2. SITES 501 AND 504: SEDIMENTS AND OCEAN CRUST IN AN AREA OF HIGH HEAT FLOW ON THE SOUTHERN FLANK OF THE COSTA RICA RIFT[1]

Shipboard Scientific Parties of Leg 68 (Site 501), Leg 69, and Leg 70[2]

LEG 68, SITE 501, HOLE 501

Date occupied: 8 July 1979

Date departed: 16 July 1979

Time on hole: 8 days

Position: 01°13.63′N; 83°44.06′W

Water depth (sea level; corrected m, echo sounding): 3457

Water depth (rig floor; corrected m, echo sounding): 3467

Bottom felt (m, drill pipe): 3466.9

Penetration (m): 337.1

Number of cores: 20

Total length of cored section (m): 147.2

Total core recovered (m): 74.53

Core recovery (%): 50.6

Oldest sediment cored:
- Depth sub-bottom (m): 264
- Nature: Cherty limestone
- Age: No paleontological age (age of magnetic anomaly, 5.9 m.y.)
- Measured velocity (km/s): 3.185

Basement:
- Depth sub-bottom (m): 264.1
- Meters of basement drilled: 73
- Nature: Basalt pillow lavas and massive flow units
- Velocity range (km/s): 4.08–5.99

Principal results: Site 501 is on 5.9 m.y. crust spread from the Costa Rica Rift. Hole 501 served as a pilot hole for re-entry in Hole 504B. The sediment section (264 m thick) was spot cored because continuous piston coring was carried out later in Hole 504. The section consists of pelagic siliceous calcareous (nannofossil) ooze, with some volcanic ash; it becomes more calcareous and indurated with depth. Near the base, chert and cherty limestone bands were recovered. Basalt basement was cored for 73 meters; it consists of alternating massive flow units and rubbly pillow units. The upper petrographic unit is nearly aphyric, the lower unit (below 25 m), plagioclase and olivine phyric. Alteration is weak to intense, with clays and carbonate minerals filling veins. The in-hole temperature at 120 meters is 32°C, consistent with site survey heat flow data. The Lynes packer was used to recover a water sample and attempt a permeability measurement. The borehole televiewer, the downhole magnetometer, and the resistivity tool were successfully deployed. A complete logging program was run.

LEGS 69 AND 70, SITE 504, HOLES 504, 504A, 504B, AND 504C

Detailed information concerning Site 504 is given in Table 1. Principal results are given below by leg and hole.

Principal results, Leg 69, Hole 504: At Hole 504 sediments were continuously piston cored to a depth of 237 meters, where cherty layers were encountered. The sediment's structures and physical properties were nearly perfectly preserved in the cores. The sedimentary section cored is mainly a siliceous nannofossil ooze of pelagic origin containing a continuous biostratigraphic record from the late Miocene to the Holocene. Discrete volcanic ash layers are few, but disseminated ash and terrigenous windblown clay minerals are present in variable amounts. The sedimentation rate based on the biostratigraphy is 43.5 m/m.y. and is rather uniform over the whole section.

Lithologically the section can be divided into three units. Unit I (late Pliocene to Holocene and 0 to 143.5 m sub-bottom) consists of an unconsolidated siliceous nannofossil ooze, dark grayish green to olive grayish green in color. A subunit between 65 and 99 meters contains larger amounts of Mn, based on X-ray fluorescence (XRF) analysis. The physical properties of Unit I are extremely uniform. Representative mean values are as follows: sonic velocity, 1.51 km/s; bulk density, 1.32 g/cc; porosity, 80%; and thermal conductivity, 0.80 W/m°C.

Unit II (late Miocene to early Pliocene and 143.5 to 227.2 m sub-bottom) is a siliceous nannofossil chalk with higher carbonate content (up to 85%). The coloration is generally the same but paler. This chalk may represent the first stage in the diagenesis of

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[1] Cann, J. R., Langseth, M. G., Honnorez, J., Von Herzen, R. P., White, S. M., et al., *Init. Repts. DSDP*, 69: Washington (U.S. Govt. Printing Office).

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Table 1. Site 504 Summary, Legs 69 and 70

Hole:	504 (Leg 69)	504A (Leg 69)	504B (Leg 69)	504B (Leg 70)	504B (total)	504C (Leg 69)
Date occupied:	0400, 20 Sept. 1979	0000, 24 Sept. 1979	7 Oct. 1979	4 Dec. 1979	—	0856, 14 Oct. 1979
Date departed:	2330, 23 Sept. 1979	0800, 29 Sept. 1979	25 Oct. 1979	13 Dec. 1979	—	0845, 15 Oct. 1979
Time on hole:	91.5 hours	128 hours	436.5 hours	190.4 hours	626.9 hours	24 hours
Position:	01°13.58′N; 83°43.93′W	01°13.61′N; 83°43.95′W	01°13.63′N; 83°43.81′W	01°13.63′N; 83°43.81′W	01°13.63′N; 83°43.81′W	01°13.64′N; 83°43.89′W[a]
Water depth (sea level; corrected m, echo-sounding):	3460	3458	3460	3460	3460	3460
Water depth (rig floor; corrected m, echo-sounding):	3470	3468	3470	3470	3470	3470
Bottom felt (m, drill pipe):	Not felt	Not felt	3473.5	3473.5	3473.5	Not felt
Penetration (m):	237	277	489	347	836	220
Number of cores:	54	7	29	41	70	(b)
Total length of cored section (m):	227	70.5	227.5	347	574.50	0
Total core recovery (m):	176	9.01	76.66	91.5	168.2	0
Percentage core recovery:	76	20.5	33.7	26.3	29.3	0
Oldest sediment cored:						
Depth sub-bottom (m):	237	264	274.5	274.5	274.5	—
Nature:	Siliceous limestones and cherts	Chert and siliceous limestone	Chert and siliceous limestone	Chert and siliceous limestone	Chert and siliceous limestone	—
Age:	Late Miocene	5.9 m.y.[c]	5.9 m.y.[c]	5.9 m.y.[c]	5.9 m.y.[c]	—
Measured velocity (km/s):	4.25	—	—	—	—	—
Basement:						
Top of basement (depth sub-bottom, m):	237	264	274.5	274.5	274.5	—
Meters of basement drilled:	—	12	214	347.5	561.5	—
Nature:	—	Basalt pillows	Basalt pillows and flows	Basalt pillows and flows	Basalt pillows and flows	—
Velocity range (km/s):	—	~5.8	5.1-6.4	5.1-6.4	5.1-6.4	—

[a] Longitude may be in error; only a few satellite navigation fixes received.

[b] Hole drilled solely for downhole temperature measurements and *in situ* pore water samples.

[c] Estimated from magnetic anomalies.

the nannofossil ooze, which is temperature controlled. At Hole 505, where temperatures are much lower at 140 meters (5°C, versus 38°C at Hole 504), chalky sediments appear only below 210 meters. The mean sonic velocity of the chalks is only slightly higher (1.54 km/s), but bulk density and thermal conductivity increase to 1.5 g/cc and 1.2 W/m°C, respectively. Porosity decreases appreciably (to 65%).

Unit III begins at 227.2 meters sub-bottom, only 10 meters above the basement. It consists of siliceous limestones and cherty layers. The outlines and colors of worm burrows and halos are preserved in the cherts and give evidence of shrinkage by a factor of 5.

The entire section of sediment is highly bioturbated: there are innumerable worm burrows, all undisturbed by the piston coring. The extent of the bioturbation may be responsible for the pattern of magnetization, which is incoherent throughout the section.

Interstitial water chemistry analysis showed significant positive gradients in Ca with increasing depth and negative gradients in Mg. However, the gradients in Hole 504 are considerably smaller than those in Hole 501, revealing large lateral gradients in pore water chemistry that may be caused by very slow pore water migration through the sediments.

Principal results, Leg 69, Holes 504A, 504B (Cores 1-29), and 504C: Hole 504A was begun as a multiple re-entry site, but it had to be abandoned after only 12 meters of basalt were drilled because the bit disintegrated, leaving the cones and supporting shanks in the bottom of the hole. Hole 504C was drilled between bit changes at Hole 504B specifically for making point temperature measurements with the Tokyo T-probe (Yokota et al., 1980) and taking *in situ* pore water samples with the Barnes sampler in the sedimentary section (to 220 m); no cores were taken. Hole 504B was established as a multiple re-entry site. Two hundred fourteen meters of basement were drilled and continuously cored. Four suites of logs were run in the basement section, and the inflatable packer was used three times to make two flow tests and to collect a large-volume sample of formation water. An ultrasonic televiewer and a downhole magnetometer were also run in the hole. The last effort made in the leg was to obtain temperature and compensated density logs in Hole 504A, which had been thermally equilibrating for a month while Site 505 and Hole 504B were being drilled.

Since most of the results come from Hole 504B, with Holes 504A and 504C providing only a small amount of supplementary data, all three holes are discussed together in this summary.

In Hole 504A the bottom of the sedimentary layer was cored along with 12 meters of basalt. The interval from 227 to 264 meters was comprised of chert and siliceous limestones of late Miocene age similar to those in Holes 501 and 504. The basement section yielded chrome-spinel-bearing basalts and lithologic units similar to those drilled in Hole 501.

The logging and experiments made at Hole 504B provided some surprising results. Two temperature logs taken 34 hours and 70 hours after circulation had stopped gave extremely low gradients to 365 meters sub-bottom and maximum temperatures only 7° above bottom water, with virtually no change between the logs. Below 365 meters extremely high gradients were observed. (Temperatures in the bottom of the hole increased up to 5°C between the logs; evidently the hole was approaching an equilibrium profile appropriate for a conductive geothermal regime [see the results for Hole 504B, Leg 70].) The temperature measurements at three points sub-bottom in Hole 504C (which is just 60 m west of Hole 504B) showed a conductive gradient of about 24.5°C/100 m in the sediments. If that gradient had held for Hole 504B the temperature at 365 meters sub-bottom would have indicated a temperature at the top of basement of about 60°C. The only reasonable interpretation of the temperature profiles at Hole 504B is that cold water was flowing down the hole at rates of up to 50 gal./hr. and issuing into the basement formation 90 meters below the sediment/basement contact. The temperature log run in Hole 504A after it had equilibrated for a month showed a conductive profile.

The flow tests with the packer sealing the annulus between the drill pipe and hole walls showed that the basement has a hydraulic permeability from 2 to 40 millidarcys.

The logging runs showed that the walls of the hole are free of projections and have relatively few voids. The logs giving information relevant to density, resistivity, compensated density, and neutron density all show that pillows and thin flows predominate in the column. There are, however, three massive flow units, one about 10 meters thick. More details of the wall structure were detected by the ultrasonic televiewer, which also showed that pillows and large fractures were common along the entire section.

The downhole magnetometer and measurements on samples showed that the basement to the depth drilled is reversely magnetized, in agreement with the magnetic anomalies measured at the sea surface. Inclinations of the magnetization are lower than in the present field.

Two samples of water were drawn at the bottom of Hole 504B reached during Leg 69. One sample was 15 gal. Both contain a mix of fresh surface seawater and seawater that had been pumped down the hole earlier and had reacted extensively with the rocks. The latter is chemically similar to the pore waters in the basal sediments. Pore waters drawn from the sediments of Hole 504C indicate even smaller gradients in the Ca and Mg concentration than in Holes 504A or 501, although the shape of the profile is similar. The results suggest that the movement of the interstitial waters through the sediments is sluggish.

In the basement section at Hole 504B three types of basalt were distinguished. One contains phenocrysts of plagioclase, lesser olivine, and minor chrome spinel; the second contains phenocrysts of plagioclase, olivine, and clinopyroxene. The third embraces a range of textures from sparsely phyric to aphyric; when phenocrysts occur they are plagioclase, olivine, and augite. Twenty lithologic units were identified, with the rock types described above complexly interbedded. All the units are intensely fractured, and slickensides were detected on a few fracture faces. Tectonically produced polymict breccias are found in at least two zones.

The alteration of the basalts is moderate, with saponite, primarily, replacing olivine and filling voids. Zones of oxidative alteration border many cracks.

XRF analyses show that the basalts are generally uniform in composition. They are only moderately fractionated, with Mg/(Mg + Fe) equalling 0.56 to 0.66, TiO_2 ranging from 0.7 to 1.4%, and Zr ranging from 30 to 100 ppm.

Principal results, Leg 70, Hole 504B: Hole 504B was re-entered on December 3, 1979 at 1343 hr. During the 14 consecutive days on site, the hole was re-entered three more times, and 347 meters of basement were cored. On December 13 a depth of 836 meters sub-bottom was reached, making Hole 504B one of the deepest holes ever drilled in oceanic crust. (Later drilling on Leg 83 extended the penetration in basement to a record depth of 1075 m.) Penetration rates varied from 2 to 6 m/hr., with an average close to 4 m/hr. Recovery varied from 0 to 100%, with an average of 26.4%.

The basement cored during Leg 70 at Hole 504B is made up of 26 petrographic units that correspond to 15 paleomagnetic units. Three major kinds of lava were encountered: massive flows (at least 23 m thick), flow breccias with highly fractured sequences of pillow lavas, and thin flows. The basalt ranges from aphyric to sparsely to highly olivine-plagioclase-clinopyroxene phyric. The association of the first two phenocryst minerals is the most common. Spinel microphenocrysts have been observed in a few units. Five petrographic types of basalt were distinguished on the basis of the occurrence of the various phenocryst minerals.

The alteration of the lowermost 347 meters of basalt drilled in Hole 504B during Leg 70 was slightly different from that of the upper 214 meters of basalt drilled during Leg 69. The main differences were as follows:

1) No calcite was observed below 660 meters sub-bottom.

2) Fe-oxyhydroxides were not common between 600 and 760 meters and below 800 meters sub-bottom.

3) Vein pyrite was not observed above 540 meters sub-bottom, but it became progressively more abundant with increasing depth. As in the Leg 69 portion of the hole, various types of smectite formed the most abundant alteration products, and the smectite was accompanied by small amounts of zeolite (analcite and natrolite were identified by X-ray diffraction [XRD]). A mixed-layer mineral was tentatively identified as saponite/talc by XRD. Olivine phenocrysts were frequently replaced by various combinations of talc, smectite, and red iddingsite (probably a Fe-oxyhydroxide-rich smectite mixture). Preliminary reflected-light observations indicated that the igneous Fe-Ti oxides were severely altered into mainly non-opaque secondary products (Fe and Ti oxyhydroxides and possibly silicates), which filled up the large cracks that separated rather small Ti-magnetite relics. The basement alteration probably took place in mainly suboxic conditions in the upper portion of the hole (i.e., down to 540 m sub-bottom), and in suboxic to anoxic conditions in the lowermost 296 meters, or at least as far as the basement was drilled. The alteration process and the resulting products do not differ, as far as our shipboard observations indicate, from those due to basalt/seawater reactions at low temperature.

The paleomagnetic data suggest 15 units with an overall mean stable inclination of −18°. Two of the units, both of which extend over five cores, have mean stable inclinations of −53° and −63°, respectively, steeper than would be expected as a result of geomagnetic secular variation. Tectonic tilt, geomagnetic excursions, stable secondary remanence, or a combination of these might be responsible for these anomalous inclinations. The overall mean intensity of magnetization is 7×10^{-3} gauss, and the overall mean Q ratio is 10.

The average sonic velocity of the basement rocks measured on board is significantly higher than the wave velocities derived from site survey data: 5.71 versus 4 to 5 km/s, respectively. This difference can be attributed to the widespread occurrence of fractures on a scale larger than exists in the cored samples; the fractures are probably responsible for the water flow.

Drilling was followed by an extensive logging and downhole measurement program. The logs that were successful over the entire basement section include the sonic, resistivity, temperature, and caliper logs. The natural gamma and neutron density logs were partially successful; the compensated density log was unsuccessful. The successful logs show prominent massive basalts at about 325, 590, and 690 meters below the mudline, and otherwise generally fractured and altered basalt. Downhole experiments included the large-scale electrical resistivity and oblique seismic experiments, the latter in cooperation with R/V *Gilliss*.

Four borehole temperature profiles and *in situ* water samples were made during the deepening of Hole 504B on Leg 70; one of each was made before any disturbance of the re-entered hole. These confirmed that the strong downward flow of cold water to 365 meters sub-bottom observed during Leg 69 was still occurring. The present flow rate down the cored hole was estimated at a few meters per hour. The data also suggest that a conductive gradient of about 0.12°C/m exists below about 440 meters sub-bottom, yielding a heat flow rate of roughly 4.8 HFU, which is in good agreement with the Leg 69 result. The maximum temperature at the bottom of the hole on the last profile measured 111°C; equilibrium temperature was estimated to be about 120°C. Formation water silica concentration increased with depth, suggesting that water chemistry varied with increasing depth as a result of reactions with warmer basement rocks.

INTRODUCTION

Although Sites 501 and 504 were drilled on three different legs they are effectively the same site. Hole 501 was the pilot hole for two re-entry holes, Holes 504A and 504B, which are only a few hundred meters away. We have therefore combined the reports written for Sites 501 and 504, including the reports for the upper and lower portions of Hole 504B, which were written on Legs 68, 69 and 70, into one chapter. In most sections, the results for Site 501 precede the results for Site 504. The background for and objectives of the drilling are presented in the introductory chapter to this volume.

OPERATIONS

Hole 501

The *Glomar Challenger* departed Puntarenas, Costa Rica, at 1049 hr. on 5 July 1979 for the experimental portion of Leg 68. At 1125 hr., after a 25-min. period to test thrusters, the *Challenger* proceeded toward the site. Towed geophysical equipment was streamed at 1630 hr. at the 349-meter contour.

The *Challenger* reached the vicinity of Site 501 on the morning of 8 July and approached the site on course 085°. The beacon was dropped at 1228 hr. that day. The precision depth recorder (PDR) water depth was 3420 meters. A sediment thickness of 250 to 300 meters was indicated by single-channel profiler records obtained by the *Challenger* and site survey investigations (Fig. 1).

The bottom hole assembly (BHA), which included the Lynes packer with a circulating subassembly, was made up. Pressure tests were conducted on the BHA. The drill pipe was run down between 1500 hr. on 8 July and 0315 hr. on 9 July. The first core was recovered at 0550 hr., establishing the seafloor depth as 3466.9 meters. Another core (Core 2) was taken to confirm this depth.

The sediment coring program from the seafloor to approximately 230 meters below it consisted of washing five joints, taking a core, and measuring heat flow (Table 2). After Core 6, which was at 226.1 to 235.6 meters sub-bottom, continuous coring was undertaken until basaltic basement was reached at 264.1 meters. We planned to core continuously until we reached a basement formation that was firm enough to run the first hydrofracture experiment and other planned experiments.

In Core 12 we recovered 1.94 meters of basalt along with rubber fragments that represented portions of the inflatable packer element, which had been torn up during the drilling. We decided to core an additional 3 meters and then subject the packer to a pressure test to evaluate its operational capability. The test showed that the packer element would not hold above 1000 psi, which jeopardized the hydrofracture experiments but still allowed some experiments to be run. After this test, a packer formation sampler (with spike) test was made. Continuous coring in basalt began again at 0845 hr. on 11 July and was completed at 1320 hr. on 12 July 1979.

The program of downhole experiments is given in Table 3. The pipe was then pulled to end operations at Site 501.

Interregnum

Thruster problems experienced during the coring of Hole 501 necessitated the dry-docking of the *Challenger* for several weeks in Curaçao in the West Indies. Since the ship was in the Caribbean, its first operations following the dry-docking were hydraulic piston coring at Site 502 in the western Caribbean and at Site 503 in the eastern Pacific. A new scientific party was on board for this coring, which occupied the remainder of Leg 68. The Costa Rica Rift drilling finally recommenced on 20 September 1979 with most of the original scientific party, and a new leg number, Leg 69, was assigned for this purpose.

Hole 504

The first hole drilled on Leg 69 is very close to Site 501. The track out from La Libertad, Ecuador, was planned so that we approached the site on a westerly course that was approximately parallel to the crustal isochrons and magnetic anomaly lineations. Observations of water depth, sediment thickness, and magnetics were made along the track.

Navigation during the first pass over Site 501 was uncertain because of the paucity of satellite fixes. The Site 501 beacon that was dropped on 8 July had ceased func-

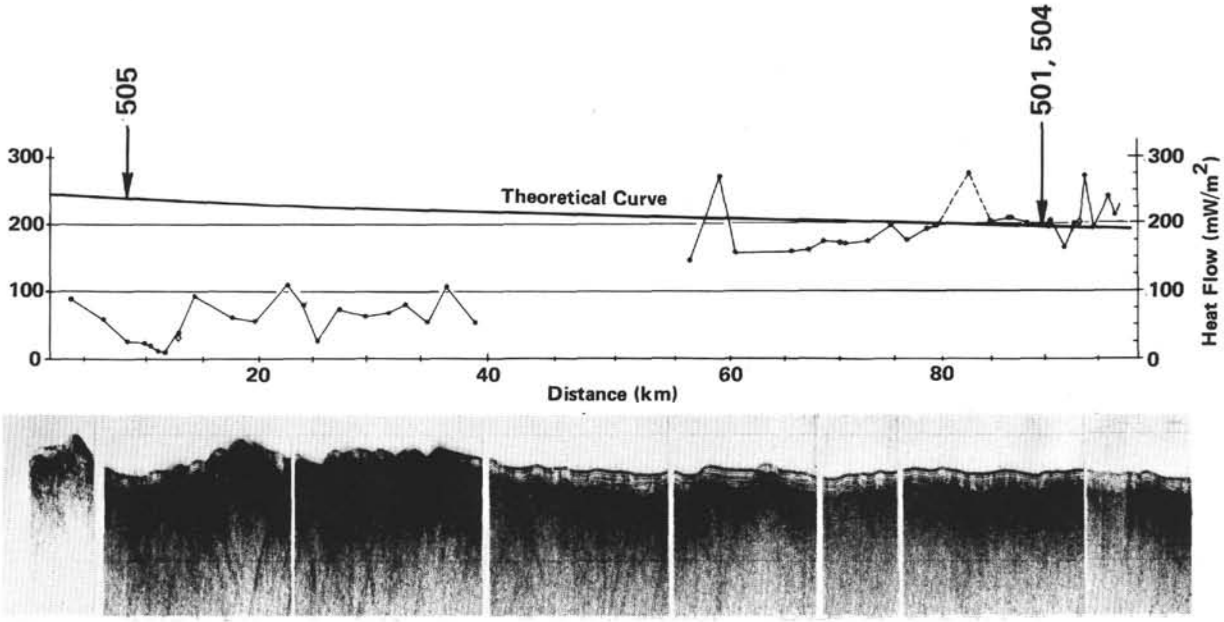

Figure 1. N-S profile of heat flow (mW/m^2) plotted as a function of distance from the Costa Rica Rift axis (off figure to left) above a similarly scaled profiler record showing basement topography and sediment thickness. Projected locations of Sites 501/504 and 505 are shown. Heat flow was measured during the site survey and during Expedition Cocotow of Scripps Institution of Oceanography (Anderson and Hobart, 1976).

Table 2. Coring summary—Sites 501 and 504.

Table 2. (Continued).

Core	Date (1979)	Time	Depth from Drill Floor (m)	Depth below Seafloor (m)	Length Cored (m)	Length Recovered (m)	Recovery (%)
Hole 501							
1	9 July	0550	3466.9–3474.5	0.0–7.6	7.6	9.44	100+
2	9	0830	3466.9–3467.0	0.0–0.1	0.1	Tr	—
—	9	—	3474.5–3522.0	(Wash 5 joints below base of Core 1)			
3	9	1115	3522.0–3531.5	55.1–64.6	9.5	9.55	100+
—	9	—	3531.5–3579.0	(Wash 5 joints below base of Core 2[a])			
4	9	1500	3579.0–3588.5	112.1–121.6	9.5	9.60	100+
—	9	—	(Make heat flow/pore water measurements)				
—	9	—	3588.5–3636.0		(Wash 5 joints)		
5	9	2055	3636.0–3645.5	169.1–178.6	9.5	4.03	42
—	9	—	(Make heat flow/pore water measurements)				
—	9	—	3645.5–3693.0		(Wash 5 joints)		
6	10	0305	3693.0–3702.5	226.1–235.6	9.5	5.20	55
7	10	0440	3702.5–3712.0	235.6–245.1	9.5	3.14	33
8	10	0620	3712.0–3721.5	245.1–254.6	9.5	0.20	2
9	10	0805	3721.5–3731.0	254.6–264.1	9.5	0.69	7
10	10	1045	3731.0–3734.0	264.1–267.1	3.0	2.10	70
11	10	1500	3734.0–3740.0	267.1–273.1	6.0	3.49	58
12	10	2155	3740.0–3747.0	273.1–280.1	7.0	1.94	28
13	11	0340	3747.0–3750.0	280.1–283.1	3.0	2.57	86
14	11	1330	3750.0–3759.0	283.1–292.1	9.0	4.17	46
15	11	1730	3759.0–3768.0	292.1–301.1	9.0	4.06	45
16	11	2230	3768.0–3772.0	301.1–305.1	4.0	1.64	41
17	12	0135	3772.0–3777.0	305.1–310.1	5.0	3.00	60
18	12	0505	3777.0–3786.0	310.1–319.1	9.0	2.19	24
19	12	0845	3786.0–3795.0	319.1–328.1	9.0	2.22	25
20	12	1320	3795.0–3804.0	328.1–337.1	9.0	5.30	59
Total					147.2	74.53	51
Hole 504							
1	20 Sept.	1430	3480.0–3484.4	10.0–14.4	4.4	4.2	95
2	20	1535	3484.4–3488.8	14.4–18.8	4.4	3.91	89
3	20	1700	3488.8–3493.2	18.8–23.2	4.4	4.4	100
4	20	1810	3493.2–3497.6	23.2–27.6	4.4	4.22	96
5	20	1920	3497.6–3502.0	27.6–32.0	4.4	3.64	83
6	20	2045	3502.0–3506.4	32.0–36.4	4.4	4.35	99
7	20	2157	3506.4–3510.8	36.4–40.8	4.4	4.35	99
8	20	2312	3510.8–3515.2	40.8–45.2	4.4	4.35	99
9	21	0050	3515.2–3519.6	45.2–49.6	4.4	4.30	98
10	21	0220	3519.6–3524.0	49.6–54.0	4.4	3.81	87
11	21	0340	3524.0–3528.4	54.0–58.4	4.4	4.24	96
12	21	0455	3528.4–3532.8	58.4–62.8	4.4	4.34	99
13	21	0615	3532.8–3537.2	62.8–67.2	4.4	3.94	90
14	21	0735	3537.2–3541.6	67.2–71.6	4.4	4.49	102
15	21	0850	3541.6–3546.0	71.6–76.0	4.4	4.25	97
16	21	1010	3546.0–3550.4	76.0–80.4	4.4	4.02	91
17	21	1130	3550.4–3554.8	80.4–84.8	4.4	4.24	96
18	21	1250	3554.8–3559.2	84.8–89.2	4.4	4.18	95
19	21	1400	3559.2–3563.6	89.2–93.6	4.4	3.32	75
20	21	1530	3563.6–3568.0	93.6–98.0	4.4	4.36	99
21	21	1645	3568.0–3572.4	98.0–102.4	4.4	4.50	102
22	21	1815	3572.4–3576.8	102.4–106.8	4.4	3.25	74
23	21	1935	3576.8–3581.2	106.8–111.2	4.4	1.55	35
24	21	2053	3581.2–2585.6	111.2–115.6	4.4	2.43	55
25	21	2210	3585.6–3590.0	115.6–120.0	4.4	4.02	91
26	21	2340	3590.0–3594.4	120.0–124.4	4.4	3.93	89
27	22	0100	3594.4–3598.8	124.4–128.8	4.4	3.86	88
28	22	0214	3598.8–3603.2	128.8–133.2	4.4	2.43	55
29	22	0322	3603.2–3607.6	133.2–137.6	4.4	3.35	76
30	22	0440	3607.6–3612.0	137.6–142.0	4.4	3.76	85
31	22	0605	3612.0–3616.4	142.0–146.4	4.4	2.99	68
32	22	0740	3616.4–3620.4	146.4–150.8	4.4	3.75	85
33	22	0900	3620.8–3625.2	150.8–155.2	4.4	2.02	46
34	22	1030	3625.2–3629.6	155.2–159.6	4.4	3.42	78
35	22	1305	3629.6–3634.0	159.6–164.0	4.4	4.01	91
36	22	1415	3634.0–3638.4	164.0–168.4	4.4	3.50	80
37	22	1540	3638.4–3642.8	168.4–172.8	4.4	3.52	81
38	22	1705	3642.8–3647.2	172.8–177.2	4.4	3.95	90
39	22	1833	3647.2–3651.6	177.2–181.6	4.4	0.49	11
40	22	1950	3651.6–3656.6	181.6–186.0	4.4	2.57	58
41	22	2125	3656.0–3660.0	186.0–190.0	4.0	3.83	96
42	22	2310	3660.0–3664.0	190.0–194.0	4.0	2.35	59
43	23	0028	3664.0–3668.0	194.0–198.0	4.0	4.52	113
44	23	0155	3668.0–3672.0	198.0–202.0	4.0	2.33	58
45	23	0320	3672.0–3676.0	202.0–206.0	4.0	2.82	71
46	23	0455	3676.0–3680.0	206.0–210.0	4.0	1.64	41
47	23	0630	3680.0–3684.0	210.0–214.0	4.0	1.70	43
48	23	0740	3684.0–3688.0	214.0–218.0	4.0	1.31	33
49	23	0905	3688.0–3692.0	218.0–222.0	4.0	1.92	48
50	23	1030	3692.0–3696.0	222.0–226.0	4.0	1.71	43
51	23	1150	3696.0–3700.0	226.0–230.0	4.0	1.78	45
52	23	1310	3700.0–3704.0	230.0–234.0	4.0	1.38	35
53	23	1415	3704.0–3707.0	234.0–237.0	3.0	1.08	36
54	23	1545	3707.0	237.0	0	0	0
Total					227	174.58	77
Hole 504A							
1	27 Sept.	2200	3694.5–3704.0	226.5–236.0	9.5	0.63	6.6
2	27	2300	3704.0–3713.5	236.0–245.5	9.5	0.05	0.5
Hole 504A (Cont.)							
3	28	0115	3713.5–3723.0	245.5–255.0	9.5	1.52	16
4	28	0330	3723.0–3729.0	255.0–261.0	6.0	1.08	18
5	28	0540	3729.0–3733.0	261.0–265.0	4.0	0.68	17
6	28	1055	3733.0–3741.0	265.0–273.0	8.0	3.22	40
7	28	1505	3741.0–3745.0	273.0–277.0	4.0	1.83	46
Total					70.5	9.01	20.58
Hole 504B, Leg 69							
(Washed to 260.5 m sub-bottom)							
1	8 Oct.	2145	3734.0–3743.5	260.5–270.0	9.5	1.24	13
2	9	0040	3743.5–3750.5	270.0–277.0	7.0	0.96	14
(Drilled)			3750.5–3751.5	277.0–278.0	1.0		
3	12	0135	3751.5–3753.5	278.8–280.0	2.0	1.35	68
4	12	0615	3753.5–3763.0	280.0–289.5	9.5	5.00	53
5	12	1025	3763.0–3772.0	289.5–298.5	9.0	2.72	30
6	12	1445	3772.0–3781.0	298.5–307.5	9.0	2.52	28
7	12	1845	3781.0–3790.0	307.5–316.5	9.0	5.87	65
8	12	2331	3790.0–3799.0	316.5–325.5	9.0	6.08	68
9	13	0315	3799.0–3808.0	325.5–334.5	9.0	1.80	20
10	13	0650	3808.0–3817.0	334.5–343.5	9.0	2.26	25
11	13	1000	3817.0–3826.0	343.5–352.5	9.0	2.50	28
12	13	1400	3826.0–3835.0	352.5–361.5	9.0	2.09	23
13	13	1750	3835.0–3844.0	361.5–370.5	9.0	5.55	62
14	13	2135	3844.0–3848.5	370.5–375.0	4.5	1.62	36
15	14	0210	3848.5–3857.5	375.0–384.0	9.0	4.10	46
16	14	0615	3857.5–3866.5	384.0–393.0	9.0	4.37	49
(Tripped pipe to change bit and make heat flow measurements)							
17	17	0615	3866.5–3871.5	393.0–398.0	5.0	2.33	47
18	17	1050	3871.5–3876.5	398.0–403.0	5.0	1.50	30
19	17	1625	3876.5–3885.5	403.0–412.0	9.0	1.87	21
20	17	2128	3885.5–3894.5	412.0–421.0	9.0	0.92	10
21	18	0110	3894.5–3903.5	421.0–430.0	9.0	4.39	49
22	18	0710	3903.5–3912.5	430.0–439.0	9.0	2.24	25
23	18	1212	3912.5–3921.5	439.0–448.0	9.0	1.10	13
24	18	1643	3921.5–3930.5	448.0–457.0	9.0	3.47	38
25	18	2220	3930.5–3936.5	457.0–463.0	6.0	2.28	38
26	19	0030	3936.5–3939.5	463.0–466.0	3.0	0.62	21
27	19	0350	3939.5–3948.5	466.0–475.0	9.0	1.28	14
28	19	0850	3948.5–3957.5	475.0–484.0	9.0	3.86	43
29	19	1120	3957.5–3962.5	484.0–489.0	5.0	0.77	15
(Tripped pipe to run experiments)							
Hole 504B, Leg 70							
30	4 Dec.	0552	3962.5–3972.0	489.0–498.5	9.5	0	0
31	4	0940	3972.0–3981.0	498.5–507.5	9.0	0	0
32	4	1503	3981.0–3990.0	507.5–516.5	9.0	2.94	33
33	4	1850	3990.0–3999.0	516.5–525.5	9.0	2.38	26
34	4	2304	3999.0–4008.0	525.5–534.5	9.0	2.21	25
35	5	0229	4008.0–4017.0	534.5–543.5	9.0	1.66	18
36	5	0650	4017.0–4026.0	543.5–552.5	9.0	4.72	52
37	5	1209	4026.0–4035.0	552.5–561.5	9.0	2.66	30
38	5	1531	4035.0–4044.0	561.5–570.5	9.0	2.30	26
39	5	1901	4044.0–4053.0	570.5–579.5	9.0	2.90	32
40	6	0009	4053.0–4057.5	579.5–584.0	4.5	5.75	100+
41	6	0448	4057.5–4066.5	584.0–593.0	9.0	4.40	49
42	6	0823	4066.5–4075.5	593.0–602.0	9.0	1.5	17
43	6	1156	4075.5–4084.5	602.0–611.0	9.0	1.39	15
44	6	1521	4084.5–4093.5	611.0–620.0	9.0	2.00	22
45	6	1820	4093.5–4102.5	620.0–629.0	9.0	1.87	21
46	6	2145	4102.5–4111.5	629.0–638.0	9.0	2.85	32
47	7	0221	4111.5–4120.5	638.0–647.0	9.0	3.82	42
48	7	0607	4120.5–4129.5	647.0–656.0	9.0	3.10	34
49	7	1331	4129.5–4138.5	656.0–665.0	9.0	2.73	30
50	8	2329	4138.5–4143.0	665.0–669.5	4.5	0.30	6
51	9	0421	4143.0–4152.0	669.5–678.5	9.0	0.90	10
52	9	0923	4152.0–4161.0	678.5–687.5	9.0	4.05	45
53	9	1153	4161.0–4165.5	687.5–692.0	4.5	0.37	8
54	9	1414	4165.5–4170.0	692.0–696.5	4.5	1.58	35
55	9	1700	4170.0–4179.0	696.5–705.5	9.0	1.27	14
56	9	2001	4179.0–4188.0	705.5–714.5	9.0	1.78	20
57	10	0027	4188.0–4197.0	714.5–723.5	9.0	3.9	43
58	10	0512	4197.0–4206.0	723.5–732.5	9.0	3.86	43
59	10	0816	4206.0–4215.0	732.5–741.5	9.0	0.40	4
60	10	1232	4215.0–4224.0	741.5–750.5	9.0	1.85	21
61	11	1752	4224.0–4228.5	750.5–755.0	4.5	2.31	26
62	11	2036	4228.5–4237.5	755.0–764.0	9.0	1.60	18
63	12	0115	4237.5–4246.5	764.0–773.0	9.0	3.85	43
64	12	0630	4246.5–4255.5	773.0–782.0	9.0	4.55	51
65	12	0948	4255.5–4264.5	782.0–791.0	9.0	1.10	12
66	12	1611	4264.5–4273.5	791.0–800.0	9.0	2.41	27
67	12	1904	4273.5–4282.5	800.0–809.0	9.0	0.95	11
68	12	2154	4282.5–4291.5	809.0–818.0	9.0	0.80	9
69	13	0013	4291.5–4300.5	818.0–827.0	9.0	1.00	11
70	13	0415	4300.5–4309.5	827.0–836.0	9.0	1.48	16
Total					574.5	168.15	29.3

[a] No heat flow/pore water measurements possible at this level because of malfunctions of heave compensator.

Table 3. Logging and downhole measurement operations—Holes 501, 504A, 504B, and 504C.

Date (1979)	Time Interval	Operations	Comment
Hole 501			
9 July	1505–1700	Downhole temperature	Valid measurement
9	2155–2400	Downhole temperature	Valid measurement
12	1330	Completion of drilling	
12	1330–1630	Packer flow tests	Inflatable element severely damaged
12	1630–2300	Clean and prepare hole for logging	
13	2300–0530	Sonic and natural gamma caliper logs	Sonic tool didn't work
13	0530–1200	Gamma compensated density, natural gamma, caliper, and temperature logs	Natural gamma questionable
13	1200–2400	Borehole televiewer	Excellent results
14	0000–1300	Downhole magnetometer	H_x, H_y, H_z good data, poor magnetic susceptibility
14	1300–1900	Temperature log and sampler	Sampler collapsed
14	1900–2345	Clean hole, flush with mud	
15	0000–0415	Laterolog, neutron density, natural gamma	Excellent natural gamma gave anomalous results in base
15	0615–1645	Large-scale resistivity experiment	Valid measurements obtained at 10-m intervals
Hole 504A			
26 Oct.	0600–0900	Temperature, caliper, natural gamma sampler	Valid results, good sample
Hole 504B, Leg 69			
19 Oct.	1130	Drilling stopped at 3962.5 m	
20/21	2020–2000	Packer flow tests at 3790 m and 3959.5 m	Flow tests valid
22	1600–2100	Natural gamma, compensated density, caliper temperature	Valid data
22/23	2145–0145	Guard resistivity, neutron density, natural gamma	Valid data
23	0200–1150	Downhole magnetometer	Unsuccessful on two runs
23	1200–2200	Borehole televiewer	Fair performance, lowering useful record obtained
23/24	2200–0200	Sonic velocity	Failed on trip down
24	0315–0800	Downhole magnetometer	Successful run
24/25	0830–2225	Packer sampler	Sampler filled, inflatable element destroyed
Hole 504B, Leg 70			
3 Dec.	3473–3933	Temperature log with Tokyo T-probe in drill bit	54 days after Leg 69 departure from hole
8	3837–4129	Temperature log with Tokyo T-probe in drill bit	30 hr after cessation of coring operations
13	0430–1100	Clean out hole, pull above mudline, drop bit, re-enter hole	
13	1305–1753	Sonic log (interval velocity and spectrum), natural gamma, caliper, maximum temperature	All tools operated satisfactorily
13/14	1836–0210	Oblique seismic experiment	Instrument malfunctioned
14	0230–1650	Large-scale electrical resistivity	Good data obtained
14	1805–2330	Temperature log; compensated density, natural gamma, caliper, and maximum temperature	Density tool did not operate. ~40 hrs. after cessation of circulation
15	0000–2115	Oblique seismic experiment	Satisfactory travel time data
15/16	2318–0510	Guard resistivity, neutron density, natural gamma	Resistivity tool failed on way down at 3800 m, density
16	0520–0915	Temperature log and water sampler	Satisfactory. ~75 hr after cessation of circulation
16	0945–1421	Guard resistivity, natural gamma, neutron density	Resistivity okay, neutron density only partly successful
16	1421–2355	Pull drill string and magnaflux BHA	
Hole 504C			
14 Oct.	1232–1410	Downhole temperature and IPWS[a]	Valid measurement
14	1601–1800	Downhole temperature and IPWS	No valid measurement—failed battery
14	1917–2100	Downhole temperature and IPWS	Valid measurement
14	2242–2400	Downhole temperature and IPWS	Valid measurement

[a] *In situ* pore water sampler.

tioning, so it could not be used as a reference. The *Glomar Challenger* maneuvered in the vicinity until a reliable fix could be obtained. The beacon for Site 504 was dropped at 0413 hr. local time on 20 September 1979 based on dead reckoning from the last reliable fix, and subsequent satellite fixes showed this new beacon to be 0.9 km due east of Site 501.

The location of Hole 504 is 250 meters east and 90 meters south of Hole 501 (Fig. 2 and Table 4). A bottom hole assembly designed for the hydraulic piston corer (HPC) was made up and the pipe was run in on the morning of 20 September. After touching bottom the bit washed down to approximately 10 meters below the mudline (3480 m below the derrick floor), and hydraulic piston coring began at that point.

Continuous hydraulic piston coring was carried out to a depth of 237 meters (53 cores) without a serious malfunction (Table 2). At this depth chert layers were encountered, as anticipated from the Site 501 results, which the HPC could not penetrate, and coring was stopped. The recovery rate of the piston coring was 95% in the upper 100 meters. Below this depth the sediment

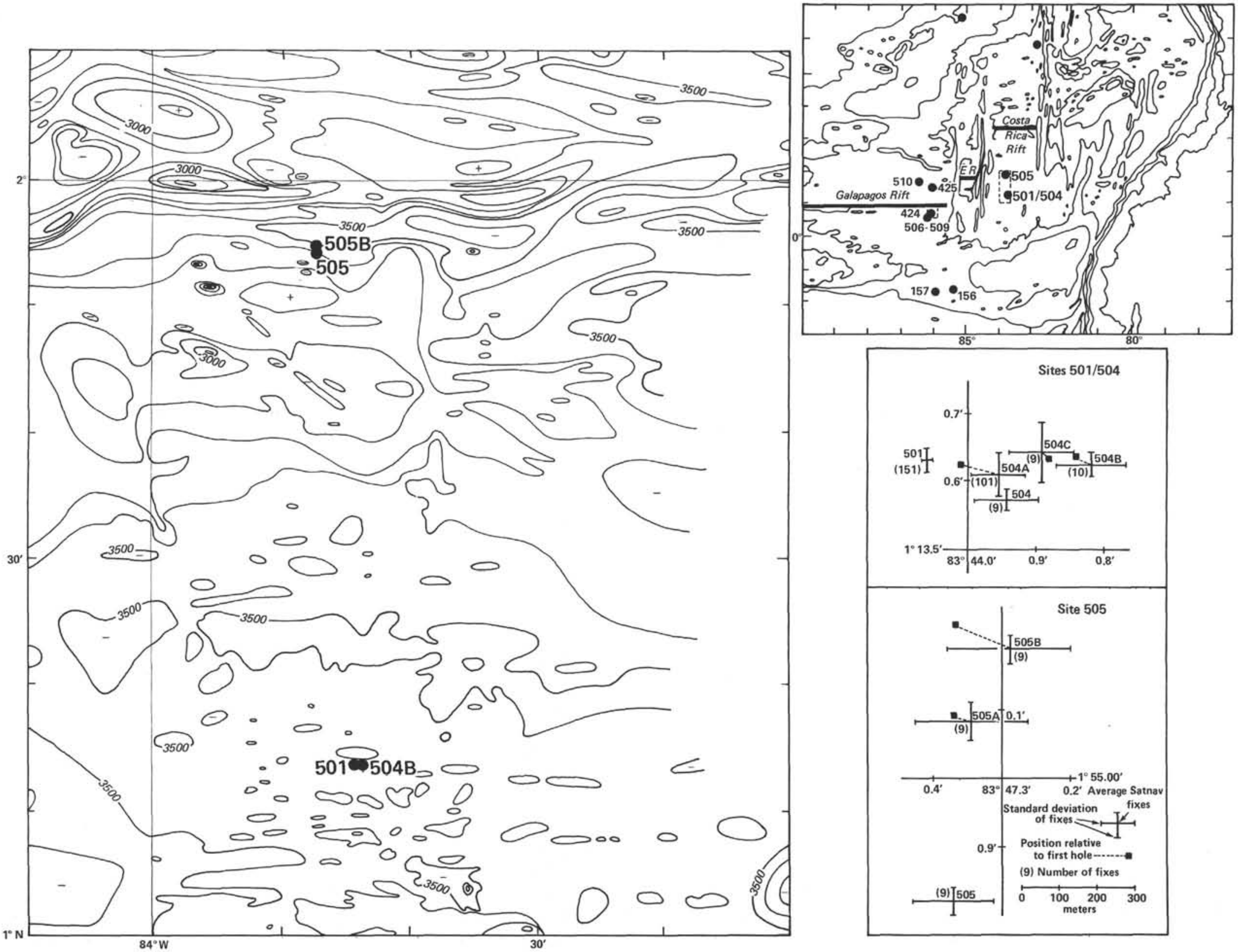

Figure 2. Bathymetry of the Costa Rica Rift flank near drill Sites 501, 504, and 505 (from CRRUST, 1982). At the upper right is an index map of the Galapagos Spreading Center; locations of other DSDP sites are shown. At lower right are magnified maps of the hole locations at the sites. For some sites, two positions are given: (1) the position based on the average of satellite navigation fixes (shown by crossed lines) and (2) positions relative to the first hole at a site based on offsets of the *Glomar Challenger's* dynamic positioning system (shown by squares).

Table 4. Positions of Holes 501 and 504.

	Mean of Satnav[a] Fixes		Relative to First Hole[b]	
Hole	Latitude N	Longitude W	Latitude N	Longitude W
501	1°13.63′	83°44.06′	—	—
504	1°13.571′	83°43.942′	—	—
504A	1°13.609′	83°43.955′	1°13.622′	83°44.007′
504B[c]	1°13.624′	83°43.819′	1°13.632′	83°43.843′
504C	1°13.642′	83°43.891′	1°13.633′	83°43.884′

[a] Satellite navigation.

[b] Location relative to the first hole drilled at the site (504) is based on offsets from the beacon set into the positioning computer. Location of first site is assumed to be the mean of Satnav fixes.

[c] Position of Hole 504B, based on Leg 70 navigation, is 1°13.63′N and 83°43.81′W.

became more consolidated and stronger, and the recovery rate decreased. A significant decrease in recovery rate also occurred between 100 meters and 115 meters sub-bottom, which does not coincide with any abrupt change in physical properties of the sediments. Full extension of the piston core barrel was achieved at each firing to a depth of 175 meters, with a single exception at 111 meters. At depths greater than 175 meters, 10 out of 15 cores showed evidence of extension shorter than 4.4 meters.

For the first 39 cores the bit was advanced 4.4 meters by washing regardless of the amount of recovery or penetration. Beginning with Core 40, the bit was washed down only 4.0 meters after each core and the bit face was raised 40 cm above the bottom of the hole before the piston corer was fired. Core 53 penetrated a chert layer that was probably a few centimeters thick and obtained a 100-cm section of softer chalk beneath. The rim of the cutting edge was peened over by the chert. A last core, Core 54, was attempted in Hole 504, but no sample was obtained and the core catcher was badly damaged.

Operations at Hole 504 ended at 2330 hr. on 23 September 1979.

Hole 504A

After the completion of drilling operations at Hole 504 the ship was shifted to a point approximately 100 meters north and 120 meters west of Hole 504. With the beacon as the reference point this location was about 100 meters east of Site 501 (Fig. 2 and Table 4), and a re-entry hole was begun. The running of the pipe was slowed by problems with the thrusters. A 90-meter section of 16-in. casing was washed down into the sediments, and the cone was set.

At that point the bit was released from the casing and washed down to a depth of 97 meters sub-bottom. A bottom hole temperature measurement and *in situ* water sampler were tried at this depth, but leakage of seawater into the pressure housing ruined the observations. A second heat flow and *in situ* pore water sampler (HF/IPWS) run was made after washing down 152 meters sub-bottom. The probe became jammed in the bit and could not be retrieved by the sandline. As a result the drill pipe was pulled back on board. Again, the heat flow and *in situ* pore water sampler observations were ruined because of the leakage of water into the pressure core.

At 0600 hr. on 27 September re-entry was made and the bit was washed to a depth of 3694.5 meters. This depth placed the bit about 7.5 meters above the first chert zone. From this depth continuous rotary coring began. The basement was reached at 3732 meters, 264 meters sub-bottom. A 14 7/8-in bit was used during the first phase of the drilling to open a hole for the second length of 11-in. casing. Drilling was slow, with much torque, and at about midnight on 28 September very high torque and no downward progress indicated possible bit damage. The drill string was pulled from the hole for a second time, and we discovered that two of the cones and the shanks that supported them had broken off the large-diameter bit and remained in the hole. Since the two large roller cones and steel fragments lying in the bottom of the hole would have taken considerable time and perhaps special equipment to remove, we decided to stop operations at Site 504 temporarily and move to Site 505. We left Site 504 at about 0800 hr. on 29 September. While we were at Site 505, a new re-entry cone was prepared for our return to Site 504.

Hole 504B, Setup and Initial Re-Entries

Following the completion of the program at Site 505 at about 1800 hr. on 7 October 1979, we returned to Site 504 to begin a second re-entry. On the way south from Site 505 standard underway geophysical measurements were made along a line parallel to, and 2 miles east of, the track made going northward. The location of Hole 504B is about 300 meters east of Hole 504A (Fig. 2).

The operation of setting up a new multiple re-entry site, which included casing the hole through 275 meters of sediment to basement, took 4 days and was completed by 2015 hr. on 8 October. At 260.5 meters sub-bottom we began coring. The first two cores contained chert and siliceous chalk. Igneous basement was encountered at 3748 meters sub-bottom.

After we drilled a short distance into basement, we flushed the hole with mud and seawater and pulled the large-diameter drill pipe out of the hole. The hole was re-entered at 1330 hr. on 10 October, and 275 meters of 11 3/4-in. casing was run into the hole and cemented into basement. After the casing operation, the string was once again pulled up on deck and a bottom hole assembly, including a standard 9 7/8-in bit, was made in preparation for basement drilling. We re-entered for the second time on 11 October at 1616 hr.

Continuous coring was carried out from 0000 hr. on 12 October to 0630 hr. on 14 October, reaching a depth of 393 meters sub-bottom. Fourteen cores, consisting of pillow basalts, one massive flow, and several thin flows, were taken. The rocks recovered were highly fractured, and sticks of core more than 20 cm long were rare. The drilling conditions were relatively good, and penetration rates were normal. On the average we required 4 to 5 hr.

to cut a 9-meter core. The heave compensator system was used during coring, and it appeared to make drilling smoother, with less torque.

Hole 504C

After Core 16 was taken at Hole 504B, we decided to change the bit. However, before bringing the bottom hole assembly back on deck, we offset 200 ft. west of the cone and washed down through the sedimentary section to 220 meters to make four bottom hole temperature measurements and take *in situ* pore water samples (Table 3). This hole was designated Hole 504C even though no cores were taken. Three of the four temperature measurements were successful, and all four of the *in situ* sampling attempts were successful, although chemical evidence indicates that the two deepest samples are strongly contaminated by circulating seawater. We believe this to be due to the incomplete closing of the valve on the sampler after the fluids in the sediment had been drawn. The heave compensator was used during the operations at Hole 504C, and this helped to hold the bit steady, even in weak sediments.

Hole 504B, Additional Coring

After the completion of Hole 504C the drill string was brought on deck. Preparations were made for the third re-entry into Hole 504B. In an effort to improve knowledge of bit movements during re-entry, a sonar reflector with a mooring weight was set on the bottom about 30 meters north of the cone. While the ship was being maneuvered back to the cone in preparation for reentry it suffered a major power failure; without power for maintaining position or operating the drilling equipment, the ship began to drift northward in the prevailing currents. This carried us into shallower water, allowing the drill string to drag along the soft bottom. When power was restored we pulled the bottom hole assembly back on board to inspect it and to magnaflux its most vulnerable sections. The bottom hole assembly proved to be sound, so we started back down immediately for another attempt at re-entry. This was achieved at 2230 hr. on 16 October. The bit was run back to the bottom of the hole, and we began the second segment of basement drilling and coring in Hole 504B. Coring was carried out without interruption until 1130 hr. on 19 October, when it stopped after a total penetration of 489 meters sub-bottom (Table 2). As before, the drilling went quite smoothly, with little torquing. The penetration rate was on the average about 40 meters per day. Core recovery was variable but predominantly low (28%). Highly fractured basalt, rounded pieces, and some brecciated basalt were recovered. The pipe was then pulled up on deck to begin the experimental and logging phase of the program.

Hole 504B, Experiments and Logging, Leg 69

The bottom hole assembly was changed to include the Lynes packer subassembly, the hydraulic bit release, and torque jars. After the packer was assembled we lowered it just below the waterline and began testing. The first test showed that the packer subassembly was not operating properly, but the fault was corrected and the assembly was successfully tested before it was sent down for a fourth re-entry.

The fourth re-entry at Hole 504B was made at 2020 hr. on 20 October. We ran down the hole to 3790 meters, where coring had revealed a massive flow unit, and conducted the first series of pulse and flow tests. The packer was successfully inflated and the plug was blown. The packer remained inflated so that several flow tests were carried out. They revealed the lower 120 meters of the hole to be quite permeable (Zoback and Anderson, this volume).

The go-devil was retrieved, the bit was lowered to the bottom of the hole, and a second series of tests was successfully executed. The packed-off section of the hole lost pressure slowly, requiring more than 15 min. to decay to 300 psi. However, it proved impossible to retrieve the go-devil. We wrestled with this problem until about 2000 hr. on 21 October, when we decided that we would have to trip the drill string.

Once back on deck we discovered that the fishing head of the go-devil was covered by over a foot of rust, but the packer element was in good condition.

The fifth re-entry for logging Hole 504B was achieved at 1330 hr on 22 October. To preserve the established temperature gradient we lowered the bottom of the pipe only 60 meters into the casing. The logs and experiments run in Hole 504B are listed in Table 3.

The drill hole proved to be remarkably clean and free of obstructions. The tools could be lowered to 3952 meters without difficulty. This was 10 to 11 meters shy of the bottom, so some type of fill blocked the lowest part of the hole.

The Soviet downhole magnetometer was run three times. During the first run, susceptibility and vertical component measurements were successfully measured, but the horizontal component measurements were highly variable (Ponomarov and Nekhoroshkov, this volume). During the second run only the horizontal components were measured, but they were again plagued by highly variable signals. A third run from 0315 to 0800 hr. on 24 October gave much better results on the horizontal sensors.

The borehole televiewer was run successfully into the hole. This was a major achievement, since the instrument had suffered significant damage in transit to the ship. In repairing it we used a transducer from one of the re-entry tool heads, and many modifications in the electronics and mechanical operation of this rather complex tool had to be made. The records were noisy, especially near the top of the hole, but performance improved greatly as the instrument was lowered deeper in the hole. With 2 days remaining at the site during Leg 69 we planned further packer tests, including drawing a large-volume sample at *in situ* pressure with the annulus of the hole packed off, and additional flow tests above and below what appeared to be a highly permeable zone where water was flowing down the hole and into the basement rocks.

The bottom hole assembly with the packer was run back downhole starting at 2300 hr. on 24 October. The sixth re-entry at Hole 504B was made at 0723 hr. on 25 October. The bit with the power subassembly in place was run into the hole to a total depth of 3962.5 meters. A bridge that had been stoppping logging tools at about 3950 meters was knocked out by the bit. The hole was flushed with 50 barrels of barite mud and then with seawater.

The packer sampler actuating tool, together with the sampler, which stands nearly 70 ft. (21.3 m) high, was dropped down the hole at 1415 hr. Pressure was applied to inflate the packer and open the sampler-filling part. When pressure was bled off, the BHA was found firmly stuck in the bottom of the hole. The sampler was retrieved with the sandline; it contained a good sample. The 15-gal. sampler space was filled with water and exsolved gas. The bit remained stuck, so some additional flow tests were made. We noted that the pressure at the bottom of the hole fell off more and more rapidly with each test. After these tests, we found that the bit could be worked up about 10 meters; then it became stuck again. However, the pipe could be rotated, indicating that the packer element had probably been broken free by torquing. The drill string was pulled up against considerable friction in the hole. Since it appeared that the hole would be endangered if we tried to run in again, we decided to end operations in Hole 504B at this point. We pulled the bit above the mudline at 2225 hr. on 25 October. We then offset the vessel to the cone at Hole 504A for logging in that hole, which had last been disturbed on 29 September (Table 2). A logging run to 3744.6 meters in Hole 504A was successful.

Hole 504B, Leg 70

The operations in Hole 504B during Leg 70 were centered mainly on the continuous coring of basement rock, and logging the hole after coring terminated. We cut 41 cores in basement between 489 and 836 meters sub-bottom over a period of about 9 days (Table 2). Table 3 gives a summary of the logging and downhole measurement operations made after we drilled and cored to final depth.

The *Glomar Challenger* arrived in the vicinity of Hole 504B on the evening of 1 December 1979 after following a generally eastward track from Site 510. Sonic pulses from the beacon left on Leg 69 were observed on the depth recorder as the vessel passed over the site, but when we returned to the vicinity (without good satellite fixes for several hours), the pulses were irregular. An occasional good beacon fix allowed the vessel to approach near enough to drop a new beacon at 2303 hr. on 1 December.

After running in the drill string to near the mudline, the sonar scanning tool was deployed for finding the re-entry cone. The tool did not rotate properly, however, and after several unsuccessful attempts we decided to pull the drill string and inspect the bit assembly. The bit was on board at 2245 hr. on 2 December. Tests indicated that nothing was wrong; the tool operated satisfactorily at the surface. Therefore, the drill string was run back down, and the sonar scanning tool was run in again. We again had difficulty rotating the scanner until we discovered that reducing the pump pressure allowed it to operate normally. In the meantime, the numerous satellite fixes received after dropping the beacon had allowed the vessel to be positioned rather accurately over the site location determined on Leg 69, and when the sonar scanning tool became operable the re-entry cone was seen only about 20 meters away. Re-entry was accomplished at 1343 hr. on 3 December after about 3 hr. of maneuvering.

After we lowered the bottom hole assembly about 40 meters into the hole to be certain that re-entry had been properly effected, we ran in the temperature measurement device (Tokyo T-probe) and Barnes pore water sampler and successfully lowered them to the bottom of the hole by running in the drill string. Then Cores 30 to 49 (Table 2) were cut until we decided to change the bit. (There was no recovery in Cores 30 and 31, evidently owing to the presence of torn pieces of the packer element left in the hole during Leg 69.) The drill string was pulled above the mudline at 1140 hr. on 7 December to drop the bit in anticipation of re-entry and to attempt some downhole measurements. However, we were unsuccessful in dropping the bit, so by 2130 hr. on 7 December the drill string was brought back on board. At the surface we discovered that the bit had dropped off, so the release had probably operated, but not completely. The bit was changed and the drill string run back down, and re-entry was accomplished at 1232 hr. on 8 December.

The Tokyo T-probe/pore water sampler was then run again as before to the bottom of the hole. Continuous coring resumed at 1245 hr. on 8 December, and Cores 50 to 60 were cut. The variations in the diameter of the recovered cores caused doubt about the condition of the bit, so we brought the drill string back on board for a bit change. The bit still appeared to be in reasonably good condition, but we replaced it with a new bit nonetheless and re-entry was accomplished at 0750 hr. on 11 December 1979. The Tokyo T-probe/pore water sampler was run as before to the bottom of the hole; a water sample was successfully obtained, but the temperature-measuring instrumentation did not function properly.

We then resumed continuous coring until 0430 hr. on 13 December 1979, during which time Cores 61 to 70 were cut. Drilling conditions remained excellent throughout, with drilling rates running at more than 4 m/hr., even though recovery was low. However, time constraints for Leg 70 required that we begin an extensive program of logging and downhole measurements at this point. Therefore the drill string was pulled above mudline, the bit was successfully released outside the hole, and re-entry was accomplished for the fourth and final time (on Leg 70) at 1055 hr., 13 December 1979.

The logging program (Table 3) was completed at about 1420 hr. on 16 December, and the drill string was brought on board shortly before midnight. Hole 504B was left clean for possible future drilling, and the ship departed for port shortly after 0018 hr. on 17 December. Seismic reflection profiling was carried out on a southerly course away from Hole 504B.

SEDIMENT STRATIGRAPHY AND LITHOLOGY

Hole 501

The sediment column for Hole 501 was spot cored (10 cores) to basement; total sediment recovery was 41.95 meters (Fig. 3). The total sediment thickness was 264 meters. Essentially the same sedimentary types were encountered as at Site 504 for the respective depth intervals, except for the top 10 meters, which were not cored at Site 504.

Core 1 of Hole 501 (0–7.6 m) consists of siliceous carbonate core. Its basic color is dark greenish gray. The calcareous biogenic fraction (average: 53%) consists mainly of nannofossils (23% of the total sediment), foraminifers (18%), and unspecified carbonate particles (12%). The siliceous biogenic fraction (average: 26%) is formed by diatoms (12%), radiolarians (8%), sponge spicules (6%), and traces of silicoflagellates. Clay-sized material in the core averages 12%. There is also a significant amount of colorless volcanic glass in the core, with an average abundance of 5.7%. Trace components are glauconite, opaque minerals, and other detrital constituents. Drilling disturbance has largely obliterated the sedimentary structures. However, the sediment seems to be bioturbated, and relief bedding is indicated by changes in the color, grain size, and composition of the sediments. Components of volcanic glass of 10 and 15% were found at 5.49 and 7.05 meters and may represent disseminated ash layers decomposed by bioturbation and drilling.

Since the remaining cores in Hole 501 resemble sediments that were continuously cored nearby at Site 504, and since the Site 504 sediments are very little disturbed by drilling, the remaining Hole 501 cores are not described here.

Site 504 Summary

The sedimentary sequence for Site 504 consists of three lithologic units (Fig. 3):

1) Unit 1 (0 to 143.5 m)—late Pleistocene to late Pliocene siliceous-nannofossil and nannofossil-radiolarian oozes, variably clay bearing;

2) Unit II (143.5 to 227.2 m)—late Plicoene to late Miocene siliceous-nannofossil chalk; and

3) Unit III (227.2 to 271 m)—late late Miocene interbedded nannofossil chalk, limestone, and chert.

In Holes 501, 504A, and 504B basaltic basement was reached at 264, 262, and 271 meters, respectively (Fig. 3). The differences are due to the slightly undulating basement relief. In Hole 504A the first limestone layer, which was intercalated in nannofossil chalk and was only a few centimeters thick, was reached at 227.2 meters. In Hole 504 the first encounter with limestone occurred deeper, at 234.2 meters. The uppermost dense limestone/chert beds shown by the televiewer record and the logging data occur between 235 and 237 meters, however. Therefore it is very likely that at Hole 504 the hydraulic piston corer went through the thin limestone layer found at Hole 504A without recovery before it reached the dense limestone/chert beds.

The oozes and chalk of Units I and II consist mainly of calcareous nannofossils, with other fossil remains such as radiolarians, diatoms, silicoflagellates, sponge spicules, and foraminifers. Within the clay-sized fraction, montmorillonite is the major constituent. Colorless rhyolitic volcanic glass and pyrite are minor but significant constituents. The pyrite and the prevailing green hues are characteristic of the reduced oxidation state throughout Units I and II. Both units are moderately to intensively bioturbated. Relict bedding is evidenced by changes in color, composition, grain-size distribution, and $CaCO_3$ content. Except for a few discrete ash layers, no sharp lithologic boundaries are apparent.

Units I and II exhibit differences in induration, marked by sudden changes in porosity, shear strength, and thermal conductivity (see Wilkens and Langseth, this volume). They also differ in color (Unit I is darker), $CaCO_3$ content (Unit II is generally higher), and fossil preservation (fossil debris is more fragmented in Unit II). Corrosion on foraminifers and echinoderm spicules is common in Unit II, as is calcitic overgrowth on discoasters. In the middle part of Unit I there is also a remarkable increase in the content of siliceous fossil remains.

Unit III was clearly derived from the same basic material as the units above, since it also has radiolarians, diatoms, silicoflagellates, sponge spicules, foraminifers, and nannofossils and is comparably burrowed. However, increased dissolution and fragmentation often make microfossil recognition difficult. Silica dissolution and pore-filling redeposition of opal-A and its transformation toward opal-CT as well as chalcedony and quartz led to a considerable degree of chertification. It is clear that the unit boundaries at Site 504 are basically diagenetic boundaries.

Lithologic Units, Site 504

Unit I (Cores 501-1 to 504-31, 0–143.5 m)

Unit I consists of siliceous-nannofossil and nannofossil-radiolarian oozes and is variably clay bearing. It may be subdivided into three subunits as follows on the basis of differences in color.

Subunit IA (Cores 501-1 to 504-13, 0–65 m)

Subunit IA is an early to late Pleistocene nannofossil-radiolarian ooze, sometimes clay bearing. Its prevailing colors are greenish gray, dusky yellow green, grayish green, and grayish yellow green, with some olive in the top 10 meters. Color layering is more frequent in the subunit's upper part but is visible throughout. Extensive bioturbation has mottled the colors considerably. *Zoophycos* burrows are especially prominent.

The average grain-size distribution shows that the subunit is composed of 5% sand-sized (> 63 μm), 84% silt-sized, and 11% clay-sized (visual estimate) material. The $CaCO_3$ content measured on board by the Karbonat Bombe method averages 41% and stems mainly from

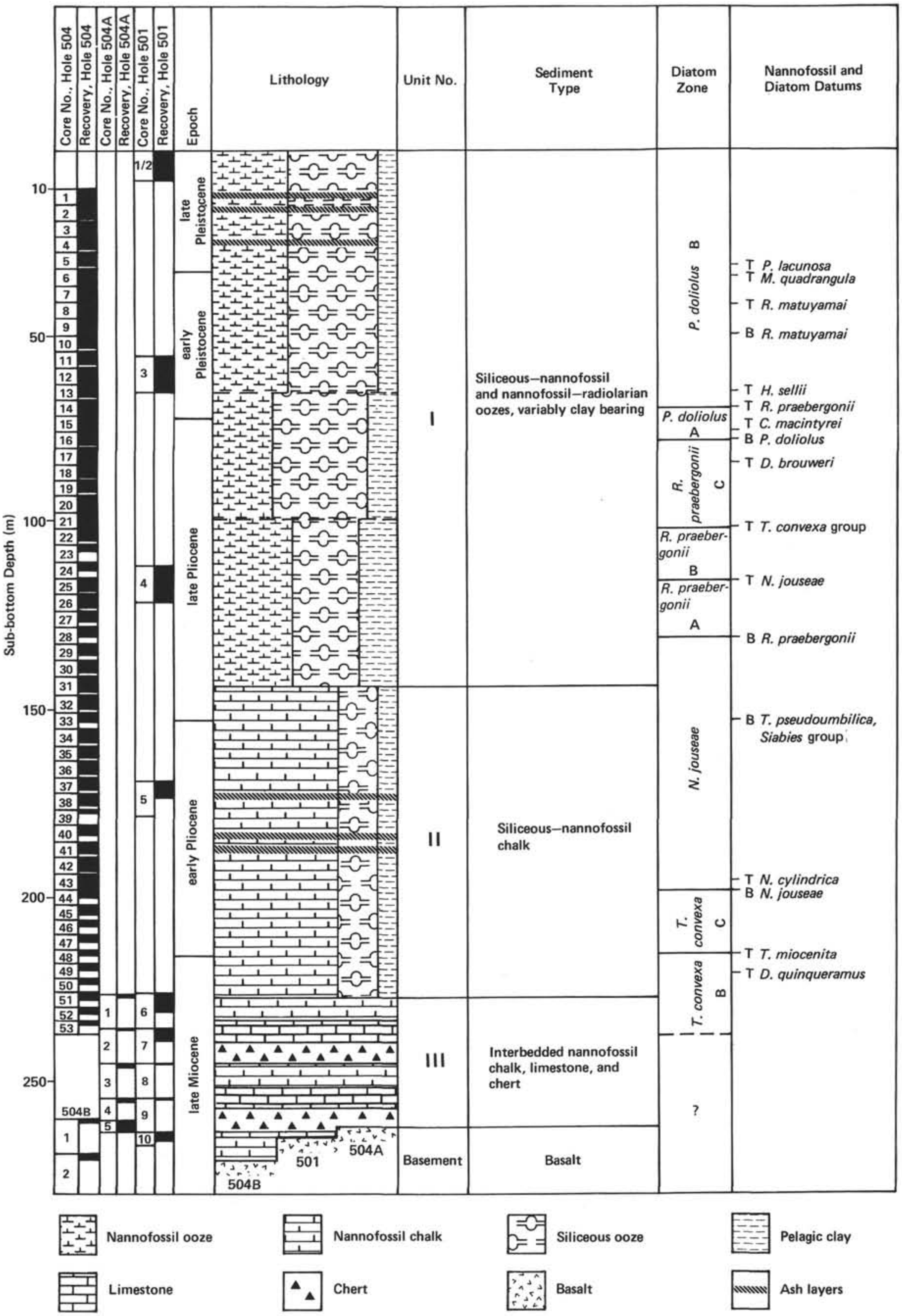

Figure 3. Summary of sediment lithology, diatom zonation scheme, and datum levels, Sites 501 and 504. A, B, C—diatom subzones. T, B—top, bottom occurrences of indicator fossils.

calcareous nannofossils and a considerably smaller portion of foraminiferal material (intact tests and fragments). The siliceous biogenic portion of the sand- and silt-sized fractions consists mainly of radiolarians and diatoms; silicoflagellates and sponge spicules are minor constituents. Montmorillonite is the major component of the clay-sized fraction. Besides three distinct volcanic ash layers (at 12.25, 14.95, and 28.75 m), there is an increased amount (2–5%) of disseminated glass at both ends of the subunit. In the middle part, glass drops below 1%. The intervals with higher volcanic glass content show more vertical burrowing.

Subunit IB (Cores 504-13 to 504-21, 65–99 m)

Subunit IB is an early Pleistocene to late Pliocene clay-bearing nannofossil-radiolarian ooze. Its prevailing colors are dusky to grayish yellow green and light to dark olive gray and olive. Color layering is less significant than in Subunit IA. Bioturbation is less significant than in Subunit IA insofar as *Zoophycos* burrows and large vertical burrows are concerned. The average grain-size distribution shows 4% sand-sized (>63 μm), 80% silt-sized, and 16% clay-sized (visual estimate) material. The clay-sized portion of the sediment is large in the upper part (up to 35%) and low in the lower part of the subunit ($<10\%$). The mean $CaCO_3$ content in the subunit is 32%. With the increasing content of clay-sized material, the $CaCO_3$ content decreases. The different grain-size fractions of Subunit IB are generally formed by the same constituents as those of the subunit above it. There is a remarkable increase in the content of siliceous fossil remains, as compared with Subunit IA; however, the preservation of all microfossils is quite poor, with only dissolution-resistant species remaining. Volcanic glass rarely exceeds 1% and is nowhere higher than 2%. No volcanic ash layers were observed.

Subunit IC (Cores 504-21 to 504-31, 99–143.5 m)

Subunit IC is a late Pliocene clay-bearing siliceous–nannofossil ooze. The prevailing colors are greenish gray in the upper part and light olive gray in the lower part of the subunit. Color layering is less significant than in Subunit IB. *Zoophycos* burrows are more frequent than in Subunit IB and are increasingly visible with depth, whereas large vertical burrows like those in the overlying subunits were not observed. As in the case of Subunit IB, large burrow halos with dark gray and purple rinds become abundant. The average grain-size distribution shows that the subunit is composed of 3% sand-sized, 76% silt-sized, and 21% clay-sized material. The clay-sized portion is large (up to 50%) in the upper half and small (6–15%) in the lower half of the subunit. The constituents of the different grain-size fractions are the same as in the subunits above. The $CaCO_3$ content averages 44%. It is lower where the clay-sized portion of the sediment is higher (minimum $CaCO_3$: 12%) and higher where the clay-sized portion is lower (maximum $CaCO_3$: 50%). Volcanic glass occurs mainly as traces. The pyrite content shows its maximum at the top of the subunit, where it reaches 3%. The firmness of the sediments of the subunit increases considerably with depth, leading abruptly into chalk.

Unit II (Cores 504-31 to 504A-1, 143.5–227.2 m)

Unit II consists of siliceous–nannofossil chalk. The sometimes clay-bearing chalk is characterized by colors of light gray, light greenish gray, and very pale green. Color changes are less numerous than in Unit I. Bioturbation is intense. Remarkable large halos around the burrows are prominent throughout the chalk sequence (see also Subunit IC). The average grain-size distribution shows 2.5% sand-sized, 87.5% clay-sized, and 10% clay-sized material. The constituents of the different grain-size fractions are the same as in Unit I. The $CaCO_3$ content of Unit II averages 69%. It rises more or less continuously toward the base of the chalk. Volcanic glass occurs mainly as traces, except for three discrete ash layers at 173, 183.4, and 187.35 meters and a glass-rich layer at 200 meters (probably a dispersed ash layer). Pyrite occurs as traces only and is therefore generally less abundant than in Unit I. In the upper half of the chalk sequence there is a remarkable increase in unspecified carbonate particles. From 168.4 meters downward irregular signs of corrosion on foraminifers become significant, and from 198 meters downward corrosion on echinoderm spicules becomes apparent as well. From 160 meters downward calcitic overgrowth of discoasters is strongly enhanced, showing increased diagenetic calcite dissolution and reprecipitation.

Unit III (Cores 504A-1 to 504B-2, 227.2–271 m)

Unit III consists of interbedded nannofossil chalk, limestone, and chert. The basic colors are light greenish gray for chalk, light greenish gray and yellowish gray for limestone, and medium dark gray for chert. All rock types show strong vertical compaction, which has produced fine horizontal lamination and flaser structures. The compaction as measured on *Zoophycos* burrows was approximately 80%. However, in the chalk as well as in the limestones, numerous open foraminifer chambers occur. The nannofossil chalks and limestones show only traces of radiolarians and diatoms. The limestones are biomicrites, showing abrupt differences in composition on a microscopic scale. Their matrix consists of unspecified carbonate and nannofossils. Where foraminifer chambers have collapsed, their fragments are arranged parallel to the lamination of the rock. Pyrite is a minor constituent but is often concentrated in the direction of the laminae. Although the chalk/limestone boundaries are sharp, there are many transitions between limestones, porcellanites, and cherts. With increasing depth a tendency toward chertification becomes more apparent, although this impression is based on limited recovery. The thickness of the layers of each rock type varies, but the chert beds never seem to exceed a few centimeters in thickness, appearing rather as layers a few millimeters thick or as stringers. Irregularly chertified portions within the limestone and nodular chert also appear. Calcitic shells in the silicified portions of the limestones are mainly filled with chalcedony, but opal-

CT lepispheres with chalcedony-filled chambers can also be seen. Partial or total replacement of the calcitic shell material also occurs.

BIOSTRATIGRAPHY

The Pliocene/Pleistocene boundary, which is defined by the last appearance of *Rhizosolenia praebergonii*, occurs 70 meters sub-bottom, in Core 14, Section 2 of Hole 504. The last occurrence of *Discoaster brouweri* occurs almost 15 meters lower, at 84 meters sub-bottom (Core 17, Section 3). However, calcareous nannofossils are so rare and poorly preserved throughout the clay-bearing interval (65–102 m sub-bottom) that the actual upper limit of the distribution of *D. brouweri* may be higher in the section. It is thus not as reliable a market for the boundary as *R. praebergonii*.

The Miocene/Pliocene boundary (last occurrence of *Thalassiosira miocenica*) occurs at 215 meters sub-bottom, in Sample 504-48,CC. The last occurrence of *D. quinqueramus* is probably just below this (220 m sub-bottom, Sample 504-49,CC.). However, overgrowth of discoasters is quite advanced at this depth, so the datum is open to question.

It was not possible to date the remainder of the section, because diagenesis has destroyed all of the diatoms and severely altered the calcareous nannofossils.

Figure 3 gives the diatom zones and datum levels for Sites 501 and 504. A few datums for calcareous nannofossils are also given. These are less reliable because of the rarity of marker species in some intervals and the generally poor preservation resulting from diagenesis (lower part) or carbonate dissolution (upper part).

SEDIMENT PHYSICAL PROPERTIES

A comprehensive program of physical properties measurement was carried out during the piston coring segment of the Site 504 investigation. Use of the hydraulic piston corer for sediment recovery allowed the measurements to be made in relatively undisturbed core sections. Compressional wave seismic velocities were measured using the Hamilton frame velocimeter. Wet bulk density, grain density, porosity, and water content analyses were carried out using gravimetric techniques. Thermal conductivity was determined using the standard needle probe apparatus. A modified Wykeham Farrance vane apparatus was used to measure sedimentary shear strength. Penetrometer measurements in close proximity to the vane shear measurements yielded relative values of the same parameter. Complete data and detailed discussion of the results in comparison with Site 505 are contained in Wilkens and Langseth (this volume).

Sonic Velocity

One Hamilton frame seismic velocity measurement was made in each section of the core. Velocities are fairly uniform throughout the column, with a mean velocity of 1.51 km/s in the interval from 10 to 145 meters sub-bottom followed by an abrupt increase to a mean of 1.53 km/s below 145 meters sub-bottom. In general the variations between maxima and minima are smooth, suggesting that the variation is real, but small excursions from the mean of up to 0.03 km/s occur in both the upper and lower units. These small excursions do not readily correlate with the other physical properties measured.

The velocity range for the entire column is 1.48 to 1.56 km/s, which is in good agreement with what is expected from unconsolidated pelagic siliceous-nannofossil ooze. Two additional velocities were measured in atypical materials. A 2-cm-thick ash layer 187 meters sub-bottom yielded a seismic velocity of 1.65 km/s, and a chert fragment from 232 meters sub-bottom, which was measured out of the core liner, had a velocity of 4.25 km/s.

Wet Bulk Density and Water Content

Determinations of wet bulk density and water content were made on each core section. From these, grain density and porosity were derived. Both wet bulk density and grain density exhibit significant variation through the sediment column. At approximately 140 meters sub-bottom mean bulk density increases abruptly from 1.32 g/cc (for the upper group of cores) to 1.48 g/cc (for the lower group of cores). Particularly gratifying is the excellent correlation between fine-scale variations in wet bulk density determined from measured samples of Hole 504 and the bulk densities computed from compensated density logs run at Site 501, some 200 meters distant from Site 504. Such measurement agreement lends weight to the interpretation of the fine-scale variations as real phenomena.

Two sections above the 140-meter level exhibit somewhat uniform wet bulk and grain densities. Between 10 and 65 meters sub-bottom and again between 90 and 140 meters sub-bottom, wet bulk density values range between 1.30 and 1.34 g/cc. Between these intervals is a zone of lower bulk density (minimum: 1.20 g/cc) and grain density (minimum: 2.24 g/cc). Below the 140-meter sub-bottom break, grain density decreases, but in contrast to the zone discussed previously, the bulk density increases.

Thermal Conductivity

Thermal conductivity ($\varkappa$) measurements were made on unconsolidated sediment using the standard needle probe technique. (The needle was inserted into the sediment core before the core was opened by drilling a small hole through the liner.) Usually the cores had been in the laboratory for several hours before the measurements were made so that they had nearly reached laboratory temperature. A measurement was made on almost every core section (every 1.5 m). In all, 121 observations were made in the cores from Hole 504.

The profile of conductivity ($\varkappa$) versus depth, like some of the other physical properties, can be divided into two distinct groups. In the interval from 10 to 140 meters sub-bottom, the values show a gradual increase with depth from values near 0.75 W/m°C near the seafloor to 0.85 W/m°C at 140 meters sub-bottom. The values near the top of the interval are in good agreement with the values measured on piston cores taken during the site survey. In the interval from 145 to 235 meters the κ values are significantly higher. Although they exhibit greater variability than the results in the upper interval, a positive gradient with depth is indicated.

Variations of thermal conductivity at the scale of 10 meters are observed in the upper (10–140 m) unit. A local maximum at 60 meters sub-bottom is followed by a local minimum centered at 75 meters sub-bottom. Significant variations at these depths also occur in the bulk density. It is well established that the thermal conductivity of unconsolidated seafloor sediment depends principally on water content. Thus, the κ measurements provide an independent indication of the variation of water content with depth. The general agreement between the κ profile and the profiles of gravimetric data provide strong support that the small-scale variations are real.

Shear Strength Tests

The penetrometer experiment is performed by dropping a needle from a height of 1 cm above the sediment and recording the depth of penetration. Penetrability exhibited a steady decrease down the core, with readings showing rather remarkable consistency through the column. There is a perceptible change in slope at approximately 55 meters sub-bottom that could indicate a change in the rate of compaction. Within this interval, initial compaction has a larger effect on penetrability than the more gradual compaction undergone at lower levels in the sediments.

Vane shear measurements were made by applying increasing torque at a constant rate to a four-bladed vane embedded in the sediment. Final values of shear strength were determined from the amount of torque applied to the vane through a calibrated spring at the time of the failure of the sediment.

Values of shear strength at the top of the core of 100 to 200 g/cm^2 are in good agreement with measurements from deep ocean piston cores of pelagic sediments. Values increase with relatively small scatter to a sub-bottom depth of 100 meters. Below 100 meters the scatter increases greatly, but after a zone of relatively low strength between 100 and 120 meters the trend continues to be one of increasing shear strength. The low strength zone coincides with an interval of poor core recovery, and cores recovered in this interval may have been affected by some mechanical disruption.

Maximum values of shear strength (1600 g/cm^2) were recorded at approximately 170 meters sub-bottom. Below this depth a rock saw was employed to split the cores. Greatly reduced values of shear strength in the bottom 60 meters of the hole are probably due to mechanical disruption during the core-splitting process.

In summary, the physical properties of the unconsolidated sediments in Hole 504 can be readily separated into two groups. Group 1 corresponds to Lithologic Unit I, which is found at 10 to 140 meters sub-bottom, and Group 2 corresponds to Lithologic Unit II, which is at 145 to 235 meters sub-bottom. Within Group 1, sonic velocities are extremely uniform over the entire interval, averaging 1.51 km/s; the gravimetric data bulk density averages 1.32 g/cc; and porosity averages 80%. There are significant variations in these parameters which are related to the composition and structure of the solid fraction. Thermal conductivity shows a small and uniform positive gradient from 10 to 145 meters sub-bottom, with variations that correlate closely with the density and porosity profiles.

In Group 2 all of the previously discussed parameters have significantly different mean values, and the change in all cases seems to occur within a zone only 5 meters thick, defining a break in the physical properties of the sedimentary column. In this deeper interval, bulk density increases to a mean of 1.48 g/cc, and porosity decreases to about 67%. This results in a significant decrease in the mean grain density to about 2.4 g/cc. In the Group 1 sediments, values of 2.55 g/cc predominate. Thermal conductivity values of the Group 2 sediments are also higher, ranging from 1.1 to 1.4 W/m^2.

SEDIMENT PORE WATER CHEMISTRY

Interstitial water analyses from the various holes show similar patterns with depth: Ca^{2+} increases and Mg^{2+} decreases over the upper 175 meters to nearly constant values below that depth, and both alkalinity and chlorinity exhibit a maximum within the upper 100 meters. Although the directions of change for the various species are the same from hole to hole, the magnitudes of these changes differ greatly for some species, in direct relation to the geographic position of the hole. Thus, the data define lateral gradients for Ca^{2+}, Mg^{2+}, and alkalinity which are nearly as large as the vertical gradients. The sediment pore water chemistry is apparently dominated by seawater/basalt reactions in the basement, and the lateral gradients are believed to result from the differential propagation of this basement signal through the sediments by diffusion or advection or both. These points are discussed further in the chapters by Mottl and others on the elemental and isotopic chemistry of the interstitial waters.

BASEMENT LITHOSTRATIGRAPHY

Hole 501

At Hole 501, we drilled 73 meters of basement, recovering 37.63 meters for 44.7% recovery. Using the occurrence of cooling-unit boundaries, phenocryst mineralogy, and rock textures as a basis, we divided this section into 11 stratigraphic units made up of three of the five types of basalt defined in the petrographic section of this chapter. (The types in Hole 501 are Types 1, 2, and 4.) In the following section, the 11 stratigraphic units recovered are described in the order encountered during drilling. A brief summary of the features of these units, information on the intervals in the cores, and the approximate depths of the units are given in Table 5.

Unit 1 (Core 10, Section 1–Core 11, Section 1; Basalt Type 2)

Six cooling margins, consisting of either pillow lavas or thin flows, were recovered in Unit 1. The basalt is almost aphyric (microphyric). Plagioclase phenocrysts (1 mm in length) are rare (<2%). The rocks contain 1 to 2% of olivine and clinopyroxene microphenocrysts. Pla-

Table 5. Summary of basement lithologic units, Hole 501.

	Position of Unit in Lithologic Column (Section, interval in cm)				
Unit	From	To	Approx. Depth Interval (m sub-bottom)	Basalt Type	Description
1	10-1, 7 (1)[a]	11-1, 85 (48)	3721–3726	2	Sequence of portions of six aphyric basalt cooling units, either pillows or thin flows
2	11-1, 89 (49)	11-3, 106 (87)	3726–3730[b]	2	Two aphyric basalt flows with small (unrecovered) pillow zone between
3	12-1, 1 (88)	12-1, 90 (98)	3730–3733	2	Sequence of portions of three aphyric basalt cooling units, either pillows or thin flows
4	12-1, 92 (99)	14-2, 144 (174)	3733–3745[b]	2	Nearly 14-m-thick aphyric basalt flow
5	14-2, 146 (175)	15-3, 148 (249)	3745–3757	1	Sequence of many small plagioclase-olivine phyric basalt pillows or thin flows
6	15-4, 2 (250)	17-2, 85 (306)	3757–3764	1	Plagioclase-olivine phyric basalt flow
7	17-2, 86 (307)	17-3, 38 (318)	3764–3767	1	Similar to Unit 5
8	17-3, 40 (319)	18-2, 30 (353)	3767–3771[b]	4	Sequence of several small plagioclase-olivine clinopyroxene phyric basalt pillows or thin flows
9	18-2, 32 (354)	18-2, 133 (365)	3771–3777	2	Aphyric basalt pillows or thin flows (only one recovered)
10	18-2, 135 (365)	20-1, 42 (408)	3777–3786	4	Sequence of small plagioclase-clinopyroxene-olivine phyric basalt pillows or thin flows
11	20-1, 43 (409)	20-4, 150 (480)	3786–3794	4	Sequence of either large (1–2 m) pillows or alternating small pillows and thicker flows of plagioclase-clinopyroxene olivine phyric basalt

[a] Numbers in parentheses represent piece numbers.

[b] Calculated on the assumption that the proportion recovered was representative of the fraction present in the interval cored.

gioclase microphenocrysts (up to 1 mm) are more abundant (5–7%). The groundmass in the bulk of the rocks recovered consists mostly of spherical, bow-tie, and radial spherulites, but sworls of skeletal plagioclase and groundmass clinopyroxene are present in the coarser samples. Vesicles are small (<0.5 mm) and rare (<0.1–1%) and filled with bright green or brown and red celadonite or olive green smectite. The rocks are pervasively, moderately altered. Olivine in all thin sections is completely replaced by clay minerals. Glassy margins, in general, are strongly altered, but some glass is preserved in most of them. Cracks are abundant and are usually filled with green or light colored clays. There are oxidized zones along some of the cracks. Red or brown clays and lesser iron hydroxides are present in the cracks, and they are dispersed throughout the rock next to the cracks.

Unit 2 (Core 11, Sections 1–3; Basalt Type 2)

The material recovered from Unit 2 suggests that this was a single flow about 5 meters thick, but the borehole televiewer indicated that a narrow pillow zone, which was not recovered, lies between two flows that are 2 to 3 meters thick apiece. The interiors of these flows are holocrystalline, with radial or microdoleritic groundmasses. A glassy margin from the topmost flow was recovered in Core 11, Section 1. The bottom portion of the two flows was not recovered, but the bottom of Core 11 is finer grained than the middle of the core, indicating that the flow bottom was near.

Unit 3 (Core 12, Section 1; Basalt Type 2)

Unit 3 consists of portions of three subaphyric basalt cooling units, either pillow lavas or thin flows. The unit is similar to Unit 1.

Unit 4 (Core 12, Section 1–Core 14, Section 2; Basalt Type 2)

Unit 4, of which we recovered 6.64 meters, consists entirely of a single flow about 7 meters thick, as revealed by logging and the downhole televiewer. The basalt is similar to the basalts of Units 1 through 3 in the percentages and dimensions of plagioclase, olivine, and clinopyroxene microphenocrysts. The central part of the unit is a holocrystalline subaphyric dolerite. The top and bottom of the flow are fine grained. The rock is massive, but it has a well-developed system of subhorizontal and vertical fractures along which secondary minerals have been deposited. In the upper 2 to 3 meters of the flow, the secondary minerals are mainly green or red clay minerals and iron hydroxides. Zones of alteration parallel the fractures and are stained red and green. With increasing depth in the flow, the abundance and thickness of the cracks decreases, and the cracks are lined with green clay minerals only. The adjacent zones of alteration are narrower and are stained dark green—red staining is absent. At about the point where the alteration zones next to the cracks have thinned to vanishing, calcite joins the crack-lining secondary mineral assemblage, occupying the central portion of the cracks between thin bands of green clays. Here, the cracks are only 1 to 3 mm wide. At the very bottom of the flow, the crack thickness is very small, but within about 20 cm, the entire sequence described previously is reversed. Calcite disappears, and green clays are associated with reddish clays and iron hydroxides at the very bottom of the flow.

It seems, therefore, that as secondary minerals were deposited from fluids circulating through the flow, and as the residual fluids worked their way along an ever-more-restricted fracture network, the availability of oxygen diminished, and the maximum solubility of calcite was exceeded. Fluids working their way into the flow from the top penetrated the flow farther than fluids at the bottom. This is related to the way the network of contraction cracks developed as the flow cooled. Heat was lost from the top more quickly than from the bottom; hence downward-growing cracks reached deeper into the flow than upward-growing cracks.

Unit 5 (Core 14, Section 2–Core 15, Section 3; Basalt Type 1)

Unit 5 consists of many small pillows or thin flows of sparsely to moderately phyric plagioclase–olivine basalt, with accessory chromite phenocrysts but no clinopyroxene phenocrysts and very few vesicles. Spinel (picotite) phenocrysts up to 0.3 mm occur as megacrysts of plagioclase and as isolated crystals in the groundmass. There are 1 to 2 grains of spinel per thin section, and in one thin section there are 4 grains. Plagioclase phenocrysts are up to 3 mm in length and make up 5 to 10% of the rock. Olivine, usually altered to pale clay minerals, is up to 1.5 mm in size and is 1 to 2% of the rock. The groundmass ranges from glassy, through spherulitic, to holocrystalline aggregates of acicular radiating plagioclase microlites intergrown with dendritic clinopyroxene and skeletal titanomagnetite. Three partly altered glassy margins were recovered. Alteration in this unit is primarily to green clays, with only rare occurrences of reddish clays and iron hydroxides.

Unit 6 (Core 15, Section 4–Core 17, Section 2; Basalt Type 1)

Unit 6 is a thick flow of the same type of basalt as in Unit 5. The central part of the flow is holocrystalline, sparsely phyric dolerite with the same percentage of plagioclase, olivine, and spinel phenocrysts as in Unit 5. The groundmass is medium grained and consists of plagioclase (~45%), clinopyroxene (~40%), altered olivine (~7–10%), and titanomagnetite (~5–7%). Alteration is similar to that present in Unit 5. Almost colorless smectite replaces olivine. Green clay minerals, Fe-hydroxides, and calcite are rare in the olivine pseudomorphs, but calcite and clays typically fill cracks.

Unit 7 (Core 17, Section 2; Basalt Type 1)

Unit 7 is made up of sparsely plagioclase–olivine phyric basalt and is completely analogous to Unit 5. The entire sequence of basalts from Units 5 to 7 may represent an eruptive cycle: pillows, flow, and more pillows, corresponding to the onset, waxing, and waning of the rate of eruption.

Unit 8 (Core 17, Section 3–Core 18, Section 2; Basalt Type 4)

Unit 8 is made up of moderately phyric pillow basalt, with 10 to 15% plagioclase phenocrysts, megacrysts, and glomerocrysts; 1 to 2% clinopyroxene phenocrysts; and 1 to 2% olivine phenocrysts. The phenocrysts reach 3 mm in size. Vesicles are almost completely absent. The basalts are very fine grained to spherulitic. Alteration is weak to moderate. Some olivine phenocrysts are still fresh. Olive green smectite is the predominant secondary mineral, lining cracks and replacing olivine. Clays, calcite, and (rarely) aragonite line the cracks.

Unit 9 (Core 18, Section 2; Basalt Type 2)

Unit 9 is a 1.1-meter cooling unit of substantially aphyric basalt. The glassy rind at the top of the cooling unit was recovered, and it contained a few phenocrysts of plagioclase and clinopyroxene up to 2 mm in size. Elsewhere, the microphenocrysts amounted to less than 1 to 2% of the rock. Chemically, this basalt may simply be an aphyric equivalent of the two more porphyritic basalt types above and below it.

Unit 10 (Core 18, Section 2–Core 19, Section 3; Basalt Type 3)

Unit 10 is moderately plagioclase–clinopyroxene–olivine phyric basalt; it is analogous to Unit 9 and perhaps equivalent to it chemically. Most rocks are very fine grained to spherulitic. Others are coarser (microdoleritic). Four glassy margins were recovered. Alteration is strong at the glassy margins to the extent that several pieces have interpillow hyaloclastite breccias cemented to them by alteration minerals. Glass and the olivine in or near the glass are completely replaced by clays. The unit consists of pillows or thin flows.

Unit 11 (Core 20; Basalt Type 3)

Unit 11 is equivalent to Unit 10 (and is very similar to Unit 8) in terms of mineralogy, petrography, and alteration. Glassy margins are strongly altered to olive green smectites and, more rarely, brown celadonite. Six glassy margins were recovered. Other grain-size transitions plus the glass margins indicate that at least 10 cooling units were partially or completely recovered. The distinction between this unit and the one immediately above is based entirely on the occurrence in this unit of two fairly large pillows or thin flows, almost completely recovered, both between 0.75 and 1 meter thick.

Holes 504A and 504B, Leg 69

During Legs 69 and 70 basement was drilled and recovered from Holes 504A and 504B. Using as criteria phenocryst assemblages, position in the hole, occurrence of cooling units, and rock texture, we divided the basalts of Hole 504B into 49 lithologic units. The basement of Hole 504A, using the same criteria, is formed of a single unit. Several of the units in Hole 504B have been subdivided into subunits according to their main textural features. In this section, we describe the lithologic units and subunits in the order encountered during drilling. Information on the intervals and depths of the units and subunits in Hole 504B is given in Table 6. Figure 4 gives a schematic representation of the lithologic units and shows the correlations in basement lithostratigraphy between Holes 501, 504A, and 504B. Five petrographic types were recognized on the basis of phenocrysts in hand samples visible with a hand lens (~10×): Type 1, plagioclase–olivine phyric basalt with

Table 6. Basement lithostratigraphy, Hole 504B.

		Depth of Base of Unit (m)			Unit Thick-	Position of Base of Unit		
Unit	Basalt Type	Below Rig Floor	Sub-bottom	Sub-basement	ness (m)	Core	Sec-tion	Level (cm)
(Seafloor)	—	3473.5	0	—	—	—	—	—
(Top of basement)	—	3746.0	274.5	—	—	—	—	—
1	2	3753.5	280.0	5.5	5.5	4	1	20
2A	1	3776.0	302.5	28.0	22.5	6	2	2
2B	1	3780.0	306.5	32.0	4.0	6	2	147
2C	1	3786.5	313.0	38.5	6.5	7	3	92
2D	1	3799.8	326.3	51.8	13.3	9	1	77
3A	2	3841.8	368.3	93.8	42.0	13	4	92
3B	2	3846.7	373.2	98.7	4.9	14	2	10
3C	2	3861.6	388.1	113.8	12.9	16	3	112
4	1	3871.8	398.3	723.8	10.2	18	1	97
5	2	3881.2	407.7	132.1	9.4	19	2	0
6	3	3881.8	408.3	133.7	0.6	19	2	45
7	1	3882.1	408.6	134.0	0.3	19	2	80
8	3	3888.4	414.9	140.3	6.3	20	1	48
9	2	3897.0	423.5	149.0	8.6	21	2	44
10	3	3898.8	425.3	150.8	1.8	21	3	28
11	2	3900.9	427.4	152.9	2.1	21	4	38
12	3	3901.2	427.7	153.2	0.3	21	4	58
13	2	3901.7	428.2	153.7	0.5	21	4	98
14	3	3903.0	429.5	155.0	1.3	21	5	47
15	2	3903.2	429.7	155.2	0.2	27	5	64
16	3	3929.4	455.9	181.4	26.6	24	3	113
17	2	3945.4	471.9	197.4	16.0	27	1	125
18	1	3949.0	475.5	201.0	3.6	28	1	32
19	3	3957.5	484.0	209.5	8.5	28	5	25
20	1	3962.5	489.0	214.5	5.0	29	2	15
		(No recovery 3962.5–3981.0 m below)						
(Top of Unit 21)	—	3981.0	507.5	233.0	—	—	—	—
21	4	3983.9	510.4	235.9	2.9	32	2	112
22	3	3999.4	525.9	251.4	15.5	34	1	43
23A	1	4001.8	528.3	253.8	2.4	34	1	122
23B	1	4009.6	536.1	261.6	7.8	35	1	70
24	3	4026.0	552.5	278.0	16.4	37	1	2
25	1	4045.0	571.5	297.0	19.0	39	1	93
26	2	4046.0	572.5	298.0	1.0	39	2	37
27	3	4062.0	588.5	314.0	16.0	41	4	60
28	5	4085.5	612.0	337.5	93.5	44	1	94
29A	3	4086.0	612.5	338.0	0.5	44	1	132
29B	3	4093.5	620.0	345.5	7.5	45	1	2
29C	3	4094.7	621.2	346.7	1.2	45	2	48
30A	2	4113.3	639.8	365.3	8.6	47	2	32
30B	2	4113.7	640.2	365.7	0.4	47	2	73
30C	2	4121.2	647.7	373.2	7.5	48	1	68
31	Breccia	4121.8	648.3	373.8	0.6	48	1	135
32	3	4123.0	649.5	375.0	1.2	48	2	110
33A	3	4129.5	656.0	381.5	6.5	49	1	2
33B	3	4142.5	669.0	394.5	13.0	50	1	36
34	3	4165.5	692.0	417.5	23.0	54	1	2
35	2	4166.2	692.7	418.2	0.7	54	1	72
36	3	4188.7	715.2	440.7	22.5	57	1	76
37	2	4197.8	724.3	449.8	9.1	58	1	77
38	3	4206.0	732.5	458.0	9.8	59	1	2
39	2	4224.0	750.5	476.0	2.8	61	1	2
40	2	4245.1	771.6	497.0	21.1	63	4	14
41	2	4245.9	772.4	497.9	0.8	63	4	97
42	3	4247.9	774.4	499.9	2.0	64	1	140
43	2	4250.3	776.8	502.3	2.4	64	3	86
44	3	4251.7	778.2	503.7	1.4	64	4	83
45	3	4266.5	793.0	518.5	14.8	66	2	51
46	2	4273.8	800.3	525.8	7.3	67	1	25
47	2	4292.5	819.0	544.5	18.7	69	1	106
48	2	4301.7	828.2	553.7	9.2	70	1	120
49	3	4302.4	828.9	554.4	0.7	70	2	40

essential chromite; Type 2, aphyric and sparsely phyric basalts with variable proportions and occurrences of phenocrysts; Type 3, plagioclase-olivine-clinopyroxene phyric basalt; Type 4, highly plagioclase-olivine-clinopyroxene phyric basalt; and Type 5, moderately plagioclase-olivine phyric basalt lacking clinopyroxene and chromite. These types are indicated in Figure 4.

Basement was drilled in Hole 504A for a little over 12 meters, but only ~5.5 meters were recovered. The recovered rock represents a sequence of pillows and thin massive flows of sparsely phyric, plagioclase-olivine-clinopyroxene basalt. Plagioclase phenocrysts are predominant both in size (up to 3 mm) and quantity (about 7%). Olivine and augite phenocrysts are a little smaller and form about 2 and 1% of the rock, respectively. The rock is holocrystalline in the interiors with ophitic or subophitic texture, and variolitic or glassy in the cooling selvages. Vesicles are small and sparse (<1 mm and 1%). They are filled with green or brown clay minerals. The basalt is moderately altered. All olivine is converted into clay minerals or carbonate. Cracks are filled with these minerals too. Poor recovery did not permit the subdivision of the petrographically uniform basement of Hole 504A into individual pillow and flow units.

The following material describes the 49 lithologic units in Hole 504B.

