6. SITE 451: EAST EDGE OF THE WEST MARIANA RIDGE

Shipboard Scientific Party[1]

HOLE 451

Date occupied: 7 March 1978

Date departed: 13 March 1978

Time on hole (hrs): 152.5

Position: 18°00.88′N; 143°16.57′E

Water depth (sea level; corrected m, echo-sounding): 2060

Water depth (rig floor; corrected m, echo-sounding): 2070

Penetration (m): 930.5

Number of cores: 102

Total length of cored section (m): 930.5

Total core recovered (m): 280.1

Core recovery (%): 30

Oldest sediment cored:
Depth sub-bottom (m): 930.5
Nature: Tuffs and volcaniclastic breccias and conglomerates
Age: Upper Miocene (NN 10)
Measured velocity (km/s): 2.7

Basement: Questionable whether or not arc basement reached

Principal results: Site 451, located on the eastern edge of the West Mariana Ridge and drilled to a depth of 930.5 meters, yielded a sequence of biogenic oozes and volcaniclastic sediments. These sediments are divided into the following units: Unit 1, 36 meters of lower Pliocene to Quaternary, grayish brown foraminiferal ooze, grading downward through interbedded grayish brown foraminiferal–nannofossil and yellow and light yellow nannofossil–foraminiferal oozes to a basal light gray nannofossil ooze, with minor ash and pumice increasing in content downward; Unit 2, 29.5 meters of upper Miocene, olive and gray carbonate-rich vitric ash and minor layers of olive-gray and very dark gray vitric tuff with intervening layers of yellowish brown foraminiferal–nannofossil chalk; Unit 3, 865.0 meters of upper Miocene volcaniclastic sediments broadly divisible into seven sub-units consisting of interbedded, varicolored green, greenish black, dark gray, dark bluish gray to black, fine vitric tuffs, vitric and vitric-lithic tuffs, breccias, and conglomerates. Many of these lithologies are tuffaceous, some bearing nannofossils and some shallow-water shell fragments, including larger foraminifers and corals, all of the upper Miocene. Basaltic clasts in the breccias are highly vesicular and, along with the pyroclastic debris in the sediment, require explosive volcanism of the type associated with island arcs. Andesite cobbles and boulders that contain plagioclase, olivine, two pyroxenes, and opaque mineral phenocrysts are probably of calc–alkalic affinities. Accumulation rates of the lower part of this volcaniclastic sequence were about 400 m/m.y. Either a basaltic boulder or the brecciated upper surface of a lava flow was encountered in the last core.

BACKGROUND AND OBJECTIVES

The age and petrology of the sedimentary and volcanic rocks of the West Mariana Ridge were not well known. Therefore the principal objective of Site 451 was to obtain this knowledge by drilling through the sedimentary veneer into the arc basement; the overall objective was to gain an understanding of the role of remnant arcs in back-arc marginal basin evolution.

The West Mariana Ridge separates the 5-km-deep Parece Vela Basin, an extinct back-arc basin to the west, from the 4-km-deep Mariana Trough, an actively spreading back-arc basin to the east (Fig. 1). The north–south trending ridge itself is generally less than 2 km deep and locally is within only 55 meters of the surface; it is interpreted to be a remnant arc left behind when the active volcanic Mariana arc broke away during back-arc spreading of the Mariana Trough (Karig, 1975). Karig and Glassley (1970) mention the presence of vesicular dacitic lavas and upper Pliocene sandstones and ashes dredged from the West Mariana Ridge at 3- to 4-km depths. They cite the high vesicularity to suggest that a shallow eruption of dacite took place and that the present depth of the dredge site required Quaternary subsidence of parts of the West Mariana Ridge. Although the seismic-refraction profiles in the Philippine Sea did not include the West Mariana Ridge proper, a profile through the southern end of the Honshu Ridge, which begins north of the junction of the West Mariana and Mariana Ridges, showed a 3-km-thick section of a 3.3-km/s layer overlying the 4.6- to 5.5-km/s basement. Site surveys indicated that 700 meters of sediment overlie a 3.9-km/s basement layer at Site 451. The location of Site 451 on the eastern edge of the West Mariana Ridge contrasts with the location of Site 448 on the western edge of the Palau-Kyushu Ridge. The extremely deep sediment wedge on the western edge of the West Mariana Ridge and the dearth of sediments in the central part of the ridge make these parts of the ridge undesirable drilling targets.

