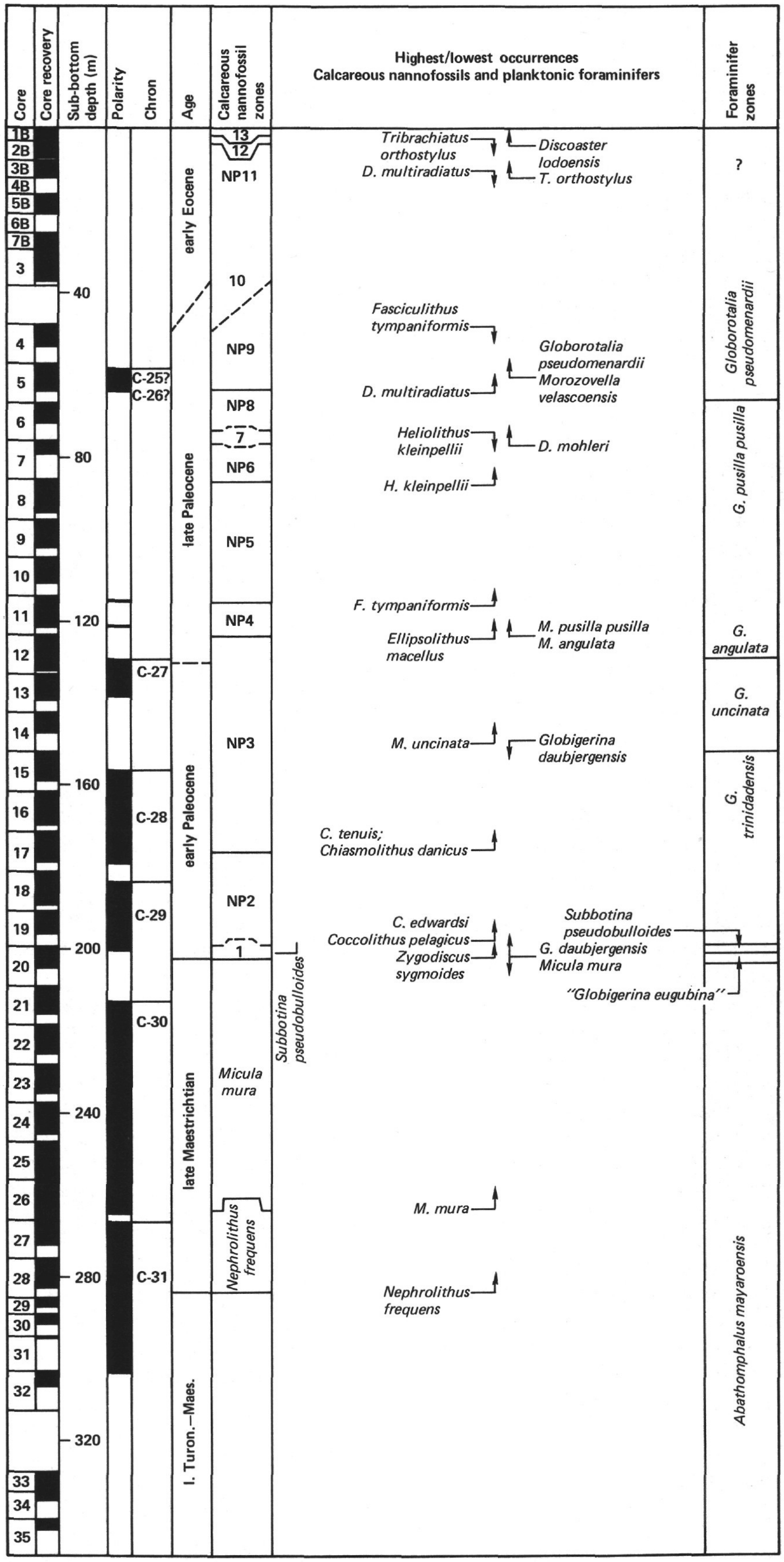

Figure 6. Biostratigraphic summary of significant calcareous planktonic microfossils, Holes 524 and 524B. Core designations, polarity, and magnetic chronology as in Fig. 4.

139–140 cm to 524-3,CC are early Eocene NP10 because of the occurrence of *D. multiradiatus* Bramlette and Riedel without Paleocene marker species.

Late Paleocene NP9 is present from Sample 524-4-1, 100–101 cm to 524-5-4, 65–66 cm because of the occurrence of *D. multiradiatus* Bramlette and Riedel and *Fasciculithus tympaniformis* Hay and Mohler. The interval from Sample 524-5-5, 65–66 cm to 524-6-3, 94–95 cm is late Paleocene NP8 because of the absence of *D. multiradiatus* Bramlette and Riedel and the absence of *Heliolithus kleinpellii* Sullivan. Sample 524-6,CC is assigned to NP7 because of the occurrence of *H. kleinpellii* Sullivan with *D. mohleri* Bukry and Percival. Samples 524-7-1, 79–80 cm to 524-7,CC belong to NP6 according to the presence of *H. kleinpellii* Sullivan without *Discoaster* spp. From Sample 524-8-1, 64–65 cm to 524-10-4, 83–84 cm NP5 is assigned because of the occurrence of *F. tympaniformis* Hay and Mohler without *H. kleinpellii* Sullivan. A late Maestrichtrian flora with NP2 was found in Samples 524-9-4, 81–82 cm and 524-9-4, 84–85 cm. From Sample 524-10-5, 94–95 cm to 524-11-6, 19–20 cm NP4 occurs, according to the presence of *Ellipsolithus macellus* (Bramlette and Sullivan) and the absence of *F. tympaniformis* Hay and Mohler. Samples 524-11,CC to 524-17-4, 22–24 cm are NP3 according to the presence of *Chiasmolithus danicus* (Bramlette) without *E. macellus* (Bramlette and Sullivan). The interval from Sample 524-17-5, 33–35 cm to 524-19,CC is assigned to NP2 because of the occurrence of *Cruciplacolithus tenuis* (Stradner) without *Chiasmolithus danicus* (Bramlette). A late Maestrichtian flora was found in Sample 524-19,CC mixed with NP2 flora. The interval from Sample 524-20-1, 9–10 cm to 524-20-3, 106 cm represents NP1 because of the absence of *Cruciplacolithus tenuis* (Stradner). The location of the Cretaceous/Tertiary boundary is not clear because of the occurrence of Maestrichtian nannoplankton in the Danian assemblage. However, the late Maestrichtian nannoplankton are from the *Micula mura* Zone, and the Danian nannoplankton represent the NP1 *Markalius astroporus* Zone.

The interval from Sample 524-20-3, 106 cm to 524-26-5, 39–40 cm belongs to the late Maestrichtian *Micula mura* Zone. Sample 524-26-6, 83–84 cm to 524-35,CC is late Turonian to Maestrichtian in age because of the presence of *M. decussata* Vekshina.

Hole 524A

Early Eocene NP10 nannoplankton occur from Sample 524A-1-1, 76–77 cm to 524A-2-2, 96–97 cm according to the occurrence of *Discoaster multiradiatus* Bramlette and Riedel without Paleocene markers. The interval from Sample 524A-2,CC to 524A-3,CC is late Paleocene NP9 according to the presence of *D. multiradiatus* Bramlette and Riedel with *Fasciculithus tympaniformis* Hay and Mohler. Sample 524A-3,CC has Quaternary NN19 nannoplankton mixed in it.

Hole 524B

An early Eocene NP13 assemblage is found in Sample 524B-1-1, 101–102 cm according to the presence of *Discoaster lodoensis* Bramlette and Riedel and the absence of *Tribrachiatus orthostylus* Shamrai. Sample 524B-1-2, 101–102 cm to Sample 524B-3-2, 107–108 cm is early Eocene NP12 according to the occurrence of *D. lodoensis* Bramlette and Riedel and *T. orthostylus* Shamrai. Sample 524B-3-3, 107–108 cm to 524B-7,CC is early Eocene NP10 according to the occurrence of *D. multiradiatus* Bramlette and Riedel without Paleocene marker species.

Planktonic Foraminifers

Early Eocene to Maestrichtian planktonic foraminifers were recovered from Hole 524.

Diverse, moderately well preserved, early Eocene faunas occur in Samples 524-1,CC through 524-3,CC. *Morozovella subbotinae, M. marginodentata, Morozovella* spp., and *Acarinina soldadoensis* are common components of these assemblages. The assemblages in Samples 524-4,CC through 524-8,CC are highly dissolved and lack stratigraphically diagnostic species. Calcareous nannofossils indicate the Paleocene/Eocene boundary to lie between Samples 524-4,CC and 524-3,CC.

The planktonic foraminifers are common and better preserved in Samples 524-9,CC through 524-18,CC. Reworking is evident in many samples, however.

Unequivocal Paleocene faunas continue down through Core 19. Sample 524-19,CC contains such early Paleocene taxa as *Globoconusa daubjergensis* and *Subbotina pseudobulloides*, as well as Cretaceous taxa, such as *Globotruncana* spp. and *Rugoglobigerina rotundata*. Samples 524-20,CC and 524-21,CC are essentially barren of planktonic foraminifers, whereas Samples 524-22,CC through 524-27,CC yield good Maestrichtian faunas. The examination of several samples within Core 20 suggest that the Cretaceous/Tertiary boundary is within Core 20. Assemblages from the lower part of Core 20 contain Cretaceous taxa, minute globigerinids and forms similar to *Globoconusa daubjergensis*. Assemblages from Section 1 of Core 20 contain typical *Globoconusa daubjergensis*, forms similar to *Subbotina pseudobulloides*, and various *Subbotina* spp. Thus, the lower part of Core 20 is assigned to the "*Globigerina eugubina*" Zone, and the upper part is assigned to the *Subbotina pseudobulloides* Zone.

Samples from Holes 524A and 524B were not examined for foraminifers.

Diatoms

Cores 1 through 3 in Hole 524 are barren of diatoms. Samples 524-4-3 87–89 cm through 524-5-2, 60–62 cm contain late Paleocene diatoms and radiolarians. Diatoms are common and moderately well preserved in Samples 524-4-3, 87–89 cm through 524-5-1, 70–72 cm; radiolarians only occur in Sample 524-5-2, 60–62 cm. Typical late Paleocene diatoms observed in Hole 524 include *Hemiaulus incurvus, H. inaequilaterus, Trinacria exsculpta, Triceratium crenulatum*, and *Fenestrella barbadensis*. A more detailed treatment of the Paleocene diatoms from Site 524 is found in Gombos (this vol.).

Benthic Foraminifers

The Late Cretaceous to early Eocene sediments in Hole 524 contain moderately diverse benthic foraminiferal assemblages that exhibit fair preservation. From the top of the section (lower Eocene) down through Core 7 in the middle part of the upper Paleocene, the benthic fauna is dominated by *Nuttalides truempyi*, with subordinate amounts of *Abyssamina quadrata, Gavelinella beccariiformis, Oridorsalis umbonatus*, and various anomalinids. The fauna in the lower part of the upper Paleocene (Cores 8 to 11) is dominated by a mixture of species, including *Hanzawaia simplex, G. beccariiformis, N. truempyi*, and *Spiroplectammina spectabilis*. A faunal change occurs across the upper Paleocene to lower Paleocene boundary. *H. simplex* becomes the dominant faunal element (comprising 20 to 30% of the assemblage). Subordinate amounts of *Anomalina* spp. and *G. beccariiformis* are present. The fauna has a distinct "Velasco" aspect (see Berggren and Aubert, 1975).

The Upper Cretaceous (Maestrichtian) fauna is more diverse than that of the lower Paleocene. Nevertheless, the Upper Cretaceous taxa differ only slightly from those in the lower Paleocene. Numerous species cross the Cretaceous/Tertiary boundary with little or no change: *G. beccariiformis, H. simplex, Aragonia ouezzanensis*, and *N. truempyi.*

A sample taken from a turbidite in the Maestrichtian sequence (Sample 524-25-5, 122 cm) contains a mixture of deep-water "Velasco" elements along with abraded specimens with a shallow water "Midway" affinity (e.g., *Cibicides alleni*). The shallow water fauna was probably transported down the flanks of the Walvis Ridge; it suggests the presence of shelf conditions in an upslope direction near Site 524 during the Late Cretaceous.

Dissolution

Dissolution conditions in the lower Tertiary sequence in Hole 524 were determined in a preliminary fashion from planktonic test fragmentation and the ratio of planktonic to benthic foraminifers. Dissolution indices are quite low in the lower Eocene. The upper Paleocene section is characterized by strongly dissolved sediments down to a position near the lower/upper Paleocene boundary (Core 10; interpolated age, 62.7 m.y.), at which point the dissolution indices begin to decline. The sediments at and immediately below the Cretaceous/Tertiary boundary, however, have been subjected to intense dissolution (Hsü, this vol.).

Sedimentation Rates

Reasonably good magnetic data were recovered from all except the upper 60 m of Hole 524, and these magnetic data provided values for the calculation of sedimentation rates for the lower three-fourths of the sequence (Fig. 7). The chronology of the paleomagnetic datums is essentially that of LaBrecque et al. (1977) as modified by Mankinen and Dalrymple (1979) using the new decay and abundance constants recommended by the International Union of Geological Sciences Subcommission on Geochronology. The upper fourth of the hole was calibrated by cross correlating the calcareous nannofossil datums from Holes 524, 524A, and 524B with the magnetic data from Hole 524B.

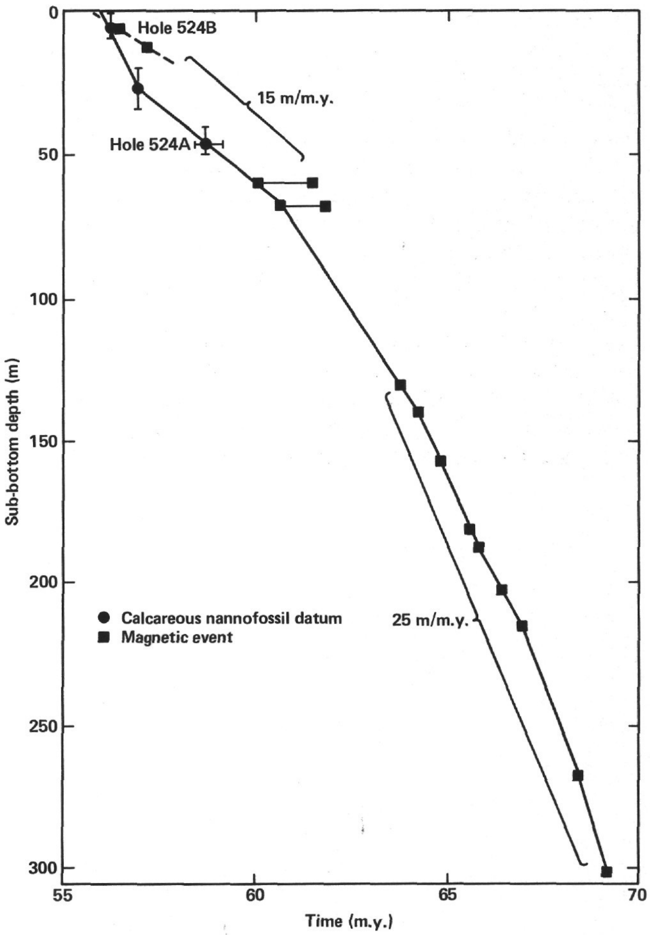

Figure 7. Sedimentation rates, Site 524 (uncorrected for compaction).

A major change in sedimentation rates occurs in Core 7 (77 m sub-bottom; interpolated age, 61.3 m.y.), where a series of volcaniclastic sands makes its first downhole appearance. These sands comprise at least 25% of the cores by Core 11 (114 m sub-bottom). These allochthonous sediments produce a marked increase in the accumulation rate in the lower part of the section.

PALEOMAGNETISM

Sediments and Sedimentary Rocks

The sediments from Site 524 proved ideal for paleomagnetic analysis. There was little, if any, viscous overprinting, and where present it was removed by alternating fields of 50 Oe. The remanent intensities were of order 0.5 to 10 μG for the soft upper sediment in Cores 1 to 7 and generally higher for the more consolidated sediment: 5 to 20 μG in Cores 8 to 15, 10 to 70 μG in Cores 16 to 20, and 50 to 500 μG in Cores 21 to 32. The large fraction of volcanic detritus is responsible for the very high intensities of the lower sections.

A combination of good recovery and high sedimentation rate together with dense sampling (every 20 to 30 cm) enabled us to produce a meaningful high-resolution paleomagnetic record from the rotary-drilled material (Fig. 8). The record extends from the bottom of Anomaly 23 (Hole 524B, Core 1) down to the normally magnetized interval below Anomaly 31 (Hole 524, Cores 32–35). The record is even continuous across the interbedded basalt layers, suggesting that the basalt formed as shallow sills or flows. Interpolation of the sedimentation rate curve enables us to define the position of the missing Anomaly 25 (Chron C-25; see Hsü, LaBrecque, et al., this vol.). It occurs at 40 m sub-bottom, in the uncored interval below the base of Hole 524B and above the usable part of Hole 524. The paleomagnetic record confirms that the Cretaceous/Tertiary boundary is in the reversed interval between Anomalies 29 and 30 (Chrons C-29 and C-30), as observed in the Gubbio section.

A new sampling technique (Fig. 9) was developed to deal with the semiconsolidated sediments of Cores 8 to 25, where conventional sampling (i.e., pushing the sample container directly into the sediment) became impossible. Preliminary tests showed that the new technique may also cause less disturbance than conventional sampling for soft sediments. The very hard samples (Cores 26–28) were cut out by circular saw.

Basalts

Three basalt units (flows or sills) separated by intercalated sediment were encountered at the bottom of Hole 524. The magnetic results obtained from these basalts are displayed in Table 2.

The magnetic inclination of the basalts fits well with the magnetic reversal pattern obtained from the overly-

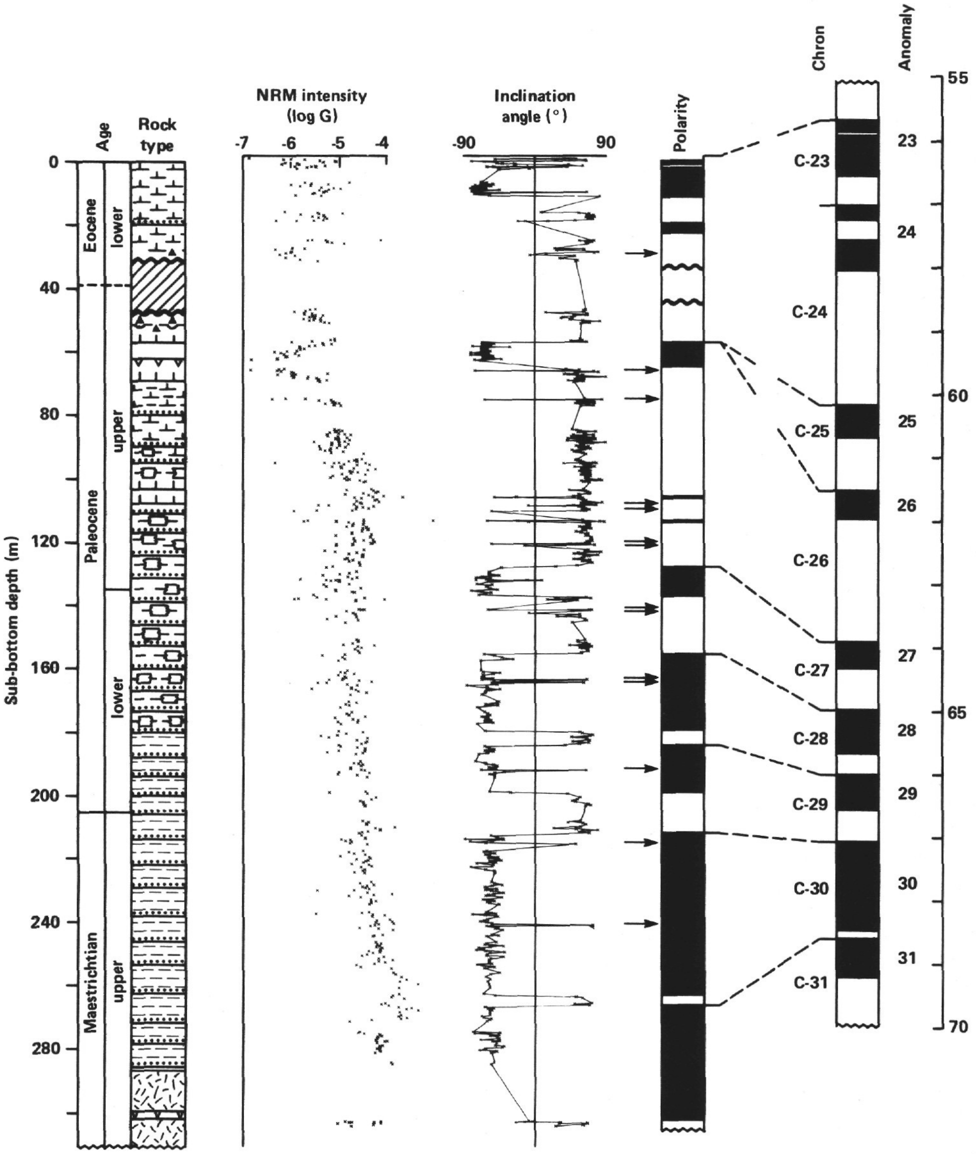

Figure 8. Summary of magnetic polarity stratigraphy at Site 524. Lithology is defined in Hsü, LaBrecque, et al. (this vol.). Solid blocks denote intervals of normal polarity. Arrows identify the positions of polarity units that are defined in single samples and are therefore tentative (see Tauxe et al., this vol.).

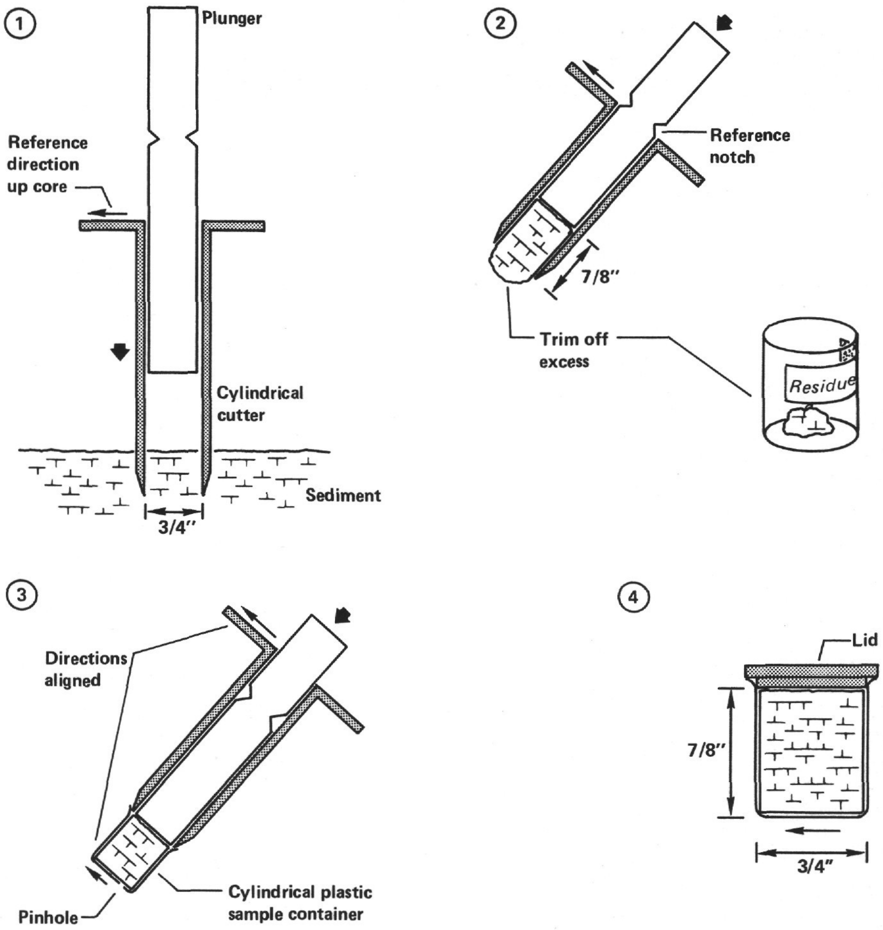

Figure 9. Method for paleomagnetic sampling of semi-consolidated sediments at Site 524.

ing sediments. From this magnetostratigraphy, it is concluded that the upper and middle units (normally magnetized) belong to Marine Magnetic Anomaly 31 (Chron C-31). The lower flow unit is reversely magnetized, as is the underlying greenish sandstone, and it probably belongs to the reversed polarity epoch following Anomaly 31 (Chron C-31).

The magnetic stability of the basalts of this site, as expressed by the median destructive force in Table 2, is considerably less than that of the basalts of the previous sites. This is probably an effect of titanomagnetite grain size. The intensity of magnetization is surprisingly high; the youngest basalts recovered from Hole 519A of this leg (about 9 m.y. old) have a lower average intensity (15.7×10^{-4} G) than the basalts at this site (about 68 m.y. old and 43.6×10^{-4} G).

Magnetic Inclination and Migration of Site 524

The magnetic inclination to be expected at the present latitude of Site 524 (29.5°S) is 48°. It can be seen in Figure 8 that the inclinations actually observed in both the sediments and the basalts are distinctly steeper than this value, namely about 60°. This discrepancy can be explained by a northward movement of the African Plate of about 11° since the Late Cretaceous. However, oceanic basement is often subjected to considerable tilting shortly after the formation of the crust, and the steep inclination values of the basalts can therefore also be explained this way. The situation is different with the sediments; they were probably deposited after any tilting had taken place. It is interesting that the sediments in the upper portion of of Hole 524, beginning with Anomaly 26 (Chron C-26), also have this steep inclination angle of about 60°. This means that little northward movement has taken place between the time of the lowermost detected anomaly in Hole 524 (Anomaly 31 or Chron C-31) and Anomaly 26 (Chron C-26) (i.e., between about 60 and 70 Ma). Most of the northward movement must have taken place after the time of Anomaly 26 (Chron C-26) (i.e., during the last 60 m.y.).

There is an alternative explanation: the steep magnetization inclination may simply record a period of abnormal behavior in the Earth's magnetic field during that period of time.

PHYSICAL PROPERTIES

Figure 10 summarizes the physical property measurements at Site 524. The foraminifer-nannofossil ooze (Cores 3–5) has a higher density than the equivalent lithology at the previous sites but has similar acoustic velocities. Below a depth of about 60 m sub-bottom the sediment is nannofossil marl, chalk, and claystone, and these variations in lithology are reflected in increases in density and acoustic velocity.

Table 2. Basalt paleomagnetism, Hole 524.

Core-Section (interval in cm) Sample	Natural remanent magnetization			Median destructive (Oe)	Susceptibility (10^{-4} G/Oe)	Q-factor
	Intensity (G)	Inclination (°)[a]	Stable inclination (°)[a]			
28-3, 10–12	99.8×10^{-6}	−44.6				
28-3, 52–54	61.0×10^{-6}	−48.5				
28-3, 70–72	32.01×10^{-3}	−38.6	−36	140	28.70	37
28-3, 109–111	24.44×10^{-3}	−49.1	−45	175	26.78	30
28-3, 139–141	79.9×10^{-6}	−50.4				
28-4, 10–12	70.8×10^{-6}	−38.6				
28-4, 52–54	69.4×10^{-6}	−41.2				
28-4, 90–92	60.6×10^{-6}	−62.5				
28-4, 139–141	70.0×10^{-6}	−70.5				
28-5, 22–24	72.8×10^{-6}	−48.2				
28-5, 70–72	56.2×10^{-6}	−55.1				
29-1, 25–27	118.5×10^{-6}	−53.8				
29-1, 71–73	129.0×10^{-6}	−57.7				
29-1, 146–148	53.48×10^{-4}	−44.7	−74	45	46.69	4
29-2, 64–66	52.06×10^{-4}	−43.4	−71	40	39.90	4
30-1, 145–147	55.76×10^{-4}	−57.8	−76	35	39.55	5
30-2, 40–42	32.66×10^{-4}	−64.4	−79	65	42.53	3
30-2, 143–145	43.59×10^{-4}	−49.4	−73	50	45.85	3
31-1, 35–37	28.92×10^{-4}	−56.8	−65	30	48.83	2
31-1, 139–141	26.66×10^{-4}	−41.6		30	45.33	2
31-2, 13–15	29.81×10^{-4}	−65.9	−66(?)	30(?)	46.90	2
31-2, 82–84	30.54×10^{-4}	−38.6	−50	30	51.80	2
32-1, 15–17	18.5×10^{-6}	−23.9				
32-1, 20–22	106.4×10^{-6}	−20.1				
32-1, 36–38	34.4×10^{-6}	−23.8				
32-1, 42–44	32.6×10^{-6}	−38.4				
32-1, 43–45	142.1×10^{-6}	36.7				
32-1, 69–71	123.5×10^{-6}	34.8				
32-1, 77–79	20.8×10^{-6}	8.4				
32-1, 120–122	79.3×10^{-6}	44.7				
32-2, 8–10	30.0×10^{-6}	0.6	25.7			
32-2, 50–52	48.8×10^{-6}	55.5	61.5			
32-2, 102–104	130.8×10^{-6}	56.6	56.7			
32-3, 9–11	105.38×10^{-4}	45.2	47	90	25.38	14
33-1, 9–11	36.36×10^{-4}	39.0	50	75	28.35	4
33-2, 5–7	33.71×10^{-4}	19.0	64	45	27.86	4
33-3, 87–89	9.44×10^{-4}	−32.3	58	125	35.35	1
33-4, 29–31	70.87×10^{-4}	24.6	49	60	37.28	6
34-1, 36–38	30.62×10^{-4}	34.4	55	85	32.55	3
34-1, 144–146	71.29×10^{-4}	15.6	58	50	30.80	8
35-1, 65–67	5.77×10^{-5}	41.2	53		2.35	0.8
35-1, 115–117	3.28×10^{-5}	62.7	60		1.86	0.6
35-1, 132–134	4.51×10^{-5}	41.0	70		1.82	0.8

[a] Positive inclination means reversed polarity on the Southern Hemisphere.

Acoustic velocity and density/water content were measured on the coarse and fine fractions of the graded beds at this site. The coarse fraction exhibited higher densities and velocities and lower penetrometer readings than the fine fraction. The coarse fraction also often exhibited acoustic velocity anistropy of 5 to 10%, with the higher velocity in the direction parallel to bedding, suggesting that the anisotropy results from grain orientation rather than compaction.

The recovered basalts were relatively uniform in appearance, but acoustic velocity, density, and thermal conductivity tended to increase with increasing depth. The acoustic velocites are lower than those found for the basalts at the sites previously drilled on this leg.

The results of the thermal conductivity measurements are summarized in Table 3. The values are consistent with those obtained for basalts at the previous sites.

INORGANIC GEOCHEMISTRY

Interstitial water profiles at Site 524 differ markedly from those at the preceding Leg 73 sites. Below 50 m sub-bottom at Site 524, Ca^{+2} concentration increases rapidly, Mg^{+2} shows a pronounced depletion, alkalinity drops significantly, and salinity peaks dramatically (Fig. 11, Table 4). These variations coincide with a lithologic change at about 80 m sub-bottom from pelagic carbonate sediments to underlying interbedded marls, calcareous claystones, and calcareous volcaniclastic sandstones. Calcium enrichments and magnesium depletions ob-

Table 3. Thermal conductivity values, Hole 524 sediments.