Unit 1 (274.5–280.0 m below seafloor [mbsf]; Basalt Type 2)

Unit 1 is sparsely phyric plagioclase-olivine-augite basalt. Thin, massive flows seem to be predominant, at least in the recovered material. Phenocrysts of plagioclase olivine and augite are small (<3 mm). Plagioclase is more abundant than olivine and augite. Phenocryst content is 5 to 10%. The augite forms glomerocrysts with plagioclase. Olivine occurs as euhedral grains. Vesicles (1-mm diameter; ~1% of rock) are round and filled with clay minerals. The groundmass is subophitic and partly spherulitic. Recovered glassy margins are flat. Alteration is moderate and rather uniform. Clay minerals completely replace olivine and fill cracks. Oxidation is rather weak. Some cracks are filled with yellow and red clay minerals.

Unit 2 (280.0–326.3 mbsf; Basalt Type 1)

Unit 2 is accessory-chromite-bearing moderately phyric pillow and massive flow basalts. We subdivided the unit into four subunits using structural and textural features.

Subunit 2A (280.0–302.5 mbsf)

Subunit 2A is a sequence of pillows and massive flows of moderately phyric basalts. The rocks are 7 to 10% euhedral and subhedral glomerocrysts and phenocrysts of plagioclase 4 to 6 mm across. Euhedral and occasionally subhedral or skeletal olivine phenocrysts up to 4 mm in size are almost completely altered to green or red clay minerals and locally to calcite. They form 2 to 3% of the rock. Euhedral or skeletal chromite phenocrysts 0.05 to 0.8 mm in size occur in the groundmass and are included in phenocrysts of plagioclase and olivine. Usually there are several grains of chromite per thin section.

Small (<0.5 mm), round vesicles are about 0.5% of the rock or are absent. Groundmass texture varies from glassy and variolitic at cooling selvages to interstitial and ophitic in interiors. Glassy pillow margins were recovered in 34 samples. Cracks are filled with green and red clay minerals and occasionally with calcite.

Subunit 2B (302.5–306.5 mbsf)

Subunit 2B is a cooling unit. The upper and the lower margins were recovered. Petrographically the rock is the same as that in Subunit 2A, but two intervals of fine-grained aphyric rock are positioned symmetrically in the unit. The intervals are succeeded by rather distinct, sharp transitions to the phyric rocks. In structure, the subunit

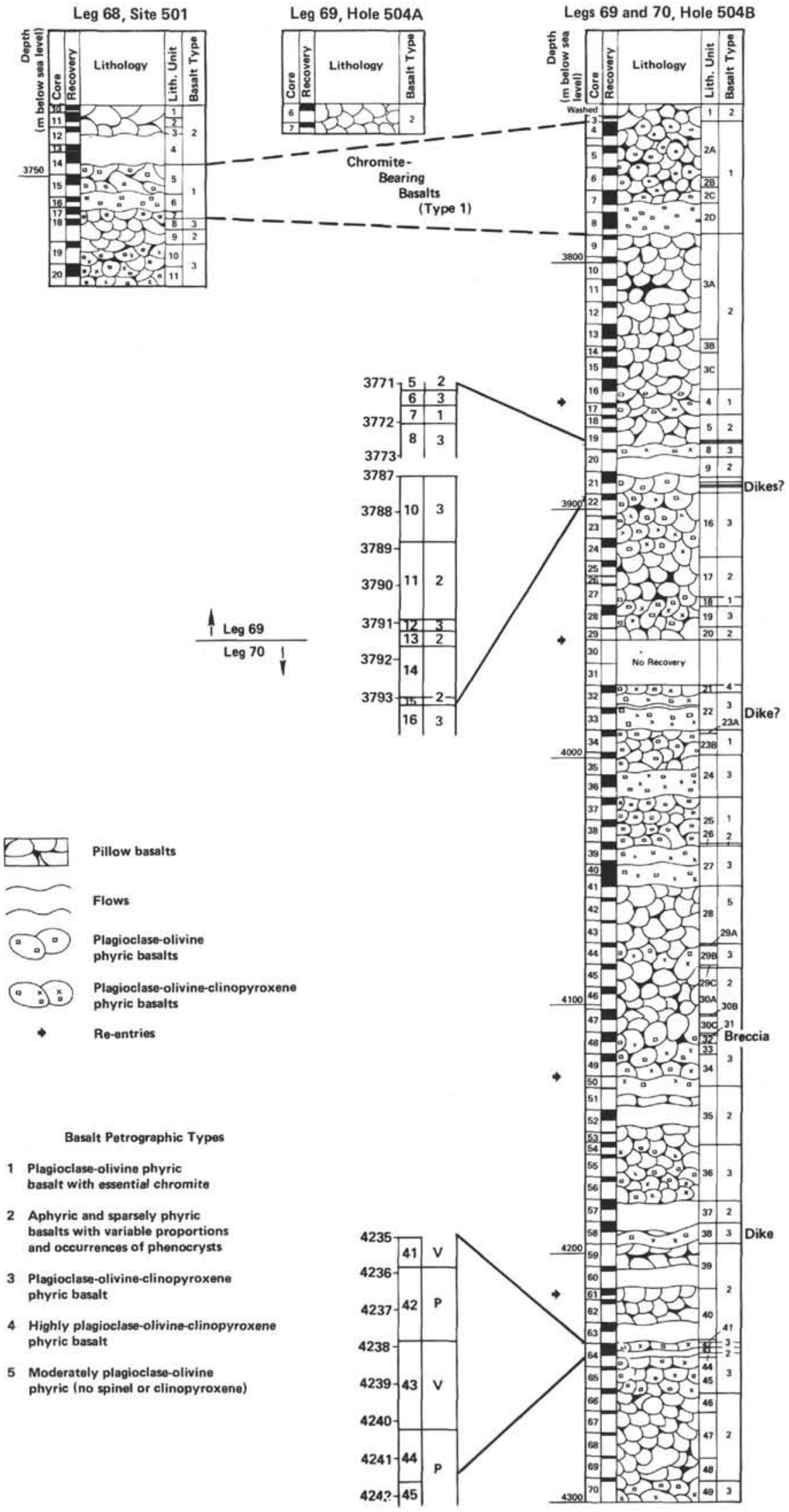

Figure 4. Summary of basement lithology at Sites 501 and 504.

is as follows: (1) upper glassy margin plus crystalline basalt, moderately plagioclase-olivine phyric—7 cm recovered; (2) aphyric (microphyric) fine-grained basalt—33 cm recovered; (3) moderately phyric plagioclase-olivine basalt of a cooling-unit interior—more than 70 cm recovered; (4) aphyric to microphyric fine-grained basalt—40 cm recovered; (5) moderately phyric plagioclase-olivine basalt with a lower glassy margin—20 cm recovered.

These rocks include intervals which are microphyric fine-grained basalt with microlites of plagioclase, a spherulitic groundmass, and sparse chrome-spinel crystals. These "aphyric" intervals are possibly thin dykes or injections into solid but hot massive flow interiors.

Subunit 2C (306.5–313.0 mbsf)

Subunit 2C is a sequence of massive flows and pillows. Petrographically it is similar to the basalts of Subunit 2A, but thin flows appear to be predominant. Glassy margins were recovered from 18 samples; 12 of them are flat.

Subunit 2D (313.0–326.3 mbsf)

Subunit 2D is a sequence of sparsely to moderately phyric basalt flows. Phenocryst content varies from 5 to 10% of the rock. There is three times as much plagioclase as olivine. The phenocrysts are mostly euhedral, but there are a few skeletal olivine phenocrysts and plagioclase glomerocrysts. The groundmass is variolitic near the cooling selvages, but deeper into the flows it consists of plagioclase microlites in a spherulitic mesostasis. The flow interiors are rather coarse grained and are ophitic in texture. The phenocrysts in the coarse interiors are two to three times as large as those of the grains in the groundmass. Because of this the rock looks aphyric megascopically. Vesicles are generally absent, but in thin section small cavities can occasionally be seen. Subunit 2D appears to consist of two massive flows; their junction is in Core 8, Section 1, as seen by a glassy margin and associated grain-size changes.

Unit 3 (326.3–388.1 mbsf; Basalt Type 2)

Unit 3 is a sequence of sparsely phyric (megascopically aphyric) plagioclase-olivine basalt pillows and massive flows, with rare augite phenocrysts. Plagioclase phenocrysts are 2 to 3 times as common as those of olivine. Clinopyroxene phenocrysts (3 to 7 per thin section) are generally smaller. Olivine and a few plagioclase phenocrysts are euhedral. Most of the plagioclase and augite forms glomerocrysts. The groundmass varies from glassy to ophitic, depending on its position on cooling units. Alteration is weak to moderate. Pillows predominate in the upper part of the unit; massive flows, toward its base. We have divided the unit into three subunits.

Subunit 3A (326.3–368.3 mbsf)

Subunit 3A is a sequence of pillows and massive flows. A number of glassy margins were recovered; most were pillow selvages. In Core 10, Section 1, highly fractured and brecciated rocks (18 cm) were recovered. Calcite occurs in cracks in the upper part of the subunit, whereas red clays and oxidation zones predominate at the base. There are thicker flows or pillows in the lower part of the subunit.

Subunit 3B (368.3–373.2 mbsf)

Subunit 3B is a pillow and thin flow sequence composed of plagioclase-olivine phyric basalt. Augite and chromite phenocrysts are absent. Glassy margins were recovered from six specimens. Green and red clay minerals replace olivine and fill cracks.

Subunit 3C (372.0–388.1 mbsf)

Subunit 3C is a sequence of pillows and flows similar to Subunit 3A. Glassy margins (mostly pillow) were recovered in 19 samples. Alteration is moderate. Green or red clay minerals replace olivine and fill cracks. Calcite is rare or absent.

Unit 4 (388.1–398.3 mbsf; Basalt Type 1)

Unit 4 is a sequence of pillows and flows of moderately to sparsely phyric plagioclase-olivine basalt with accessory chromite. Phenocrysts of augite are absent. Petrographically, the unit is similar to Unit 2.

These basalts contain euhedral plagioclase phenocrysts and glomerocrysts. The size of the phenocrysts can differ from rock to rock, varying from 2 to 3 mm at one to 4 to 7 mm at another. The phenocryst concentration is 7 to 10%. Euhedral or skeletal olivine up to 3 to 4 mm forms about 3% of the rock. Chromite can be euhedral or skeletal, with a grain size of 0.1 to 0.7 mm. There are several grains per thin section. The groundmass is glassy or variolitic at cooling selvages and interstitial to ophitic in flow interiors. Glassy margins were recovered in 18 samples. They are mostly flat. Pillows are predominant in the upper part of the unit. Alteration is moderate, with red and green clay minerals filling cracks and replacing olivine. Calcite in veins and olivine pseudomorphs is more rare.

Unit 5 (398.3–407.7 mbsf; Basalt Type 2)

Unit 5 is a sequence of pillows and thin massive flows of sparsely phyric, plagioclase-olivine basalt. Phenocrysts of plagioclase and olivine, 2 to 4 mm in size, are mostly euhedral. They constitute 5 to 7% and 2 to 3% of the rocks, respectively. Augite phenocrysts are absent. Fine euhedral chromite crystals were found in one of the thin sections. The groundmass consists of plagioclase microlites and spherulitic mesostasis near cooling selvages. In holocrystalline interiors the groundmass is ophitic. Vesicles up to 1 mm in diameter constitute ~1% of the rocks and occur mainly in the upper part of the unit. Alteration is moderate. Secondary minerals are green and red clay, and Fe-hydroxides replace olivine and fill cracks and vesicles. Calcite is almost absent. Massive flows appear to be predominant, at least at the base of the unit. Only one glassy (pillow) margin was recovered.

Unit 6 (407.7–408.3 mbsf; Basalt Type 3)

Unit 6 is moderately phyric plagioclase-olivine-augite basalt. The phenocryst content is about 7% plagioclase, 3% olivine, and 1% clinopyroxene. The groundmass is holocrystalline and microlitic. Vesicles are absent. A breccia with fragments of this rock and green smectite cement was recovered from the central part of the unit. Smectite also forms olivine pseudomorphs and fills cracks.

Unit 7 (408.3–408.6 mbsf; Basalt Type 1)

Unit 7 is fine-grained, sparsely phyric (microphyric) basalt with small phenocrysts of plagioclase, olivine, and accessory chromite. The rock is petrographically similar to Unit 5 and may be a dike.

Unit 8 (408.6–414.9 mbsf; Basalt Type 3)

Unit 8 is a moderately phyric plagioclase–olivine–augite basalt which appears to be a continuation of the basalts of Unit 6 crossed by the basalt dike(?) of Unit 7. This unit is mainly a pillow sequence: six specimens of glassy pillow margins were recovered from it.

Unit 9 (414.9–423.5 mbsf; Basalt Type 2)

Unit 9 is an aphyric (microphyric) basalt flow. Plagioclase phenocrysts (about 5%) are euhedral or form glomerocrysts; grain size is 2 to 3 mm. The rock is holocrystalline with ophitic texture. Cooling selvages were not recovered. Almost all of the samples recovered demonstrate oxidation zonality in secondary clay minerals. In addition, calcite occurs in the central parts of the crack fillings.

Unit 10 (423.5–425.3 mbsf; Basalt Type 3)

Unit 10 is moderately phyric basalt, with plagioclase, augite, and olivine phenocrysts. The grain size of the phenocrysts is 3 to 5 mm. The plagioclase and augite are mainly in glomerocrysts, and the olivine is in single euhedral grains. The plagioclase and clinopyroxene phenocrysts contents are approximately 5% each; olivine is 3%. The groundmass is mainly variolitic, with about 10% plagioclase microlites. The unit represents a thin flow or a dike with the lower glassy margin recovered. The rock is highly fractured. Alteration is moderate. Green smectite is the principal secondary mineral.

Unit 11 (425.3–427.4 mbsf; Basalt Type 2)

Unit 11 is an almost aphyric (sparsely microphyric) plagioclase-olivine basalt flow. Sparse phenocrysts of plagioclase (about 5%) and olivine (< 1%) range in size up to 3 and 2 mm, respectively. The texture of the groundmass varies from variolitic to ophitic. Alteration is locally rather strong. Dark gray smectite, a red clay mineral, and iron hydroxide partly replace the variolitic groundmass. The rock is highly fractured. Cooling selvages were not recovered.

Unit 12 (427.4–427.7 mbsf; Basalt Type 3)

The type of rock in Unit 12 is the same as that in Unit 10: moderately phyric basalt with phenocrysts of plagioclase, augite, and olivine.

Unit 13 (427.7–428.2 mbsf; Basalt Type 2)

Unit 13 is an almost aphyric pillow basalt, with small plagioclase and olivine phenocrysts (2–3 mm). The phenocryst content is about 5% plagioclase and 2 to 3% olivine. The groundmass is glassy, variolitic, or microlitic, with a spherulitic mesostasis. Glassy margins were recovered in four specimens, but they may have come from a single pillow. The rock is rather fresh, with green smectite replacing olivine and filling cracks. Petrographically the rock is similar to Units 9 and 11.

Unit 14 (428.2–429.5 mbsf; Basalt Type 3)

Unit 14 is moderately phyric basalt with phenocrysts of plagioclase (about 5%), augite (about 5%), and olivine (about 3%). Petrographically the rock is the same as that in Units 10 and 12 (Type 3). The unit appears to represent flows. Three recovered glassy margins are flat. The rock is rather fresh. Olivine is partly altered to smectite and calcite.

Unit 15 (429.5–429.7 mbsf; Basalt Type 2)

Unit 15 is a thin interval (possibly a dike) of fine-grained megascopically aphyric basalt. Microphenocrysts of plagioclase and olivine (5–7% and 2–3%, respectively) are mainly euhedral. The grain size for both is 0.5 to 1.5 mm. Accessory-chromite grains are much smaller (~0.1 mm). The groundmass is microlitic (plagioclase), with a spherulitic mesostasis. Petrographically the unit is similar to Unit 7.

Unit 16 (429.7–455.9 mbsf; Basalt Type 3)

Unit 16 is a pillow and possibly massive flow sequence of moderately phyric, plagioclase–olivine–augite basalts. Petrographically the rock is similar to that in Units 10 and 12. The phenocryst grain size is 2 to 5 mm. Most of the phenocrysts are euhedral, but the augite phenocrysts in the upper part of the unit are a little rounded and usually twinned. The augite in the lower part of the unit, where it is a little more abundant, forms euhedral phenocrysts and glomerocrysts with and without plagioclase. The average abundance of augite phenocrysts is 1 to 2%; of plagioclase phenocrysts, 10%; and of olivine phenocrysts, 3 to 4%. The groundmass is mainly variolitic, with 10 to 15% of plagioclase microliths. Vesicles are almost absent. Glassy pillow margins were recovered in 33 samples. The rock is fractured, pillows usually strongly so. Alteration (clay minerals) is moderate.

Unit 17 (455.9–471.9 mbsf; Basalt Type 2)

Unit 17 is a massive flow sequence of megascopically aphyric (microphyric) plagioclase–clinopyroxene–olivine basalts. Microphenocrysts of these minerals reach 2 mm in size. The rock is about 4% plagioclase (mainly glomerocrysts), 3% augite (glomerocrysts), and 1% olivine (euhedral). Vesicles are almost absent. The groundmass is glassy or variolitic, with some plagioclase microlites near cooling selvages, and it is ophitic in flow interiors. Ten glassy margins were recovered, several of them flat. Alteration is moderate and locally strong. Bright green and red clay minerals are rather abundant.

Unit 18 (471.9–475.5 mbsf; Basalt Type 1)

Unit 18 is sparsely phyric plagioclase–olivine basalt (possibly a dike) with accessory chromite. The rock is petrographically similar to Units 2 and 4. Phenocryst size is 2 to 5 mm (~7% plagioclase, 2-3% olivine). The groundmass is microlitic with a spherulitic mesostasis. The rock is moderately altered. Secondary minerals (green and red clay) replace olivine completely or partly and fill cracks. Only one glassy margin was recovered; it was at the very end of the unit.

Unit 19 (475.5–484.0 mbsf; Basalt Type 3)

Unit 19 is a sequence of pillows and flows of sparsely phyric basalts. Plagioclase, olivine, and augite phenocrysts are euhedral, subhedral, and anhedral (in glomerocrysts). The content and grain size of plagioclase are 5 to 7% and 3 to 5 mm; of olivine, 3% and 2 to 4 mm; and of augite, 1% (in the upper part of the unit) to 3% (at its end) and 2 to 3 mm. The groundmass is glassy or variolitic at cooling selvages and coarse grained and ophitic in interiors of cooling units. Glassy margins were recovered in 8 specimens. They are flat or curved. The rock is highly fractured and locally brecciated. Alteration is moderate. Red and green clay minerals fill cracks and replace olivine. The red mineral is predominant in the upper part of the unit. Calcite occurs here as well.

Unit 20 (484.0–489.0 mbsf; Basalt Type 2)

Unit 20 consists of aphyric holocrystalline basalt. Sparse plagioclase and olivine phenocrysts (about 1%) are mostly euhedral. Their size (2–4 mm) is only 2 to 3 times as high as the grain size of the groundmass. The texture is ophitic. The rock is fractured and brecciated. Breccia samples were recovered from the upper part of the unit. They consist of aphyric basalt fragments and green smectite cement.

Hole 504B, Leg 70

Twenty-nine lithologic units were defined for the 347 meters of basement cored in Hole 504B during Leg 70, bringing the total number of lithologic units to 49. Because of the sometimes poor recovery (average recovery was 26.4%, with less than 10% in five cores and 10–20% in 11 others), it was sometimes difficult to determine the proper location for the boundary between different units. Further, the lithologic units do not necessarily correspond to the geochemistry of the basalt; rather, they represent a tentative division that reflects the recovered material. There was a break in recovery between the portions of the hole cored on Legs 69 and 70 corresponding to Cores 30 and 31 (see Operations).

Unit 21 (507.5–510.4 mbsf; Basalt Type 4)

Unit 21 consists of several thin lava flows separated by glassy rims on the top or bottom of oriented rock pieces. The flows are spinel-bearing, highly olivine–plagioclase–clinopyroxene phyric basalts. They are medium grained and display subglomerophyric textures. The phenocryst content is high (greater than 40%); the proportions among the various kinds of phenocrysts are variable. The phenocrysts vary in size, with those of olivine less than 4 mm, those of plagioclase less than 3 mm, and those of clinopyroxene less than 5 mm. Plagioclase and clinopyroxene are subhedral to anhedral and often intergrown; olivine is euhedral. The groundmass exhibits mature sheaf textures and is variolitic in glassy margins. The basalts are partly fractured, and the fractures are filled with smectites and Fe–oxides. Thus, alteration is oxidative. Olivine is replaced by smectite and hematite.

Unit 22 (510.4–525.9 mbsf; Basalt Type 3)

Unit 22 consists of two flows which are separated at 517.5 meters by a possible dike. The basalt flows are fine- to medium-grained, highly plagioclase–olivine phyric basalts. Euhedral olivine crystals are up to 1.2 mm in size, euhedral plagioclase laths less than 1.2 mm in length. Rock texture ranges from hyalo-ophitic to ophitic. The appearance of the rock is massive; alteration is moderate and appears to be oxidative. Olivine is completely replaced by iron hydroxides and clay minerals.

The dike consists of fine-grained variolitic basalt, with glassy rims on the sides of oriented rock pieces.

Unit 23 (525.9–536.1 mbsf, Basalt Type 1)

Unit 23 is divided into Subunits 23A and 23B. It is made up of pillows and thin flows.

Subunit 23A (525.9–528.3 mbsf)

In Subunit 23A glassy margins are abundant, and they occur at the top, bottom, or sides of many rock pieces. The basalts are spinel bearing and highly plagioclase–olivine phyric. They display a medium-grained, hyalo-ophitic texture. Fine-grained rocks with glassy to variolitic texture occur near and next to the glassy margins. Olivine is euhedral (less than 0.8 mm) and partly replaced by smectite. Subhedral plagioclase laths are up to 1.2 mm in length. The groundmass shows a mature sheaf texture and is partly replaced by iron hydroxides. The alteration is oxidative.

Subunit 23B (528.3–536.1 mbsf)

Subunit 23B is similar to Subunit 23A in that it consists of pillows and thin flows; it is distinguished from the former because of its finer grain size. Subunit 23B is only aphyric to sparsely phyric. The rocks are more altered than those in Subunit 23A.

Unit 24 (536.1–552.5 mbsf; Basalt Type 3)

Unit 24 is a massive flow made up of sparsely to moderately plagioclase–clinopyroxene–olivine phyric basalt. The phenocrysts are subhedral plagioclase laths (less than 1.5 mm in length), subhedral clinopyroxene (<0.5 mm), and euhedral to subhedral olivine (<0.25 mm). The texture is subophitic to intersertal and medium to coarse grained. Alteration is only slight and oxidative. Pyrite occurs as veinlets and scattered grains.

Unit 25 (552.5–571.5 mbsf; Basalt Type 1)

Unit 25 is a sequence of highly fractured pillows and flows. Numerous glassy margins occur at the top, bottom, and sides of oriented samples. Flow breccia occurs near the top and bottom of the unit. The basalt is fine to medium grained, sparsely to moderately plagioclase–olivine–clinopyroxene phyric. Accessory spinel occurs in one sample near the bottom of the sequence (Piece 462). The rock texture is hyalo-ophitic to slightly intersertal. The groundmass has immature and mature sheaf texture. Olivine is euhedral (< 1.7 mm) and totally replaced by smectite. Subhedral or euhedral plagioclase laths (< 1.1 mm) and anhedral to subhedral clinopyroxenes are often gathered in clusters. The alteration is oxidative.

Unit 26 (571.5–572.5 mbsf; Basalt Type 2)

Unit 26 is massive basalt with a flow breccia at the top. It is medium grained, sparsely plagioclase–olivine phyric basalt, intersertal in texture, with anhedral olivine phenocrysts greater than 0.35 mm and blocky plagioclase phenocrysts greater than 1 mm. Smectites replace olivine and glass.

Unit 27 (572.5–588.5 mbsf; Basalt Type 3)

Unit 27 is a massive flow with a grain size that changes from fine (at the top and bottom) to medium to coarse (towards the center). It is made up of moderately plagioclase–olivine–clinopyroxene phyric basalt. Euhedral olivine (less than 1.5 mm) and some zoned subhedral plagioclase laths (less than 2.5 mm) are always present, but subhedral to anhedral, sometimes twinned clinopyroxene (less than 1 mm) is only present in some of the thin sections. The rock texture is ophitic to intersertal. Alteration is either nonoxidative or a slightly oxidative. Pyrite is common at the bottom of the unit.

Unit 28 (588.5–612.0 mbsf; Basalt Type 5)

Unit 28 consists of fine- to medium-grained, sparsely to moderately plagioclase–clinopyroxene phyric basalt flows. Subhedral plagioclase laths are less than 1.2 mm in length, clinopyroxene is anhedral to euhedral (less than 1 mm). Glassy margins occur at the top, bottom, and center of pieces; breccia occurs at the top and center. Oxidative alteration occurs at the top and bottom of this unit, as shown by the presence of iron hydroxides.

Unit 29 (612.0–621.2 mbsf; Basalt Type 3)

Unit 29 is made up of highly fractured pillows and flows, with small glomerophyric flows at the top and bottom. We have divided the unit into three subunits.

Subunit 29A (612.0–612.5 mbsf)

Subunit 29A is a small subunit of fine- to medium-grained glomerophyric basalt. Green clinopyroxene can be observed in hand specimen. Small cracks are coated with smectites.

Subunit 29B (612.5–620.0 mbsf)

Subunit 29B consists of pillows and thin flows with breccias and glassy margins. The basalt is fine to medium grained, moderately plagioclase–clinopyroxene–olivine phyric, and has hyalopilitic textures. Euhedral olivine (< 0.6 mm) is replaced by smectite. There are also plagioclase laths (< 0.9 mm) and subhedral clinopyroxenes (< 0.8 mm). The groundmass has a mature sheaf texture and is partly replaced by smectites. Pyrite occurs in veins. Some of the alteration was nonoxidative; a slightly oxidative stage followed by the formation of pyrite was also in evidence.

Subunit 29C (620.0–621.2 mbsf)

Subunit 29C is a small glomerophyric basalt flow. Green clinopyroxene occurs in hand specimen. Small cracks are coated with smectites.

Unit 30 (621.2–647.7 mbsf; Basalt Type 2)

Unit 30 is made up of pillows and flows which are highly fractured in some parts. We have divided the unit into three subunits.

Subunit 30A (621.2–639.8 mbsf)

Subunit 30A is a sequence of pillows and flows. Breccias and glassy rims are common in the upper part of the subunit. Two flows are separated by glassy margins in the lower part. The basalts are medium grained, moderately plagioclase–olivine–clinopyroxene phyric, and contain accessory spinel. They are hyalo-ophitic. Subhedral olivine (< 0.6 mm) is completely replaced by smectite. Plagioclase forms subhedral to euhedral zoned laths (< 1.5 m); clinopyroxene is subhedral and sometimes twinned (< 1.5 mm). The groundmass exhibits mature to immature sheaf texture and is partly replaced by smectite. Numerous fractures are filled with green smectite; pyrite occurs as small patches (< 0.5 mm) in some of the fractures. The alteration was nonoxidative.

Subunit 30B (639.8–640.2 mbsf)

Subunit 30B is a poorly recovered rubble of thin flows. The basalts are highly plagioclase–clinopyroxene–olivine phyric, with glassy margins on every piece. They are fine grained, displaying subglomerophyric and subvariolitic textures. The glassy rims are completely altered to green smectite. Olivine is replaced by smectite.

Subunit 30C (640.2–647.7 mbsf)

In the upper half of Subunit 30C there is a highly plagioclase–clinopyroxene–olivine phyric basalt flow, and in the lower half there is a sparsely plagioclase–clinopyroxene–olivine phyric basalt flow. The rock is highly fractured in the upper part and slightly to moderately fractured in the lower part. The basalt is medium grained, displaying subglomerophyric texture with intersertal groundmass in the upper flow; in the lower flow it is hyalopilitic with intersertal groundmass. Plagioclase (< 1.6 mm) forms subhedral laths, and clinopyroxene is euhedral (< 1.6 mm). Euhedral olivine (< 0.3 mm) is completely replaced by smectite. The fractures are filled with green smectite and abundant pyrite. The alteration is nonoxidative.

Unit 31 (647.7–648.3 mbsf; breccia)

Unit 31 is made up of basalt breccia. The breccia consists of angular to subangular basalt fragments 1 mm to 1 cm in diameter in a matrix of green smectite.

Unit 32 (648.3–649.5 mbsf; Basalt Type 3)

Unit 32 is a massive basalt flow made up of fine-grained, sparsely to moderately plagioclase–clinopyroxene-olivine phyric basalt. It has hyalo-ophitic texture with mature sheafs in the groundmass. Subhedral plagioclase (< 0.9 mm) and clinopyroxene (< 1.3 mm) phenocrysts have rounded corners. Alteration consists of the incomplete replacement of olivine by smectite and the filling of fractures with green smectite and pyrite. It is nonoxidative.

Unit 33 (649.5–669.0 mbsf; Basalt Type 3)

Unit 33 is a unit of pillows and flows with numerous glassy margins. The unit consists of two subunits.

Subunit 33A (649.5–656.0 mbsf)

Subunit 33A is a pillow sequence, with possibly one small flow in the middle of the unit. Glassy margins occur at the top, bottom, and sides of oriented rock pieces. The basalt is fine to medium grained, aphyric to plagioclase-clinopyroxene-olivine phyric with hyalo-ophitic to variolitic texture. Blocky plagioclase phenocrysts (< 1.5 mm) are most common. Clinopyroxene phenocrysts (rare, < 1.5 mm) are also blocky. Euhedral olivine (rare, < 0.2 mm) is replaced by smectite. The alteration is oxidative in the upper part, as indicated by the presence of Fe-oxides, and nonoxidative in the lower part. The fractures are filled with green smectite and minor zeolite. In addition, pyrite occurs in the lower part.

Subunit 33B (656.0–669.0 mbsf)

In terms of petrology, Subunit 33B is very similar to Subunit 33A, but the basalts are more or less brecciated. Smectite and pyrite occur as fracture fillings; therefore the alteration is mostly nonoxidative. It is oxidative at the bottom of the unit, as indicated by the presence of Fe-oxides.

Unit 34 (669.0–692.0 mbsf)

Unit 34 is massive, coarse-grained ophitic basalt, with a glassy margin on the top. Plagioclase forms subhedral laths (0.03–1.5 mm), and clinopyroxene is anhedral (0.08–1.2 mm). Euhedral olivine (0.08–0.7 mm) is completely replaced by green smectite. Glass amounts to up to 10% of the interior of the flow; it is completely replaced by smectite. Skeletal magnetite (0.04 mm) occurs in this glassy area. The texture is ophitic to intersertal. Veins are filled with smectite and pyrite; the alteration is nonoxidative.

Unit 35 (692.0–692.7 mbsf; Basalt Type 2)

Unit 35 is an interval of fine-grained aphyric basalt displaying hyalo-ophitic texture.

Unit 36 (692.7–715.2 mbsf; Basalt Type 3)

Unit 36 consists of several basalt flows that are separated from each other by glassy margins. The rocks are fine- to medium-grained aphyric vesicular basalts with hyalo-ophitic to hyalopilitic texture. The groundmass has a mature sheaf texture. Vesicles 0.1 to 0.3 cm in diameter are scattered through the rock and constitute about 5% of it. They are empty in the fresh parts, coated or filled with green smectite in the altered parts. Fractures are filled with dark green smectite and pyrite.

Unit 37 (715.2–724.3 mbsf; Basalt Type 2)

Unit 37 is a slightly fractured, medium- to coarse-grained, sparsely olivine phyric basalt. The texture is subophitic to intergranular with some intersertal areas. The only phenocryst is subhedral olivine (< 1.2 mm), which is completely replaced by smectite. Fractures and veinlets are filled with smectite and pyrite.

Unit 38 (724.3–732.5 mbsf; Basalt Type 3)

Unit 38 is coarse-grained subophitic basalt and is probably a dike. The upper contact of the dike is well documented; one oriented rock piece shows a glassy margin with a 2-cm-thick fragment of the overlying unit as an inclusion next to the glassy margin. A gradual increase in grain size can be observed toward the center of the dike. The lower contact was not recovered. The basalt has ophitic to intergranular texture. Phenocrysts are euhedral olivine (0.5–0.7 mm), subhedral plagioclase (0.15–0.9 mm), and subhedral clinopyroxene (0.04–2 mm). Olivine is completely replaced by smectite. Veinlets are filled with dark green smectite and pyrite. The alteration is nonoxidative.

Unit 39 (732.5–750.5 mbsf; Basalt Type 2)

Unit 39 consists of a medium-grained, aphyric to moderately plagioclase-olivine phyric basalt. Some brecciated pieces were observed in the upper part. Plagioclase forms subhedral laths (< 0.4 mm), which are often grouped in clumps. Euhedral olivine (< 1.6 mm) is completely replaced by yellow green smectite. Green smectite occurs as a fracture filling together with pyrite. The alteration is nonoxidative.

Unit 40 (750.5–771.6 mbsf; Basalt Type 2)

Unit 40 consists of pillows and flows which are separated by glassy margins. The rocks are moderately to highly fractured, fine to medium grained. They are moderately plagioclase-olivine phyric basalts displaying hyalo-ophitic texture. Phenocrysts are euhedral olivine (< 1.0 mm) and subhedral plagioclase laths (< 1.3 mm). The groundmass has a mature sheaf texture. Green smectite completely replaces olivine and glass; fractures are filled with smectite and some pyrite. The alteration is nonoxidative.

Unit 41 (771.6–772.4 mbsf; Basalt Type 2)

Unit 41 is a small unit of massive, medium- to coarse-grained, highly plagioclase-olivine phyric basalt with subophitic to intersertal texture. Plagioclase forms subhedral laths (< 1.2 mm). Euhedral olivine (< 0.6 mm) is completely replaced by green smectite. The alteration is moderate and nonoxidative, and veinlets are filled with smectite.

Unit 42 (772.4–774.4 mbsf; Basalt Type 3)

Unit 42 consists of highly fractured pillows; glassy margins at the top, bottom, and sides of oriented rock pieces are common. The basalt is fine grained, moderately olivine-plagioclase phyric. Alteration is moderate to high. Fractures are filled with green smectite; some fractures are up to 10 mm thick, giving the rock a brecciated appearance. Iron hydroxides occur in some fractures, and pyrite is common toward the bottom of the unit, where it occurs together with iron hydroxides.

Unit 43 (774.4-776.8 mbsf; Basalt Type 2)

Unit 43 is a unit of a massive, fine- to medium-grained aphyric basalt with hyalo-ophitic texture. The groundmass has a mature sheaf texture. Toward the bottom of the unit the rocks are more fractured and brecciated, with fewer glassy margins. Smectite fills fractures and replaces the groundmass. Pyrite is common, sometimes forming aggregates up to 3 mm in size. The alteration is nonoxidative.

Unit 44 (776.8-778.2 mbsf; Basalt Type 3)

Unit 44 consists of massive, coarse-grained, highly plagioclase-pyroxene phyric basalt with subophitic to intersertal texture. Plagioclase (<1.2 mm) forms subhedral laths, and clinopyroxene (<1.2 mm) is anhedral. Smectite completely replaces glass and olivine and occurs as a fracture filling. Pyrite occurs in some veins. The alteration is nonoxidative.

Unit 45 (778.2-793.0 mbsf; Basalt Type 3)

Unit 45 consists of highly fractured, fine- to medium-grained, highly plagioclase-olivine-clinopyroxene phyric basalt pillows and thin flows. Glassy margins and brecciated basalts are numerous. The basalts have hyalo-ophitic to hyalopilitic texture; the groundmass has a mature sheaf texture. The phenocrysts are euhedral olivine (<0.7 mm), euhedral, lathy plagioclase (<1.2 mm), and subhedral clinopyroxene (<3 mm). Fractures are numerous and filled with green smectite.

Unit 46 (793.0-800.3 mbsf; Basalt Type 2)

Unit 46 is a unit of massive medium-grained aphyric basalt with subophitic to intersertal texture. The groundmass consists of olivine-plagioclase-clinopyroxene and titanomagnetite microphenocrysts. About 10% glass occurs in the groundmass, completely replaced by green smectite. Fractures are filled with smectite, a yellow brown material, and scattered clots and clusters of pyrite crystals.

Unit 47 (800.3-819.0 mbsf; Basalt Type 2)

Unit 47 consists mostly of fractured, fine- to medium-grained aphyric to sparsely olivine-clinopyroxene phyric basalt. The texture is hyalopilitic to hyalo-ophitic or subophitic to intersertal. Because of the poor recovery in Cores 67 to 69, it is not possible to subdivide this unit, although there are differences in grain size and appearance in hand specimens. Veinlets are filled with smectite, zeolite, and pyrite.

Unit 48 (819.0-828.2 mbsf; Basalt Type 2)

Unit 48 consists of fine- to medium-grained, moderately plagioclase-olivine-clinopyroxene phyric basalt with intergranular texture. Euhedral olivine (<0.7 mm) is partly replaced by smectite; euhedral plagioclase laths (<0.8 mm) and subhedral clinopyroxene (<0.4 mm) are the other phenocrysts. Smectite completely replaces glass and fills veinlets.

Unit 49 (828.2-828.9 mbsf; Basalt Type 3)

Unit 49 is fairly massive, coarse-grained, ophitic basalt. The mineralogy consists of 8% subhedral olivine (<2.0 mm) completely replaced by dirty green smectite, 40% euhedral plagioclase laths (<1.2 mm), and 40% anhedral clinopyroxene (<1 mm); 5% skeletal or microlitic titanomagnetite (<0.08 mm) occurs in some glassy areas. The glass forms about 7% of the rock. Alteration consists of smectite replacing glass and occurring as a fracture filling, together with zeolite.

BASEMENT IGNEOUS PETROGRAPHY

Hole 504A

The basaltic basement recovered from Hole 504A belongs to a single petrographic unit identical to the Type 2 basalt of Hole 504B; that is, a sparsely plagioclase-olivine-clinopyroxene phyric basalt.

Plagioclase forms 30 to 45% of the rock as phenocrysts, glomerocrysts, or microlites. The proportion of phenocrysts to glomerocrysts is variable. Generally phenocrysts (maximum length: 1.0 mm; average: 0.4-0.6 mm) are more common, but glomerocrysts account for a large proportion of the macroscopic feldspar because of their large size (maximum diameter: 1.2-2.5 mm; average: 1.0-1.2 mm), which is often twice that of single phenocrysts.

Glomerocrysts range from 0.6 to 2.5 mm in diameter, comprising many (15-20) small, randomly arranged euhedral and subhedral phenocrysts. No pronounced crystal zoning was observed. Some cores contain glass inclusions. Skeletal forms resulting from growth at marked undercoolings and the colander-like perforations induced by clay alteration occur but are rare.

Phenocrysts are euhedral or subhedral, with some degree of zoning toward more sodic rims. In a few cases, minor anorthite-rich layers are evident within more albitic rims, indicating oscillations in magma composition during crystallization. Many of the phenocrysts show mosaics of hairline fractures filled by clays. In the rare cases where the phenocrysts are situated in zones of intensive alteration, the phenocryst cores have been totally replaced, their rims remaining intact.

Microlites are common, forming 20 to 40% of the rock (maximum length: 0.6 mm; average: less than 0.2 mm). They can be euhedral or subhedral and are dendritic and skeletal. In many samples they show strong alteration. Optically measured, the plagioclase has a range in anorthite composition between An_{67} and An_{78} (average: An_{72}), with rims from An_{60} to An_{67}.

Olivine is found as euhedral and subhedral phenocrysts and as a minor component of the groundmass. The phenocrysts, which are pseudomorphed by clays and calcite, vary in size from 0.2 to 1.0 mm (average: 0.3-0.5 mm). They form 2 to 3% of the rock. Groundmass olivine is present as anhedral or subhedral grains 0.05 to 0.15 mm in diameter; it can occasionally be skeletal.

Clinopyroxene occurs as single grains, aggregates, and as a component of the groundmass. It constitutes 40% of the rock.

Ophitic and subophitic clinopyroxene is common in these rocks (5%), consisting of single anhedral grains (0.1–0.4 mm) or aggregates that enclose plagioclase microlites. The clumps (maximum diameter: 1.2 mm; average: 0.4–0.8 mm) are rarely completely ophitic and exhibit radial extinction in polarized light; this is probably the result of crystal growth.

Clinopyroxene in the groundmass can occur in several different forms, including granules and spherulites. Most of the rocks except those chilled at pillow margins have a 3 to 5% proportion of anhedral augite in their groundmass (0.05–0.1 mm). These grains often have arborescent sprays of clinopyroxene linking them to the pyroxene component of the spherulites, although they can be distinct. Sprays are absent from the larger ophitic crystals and aggregates.

The remainder of the rock is groundmass (~40–50%). The groundmass contains granular clinopyroxene, subhedral olivine, and acicular plagioclase in a spherulitic matrix composed of clinopyroxene, plagioclase, and opaques. In fine-grained rocks the mesostasis appears dark brown and is composed of fan spherulites. In coarser rocks the matrix becomes paler, and the fan spherulites develop into plumose fans and then into dendrites. Some samples have a more variolitic texture consisting of irregular patches of dark fan spherulites in a light dendritic matrix.

Opaques constitute up to 3% of the rocks. Primary opaques include titanomagnetite and Fe-rich sulfides (pyrrhotite). Titanomagnetites occur as skeletal to euhedral crystals. Primary sulfides occur as blobs disseminated in the glass and mesostasis.

Secondary opaques include pyrite and Fe-oxides. Secondary pyrite occurs as euhedral and subhedral grains in and around vesicles, and as long, wide, veinlike aggregates of skeletal pyrite which permeate the rock. Pyrite close to vesicles may also form discontinuous rims around cavities and occasionally around olivine pseudomorphs. Except when veinlike aggregates are present, secondary pyrite is found only as a trace (<0.5%).

Titanomagnetite (average: 2%) is confined to the mesostasis and occurs as crystals, most of which are very tiny. The larger grains are generally skeletal, although euhedral and subhedral grains do occur. Grains are disseminated but can occasionally be concentrated as discontinuous strings between clinopyroxene crystals and spherulite sprays.

Fe-oxide minerals, possibly hematite or goethite, are found in several samples as layered linings of vesicles and veins.

Holes 501 and 504B

The basement recovered from Holes 501 and 504B can be divided into five petrographic groups on the basis of the phenocrysts observed in thin sections. These may differ somewhat from those observed with a hand lens, which form the basis of the lithologic units (Fig. 4), but the numbers and intervals of the petrographic types correspond to those of the lithologic units. The five basalt types are as follows:

Type	Thin-Section Phenocryst Assemblage
1	Moderately plagioclase, olivine, and chrome spinel phyric (no green clinopyroxene)
2	Moderately plagioclase and augite phyric (no spinel, no green clinopyroxene, and no olivine)
3	Moderately plagioclase, olivine, and green clinopyroxene phyric (no spinel)
4	Highly plagioclase, olivine, and green clinopyroxene phyric (no augite)
5	Variably plagioclase, olivine, ± augite phyric (no spinel and no green clinopyroxene)

Type 1

Basalts of Type 1 are sparsely to moderately plagioclase–olivine phyric with accessory chrome spinel and no green clinopyroxene phenocrysts.

Megascopically, the plagioclase occurs as glomerocrysts and single phenocrysts, which together form 5 to 10% of the rock. Plagioclase microlites and a proportion of the groundmass account for a further 20 to 30% of average Type 1 basalt.

Glomerocrysts can form up to 7% of the rock, with average dimensions between 0.6 and 1.2 mm (maximum length: 2.0 to 2.5 mm). Phenocrysts contributing to these chaotic clumps may be euhedral or subhedral and are often poikilitic, containing anhedral plagioclase crystals. Glass inclusions are sometimes present in crystal cores, but they are not common. Some degree of zoning can usually be seen, but it is never as pronounced as that visible in the larger phenocrysts. More albitic rims with oscillations for more anorthitic plagioclase, as present in Type 2 basalts, are virtually absent. Clay minerals are common along cracks in the smaller grains, forming glomerocrysts.

Phenocrysts are generally euhedral or subhedral, forming 3 to 8% of the rock. The largest are 2.0 to 3.0 mm long, and the average is 0.4 to 0.8 mm. There appears to be no relationship between the size of individual phenocrysts and glomerocrysts in the same rock. Generally the sizes of the phenocrysts are distributed evenly between two extremes, although occasionally they fall into two distinct groups with no intermediate-sized grains. In such cases the largest phenocrysts are 2.5 to 2.8 mm long (average: ~1.5–2.0 mm), and the smaller are around 0.8 mm (average: 0.3–0.6 mm). Many phenocrysts contain glass inclusions in their cores, and some contain anhedral plagioclase grains. Skeletal textures are common. There are rare examples of phenocrysts with margins made of tightly packed dendrites and parallel strings of clay (altered glass?). Zoning to more sodic rims is common, sometimes with calcic oscillations near their cores.

Clay fills cracks in some phenocrysts. Plagioclase composition varies between An_{68} and An_{78} (average: An_{75}); rims are approximately An_{65}.

Plagioclase also forms dendritic groundmass and microlites, totaling 20 to 30% of the rock. The phenocrysts vary in size from 0.05 to 0.8 mm, with morphologies varying from euhedral through skeletal to dendritic. Microlites often form radiating subophitic textures when granular pyroxene is present, but generally they have no orientation. Clay fillings are common in fractures.

Olivine phenocrysts (2–3%) occur as euhedral and subhedral grains. There is usually a gradation in phenocryst size from larger (1.2–1.5 mm) to smaller (average: 0.1–1.4 mm). These phenocrysts are distinct from intersertal groundmass olivine (0.025–0.05 mm). These proportions vary; groundmass olivine is anhedral and granular, but clumps of skeletal crystals (0.2 mm long) occur occasionally. Both phenocryst and matrix olivine (total ~10%) are pseudomorphed by clays.

Clinopyroxene (~35% of the rock) is an important component of the groundmass, where it forms spherulites. A small percentage forms subhedral grains or skeletal laths (0.05–0.2 mm long) distinct from the mesostasis. These often have arborescent sprays connecting them with the spherulitic matrix. Rarely grains coalesce to form vague ophitic textures enclosing plagioclase microlites (maximum diameter: 0.8 mm).

The proportions of groundmass and mesostosis are dependent on the degree of chilling the basalt has undergone. Near the margins the matrix may form 85% of the rock, but where there is a high proportion of acicular plagioclase (flow interiors), the matrix forms only 40%. Small spherulites at margins (0.1–0.15 mm in diameter) become progressively larger toward interiors. Fan spherulites develop into plumes and then into dendrites of plagioclase and clinopyroxene dusted with opaques. In the coarser basalts, the pyroxene dendrites may become skeletal.

Euhedral chrome-spinel phenocrysts (< 3 mm) generally form less than 0.5% of the rock. They can be vermicular and sometimes skeletal. Most chrome spinel is disseminated in the mesostasis, but it can be poikilitically enclosed in olivine or plagioclase phenocrysts.

Type 2

Basalts of Type 2 are moderately plagioclase and augite phyric. Ophitic, subophitic, and intersertal textures are dominant, with finer-grained equivalents resulting in glassy to variolitic basalts.

The plagioclase crystals are sometimes zoned, often twinned according to albite, pericline, and Carlsbad laws, and exhibit blocky to equant, lathy morphologies. Anorthite content was determined optically for the phenocryst phases as An_{80} to An_{90}. No major change in An content occurs within stratigraphic succession in either the matrix or phenocrystic plagioclase. In all cores the median of the matrix crystals is less anorthite rich than that of the phenocrysts. This relationship is to be expected if the phenocrysts crystallized in a basaltic parent that was slightly less differentiated or hotter than the erupted lava.

Clinopyroxene phenocrysts are subhedral to anhedral, rarely twinned, occur usually in agglomerates of two or more, and may (rarely) appear resorbed. These crystals are biaxial positive with a large 2V and have maximum extinction angles that never exceed 45°. The maximum extinction angles generally range from 35° to 45°. In plane-polarized light the relief is high against plagioclase laths and somewhat lower than olivine; these crystals also exhibit a light green hue in plane-polarized light but are not pleochroic. Although 2V angles could not be measured accurately, the previous description is appropriate for augite.

Groundmass textures range from glassy to completely crystallized and intergranular. Several different textures are often present in one sample, progressing from a glassy rind to an intermediate zone of variolites toward a core of hyalopilitic texture. Generally, such samples represent a flow or pillow margin. Microlites in these samples are generally of two morphological and mineralogical types: (1) acicular plagioclase (approximately An_{58-60}), and (2) anhedral granular, clinopyroxene (maximum extinction angle between 30° and 45°).

Type 3

Basalts of Type 3 are moderately plagioclase–olivine–clinopyroxene phyric. They are petrographically distinguished from the other groups by their high phenocryst content (15–20%) and by the presence of large single augite crystals.

Megascopic plagioclase is in the form of phenocrysts and glomerocrysts, which together form 20 to 25% of the rock.

Phenocrysts range in size from 0.2 to 3.5 mm. The number of phenocrysts of each size is about the same. There is, however, a tendency for some basalts to have a higher proportion of phenocrysts in the ranges from 0.4 to 0.6 mm and 0.8 to 1.5 mm. In cases where the phenocrysts are predominantly of one of these sizes, large grains (3.0–4.0 mm) are rare. Irrespective of size, most of the phenocrysts are euhedral, with a few subhedral and dendritic forms. Twinning can be complex or simple; generally one or the other will be dominant in any single thin section. Zoning varies between rocks from being vague on extinction to distinct in albite-rich rims. Phenocrysts with vague oscillatory zoned cores and sharp thin sodic rims are most common. Phenocryst cores with glass inclusions are rare, as are phenocrysts with skeletal textures. Occasionally the larger phenocrysts are poikilitic, containing small euhedral feldspar grains. A parallel alignment of megacrystic plagioclase and small phenocrysts occurs in some localized areas. Generally the plagioclase is fresh, but near areas of intense alteration crystal cores may be partially or completely pseudomorphed by clays, leaving only the sodic rim intact.

Plagioclase glomerocrysts tend to be more common than individual phenocrysts in these basalts, but they are comparable in size, ranging between 0.8 and 4.0 mm at their widest point. The glomerocrysts are composed of 5 to 30 phenocrysts of varying size, but in general the small glomerocrysts are made of correspondingly small phenocrysts. Individual grains are euhedral or subhedral but never dendritic. In general, clumps are loosely and chaotically arranged. They are formed of phenocrysts which are often poikilitic, completely or partially containing anhedral or subhedral plagioclase grains. Phenocrysts show complex twinning and invariably have some degree of oscillatory zoning in their cores, with a sharp outer rim. There are no glass inclusions. Alteration, if sufficiently intense, can replace cores, but it leaves rims intact. The composition of the plagioclase in these rocks varies between An_{68} and An_{82} (average: $\sim An_{75}$), with rims of about An_{63}.

Plagioclase also occurs as microlites, forming 5 to 15% of the rock, the proportion appearing to be dependent on the crystallinity of the groundmass. The microlites vary in size from 0.05 to 0.8 mm, the largest often grading into the size of microphenocrysts and being distinguished only by their narrow form. They show no consistent orientation, but they are occasionally included in radiating ophitic clinopyroxene clumps. The smaller microlites are skeletal and dendritic; the larger microlites are only euhedral. They are strongly corroded by clays in localized areas of intense alteration.

Olivine forms 3 to 8% of the basalts from this group, as euhedral or subhedral grains. The grains range in size from 0.1 to 1.6 mm, but most are between 0.3 and 0.5 mm. Olivine is generally found as single grains, but occasionally aggregates of several (three or four) phenocrysts may occur, with rare ophitic textures. In basalts where the phenocrysts are generally larger than normal, olivine can be divided into two size ranges: phenocrysts and groundmass-sized grains (0.1–0.2 mm). Alteration is intense in most of these rocks, with colored clays replacing both the phenocryst and the groundmass olivine.

Clinopyroxene is present in the form of large phenocrysts and aggregates (2–15%) and as spherulites in the groundmass. The phenocrysts are euhedral or anhedral, and they generally occur in two size ranges. The larger grains are around 0.2 to 4.2 mm in length, the smaller about 0.05 to 0.2 mm. Usually there are only three or four large phenocrysts, and they generally show some degree of simple twinning (sector or straight). There is a tendency for the smaller grains (0.05–0.1 mm) to be more ophitic than those in the size range from 0.2 to 4.2 mm. Grains commonly coalesce to form radiating ophitic clumps with diameters up to 2.0 mm; alternatively, they are single and intersertal to the groundmass, acting as nuclei for fan spherulites. Smaller phenocrysts and aggregates are often dendritic and connected with the clinopyroxene of the groundmass by arborescent sprays. This is particularly pronounced in the less dense aggregates. Rarely, the larger single phenocrysts are poikilitic, containing small euhedral plagioclase grains.

The groundmass of these basalts is predominantly of fine-grained spherulitic form. Depending on the degree of crystallinity, it can form 60 to 80% of the rock. In general, the more spherulitic the groundmass, the lower the percentage of the plagioclase microlites and augite aggregates present. Away from pillow margins, where rounded spherulites nucleating around laths and grains are most common, the matrix becomes progressively more fanlike, then plumose, and finally dendritic. The groundmass of many basalts has a vaguely variolitic texture. A matrix of granular augite and acicular plagioclase may be randomly spotted with areas comprising dense spherulitic textures. The matrix in all these basalts is heavily dusted with opaques.

A few of the basalts in the upper half of the core show the effects of autointrusion; others show intensive fault brecciation.

Autointrusion can be found in Lithologic Unit 3 of Hole 504B from 85 cm down Core 15-5 to the top of Core 16-2. It appears as fingers and spots of fine-grained basalt ramifying a coarser host. The basalts involved are not as strongly phyric as many of the others included in Type 3, but they nevertheless contain the required phenocrysts of clinopyroxene. In thin section both the coarse- and the fine-grained basalts contain phenocrysts of plagioclase and clinopyroxene that are comparable in size and percentage (5–10%). Near contacts the finer basalt has a dark, dense matrix composed of fan spherulites and rare microlites. In plane polarized light, dark and light flow laminations can be seen running parallel to the contact; the laminations contain similarly oriented acicular plagioclase. Farther from the contact the matrix becomes less compact and lighter in color. As the microlite content increases, flow laminations lose all orientation, fans become plumose, and granular augite begins to appear. Such relationships suggest injection and chilling. Contacts are lobate and rounded, the result of intrusion while the host was still plastic and deformable. The host has a coarser groundmass of acicular plagioclase with dendritic and granular augite. Phenocrysts close to the contact can be partially enveloped by intruding material.

From the evidence it would appear that a source of hot new magma of composition similar to that already present (possibly in a magma chamber) became available for injection into a host that was cooler but still partially molten.

Breccias appear at several horizons in the core. In thin section the breccias comprise subrounded fragments up to 4 mm across. The fragments can be shattered parts of mineral grains or pieces of rock broken from the adjacent fracture wall or elsewhere. The polymict form of this breccia is clearly seen from the presence of pillow margins, aphyric, and Type 3 basalts in the same thin section. The breccia acted as a channel for intense alteration, replacing partially or completely all but the largest or most resistant rock fragments. These are now held in a matrix of clay.

Type 4

Type 4 basalts occur in Holes 504B and 505 and are moderately plagioclase-olivine-clinopyroxene phyric. They are differentiated from Type 1 basalts by the presence of clinopyroxene phenocrysts and by the size of the phenocryst component of the rock. About 30% of the basalt is made up of phenocrysts, of which 20% are plagioclase and 10% are olivine, with traces of clinopyroxene.

Plagioclase occurs as phenocrysts and glomerocrysts of variable size (maximum length and diameter: 2.5 mm; average: 1.5–2.0 mm). Composition is constant for all the plagioclase morphologies (An_{78}–An_{85}); pronounced zoning toward a more sodic rim is common. Anhedral glass inclusions occur in the cores of several crystals; less common are ophitic plagioclase megacrysts containing inclusions of anhedral olivines and chrome spinel. There are some partially resorbed feldspar phenocrysts.

Olivine (2.5–1.0 mm) is present as euhedral or subhedral phenocrysts, some of which are skeletal, and as glomerocrysts. The glomerocrysts are often ophitic or subophitic, the grains having inclusions of euhedral plagioclase. Blue and green smectites partially replace the larger olivine phenocrysts and all of the groundmass olivine.

There are a few clinopyroxene phenocrysts. In general, they are anhedral and twinned (4.0–1.0 mm long). Their rounded and corroded appearance suggests a degree of resorption. In hand specimen they appear as bright emerald green crystals.

The groundmass is identical to that of type, containing plagioclase microlites (10–20%) in a spherulitic mesostasis (50–55%).

Pyrite and titanomagnetite form ~2% of the basalt. Pyrite is limited to veining and is consequently secondary. Submicroscopic titanomagnetite is disseminated in the mesostasis as euhedral grains.

Type 5

Type 5 basalts are plagioclase–olivine–augite phyric, with augite occurring only as glomerocrystic clumps with plagioclase. Phenocryst contents are variable, so for the purpose of discussion only their extremes are considered. These are microphyric and sparsely to moderately phyric basalts. All gradations between are found.

The petrographic characteristics of the sparsely to moderately phyric Type 2 basalts have been described in detail in the discussion of Hole 504A, where the only basalt recovered was of this type.

The microphyric (subaphyric) basalts of Type 2 differ from more phyric basalts in having only 6% or less of phenocrysts (<1.0–1.5 mm in length). The phenocrysts are composed of plagioclase and olivine.

Plagioclase forms 10 to 15% of the rock as phenocrysts, glomerocrysts, and microlites. Most of the phenocrysts found in these basalts fall into one of two ranges: 0.2 to 0.7 mm (average: 0.4–0.6 mm) and 0.8 to 1.0 mm long. Rocks containing only the larger phenocrysts are relatively rare; they generally occur in combination with smaller phenocrysts or are (more commonly) absent. Irrespective of size, phenocrysts are generally euhedral and normally zoned; one case of sector zoning was observed. There is a very gradual increase in soda content from the cores towards rims, lacking sharp or oscillatory changes during growth. A few of the smaller phenocrysts appear corroded and almost anhedral in form, indicative of partial resorption or magmatic abrasion. Twinning is simple in the majority of grains, consisting of one or two broad twins. The smaller phenocrysts tend to be more dendritic than the larger grains. Inclusions are rare or absent. Alteration appears as clay-filled cracks and is most pronounced in the smallest phenocrysts.

Glomerocrysts of plagioclase are rare (one or two per thin section) or absent. They are formed of chaotic clumps of 5 to 10 euhedral or subhedral phenocrysts (0.2–0.4 mm), some of which are partially or completely enclosed by others. Generally they are 0.8 to 1.2 mm across. Glomerocrystic grains are identical to single phenocrysts in zoning, simple twinning, and occasional dendritic morphology. Plagioclase composition varies between An_{74} to An_{82} (average: An_{76}), with rims of approximately An_{68}.

Most plagioclase is in the form of microlites (10–20%). The microlites range in size from 0.05 to 1.6 mm, but average 0.1 to 0.4 mm, depending on the crystallinity of the rock. Generally they have a random orientation, but they may form radiating ophitic textures when granular augite is present in the groundmass. Most microlites are subhedral or euhedral. Skeletal forms are not common. They can be dendritic, and in pillow margins they act as nuclei for fan spherulites.

Olivine phenocrysts form 3 to 4% of the basalts. They range in size from 0.05 to 0.4 mm, with an average between 0.2 and 0.3 mm. Grains are commonly euhedral or (rarely) subhedral. In most sections olivine is completely replaced by clays or Fe-oxide minerals.

Clinopyroxene occurs as single grains and as amorphous aggregates, forming in total 10 to 25% of the rock. Single grains are at maximum 0.3 mm long (average: 0.05–0.2 mm) and are therefore large components of the groundmass rather than microphenocrysts. They range from euhedral to subhedral. Single grains, which are occasionally skeletal in form, are randomly scattered in the rock, but the grains sometimes coalesce to form clumps. Rarely, individual grains are subophitic with plagioclase and exhibit undulose extinction (average diameter: 0.1–0.2 mm). The grains sometimes act as nuclei for poorly developed bow-tie structures, but generally they are texturally independent of the groundmass. Clumps are distinct from other aggregates of smaller diffuse granules (0.05 mm) in that they are made of clear subhedral grains and are nonophitic.

Aggregates of augite, on the other hand, are composed of a mass of anhedral granules and are always ophitic. Each aggregate can be 0.2 to 0.4 mm across, but most are about 0.2 mm. Occasionally several loose aggregates coalesce to form continuous areas of ophitic texture in a dense spherulitic groundmass. In coarser basalt, ophitic areas increase in proportion to the amount of granular augite. The grains that form these aggregates have arborescent sprays joining them to the matrix, but they are absent from most of the clumped and phenocrystic augite.

Dense fanlike spherulites are characteristic of fine-grained rocks; they contain only a small number of microlites and granular augite. Acicular plagioclase crystals may occasionally act as nuclei for spherulite growth. Fan spherulites vary from fanlike to plumose and finally to dendritic as the basalt coarsens. Also associated with the coarsening basalt is an increase in augite content in the form of aggregates, clumps, and grains. Coarse rocks usually have a variolitic matrix, whereas areas of dense spherulites heavily dusted with opaques are scattered in a more plumose and granular-ophitic groundmass rich in microlites.

Opaque Mineralogy

Titanomagnetite and primary sulfide spherules are ubiquitously found in the interstices of silicate phases (regardless of the basic texture), and they never occur in an equigranular-intergranular relationship with the silicates. Crystal textural and morphological relationships indicate that the silicates crystallized before the interstitial phases. This relationship implies that the final crystallization of these opaques occurred well after the main silicate-crystal framework of the solidifying melt had been established. In addition, the sulfide spherules are flattened against both the silicate crystals and the titanomagnetites, indicating that these spherules represent droplets of an immiscible sulfide melt, liquidated from the silicate magma, that solidified after the main stage of silicate and oxide crystallization.

Titanomagnetites dominate the opaque mineral phases in grain size and abundance, ranging from 5 to 10 μm in average diameter in different samples and constituting from 4 to 10% of rock volume in different samples. These oxides often occur in areas where the primary interstitial silicate matrix has been replaced by smectite. In such areas two types of alteration of the primary oxides were recognized: (1) direct oxidation to red, Fe-oxyhydroxide and (2) development of "oxidative shrinkage" cracks. These alteration products are rare in the polished thin sections available, occurring only in thin sections from Hole 504B, Core 39, Section 1, 43–50 cm and Hole 504B, Core 52, Section 3, 97–99 cm, respectively.

Primary sulfide spherules are less common than in the Galapagos Rift samples drilled on Legs 54 and 70, but they occur in all samples where the titanomagnetites are large enough to discern morphology (> 5 μm).

Conclusions

All basalt types carry mineralogical evidence for complex crystallization histories. This evidence includes partially resorbed plagioclase and clinopyroxene phenocrysts, plagioclase phenocryst interiors rich in inclusions, pronounced oscillatory zoning, and diverse phenocryst and microphenocryst morphologies that indicate formation at a range of undercoolings. The fact that the petrographic types display different combinations of these characteristics suggests that they were subjected to different influences during their formation. The groundmass is very similar for all basalt types and would appear to indicate that a similar magma type was involved in all cases, but that the magmas were subjected to different conditions of crystal fractionation and phenocryst addition to form each petrographic group.

BASEMENT ALTERATION PETROGRAPHY, SITES 501 AND 504

Mineralogy

Alteration of the basalts in Sites 501 and 504 appears in glassy margins, olivine and plagioclase crystals, veins, and miarolitic voids. The alteration minerals determined on board the *Glomar Challenger* are clay minerals, talc(?), carbonates, phillipsite, natrolite, analcime, iron hydroxides and/or iddingsite, and pyrite. The minerals occur as fillings of vesicles and veins and as replacements of olivine and sometimes plagioclase crystals. Other secondary minerals, such as quartz, K-feldspar, apophyllite, anhydrite, gyrolite, melanite, and aegirine augite, were found during shore-based studies.

Clay Minerals

Clay minerals are present in all three holes. The five types listed in Table 7 were distinguished.

The clay mineral typed as GY was analyzed on the ship by XRF during Leg 69; it seems to be saponite.

The mineral typed as EY, which was identified as talc in Hole 504B on board the ship using X-ray diffraction, was revealed on shore to be a Mg-rich clay mineral which is particularly colorless and highly birefringent (Honnorez et al., this volume). Possible interlayered talc–saponite minerals were identified by XRD in Cores 34, 37, 48, 56, and 57.

Carbonates

Carbonates occur in Hole 501 (Cores 12–17 and 20), in Hole 504A (Core 6), and in Hole 504B (Cores 3–9, 14, 16, 17, 20–24, 27, 28, 33 to 35, 37 to 41, and 48). The presence of calcite in Hole 504B (Core 44) was confirmed by XRD during Leg 70. In Hole 504B carbonates are particularly abundant in veins, where they are associated with clay minerals, analcime, and other zeolites. Carbonates occur associated with clay minerals as a product of olivine alteration in Hole 504B, Cores 5 to 9, 16, 17, 21 to 24, 27, 38, 41, and 45.

Phillipsite

Phillipsite is present in altered glassy margins, where it is associated with clays. It shows fan-shaped aggregates of elongated or square crystals with very low birefringence. A large radiating clump of crystals (1 cm

Table 7. Clay minerals in basalts of Sites 501 and 504.

Type	Color in Normal Light	Color in Crossed Polars	Habit	Mode of Occurrence
GY	Greenish yellow	Gray to yellow (first order)	Fibers	Breccia cement, glassy margins
EY	Pale yellow green to colorless	Gray (first order) to yellow (second order)	Fibers	Olivine replacement, vesicle and vein fillings (plagioclase replacement)
G	Green	Anomalous dark green	Granules	Olivine replacement, vesicle and vein fillings
BG	Blue green	Anomalous bluish gray	Fibers	Olivine replacement
DG	Dark olive green	Gray to red (first order); sometimes superimposed on anomalous green	Fibers	Olivine replacement, vein fillings

across) was found in Hole 504B on the surface of Core 11, Section 3, Piece 1079.

Zeolites

Various unidentified zeolites occur in Cores 35 to 41 of Hole 504B. Megascopically, a white zeolite occurs in veins as fibroradiate aggregates up to 10 mm in width; the aggregates are associated with dark green smectite and sometimes analcite. Natrolite was identified by XRD in veins of Cores 35 to 37. White material that occurs in veins below Core 49 is quartz (Honnorez et al., this volume).

Analcime

Analcime occurs in Hole 504B (Cores 35, 37, and 38) as colorless transparent crystals (to 1.0 mm in size) in open cracks and veins, where it is in association with clay minerals, probably natrolite, calcite, and sometimes a light bluish transparent mineral. The presence of analcime in Core 35 was confirmed by XRD.

Iddingsite

Different kinds of iddingsite (i.e., various mixtures of clay minerals and iron hydroxides) occur in Holes 501 and 504B. It occurs as red, orange, or brownish material that has abnormal dark red, orange, and brown colors in crossed polars. It was found in and around the cracks of olivine phenocrysts, which are completely replaced by clay minerals. An iddingsitelike material, compositionally identical to that replacing olivines (Honnorez et al., this volume), also occurs in the matrix, cracks, vesicles, and miarolitic voids, generally in association with clay minerals.

Iddingsite and iddingsitelike material may be responsible for the red color of "alteration halos" around cracks.

Pyrite

Pyrite appears in variable amounts in veins, where it is associated with dark green smectite. It is rare in Holes 501, 504A, and the upper part of the Hole 504B but more common in the lower part of Hole 504B (e.g., Cores 36, 38, 40, 41, 45, 47–50, 52, and 54–70). The frequency, abundance, and size of the grains of pyrite increase with depth (maximum length: 2 mm; maximum length of agglomerates of crystals: 6 mm).

Alteration Zoning around Cracks

Oxidative alteration is often marked by zoning along cracks. The materials that appear as one moves from the fresh rock to a crack or exposed surface are as follows: (1) Type EY clay mineral; (2) Type EY clay mineral plus iddingsite; and (3) Type G clay mineral (not always present). This disposition is general in Hole 501 and in the upper part of the Hole 504B. Below Core 39 in Hole 504B it disappears.

Replacement of Igneous Minerals

Pyroxene crystals are almost always fresh (see Laverne, this volume).

Plagioclase crystals are sometimes partly altered to clay minerals (Type EY), and more rarely are replaced by analcite and other zeolites (Cores 35, 37, and 38). Titanomagnetite crystals are often rather strongly altered; they are frequently almost completely replaced by nonopaque minerals or mineral assemblages. In such cases, fresh titanomagnetite occurs as tiny (<0.001 mm) relics scattered in the alteration products, and the original titanomagnetite crystal outlines are visible only in transmitted light. The nature of the alteration products could not be identified on the ship because of the rather poor polish of the sections. Titanomaghemite and other Fe–Ti oxides/hydroxides are probably present, as well as sphene.

Olivine is always at least partly altered, and most of the time it is completely altered. The following associations occur as a replacement for olivine: (1) pale green smectite (Type EY); (2) colorless to pale green smectite (Type EY) plus iddingsite; (3) blue green smectite (Type BG); (4) green smectite (Type G); and (5) pale green smectite (Type EY) plus dark olive green smectite (Type DG) plus opaque needles.

The Type (2) association occurs in red halos around cracks, whereas Type (1) occurs outside the halos, in the nonoxidized zones. The Type (1), (2), and (4) associations are common in the upper part of the hole (above Core 39). The Type (3) association occurs above Core 39, but it is rare. The Type (5) association occurs below Core 39. The Type (1) and (2) associations were observed in the same thin section (Sample 504B-33-2 [Piece 207]). One part of the thin section shows Type (1) alteration, whereas the other part shows Type (2) alteration. The contact between these two zones is very sharp, with the same olivine phenocryst exhibiting both types of alteration. The zonation is controlled by the presence of a crack (see preceding material).

Variation of Alteration with Lithologic Type

Alteration varies with the two main lithologic types of lava. The first type comprises the pillow basalts and breccias, which are characterized by the presence of glass, fine-grained basalts, and numerous cracks. The alteration minerals are varied and abundant (analcime, pyrite, calcite, smectites, zeolites). They fill thick (8-mm) cracks and replace glass and olivine. The second type comprises the massive basalts, which are medium grained and probably represent flows most of the time. Cracks are much rarer and thinner (<0.5 mm in width). In these, alteration is typically less advanced; however, the alteration minerals are similar to those in the pillows and breccias.

Variation of Alteration with Depth

Some variation in the alteration of the basalts with depth can be observed. The amount of pyrite increases with depth, whereas the abundance of carbonate decreases. In Hole 504B iddingsite is rare below Core 39; zeolites and analcime do not occur below Core 39; and phillipsite does not occur below Core 23. In addition, the Type (1), (2), (3), and (4) associations of olivine replacement do not occur below Core 39, whereas the Type (5) association seems to be present only below Core 39.

It was obvious on board that Core 39 of Hole 504B corresponded roughly to a boundary between two kinds of alteration, and this was confirmed on shore (Honnorez et al., this volume). The Core 39 boundary was not sharp, however, but extended for several cores.

The amount of altered material (although not necessarily the intensity of the alteration) depends also on lithologic type, including the density of the fractures, the grain size, the pore space volume and so forth—in other words, effective permeability. The tendency of a rock to alter depends on the latter parameter.

In summary, the basalts of Sites 501 and 504 show two types of alteration: oxidative alteration, which occurs in Holes 501 and 504A and in the upper part of the Hole 504B (to about Core 39), and a nonoxidative, possibly reducing type of alteration, which occurs in the lower part of Hole 504B (below about Core 39).

BASEMENT CHEMISTRY, SITES 501 AND 504

This discussion of the chemistry of the basalts in Holes 501, 504A, and 504B is based on (1) shipboard XRF measurements, (2) shore-based trace element data (Etoubleau et al., this volume), and (3) the composition of the natural basaltic glasses as determined by electron microprobe (Natland et al., this volume).

The XRF data show that the basalts are relatively basic, with values of Mg/(Mg + Fe) from 0.56 to 0.66 (mean: 0.61); Ni from 70 to 170 ppm; Zr from 30 to 100 ppm (with a concentration near 55 ppm); and TiO_2 from 0.7 to 1.4% (with a concentration near 1.0%). No ferrobasalts were encountered.

Except for two small intervals, all the basalts are depleted (N-type) mid-ocean ridge basalts. In fact, they have such low abundances of mobile-incompatible (hygromagmatophile) elements that they can be considered particularly depleted variants of N-type mid-ocean ridge basalts. The two exceptional intervals occur from Cores 16 to 18 and 54 to 56 (Lithologic Units 4, 5, and 36). They contain basalts with elevated abundances of K_2O, Na_2O, and certain trace elements, and they have different ratios of Nb/Zr and La/Ta (Etoubleau et al., this volume). These lavas appear to have had a less depleted mantle source than the others.

The other basalts show a rather remarkable degree of uniformity, so much so that discrete chemical types in many cases could not be distinguished using XRF major oxide data because of the effects of phenocrysts and alteration. Better results were obtained using natural glass composition. Natland et al. (this volume) define 16 compositional groups that occupy different stratigraphic levels in the holes. Thirteen of these occur in Hole 504B, with an additional one in both Holes 501 and 504A. The least evolved glass compositions occur in Core 35. They have 9.2 to 9.5% MgO and are only 0.81 to 0.83% TiO_2. They are among the most magnesian glasses analyzed from the eastern Pacific. The generally depleted character of the basalts is verified by the low percentage of K_2O (0.02–0.05%) and P_2O_5 (0.07–0.11%) in the composition of the glass. The largest coherent group of glass spans Cores 37 to 50 in Hole 504B. A smaller coherent group spans Cores 4 to 14 of Hole 504B; it occurs as well in Holes 501 and 504A. These and all other groups evidently represent individual eruptive units, and they appear in the pillows, flows, and breccias of most of the principal petrographic types. The abundance and occurrence of phenocrysts thus have little relationship to rock chemistry. The phenocrysts must therefore either be mechanical concentrates due to gravity sorting or flowage differentiation or have been introduced during magma mixing. As regards mixing, the extreme uniformity of the composition of both the whole rock and the glass implies uniformity in the magmatic processes at the Costa Rica Rift. In all likelihood, the uniformity reflects the effectiveness of a steady-state magma chamber in buffering magma compositions, primarily by mixing, prior to eruption.

Sr AND Pb ISOTOPIC COMPOSITION OF HOLE 504B BASALTS

Fourteen whole rock samples taken from Hole 504B at 40- to 60-meter intervals were analyzed for $^{87}Sr/^{86}Sr$ ratios and Sr and Rb concentrations. With one exception, samples were taken from holocrystalline pillows or massive basalts. Basalts containing major smectite or zeolite veins were not sampled because the intention of the study was to determine the degree of isotopic exchange between the crystalline bulk rock and seawater.

Seven samples from the upper 260 meters of the hole, down to Core 34, have Sr isotope ratios of 0.70287 to 0.70377, with an average of 0.70324, and Rb values of 1.3 to 9.5 ppm. Six samples from the lower 300 meters of the hole have a very restricted Sr isotope ratio range (0.70255–0.70279) and an average value of 0.70265, the value for fresh oceanic basalts. The Rb values are less than 0.5 ppm.

The elevated Sr isotopic values in the upper part of the hole can be interpreted in terms of limited isotopic exchange with seawater, which has a value of $^{87}Sr/^{86}Sr$ of 0.7091. Assuming an initial basaltic value of 0.70265, the present range of values in the upper basalts implies a 3 to 17% (mean 9%) contribution of seawater Sr. This Sr must be located mainly in the secondary smectites, which, together with minor iddingsite, replaces olivine in the upper basalts. In the lower half of the hole the basalts contain at least as much secondary smectite, but seawater Sr is negligible. This indicates that relative to the higher basalts, the lower basalts had notably less access to unmodified seawater. This could be the result of earlier filling of fractures, the lower flux of seawater in the lower basalts, or the reaction of the lower basalts primarily with isotopically modified seawater.

Pb isotopic ratios measured in 10 of the samples fall within the less radiogenic portion of the field of mid-ocean ridge basalts. The ratios define a linear trend in a plot of $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ and a roughly linear trend in a plot of $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$. There is no particular downhole trend in values. The observed variation is rather surprising, in view of the very limited variation in the composition of the fresh basalts and glasses in Hole 504B.

BASEMENT STRUCTURE IN HOLES 501 AND 504B

The orientation of glassy rinds and the inclination of fractures in oriented samples was determined for both Holes 501 and 504B. In all, 6302 fractures were counted. The rocks consist of alternating pillows and massive flows. The same general patterns of fracture inclination persist throughout both holes: namely, inclined fractures are proportionally more abundant in massive flows than in pillow units, but massive flows have fewer fractures overall. The total length of oriented recovered rock on which fracture inclinations could be counted was measured, and the average number of fractures per lithologic unit was determined. There are, overall, 1.82 fractures per centimeter of length of recovered oriented rock in Hole 504B. Pillow units in general average one fracture every 2 cm or less, whereas flows have fractures about every 2 cm or greater. The thickest massive flows have fractures every 3.5 to 4.5 cm. There is no tendency for the frequency of fractures in the pillow units to increase with depth, but there is some tendency for the fracture density in flows to increase with depth. However, this may merely reflect the occurrence of relatively thin flows deeper in the hole.

The orientation of glass rinds indicates that pillows predominate in the hole, with few, if any, sheet flows. Autoclastic breccia zones cemented by clays were recovered more frequently toward the bottom of the hole, as were hyaloclastites. It was not possible to count fractures in such material. In all likelihood, however, this type of material is more abundant throughout the hole than is indicated by the recovery, and it is this material that is primarily responsible for the porosity of the crust.

BASEMENT PHYSICAL PROPERTIES, SITE 504

Basement physical properties measured at Site 504 include sonic velocity, wet bulk density, porosity, and thermal conductivity. Seismic velocity was determined with the Hamilton frame velocimeter from minicore samples cut for paleomagnetic study; wet bulk density–porosity samples were taken from the same piece of basalt and analyzed using gravimetric techniques. Thermal conductivity was, in almost all cases, determined for the same basalt piece that supplied the minicore and porosity sample.

Complete data and their interpretations are presented in Karato et al. (this volume).

Wet bulk density ranges from 2.73 to 3.02 g/cc, with an average of 2.9 ± 0.06 g/cc. There is a general trend for wet bulk density to increase with depth; values are less than 2.90 g/cc in the upper part of Hole 504B and greater than 2.90 g/cc in the lower part. Grain density, which has a mean value of 3.00 ± 0.03 g/cc and a range from 2.92 to 3.07 g/cc, also increases with depth; values are generally below 3.00 g/cc in the upper levels and greater than this value in lowermost cores. Porosity ranges from 1.3 to 13.3%, with a mean of 5.0 ± 2.2%; it appears to exhibit a small decrease lower in the hole.

Thermal conductivity measurements yield an average value of 1.67 ± 0.09 W/m°C. The measurements range from 1.47 to 1.87 W/m°C and exhibit no correlation with porosity, density, or depth.

Seismic velocities average 5.75 ± 0.30 km/s, with a range of 4.40 to 6.34 km/s, and show reasonable correlations with both wet bulk density and porosity; however, there is no obvious change in velocity with increasing depth.

BASEMENT PALEOMAGNETISM

Sites 501 and 504 lie on a positive magnetic anomaly that runs east and west, parallel to the crest of the Costa Rica Rift. At this place, such a positive anomaly signifies reversely magnetized crust, with a close relation between the nearly symmetrical anomalies and the causative blocks of crust. Since the inclination of the Earth's field at this latitude is low, secular variation is expected to produce excursions to both positive and negative inclinations through time, so polarity of magnetization cannot be determined from inclination. However, detection of a superimposed viscous component of magnetization of opposite polarity during alternating-current demagnetization often indicates reversed natural remanent magnetization in samples of low inclination. Such a viscous component was detected in the basalts of Sites 501 and 504, confirming the reversed polarity indicated by the anomaly. If the revised time scale of LaBrecque et al. (1977) is used, the age of the crust at the sites is 5.9 m.y.

A detailed account of the shipboard paleomagnetic measurements is given by Furuta and Levi (this volume). Briefly, the results are as follows. Twenty-eight minicores from Site 501 and 130 from Site 504 were measured for inclination before and after alternating-current demagnetization, for intensity of magnetization, and for susceptibility. Intensity of natural remanent magnetization (J_n) showed a wide scatter of values, ranging from 0.1×10^{-3} gauss to 30×10^{-3} gauss. There is no systematic variation of J_n with depth in the hole. J_n is much more closely related to grain size, with higher J_n values generally corresponding to the finer-grained basalts and lower J_n to the more coarsely crystalline cores of massive flows. A suitable mean J_n for both sites would be 5 to 10×10^{-3} gauss, depending on the method of averaging.

Inclination after alternating-current demagnetization varies broadly with depth in the crust. In Hole 501 and the upper part of Hole 504B, inclinations are generally shallow, ranging from about +10° to −20°, with a general bias to negative inclinations. Deeper in Hole 504B, inclinations become generally steeper, on the average, with the maximum positive inclination remaining close to +10°, while negative inclinations reach −60° or −80° in parts of the core. The mean inclination is about −10° in the upper part of the hole and −40° near the bottom.

The ratio of remanent to induced magnetization (Q) is generally high, as is usual in ocean floor basalts. It ranges from 0.1 to 108, with a mean of about 10, depending on the method of computation. The value of Q is generally positively correlated with J_n, since the specific remanent intensity usually decreases, whereas susceptibility generally increases, with particle size.

Magnetic units were defined in Hole 504B on the basis both of J_n and inclination after demagnetization. The latter proved to be a more powerful guide where inclinations are more variable (in the lower part of the hole). Nine units were defined in this way in the upper part of Hole 504B on Leg 69, and 15 units were defined in the lower part of the hole on Leg 70. Boundaries between magnetic units often correspond to the lithologic boundaries or zones of brecciation seen in the core.

Further discussion of these results and details of the shipboard measurements are to be found in Furuta and Levi (this volume).

DOWNHOLE MEASUREMENTS AT SITES 501 AND 504

Logging

Logging runs were made in Hole 501 and twice in Hole 504B, once at the end of Leg 69, when basement penetration was 214 meters, and again at the end of Leg 70, when basement penetration had reached 561.5 meters. The logs run at various times are listed in Table 3.

The porosity-related logs, such as compensated density, resistivity, neutron porosity, and sonic velocity, all agree in identifying very clearly the massive flow units and in showing the pillowed sections as being of higher and more variable porosity. Zones of very high porosity may be related to zones of faulting or brecciation in the hole. The caliper log showed the hole to be close to bit size throughout, but zones of relative enlargement of the hole occur, which may prove to be related to lithologic changes in the section. The natural gamma count is generally low, although there are small peaks (perhaps related to K-enrichment) in zones of oxidative alteration. A more complete discussion of the logging results can be found in Cann and Von Herzen (this volume).

Temperature Measurements

The Tokyo T-probe/pore water sampler was used to make four temperature measurements within the sediments in the high heat flow area, one in Hole 501 and three in Hole 504C. The results are discussed in detail in Becker et al. (this volume). The four temperature points define a steady increase in temperature with depth, with a decreasing gradient related to increasing thermal conductivity. When appropriately combined, the mean temperature gradient and average thermal resistance of the sediments indicate a heat flow of 194 mW m^{-2}, a value in excellent agreement with the seafloor measurements made during the site survey work. These measurements show that the heat flow through the sediments is in conductive equilibrium. The value obtained is in good agreement with that theoretically expected in a crust aged 5.9 m.y. (Parsons and Sclater, 1977). The temperature indicated for the sediment basalt contact at Hole 504B is 56°C.

A total of eight high-resolution temperature logs were made in three holes at Sites 501 and 504. Two profiles were measured in Hole 501, one 16 hours and the other 45 hours after drilling and circulation had stopped in the hole. Both curves are strongly affected by drilling disturbance, but some thermal recovery occurred during the 29 hours between measurements. Theory, such as that of Bullard (1947), predicts much faster recovery, indicating that Hole 501, like Hole 504B (Becker et al., this volume) was being chilled by a downward flow of seawater. Similar downflow has been indicated at three other DSDP sites (Sites 332, 396, and 456), which happen to be the only basement-penetrating sites at which adequate temperature measurements were made (Hyndman et al., 1976; Erickson and Hyndman, 1979; and Uyeda and Horai, 1982).

A temperature profile was measured in Hole 504A 28 days after it had been abandoned 12 meters into basement after bit failure. Re-entering the hole disturbed the temperature in the top 180 meters of the sediments, but in the lower 80 meters of the hole temperatures had nearly returned to equilibrium. The measured profile shows temperature near the bottom of the hole to be 2 to 3°C higher than in Hole 504C, suggesting that heat flow may be somewhat higher at Hole 504A.

In Hole 504B, two temperature logs were made at the end of drilling on Leg 69. Another log was run during Leg 70, 40 days after the last disturbance of the hole on Leg 69. Two more temperature logs were run during Leg 70 after the hole had been deepened to 561.5 meters into basement. The logs all indicate a significant downward flow of water in the hole to depths of 365 to 440 meters sub-bottom (90–170 m into basement). Below that level the close approximation of the measured gradient to that estimated by conductive theory strongly suggests that downward flow is insignificant. The existence of downward flow is most clearly demonstrated by the departure of the measured gradient from the conductive gradient established nearby in other holes even over a period longer than 1 month. The rate of downward flow can be estimated by using theory given by Jaeger (1961). On this basis, the profiles measured on Leg 69 indicate a downward velocity of 80 to 100 meters per hour (Becker et al., this volume).

At depths greater than about 440 meters sub-bottom, the logged temperatures, when corrected for drilling disturbance, fall on a uniform gradient of 0.12°C/m down to depths of at least 800 meters sub-bottom. Thermal conductivity measurements on basement rocks yield a mean value of 1.7 W/m °C, which, when combined with the temperature gradient, gives a value of 204 mW m^{-2} for conductive heat flux. This is in excellent agreement with the measurements in the sediments and suggests a purely conductive *in situ* thermal regime over the whole section drilled.

The downward flow of water in the hole detected by the temperature measurements requires an *in situ* pressure within the basement that is significantly less than hydrostatic. Maintenance of the flow over long periods requires that this extend over a relatively large volume of crust. Both of these points are taken up in the next section.

Flow Tests with the Packer

Flow tests were carried out with the Lynes packer at two levels in Hole 504B at the end of Leg 69, when the drill had penetrated 214 meters of basement (Zoback and Anderson, this volume). The packer was set 172.5 meters and 3 meters above the bottom of the hole. Therefore one test was within, and one below, the zone in which water was deduced to be flowing into the basement. The decay curves indicated permeabilities of 2 to 40 millidarcys.

Three other hydraulic characteristics of the basement were brought out by the tests. First, extrapolation of the pressure decay curves from the successful flow tests indicated a pore water pressure in the bottom of the hole at 214 meters into basement of 8 to 12 bars below hydrostatic. The existence of such a negative pressure had been predicted from the temperature measurements. Second, it proved to be possible to pump large volumes of water readily into the basement at only small overpressures (15 to 20 bars). Third, it was not possible to maintain excess pressures on the formation larger than 50 bars, even with the pumps running at maximum rate. This behavior probably resulted from the opening of existing cracks in the rock when the lithostatic load was exceeded, which occurred at overpressures of about 50 bars. The opening of the cracks greatly increases the permeability of the rock and thus limits the pressures that can be reached.

DOWNHOLE WATER SAMPLING AND EXPERIMENTS IN HOLE 504B

Water Samples in Basement

Basement water samples were collected with a Gearhart-Owen downhole sampler (469 m), the Lynes packer (476 m), and the Barnes *in situ* sampler (460, 640, and 715 m). All the samples collected were diluted to some extent by fresh surface seawater. Moreover, water pumped into the hole earlier reacted quickly and extensively with the basalts; hence, the samples recovered were actually mixes of fresh and reacted seawater only. No formation water was recovered (see Hart and Mottl, et al., this volume). Samples were collected from depths of 460, 469, 476, 640, and 715 meters below the seafloor (185, 194, 201, 365, and 440 meters below the top of the basement). All the samples had Ca and Si concentrations greater than and Mg concentrations less than the surface or bottom water. The molar excess of Ca over bottom water values was the same as the molar deficiency of Mg, just as observed in the sediment pore waters, suggesting that the reacted seawater quickly came to have Ca and Mg contents similar to the pore waters of the basal sediments, as would be expected if the chemical reactions of seawater within the basement controlled the composition of the sediment pore waters. The ratio between the excess of Si above bottom water and the excess of Ca above bottom water increases steadily with depth in the hole, reflecting an increase in Si in the reacted waters as the temperature increases with depth. This suggests that the reacted waters did not mix well vertically after they were pumped into the hole. The chemistry of waters sampled in basement is discussed in more detail in Mottl, Anderson et al. (this volume) and Hart and Mottl (this volume).

Oblique Seismic Experiment

The oblique seismic experiment (OSE) was proposed to study the detailed structure of Layer 2 in oceanic crust. Such an experiment was conducted at the end of Leg 70 in Hole 504B. In an OSE, the noise signal from shots fired at the surface at ranges up to 12 km are measured at an oceanic crustal borehole. The objectives of the experiment include (1) determining the lateral extent of the structure intersected by the hole; (2) analyzing the role of cracks in the velocity structure of oceanic crust; (3) detecting anisotropy in Layers 2 and 3; and (4) measuring attenuation in oceanic crust.

The shooting ship for the Leg 70 OSE was the R/V *Gilliss*, which sailed from and then returned to Panama (8 to 19 December 1979). During the experiment, the three-component geophone malfunctioned because of low-resistance shorts in the bulkhead connectors into the geophone and amplifier pressure cases (Stephen et al., 1980; and Stephen, this volume). The malfunctions could have been the result of connector faults or the high temperatures encountered in the hole. The net result was that rather than having three geophone signals (one for the vertical and two for the horizontal signal components), the three signals were mixed with one another. Consequently, only travel time information was collected; the amplitude data were meaningless.

The geophone was clamped at 3790 and 4280 meters below the seafloor. At each depth a cross pattern of shots with lines oriented parallel and perpendicular to the spreading direction in the area was fixed. Shots were fired out to ranges of 12 km at a spacing of 0.5 km. Three ocean bottom hydrophones were also deployed during the experiment to obtain data for comparison with the OCE data and to provide reverse profiles.

The travel time data are sufficient to determine the velocity structure in the upper 1500 meters of crust out to ranges of about 6.01 cm from the borehole. The comparison of these velocities with laboratory data, logging data, and regional seismic refraction surveys will constrain models of crack distribution in upper oceanic crust. Anisotropy was not observed in the travel time data, which had a resolution of approximately ±0.1 km/s. Since the amplitudes were not reliable, attenuation was not measured.

Electrical Resistivity Experiment

A relatively large-scale electrical resistivity experiment was carried out in Hole 504B after the completion of drilling on Leg 70. The experiment, which is described in detail by Francis (1982), utilizes a current electrode at the bottom of an insulated cable that is attached to a logging winch, with three voltage electrodes attached at variable spacings above. The current generated aboard the vessel is allowed to flow into the rock, and the voltage drops due to rock resistivity are recorded on board the ship. The resistivity structure in the basement section of Hole 504B was found to reflect the induction log resistivity, although it was somewhat attenuated in both magnitude and variation (Von Herzen et al., this volume).

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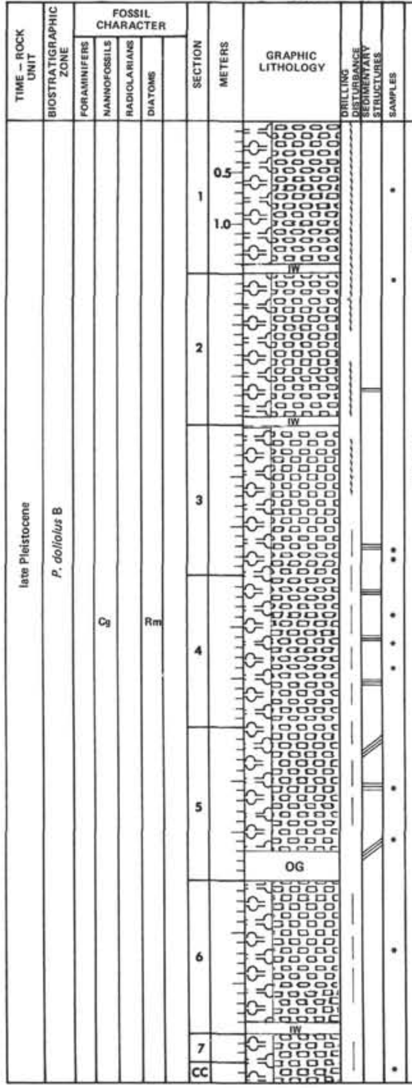
SITE 501 HOLE CORE 1 CORED INTERVAL 0.0–7.6 m



LITHOLOGIC DESCRIPTION

5GY 5/1
with
5Y 4/4

5GY 5/1
with
5Y 4/4,
2.5Y 4/4

SILICEOUS–CARBONATE OOZE

- Intense to moderate deformation.
- Basic color is 5GY 5/1 (clay) with olive, scattered black spotting/mottling, gray brown and browns.
- Evidence of relict bedding and possible bioturbation.
- Varying percentages of volcanic glass.
- Generally sponge spicules > diatoms > radiolarians > silicoflagellates and nannofossils > foraminifer > unspecified carbonate. Siliceous average 30% and carbonate 50%.
- *Some introduction of clay (mud) in lower sections.*

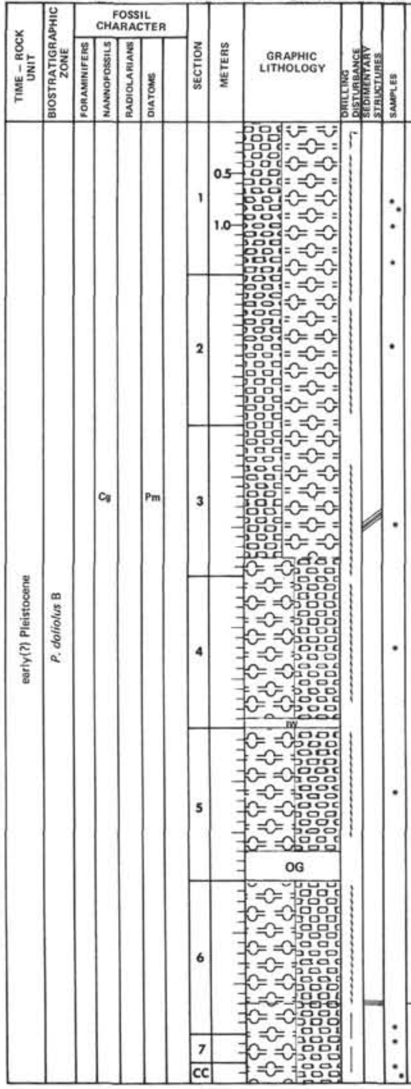
SMEAR SLIDE SUMMARY

	1-75	2-10	3-127 M	3-142 M	4-44 M	4-70
Detritals	TR	<5	<5	TR	TR	–
Clay	5	15	15	20	8	10
Volcanic glass	TR	10	7	–	7	5
Glauconite	TR	–	–	–	–	–
Opaques	–	TR	TR	TR	TR	–
Carbonate unspec.	15	5	20	15	20	15
Foraminifers	15	15	15	30	10	25
Nannofossils	20	20	20	20	25	25
Diatoms	15	15	8	5	15	10
Radiolarians	5	10	5	5	10	10
Sponge spicules	20	5	5	5	5	TR
Silicoflagellates	5	TR	TR	TR	TR	TR

	4-99 M	5-65	5-108	6-75	CC
Detritals	< 5	TR	10	TR	1
Clay	15	5	15	12	12
Volcanic glass	10	5	15	3	TR
Opaques	–	–	5	–	–
Carbonate unspec.	5	10	15	10	15
Foraminifers	15	20	5	20	35
Nannofossils	20	35	15	25	20
Diatoms	20	7	12	15	10
Radiolarians	5	20	5	10	5
Sponge spicules	5	3	3	5	2
Silicoflagellates	TR	TR	–	TR	–

NOTE: Core 2, 0.0–0.1 m: Core taken to confirm sea floor depth. <0.1 m of SILICEOUS CARBONATE OOZE recovered.

SITE 501 HOLE CORE 3 CORED INTERVAL 55.1–64.6 m



LITHOLOGIC DESCRIPTION

5GY 5/1
with
5Y 4/1

5GY 4/1
with
5Y 4/1,
5Y 5/1

5Y 4/3
with
5Y 4/4

SILICEOUS–CARBONATE (WITH VARIATIONS) TO CARBONATE–SILICEOUS OOZES

- Intense to moderate deformation with stiffer lithology at Section 6, 120 cm.
- Basic color is 5GY 5/1 (clay) with dark 5Y 4/1, 5Y 5/1, and olive (5Y 4/3, 5Y 4/4) starting in Section 6. Black mottling, specking, and streaking.
- Evidence of relict bedding, bioturbation (including pyritized worm burrows, gastropod and bivalve fragments, variable percent of volcanic glass.
- Generally diatoms > sponge spicules = radiolarians > silicoflagellates; nannofossils > foraminifer > unspecified carbonate. Siliceous 30–55% and carbonate 40–50%.

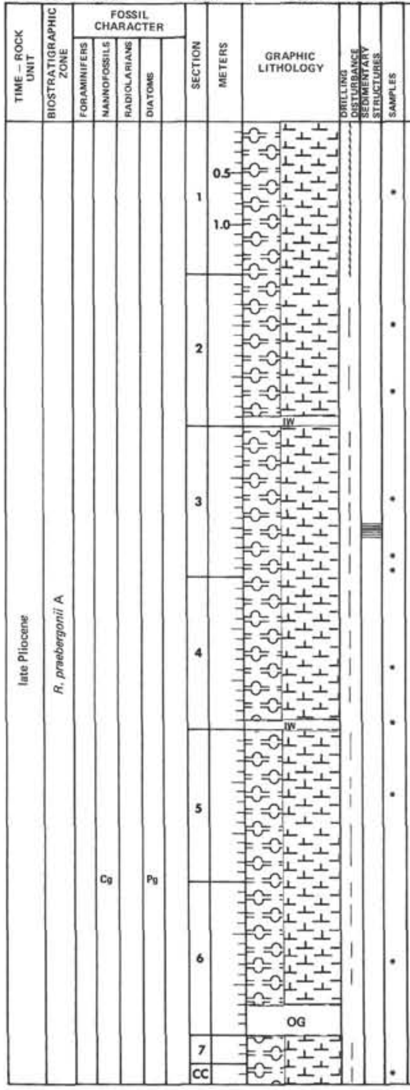
SMEAR SLIDE SUMMARY

	1-83 M	1-90	1-105 M	1-145	2-75	3-100
Detritals	–	TR	5	TR	–	–
Clay	5	5	–	–	7	5
Volcanic gl···	3	5	–	4	8	–
Pyrite	7	–	70	1	TR	–
Opaques	–	–	–	–	–	1
Carbonate unspec.	10	10	15	15	5	5
Foraminifers	5	10	10	5	10	5
Nannofossils	20	35	–	15	25	25
Diatoms	30	21	–	40	35	30
Radiolarians	10	5	–	10	10	10
Sponge spicules	5	5	–	5	5	15
Silicoflagellates	5	4	–	5	5	4

	4-75	5-65	6-145	7-10	CC	CC
Detritals	–	–	–	TR	–	<1
Clay	5	30	30	23	20	10
Volcanic glass	–	<1	3	<1	3	3
Glauconite	–	–	–	–	–	TR
Pyrite	–	<1	3	1	1	–
Opaques	–	–	–	–	–	2
Carbonate unspec.	5	15	–	15	10	15
Foraminifers	5	–	10	10	20	20
Nannofossils	50	30	28	30	25	30
Diatoms	20	2	10	10	13	5
Radiolarians	5	15	10	10	5	5
Sponge spicules	10	–	3	–	–	10
Silicoflagellates	–	5	3	–	3	–

Information on core description sheets, for ALL sites, represents field notes taken aboard ship under time pressure. Some of this information has been refined in accord with post-cruise findings, but production schedules prohibit definitive correlation of these sheets with subsequent findings. Thus the reader should be alerted to the occasional ambiguity or discrepancy.

SITE 501 HOLE CORE 4 CORED INTERVAL 112.1–121.6 m



LITHOLOGIC DESCRIPTION

5GY 7/1
with
5Y 7/1

5GY 6/4
with
5GY 7/1,
5GY 6/1

5Y 5/2
5GY 6/1

SILICEOUS NANNOFOSSIL OOZE WITH
CLAYEY SILICEOUS NANNOFOSSIL OOZE

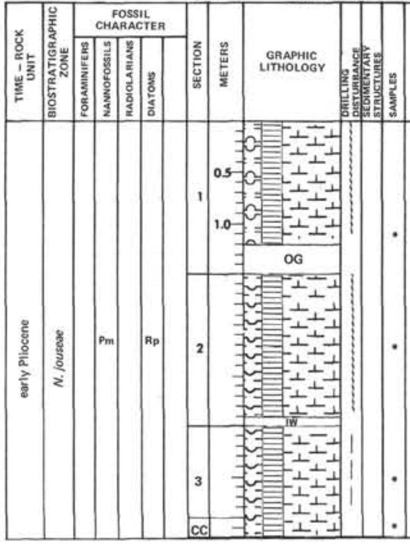
- Intense, moderate to slight deformation in downcore direction.
- Dominant color 5GY 7/1 (clay) with 5Y 7/1, 5YG 7/1, and 5Y 5/2 with black streaks and spotting throughout, representing pyrite.
- Relict bedding(?), bioturbation (rind burrows, chondrites), black ash beds.
- Siliceous ≅ 30%, carbonate ≅ 50–60%. Sponge spicules > diatoms > radiolarians > silicoflagellates.

SMEAR SLIDE SUMMARY

	1-75	2-50	2-120	3-75	3-130 M	3-149
Detritals	–	–	–	TR	8	–
Clay	15	20	10	15	–	30
Volcanic glass	2	2	2	–	90	–
Pyrite	–	–	TR	–	2	–
Opaques	TR	3	TR	2	–	–
Carbonate unspec.	3	5	10	5	–	42
Foraminifers	5	7	3	3	–	5
Nannofossils	51	43	52	54	–	–
Diatoms	5	10	15	3	–	10
Radiolarians	3	5	3	3	–	10
Sponge spicules	15	15	5	15	–	–
Silicoflagellates	1	–	–	–	–	3

	4-90	4-145	5-65	6-80	CC
Detritals	–	< 1	–	–	–
Clay	10	10	20	10	5
Volcanic glass	TR	1	5	–	1
Opaques	1	–	–	2	–
Carbonate unspec.	2	18	15	10	5
Foraminifers	5	5	–	7	2
Nannofossils	70	30	25	41	65
Diatoms	3	20	15	7	15
Radiolarians	2	10	5	3	2
Sponge spicules	7	–	10	20	5
Silicoflagellates	–	5	5	–	–

SITE 501 HOLE CORE 5 CORED INTERVAL 169.1–178.6 m



LITHOLOGIC DESCRIPTION

5Y 7/1
to
5GY 7/1

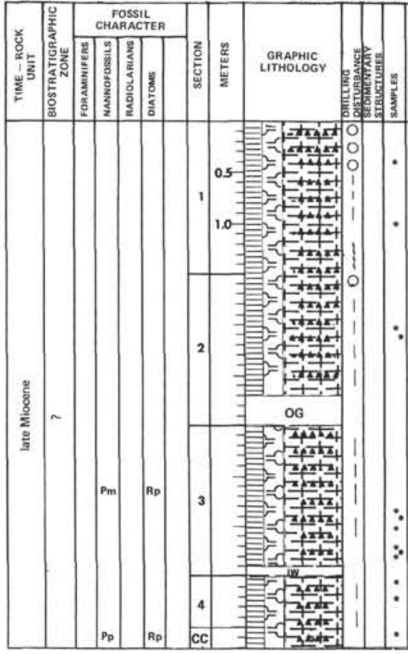
SILICEOUS CLAYEY NANNOFOSSIL OOZE

- Intense deformation but stiff to moderate with chalky zones.
- Dominate colors 5Y 7/1 to 5GY 7/1 with black streaking/spotting.
- Burrow mottling (bioturbation) obvious.

SMEAR SLIDE SUMMARY

	1-105	2-75	3-50	CC
Clay	15	25	20	20
Volcanic glass	–	–	TR	–
Glauconite	1	–	–	–
Opaques	1	1	2	TR
Carbonate unspec.	–	3	3	5
Foraminifers	5	3	3	3
Nannofossils	68	60	52	61
Diatoms	2	2	5	3
Radiolarians	3	1	5	3
Sponge spicules	5	5	10	5

SITE 501 HOLE CORE 6 CORED INTERVAL 226.1–235.6 m



LITHOLOGIC DESCRIPTION

5GY 7/1
with
5Y 4/1

CLAYEY SILICEOUS NANNOFOSSIL CHALK
(CLAYEY DIATOMACEOUS NANNOFOSSIL CHALK)

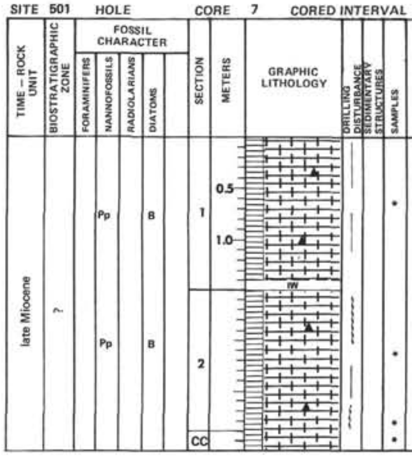
- Generally moderate–slight deformation with soupy zones in Section 1. Chalk is zoned.
- Basic color 5GY 7/1, 5Y 4/1 with black streaks.
- Intense recognizable bioturbation (zoophycus, chondrites, rind burrows).

SMEAR SLIDE SUMMARY

	1-42 M	1-100	2-61	2-63	3-88	3-99	3-104
Detritals	2	–	1	–	–	–	–
Clay	30	20	25	25	20	20	20
Pyrite	1	–	–	–	1	–	1
Carbonate unspec.	7	10	10	5	20	10	10
Foraminifers	3	3	5	5	–	–	1
Nannofossils	37	42	45	47	47	45	50
Diatoms	10	10	5	8	10	10	10
Radiolarians	5	10	5	7	10	15	5
Sponge spicules	3	3	2	1	TR	1	3
Silicoflagellates	2	2	2	2	2	–	1

	3-129	3-130	3-131	4-9	4-24	CC
Detritals	TR	–	–	TR	TR	–
Clay	25	25	30	15	20	17
Volcanic glass	–	–	–	TR	–	3
Glauconite	–	–	–	–	–	TR
Pyrite	1	–	–	1	–	–
Carbonate unspec.	10	10	10	8	10	3
Nannofossils	32	45	40	40	37	52
Diatoms	25	20	10	25	20	15
Radiolarians	3	5	10	5	5	5
Sponge spicules	5	5	–	5	5	3
Silicoflagellates	TR	TR	–	2	3	2

SITE 501 HOLE CORE 7 CORED INTERVAL 235.6–245.1



LITHOLOGIC DESCRIPTION

5GY 7/1
with
5Y 6/1

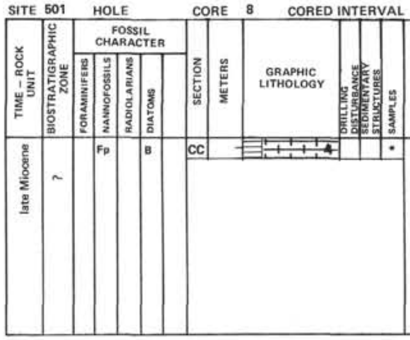
CLAYEY NANNOFOSSIL CHALK WITH CHERT;
CLAYEY NANNOFOSSIL LIMESTONE

- Moderate with some intense deformation–chalk–limestone–chert zones.
- Colors mottled via bioturbation (intense), black streaks throughout.

SMEAR SLIDE SUMMARY

	1-69	2-69	2-138
Clay	15	10	10
Volcanic glass	1	1	–
Pyrite	1	–	–
Zeolites	1	1	1
Carbonate unspec.	3	–	10
Nannofossils	78	83	77
Diatoms	1	3	1
Radiolarians	1	2	1

SITE 501 HOLE CORE 8 CORED INTERVAL 245.1–254.6 m



LITHOLOGIC DESCRIPTION

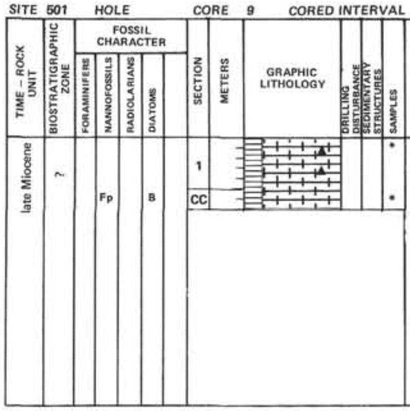
5GY 7/1–5Y 6/1

CLAYEY NANNOFOSSIL LIMESTONE
WITH CHERT (AS STRINGERS)

SMEAR SLIDE SUMMARY

	CC
Clay	10
Carbonate unspec.	8
Foraminifers	4
Nannofossils	78
Diatoms	2
Radiolarians	3

SITE 501 HOLE CORE 9 CORED INTERVAL 254.6–264.1 m



LITHOLOGIC DESCRIPTION

5GY 6/1
5GY 5/1
5GY 7/1

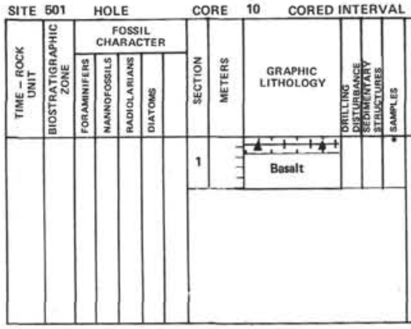
CLAYEY LIMESTONE (CHALK) WITH CHERT

- Faint laminations, stringers, or horizontal mottling via bioturbation. Chert dark (5Y 4/1) with patchy distribution.

SMEAR SLIDE SUMMARY

	1-10	CC
Detritals	90	–
Clay	–	15
Volcanic glass	–	1
Pyrite	1	–
Carbonate unspec.	10	5
Nannofossils	–	76
Diatoms	–	1
Radiolarians	–	1
Silicoflagellates	–	1

SITE 501 HOLE CORE 10 CORED INTERVAL 264.1–267.1 m



LITHOLOGIC DESCRIPTION

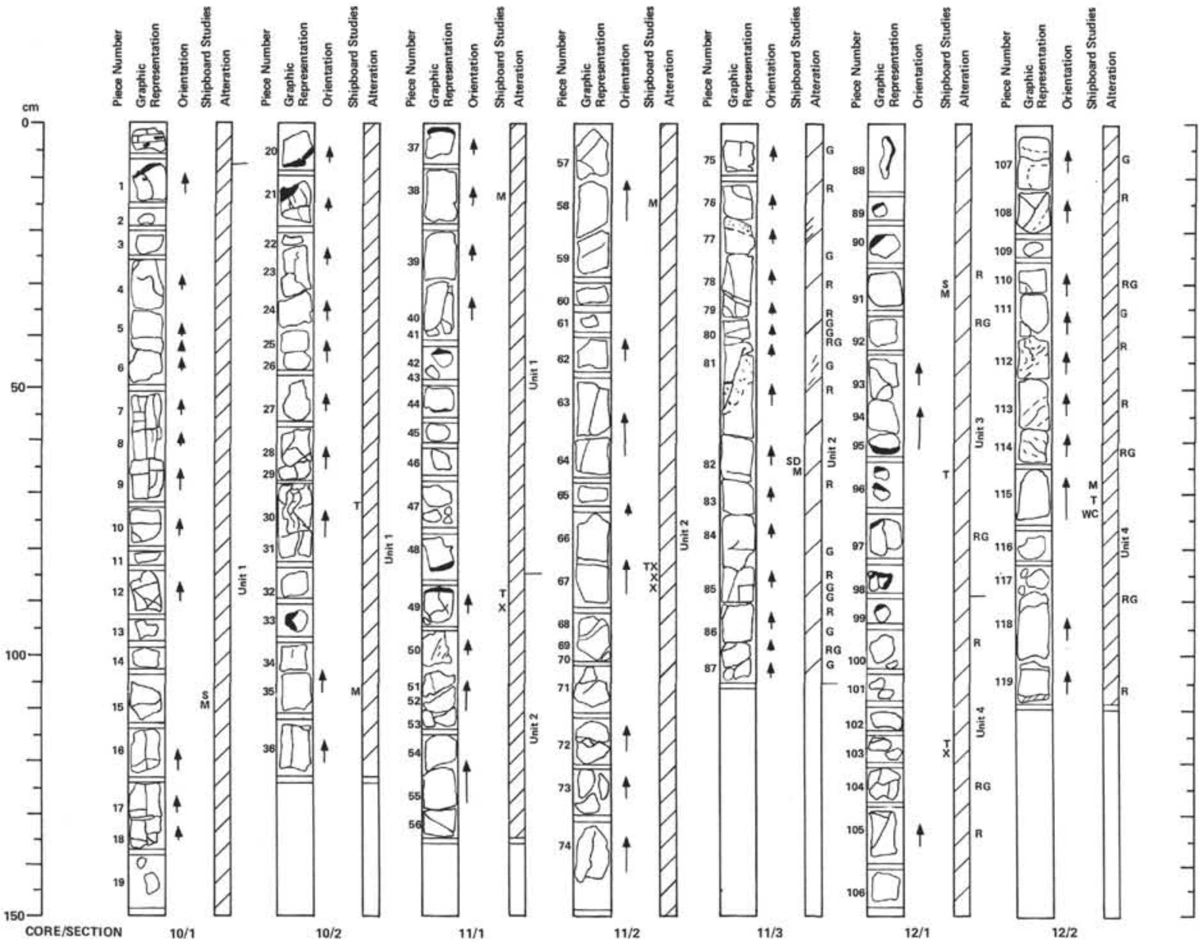
5Y 7/1–5G 6/1

NANNOFOSSIL LIMESTONE
WITH CHERT (OVER BASALT)

- Bioturbated, chert as stringers.

SMEAR SLIDE SUMMARY

	1-3
Opaques	1
Carbonate unspec.	30
Nannofossils	70



SITE 501, CORE 10 3731–3734 m (264.1–267.1 mbsf)

Topmost piece, Section 1, is bioturbated burrowed limestone with small (< 1 cm) chert nodules, the lowest sedimentary rock recovered above basalts.

MODERATELY ALTERED APHYRIC BASALT

The core consists of basalt which is aphyric except for small plagioclase microphenocrysts in the finest grained (near-glassy) pieces. The rock has abundant fractures, mostly vertical and horizontal, filled with both red and green clay minerals. Glass occurs on the tops of pieces 1, 7, and 21, on the bottom of piece 20, and also on piece 33 (unoriented). Olivine, once present, is now replaced by clays. Alteration zones are adjacent to cracks in piece 30, yellowish gray nearest the *cracks, gray further into the rock.*

Thin Section Descriptions

Sample 10-1, 9–10 cm, Piece 1: Section through glassy pillow margin into interior, with euhedral olivine microphenocrysts and plagioclase spherulites. Smectites and pyrite replace olivine and fill vesicles. Small glomerocrysts of euhedral plagioclase and anhedral clinopyroxene are scattered about.

Sample 10-1, 120 cm, Piece 16: Pillow interior. The section has less than 5% euhedral olivine microphenocrysts (0.03–0.3 mm), and 20–40% euhedral to acicular plagioclase crystals arrayed in radial sworls. Clinopyroxene and titanomagnetite are between the plagioclase crystallites; the latter has skeletal morphology. Oxidation is along cracks, with Fe-hydroxides and clay minerals in cores of vesicles, veins, and replacing olivine. Green clays also occur in vesicles or their outer rims.

Sample 10-2, 74 cm, Piece 30: Pillow interior. The section is very similar to 10-1, 120 cm, but with slightly more spherulitic mesostasis. Oxidation is developed in narrow zones, with bright brown clays in cores of vesicles and the interior parts of olivine pseudomorphs.

SITE 501, CORE 11 3734–3740 m (267.1–273.1 mbsf)

MODERATELY ALTERED APHYRIC BASALT

The basalt is aphyric (microphyric), with glass on several pieces up to 49. Below that, the rest of the core is one massive cooling unit. The massive material was recovered in oriented sections; one especially long one is in Section 2. Alteration is concentrated in zones adjacent *to cracks, where olivine microphenocryst pseudomorphs replaced by* reddish clays can easily be seen. There is no piece 59, inadvertently skipped during labelling.

Thin Section Descriptions

Sample 11-1, 85 cm, Piece 49: Pillow rim. The section crosses three zones: 1) glass, partly palagonitized, palagonite largely smectites; 2) a zone with abundant dark brown spherulites cored with plagioclase crystals, and associated minor (1–5%) euhedral olivines; 3) a zone of coalesced spherulites with prominent sworls of acicular plagioclase.

Sample 11-2, 87 cm, Piece 67: Flow interior. The rock is holocrystalline, with less than 1% olivine microphenocrystt up to 1 mm in diameter, about 50% plagioclase crystals (0.03–3 mm), 20–40% clinopyroxene (0.03–1 mm), and 5–10% titanomagnetite. Clay minerals replace olivine and fill vesicles and cracks. Fe-oxyhydroxides are associated with clays near cracks. Vesicles have concentrically zoned clay fillings.

SITE 501, CORE 12 3740–3747 m (273.1–280.1 mbsf)

MODERATELY ALTERED APHYRIC BASALT

The basalt is aphyric (microphyric), with glass on several pieces up to 99. Below that, the rest of the core is part of one single cooling unit which extends into Core 14. Olivine crystals are replaced by smectites. Glass and microphyric zones are also altered. There are marked alteration zones around most cracks which are filled with various (R, G, C) secondary minerals. These consist of a yellow zone next to the cracks around 5 mm thick, a red zone about 4 mm thick, and unaltered basalt.

Thin Section Descriptions

Sample 12-1, 74 cm, Piece 96: Pillow rim. The section is cut through the margin of a pillow, and extends from the spherulitic zone next to glass to the zone of radiating acicular plagioclase crystals. Most of the rock (70%) is dark spherulitic mesostasis. Plagioclase (5–50%), clinopyroxene (1–5%), titanomagnetite (1–5%), and olivine (0.5–1%) are present as tiny crystals (0.3–3 mm). Clay minerals replace olivine, fill vesicles, and line cracks in the glassiest parts of the rock.

Sample 12-1, 129 cm, Piece 103: Flow interior, near upper edge. The section is very similar to that previously described, except plagioclase is more abundant (10–20%), and has a more uniform spherulitic texture. Clay minerals replace olivine and fill vesicles. They are bright brown in color rather than green.

Sample 12-2, 76 cm, Piece 115: Flow interior. The rock is holocrystalline, with ophitic texture. Plagioclase (50%) is the most abundant mineral, and includes rare megacrysts (glomerocrysts) filled with glass inclusions. These can be 3–10 mm across. Clinopyroxene (40%), and titanomagnetite (5–10%) are smaller. Rare vesicles are round and filled with aragonite(?). Secondary minerals include green clays locally oxidized to bright brown colors.

BULK ANALYSIS:

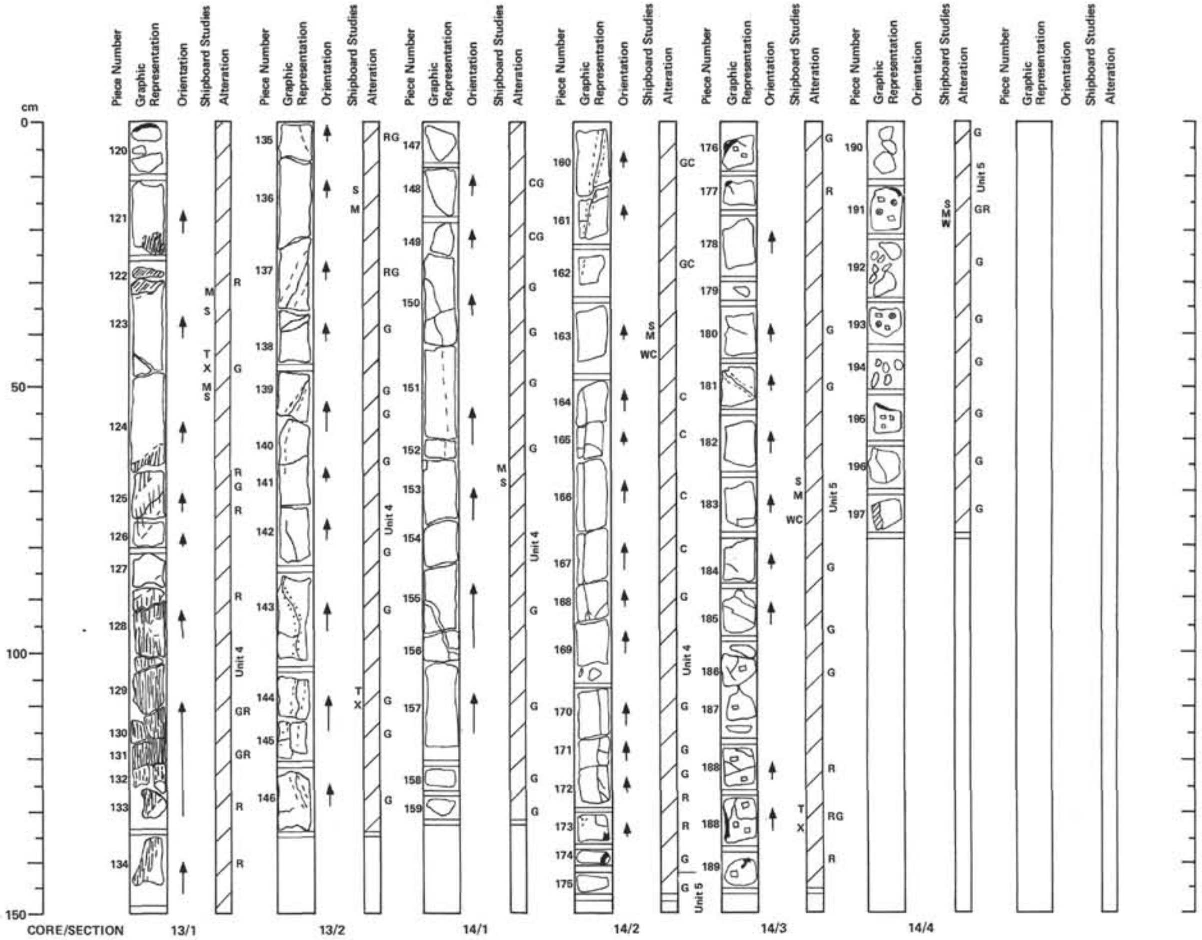
Core-Section	10-1	10-1	11-1	11-2	12-1	12-1
Interval (cm)	12–16	120–124	85–88	87–89	12–9	59–62
SiO_2	49.64	49.45	49.88	49.65	49.23	50.27
TiO_2	1.03	1.07	1.04	1.07	1.11	1.14
Al_2O_3	14.95	15.23	14.73	14.61	15.40	15.85
Fe_2O_3	11.26	10.60	11.91	11.89	11.42	10.44
MnO	0.19	0.18	0.19	0.18	0.18	0.15
MgO	7.88	7.76	7.89	7.69	7.47	7.83
CaO	12.31	12.29	12.24	12.10	11.90	11.69
Na_2O	2.18	2.15	2.36	1.95	2.27	2.49
K_2O	0.10	0.15	0.35	0.42	0.35	0.23
P_2O_5	0.09	0.09	0.10	0.13	0.12	0.09
Total	99.63	98.97	100.49	99.69	99.45	100.18
LOI	0.97	2.34	1.57	2.25	2.54	3.15

MAGNETIC DATA:

Core-Section, Interval (cm)	NRM	INCL.	Susceptibility
10-1, 75–77	13.970	– 3.5	1472
10-1, 108–110	3.441	– 5.3	1464
10-2, 16–18	3.262	+ 0.4	1568
11-1, 14–16	2.748	+ 1.3	1456
11-2, 16–18	1.927	+ 2.2	1560
11-3, 63–65	3.280	+10.5	1536
12-1, 30–32	1.310	– 2.5	1904
12-2, 70–72	1.796	+ 9.1	1712

PHYSICAL PROPERTIES:

Core-Section, Interval (cm)	V (∥)	V (⊥)	GRAPE	Wet-Bulk	Porosity
10-1, 108	5.42?	5.19?	2.88	—	—
10-1, 108	5.31	—	—	—	—
10-2, 116	5.56	—	3.03	2.91	3.42
11-1, 14	6.5?	—	2.92	—	—
11-3, 63	5.81	5.90	4.09?	—	—
11-3, 63	5.69	—	—	—	—
12-1, 30	5.61	5.51	2.83	2.84	7.04
12-2, 70	4.96	4.90	2.92	2.79	8.33



BULK ANALYSIS:

Core-Section	13-1	13-2	14-1	14-1	14-2	14-3
Interval (cm)	47–49	112–114	10–25	59–62	121–126	135–138
SiO_2	49.72	49.81	50.05	50.62	50.47	50.00
TiO_2	1.05	1.06	1.04	1.03	1.06	0.87
Al_2O_3	15.01	14.84	14.62	14.72	14.77	16.07
Fe_2O_3	10.51	10.74	11.28	11.28	11.06	9.67
MnO	0.15	0.16	0.17	0.17	0.17	0.19
MgO	8.23	8.55	8.49	8.57	7.76	8.34
CaO	12.10	12.19	12.27	12.27	12.08	12.78
Na_2O	2.13	1.88	2.09	2.03	2.30	1.96
K_2O	0.02	0.03	0.03	0.02	0.02	0.05
P_2O_5	0.07	0.07	0.07	0.08	0.09	0.06
Total	98.99	99.33	100.11	100.79	99.78	99.99
LOI	1.61	1.96	1.13	1.147	1.27	0.81

MAGNETIC DATA:

Core-Section, Interval (cm)	NRM	INCL.	Susceptibility
13-1, 52–54	2.869	+ 9.0	1760
13-2, 16–18	0.572	+10.6	1888
14-1, 68–70	0.938	+11.6	1744
14-2, 44–46	1.199	+13.7	1936
14-3, 72–74	3.148	+11.6	1488
14-4, 20–22	0.386	–12.7	832

PHYSICAL PROPERTIES:

Core-Section, Interval (cm)	V (∥)	V (⊥)	GRAPE	Wet-Bulk	Porosity
13-1, 52	5.52	5.43	2.98	—	—
13-2, 16	5.63	5.59	3.02	—	—
14-1, 68	6.187	5.947	2.91	2.93	3.68
14-2, 44	5.99	5.98	3.07	2.92	2.78
14-3, 72	5.67	5.51	2.91	2.82	6.41
14-4, 20	5.80	5.76	2.84	2.91	1.72

SITE 501, CORE 13 3747–3750 m (280.1–283.1 mbsf)

MASSIVE MODERATELY ALTERED APHYRIC BASALT

A continuation of the massive flow whose top is in Core 12. The basalt is uniform, fine- to medium-grained, and moderately altered. Olivine pseudomorphs (smectite) are rare (1%). Vesicles are absent. Yellow and orange oxidized zones adjacent to cracks at the top of the core gradually narrow and darken downward, where they are filled mainly with green clays. Fractures, spaced every 5–15 cm along the core, are predominantly inclined. The topmost piece in the core (120) has glass and apparently fell down the hole.

Thin Section Descriptions

Sample 13-1, 47 cm, Piece 122: Interior of massive flow. The section is holocrystalline, with about 50% plagioclase (0.3–3 mm), 20–40% clinopyroxene (0.3–1 mm), 5–10% titanomagnetite (0.03–0.1 mm), and 10–20% mesostasis. Titanomagnetite is optically homogeneous and isotropic. Smectites partially replace the mesostasis and olivine. Vesicles (0.5–1%) are lined with smectite. Late-magmatic pyrite grains occur in the mesostasis.

Sample 13-1, 147 cm, Piece 134: Interior of massive flow. The rock is nearly holocrystalline, with ophitic texture. Its mode is similar to the sample previously described. The rock appears more altered, however, with no fresh olivine, and the central parts of vesicles and olivine pseudomorphs filled with light brown smectite and or iron oxyhydroxides.

Sample 13-3, 112 cm, Piece 144: Interior of massive flow. Similar to 13-1, 147 cm piece 134. The rock is ophitic. Olivine is completely converted into clays. Smectites occur mainly in the centers of vesicles or olivine pseudomorphs.

SITE 501, CORE 14 3750–3759 m (283.1–292.1 mbsf)

MASSIVE BASALT ABOVE AT LEAST TWO MODERATELY PLAGIOCLASE-PHYRIC PILLOWS

Sections 1 and 2 are the bottom of the massive flow described in Cores 12 and 13. The rock is very massive and medium-grained. Piece 147, however, appears to have fallen from the pillow units above the massive flow. Alteration in the massive flow is less than in Cores 12 and 13, and dominated by green smectites filling cracks, associated with minor calcite. At the bottom of the flow, reddish clays and/or iron oxyhydroxides again occur.

The pillowed basalts (Sections 3 and 4) are moderately altered, with green smectites, red smectites and/or iron oxyhydroxides, and no calcite. Plagioclase phenocrysts 2–3 mm across occur throughout, but are best seen on finer-grained rocks. Several pieces have glass on the tops or sides. Piece 181 has an alteration rind.

Thin Section Descriptions

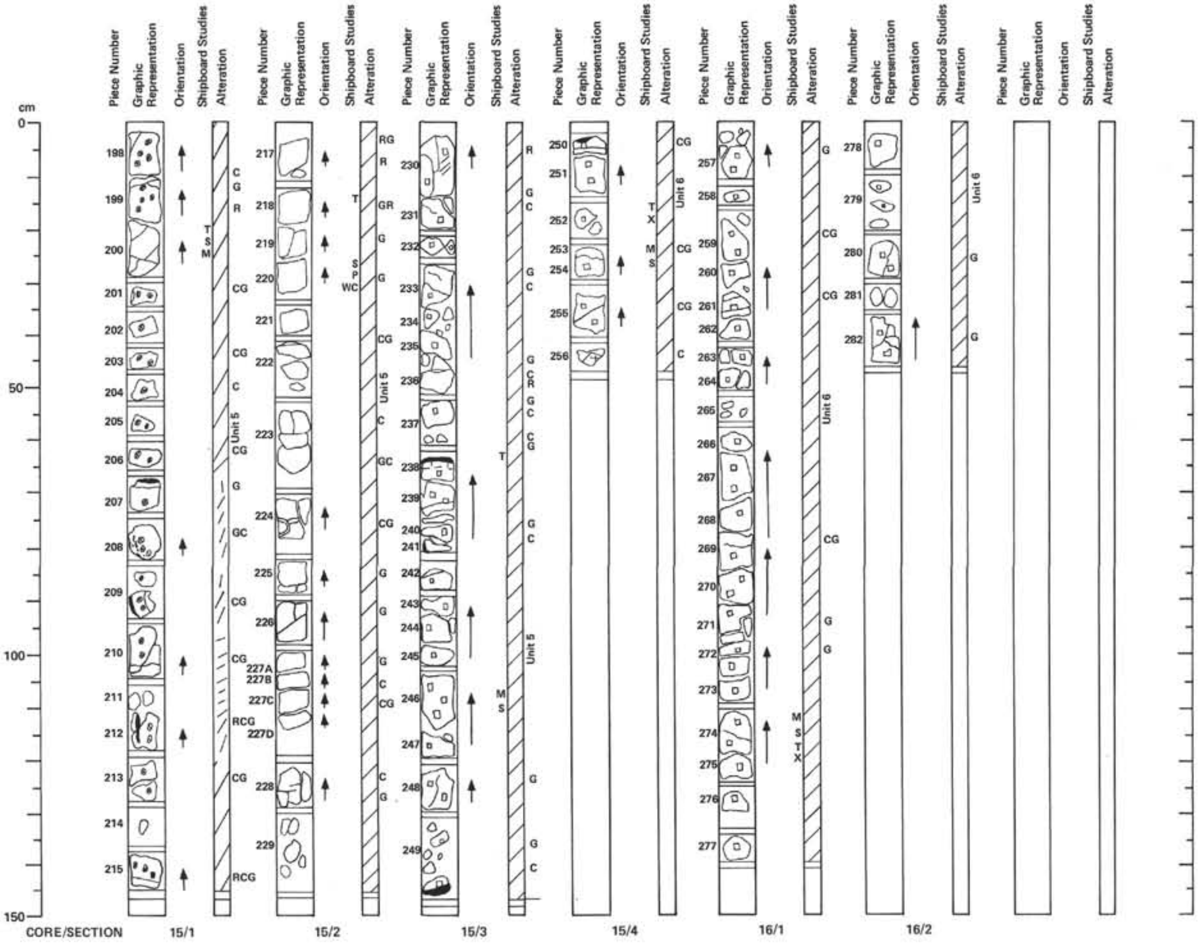
Sample 14-1, 61 cm, Piece 152: Flow interior. The rock is holocrystalline, with doleritic texture. It has a mode similar to holocrystalline rocks in Core 13. Olive green smectite replaces olivine and fills vesicles.

Sample 14-2, 118 cm, Piece 170: Flow interior. The rock is holocrystalline, with doleritic texture. It's mode is similar to sample described in Core 13. Olive green smectite replaces olivine and fills vesicles.

Sample 14-2, 146 cm, Piece 175: Base of massive flow. The rock has intersertal texture, with 10–20% euhedral to skeletal plagioclase crystals (0.03–3 mm), and minor amounts of olivine and clinopyroxene in a spherulitic mesostasis. Green clays, pyrite, and Fe-oxides replace olivine and fill vesicles. Clinopyroxene and plagioclase are locally clumped in scattered micro-glomerocrysts.

Sample 14-3, 135 cm, Piece 188: Pillow margin. The section is predominantly glassy-spherulitic, with 1–5% olivine microphenocrysts, 10–20% euhedral, skeletal, and spherulitic plagioclase crystals (0.3–3 mm) and traces of titanomagnetite and Cr-spinel. Colorless smectite and red Fe-oxyhydroxides replace olivine.

Sample 14-4, 21 cm, Piece 191: Pillow margin. The section is predominantly glassy-spherulitic, with 0.5–1% olivine crystals (0.3–1 mm), 10–20% euhedral, skeletal, and spherulitic plagioclase crystals (0.3–3 mm) and no resolvable clinopyroxene. Titanomagnetite and Cr-spinel are present in traces. Colorless smectite replaces olivine. Vesicles are absent.



SITE 501, CORE 15 — 3759–3768 m (292.1–301.1 mbsf)

SPARSELY-MODERATELY PLAGIOCLASE PHYRIC PILLOW BASALTS

The rocks are very fine-grained to glassy with spherulites (variolites) visible on many pieces. Plagioclase phenocrysts are 1–3 mm, skeletal to euhedral, some in clumps, and form 5–10% of the rock. The rocks are moderately to intensely altered, with green clays, calcite, and red clays and/or iron oxyhydroxides filling cracks, filling vesicles, and permeating the groundmass. Glass margins occur on the tops, bottoms, and sides of many pieces. There is no predominant fracture orientation. Former plagioclase microphenocrysts are now replaced by clays.

Thin Section Descriptions

Sample 15-4, 18 cm, Piece 252: Pillow interior. The rock is intersertal, with about 20–40% spherulitic mesostasis, 20–40% plagioclase (0.3–3 mm), 5–10% olivine replaced by smectite (0.3–1 cm), 1–5% titanomagnetite, and 0.5–1% clinopyroxene. There are traces of Cr-spinel.

SITE 501, CORE 16 — 3768–3772 m (301.1–305.1 mbsf)

SPARSELY PLAGIOCLASE-OLIVINE PHYRIC BASALTS

No glass margins were recovered except at the very top of Section 1. The sequence thus may be a flow or large pillow. The basalt is sparsely phyric, with about 5% plagioclase phenocrysts, including some clumps, and 1–2% olivine phenocrysts now replaced largely by green clays. Along cracks there are oxidation zones consisting of yellow, brown, or red material, up to 2–3 cm wide. Cracks are filled with green clays or calcite. Pieces in Section 2 have spherulitic surface textures, and probably were near glass margins.

Thin Section Description

Sample 16-1, 118 cm, Piece 274: Pillow interior. The sample is holocrystalline, with about 50% plagioclase, 20–40% clinopyroxene, 1–5% olivine, 1–5% titanomagnetite, and traces of Cr-spinel. Crystals are euhedral or subhedral, except for clinopyroxene, which is fan-spherulitic in part. Ti-magnetite is skeletal. Smectites, clays, and Fe-oxyhydroxides replace olivine. The section crosses an oxidation boundary in which bright yellow or brown, rather than colorless, smectite predominates.

BULK ANALYSIS:

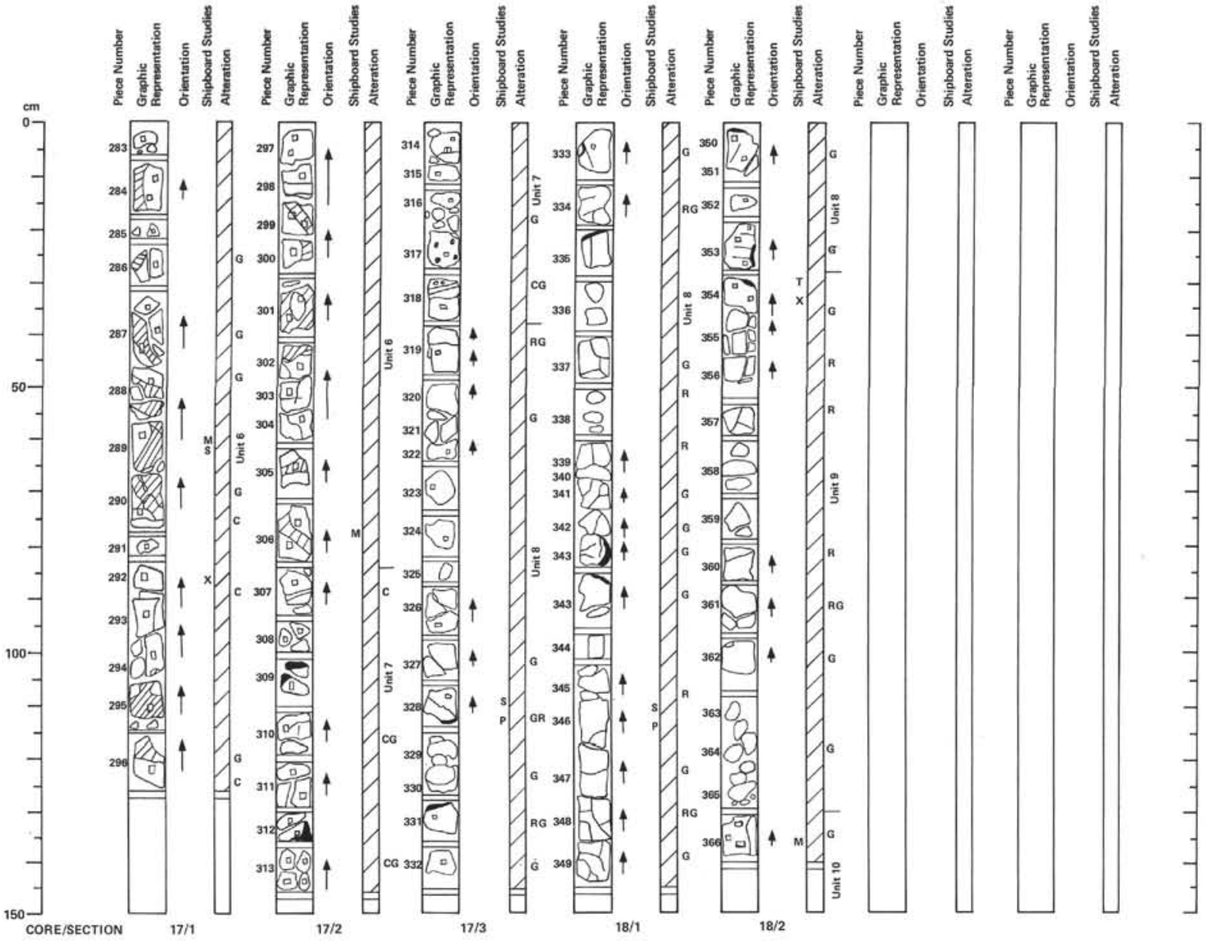
Core-Section	15-1	15-4	16-1	16-1
Interval (cm)	135–138	18–19	118–120	118–120
SiO_2	49.68	49.58	49.05	49.37
TiO_2	0.87	0.87	0.85	0.86
Al_2O_3	16.08	15.92	16.30	16.29
Fe_2O_3	10.10	9.63	9.80	9.64
MnO	0.18	0.17	0.17	0.16
MgO	7.59	7.93	8.75	8.62
CaO	12.97	13.01	12.66	12.69
Na_2O	1.86	2.16	2.04	1.82
K_2O	0.15	0.06	0.08	0.04
P_2O_5	0.07	0.08	0.08	0.06
Total	99.55	99.41	99.78	99.55
LOI	2.39	1.80	2.40	2.13

MAGNETIC DATA:

Core-Section, Interval (cm)	NRM	INCL.	Susceptibility
15-1, 22–24	11.596	–16.2	666
15-2, 28–30	11.318	–18.8	464
15-3, 106–108	21.148	–10.6	573
15-4, 28–30	14.288	+12.6	680
16-1, 116–118	14.357	–14.4	712

PHYSICAL PROPERTIES:

Core-Section, Interval (cm)	V (∥)	V (⊥)	GRAPE	Wet-Bulk	Porosity
15-1, 22	5.31?	5.63?	2.63	2.84	4.72
15-2, 28	6.10?	6.65?	2.92	2.87	2.56
15-3, 106	6.09?	6.33?	3.02	2.84	0.00
15-4, 28	5.98?	6.32?	2.79	2.75	5.26
16-1, 116	5.56?	5.99?	3.04	2.91	0.35



BULK ANALYSIS:

Core-Section	17-1	18-1	18-2	18-2	18-3
Interval (cm)	86–89	119–124	34–37	89–93	100–103
SiO_2	50.01	49.15	49.47	50.63	49.97
TiO_2	0.89	0.89	0.93	1.02	0.91
Al_2O_3	15.83	15.81	15.23	14.80	16.04
Fe_2O_3	9.92	10.27	10.81	11.02	10.11
MnO	0.16	0.18	0.18	0.19	0.18
MgO	8.05	7.90	7.63	7.75	8.15
CaO	12.83	12.73	12.54	12.22	12.78
Na_2O	2.03	2.06	1.99	2.05	2.01
K_2O	0.03	0.12	0.25	0.35	0.11
P_2O_5	0.07	0.07	0.08	0.08	0.07
Total	99.82	99.18	99.11	100.11	100.33
LOI	2.50	1.78	–	1.20	2.11

MAGNETIC DATA:

Core-Section, Interval (cm)	NRM	INCL.	Susceptibility
17-1, 56–58	3.007	–14.0	1104
17-2, 80–82	19.547	–17.2	608
17-3, 116–118	9.589	–13.6	1312
18-1, 116–118	8.048	+ 2.2	1104
18-2, 136–138	3.680	– 9.0	1280

PHYSICAL PROPERTIES:

Core-Section, Interval (cm)	V (∥)	V (⊥)	GRAPE	Wet-Bulk	Porosity
17-1, 56	5.65	5.60	2.93	2.86	2.43
17-2, 80	5.85	5.82	3.01	2.87	0.77
17-3, 116	5.92?	5.88?	2.94	2.81	6.59
18-1, 116	5.71	5.65	2.88	2.83	3.31
18-2, 136	5.55	5.56	2.99	2.87	3.94
19-2, 90	5.51?	5.30?	2.96	2.83	5.42

SITE 501, CORE 17 3772–3777 m (305.1–310.1 mbsf)

SPARSELY PLAGIOCLASE-OLIVINE PHYRIC BASALT ABOVE SPARSELY PLAGIOCLASE-CLINOPYROXENE-OLIVINE PHYRIC PILLOW BASALTS

Plagioclase-olivine phyric basalt extends through Section 1 through piece 306 of Section 2. It appears to be part of a single flow, and is moderately to intensely altered. Wide alteration zones (up to 3 cm) are developed next to cracks and fractures, which are filled with green clays and calcite. Olivine crystals are replaced by green smectite, red in the oxidized zones.

The pillow basalts have predominant plagioclase phenocrysts (5–10%), lesser olivine (1%) and scattered emerald green clinopyroxene phenocrysts. Olivine is fresh in several pieces. Glass rinds occur on several pieces. Alteration is less extensive than in previous cores. No alteration zones are next to cracks.

Thin Section Descriptions

Sample 17-1, 48 cm, Piece 288: Doleritic flow interior. The sample has about 50% plagioclase, 20–40% clinopyroxene, 1–5% olivine, 1–5% titanomagnetite, and traces of Cr-spinel. Smectites and pyrite replace olivine and fill vesicles. Smectite is colorless except in an oxidized zone where it is red.

Sample 17-1, 86 cm, Piece 292: The section is essentially identical to sample 17-1, 48 cm, piece 288.

Sample 17-2, 105 cm, Piece 309: Pillow margin. The sample is predominantly glassy-spherulitic, with about 10–20% euehdral to skeletal plagioclase crystallites *0.03–3* mm long, 1–5% olivine 0.3–1 mm across, and traces of Cr-spinel. Very pale smectites replace olivine.

Sample 17-3, 10 cm, Piece 315: A somewhat coarser-grained pillow interior. Texture is intersertal-spherulitic with 10–20% plagioclase, 1–5% olivine, 1–5% clinopyroxene, 1–5% titanomagnetite, and traces of Cr-spinel. Colorless smectites replace olivine and fill vesicles in part of the seciton.

SITE 501, CORE 18 3777–3786 m (310.1–319.1 mbsf)

MODERATELY PLAGIOCLASE-CLINOPYROXENE-OLIVINE PHYRIC AND APHYRIC PILLOW BASALTS

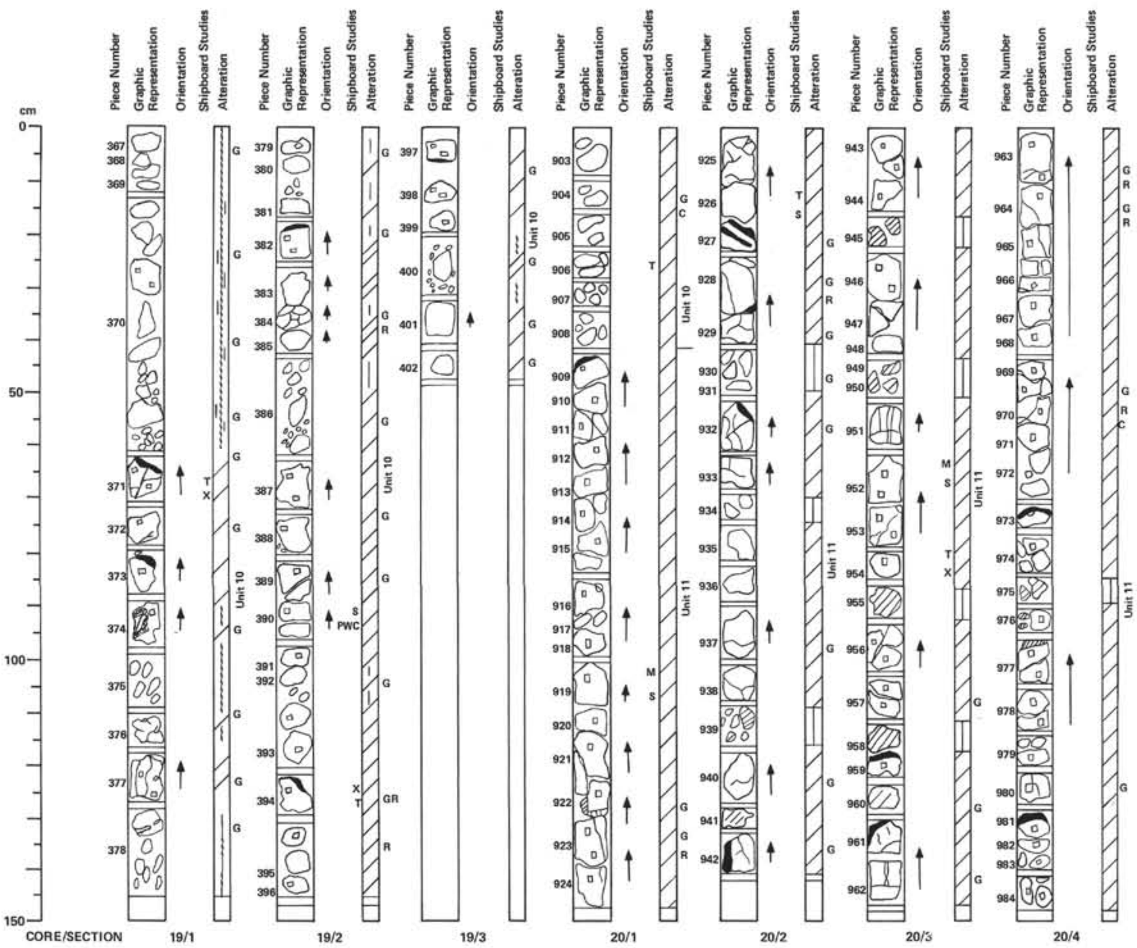
Portions of several cooling units with glassy margins were recovered in this core. Plagioclase (1–5%), olivine (1%) and clinopyroxene (1%) phenocrysts occur in most pieces except 355–365 in Section 2, which are aphyric. However, the upper piece of the "aphyric" cooling unit has some phenocrysts, hence the aphyric pieces may be equivalent to the phyric basalts, except for phenocrysts. The pieces are fairly highly fractured. All are pervasively, moderately altered with green clays in vesicles and patches, and replacing olivine. There are thick clay zones next to glass on pieces 333 and 343.

Thin Section Descriptions

Sample 18-1, 118 cm, Piece 346: Pillow interior, with intersertal texture. The rock has about 40% spherulitic mesostasis, an equivalent proportion of plagioclase crystals (some phenocrysts, some acicular in the groundmass). Clinopyroxene (1–5%) occurs as isolated phenocrysts, in clumps with plagioclase, and in the groundmass. Titanomagnetite (1–5%), olivine (1–5%), and Cr-spinel (trace amounts) also occur. Smectites (green and bright brown) replace olivine and fill vesicles (also present in trace amounts).

Sample 18-2, 31 cm, Piece 354: Pillow rim. The rock is predominantly glassy-spherulitic with 5–10% plagioclase in acicular sworls, and less than 1% each of euhedral olivine and dendritic clinopyroxene. Smectites replace olivine and glass, and fill small veins. A zeolite(?) occurs in a vein with smectite. It has low birefringence (0.001) and is twinned and sectored.

Sample 18-2, 89 cm, Piece 360: Pillow interior, subophitic texture. The rock has 1–5% euhedral olivine up to 1 mm in size, 20–40% plagioclase up to 3 mm in size (including some phenocrysts), and 10–20% clinopyroxene crystals up to 1 mm. There is 1–5% titanomagnetite. The remainder is spherulitic mesostasis. Green smectite replaces olivine. Veins of iron hydroxides, including hematite(?) crystals lace the section .



SITE 501, CORE 19 **3786–3795 m (319.1–328.1 mbsf)**

MODERATELY TO INTENSELY ALTERED PLAGIOCLASE-OLIVINE-CLINOPYROXENE MODERATELY PHYRIC PILLOW BASALT

The core consists of thin, rubbly pillows, or thin flows, with glass and altered glass on many pieces. Others are very fine-grained. Phenocrysts of plagioclase (1–5%), olivine (1%), and clinopyroxene (trace) occur singly or in clumps. None are larger than about 5 mm. Alteration is most intense in glassy zones which are brecciated and largely converted to green clays. The rocks are highly fractured. There are traces of red clays and/or iron oxyhydroxides in Section 2. Piece 400 consists of several small fragments all in a bag.

Thin Section Descriptions

Sample 19-1, 68 cm, Piece 371: Pillow rim. There are two thin sections of this sample, both consisting of more than 90% altered glass, with 5–10% acicular plagioclase, and less than 1% each of euhedral olivine and subhedral clinopyroxene, the latter typically clumped with plagioclase. Olivine is replaced by olive green smectite, and glass by dark brown smectite.

Sample 19-2, 19 cm, Piece 382: Pillow rim. The sample has about 85% spherulitic mesostasis, dark brown in color, with a strongly altered groundmass (smectites, Fe-oxyhydroxides). There are about 10–20% acicular plagioclase needles up to 1 mm long, and 1–5% each of euhedral olivine, subhedral clinopyroxene, and tiny titanomagnetites. Smectites also replace olivine.

SITE 501, CORE 20 **3785–3794 m (328.1–337.1 mbsf)**

SPARSELY PLAGIOCLASE-OLIVINE-CLINOPYROXENE PHYRIC PILLOW BASALTS

The core consists of several distinct pillow cooling units with upper, lower and inclined glass margins, plus an interpillow breccia (pieces 403–408). There are 1–5% plagioclase phenocrysts, 1% olivine phenocrysts, and scattered emerald green clinopyroxene phenocrysts, none larger than about 5 mm, typically 3 mm, some in clumps. Alteration is moderate to intense, with green clays and calcite scattered down the core, especially near glass margins. Vesicles are rare and filled with dark green clays. Piece 422 has a thick green-smectite crack filling. Other extensively altered glassy-interpillow zones are pieces 430, 431, 433, 439, 445, 450, 455, and 458.

BULK ANALYSIS:

Core-Section	19-1	19-2	20-2	20-3
Interval (cm)	68–71	124–127	137–141	81–84
SiO_2	49.83	49.41	49.89	49.75
TiO_2	1.04	0.96	0.90	0.90
Al_2O_3	17.39	15.47	14.93	15.06
Fe_2O_3	9.24	10.54	10.88	10.96
MnO	0.13	0.17	0.20	0.19
MgO	8.66	8.20	8.15	7.94
CaO	10.60	12.51	12.61	12.65
Na_2O	2.22	2.05	1.94	1.96
K_2O	0.31	0.18	0.12	0.24
P_2O_5	0.09	0.07	0.08	0.07
Total	99.51	99.56	99.70	99.72
LOI	5.57	1.94	1.00	1.36

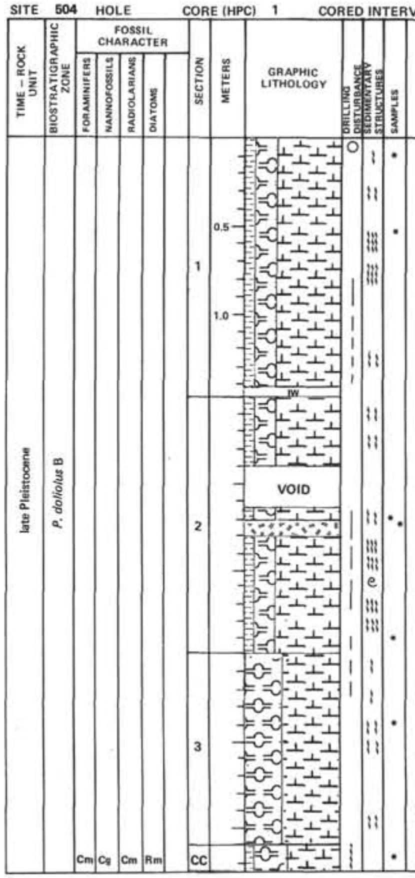
MAGNETIC DATA:

Core-Section, Interval (cm)	NRM	INCL.	Susceptibility
19-2, 90–92	3.534	+ 4.0	1432
20-1, 106–109	2.346	− 6.2	1320
20-2, 11–13	4.888	− 9.3	1424
20-3, 64–66	4.216	+ 7.2	1267

PHYSICAL PROPERTIES:

Core-Section, Interval (cm)	V (∥)	V (⊥)	GRAPE	Wet-Bulk	Porosity
20-1, 106	5.77?	6.08?	3.03	—	—
20-2, 11	4.75?	4.08?	2.98	—	—
20-3, 64	5.68?	6.03?	3.06	2.92	5.33

SITE 504 HOLE CORE (HPC) 1 CORED INTERVAL 10.0–14.4 m



LITHOLOGIC DESCRIPTION

5GY 5/2

5GY 5/2–
5G 4/1

5GY 5/2

5GY 5/2

5GY 5/2–
5G 5/2

5GY 5/2–
10GY 5/2

5GY 5/2

5GY 5/2–
5G 4/1

5GY 5/2–
5GY 3/2

SILICEOUS NANNOFOSSIL OOZE

- Basic color: dusky yellow green (5GY 5/2) with variations to grayish olive green and dark grayish green (5GY 3/2, 10GY 5/2, 5G 4/1, and 5G 5/2).
- Bioturbation moderate to intense.
- Gray (N5) streaks, spots, and shaded areas refer to pyrite around or in burrows.
- Prominent light gray (N6–9) ash layer between 2.23–2.30 m.
- Gastropod or bivalve shells at 2.53 m, included in burrow.
- Generally nannofossils > foraminifers; diatoms = radiolarians > silicoflagellates > sponge spicules.

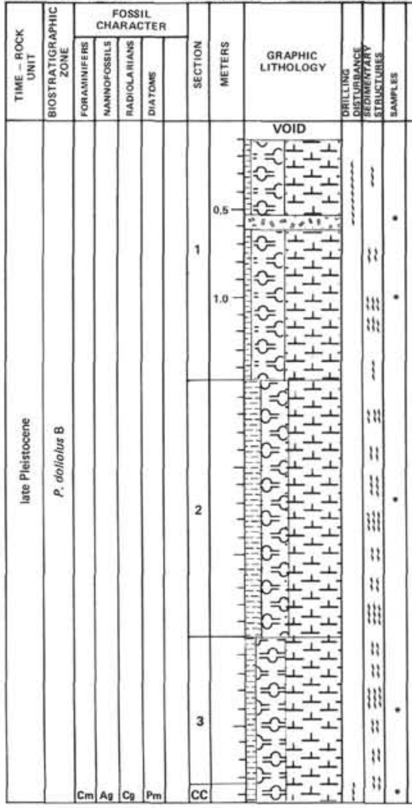
SMEAR SLIDE SUMMARY

	Siliceous nannofossil ooze	Siliceous nannofossil ooze	Ash	Ash	Siliceous nannofossil ooze	Siliceous nannofossil ooze	Siliceous nannofossil ooze
	1-10	1-56	2-73	2-78	2-145	3-40	CC
Feldspar	–	–	10	1	–	–	–
Pyrite	TR	TR	–	–	3	2	2
Other heavy minerals	–	–	10	1	–	–	<1
Clay minerals	12	15	–	–	10	–	15
Volcanic glass (lt)	2	2	80	98	–	1	1
Zeolite	TR	–	–	–	–	–	–
Carbonate unspec.	10	5	–	–	10	8	10
Foraminifers	3	1	–	–	7	10	5
Calc. nannofossils	45	40	–	–	57	44	38
Diatoms	10	15	–	–	5	15	10
Radiolarians	10	15	–	–	5	15	10
Sponge spicules	2	1	–	–	1	2	1
Silicoflagellates	3	3	–	–	2	3	5
Mica	–	–	–	–	TR	–	<1

CARBONATE BOMB

1, 46–47 cm (ash) = 0%
2, 26–27 cm = 26%
3, 46–47 cm = 41%

SITE 504 HOLE CORE (HPC) 2 CORED INTERVAL 14.4–18.8 m



LITHOLOGIC DESCRIPTION

5GY 5/2

5GY 5/2–
10GY 5/2

5GY 5/2

5GY 5/2–
10GY 5/2
5GY 5/2
5GY 5/1

5GY 6/1

5GY 6/2

5GY 5/1

5Y 6/2

5GY 5/1

SILICEOUS NANNOFOSSIL OOZE

- Basic colors: greenish gray to grayish green, dusky yellow green (5GY 5/1–6/1, 10GY 5/2–5GY 5/2).
- Bioturbation moderate to intense.
- Gray (N5) streaks, spots and shaded areas refer to pyrite around or in burrows.
- Prominant gray to light gray (N5–6) ash layer between 0.55–0.63 cm (responsible for core disturbance above).
- Zoophycus "spreiten" burrows between 0.80–1.70 m common.

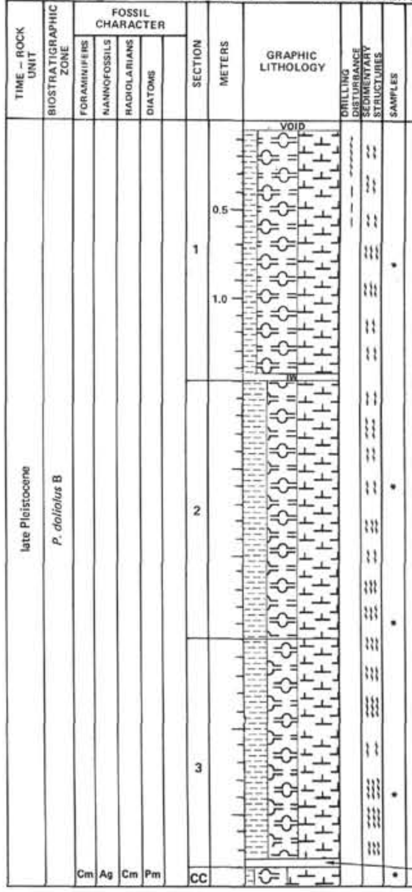
SMEAR SLIDE SUMMARY

	Ash	Siliceous nannofossil ooze	Siliceous nannofossil ooze	Siliceous nannofossil ooze	
	1-59	1-100	2-70	3-40	CC
Feldspar	10	–	–	–	–
Pyrite	–	TR	–	TR	2
Other heavy minerals	2	–	–	–	–
Clay minerals	–	5	15	10	3
Volcanic glass (lt)	80	TR	1	1	3
Carbonate unspec.	–	3	–	–	10
Foraminifers	–	15	7	10	1
Calc. nannofossils	–	45	50	50	50
Diatoms	–	25	15	15	15
Radiolarians	–	5	5	7	15
Sponge spicules	–	2	5	5	TR
Silicoflagellates	–	–	2	2	TR
Mica	8	–	–	–	–

CARBONATE BOMB

1, 46–47 cm = 30%
2, 46–47 cm = 38%
3, 46–47 cm = 39%

SITE 504 HOLE CORE (HPC) 3 CORED INTERVAL 18.8–23.2 m



LITHOLOGIC DESCRIPTION

5GY 5/1

5GY 6/2

5GY 5/1

5GY 6/1

5GY 5/1

5GY 5/1

5GY 6/1

IW

CLAY-BEARING SILICEOUS NANNOFOSSIL OOZE

- Basic color:greenish gray to dark greenish gray (5GY 6/1–5/1).
- Bioturbation moderate to intense.
- Gray (N5) streaks, spots and shaded areas refer to pyrite around or in burrows.
- Prominant vertical burrow between 0.55–0.90 m.

SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze	Siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze
	1-84	2-60	2-142	3-90	CC
Pyrite	TR	TR	TR	1	1
Clay minerals	15	20	20	10	12
Volcanic glass (lt)	–	–	2	1	TR
Zeolites	TR?	–	–	–	–
Carbonate unspec.	5	–	3	2	5
Foraminifers	5	7	5	4	2
Calc. nannofossils	35	35	35	48	54
Diatoms	8	10	14	15	10
Radiolarians	10	10	13	12	10
Sponge spicules	18	5	4	2	2
Silicoflagellates	3	3	4	5	5

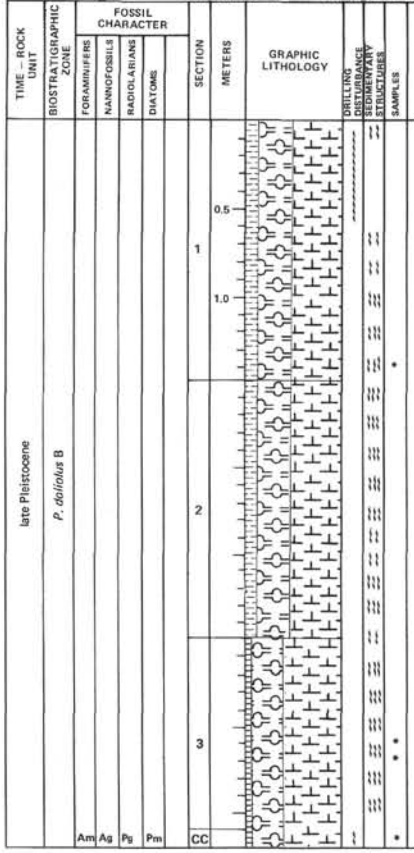
CARBONATE BOMB

1, 46–47 cm = 42%

2, 96–97 cm = 49%

3, 76–77 cm = 47%

SITE 504 HOLE CORE (HPC) 4 CORED INTERVAL 23.2–27.6 m



LITHOLOGIC DESCRIPTION

5GY 6/1

5GY 5/1

5Y 4/2–
5GY 5/1

5GY 6/2

5GY 5/2

5GY 6/2

5GY 4.5/2

5GY 5/2–
10GY 5/2

5GY 6/2

CLAY-BEARING SILICEOUS NANNOFOSSIL OOZE

- Basic color: greenish gray–dusky yellow green (5GY 6/1–5GY 5/2); variations to grayish green (10GY 5/2), dark greenish gray (5GY 5/1), and olive gray (5Y 4/2).
- Bioturbation intense.
- Gray (N5) streaks, spots and shaded areas common, refer to pyrite in and around burrows.

SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil ooze	Siliceous nannofossil ooze	Siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze
	1-140	3-60	3-70	CC
Pyrite	2	TR	TR	TR
Clay minerals	12	7	6	12
Volcanic glass (lt)	2	TR	1	TR
Carbonate unspec.	8	5	5	3
Foraminifers	6	5	10	2
Calc. nannofossils	40	55	45	65
Diatoms	12	15	15	10
Radiolarians	12	10	15	10
Sponge spicules	3	2	3	1
Silicoflagellates	3	1	TR	5
Chlorite	–	–	–	TR

CARBONATE BOMB

1, 96–97 cm = 14%

2, 96–97 cm = 15%

3, 96–97 cm = 51%

SITE 504 HOLE CORE (HPC) 5 CORED INTERVAL 27.6–32.0 m

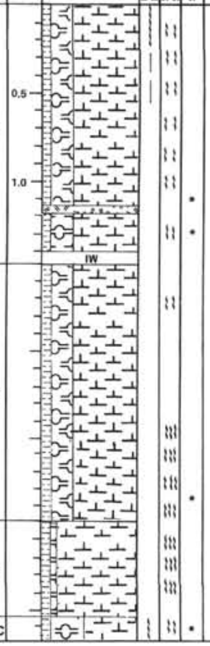
TIME – ROCK UNIT: late Pleistocene

BIOSTRATIGRAPHIC ZONE: *P. doliolus* B

FOSSIL CHARACTER (FORAMINIFERS, NANNOFOSSILS, RADIOLARIANS, DIATOMS):

SECTION	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS
3		Cg		Cg
CC	Pm	Pg	Cg	Pm

SECTION: 1, 2, 3, CC



LITHOLOGIC DESCRIPTION

SILICEOUS NANNOFOSSIL OOZE

- Basic color: greenish gray to dusky yellow green (5GY 6/1 to 5GY 5/2).
- Bioturbation moderate to intense.
- Zoophycus "spreiten" burrows frequent between 2.40–3.50 m.
- Gray (N5) streaks, spots and shaded areas around or in burrows refer to pyrite.
- Prominent ash layer between 1.13–1.15 m, gray (N5).

5GY 6/1

5GY 6/2

5GY 5/2

5GY 5/2–4/2

SMEAR SLIDE SUMMARY

	Nannofossil ooze	Clay-bearing siliceous nannofossil ooze	Siliceous nannofossil ooze	
	1-112	1-130	2-135	CC
Feldspar	2	–	–	–
Pyrite	4	TR	1	1
Clay minerals	5	15	9	–
Volcanic glass (lt)	–	3	TR	2
Carbonate unspec.	10	5	10	7
Foraminifers	3	3	–	TR
Calc. nannofossils	67	60	68	55
Diatoms	3	8	5	15
Radiolarians	3	7	4	15
Sponge spicules	1	2	1	TR
Silicoflagellates	1	TR	1	5
Mica	–	–	TR	–

CARBONATE BOMB

1, 96–97 cm = 41%
2, 96–97 cm = 30%
3, 34–35 cm = 13%

SITE 504 HOLE CORE (HPC) 6 CORED INTERVAL 32.0–36.4 m

TIME – ROCK UNIT: early Pleistocene

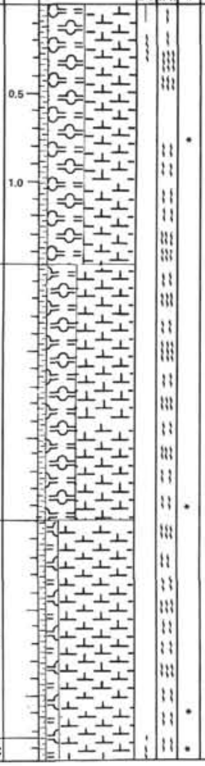
BIOSTRATIGRAPHIC ZONE: *P. doliolus* B

FOSSIL CHARACTER (FORAMINIFERS, NANNOFOSSILS, RADIOLARIANS, DIATOMS):

SECTION	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS
1		Cg		Cm
1		Cg		Cg
3		Cg		Pm
CC	Cm	Cg	Cg	Cm

Top *M. quadrangula*

SECTION: 1, 2, 3, CC



LITHOLOGIC DESCRIPTION

SILICEOUS NANNOFOSSIL OOZE

- Basic color: dusky yellow green–grayish yellow green (5GY 5/2–5GY 6/2).
- Bioturbation moderate to intense.
- Zoophycus "spreiten" burrows frequent between 0.30–2.50 m.
- Gray (N5) streaks, spots, and shaded areas around burrows refer to pyrite.
- Remarkable "halos" around burrows between 0.77–0.81, 1.20–1.26, 1.25–1.30 m.

5GY 5/2

5GY 6/2

5GY 5/2

5GY 6/2

5GY 5/2

5GY 5–6/2

5GY 5/2

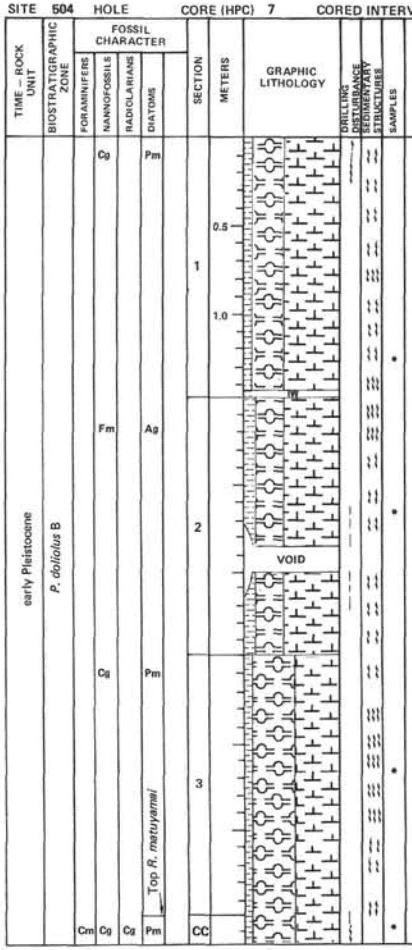
SMEAR SLIDE SUMMARY

	Siliceous nannofossil ooze	Siliceous nannofossil ooze	Siliceous nannofossil ooze
	1-80	2-140	3-110
Pyrite	TR	TR	6
Clay minerals	9	10	10
Volcanic glass (lt)	TR	1	–
Carbonate unspec.	5	5	10
Foraminifers	3	3	1
Calc. nannofossils	50	56	61
Diatoms	15	10	5
Radiolarians	10	10	5
Sponge spicules	5	2	1
Silicoflagellates	3	3	1

CARBONATE BOMB

1, 96–97 cm = 30%
2, 96–97 cm = 51%
3, 96–97 cm = 48%

SITE 504 HOLE CORE (HPC) 7 CORED INTERVAL 36.4–40.8 m



LITHOLOGIC DESCRIPTION

5GY 6/2

SILICEOUS NANNOFOSSIL OOZE

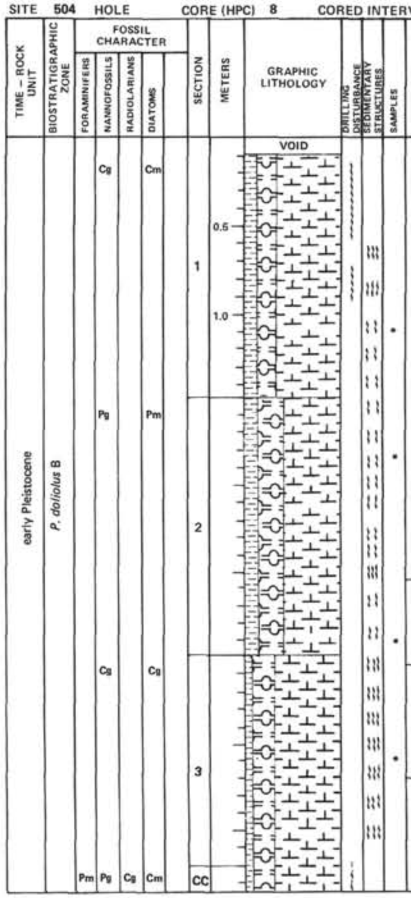
- Basic color: grayish yellow green (5GY 6/2).
- Bioturbation moderate to intense.
- Zoophyous "christmas tree" between 3.80–3.95 m; subhorizontal burrows frequent between 1.50–1.75 m and 3.30–3.75 m (mainly Zoophycus "spreiten" burrows).
- Grey (N5) streaks, spots, and shaded areas around or in burrows refer to pyrite.
- Void in Section 2 caused by stretching ("boudinage").

SMEAR SLIDE SUMMARY

	Siliceous nannofossil ooze	Siliceous nannofossil ooze	Siliceous nannofossil ooze
	1-128	2-65	3-67
Pyrite	1	TR	TR
Clay minerals	10	10	7
Volcanic glass (lt)	2	TR	TR
Carbonate unspec.	5	5	5
Foraminifers	3	2	3
Calc. nannofossils	45	55	45
Diatoms	15	10	15
Radiolarians	10	12	15
Sponge spicules	3	2	5
Silicoflagellates	5	5	5

CARBONATE BOMB
1, 96–97 cm = 33%
2, 105–106 cm = 51%
3, 96–97 cm = 45%

SITE 504 HOLE CORE (HPC) 8 CORED INTERVAL 40.8–45.2 m



LITHOLOGIC DESCRIPTION

5GY 6/2

5GY 5/2

5GY 6/2

5GY 5/2

SILICEOUS NANNOFOSSIL OOZE

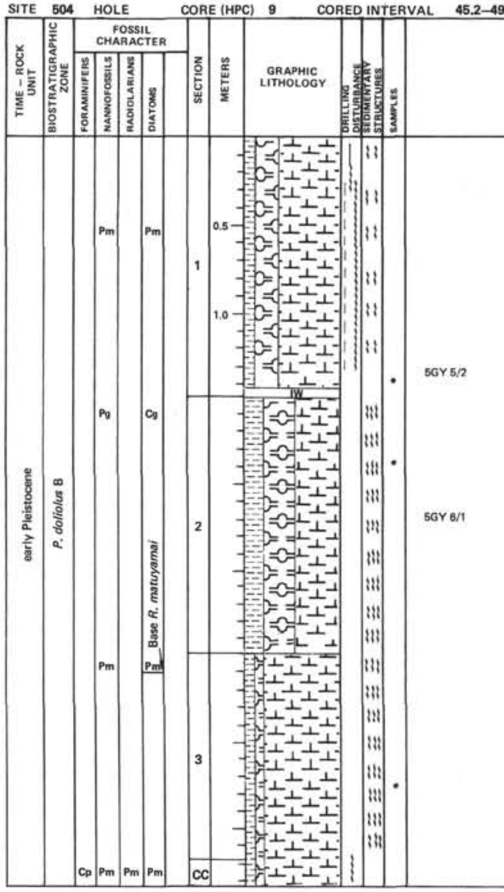
- Basic color: dusky yellow green (5GY 6/2–5GY 5/2).
- Bioturbation intense to moderate.
- Zoophycus "spreiten" burrows between 0.95–1.05 m, subhorizontal.
- Gray (N5) streaks, spots, and shaded areas around or in burrows refer to pyrite.
- Elliptical burrows concentrated around 3.15 m.
- Slight variations on basic colors as a result of burrowing.

SMEAR SLIDE SUMMARY

	Siliceous nannofossil ooze	Siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze	Siliceous nannofossil ooze
	1-110	2-35	2-140	3-60
Feldspar	–	TR	–	TR
Pyrite	3	5	TR	TR
Clay minerals	10	10	20	–
Volcanic glass (lt)	TR	TR	1	TR
Carbonate unspec.	10	5	8	10
Foraminifers	1	2	2	3
Calc. nannofossils	62	64	43	68
Diatoms	5	5	10	6
Radiolarians	5	5	8	6
Sponge spicules	2	2	3	3
Silicoflagellates	2	2	5	3
Mica	TR	–	–	TR

CARBONATE BOMB
1, 96–97 cm = 37%
2, 96–97 cm = 46%
3, 96–97 cm = 43%

SITE 504 HOLE CORE (HPC) 9 CORED INTERVAL 45.2–49.6 m



LITHOLOGIC DESCRIPTION

SILICEOUS NANNOFOSSIL OOZE

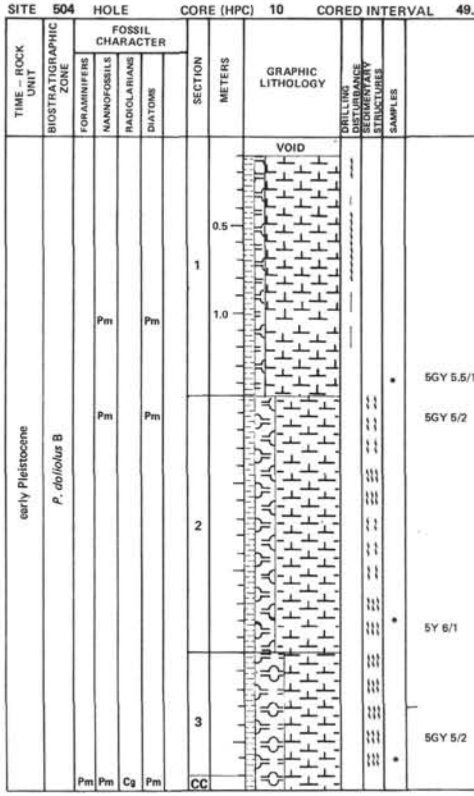
- Basic color: Greenish gray (5GY 6/1).
- Bioturbation moderate between 0.00–1.40 m, intense between 1.50–4.18 m.
- Zoophycus "spreiten" burrows abundant between 1.60–2.65 m.
- Gray (N5) streaks, spots, and shaded areas around or in burrows refer to pyrite.

SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil ooze 1-140	Clay-bearing siliceous nannofossil ooze 2-38	Clay-bearing siliceous nannofossil ooze 3-74
Pyrite	TR	TR	1
Clay minerals	15	20	10
Volcanic glass (lt)	TR	1	TR
Carbonate unspec.	10	5	10
Foraminifers	5	5	2
Calc. nannofossils	45	37	69
Diatoms	10	10	3
Radiolarians	7	10	3
Sponge spicules	5	5	1
Silicoflagellates	3	7	1
Mica	–	–	TR

CARBONATE BOMB
1, 122–123 cm = 39%
2, 96–97 cm = 54%
3, 96–97 cm = 25%

SITE 504 HOLE CORE (HPC) 10 CORED INTERVAL 49.6–54.0 m



LITHOLOGIC DESCRIPTION

SILICEOUS NANNOFOSSIL OOZE

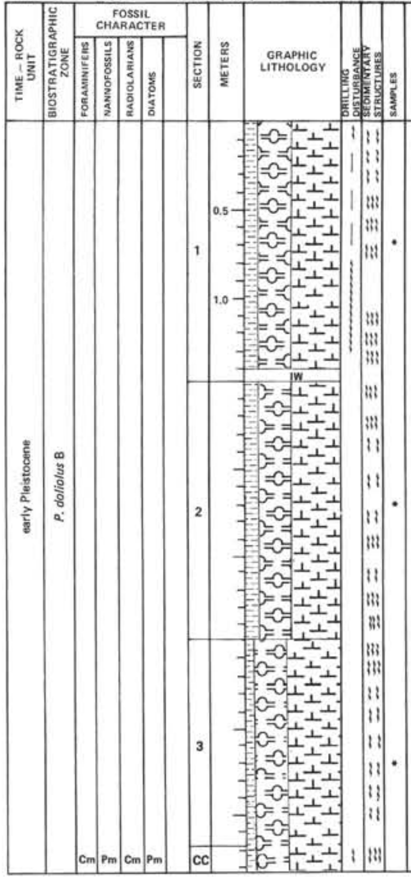
- Basic color: dusky yellow green to light olive green (5GY 5/2 to 5Y 6/1), with variations towards grayish yellow green (5GY 7/2) and light olive gray (5GY 5/1), as a result of burrowing.
- Bioturbation moderate to intense.
- Prominent Zoophycus "spreiten" burrows between 1.95–2.20 m and 3.00–3.70 m, subhorizontal.
- Gray (N5) streaks, spots, and shaded areas around or in burrows refer to pyrite.

SMEAR SLIDE SUMMARY

	Siliceous nannofossil ooze 1-140	Siliceous nannofossil ooze 2-130	Siliceous nannofossil ooze 3-60
Pyrite	3	3	3
Clay minerals	10	10	10
Volcanic glass (lt)	TR	1	1
Carbonate unspec.	10	10	10
Foraminifers	TR	TR	TR
Calc. nannofossils	64	57	48
Diatoms	3	6	10
Radiolarians	3	6	10
Sponge spicules	5	5	4
Silicoflagellates	2	2	2

CARBONATE BOMB
1, 136–137 cm = 52%
2, 96–97 cm = 34%
3, 46–47 cm = 35%

SITE 504 HOLE CORE (HPC) 11 CORED INTERVAL 54.0–58.4 m



LITHOLOGIC DESCRIPTION

5GY 5/2–
10GY 5/2

5GY 5/2

10GY 5/2

5GY 5/2–
5GY 3/2

5GY 5/2–
10GY 5/2

5GY 5/2

SILICEOUS NANNOFOSSIL OOZE

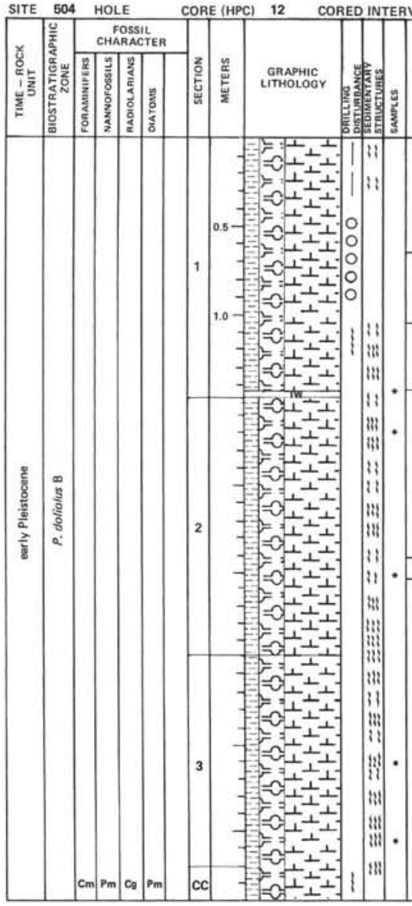
- Basic color: dusky yellow green to grayish green (5GY 5/2 to 10GY 5/2); variation towards grayish olive green at 3.10 m.
- Bioturbation moderate to intense.
- Zoophycus "spreiten" burrows between 0.40–0.70, 1.10–1.40, 2.90–3.20 m, subhorizontal.
- Dark grayish (N4–5) streaks, spots and shaded areas in and around burrows refer to pyrite.

SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze	Siliceous nannofossil ooze
	1-70	2-70	3-70
Feldspar	–	TR	–
Pyrite	1	–	TR
Clay minerals	15	15	10
Volcanic glass (lt)	–	TR	1
Carbonate unspec.	10	10	10
Foraminifers	5	5	1
Calc. nannofossils	30	30	48
Diatoms	10	10	10
Radiolarians	10	10	10
Sponge spicules	5	5	5
Silicoflagellates	5	4	5
Mica	–	TR	–

CARBONATE BOMB
1, 46–47 cm = 46%
2, 46–47 cm = 61%
3, 46–47 cm = 63%

SITE 504 HOLE CORE (HPC) 12 CORED INTERVAL 58.4–62.8 m



LITHOLOGIC DESCRIPTION

5GY 5/2–
5GY 7/2

5GY 7/2–
5GY 6/2

5GY 6/2

5GY 7/2–
5GY 5/2

5GY 5/2–
5GY 7/2

5GY 7/2

5GY 5/2

5GY 7/2–
5GY 5/2

5GY 5/2–
5GY 3/2

5GY 7/2

5GY 5/2

SILICEOUS NANNOFOSSIL OOZE

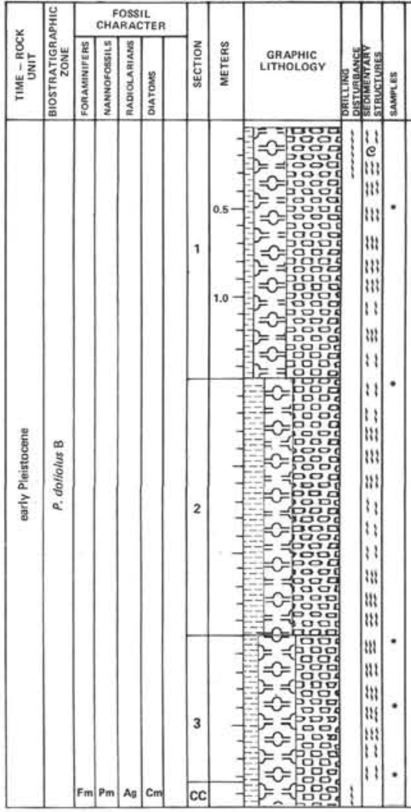
- Basic color: dusky yellow green–grayish yellow green (5GY 5/2–5GY 7/2); variation to 5GY 3/2.
- Bioturbation moderate to intense.
- Prominent Zoophyous "spreiten" burrows between 1.60–2.40, 2.90–3.20, 4.00–4.20 m, subhorizontal.
- Gray (N5) streaks, spots, and shaded areas (sometimes "halos") around or in burrows refer to pyrite.

SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil ooze	Siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze	Siliceous nannofossil ooze	Siliceous nannofossil ooze
	1-145	2-20	2-100	3-60	3-107
Feldspar	TR	–	–	TR	TR
Pyrite	3	3	3	2	2
Other heavy minerals	TR	–	TR	TR	TR
Clay minerals	15	15	10	10	10
Volcanic glass (lt)	1	TR	TR	TR	TR
Carbonate unspec.	10	10	15	10	10
Foraminifers	TR	TR	TR	TR	TR
Calc. nannofossils	43	40	41	50	51
Diatoms	10	15	15	12	12
Radiolarians	10	10	10	8	8
Sponge spicules	3	4	3	5	5
Silicoflagellates	5	3	3	3	2

CARBONATE BOMB
1, 26–27 cm = 57%
2, 46–47 cm = 43%
3, 46–47 cm = 44%

SITE 504 HOLE CORE (HPC) 13 CORED INTERVAL 62.8–67.2 m



LITHOLOGIC DESCRIPTION

5GY 5/2
5GY 7/2–5GY 5/2
5GY 5/2
5GY 7/2–5GY 5/2
5GY 5/2
5GY 7/2–5GY 5/2
5GY 5/2
5GY 7/2–5GY 5/2
5GY 5/2
5GY 7/2–5GY 5/2
5GY 5/2–5GY 7/2
5Y 4/3–5Y 4/4

CLAY-BEARING SILICEOUS NANNOFOSSIL OOZE

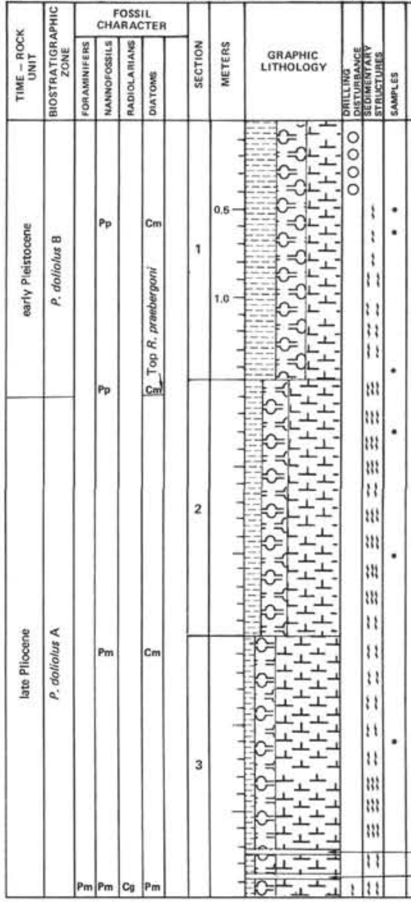
- Basic color: 0.0–3.35 m – dusky yellow green–grayish yellow green (5GY 5/2–5GY 7/2) and 3.35–3.98 – olive (5Y 4/3–5Y 4/4).
- Bioturbation moderate to intense.
- Zoophycus "spreiten" burrows between 0.75–1.05, 2.20–2.50, and 3.30–3.70 m.
- Prominent vertical burrow between 1.05–1.20 m.
- Strong H_2S odor when core was split.
- Gray (N5) streaks, spots, and shaded areas in and around burrows refer to pyrite.

SMEAR SLIDE SUMMARY

	Siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze	Siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze
	1-50	2-2	3-3	3-39	3-83
Pyrite	2	TR	2	4	1
Other heavy minerals	TR	–	–	–	–
Clay minerals	10	20	15	20	15
Volcanic glass (lt)	TR	2	TR	1	1
Carbonate unspec.	10	10	10	12	10
Foraminifers	2	–	5	TR	TR
Calc. nannofossils	44	50	45	35	38
Diatoms	15	12	15	12	15
Radiolarians	10	9	10	9	10
Sponge spicules	5	5	5	5	7
Silicoflagellates	2	2	2	3	3

CARBONATE BOMB
1, 46–47 cm = 50%
2, 46–47 cm = 40%
3, 46–47 cm = 49%

SITE 504 HOLE CORE (HPC) 14 CORED INTERVAL 67.2–71.6 m



LITHOLOGIC DESCRIPTION

5Y 3/2
5Y 4/2–4/3
5GY 5/2
5Y 3/2
5GY 5/2–5Y 3/2
5GY 5/2
5GY 5/2–5Y 4/3
VOID
VOID
5GY 5/2–5Y 4/3

CLAY-BEARING SILICEOUS NANNOFOSSIL OOZE

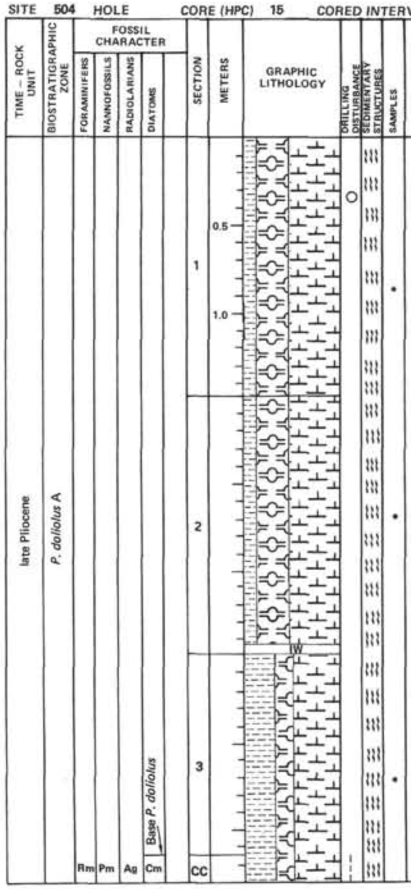
- Basic color: dusky yellow green to dark olive and olive (5GY 5/2 to 5Y 3/2 and 4/2).
- Bioturbation moderate to intense.
- Sub-vertical burrows abundant between 3.30–4.00 m.
- Scattered foraminifer tests visible.
- Gray (N5) streaks, spots, and shaded areas (sometimes "halos") in and around burrows refer to pyrite.

SMEAR SLIDE SUMMARY

	Rust	Siliceous nannofossil marl	Clay-bearing siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze	Siliceous nannofossil ooze
	1-51	1-62	1-146	2-30	2-100	3-60
Feldspar	–	–	–	–	–	TR
Pyrite	–	1	1	1	TR	2
Other heavy minerals	–	–	–	2	–	–
Clay minerals	–	50	15	8	30	10
Volcanic glass (lt)	–	–	2	3	3	TR
Carbonate unspec.	–	5	10	10	5	7
Foraminifers	TR	1	TR	–	TR	2
Calc. nannofossils	10	25	41	48	40	58
Diatoms	TR	7	12	10	8	8
Radiolarians	TR	6	10	8	6	6
Sponge spicules	–	2	6	6	3	5
Silicoflagellates	–	2	3	4	2	2
Rust	90	–	–	–	–	–
Mica	–	–	–	1	–	–

CARBONATE BOMB
1, 66–67 cm = 8%
2, 46–47 cm = 18%
3, 46–47 cm = 30%

SITE 504 HOLE CORE (HPC) 15 CORED INTERVAL 71.6–76.0 m



5GY 3/2
5Y 4/2
2.5Y 3/2
5Y 3/2
2.5Y 3/2
5Y 4/2

LITHOLOGIC DESCRIPTION

CLAY-BEARING SILICEOUS NANNOFOSSIL OOZE

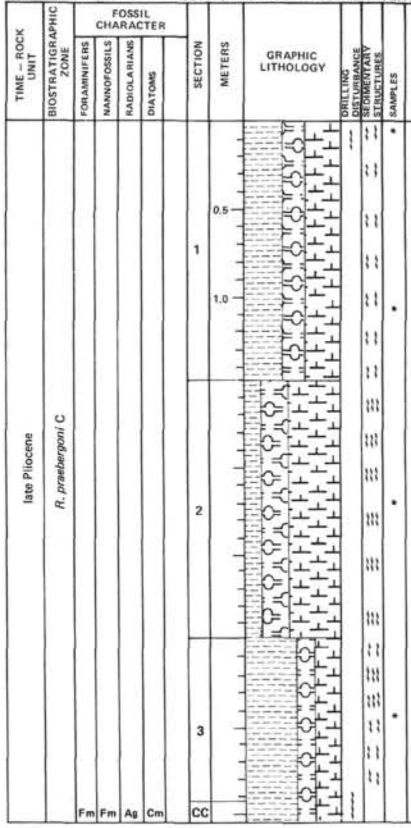
- Basic color: 0.0–1.50 m – grayish olive green (5GY 3/2); 1.50–3.00 m – olive gray (5Y 4/2); and 3.00–4.30 m – olive gray to very dark grayish brown (5Y 4/2 to 2.5Y 3/2).
- Bioturbation intense.
- Gray (N5) streaks, spots, and shaded areas in and around burrows refer to pyrite.
- Scattered foraminifer tests visible.

SMEAR SLIDE SUMMARY

	Siliceous nannofossil ooze	Siliceous nannofossil ooze	
	1-87	2-70	3-71
Feldspar	TR	–	5
Pyrite	1	3	–
Clay minerals	10	10	25
Volcanic glass (lt)	TR	TR	TR
Carbonate unspec.	6	6	5
Foraminifers	–	3	2
Calc. nannofossils	46	43	45
Diatoms	15	15	6
Radiolarians	10	10	4
Sponge spicules	6	7	3
Silicoflagellates	5	3	3
Mica	TR	TR	TR

CARBONATE BOMB
1, 116–117 cm = 9%
2, 46–47 cm = 6%
3, 46–47 cm = 22%

SITE 504 HOLE CORE (HPC) 16 CORED INTERVAL 76.0–80.4 m



5GY 5/2
2.5Y 3/2–
5Y 4/2
5Y 4/2
5Y 3/2–
5Y 4/2
5Y 4/2
5GY 5/2–
5Y 4/2
5Y 4/2
5Y 4/2–
5Y 5/2
5Y 3/2
5Y 4/2

LITHOLOGIC DESCRIPTION

CLAY-BEARING SILICEOUS NANNOFOSSIL OOZE

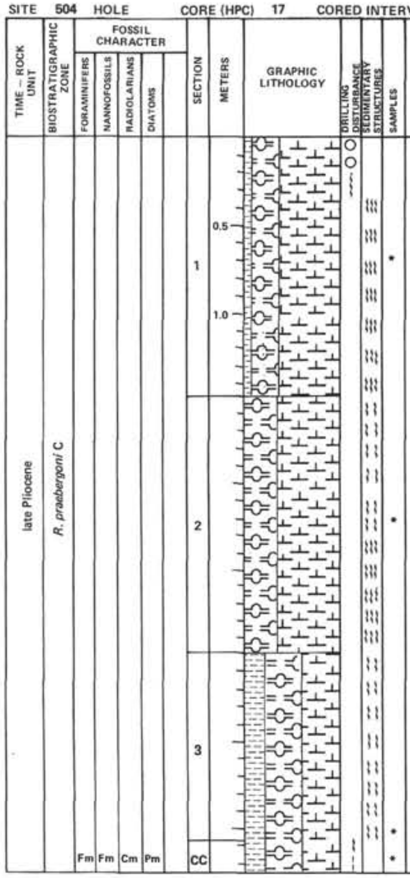
- Basic color: dusky yellow green–olive gray (5GY 5/2–5Y 4/2), variations to dark olive (5Y 3/2), olive gray (5Y 5/2), and very dark grayish brown (2.5Y 3/2).
- Bioturbation moderate to intense.
- Gray (N5) streaks, spots, and shaded areas in or around burrows refer to pyrite.
- Scattered foraminifers visible.

SMEAR SLIDE SUMMARY

	Rust	Siliceous nannofossil marl	Clay-bearing siliceous nannofossil ooze	Siliceous nannofossil marl
	1-7	1-106	2-70	3-44
Quartz	–	6	–	–
Feldspar	–	3	–	–
Pyrite	–	2	2	1
Clay minerals	–	40	15	50
Volcanic glass (lt)	–	1	2	–
Carbonate unspec.	–	5	8	5
Calc. nannofossils	–	27	43	23
Diatoms	–	5	8	8
Radiolarians	–	5	8	7
Sponge spicules	–	3	10	3
Silicoflagellates	–	3	4	2
Rust	100	–	–	–
Mica	–	TR	–	–

CARBONATE BOMB
1, 46–47 cm = 28%
2, 46–47 cm = 27%
3, 46–47 cm = 21%

SITE 504 HOLE CORE (HPC) 17 CORED INTERVAL 80.4–84.8 m



LITHOLOGIC DESCRIPTION

5Y 4/2
5Y 6/2
5Y 5/2–
5Y 4/2
5Y 4/4
5Y 4/2
5Y 4/4
5Y 4/2
5Y 4/4
10YR 3/2
5Y 4/4
10YR 3/2

SILICEOUS NANNOFOSSIL OOZE TO
CLAY-BEARING SILICEOUS NANNOFOSSIL OOZE

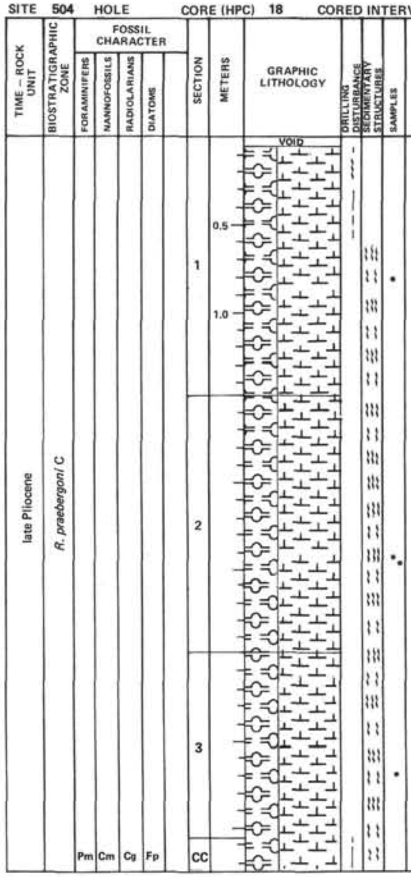
- Basic color: 0.0–3.20 m – olive gray to olive (5Y 4/2, 5/2 to 5Y 4/4); 3.20–4.24 m – olive to very dark grayish brown (5Y 4/4 to 10YR 3/2); intercalation of light olive gray (5Y 6/2) between 0.25–0.35 m.
- Bioturbation moderate to intense.