Section	Thermal conductivity (W/m °C)
Sediments[a]	
5-2	1.64
6-2	1.59
8-2	1.57
9-1	1.54
10-2	1.48
10-4	1.37
11-5	1.54
12-3	1.44
13-4	1.38
15-2	1.94
16-2	1.49
17-2	1.81
18-	1.43
21-5	1.30
22-4	1.29
Basalts	
29-2	1.48
30-2	1.73
31-1	1.78
33-1	1.82

[a] Mean value of thermal conductivity of sediments is 1.52 W/m °C; standard deviation is 0.66.

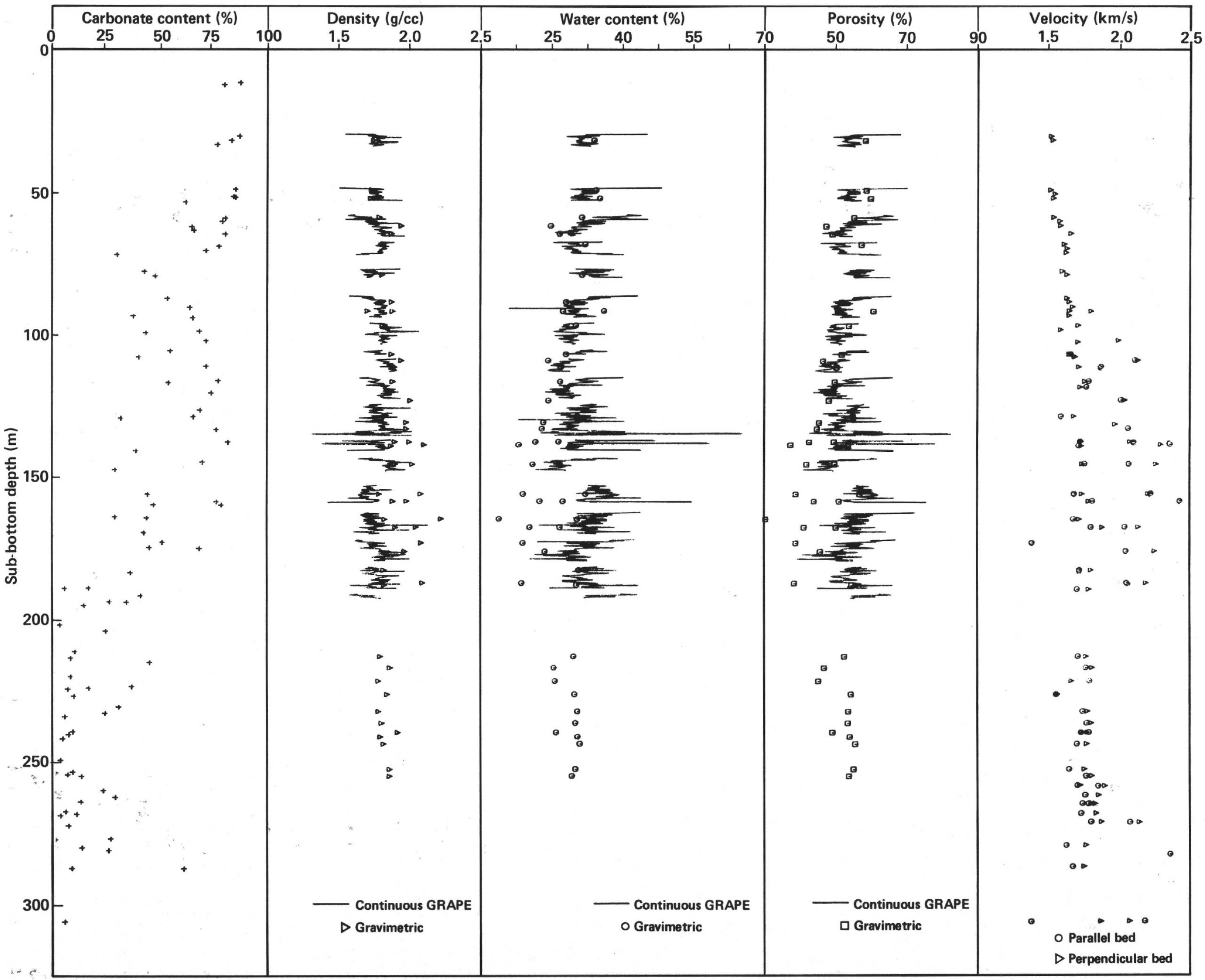

Figure 10. Summary of physical properties, Site 524.

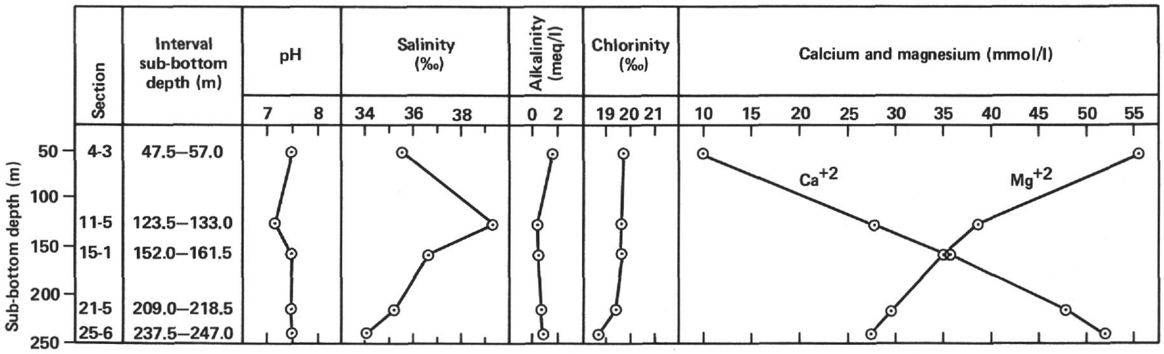

Figure 11. Interstitial water profiles, Hole 524.

Table 4. Summary of shipboard geochemical data, Hole 524.

Core-Section (interval in cm)	Sub-bottom depth (m)	pH	Alkalinity (meq/l)	Salinity (‰)	Calcium (mmol/l)	Magnesium (mmol/l)	Chlorinity (‰)
4-3, 140–150	47.5–57.0	7.46	1.936	35.5	9.9	55.48	19.71
11-5, 140–150	123.5–133.0	7.10	0.391	39.3	27.89	38.57	19.64
15-1, 140–150	152.0–161.5	7.48	0.916	36.6	35.76	34.90	19.64
21-5, 140–150	209.0–218.5	7.47	1.806	35.2	47.92	29.60	19.41
25-6, 140–150	237.5–247.0	7.50	1.12	34.1	52.02	27.42	18.70

served at a number of DSDP sites in other areas have been ascribed to the dissolution of biogenic calcite and the subsequent formation of dolomite and/or the alteration of volcanic rocks, which releases Ca^{+2} from plagioclase and/or mafic minerals and locks up Mg^{+2} in authigenic smectites (e.g., Sayles and Manheim, 1975; Lawrence et al., 1975). Both processes may have operated at Site 524, because nannofossil marls and claystones give way to interbedded calcareous (dolomitic?) claystones and volcaniclastic sandstones downsection. Many of the volcanic rock fragments in the sandstones are rounded and completely altered to green clay; the fragments were probably already clay at the time of transport. However, the matrix of the sandstones also appears to be authigenic green clay. Green clay also lines fractures and fills vesicles in the basalts that are interbedded with the sediments near the base of the hole.

HISTORY OF THE WALVIS RIDGE AS REVEALED BY DRILLING AT SITE 524

Site 524 is on a fan at the end of a major canyon that drains the Walvis Ridge (Fig. 1). Magnetic Anomaly 32 can be traced into the central Walvis Ridge, which is therefore considered to be of early Maestrichtian age (LaBrecque et al., this vol.). The shallow zones of the Walvis Ridge approach a water depth of 2500 m. Therefore, by applying the Sclater cooling curve, we would expect the Walvis Ridge to have been at or near sea level during its formation in the Maestrichtian.

A dark reflector occurs at 0.3 s sub-bottom in the seismic data (Fig. 2). This reflector corresponds to the zone where we encountered alkali basalt sills and flows likely to be of mid-Maestrichtian age. Above this zone the sedimentary section thickens toward the central Walvis Ridge. The seismic reflectors diverge toward the ridge, indicating a sedimentary wedge.

LaBrecque et al. (this vol.) and LaBrecque and Rabinowitz (in press) show that the combined DSDP results and the marine geophysical data indicate that the Walvis Ridge was generated along the eastern pseudofault of a southward-propagating rift zone. The propagating rift (the Walvis propagator) rifted 17-m.y. crust on the African plate and passed just to the west of Site 524 during the Maestrichtian. The Walvis propagator was active from Aptian to likely mid-Eocene time.

SUMMARY AND CONCLUSIONS

Stratigraphy and Lithology

The youngest sediments at Site 524 are middle lower Eocene in age. The lower Eocene and upper Paleocene sediments (Unit 1; NP8-12) are mainly nannofossil oozes, with thin layers of chalk and limestone. Chert nodules are present in the chalk and limestone that contain siliceous fossils (diatoms, radiolaria, and sponge spicules). Thin beds of volcanic ash and glauconitic sands are present. The upper and lower Paleocene sediments (Unit 2) are nannofossil marls and claystones with numerous intercalations of resedimented sands. The sands include both bioclastic and volcaniclastic debris and glauconite. The lower Paleocene and Upper Cretaceous sediments (Unit 3) are mainly claystones and sandstones with nannofossil marls. This unit is distinguished from the overlying unit by lower $CaCO_3$ content. The lowest upper and middle Maestrichtian unit (Unit 4) includes marly claystone, volcaniclastic sandstone, volcanic breccias, and basalts.

The sedimentary history suggests that during the Late Cretaceous and Paleocene epochs this site may have been located in a small perched basin where much sediment was deposited by turbidity currents coming down a submarine canyon (Fig. 1). The basement formed by seafloor spreading is believed to be Santonian in age and lies 1 to 2 km below the youngest volcanic rocks. Tectonic and volcanic activities may have kept the seafloor at a shallower than normal depth during the latest Cretaceous and earliest Tertiary periods. After the early Eocene, the seafloor at this site may have sunk to a depth near or below the CCD. However, the absence of red clay as a residue of dissolution may be indicative of bottom current erosion.

Correlation of Biostratigraphy, Magnetostratigraphy, and Seafloor Anomalies

The correlation of magnetostratigraphy with seafloor anomalies is excellent from the top of Chron C-27-N to the top of Chron C-31-R (Fig. 8). The correlation of the uppermost 100 m is, however, somewhat uncertain.

The top of the core belongs to the nannofossil zone NP13. Core 1 from Hole 524 and Core 1 from Hole 524B both include the lowest occurrence (LO) of *Discoaster lodoensis*. At the Contessa section of Italy, Zone NP13 falls within Chron C-23, and the LO of *D. lodoensis* falls within Chron C-24-N1 (Lowrie et al., 1982). The NP11/NP10 boundary has been defined on the basis of the highest occurrence (HO) of *Tribrachiatus orthostylus* in Sample 524-3-3, 107 cm. The boundary falls near the top of C-24-R2 at Contessa. This information suggests that a reversal from positive to negative polarity in Section 524B-4-1 could be the boundary between subchrons C-24-N2 and C-24-R2 (see Fig. 12). If these correlations are correct, the data indicate that the sequence from Chron C-23 to C-24 has been much condensed because of dissolution.

The top of Chron C-25-N falls just below the NP10/NP9 boundary at Contessa. This biostratigraphic information identifies the polarity change at 58.2 m sub-bottom in Hole 524 (Figs. 6 and 12) as the boundary between C-24-R and C-25-N. The normal polarity epoch of Core 5 (Fig. 6) is thus correlated with Anomaly 25, not Anomaly 26. Chron C-26-N has not been identified in our magnetostratigraphy, probably because the recovery at about 80 m sub-bottom (Cores 6 and 7) was very poor. The negatively polarized interval represented by NP5 to NP3 sediments from 85 to 129 m sub-bottom (Cores 8–12) should be dated as Chron C-26-R (Fig. 12). Such a placement would be in agreement with the biostratigraphic information from Leg 74, where the top of Chron C-26-N is near the NP7/NP6 boundary (W. Berggren, pers. comm.).

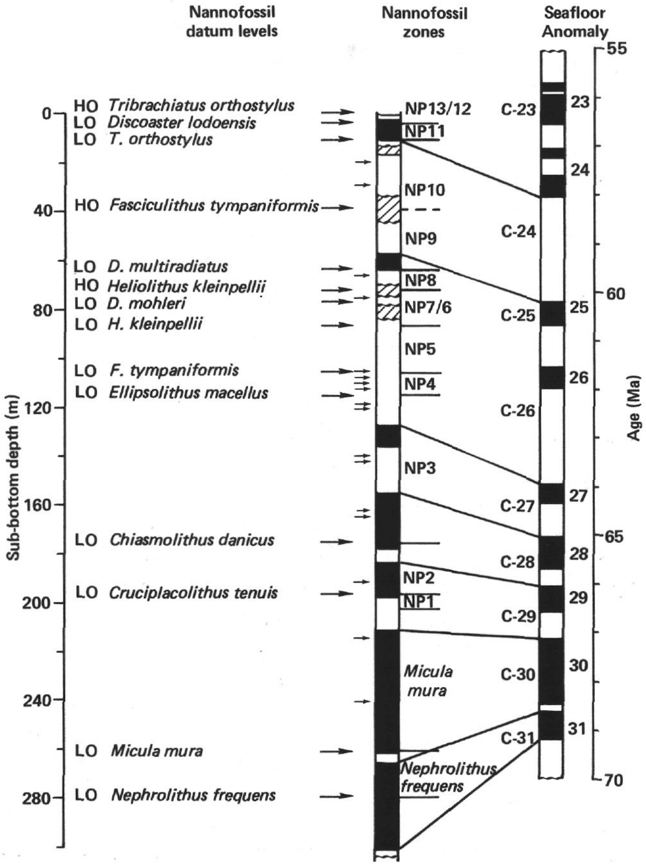

Figure 12. Magnetostratigraphy and biostratigraphy, Site 524. Magnetic chronology as defined in Hsü, LaBrecque, et al. (this vol.); polarity as in Fig. 4.

Farther downhole, the correlation of magnetostratigraphy and seafloor anomaly is not difficult. The boundaries of the foraminifer zones occur at the same levels in terms of magnetostratigraphy as at Contessa. Our section is five times as expanded, however (75 vs. 14 m). Furthermore, both the nannofossils and foraminifers could be zoned at Site 524, whereas only the foraminifers could be zoned at Contessa. Site 524 is, therefore, the better section for calibrating the first and last appearances of key Paleocene species. The datums found at Site 524 include LO *Fasciculithus tympaniformis*, LO *Ellipsolithus macellus*, LO *Chiasmolithus danicus*, LO *Cruciplacolithus tenuis*, LO *C. edwardsi*, LO *Zygodiscus sigmoides*, HO *Micula mura*, HO *Lithraphidites quadratus*, HO *Nannotetrina frequens*, LO *Morozovella pusilla pusilla*, LO *M. angulata*, LO *M. uncinata*, HO *Globigerina daubjergenesis*, LO *Globotruncana trinidadensis*, and LO "*Globigerina eugubina*." Their correlation to magnetostratigraphy is shown by Figure 12.

The correlation of the foraminifer and nannofossil zonal boundaries to the magnetostratigraphic chrons as presented here compare favorably with the results by Lowrie et al. at Contessa. Interested readers should refer to the biostratigraphic summary at this site and the chapter in this volume by Poore et al. for more details.

Calcite Dissolution, Sedimentation Rates, and Paleoceanography

The Upper Cretaceous and Paleocene sequence includes many turbidites. Backtracking suggests that the paleodepth of the site was less than 3500 m before the Eocene. Both factors contributed to the fair preservation of calcareous fossils. One exception is noted: the calcareous nannofossils in the sediments 1.2 m below the Cretaceous/Tertiary boundary (the bottom of Core 20 in Hole 524) are poorly preserved. The dissolution of the planktonic foraminifers is even more impressive; the sediments 10 to 15 m immediately beneath the boundary are almost barren of calcareous plankton. This phenomenon has been noted at other deep sea drilling sites. For example, Iaccarino and Premoli Silva (1979) found practically no planktonic foraminifer fossils in the Cretaceous/Tertiary boundary clay and none for several meters below the boundary at Hole 398D. At Site 524 we also noted a sharp decrease (from about 40 to 2%) in the $CaCO_3$ content of the sediments in the 0.5 m below the Cretaceous/Tertiary contact. A simple-minded explanation would postulate the rise of the lysocline during the late Maestrichtian, resulting in the dissolution of first the planktonic foraminifers and finally all of the calcium carbonate in the sediment at the Cretaceous/Tertiary boundary. However, all the other environmental indicators suggest that conditions of sedimentation were stable before the terminal Cretaceous event (see Hsü et al., 1982). I prefer, therefore, to assume the seafloor dissolution of the sediments at shallow sub-bottom depths during the terminal Cretaceous event.

Because of the presence of a boundary clay in pelagic sequences deposited in very shallow waters, Worsley (1974) and others have postulated that the CCD rose to the photic zone during the terminal Cretaceous crisis. The rise of the CCD could be explained by a drastic reduction in supply during the terminal Cretaceous event, when the fertility of planktonic organisms was suppressed. Another explanation for the dissolution is that ocean chemistry changed "temporarily" because of oceanic infertility and/or chemical pollution after a catastrophic event (Hsü et al., 1982). The earliest Tertiary nannofossils and foraminifers are commonly well preserved, however (K. Perch-Nielsen, pers. comm.), and this would suggest that an "acid ocean," if one ever existed, lasted a very short time, probably on the order of a few thousand years.

The presence of a very undersaturated bottom water would have resulted not only in the dissolution of the topmost sediments of the ocean bottom but also in a steep gradient in the concentration of dissolved ions in the interstitial water. Silica, for example, is undersaturated in bottom waters today, and a concentration gradient in interstitial water is responsible for the dissolution and transfer of dissolved biogenic silica from sediments a few meters below the bottom to the bottom waters of the oceans. By analogy, the dissolution of the planktonic foraminifers and the poor preservation of the nannofossils in the uppermost Maestrichtian sediments may be the result of the gross undersaturation of the bottom water during and shortly after the terminal Cretaceous event.

The sequence became mainly pelagic toward the end of the Paleocene. The site sank below the lysocline during Chron C-24, and it probably sank below the CCD after Chron C-23, when its paleodepth should have been 3700 m. No sediments younger than early Eocene are present, possibly because dissolution removed much calcite but more probably (in view of the absence of insoluble residue) because of active erosion by bottom currents controlled by the morphology of the Walvis Ridge. In Hole 20, which was drilled into a somewhat younger crust on Anomaly 30, we found a condensed Paleocene and Eocene sequence and a fairly complete Oligocene sequence; the site there only sank below the CCD during the early Miocene.

The Late Cretaceous sedimentation rate for Unit 3 is 34 m/m.y. The average Paleocene sedimentation rate for Units 2 and 3 is 28 m/m.y. These rates are two or three times the normal Tertiary pelagic sedimentation rates in the South Atlantic. The faster rates at this site obviously resulted from frequent turbidite deposition. The upper Paleocene unit, Unit 1, has a sedimentation rate of about 11 m/m.y., which is about normal for pelagic deposits.

Diatoms and radiolarians are present in the upper Paleocene sediments. Their paleoceanographic significance is not certain. Paleomagnetic data indicate that the latitude of this site should have been more than 42°S at the beginning of the Tertiary (Tauxe et al., this vol.). The siliceous organisms probably grew in relatively nutrient-rich waters of a "west wind drift" belt on the fringe of the Paleocene Antarctic Convergence.

Cretaceous/Tertiary Boundary Event

The discovery of an amplified sequence of sediments at the Cretaceous/Tertiary boundary was greatly hoped for but nevertheless surprising. The top of the Cretaceous is marked by a nannoplankton flora belonging to the *Micula mura* Zone. The exact position of the contact, as determined by shore-based studies of nannofossil samples taken at 1- to 5-cm intervals, is placed at 203.55 m sub-bottom (Core 20, Section 3, 105 cm) (Pl. 3). The sediments have been thoroughly bioturbated below the contact and hardly at all above it. The boundary clay itself is almost devoid of indigenous marine plankton and includes a relic Cretaceous nannoflora. Relatively rich nannofossil flora, foraminifer fauna, and good trace fossils are not present again until the stratigraphic level of NP2, about 0.5 m.y. after the end of the Cretaceous.

The expanded transition at this site confirms previous observations from condensed sections on land that (1) marine plankton became very rare in the sediments deposited after a terminal Cretaceous crisis, (2) the first Tertiary nannoplankton includes *Thoracosphaera* spp., and (3) the Cretaceous/Tertiary contact falls with Chron C-29-R.

The terminal Cretaceous event is discussed in detail in Hsü (this vol.) and Hsü et al. (1982).

Cenozoic Ages and Seafloor Spreading Rates

The Paleocene/Eocene boundary, as defined by the top of NP9 (Fig. 6), lies within the unsampled interval from 38.0 to 47.5 m sub-bottom in Hole 524 (between Cores 3 and 4). This interval is within Chron C-24-R (the long reversed interval of Chron C-24). The boundary therefore has an extrapolated magnetostratigraphic age of about 59 m.y., if the Cenozoic is assumed to have a 66.5-m.y. age. The boundary's radiometric age, however, is 53 m.y. The NP4/NP5 boundary falls within Chron C-26-R and therefore has an extrapolated magnetostratigraphic age of 63 m.y., but its radiometric age is 59 m.y. (Odin and Curry, 1981). Furthermore, the placement of the LO of *Discoaster lodoensis* at a level just below the top of Chron C-24-N would give it a magnetostratigraphic age of 57 m.y., although according to radiometry the first appearance datum (FAD) of this species should be younger than 51 m.y. (which may explain the common tendency to correlate NP13 with Chron C-21-N, which has a magnetostratigraphic age of 50 m.y.). Using an age of 63.5 m.y. for the beginning of the Cenozoic, however, would result in magnetostratigraphic ages of 56.5, 60.5, and 54 m.y. for the top of the

Paleocene, the top of NP4, and the FAD of *D. lodoensis* (top of Chron C-24), respectively. The discrepancies would thus be reduced to about 2 or 3 Ma for those datum levels, still a considerable difference.

The radiometric age of the Cretaceous/Tertiary boundary was obtained by dating continental beds in New Mexico and Alberta in western North America. The sediments in New Mexico have a controversial lithostratigraphy and magnetostratigraphy (see Alvarez and Vann, 1979; Lindsay et al., 1979; and Fassett, 1979). The sequences in Alberta, on the other hand, have been dated accurately by palynology, by vertebrate fauna, and by magnetostratigraphy (Lerbekmo et al., 1979). A 65- to 66-m.y. date from Late Cretaceous sediments from the Kneehill tuff of Central Alberta (Lerbekmo et al., 1979) has been correlated with the middle part of Chron C-30-N. In the Red Deer Valley, Alberta, the Cretaceous/Tertiary boundary is defined by the level where the mass extinction of the *Aquilapollenites* flora, which lies a few meters above the highest occurrences of *Triceratops* (dinosaur), took place. Bentonites at levels 17.5, 17, and 11 m above and 1 m below the pollen datum had respective ages of 63.0/63.0/63.3, 62.8/63.0, 62.7/63.0, and 63.0/63.3/63.5/63.5 m.y. Lerbekmo et al. (1979), using hypothetical sedimentation rates, placed the boundary at a horizon that is some 0.1 m.y. older than the beginning of Chron C-29-N and has a radiometric age of 63.1 m.y. After reviewing all the available evidence, Odin (pers. comm., 1982) recommends a 63.5-m.y. age for the base of the Cenozoic.

We submitted two basalt samples from Site 524 to E. H. McKee (U.S. Geological Survey, Menlo Park, Calif.) for potassium-argon dating. The lower sample was from a stratigraphically uncertain horizon and gave a 73.6-m.y. age. The upper sample was from a horizon in Core 31 just below the *Nephrolithus frequens* Zone, near the base of the Chron C-31-N; the K/Ar age is 64.9 ± 0.8 m.y. This basalt may be part of a sill. However, submarine sills in sediments of nearly contemporaneous age are not uncommon, and the natural remanent magnetization of the basalt indicates that the basalt K/Ar date gives an estimated age of Chron C-31-N. Assuming a 66.5-m.y. age for the Cretaceous/Tertiary boundary (Tauxe et al., this vol.) gives a 69-m.y. age to the Chron C-31-N basalt. However, if we use the 63.5-m.y. date, the extrapolated magnetostratigraphic age for the basalt would be 64.6 m.y., in very close agreement with its radiometric age.

In conclusion, the deviations from a linear seafloor spreading rate can almost be eliminated if we accept the 63.5-m.y. radiometric date (instead of 66.5 m.y.) for the beginning of the Cenozoic. If the spreading rate was slightly nonlinear, the accumulative discrepancies reached a maximum during the middle Eocene (NP15), and the rate became "normal" again (the same as in pre-Eocene times) during the early Oligocene.

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Date of Initial Receipt: August 12, 1982

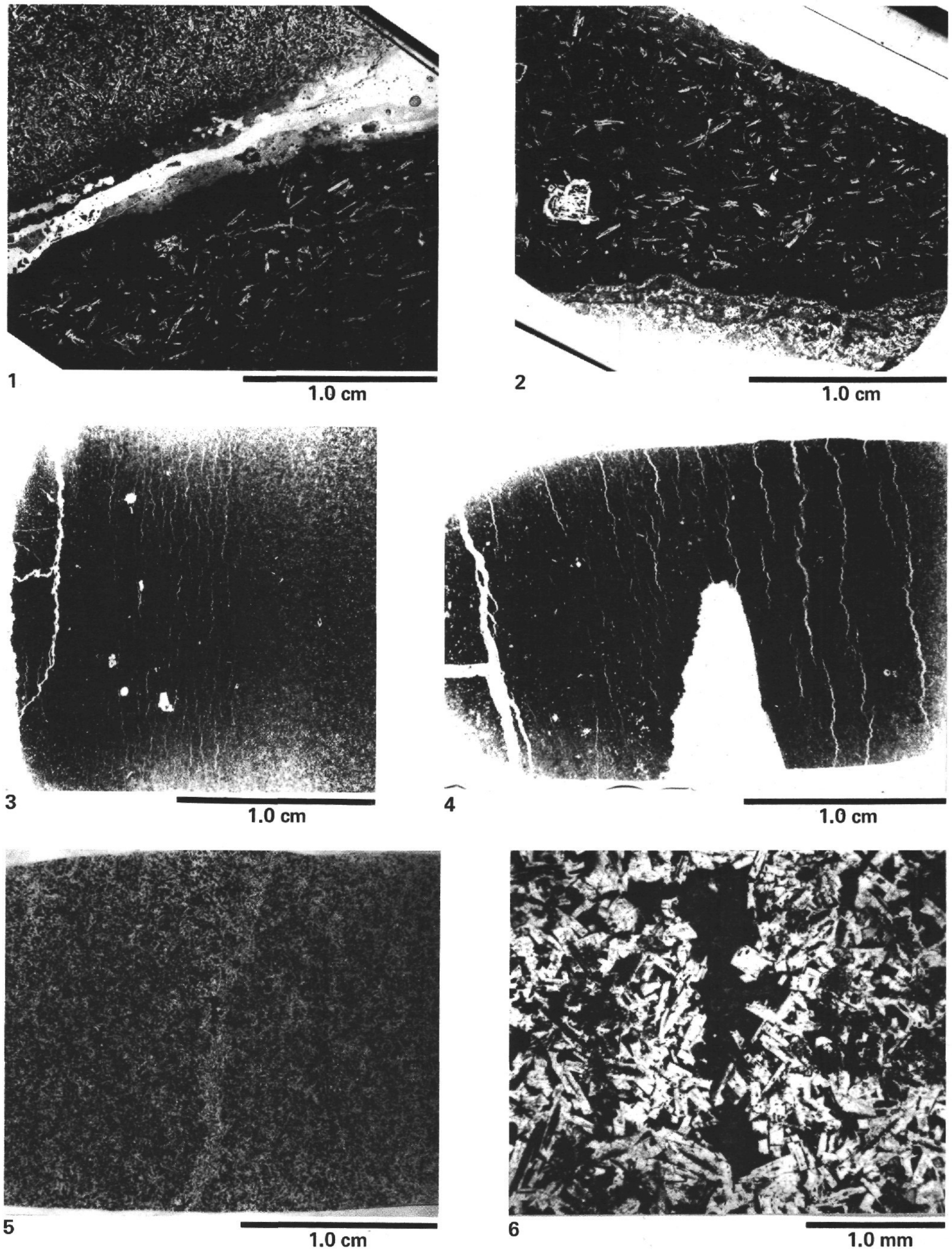


Plate 1. Photomicrographs of igneous rocks at Site 524. **1.** Upper contact, central portion of tholeiitic multiple sill. Very fine-grained to spherulitic microphyric rock (dark) against very coarse-grained phase (mottled gray). Boundary mostly separated by crack lined with smectite (light gray) and filled with calcite. Grain size in darker phase coarsens away from contact. Sample 524-33-1, 93–101 cm. **2.** Lower contact, central portion of tholeiitic multiple sill. Very fine-grained (dark) rock appears next to very coarse-grained (light gray) rock. The coarse phase has a thin zone of recrystallization to fine grain (medium gray). Darker phase coarsens away from contact. Sample 524-33-4, 2–5 cm. **3.** Contraction fractures in pillow margin. Left side is close to pillow rim, having spherulitic texture of Zone 3. Note how cracks broaden and become more widely spaced to the right (away from the rim). Most cracks are filled with calcite or smectite, although some contain some feldspar. Thick calcite-filled fractures in the upper part crosscut smaller fractures and are typical of borders of rock units with quench textures. Sample 524-28-3, 102–105 cm. Alkalic basalt. **4.** Contraction fractures in upper margin of alkalic upper sill. Left side is close to sill margin, with dendritic quench texture of Zone 5. Note how cracks broaden and become more widely spaced away from sill margin. Cracks are filled with plagioclase and calcite. Blank wedge inside is saw blade cut. Thick calcite veinlets cut outermost margin zone. Sample 524-29-1, 102–105 cm. **5.** Feldspar veinlet in very coarse-grained interior of upper alkalic sill. Note vug in veinlet just left of center. Sample 524-31-2, 87–90 cm. **6.** Vug in feldspar veinlet shown in Fig. 5. Vug is filled with smectite. Veinlet is predominantly plagioclase with interstitial smectite and devoid of opaque minerals. Same sample as Fig. 5.