SMEAR SLIDE SUMMARY

	Siliceous nannofossil ooze	Siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze
	1-70	2-70	3-100
Feldspar	–	–	TR
Clay minerals	5	–	20
Carbonate unspec.	5	–	5
Calc. nannofossils	60	50	45
Diatoms	15	15	5
Radiolarians	5	10	10
Sponge spicules	–	–	5
Silicoflagellates	10	5	10

CARBONATE BOMB
1, 46–47 cm = 39%
2, 46–47 cm = 37%
3, 46–47 cm = 30%

SITE 504 HOLE CORE (HPC) 18 CORED INTERVAL 84.8–89.2 m



LITHOLOGIC DESCRIPTION

5Y 3/2
5Y 3/2–4/2
5GY 5/2
5Y 4/4
5Y 4/3
5GY 5/2
5GY 6/2
5Y 5/2
5Y 4/3
5Y 6/2

CLAY-BEARING SILICEOUS NANNOFOSSIL OOZE

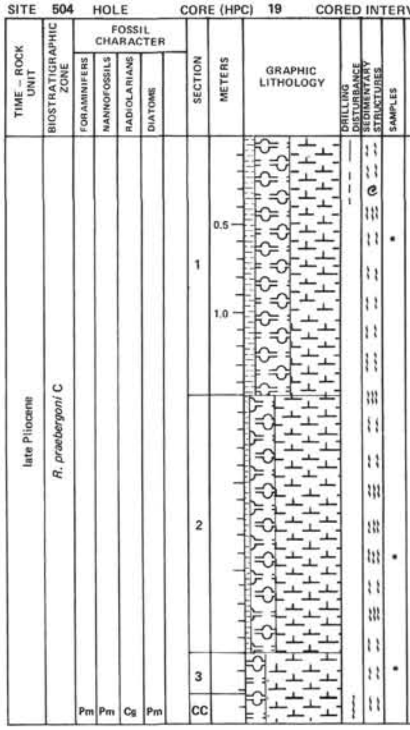
- Basic color: dark olive gray–olive gray (5Y 3/2–4/2) to dusky yellow green–grayish yellow green (5GY 5/2–6/2), with variations of moderate olive brown–olive (5Y 4/4–4/3) and light olive gray (5Y 6/2).
- Bioturbation moderate to intense.
- Gray (N5) streaks, spots, and shaded areas in and around burrows refer to pyrite.

SMEAR SLIDE SUMMARY

	Siliceous nannofossil ooze	Pyritic siliceous nannofossil ooze	Siliceous nannofossil ooze	Siliceous nannofossil ooze
	1-80	2-92	2-95	3-70
Pyrite	–	30	–	3
Volcanic glass (lt)	TR	TR	TR	TR
Carbonate unspec.	10	5	5	–
Calc. nannofossils	50	30	50	50
Diatoms	10	15	15	15
Radiolarians	10	10	10	10
Sponge spicules	5	2	3	5
Silicoflagellates	5	5	5	10

CARBONATE BOMB
1, 46–47 cm = 11%
2, 46–47 cm = 8%
3, 46–47 cm = 48%

SITE 504 HOLE CORE (HPC) 19 CORED INTERVAL 89.2–93.6 m



LITHOLOGIC DESCRIPTION

5Y 4/2

2.5Y 4/2

5Y 5/2

5Y 6/2

5Y 5/2

SILICEOUS NANNOFOSSIL OOZE

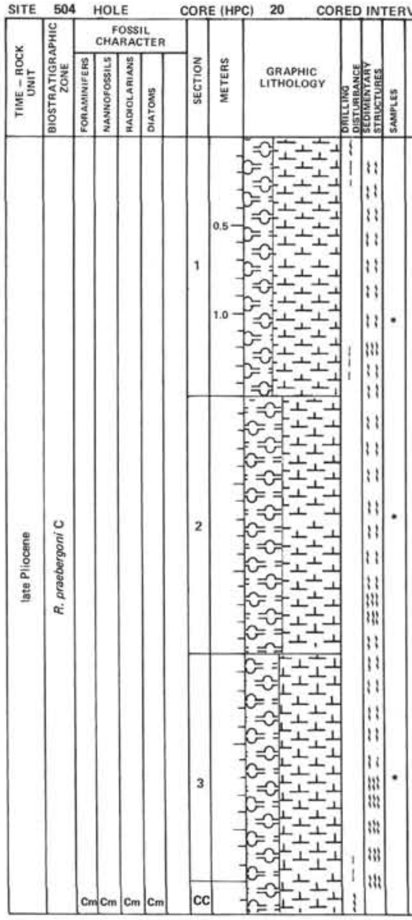
- Basic color: olive gray (5Y 5/2) with variations to olive gray and light olive gray (5Y 4/2 and 5Y 6/2); from 0.74–1.50 m transition from dark grayish brown to olive gray (2.5Y 4/2 to 5Y 5/2).
- Bioturbation moderate to intense.
- Gray (N5) streaks and spots refer to pyrite.
- Shell fragment at 0.33 m.

SMEAR SLIDE SUMMARY

	Siliceous nannofossil ooze	Siliceous nannofossil ooze	Siliceous nannofossil ooze
	1-60	2-90	3-9
Feldspar	–	TR	1
Pyrite	–	TR	–
Clay minerals	10	5	–
Volcanic glass (lt)	–	–	TR
Carbonate unspec.	5	10	10
Calc. nannofossils	45	50	50
Diatoms	20	10	10
Radiolarians	10	10	10
Sponge spicules	3	2	–
Silicoflagellates	5	9	5

CARBONATE BOMB
1, 139–140 cm = 32%
2, 46–47 cm = 34%

SITE 504 HOLE CORE (HPC) 20 CORED INTERVAL 93.6–98.0 m



LITHOLOGIC DESCRIPTION

5GY 6/2–
5Y 6/2

5GY 6/2

5Y 6/2

5Y 5/2

5GY 6/2

SILICEOUS NANNOFOSSIL OOZE

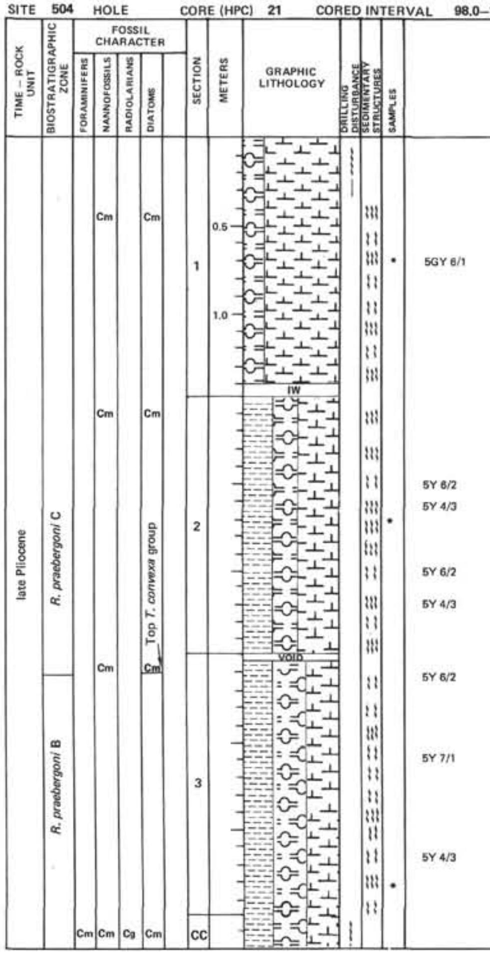
- Basic color: grayish yellow green to light olive gray (5GY 6/2–5Y 6/2).
- Bioturbation moderate to intense.
- Zoophycus "spreiten" burrows frequent between 3.70–4.30 m, grayish yellow green (5GY 7/2).
- Gray (N5) streaks, spots, as well as rinds around burrow "halos" refer to pyrite.
- Burrow "halos" at 1.03 m and 2.75 m.

SMEAR SLIDE SUMMARY

	Siliceous nannofossil ooze	Siliceous nannofossil ooze	Siliceous nannofossil ooze
	1-105	2-70	3-70
Feldspar	TR	TR	TR
Pyrite	TR	–	TR
Volcanic glass (lt)	TR	TR	TR
Carbonate unspec.	10	5	10
Calc. nannofossils	55	50	45
Diatoms	10	15	10
Radiolarians	10	10	12
Sponge spicules	–	5	5
Silicoflagellates	10	10	10

CARBONATE BOMB
1, 46–47 cm = 43%
2, 46–47 cm = 53%
3, 46–47 cm = 46%

SITE 504 HOLE CORE (HPC) 21 CORED INTERVAL 98.0–102.4 m



LITHOLOGIC DESCRIPTION

CLAY-BEARING NANNOFOSSIL OOZE

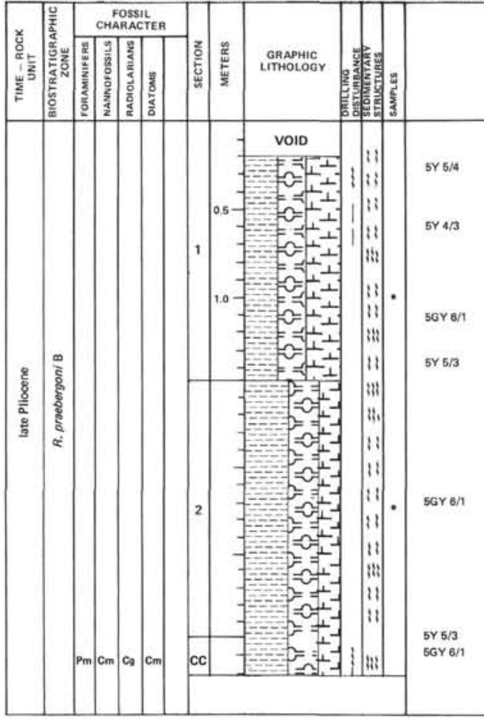
- Basic color: 0.0–1.40 m – greenish gray (5GY 6/1); 1.50–4.65 m – olive to light olive gray (5Y 4/3 to 5Y 6/2), with variation to light gray (5Y 7/1) between 3.50–4.00 m.
- Bioturbation moderate to intense.
- Zoophycus "spreiten" burrows between 3.90–4.40 m, subhorizontal.
- Gray (N5) streaks, spots, and shaded areas in and around burrows refer to pyrite.

SMEAR SLIDE SUMMARY

	Siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze
	1-70	2-70	3-130
Feldspar	TR	–	TR
Pyrite	TR	TR	2
Other heavy minerals	–	1	TR
Clay minerals	–	30	30
Volcanic glass (lt)	TR	TR	2
Carbonate unspec.	–	3	3
Foraminifers	25	–	1
Calc. nannofossils	50	43	30
Diatoms	10	10	15
Radiolarians	5	8	10
Sponge spicules	5	2	2
Silicoflagellates	5	3	5

CARBONATE BOMB
1, 47–48 cm = 59%
2, 47–48 cm = 39%
3, 47–48 cm = 50%

SITE 504 HOLE CORE (HPC) 22 CORED INTERVAL 102.4–106.8 m



LITHOLOGIC DESCRIPTION

SILICEOUS NANNOFOSSIL MARL TO CALCAREOUS SILICEOUS MARL

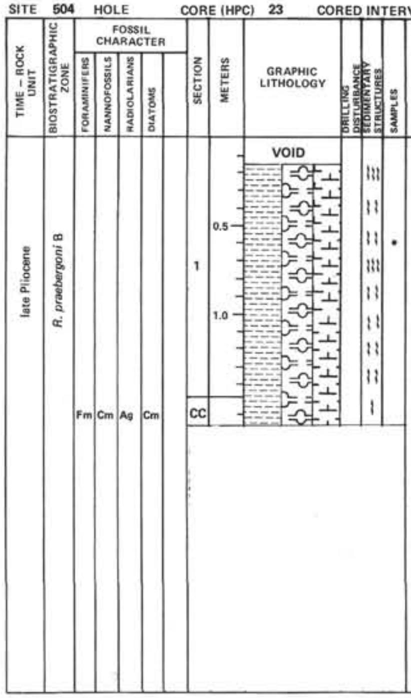
- Basic color: greenish-gray (5GY 6/1) with gradational changes into olive (5Y 5/4–4/3–5/3).
- Bioturbation moderate to intense.
- Gray (N5) streaks, spots, and shaded areas in and around burrows refer to pyrite.

SMEAR SLIDE SUMMARY

	Siliceous nannofossil marl	Calcareous siliceous marl
	1-100	2-70
Feldspar	TR	TR
Pyrite	1	2
Other heavy minerals	TR	TR
Clay minerals	40	48
Volcanic glass (lt)	1	2
Carbonate unspec.	5	–
Foraminifers	2	2
Calc. nannofossils	25	15
Diatoms	10	15
Radiolarians	10	10
Sponge spicules	3	3
Silicoflagellates	3	3

CARBONATE BOMB
1, 47–48 cm = 31%
2, 47–48 cm = 34%

SITE 504 HOLE CORE (HPC) 23 CORED INTERVAL 106.8–111.2 m



LITHOLOGIC DESCRIPTION

5Y 5/2

5GY 6/1–
5G 7/1

5Y 5/2

SILICEOUS NANNOFOSSIL MARL

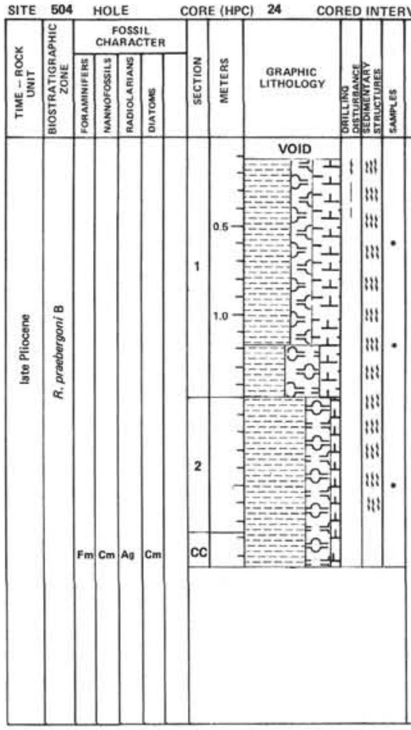
- Basic color: olive gray (5Y 5/2) with transitions into light olive gray to light greenish gray (5GY 6/1 to 5G 7/1).
- Bioturbation moderate to intense.
- Prominent burrow "halo" at 1.03 cm.
- Gray (N5) streaks, spots, and shaded areas around or in burrows refer to pyrite.

SMEAR SLIDE SUMMARY

	Siliceous nannofossil marl
	1-60
Pyrite	1
Other heavy minerals	TR
Clay minerals	40
Volcanic glass (lt)	TR
Carbonate unspec.	3
Calc. nannofossils	25
Diatoms	10
Radiolarians	10
Sponge spicules	5
Silicoflagellates	6

CARBONATE BOMB
1, 47–48 cm = 14%

SITE 504 HOLE CORE (HPC) 24 CORED INTERVAL 111.2–115.6 m



LITHOLOGIC DESCRIPTION

CALCAREOUS SILICEOUS MARL

- Basic color: greenish gray (5GY 6/1) with transitions into olive gray (5Y 5/2) and grayish green (5Y 6/1).
- Bioturbation intense.

5GY 6/1

SMEAR SLIDE SUMMARY

5Y 5/2

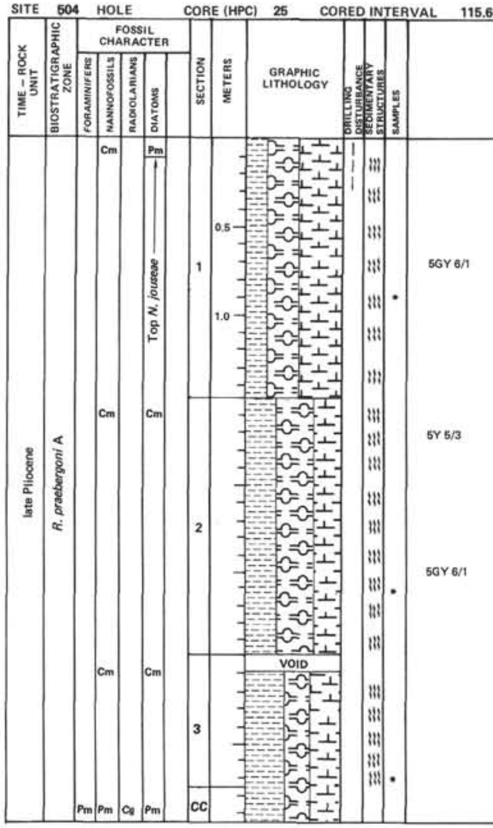
5GY 6/1

5Y 6/1

	Siliceous nannofossil marl	Calcareous siliceous marl	Calcareous siliceous marl
	1-60	1-119	2-50
Feldspar	TR	TR	–
Pyrite	2	8	TR
Other heavy minerals	TR	1	–
Clay minerals	45	40	60
Volcanic glass (lt)	1	2	TR
Carbonate unspec.	5	3	2
Foraminifers	–	1	2
Calc. nannofossils	15	10	10
Diatoms	16	10	10
Radiolarians	10	10	8
Sponge spicules	5	5	5
Silicoflagellates	6	5	3

CARBONATE BOMB
1, 47–48 cm = 55%
2, 47–48 cm = 46%

SITE 504 HOLE CORE (HPC) 25 CORED INTERVAL 115.6–120.0 m



LITHOLOGIC DESCRIPTION

CLAY-BEARING SILICEOUS NANNOFOSSIL OOZE TO SILICEOUS NANNOFOSSIL MARL

- Basic color: grayish-green (5GY 6/1) with transition into olive (5Y 5/3) between 1.50–2.00 m.
- Bioturbation intense.
- Gray (N5) spots, streaks, and shaded areas around and in burrows refer to pyrite.

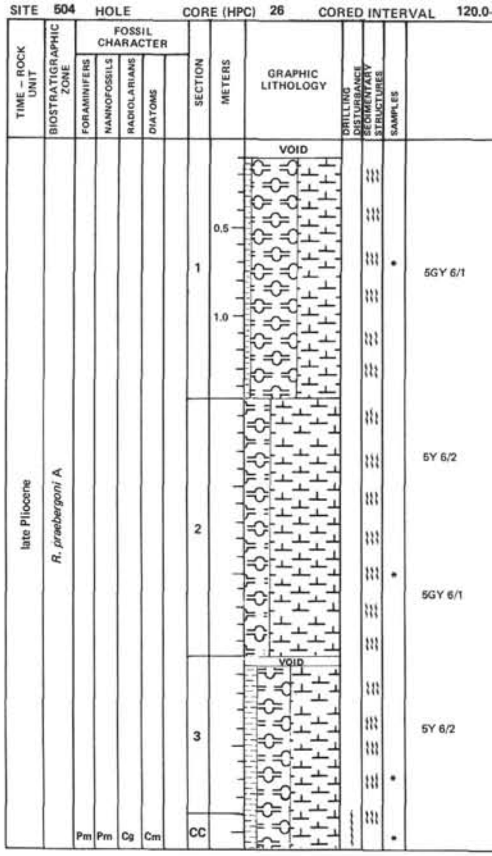
SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze	Siliceous nannofossil marl
	1-90	2-112	3-70
Feldspar	–	TR	TR
Pyrite	TR	TR	1
Other heavy minerals	1	–	TR
Clay minerals	20	30	40
Volcanic glass (lt)	1	2	2
Carbonate unspec.	5	3	2
Foraminifers	2	–	3
Calc. nannofossils	38	25	25
Diatoms	15	20	10
Radiolarians	10	15	8
Sponge spicules	3	2	3
Silicoflagellates	5	3	6

CARBONATE BOMB

1, 47–48 cm = 54%
2, 47–48 cm = 31%
3, 47–48 cm = 53%

SITE 504 HOLE CORE (HPC) 26 CORED INTERVAL 120.0–124.4 m



LITHOLOGIC DESCRIPTION

SILICEOUS NANNOFOSSIL OOZE TO
CLAY-BEARING SILICEOUS NANNOFOSSIL OOZE

- Basic color: greenish gray to light olive gray (5GY 6/1 to 5Y 6/2).
- Bioturbation intense.
- Zoophycus "spreiten" burrows between 1.50–3.10 m.
- Remarkable "halo" around burrow at 2.10 m.
- Gray (N5) streaks, spots, and shaded areas around and in burrows refer to pyrite.

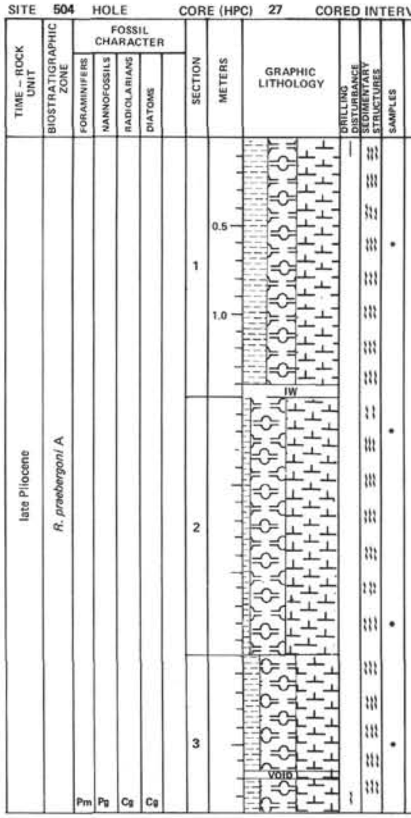
SMEAR SLIDE SUMMARY

	Siliceous nannofossil ooze	Siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze
	1-70	2-100	3-70
Pyrite	TR	1	1
Other heavy minerals	TR	TR	–
Clay minerals	8	–	10
Volcanic glass (lt)	TR	TR	TR
Carbonate unspec.	10	7	15
Foraminifers	–	2	–
Calc. nannofossils	36	55	34
Diatoms	15	15	15
Radiolarians	15	10	15
Sponge spicules	10	8	7
Silicoflagellates	6	2	3

CARBONATE BOMB

1, 47–48 cm = 49%
2, 47–48 cm = 44%
3, 47–48 cm = 45%

SITE 504 HOLE CORE (HPC) 27 CORED INTERVAL 124.4–128.8 m



LITHOLOGIC DESCRIPTION

5Y 6/2

5Y 5/2

5Y 6/2

5Y 5/2

5Y 4/4

5Y 6/1

CLAY-BEARING SILICEOUS NANNOFOSSIL OOZE

- Basic color: 0.0–1.50 m – light olive gray to olive gray (5Y 6/2 to 5/2); 1.50–3.90 m – grayish green to moderate olive brown (5Y 6/1 to 4/4).
- Bioturbation intense.
- Zoophycus "spreiten" burrow between 0.30–0.70 m.

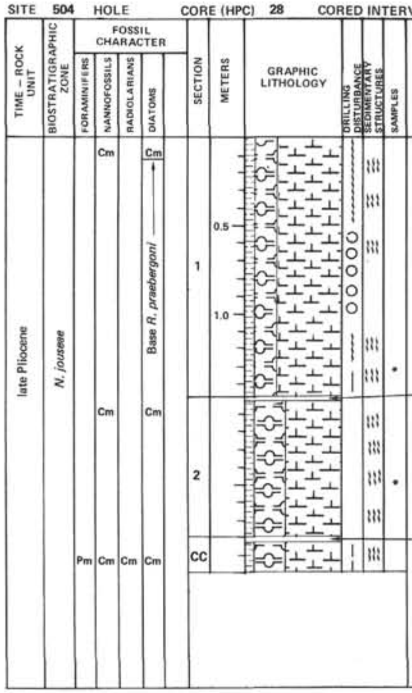
SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze	Siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze
	1-62	2-20	2-130	3-50
Feldspar	TR	–	–	–
Pyrite	1	TR	2	2
Other heavy minerals	TR	–	–	TR
Clay minerals	30	10	7	10
Volcanic glass (lt)	1	TR	TR	TR
Carbonate unspec.	5	3	15	15
Foraminifers	–	–	3	–
Calc. nannofossils	35	50	45	33
Diatoms	10	15	10	15
Radiolarians	8	10	10	10
Sponge spicules	3	8	5	10
Silicoflagellates	7	3	3	5

CARBONATE BOMB

1, 47–48 cm = 33%
2, 47–48 cm = 36%
3, 47–48 cm = 39%

SITE 504 HOLE CORE (HPC) 28 CORED INTERVAL 128.8–133.2 m



LITHOLOGIC DESCRIPTION

5Y 6/2–6/1

5Y 6/1

5Y 6/2–6/1

VOID

5Y 6/2

VOID
5Y 5/2

CLAY-BEARING SILICEOUS NANNOFOSSIL OOZE

- Basic color: light gray to light olive gray (5Y 6/1 to 6/2).
- Bioturbation intense.
- Zoophycus "spreiten" burrow at 2.16 m.
- Gray (N5) streaks, spots, and shaded areas around or in burrows refer to pyrite.

SMEAR SLIDE SUMMARY

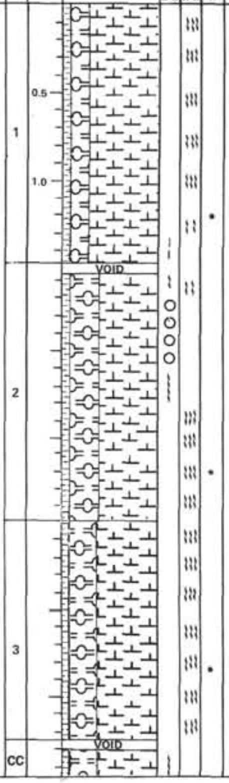
	Clay-bearing siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze
	1-130	2-50
Pyrite	2	3
Clay minerals	10	10
Volcanic glass (lt)	–	TR
Carbonate unspec.	15	10
Foraminifers	5	–
Calc. nannofossils	47	50
Diatoms	7	10
Radiolarians	6	10
Sponge spicules	5	5
Silicoflagellates	3	2

CARBONATE BOMB

1, 46–47 cm = 38%
2, 46–47 cm = 50%

SITE 504 HOLE CORE (HPC) 29 CORED INTERVAL 133.2–137.6 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FOSSIL CHARACTER: FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	
late Pliocene	*N. jouseae*	Fm	Pm	Ag	Pm	



LITHOLOGIC DESCRIPTION

5Y 6/2

5Y 6/1

5Y 6/1–6/2

5Y 6/1

CLAY-BEARING SILICEOUS NANNOFOSSIL OOZE

- Basic color: gray to light olive gray (5Y 6/1 to 5Y 6/2).
- Bioturbation intense.
- Zoophycus "spreiten" between 3.20–3.35 m.
- Many large "halos" around burrows with gray (N5) rinds.
- Gray (N5) streaks and spots around or in burrows refer to pyrite.

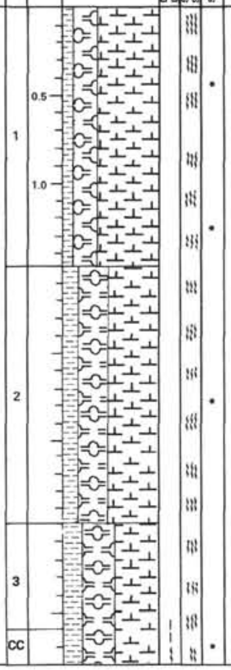
SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze
	1-120	2-120	3-85
Pyrite	3	3	TR
Clay minerals	10	10	10
Volcanic glass (lt)	1	TR	TR
Carbonate unspec.	20	15	15
Foraminifers	5	–	–
Calc. nannofossils	51	47	47
Diatoms	7	10	10
Radiolarians	6	7	10
Sponge spicules	4	5	5
Silicoflagellates	3	3	3
Mica	TR	–	TR

CARBONATE BOMB
1, 46–47 cm = 47%
2, 106–107 cm = 50%
3, 46–47 cm = 46%

SITE 504 HOLE CORE (HPC) 30 CORED INTERVAL 137.6–142.0 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FOSSIL CHARACTER: FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS
late Pliocene	*N. jouseae*	Fm	Pm	Ag	Cm



LITHOLOGIC DESCRIPTION

5Y 6/2–5/2

5Y 6/2

5Y 6/2–5/2

5Y 6/2

5Y 6/1–6/2

5Y 7/1–6/2

CLAY-BEARING SILICEOUS NANNOFOSSIL OOZE

- Basic color: light olive gray (5Y 6/2) with transitions into olive gray (5Y 5/2), and gray to light gray (5Y 6/1 to 7/1).
- Bioturbation intense.
- Many subhorizontal burrows between 0.0–1.50 m, less in lower part.
- Prominent "halo" around burrow at 2.10 m.
- Dark grayish rinds, streaks, and spots around or in burrows refer to pyrite.

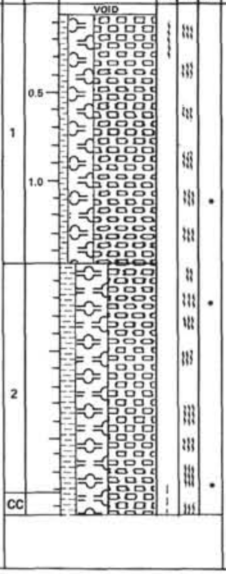
SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze
	1-44	1-128	2-79	CC, 9
Pyrite	TR	–	1	TR
Clay minerals	10	15	15	20
Volcanic glass (lt)	TR	TR	TR	TR
Zeolites	–	TR	TR	–
Carbonate unspec.	20	20	25	25
Foraminifers	–	–	TR	–
Calc. nannofossils	40	47	30	22
Diatoms	10	5	10	10
Radiolarians	10	5	10	10
Sponge spicules	5	5	7	10
Silicoflagellates	5	3	2	3
Mica	TR	TR	–	–

CARBONATE BOMB
1, 46–47 cm = 52%
2, 46–47 cm = 49%
3, 46–47 cm = 52%

SITE 504 HOLE CORE (HPC) 31 CORED INTERVAL 142.0–146.4 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FOSSIL CHARACTER			
		FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS
late Pliocene	*N. jouseae*	Fm	Pm	Am	Fp



LITHOLOGIC DESCRIPTION

5Y 7/1–6/2
5Y 7/1–6/2
5Y 6/2
5Y 7/1–7/2
5Y 7/1–6/1
5Y 7/1–6/2

CLAY-BEARING SILICEOUS NANNOFOSSIL OOZE

- Basic color: light gray to light olive gray (5Y 7/1 to 5Y 6/2).
- Bioturbation intense.
- Many large "halos" around burrows with light grayish (N7) to gray (N6) rinds referring to pyrite; also to spots and streaks.

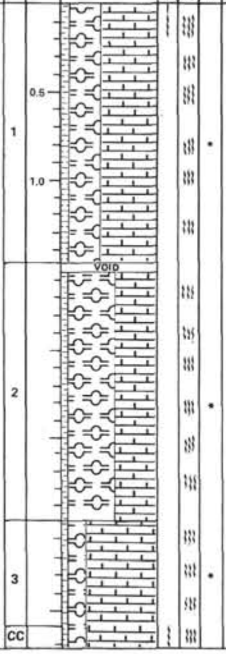
SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze	Clay-bearing siliceous nannofossil ooze
	1-113	2-22	2-130
Feldspar	–	TR	–
Pyrite	2	TR	TR
Clay minerals	10	10	20
Volcanic glass (lt)	TR	TR	TR
Zeolites	TR	TR	–
Carbonate unspec.	20	20	30
Calc. nannofossils	41	38	28
Diatoms	10	10	8
Radiolarians	10	10	7
Sponge spicules	5	10	5
Silicoflagellates	2	2	2

CARBONATE BOMB
1, 46–47 cm = 67%
2, 46–47 cm = 55%

SITE 504 HOLE CORE (HPC) 32 CORED INTERVAL 146.4–150.8 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FOSSIL CHARACTER			
		FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS
late Pliocene	*N. jouseae*	Fp	Fp	Am	Fp



LITHOLOGIC DESCRIPTION

5Y 7/1
5Y 7/1–6/2
5Y 7/1
5Y 7/1–6/2
5Y 7/1
5Y 7/1–6/2
5Y 7/1

CLAY-BEARING SILICEOUS NANNOFOSSIL CHALK

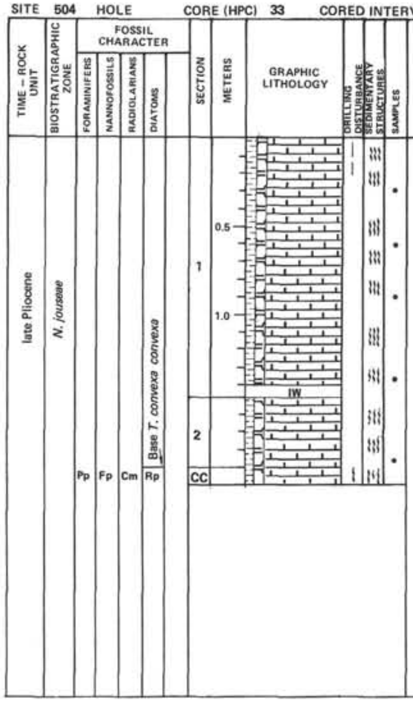
- Basic color: light gray to gray (5Y 7/1 to 5Y 6/2).
- Bioturbation intense.
- Many large "halos" with dark to light gray (N5–7) rinds referring to pyrite, also present as spots and streaks.
- Prominent vertical burrow between 3.40–3.53 m.
- Orientation of most of the burrows mainly horizontal.

SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk
	1-80	2-81	3-30
Pyrite	TR	1	TR
Clay minerals	10	10	10
Volcanic glass (lt)	TR	TR	TR
Carbonate unspec.	15	25	10
Calc. nannofossils	45	30	70
Diatoms	10	10	3
Radiolarians	8	10	3
Sponge spicules	7	10	3
Silicoflagellates	5	4	1

CARBONATE BOMB
1, 46–47 cm = 68%
2, 46–47 cm = 64%
3, 46–47 cm = 75%

SITE 504 HOLE CORE (HPC) 33 CORED INTERVAL 150.8–155.2 m



LITHOLOGIC DESCRIPTION

5Y 7/1–10G 8/2

5Y 6/1–5G 7/2

5Y 7/1–10G 8/2

CLAY-BEARING SILICEOUS NANNOFOSSIL CHALK

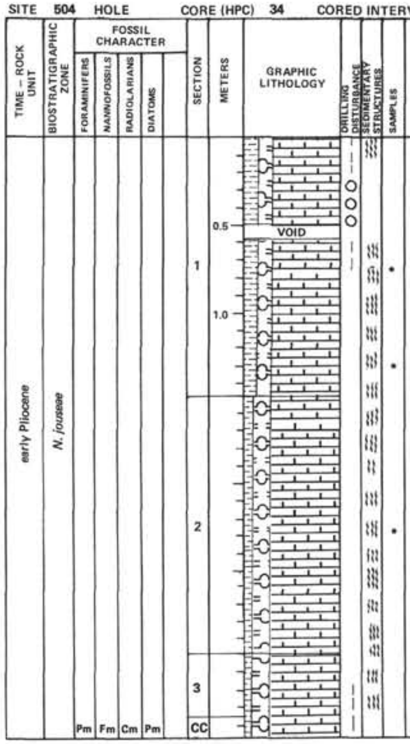
- Basic color: light gray to very pale green (5Y 7/1 to 10G 8/2).
- Bioturbation intense.
- "Halos" with grayish blue (5PB 5/2) to dusky blue (5PB 3/2) rinds referring to pyrite; also pyritic streaks and spots are very common.

SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk
	1-30	1-61	1-90	1-136	2-37
Pyrite	TR	TR	1	TR	TR
Other heavy minerals	–	–	–	–	TR
Clay minerals	10	10	10	10	10
Volcanic glass (lt)	TR	TR	TR	TR	TR
Carbonate unspec.	10	20	10	20	20
Calc. nannofossils	70	55	70	55	60
Diatoms	4	6	3	5	3
Radiolarians	3	5	3	5	3
Sponge spicules	2	3	2	3	3
Silicoflagellates	1	1	1	2	1

CARBONATE BOMB
1, 46–47 cm = 66%

SITE 504 HOLE CORE (HPC) 34 CORED INTERVAL 155.2–159.6 m



LITHOLOGIC DESCRIPTION

5Y 7/1–10G 8/2

5GY 5/2–5GY 3/2

5Y 7/1–10G 8/2

5Y 7/1–10G 8/2

10GY 5/2

5Y 7/1–10G 8/2

SILICEOUS NANNOFOSSIL CHALK

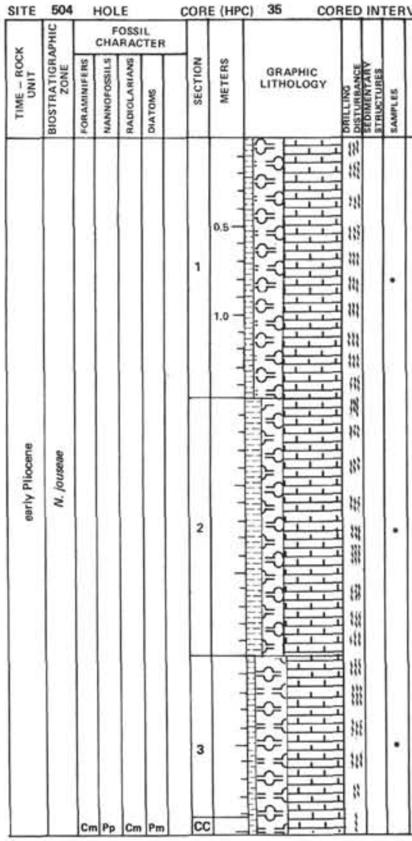
- Basic color: light gray to very pale green (5Y 7/1 to 10G 8/2) with transitions into dusky yellow green to grayish olive green (5GY 5/2 to 5GY 3/2) and grayish green (10GY 5/2).
- Bioturbation intense.
- "Halos" with dusky blue (5PB 3/2) rinds referring to pyrite common.
- Dusky blue (5PB 3/2) spots and streaks refer to pyrite.

SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk
	1-75	1-130	2-78
Pyrite	TR	TR	TR
Clay minerals	10	20	10
Volcanic glass (lt)	TR	–	–
Carbonate unspec.	30	20	30
Calc. nannofossils	45	45	40
Diatoms	6	5	8
Radiolarians	5	4	6
Sponge spicules	3	3	4
Silicoflagellates	1	3	2

CARBONATE BOMB
1, 86–87 cm = 50%
2, 46–47 cm = 69%

SITE 504 HOLE CORE (HPC) 35 CORED INTERVAL 159.6–164.0 m



LITHOLOGIC DESCRIPTION

5Y 7/1–
10GY 7/2

5Y 6/2–
10GY 7/2

5Y 7/1–
10GY 7/2

5Y 6/2–
10GY 7/2

5Y 7/1–
10G 7/2

5Y 7/1–5G 7/2

CLAY-BEARING SILICEOUS NANNOFOSSIL CHALK

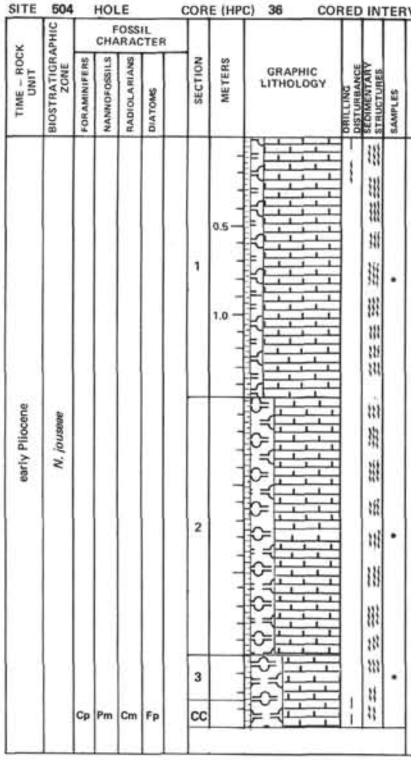
- Basic color: light gray to pale yellow green (5Y 7/1 to 10GY 7/2) with transitions to gray (5Y 6/2) and pale green (5G 7/2).
- Bioturbation intense.
- "Halos" around burrows with gray (N4–7) and grayish blue (5PB 5/2) rinds referring to pyrite.
- Gray and grayish blue streaks and spots.
- Prominent approximately vertical burrows at 0.93–1.00 m and 2.45–2.60 m.
- Subhorizontal burrows frequent.

SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk
	1-80	2-77	3-50
Pyrite	TR	TR	TR
Clay minerals	10	15	10
Volcanic glass (lt)	TR	TR	TR
Carbonate unspec.	20	26	15
Calc. nannofossils	42	35	50
Diatoms	10	10	10
Radiolarians	10	10	10
Sponge spicules	5	3	4
Silicoflagellates	3	1	1

CARBONATE BOMB
1, 46–47 cm = 55%
2, 46–47 cm = 54%
3, 46–47 cm = 62%

SITE 504 HOLE CORE (HPC) 36 CORED INTERVAL 164.0–168.4 m



LITHOLOGIC DESCRIPTION

5Y 7/1–
10G 8/2

10G 8/2

5G 8/1–
10G 8/2

CLAY-BEARING SILICEOUS NANNOFOSSIL CHALK

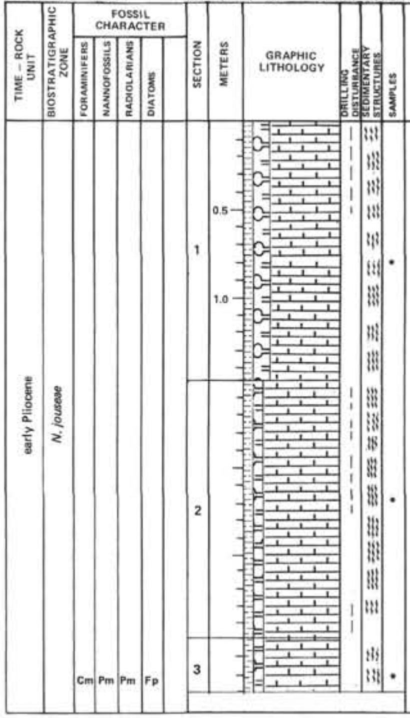
- Basic color: very pale green (10G 8/2) with transitions to light gray (5Y 7/1) and light greenish gray (5G 8/1).
- Bioturbation intense.
- "Halos" around burrows with grayish purple (5P 4/2) to dusky blue (5PB 3/2) rinds common between 1.50–3.00 m; refer to pyrite.
- Dusky blue streaks and spots refer to pyrite.
- Burrows mainly subhorizontal.

SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk
	1-80	2-80	3-15
Pyrite	TR	TR	TR
Other heavy minerals	–	–	TR
Clay minerals	10	10	10
Volcanic glass (lt)	TR	TR	TR
Carbonate unspec.	10	30	30
Calc. nannofossils	79	40	37
Diatoms	5	10	10
Radiolarians	3	7	8
Sponge spicules	2	2	3
Silicoflagellates	1	1	2
Mica	TR	–	–

CARBONATE BOMB
1, 47–48 cm = 76%
2, 47–48 cm = 68%

SITE 504 HOLE CORE (HPC) 37 CORED INTERVAL 168.4–172.8 m



LITHOLOGIC DESCRIPTION

5G 7/1–
10G 8/2

CLAY-BEARING SILICEOUS NANNOFOSSIL CHALK

- Basic color: light greenish gray to very pale green (5G 7/1 to 10G 8/2).
- Bioturbation intense.
- Prominent vertical burrow between 2.50–2.65 m.
- Grayish purple (5P 4/2) streaks, spots, and "halo" rinds around burrows refer to pyrite.
- Subhorizontal burrows frequent between 2.50–2.80 m.

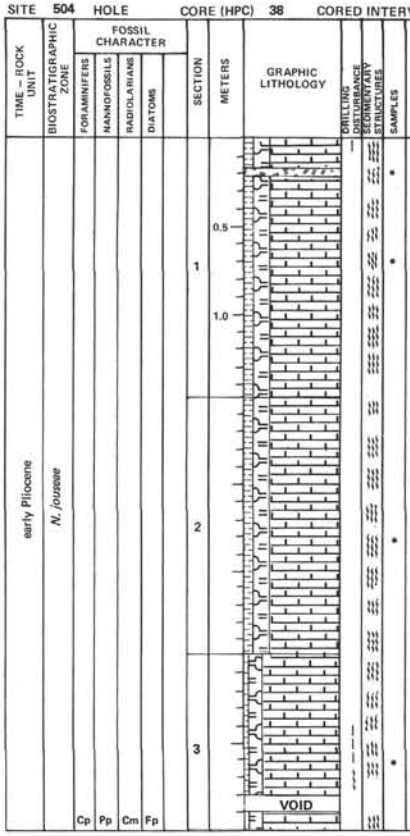
SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk
	1-80	2-70	3-20
Pyrite	TR	TR	TR
Other heavy minerals	TR	TR	–
Clay minerals	10	10	10
Volcanic glass (lt)	1	TR	1
Carbonate unspec.	20	30	35
Foraminifers	3	2	–
Calc. nannofossils	50	45	40
Diatoms	7	5	5
Radiolarians	4	5	5
Sponge spicules	2	1	2
Silicoflagellates	2	2	2

CARBONATE BOMB

1, 47–48 cm = 66%
2, 47–48 cm = 71%

SITE 504 HOLE CORE (HPC) 38 CORED INTERVAL 172.8–177.2 m



LITHOLOGIC DESCRIPTION

5GY 4/1

5G 7/1–
10G 8/2

CLAY-BEARING SILICEOUS NANNOFOSSIL CHALK

- Basic color: light greenish gray to very pale green (5G 7/1 to 10G 8/2).
- Redistributed dark greenish gray (5GY 4/1) volcanic ash layer between 0.17–0.21 cm.
- Bioturbation intense.
- Horizontal burrows frequent between 0.20–1.50 m and 1.80–1.95 m.
- Nearly round burrows between 2.40–2.50 m.
- Streaks, spots, and "halo" rinds with gray and purple hues frequent.

SMEAR SLIDE SUMMARY

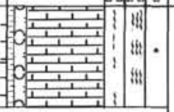
	Ash	Clay-bearing siliceous nannofossil chalk	Siliceous nannofossil chalk	Siliceous nannofossil chalk
	1-19	1-70	2-80	3-60
Pyrite	5	TR	1	TR
Other heavy minerals	–	–	TR	TR
Clay minerals	–	10	5	5
Volcanic glass (lt)	90	TR	2	1
Carbonate unspec.	–	25	20	20
Calc. nannofossils	–	50	50	60
Diatoms	5	8	10	5
Radiolarians	–	5	7	5
Sponge spicules	–	1	3	2
Silicoflagellates	–	2	2	2

CARBONATE BOMB

1, 47–48 cm = 79%
2, 47–48 cm = 69%
3, 47–48 cm = 78%

SITE 504 HOLE CORE (HPC) 39 CORED INTERVAL 177.2–181.6 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FOSSIL CHARACTER: FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS
early Pliocene	*N. jouseae*	Cm	Pp	Cm	Fm	1 CC	0.5



LITHOLOGIC DESCRIPTION

5G 7/1

SILICEOUS NANNOFOSSIL CHALK

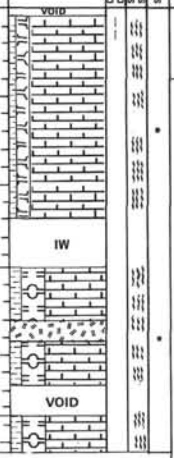
- Basic color: light greenish gray (5G 7/1).
- Bioturbation intense.
- Purple and gray streaks and spots.

SMEAR SLIDE SUMMARY

	Siliceous nannofossil chalk
	1-24
Pyrite	TR
Clay minerals	5
Volcanic glass (lt)	TR
Carbonate unspec.	35
Calc. nannofossils	48
Diatoms	5
Radiolarians	5
Sponge spicules	1
Silicoflagellates	1

SITE 504 HOLE CORE (HPC) 40 CORED INTERVAL 181.6–186.0 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FOSSIL CHARACTER: FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS
early Pliocene	*N. jouseae*	Pm	Pp	Cg	Pp	1 2 CC	0.5 1.0



LITHOLOGIC DESCRIPTION

5Y 7/2

5GY 8/1

SILICEOUS NANNOFOSSIL OOZE

- Basic color: light gray to light greenish gray (5Y 7/2 to 5GY 8/1).
- Somewhat dispersed gray volcanic ash layer between 1.80–1.93 m.
- Bioturbation intense.
- Streaks, spots, and "halo" rinds in gray and faint purple hues.

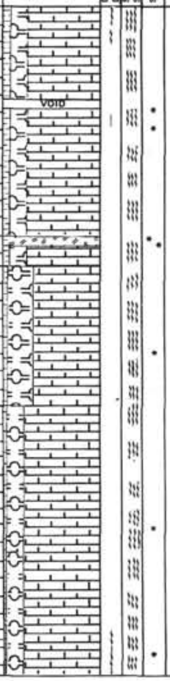
SMEAR SLIDE SUMMARY

	Siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk
	1-70	2-40
Pyrite	TR	TR
Other heavy minerals	TR	–
Clay minerals	5	10
Volcanic glass (lt)	–	TR
Carbonate unspec.	20	5
Calc. nannofossils	60	60
Diatoms	8	10
Radiolarians	5	8
Sponge spicules	2	5
Silicoflagellates	–	2

CARBONATE BOMB
1, 47–48 cm = 73%
2, 47–48 cm = 69%

SITE 504 HOLE CORE (HPC) 41 CORED INTERVAL 186.0–190.0 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FOSSIL CHARACTER: FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS
early Pliocene	*N. jouseae*	Cm	Pp	Cm	Fp	1 2 3 CC	0.5 1.0



LITHOLOGIC DESCRIPTION

5GY 7/1

N3
5GY 7/1

5Y 7/2

5GY 8/1

SILICEOUS NANNOFOSSIL CHALK

- Basic color: 0.0–1.75 m – light greenish gray to light gray (5GY 7/1 to 5Y 7/2); 1.75–3.88 m – light greenish gray (5GY 8/1).
- Dark gray (N3) volcanic ash layer between 1.32–1.36 m.
- Bioturbation intense.
- Horizontal burrows between 1.85–1.97 m.
- "Halos" with gray and purple rinds around burrows frequent between 0.10–1.30 m.
- Streaks and spots with gray and purple hues throughout the core.

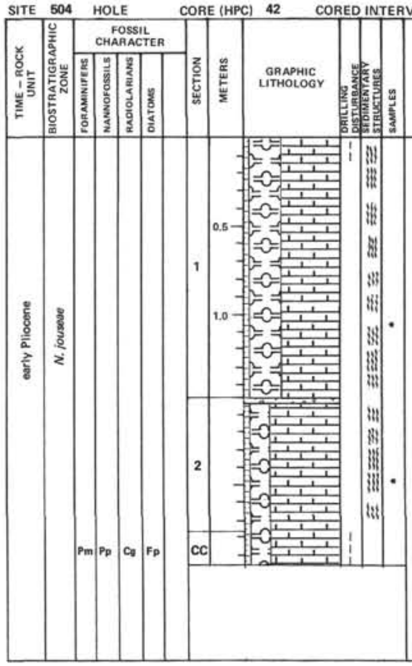
SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk	Siliceous nannofossil chalk	Ash	Siliceous nannofossil chalk	Siliceous nannofossil chalk
	1-58	1-70	1-132	1-135	2-50	3-70
Pyrite	TR	–	–	5	1	TR
Clay minerals	10	10	10	–	5	5
Volcanic glass (lt)	–	TR	–	95	TR	TR
Carbonate unspec.	10	15	–	–	15	25
Foraminifers	–	–	–	–	3	2
Calc. nannofossils	61	50	60	–	50	55
Diatoms	10	8	10	–	10	5
Radiolarians	6	7	5	–	10	5
Sponge spicules	2	5	4	–	3	2
Silicoflagellates	1	5	1	–	2	1

CARBONATE BOMB
1, 47–48 cm = 78%
2, 44–45 cm = 67%
3, 47–48 cm = 84%

Important:
Section 2 is only 80 cm long, but is continuous with Section 3.

SITE 504 HOLE CORE (HPC) 42 CORED INTERVAL 190.0–194.0 m



LITHOLOGIC DESCRIPTION

5GY 8/1

SILICEOUS NANNOFOSSIL CHALK

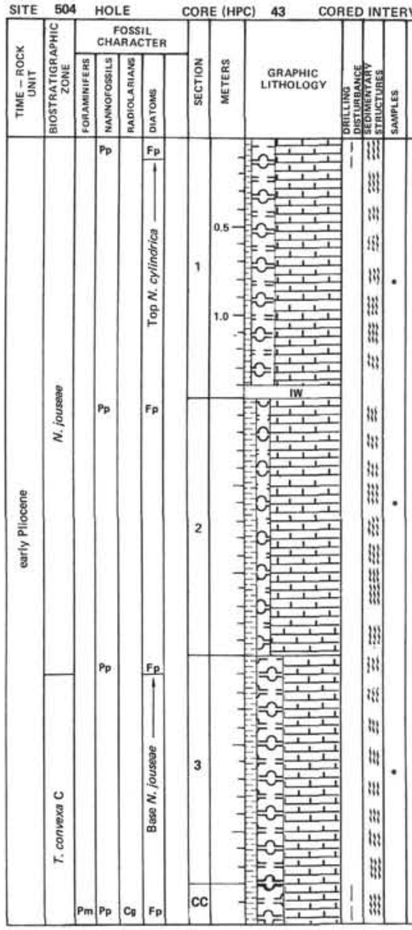
- Basic color: light greenish gray (5GY 8/1).
- Thin gray volcanic ash layer at 1.48 m.
- Bioturbation intense.
- Gray streaks, spots, and "halo" rinds.

SMEAR SLIDE SUMMARY

	Siliceous nannofossil chalk	Siliceous nannofossil chalk
	1-106	2-48
Pyrite	TR	TR
Clay minerals	5	5
Volcanic glass (lt)	TR	TR
Carbonate unspec.	20	10
Foraminifers	2	–
Calc. nannofossils	45	65
Diatoms	10	8
Radiolarians	8	7
Sponge spicules	2	3
Silicoflagellates	8	2

CARBONATE BOMB
1, 47–48 cm = 88%
2, 47–48 cm = 80%

SITE 504 HOLE CORE (HPC) 43 CORED INTERVAL 194.0–198.0 m



LITHOLOGIC DESCRIPTION

5GY 8/1

5GY 7/2–8/1

SILICEOUS NANNOFOSSIL CHALK

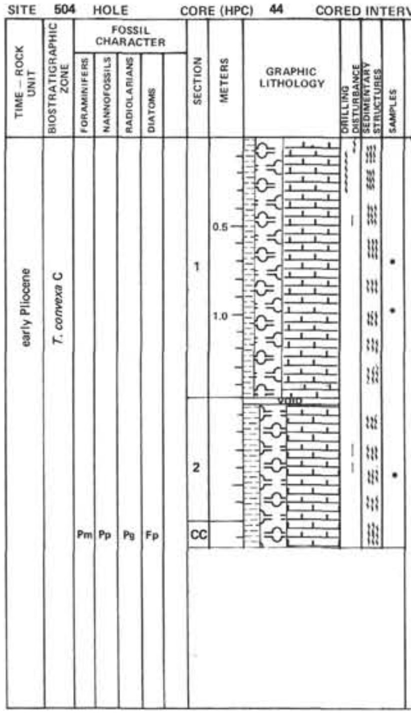
- Basic color: light greenish gray (5GY 8/1) with transitions to grayish yellow green (5GY 7/2) between 3.00–4.32 m.
- Bioturbation intense.
- Many tiny burrows between 3.35–3.70 m.
- Streaks, spots, and "halo" rinds around burrows throughout the core.

SMEAR SLIDE SUMMARY

	Siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk
	1-80	2-60	3-67
Pyrite	TR	TR	–
Other heavy minerals	TR	TR	–
Clay minerals	5	10	10
Volcanic glass (lt)	TR	TR	TR
Carbonate unspec.	20	10	8
Foraminifers	1	3	–
Calc. nannofossils	50	60	60
Diatoms	10	7	8
Radiolarians	10	6	6
Sponge spicules	2	2	3
Silicoflagellates	2	2	5

CARBONATE BOMB
1, 47–48 cm = 74%
2, 47–48 cm = 79%
3, 47–48 cm = 78%

SITE 504 HOLE CORE (HPC) 44 CORED INTERVAL 198.0–202.0 m



LITHOLOGIC DESCRIPTION

5GY 8/1

5GY 7/2

5GY 8/1

5GY 9/2

5GY 8/1

CLAY-BEARING SILICEOUS NANNOFOSSIL CHALK

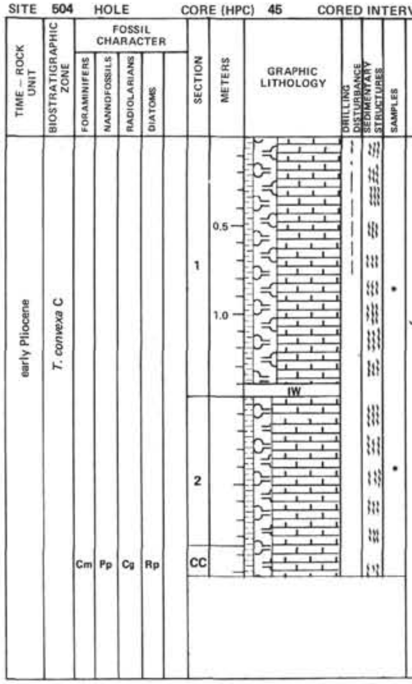
- Basic color: light greenish gray to grayish yellow green (5GY 8/1 to 5GY 7/2).
- Bioturbation intense.
- Pale purple and gray streaks, spots, and "halo" rinds throughout the core.
- Many small burrows between 1.36–1.50 m.
- Scattered horizontal burrows.

SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk
	1-70	1-99	2-42
Pyrite	–	TR	TR
Clay minerals	15	10	15
Carbonate unspec.	10	10	10
Foraminifers	2	–	3
Calc. nannofossils	55	55	55
Diatoms	10	10	8
Radiolarians	8	8	6
Sponge spicules	2	3	1
Silicoflagellates	3	5	2

CARBONATE BOMB
1, 47–48 cm = 65%
2, 47–48 cm = 83%

SITE 504 HOLE CORE (HPC) 45 CORED INTERVAL 202.0–206.0 m



LITHOLOGIC DESCRIPTION

5GY 8/1–
5G 8/1

CLAY-BEARING SILICEOUS NANNOFOSSIL CHALK

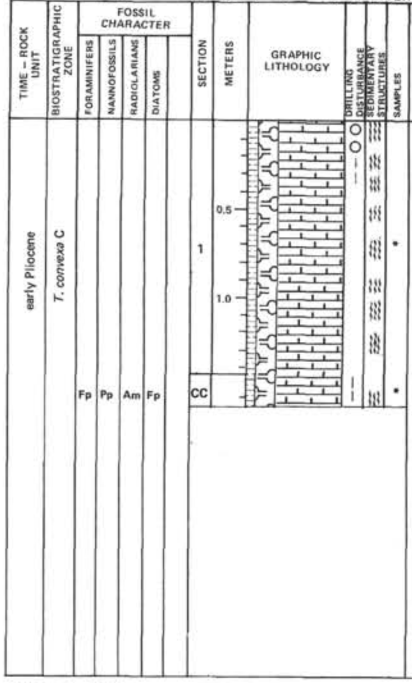
- Basic color: light greenish gray (5GY 8/1–5G 8/1).
- Bioturbation intense.
- Burrows light olive gray (5Y 6/1).
- Streaks, spots, and "halo" rinds gray and faint purple.

SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk
	1-85	2-40
Pyrite	TR	TR
Other heavy minerals	TR	TR
Clay minerals	10	10
Volcanic glass (lt)	TR	TR
Carbonate unspec.	10	20
Calc. nannofossils	60	55
Diatoms	8	5
Radiolarians	6	3
Sponge spicules	4	5
Silicoflagellates	2	2

CARBONATE BOMB
1, 47–48 cm = 80%
2, 47–48 cm = 75%

SITE 504 HOLE CORE (HPC) 46 CORED INTERVAL 206.0–210.0 m



LITHOLOGIC DESCRIPTION

5G 8/1–
5GY 8/1

CLAY-BEARING SILICEOUS NANNOFOSSIL CHALK

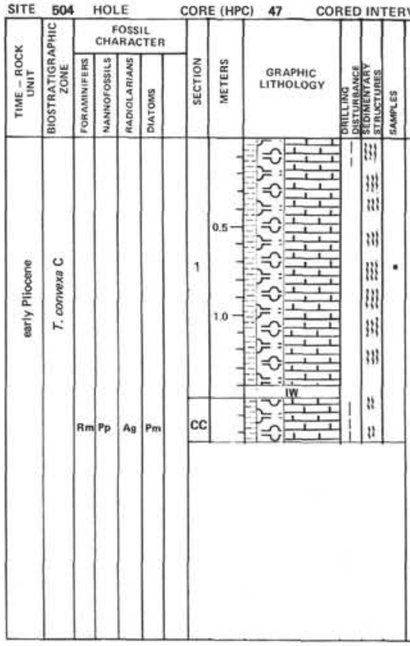
- Basic color: light greenish gray (5G 8/1–5GY 8/1).
- Bioturbation intense.
- Burrows light olive gray (5Y 6/1).
- Streaks, spots, and shaded areas around burrows with purple hues.

SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil chalk
	1-70
Pyrite	TR
Other heavy minerals	TR
Clay minerals	15
Volcanic glass (lt)	TR
Carbonate unspec.	20
Foraminifers	1
Calc. nannofossils	50
Diatoms	5
Radiolarians	4
Sponge spicules	2
Silicoflagellates	3

CARBONATE BOMB
1, 47–48 cm = 80%

SITE 504 HOLE CORE (HPC) 47 CORED INTERVAL 210.0–214.0 m



LITHOLOGIC DESCRIPTION

5G 8/1–
5GY 8/1

CLAY-BEARING SILICEOUS NANNOFOSSIL CHALK

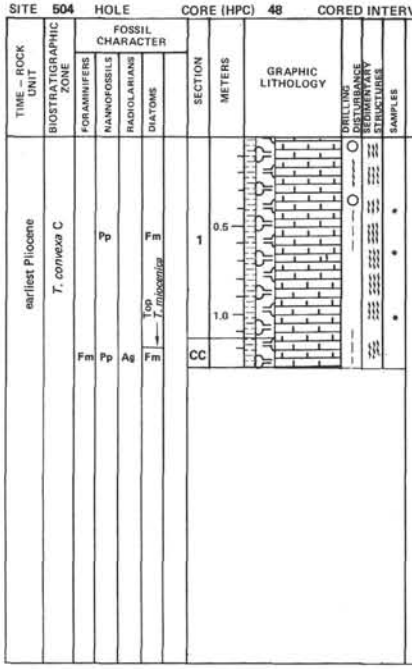
- Basic color: light greenish gray (5G 8/1–5GY 8/1).
- Bioturbation intense.
- Light purple burrow traces and light olive gray (5Y 6/1) burrow fillings.

SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil chalk
	1-70
Pyrite	TR
Clay minerals	15
Volcanic glass (lt)	TR
Carbonate unspec.	10
Foraminifers	3
Calc. nannofossils	45
Diatoms	10
Radiolarians	8
Sponge spicules	5
Silicoflagellates	4

CARBONATE BOMB
1, 47–48 cm = 80%

SITE 504 HOLE CORE (HPC) 48 CORED INTERVAL 214.0–218.0 m



LITHOLOGIC DESCRIPTION

5G 8/1

CLAY-BEARING SILICEOUS NANNOFOSSIL CHALK

- Basic color: light greenish gray (5G 8/1–5GY 8/1).
- Bioturbation intense.
- Subhorizontal burrows frequent between 0.35–0.80 m, marked by purple rinds.
- Prominent vertical "spreiten" burrow with pale green (10GY 6/2) filling between 0.78–0.86 m.

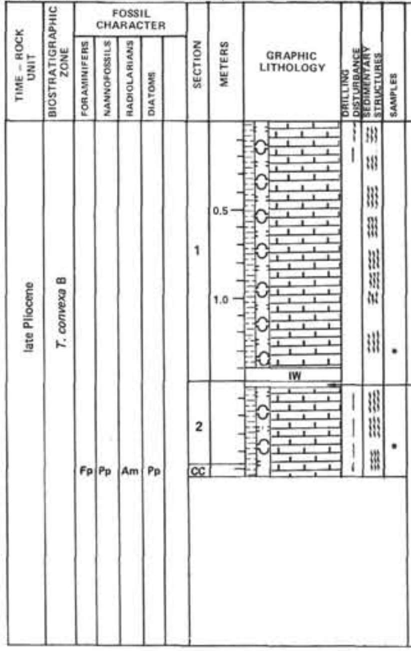
5G 8/1–
5GY 8/1

SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil chalk	Clay-bearing siliceous nannofossil chalk
	1-41	1-100
Pyrite	1	TR
Clay minerals	15	10
Volcanic glass (lt)	TR	–
Carbonate unspec.	5	15
Calc. nannofossils	68	60
Diatoms	8	8
Radiolarians	5	6
Sponge spicules	2	1
Silicoflagellates	1	1
Mica	TR	–

CARBONATE BOMB
1, 47–48 cm = 74%

SITE 504 HOLE CORE (HPC) 49 CORED INTERVAL 218.0–222.0 m



LITHOLOGIC DESCRIPTION

5GY 8/1–
5G 8/1

VOID

CLAY-BEARING SILICEOUS NANNOFOSSIL CHALK

- Basic color: light greenish gray (5GY 8/1–5G 8/1).
- Bioturbation intense.
- Purple and pale green "halos", streaks and spots around burrows.
- Pale olive burrow fillings between 1.20–1.30 m and 150–1.80 m.

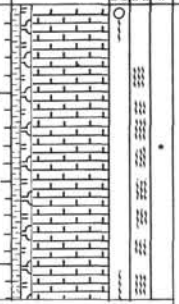
SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil chalk
	2-36
Pyrite	TR
Clay minerals	10
Carbonate unspec.	10
Calc. nannofossils	65
Diatoms	8
Radiolarians	5
Sponge spicules	1
Silicoflagellates	1

CARBONATE BOMB
1, 47–48 cm = 78%

SITE 504 HOLE CORE (HPC) 50 CORED INTERVAL 222.0–226.0 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS
late Miocene	*T. convexa* B	Pm	Pp	Ag	Pp	1 2	0.5 1.0



LITHOLOGIC DESCRIPTION

5GY 8/1–
5G 8/1

CLAY-BEARING SILICEOUS NANNOFOSSIL CHALK

- Basic color: light greenish gray (5GY 8/1–6G 8/1).
- Light olive (5Y 6/1) intercalation between 0.68–0.80 m and 1.47–1.50 m.
- Bioturbation intense.
- Dusky grayish, purple, and pale green shades around burrows.

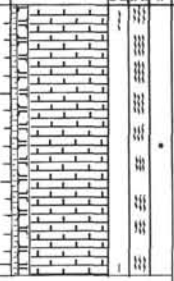
SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil chalk
	1-80
Clay minerals	10
Volcanic glass (lt)	TR
Carbonate unspec.	10
Calc. nannofossils	70
Diatoms	2
Radiolarians	2
Sponge spicules	5
Silicoflagellates	1

CARBONATE BOMB
1, 46–47 cm = 77%

SITE 504 HOLE CORE (HPC) 51 CORED INTERVAL 226.0–230.0 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS
late Miocene	*T. convexa* B	Pm	Pp	Cg	Pp	1 CC	0.5 1.0



LITHOLOGIC DESCRIPTION

5GY 8/1–
5G 8/1

CLAY-BEARING SILICEOUS NANNOFOSSIL CHALK

- Basic color: light greenish gray (5GY 8/1–5G 8/1).
- Olive (5Y 6/2) intercalation between 0.20–0.45 cm.
- Bioturbation intense.
- Purple and pale green shades around burrows.
- Subhorizontal burrows frequent between 0.50–0.85 m.

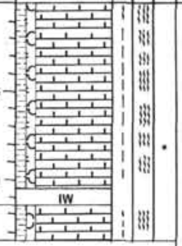
SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil chalk
	1-80
Pyrite	TR
Clay minerals	10
Volcanic glass (lt)	TR
Carbonate unspec.	10
Calc. nannofossils	65
Diatoms	6
Radiolarians	3
Sponge spicules	5
Silicoflagellates	1
Mica	TR

CARBONATE BOMB
1, 46–47 cm = 71%

SITE 504 HOLE CORE (HPC) 52 CORED INTERVAL 230.0–234.0 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS
late Miocene	*T. convexa* B	Rm	Pp	Fm	Cm	1 CC	0.5 1.0



LITHOLOGIC DESCRIPTION

5G 8/1–
5G 6/1

5G 8/1

CLAY-BEARING SILICEOUS NANNOFOSSIL OOZE

- Basic color: light greenish gray–greenish gray (5G 8/1–5G 6/1).
- Bioturbation intense.
- Subhorizontal burrows frequent between 0.10–1.06 m.
- Tiny burrows between 0.20–0.30 m.
- Purple and pale green shades around burrows.

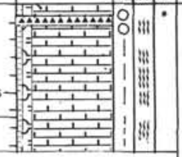
SMEAR SLIDE SUMMARY

	Clay-bearing siliceous nannofossil chalk
	1-80
Pyrite	TR
Clay minerals	10
Volcanic glass (lt)	TR
Carbonate unspec.	5
Calc. nannofossils	70
Diatoms	7
Radiolarians	5
Sponge spicules	2
Silicoflagellates	1

CARBONATE BOMB
1, 46–47 cm = 82%

SITE 504 HOLE CORE (HPC) 53 CORED INTERVAL 234.0–237.0 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS
late Miocene	*T. convexa* B	Fp	Pp	Ag	Cg	1 CC	0.5



LITHOLOGIC DESCRIPTION

5Y 5/1

5GY 8/1

5G 8/1

SILICEOUS NANNOFOSSIL CHALK
WITH CHERT–LIMESTONE

- Basic color: chalk, light green gray (5GY 8/1–5G 8/1). Chert–limestone, gray (5Y 5/1).
- Bioturbation in chalk intense.
- Light gray (N7) shades around burrow.

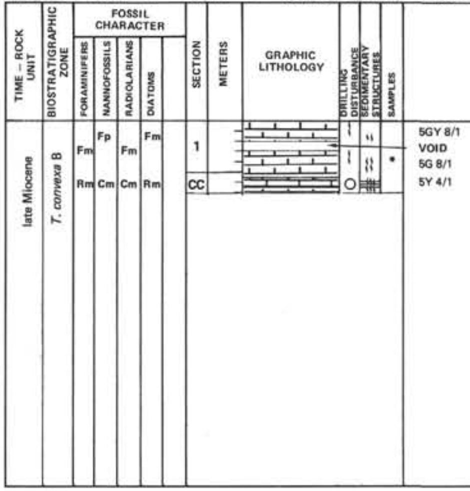
SMEAR SLIDE SUMMARY

	Siliceous nannofossil chalk
	1-6
Clay minerals	5
Carbonate unspec.	10
Calc. nannofossils	70
Diatoms	8
Radiolarians	4
Sponge spicules	2
Silicoflagellates	1

CARBONATE BOMB
1, 32–33 cm = 71%

NOTE: Core 54, 237.0 m: NO RECOVERY.

SITE 504 HOLE A CORE 1 CORED INTERVAL 226.5–236.0 m



LITHOLOGIC DESCRIPTION

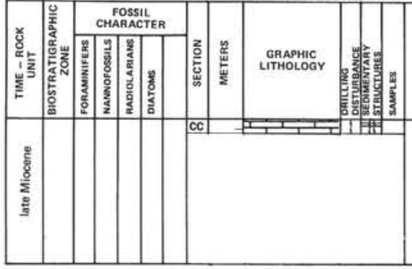
NANNOFOSSIL CHALK

- Basic color: light greenish gray (5GY 8/1, 5G 8/1).
- Inclusion of silicified olive gray (5Y 4/1) laminated limestone between 50 and 70 cm with medium dark gray (N4) chert zones.
- Bioturbation in both lithologies moderate to intense.
- Limestone to about 80% compacted as deduced from vertical compression of burrows.

SMEAR SLIDE SUMMARY

	1-40 M
Carbonate unspec.	5
Calc. nannofossils	80
Foraminifers	TR
Diatoms	1
Radiolarians	TR
Silicoflagellates	TR
Sponge spicules	10
Total detritals	TR
Volcanic glass	TR
Pyrite	1

SITE 504 HOLE A CORE 2 CORED INTERVAL 236.0–245.5 m

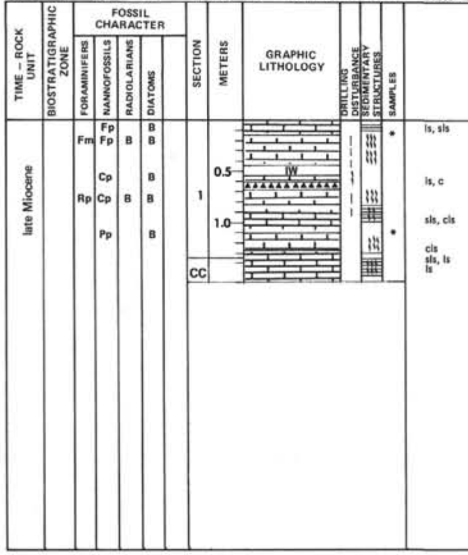


LITHOLOGIC DESCRIPTION

LIMESTONE

- Basic color: light greenish gray (5GY 8/1) to yellowish gray (5Y 8/1) with shades of light gray (N7) and medium dark gray (N4).
- Burrows abundant and extremely flattened by compaction.
- Lamination due to compacted burrows and differentiation in silicification.

SITE 504 HOLE A CORE 3 CORED INTERVAL 245.5–255.5 m



LITHOLOGIC DESCRIPTION

LIMESTONE (ls), PARTIALLY SILICIFIED (sls), AND CHERTY (cls); NANNOFOSSIL CHALK; CHERT (c)

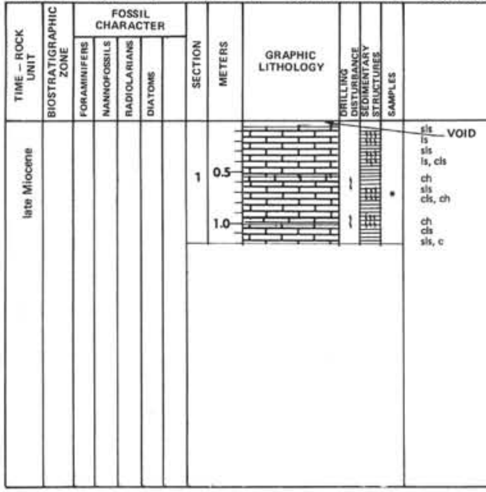
- Basic color: light greenish gray (5GY 8/1) and yellowish grey (5Y 8/1) for chalk and limestones, light gray (N7) and medium dark gray (N4) for chert.
- Burrows abundant in chalk and limestone.
- Burrows in limestone vertically compacted.
- Limestones horizontally laminated (compacted burrows and different stages of silicification).

SMEAR SLIDE SUMMARY

	Chalk 1-18 M	Chalk[a] 1-110
Carbonate unspec.	50	40
Calc. nannofossils	40	55
Foraminfiers	10	–
Clay minerals	TR	5
Mica	TR	–

[a] No siliceous debris

SITE 504 HOLE A CORE 4 CORED INTERVAL 255.0–261.0 m



LITHOLOGIC DESCRIPTION

LIMESTONE (ls), PARTIALLY SILICIFIED (sls), AND CHERTY (cls); NANNOFOSSIL CHALK (ch); CHERT (c)

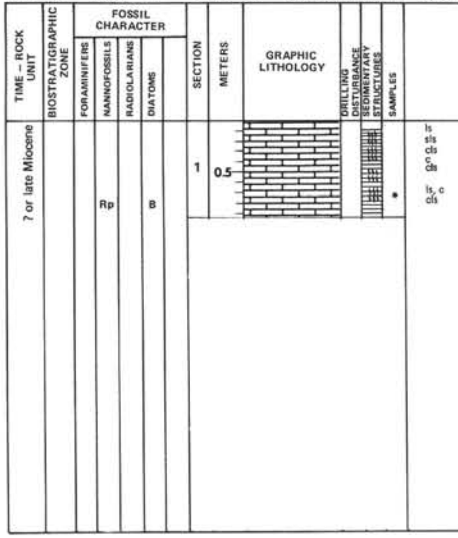
- Basic color: light greenish gray (5GY 8/1) to yellowish gray (5Y 8/1) for chalk and limestone; light gray (N7) to medium dark gray (N4) for cherts and some of the siliceous parts of limestone.
- Bioturbation in chalk intense.
- Burrows in limestone abundant but strongly compacted vertically.
- Limestone horizontally laminated (compacted burrows and different stages of silicification); also flaser bedding.

SMEAR SLIDE SUMMARY

	Chalk 1-75 M
Carbonate unspec.	60
Calc. nannofossils	40

Several isotropic grains (apophyllite?, phillipsite?)

SITE 504 HOLE A CORE 5 CORED INTERVAL 261.0–265.0 m



LITHOLOGIC DESCRIPTION

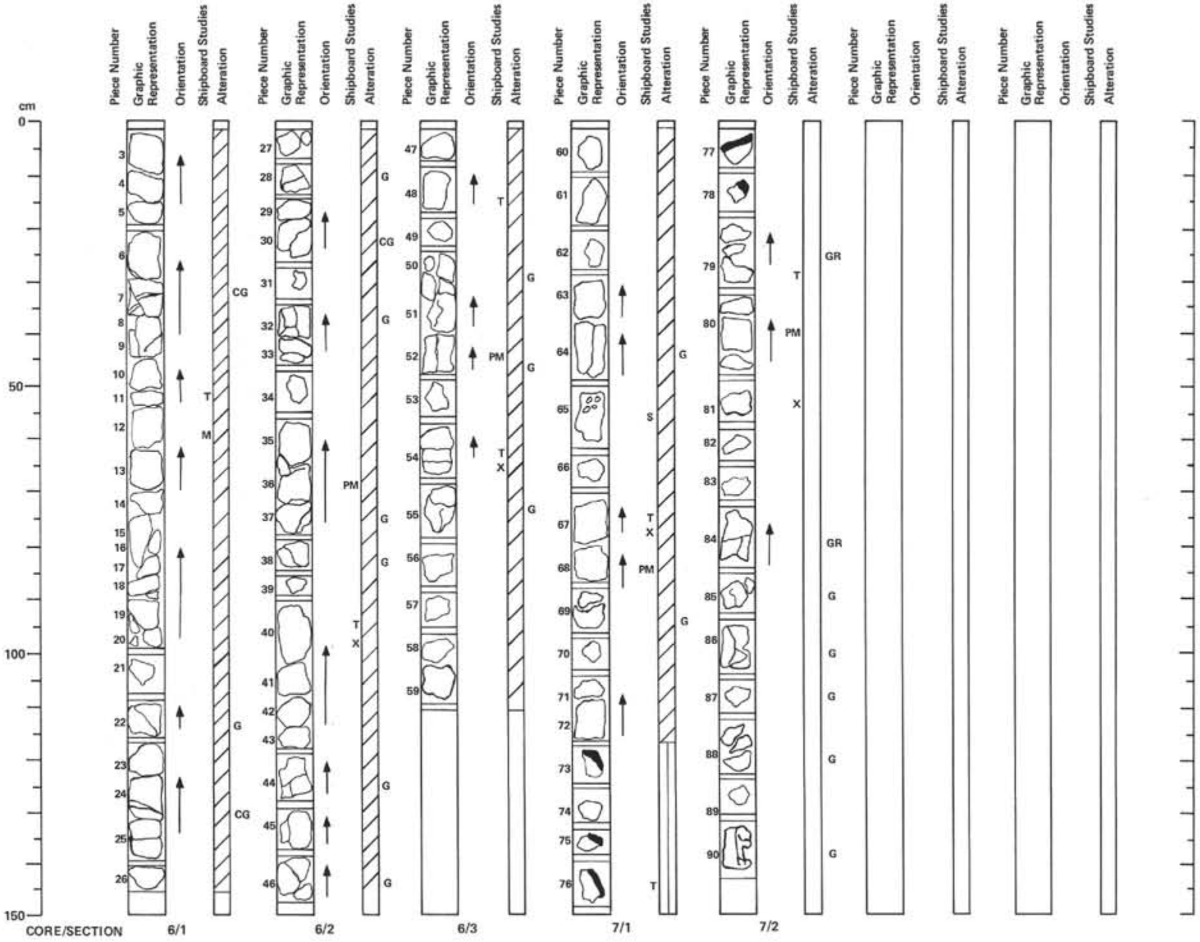
LIMESTONE (ls), PARTIALLY SILICIFIED (sls), AND CHERTY (cls); CHERT (c)

- Basic color: light greenish gray (5GY 8/1) to yellowish gray (5Y 8/1) for limestone; light gray (N7) to medium dark gray (N4) for cherts and some of the siliceous parts of limestone.
- Limestone/chert boundaries sometimes transtional (nebulous appearance).
- Abundant burrows vertically compacted. Compaction measured on Zoophycos burrow: 80%.
- Limestone horizontally laminated (compacted burrows and different stage of silicification).
- Flintstone nodules between 75–80 cm.

SMEAR SLIDE SUMMARY

	Chalk 1-75 M
Carbonate unspec.	80
Calc. nannofossils	18
Foraminifers	2
Clay minerals	TR

(several fragments of chalcedony)



BULK ANALYSIS:

Core-Section	6-1	6-2	6-3	7-1	7-2
Interval (cm)	64–67	96–98	63–65	75–77	51–53
SiO_2	50.29	49.87	50.45	49.56	50.70
TiO_2	1.05	1.06	1.11	1.09	1.12
Al_2O_3	14.60	15.18	15.18	14.98	15.45
Fe_2O_3	11.28	11.01	10.21	11.20	9.22
MnO	0.18	0.18	0.19	0.18	0.18
MgO	7.89	7.96	8.39	8.29	8.56
CaO	12.30	12.49	12.51	12.18	12.30
Na_2O	2.12	2.33	2.16	2.16	2.32
K_2O	0.04	0.21	0.07	0.16	0.04
P_2O_5	0.10	0.09	0.10	0.13	0.10
Total	99.85	100.38	100.37	99.93	99.99
LOI	0.68	0.99	0.95	1.05	1.22
Mg/Mg+Fe	0.581	0.589	0.619	0.594	0.648
Ca/Ca+Al	0.434	0.428	0.428	0.425	0.420
Ni	146	112	72	93	122
Sr	69	73	75	76	78
Zr	63	56	59	59	64
H_2O	0.55	0.80	0.72	0.81	0.87
CO_2	0.05	0.08	0.09	0.05	0.09

PHYSICAL PROPERTIES:

Core-Section, Interval (cm)	Water Content	Porosity	Wet-Bulk	GRAPE	Sonic Velocity
6-1, 53–55	0.60	1.75	3.00	3.06	5.80
6-2, 65–71	2.36	6.63	2.88	2.99	5.22
6-3, 43–45	2.93	8.43	2.94	2.99	5.29
7-1, 78–79	2.99	8.49	2.91	2.97	5.05
7-2, 38–39	1.84	5.30	2.95	2.91	5.29

THERMAL CONDUCTIVITY:

Core-Section, cm	κ
6-1, 47	1.74
6-2, 75	1.66
6-3, 100	1.65
7-1, 0	1.63
7-2, 100	1.60

HOLE 504A, CORE 6 3733.0–3741.0 m (265.0–273.0 mbsf)

SPARSELY PLAGIOCLASE-OLIVINE-CLINOPYROXENE MICROPHYRIC BASALT

Uniform, fairly massive basalt with a few per cent phenocrysts, mainly of plagioclase and olivine, with rarer clinopyroxene. Clinopyroxene phenocrysts are absent in Sections 2 and 3. Olivine phenocrysts are replaced with light green smectite. Vesicles are rare (1%) and small (0.5 mm). Cracks and fracture surfaces are lined with calcite in Section 1, and with green or orange clays elsewhere. Pyrite grains are associated with smectites in Sections 2 and 3. Glassy margins are absent.

Thin Section Descriptions

Sample 6-1, 51–53 cm: Ophitic medium-grained basalt from a flow interior. There are a few per cent plagioclase, clinopyroxene and olivine phenocrysts up to 1.5 mm set in a groundmass dominated by plagioclase and clinopyroxene, with a few per cent olivine and titanomagnetite. There are about 1% vesicles up to 2 mm in diameter filled with smectites. Clays and calcite line veins.

Sample 6-1, 57–59 cm: This sample is virtually identical to 6-1, 51–53 cm.

Sample 6-2, 94–96 cm: This sample resembles the two previously described, except that it contains about 15% plagioclase and 5% clinopyroxene phenocrysts up to 2 mm in diameter.

Sample 6-3, 13–17 cm, Piece 48: The sample is from a flow interior. It is holocrystalline with subophitic texture except between clinopyroxene and plagioclases, where it can be variolitic. There are a few per cent olivine pseudomorphs, rare plagioclase glomerocrysts, and mostly separate crystals of plagioclase and clinopyroxene dividing the groundmass. There are irregular patches of smectite showing strong oxidative staining their cores. There is similar, or reversed, zonation in veins.

Sample 6-3, 61–62 cm: This is a variolitic to microphyric thin section from a flow interior. There are a few per cent olivine crystals, but most of the rock is divided between plagioclase and clinopyroxene. The section includes a vein lined with orange clays, and surrounded by a zone of oxidative orange staining grading away from the crack to non-oxidative green clays.

HOLE 504A, CORE 7 3741.0–3745.0 m (273.0–277.0 mbsf)

SPARSELY PHYRIC TO APHYRIC BASALT

The upper part of Section 1 is a continuation of the basalts in Core 6. Beginning with Piece 73 (117 cm), the core contains a number of chilled margins indicating the presence of pillows. The pillows are more intensely altered than the massive rocks at the top of Section 1. They also contain small plagioclase, olivine, and clinopyroxene phenocrysts. Secondary minerals are smectites replacing olivine and filling veins. In Section 2, there are oxidation zones up to 1 cm wide next to veins. These show a zonation of orange or red, yellow, and dark green smectites from the vein inward.

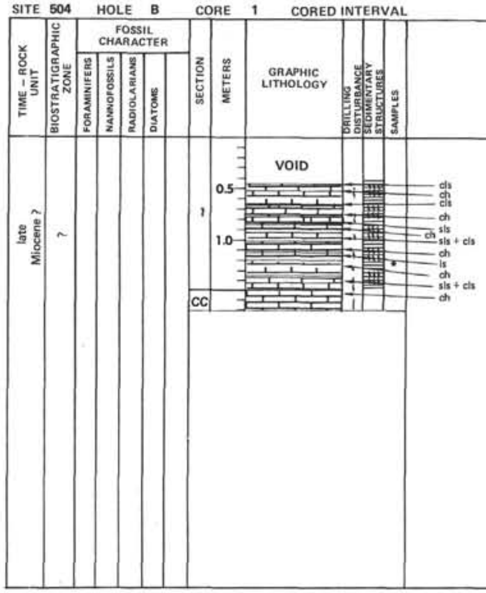
Thin Section Descriptions

Sample 7-1, 75–78 cm: Sample from flow interior. The texture ranges from ophitic to variolitic, with scarce plagioclase and no olivine phenocrysts. The section is about evenly divided between euhedral to skeletal plagioclase, and skeletal to anhedral clinopyroxene, with a small percentage of olivine and about 20% of a spherulitic mesostasis. Olivines are replaced by smectites.

Sample 7-1, 141–145 cm: Sample from pillow rim. The rock is dominantly spherulitic, with less than 5–10% plagioclase (euhedral) and clinopyroxene (skeletal), and rare granular olivine replaced by smectite. Vesicles are up to 1 mm and filled with smectites.

Sample 7-2, 28–30 cm: The sample is from a spherulitic pillow interior, with over 10% plagioclase microphenocrysts, and lesser olivine and clinopyroxene crystals. About 60% of the section is spherulitic mesostasis, with fairly abundant dust-like titanomagnetite. There are traces of chrome spinel. Green smectites replace olivine and fill round vesicles, some of them >1 mm in diameter.

SITE 504 HOLE B CORE 1 CORED INTERVAL



LITHOLOGIC DESCRIPTION

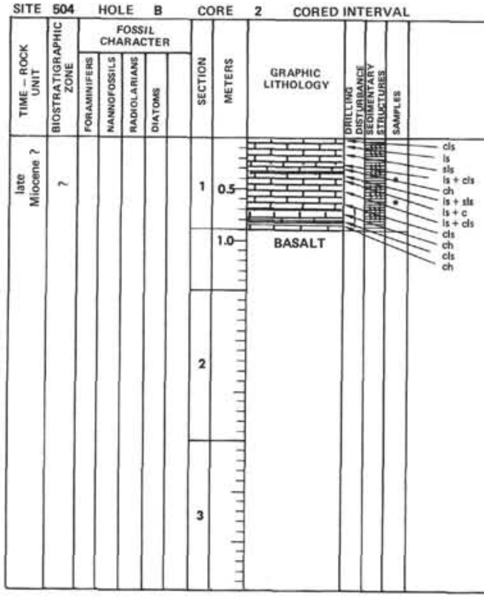
NANNOFOSSIL CHALK (ch) WITH LIMESTONE (ls), PARTIALLY SILICIFIED (sls) OR CHERTY (cls)

- Basic color: light greenish gray (5G 8/1–5GY 8/1) for chalk; grayish yellow green to light greenish gray (5GY 7/2–5G 8/1) and yellowish gray to pale olive (5Y 7/2–10Y 6/2) for limestone; grayish yellow (5GY 7/2) for silicified and light olive gray (5Y 5/2) for cherty limestones.
- All rock types are finely laminated and show intense burrowing.
- Limestones often have very thin chert streaks and lenses included.
- Rock type boundaries often gradational.
- Dusky blue (5PB 3/2) to dark gray (N3) burrow halos frequent.
- At 97 cm dendritic limestone chertification.
- Burrows are strongly compacted even in chalk.

SMEAR SLIDE SUMMARY

	1-125
Pyrite	1
Other heavy minerals	TR
Foraminifers	TR
Calc. nannofossils	86
Diatoms	TR
Radiolarians	3
Sponge spicules	3
Silicoflagellates	1

SITE 504 HOLE B CORE 2 CORED INTERVAL



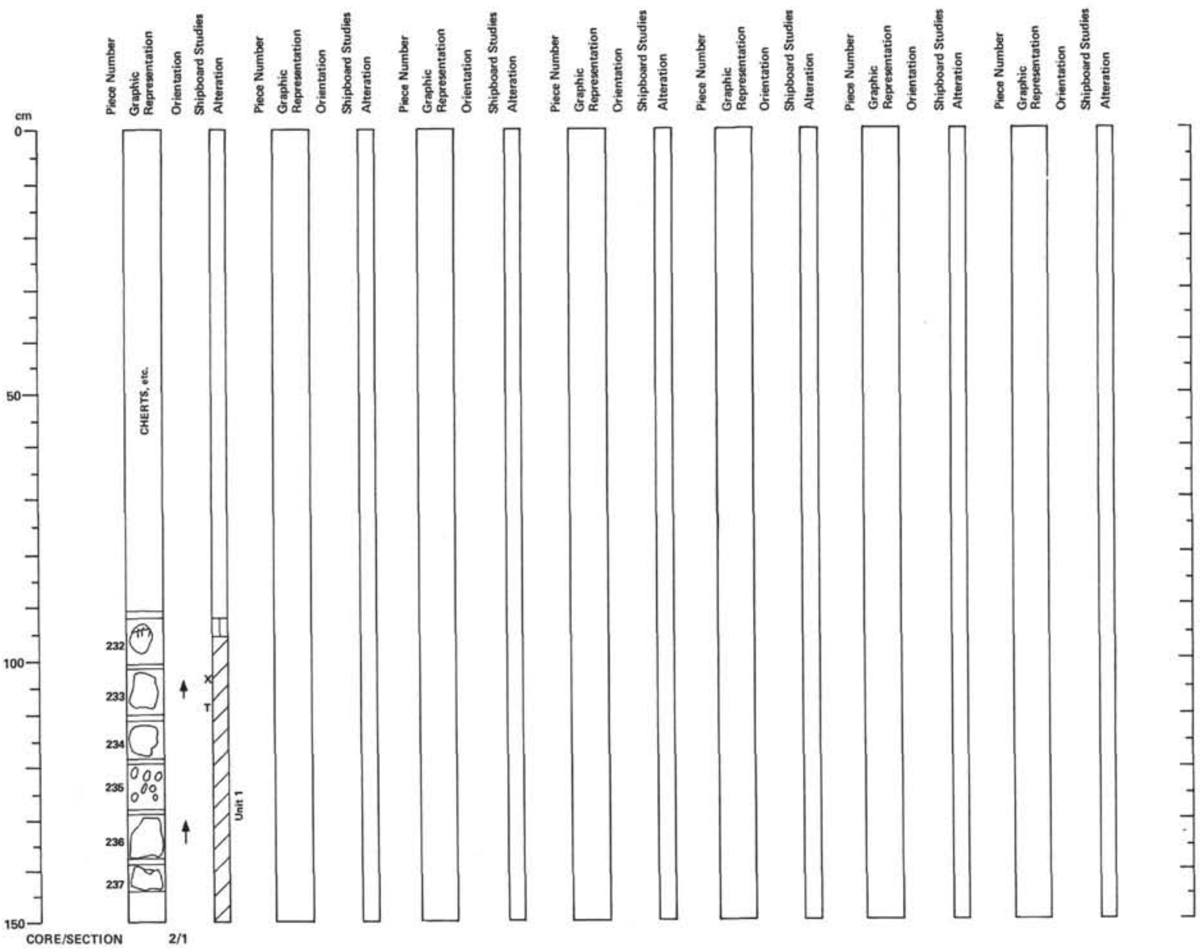
LITHOLOGIC DESCRIPTION

LIMESTONE (ls), PARTIALLY SILICIFIED (sls), AND CHERTY (cls) WITH NANNOFOSSIL CHALK (ch) AND CHERT (c) INTERCALATIONS

- Basic color: yellowish gray to pale olive (5Y 7/2–10Y 6/2) for limestone; olive gray (5Y 4/2) for chert; grayish yellow green (5GY 7/2) for chalk.
- All rock types are finely laminated and show intense burrowing.
- Burrows are strongly compacted even in chalk.
- Purple to bluish gray halos and shades in limestone.
- Various stages of silicification occur.
- Rock type boundaries gradational.

SMEAR SLIDE SUMMARY

	(scraped off from limestone)	(scraped off from limestone)
	1-45	1-62
	M	
Carbonate unspec.	85	30
Calc. nannofossils	5	70
Unspec. silica	5	–
Clay	3	TR
Feldspar	TR	–
Heavy minerals	TR	–



HOLE 504B, CORE 2 **3748.0–3751.5 m (274.5–278.0 mbsf)**

CHERTS, CHERTY LIMESTONES, AND SPARSELY PHYRIC BASALT (lithologic unit 1)

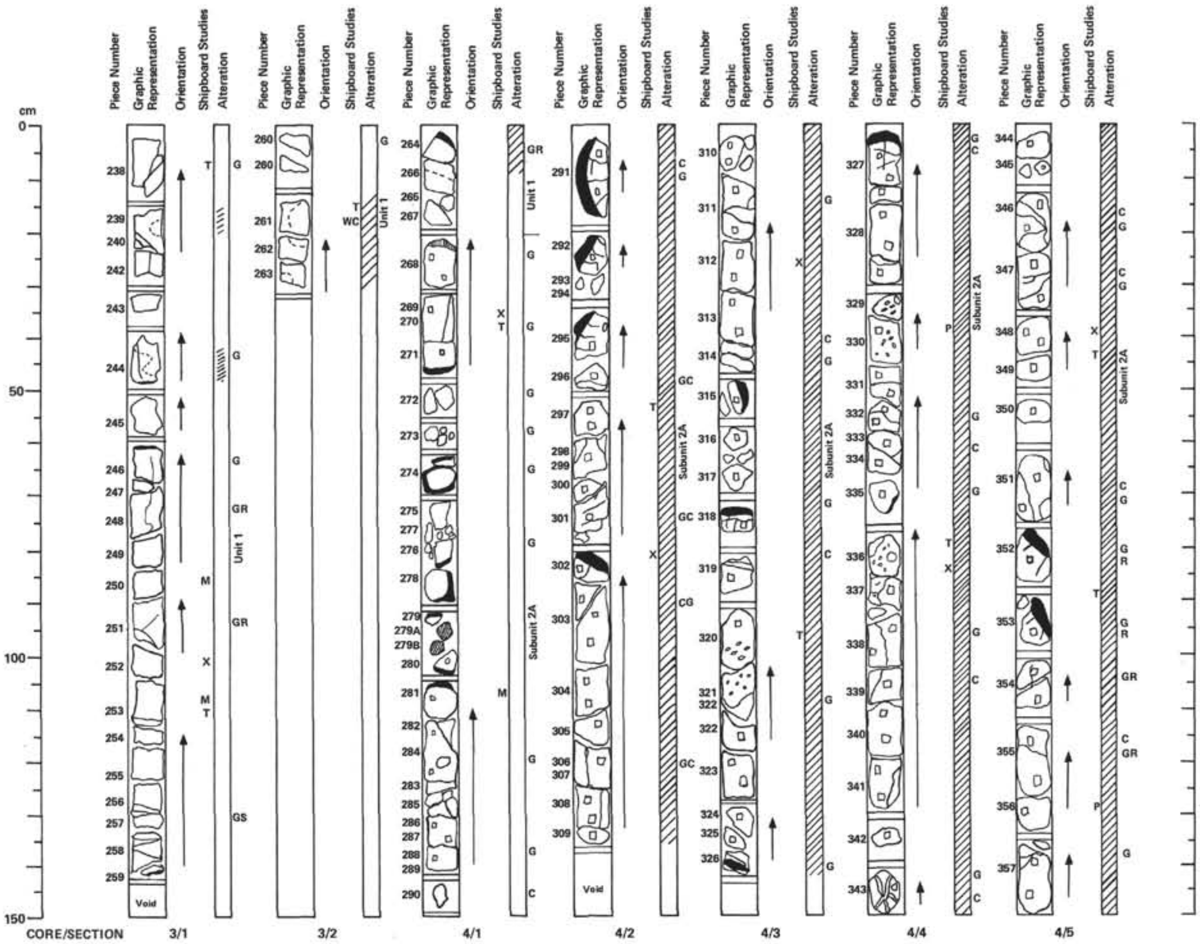
The upper part of the core (Section 1, 2–93 cm) consists of alternating pieces of cherts, cherty limestones, and cherts, described on the previous sediment barrel sheet. In this core, five separate pieces of basalt and numerous smaller chips were recovered. The topmost piece of basalt is fine-grained and quite dark, evidently originally adjacent to glass. There are scattered plagioclase and olivine phenocrysts, in all the basalts, with olivines altered to pale green clays. Vesicles are small (<1 mm), and rare (< 1%),usually filled with clays.

Thin Section Description

Sample 2-1, 105–107 cm, Piece 233: This sample, from a pillow interior, is predominantly spherulitic, with fine clinopyroxene and plagioclase crystals set in a matrix of clays and glass. Most plagioclases are microlites, but there are a few phenocrysts up to 3 mm across. Opaques include dust-like to skeletal titanomagnetite, and disseminated, probably primary pyrite. Olivine is replaced by smectite, which also fills vesicles.

BULK ANALYSIS:

Core-Section	2-1
Interval (cm)	107–110
SiO_2	50.63
TiO_2	1.11
Al_2O_3	15.59
Fe_2O_3	9.46
MnO	0.17
MgO	8.07
CaO	12.57
Na_2O	2.17
K_2O	0.06
P_2O_5	0.09
Total	99.92
LOI	0.98
Mg/Mg+Fe	0.623
Ca/Ca+Al	0.423
Ni	129
Sr	77
Zr	60
H_2O	0.90
CO_2	0.14



BULK ANALYSIS:

Core-Section	3-1	4-1	4-2	4-3	4-4	4-5
Interval (cm)	102–105	32–38	52–58	27–30	83–87	36–41
SiO_2	49.63	49.76	49.61	50.13	49.83	49.47
TiO_2	1.07	0.88	0.90	0.88	0.88	0.91
Al_2O_3	14.98	16.04	16.22	15.84	16.18	16.09
Fe_2O_3	11.70	9.66	9.86	9.77	9.76	9.91
MnO	0.17	0.17	0.18	0.17	0.17	0.18
MgO	7.89	8.20	7.61	8.28	8.19	7.98
CaO	12.21	13.09	13.35	13.07	12.92	13.30
Na_2O	1.93	1.70	1.89	1.87	2.02	2.09
K_2O	0.31	0.12	0.07	0.03	0.15	0.08
P_2O_5	0.10	0.08	0.08	0.07	0.06	0.06
Total	99.99	99.71	99.77	100.11	100.16	100.07
LOI	1.01	0.57	1.23	0.94	1.55	1.06
Mg/Mg+Fe	0.572	0.627	0.605	0.627	0.624	0.615
Ca/Ca+Al	0.426	0.426	0.428	0.429	0.421	0.429
Ni	76	134	139	140	153	136
Sr	73	69	70	66	74	71
Zr	58	50	50	49	45	50
H_2O	0.96	0.54	1.02	1.28	1.28	1.07
CO_2	0.07	0.03	0.13	2.24	0.11	0.12

MAGNETIC DATA:

Core-Section, Interval (cm)	NRM	INCL.	MDF
3-1, 87–89	4,151	−11.8	120
3-1, 108–110	7,095	2.6	110
4-1, 108–110	9,505	−18.3	260
4-2, 101–103	21,063	−17.1	240
4-3, 122–124	15,062	−15.5	400
4-4, 41–43	7,420	− 3.2	210
4-5, 124–126	10,671	−15.9	230

PHYSICAL PROPERTIES:

Core-Section, Interval (cm)	Water Content	Porosity	Wet-Bulk	GRAPE	Sonic Velocity
4-1, 111–112	3.87	10.42	2.76	2.91	6.391
4-2, 102–104	0.97	2.74	2.91	2.87	6.213
4-3, 123–125	2.81	7.75	2.83	2.78	5.774
4-4, 42–44	2.58	7.19	2.85	2.78	5.557
4-5, 125–127	1.77	4.98	2.88	2.79	5.717

THERMAL CONDUCTIVITY:

Core-Section, cm	κ
4-2, 105	1.83
4-4, 40	1.66

HOLE 504B, CORE 3 3751.5–3753.5 m (278.0–280.0 mbsf)

APHYRIC BASALT (lithologic unit 1)

The core consists of light gray aphyric basalt with several flat upper and lower glassy rinds. The basalt may either be pillows or thin, flat-lying flows. The basalts contain sparse crystals of olivine replaced by smectites. Small vesicles and cracks up to 2 mm wide are abundant, filled with yellow, red, orange, or green clays. Section 1 contains one apparently completely recovered cooling unit (60–145 cm).