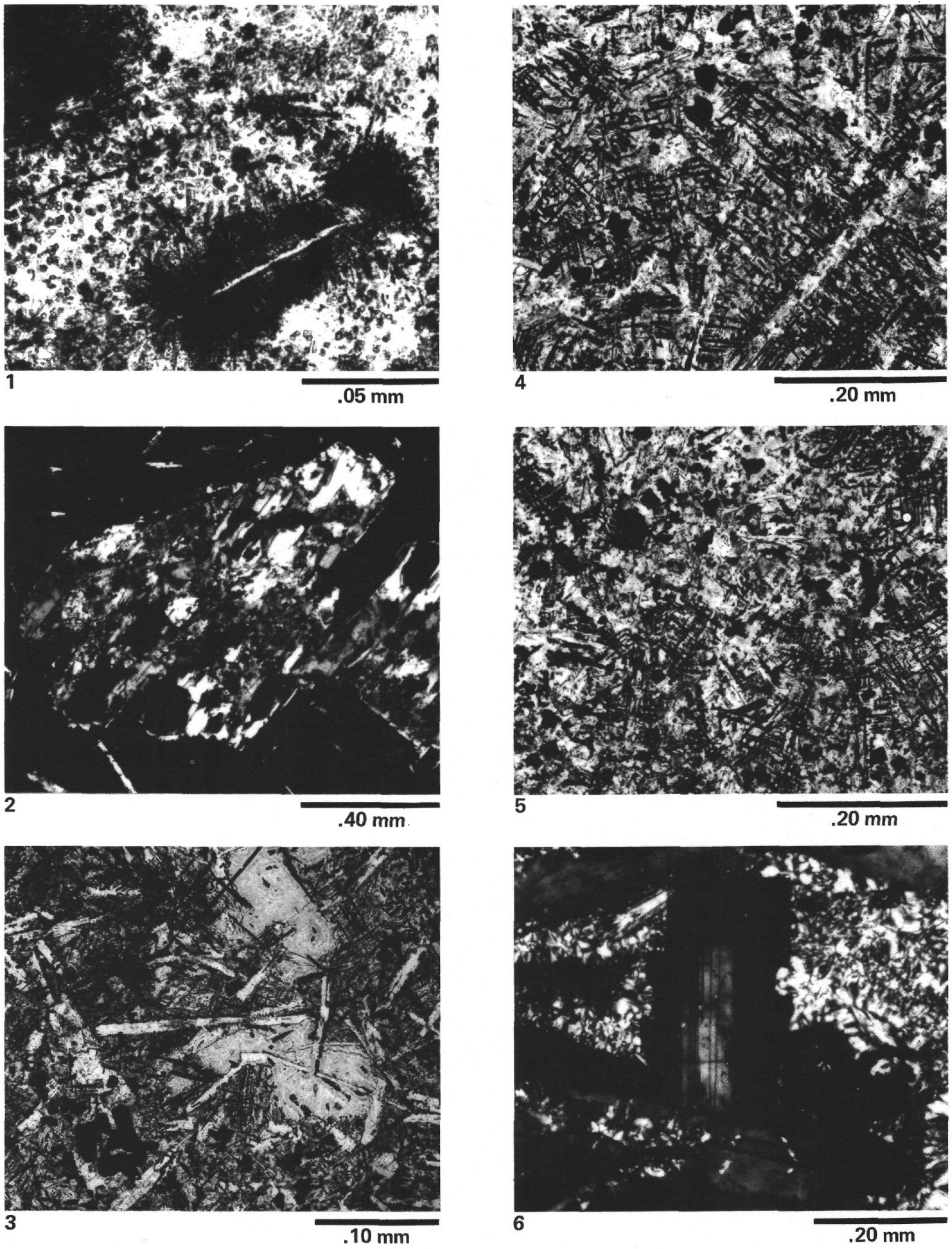


Plate 2. Photomicrographs of igneous rocks at Site 524. **1.** Reticulate spherulitic texture, Zone 2, with devitrified glass matrix. Pillow unit, alkalic basalt, Sample 524-28-3, 80–84 cm, Piece b. **2.** Corroded plagioclase xenocryst partially replaced by inclusion-filled Na-spar (mottled gray). Black spots are plucked areas. Pillow unit, alkalic basalt, Sample 524-28-3, 70–72 cm. Crossed nichols. **3.** Reticulate ilmenitic opaque mineral in pillow, 8 to 10 cm from the rim. Same sample as Fig. 2. **4.** Reticulate ilmenitic opaque mineral in pillow 10 cm from the rim. Alkalic basalt, Sample 524-28-3, 93–97 cm. Compare with Fig. 5. **5.** Reticulate ilmenitic opaque mineral in sill 3 cm from margin. Alkalic basalt of upper sill, Sample 524-29-1, 102–105 cm. Compare with Fig. 4. **6.** Alkali feldspar mantle (at extinction) on plagioclase in alkalic basalt. Albite twinning shows orientation of (010). Axial plane in alkali feldspar is normal to (010). Section normal to X (Bxa), 2V = 35–40°. Interior of upper sill, Sample 524-31-1, 108–111 cm. Crossed nichols.

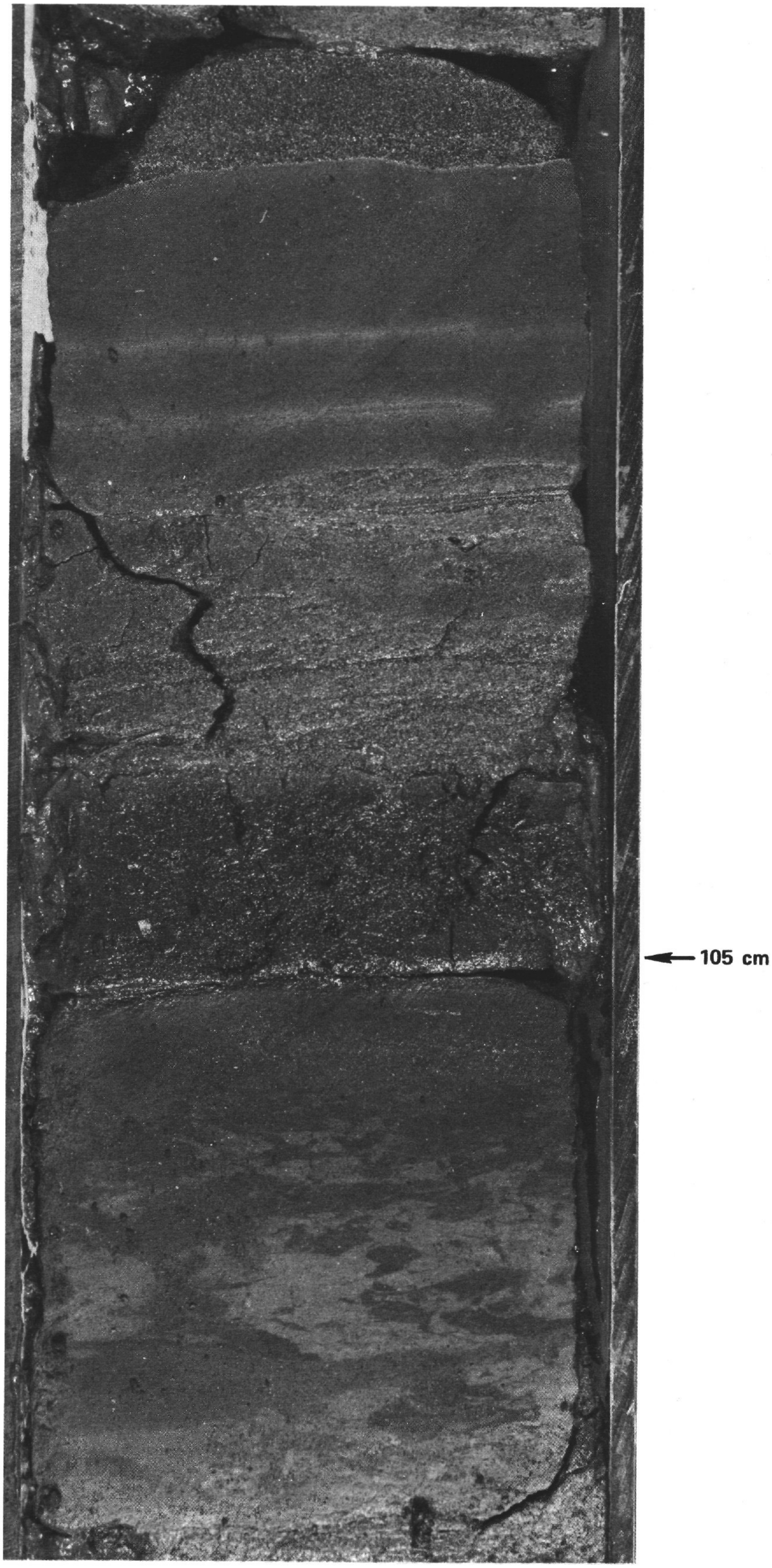
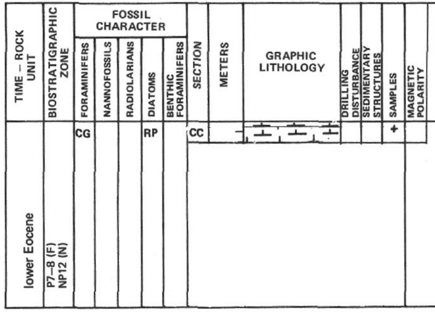


Plate 3. Cretaceous/Tertiary boundary. The boundary is placed at Core 20, Section 3, 105 cm. Note the virtual absence of signs of bioturbation in the earliest Tertiary sediments.

SITE 524 HOLE CORE 1 CORED INTERVAL 0.0–1.5 m



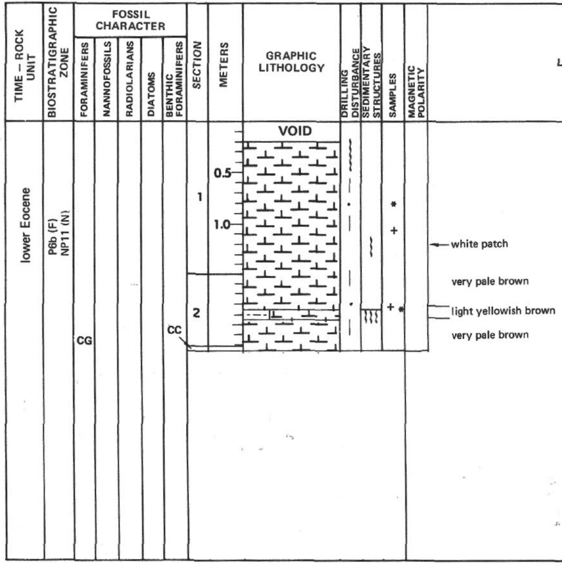
LITHOLOGIC DESCRIPTION

Trace of NANNOFOSSIL OOZE in Core-Catcher.

ORGANIC CARBON AND CARBONATE

	CC
Organic carbon	–
Carbonate	50

SITE 524 HOLE CORE 2 CORED INTERVAL 9.5–19.0 m



LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very pale brown (10YR 8/3), homogeneous except for scattered white patches and burrows and a thin interval in Section 2 (37–45 cm) of light yellowish brown (10YR 6/4), burrowed MARLY NANNOFOSSIL OOZE. Top 20 cm disturbed by drilling; remainder of core moderately disturbed.

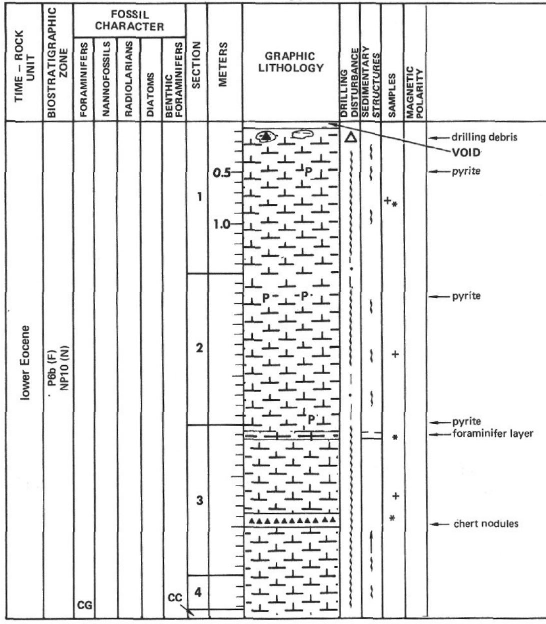
SMEAR SLIDE SUMMARY

	1-86 D	2-39 M
TEXTURE:		
Sand	–	–
Silt	95	85
Clay	5	15
COMPOSITION:		
Heavy minerals	–	TR
Clay	5	15
Micronodules	TR	5
Carbonate unspec.	10	10
Foraminifers	–	TR
Calc. nannofossils	85	65
Iron-oxides	–	5

ORGANIC CARBON AND CARBONATE

	1-110	2-36
Organic carbon	–	–
Carbonate	87	*80*

SITE 524 HOLE CORE 3 CORED INTERVAL 28.5–38.0



LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very pale brown (10YR 8/3) with scattered burrows and white patches throughout. Grayish pyrite-rich zones also common (as marked). Thin layer of FORAMINIFER NANNOFOSSIL OOZE in Section 3 has sharp basal contact and gradational top. Brown CHERT nodules with chalk rinds in Section 3 composed of opal-CT and quartz (XRD). Similar fragments in drilling debris at top of core. Dark brown (10YR 3/3) CLAY fragment also occurs in drilling debris at top. Most of core is very deformed by drilling.

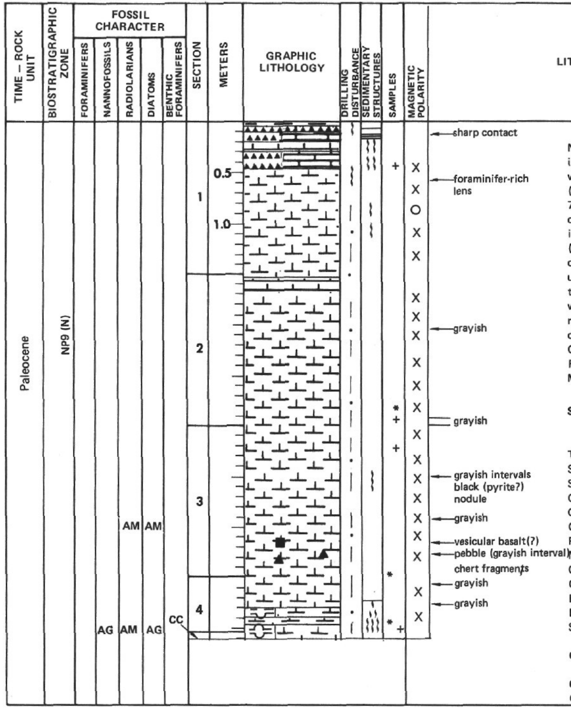
SMEAR SLIDE SUMMARY

	1-89 D	3-15 M
TEXTURE:		
Sand	5	40
Silt	90	50
Clay	5	10
COMPOSITION:		
Quartz	–	TR
Clay	5	5
Carbonate unspec.	10	–
Foraminifers	5	40
Calc. nannofossils	80	50

ORGANIC CARBON AND CARBONATE

	1-79	2-83	3-79
Organic carbon	–	–	–
Carbonate	87	83	76

SITE 524 HOLE CORE 4 CORED INTERVAL 47.5–57.0 m



LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE partly lithified to CHALK in places. Ooze is very pale brown (10YR 8/3) to white (5YR 8/1–10YR 8/2) and pinkish white (7.5YR 8/2) with thin (1–3 cm) light gray (5YR 7/4) intervals (more pyrite?-rich). Top Section 1 contains dark reddish brown (10YR 5/2) CHERT in sharp contact with burrowed, light brownish gray (10YR 6/2) SILICEOUS LIMESTONE. Fragments of pale brown CHALK and SILICEOUS LIMESTONE underly with this. Top of siliceous limestone contains two brown layers that cut burrows. Burrows cut white nodule in limestone at 35 cm; pyritized burrows also present. Vesicular basalt(?) fragment and chips of chert in Section 3. Very pale brown SILICEOUS (radiolarians, diatoms, spicules) NANNOFOSSIL OOZE in base Section 4 and Core-Catcher. Moderate drilling disturbance.

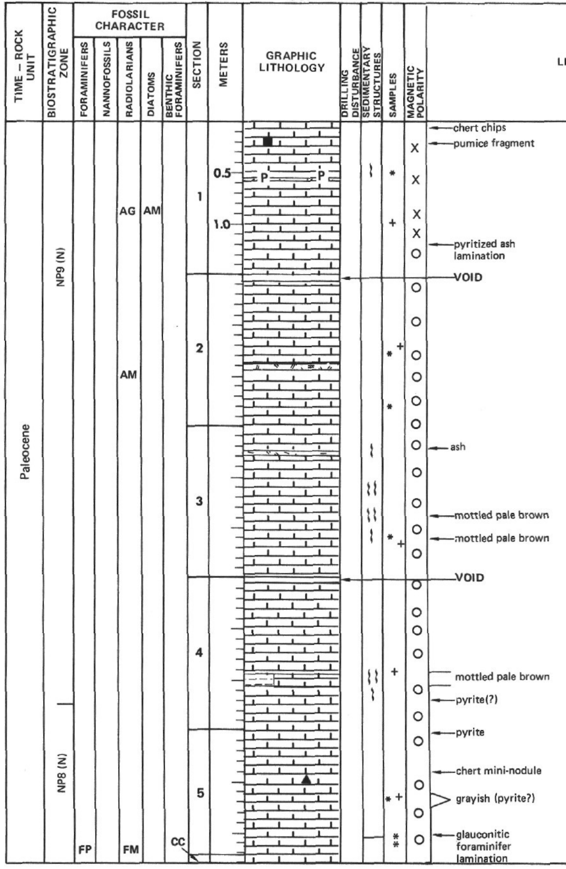
SMEAR SLIDE SUMMARY

	2-131	4-6	4-45
	D	M	M
TEXTURE:			
Sand	–	–	–
Silt	100	95	90
Clay	–	5	10
COMPOSITION:			
Clay	TR	5	5
Pyrite	–	2	5
Micronodules	–	2	–
Carbonate unspec.	–	–	10
Calc. nannofossils	100	91	45
Diatoms	–	–	5
Radiolarians	–	–	10
Sponge spicules	–	–	10

ORGANIC CARBON AND CARBONATE

	1-49	2-148	3-24	4-51
Organic carbon	–	–	–	–
Carbonate	85	84	85	62

SITE 524 HOLE CORE 5 CORED INTERVAL 57.0–66.5 m



LITHOLOGIC DESCRIPTION

NANNOFOSSIL CHALK, pinkish white (7.5YR 8/2) with several mottled and burrowed very pale brown (10YR 8/3) marly intervals. Three layers of pyritized dark grayish brown (10YR 4/2) in Sections 1–3 have sharp basal contacts. Pumice fragment and chert chips in top Section 1. Thin lamination of glauconitic foraminifers at 105 cm, Section 5. Small (2–3 cm) chert nodule also in Section 5.

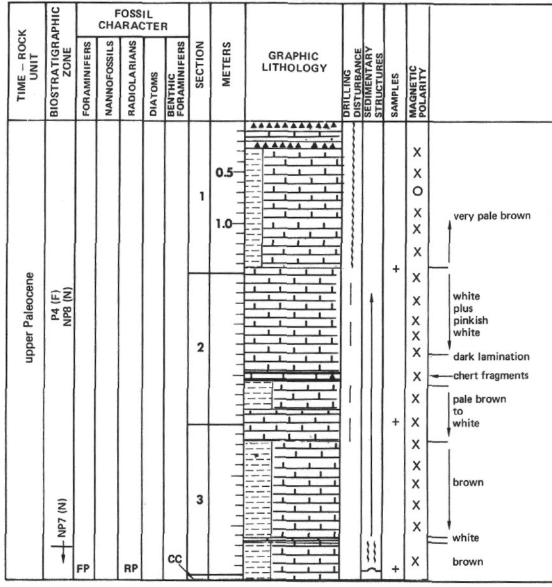
SMEAR SLIDE SUMMARY

	1-52	2-87	2-134	3-114	5-73
	M	M	D	D	D
TEXTURE:					
Sand	75	15	25	5	5
Silt	15	65	55	70	75
Clay	10	20	20	25	20
COMPOSITION:					
Quartz	–	5	5	–	20
Clay	10	15	20	15	–
Volcanic glass	70	10	25	TR	–
Palagonite	5	5	5	1	TR
Pyrite	TR	TR	TR	1	–
Carbonate unspec.	–	25	25	10	10
Foraminifers	–	–	TR	3	5
Calc. nannofossils	15	35	15	70	60
Diatoms	–	–	–	TR	–
Radiolarians	–	TR	TR	–	–
Sponge spicules	–	5	5	–	–

ORGANIC CARBON AND CARBONATE

	1-104	2-74	3-115	4-90	5-66
Organic carbon	–	–	–	–	–
Carbonate	80	79	65	60	80

SITE 524 HOLE CORE 6 CORED INTERVAL 66.5–76.0 m



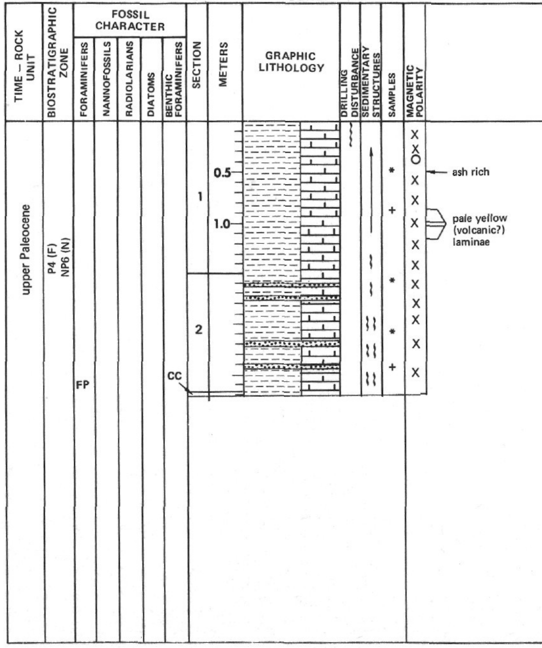
LITHOLOGIC DESCRIPTION

NANNOFOSSIL CHALK, pinkish white (7.5YR 8/2), and white (10YR 8/2) to pale brown (10YR 6/3) and very pale brown (10YR 8/3), NANNOFOSSIL MARL as shown. Burrows common in lower two sections. Scattered patches of dark ash(?) in Section 1. Section 1 also contains several fragments of brown (10YR 5/3) to dark brown (10YR 4/3) CHERT coated with chalk rind. LIMESTONE with chert fragments at 99–102 cm, Section 2. (Core-Catcher was very small; given to paleontologists.)

ORGANIC CARBON AND CARBONATE

	1-144	2-144	3-144
Organic carbon	–	–	–
Carbonate	77	71	30

SITE 524 HOLE CORE 7 CORED INTERVAL 76.0–85.5 m



LITHOLOGIC DESCRIPTION

NANNOFOSSIL CLAYSTONE grayish brown (10YR 5/2) and light brownish gray (10YR 6/2) in Section 1 grading to pinkish gray (7.5YR 7/2) and pinkish white (7.5YR 8/2) in Section 2; burrowed throughout. Scattered thin volcaniclastic sandstone layers in both sections. In Section 2 these grade from pale yellow tops to coarser and darker yellow volcanic-rich bases; lower contacts burrowed. (Core-Catcher was given to paleontologists.)

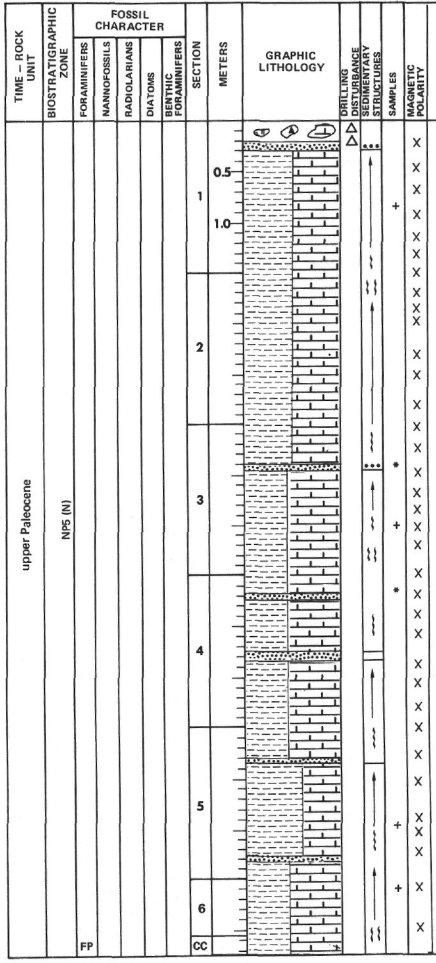
SMEAR SLIDE SUMMARY

	1-56 M	2-13 M	2-63 M
TEXTURE:			
Sand	15	30	30
Silt	60	40	40
Clay	25	30	30
COMPOSITION:			
Quartz	10	10	10
Clay	15	20	20
Volcanic glass	25	15	20
Palagonite	5	5	5
Glauconite	–	10	5
Micronodules	–	–	TR
Carbonate unspec.	10	15	15
Foraminifers	–	TR	–
Calc. nannofossils	30	15	20
Diatoms	TR	–	–
Sponge spicules	5	5	5
Fish remains	TR	TR	TR

ORGANIC CARBON AND CARBONATE

	1-83	2-91
Organic carbon	–	–
Carbonate	42	48

SITE 524 HOLE CORE 8 CORED INTERVAL 85.5–95.0 m



LITHOLOGIC DESCRIPTION

NANNOFOSSIL MARL and CLAYSTONE with abundant thin (1 mm–2 cm) layers of VOLCANICLASTIC SANDSTONE. Marl is pinkish gray (7.5YR 7/2) changing to light gray (10YR 7/1) and gray (10 YR 6/1) down section. Burrows are common. Sandstone layers are greenish gray (5G 6/1) to yellowish (5Y 7/6). Many have sharp basal contacts and two upper layers (Sections 1 and 3) are graded. Top 20 cm of Section 1 is drilling breccia of chert, volcaniclastic sandstone, chalk and bryozoan(?) fragments.

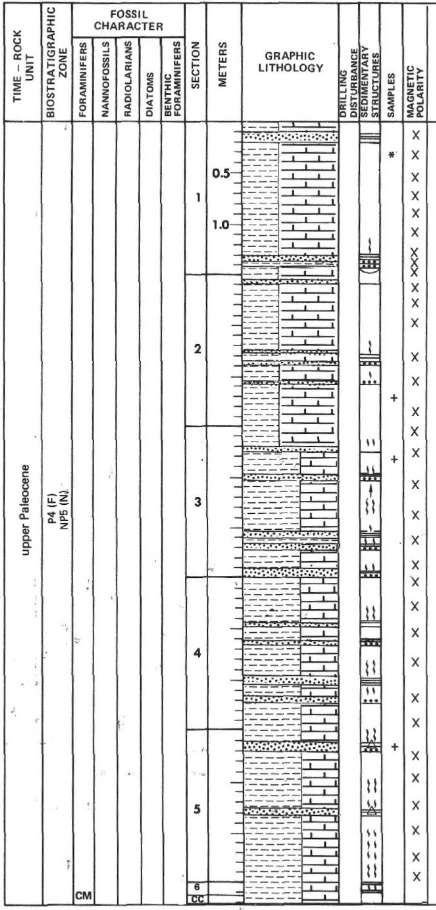
SMEAR SLIDE SUMMARY

	3-40 M	4-20 M
TEXTURE:		
Sand	25	15
Silt	55	70
Clay	20	15
COMPOSITION:		
Quartz	15	5
Clay	10	15
Volcanic glass	30	10
Palagonite	10	5
Glauconite	10	10
Carbonate unspec.	15	25
Foraminifers	–	TR
Calc. nannofossils	10	20
Sponge spicules	TR	TR
Fish remains	TR	TR

ORGANIC CARBON AND CARBONATE

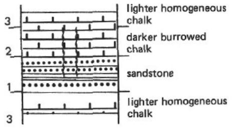
	1-82	3-100	5-95	6-12
Organic carbon	–	–	–	–
Carbonate	53	64	37	65

SITE 524 HOLE CORE 9 CORED INTERVAL 95.0–104.5 m



LITHOLOGIC DESCRIPTION

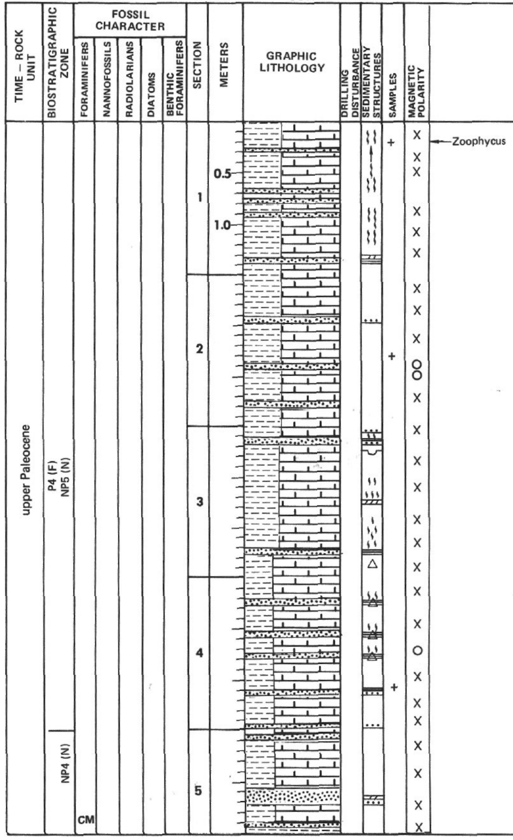
Interbedded NANNOFOSSIL MARL CLAYSTONE and (CALCAREOUS, GLAUCONITIC) VOLCANICLASTIC SANDSTONE. Marl is light gray (5Y 7/1) grading to greenish gray (5G 6/1) and bioturbated just above many sandstone layers. Sandstones are greenish gray (5G 6/1) to dark greenish gray (5G 4/1), occasionally with a yellowish tinge. Thickness ranges several mm to several cm. Many are graded and fine upward finally passing to burrowed chalk. Laminations common. Typical sequence:



ORGANIC CARBON AND CARBONATE

	2-129	3-34	5-17
Organic carbon	–	–	–
Carbonate	68	43	71

SITE 524 HOLE CORE 10 CORED INTERVAL 104.5–114.0 m



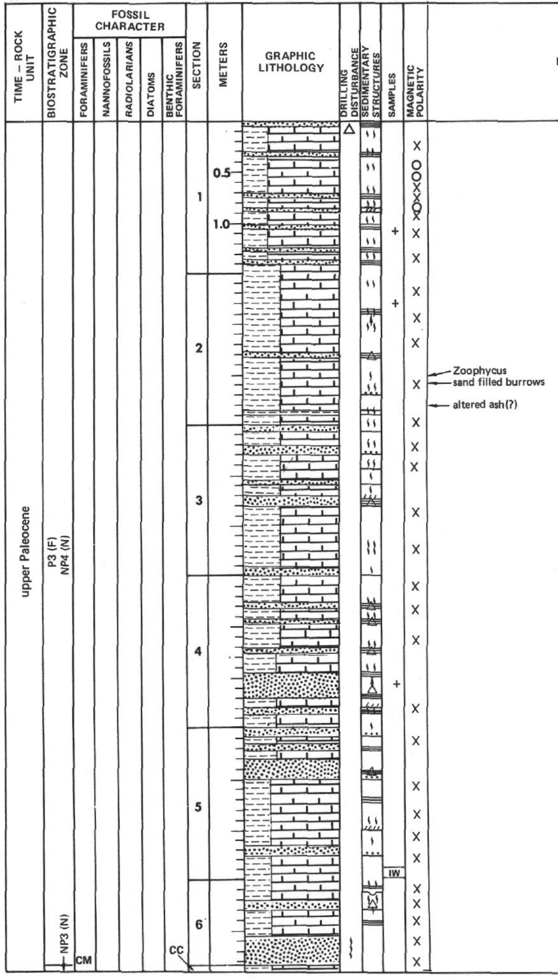
LITHOLOGIC DESCRIPTION

Interbedded light gray (N7) to darker, light olive gray (5Y 6/1) NANNOFOSSIL MARL and greenish gray (5G 8/1) to dark greenish gray (5G 4/1) SANDSTONE. Marl is darker and more intensely burrowed just above sandstone layers. Sandstone is calcareous and volcaniclastic. Sedimentary structures in sandstones as marked. Typical sequence illustrated on description form for Core 9 (i. e. grading followed upwards by laminations, then burrowed top).