Thin Section Descriptions

Sample 3-1, 6–8 cm, Piece 238: The texture is dendritic to microphyric, with a very dark groundmass, typical of the interior of small flows or pillows. Plagioclase crystals are most abundant, but most of the rock is spherulitic mesostasis. There is a crack with a light brown fibrous clay in the middle of the section.

Sample 3-1, 82–89 cm, Piece 250: The sample is about evenly divided between plagioclase and clinopyroxene in a skeletal to dendritic microlitic groundmass. There are some small plagioclase microphenocrysts. The mesostasis is very dark, a consequence of abundance of titanomagnetites and residual dark glass. Yellow-brown clays replace olivine and fill vesicles.

Sample 3-2, 17–19 cm, Piece 261: Texturally, this sample is virtually identical to Piece 238, but it contains some fresh olivines, and has an oxidized band crossing one side of the section. The zone contains distinctly green or yellow-red secondary minerals, clays, and iron hydroxides, whereas clays in the "fresh" zone are pale yellow.

HOLE 504B, CORE 4 3753.5–3763.0 m (280.0–289.5 mbsf)

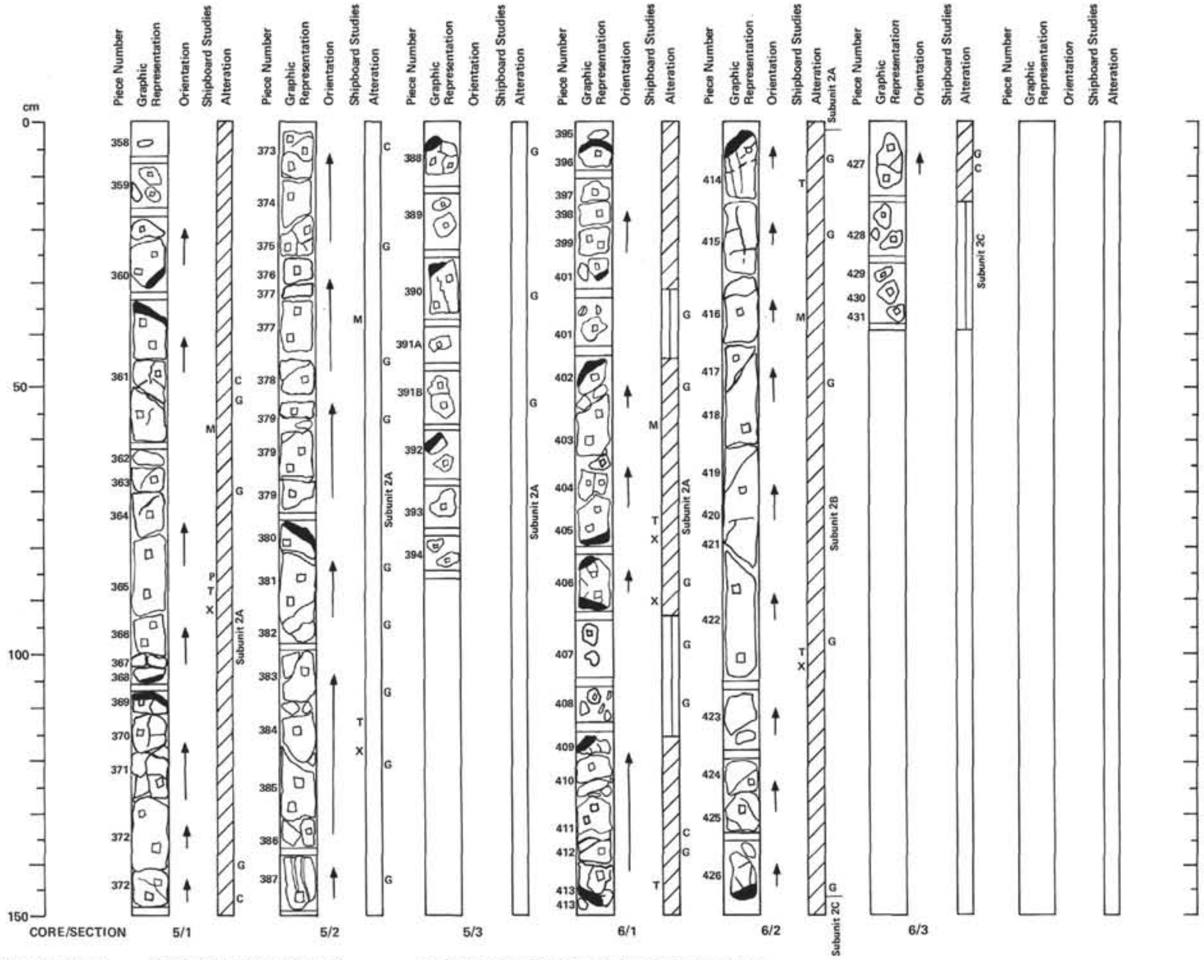
CHROMITE-BEARING, MODERATELY PHYRIC PLAGIOCLASE-OLIVINE BASALT PILLOWS (lithologic subunit 2A)

The topmost 4 pieces are very sparsely phyric (unit 1), with a glassy rind at the top. There are less than 1% each plagioclase and olivine phenocrysts, with plagioclases 1–2 mm. Olivine is completely replaced by dark green clays.

The rest of the core (subunit 2A) consists of sparsely to moderately plagioclase-olivine phyric pillows, with essential chromite. Plagioclase phenocryst abundances range up to 10%. Glass rinds occur on the tops, bottoms, and sides of pieces, many of them are inclined. Green smectites predominate as vein and fracture fillings, but there are local occurrences of red smectite and some zones of brownish oxidative alteration. Rare vesicles are small (0.5–1 mm) and not present in every piece. There are rare calcite veins.

Thin Section Descriptions

The thin sections are from pillow rims (PR), fine-grained pillow interiors (FPI) or coarse-grained pillow interiors (CPI), as follows: 4-1, 32–36 cm, Piece 269 (FPI); 4-2, 80–84 cm, Piece 302 (PR); 4-3, 92–96 cm, Piece 320 (FPI); 4-4, 41–43 cm and 92–96 cm, Piece 330 (CPI); 4-4, 83–87 cm, Piece 336 (CPI); 4-5, 36–41 cm, Piece 348 (FPI); and 4-5, 87–89 cm, Piece 353 (PR). PR samples range from glassy to spherulitic with up to 10% plagioclase phenocrysts and microphenocrysts, lesser olivines, generally replaced by smectite, and some chromite. The difference between these and FPI and CPI samples is both crystallinity and grain size, increasing in the respective order given. CPI samples are nearly holocrystalline with fairly coarse plagioclases enclosed partly by anhedral clinopyroxene. FPI samples are dendritic, microlitic, and skeletal, verging in some cases on spherulitic. Secondary minerals are mainly smectites after olivine, filling small veins, and filling vesicles. Colors of clays range from green (dominant) to lesser oranges and reds.



BULK ANALYSIS:

Core-Section	5-1	5-2	6-1	6-1	6-2
Interval (cm)	86–92	110–115	79–80	88–90	98–105
SiO_2	49.15	49.52	49.73	53.28	49.48
TiO_2	0.89	0.90	0.92	0.11	0.93
Al_2O_3	15.88	16.55	16.46	6.38	15.41
Fe_2O_3	10.07	9.22	9.86	10.83	10.49
MnO	0.18	0.18	0.16	0.08	0.16
MgO	8.51	8.08	8.56	25.14	8.20
CaO	13.07	13.36	11.99	1.28	12.83
Na_2O	1.88	2.08	1.84	1.88	1.90
K_2O	0.12	0.03	0.12	0.15	0.19
P_2O_5	0.07	0.08	0.07	0.01	0.06
Total	99.82	100.00	99.71	99.14	99.65
LOI	0.96	124	1.17	6.66	0.83
Mg/Mg+Fe	0.626	0.634	0.632	0.821	0.608
Ca/Ca+Al	0.428	0.423	0.398	0.154	0.431
Ni	140	141	145	72	115
Sr	70	72	79	74	69
Zr	53	49	58	11	53
H_2O	0.83	0.92	1.24	5.93	0.59
CO_2	0.06	0.08	0.07	0.56	0.03

MAGNETIC DATA:

Core-Section, Interval (cm)	NRM	INCL.	MDF
5-1, 57–59	12,750	– 8.5	170
5-2, 41–43	17,565	–15.4	180
6-1, 55–57	9,212	–11.7	430
6-2, 36–38	5,053	–11.9	145

PHYSICAL PROPERTIES:

Core-Section, Interval (cm)	Water Content	Porosity	Wet-Bulk	GRAPE	Sonic Velocity
5-1, 57–59	2.34	6.62	2.90	2.74	5.668
5-2, 41–43	1.75	4.72	2.88	2.78	5.645
6-1, 54–56	2.57	7.05	2.81	2.75	5.670
6-2, 40–41	2.15	6.04	2.88	2.75	5.716

THERMAL CONDUCTIVITY:

Core-Section, cm	κ
5-2, 40	1.78
6-1, 57	1.64

HOLE 504B, CORE 5 3763.0–3772.0 m (289.5–298.5 mbsf)

CHROMITE-BEARING, MODERATELY PHYRIC PLAGIOCLASE OLIVINE PILLOW BASALT (lithologic unit 2A)

The core is a sequence of several cooling units with inclined upper or lower glass margins (probably pillows). Plagioclase phenocrysts are up to 7 mm across (most 2–4 mm), and form up to 10% of the rock. Olivines are up to 2 mm and 2%, but are replaced by light green or brown smectite. Cracks are filled with light green smectite and sometimes with calcite. There are some zones of oxidative alteration next to cracks. Vesicles are rare to absent.

Thin Section Descriptions

All three thin sections from this core are from fine-grained pillow interiors. They are Samples 5-1, 86–73 cm, Piece 365; 5-1, 110–115 cm, Piece 384; and 5-3, 46–48 cm, Piece 391. All are dominated by a spherulitic mesostasis, with a few per cent microlitic plagioclase, dendritic clinopyroxene and granular or euhedral olivine, now replaced by clays and Fe-hydroxides. Chrome spinel is a minor but ubiquitous mineral. Spherulitic textures are plumose. Rare cracks are lined with yellow clays. There are recrystallized glassy inclusions in scattered plagioclase phenocrysts.

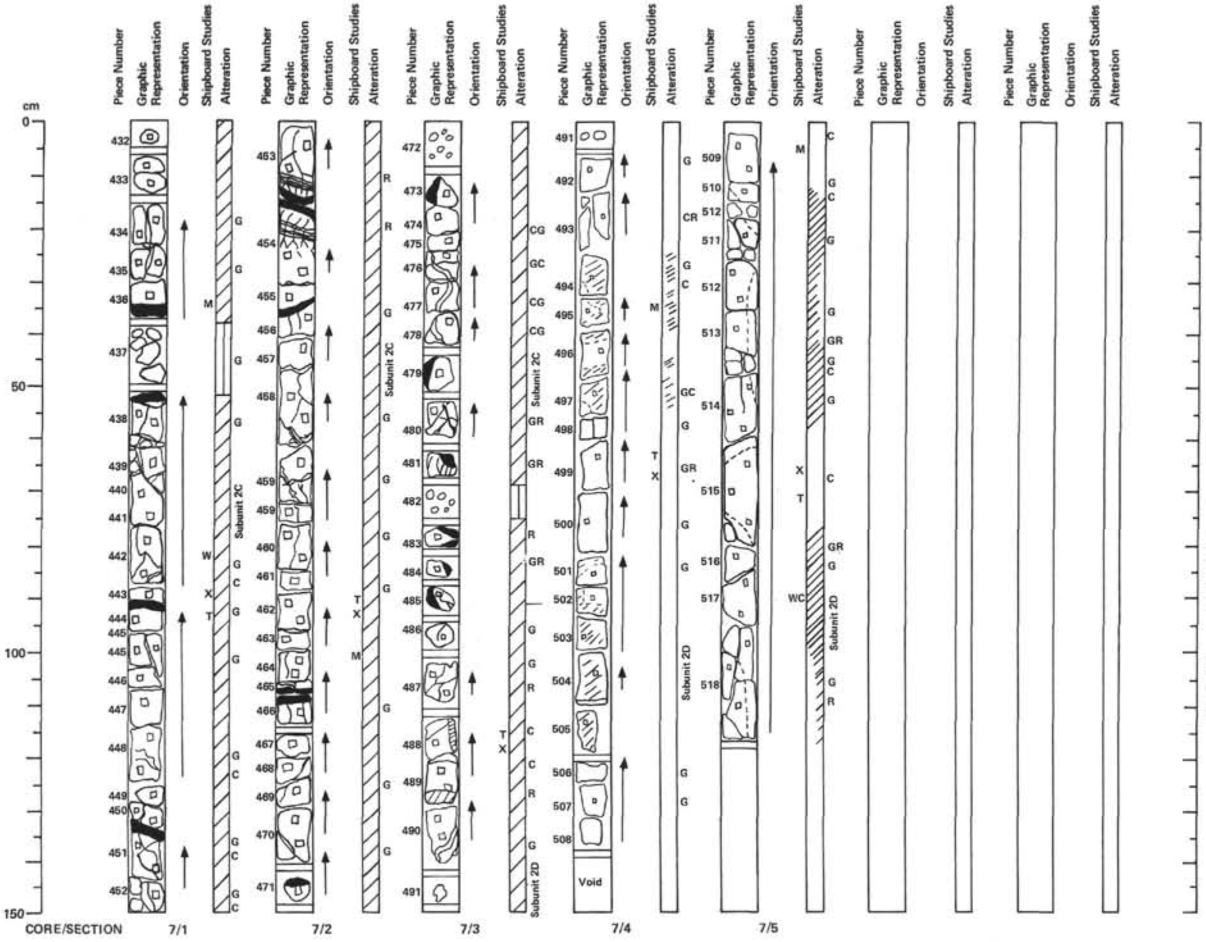
HOLE 504B, CORE 6 3772.0–3781.0 m (298.5–307.5 mbsf)

CHROMITE-BEARING, MODERATELY PHYRIC PLAGIOCLASE OLIVINE PILLOW BASALTS (lithologic units, 2A, 2B, and 2C)

This core is similar to Core 5 in that it consists of several fairly completely cored cooling units, each with inclined upper and lower glass rims, hence evidently pillows. Plagioclase phenocrysts are up to 5 mm and 10%, olivine up to 2 mm and 2%. Olivines are replaced by smectite and carbonate. Vesicles are rare to absent. Glassy zones are somewhat brecciated and quite altered to light green smectite. Cracks are filled with light green smectite and (Piece 412) calcite, and some have a faint oxidation rim adjacent to them. The core contains part or all of three lithologic subunits, with subunit 2B a single 1.5 m cooling unit in Section 2 (Pieces 414–426).

Thin Section Descriptions

Two thin sections were prepared from this core, Sample 6-1, 78–79 cm, Piece 405, which is spherulitic, and Sample 6-2, 11–13 cm, Piece 414, which is dendritic to microphyric. There are a few per cent palgioclase and rarer altered olivine phenocrysts in both sections. Olivine is replaced by fibrous yellow smectites. Piece 405 has no vesicles and a crack with yellow-green clay minerals. Piece 416 has rare vesicles and light green minerals filling vesicles and replacing parts of the groundmass.



BULK ANALYSIS:

Core-Section	7-1	7-2	7-3	7-4	7-5
Interval (cm)	91–93	91–96	116–120	64–69	71–74
SiO_2	50.02	49.25	50.38	49.51	50.47
TiO_2	0.93	0.88	0.91	0.89	0.91
Al_2O_3	16.69	15.86	15.93	16.16	16.22
Fe_2O_3	9.23	9.89	9.90	10.03	9.40
MnO	0.17	0.18	0.16	0.18	0.16
MgO	7.59	8.65	7.65	8.06	8.24
CaO	13.23	13.04	13.13	13.13	13.03
Na_2O	1.97	1.79	1.88	1.83	2.11
K_2O	0.07	0.09	0.02	0.13	0.03
P_2O_5	0.08	0.07	0.06	0.08	0.08
Total	99.98	99.70	100.02	100.00	100.65
LOI	1.03	0.77	1.04	1.15	1.21
Mg/Mg+Fe	0.620	0.634	0.605	0.614	0.635
Ca/Ca+Al	0.419	0.428	0.428	0.425	0.422
Ni	140	155	129	131	140
Sr	74	66	67	69	71
Zr	53	50	57	49	50
H_2O	0.94	0.74	0.78	0.95	0.72
CO_2	0.04	0.02	0.05	0.06	0.11

MAGNETIC DATA:

Core-Section, Interval (cm)	NRM	INCL.	MDF
7-1, 33–35	11,690	– 5.5	550
7-2, 98–100	14,670	—	—
7-3, 127–129	12,010	– 5.3	120
7-4, 35–37	8,878	– 4.5	130
7-5, 3–5	8,584	– 5.5	100

PHYSICAL PROPERTIES:

Core-Section, Interval (cm)	Water Content	Porosity	Wet-Bulk	GRAPE	Sonic Velocity
7-1, 33–35	1.56	4.37	2.88	2.86	6.261
7-2, 99–100	0.95	2.69	2.91	2.77	5.828
7-3, 127–129	1.55	4.40	2.90	2.75	5.769
7-4, 35–37	1.49	4.20	2.90	2.83	6.042
7-5, 2–4	1.16	3.29	2.91	2.85	5.912

THERMAL CONDUCTIVITY:

Core-Section, cm	κ
7-2, 102	1.56
7-2, 102	1.55
7-3, 127	1.82

HOLE 504B, CORE 7 3781.0–3790.0 m (307.5–316.5 mbsf)

MODERATELY PLAGIOCLASE-OLIVINE PHYRIC BASALT WITH ESSENTIAL CHROMITE (lithologic subunit 2C [to Piece 485] and 2D)

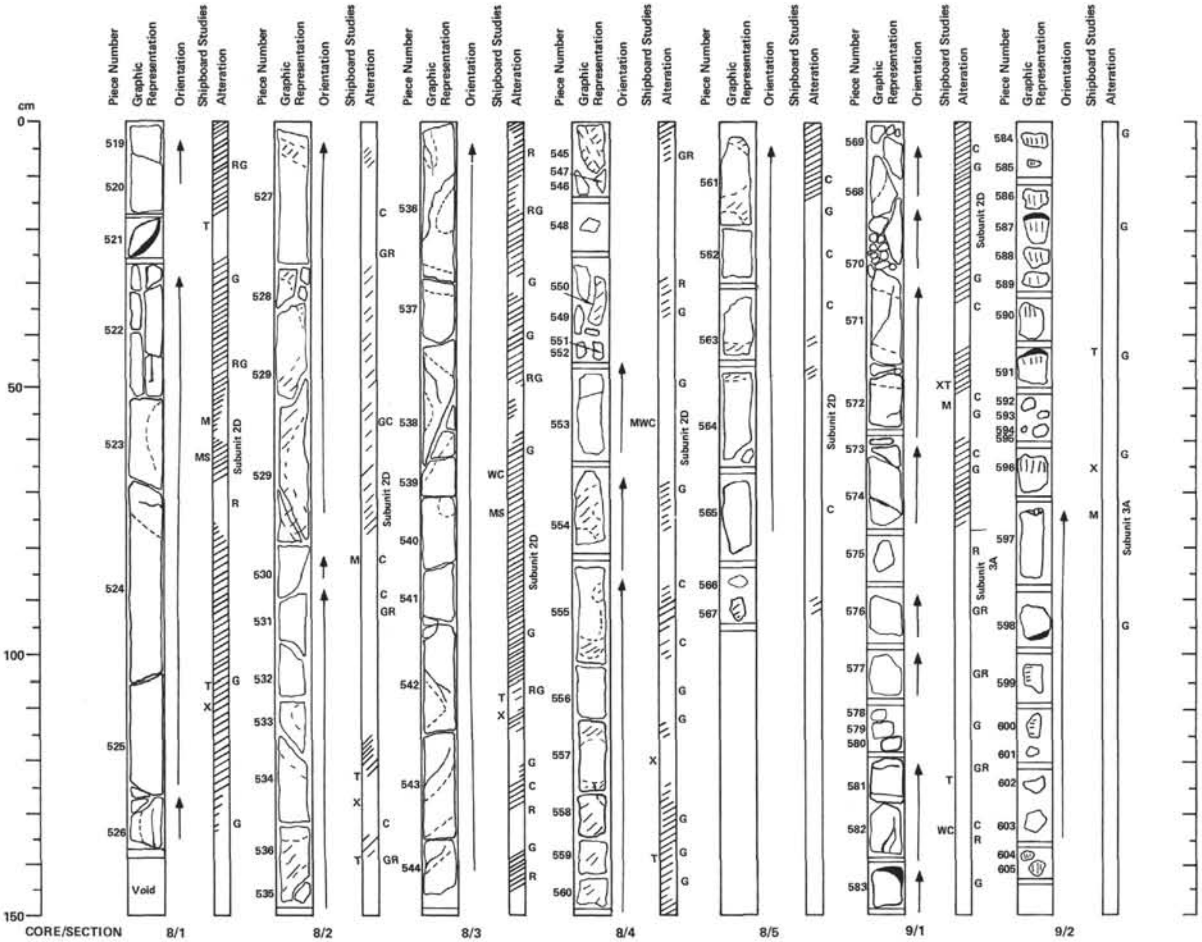
This core comprises the greater part of lithologic subunit 2C, which is a sequence of pillow basalts, and the upper part of subunit 2D, two massive flows. Subunit 2C extends down to Piece 485, and 2D is below.

Subunit 2C in this core contains up to 10% plagioclase phenocrysts *up to 4 mm in size, and up to 3% olivine phenocrysts, up to 2 mm.* Vesicles are rare or absent. There are a number of glass margins, many of them inclined, indicative of pillows rather than flat flows. Cracks are abundant and filled with light green smectite. Olivine is completely replaced by smectite, and some calcite. There are some interpillow breccias (e.g. Piece 437). Oxidative alteration seems more prominent in glassy zones.

The massive material toward the bottom of the core has more widely spaced fractures, and the adjacent rocks show quite distinctive zones of alteration. The cracks contain cores of dark green clays, and a lining on either side of fibrous light green clays. Thence there are red, yellow, and green alteration zones proceeding into the rock. Section 7–5 has some aragonite veining. There is fresh olivine in Piece 515. In general, although this has about the same proportion of phenocrysts as subunit 2C, the groundmass is sufficiently coarse-grained to obscure the macroscopic distinction between phenocrysts and groundmass crystals.

Thin Section Descriptions

Five thin sections were prepared from this core, one from a pillow rim (Sample 7-1, 93–96 cm, Piece 444), two from fine-grained pillow interiors (Samples 7-2, 87–89 cm, Piece 462 and 7-3, 116–120 cm, Piece 488), and two from the coarse-grained flow of lithologic subunit 2D (Samples 7-4, 63–65 cm, Piece 499 and 7-5, 67–70 cm, Piece 515). Sample Piece 444 has a dominantly spherulitic texture with greater than 10% plagioclase phenocrysts and 1–2% olivine phenocrysts. There are many cracks filled with clays and phillipsite. Small remnants of glass are completely altered. Samples Piece 462 and 488 have microlitic to intersertal textures with about the same proportions of phenocrysts as Piece 444, and including chrome spinel. There are three morphologies to plagioclase phenocrysts (subophitic glomerocrysts, glomerocrysts with chaotically arranged tabular crystals, and isolated euhedral to skeletal crystals). Some show strong normal zoning. Olivine phenocrysts are altered to pale brown or green clays, or iron hydroxides in oxidized zones. Sample Piece 488 has a red oxidized zone along one length of the thin section. The samples from the coarse-grained flow (Pieces 499 and 515) have ophitic textures, with plagioclases partially enclosed by clinopyroxenes, and interstitial patches with abundant titanomagnetite and smaller dendritic or spherulitic clinopyroxene. Olivines are replaced by clays. Sample Piece 515 has a fibrous carbonate in a vein as well as yellow-brown vein-filling clays.



BULK ANALYSIS:

Core-Section	8-1	8-2	8-3	8-4	9-1	9-2
Interval (cm)	109–115	125–131	113–116	120–124	54–58	63–68
SiO_2	49.59	50.08	49.43	50.53	49.76	49.25
TiO_2	0.90	0.88	0.88	0.89	0.88	0.98
Al_2O_3	16.29	15.25	16.54	16.27	15.96	16.29
Fe_2O_3	9.84	9.37	9.99	8.79	9.84	10.12
MnO	0.15	0.15	0.16	0.18	0.16	0.16
MgO	8.08	8.14	7.49	8.22	8.01	7.94
CaO	13.02	13.08	13.20	13.29	13.07	12.35
Na_2O	1.97	1.76	2.05	2.14	1.78	2.07
K_2O	0.13	0.02	0.10	0.03	0.03	0.16
P_2O_5	0.07	0.06	0.06	0.07	0.08	0.08
Total	100.04	99.81	99.90	100.41	99.57	99.40
LOI	1.15	1.15	1.13	1.18	1.28	1.13
Mg/Mg+Fe	0.619	0.632	0.598	0.649	0.617	0.608
Ca/Ca+Al	0.421	0.423	0.420	0.426	0.427	0.408
Ni	103	126	99	156	143	105
Sr	72	71	71	71	68	63
Zr	51	47	49	55	52	51
H_2O	0.60	0.63	0.95	0.74	0.80	0.95
CO_2	0.05	0.02	0.05	0.13	0.08	0.08

MAGNETIC DATA:

Core-Section, Interval (cm)	NRM	INCL.	MDF
8-1, 59–61	1,648	−11.8	75
8-2, 86–88	6,179	− 6.4	110
8-3, 73–75	4,204	− 6.8	115
8-4, 58–60	5,398	− 0.4	110
9-1, 51–53	28,817	−14.2	200
9-2, 73–75	3,145	−14.6	130

PHYSICAL PROPERTIES:

Core-Section, Interval (cm)	Water Content	Porosity	Wet-Bulk	GRAPE	Sonic Velocity
8-1, 63–65	1.51	4.30	2.92	2.87	5.935
8-2, 86–88	1.83	5.19	2.91	2.82	5.767
8-3, 72–74	2.63	7.29	2.84	2.79	5.771
8-4, 58–60	2.44	6.82	2.87	2.81	5.69
9-1, 51–53	1.21	3.41	2.89	2.84	6.04
9-2, 73–75	2.22	6.23	2.87	2.78	5.62

THERMAL CONDUCTIVITY:

Core-Section, cm	κ
8-2, 86	1.68
8-4, 58	1.69
9-1, 136	1.72
9-2, 78	1.65

HOLE 504B, CORE 8 3790.0–3799.0 m (316.5–325.5 mbsf)

MASSIVE CHROMITE-BEARING PLAGIOCLASE-OLIVINE BASALTS (lithologic unit 2D)

The basalts from Core 8 are part of two massive flows beginning in Section 7–3 and ending in Section 9–1. The base of the upper flow is a glass rind in Section 8-1, Piece 521. The basalts consist of fine-grained, light gray, coarse-grained material broken up by inclined fractures with adjacent zones of alteration. Formerly olivine phenocrysts (1–2%) are now replaced by clays. The alteration zones are red or yellow in color, adjacent to fractures or cracks lined with yellow-red smectites. Vesicles in these zones have yellow-red smectites, whereas in "fresh" zones they have green smectites. Vesicles are rare through most of the core. Calcite lines fractures lower in the core.

Thin Section Descriptions

Two thin sections were prepared of these massive basalts: Samples 8-1, 107–109 cm, Piece 529 and 8-2, 134–135 cm, Piece 534. The first is dendritic-ophitic, and the second ophitic in texture. The rocks consist mainly of plagioclase and olivine, with rare fresh clinopyroxene and minor titanomagnetite. Vesicles are filled with dark brown fibrous clays and Fe-hydroxides or yellow-green granular clays. Piece 534 has distinct red and yellow oxidized zones, in which clays of those respective colors are abundant in the groundmass.

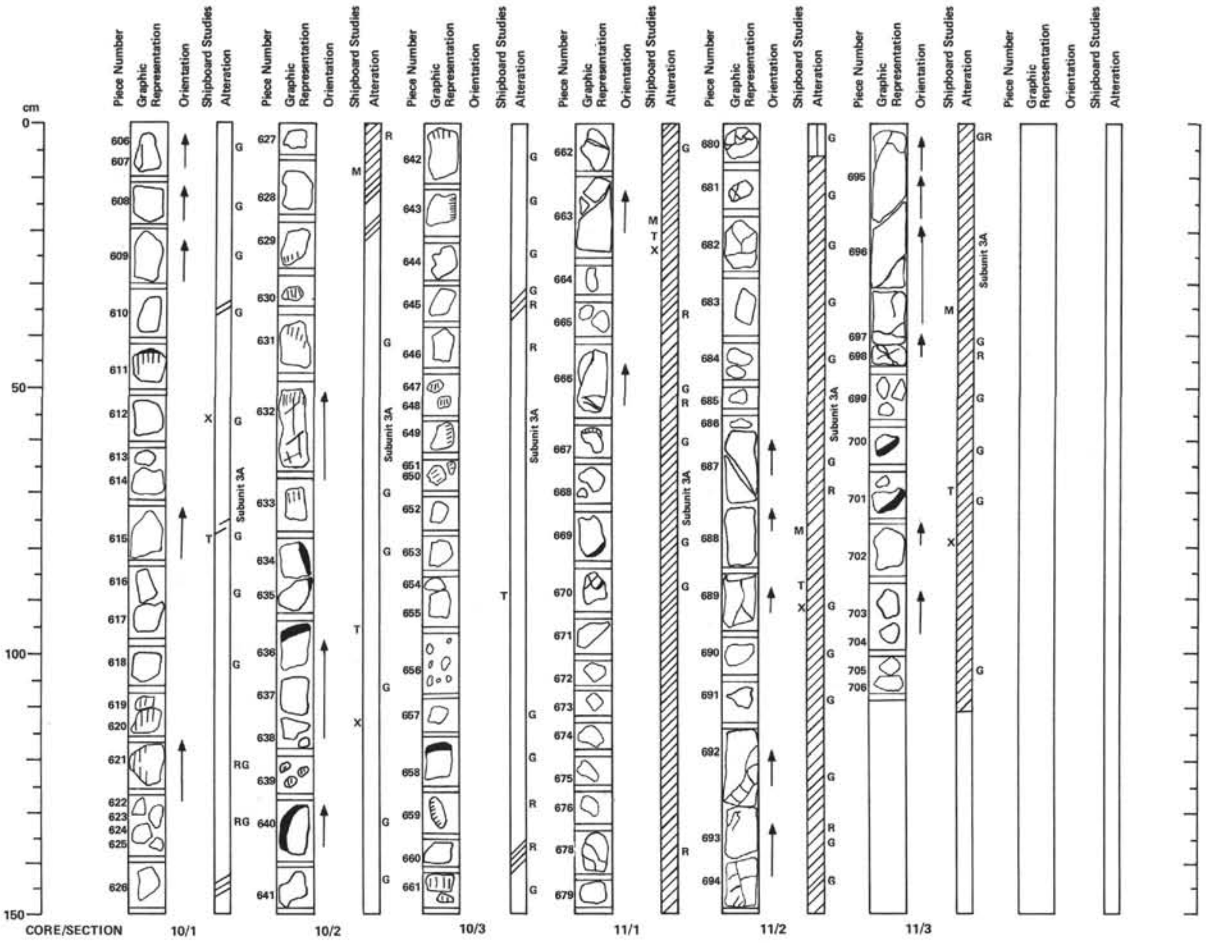
HOLE 504B, CORE 9 3799.0–3808.0 m (325.5–334.5 mbsf)

MODERATELY OLIVINE-PLAGIOCLASE PHYRIC BASALT (lithologic unit 2D) AND APHYRIC-SPARSELY PHYRIC PILLOW BASALT (lithologic unit 3A)

Pieces 569–574 in Section 9-1 are the bottom portion of the massive material recovered mainly in Cores 7 and 8 (end lithologic unit 2D). Below these, in the rest of the core are aphyric or sparsely phyric portions of pillows several glassy rinds. These rocks are extremely fine-grained, and vary in color depending on proximity to glass rinds (coarser-grained rocks are lighter gray). Spherulites can be seen next to glass. Olivine phenocrysts, which are scarce, are altered to dark green clays. Piece 597 includes a pillow breccia, and has an oxidized rim containing yellow-red clays.

Thin Section Descriptions

Three thin sections were made from rocks in this core. One, Sample 9-1, 46–50 cm, Piece 572, is from the base of the massive flow, and resembles those described under Core 8. It has olivine altered to clays and some calcite, and is fairly coarse-grained. Sample 9-1, 120–123 cm, Piece 581 is a dendritic to microphyric portion of a pillow interior, but has a striking zonation of alteration patterns, ranging from oxidized (red) next to a crack, a green zone away from that, and a distant yellow brown zone. These are characterized by secondary orange clays and iron hydroxides, green clays, and fibrous yellow clays respectively. The crack has an orange-red rim and is filled with light yellow fibrous clays. Sample 9-2, 43–47 cm, Piece 591 is a spherulitic sample from a pillow rim. There are rare granular olivines replaced by clays, and microlitic to spherulitic plagioclase needles in a dark spherulitic mesostasis. There are rare cracks filled with light green fibrous clay minerals.



BULK ANALYSIS:

Core-Section	10-1	10-2	11-1	11-2	11-3
Interval (cm)	53–58	113–118	16–21	86–95	74–83
SiO_2	49.99	50.32	50.59	50.56	50.33
TiO_2	1.03	0.98	0.98	0.99	0.98
Al_2O_3	16.31	15.46	15.51	15.40	15.32
Fe_2O_3	9.44	9.77	9.50	9.63	9.18
MnO	0.16	0.17	0.17	0.16	0.17
MgO	7.74	8.32	8.16	8.32	8.51
CaO	12.21	12.63	12.62	12.78	12.72
Na_2O	2.38	2.44	2.18	2.22	2.45
K_2O	0.17	0.18	0.18	0.13	0.11
P_2O_5	0.09	0.08	0.08	0.09	0.07
Total	99.48	100.35	99.97	100.28	99.84
LOI	1.01	0.78	0.63	1.04	0.66
Mg/Mg+Fe	0.619	0.628	0.630	0.631	0.647
Ca/Ca+Al	0.405	0.426	0.425	0.430	0.430
Ni	108	108	111	119	108
Sr	86	80	80	81	80
Zr	58	56	51	52	52
H_2O	0.92	0.79	0.64	0.78	0.63
CO_2	0.10	0.10	0.04	0.12	0.05

MAGNETIC DATA:

Core-Section, Interval (cm)	NRM	INCL.	MDF
10-2, 11–13	2,987	–41.4	140
11-1, 19–21	475	–30.0	180
11-2, 76–78	818	–32.4	160
11-3, 27–29	818	32.3	170

PHYSICAL PROPERTIES:

Core-Section, Interval (cm)	Water Content	Porosity	Wet-Bulk	GRAPE	Sonic Velocity
10-2, 11–13	2.51	6.98	2.85	2.77	5.59
11-1, 19–21	1.51	4.30	2.92	2.83	6.04
11-2, 76–78	2.09	5.85	2.87	2.83	5.89
11-3, 27–29	2.32	6.45	2.85	2.76	5.86

THERMAL CONDUCTIVITY:

Core-Section, cm	κ
10-2, 24	1.66
10-3, 83	1.10
11-1, 20	1.70

HOLE 504B, CORE 10 3808.0–3817.0 m (334.5–343.5 mbsf)

APHYRIC TO SPARSELY PLAGIOCLASE-OLIVINE PHYRIC PILLOW BASALTS (lithologic unit 3A)

These basalts are fragments of pillows, and are generally light to dark gray, with darker colors nearer glassy rinds. There is one fairly completely cored cooling unit encompassing Pieces 611–621. Alteration is low to moderate, primarily green smectites after rare olivine and filling cracks, and locally red smectites. Glass rinds are at the tops, bottoms, and sides of several pieces, and some have a definite curvature, indicating a pillow structure. There is a breccia with abundant green clays and possibly phillipsite between Pieces 650–656. Variolitic features occur on a number of pieces.

Thin Section Descriptions

Three thin sections were prepared from this core: Sample 10-1, 74–83 cm, Piece 615, a breccia; Sample 10–2, 95–100 cm, Piece 636; and Sample 10-3, 88–92 cm, Piece 655, pillow rims. All are glassy to spherulitic, with a few per cent plagioclase and rarer olivine microphenocrysts. Olivine is generally altered to smectites. In the breccia, smectite is a vein cement in which it forms radiating aggregates, and may be associated with Mn-oxides. Piece 636 contains phillipsite in glass, and alteration zonation next to cracks. Calcite, chalcedony(?) and smectites are in vein-like aggregates in Piece 655.

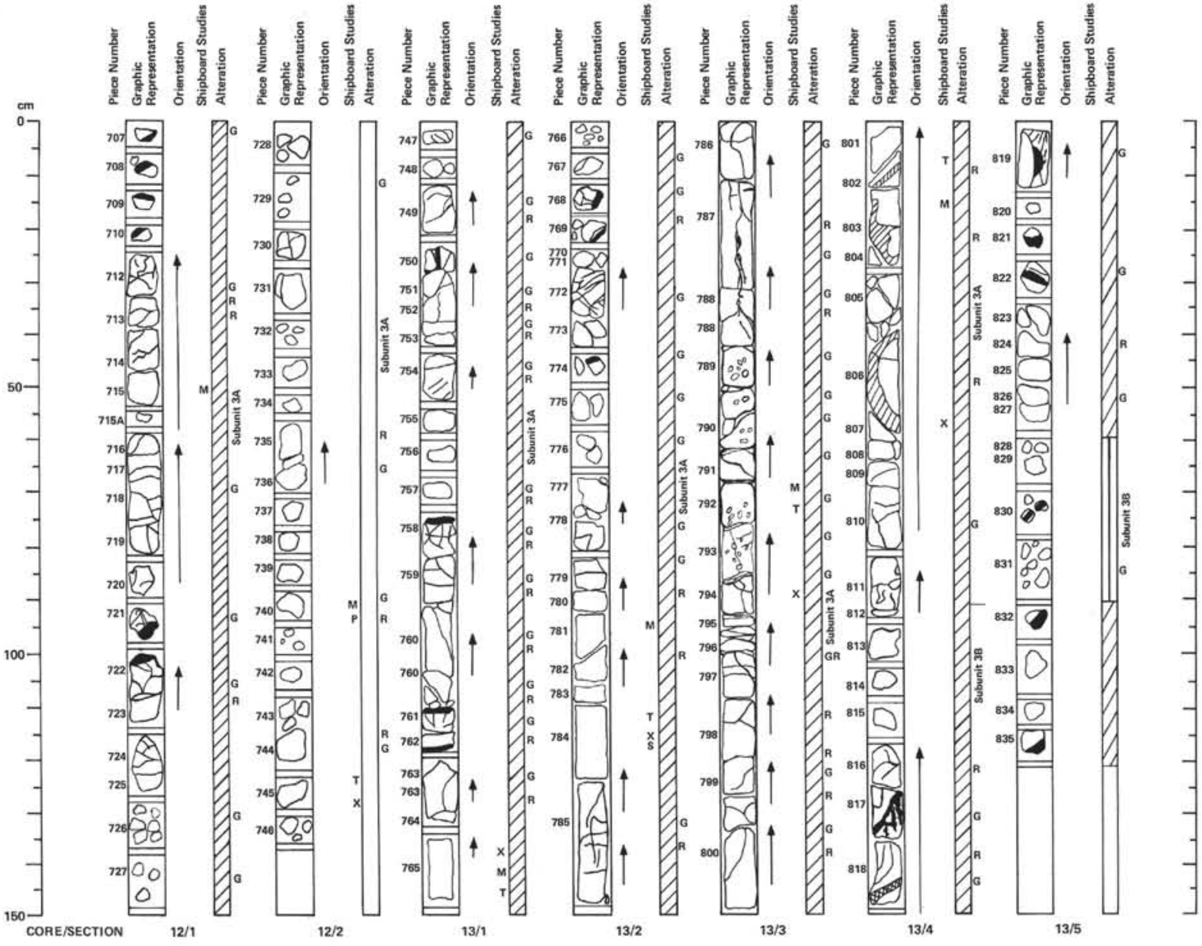
HOLE 504B, CORE 11 3817.0–3826.0 m (343.5–352.5 mbsf)

SPARSELY PLAGIOCLASE-OLIVINE PHYRIC PILLOW BASALT (lithologic unit 3A)

The basalt is rather uniform and fine-grained throughout most of Sections 1 and 2, indicating either a large pillow or a flow several meters thick. There are microphenocrysts of plagioclase and olivine up to 1 mm totalling not more than 2% of the rock, but the olivines are replaced by smectites. Piece 680 is brecciated with light green smectite. In Section 3, there are chilled glass margins (Pieces 700, 701). A thick green smectite is in the space between the chilled margins.

Thin Section Descriptions

Three thin sections were made from samples in Core 11, two from the upper more massive basalt, and one from a pillow rim in Section 3. The coarser-grained samples (11-1, 16–21 cm, Piece 662 and 11-2, 90–95 cm, Piece 682) are nonetheless dominantly spherulitic in texture, with rare phenocrysts of plagioclase and (altered) olivine. Piece 682 has an oxidized zone on one side, containing vesicles with orange-red clays and iron hydroxides. The rest of the section is green, with vesicles and portions of the groundmass made up of green clays. The pillow rim sample (11-3, 67–73 cm, Piece 701) is dominated by a spherulitic mesostasis, but has over 10% euhedral plagioclase microphenocrysts and microlites centered on the phenocrysts. Smectites replace portions of the groundmass and fill cracks. Both smectites and iron hydroxides replace olivine.



BULK ANALYSIS:

Core-Section	12-2	13-1	13-2	13-3	13-4
Interval (cm)	123–127	135–140	113–119	87–94	44–49
SiO_2	50.25	50.38	50.44	50.07	50.95
TiO_2	0.96	0.95	0.99	0.96	0.97
Al_2O_3	15.07	15.21	15.34	15.09	15.73
Fe_2O_3	9.79	9.81	9.39	10.15	8.51
MnO	0.17	0.17	0.14	0.19	0.16
MgO	8.26	8.35	8.18	8.17	8.45
CaO	12.70	12.55	12.70	13.03	12.81
Na_2O	2.13	2.12	2.23	1.91	2.07
K_2O	0.16	0.31	0.14	0.19	0.02
P_2O_5	0.07	0.07	0.07	0.08	0.08
Total	99.56	99.92	99.62	99.84	99.75
LOI	0.56	1.04	1.11	0.87	1.17
Mg/Mg+Fe	0.626	0.628	0.633	0.615	0.663
Ca/Ca+Al	0.434	0.429	0.429	0.440	0.425
Ni	96	104	119	101	108
Sr	75	77	82	75	81
Zr	51	52	58	58	51
H_2O	0.55	0.78	0.70	0.63	0.84
CO_2	0.02	0.04	0.08	0.05	0.11

MAGNETIC DATA:

Core-Section, Interval (cm)	NRM	INCL.	MDF
12-1, 50–52	2,087	–30.6	160
12-2, 107–109	1,016	–29.1	170
13-1, 140–142	848	–18.8	180
13-2, 100–102	2,037	—	—
13-3, 71–73	4,497	–30.9	140
13-4, 15–17	4,400	–30.0	80

PHYSICAL PROPERTIES:

Core-Section, Interval (cm)	Water Content	Porosity	Wet-Bulk	GRAPE	Sonic Velocity
12-1, 50–52	3.35	9.18	2.81	2.77	5.67
12-2, 107–109	1.25	3.58	2.94	2.82	6.01
13-1, 140–142	2.61	7.23	2.84	2.74	5.43
13-2, 99–100	2.25	6.25	2.85	2.76	5.67
13-3, 71–73	2.06	5.77	2.88	2.79	5.73
13-4, 15–17	2.38	6.65	2.86	2.76	5.66

THERMAL CONDUCTIVITY:

Core-Section, cm	κ
13-2, 100	1.76
13-4, 20	1.70

HOLE 504B, CORE 12 **3826.0–3835.0 m (361.5–370.5 mbsf)**

SPARSELY PLAGIOCLASE-OLIVINE MICROPHYRIC BASALT (lithologic unit 3A)

This core contains extremely fine-grained portions of sparsely phyric pillow. There are about 2% microphenocrysts of plagioclase and olivine up to 1 mm across, with plagioclase dominating, and olivines replaced by green smectites. There are myriads of cracks filled mainly with green smectite, to a lesser extent with reddish smectite.

Thin Section Description

Sample 12-1, 173–177 cm, Piece 745: This sample is from a pillow interior, and has a dominantly spherulitic mesostasis. There are scattered microphenocrysts of olivine and plagioclase, and less than 1% vesicles up to 1 mm across. The section has a reddish zone near its bottom, and a yellow zone on one side, in which orange and yellow smectites predominate. Most of it is grayish green in color, the green coming from green smectites in the groundmass.

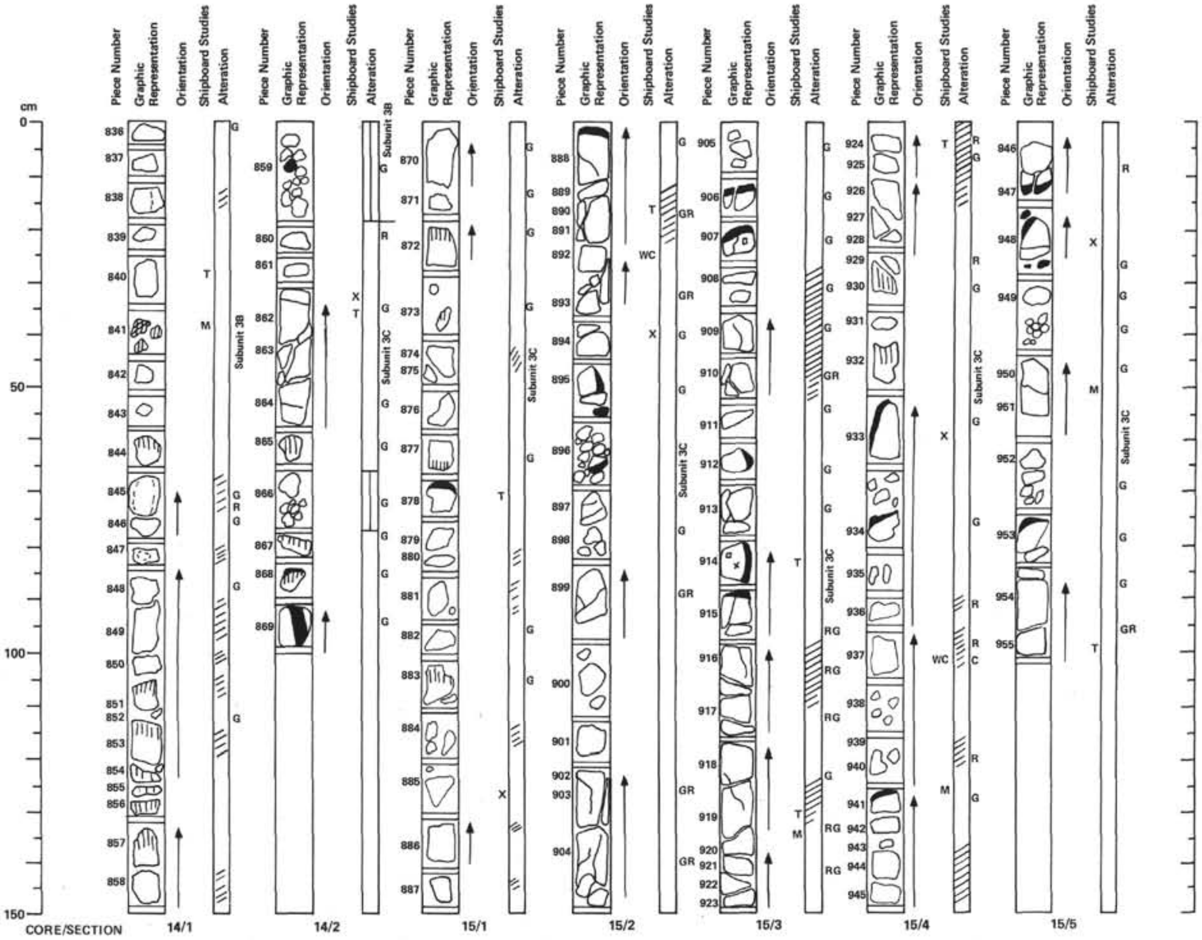
HOLE 504B, CORE 13 **3835.0–3844.0 m (361.5–370.5 mbsf)**

APHYRIC BASALT PILLOWS (lithologic subunit 3A [Pieces 747–812] and subunit 3B [Pieces 813–835])

Sections 1 and 2 contain several glass rinds, indicating the presence of small pillows. Sections 3 and 4 contain more massive rocks, but Section 5 again contains glass rinds. There may thus be a flow or large pillow in Sections 3 and 4. The basalts contain about 1% phenocrysts of plagioclase and lesser olivine up to 2 mm across. Vesicles are rare or absent. Cracks are filled with green or red smectites, and olivines are replaced by smectites. There is a peculiar pitted zone in Section 3 (Pieces 789–793) which appears to have spots of leaching. These are now filled with green smectites. Some of the spots are located along cracks. There is striking oxidation zonation in Section 3 and especially Section 4 (Pieces 801–806). There are a number of smectite veins up to 1 cm wide in Sections 4 and 5 (Pieces 817, 818, 819, and 822). Glass margins are quite altered.

Thin Section Descriptions

Four thin sections were prepared from this core, all from pillow or flow interiors (Samples 13-1, 143–150 cm, Piece 765; 13-2, 117–119 cm, Piece 784; 13-3, 73–75 cm, Piece 792; and 13-4, 7–10 cm, Piece 802). They contain a few per cent phenocrysts, mainly plagioclase with lesser olivine, set ina spherulitic to dendritic mesostasis. All but Piece 792 are about 50% microlites, mainly plagioclase, and Piece 792 has 5–10% plagioclase microlites. Alteration is fairly pervasive, with smectites (and some pyrite) replacing olivine, as well as portions of the groundmass. The smectites are mainly green, but there are local zones of oxidation where smectites are orange or red and associated with iron hydroxides. Piece 802 is adjacent to a crack, next to which is a sequence of green, red, and yellow zones, with increasing distance from the crack. These contain green, red, and yellow smectites, respectively.



BULK ANALYSIS:

Core-Section	14-2	15-1	15-2	15-3	15-4	15-5
Interval (cm)	34–40	125–129	38–44	133–137	58–62	17–22
SiO_2	50.38	50.00	50.04	50.06	50.10	50.16
TiO_2	0.92	0.91	0.95	0.92	0.92	0.93
Al_2O_3	15.43	14.64	15.21	15.35	14.49	15.26
Fe_2O_3	9.98	10.71	10.31	9.34	10.80	10.26
MnO	0.16	0.19	0.18	0.16	0.18	0.18
MgO	8.44	8.49	8.19	8.64	8.69	8.34
CaO	12.71	13.00	12.82	12.89	12.74	12.84
Na_2O	1.88	1.67	2.01	2.03	1.89	1.92
K_2O	0.13	0.07	0.10	0.11	0.11	0.15
P_2O_5	0.07	0.07	0.07	0.07	0.06	0.07
Total	100.10	99.75	99.88	99.57	99.98	100.11
LOI	1.01	0.31	0.70	0.98	0.26	0.64
Mg/Mg+Fe	0.626	0.611	0.611	0.647	0.614	0.617
Ca/Ca+Al	0.428	0.447	0.434	0.433	0.444	0.433
Ni	118	103	110	126	103	103
Sr	67	61	65	65	60	61
Zr	48	54	49	51	53	48
H_2O	0.75	0.57	0.78	0.75	0.49	0.55
CO_2	0.07	0.01	0.14	0.07	0.06	0.06

MAGNETIC DATA:

Core-Section, Interval (cm)	NRM	INCL.	MDF
14-1, 39–41	7,014	–28.7	160
15-2, 26–28	1,244	–32.3	160
15-3, 138–140	1,706	–24.2	150
15-4, 129–131	5,707	–31.0	180
15-5, 52–54	2,642	–23.3?	125

PHYSICAL PROPERTIES:

Core-Section, Interval (cm)	Water Content	Porosity	Wet-Bulk	GRAPE	Sonic Velocity
14-1, 39–41	3.23	8.85	2.81	2.78	5.55
15-2, 27–29	1.92	5.40	2.88	2.82	5.80
15-3, 138–140	1.59	4.51	2.91	2.76	5.79
15-4, 130–132	1.22	3.49	2.94	2.95	6.22
15-5, 52–54	3.06	8.46	2.83	2.73	5.378

THERMAL CONDUCTIVITY:

Core-Section, cm	κ
14-1, 63	1.67
15-1, 140	1.71
15-3, 110	1.71

HOLE 504B, CORE 14 3844.0–3848.5 m (370.5–375.0 mbsf)

SPARSELY OLIVINE MICROPHYRIC BASALT (lithologic subunit 3B [Pieces 836–859] and subunit 3C [Pieces 860–869])

This short core contains sparsely olivine microphyric pillow basalt, with abundant spherulitic zones, and some glass margins. Olivine is less than 1% of the rock, less than 1 mm across, and invariably altered to smectites. Vesicles are rare. There are many cracks lined with green smectites. Lower in the core, there are some plagioclase phenocrysts (a glomerocryst in Piece 840, scattered phenocrysts in glassy samples Pieces 868 and 869). Piece 869 has a glassy rim in the middle of the piece (a cored pillow junction).

Thin Section Descriptions

Two similar thin sections, both of fan/plumose spherulitic basalts near pillow rims, were made from Core 14 materials. Sample 14-1, 31–35 cm, Piece 840 has a few large plagioclase phenocrysts and abundant clinopyroxene and plagioclase microlites. Plagioclase phenocrysts carry abundant glass inclusions, now altered to clays. There are few vesicles, and those are filled or lined with brown clays. Sample 14-2, 32–34 cm, Piece 862 is similar, but a bit more crystalline, and has red, green, and yellow zones of alteration paralleling a crack at one end of the thin section. The red zone is next to the crack. Clays of the colors mentioned partially replace the mesostasis in the respective zones.

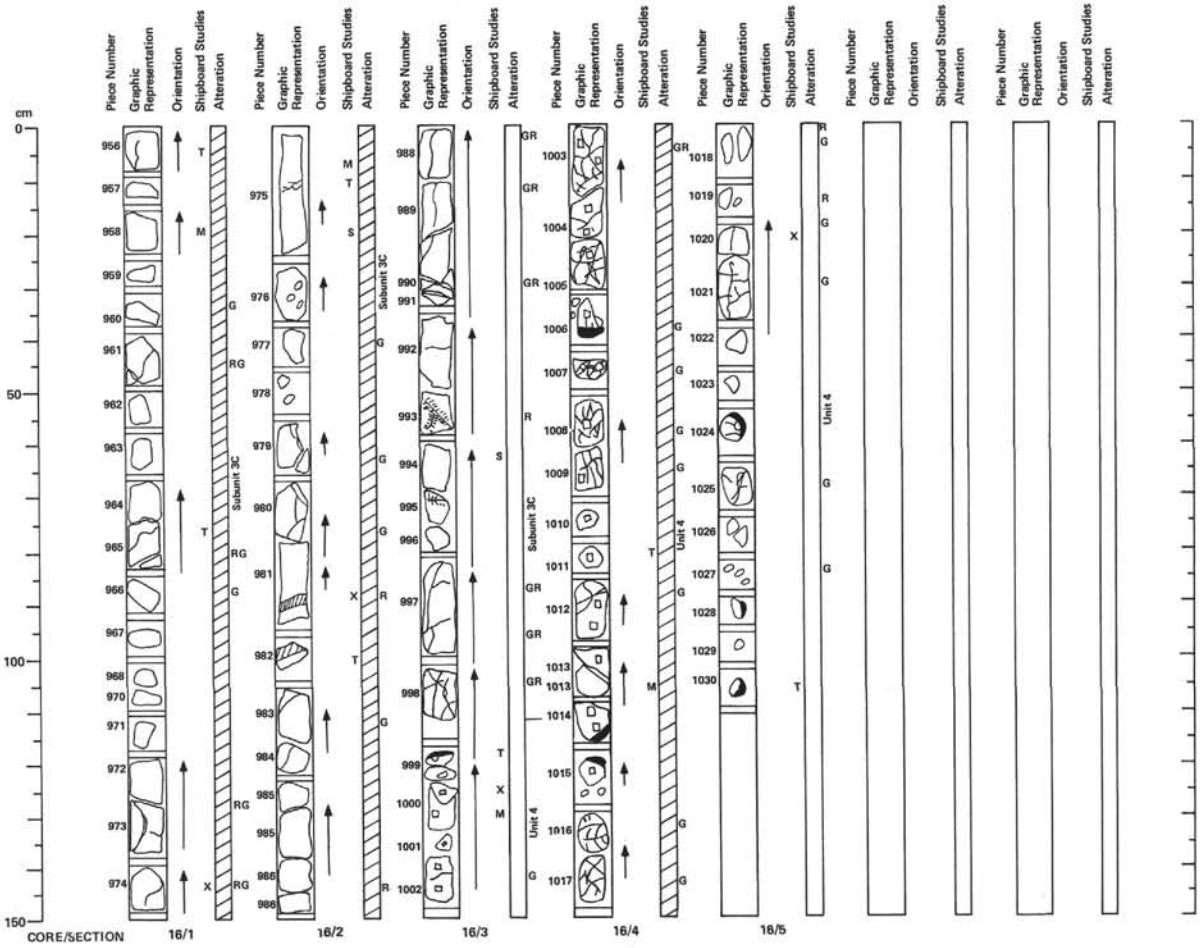
HOLE 504B, CORE 15 3848.5–3857.5 m (375.0–384.0 mbsf)

PLAGIOCLASE-OLIVINE SPARSELY MICROPHYRIC PILLOW BASALT (lithologic unit 3C)

These are very fine-grained basalts with numerous spherulitic zones and some glassy rims, variably at the top, bottom, or sides of pieces. There is some fresh olivine but most is altered. There are about 1–2% plagioclase phenocrysts up to 2 mm and traces of clinopyroxene phenocrysts. The rocks are quite fractured, with most fractures evidently produced by pillow cooling and contraction (radial, away from glass margins). Fractures are generally lined with green or red smectites. Fracturing of some pieces is intense enough for them to be effectively breccias (e.g. Pieces 870, 872). Calcite occurs in Piece 937. A peculiar grain size variation occurs in Pieces 954 and 955, perhaps the result of magma hybridization or auto-intrusion in a plastic state.

Thin Section Descriptions

Four thin sections were prepared from Core 15, two of pillow rims (Samples 15-1, 70–72 cm, Piece 878 and 15-3, 84–86 cm, Piece 914) and two of coarser pillow interiors (Samples 15-2, 9–21 cm, Piece 891 and 15-4, 6–8 cm, Piece 925). Pieces 878 and 914 include glass and spherulitic zones, with a few per cent plagioclase and olivine microphenocrysts. Olivine is replaced, and cracks filled, by smectites. Pieces 891 and 925 are fan-sheaf spherulitic, and ophitic spherulitic, respectively, with respectively higher proportions of groundmass plagioclase and clinopyroxene, ranging from skeletal to dendritic in morphology. Titanomagnetite is skeletal. There is sharp oscillatory zoning on plagioclase microphenocrysts. Vesicles are minor (less than 1%), irregular in shape, and filled with green or brown clays. Piece 891 has the same sequence of red, green, and yellow alteration zones described in previous sections as being adjacent to cracks (although the crack did not survive the thin sectioning process).



HOLE 504B, CORE 16 3857.5–3866.5 m (384.0–393.0 mbsf)

SECTIONS 16-1, 16-2, and 16-3, Pieces 956–998 (lithologic unit 3C): SPARSELY PLAGIOCLASE-OLIVINE CLINOPYROXENE PHYRIC BASALT; SECTIONS 16-3, 16-4, and 16-5, Pieces 999–1030 (lithologic unit 4): MODERATELY PLAGIOCLASE-OLIVINE PHYRIC PILLOW BASALT

Most of Sections 16-1, 16-2, and 16-3 is a single, fairly massive flow with scattered phenocrysts totalling about 1% of the rock. Alteration is moderate, with olivines replaced by smectites, green and lesser red smectites lining cracks and replacing portions of the groundmass, and distinctive red oxidized zones occurring in Section 16-2. Some of the rocks in Section 16-1 appear to be mixtures of two or more magmas streaked or blended plastically together. The contrasting materials appear as zones of different crystallinity in the rocks. Near the bottom of Section 16-3, are moderately plagioclase-olivine phyric pillow basalts (lithologic unit 4), with up to 10% plagioclase and 5% olivine phenocrysts up to 4 mm across. Vesicles are rare, and absent in some pieces. Olivine is converted into red and green clay minerals and calcite. Cracks are abundant and filled with green smectite. Pieces 1006–1009 are brecciated.

Thin Section Description

Seven thin sections were made from pieces of this core, four and three respectively from the two major rock types. Sample 16-1, 3–6 cm, Piece 956 is from near the top of the flow, and is dominated by a spherulitic mesostasis. There are thin injections(?) of a fine-grained but holocrystalline material, indicative of the hybridization described above. The three other sections (Samples 16-1, 81–83 cm, Piece 965; 16-2, 12–14 cm, Piece 975; and 16-2, 97–100 cm, Piece 982), are coarser-grained, being microphyric or ophitic, with no spherulitic zones. These, too, show signs of autointrusion in a plastic state. Olivines are replaced by smectites, and Piece 965 has an outer oxidized zone with iron hydroxides, and inner zone with brown smectites. Vesicles are absent in all three sections.

The three thin sections made from the pillow basalts (Samples 16-3, 102–105 cm, Piece 999; 16-4, 82–84 cm, Piece 1011; and 16-5, 106–108 cm, Piece 1030) have primarily spherulitic groundmasses in which prominent and fairly abundant (5–10% apiece) phenocrysts of plagioclase and olivine are set. Plagioclase phenocrysts have sharp normal zoning and some have oscillatory zoning. Olivines are generally altered to smectites. The groundmass is mainly dark fan spherulites, but in some cases clinopyroxene crystals are concentrated and form ophitic aggregates. These are connected to the matrix by arborescent sprays. Plagioclase phenocrysts are sometimes grouped into glomerocrysts.

BULK ANALYSIS:

Core-Section	16-1	16-2	16-3	16-5
Interval (cm)	141–143	89–92	129–134	21–26
SiO_2	49.21	49.32	49.21	49.41
TiO_2	0.98	0.82	0.90	0.94
Al_2O_3	14.63	15.48	15.59	15.96
Fe_2O_3	11.36	10.93	9.76	9.42
MnO	0.19	0.17	0.18	0.21
MgO	8.04	8.09	8.85	8.56
CaO	12.53	12.97	12.92	12.86
Na_2O	2.02	1.73	1.92	1.78
K_2O	0.29	0.10	0.11	0.14
P_2O_5	0.09	0.07	0.09	0.09
Total	99.34	99.68	99.53	99.39
LOI	0.97	0.93	1.38	1.05
Mg/Mg+Fe	0.584	0.594	0.642	0.643
Ca/Ca+Al	0.438	0.432	0.430	0.423
Ni	78	87	174	175
Sr	61	63	90	90
Zr	52	47	52	57
H_2O	–	0.62	1.01	0.86
CO_2	–	0.05	0.25	0.12

PHYSICAL PROPERTIES:

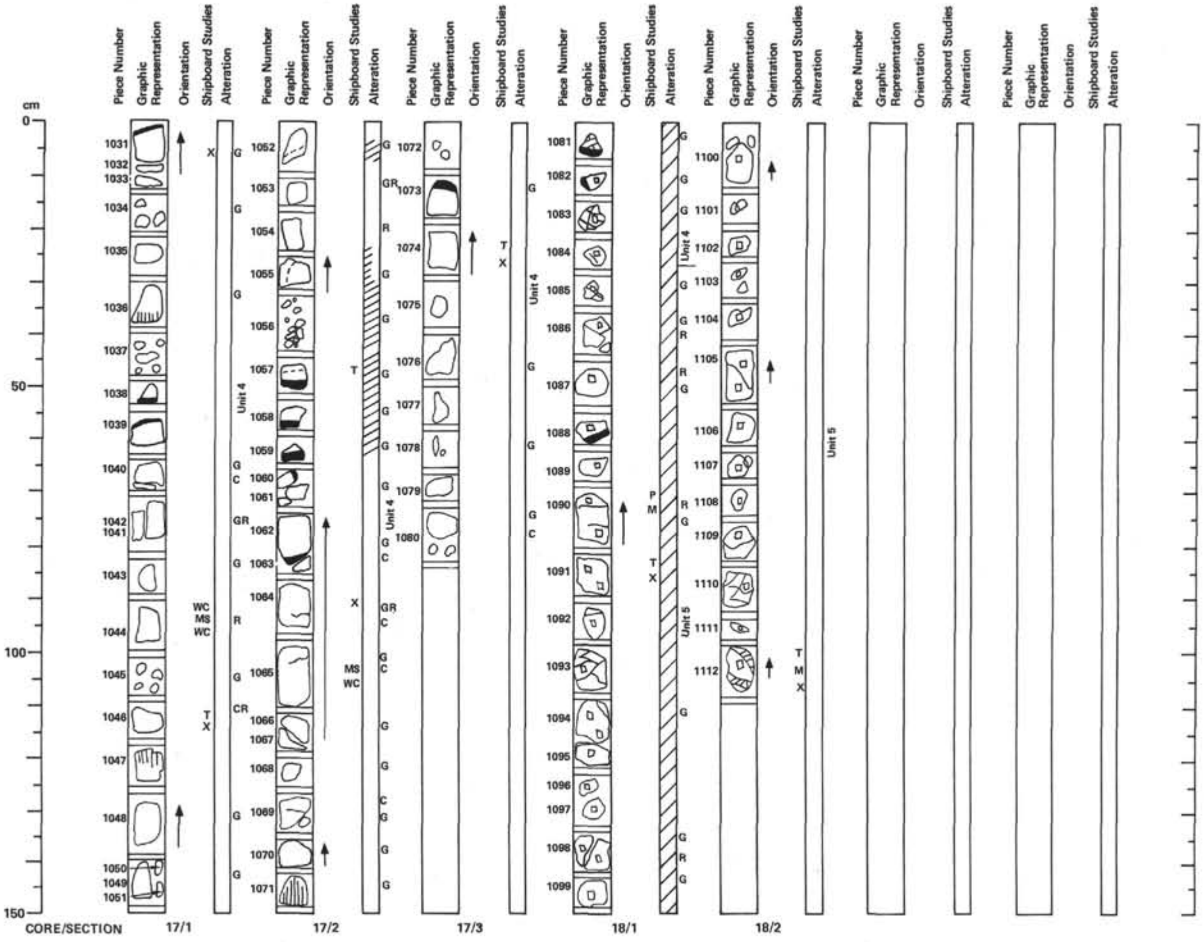
Core-Section, Interval (cm)	Water Content	Porosity	Wet-Bulk	GRAPE	Sonic Velocity
16-1, 20–22	2.35	6.57	2.87	2.82	5.569
16-2, 6–8	2.33	6.47	2.85	2.76	5.320
16-3, 66–68	1.63	4.65	2.92	2.85	5.886
16-3, 134–136	1.61	4.54	2.90	2.81	5.880
16-4, 103–105	2.14	5.98	2.86	2.87	5.883

MAGNETIC DATA:

Core-Section, Interval (cm)	NRM	INCL.	MDF
16-1, 20–22	2,231	−23.5	130
16-2, 6–8	833	−30.0	180
16-3, 66–68	240	−34.0	240
16-3, 134–136	6,525	−39.9	150
16-4, 105–107	7,054	—	—

THERMAL CONDUCTIVITY:

Core-Section, cm	κ
16-1, 2	1.70
16-3, 66	1.70
16-3, 130	1.77



HOLE 504B, CORE 17 3866.5–3891.5 m (393.0–398.0 mbsf)

SPARSELY TO MODERATELY PLAGIOCLASE-OLIVINE PHYRIC PILLOW BASALT (lithologic unit 4)

A continuation of the pillow basalts of Core 16. Glass rinds and spherulitic zones are abundant, but phenocrysts are scarcer than in Core 16, with about 5% plagioclase and 5–7% olivine altered to green or red clays and carbonates. Some pieces have small but visible grains of chromite. Alteration is minor to moderate, with a zone of oxidative alteration near the top of Section 17-2. Veins are lined with green or red smectite and calcite. Oxidized zones occur especially in pillow margins. The rocks are highly fractured. A radiating phillipsite cluster occurs in Piece 1079.

Thin Section Descriptions

One thin section was made from each section (Samples 17-1, 110–114 cm, Piece 1046; 17-2, 46–49 cm, Piece 1054; and 17-3, 22–24 cm, Piece 1074). All three are dominated by variolitic or fan-spherulitic groundmasses. Plagioclase and olivine phenocrysts are euhedral and granular respectively, the latter being replaced by green or clear clay minerals, and calcite.

HOLE 504B, CORE 18 3871.0–3876.5 m (398.0–403.0 mbsf)

SPARSELY PLAGIOCLASE OLIVINE PHYRIC PILLOW BASALTS AND FLOW (lithologic unit 4, to Piece 1084; lithologic unit 5, Pieces 1085–1112)

For descriptions of lithologic unit 4, see Core 17. Lithologic unit 5 is a sequence of pillows and thin flows of sparsely plagioclase olivine phyric basalt. Plagioclase phenocrysts and glomerocrysts are up to 5 mm across, and olivines up to 2 mm across. They total 5% and 2% respectively. Vesicles are 1% and up to 2 mm. There are a number of pieces with glassy or spherulitic margins, and fractures lined with green or red smectites are abundant. Clay minerals also replace olivine.

Thin Section Descriptions

One thin section from each section was prepared (Samples 18-1, 84–86 cm, Piece 1091 and 18-2, 100–102 cm, Piece 1112). Each is porphyritic, with 5–10% smectites. The groundmass is spherulitic to microlitic. Plagioclase phenocrysts are normally zoned, with only traces of oscillatory zoning in larger crystals. Groundmasses are plumose to dendritic, verging on the granular. Olivine is replaced and vesicles filled by smectite, and sometimes pyrite. Iron hydroxide staining occurs in both sections.

BULK ANALYSIS:

Core-Section	17-1	17-1	17-2	17-3	18-1	18-2
Interval (cm)	3–6	110–114	94–97	22–24	84–88	98–102
SiO_2	53.52	49.27	49.65	49.93	49.13	49.95
TiO_2	0.03	0.91	0.92	0.95	1.24	1.33
Al_2O_3	6.48	15.69	15.94	15.70	16.85	16.72
Fe_2O_3	10.63	9.89	9.90	9.86	10.19	8.44
MnO	0.06	0.18	0.19	0.19	0.18	0.22
MgO	25.70	9.06	8.46	8.39	6.92	7.03
CaO	1.32	12.51	12.88	12.77	12.81	13.05
Na_2O	1.79	1.95	2.08	1.88	2.38	2.41
K_2O	0.08	0.11	0.14	0.21	0.39	0.12
P_2O_5	0.01	0.09	0.09	0.09	0.16	0.18
Total	99.62	99.66	100.25	99.97	100.25	99.45
LOI	6.16	1.22	1.03	0.84	1.72	1.58
Mg/Mg+Fe	0.827	0.645	0.629	0.628	0.574	0.623
Ca/Ca+Al	0.156	0.420	0.423	0.425	0.409	0.415
Ni	–	174	158	138	110	160
Sr	–	82	84	83	153	182
Zr	–	57	57	58	87	95
H_2O	–	0.88	0.93	0.74	1.29	1.12
CO_2	–	0.10	0.07	0.03	0.09	0.11

MAGNETIC DATA:

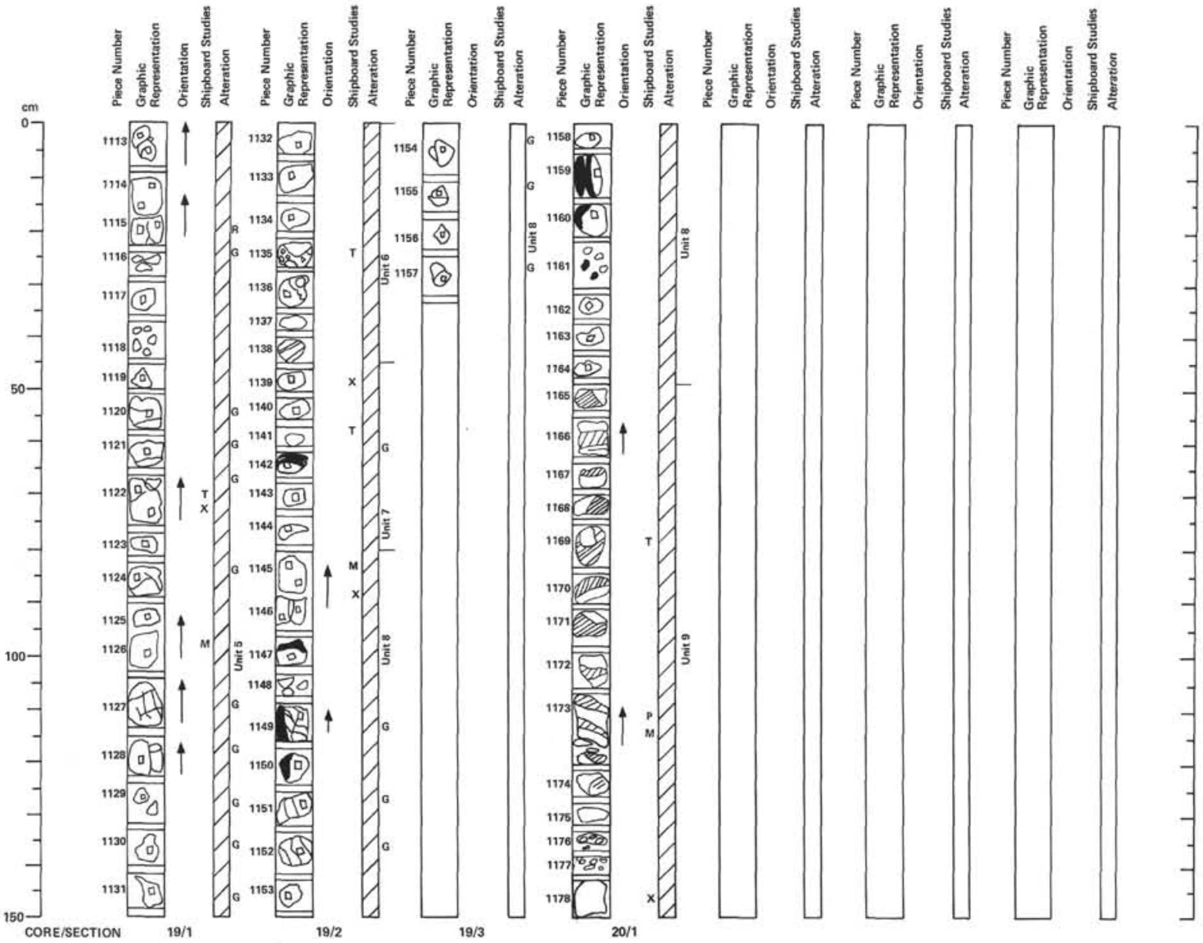
Core-Section, Interval (cm)	NRM	INCL.	MDF
17-1, 96–98	4,702	−12.0	160
17-2, 104–106	6,498	17.1	145
18-1, 71–73	13,813	−23.7	110

PHYSICAL PROPERTIES:

Core-Section, Interval (cm)	Water Content	Porosity	Wet-Bulk	GRAPE	Sonic Velocity
17-1, 96–98	1.42	4.01	2.91	2.82	5.978
17-2, 104–106	2.14	6.03	2.89	2.80	5.864
18-1, 71–73	4.33	11.52	2.73	2.66	5.112

THERMAL CONDUCTIVITY:

Core-Section, cm	κ
17-2, 104	1.58
18-1, 77	1.60



BULK ANALYSIS:

Core-Section	19-1	19-2	19-2	20-1
Interval (cm)	73–77	46–49	88–92	142–145
SiO_2	49.26	49.69	49.71	49.63
TiO_2	1.37	1.23	0.86	1.01
Al_2O_3	17.22	17.41	16.16	16.21
Fe_2O_3	9.43	9.04	9.88	10.07
MnO	0.20	0.18	0.18	0.18
MgO	6.49	6.71	7.87	7.64
CaO	13.28	13.08	13.21	12.97
Na_2O	2.33	2.17	2.07	2.17
K_2O	0.15	0.15	0.15	0.14
P_2O_5	0.19	0.17	0.06	0.11
Total	99.92	99.88	100.15	100.13
LOI	1.56	1.61	0.99	1.55
Mg/Mg+Fe	0.577	0.595	0.612	0.600
Ca/Ca+Al	0.412	0.406	0.426	0.421
Ni	117	123	121	114
Sr	178	159	68	96
Zr	96	85	51	54
H_2O	1.17	1.23	0.66	1.08
CO_2	0.09	0.15	0.07	0.07

MAGNETIC DATA:

Core-Section, Interval (cm)	NRM	INCL.	MDF
19-1, 101–103	7,015	−25.2	210
19-2, 86–88	2,759	−10.1	125
20-1, 109–111	2,500	−31.4	105

PHYSICAL PROPERTIES:

Core-Section, Interval (cm)	Water Content	Porosity	Wet-Bulk	GRAPE	Sonic Velocity
19-1, 103–105	1.93	5.34	2.84	2.77	5.858
19-2, 88–89	1.44	4.13	2.95	2.87	6.268
20-1, 116–117	1.72	4.84	2.88	2.94	5.585

THERMAL CONDUCTIVITY:

Core-Section, cm	κ
19-2, 83	1.67

HOLE 504B, CORE 19 *3876.5–3885.5 m (403.0–412.0 mbsf)*

A SEQUENCE OF SEVERAL LITHOLOGIC UNITS

PIECES 111–1131: A continuation of lithologic unit 5, previously described under Core 18. **PIECES 1132–1138 (lithologic unit 6):** Sparsely to moderately phyrict basalt. Phenocrysts are plagioclase, about 7% up to 4 mm, and *olivine*, about 3% and up to 2–3 mm replaced by smectites. Vesicles are absent. Piece 1135 has a breccia attached to a larger rock fragment. The basalts resemble those of Core 17 rather than Core 18. **PIECES 1139–1144 (lithologic unit 7):** Fine-grained, sparsely phyric basalt resembling Core 18. Phenocrysts are plagioclase (3–4% up to 3 mm) and olivine (1–2% up to 2 mm). Vesicles are absent. Groundmass is intersertal except for Piece 1142, which is glassy. Olivine is converted to green smectite. **PIECES 1145–1157 (lithologic unit 8):** Moderately phyric plagioclase-olivine-clinopyroxene basalt. Plagioclase phenocrysts are about 10% and up to 4 mm, olivine 3% and up to 3 mm, and clinopyroxene, less than 1% and up to 3 mm. Some pieces are glassy, others spherulitic, and most microlitic. There are veins and pseudomorphs (after olivine) of green smectite.

Thin Section Descriptions

Sample 19-1, 73–77 cm, Piece 1122: The section consists of less than 5% olivine and 5–10% plagioclase phenocrysts with rare clinopyroxene phenocrysts set in a dense fan spherulitic groundmass. Plagioclase phenocrysts have normal and oscillatory zoning. Some are skeletal and poikilitic enclosing anhedral plagioclase, others are multiply twinned. Brown clays replace olivine and fill vesicles.

Sample 19-2, 22–24 cm, Piece 1135: The section resembles Piece 1122 except that the groundmass is more microlitic. The plagioclase phenocrysts and glomerocrysts are largely skeletal and normally zoned. The glomerocrysts are intergrown with altered olivine. Clays are about 30% of the rock, in the matrix and after olivine. The sample has a breccia pasted on one side. It is mainly altered glass and spherulitic *material, finer-grained than the clast. Plagioclase* is partly altered to clays in tha breccia.

Sample 19-2, 58–60 cm, Piece 1141: There are 5–10% euhedral, tabular, and skeletal plagioclase phenocrysts and less than 1% olivine phenocrysts set in a spherulitic matrix. Some of the spherulites contain acicular needle-like skeletal plagioclase arrayed in sworls. Titanomagnetite grows between clinopyroxene dendrites and at junctions of spherulites. There are round spherulites at one end of the section, and coarser plumose spherulites at the other. Clays replace olivine and clinopyroxene and fill rare, round vesicles.

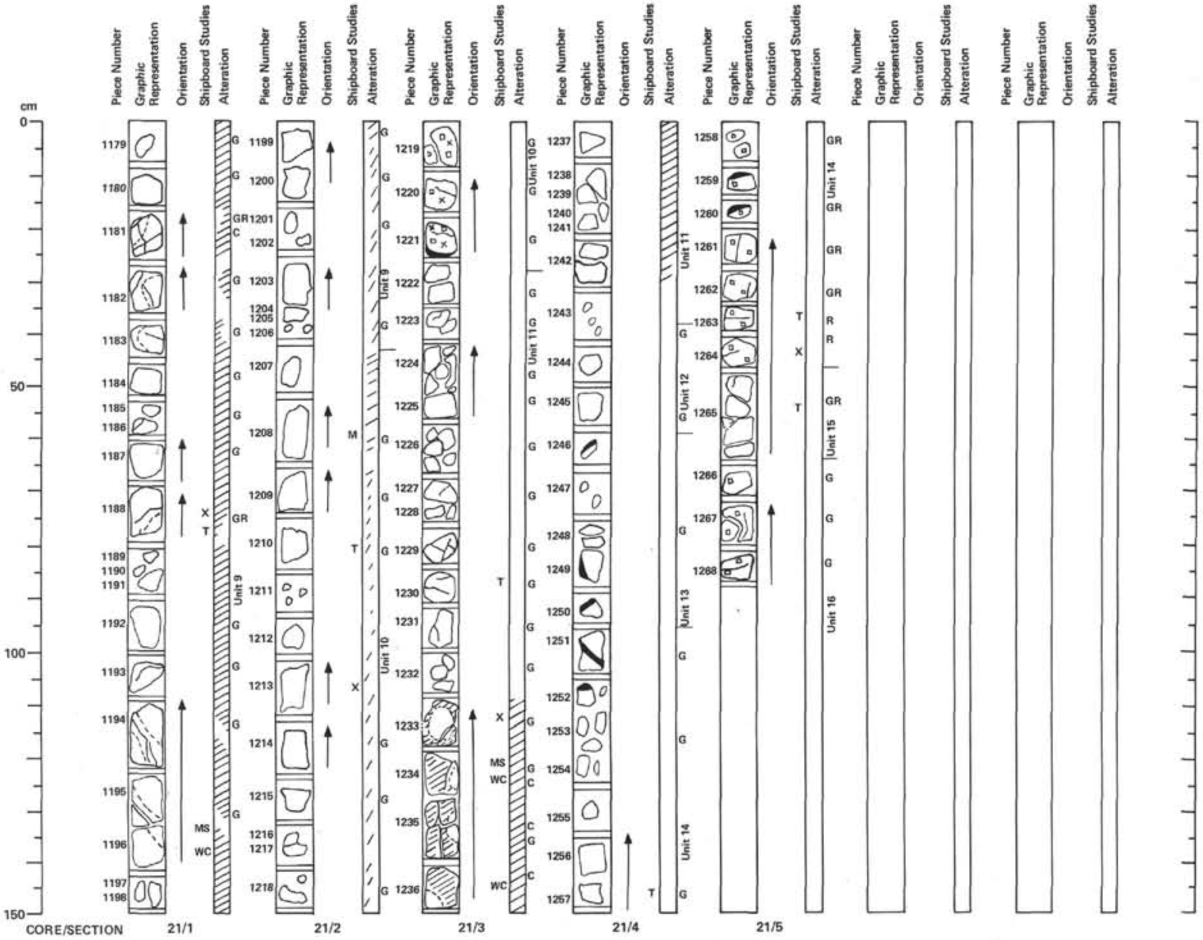
HOLE 504B, CORE 20 *3885.5–3894.5 m (412.0–421.0 mbsf)*

PORTIONS OF TWO LITHOLOGIC UNITS

PIECES 1158–1164 (lithologic unit 8): A continuation of the material described under Core 19. **PIECES 1165–1178 (lithologic unit 9):** This is a sparsely plagioclase phyric basalt, probably a single cooling unit, perhaps a flow. Plagioclase phenocrysts (about 5%) are euhedral or form glomerocrysts up to 3 mm across. The rock is fairly crystalline with ophitic texture, and lacks chilled cooling selvages. Almost all samples have a strong oxidation zonation. Calcite occurs in the central parts of crack fillings which are otherwise lined with clays.

Thin Section Description

Sample 20-1, 77–80 cm, Piece 1169: This sample, from a flow interior, is nearly holocrystalline, and about equally divided between plagioclase and clinopyroxene, with minor titanomagnetite and intergranular spherulitic zones. Texture is subophitic to intersertal. There are euhedral to subhedral large plagioclases enclosed by and enclosing anhedral to dendritic coarse clinopyroxene and minor titanomagnetite-rich mesostasis. There is a prominent zonation in the thin section (green at one end, red at the other). Interstitial patches in the red zone have dull reflective Fe-hydroxides with red internal reflectors. Green smectites form patches in the green zone and are associated with pyrite.



BULK ANALYSIS:

Core-Section	21-1	21-2	21-3	21-5
Interval (cm)	70–75	101–105	110–115	43–46
SiO_2	49.66	49.60	50.05	49.81
TiO_2	1.00	0.76	0.99	0.74
Al_2O_3	16.59	16.76	15.85	16.09
Fe_2O_3	9.79	9.45	9.66	9.72
MnO	0.16	0.17	0.20	0.18
MgO	7.57	7.76	7.75	8.51
CaO	12.96	13.49	13.13	13.20
Na_2O	2.16	1.82	2.14	1.81
K_2O	0.12	0.09	0.04	0.12
P_2O_5	0.09	0.07	0.08	0.06
Total	100.10	99.97	99.89	100.24
LOI	1.68	1.07	1.32	0.96
Mg/Mg+Fe	0.605	0.619	0.614	0.634
Ca/Ca+Al	0.415	0.423	0.430	0.427
Ni	133	121	121	139
Sr	97	58	95	55
Zr	59	41	60	36
H_2O	1.11	0.81	0.84	0.70
CO_2	0.05	0.05	0.12	0.09

MAGNETIC DATA:

Core-Section, Interval (cm)	NRM	INCL.	MDF
21-1, 137–139	2,097	−33.6	145
21-2, 57–61	10,847	—	—
21-3, 123–125	3,500	−29.2	90
21-4, 136–138	3,709	−26.0	170

PHYSICAL PROPERTIES:

Core-Section, Interval (cm)	Water Content	Porosity	Wet-Bulk	GRAPE	Sonic Velocity
21-1, 137–140	2.45	6.83	2.85	2.80	5.546
21-2, 59–61	2.27	6.32	2.85	2.79	5.671
21-3, 123–125	1.57	4.44	2.90	2.81	5.738
21-4, 136–138	2.23	6.23	2.86	2.79	5.828

THERMAL CONDUCTIVITY:

Core-Section, cm	κ
21-2, 59	1.66
21-4, 136	1.57

HOLE 504B, CORE 21 3894.5–3905.5 m (421.0–430.0 mbsf)

A SEQUENCE OF SEVERAL LITHOLOGIC UNITS

PIECES 1179–1206: A continuation of lithologic unit 9. Pieces 1179–1180 are breccias or part breccias. Piece 1182 has slickensides in smectites indicating reverse faulting. Similar faults are in Piece 1183. Veins are filled with green or red smectites. Alteration is moderate to intense.

PIECES 1207–1221 (lithologic unit 10): Plagioclase-olivine phyric basalt (plagioclase 5–10% up to 2 mm; olivine 5% up to 3 mm).

PIECES 1222–1242 (lithologic unit 11): Nearly aphyric plagioclase-olivine basalt, possibly a flow, generally coarse-grained.

PIECES 1243–1245 (lithologic unit 12): Similar to unit 10.

PIECES 1246–1250 (lithologic unit 13): Aphyric pillow lavas with rare olivine microphenocrysts and several fresh glassy margins.

PIECES 1251–1264 (lithologic unit 14): Moderately phyric basalt with phenocrysts of plagioclase (about 5%) and olivine (about 3%). Three recovered glassy margins are flat. One is within Piece 1251. Unit resembles units 10 and 12.

PIECE 1265 (lithologic unit 15): Aphyric basalt, perhaps a dike. Very fine-grained basalt with a few microphenocrysts of olivine and plagioclase.

PIECES 1266–1268 (lithologic unit 16): Moderately olivine-plagioclase-olivine phyric basalt. Plagioclase is 10%, olivine 3%, and clinopyroxene less than 1% of the rock, all up to 3–4 mm. Olivine is altered to green clays with calcite cores.

GENERAL SUMMARY: The alternation within a few meters of 8 lithologic units with contrasting textures and phenocryst modes suggests a repetition by faulting, or diking. Although most of the rocks are fine-grained, a number of the lithologic units lack glass rinds, suggesting that the sequence was not produced by overlapping of flows or pillows from different sources. Alteration is similar to cores above and below, with olivines replaced by green smectites, and veins and fractures lined with smectites and calcite. The occurrence of slickensides in lithologic unit 9 is support for the hypothesis that faulting has produced the repetition of units.

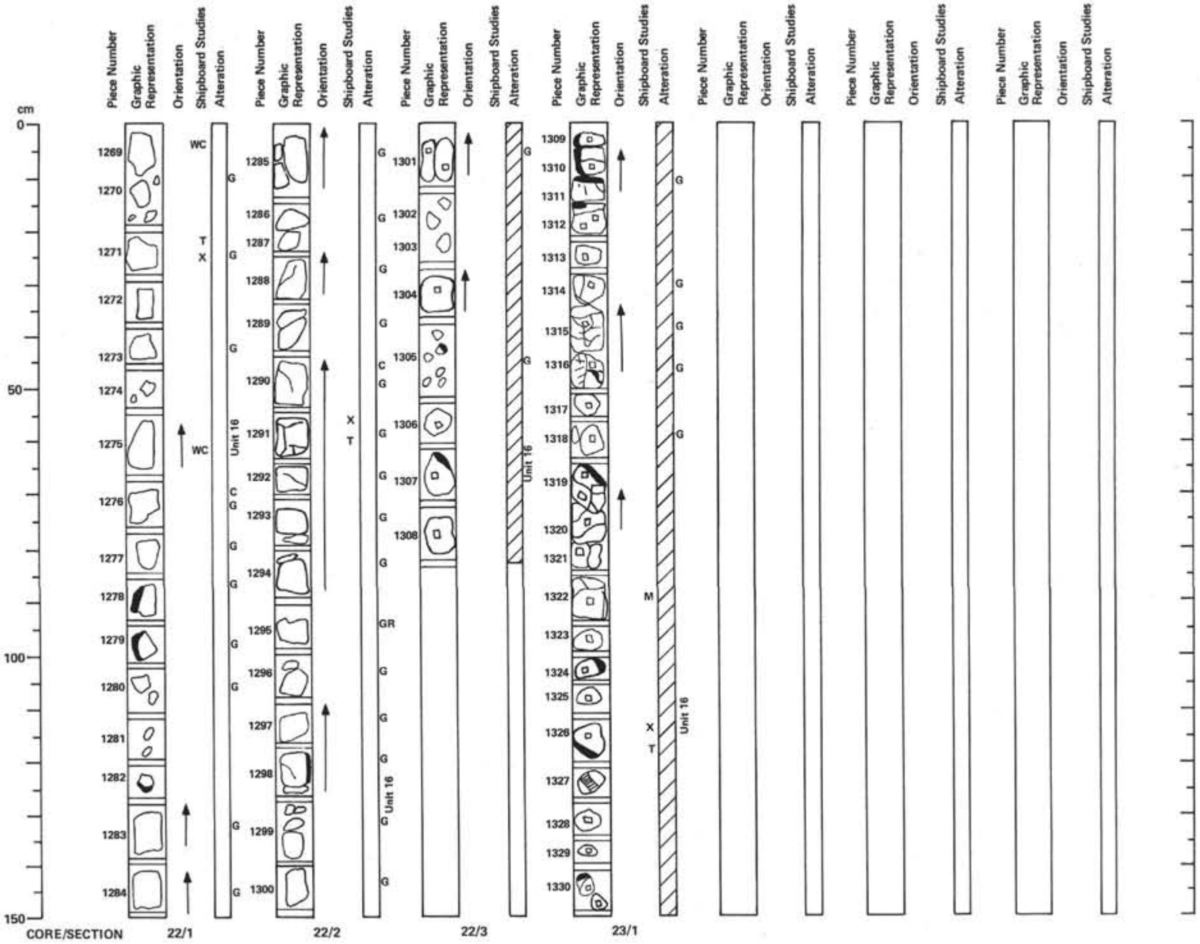
Thin Section Descriptions

Sample 21-1, 10–75 cm, Piece 1188 (lithologic unit 9): Aphyric subophitic basalt, with about 40% plagioclase and 50% clinopyroxene, and subordinate intergranular titanomagnetite and spherulitic zones. There is a complete gradation in grain size down to spherulitic, but overall the sample is quite coarse-grained. Interstitial patches have clays and secondary iron hydroxides, which are fairly reflective.

Sample 21-2, 78–80 cm, Piece 1210 (lithologic unit 10): Sample from a pillow rim with a dominantly spherulitic mesostasis. Plagioclase phenocrysts (5–10%) occur as: 1) coarse anhedral glomerocrysts; 2) small, loosely clumped glomerocrysts of euhedral crystals; and 3) single crystals. Clinopyroxene phenocrysts are rounded and poikilitically enclose plagioclase. Olivine is altered to clays, and euhedral. The groundmass is partly plumose spherulites, and partly coarser-grained wtih abundant sworls of acicular plagioclase. There is minor chrome spinel. Clays are interstitial and replace olivine and clinopyroxene.

Sample 21-5, 37–39 cm, Piece 1263 (lithologic unit 14): This sample, from a pillow interior, has about 50% spherulitic material partly replaced by brown clays. It has abundant microlitic to acicular plagioclase. Plagioclase phenocrysts occur in the same three categories as in Piece 1210. The groundmass has distinct acicular plagioclases between which are abundant titanomagnetites. Olivines are replaced by clays.

Sample 21-5, 52–54 cm, Piece 1265 (lithologic unit 15): Scattered (1–5%) euhedral plagioclase phenocrysts are set in a spherulitic groundmass with minor acicular plagioclase microlites. Titanomagnetite is concentrated between spherulitic bundles. Spherulites have a fuzzy appearance (alteration?). Titanomagnetites are pitted, corroded, and cracked, a sign of thermal degradation. Clinopyroxene, if once present, is now altered. There are red, internally reflective oxides in cracks, and a green clay-filled crack at one end.



HOLE 504B, CORE 22 3903.5–3912.5 m (430.0–439.0 mbsf)

MODERATELY PLAGIOCLASE-OLIVINE-CLINOPYROXENE PHYRIC PILLOW BASALTS (lithologic unit 16)

This is a continuation of the lithologic unit described at the end of Section 21-5. The basalts have about 8% plagioclase phenocrysts up to 2–3 mm, 5% olivine phenocrysts up to 2 mm, now replaced by green and red smectites, and 1% clinopyroxene phenocrysts up to 5 mm. There are a number of fresh glassy margins in the core. Vesicles are absent. Pieces 1290–1293 are dissected by hairline fractures filled by green smectite. Piece 1291 has phillipsite on its surface. Glass in Piece 1298 is almost completely altered.

Thin Section Descriptions

Sample 22-1, 23–25 cm, Piece 1271: The rock is mainly spherulitic on one side, and about half microlitic, half spherulitic on the other. There are a few per cent plagioclase phenocrysts occurring both as isolated crystals and as glomerocrysts intergrown with olivine. Clays fill veins, replace olivine, and are associated with a black, isotropic, iron hydroxide. Chrome spinel occurs in a microbrecciated crack.

Sample 22-2, 60–62 cm, Piece 1291: Plagioclase phenocrysts occur as single, tabular crystals, single anhedral crystals, clumps of tabular crystals, or intergrowths with clinopyroxene in glomerocrysts. Clinopyroxene microphenocrysts in the groundmass are tabular to anhedral, and some are intergrown with acicular plagioclase. The rock has two prominent green-clay-filled cracks paralleling one end (closest to and parallel to pillow rim). One goes right through a rounded (resorbed) clinopyroxene phenocryst.

HOLE 504B, CORE 23 3912.5–3930.5 m (448.0–457.0 mbsf)

MODERATELY PLAGIOCLASE-OLIVINE-CLINOPYROXENE PHYRIC PILLOW BASALT (lithologic unit 16)

A continuation of the lithologic unit described mainly in Core 22. Plagioclase phenocrysts are 10% of the rock and up to 4 mm, olivines 3% and up to 3 mm, and clinopyroxene 3% and up to 3 mm. Vesicles are absent. Olivine is converted into green smectite and rare calcite. Cracks are filled with green smectite and carbonates. Piece 1327 seems to be an erratic from the rock types of Cores 20 and 21, with the red oxidation zones.

Thin Section Description

Sample 23-1, 115–118 cm, Piece 1326: This is from a pillow rim, and is glassy-spherulitic, and porphyritic, with fewer than 5% each phenocrysts of plagioclase, olivine, and clinopyroxene. The plagioclases occur as isolated crystals, small tabular crystals in clumps, and as glomerocrysts intergrown with clinopyroxene and olivine. Clinopyroxene phenocrysts are euhedral and rounded; one clump of four occurs. Olivine is altered to clays. The groundmass has about 20% plagioclase microlites intergrown with anhedral clinopyroxene. Glass occurs on one edge, then several spherulitic zones (isolated rounded spherulites, coalesced rounded spherulites, sheaf-spherulites). Pyrite occurs associated with green clays in the matrix. A chromian spinel is trapped in a plagioclase phenocryst.