ORGANIC CARBON AND CARBONATE

	1-20	2-86	4-103
Organic carbon	–	–	–
Carbonate	55	40	71

SITE 524 HOLE CORE 11 CORED INTERVAL 114.0–123.5 m



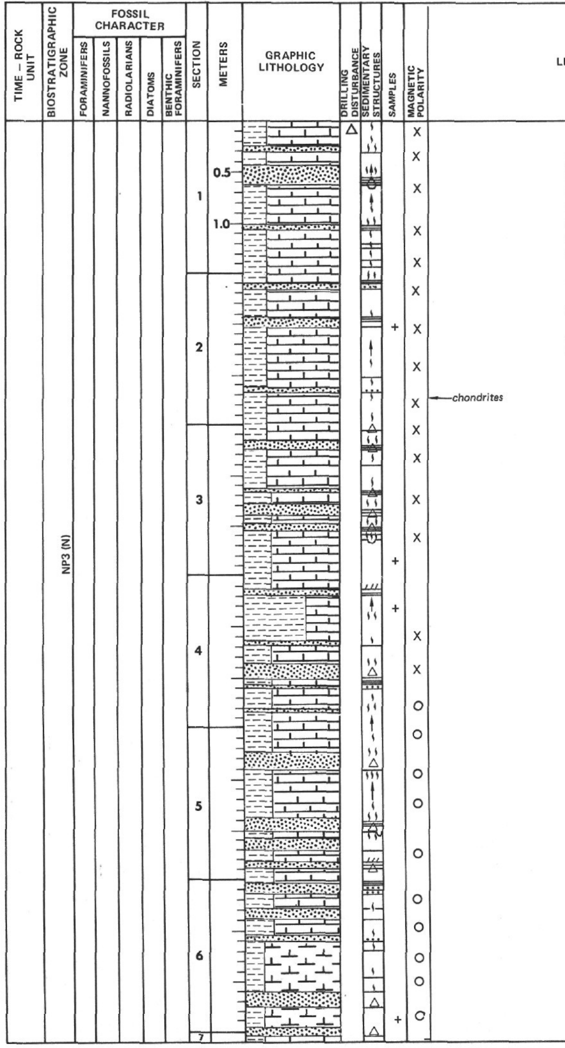
LITHOLOGIC DESCRIPTION

Interbedded greenish gray (5Y 6/1) and light gray (N7) NANNOFOSSIL MARL and light greenish gray (5GY 6/1) SANDSTONE. MARL varies from darker color and more burrowed above sandy layers, to lighter color and homogeneous below next overlying sandstone. Sandstones are very fine- to medium-grained, calcareous and volcaniclastic. They occur as thin (approximately 1–20 cm) interbeds every approximately 5–10 cm with sharp basal contacts *and gradational, burrowed tops. Many are laminated* and fine upward as marked (see Core 9 for typical sandstone sequence).

ORGANIC CARBON AND CARBONATE

	1-114	2-35	4-101
Organic carbon	–	–	–
Carbonate	77	54	74

SITE 524 HOLE CORE 12 CORED INTERVAL 123.5–133.0 m



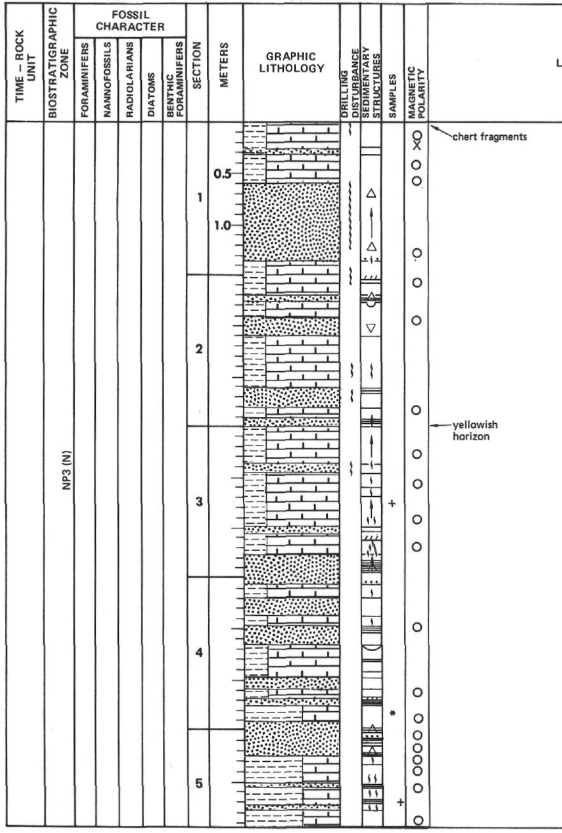
LITHOLOGIC DESCRIPTION

Interbedded NANNOFOSSIL MARL *and* SANDSTONE. Marl is light gray (N7) to greenish gray (5G 6/1) becoming darker and more intensely burrowed near top of sandstone layers. Sandstones are fine- to medium-grained and composed of greenish volcaniclastic material, carbonate bioclastic debris and glauconite(?). They occur as thin (1–20 cm) layers spaced every (2–10 cm) with sharp bases and burrowed gradational tops. Many fine upward and are laminated; few are microcross-laminated as marked.

ORGANIC CARBON AND CARBONATE

	2-56	3-137	4-34	6-134
Organic carbon	–	–	–	–
Carbonate	68	65	31	76

SITE 524 HOLE CORE 13 CORED INTERVAL 133.0–142.5 m



LITHOLOGIC DESCRIPTION

Interbedded NANNOFOSSIL MARL, CLAYSTONE, and SANDSTONE. Marl is light gray (N7) and greenish gray (5G 6/1) to brownish gray (5YR 4/1); darker colors more clay-rich. Sandstones fine- to medium-grained and compositionally and structurally similar to previous core. Sandstone at 138–150 cm, Section 2 has a yellowish (oxidized?) horizon. Sandstone at base Section3–top Section 4 has a coarse-grained base with several large bryozoan fragments. Sandstone at top Section 5 consists of two amalgamated graded or fining upward sequences.

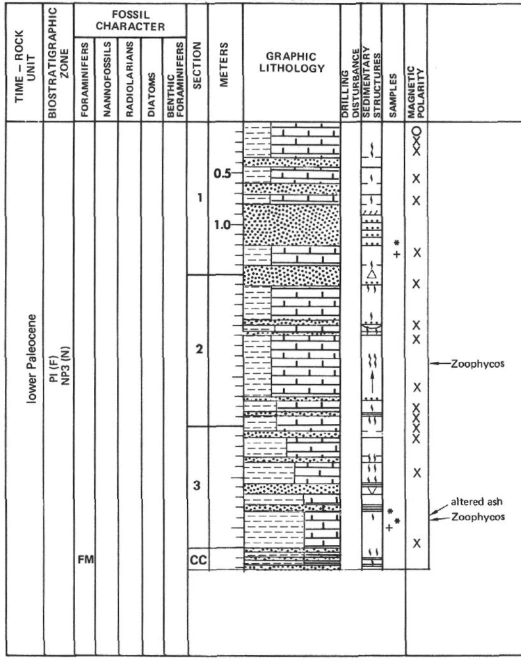
SMEAR SLIDE SUMMARY

	4-133
	D
TEXTURE:	
Sand	10
Silt	60
Clay	30
COMPOSITION:	
Clay	20
Carbonate unspec.	20
Foraminifers	5
Calc. nannofossils	55

ORGANIC CARBON AND CARBONATE

	3-75	5-77
Organic carbon	–	–
Carbonate	82	38

SITE 524 HOLE CORE 14 CORED INTERVAL 142.5–152.0 m



LITHOLOGIC DESCRIPTION

Interbedded NANNOFOSSIL MARL and SANDSTONE. Marl is light gray (N7) and dark yellowish brown (10YR 4/2) grading to burrowed and more clay-rich brownish gray (5YR 4/1) marl above sandstone layers. Sandstones are fine- to medium-grained with bioclastic carbonate and volcaniclastic debris the main compositional components as in previous core. Thin (1–40 cm) layers spaced approximately 2–10 cm apart have sharp bases and burrowed gradational tops. Parallel laminations and grading common. Four graded intervals in sandstone between 70–120 cm in Section 1. Several large Zoophycos burrows in marl as marked.

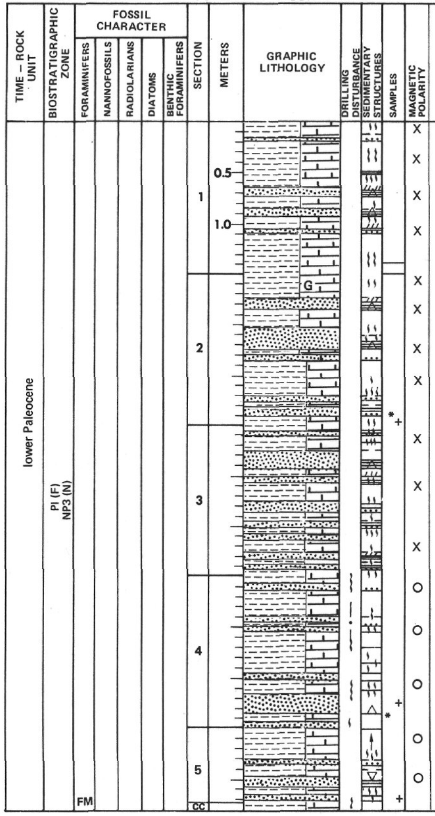
SMEAR SLIDE SUMMARY

	1-122	3-91	3-86
	D	D	M
TEXTURE:			
Sand	1	–	30
Silt	95	50	30
Clay	4	50	40
COMPOSITION:			
Feldspar	–	TR	10
Clay	5	50	40
Volcanic glss	–	TR	30
Pyrite	–	–	5
Micronodules	–	1	–
Carbonate unspec.	–	49	5
Foraminifers	1	–	–
Calc. nannofossils	94	–	10

ORGANIC CARBON AND CARBONATE

	1-129	3-90
Organic carbon	–	–
Carbonate	70	29

SITE 524 HOLE CORE 15 CORED INTERVAL 152.0–161.5 m



LITHOLOGIC DESCRIPTION

Interbedded NANNOFOSSIL MARL, CLAYSTONE, and SANDSTONE. Marl is brown (10YR 5/3), dark brown (10YR 4/3) to dark grayish brown (10YR 4/2) and moderately burrowed. Progressive color change and decrease in carbonate content from marl in previous cores. Thin (approximately 1–20 cm) sandstone interbeds are greenish gray (5GY 6/1) to medium bluish gray (5B 5/1), very fine- to medium-grained, generally graded and often laminated. Sandstones often overlain by darker burrowed marl. Thin section of sandstone in Core-Catcher has bioclastic carbonate a major component.

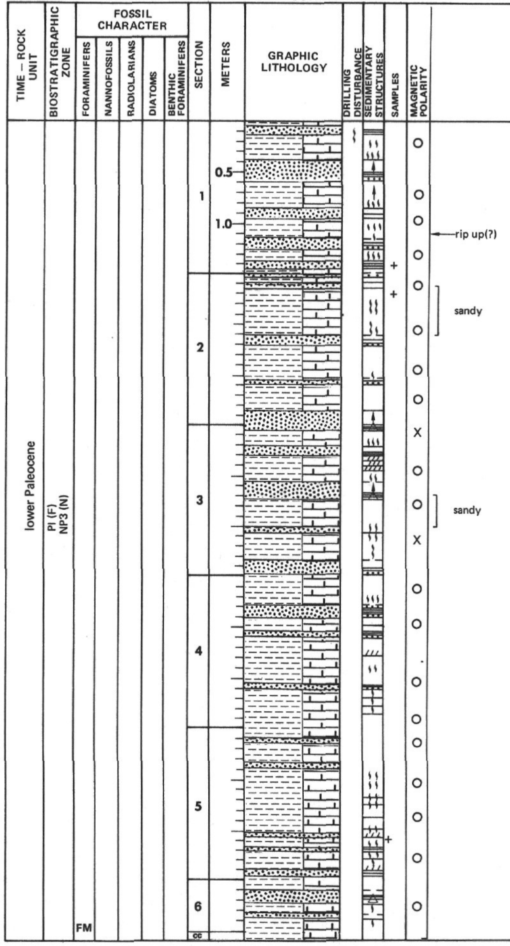
SMEAR SLIDE SUMMARY

	2-147	4-136
	D	D
TEXTURE:		
Sand	15	35
Silt	50	40
Clay	35	25
COMPOSITION:		
Quartz	5	5
Feldspar	TR	–
Heavy minerals	–	TR
Clay	50	25
Volcanic glass	10	20
Palagonite	–	5
Glauconite	5	5
Micronodules	–	5
Carbonate unspec.	10	10
Foraminifers	10	5
Calc. nannofossils	25	20
Sponge spicules	–	TR
Iron-oxides	5	–

ORGANIC CARBON AND CARBONATE

	2-148	4-120	5-70
Organic carbon	–	–	–
Carbonate	44	76	47

SITE 524 HOLE CORE 16 CORED INTERVAL 161.5–171.0 m



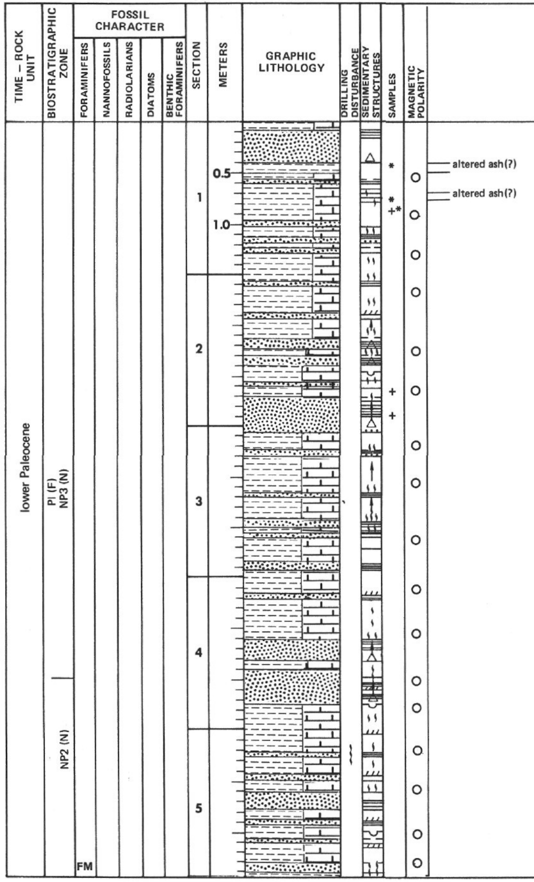
LITHOLOGIC DESCRIPTION

Interbedded brown (10YR 5/3) to dark grayish brown (10YR 4/2) NANNOFOSSIL CLAYSTONE and medium bluish gray (5B 5/1) to pale yellow (5Y 7/4) SANDSTONE. Claystone is burrowed. Sandstones are compositionally and structurally similar to those in previous core (i.e. bioclastic carbonate and dark green fragments [glauconite? or volcanic rock fragments?] common). Grading, laminations, cross-laminations and fining upward sequences common. Sand sometimes fills burrows in underlying marl and vice versa.

ORGANIC CARBON AND CARBONATE

	1-142	2-28	5-102
Organic carbon	–	–	–
Carbonate	29	44	42

SITE 524 HOLE CORE 17 CORED INTERVAL 171.0–180.5 m



LITHOLOGIC DESCRIPTION

Interbedded NANNOFOSSIL CLAYSTONE and SANDSTONE. CLAYSTONE is reddish brown (5YR 5/3) to pale brown (5YR 5/2) with increasing carbonate content. Sandstones are greenish gray (5G 6/1) to dark greenish gray. Many are laminated in parts and graded. Several are microcross-laminated. Sandstone layers are thin (1–30 cm) and spaced approximately 5–10 cm. Volcanic rock fragments and bioclastic carbonate are major components. Several greenish claystone layers occur in Section 1 and Section 3 (69–90 cm).

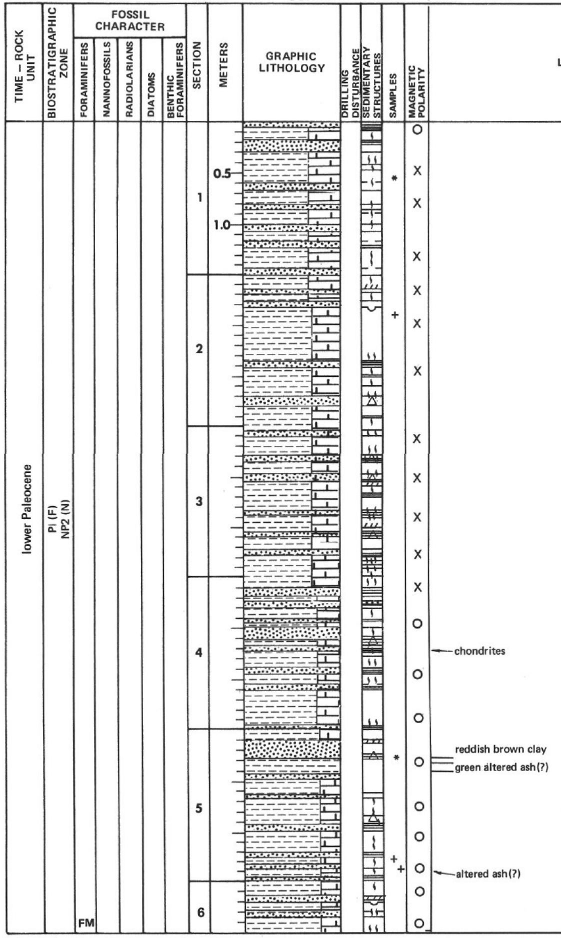
SMEAR SLIDE SUMMARY

	1-43 M	1-84 D	1-98 D
TEXTURE:			
Sand	–	5	40
Silt	80	65	30
Clay	20	30	30
COMPOSITION:			
Quartz	TR	5	–
Feldspar	–	–	5
Clay	20	20	20
Volcanic glass	80	TR	–
Palagonite	–	–	5
Micronodules	–	5	–
Carbonate unspec.	TR	10	10
Foraminifers	–	–	30
Calc. nannofossils	2	60	30

ORGANIC CARBON AND CARBOANTE

	1-89	2-117	2-148
Organic carbon	–	–	–
Carbonate	31	45	68

SITE 524 HOLE CORE 18 CORED INTERVAL 180.5–190.0 m



LITHOLOGIC DESCRIPTION

Interbedded brown (5Y 4/4) reddish brown (5Y 4/4) NANNOFOSSIL CLAYSTONE and greenish gray (5GY 5/1) to dark greenish gray (5G 4/1) SANDSTONE. CLAYSTONE is burrowed; darker colors approximately less carbonate. Sandstone is very fine- to medium-grained and occurs as thin (1–20 cm) interbeds every 1–10 cm. Sandstones contain abundant carbonate (bioclastic and cement) and dark greenish fragments (glauconite? and/or volcanic lithic fragments). Structures include parallel and microcross laminations and graded sequences as shown. Succession of structures as illustrated schematically for Core 9. Claystone is distinctly more reddish brown than previous cores; several intervals (e. g. Section 5, 25–35 cm) contain no carbonate. Green clay in Section 5 (35–40 cm) may be altered ash.

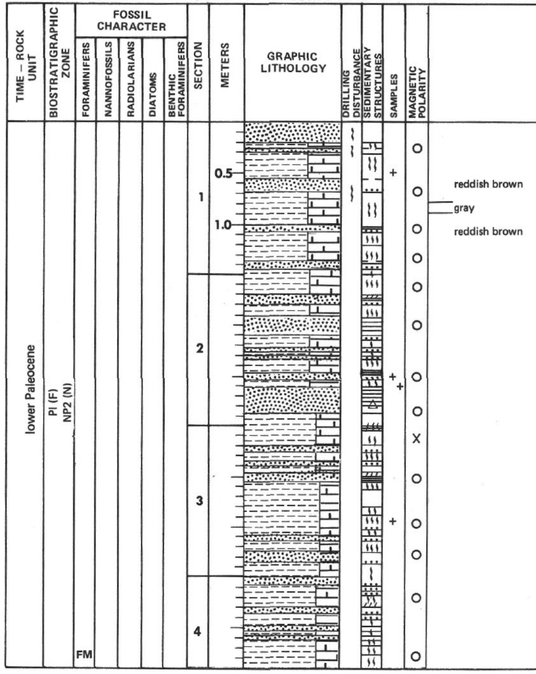
SMEAR SLIDE SUMMARY

	1-60 D	5-30 M
TEXTURE:		
Sand	70	–
Silt	20	20
Clay	10	80
COMPOSITION:		
Feldspar	20	–
Clay	10	80
Micronodules	–	TR
Carbonate unspec.	70	–
Calc. nannofossils	TR	TR
Iron-oxides	–	20

ORGANIC CARBON AND CARBONATE

	2-44	5-128	5-138
Organic carbon	–	–	–
Carbonate	36	16	5

SITE 524 HOLE CORE 19 CORED INTERVAL 190.0–199.5 m



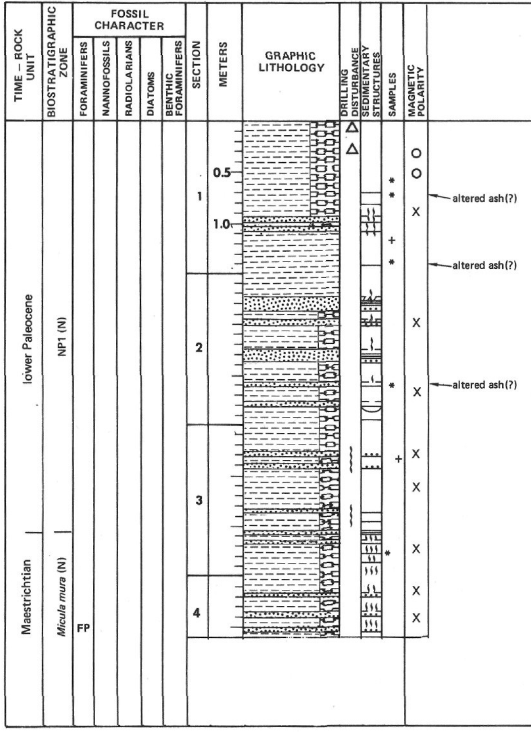
LITHOLOGIC DESCRIPTION

Interbedded reddish brown (5YR 5/3) to dark reddish brown (5YR 3/3) NANNOFOSSIL (CALCAREOUS) CLAYSTONE and medium to light bluish gray (5B 5/1–4/1), olive (5Y 5/3) and dark yellowish brown (10YR 4/4), SANDSTONE. Claystone is burrowed as marked and sandy in places. Sandstone is calcareous (yellowish brown) to volcaniclastic(?) and glauconitic(?) (bluish gray) and occurs as thin layers as in previous cores. Grading, parallel and cross-laminations as shown.

ORGANIC CARBON AND CARBONATE

	1-53	2-109	2-117	3-92
Organic carbon	–	–	–	–
Carbonate	41	26	34	14

SITE 524 HOLE CORE 20 CORED INTERVAL 199.5–209.0 m



LITHOLOGIC DESCRIPTION

Interbedded CALCAREOUS CLAYSTONE and SANDSTONE. Claystone is reddish brown to dark reddish brown (5YR 3/2–3/3) homogeneous to moderately burrowed. Several grayish blue (5PB 5/2) to pale blue (5B 6/2) layers of altered ash(?) occur in Sections 1 and 2 as marked. Claystone generally contains less carbonate than previous cores. Sandstone occurs as thin (1–20 cm) interbeds spaced about 5–20 cm. Many are graded and laminated; drilling disturbance often obscures upper contact. Carbonate content appears less and volcanic lithic/glauconite more than previous cores. Top 25 cm of core is drilling breccia of claystone and sandstone.

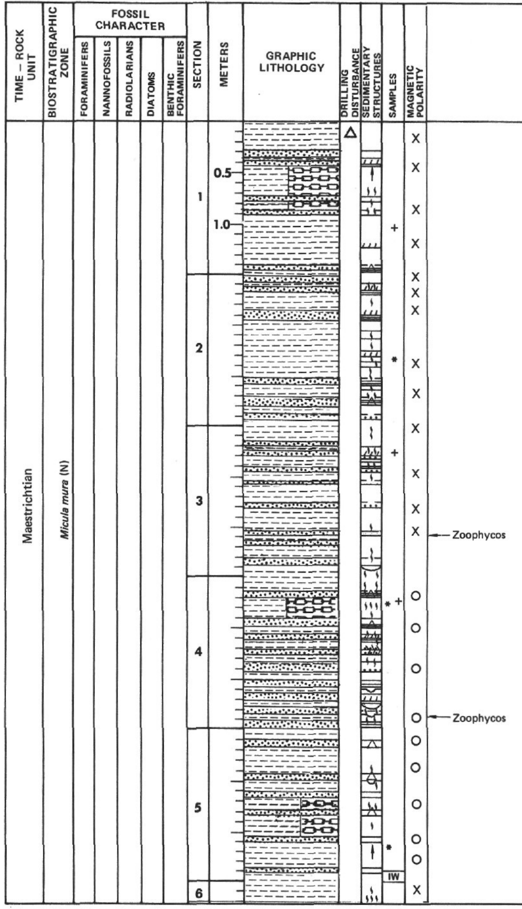
SMEAR SLIDE SUMMARY

	1-64	1-72	1-147	2-117	3-130
	D	M	M	D	D
TEXTURE:					
Sand	15	–	10	10	5
Silt	40	20	40	30	50
Clay	45	80	50	60	45
COMPOSITION:					
Quartz	5	15	10	5	5
Feldspar	TR	TR	–	–	–
Heavy minerals	TR	–	–	–	–
Clay	40	10	25	40	15
Volcanic glass	15	65	20	30	10
Palagonite	TR	–	10	5	5
Glauconite	–	5	–	–	–
Micronodules	TR	–	5	5	TR
Carbonate unspec.	20	TR	–	5	20
Foraminifers	15	–	–	–	–
Calc. nannofossils	5	TR	5	5	40
Sponge spicules	TR	5	5	–	5
Iron-oxides	–	–	20	5	–

ORGANIC CARBON AND CARBONATE

	1-117	3-34
Organic carbon	–	–
Carbonate	3	24

SITE 524 HOLE CORE 21 CORED INTERVAL 209.0–218.5 m



LITHOLOGIC DESCRIPTION

Interbedded CLAYSTONE, CALCAREOUS CLAYSTONE, and SANDSTONE. Claystone is reddish brown (5Y 4/3) to light reddish brown (10YR 5/3), (light colors = more calcareous) and moderately burrowed to homogeneous. Thin (1–10 cm) sandstone interbeds are spaced approximately 2–20 cm. Most are bluish gray to greenish gray (5GY 5/1) and volcanic-rich. Scours, grading, parallel and cross-laminations common as marked. Most tops of sandstone layers pass gradationally to burrowed claystone. Bottom contacts are sharp.

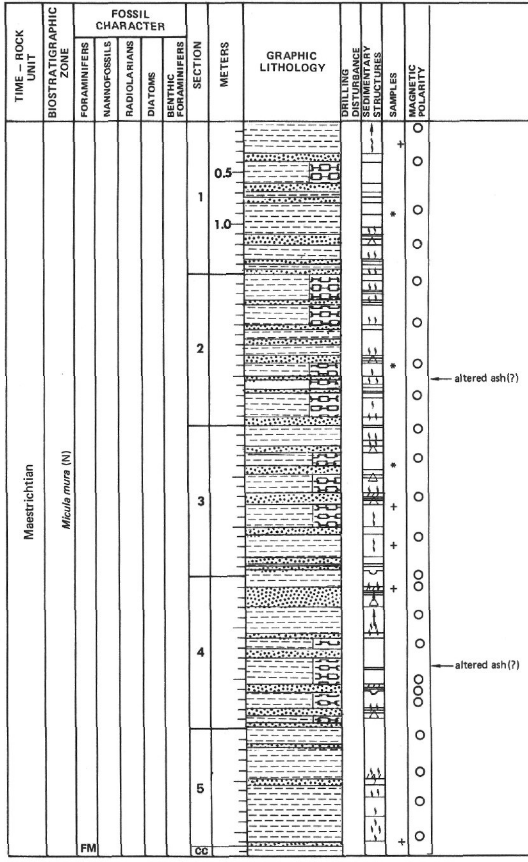
SMEAR SLIDE SUMMARY

	2-89 D	4-29 D	5-116 M
TEXTURE:			
Sand	–	5	25
Silt	20	40	10
Clay	80	55	65
COMPOSITION:			
Quartz	5	–	–
Feldspar	–	–	15
Clay	75	32	55
Volcanic glass	5	5	5
Palagonite	–	TR	–
Carbonate unspec.	5	30	15
Calc. nannofossils	5	30	10
Fe-oxides	5	5	–

ORGANIC CARBON AND CARBONATE

	1-100	3-25	4-27
Organic carbon	–	–	–
Carbonate	10	8	45

SITE 524 HOLE CORE 22 CORED INTERVAL 218.5–228.0 m



LITHOLOGIC DESCRIPTION

Interbedded CLAYSTONE, CALCAREOUS CLAYSTONE, and SANDSTONE. Claystone is reddish brown (5YR 4/3) to light reddish brown (10YR 5/3) (lighter color = more carbonate) and homogeneous to moderately burrowed as marked. Sandstone is bluish gray to greenish gray (5GY 5/1), very fine- to medium-grained with parallel and cross-laminations, grading and scours as marked. Composition, thickness, and spacing of sandstone interbeds similar to previous core.

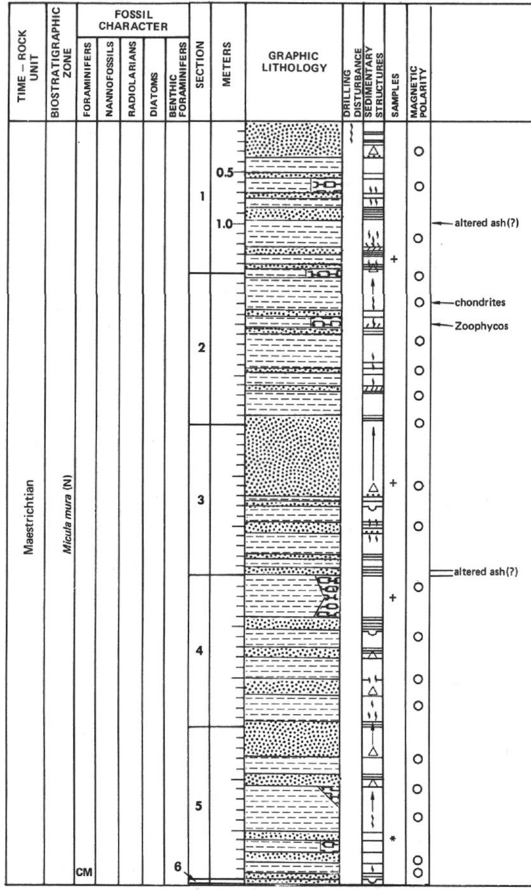
SMEAR SLIDE SUMMARY

	1-93 D	2-95 D	3-49 M
TEXTURE:			
Sand	–	2	10
Silt	25	70	70
Clay	75	28	20
COMPOSITION:			
Feldspar	10	2	TR
Heavy minerals	2	–	–
Clay	75	28	20
Volcanic glass	3	5	70
Carbonate unspec.	TR	40	–
Calc. nannofossils	TR	20	–
Iron-oxides	10	5	10

ORGANIC CARBON AND CARBONATE

	1-21	3-83	3-128	4-16	5-114
Organic carbon	–	–	–	–	–
Carbonate	8	36	16	6	9

SITE 524 HOLE CORE 23 CORED INTERVAL 228.0–237.5 m



LITHOLOGIC DESCRIPTION

Interbedded CLAYSTONE, CALCAREOUS CLAYSTONE, and SANDSTONE. Claystone is reddish brown (5YR 4/2; less carbonate) to grayish brown (2.5Y 5/2; more carbonate) and homogeneous to burrowed. Sandstone is bluish to greenish gray (5GY 5/1) occurring as thin interbeds about every 2–20 cm in claystone. Thick sandstone in base Section 2–top Section 3 is graded with laminated top; grain size from coarse (base) to very fine (top). Volcanic rock fragments and bioclastic carbonate (bryozoans) = principal components. Several green clay (altered ash?) layers in Sections 1 and 3.

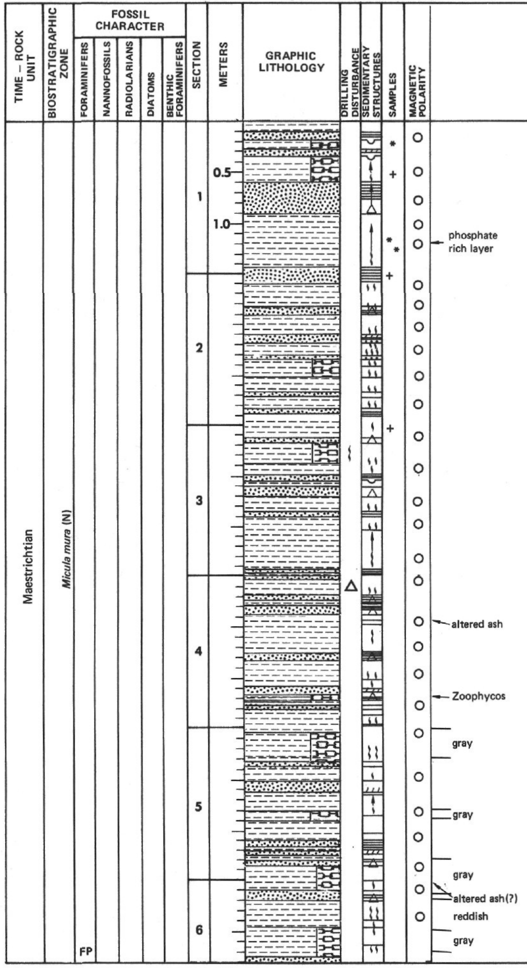
SMEAR SLIDE SUMMARY

	5-110 D
TEXTURE:	
Sand	20
Silt	70
Clay	10
COMPOSITION:	
Feldspar	5
Clay	25
Volcanic glass	70
Glauconite	TR
Carbonate unspec.	TR

ORGANIC CARBON AND CARBONATE

	1-139	3-59	4-24
Organic carbon	–	–	–
Carbonate	30	24	5

SITE 524 HOLE CORE 24 CORED INTERVAL 237.5–247.0 m



LITHOLOGIC DESCRIPTION

Interbedded reddish brown (5YR 4/3) CLAYSTONE, grayish brown (2.5Y 5/2) CALCAREOUS CLAYSTONE and dark greenish gray (5G 4/1) SANDSTONE. Claystone is burrowed. Sandstone occurs as thin interbeds in claystone as in previous core. Sedimentary structures as shown. Dark color of sandstone reflects volcaniclastic component. Several intervals of green clay (altered ash?) in Sections 4 and 5 as marked. Dusky red claystones at 130–133 cm (Section 1) and 123–124 cm (Section 4) are iron-rich.

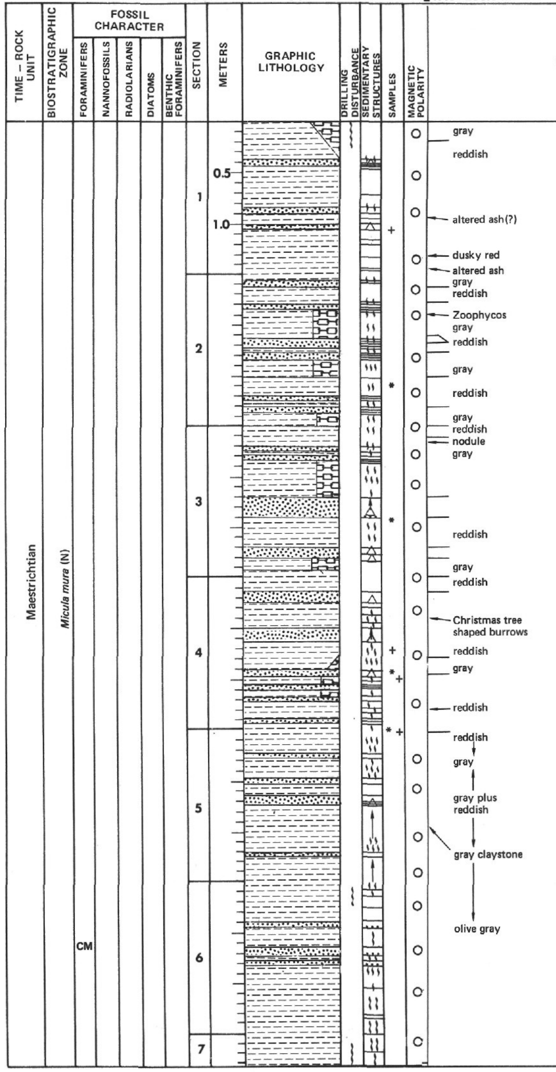
SMEAR SLIDE SUMMARY

	1-24 D	1-121 D	1-130 M
TEXTURE:			
Sand	–	–	–
Silt	10	20	10
Clay	90	80	90
COMPOSITION:			
Feldspar	2	2	2
Clay	80	80	50
Volcanic glass	5	–	3
Micronodules	5	–	–
Carbonate unspec.	6	–	–
Calc. nannofossils	2	15	–
Iron-oxides	–	–	45

ORGANIC CARBON AND CARBONATE

	1-54	2-5	3-3
Organic carbon	–	–	–
Carbonate	9	7	4

SITE 524 HOLE CORE 25 CORED INTERVAL 247.0–256.5 m



LITHOLOGIC DESCRIPTION

Interbedded CLAYSTONE, CALCAREOUS CLAYSTONE, and SANDSTONE. Claystone is dark reddish gray (5YR 4/2) and dark gray (5Y 4/1) to gray (10YR 5/1). Gray claystone generally more calcareous. Burrows common. Sandstone is dark gray (5Y 4/1) to greenish gray (5G 6/1) containing abundant volcanic debris. Sandstone interbeds are thin (1–20 cm) and spaced approximately 1–10 cm as in previous cores; many are laminated, graded, and fine upward. Several greenish clay (altered ash?) layers in Section 1. Egg-shaped clay nodule (approximately 2 cm diameter), in top Section 3. Christmas tree-shaped burrows in top Section 4 (approximately 40 cm).

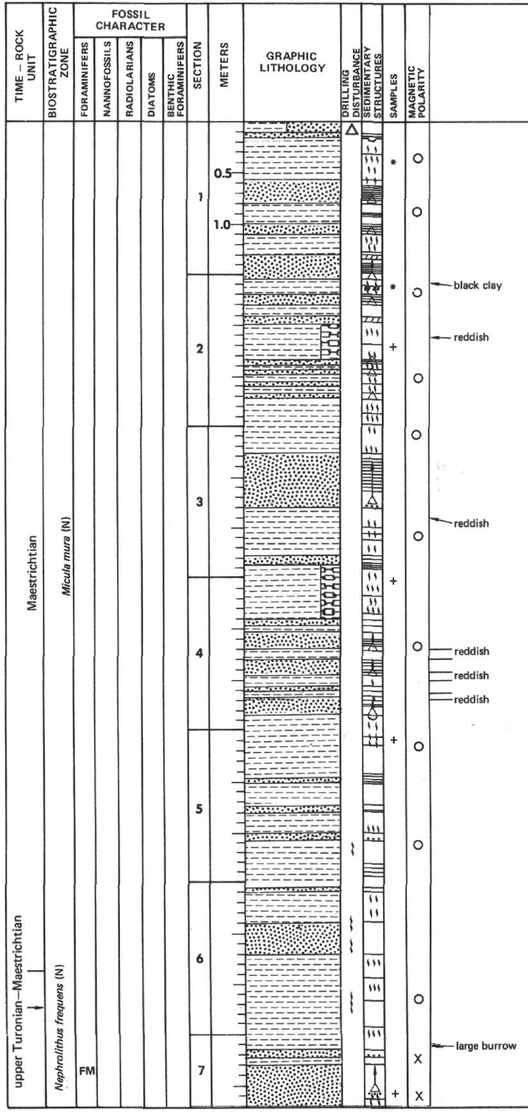
SMEAR SLIDE SUMMARY

	2-117 D	3-98 D	4-94 D	5-7 D
TEXTURE:				
Sand	10	–	–	10
Silt	40	30	20	30
Clay	50	70	80	60
COMPOSITION:				
Quartz	5	10	5	10
Feldspar	–	TR	TR	TR
Clay	30	55	70	65
Volcanic glass	15	15	15	20
Palagonite	5	–	TR	–
Micronodules	TR	5	–	TR
Carbonate unspec.	20	5	10	10
Calc. nannofossils	20	–	TR	5
Sponge spicules	5	TR	–	TR
Fish remains	TR	–	–	–

ORGANIC CARBON AND CARBONATE

	1-110	4-70	4-96	5-9
Organic carbon	–	–	–	–
Carbonate	3	9	1	6

SITE 524 HOLE CORE 26 CORED INTERVAL 256.5–266.0 m



LITHOLOGIC DESCRIPTION

Interbedded CLAYSTONE, CALCAREOUS CLAYSTONE, and SANDSTONE. Claystone is gray (10YR 5/1) and dark gray (10YR 4/1) to dark reddish gray (5YR 4/2) and dark brown (7.5YR); lighter colors generally more calcareous. Sandstone is greenish black (5G 2/1) to olive black (5Y 2/1) and dark greenish gray (5G 4/1) and volcaniclastic. Sedimentary structures and bedding characteristics similar to previous core (as marked).

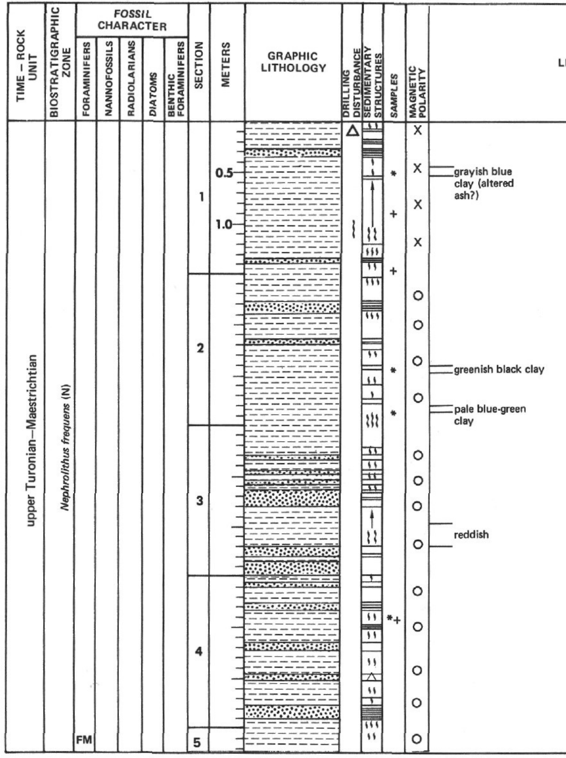
SMEAR SLIDE SUMMARY

	1-40 D	2-11 M
TEXTURE:		
Sand	15	–
Silt	10	20
Clay	75	80
COMPOSITION:		
Quartz	5	–
Feldspar	5	–
Clay	70	80
Volcanic glass	15	–
Micronodules	TR	–
Carbonate unspec.	5	–
Calc. nannofossils	TR	–
Sponge spicules	TR	–
Volcanic rock fragments	–	15

ORGANIC CARBON AND CARBONATE

	2-70	4-5	5-10	7-53
Organic carbon	–	–	–	–
Carbonate	23	29	12	5

SITE 524 HOLE CORE 27 CORED INTERVAL 266.0–275.5 m



LITHOLOGIC DESCRIPTION

Interbedded CLAYSTONE, CALCAREOUS CLAYSTONE, and VOLCANICLASTIC SANDSTONE. Claystone is dark gray (2.5Y 4/1) and gray (5YR 5/1, 10YR 6/1) to reddish gray (5YR 5/2). Carbonate content is variable; burrows common. Sandstones contain abundant dark greenish gray (5G 4/1) to greenish black (5GY 2/1) volcanic debris. Top of *core has fewer interbeds than previous cores although* frequency increases again down core. Bedding characteristics (i. e. laminations, grading) similar to previous core. Most sandstones are very fine-grained. Several grayish blue, pale blue green and greenish black claystone layers (altered ash?) in Sections 1 and 2 as marked.

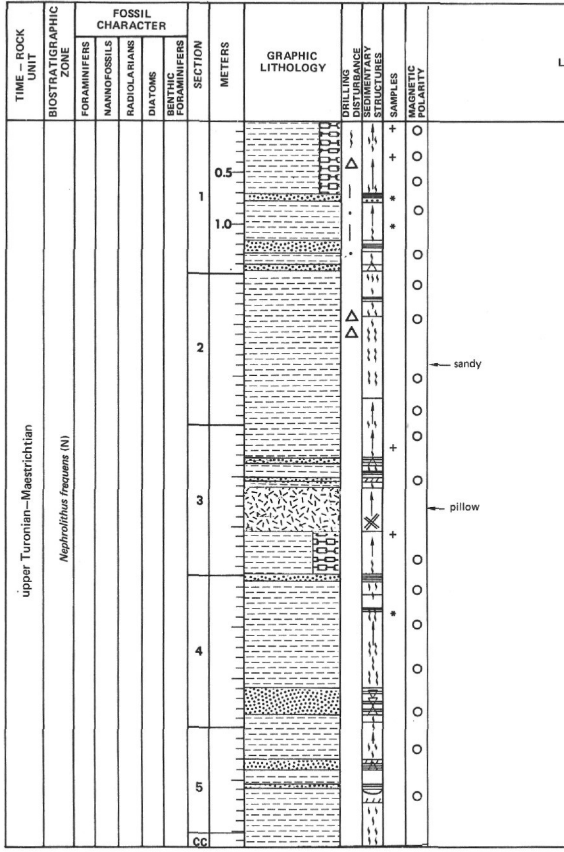
SMEAR SLIDE SUMMARY

	1-51 M	2-94 M	2-131 M	4-47 D
TEXTURE:				
Sand	10	–	–	5
Silt	20	20	10	25
Clay	70	80	90	70
COMPOSITION:				
Quartz	10	5	5	2
Feldspar	5	5	TR	3
Heavy minerals	–	5	–	–
Clay	55	75	85	–
Volcanic glass	15	5	5	–
Palagonite	5	–	5	–
Micronodules	TR	TR	–	–
Carbonate unspec.	5	–	–	–
Calc. nannofossils	5	–	–	–
Sponge spicules	TR	–	–	–
Fibrous mineral?	–	5	–	–

ORGANIC CARBON AND CARBONATE

	1-90	1-145	4-47
Organic carbon	–	–	–
Carbonate	11	3	7

SITE 524 HOLE CORE 28 CORED INTERVAL 275.5–285.0 m



LITHOLOGIC DESCRIPTION

Interbedded CLAYSTONE, CALCAREOUS CLAYSTONE, VOLCANICLASTIC SANDSTONE, and BASALT. Claystone is light gray (5Y 6/1), olive gray (5Y 4/1) to grayish brown (10YR 5/2) and burrowed throughout. Sandstone is greenish black (5G 2/1) with abundant volcanic debris; many bluish green grains are altered volcanic lithic fragments. *Frequency less and thickness somewhat* greater than sandstone interbeds of previous cores. Layer between 107–131 cm, Section 4 has several reversely graded zones above normal graded intervals. Basalt in Section 3 is dark gray and aphyric with several 5 mm-thick fine-grained (aphanitic) zones at 80 cma nd 99 cm. Abundant calcite- and smectite-filled veins and vesicles. (See igneous rock form for more complete description of basalt.)

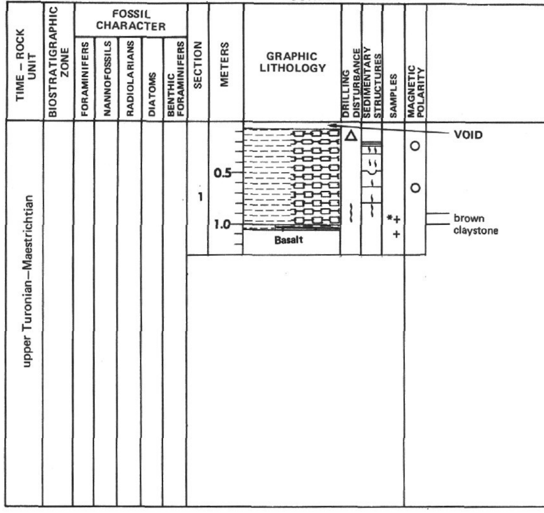
SMEAR SLIDE SUMMARY

	1-84 D	1-108 D	4-47 D
TEXTURE:			
Sand	–	–	5
Silt	30	50	25
Clay	70	50	70
COMPOSITION:			
Quartz	–	–	5
Heavy minerals	–	–	5
Clay	70	38	70
VOlcanic glass	25	–	10
Micronodules	5	2	TR
Carbonate unspec.	–	40	TR
Calc. nannofossils	–	20	10

ORGANIC CARBON AND CARBONATE

	1-8	1-34	3-26	3-117
Organic carbon	–	–	–	–
Carbonate	27	1	13	26

SITE 524 HOLE CORE 29 CORED INTERVAL 285.0–289.0 m



LITHOLOGIC DESCRIPTION

CALCAREOUS CLAYSTONE, olive gray (5YR 5/4) to dark grayish brown (10YR 4/2), burrowed with thin (1–2 cm) interbeds of greenish gray VOLCANICLASTIC SANDSTONE. Dark brown (5YR 3/4) calcareous claystone occurs just above a light gray (10YR 7/1) CLAYEY LIMESTONE *which directly* overlies BASALT.

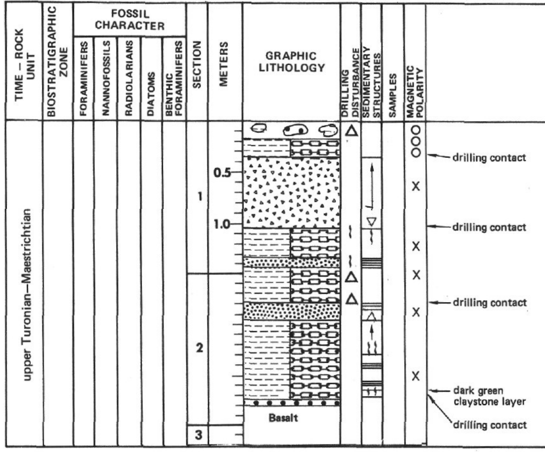
SMEAR SLIDE SUMMARY

	1-94 M
TEXTURE:	
Sand	10
Silt	10
Clay	80
COMPOSITION:	
Clay	75
Volcanic glass	10
Carbonate unspec.	10
Calc. nannofossils	5

ORGANIC CARBON AND CARBONATE

	1-96	1-112
Organic carbon	–	–
Carbonate	8	61

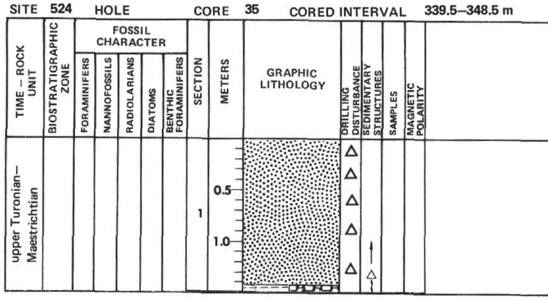
SITE 524 HOLE CORE 32 CORED INTERVAL 303.5–312.5 m



LITHOLOGIC DESCRIPTION

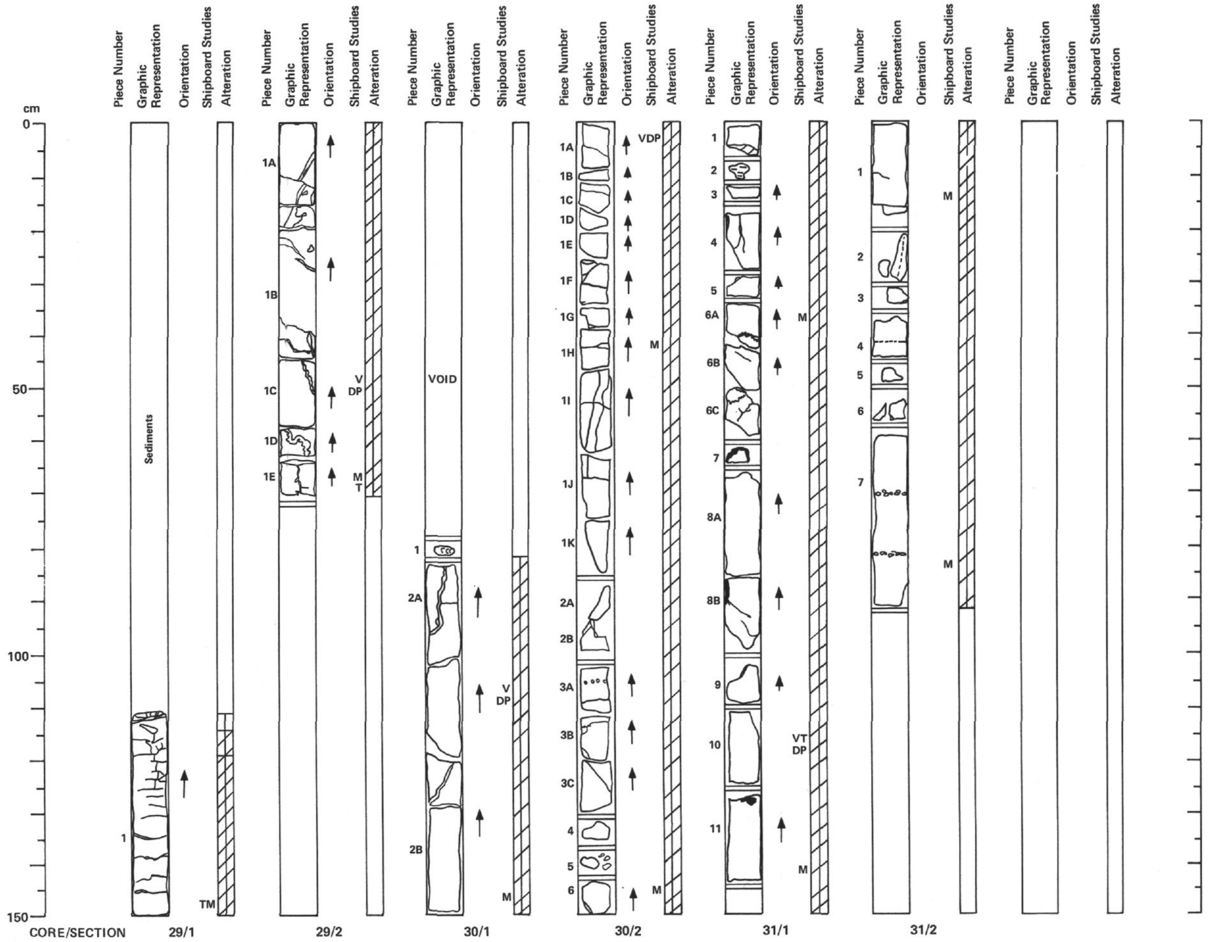
Interbedded CALCAREOUS CLAYSTONE, VOLCANICLASTIC SANDSTONE, and VOLCANIC BRECCIA. Claystone is olive gray (5Y 4/1) and burrowed; dark green claystone layer with distinct burrows occurs at 104 cm, Sec. 2. Sandstone is greenish black (5G 2/1), laminated and sometimes graded. Volcanic breccia is apparently reversely graded with a large aphanitic fragment near its top and abundant angular lithic fragments of scoriaceous basalt. BASALT at base of Section 1 is very fine-grained and vesicular at upper contact; rock is altered brown and vesicles flattened and elongated parallel to contact. Grain size increases to very coarse at base. Drilling breccia at top of core.

SITE 524 HOLE CORE 35 CORED INTERVAL 339.5–348.5 m



LITHOLOGIC DESCRIPTION

VOLCANICLASTIC SANDSTONE, dark greenish gray (5G 4/1), broken by drilling; very poorly sorted fine- to very coarse-grained composed mostly of angular basalt fragments set in a green clayey matrix, *with zeolites. Many fragments altered to clay.* Grain size fines upward in one piece. Grayish brown (2.5YR 5/2) CALCAREOUS CLAYSTONE occurs at base of core.



SITE 524, CORE 28, SECTION 3, 279.1–279.6 m

Macroscopic Description

See sediment description form.

Thin Section Summaries

Contact Zone below claystone at 61 cm, Sec. 3: Dark brown glass with tiny (~0.01 mm and less) spinifex plagioclase (hollow skeletal, swallow tails) microlites rimmed with spherulitic mantles. Spherulite zone noted away from contact. Section too thick and glass too dark for detailed examination (problem with plucking).

Interior of pillow at 71 cm, Sec. 3: Slight phyric basalt with sparse (<1%) relatively large plagioclase phenocrysts (0.7–1.6 mm) set in a hyalopilitic fine quench matrix composed of Na-rich (R. I. < 1.55), skeletal (hollow cores with smectite filling and crude swallowtails), elongate (0.04–0.5 mm, L/W = 1/3–1/35) plagioclase microlites; abundant ilmenite dendrite needles (0.001–0.004 mm thick and 0.04–0.2 mm long) in rectangular boxwork pattern; more sparse magnetite cubes and octahedra in two generations (first = 0.02–0.25 mm, second = 0.004–0.015 mm); skeletal pyroxene(?) anhedral (~ 0.006 mm); and hollow skeletal apatite euhedra (0.004–0.008 mm). All these in a mesostasis of pale green smectite or chlorite (devitrified glass?). Plagioclase phenocrysts about half replaced by inclusion-filled albite and some smectite or chlorite. Approximate mode: plagioclase phenocrysts <1, plagioclase microlites 30–40, ilmenite 10–15, magnetite 3–5, clinopyroxene 3–5, apatite 1–3, devitrified glass 40–50.

Shipboard Studies

Sample	D	P	V⊥	V∥	NRM1	NRM2	S. I.
Sec. 3, 71 cm	–	–	–	–	32.014	–38.6	–36
Sec. 3, 110 cm	–	–	–	–	24.443	–49.1	–45

SITE 524, CORE 29, SECTIONS 1–2, 286.1–287.2 m

MAJOR ROCK TYPES – BASALT (or DIABASE), CLAYSTONE, SANDSTONE

Macroscopic Description

Basalt (or Diabase) – Dark gray, aphyric. Sec. 1 has numerous calcite-filled veins arranged perpendicular to core axis and spaced every 2–3 cm. Calcite veins in Sec. 2 more irregular, some with green clay rims.

Sandstone and Claystone – see sediment description form.

Thin Section Summaries

Section 1, Piece 1: Fine- to medium coarse-grained aphyric olivine(?) basalt (or diasbase) with intergrown intersertal texture, composed of dominant tabular, weakly compositionally zoned plagioclase anhedra (0.05–0.3 mm, $An_{43-?}$, R. I. <1.55) and subordinate intergranular, mostly subhedral grains of clinopyroxene (0.005–0.1 mm), opaque minerals (0.005–0.35 mm) and apatite needles (0.01–0.15 mm, L/W ~1/12), with intersertal patches of greenish brown smectite. There are sparse smectite patches that appear to be pseudomorphs of small (0.05–0.1 mm) euhedral olivine grains. Note: Sparse (<1%) clinopyroxene microphenocrysts (0.15–0.25 mm). Approximate mode: plagioclase 35–45, clinopyroxene 15–20, opaques 15–20, devitrified glass (smectite) 15–20, apatite 1–2, olivine(?) 2–3.

Section 2, Core-Catcher: Coarse-grained to very coarse-grained basalt or diabase, composed of anhedral to subhedral, strongly zoned (An_{45-17}) plagioclase (0.09–0.95 mm) with intergranular clinopyroxene ($2V_z$~55–60) (0.01–0.15 mm) and opaques (magnetite 0.01–0.35 mm and illmenite) and intersertal olive brown smectite (high birefringence). Abundant (for this mineral) apatite (3–5%, 0.02–0.35 mm) of stubby to needle prismatic habit, often with hollow center. Apatite is euhedral and cuts across plagioclase. Ilmenite and magnetite are sometimes hollow skeletal.

Shipboard Studies

Sample	D	P	V⊥	V∥	NRM1	NRM2	S. I.
Sec. 1, Piece 1	–	–	–	–	53.485	–44.7	–74
Sec. 2, Piece 1C	2.70	14.0	4.33	4.65	–	–	–
Sec. 2, Piece 1E	–	–	–	–	52.067	–43.4	–71

SITE 524, CORE 30, SECTIONS 1–2, 289.0–292.0 m

MAJOR ROCK TYPE – BASALT (or DIABASE)
MINOR ROCK TYPE – CALCAREOUS CLAYSTONE

Macroscopic Description

Basalt (or Diabase) – Dark gray, aphyric, coarse-grained basalt or diabase. Even grained, massive with widely spaced fractures (2–10 cm). Fractures in Piece 2A–B (Sec. 1) filled with calcite and minor pyrite; some lined with green clay. Fractures in Pieces 1A, 1C, and 1I–K (Sec. 2) parallel lines of irregular vesicles. Pyrite or blue green clay lines vesicles.