BULK ANALYSIS:

Core-Section	22-1	22-2	23-1
Interval (cm)	25–28	56–62	112–117
SiO_2	49.29	49.62	49.79
TiO_2	0.70	0.74	0.88
Al_2O_3	16.23	16.60	16.42
Fe_2O_3	9.24	9.26	9.77
MnO	0.19	0.17	0.17
MgO	9.68	8.37	7.71
CaO	12.88	13.42	13.15
Na_2O	1.67	1.77	1.95
K_2O	0.09	0.07	0.14
P_2O_5	0.06	0.06	0.07
Total	100.03	100.08	100.05
LOI	1.90	1.14	0.61
Mg/Mg+Fe	0.675	0.642	0.610
Ca/Ca+Al	0.419	0.424	0.421
Ni	139	131	117
Sr	50	53	67
Zr	33	36	49
H_2O	1.47	0.77	0.53
CO_2	0.12	0.04	0.03

MAGNETIC DATA:

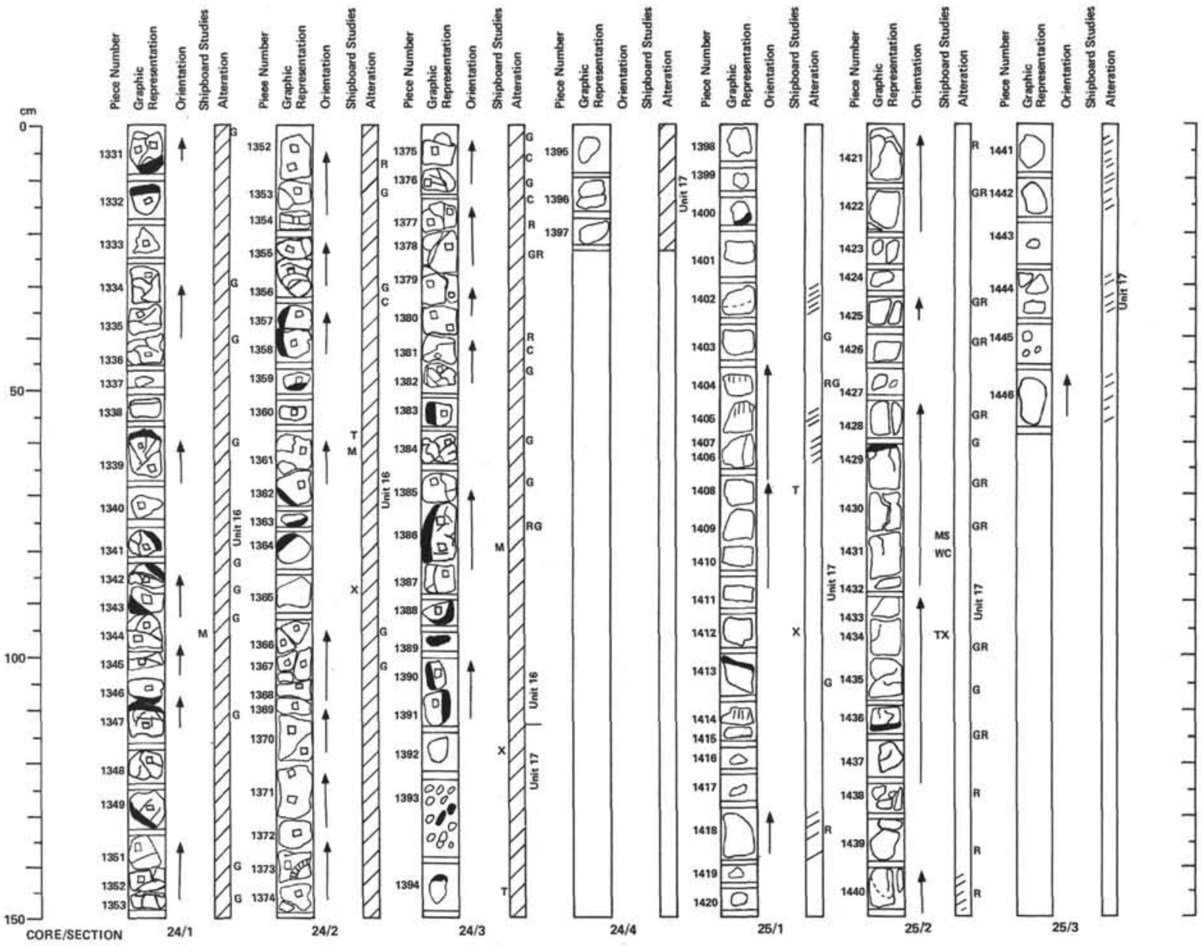
Core-Section, Interval (cm)	NRM	INCL.	MDF
22-1, 62–64	4,294	−26.5	370
23-1, 88–90	4,855	−40.0	160

PHYSICAL PROPERTIES:

Core-Section, Interval (cm)	Water Content	Porosity	Wet-Bulk	GRAPE	Sonic Velocity
22-1, 62–64	1.98	5.54	2.87	2.84	5.944
23-1, 90–92	1.39	4.06	2.92	2.86	6.187

THERMAL CONDUCTIVITY:

Core-Section, cm	κ
22-1, 62	1.67
23-1, 84	1.65



HOLE 504B, CORE 24 3912.5–3925.5 m (439.0–448.0 mbsf)

PIECES 1331–1391: MODERATELY PLAGIOCLASE-OLIVINE-CLINOPYROXENE PHYRIC PILLOW BASALT (lithologic unit 16); PIECES 1392–1397: SPARSELY OLIVINE PLAGIOCLASE PHYRIC BASALT (lithologic unit 17)

The basalts in Sections 24-1, 24-2, and most of 24-3 are similar to those of Cores 22 and 23 in having about 10% plagioclase phenocrysts, 4% olivine phenocrysts, and 2% clinopyroxene phenocrysts, between 3 and 5 mm in diameter. Glassy zones, largely or partly altered to smectites, are abundant, indicating very small pillows. Alteration is moderate to intense. Fractures lined with green or brown smectites are abundant.

Basalts from Section 12-3, Piece 1392 downward, are sparsely phyric, almost aphyric plagioclase-olivine fine-grained basalt having several fresh glassy margins. Here, too, cracks are filled with green and red clay minerals, and there are red, yellow, and gray zones of alteration.

Thin Section Description

Sample 24-2, 58–62 cm, Piece 1361: This is a moderately porphyritic plumose spherulitic basalt, with about 10% plagioclase phenocrysts and 1% or less phenocrysts of olivine and clinopyroxene. There are 4 types of plagioclase phenocrysts: 1) poikilitically enclosed by clinopyroxene in glomerocrysts; 2) in clumps of large, euhedral crystals; 3) as smaller euhedral crystals in chaotic arrangement in glomerocrysts; and 4) as isolated crystals. The groundmass is brown and spherulitic, with titanomagnetite between spherulites. The groundmass has tiny acicular plagioclase intergrown with anhedral clinopyroxene. Clays and pyrite replace olivine, and clays fill veins.

HOLE 504B, CORE 25 3930.0–3936.5 m (457.0–463.0 mbsf)

APHYRIC OR VERY SPARSELY OLIVINE-PLAGIOCLASE PHYRIC BASALT (lithologic unit 17)

This core contains a continuation of the pillow basalts described under Core 24. There are sparse olivine microphenocrysts visible in some samples, but which are replaced by clays. Fresh glassy margins and zones of spherulites abound. A nearly completely recovered pillow or cooling unit is in Section 25-2 (Pieces 1429–1436). There are numerous cracks lined with green or red smectites.

Thin Section Description

Sample 25-1, 70–72 cm, Piece 1408: This sample, from a pillow interior, ranges from subophitic to coarsely spherulitic. There are about equal proportions of plagioclase, clinopyroxene, and spherulitic mesostasis. The subophitic material appears as clumps of coarsely intergrown plagioclase and clinopyroxene. Titanomagnetite is largely restricted to the spherulitic zones. There are no obvious phenocrysts, but a continuum of grain sizes. There is much interstitial stuff replaced by red and green smectites, and associated reflective iron hydroxides. Titanomagnetite is slightly pitted and cracked.

BULK ANALYSIS:

Core-Section	24-1	24-2	24-3	25-1	25-2
Interval (cm)	62–66	85–88	104–106	94–98	96–99
SiO_2	49.48	49.62	49.57	50.20	50.89
TiO_2	0.85	0.88	1.00	0.99	1.01
Al_2O_3	15.96	15.82	16.19	14.71	15.13
Fe_2O_3	9.89	9.77	9.52	10.56	9.24
MnO	0.18	0.18	0.18	0.19	0.16
MgO	8.60	8.49	8.54	8.37	8.64
CaO	12.99	13.08	12.89	12.84	12.92
Na_2O	1.96	1.93	1.99	2.01	2.38
K_2O	0.08	0.09	0.15	0.09	0.11
P_2O_5	0.09	0.08	0.08	0.08	0.07
Total	99.87	99.94	100.11	100.04	100.55
LOI	0.83	0.77	0.83	0.18	0.63
Mg/Mg+Fe	0.637	0.632	0.640	0.611	0.649
Ca/Ca+Al	0.425	0.429	0.420	0.442	0.437
Ni	132	115	118	93	115
Sr	63	61	90	69	70
Zr	46	48	60	54	53
H_2O	0.78	0.64	0.65	0.40	0.64
CO_2	0.06	0.06	0.08	0.09	0.07

MAGNETIC DATA:

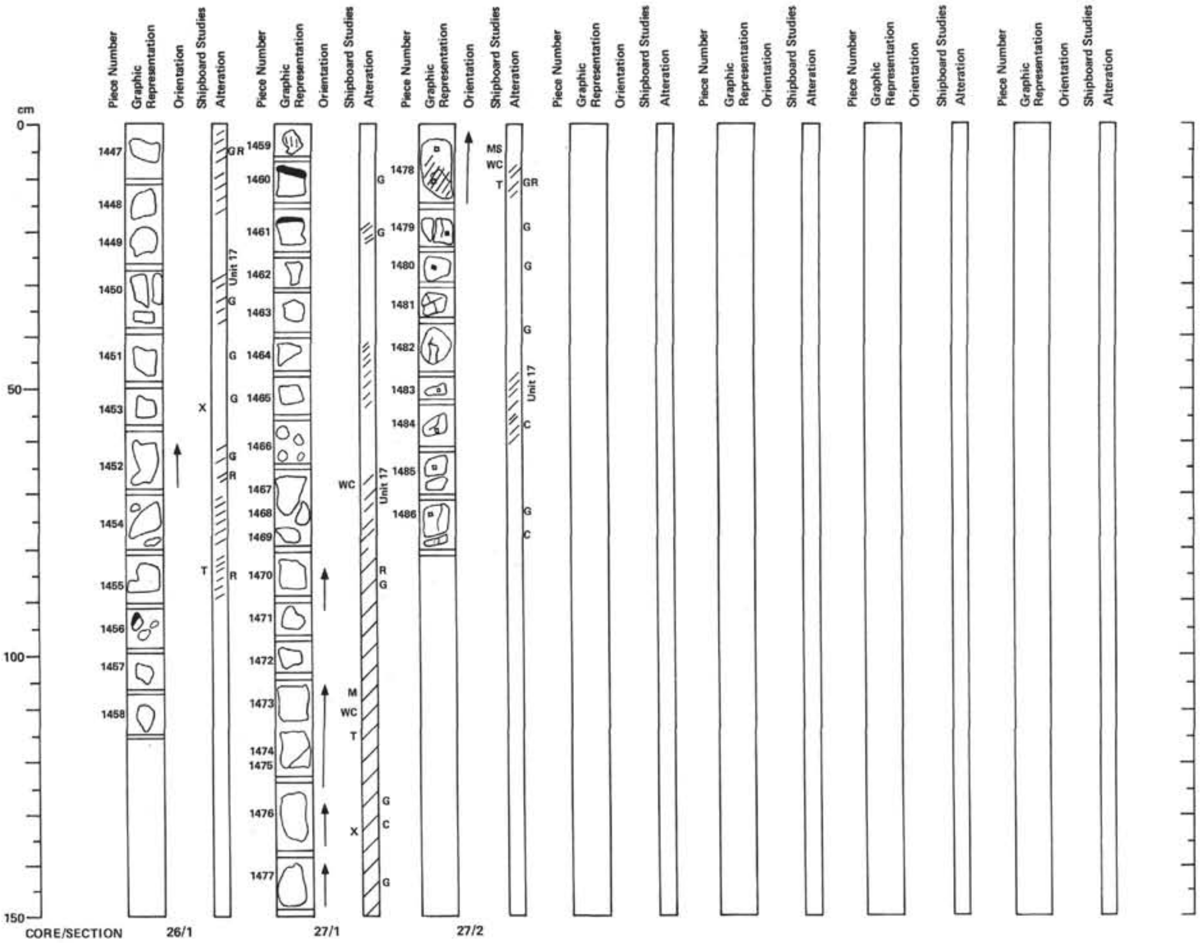
Core-Section, Interval (cm)	NRM	INCL.	MDF
24-1, 100–102	6,540	–28.9	170
24-2, 62–64	6,317	–35.7	180
24-3, 76–78	5,830	–28.6	180
25-2, 83–85	709	–25.3	110

PHYSICAL PROPERTIES:

Core-Section, Interval (cm)	Water Content	Porosity	Wet-Bulk	GRAPE	Sonic Velocity
24-1, 102–103	2.01	5.75	2.86	2.73	5.665
24-2, 64–65	1.76	5.10	2.90	2.60	5.784
24-3, 77–78	1.13	3.32	2.94	2.86	6.002
25-2, 83–85	1.88	5.42	2.88	2.81	5.876

THERMAL CONDUCTIVITY:

Core-Section, cm	κ
24-2, 7	1.65
25-2, 83	1.89



HOLE 504B, CORE 26 3936.5–3939.5 m (463.0–466.0 mbsf)

APHYRIC BASALT (lithologic unit 17)

Light gray, aphyric basalt with scattered, rare olivine microphenocrysts altered to clays, and one piece with fresh glass. Alteration is minor to moderate, with an oxidation zone in Pieces 1453–1454. The core was only 3 meters long, and recovery was low, hence there is only this one section.

Thin Section Description

Sample 26-1, 86–89 cm, Piece 1455: This sample has a few per cent each microphenocrysts of plagioclase and olivine, but is mostly microlitic to spherulitic in texture. The groundmass is divided into: 1) stellate clumps of radiating plagoclase and anhedral clinopyroxene and 2) plumose spherulites with titanomagnetite-rich interstital zones, dark brown in color. Clays replace olivine and occur interstitially. Fe-hydroxides also occur in olivines and form the core of a vein on one edge of the thin section.

HOLE 504B, CORE 27 3939.5–3948.5 m (466.0–475.0 mbsf)

PARTS OF TWO LITHOLOGIC UNITS

PIECES 1459–1475 (lithologic unit 17): As described in previous cores. Fresh glass occurs on two pieces. Alteration is minor to moderate.

PIECES 1476–1482 (lithologic unit 18): These have about 7% plagioclase phenocrysts (2–5 mm) and 2–3% olivine phenocrysts (up to 2 mm). There is accessory chromite. The rock is moderately altered, with secondary green and red clay minerals replacing olivine and partly or completely filling cracks. Piece 1477 is a breccia. There are offset veins filled with green smectite in Piece 1481.

Thin Section Description

Sample 27-2, 11–13 cm, Piece 1478: This sample, from a pillow interior, has about 5% plagioclase phenocrysts and glomerocrysts in a microlitic groundmass composed mainly of acicular plagioclase and plumose spherulitic interstitial material. Mafic phenocrysts (olivine? clinopyroxene?) are now replaced by clays. Titanomagnetite is rare, perhaps most of it has been altered. Clays are abundant in interstital zones and as replacements for mafic phenocrysts.

BULK ANALYSIS:

Core-Section	26–1	27–1
Interval (cm)	52–54	130–134
SiO_2	50.36	49.60
TiO_2	1.00	1.12
Al_2O_3	15.06	17.68
Fe_2O_3	9.98	9.07
MnO	0.18	0.16
MgO	8.43	6.39
CaO	12.71	13.34
Na_2O	2.25	2.95
K_2O	0.17	0.09
P_2O_5	0.07	0.10
Total	100.21	100.50
LOI	0.54	1.41
Mg/Mg+Fe	0.626	0.583
Ca/Ca+Al	0.434	0.407
Ni	103	168
Sr	69	114
Zr	55	69
H_2O	0.63	1.21
CO_2	0.05	0.16

MAGNETIC DATA:

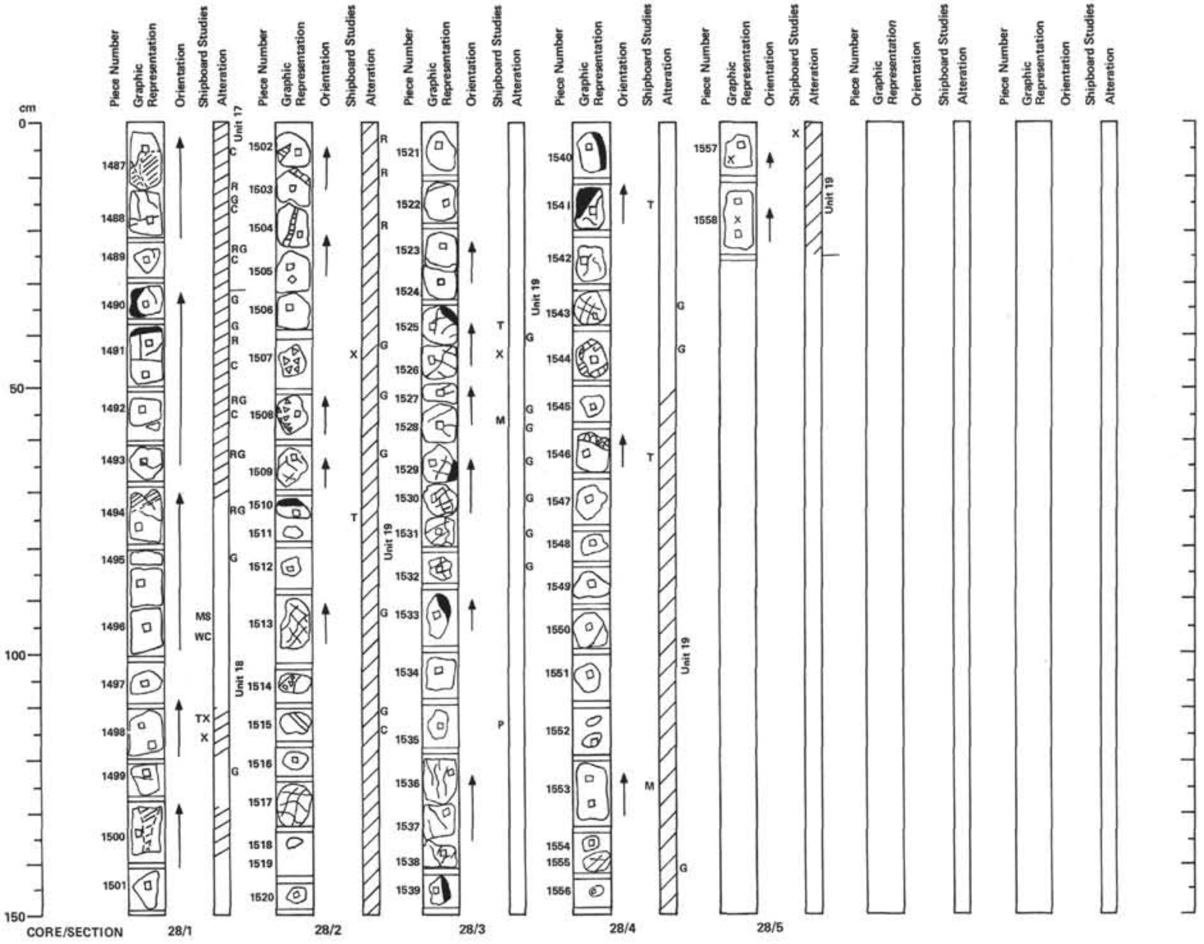
Core-Section, Interval (cm)	NRM	INCL.	MDF
27-1, 109–111	878	– 6.7	85
27-2, 106–108	4,496	–15.8	200

PHYSICAL PROPERTIES:

Core-Section, Interval (cm)	Water Content	Porosity	Wet-Bulk	GRAPE	Sonic Velocity
27-1, 109–111	1.71	4.93	2.89	2.88	5.747
27-2, 106–108	3.99	10.93	2.74	2.69	5.107

THERMAL CONDUCTIVITY:

Core-Section, cm	κ
27-1, 106	1.63
27-1, 106	1.64



HOLE 504B, CORE 28 3948.5–3957.5 m (475.0–484.0 mbsf)

PIECES 1487–1490 (lithologic unit 18): SPARSELY PLAGIOCLASE OLIVINE PHYRIC BASALT; PIECES 1491–1556 (lithologic unit 19): SPARSELY–MODERATELY PLAGIOCLASE-OLIVINE-CLINOPYROXENE PHYRIC BASALT

Pieces 1487–1490 are a continuation of lithologic unit 18, described under previous cores. In this core they are moderately altered, to red smectites and calcite, and include one piece (1490) with a glassy rind.

Below Piece 1490 are basalts with 5–10% plagioclase phenocrysts up to 3 mm, about 3% olivine phenocrysts, also up to 3 mm, and 1–2% clinopyroxene phenocrysts, up to 2 mm. Textures range from nearly glassy to intersertal microlitic. Alteration is minor to moderate, mainly oxidative in Section 28-1, and non-oxidative (green smectites and calcite) below. Olivine is entirely replaced by green clays. Piece 1546 is a breccia.

Thin Section Descriptions

Sample 28-1, 110–113 cm, Piece 1498: This sample, from a pillow interior, is subophitic. It has scattered plagioclase and clinopyroxene phenocrysts and glomerocrysts in a matrix nearly as coarse-grained as the phenocrysts. The sample has titanomagnetite-rich interstital patches. The titanomagnetite shows evidence for thermal degradation (wormy edges, cracks, etc.). One end of the section shows oxidative alteration. Interstitial zones are replaced by uniform Fe-hydroxides and/or clay, which has eaten into Ti-magnetites.

Sample 28-2, 73–76 cm, Piece 1311: This sample is from a pillow rim and is intensely altered. It has a mainly relict spherulitic groundmass, with all clinopyroxene and some plagioclase phenocrysts replaced by clays. The sample is brecciated, with clays cementing pieces together. There are many broken mineral (plagioclase) grains in the cracks.

Sample 28-4, 12–16 cm, Piece 1541: This is a glassy to spherulitic pillow rim sample, with 5–10% plagioclase phenocrysts, and a few olivine and clinopyroxene phenocrysts. Plagioclases are euhedral, clinopyroxenes subhedral, olivines skeletal. Glass is altered on one side completely to clays. The sample is more or less a breccia, with many fractured mineral grains.

Sample 28-3, 62–63 cm, Piece 1546: This sample, from a pillow interior, has an intersertal to subophitic texture, with over 30 each plagioclase and clinopyroxene crystals. Plagioclase and clinopyroxene form glomerocrysts, and much of the plagioclase is skeletal. Clays replace olivine and much of the groundmass. A moderately reflective iron hydroxide mineral also occurs in the olivines.

BULK ANALYSIS:

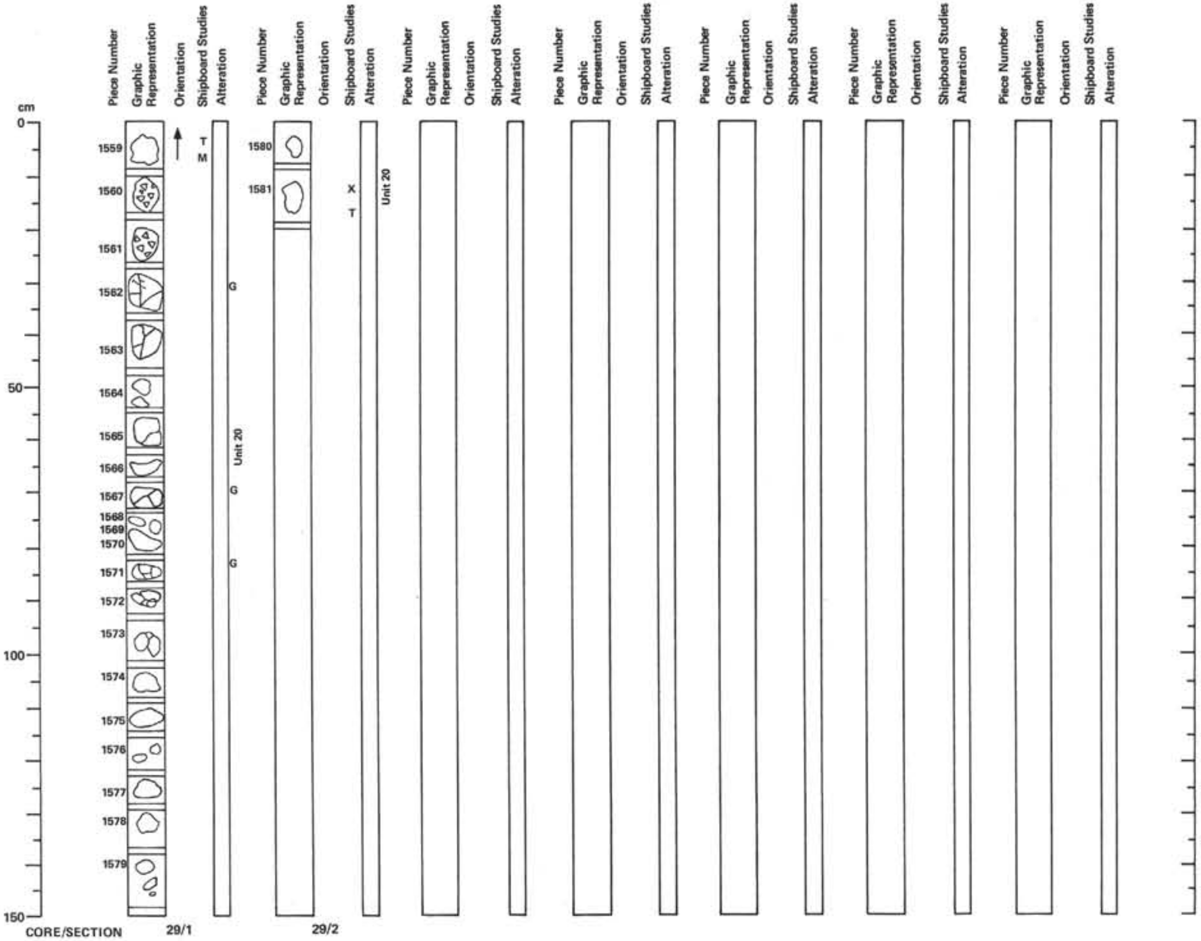
Core-Section	28-1	28-2	28-3	28-3	28-4	28-5
Interval (cm)	110–116	39–43	33–37	35–40	23–27	6–9
SiO_2	50.22	49.51	49.91	53.76	49.26	50.08
TiO_2	0.94	1.09	0.93	0.03	0.93	0.91
Al_2O_3	15.27	16.92	16.10	6.07	15.96	15.99
Fe_2O_3	10.38	10.06	9.82	11.36	10.11	9.49
MnO	0.16	0.17	0.18	0.06	0.19	0.17
MgO	8.05	6.75	7.94	25.19	7.85	8.07
CaO	12.94	12.93	13.12	1.31	13.19	13.21
Na_2O	1.90	2.29	1.92	2.09	1.86	1.94
K_2O	0.18	0.10	0.04	0.15	0.09	0.02
P_2O_5	0.08	0.11	0.08	0.03	0.09	0.08
Total	100.12	99.93	100.04	100.04	99.53	99.96
LOI	0.94	1.65	0.43	6.53	0.40	0.97
Mg/Mg+Fe	0.606	0.571	0.616	0.815	0.606	0.627
Ca/Ca+Al	0.435	0.410	0.426	0.164	0.429	0.429
Ni	114	160	100	–	93	107
Sr	52	108	60	–	60	59
Zr	44	71	45	–	52	49
H_2O	0.67	1.61	0.45	–	0.54	0.68
CO_2	0.12	0.55	0.06	–	0.05	0.07

MAGNETIC DATA:

Core-Section, Interval (cm)	NRM	INCL.	MDF
28-1, 95–97	3,256	6.1	60
28-3, 56–58	4,408	–46.3	160
28-4, 123–125	380	–42.9	200

PHYSICAL PROPERTIES:

Core-Section, Interval (cm)	Water Content	Porosity	Wet-Bulk	GRAPE	Sonic Velocity
28-1, 95–97	1.74	5.02	2.89	2.87	5.842
28-3, 56–58	1.30	3.81	2.92	2.91	5.816
28-4, 123–125	1.80	5.17	2.87	2.76	5.600



HOLE 504B, CORE 29 3957.5–3962.5 m (484.0–489.0 mbsf)

APHYRIC BASALT (lithologic unit 20)

There are fewer than 1% total phenocrysts of plagioclase and olivine in this core. There are a number of highly fractured, brecciated pieces toward the top of the core. Alteration is moderate, mainly to green smectites, especially along cracks. Piece 1559 is oxidized.

Thin Section Description

Sample 29-1, 5–7 cm, Piece 1559: This sample, from a pillow interior, has a hyalopilitic texture with scattered plagioclase phenocrysts. Clays fill cracks and glass(?) inclusions in the plagioclase. The rock is largely transformed to clays. One edge is a clay-filled fracture. There are one or two chrome spinels, and rare vesicles filled with clays.

BULK ANALYSIS:

Core-Section	29-2
Interval (cm)	11–16
SiO_2	50.49
TiO_2	0.99
Al_2O_3	14.90
Fe_2O_3	9.78
MnO	0.17
MgO	8.49
CaO	12.83
Na_2O	2.36
K_2O	0.15
P_2O_5	0.08
Total	100.24
LOI	0.96
Mg/Mg+Fe	0.632
Ca/Ca+Al	0.439
Ni	103
Sr	70
Zr	52
H_2O	0.55
CO_2	0.07

MAGNETIC DATA:

Core-Section, Interval (cm)	NRM	INCL.	MDF
29-1, 4–6	6,159	−20.0	140

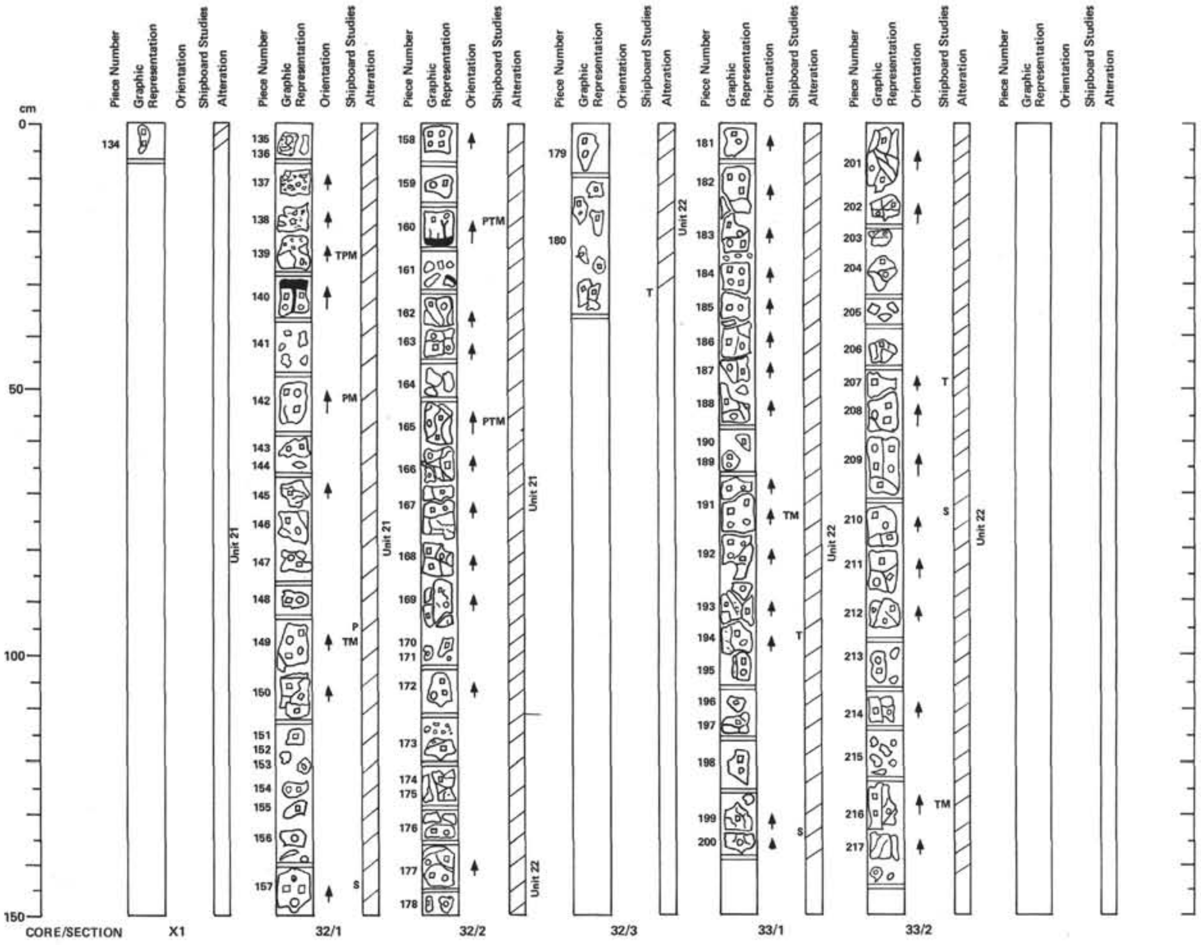
PHYSICAL PROPERTIES:

Core-Section, Interval (cm)	Water Content	Porosity	Wet-Bulk	GRAPE	Sonic Velocity
29-1, 5–6	3.98	10.86	2.73	2.63	5.106

THERMAL CONDUCTIVITY:

Core-Section, cm	κ
29-1, 15	1.35

Note: No recovery, Cores 30 and 31.



70-504B-32 Depth: 3971,0–3980,0 m (507,5–516,5 mbsf)
70-504B-33 Depth: 3980,0–3989,0 m (516,5–525,5 mbsf)

X1, CC

Dominant Lithology: Medium- to coarse-grained phyric basalt

Macroscopic Description: Medium- to coarse-grained olivine-pyroxene-plagioclase phyric basalt. The basalt is altered. No vesicles are present. The rock fragment is rounded and probably has fallen into the hole.

32-1–32-2, Pieces 135–172 (Unit 21)

Dominant Lithology: Highly olivine-plagioclase-clinopyroxene phyric basalt.

Macroscopic Description: Fine- to medium-grained highly olivine-plagioclase phyric basalt. Evidences of alteration and oxidation are observed. Numerous fractures filled with smectite are present. The smectite also occurs as pseudomorphs and coatings. Some altered olivine(?) phenocrysts are stained (brown to red). Glassy margins and rims are found in Pieces 140, 160, 173, and 176. These are used to define units.

Thin Section Descriptions

32-1, 22–26 cm (Piece 139):

Name: Basalt breccia – plagioclase, olivine, clinopyroxene phyric lithic fragment

Texture: Variolitic lithic fragments

Phenocrysts: Olivine, 5%, 0.6x0.5 mm, euhedral; plagioclase, 15%, 0.9x0.2 mm, blocky; clinopyroxene, 5%, 1.0x0.5 mm, euhedral-subhedral

Groundmass: Glass 25%, represented by variolites, breccia matrix

Alteration: Smectites, 5% replacing olivine

32-1, 96–98 cm (Piece 149):

Name: Medium-grained plagioclase clinopyroxene olivine highly phyric basalt

Texture: Glomerophyric

Phenocrysts: Olivine, 10%, 0.2x0.5 mm, euhedral; plagioclase, 24%, 1.5x0.2 mm, subhedral to anhedral; clinopyroxene, 6%, 0.7x0.5 mm

Groundmass: Olivine, 10%, 0.08x0.04 mm, anhedral; plagioclase, 20%, 0.16x0.01 mm, microlites; clinopyroxene, 3%, 0.08x0.06 mm, anhedral; magnetite, 5%, < 0.008, skeletal; glass, 5%; hematite, 1%; pyroxene and plagioclase, 15%, mature sheaf texture

Alteration: Smectite (clays), < 1%, replacing glass or filling tiny voids

32-2, 19–21 cm (Piece 160):

Name: Plagioclase, olivine, clinopyroxene phyric basalt

Texture: Variolitic

Phenocrysts: Olivine, 2%, 0.8x0.6 mm, euhedral; plagioclase, 30%, 1.5x0.8 mm, blocky laths, clusters; clinopyroxene, 13%, 0.9x0.6 mm, euhedral/anhedral, often glomerophyric

Groundmass: Glass, 63%, variolites; magnetite, 3%

Alteration: Smectite (clays), 10%, scattered and replacing olivine and glass

32-2, 55–57 cm (Piece 165):

Name: Medium-grained highly plagioclase phyric basalt

Texture: Subglomerophyric

Phenocrysts: Olivine, 5%, euhedral, totally replaced; plagioclase, 13%, 0.8x0.3 mm, euhedral, subhedral laths; clinopyroxene, 12%, 0.3x0.5 mm, subhedral

Groundmass: Glass, 60%, immature, sheaf texture; olivine, 2%, 0.08x0.05 mm, anhedral; plagioclase, 2%, 0.15x0.01 mm, microlites; clinopyroxene, 0.08x0.05 mm, anhedral; magnetite, 6%, < 0.008 mm, skeletal

Alteration: Smectite (clays), 5%, replacing olivine

32-2–33-2, Piece 173–217 (Unit 22)

Dominant Lithology: Highly olivine-plagioclase phyric altered basalt

Macroscopic Description: Very fine- to medium-grained highly olivine-plagioclase phyric altered basalt. Olivine phenocrysts are frequently altered by a green (smectite)? material. Oxidized veins (1–2 cm thick) are present where olivine is replaced by a dark brown mineral and plagioclase by a pale orange mineral. The apparent Fe-oxidation appears to be controlled by the fracture pattern. Blue green smectite is ubiquitous, in cracks, voids, and veins.

Thin Section Descriptions

32-3, 28–30 cm (Piece 180):

Name: Medium-grained highly olivine plagioclase phyric basalt

Texture: Glomerophyric

Phenocrysts: Olivine, 5%, 0.6x0.5 mm, euhedral; plagioclase, 10%, 0.25x0.08 mm, zoned euhedral laths

Groundmass: Olivine (+ pyroxene?), 25%, 0.04x0.04 mm, anhedral; plagioclase, 38%, 0.25x0.15 mm, microlites, magnetite, 3%, 0.04x0.008 mm, skeletal; glass, 5%, replaced by smectite and associated with magnetite; pyroxene plus plagioclase, 15%, mature sheaf texture.

Alteration: Smectite (clays), replacing glass, olivine, and infillings; hematite, surrounding olivine and filling fractures

33-1, 73–75 cm (Piece 191):

Name: Medium- to coarse-grained plagioclase-olivine highly phyric basalt.

Texture: Hyalo-ophitic

Phenocrysts: Olivine, 5%, 1.0x0.7 mm, euhedral; plagioclase, 10%, 1.2x0.4 mm, lath-like euhedral

Groundmass: Olivine, 10%, 0.04x0.04 mm, anhedral; plagioclase, 35%, 0.25x0.02 mm, microlites; clinopyroxene, 12%, 0.04x 0.4 mm, anhedral; magnetite, 5%, 0.16x0.16 mm, skeletal; spinel, < 1%, 0.04x0.04, euhedral

Vesicles: 1%, scattered and filled with smectite or hematite, irregular

Alteration: Smectite and hematite replacing olivine, filling voids and fractures. Talc(?) replacing olivine.

33-2, 50–52 cm (Piece 207):

Name: Medium- to coarse-grained highly plagioclase, olivine phyric basalt

Texture: Hyalo-ophitic

Phenocrysts: Olivine, 20%, 1.5x1.0 mm, euhedral; plagioclase, 15%, 0.7x0.4 mm, euhedral laths, clinopyroxene, 1%, 1.2x0.5 mm, euhedral

Groundmass: Olivine, 5%, 0.07x0.07 mm, anhedral; plagioclase, 20%, 0,2 mmx0.01 mm, microlites; clinopyroxene, 5%, 0.7x0.07 mm, anhedral; magnetite, 4%, < 0.01 mm, skeletal; glass, 5%, interstitial to silicates; pyroxene and plagioclase, 20%, mature sheaf texture

Vesicles: 5%, scattered and filled with smectite or hematite

Alteration: Smectite, talc or talc plus hematite replacing olivine; hematite observed in voids and cracks

33-2, 126–129 cm (Piece 126):

Name: Medium- to coarse-grained subophitic basalt (moderately plagioclase-olivine phyric)

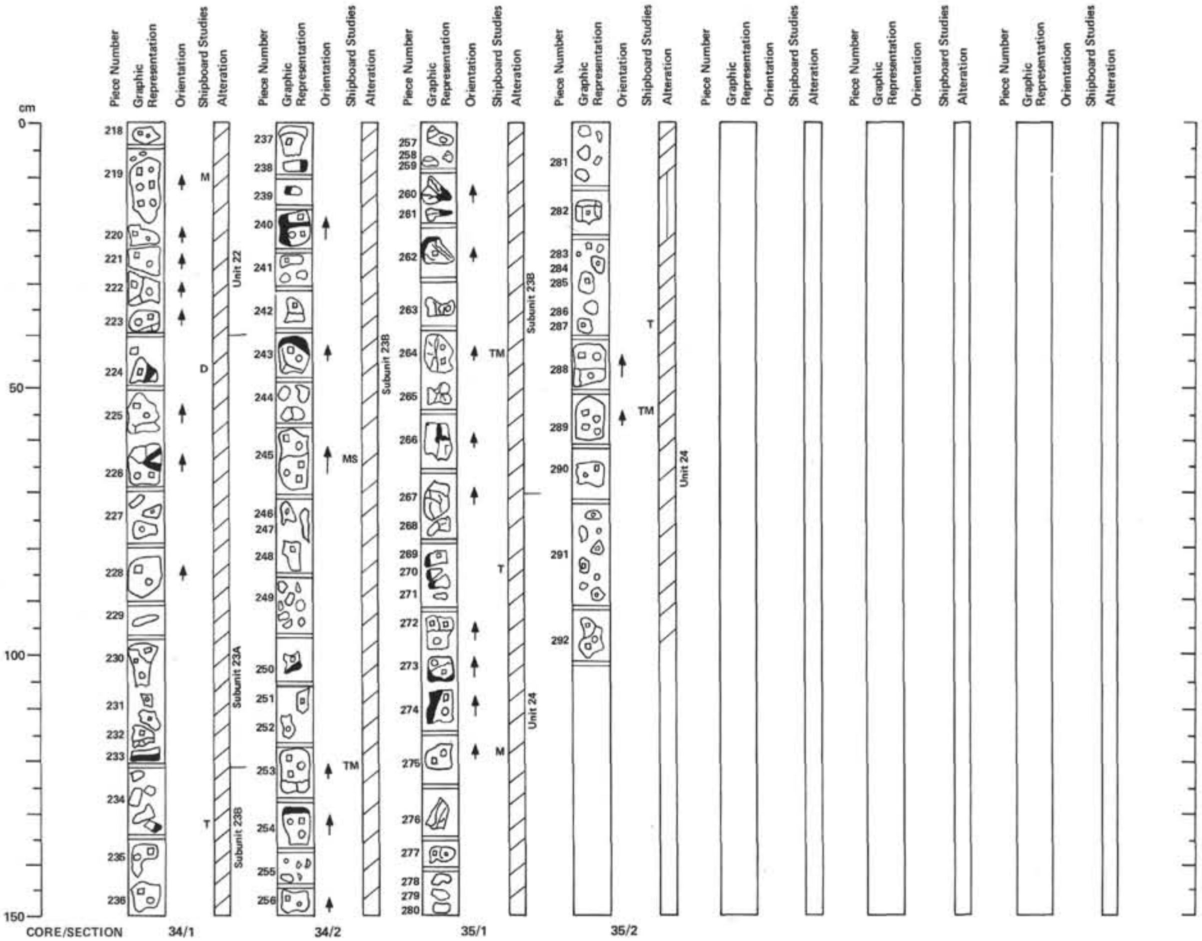
Texture: Ophitic with some small areas of glass

Phenocrysts: Olivine, 2%, 1.8x1.6 mm, euhedral; plagioclase, 2%, 1.2x1.0, subhedral laths

Groundmass: Plagioclase, 40%, 0.08x0,008 to 0.7x0.3 mm, laths; clinopyroxene, 36%, 0.16x0.15 mm, anhedral; magnetite, 15%, 0.024x0.002 mm, microlites and skeletal crystals; glass, 5%; spinel, 1%, 0.1x0.1 mm, euhedral

Vesicles: 1%, 0.08 mm, scattered and filled with smectite and Fe-oxide

Alteration: Smectite, < 1%, and Fe-oxides, trace, replacing glass and olivine respectively



70-504B-34 Depth: 3989.0–3998.0 m (525.5–534.5 mbsf)
70-504B-35 Depth: 3998.0–4007.0 m (534.5–543.5 mbsf)

34-1, Pieces 218–223 (Unit 22 continued)

Dominant Lithology: Highly olivine-plagioclase phyric altered basalt

Macroscopic Description: Medium-grained olivine-plagioclase moderate to highly phyric, altered basalt. Basalt contains numerous veinlets filled with green smectite. Conspicuous zones of a reddish alteration mineral up to 2–3 cm across are present (e.g. Piece 219). Within these zones olivine crystals are crossed by Fe-oxide or iddingsite(?) filled fractures.

34-1, Pieces 224–233 (Unit 23A)

Dominant Lithology: Highly plagioclase olivine phyric basalt

Macroscopic Description: Medium-grained, moderately to highly plagioclase olivine phyric basalt. Numerous samples have fresh (Piece 243) or altered (Pieces 234, 239, 240, 250) glassy rims, and suggest a pillow unit. All samples are altered. Small veinlets are filled with green and light white-green material (smectite and calcite?). In some fractures reddish-brown iron-oxide (hematite) occurs. Olivine is replaced in almost all samples by iron oxide or by iddingsite(?).

Thin Section Descriptions

34-1, 133–134 cm (Piece 234):

Name: Fine-grained highly plagioclase olivine phyric basalt

Texture: Glassy, variolitic to subvariolitic

Phenocrysts: Olivine, 2%, 0.8x0.7 mm, euhedral; plagioclase, 10%, 1.0x0.7 mm, subhedral laths

Groundmass: Plagioclase, 6%, 0.2x0.005 mm, microlites; magnetite, 2%, < 0.008 mm; glass, 10%, pyroxene plus plagioclase, 70%, variolitic and subvariolitic texture

Alteration: Smectite (clays) replacing glass

34-2, 118–120 cm (Piece 253):

Name: Medium-grained highly plagioclase olivine phyric basalt

Texture: Hyalo-ophitic

Phenocrysts: Olivine, 7%, 0.8x0.6 mm, euhedral; plagioclase, 7%, 1.2x0.8 mm, euhedral or subhedral laths

Groundmass: Olivine, 5%, 0.08x0.08 mm, anhedral; plagioclase, 25%, 0.08x0.005 mm, microlites; magnetite, 6%, < 0.008 mm, skeletal and scattered throughout the whole rock; pyroxene plus plagioclase, 50%, mature sheaf texture

Alteration: Fe-oxides, filling fractures, and replacing groundmass and phenocrysts

34-1–35-1, Pieces 234–267 (Unit 23B)

Dominant Lithology: Moderately plagioclase olivine phyric basalt

Macroscopic Description: Fine- to medium-grained moderately plagioclase-olivine phyric basalt. Veins of a white radiating mineral (zeolite) are present. Glass rim fragments, partially altered to green smectite, are observed (e.g. Pieces 273 and 274). Brownish-yellow alteration zones are always observed between dark pillow rim and grayish crystalline basalt.

Thin Section Descriptions

35-1, 44–46 cm (Piece 264):

Name: Medium-grained aphyric basalt (flow interior)

Texture: Hyalopilitic

Phenocrysts: None

Groundmass: Plagioclase, 35%, 0.4x0.02 mm, microlites; clinopyroxene, 8%, 0.06x0.01 mm, anhedral; magnetite, 8%, 0.01 mm, skeletal; spinel, < 1%, 0.06x0.06, euhedral; pyroxene + plagioclase, 40%, mature sheaf texture (partly replaced by iron-hydroxide or oxide)

Vesicles: Miarolitic voids, 9%, 0.3x0.15 mm, filled with smectite and Fe-hydroxides, very irregular shapes

Alteration: Clays (smectite) filling miarolitic voids; Fe-oxides replacing the fine groundmass (pyroxene + plagioclase)

35-1–35-2, Pieces 268–292 (Unit 24)

Dominant Lithology: Sparsely to moderately plagioclase-clinopyroxene-olivine phyric basalt.

Macroscopic Description: Fine-griained moderately plagioclase-olivine phyric basalt. No glassy rims are present. With the formation of Fe-oxides two different alteration colors occur; yellowish gray (Pieces 284, 285) and reddish-brownish (Pieces 288, 290). These may reflect different oxidation states. From Piece 282 to the end of the core the lithologic unit is more massive.

Thin Section Descriptions

35-1, 84–85 cm (Piece 270):

Name: Fine-grained sparse to moderate plagioclase olivine basalt (next to glassy margin)

Texture: Glassy, variolitic and subvariolitic

Phenocrysts: Olivine, 1%, 0.64x0.3 mm, euhedral to anhedral; plagioclase, 2%, 1.5x0.4 mm, euhedral laths

Groundmass: Olivine, 5%, 0.1x0.1 mm, euhedral; plagioclase, 10%, 0.5x0.006 mm, microlites; pyroxene + plagioclase, 82%, variolitic to subvariolitic

Alteration: Clay(?) replacing olivine

35-2, 34–36 cm (Piece 287):

Name: Medium-grained moderately plagioclaste olivine phyric basalt (flow interior)

Texture: Hyalo-ophitic, subglomerophyric

Phenocrysts: Olivine, 1%, 0.25x0.2 mm, subhedral; plagioclase, 5%, 1.0x0.6 mm, subhedral laths

Groundmass: Olivine, 4%, 0.02x0.02 mm, anhedral; plagioclase, 40%, 0.08x0.008 mm, microlites; magnetite, 6%, < 0.008 mm, skeletal(?); spinel, 1%, euhedral; pyroxene and plagioclase, 40%, mature sheaf texture

Vesicles: Miarolitic voids, 4%, ~ 0.7 mm, scattered infilled with smectite(?), very irregular in shape

Alteration: Brown smectite(?) filling in voids; Fe-oxide filling some voids and replacing part of the groundmass

35-2, 53–56 cm (Piece 289):

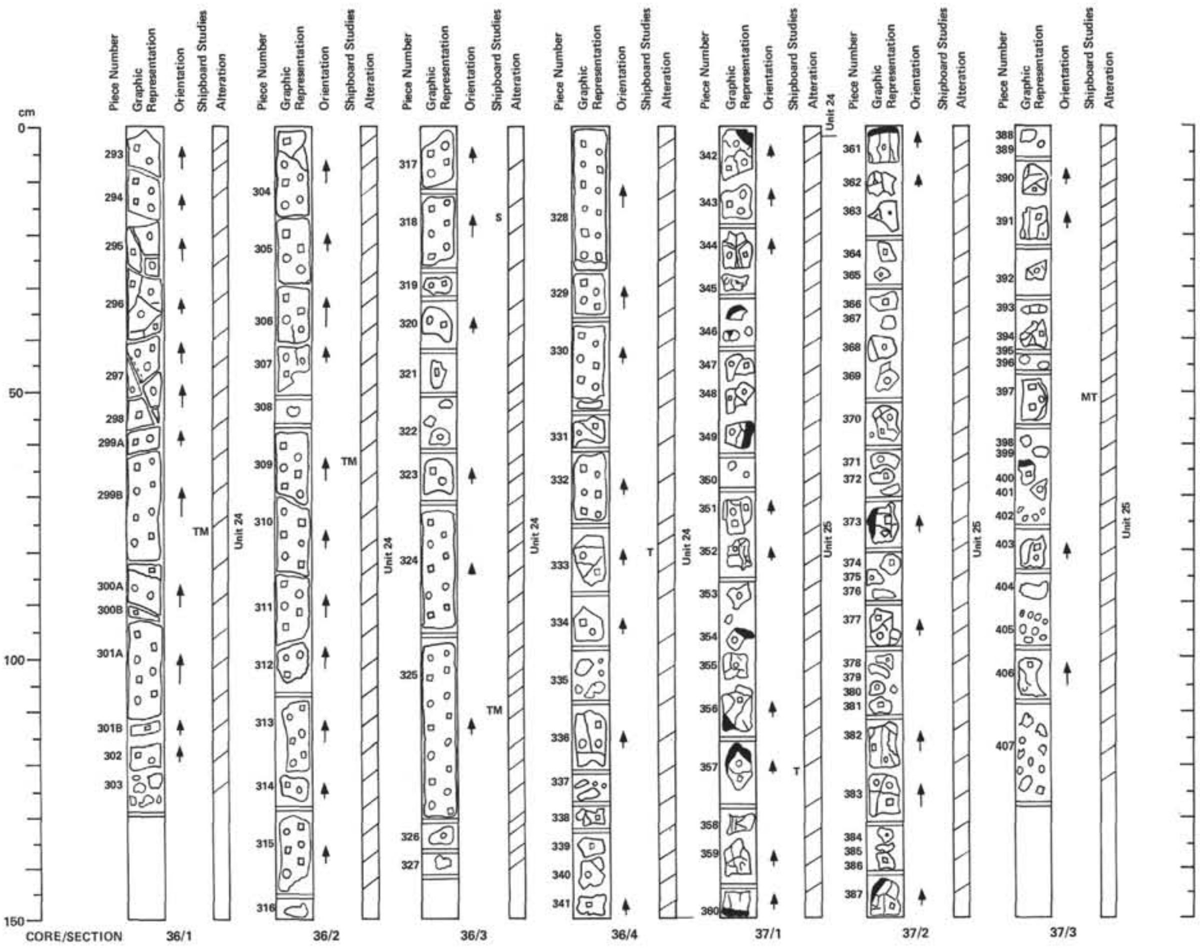
Name: Sparsely plagioclase-olivine phyric basalt (next to glassy margin)

Texture: Hyalo-ophitic

Phenocrysts: Olivine, 1–2%, enhedral to subhedral (slightly altered in cracks to iddingsite); plagioclase, 3%, 1.0x0.6 mm, blocky-equant

Groundmass: Plagioclase, 25–30%, skeletal laths; magnetite, 8–10%, 0.05 mm, skeletal; glass, 60%, quenched plagioclase or clinopyroxene needles

Alteration: Smectite, < 1% scattered and replacing glass; Fe-oxides, 2–5%, replacing magnetite and glass



70-504B-36 Depth: 4007.0–4016.0 m (543.5–552.5 mbsf)
70-504B-37 Depth: 4016.0–4025.0 m (552.5–561.5 mbsf)

36-1–36-4, Pieces 293–341 (Unit 24 continued)

Dominant Lithology: Sparsely to moderately plagioclase-clinopyroxene-olivine phyric basalt.

Macroscopic Description: Medium- to coarse-grained massive highly olivine plagiolcase phyric basalt. Olivine phenocrysts (1–2 mm) are frequently altered. No glassy rims or brown alteration (oxidation) is observed. Fractures are less numerous and thinner than in previous lithostratigraphic unit. Pyrite occurs as a minor vein filling mineral. Some rare crystals of pyrite are also observed. Veins of smectite (e.g. Pieces 328, 330, 331, 333) and zeolites (e.g. Pieces 330, 331, 336) are present.

Thin Section Descriptions

36-1, 78–80 cm (Piece 299):

Name: Medium-grained sparsely plagioclase-clinopyroxene phyric basalt (flow interior)

Texture: *Subophitic to intersertal*

Phenocrysts: Plagioclase, 1%, 1.2x0.6 mm, subhedral zoned laths; clinopyroxene, <1%, 0.5x0.4 mm, subhedral

Groundmass: Plagioclase, 35%, 0.8x0.04 mm, euhedral laths; clinopyroxene, 37%, 0.24x0.20 mm, anhedral; magnetite, 5%, 0.06x0.05 mm, euhedral, glass, 20%, completely replaced by smectite

Vesicles: Miarolitic voids; 2%, 0.80 mm, scattered, filled with smectite or void, very irregular shape

Alteration: Smectite, 22% replacing glass or filling voids

36-2, 68–70 cm (Piece 309):

Name: Medium-grained sparsely plagioclase phyric basalt (flow interior)

Texture: Subophitic to intersertal (some glassy areas)

Phenocrysts: Olivine, < 1%, 0.8x0.4 mm, subhedral, totally replaced by green smectite and talc; plagioclase, 2%, 1.2x0.6 mm, subhedral laths

Groundmass: Plagioclase, 37%, 0.6x0.05 mm, euhedral laths; clinopyroxene, 37%, 0.3x0.2 mm, anhedral; magnetite, 4%, 1.06x0.4 mm, subhedral or skeletal (< 0.008 mm); glass, 20%, replaced by smectite

Vesicles: Voids, 4%, 0.8x0.3 mm, scattered, irregular shape and filled with smectite

Alteration: Smectite, 20%, replacing glass and filling voids

36-3, 101–103 cm (Piece 325):

Name: Medium- to coarse-grained moderately to highly plagioclase-clinopyroxene *phyric basalt (flow interior)*

Texture: Ophitic to intersertal

Phenocrysts: Plagioclase, 2%, 1.1x0.6 mm, subhedral laths; clinopyroxene 2%, 1.2x1.0 mm, subhedral

Groundmass: Plagioclase, 38%, 0.5x0.03 mm, subhedral laths; clinopyroxene, 38%, 0.2x0.2 mm, anhedral; magnetite, 5%, 0.05x0.05, skeletal; glass, 15%

Alteration: Smectite, 15% replacing glass

36-4, 78–82 cm (Piece 333):

Name: Medium-grained moderately to highly plagioclase-clinopyroxene phyric basalt (flow interior)

Texture: Subophitic to slightly intersertal

Phenocrysts: Plagioclase, 3%, 0.6x0.2 mm, subhedral laths; clinopyroxene, 9%, 2.5x1.0 mm, subhedral laths

Groundmass: Plagioclase, 40%

37-1–37-3, Pieces 342–407 (Unit 25)

Dominant Lithology: Sparsely to moderately plagioclase-olivine-clinopyroxene phyric basalt

Macroscopic Description: Fine- to medium-grained moderately plagioclase-olivine phyric basalt. The basalt is highly fractured with abundant glassy rims and glass zones. Many olivine phenocrysts appear to be altered to smectite. Zeolites, smectite and calcite are present as veins minerals. Oxidation products in veins are also observed.

Thin Section Descriptions

37-1, 115–118 cm (Piece 357):

Name: Fine-grained, moderately plagioclase, clinopyroxene-olivine phyric basalt (next to glassy margin)

Texture: Subvariolitic to subglomerophyric (hyalo-ophitic)

Phenocrysts: Olivine, < 2%, 0.5x0.3 mm, euhedral; plagioclase, 3%, 1.1x0.25 mm, *subhedral laths; clinopyroxene*, 1%, 0.45x 1.5 mm, anhedral

Groundmass: Plagioclase, 10%, 0.9x0.04 mm maximum, 0.25x 0.005 mm minimum, microlites; clinopyroxene, 2%, 0.08x 0.06 mm, anhedral; magnetite, 3%, < 0.008 mm; pyroxene plus plagioclase, 80%, immature sheaf texture

Alteration: Smectite and iddingsite replacing olivine

37-3, 51–54 cm (Piece 397):

Name: Medium-grained sparsely plagioclase olivine, clinopyroxene phyric basalt (flow interior)

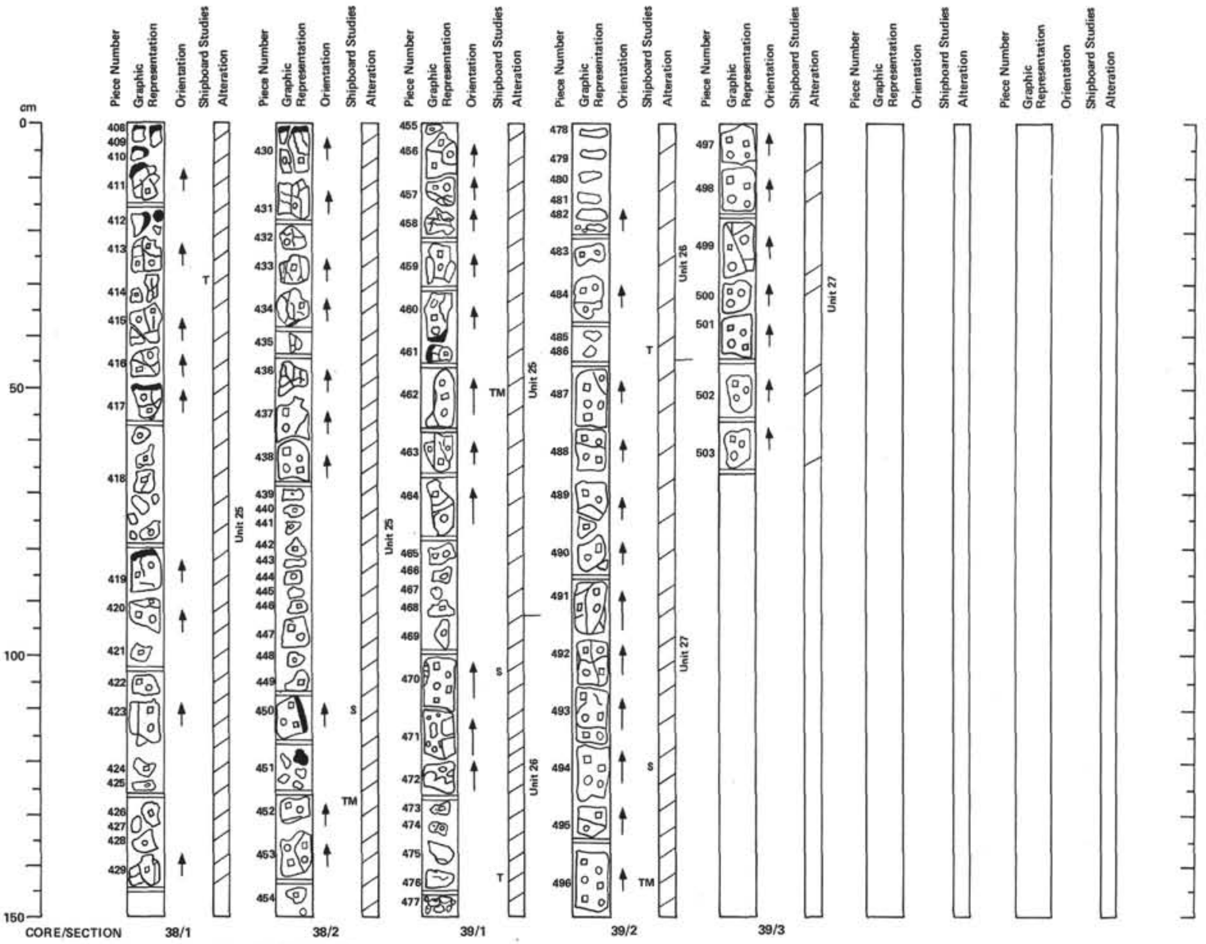
Texture: Hyalo-ophitic

Phenocrysts: Olivine, 1%, 0.4x0.4 mm, euhedral; plagioclase, 1%, 1.0x0.35 mm, subhedral laths, clinopyroxene, < 1%, 0.2x 0.2 mm, anhedral

Groundmass: Plagioclase, 30%, 0.4x0.02 mm, microlites; clinopyroxene, 20%, 0.06x0.04 mm, anhedral; magnetite, 7%, < 0.008 mm, skeletal; glass, 4%; pyroxene + plagioclase, 36%, mature sheaf texture

Vesicles: Miarolitic voids, 3%, filled with iron-oxide or smectite

Alteration: *Smectite and hematite, 10%, replacing olivine; zeolites(?) replacing a few plagioclase phenocrysts*



70-504B-38 Depth: 4025.0–4034.0 m (561.5–570.5 mbsf)
70-504B-39 Depth: 4034.0–4043.0 m (570.5–579.5 mbsf)

38-1–39-1, Pieces 408–468 (Unit 25 continued)

Dominant Lithology: Moderate plagioclase-olivine-clinopyroxene phyric basalt

Macroscopic Description: Fine- to medium-grained moderately phyric plagioclase-olivine phyric basalt. Highly fractured with veins throughout. Vein include calcite (e.g. Piece 413), zeolites (e.g. Pieces 413, 417), and pyrite (e.g. Piece 420). Glass rims and glass zones are present throughout. Green smectite is dominant mineral in veins and fragment coatings.

Thin Section Descriptions

38-1, 28–31 cm (Piece 414):

Name: Medium-grained moderately olivine-plagioclase-clinopyroxene phyric basalt (flow interior)

Texture: Hyalo-ophitic

Phenocrysts: Olivine, 5%, 1.7x0.8 mm, euhedral; plagioclase, 4%, 0.8x0.16 mm, euhedral laths; clinopyroxene, 1%, 0.4x0.3 mm, anhedral

Groundmass: Plagioclase, 30%, 0.3x0.01 mm, microlites; clinopyroxene, 5%, 0.08x0.06 mm, anhedral; magnetite, 2%, 0.01x 0.01 mm, skeletal; pyroxene + plagioclase, 45%, mature sheaf texture

Vesicles: Miarolitic voids, 8%, 0.6x0.8 mm, filled with smectite (core) and iron hydroxides (rind), irregular shape

Alteration: Calcite, in fractures, voids associated with smectite; smectite and iddingsite, replacing olivine and in voids and fractures; Fe-hydroxides and Fe-oxides in voids.

38-2, 129–131 cm (Piece 452):

Name: Medium-grained, moderately olivine plagioclase clinopyroxene phyric basalt (flow interior)

Texture: Hyalo-ophitic

Phenocrysts: Olivine, 2%, 0.7x0.3 mm, euhedral; plagioclase, 2%, 1.2x0.3 mm, subhedral or euhedral laths; clinopyroxene, 1%, 0.35x0.30 mm, anhedral

Groundmass: Olivine, 3%, 0.2x0.05 mm, euhedral or anhedral; plagioclase, 25%, 0.2x0.01 mm, microlites; clinopyroxene, 2%, 0.04x0.04 mm; magnetite, 5%, 0.01x0.008 mm, skeletal; glass, 5%; pyroxene + plagioclase, 55%, mature sheaf texture

Vesicles: Voids, 0.4x0.4 mm, irregular and scattered

Alteration: Calcite, green and brown smectite, Fe-oxides and Fe-hydroxides replacing glass olivine and miarolitic voids

39-1, 48–50 cm (Piece 462):

Name: Fine-grained plagioclase clinopyroxene moderately phyric basalt (flow interior)

Texture: Subglomerophyric

Phenocrysts: Olivine, < 1%, 0.8x0.6 mm, euhedral; plagioclase, 5%, 1.1x0.5 mm, subhedral to euhedral laths; clinopyroxene, < 1%, 0.3x0.3 mm, anhedral

Groundmass: Plagioclase, 24%, 0.8x0.04 mm, microlites or laths; clinopyroxene, 3%, 0.05x0.05 mm, anhedral; magnetite, 3%, < 0.008 mm, skeletal; spinel, < 1% pyroxene plus plagioclase, 65%, immature and mature sheaf texture

39-1–39-2, Pieces 469–486 (Unit 26)

Dominant Lithology: Sparsely plagioclase-olivine phyric basalt

Macroscopic Description: Medium-grained sparsely olivine plagioclase phyric basalt. The rock texture is medium-grained and uniform having a massive appearance. Fractures, veins, and glass are rare. A breccia zone is present from 110–135 cm. The breccia fragments are angular with a brownish alteration common. The breccia matrix is rich in green smectite.

Thin Section Description

39-1, 140–142 cm (Piece 476):

Name: Sparsely olivine-plagioclase phyric basalt (flow interior)

Texture: Intersertal with oophitic areas

Phenocrysts: Olivine, 2–3%, 0.35x0.35 mm, euhedral, plagioclase, 2–3%, 1.3x0.8 mm, blocky

Groundmass: Olivine, 30%, 0.7x0.7 mm, anhedral; plagioclase, 35%, 0.8x0.1 mm, skeletal to lathy, magnetite, 5–10%, 0.1x 0.05 mm, skeletal; glass, 25–30%, represented by microlites and altered zones

Alteration: Smectite, replacing olivine and glass, scattered; oxides, replacing glass and magnetite, scattered

39-2–3, Pieces 487–503 (Unit 27)

Dominant Lithology: Moderately plagioclase-olivine-clinopyroxene phyric basalt

Macroscopic Description: Fine- to medium-grained sparsely to moderately plagioclase olivine phyric basalt. The appearance of this unit is very fresh. No glassy rims or visible alteration can be observed in the zones next to fractures. Minor alteration or vein filling minerals (zeolites, smectites) are observed in fractures.

Thin Section Descriptions

39-2, 40–42 cm (Piece 488):

Name: Fine- to medium-grained highly plagioclase-olivine phyric basalt (flow interior?)

Texture: Hyalo-ophitic with groundmass being mature to immature sheaf texture

Phenocrysts: Olivine, 4%, 1.0x0.8 mm, euhedral; plagioclase, 10%, 1.1x0.5 mm, subhedral laths, sometimes zoned and cut by opaque veins; clinopyroxene, 1%, 0.4x0.32 mm, euhedral

Groundmass: Olivine, 3%, 0.06x0.05 mm, euhedral; palgioclase, 10%, 0.12x0.006 mm microlites; clinopyroxene, 2%, 0.02x 0.02 mm, anhedral; magnetite, 5%, skeletal; pyroxene + plagioclase, 70%, mature to immature sheaf texture

Vesicles: Miarolitic voids, 2%, filled with smectite

Alteration; Smectite(?) replacing olivine crystals

39-2, 135–138 cm (Piece 496):

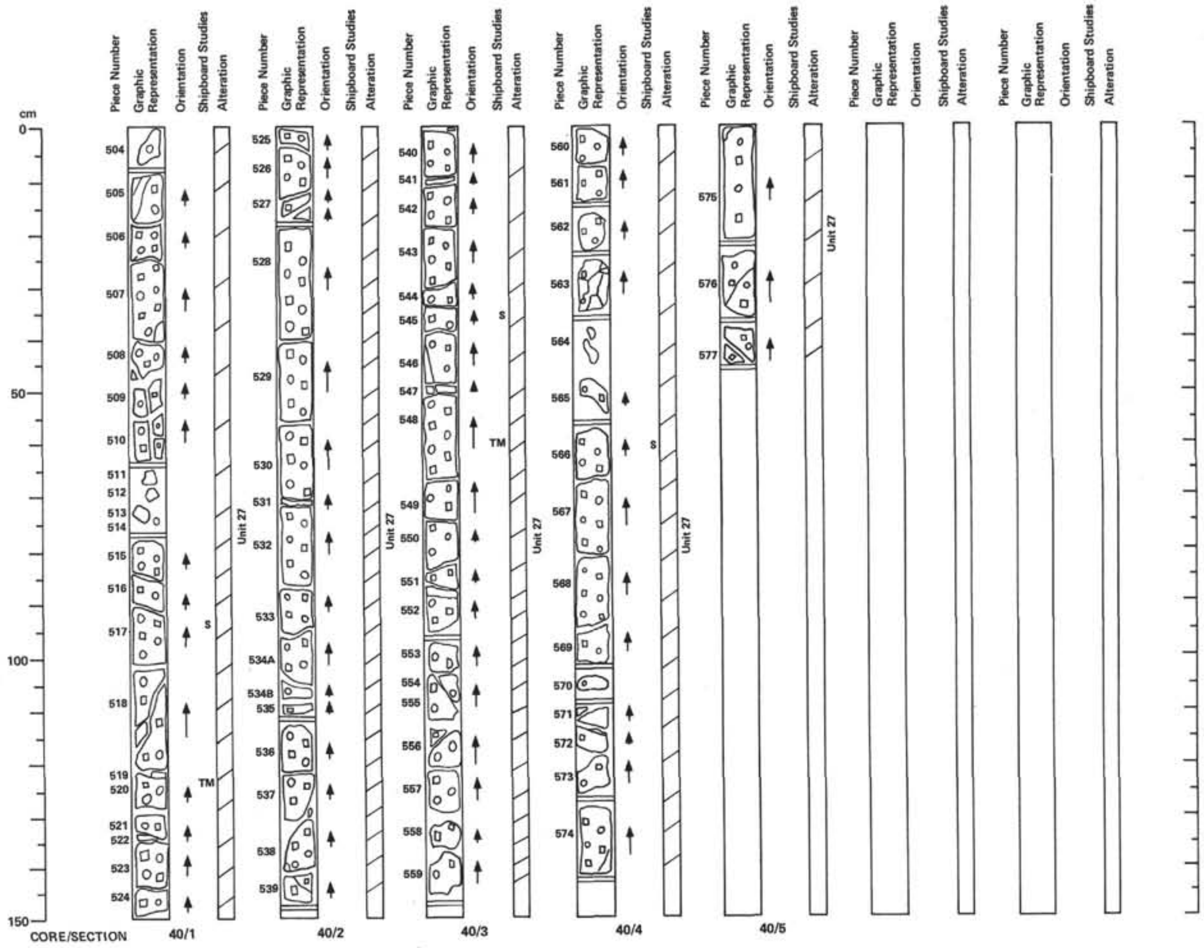
Name: Medium-grained moderately olivine plagioclase phyric basalt (flow interior)

Texture: Oophitic to intergranular

Phenocrysts: Olivine, 2%, 0.8x0.5 mm, euhedral; plagioclase, 8%, 1.2x0.5 mm, subhedral laths

Groundmass: Plagioclase, 40%, 0.2x0.03 mm, laths; clinopyroxene, 40%, 0.35x0.30 mm, anhedral; magnetite, 3%, 0.01x 0.01 mm, skeletal; glass, 7%

Alteration: Smectite, talc, 2%, replacing olivine (partly) and glass



70-504B-40 **Depth: 4043.0–4047.5 m (579.5–584.0 mbsf)***

40-1–40-5, Pieces 504–577 (Unit 27 continued)

Dominant Lithology: Moderately plagioclase-olivine-clinopyroxene phyric basalt.

Macroscopic Description: Medium- to coarse-grained, moderately plagioclase-olivine-clinopyroxene phyric massive basalt flow. Plagioclase is the most abundant phenocryst (~ 8%), olivine is completely replaced by smectite. The alteration is slight, glass is partly replaced by smectite. A few fractures are coated or filled with light-green to dark-green smectite and less calcite.

Thin Section Descriptions

40-1, 124–126 cm (Piece 520):

Name: Medium- to coarse-grained moderately plagioclase-olivine-clinopyroxene phyric basalt.

Texture: Ophitic to intersertal

Phenocrysts: 5% subhedral, sometimes zoned plagioclase (2.5x 1.5 mm), 2% euhedral olivine (1.3x1.0 mm), < 1% subhedral clinopyroxene (1.0x0.8 mm)

Groundmass: 40% plagioclase laths (0.4x0.04 mm), 40% anhedral clinopyroxene (0.35x0.25 mm), 3% skeletal magnetite (0.08x 0.05 mm) located in glassy areas, < 10% glass interstitial to silicates

Alteration: Smectite replacing glass and olivine

40-3, 56–58 cm (Piece 548):

Name: Medium- to coarse-grained, moderately plagioclase-clinopyroxene-olivine phyric basalt.

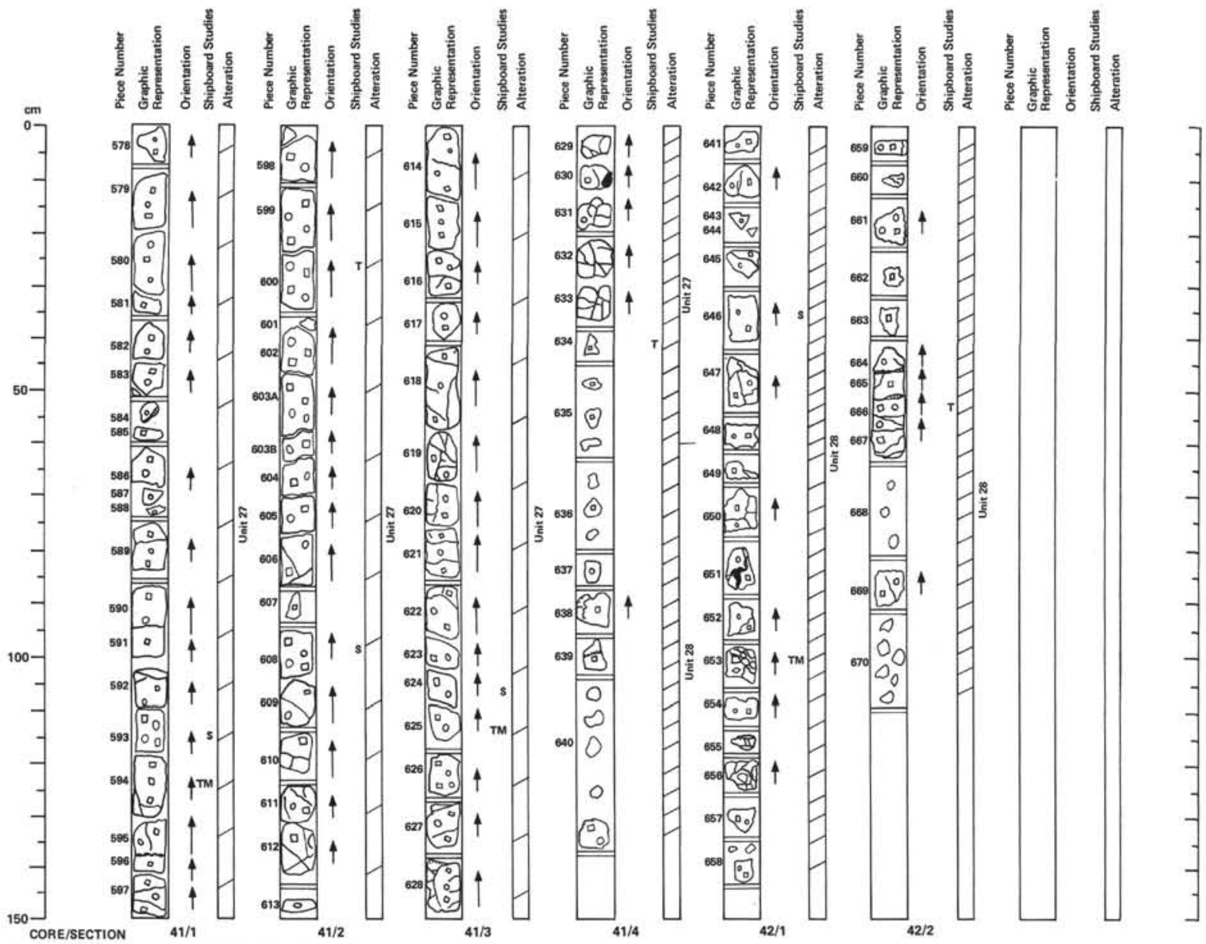
Texture: Ophitic to intersertal

Phenocrysts: 8% subhedral plagioclase laths (1.4x0.7 mm), sometimes zoned, 2% subhedral to anhedral, twinned clinopyroxene (1.2x1.2 mm), 1% euhedral olivine (0.7x0.5 mm)

Groundmass: 35% subhedral plagioclase laths (0.5x0.1 mm), 35% anhedral clinopyroxene (0.55x0.4 mm), 8% subhedral olivine (0.08x0.05 mm), 5% magnetite (0.06x0.06 and 0.02x 0.01 mm), 6% glass

Alteration: Glass and olivine is replaced by smectite

***Note: 4.5 m were cored, 5.25 m basalt were recovered. Discrepancy may be the result of material dropping out of Core 39, or left unsampled between base of core and base of core bit. There are also potential inaccuracies in recording length of pipe from the rig floor.**



70-504B-41 Depth: 4047.5–4056.5 m (584.0–593.0 mbsf)
70-504B-42 Depth: 4056.5–4065.5 m (593.0–602.0 mbsf)

41-1–41-4, Pieces 578–635 (Unit 27 continued)

Dominant Lithology: Moderately plagioclase-olivine-clinopyroxene phyric basalt.

Macroscopic Description: Medium- to coarse-grained moderately plagioclase-olivine-clinopyroxene phyric massive basalt flow. Plagioclase is the most abundant phenocryst (~ 8%), olivine is completely replaced by smectite. The alteration is slight, glass is partly replaced by smectite. A few fractures are filled with light-green or brown-green smectite.

Thin Section Descriptions

41-1, 118–130 cm (Piece 594):

Name: Medium- to coarse-grained highly plagioclase-olivine-phyric basalt

Texture: Ophitic to slightly intersertal

Phenocrysts: 8% subhedral lathy plagioclase (0.6x0.25 mm), 7% euhedral olivine (2.5x1.5 mm)

Groundmass: 36% subhedral plagioclase laths (0.15x0.01 mm); 35% anhedral clinopyroxene (0.15x0.15 mm); 3% skeletal magnetite (0.08x0.08 mm); < 1% subhedral spinel (0.12x 0.12 mm), 5% glass

Alteration: Glass replaced by green smectite, olivine replaced by pale green smectite and talc

41-2, 21–24 cm (Piece 500):

Name: Medium- to coarse-grained moderately plagioclase-olivine-phyric basalt

Texture: Ophitic to intersertal

Phenocrysts: 5% blocky or lathy plagioclase (0.6x0.3 mm); 5% subhedral olivine (0.6x0.5 mm); < 1% subhedral spinel

Groundmass: 40% plagioclase laths (0.7x0.1 mm); 40% anhedral olivine (0.1x0.1 mm); 5–10% glass

Alteration: Glass and olivine replaced by brown-green smectite

41-3, 112–115 cm (Piece 625):

Name: Medium-grained highly plagioclase-olivine-clinopyroxene phyric basalt

Texture: Hyalo-ophitic

Phenocrysts: 8% euhedral plagioclase laths (0.65x0.5 mm); 5% euhedral olivine (0.7x0.5 mm); < 1% subhedral clinopyroxene (0.4x0.4 mm)

Groundmass: 35% plagioclase laths (0.16x0.02 mm); 35% anhedral clinopyroxene (0.08x0.08 mm); 3% subhedral olivine (0.06x0.03 mm); 5% skeletal magnetite (0.025x0.02 mm), 9% glass

Alteration: Glass and olivine replaced by green smectite

41-4–42-2, Pieces 636–670 (Unit 28)

Dominant Lithology: Sparsely to moderately plagioclase-clinopyroxene phyric basalt.

Macroscopic Description: Fine- to medium-grained sparsely to moderately plagioclase-clinopyroxene phyric basalt flows. The flows have glassy margins and are sometimes brecciated. The alteration *is moderate consisting of smectite replacing groundmass.* Fractures are filled with smectite. Fe-oxides occur in groundmass and fractures on Pieces 632–638, therefore the alteration is oxidative.

Thin Section Descriptions

41-4, 42–43 cm (Piece 634):

Name: Medium- to coarse-grained slightly to moderately plagioclase-olivine phyric basalt

Texture: Hyalo-ophitic

Phenocrysts: 2% broken plagioclase laths (0.8x0.2 mm), 2% euhedral olivine

Groundmass: 40% plagioclase and clinopyroxene microlites having mature sheaf texture; 20% plagioclase laths (0.5x0.01 mm); 17% anhedral clinopyroxene (0.1x0.06 mm); 5% anhedral olivine (0.06x0.04 mm); 3% skeletal magnetite (0.01x 0.01 mm); 5% glass; 6% miarolitic voids and cracks of irregular shape

Alteration: Green smectite completely replaces glass and olivine and fills the miarolitic voids

42-1, 97–99 cm (Piece 653):

Name: Medium- to coarse-grained moderately plagioclase phyric basalt

Texture: Subophitic with some intersertal areas

Phenocrysts: 8% euhedral plagioclase laths, sometimes zoned (1.2x0.5 mm)

Groundmass: 45% anhedral clinopyroxene (0.2x0.1 mm); 35% subhedral plagioclase laths (0.4x0.1 mm); 2% euhedral olivine (0.2x0.25 mm); 5% skeletal magnetite; 5% glass

Alteration: Glass and olivine completely replaced by smectite

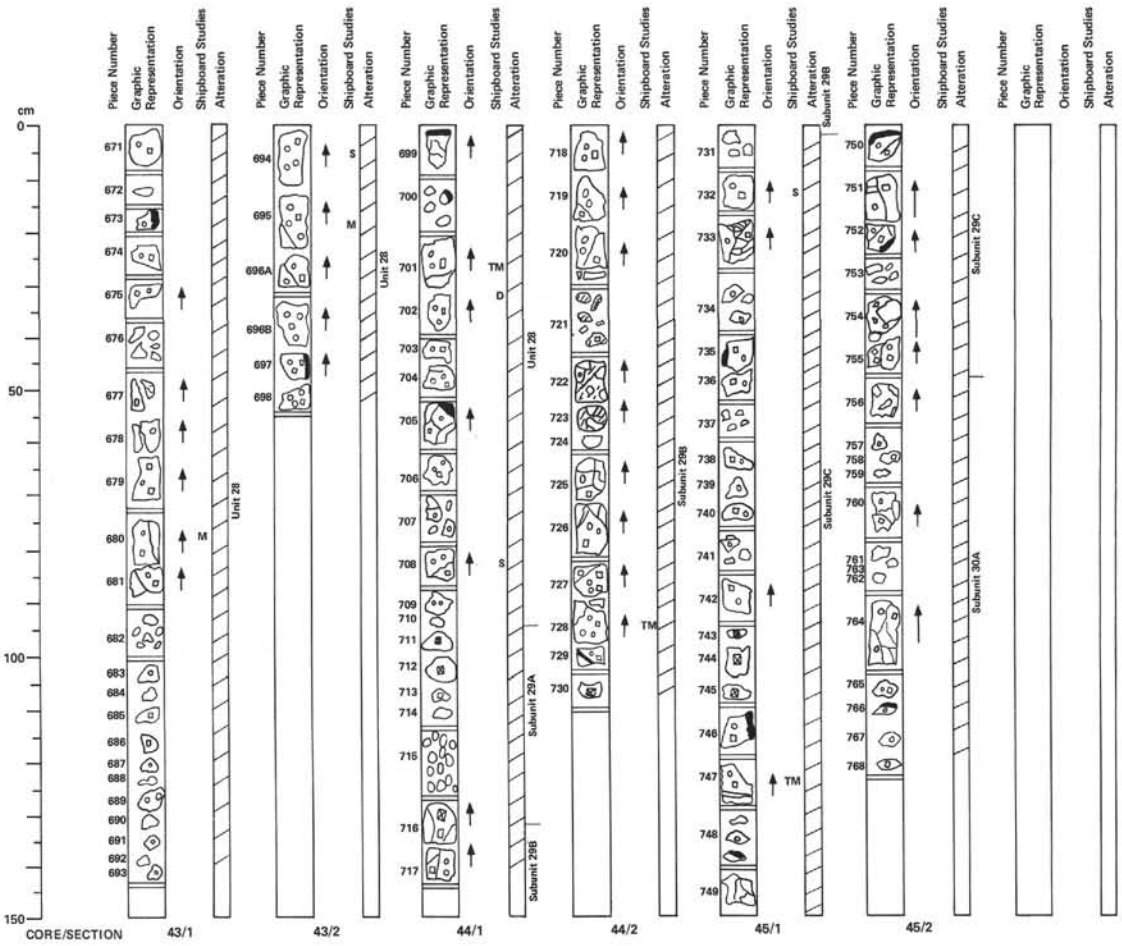
42-2, 48–51 cm (Piece 666):

Name: Medium- to coarse-grained subophitic basalt

Texture: Ophitic to intersertal

Phenocrysts: 38% subhedral plagioclase laths (1.2x0.16 mm); 38% anhedral clinopyroxene (0.5x0.4 mm); < 5% euhedral olivine (1.0x0.6 mm); 4% skeletal magnetite (0.04 mm); 14% glass

Alteration: Olivine is replaced by smectite and talc



70-504B-43 Depth: 4065.5–4074.5 m (602.0–611.0 mbsf)
70-504B-44 Depth: 4074.5–4083.5 m (611.0–620.0 mbsf)
70-504B-45 Depth: 4083.5–4093.5 m (620.0–629.0 mbsf)

43-1–44-1, Pieces 671–710 (Unit 28 continued)

Dominant Lithology: Sparsely to moderately plagioclase-clinopyroxene-phyric basalt.

Macroscopic Description: Fine- to medium-grained sparsely to moderately plagioclase-clinopyroxene-phyric basalt flows. The flows have glassy margins and are sometimes brecciated. The alteration is moderate consisting of smectite replacing groundmass. Fractures are filled with smectite. Fe-oxides occur in groundmass and fractures on Pieces 694–698.

Thin Section Description

44-1, 22–24 cm (Piece 701):

Name: Fine-grained moderately plagioclase-clinopyroxene-phyric basalt

Texture: Variolitic to hyalopilitic

Phenocrysts: 10–15% plagioclase laths (0.7x0.25 mm); 1% euhedral clinopyroxene (1x1 mm)

Groundmass: 10% skeletal plagioclase laths (0.5x0.05 mm); 3% skeletal magnetite; 75% glass

44-1, Pieces 711–716 (Subunit 29A)

Dominant Lithology: Glomerophyric basalt

Macroscopic Description: Fine- to medium-grained glomerophyric basalt. A few olivine phenocrysts have been replaced by smectite. Some fractures are coated with smectite.

44-1–45-1, Pieces 717–730 (Subunit 29B)

Dominant Lithology: Moderately plagioclase-clinopyroxene-olivine-phyric basalt

Macroscopic Description: Unit of pillows and/or thin flows with breccias and glassy margins. Fine- to medium-grained, moderately plagioclase-clinopyroxene-olivine-phyric basalt. Smectite replaces olivine and partly the groundmass. Pyrite occurs in veins.

Thin Section Description

44-1, 88–91 cm (Piece 728):

Name: Fine- to medium-grained moderately plagioclase-clinopyroxene-olivine-phyric basalt

Texture: Hyalopilitic

Phenocrysts: 3% subhedral plagioclase laths (0.9x0.3 mm); 3% subhedral clinopyroxene (0.8x0.5 mm); 2% euhedral olivine (0.6x0.16 mm)

Groundmass: 45% plagioclase and clinopyroxene microlites with mature sheaf texture; 20% plagioclase laths (0.2x0.01 mm); 7% subhedral olivine (0.6x0.16 mm); 5% anhedral clinopyroxene (0.04x0.03 mm); 5% magnetite (0.01x0.01 mm); 7% glass

Alteration: Glass is replaced by smectite, olivine is replaced by smectite and talc

45-1–45-2, Pieces 731–755 (Subunit 29C)

Dominant Lithology: Fine-grained glomerophyric basalt.

Thin Section Description

45-1, 118–121 cm (Piece 747):

Name: Medium-grained, moderately plagioclase-olivine-clinopyroxene-phyric basalt

Texture: Hyalo-ophitic

Phenocrysts: 3% euhedral plagioclase laths (0.9x0.6 mm); 2% euhedral olivine; < 1% subhedral clinopyroxene (0.4x0.3 mm)

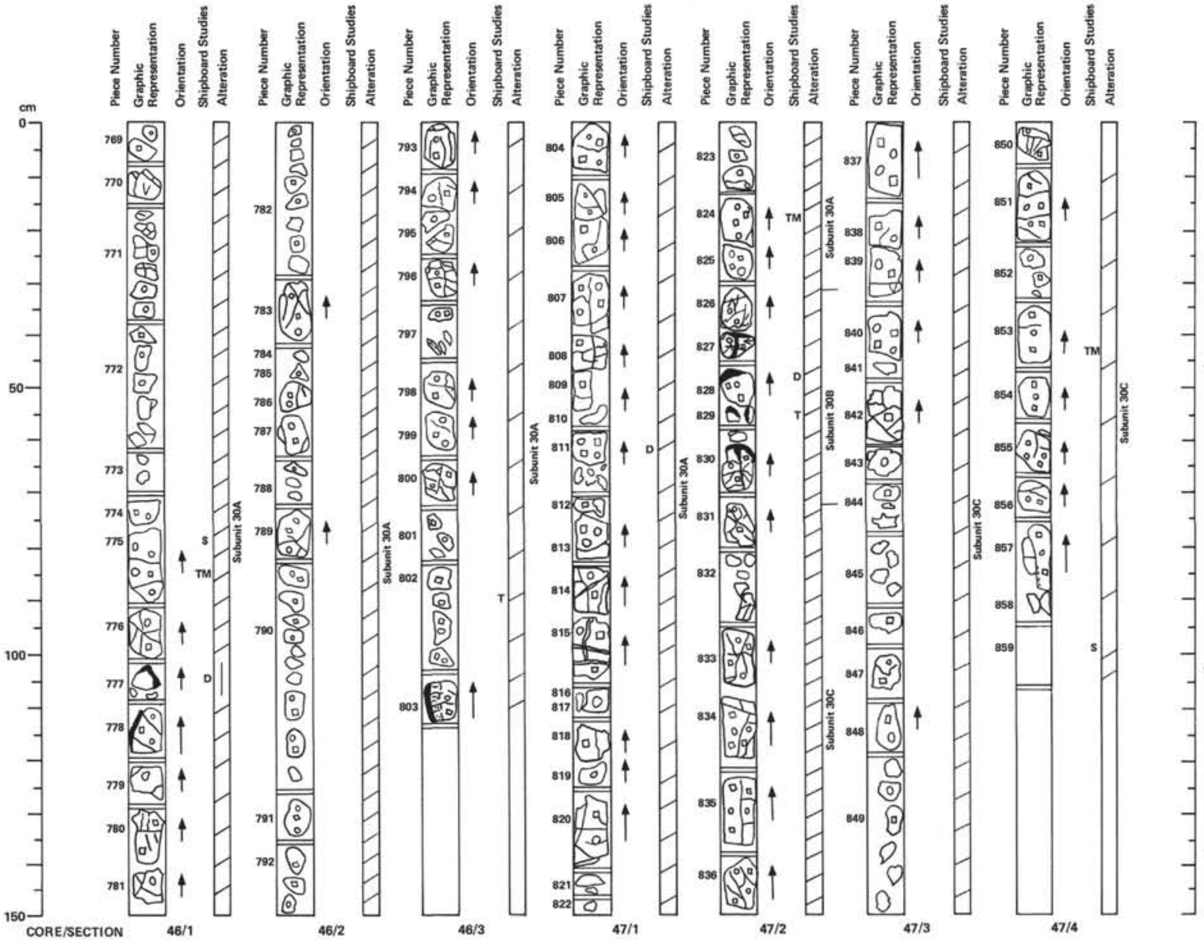
Groundmass: 30% plagioclase and clinopyroxene microlites with mature sheaf texture; 22% plagioclase laths (0.3x0.03 mm); 22% clinopyroxene (0.06x0.04 mm); 7% subhedral olivine (0.08x0.08 mm); 4% skeletal magnetite (0.01x0.01 mm); < 1% subhedral spinel (0.04x0.04 mm); 5% glass, 5% miarolitic voids (0.04x0.03 mm)

Alteration: Smectite and calcite replaces olivine and glass. The miarolitic voids are filled with a colorless smectite.

45-2, Pieces 756–768 (Subunit 30A)

Dominant Lithology: Moderately plagioclase-olivine-clinopyroxene-phyric basalt.

Macroscopic Description: Sequence of pillows and/or thin flows. Breccia and glassy rims are common. Medium-grained, moderately plagioclase-olivine-clinopyroxene-phyric basalt.



70-504B-46 **Depth: 4092.5–4101.5 m (629.0–638.0 mbsf)**
70-504B-47 **Depth: 4101.5–4110.5 m (638.0–647.0 mbsf)**

46-1–47-2, Pieces 769–825 (Subunit 30A continued)

Dominant Lithology: Moderately plagioclase-olivine-clinopyroxene phyric basalt.

Macroscopic Description: Fine- to medium-grained moderately olivine-plagioclase-phyric basalt. The rocks appear to be fresh. Alteration minerals (smectite) occur in fractures. Olivine phenocrysts are partly or completely replaced by smectite in some areas. Pyrite is also observed in some fractures (e.g. Pieces 805–809, 814–815). Glass rims and margins are scarce. However Pieces 827–830 contain abundant glassy rims with the rim material frequently altered to green smectite. For this reason the section is designated Subunit 28F.

Thin Section Description

46-1, 80–83 cm (Piece 775):

Name: Fine- to medium-grained moderately plagioclase-clinopyroxene, olivine-phyric basalt (next to glassy margin).

Texture: Subglomerophyric to hyalo-ophitic

Phenocrysts: Olivine, 3%, 0.4x0.4 mm, subhedral; plagioclase, 2%, 1.5x0.5 mm, subhedral zoned laths; clinopyroxene, 2%, 1.5x0.5 mm, laths with rounded corners, twinned

Groundmass: Olivine, 2%, 0.16x0.08 mm, subhedral; plagioclase, 19%, 0.3x0.03 mm and 0.3x0.008 mm, microlites; clinopyroxene, 8%, 0.08x0.08 mm, anhedral; magnetite, 6%, skeletal; pyroxene + plagioclase, 70%, mature to immature sheaf texture

Alteration: Smectite replacing olivine

47-2, Pieces 826–830 (Subunit 30B)

Dominant Lithology: Highly plagioclase-clinopyroxene-olivine-phyric basalt.

Macroscopic Description: Fine-grained highly plagioclase-clinopyroxene-olivine-phyric basalt. Rubble of thin lava flow. Glassy margins on every piece of basalt. Glassy rims are completely altered to green smectite.

Thin Section Description

47-2, 55–57 cm (Piece 829):

Name: Fine-grained highly plagioclase clinopyroxene phyric basalt (next to glassy margin)

Texture: Subgomerophyric and subvariolitic

Phenocrysts: Plagioclase, 7%, 0.6x0.16 mm, euhedral laths; clinopyroxene, 7%, 3.0x1.0 mm, euhedral (corners are rounded and often twinned)

Groundmass: Olivine, 1%, 0.13x0.10 mm, euhedral; plagioclase, 6%, 0.2x0.08 mm laths, 0.4x0.008 mm, microlites; clinopyroxene 2%, 0.04x0.04 mm, anhedral; magnetite, 7%, pyroxene + plagioclase, 70%, subvariolitic texture

Alteration: Smectite replacing olivine

47-2–47-4, Pieces 831–859 (Subunit 30C)

Dominant Lithology: Highly plagioclase-clinopyroxene-olivine-phyric basalt.

Macroscopic Description: Medium- to coarse-grained highly plagioclase-clinopyroxene-phyric basalt. The rocks are highly fractured with fractures filled with green smectite and pyrite. Alteration is non-oxidative.

Thin Section Description

47-4, 42–45 cm (Piece 853):

Name: Medium- to coarse-grained highly plagioclase-clinopyroxene-phyric basalt (flow interior)

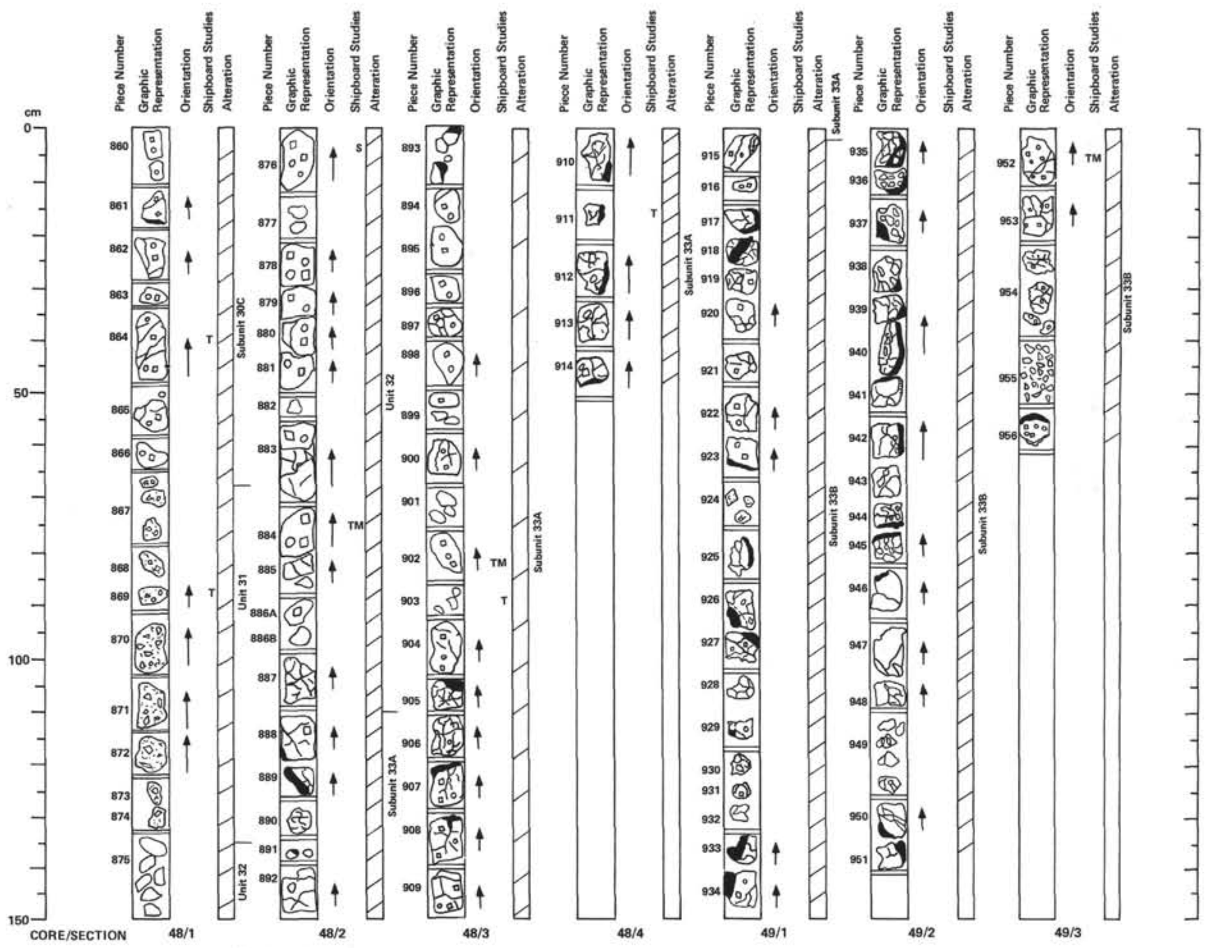
Texture: Subglomerophyric with subophitic (to intersertal) groundmass

Phenocrysts: Olivine, 1%, 0.5x0.3 mm, euhedral; plagioclase, 7%, 1.6x0.5 mm, subhedral laths; clinopyroxene, 7%, 1.6x 1.0 mm, euhedral. The plagioclase and clinopyroxene is often gathered in the same areas.

Groundmass: Plagioclase, 35%, 0.25x0.01 mm, microlaths; clinopyroxene, 35%, 0.08x0.06 mm, anhedral; magnetite, 6%, 0.05x0.03 mm, skeletal; glass, 6%

Vesicles: Voids, scattered irregular (may be due to thin section preparation

Alteration: Brown-green smectite replacing glass



70-504B-48 Depth: 4110.5–4119.5 m (647.0–656.0 mbsf)
70-504B-49 Depth: 4119.5–4128.5 m (656.0–665.0 mbsf)

48-1, Pieces 860–866 (Subunit 30C continued)

Dominant Lithology: Sparsely plagioclase-clinopyroxene-olivine-phyric basalt.