Calcareous Claystone – Piece 1 (Sec. 1) is olive gray calcareous claystone with a large horizontal zoophycos burrow.

Shipboard Studies

Sample	D	P	V⊥	V∥	NRM1	NRM2	S. I.
Sec. 1, Piece 2A	2.73	11.0	4.57	4.76	–	–	–
Sec. 1, Piece 2B	–	–	–	–	55.769	–57.8	–76
Sec. 2, Piece 1A	2.74	11.2	4.64	5.15	–	–	–
Sec. 2, Piece 1H	–	–	–	–	32.663	–64.4	–79
Sec. 2, Piece 6	–	–	–	–	43.596	–49.4	–73

SITE 524, CORE 31, SECTIONS 1–2, 294.5–296.9 m

MAJOR ROCK TYPE – BASALT (or DIABASE)
MINOR ROCK – CALCAREOUS CLAYSTONE

Macroscopic Description

Basalt (or Diabase) – Dark gray, aphyric, coarse, even-grained basalt *(or diabase) with rare fractures filled with green clay. Small pyrite* crystals in fractures and in discolored zones. Moderate alteration.

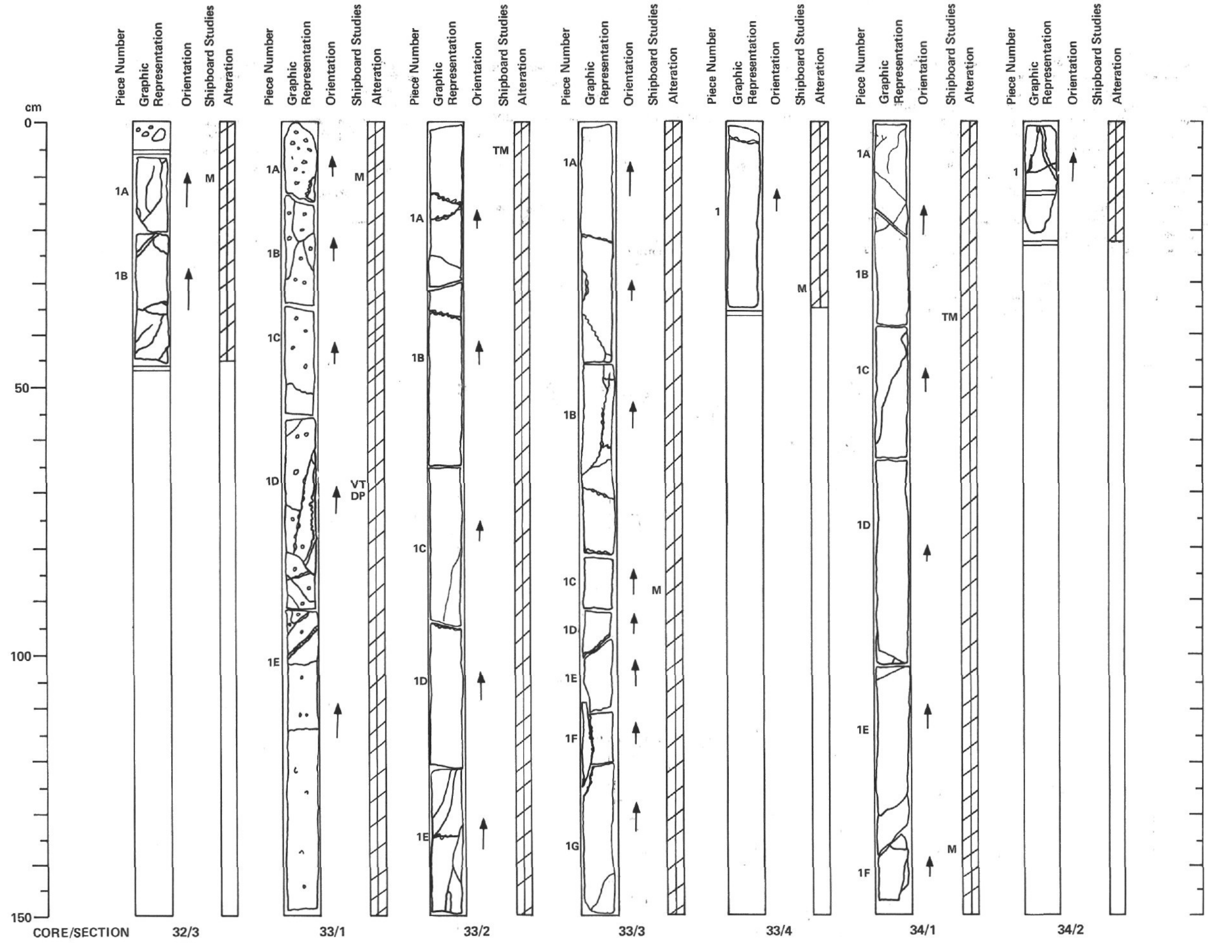
Calcareous Claystone – Piece 2 (Sec. 1) is reddish brown calcareous claystone.

Thin Section Summary

Section 1, Piece 10: Rock is very similar in texture and mineralogy to Core 29, Sec. 2, Core-Catcher, but slightly coarser and plagioclase grains show beautifully developed epitaxial mantles of alkali feldspar or oligoclase, optics (Ax. Pl⊥ 010, $2V_x$ <60°) indicate 3 possibilities, in order of likelihood: 1) anorthoclase or Na-sanidine, 2) oligoclase, and 3) K-rich sanidine. Choice 1 is favored because of sharply defined mantle boundary, oligoclase should give more gradational transition, and smaller R. I. difference than would be expected with K-rich sanidine.

Shipboard Studies

Sample	D	P	V⊥	V∥	NRM1	NRM2	S. I.
Sec. 1, Piece 6A	–	–	–	–	28.924	–56.8	–65
Sec. 1, Piece 10	2.78	11.8	4.46	4.50	–	–	–
Sec. 1, Piece 11	–	–	–	–	26.664	–41.6	–
Sec. 2, Piece 1	–	–	–	–	29.817	–65.9	–66?
Sec. 2, Piece 7	–	–	–	–	30.548	–38.6	–50



SITE 524, CORE 32, SECTION 3, 306.3–310.8 m

MAJOR ROCK TYPE – BASALT (or DIABASE)

Macroscopic Description

Basalt (or Diabase) – Dark gray, aphyric and coarse-grained. Grain size coarsens slightly downward. Calcite-filled fractures common with sporadic pyrite mineralization. Finely (< 2 mm) and very sparsely ($\ll$1%) vesicular with irregular vesicles filled with dark green clay.

Shipboard Studies

Sample	D	P	V⊥	V‖	NRM1	NRM2	S. I.
Sec. 3, Piece 1A	–	–	–	–	105.38	45.2	47

SITE 524, CORE 33, SECTIONS 1–4, 327.5–332.2 m

MAJOR ROCK TYPE – BASALT (or DIABASE)

Macroscopic Description

Basalt (or Diabase) – Dark gray, aphyric, very coarse-grained. Calcite-filled veinlets marked with sporadic pyrite common; other veinlets filled with dark green clay. Finely porphyritic with augite(?) or olivine scattered throughout. Piece 1A in Sec. 1 and 2 most vesicular with vesicles decreasing down section. Possible flow unit contact in Piece 1E Sec. 1 (dipping at 95–101 cm) where above the basalt coarsens downward toward contact and below basalt fines upward toward contact. Lower unit most likely a sill. Very coarse-grained texture in center of Sec. 3. Basal unit contact in Piece 1, Sec. 4 at 4 cm. Upper unit grades downward from medium-grained to very fine-grained and strongly microporphyritic texture in zone < 1 cm from contact (chilled border). Lower unit coarse up to contact. Interpreted as multiple sill.

Thin Section Summaries

Section 1, Piece 1D: Coarse- to very coarse-grained, phyric olivine(?), diabase with seriate intergranular and subophitic texture. Rock has very coarse (0.5–3.8 mm) plagioclase phenocrysts (An_{65-55}), most complexly twinned and contain slightly zoned core with an altered (smectite) border and an outer clear strongly zoned rim. These phenocrysts, together with zoned euhedral to subophitic clinopyroxene microphenocrysts (0.75 mm) grade into a groundmass of zoned plagioclase (0.01–0.5 mm, An_{62-47}), intergranular clinopyroxene (0.005–0.01 mm), and magnetite ilmenite opaque minerals (0.004–0.12 mm). There are possible smectite pseudomorphs of euhedral olivine (0.09–0.3 mm). All clinopyroxene appears to be normal augite (colorless in thin section, $2V_z \sim 60°$). Smaller (0.005–0.04) most abundant clinopyroxene grains dominate pyroxene total and occur in peculiar aggregated clusters, reminiscent of metamorphic textures. Approximate mode: plagioclase 30–40, clinopyroxene 30–40, opaques 15–20, smectite 5–10, olivine(?) 1–3.

Section 2, Piece 1A: Coarse- to very coarse-grained phyric diabase, similar to Core 33, Sec. 1, 69–72 cm Piece 1D in mineralogy and textures, but with distinctive minor differences:

1.) Grain sizes

	This rock	33-1, 69–72 cm, Piece 1D
plagioclase phenocrysts	0.5–1.1	0.5–3.8
clinopyroxene phenocrysts	0.5–1.1	0.5–0.75
opaques	0.02–0.3	0.004–0.12

2.) Plagioclase is considerably altered to smectite in cores of grains.
3.) Opaques tend to aggregate into clots and very elongate stringers.
4.) Small (0.01–0.04 mm) clinopyroxene granules in tight clusters, many of which look very much like pseudomorphs of olivine (0.3–0.4 mm long). REACTION RELN?
5.) Sparse green chlorite in what look to be altered pseudomorphs of olivine.

Plagioclase composition is similar to that of rock Core 33, Sec. 1, 69–72 cm Piece 1D, e.g. An_{65-30}.

Shipboard Studies

Sample	D	P	V⊥	V‖	NRM1	NRM2	S. I.
Sec. 1, Piece 1A	–	–	–	–	36.36	39.0	50
Sec. 1, Piece 1D	2.81	9.8	5.15	5.29	–	–	–
Sec. 2, Piece 1A	–	–	–	–	33.712	19.0	64
Sec. 3, Piece 1C	–	–	–	–	9.446	–32.3	58
Sec. 4, Piece 1	–	–	–	–	70.87	24.6	49

SITE 524, CORE 34, SECTIONS 1–2, 332.5–334.2 m

MAJOR ROCK TYPE – BASALT (or DIABASE)

Macroscopic Description

Basalt (or Diabase) – Dark gray, aphyric as in Core 33 with similar calcite-pyrite-clay-filled fractures and veins.

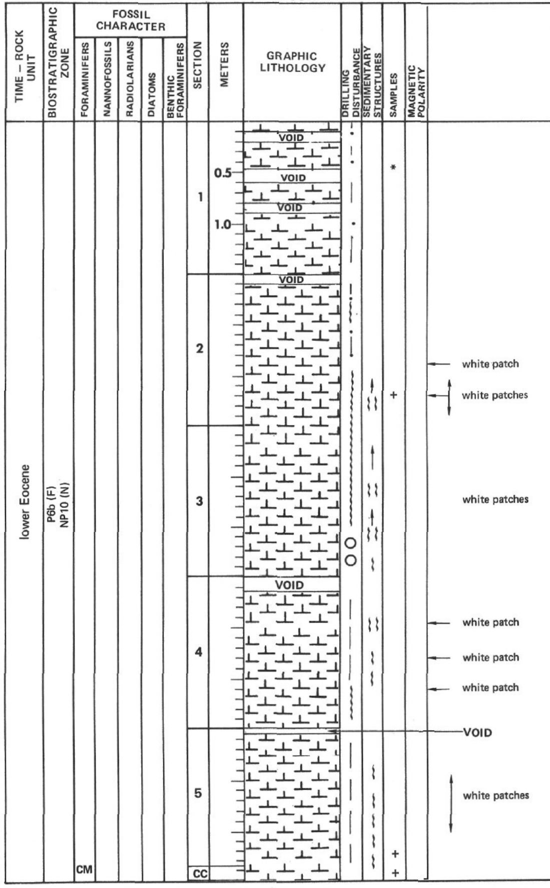
Thin Section Summary

Sec. 1, Piece 1B: Texture and mineralogy identical to Piece 1D, Sec. 1, Core 33.

Shipboard Studies

Sample	D	P	V⊥	V‖	NRM1	NRM2	S. I.
Sec. 1, Piece 1B	–	–	–	–	30.623	34.4	55
Sec. 1, Piece 1F	–	–	–	–	71.29	19.6	58

SITE 524 HOLE A CORE 1 CORED INTERVAL 28.5–38.0 m



LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very pale brown (10YR 8/3), homogeneous to moderately burrowed. Scattered white patches (burrows) have grayish haloes.

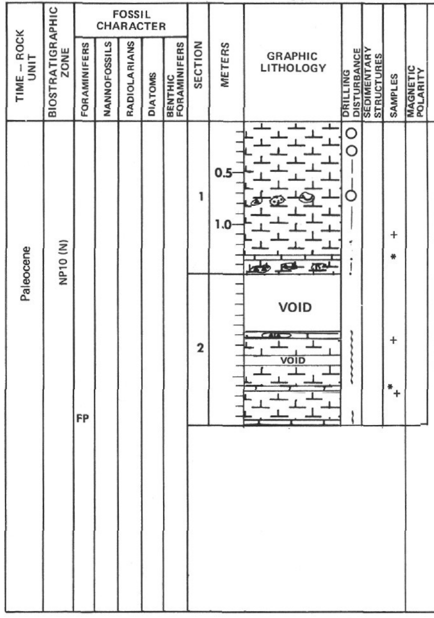
SMEAR SLIDE SUMMARY

	1-40 D
TEXTURE:	
Sand	5
Silt	90
Clay	5
COMPOSITION:	
Quartz	TR
Clay	TR
Palagonite	TR
Carbonate unspec.	5
Foraminifers	10
Calc. nannofossils	85

ORGANIC CARBON AND CARBONATE

	2-120	5-120	CC, 11
Organic carbon	–	–	–
Carbonate	88	89	78

SITE 524 HOLE A CORE 2 CORED INTERVAL 38.0–47.5 m



LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very pale brown (10YR 7/3) homogeneous, deformed by drilling. CHERT, SANDSTONE and VOLCANIC ROCK FRAGMENTS occur in Section 1. Sandstone is calcite-cemented quartz sand. Ooze partially lithified to chalk in Section 1 and to limestone in Section 2. Limestone at 50 cm, Section 2 has indurated chert nodule. Foraminifer ooze occurs in Section 2.

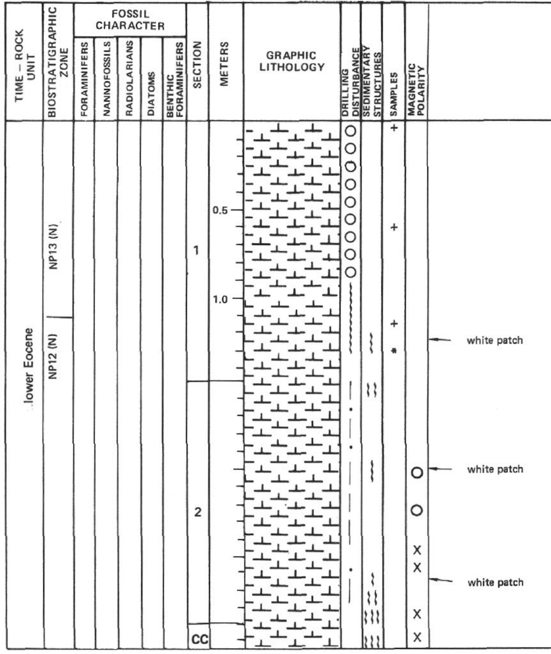
SMEAR SLIDE SUMMARY

	1-132 D	2-114 M
TEXTURE:		
Sand	1	20
Silt	90	70
Clay	9	10
COMPOSITION:		
Quartz	5	TR
Feldspar	TR	TR
Clay	5	5
Volcanic glass	10	TR
Carbonate unspec.	10	15
Foraminifers	10	20
Calc. nannofossils	60	60
Sponge spicules	TR	–

ORGANIC CARBON AND CARBONATE

	1-110	2-65	2-114
Organic carbon	–	–	–
Carbonate	86	67	81

SITE 524 HOLE B CORE (HPC) 1 CORED INTERVAL 0.0–3.0 m



LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very pale brown (10YR 8/4–10YR 7/3) becoming darker (brownish yellow, 10YR 6/6) near base of core. Burrows (white patches) common. Intense drilling disturbance.

SMEAR SLIDE SUMMARY

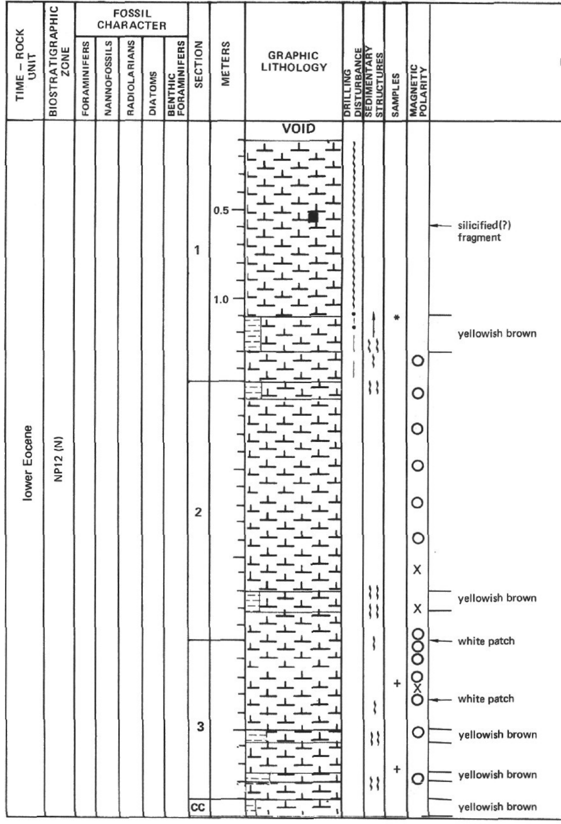
	1-130 M
TEXTURE:	
Sand	–
Silt	10
Clay	90
COMPOSITION:	
Quartz	TR
Mica	TR
Clay	90
Volcanic glass	5
Palagonite	5
Micronodules	TR
Carbonate unspec.	TR

(Smear slide of HCl-treated residue)

ORGANIC CARBON AND CARBONATE

	1-8	1-60	1-111
Organic carbon	–	–	–
Carbonate	70	67	92

SITE 524 HOLE B CORE (HPC) 2 CORED INTERVAL 3.0–7.5 m



LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very pale brown (10YR 7/4) and MARLY NANNOFOSSIL OOZE, yellowish brown (10YR 5/6). Burrowed, especially where color changes, with scattered white patches. Black and pale brown (silicified?/phosphatic?) rock fragment in Section 1.

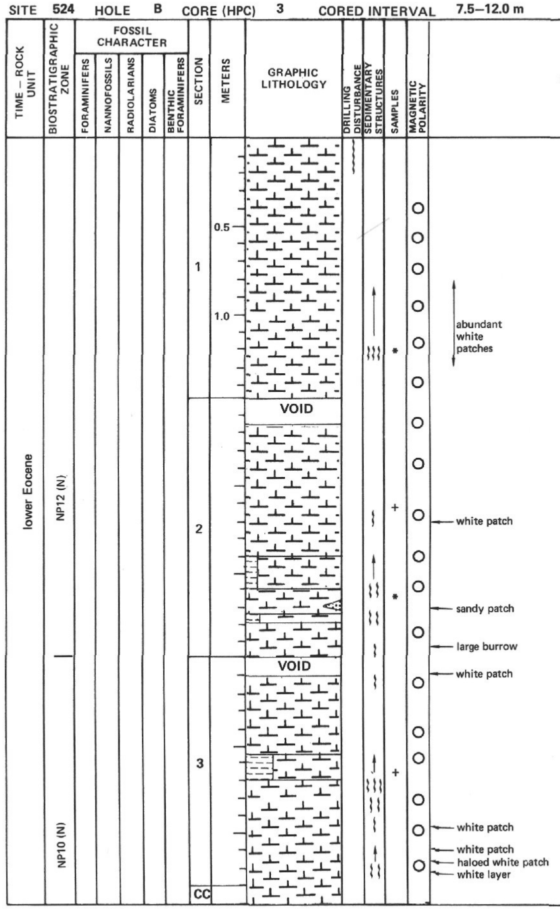
SMEAR SLIDE SUMMARY

	1-112 M
TEXTURE:	
Sand	–
Silt	85
Clay	15
COMPOSITION:	
Clay	15
Calc. nannofossils	84
Iron-oxides	1

ORGANIC CARBON AND CARBONATE

	3-24	3-75
Organic carbon	–	–
Carbonate	93	75

SITE 524 HOLE B CORE (HPC) 3 CORED INTERVAL 7.5–12.0 m



LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very pale brown (10YR 7/4) and MARLY NANNOFOSSIL OOZE, yellowish brown (10YR 5/6); burrowed with scattered white patches. Sandy patch in Section 2 contains abundant volcanic rock fragments. Minimal drilling disturbance.

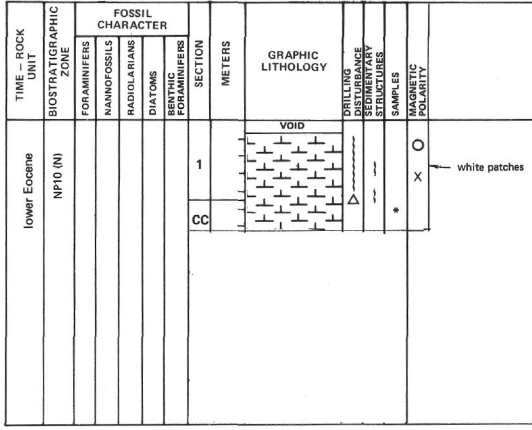
SMEAR SLIDE SUMMARY

	1-120 D	2-116 M
TEXTURE:		
Sand	5	80
Silt	85	20
Clay	10	–
COMPOSITION:		
Feldspar	–	20
Clay	5	–
Volcanic glass	–	10
Carbonate unspec.	5	–
Foraminifers	5	–
Calc. nannofossils	85	10
Rock fragments	–	60

ORGANIC CARBON AND CARBONATE

	2-62	3-65
Organic carbon	–	–
Carbonate	91	64

SITE 524 HOLE B CORE (HPC) 4 CORED INTERVAL 12.0–16.0 m



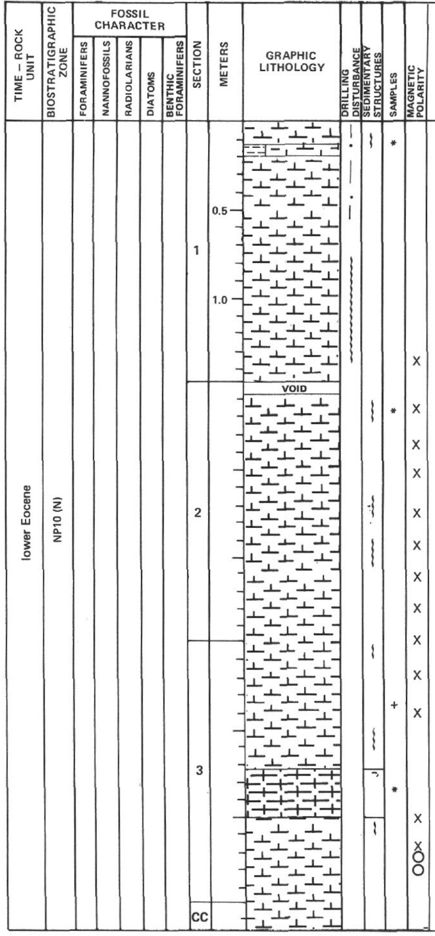
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very pale brown (10YR 8/3) with several scattered white patches and one yellowish brown marly patch. Core-Catcher is mixed very pale brown and light gray ooze.

SMEAR SLIDE SUMMARY

	CC, 14 D
TEXTURE:	
Sand	1
Silt	90
Clay	9
COMPOSITION:	
Clay	5
Carbonate unspec.	7
Foraminifers	2
Calc. nannofossils	85
Iron-oxides	1

SITE 524 HOLE B CORE (HPC) 5 CORED INTERVAL 16.0–20.5 m



LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very pale brown (10YR 8/3) homogeneous with some dark yellowish brown (10YR 4/4) MARLY NANNOFOSSIL OOZE mixed by drilling in top of Section 1. FORAMINIFER OOZE in Section 3 has sharp top and basal contacts but no grading. Moderate drilling disturbance in Section 1.

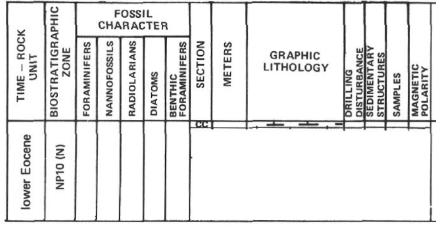
SMEAR SLIDE SUMMARY

	1-19 M	2-20 D	3-84 M
TEXTURE:			
Sand	–	TR	60
Silt	80	95	40
Clay	20	5	–
COMPOSITION:			
Feldspar	–	–	1
Clay	20	5	10
Volcanic glass	TR	–	–
Foraminifers	TR	1	50
Calc. nannofossils	80	94	39

ORGANIC CARBON AND CARBONATE

	3-38
Organic carbon	–
Carbonate	85

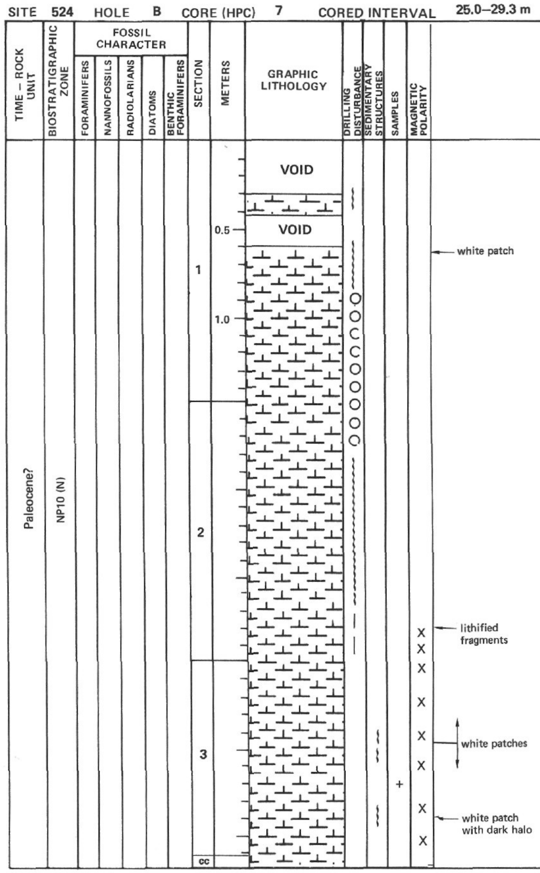
SITE 524 HOLE B CORE (HPC) 6 CORED INTERVAL 20.5–25.0 m



LITHOLOGIC DESCRIPTION

Trace of NANNOFOSSIL OOZE in Core-Catcher.

SITE 524 HOLE B CORE (HPC) 7 CORED INTERVAL 25.0–29.3 m

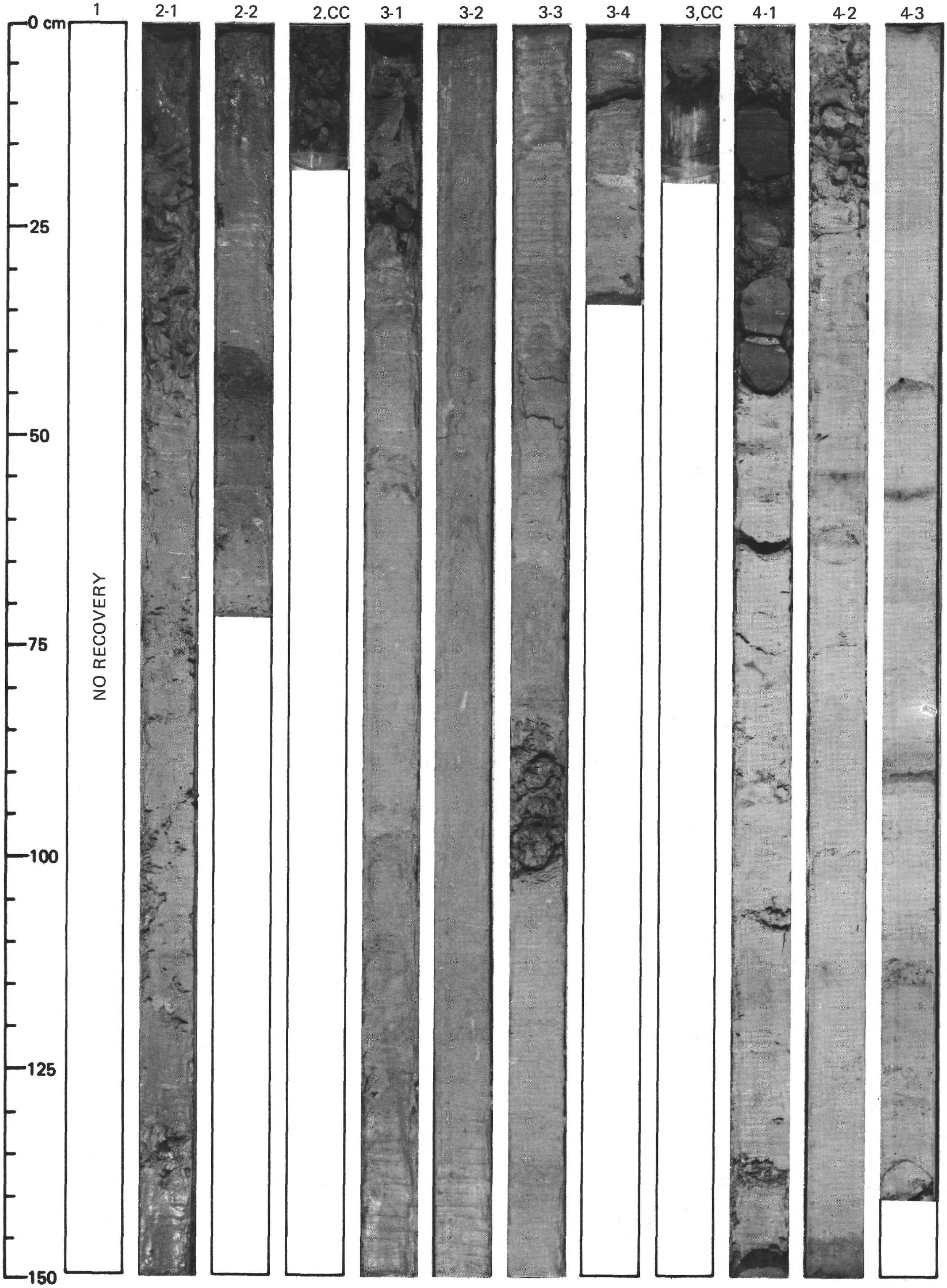


LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very pale brown (10YR 7/4), very deformed; with scattered white patches and some partially lithified pieces in Section 2.

ORGANIC CARBON AND CARBONATE

	3-70
Organic carbon	–
Carbonate	86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75
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125
150
1
NO RECOVERY
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2-2
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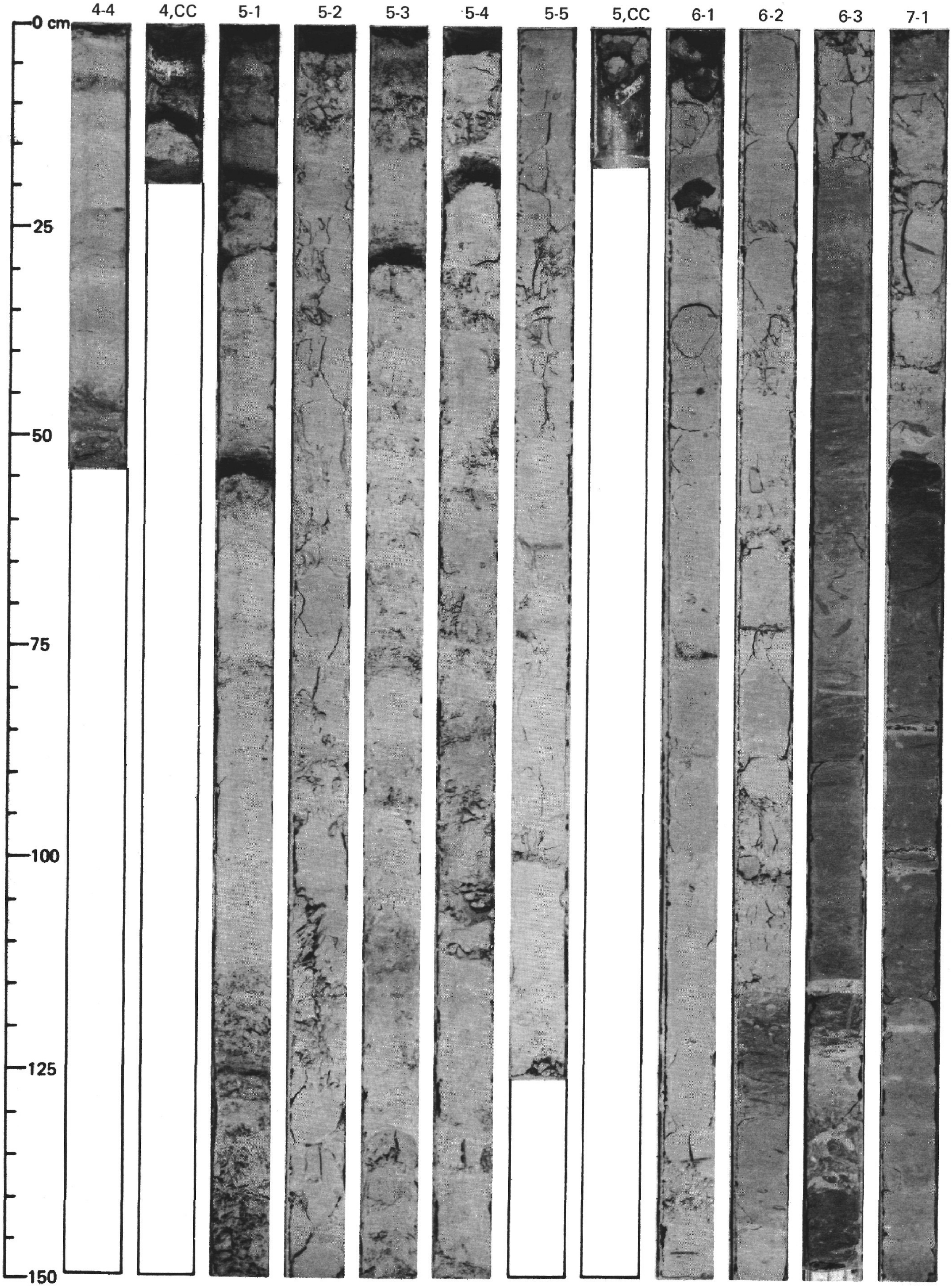
3,CC
4-1
4-2
4-3


4-4
4,CC
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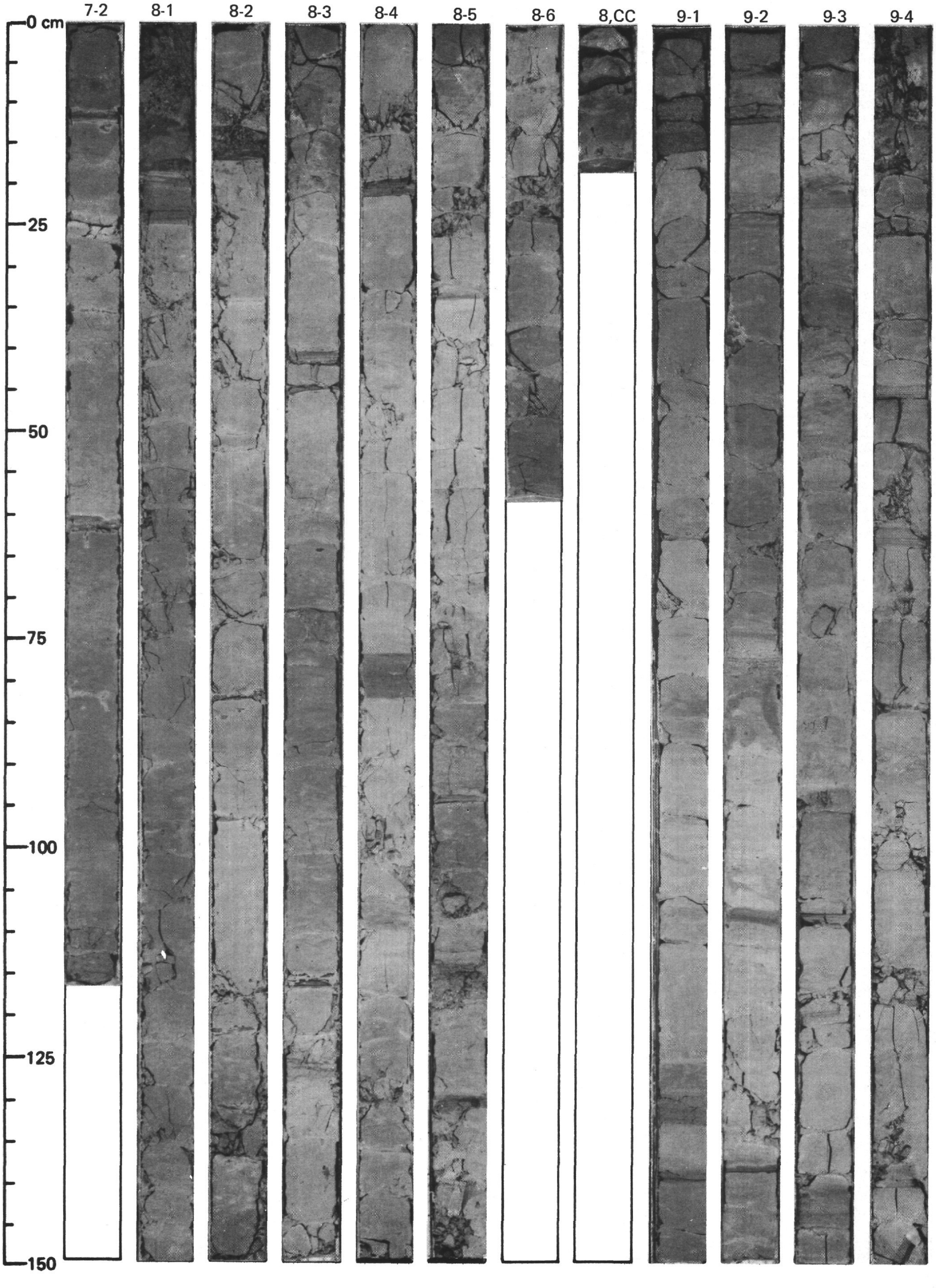
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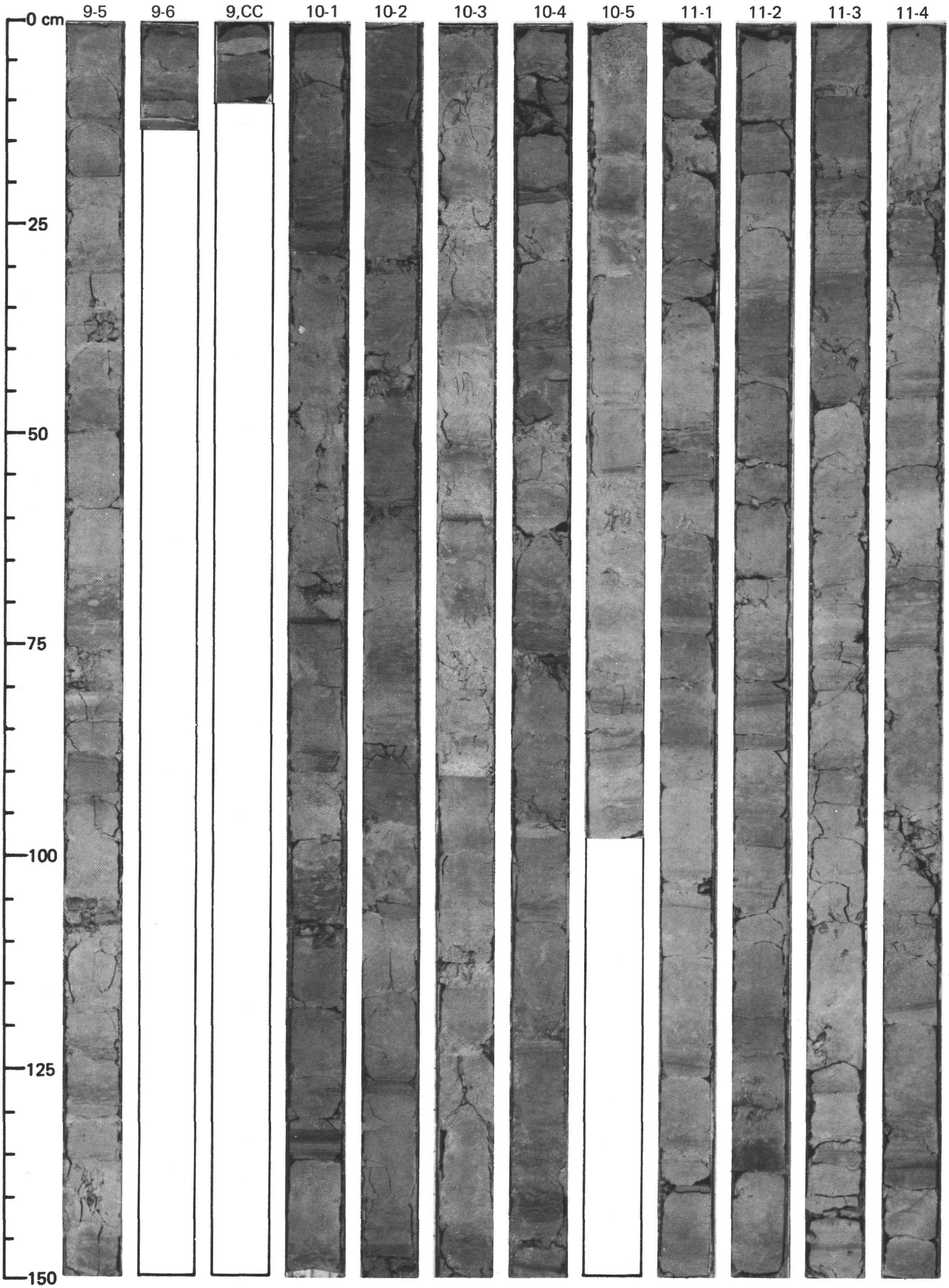
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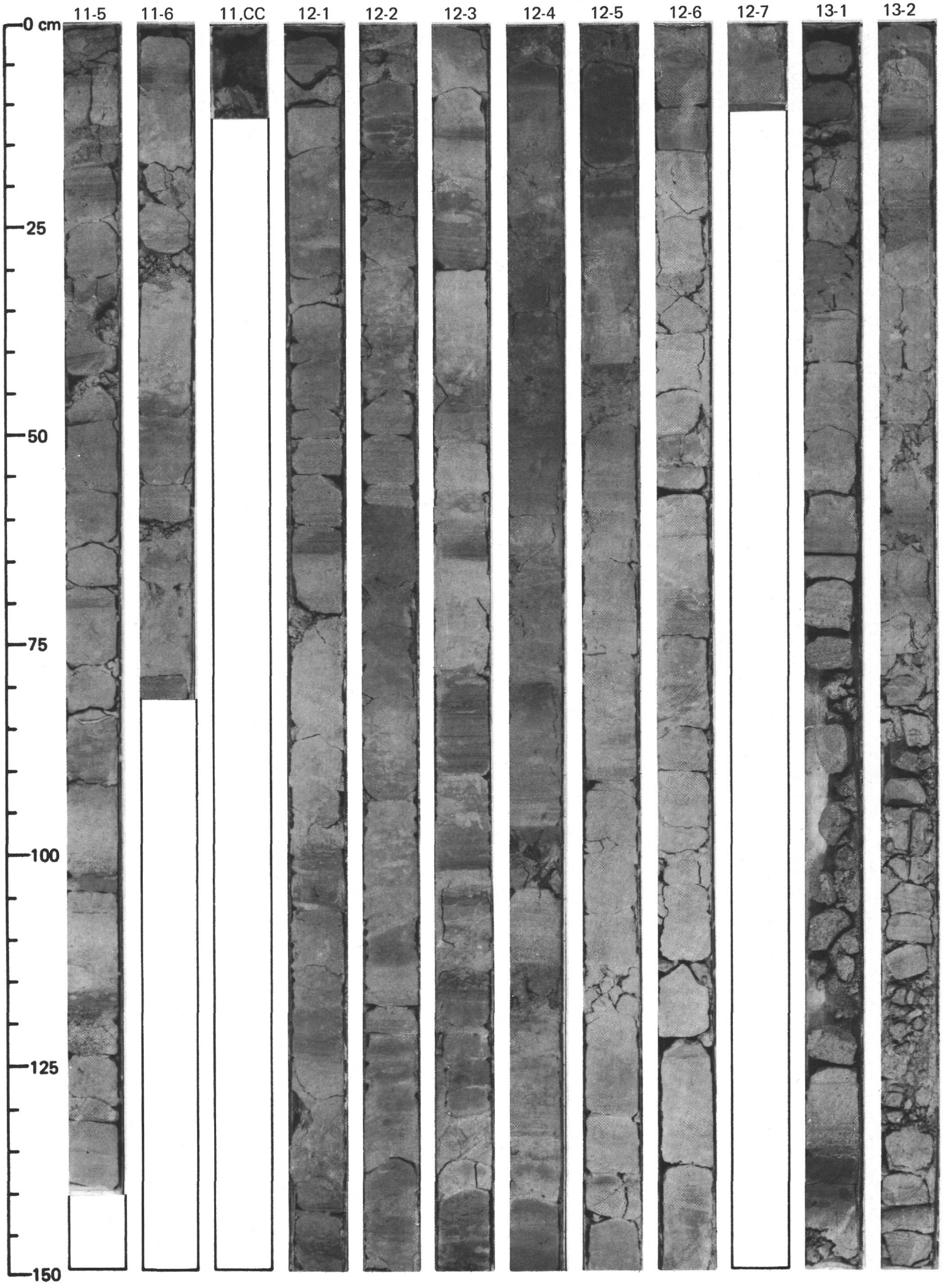
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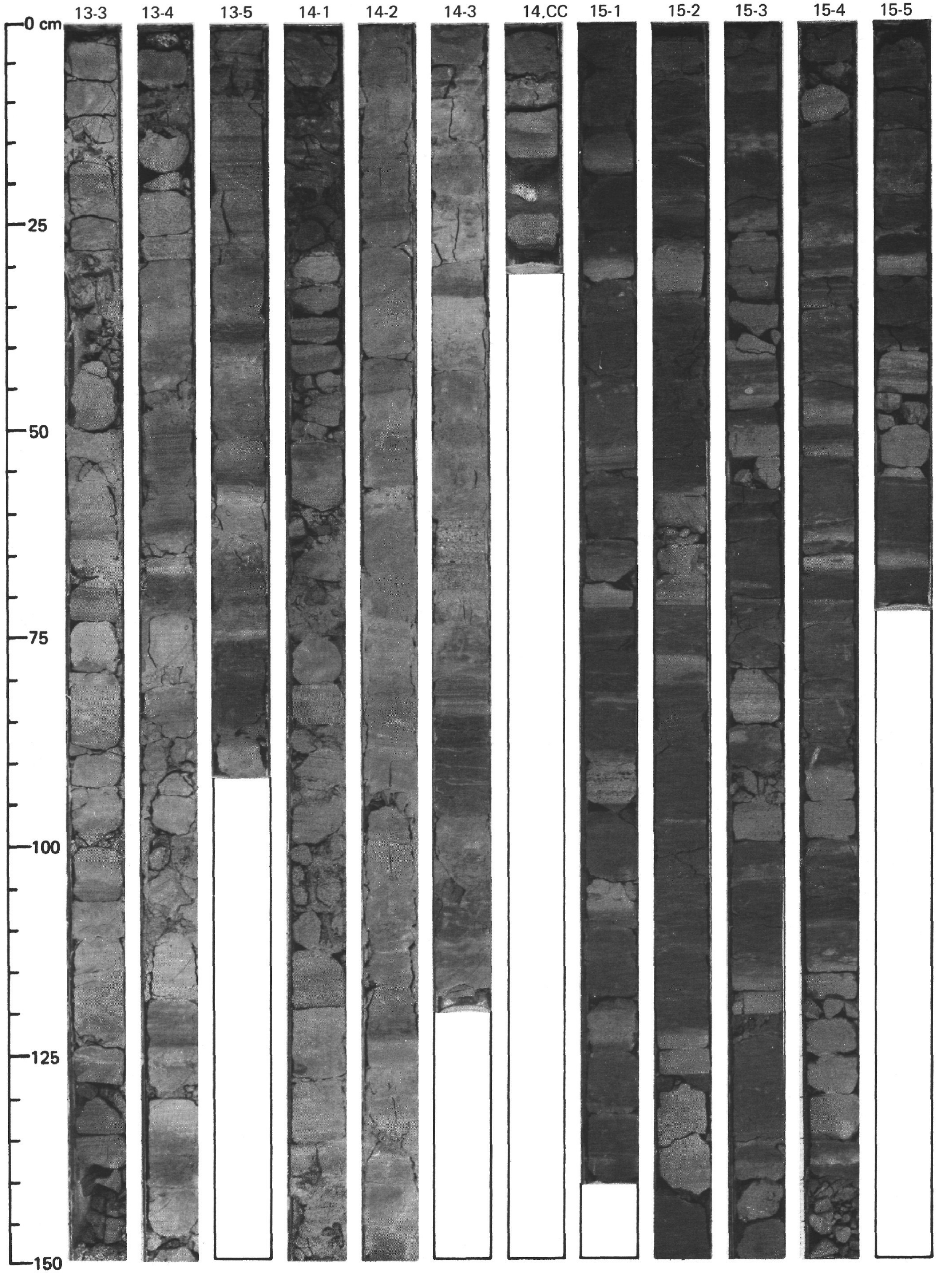