Macroscopic Description: Medium-grained sparsely to moderately phyric plagioclase-olivine basalt. The basalt is medium-grained, moderately fractured with green smectite the dominant mineral filling the fractures. Pyrite occurs in fractures (e.g. Pieces 860, 861, and 865). No zeolites and obvious oxidative alteration are observed.

Thin Section Description

48-1, 46–49 cm (Piece 864):

Name: Fine- to medium-grained sparsely plagioclase-clinopyroxene-olivine phyric basalt (flow interior)

Texture: Hyalopilitic with an intersertal groundmass

Phenocrysts: Olivine, < 1%, 0.4x0.025 mm, subhedral; plagioclase, < 1%, 0.45x0.4 mm, subhedral laths; clinopyroxene, 1%, 1.5x1.1 mm, euhedral

Groundmass: Plagioclase, 40%, 0.25x0.025 mm, subhedral laths; clinopyroxene, 35%, 0.4x0.04 mm, anhedral; magnetite, 4%, 0.015x0.015 mm, skeletal; glass, 5% replaced by smectite; pyroxene + plagioclase, 15%, mature sheaf texture

Vesicles: Miarolitic voids, 10%, 1.2x0.7 mm, partly filled with smectite, irregular shape

Alteration: Brown and green smectite replacing olivine and glass

48-1, Pieces 867–874 (Unit 31)

Dominant Lithology: Basalt breccia

Macroscopic Description: Abundant 1 mm–1 cm sized angular to subangular basalt fragments in a matrix of green smectite and glass. Pieces 868 and 870 contain fragments > 3 cm in diameter.

Thin Section Description

48-1, 90–92 cm (Piece 869):

Name: Basalt breccia (glassy margin)

Texture: Lithic fragments are glassy to variolitic

Phenocrysts: Olivine, < 1%, 0.5x0.5 mm, subhedral to euhedral; plagioclase, 5%, 1.0–0.5 mm, lathy clinopyroxene, < 1%, 0.5x0.5 mm, subhedral-anhedral

Groundmass: Glass, 95%

Alteration: Smectite replacing original matrix and glassy fragments

48-1—48-2, Pieces 875—887 (Unit 32)

Dominant Lithology: Sparsely to moderately plagioclase-clinopyroxene-olivine-phyric basalt

Macroscopic Description: Fine-grained, sparsely to moderately plagioclase-clinopyroxene-olivine-phyric basalt. This unit represents a massive basalt flow. Alteration occurs mainly in the small fractures where smectite and pyrite are found. Olivine is also altered to smectite

Thin Section Description

48-2, 75–78 cm (Piece 884):

Name: Fine-grained sparsely to moderately plagioclase-clinopyroxene-olivine-phyric basalt (next to glassy margin)

Texture: Hyalo-ophitic

Phenocrysts: Olivine, 1%, 1.0x0.5 mm, euhedral; plagioclase, 2%, 0.9x0.7 mm, subhedral laths with rounded corners; clinopyroxene, 1%, 1.3x0.6 mm, subhedral elongated laths with rounded corners

Groundmass: Olivine, 4%, 0.02x0.03 mm and 0.4x0.3 mm, euhedral; plagioclase, 40%, 0.12x0.01 mm, microlites; clinopyroxene, 17%, 0.05x0.04 mm, anhedral; magnetite, 5%, 0.01 mm, skeletal; pyroxene + plagioclase, 30%, mature sheaf texture

Alteration: Smectite replacing olivine

48-2–48-4, Pieces 888–914 (Subunit 33A)

Dominant Lithology: Aphyric to moderately plagioclase-clinopyroxene-olivine-phyric basalt.

Macroscopic Description: Fine- to medium-grained aphyric to moderately plagioclase-clinopyroxene-olivine-phyric basalt. This unit represents a pillow sequence with possibly a small flow in the middle of the unit. The alteration is oxidative in the upper portion as evidenced by the red-brown Fe-oxides in the fractures and replacing olivine. Alteration in the lower half is reducing as evidenced by the presence of pyrite. Fracturing is intense with glassy margins present on top, sides and bottoms of oriented rocks.

Thin Section Descriptions

48-3, 82–85 cm (Piece 902):

Name: Medium-grained plagioclase-phyric basalt (flow interior)

Texture: Sub-ophitic to intersertal

Phenocrysts: Olivine, < 1%, subhedral; plagioclase, 15%, 1x0.8 mm, equant to blocky

Groundmass: Plagioclase, 25–30%, 0.5x0.08 mm, skeletal; clinopyroxene, 25–30%, 0.3x0.3 mm, euhedral; magnetite, 5–8%, skeletal glass, 25%

Alteration: Clays (smectite), 5–10% replacing glass and olivine

48-3, 85–86 cm (Piece 903):

Name: Fine- to medium-grained aphyric basalt (next to glassy margin, variolitic patches)

Texture: Hyalo-ophitic

Groundmass: Olivine, 10%, 0.1x0.1 mm; plagioclase, 25%, 0.7x 0.05 mm; glass, 65%, observed as variolites

Alteration: Smectite, 10%, scattered and replacing glass pockets

48-4, 14–16 cm (Piece 910):

Name: Fine-grained plagioclase-clinopyroxene-phyric basalt (glassy margin)

Texture: Variolitic texture

Phenocrysts: Plagioclase, 20%, 1.5x0.7 mm, equant; clinopyroxene, < 1%, 1.5x1.5 mm, blocky laths

Groundmass: Magnetite, < 5%, glass, 80%, observed as variolites

49-1–49-3, Pieces 915–956 (Subunit 33B)

Dominant Lithology: Moderately plagiolcase-olivine-phyric basalt.

Macroscopic Description: Fine- to medium-grained moderately plagioclase-olivine-phyric basalt. The basalts are very often brecciated. Smectite and pyrite occur as fracture infillings, suggesting the alteration is non-oxidative. Glassy rims and margins are abundant.

Thin Section Description

49-3, 5–7 cm (Piece 952):

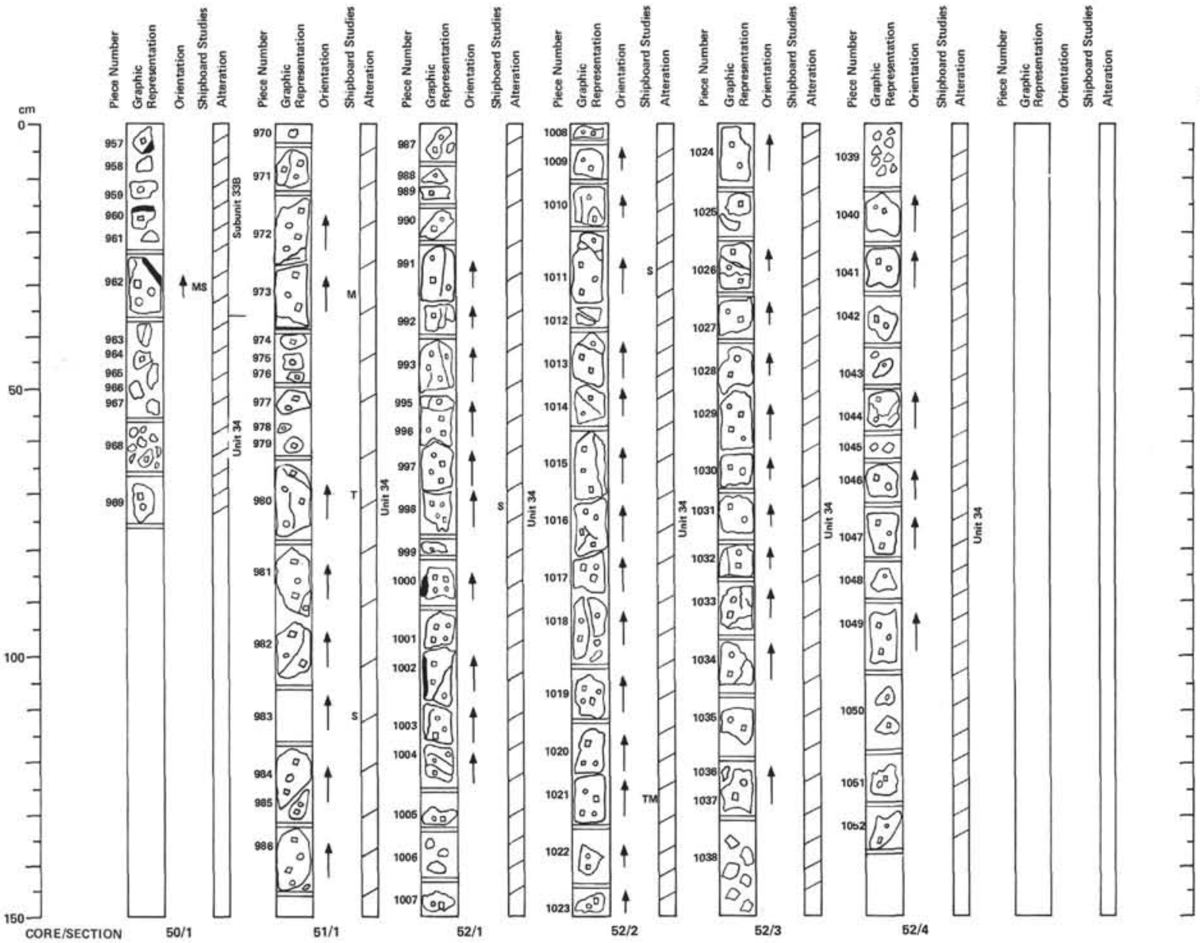
Name: Fine-grained olivine-plagioclase-phyric basalt (glassy margin, next to glassy margin)

Texture: Variolitic with areas of hyalopilitic

Phenocrysts: Olivine, 1%, 0.2x0.2 mm, euhedral; plagioclase, 10%, 1x0.3 mm

Groundmass: Olivine, 10%, 0.1x0.1 mm, anhedral; plagioclase, 20%, 0.4x0.03 mm, skeletal laths, magnetite, < 5%; glass, 65%, variolites and sheaf texture

Alteration: Brown smectite, 5–10%, scattered, replacing olivine and glass



70-504B-50 Depth: 4128.5–4133.0 m (665.0–669.5 mbsf)
70-504B-51 Depth: 4133.0–4142.0 m (669.5–678.5 mbsf)
70-504B-52 Depth: 4142.0–4151.0 m (678.5–687.5 mbsf)

50-1, Pieces 957–962 (Subunit 33B continued)

Dominant Lithology: Moderately plagioclase-olivine-phyric basalt.

Macroscopic Description: Fine- to medium-grained moderately plagioclase-olivine-phyric basalt. Smectite replaces olivine and groundmass, with smectite also observed filling fractures. Fe-oxides (Piece 957) and pyrite (Pieces 958–962) occur as secondary minerals in veinlets and fractures. Glassy rims are observed in Pieces 957, 960, and 962.

50-1–52-4, Pieces 963–1052 (Unit 34)

Dominant Lithology: Sparsely to moderately plagioclase-olivine-phyric basalt.

Macroscopic Description: Medium- to coarse-grained sparsely to moderately plagioclase-olivine-phyric basalt. This unit is a massive coarse ophitic basalt with a glassy margin at the top. Olivine phenocrysts and portions of the groundmass are replaced by smectite. Veins are filled with smectite and pyrite, indicating a non-oxidizing condition. In Piece 1002 a small dextral fault occurs, displacement is 4–5 mm.

Thin Section Descriptions

51-1, 72–74 cm (Piece 980):

Name: Coarse-grained sub-ophitic basalt (flow interior)

Texture: Ophitic to intersertal

Phenocrysts: Olivine, 4%, 0.7x0.4 mm, euhedral; plagioclase, 4%, 1.5x0.5 mm, subhedral laths; clinopyroxene, 1%, 1.2x 0.5 mm, anhedral

Groundmass: Olivine, 13%, 0.1x0.08 mm, euhedral; plagioclase, 35%, 0.3x0.03 mm, subhedral laths; clinopyroxene, 30%, 0.08x0.08 mm, anhedral; magnetite, 5%, 0.04x0.04 mm, skeletal; glass, 8%

Alteration: Green smectite and talc replacing olivine; smectite replacing glass

52-2, 132–134 cm (Piece 1021):

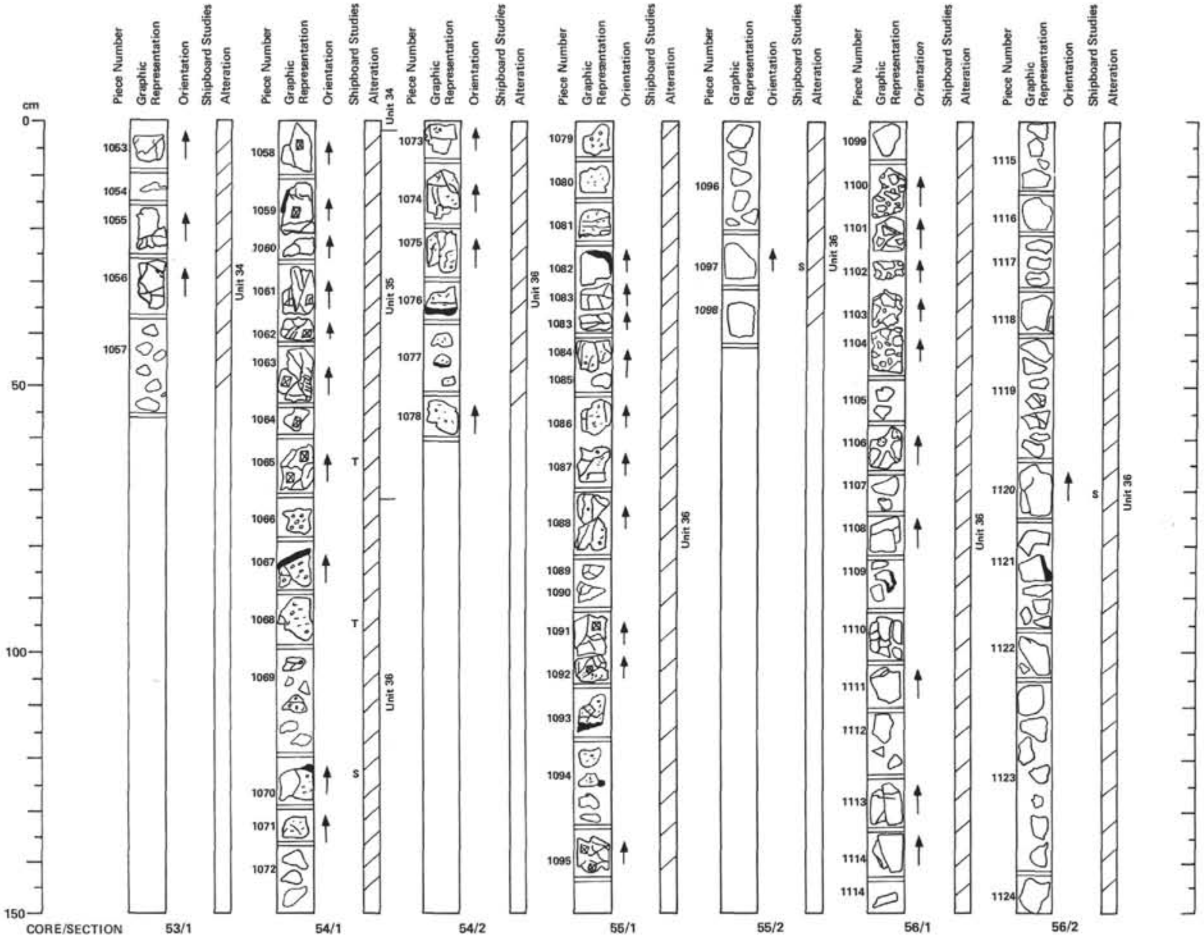
Name: Coarse-grained sub-ophitic plagioclase-clinopyroxene-olivine basal (flow interior)

Texture: Ophitic to intersertal

Phenocrysts: Plagioclase, 7%, 1.2x0.2 mm, subhedral laths; clinopyroxene, 2%, 1.6x0.6 mm, anhedral

Groundmass: Olivine?, 5%, 0.2x0.3 mm, anhedral, completely replaced by green smectite; plagioclase, 38%, 0.3x0.02 mm, subhedral laths; clinopyroxene, 37%, 0.3x0.25 mm anhedral; magnetite, 4%, 0.08x0.06 mm, skeletal; glass, 7%

Alteration: Green smectite replacing glass and olivine(?)



70-504B-53	Depth: 4151.0–4155.5 m (687.5–692.0 mbsf)
70-504B-54	Depth: 4155.5–4160.0 m (692.0–696.5 mbsf)
70-504B-55	Depth: 4160.0–4169.0 m (696.5–705.5 mbsf)
70-504B-56	Depth: 4169.0–4178.0 m (705.5–714.5 mbsf)

53-1, Pieces 1053–1057 (Unit 34 continued)

Dominant Lithology: Sparsely to moderately plagioclase-olivine-phyric basalt.

Macroscopic Description: Medium- to coarse-grained sparsely to moderately plagioclase-olivine-phyric basalt. Olivine phenocrysts and portions of the groundmass are replaced by smectite. The rocks are highly fractured. In some open spaces in the veins rhombohedral(?) crystals and botryoidal masses have been deposited on top of smectite.

54-1, Pieces 1058–1065 (Unit 35)

Dominant Lithology: Fine-grained aphyric basalt.

Macroscopic Description: Moderate to highly vesicular fine-grained aphyric basalt. Vesicles are mostly filled with dark green smectite.

Thin Section Description

54-1, 62–64 cm (Piece 1065):

Name: Fine-grained aphyric basalt (next to glassy margins)

Texture: Hyalopilitic

Groundmass: Olivine, 3%, 0.25x0.20 mm, subhedral; plagioclase, 10%, 0.5x0.08 mm, laths, 0.3x0.01 mm, microlites; clino*pyroxene, 5%, 0.03x0.03 and 0.25x0.08 mm*, anhedral; magnetite, 2%, 0.01x0.01 mm, skeletal; pyroxene + plagioclase, 80%, mature sheaf texture

Alteration: Green smectite replacing olivine

54-1–56-2, Pieces 1066–1124 (Unit 36)

Dominant Lithology: Fine- to medium-grained vesicular aphyric to sparsely glomerophyric basalt.

Macroscopic Description: Fine- to medium-grained vesicular aphyric to sparsely glomerophyric basalt. This unit consists of several basalt flows which are separated from each other by glassy margins. Vesicles comprise approximately 5% of the basalts (0.1–0.3 mm diameter) and are scattered throughout. The vesicles are empty in the fresh rocks and contain green smectite in the altered rocks. Fractures are filled with pyrite and dark green smectite.

Thin Section Description

54-1, 91–94 cm (Piece 1068):

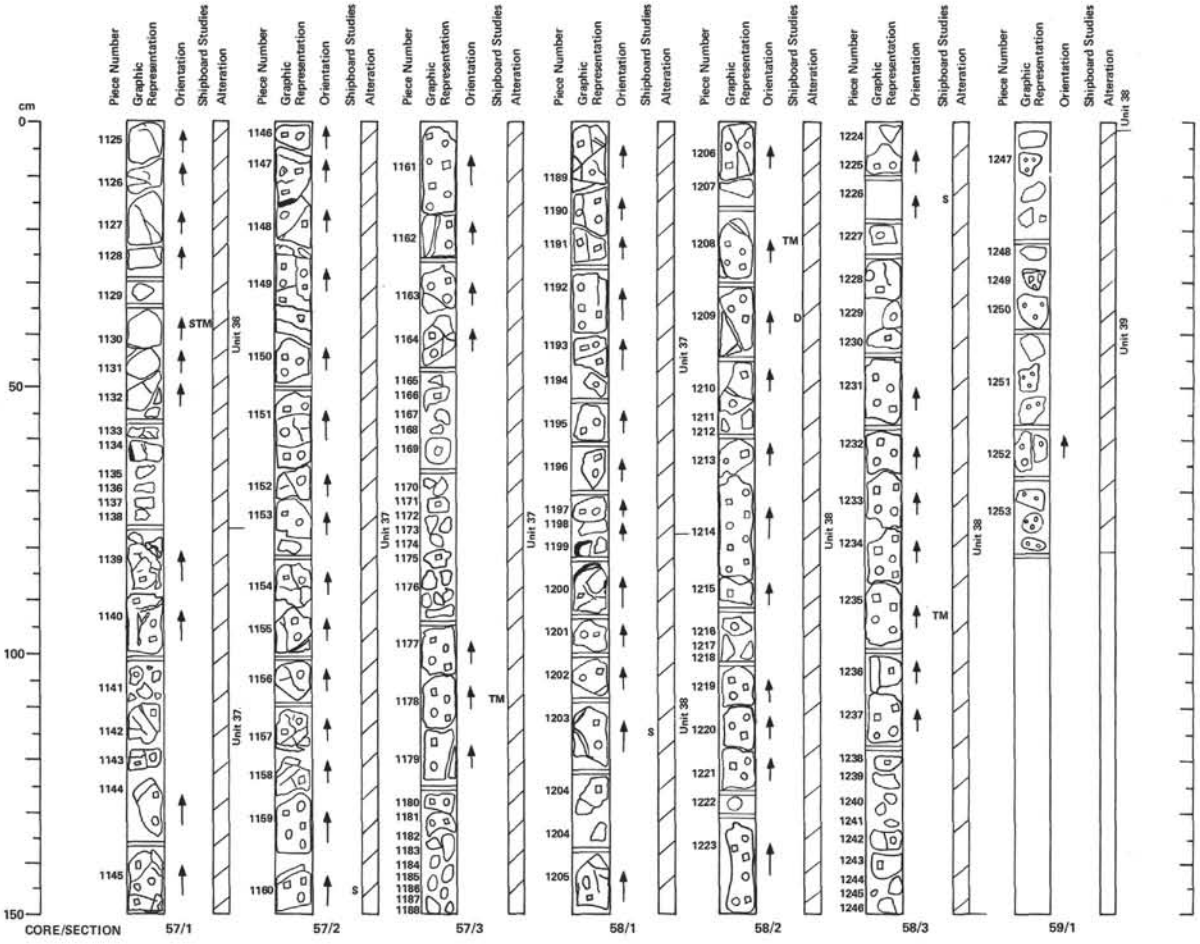
Name: Fine- to medium-grained aphyric vesicular basalt (next to glassy margin)

Texture: Hyalo-ophitic to hyalopilitic

Groundmass: *Olivine? replaced by smectite;* plagioclase, 12%, 0.4x0.03 mm, laths; clinopyroxene, 8%, 0.05x0.04 mm; magnetite, 3%, 0.02x0.01 mm, skeletal; pyroxene + plagioclase, 76%, mature sheaf texture

Vesicles: 5%, 0.12 mm, round and filled with smectite

Alteration: Smectite in vesicles and replacing olivine(?)



70-504B-57 Depth: 4178.0–4187.0 m (714.5–723.5 mbsf)
70-504B-58 Depth: 4187.0–4196.0 m (723.5–732.5 mbsf)
70-504B-59 Depth: 4196.0–4205.0 m (732.5–741.5 mbsf)

57-1, Pieces 1125–1138 (Unit 36 continued)

Dominant Lithology: Medium-grained vesicular aphyric to sparsely glomerophyric basalt.

Macroscopic Description: Medium-grained vesicular aphyric to sparsely glomerophyric basalt. Vesicles are filled with dark green smectite. Fractures in Pieces 1127 and 1131 are filled with dark green smectite and pyrite. Red-brown Fe-oxides are present in fractures toward the bottom of the unit (e.g. Pieces 1133–1138).

Thin Section Description

57-1, 40–42 cm (Piece 1130):

Name: Medium-grained vesicular aphyric basalt (flow interior)

Texture: Hyalo-ophitic to hyalopilitic

Groundmass: Olivine?, 3%, subhedral to anhedral; plagioclase, 35%, 0.25x0.015 mm, microlites; clinopyroxene, 32%, 0.08x 0.08 mm, anhedral; magnetite, 4%, 0.02x0.02 mm, skeletal; glass, 8%; pyroxene + plagioclase, 15%, mature sheaf texture

Vesicles: 3%, 0.3 mm, scattered, some filled with smectite, round

Alteration: Green-brown smectite replacing glass, olivine(?), and filling vesicles

57-1–58-1, Pieces 1139–1198 (Unit 37)

Dominant Lithology: Sparsely to moderately olivine phyric basalt.

Macroscopic Description: Medium- to coarse-grained sparsely olivine phyric basalt. Fractures, minor in abundance, are filled with green smectite. Pyrite occurs as patches in some veins. Green smectite is the dominant vein-filling mineral.

Thin Section Description

57-3, 112–114 cm (Piece 1178):

Name: Medium- to coarse-grained sparsely olivine phyric and subophitic basalt (flow interior)

Texture: Sub-ophitic to intergranular

Phenocrysts: Olivine, 2%, 1.2x0.8 mm, subhedral

Groundmass: Olivine, 7%, 0.25x0.25 mm, subhedral; plagioclase, 40%, 0.4x0.02 mm, laths; clinopyroxene, 42%, 0.35x0.30 mm, anhedral to subhedral; magnetite, 3%, 0.04x0.04 mm, skeletal; glass, 7%

Alteration: Smectite replacing olivine and glass

58-1, Pieces 1199–1246 (Unit 38)

Dominant Lithology: Coarse-grained subophitic basalt dyke.

Macroscopic Description: Medium- to coarse-grained moderately plagioclase-olivine-phyric basalt. The upper contact of the dyke is well documented showing a glassy margin on an oriented piece with a 2x2 cm thick fragment of the overlying unit as an inclusion next to the glassy margin. The lower contact was not recovered. Olivine is replaced by smectite and low talc. Veinlets are composed of dark green smectite and pyrite. The alteration is non-oxidative.

Thin Section Description

58-2, 25–27 cm (Piece 1208):

Name: Coarse-grained subophitic basalt (flow interior)

Texture: Ophitic to intergranular

Phenocrysts: Olivine, 3%, 0.7x0.5 mm, euhedral; plagioclase, 12%, 0.9x0.7 mm, subhedral; clinopyroxene, 5%, 2.0x0.8 mm, subhedral

Groundmass: Plagioclase, 35%, 0.25x0.02 mm, subhedral laths; clinopyroxene, 37%, 0.15x0.15 mm, anhedral; magnetite, 5%, 0.05x0.04 mm, skeletal; glass, 3%

Alteration: Smectite replacing glass and olivine

58-3, 97–99 cm (Piece 1235):

Name: Coarse-grained highly clinopyroxene-plagioclase-phyric basalt (flow interior)

Texture: Subophitic

Phenocrysts: Olivine, < 1%, 0.8x0.4 mm, euhedral; plagioclase, 8%, 1.1x0.5 mm, subhedral to anhedral; clinopyroxene, 8%, 1.8x1.0 mm, subhedral to anhedral

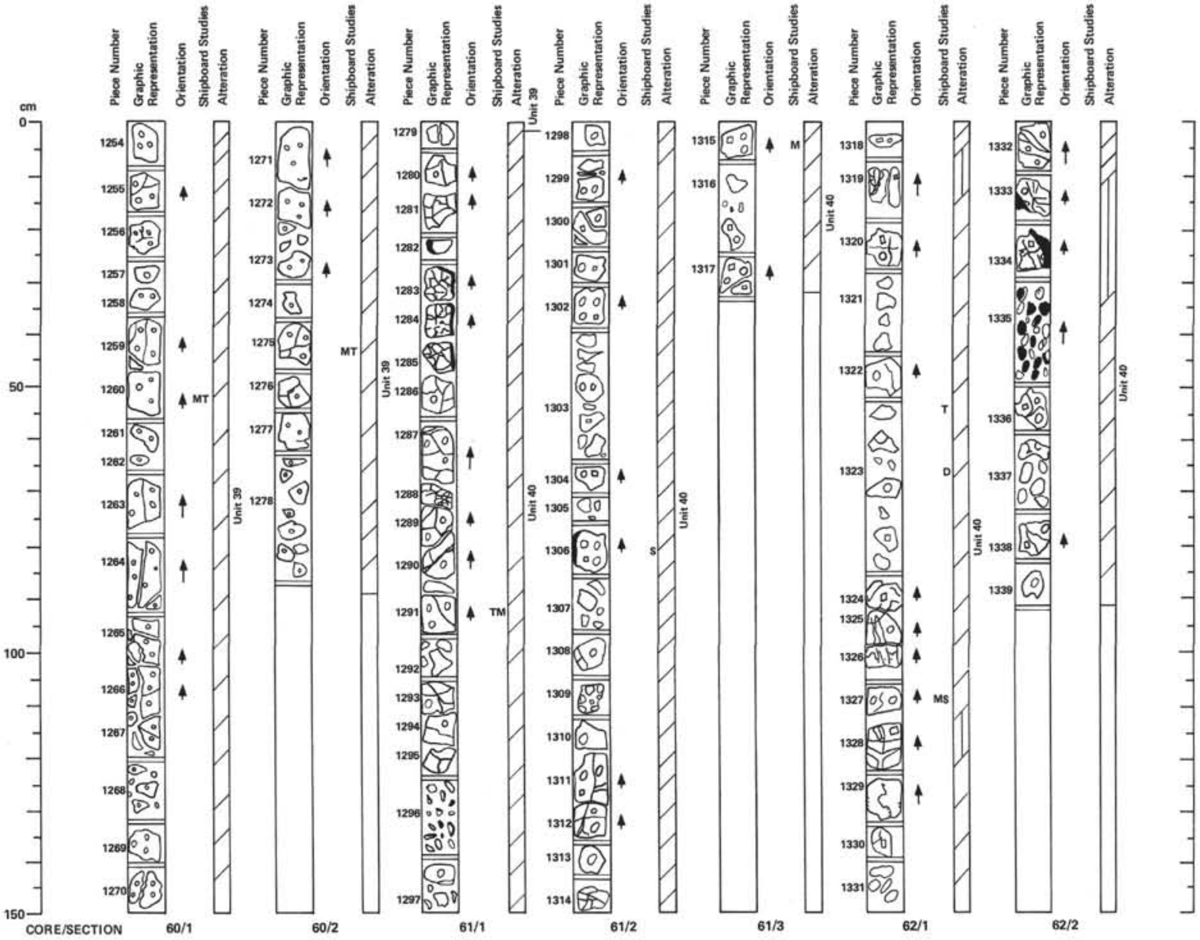
Groundmass: Olivine, 7%, 0.2x0.15 mm, subhedral; plagioclase, 32%, 0.25x0.03 mm, laths; clinopyroxene, 35%, 0.2x0.2 mm, anhedral; magnetite, 4%, 0.06x0.05 mm, skeletal; glass, 6%

Alteration: Smectite replacing glass and olivine

59-1, Pieces 1247–1253 (Unit 39)

Dominant Lithology: Aphyric to moderately plagioclase-olivine-phyric basalt.

Macroscopic Description: Medium- to coarse-grained aphyric to moderately plagioclase-olivine-phyric basalt. Green smectite and talc(?) have replaced the olivine phenocrysts. Pyrite and green smectite occur as fracture fillings. The alteration is non-oxidative. Some brecciated pieces occur in the upper part of this unit.



70-504B-60 Depth: 4205.0–4214.0 m (741.5–750.5 mbsf)
70-504B-61 Depth: 4214.0–4218.5 m (750.5–755.0 mbsf)
70-504B-62 Depth: 4218.5–4228.5 m (755.0–764.0 mbsf)

60-1–60-2, Pieces 1254–1278 (Unit 39 continued)

Dominant Lithology: A phyric to moderately plagioclase-olivine-phyric basalt.

Macroscopic Description: Medium- to coarse-grained aphyric to moderately plagioclase-olivine-phyric basalt. Olivine crystals are altered to dark green smectite, pyrite crystals are found in veins (e.g. Piece 1273) as is green smectite. The alteration is non-oxidative.

Thin Section Descriptions

60-1, 48–50 cm (Piece 1260):

Name: Medium-grained aphyric basalt (flow interior)

Texture: Intergranular to intersertal

Groundmass: Olivine, 10%, 0.4x0.25 mm, euhedral; plagioclase, 38%, 0.35x0.03 mm laths; clinopyroxene, 37%, 0.16x0.16 mm, anhedral; magnetite, 5%, 0.08x0.08 mm, skeletal; glass, 10%

Alteration: Green Smectite replacing glass and olivine

60-2, 41–44 cm (Piece 1275):

Name: Medium-grained highly olivine-plagioclase-phyric basalt (flow interior)

Texture: Subglomerophyric, hyalo-ophitic to hyalopilitic

Phenocrysts: Olivine, 8%, 1.8x1.0 mm, euhedral; plagioclase, 8%, 0.4x0.1 mm, subhedral laths

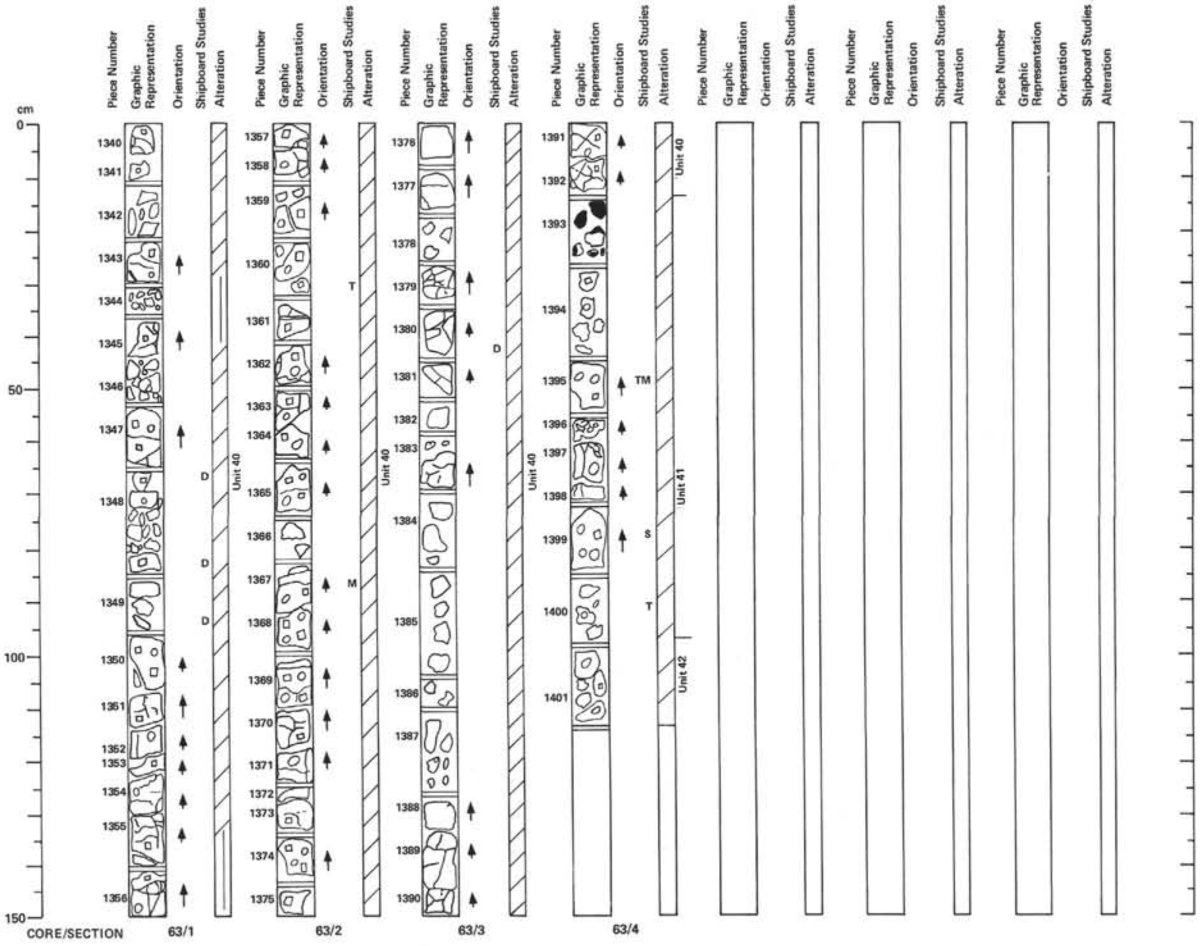
Groundmass: Olivine, 7%, 0.04x0.04 mm, subhedral; plagioclase, 15%, 0.2x0.02 mm, microlites; clinopyroxene, 15%, 0.03x 0.03 mm, anhedral; magnetite, 5%, 0.01x0.01 mm, skeletal; pyroxene + plagioclase, 42%, very mature sheaf texture

Alteration: Yellow green smectite replacing olivine and partly filling fractures. Blue green smectite replacing glass

61-1–62-2, Pieces 1279–1339 (Unit 40)

Dominant Lithology: Moderately plagioclase-olivine-phyric basalts.

Macroscopic Description: Fine- to medium-grained, moderately to highly fractured, moderately plagioclase-olivine-phyric basalt. This unit consists of pillows and/or flows which are seperated by glassy margins. Alteration is evidenced by the presence of green smectite completely replacing olivine and glass; fractures are filled with smectite and some pyrite. The alteration is non-oxidative. Phenocrysts are euhedral olivine (< 1.0 mm) and subhedral lathy plagioclase (< 1.3 mm). The groundmass has a mature sheaf texture.



70-504B-63 **Depth: 4227.5–4236.5 m (764.0–773.0 mbsf)**

63-1–63-4, Pieces 1340–1392 (Unit 40 continued)

Dominant Lithology: Moderately plagioclase-olivine-phyric basalt.

Macroscopic Description: Fine- to medium-grained moderately to highly fractured, moderately plagioclase-olivine, phyric basalt. The basalts are moderately to highly altered as documented by numerous smectite-filled fractures and veinlets. Olivine is replaced by smectite. Pyrite is also observed in fractures. Some plagioclase phenocrysts have a maximum length of up to 2 mm. Phenocrysts are euhedral olivine (< 1.0 mm) and subhedral lathy plagioclase. The groundmass has a mature sheaf texture.

Thin Section Description

63-3, 30–33 cm (Piece 1360):

Name: Medium-grained, moderately plagioclase-olivine-phyric basalt (flow interior)

Texture: Hyalo-ophitic

Phenocrysts: Olivine, 2%, 1.0x0.5 mm, euhedral; plagioclase, 5%, 1.3x0.4 mm, subhedral laths

Groundmass: Olivine, 4%, 0.06x0.3 mm, subhedral; plagioclase, 10%, 0.02x0.2 mm, microlites; clinopyroxene, 5%, 0.06x 0.06 mm, anhedral; magnetite, 6%, 0.04x0.04 mm, skeletal; glass, 8%; pyroxene + plagioclase, 58%, very mature sheaf texture

Vesicles: Miarolitic voids, 2%, scattered, irregular shaped and filled with green smectite

Alteration: Green smectite replacing glass; green smectite, talc(?) and opaques(?) replacing olivine

63-4, Pieces 1393–1400 (Unit 41)

Dominant Lithology: Moderately to highly plagioclase-olivine-phyric basalt.

Macroscopic Description: Small unit of massive, medium- to coarse-grained, moderately to highly plagioclase-olivine-phyric basalt. Fractures contain smectite. Smectite also occurs in veinlets and replaces olivine and glass. Glassy rims are abundant. Alteration is moderate and non-oxidative.

Thin Section Description

63-4, 45–48 cm (Piece 1395):

Name: Medium- to coarse-grained highly plagioclase-olivine-phyric basalt (flow interior)

Texture: Subophitic to intersertal

Phenocrysts: Olivine, 5%, 0.6x0.2 mm, euhedral; plagioclase, 8%, 1.2x0.6 mm, subhedral laths

Groundmass: Plagioclase, 38%, 0.12x0.02 mm, laths; clinopyroxene, 37%, 0.12x0.10 mm, anhedral; magnetite, 4%, 0.02x0.02 mm, skeletal or elongated; glass, 3%

Vesicles: Miarolitic voids, 5%, 0.8x0.2 mm, filled with green smectite, irregular shape

Alteration: Smectite and talc(?) replacing olivine, smectite replacing glass

63-4, 60–61 cm (Piece 1400):

Name: Medium-grained highly plagioclase-olivine-phyric basalt (next to glassy margin)

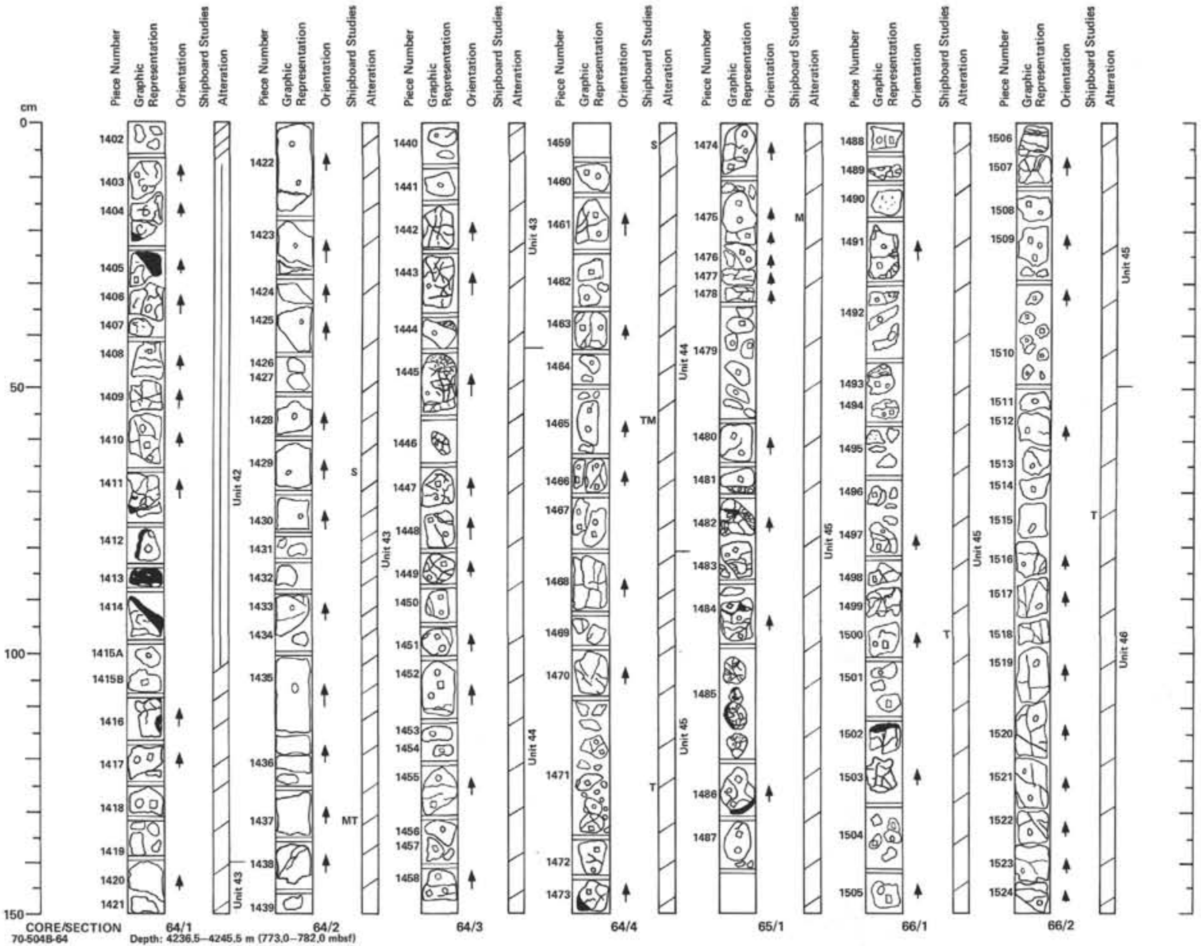
Texture: Hyalo-ophitic

Phenocrysts: Olivine, 5%, 0.6x0.5 mm, euhedral; plagioclase, 12%, 4x2 mm, rounded or euhedral laths, 1.5x0.5 mm, subhedral laths

Groundmass: Olivine, 15%, 0.1x0.1 mm, subhedral; plagioclase, 25%, 0.4x0.01 mm, microlites; clinopyroxene, 15%, 0.06x0.06 mm, anhedral; magnetite, 8%, 0.03x0.03 mm, skeletal; glass, 10%, pyroxene + plagioclase, 10%, very mature sheaf texture

Alteration: Smectite replacing glass and olivine

63-4, Piece 1041 (Unit 42):
See Description next page.



70-504B-64 Depth: 4236.5–4245.5 m (773.0–782.0 mbsf)
70-504B-65 Depth: 4245.5–4254.5 m (782.0–791.0 mbsf)
70-504B-66 Depth: 4254.5–4263.5 m (791.0–800.0 mbsf)

64-1, Pieces 1402–1419 (Unit 42 continued)

Dominant Lithology: Moderately olivine-plagioclase-phyric basalt

Macroscopic Description: Fine-grained moderately olivine-plagioclase-phyric basalt. The unit consists of highly fractured pillows. Glassy margins are found at the top, sides, and bottom of oriented samples. Fractures are filled with green smectite. Fe-oxides occur in some fractures with pyrite common toward the bottom of the unit occurring with hematite.

64-1–64-3, Pieces 1420–1444 (Unit 43)

Dominant Lithology: Fine- to medium-grained aphyric basalt.

Macroscopic Description: Fine- to medium-grained aphyric basalt. The bottom of the unit is more fractured and brecciated and has a few glassy margins. Smectite fills fractures and replaces groundmass. Pyrite is common forming aggregates up to 3 mm in size. Alteration is non-oxidative.

Thin Section Description

64-2, 129–131 cm (Piece 1437):

Name: Fine-grained aphyric basalt (next to glassy margin or flow interior)

Texture: Hyalopilitic to hyalo-ophitic

Groundmass: Olivine, < 2%, 0.3x0.15 mm, subhedral; plagioclase, 10%, 0.32x0.02 mm and 0.12x0.10 mm, laths, clinopyroxene, 10%, 0.1x0.08 mm, anhedral; magnetite, 8%, 0.02x0.02 mm, skeletal; glass, 5%; pyroxene + plagioclase, 67%, very mature sheaf texture

Alteration: Green smectite replacing glass and olivine

64-3–64-4, Pieces 1445–1467 (Unit 44)

Dominant Lithology: Highly plagioclase-pyroxene-phyric basalt.

Macroscopic Description: Massive, coarse-grained, highly plagioclase-pyroxene-phyric basalt. Smectite completely replaces glass and olivine and occurs in fractures. Pyrite is also present in some veins.

Thin Section Description

64-4, 51–53 cm (Piece 1465):

Name: Coarse-grained plagioclase-pyroxene highly phyric basalt (flow interior)

Texture: Subophitic to intersertal

Phenocrysts: Plagioclase, 6%, 1.2x0.5 mm, subhedral laths; clinopyroxene, 6%, 1.2x0.8 mm, anhedral

Groundmass: Olivine, 2%, 0.3x0.08 mm, euhedral; plagioclase, 35%, 0.4x0.04 mm, subhedral laths; clinopyroxene, 32%, 0.2x0.2 mm, anhedral; magnetite, 4%, 0.05x0.04 mm, skeletal; glass, 15%

Alteration: Green smectite replacing glass and olivine

64-4–66-2, Pieces 1468–1510 (Unit 45)

Dominant Lithology: Moderately to highly plagioclase-olivine-phyric basalt.

Macroscopic Description: Highly fractured, fine- to medium-grained, moderately to highly plagioclase-olivine-pyroxene-phyric basalt pillows and/or thin flows. Glassy margins and brecciated basalts are abundant. Smectite completely replaces olivine and the groundmass in brecciated pieces. Fractures are filled with green smectite.

Thin Section Descriptions

64-4, 123–125 cm (Piece 1471):

Name: Medium-grained highly plagioclase-olivine-phyric basalt (flow interior)

Texture: Hyalo-ophitic to hyalopilitic (subglomerophyric)

Phenocrysts: Olivine, 4%, 0.7x0.5 mm, euhedral; plagioclase, 6%, 1.2x0.4 mm, euhedral laths; clinopyroxene, 1%, 2.0x0.5 mm, subhedral

Groundmass: Olivine, 3%, 0.01x0.01 mm, subhedral; plagioclase, 6%, 0.25x0.01 mm, microlites; clinopyroxene, 3%, 0.06x0.05 mm, anhedral; magnetite, 4%, 0.01x0.01 mm, skeletal; pyroxene + plagioclase, 73%, mature sheaf texture

Vesicles: Vein, 6 mm thick filled with radiating zeolite crystals

Alteration: Green and colorless smectite replacing olivine

66-1, 98–100 cm (Piece 1500):

Name: Fine- to medium-grained plagioclase-clinopyroxene-olivine basalt (next to glassy margin)

Texture: Hyalo-ophitic to hyalopilitic

Phenocrysts: Olivine, 1%, 0.3x0.2 mm, euhedral; plagioclase, 3%, 1.2x0.25 mm, euhedral laths; clinopyroxene, 4%, 0.3x 0.1 mm, laths with rounded corners

Groundmass: Plagioclase, 7%, 0.12x0.01 mm, microlites; clinopyroxene, 2%, 0.04x0.04 mm, anhedral; magnetite, 3%, < 0.008 mm; pyroxene + plagioclase, 80%, subvariolitic to immature sheaf texture

Alteration: Green and colorless smectite replacing olivine

66-2, Pieces 1511–1524 (Unit 46)

Dominant Lithology: Aphyric basalt.

Macroscopic Description: Massive medium-grained aphyric basalt. Glass in the groundmass is completely replaced by green smectite. Fractures are filled with smectite. The fractures also contain scattered clusters of pyrite crystals.

Thin Section Description

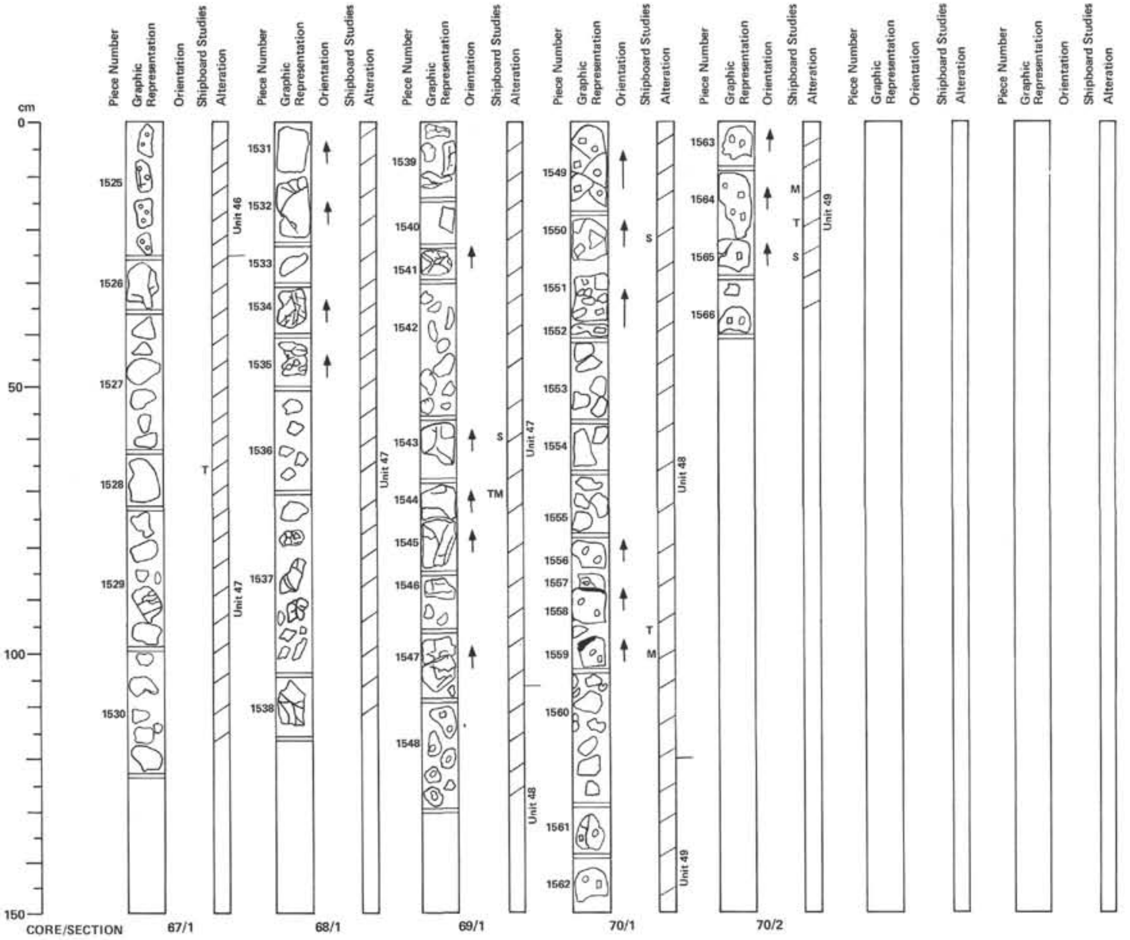
66-2, 71–73 cm (Piece 1515):

Name: Medium-grained aphyric basalt (flow interior)

Texture: Subophitic to intersertal

Groundmass: Olivine, 4%, 0.16x0.16 mm, subhedral; plagioclase, 40%, 0.3x0.02 mm, subhedral laths; clinopyroxene, 40%, 0.25x0.25 mm, anhedral

Alteration: Green smectite replacing glass and olivine



70-504B-67 **Depth: 4263.5–4272.5 m (800.0–809.0 mbsf)**
70-504B-68 **Depth: 4272.5–4281.5 m (809.0–818.0 mbsf)**
70-504B-69 **Depth: 4281.5–4290.5 m (818.0–827.0 mbsf)**
70-504B-70 **Depth: 4290.5–4300.5 m (827.0–836.0 mbsf)**

67-1, Piece 1525 (Unit 46 continued)

Dominant Lithology: Aphyric basalt.

Macroscopic Description: Massive medium-grained aphyric basalt. Groundmass consists of olivine, plagioclase, and clinopyroxene. Glass in the groundmass is completely replaced by smectite. Fractures are filled with smectite with some containing clusters of pyrite.

67-1–69-1, Pieces 1526–1547 (Unit 47)

Dominant Lithology: Aphyric to sparsely olivine-clinopyroxene-phyric basalt.

Macroscopic Description: Fine- to medium-grained aphyric to sparsely olivine-clinopyroxene-phyric basalt. Dark green smectite completely replaces glass and olivine. Veinlets are filled with smectite, zeolite, and pyrite. The rocks recovered are highly fractured and brecciated in zones.

Thin Section Descriptions

67-1, 55–60 cm (Piece 1528):

Name: Fine- to medium-grained very sparsely olivine-clinopyroxene-phyric basalt (next to glassy margin)

Texture: Hyalopilitic to hyalo-ophitic

Phenocrysts: Olivine, < 1%, 0.6x0.4 mm, euhedral; clinopyroxene, < 1%, 0.5x0.3 mm, subhedral

Groundmass: Plagioclase, 14%, 0.6x0.2 mm, microlites; clinopyroxene, 7%, 0.2x0.2 mm, anhedral; magnetite, 4%, 0.01x 0.01 mm, skeletal; glass, 5%; pyroxene + plagioclase, 70%, immature to mature sheaf texture

Alteration: Green smectite replacing olivine and glass

69-1, 66–68 cm (Piece 1544):

Name: Medium-grained aphyric basalt (flow interior)

Texture: Subophitic to intersertal

Groundmass: Plagioclase, 40%, 0.2x0.03 mm, lath; clinopyroxene, 40%, 0.12x0.10 mm, anhedral; magnetite, 10%, 0.04x 0.04 mm, skeletal; glass, 10%

Alteration: Smectite replacing glass

69-1–70-1, Pieces 1548–1560 (Unit 48)

Dominant Lithology: Moderately plagioclase-olivine-clinopyroxene-phyric basalt

Macroscopic Description: Fine- to medium-grained sparsely to moderately plagioclase-olivine-clinopyroxene-phyric basalt. Phenocrysts of euhedral olivine is partly replaced by smectite. Euhedral plagioclase and subhedral clinopyroxene are also phenocrysts. Smectite completely replaces glass, olivine and and fills veins.

Thin Section Description

70-1, 93–94 cm (Piece 1558):

Name: Fine- to medium-grained moderately plagioclase-olivine-clinopyroxene-phyric basalt (flow interior)

Texture: Intergranular

Phenocrysts: Olivine, 1%, 0.65x0.6 mm, euhedral; plagioclase, 3%, 0.8x0.5 mm, euhedral laths; clinopyroxene, 1%, 0.4x0.4 mm, subhedral

Groundmass: Olivine, 14%, 0.08x0.08 mm, subhedral; plagioclase, 40%, 0.16x0.02 mm, microlites; clinopyroxene, 35%, 0.04x0.04, anhedral; magnetite, 3%, 0.02x0.02 mm, skeletal; glass(?), 3%

Alteration: Smectite replacing glass and chlorite

70-1–70-2, Pieces 1561–1566 (Unit 49)

Dominant Lithology: Massive coarse-grained ophitic basalt.

Macroscopic Description: Massive coarse-grained ophitic basalt. Alteration consists of smectite replacing glass and as a fracture filling with zeolite.

Thin Section Description

70-2, 16–18 cm (Piece 1564):

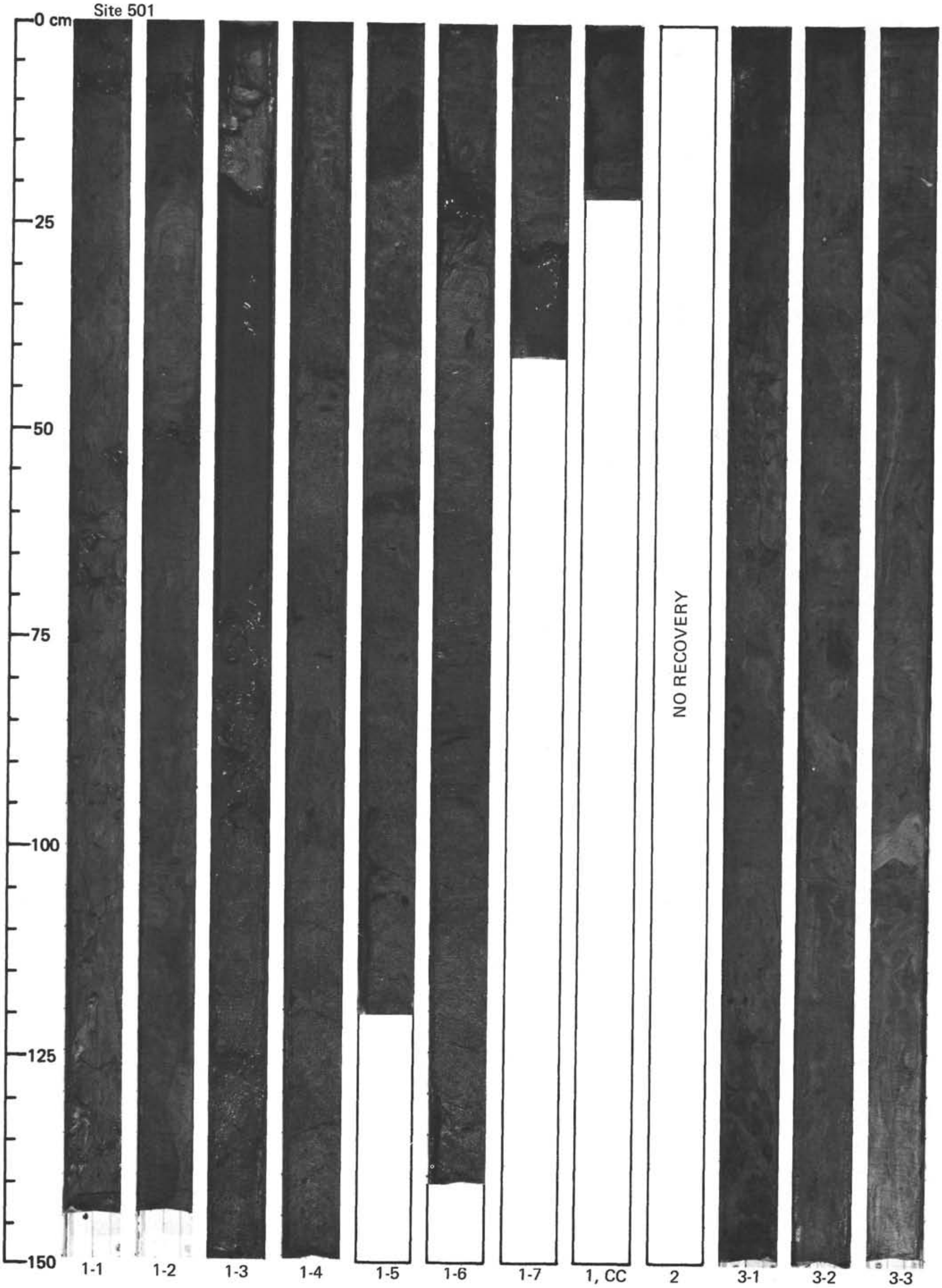
Name: Coarse-grained ophitic basalt (flow interior)

Texture: Ophitic, with some glassy areas

Phenocrysts: Olivine, 8%, 2.0x1.8 mm, subhedral; plagioclase, 40%, 1.2x0.35 mm and 0.4x0.06 mm, euhedral laths; clinopyroxene, 40%, 1.0x0.8 mm, anhedral

Groundmass: Magnetite, 5%, 0.08x0.08 mm, skeletal or microlites, glass, 7%

Alteration: Green smectite replacing glass and olivine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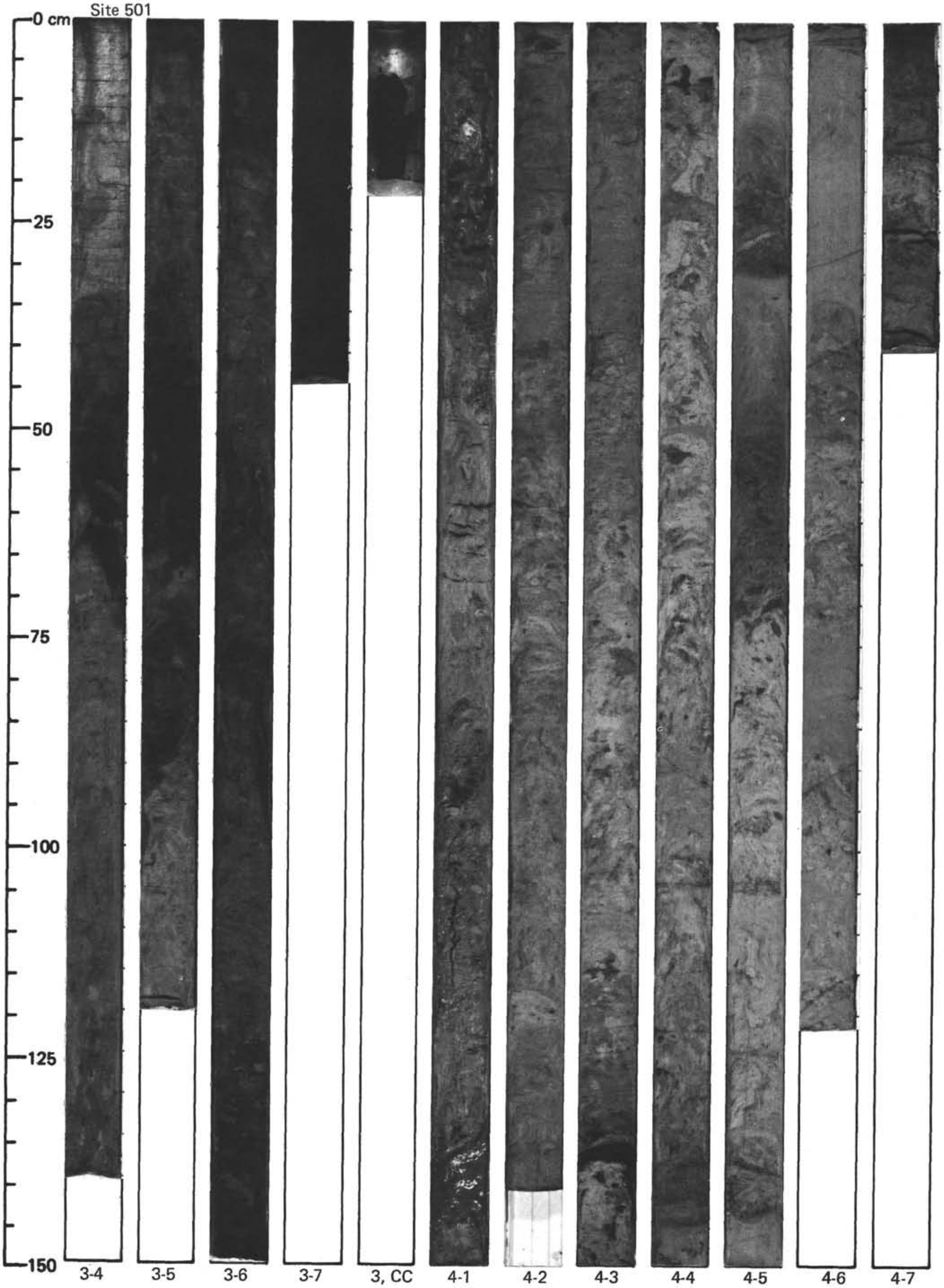
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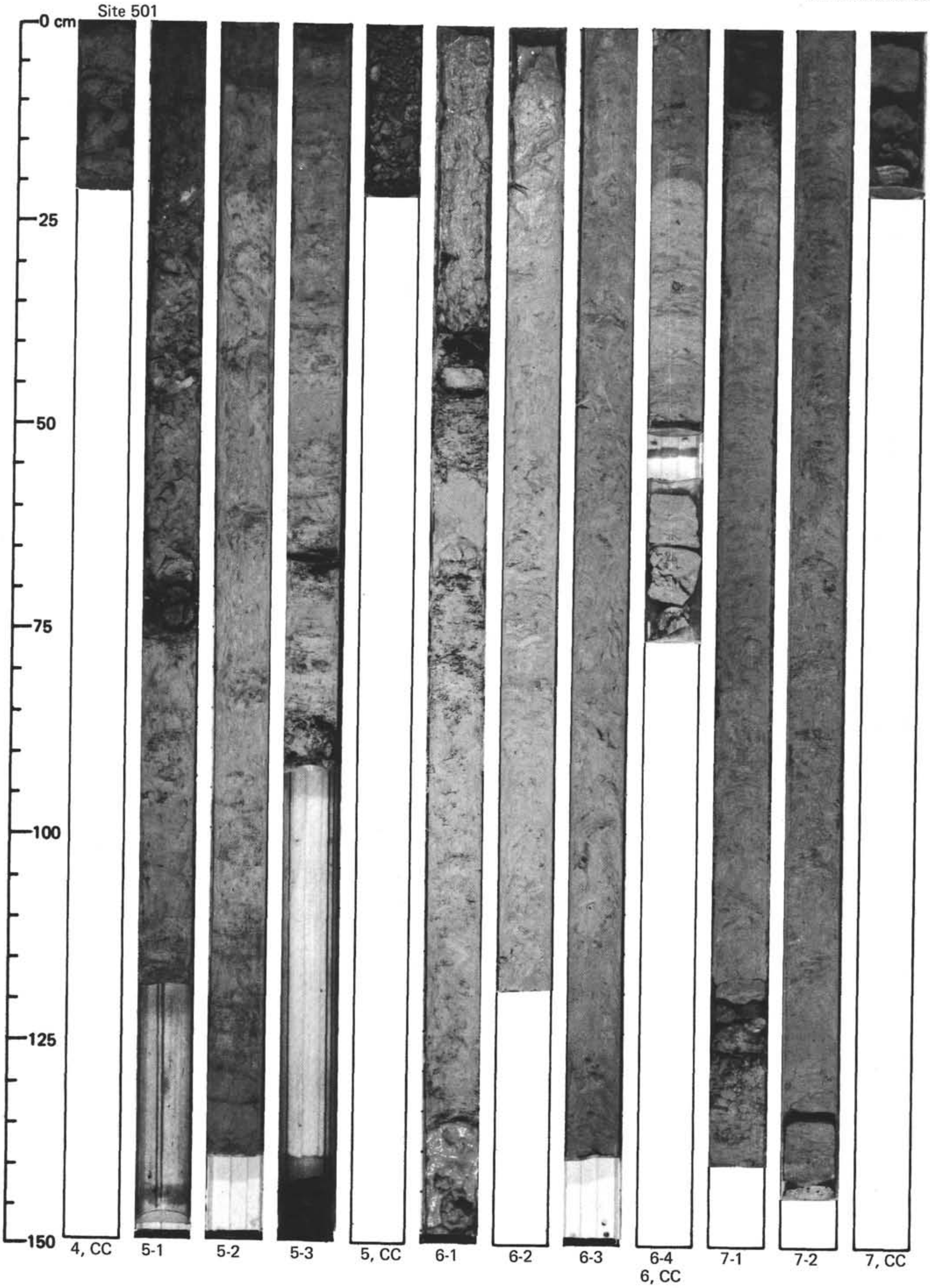
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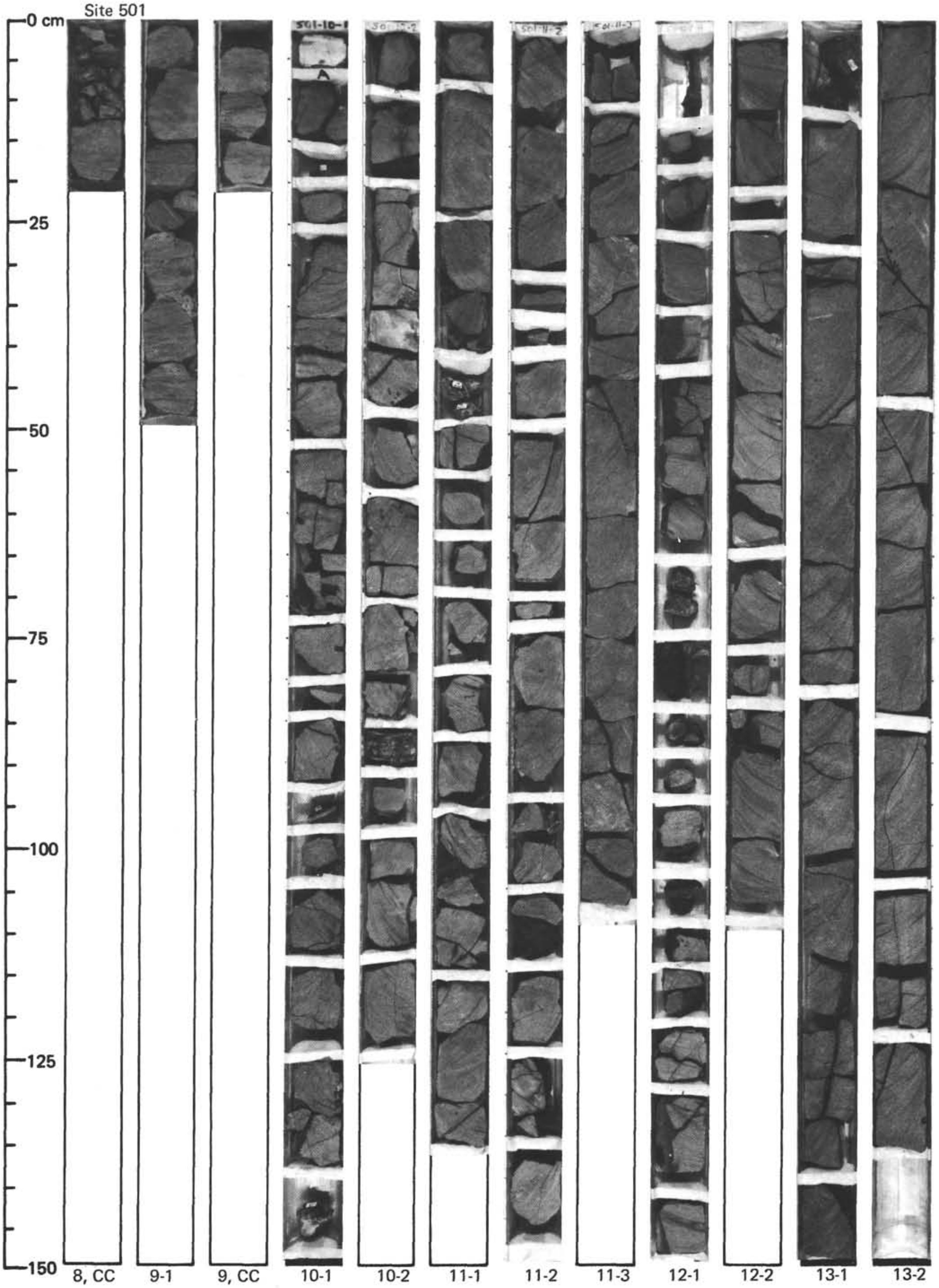
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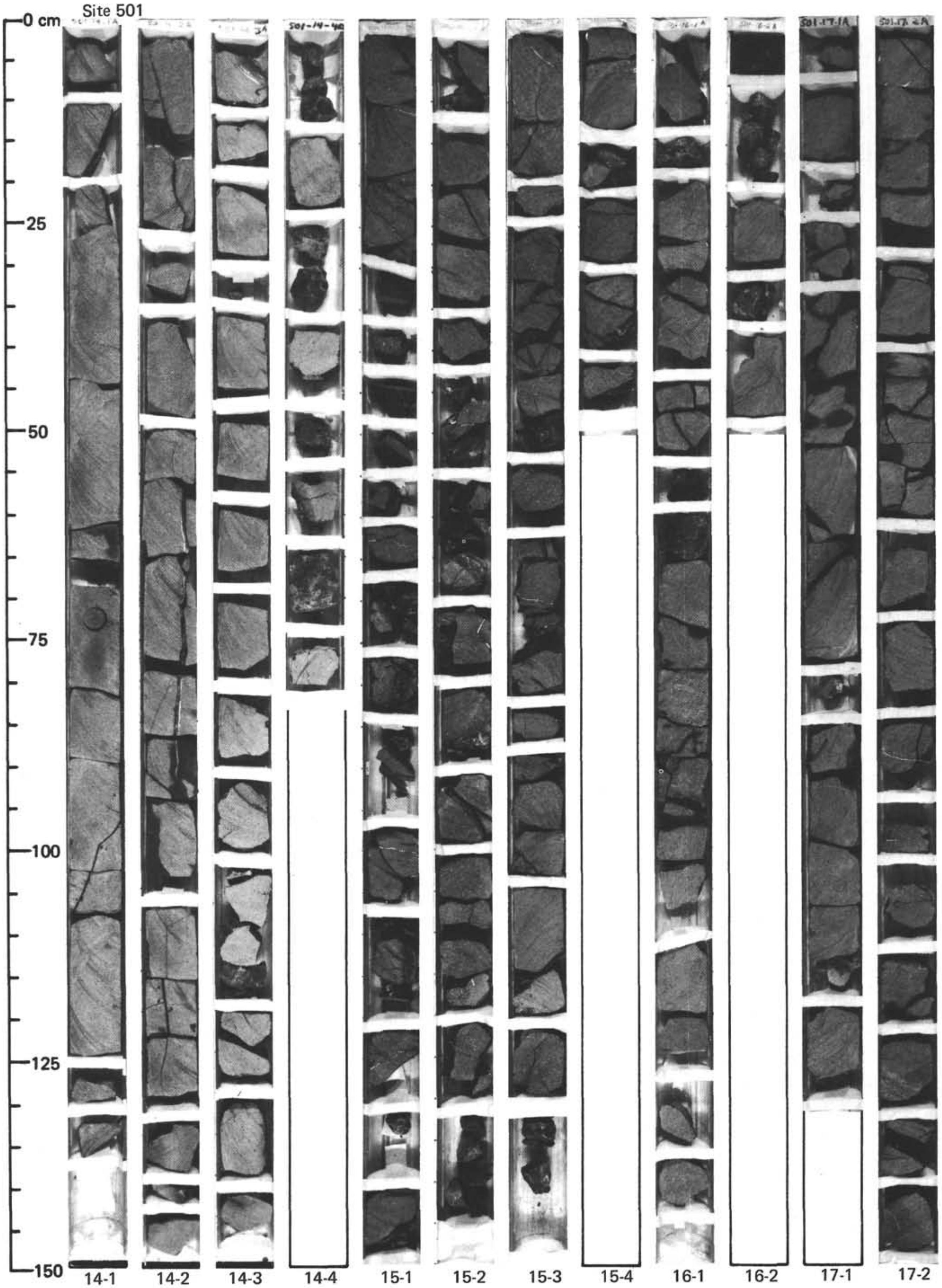
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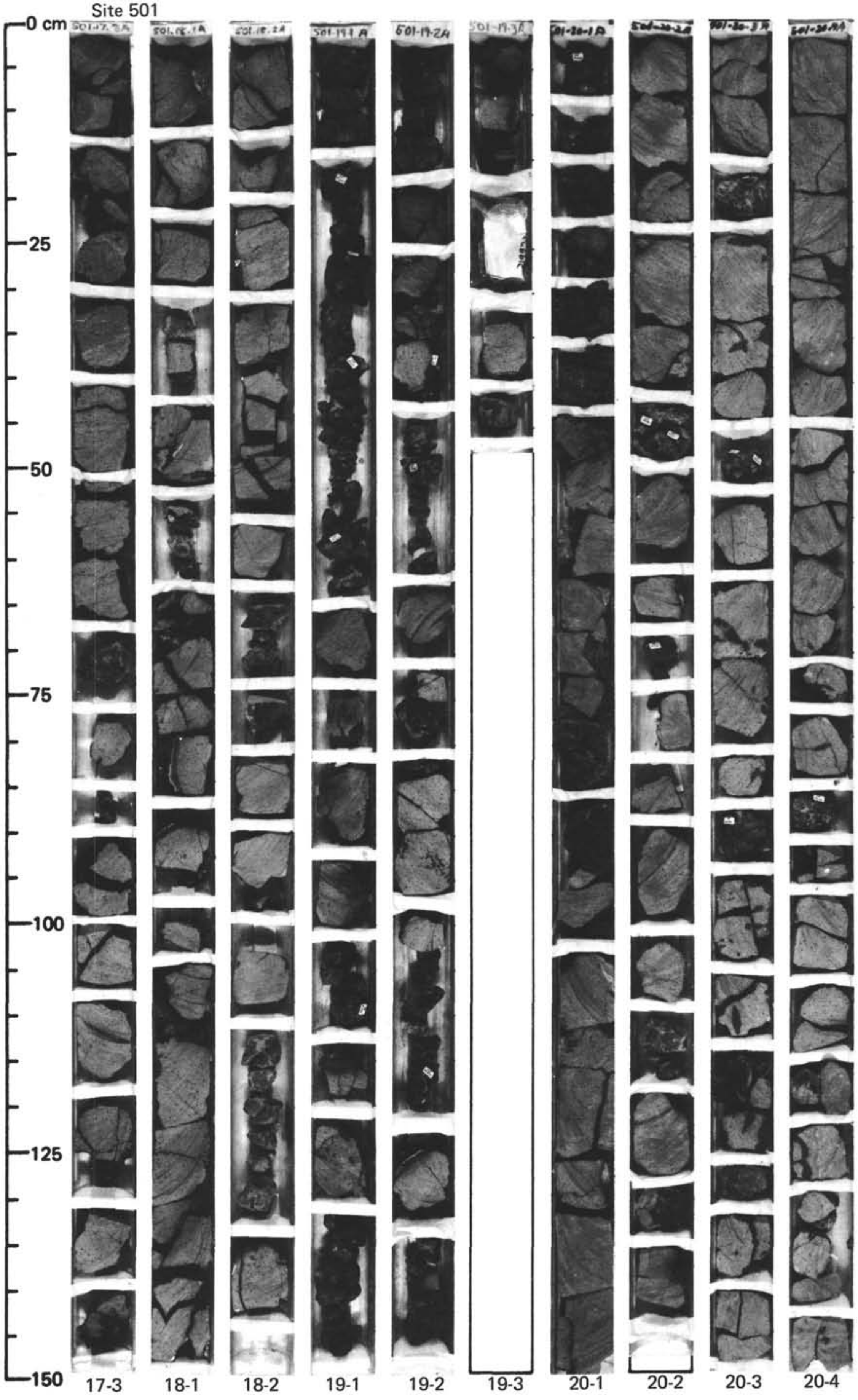
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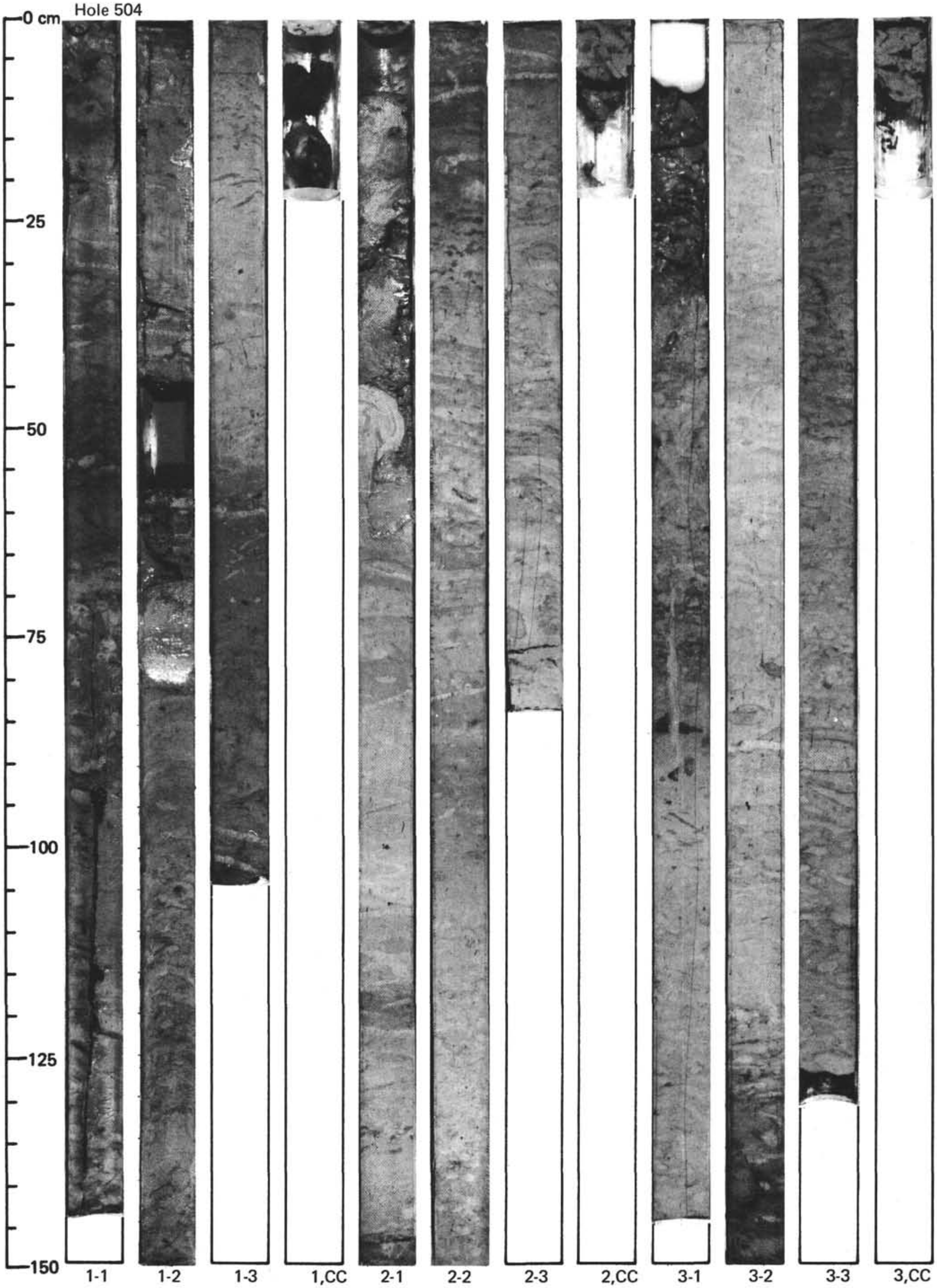
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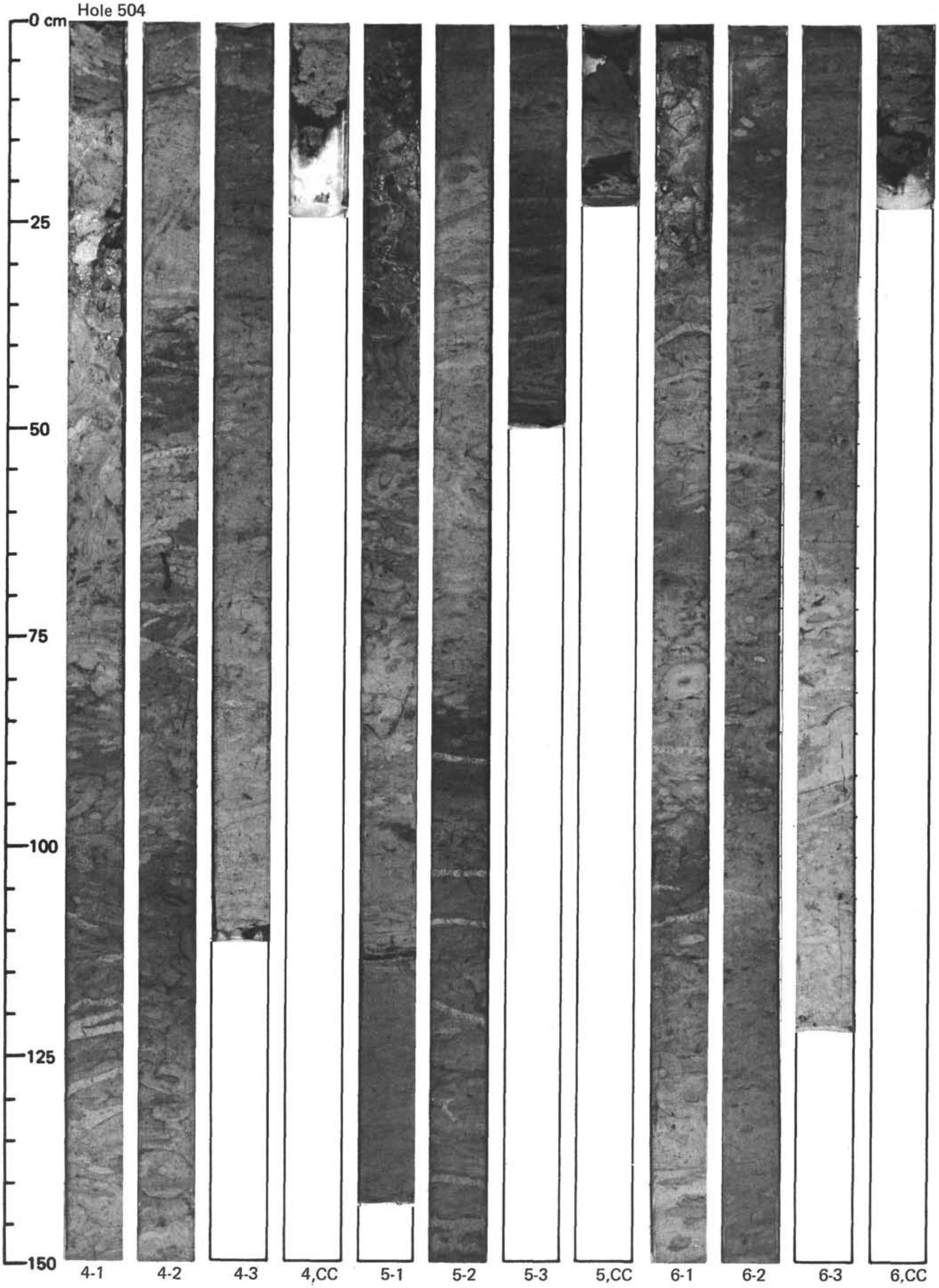
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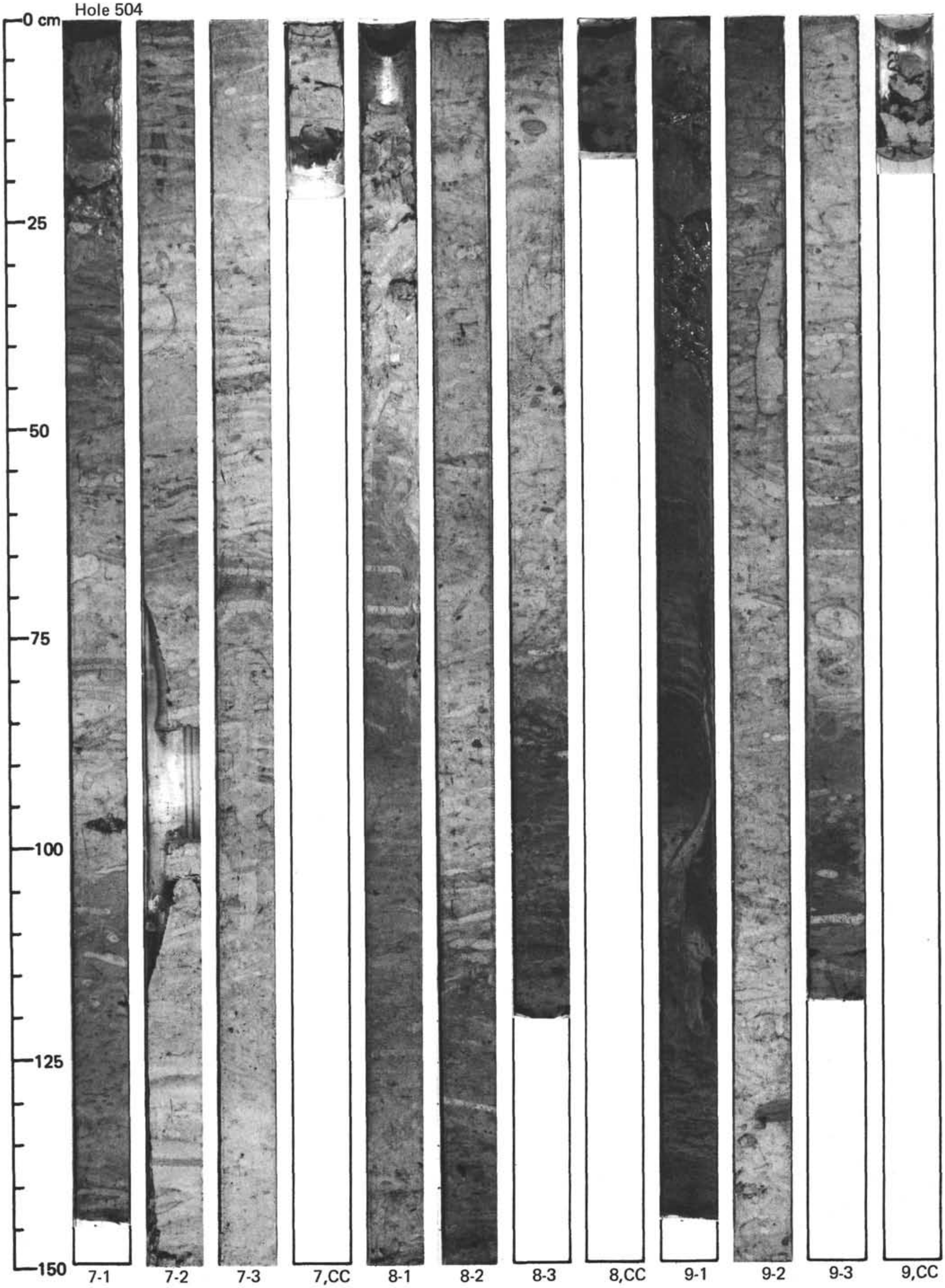
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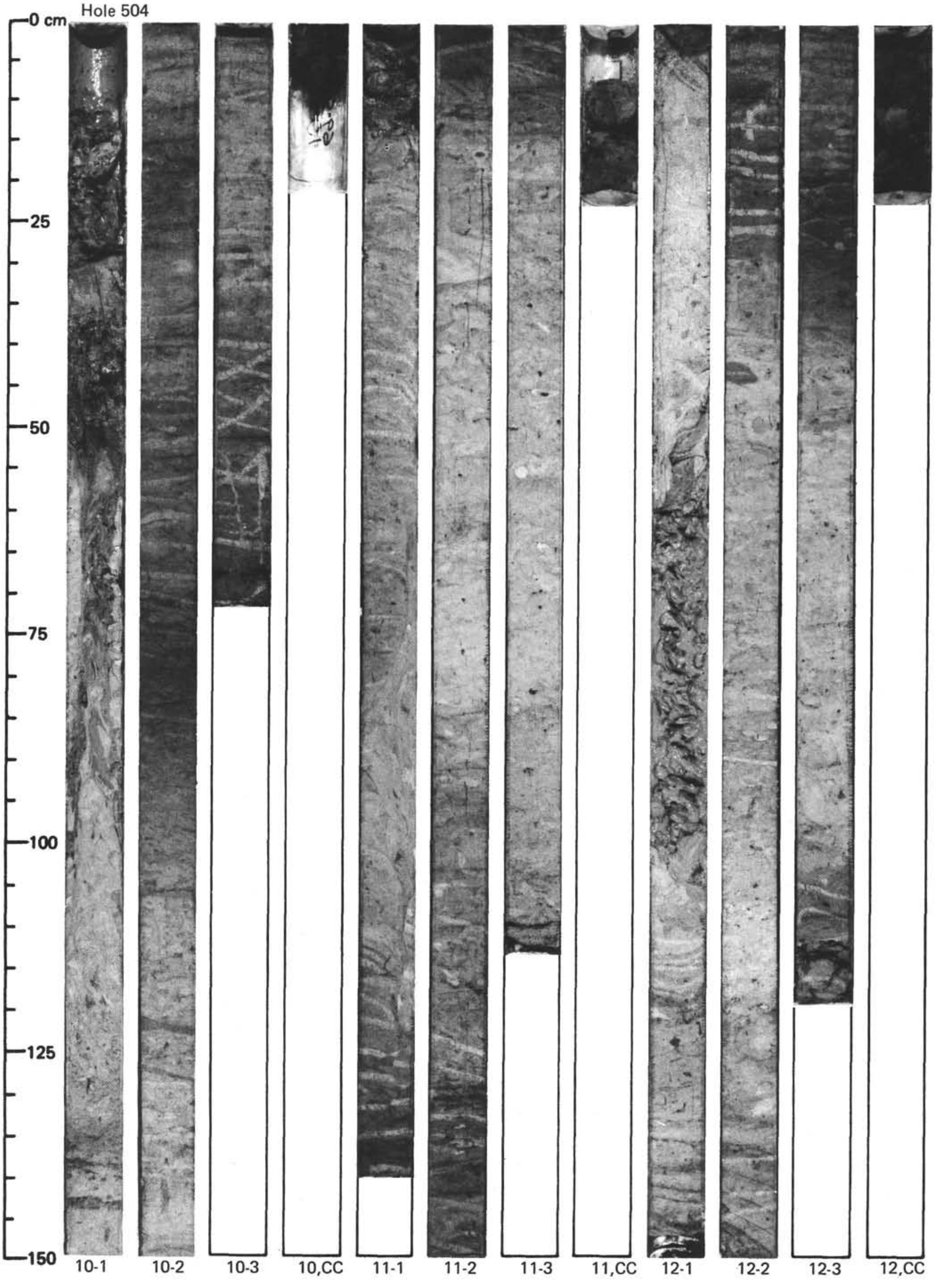
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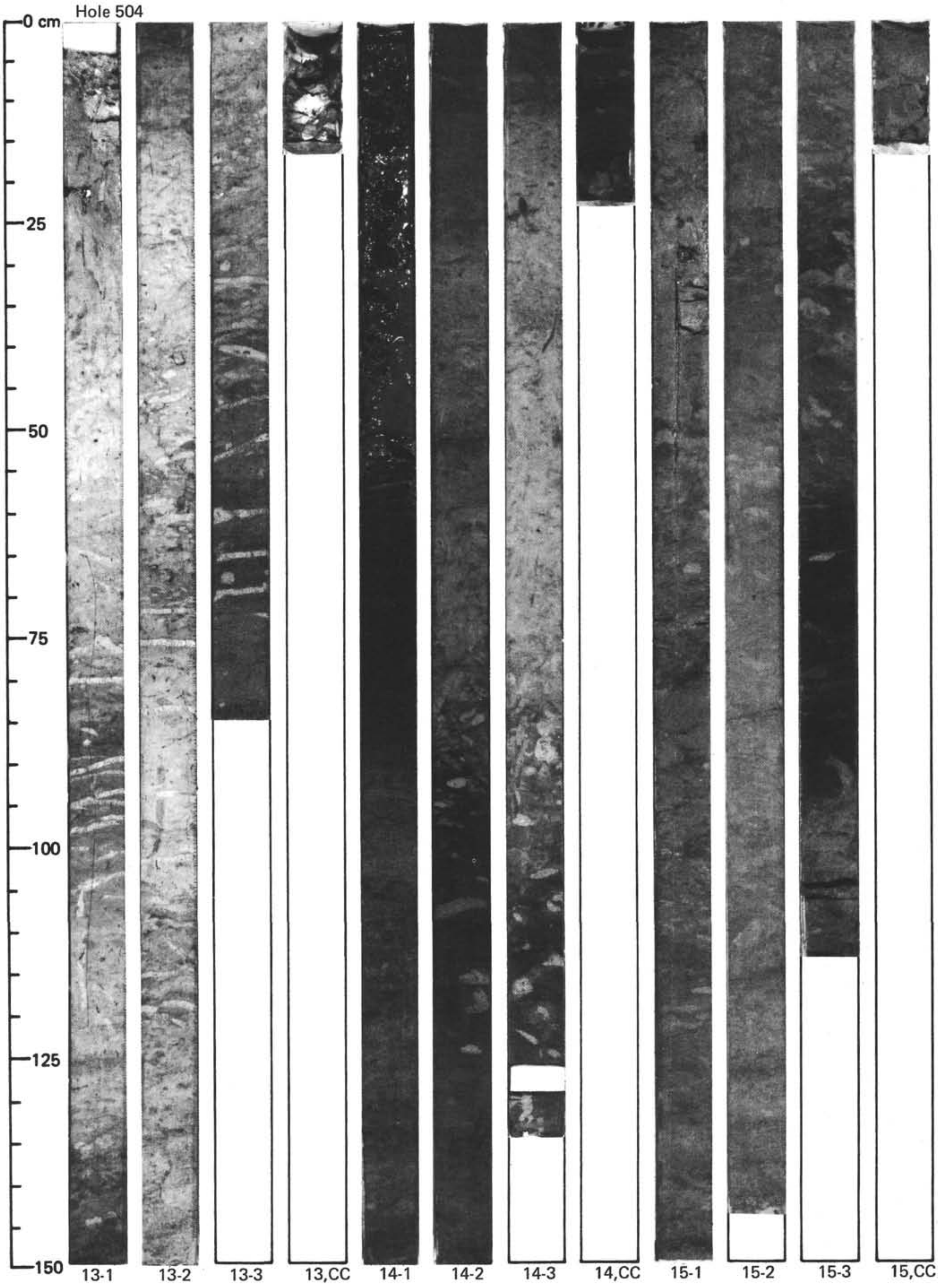
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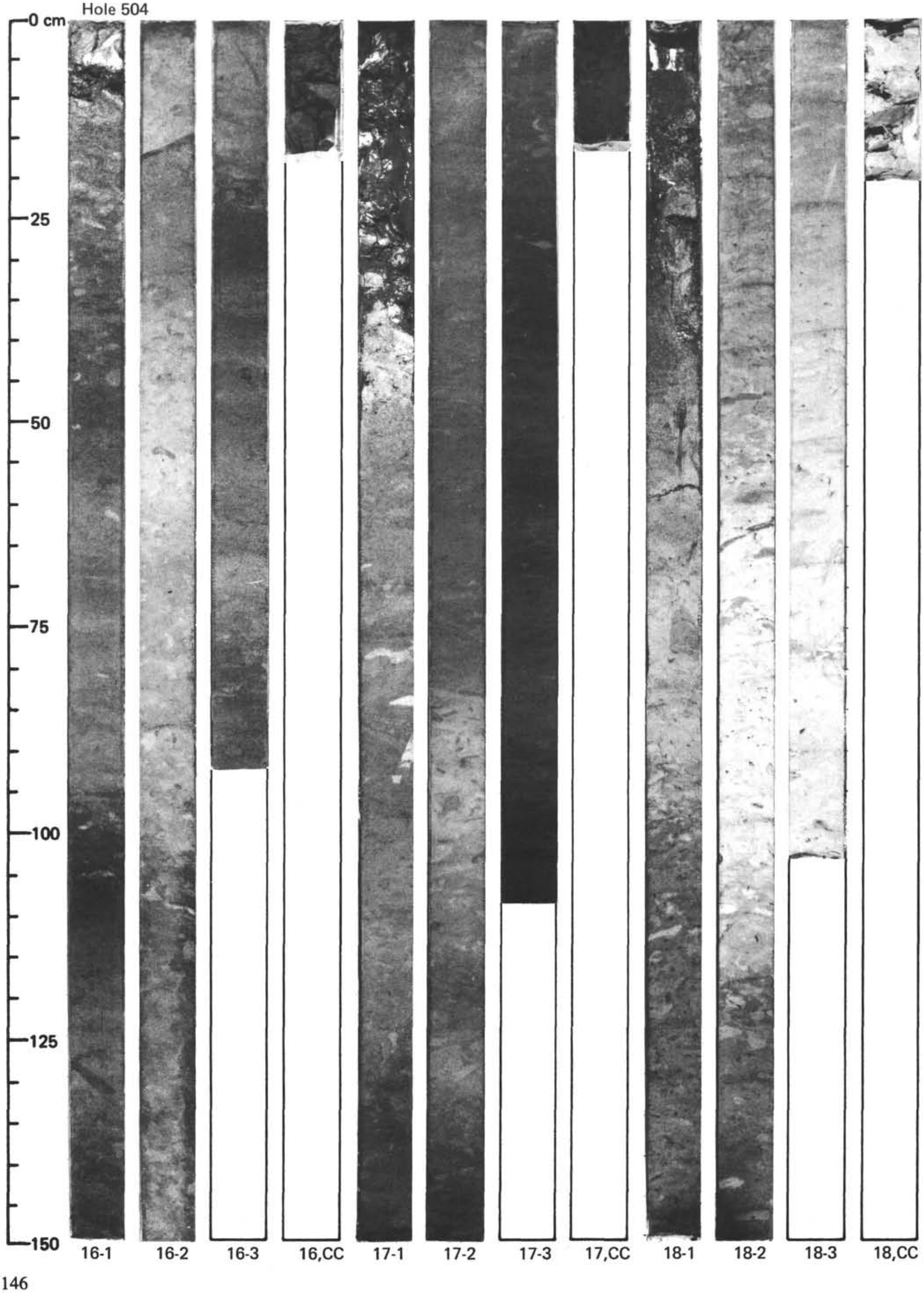
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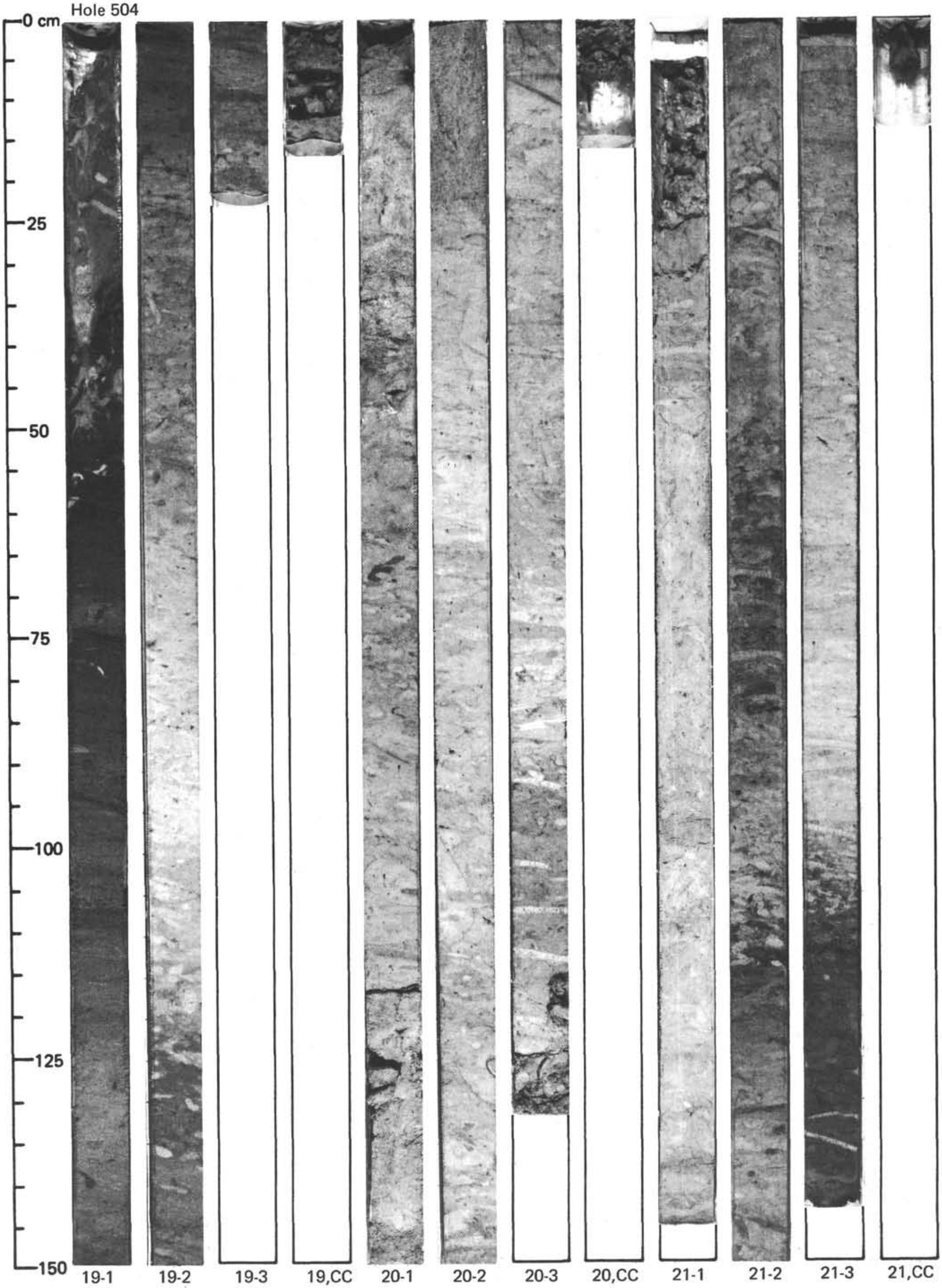
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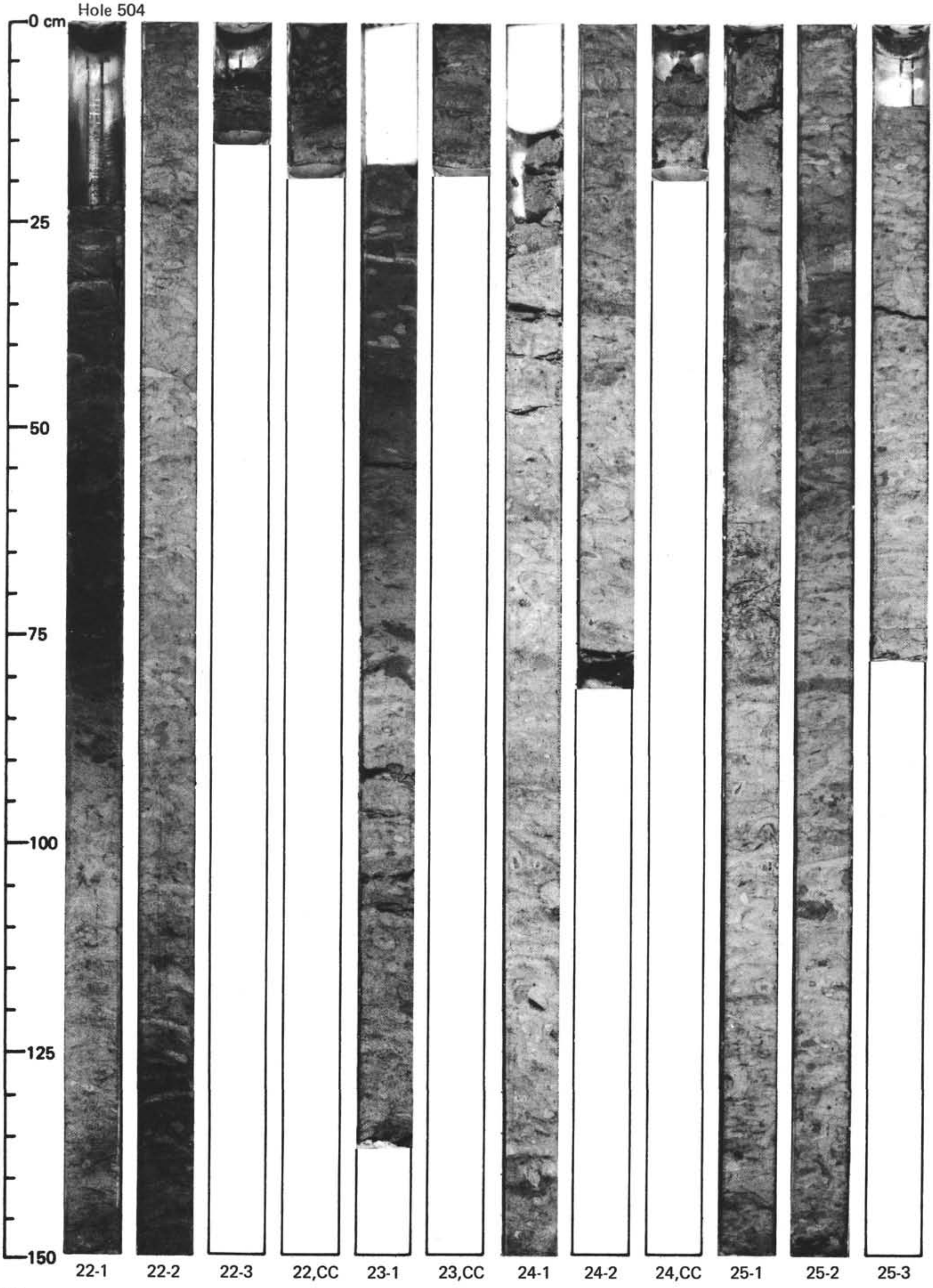
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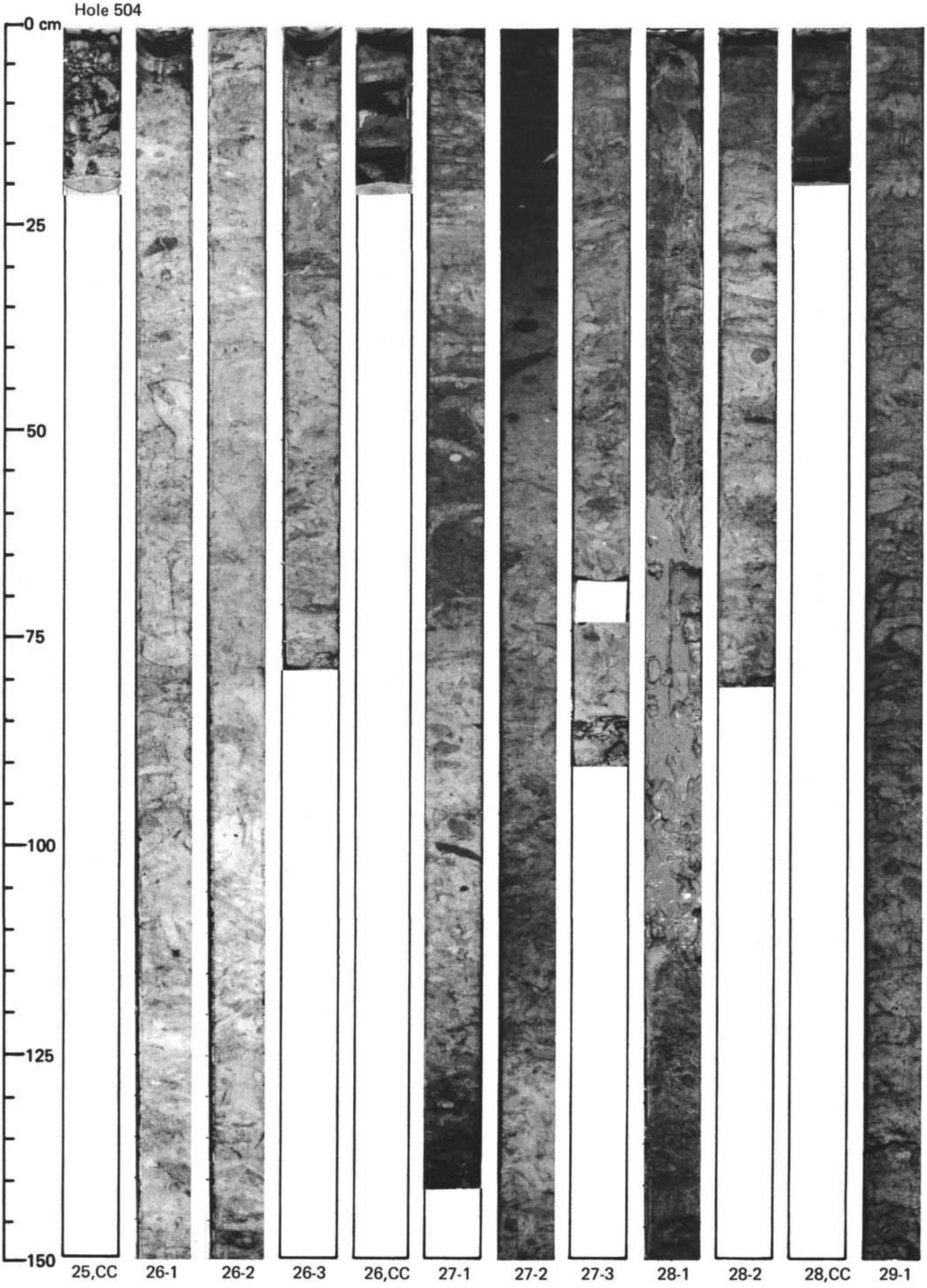
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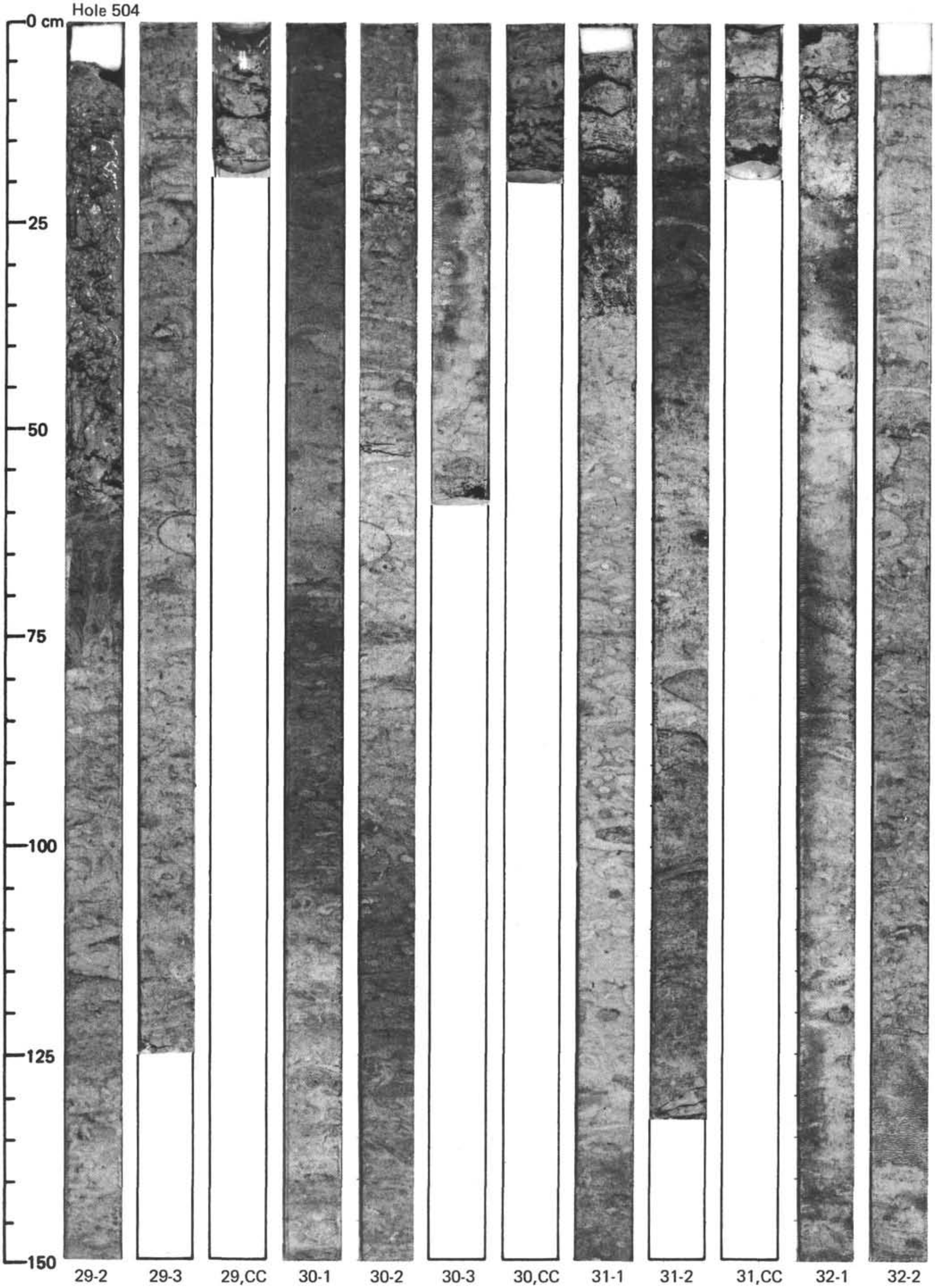
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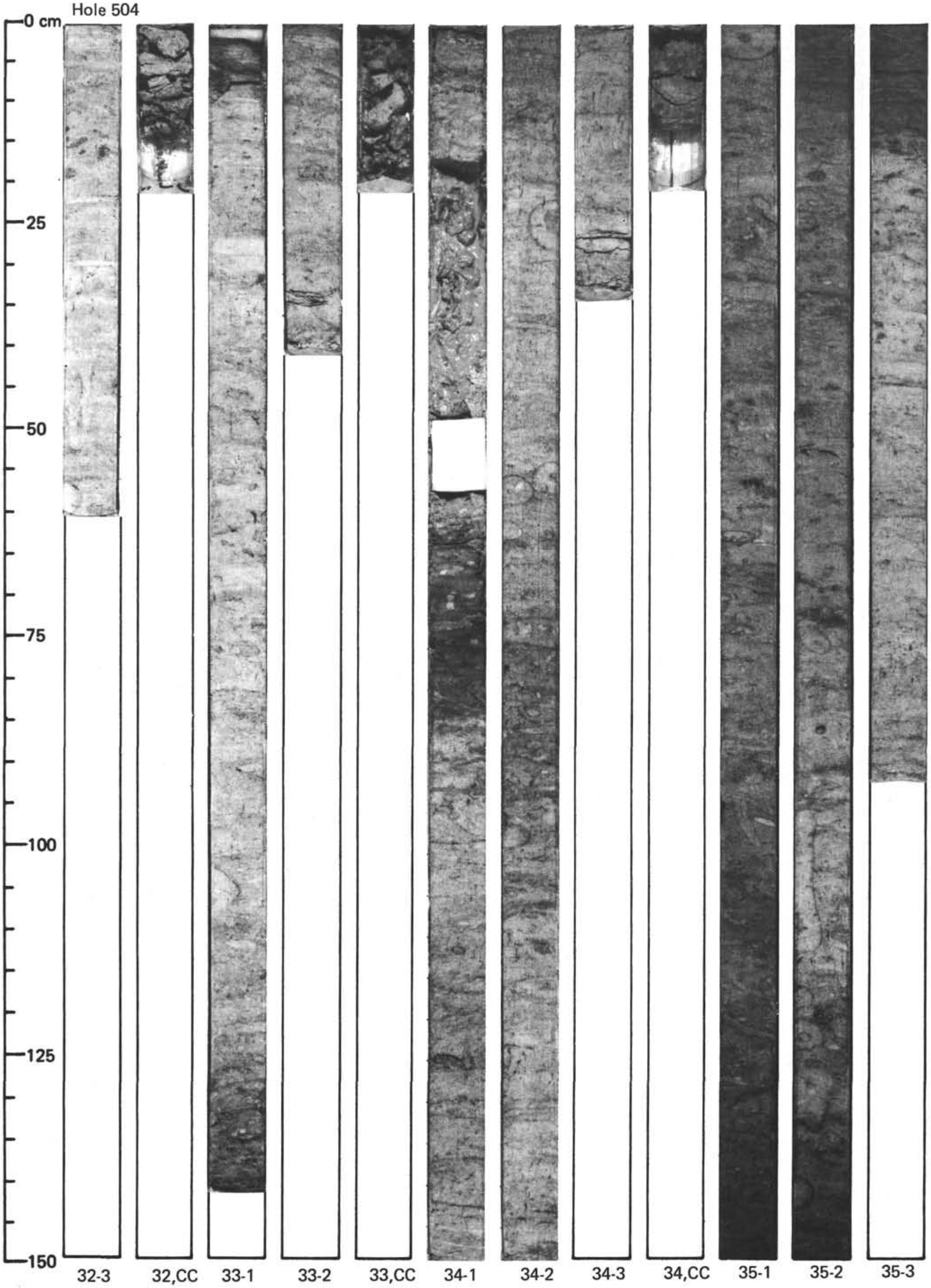
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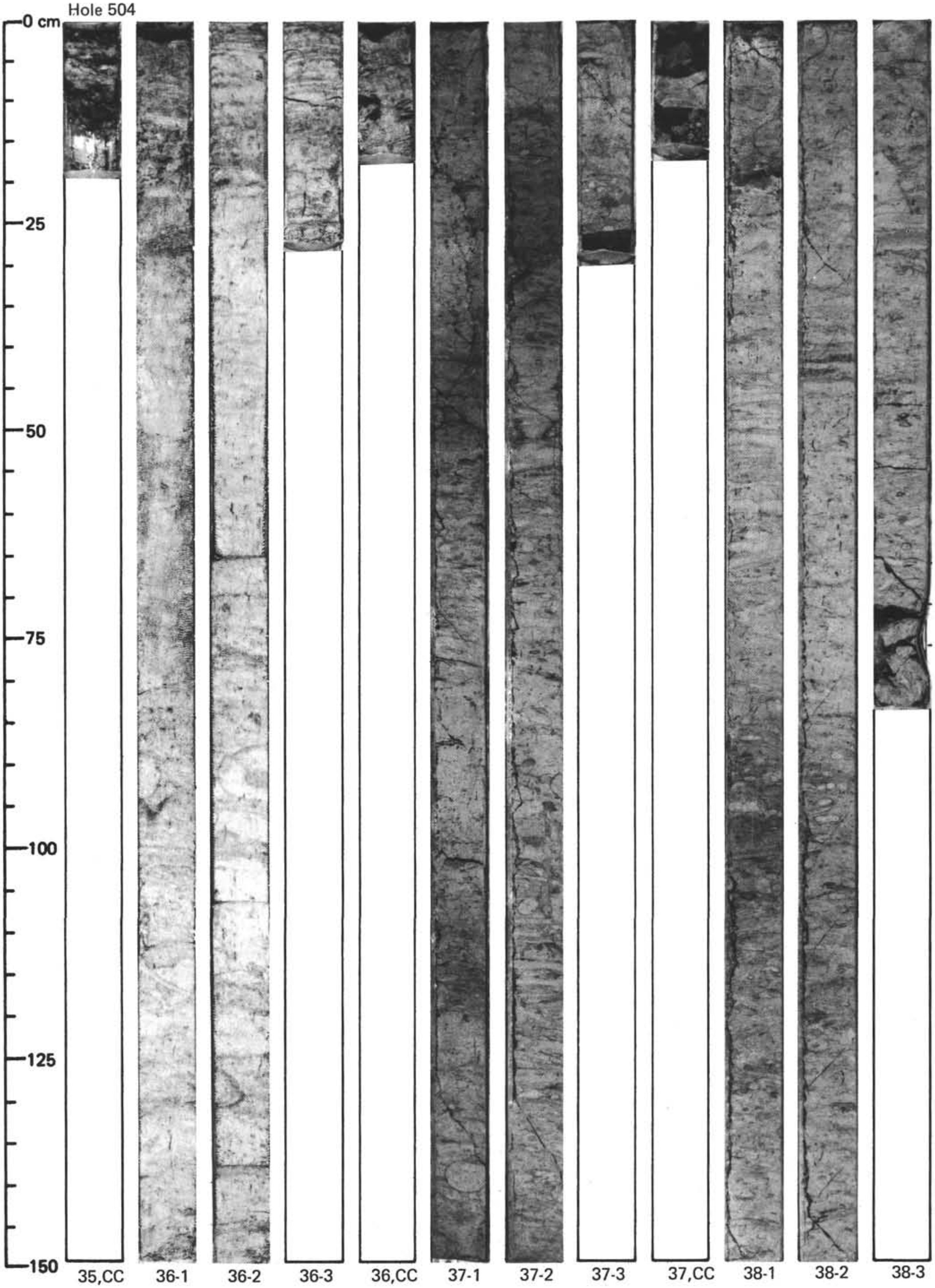
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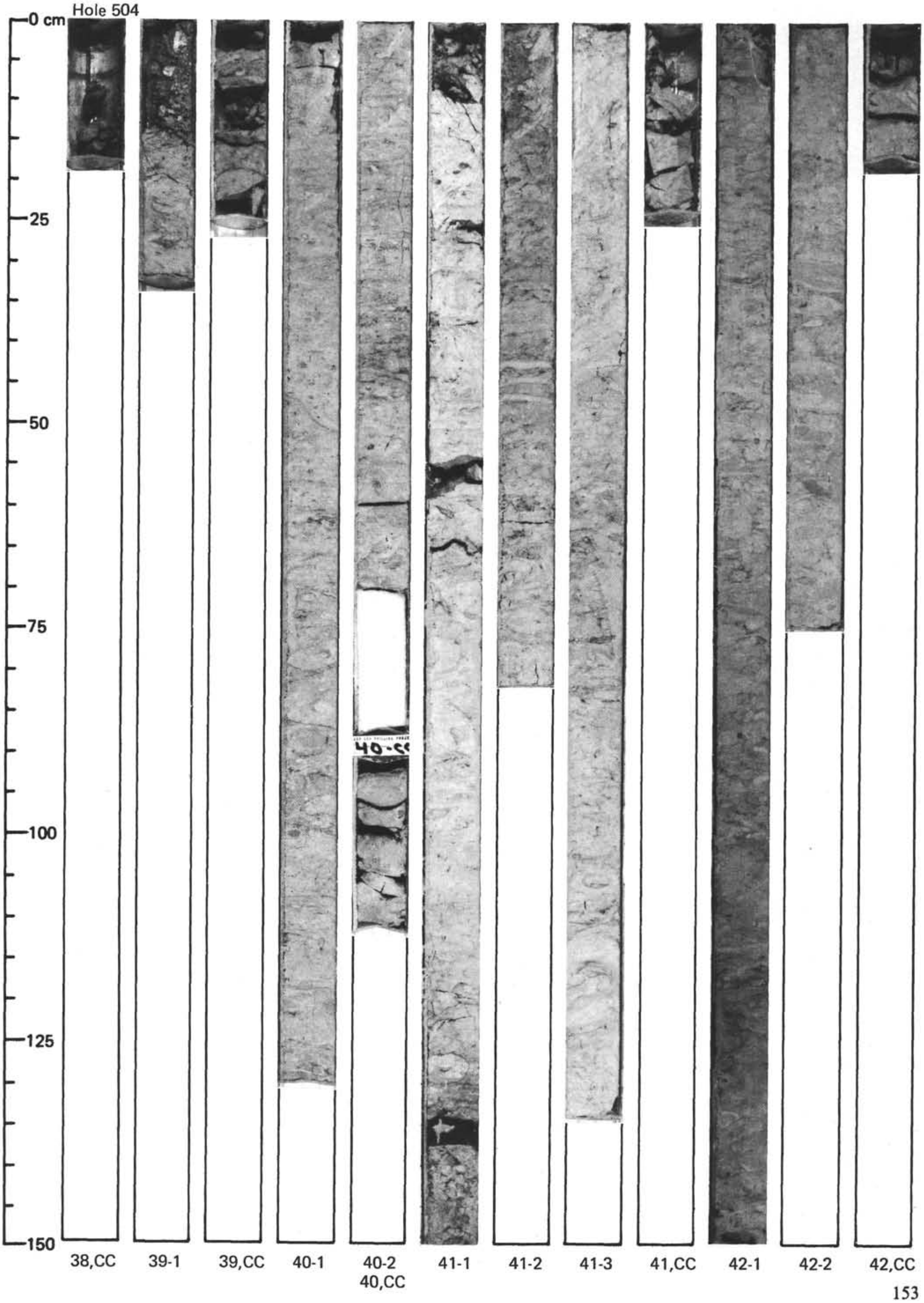
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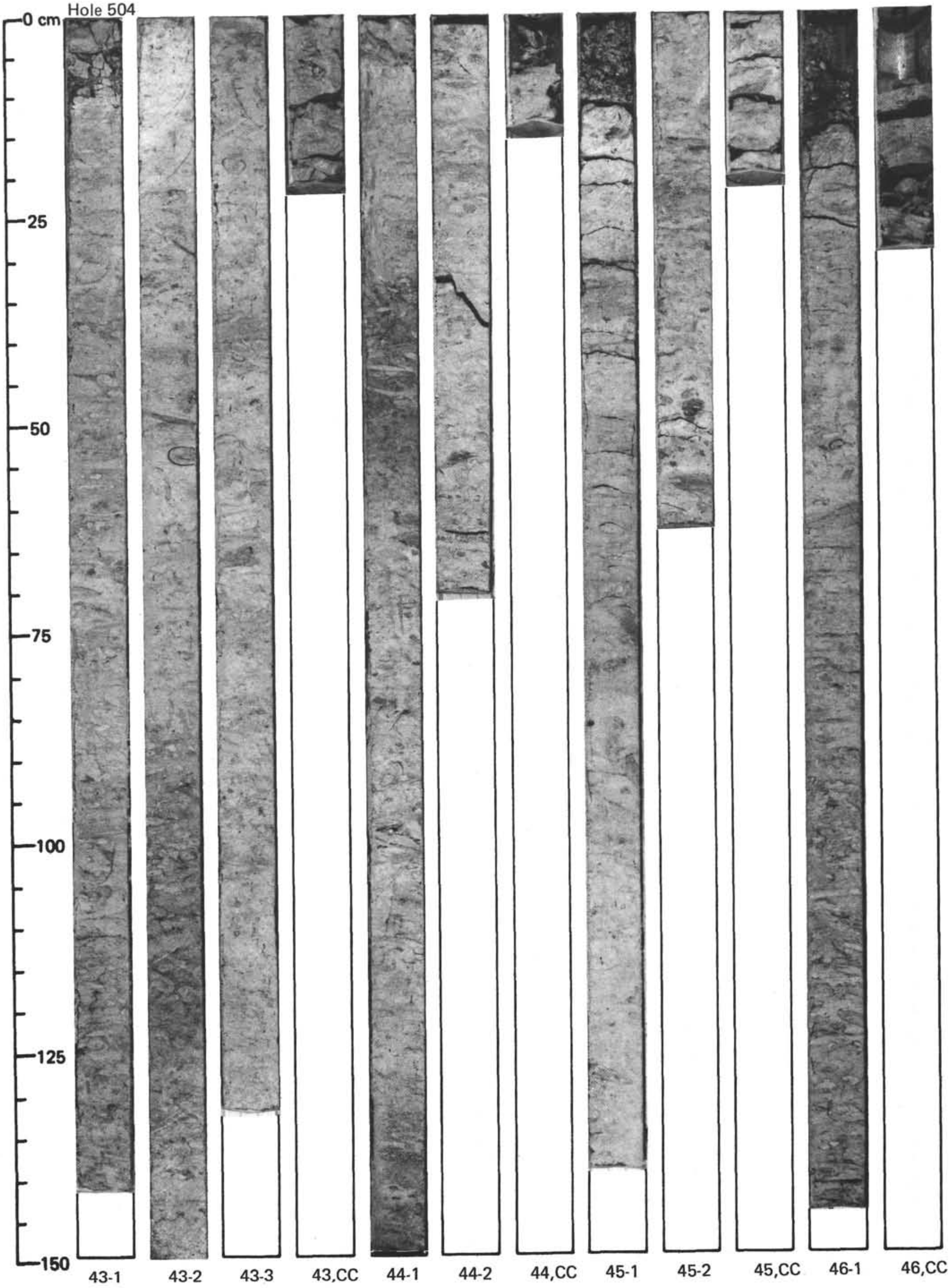
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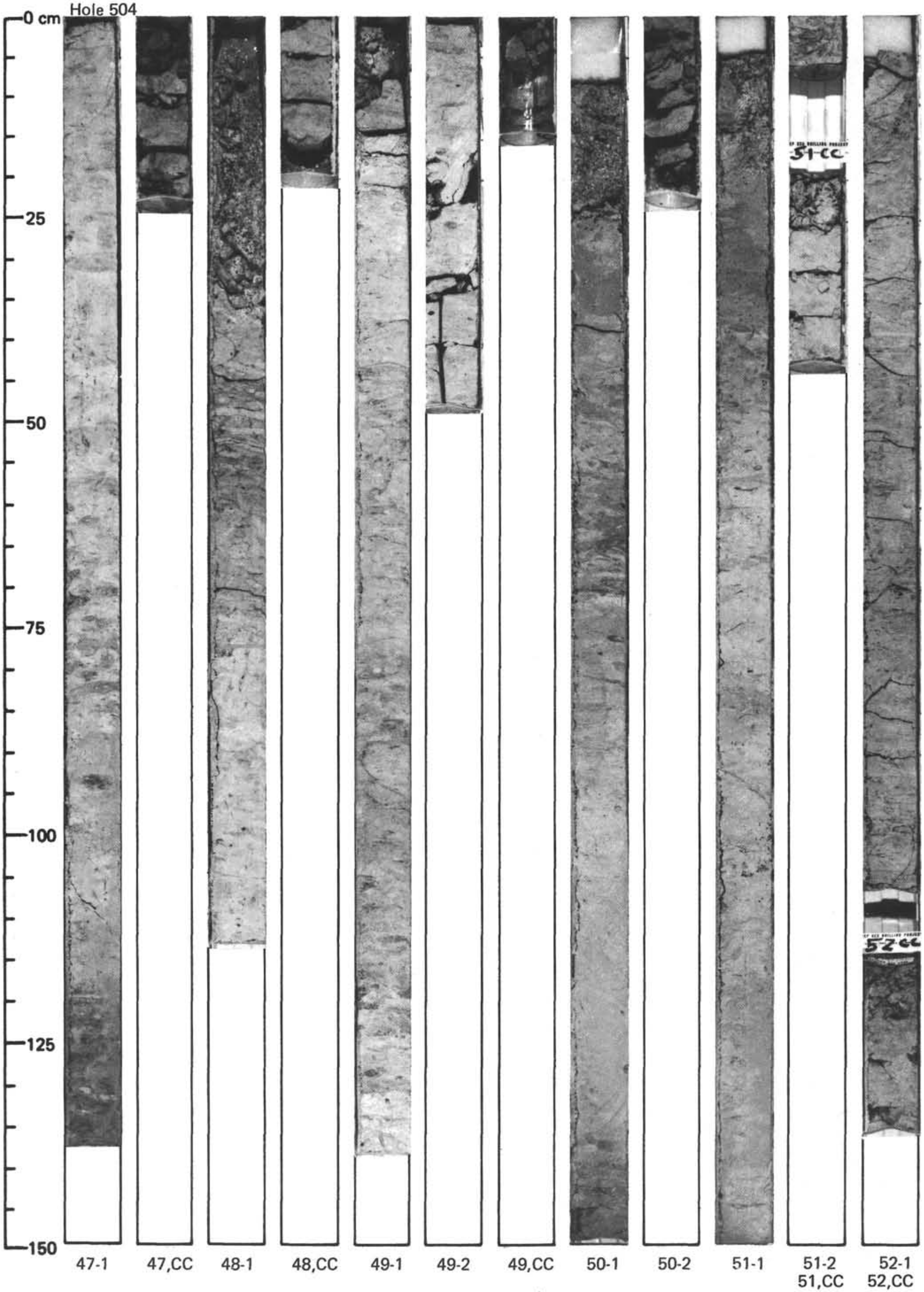
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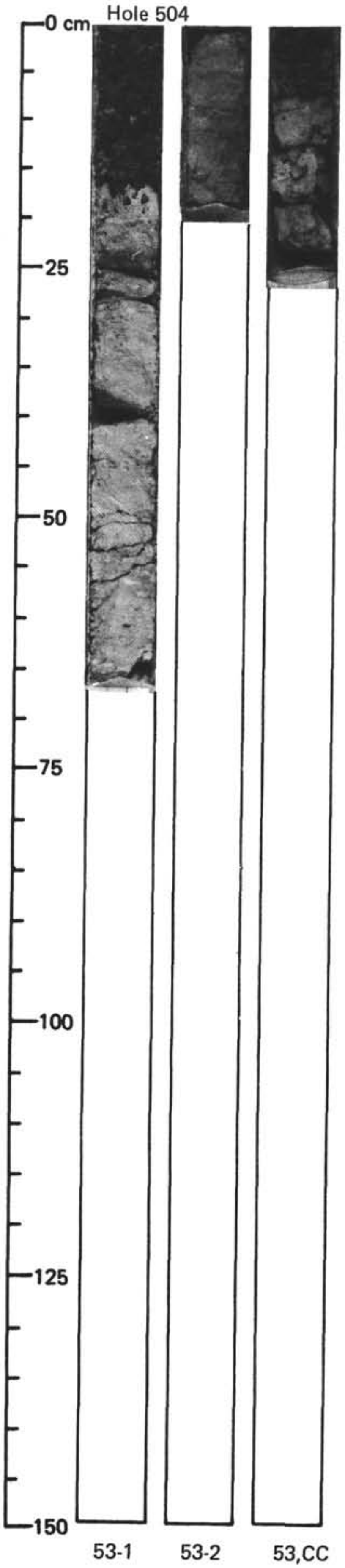
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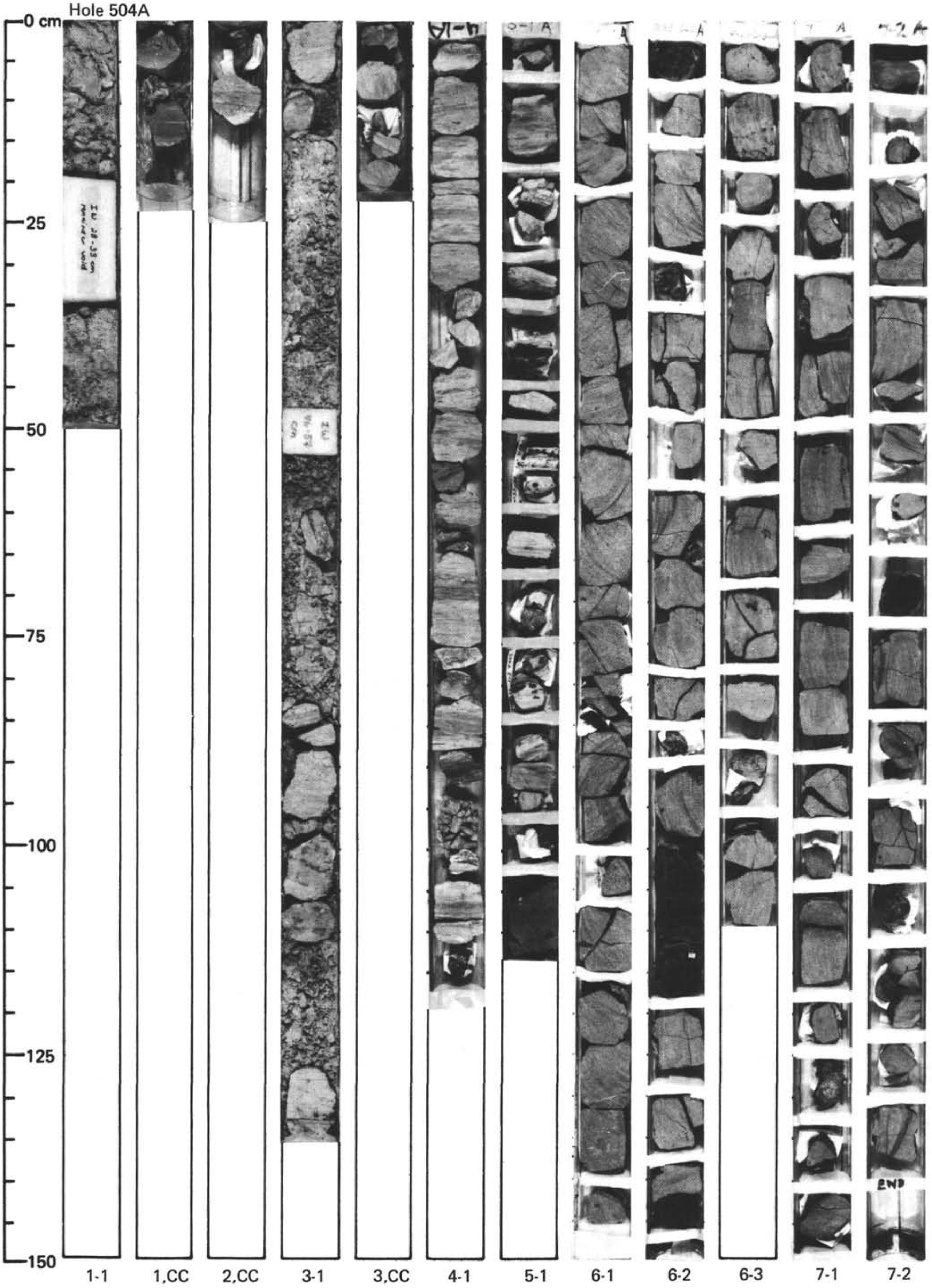
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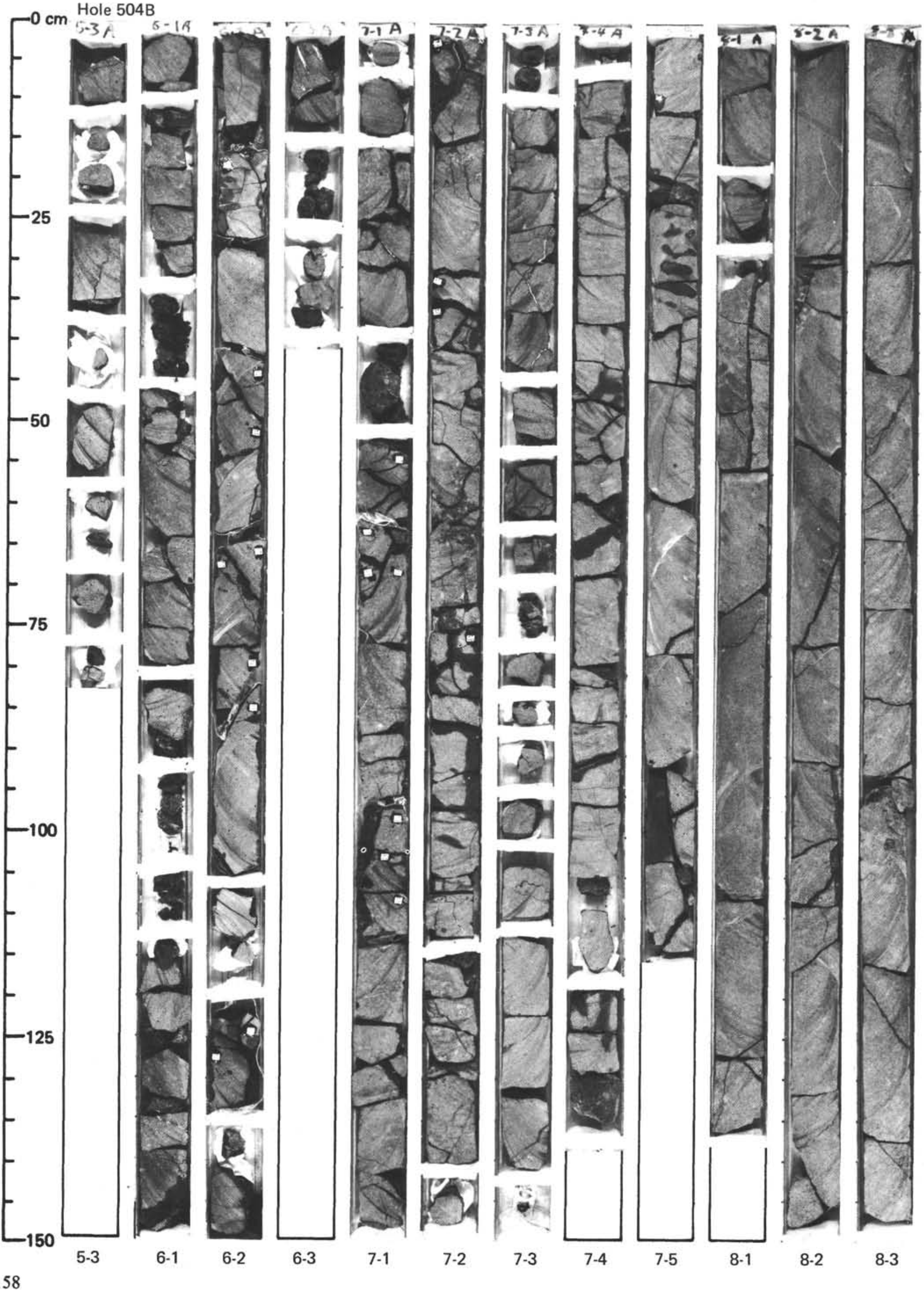
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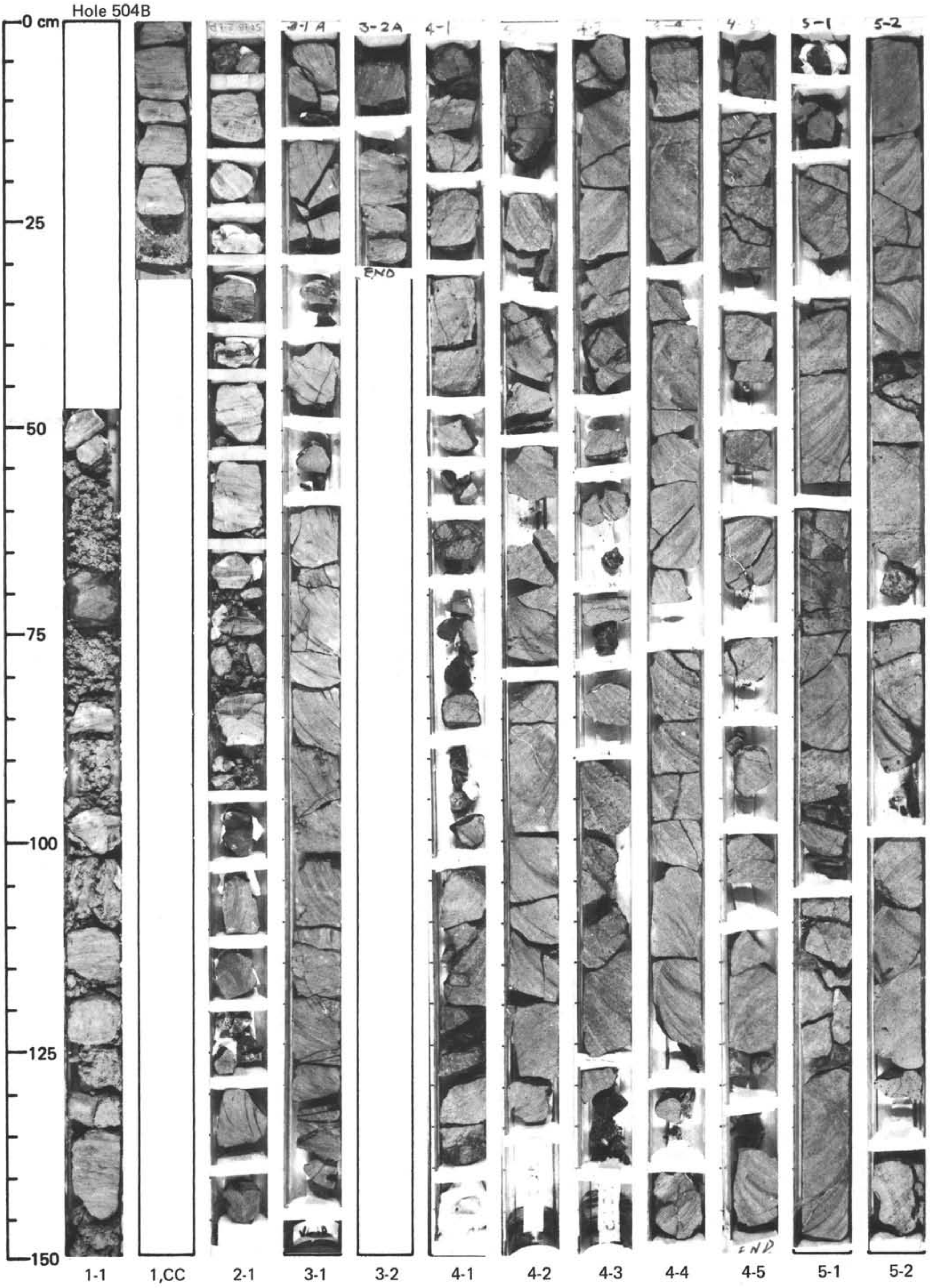
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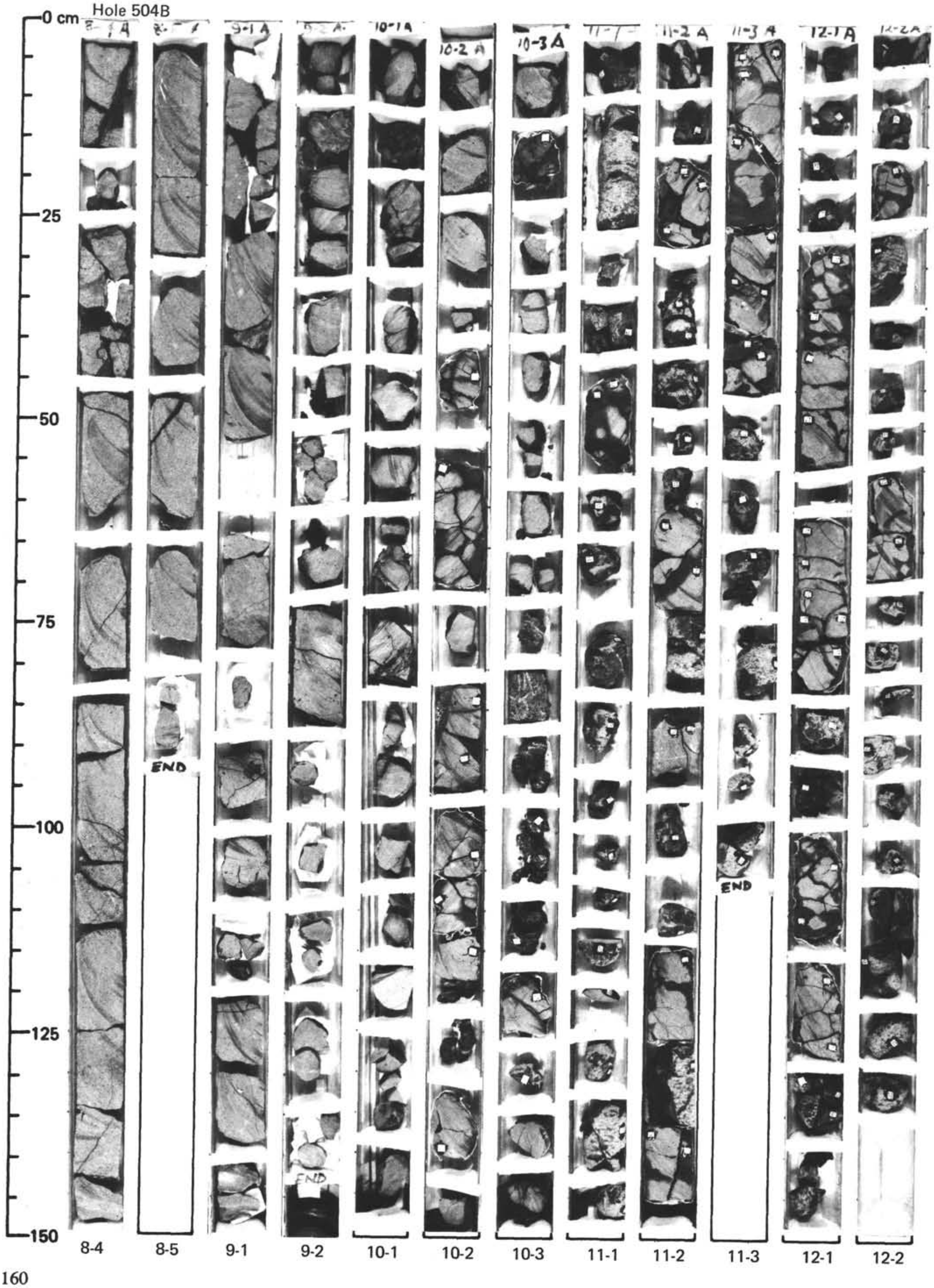
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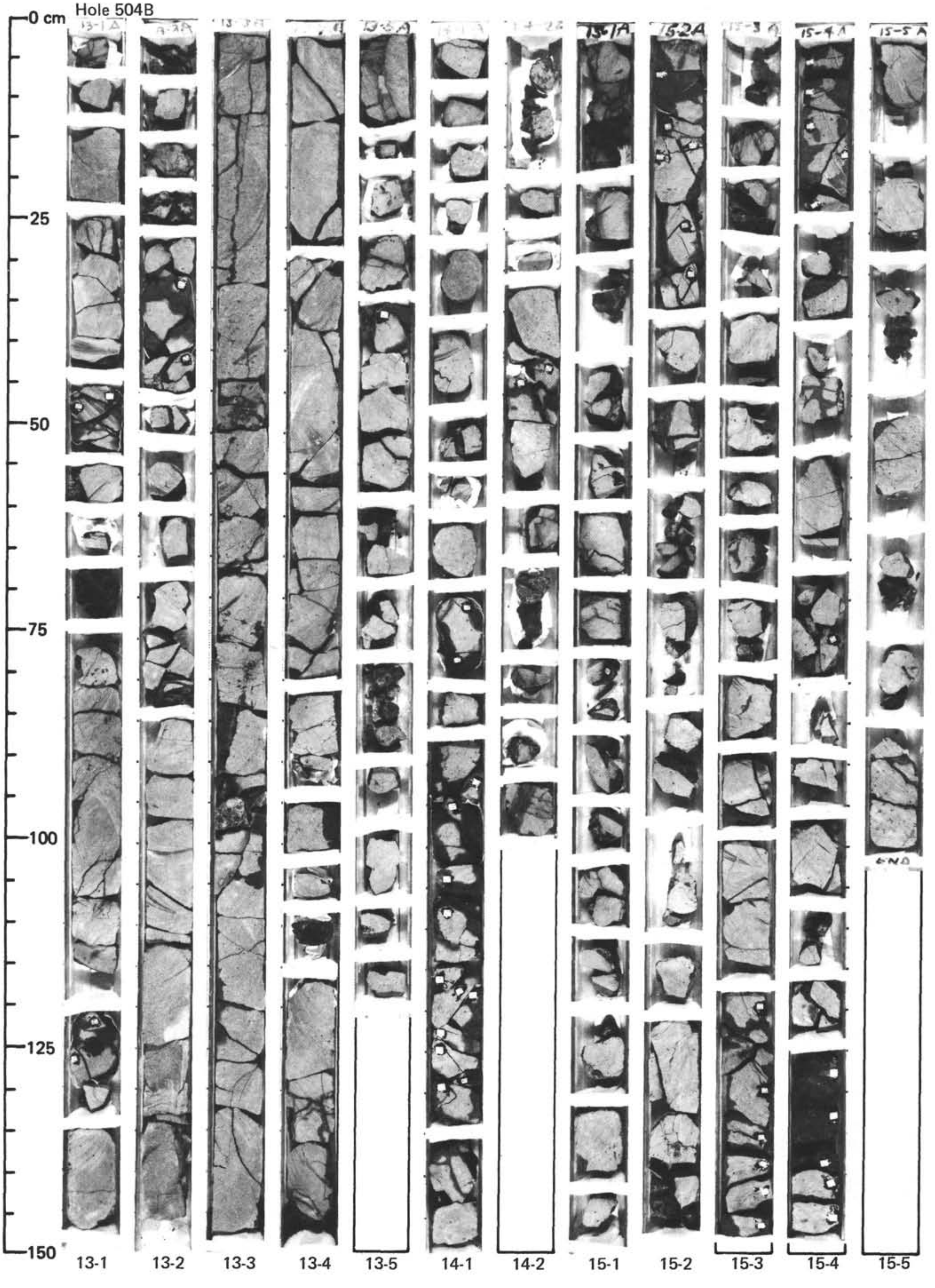
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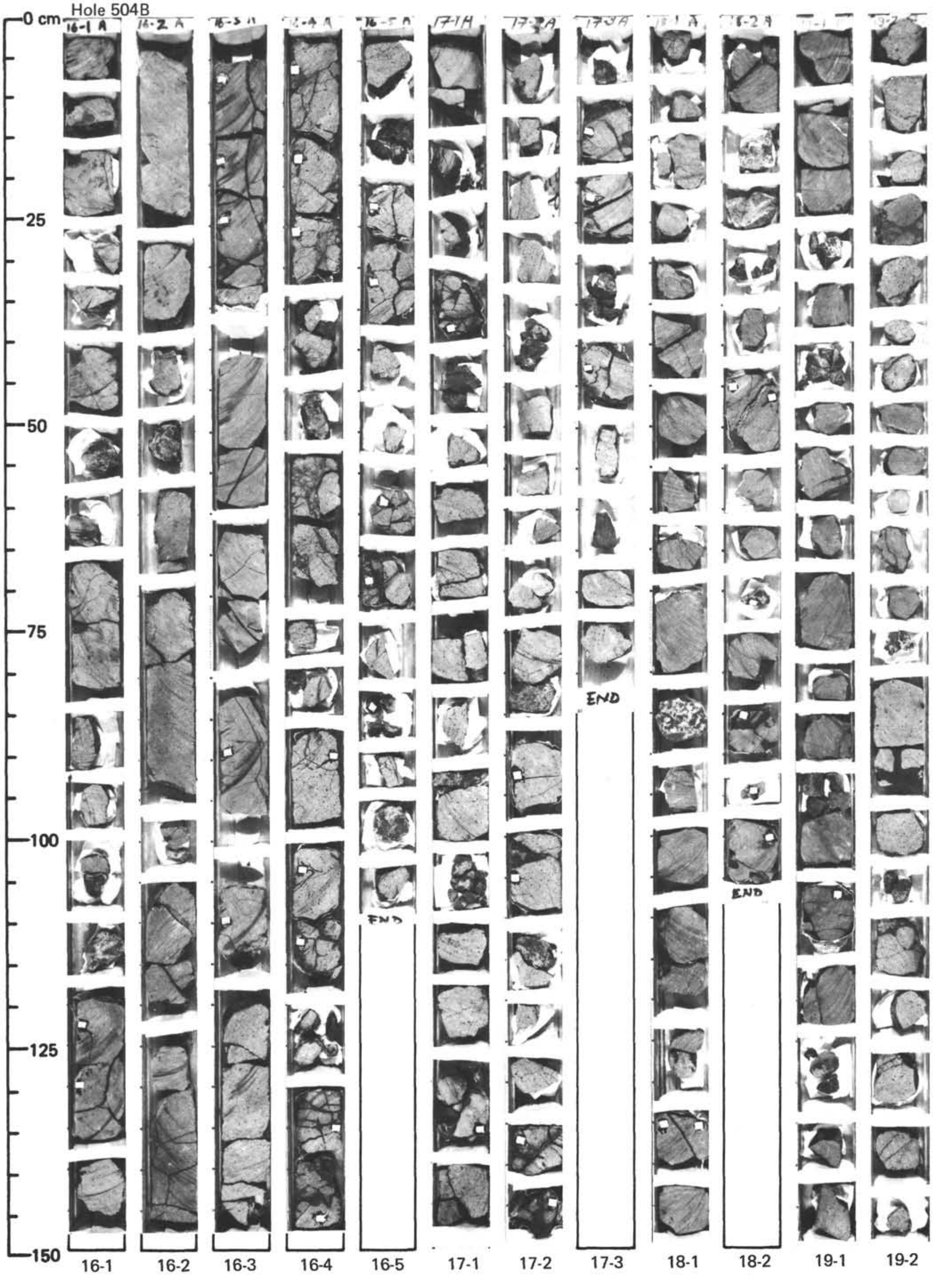
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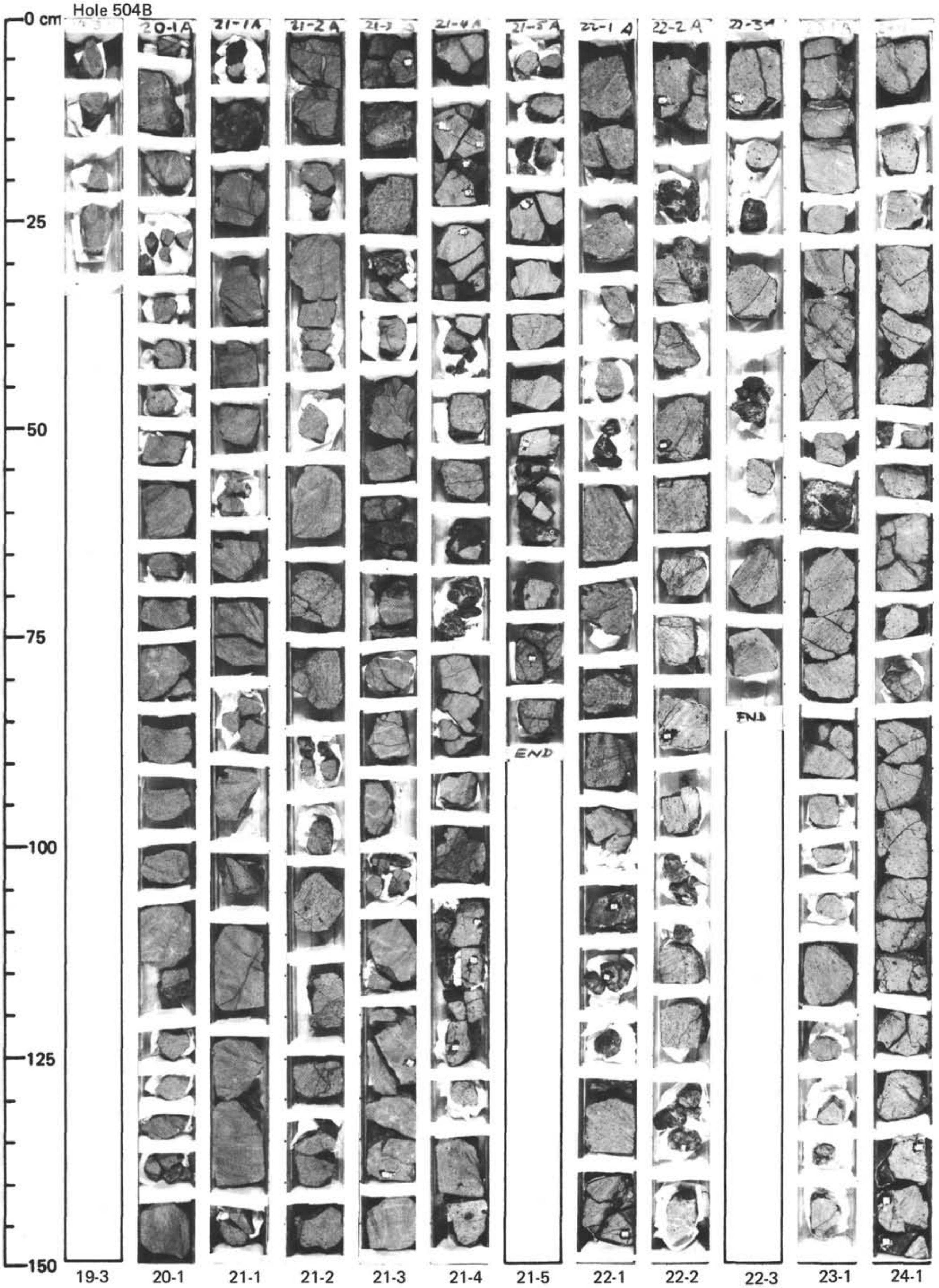
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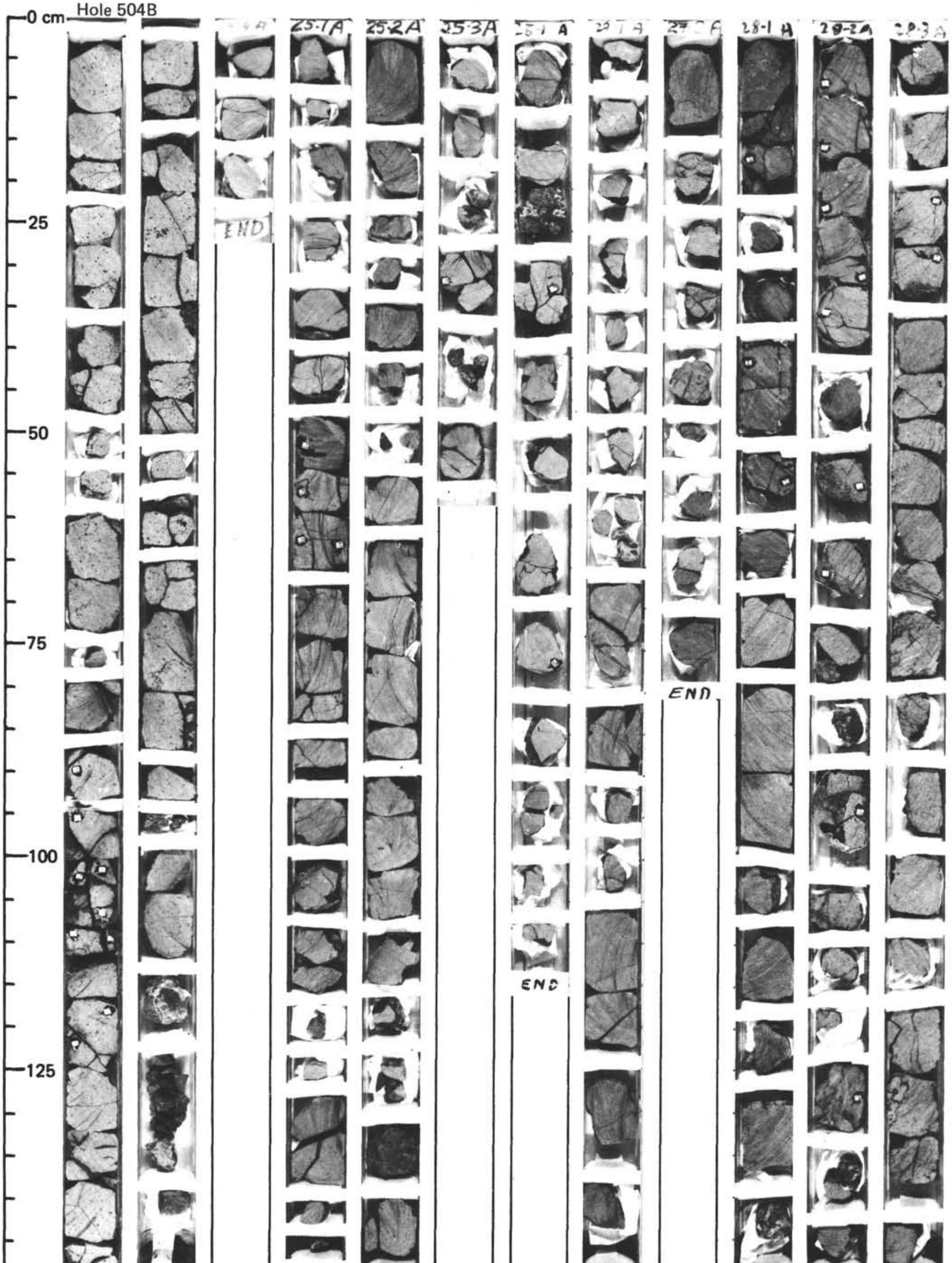
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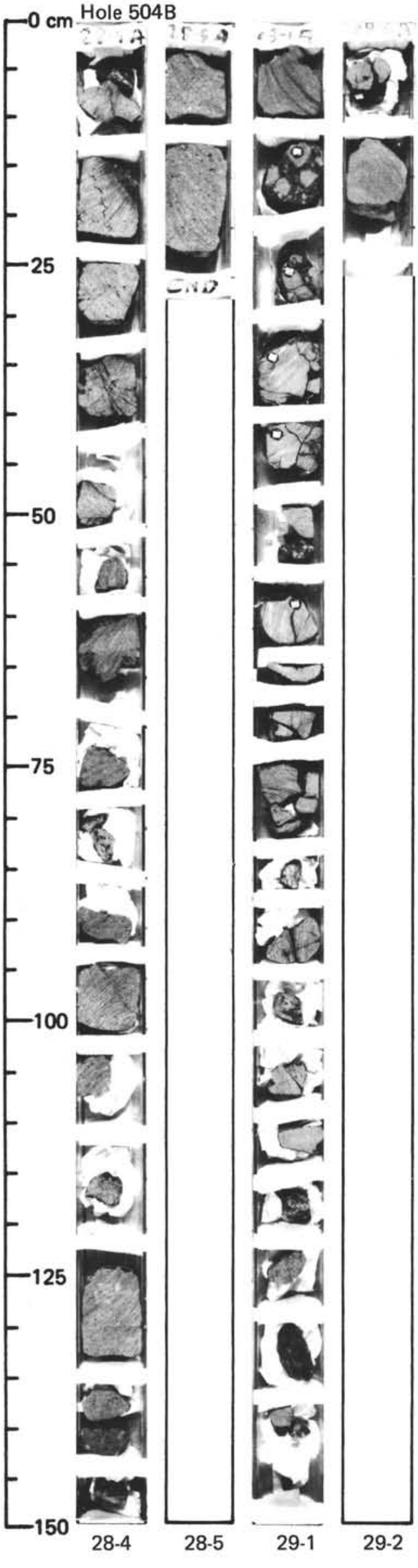
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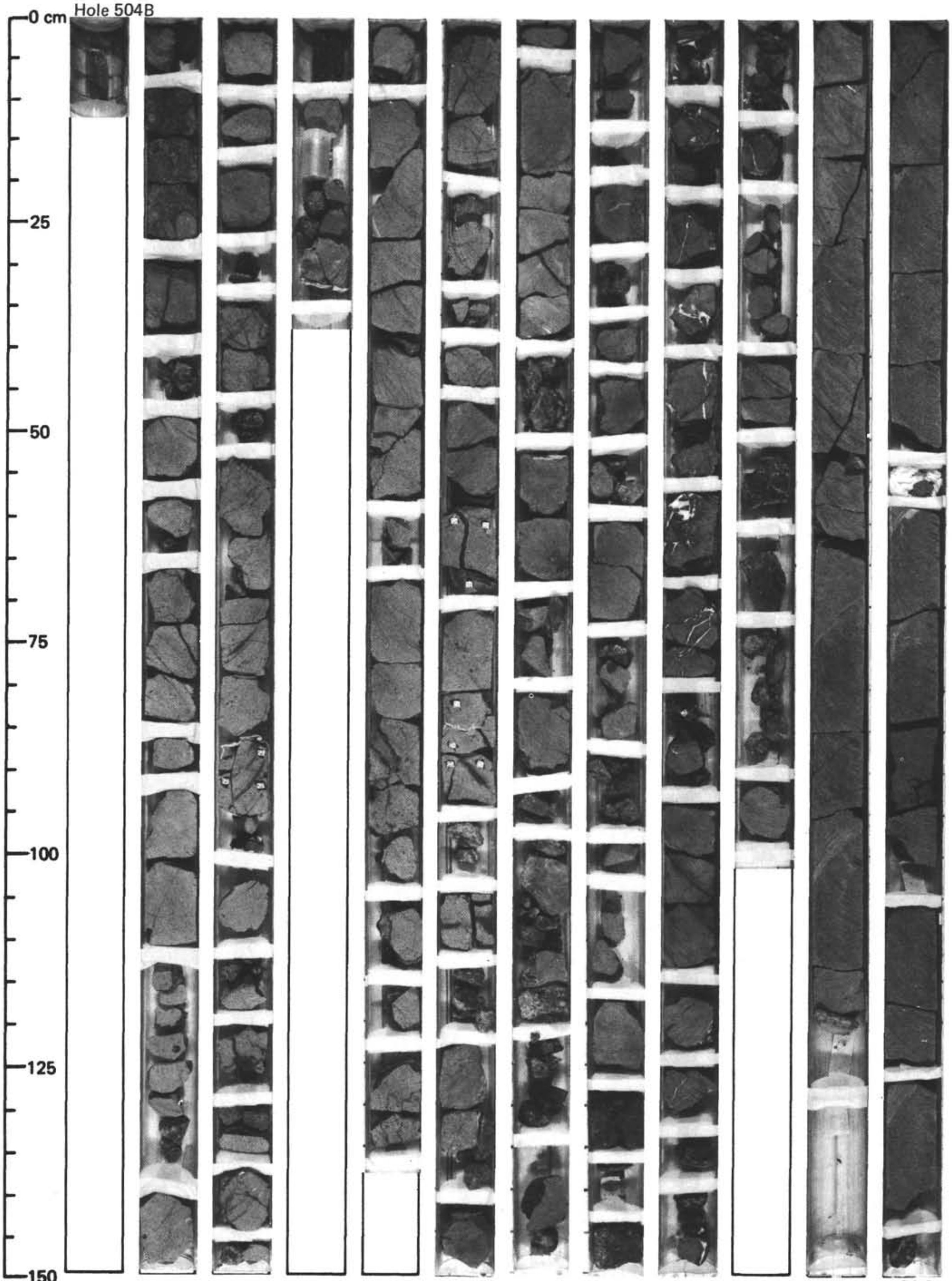
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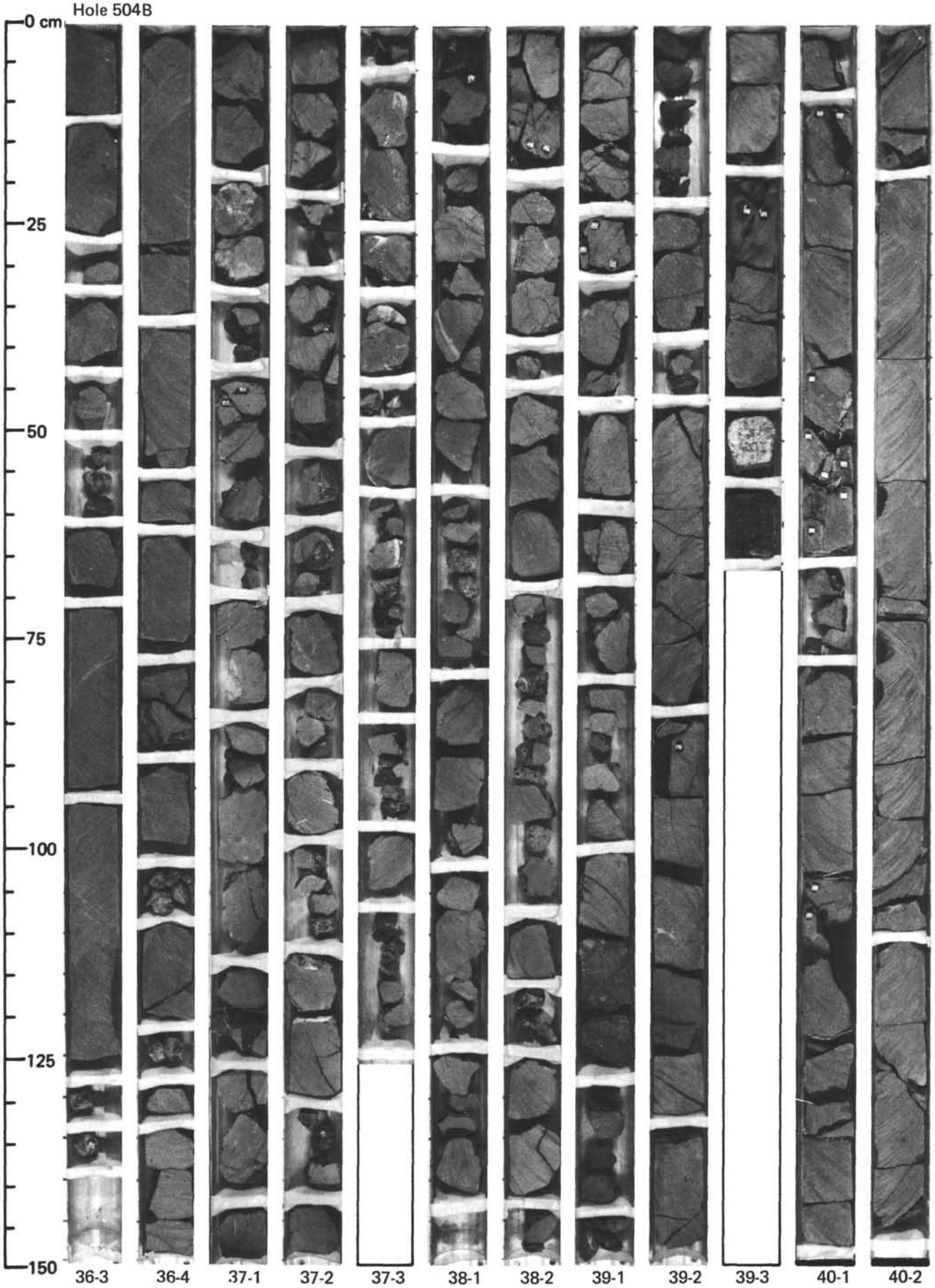
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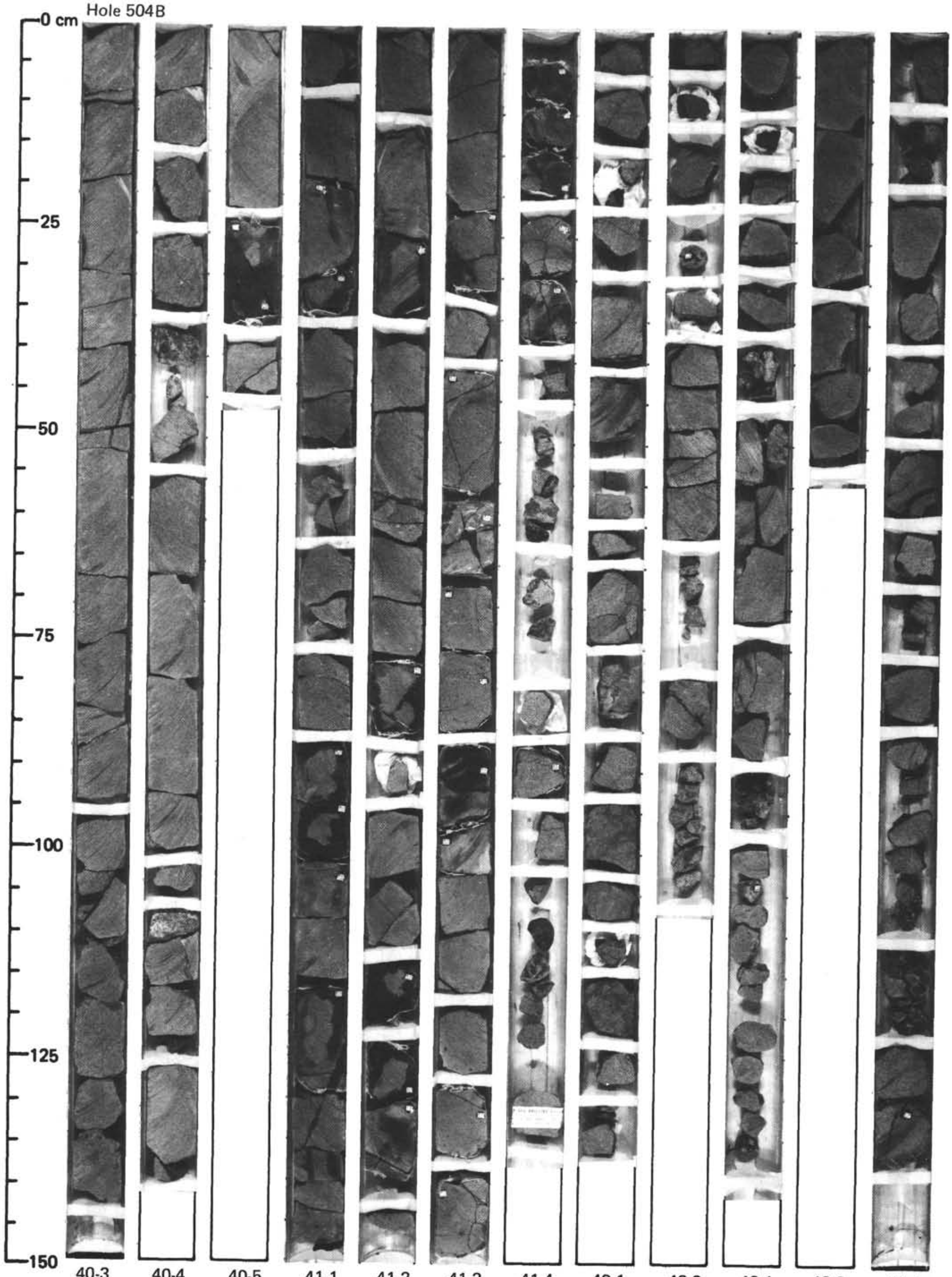
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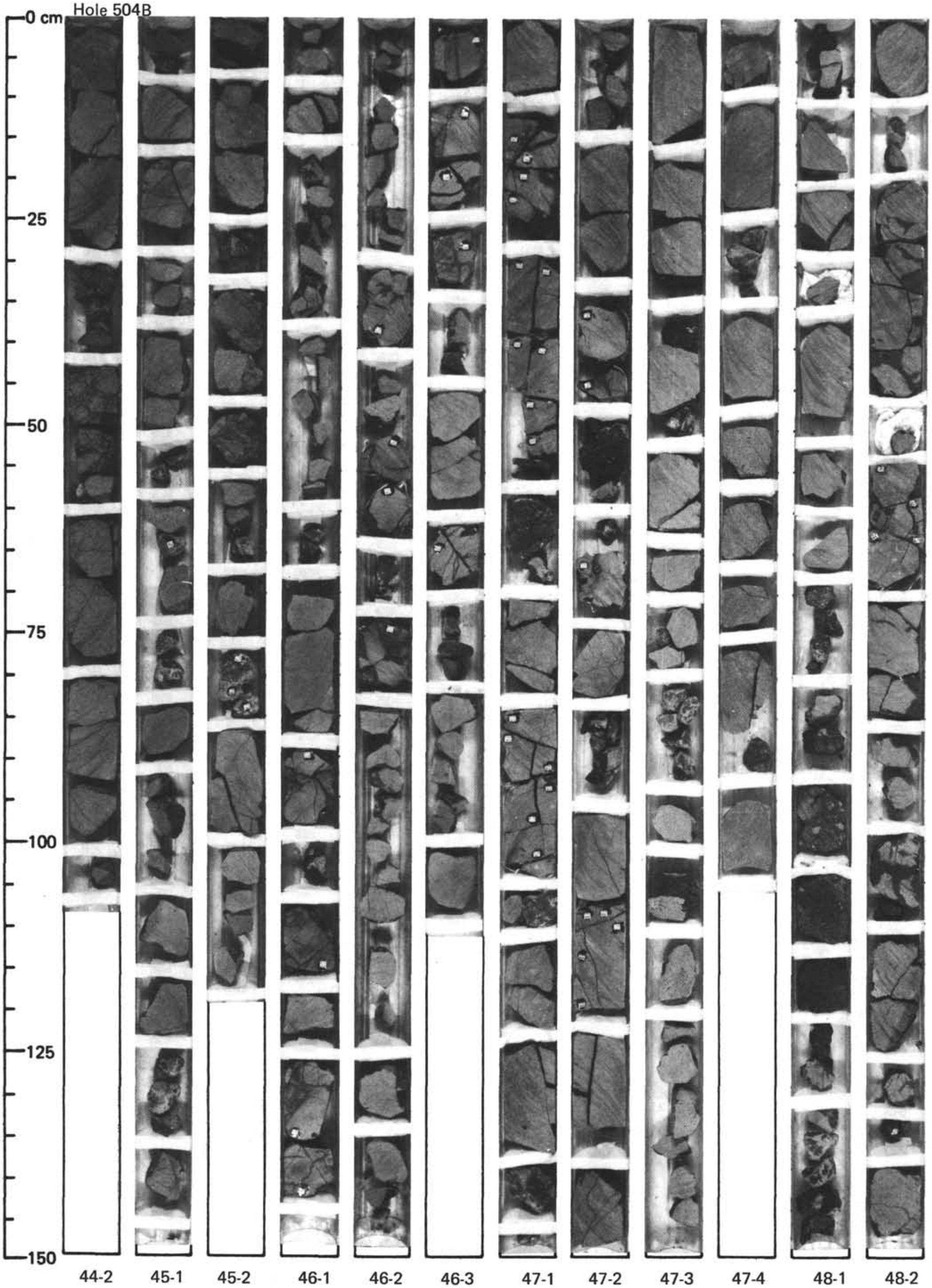
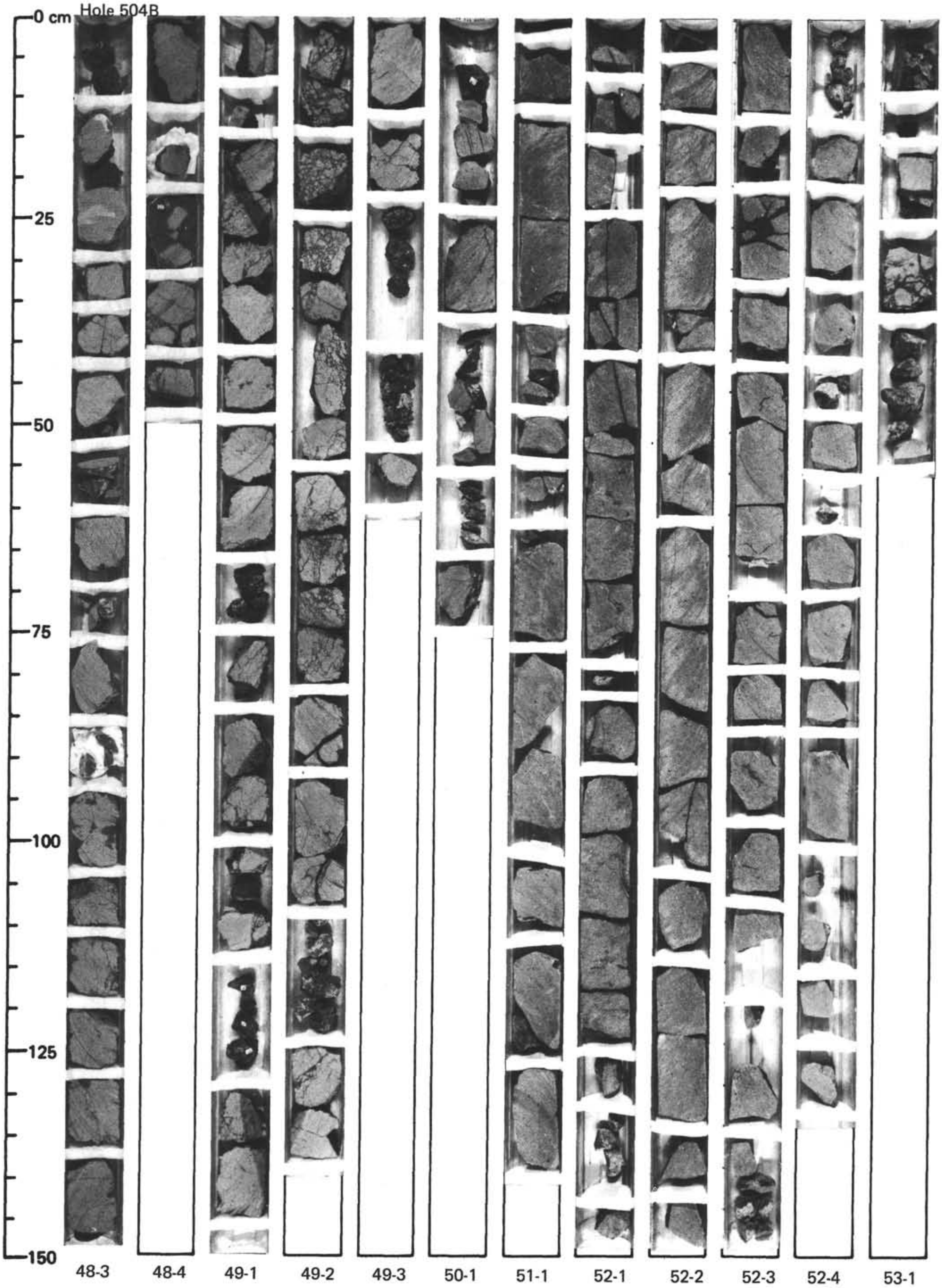
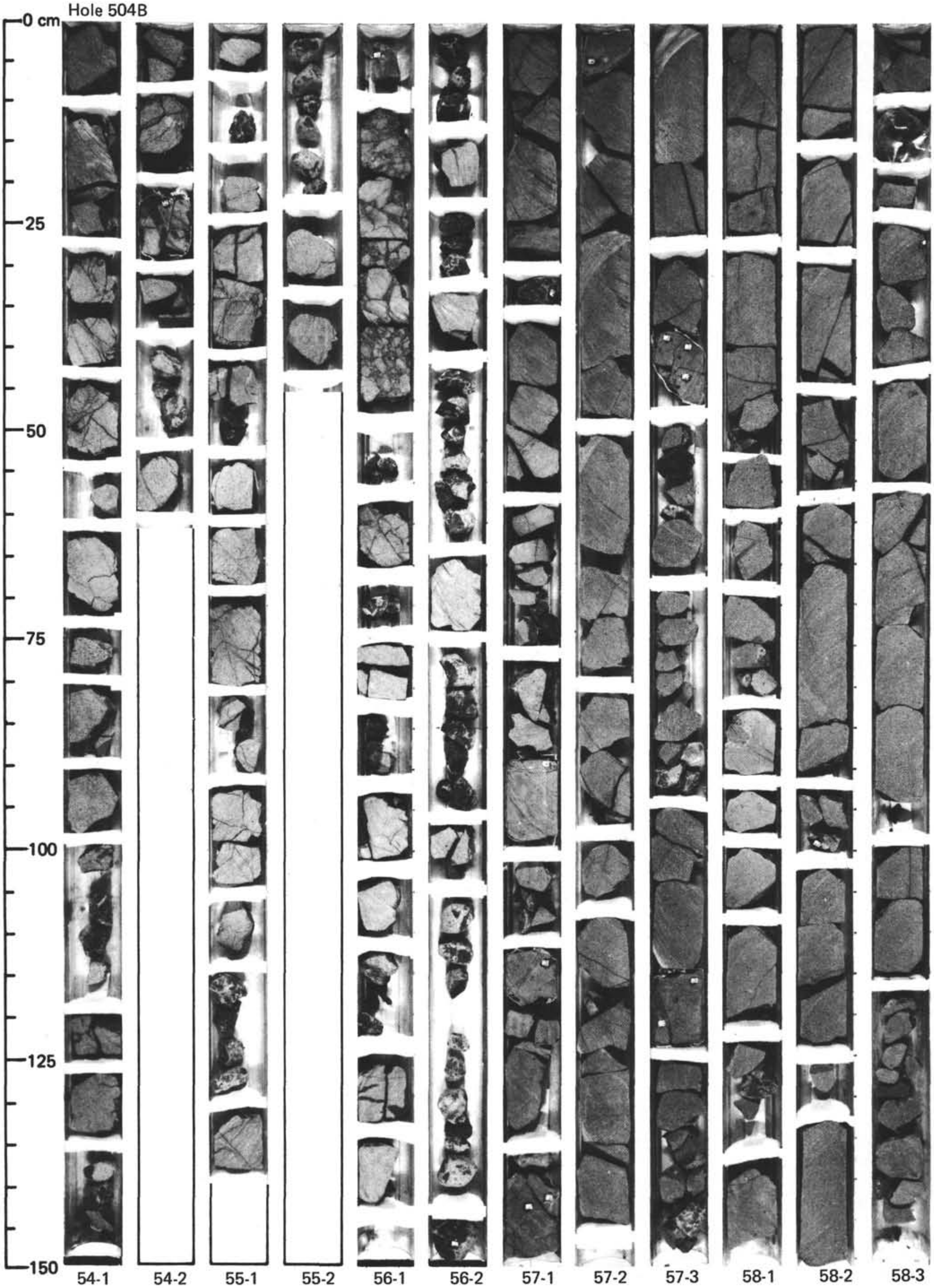
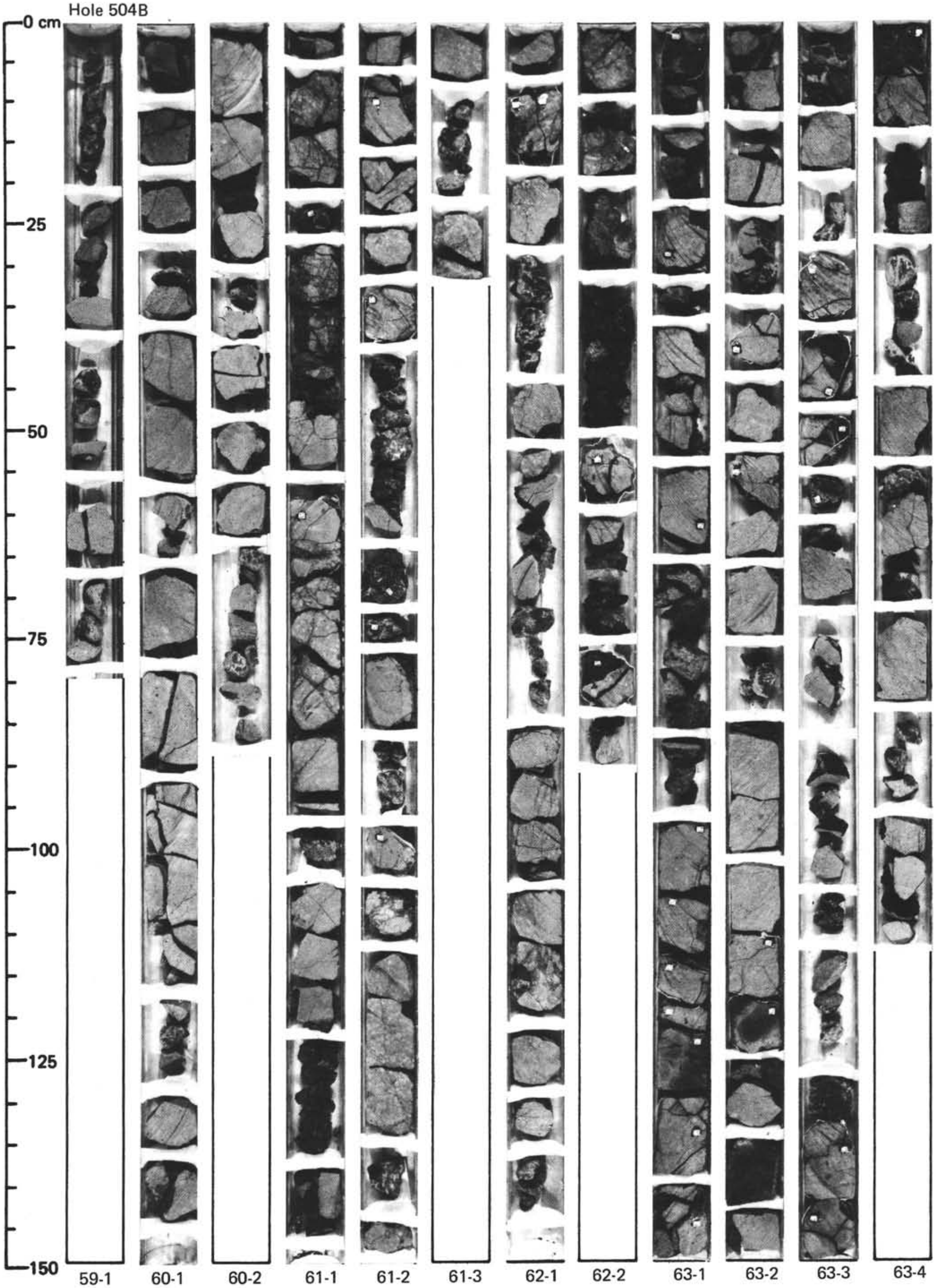
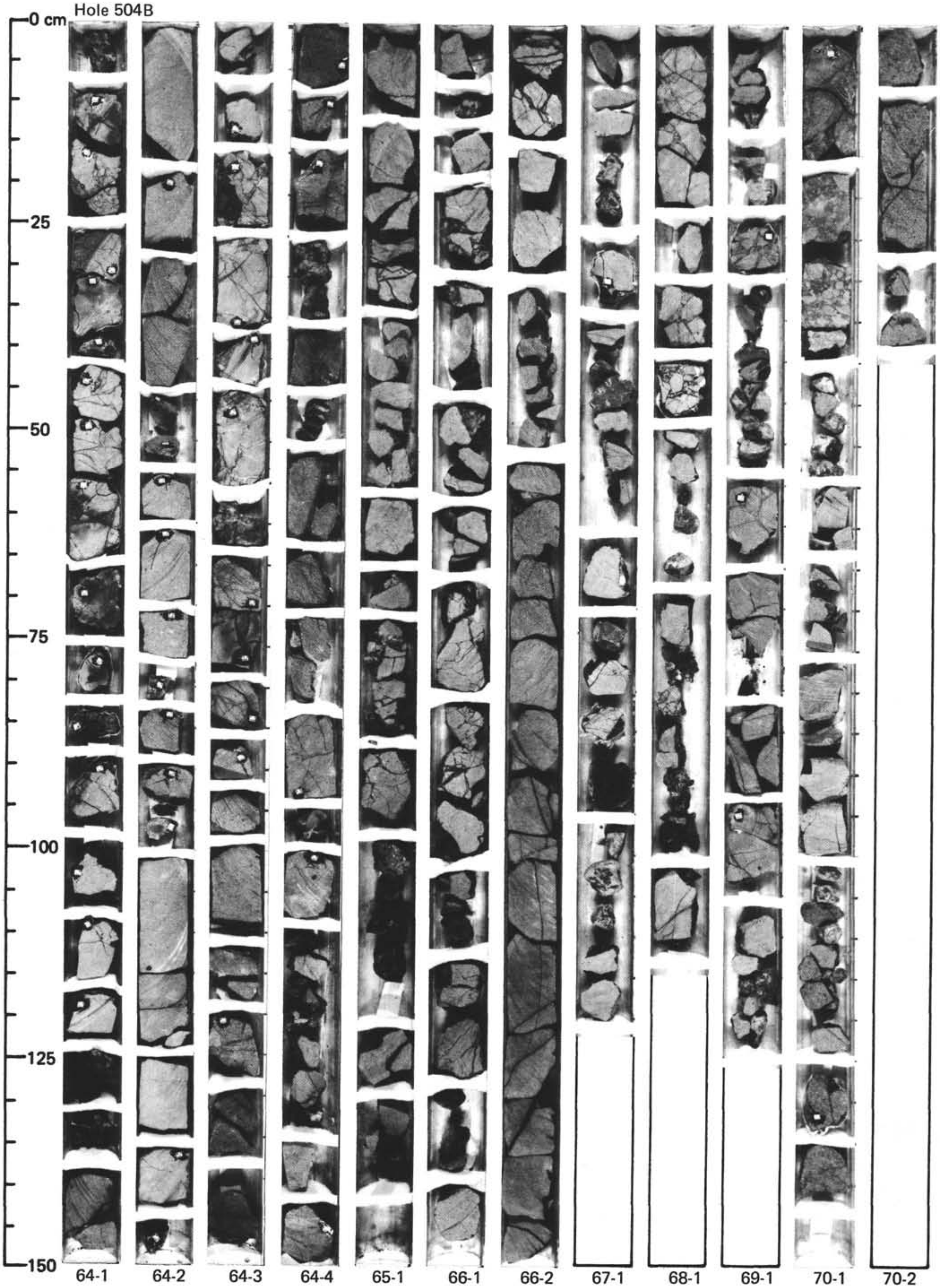
40-3
40-4
40-5
41-1
41-2
41-3
41-4
42-1
42-2
43-1
43-2
44-1


0 cm
25
50
75
100
125
150
Hole 504B
44-2
45-1
45-2
46-1
46-2
46-3
47-1
47-2
47-3
47-4
48-1
48-2


Hole 504B
0 cm
25
50
75
100
125
150
48-3
48-4
49-1
49-2
49-3
50-1
51-1
52-1
52-2
52-3
52-4
53-1


Hole 504B
0 cm
25
50
75
100
125
150
54-1
54-2
55-1
55-2
56-1
56-2
57-1
57-2
57-3
58-1
58-2
58-3


Hole 504B
0 cm
25
50
75
100
125
150
59-1
60-1
60-2
61-1
61-2
61-3
62-1
62-2
63-1
63-2
63-3
63-4


Hole 504B
0 cm
25
50
75
100
125
150
64-1
64-2
64-3
64-4
65-1
66-1
66-2
67-1
68-1
69-1
70-1
70-2