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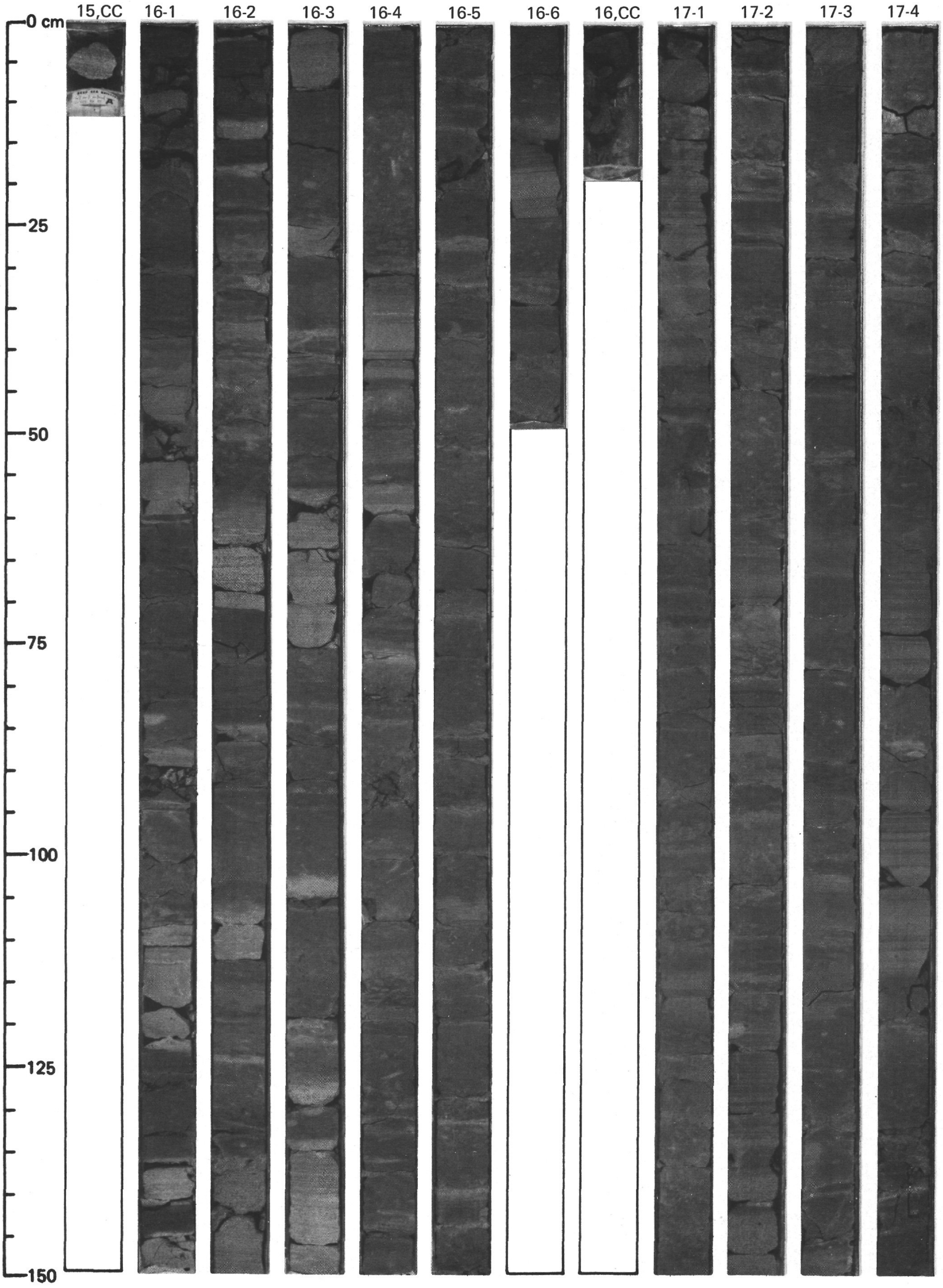
15,CC
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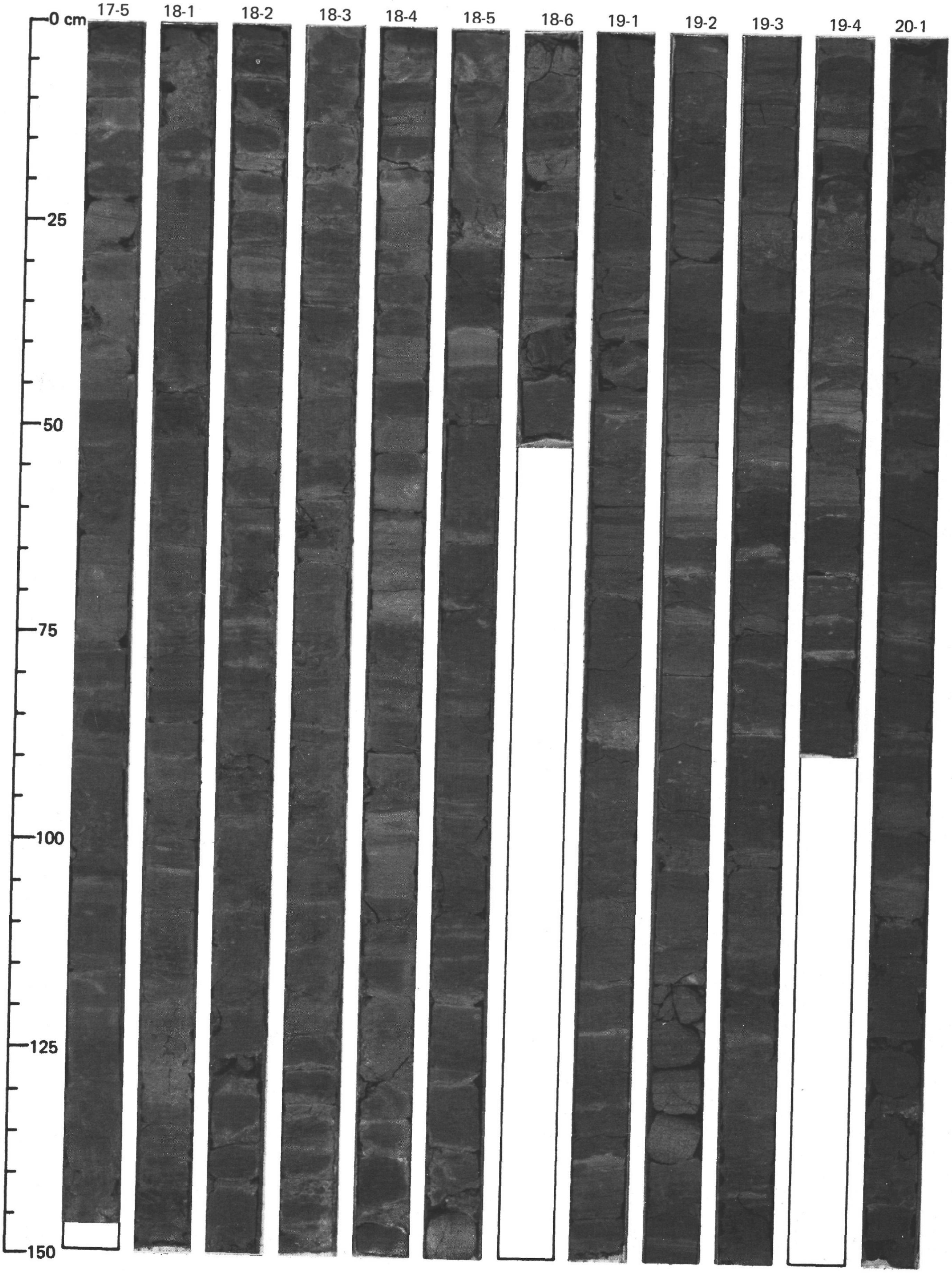
0 cm
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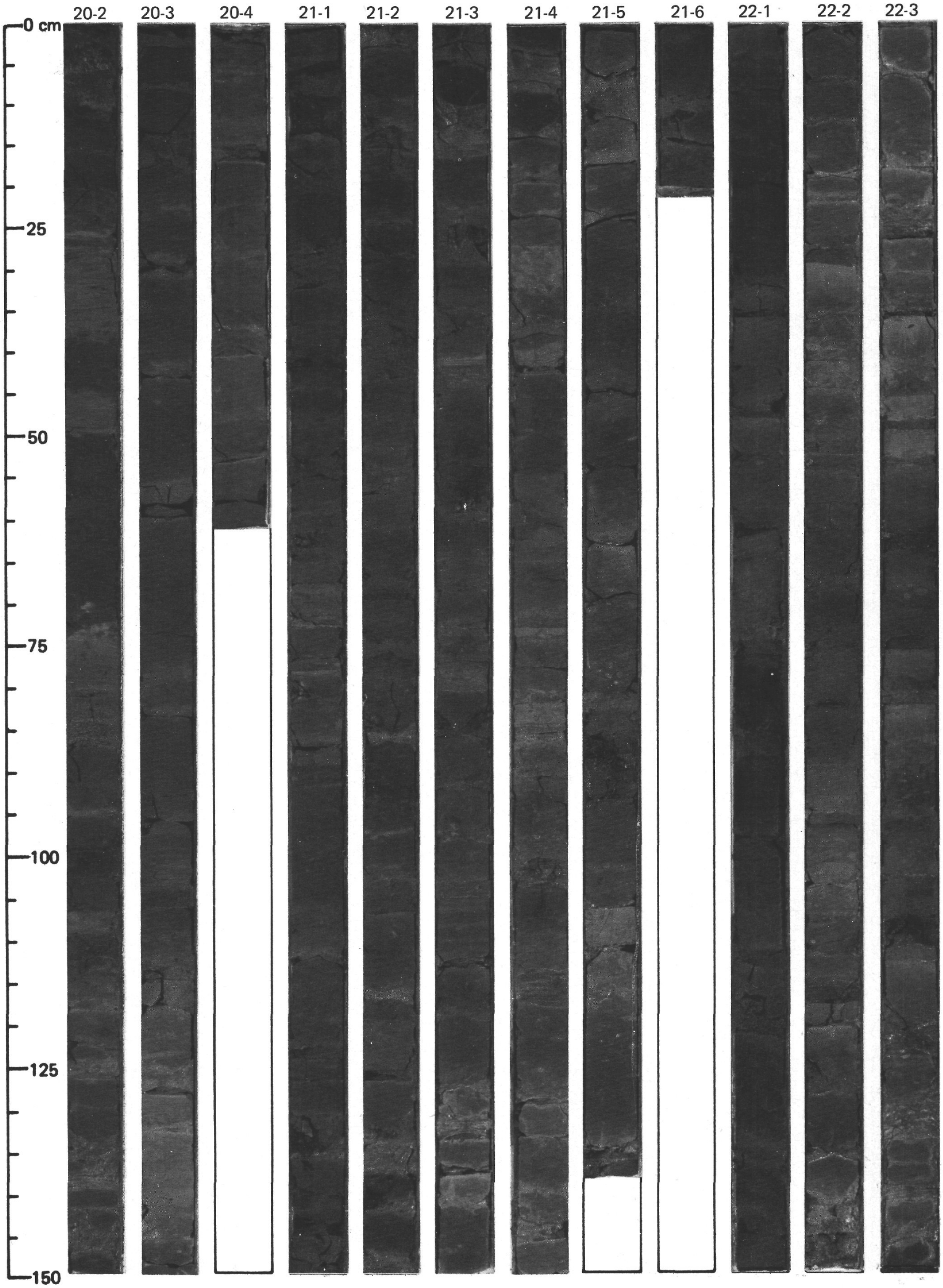
20-1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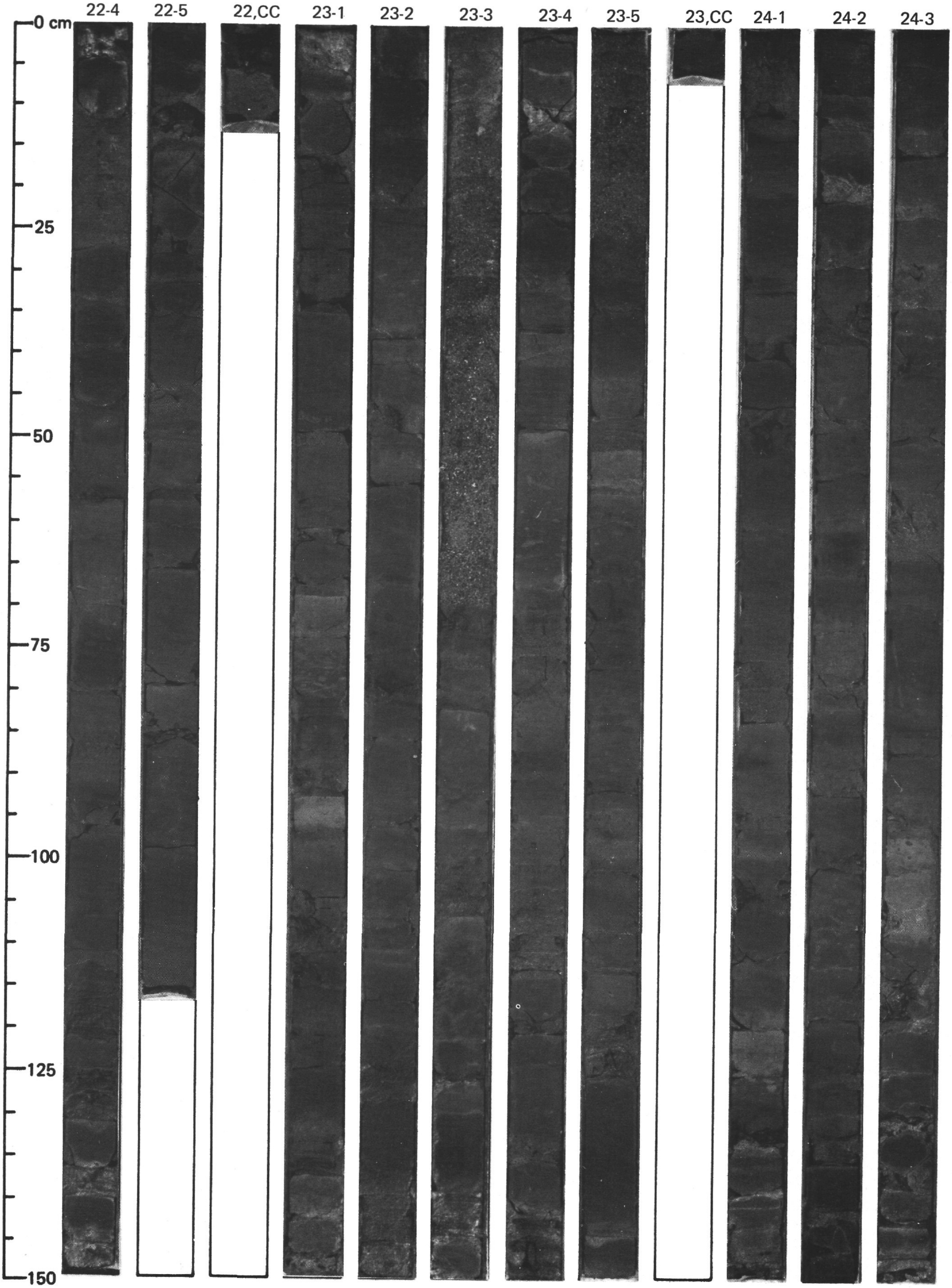
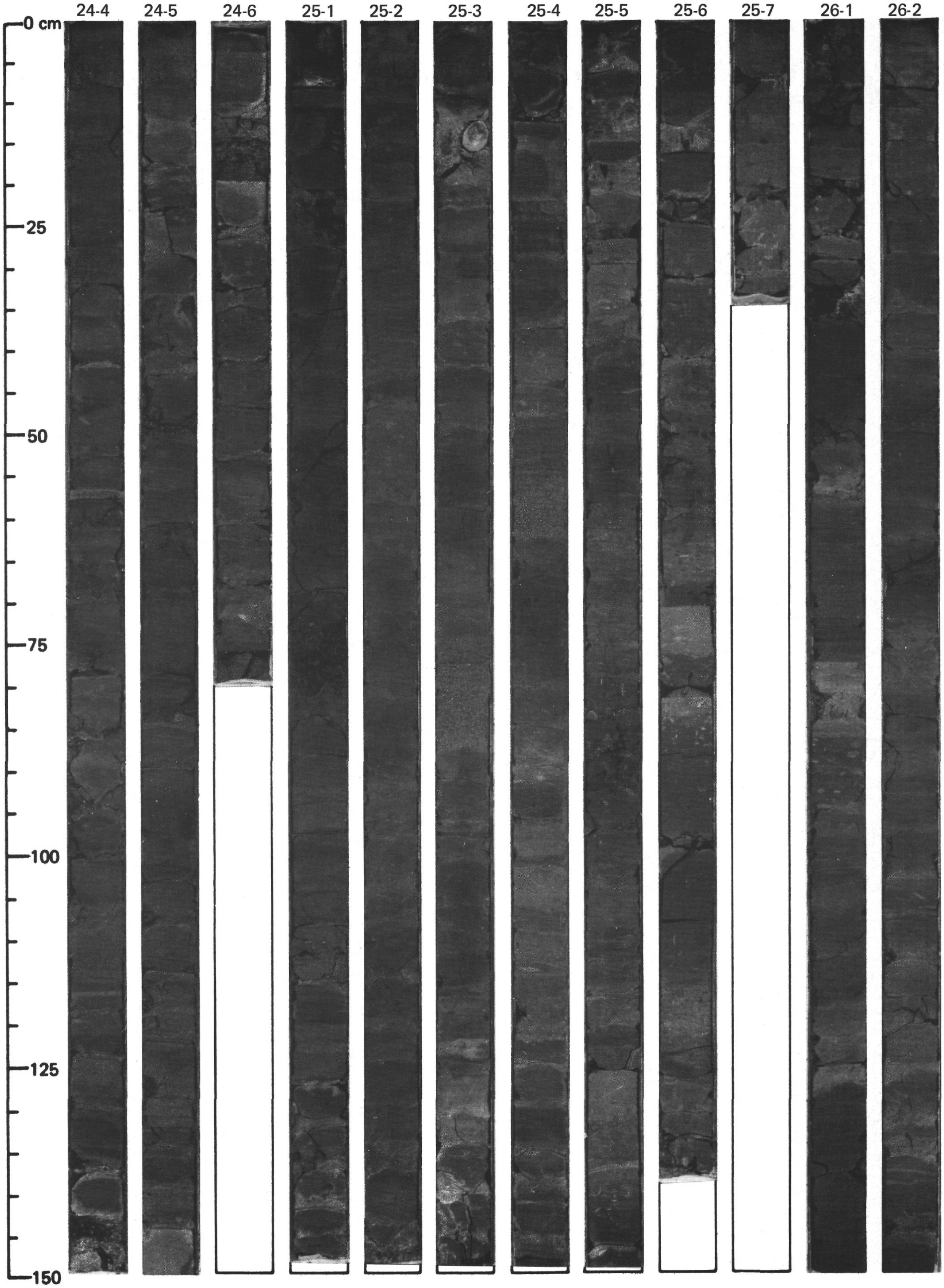
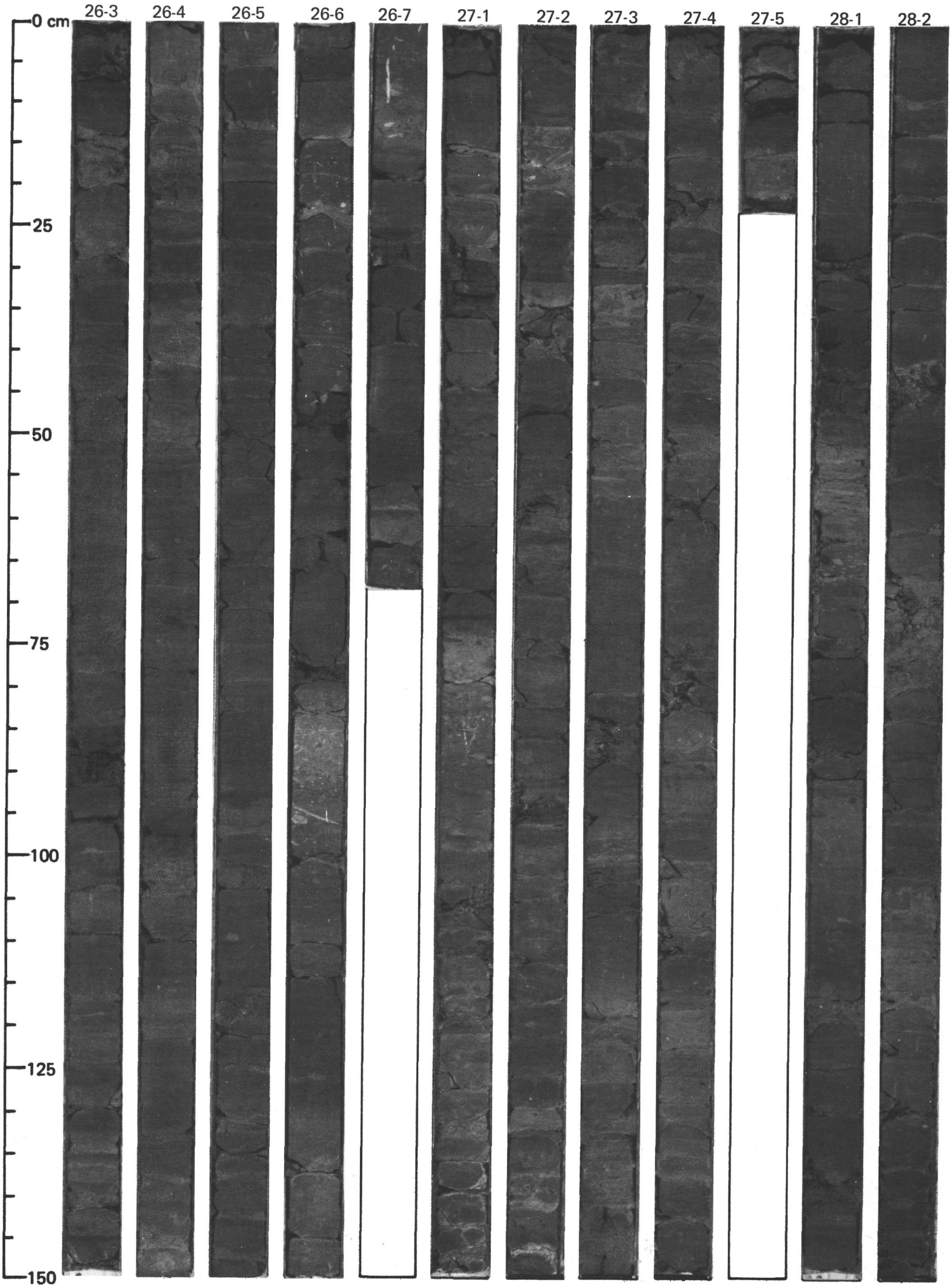
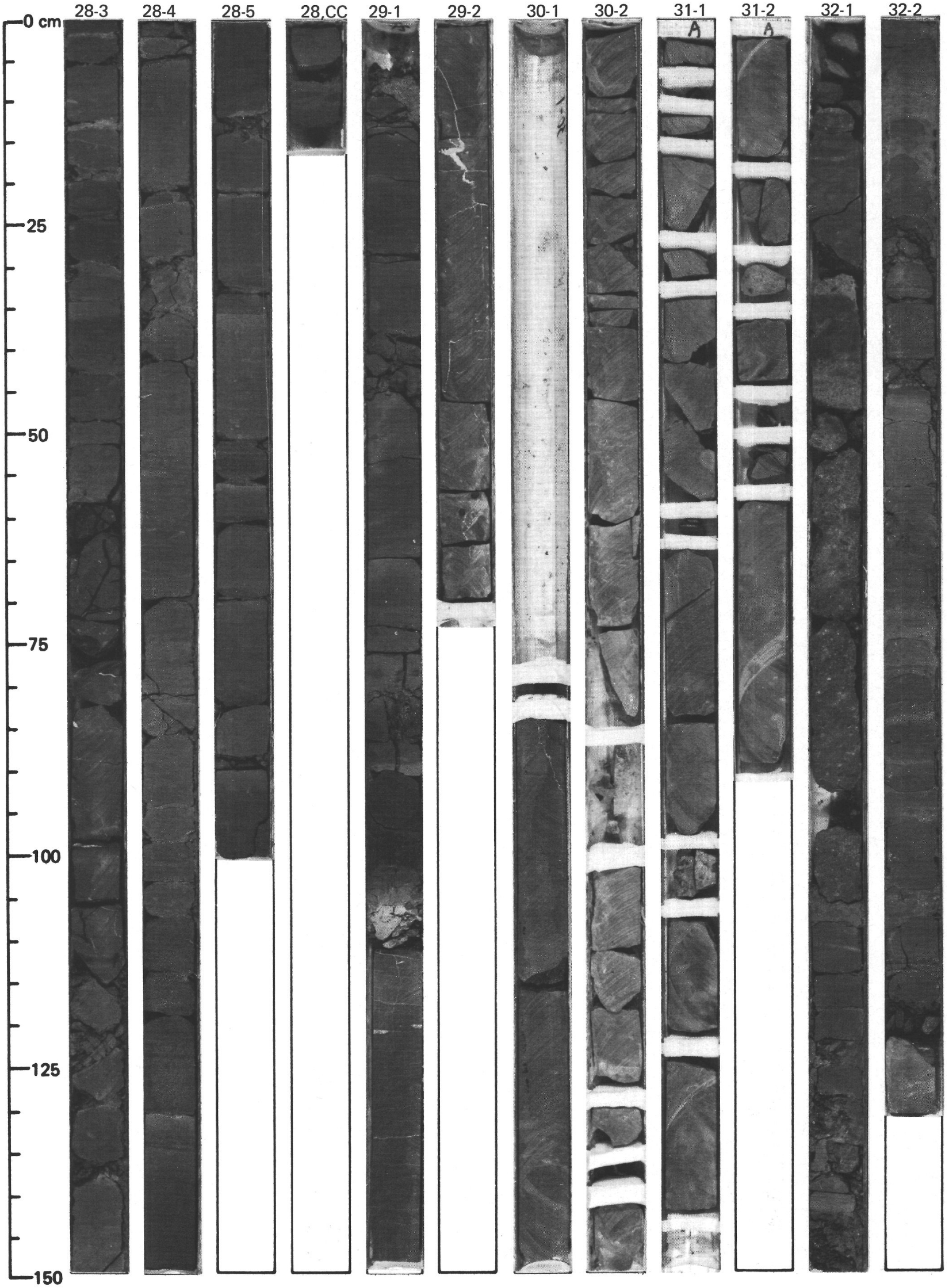
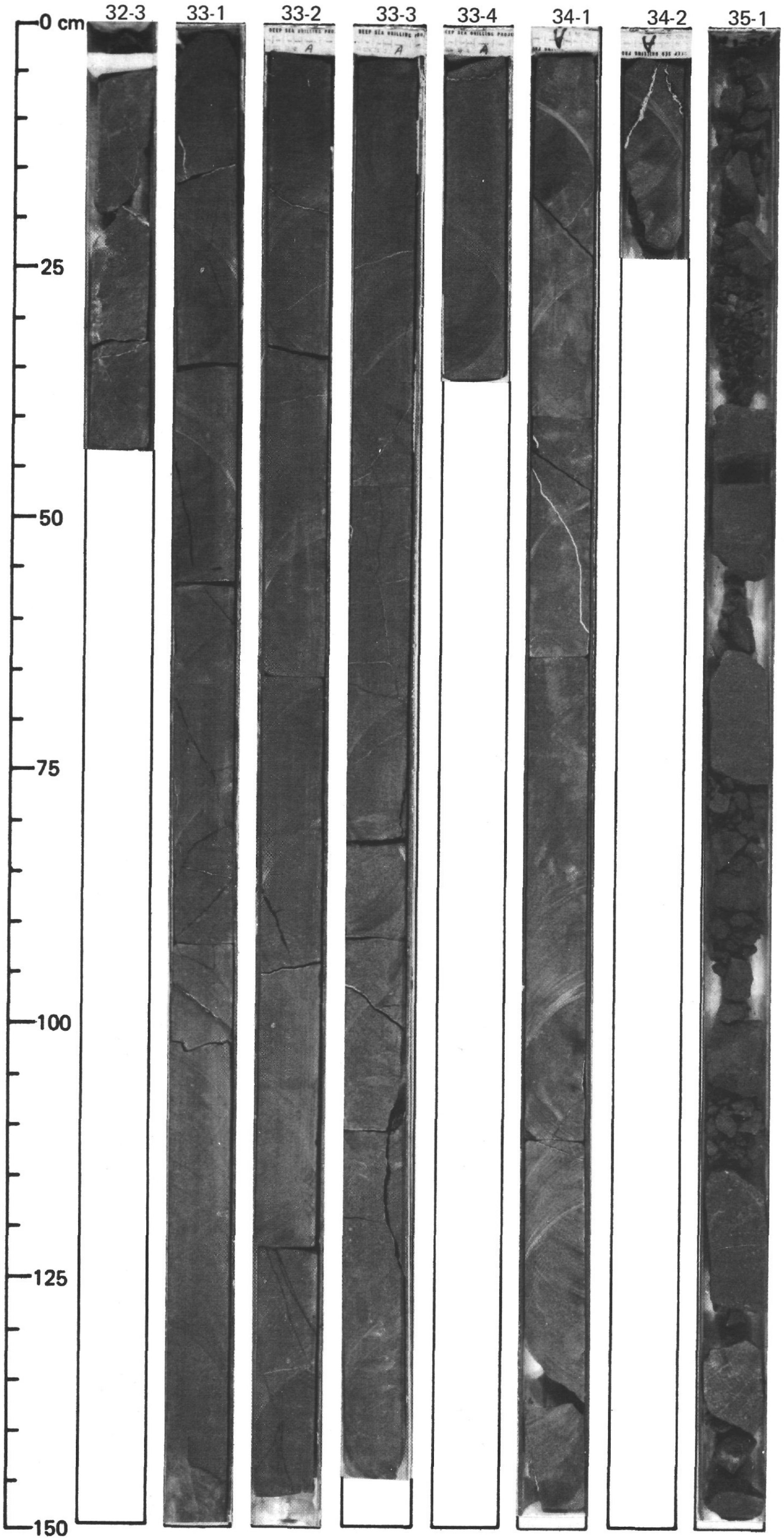
21-4
21-5
21-6
22-1
22-2
22-3
0 cm
25
50
75
100
125
150

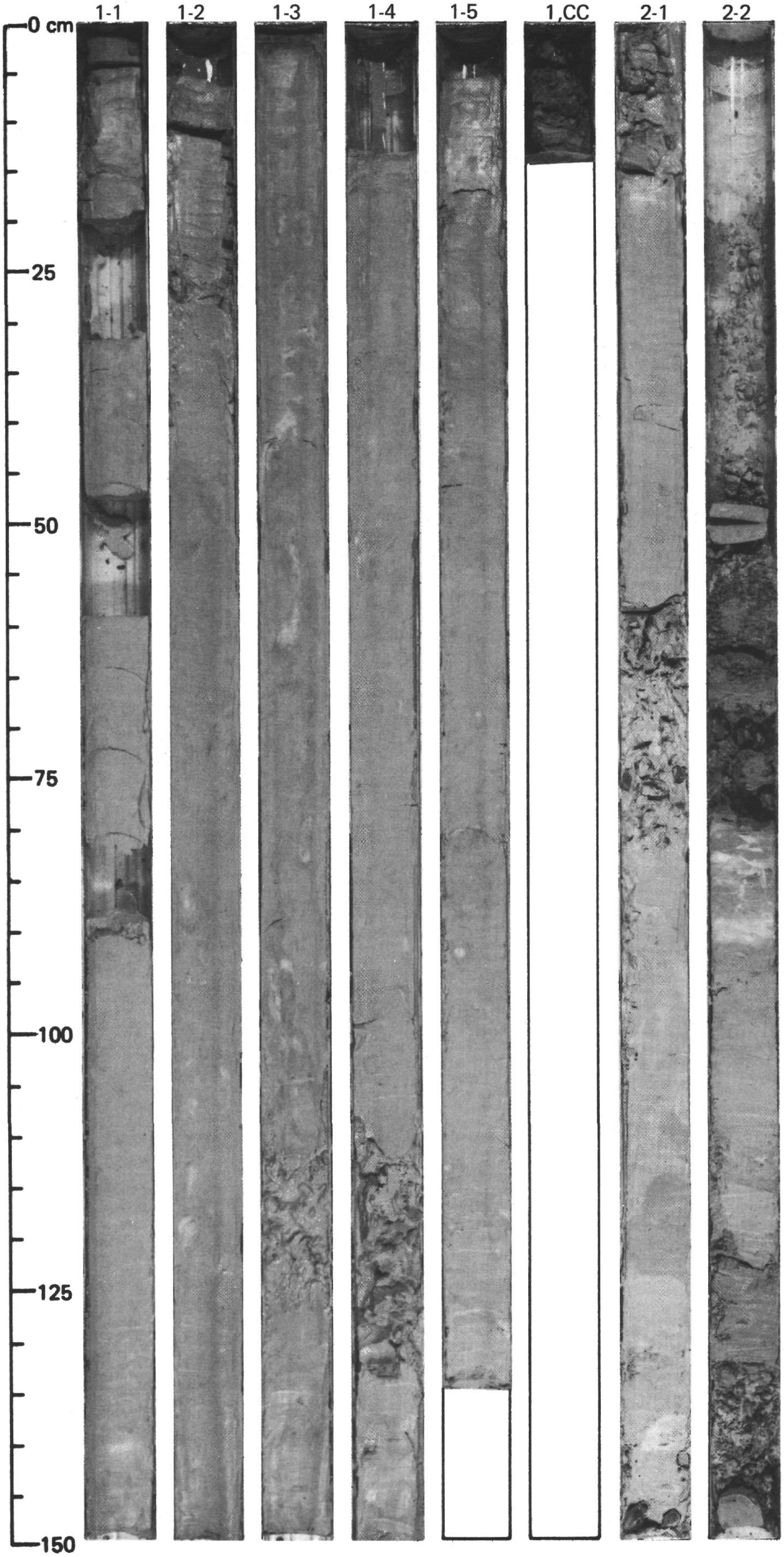

22-4
22-5
22,CC
23-1
23-2
23-3
23-4
23-5
23,CC
24-1
24-2
24-3
0 cm
25
50
75
100
125
150

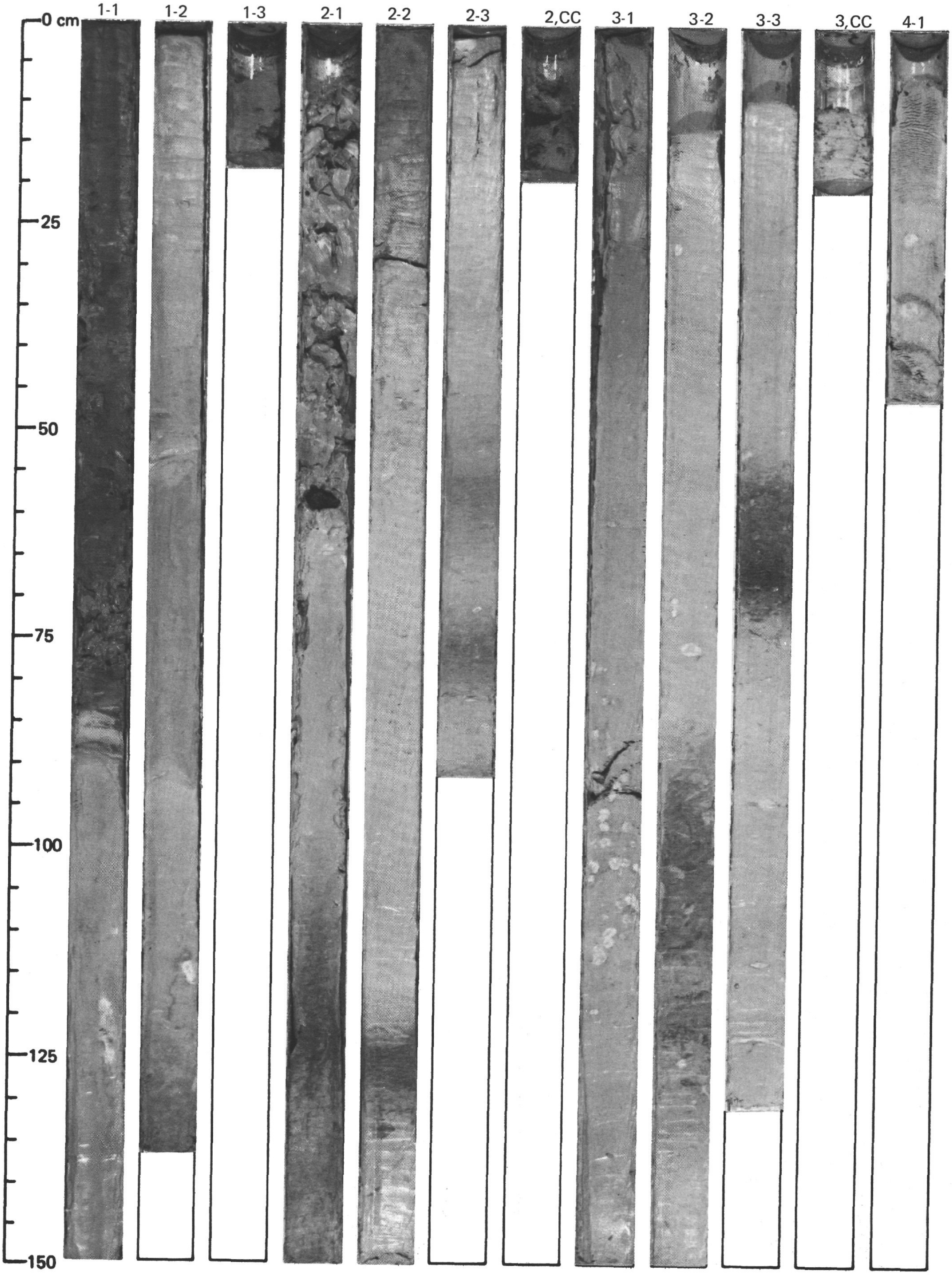

24-4
24-5
24-6
25-1
25-2
25-3
25-4
25-5
25-6
25-7
26-1
26-2
0 cm
25
50
75
100
125
150

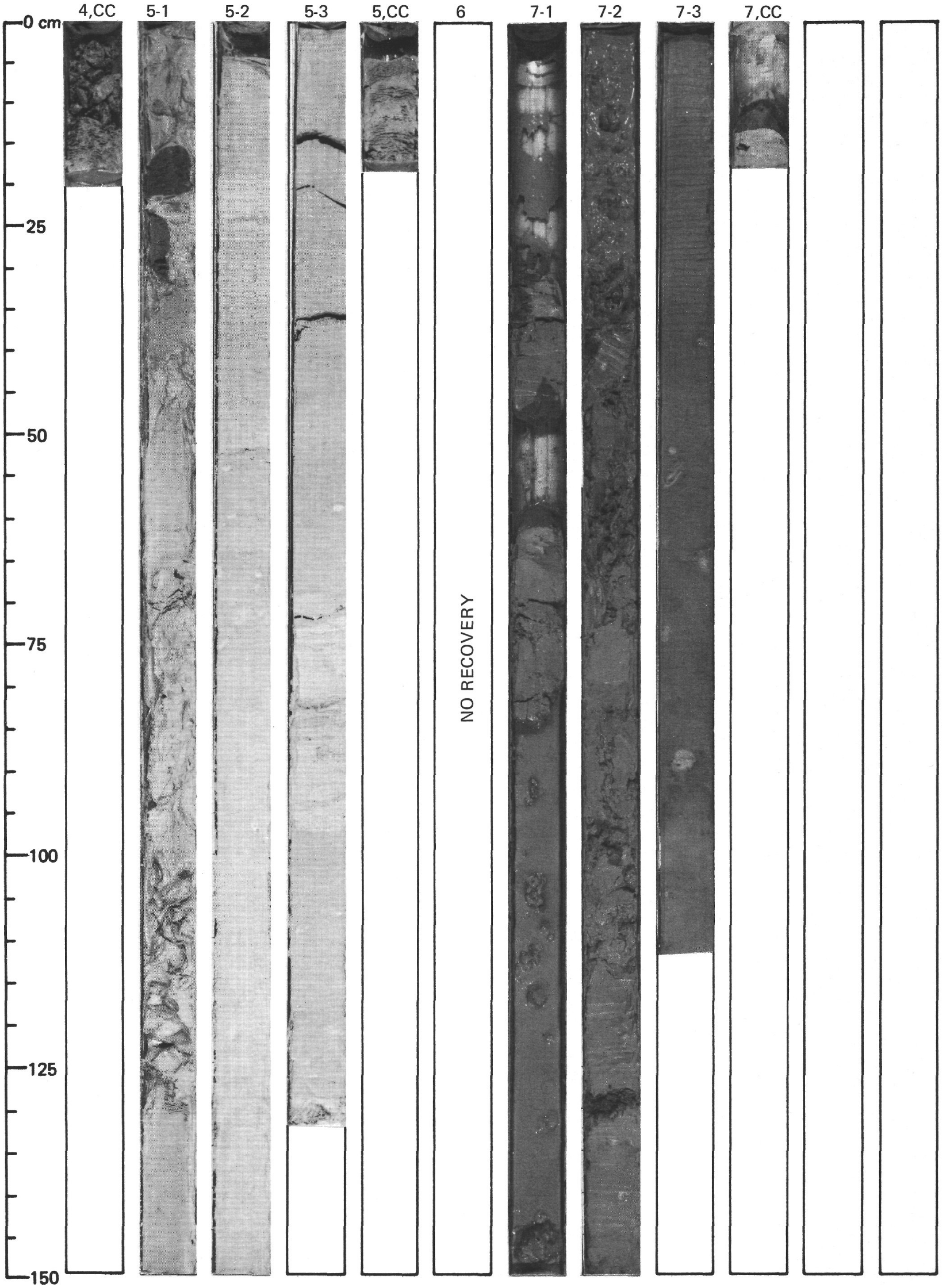

0 cm
25
50
75
100
125
150
26-3
26-4
26-5
26-6
26-7
27-1
27-2
27-3
27-4
27-5
28-1
28-2


28-3
28-4
28-5
28,CC
29-1
29-2
30-1
30-2
31-1
31-2
32-1
32-2
0 cm
25
50
75
100
125
150
A
A


0 cm
25
50
75
100
125
150
32-3
33-1
33-2
33-3
33-4
34-1
34-2
35-1


1-1
1-2
1-3
1-4
1-5
1,CC
2-1
2-2
0 cm
25
50
75
100
125
150


1-1
1-2
1-3
2-1
2-2
2-3
2,CC
3-1
3-2
3-3
3,CC
4-1
0 cm
25
50
75
100
125
150


4,CC
5-1
5-2
5-3
5,CC
6
7-1
7-2
7-3
7,CC
0 cm
25
50
75
100
125
150
NO RECOVERY