Preliminary site surveys indicated that the West Mariana Ridge is bounded by a steep scarp facing the

[1] Loren Kroenke (Co-Chief Scientist), Hawaii Institute of Geophysics, University of Hawaii, Honolulu, Hawaii; Robert Scott (Co-Chief Scientist), Department of Geology, Texas A&M University, College Station, Texas; Kathy Balshaw, Department of Geology, Rice University, Houston, Texas; Simon Brassell, School of Chemistry, University of Bristol, Bristol, United Kingdom; Pierre Chotin, Laboratoire de Géologie Structurale, Universite Pierre et Marie Curie, Paris, France (now at: Départment de Géologie, Université Mohammed V, Rabat, Morocco); Mary E. Heiman, Stratigraphy Laboratory, Mobil Oil Company, Dallas, Texas (now at: F and H Biostratigraphic Associates, Laramie, Wyoming); Teruaki Ishii, Ocean Research Institute, University of Tokyo, Tokyo, Japan; Barbara H. Keating, Hawaii Institute of Geophysics, University of Hawaii, Honolulu, Hawaii; Erlend Martini, Geologisch-Paläontologisches Institut, Johann-Wolfgang-Goethe-Universitat, Frankfurt am Main, Federal Republic of Germany; David P. Mattey, Department of Geology, Bedford College, University of London, London, United Kingdom (now at: Department of Geological Sciences, University of Birmingham, Birmingham, England); Kelvin Rodolfo, Department of Geological Sciences, University of Illinois, Chicago, Illinois; Renzo Sartori, Laboratorio di Geologia Marina del C.N.R., Bologna, Italy; Fritz Theyer, Hawaii Institute of Geophysics, University of Hawaii, Honolulu, Hawaii; John L. Usher, Deep Sea Drilling Project, Scripps Institution of Oceanography, La Jolla, California; and Guram Zakariadze, Institute of Geology, Georgian Academy of Sciences, Tbilisi, U.S.S.R. (now at: V. I. Vernadsky Inst. of Geochem. and Analyt. Chem., U.S.S.R. Acad. of Sciences, Vorobyewskoe chaussee 47A, 117334 Moscow, U.S.S.R.).

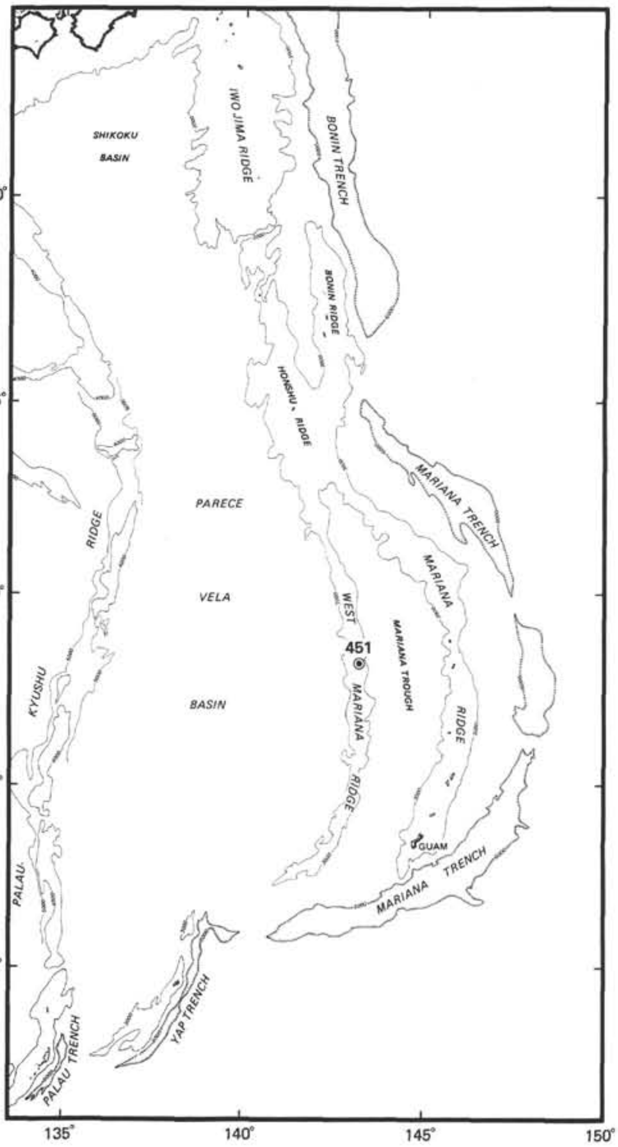


Figure 1. Location of Site 451 on the eastern edge of the West Mariana Ridge. (The site is indicated by a concentric circle.)

Mariana Trough (Figs. 2 and 3). The locations of the survey track lines are shown in Figure 4. Numerous volcanic peaks surmount the ridge within the vicinity of the survey. The eastern edge of the ridge also seems to be broken into a series of steps or ledges, some of which have sediment ponds (for example, see the central part of Profile V), perhaps an excellent place to attempt to reach basement. Sonobuoy results (Fig. 5) suggested that about 1 km of sediment (2.0 km/s) overlies a higher-velocity layer (4.2 km/s) that may be volcanic-arc basement. (This is identical to the velocity of Site 448 arc-volcanic rocks.) The 5- to 6-km/s layer found 1.3 to 1.5 km below the 4.2-km/s layer may also represent oceanic basement. Semblance calculations made on the multichannel seismic data, also acquired during the site surveys in the vicinity of Site 451, indicate that approximately 700 meters of sediments overlie a 3.9-km/s basement layer. Murauchi et al. (1968) point out that at

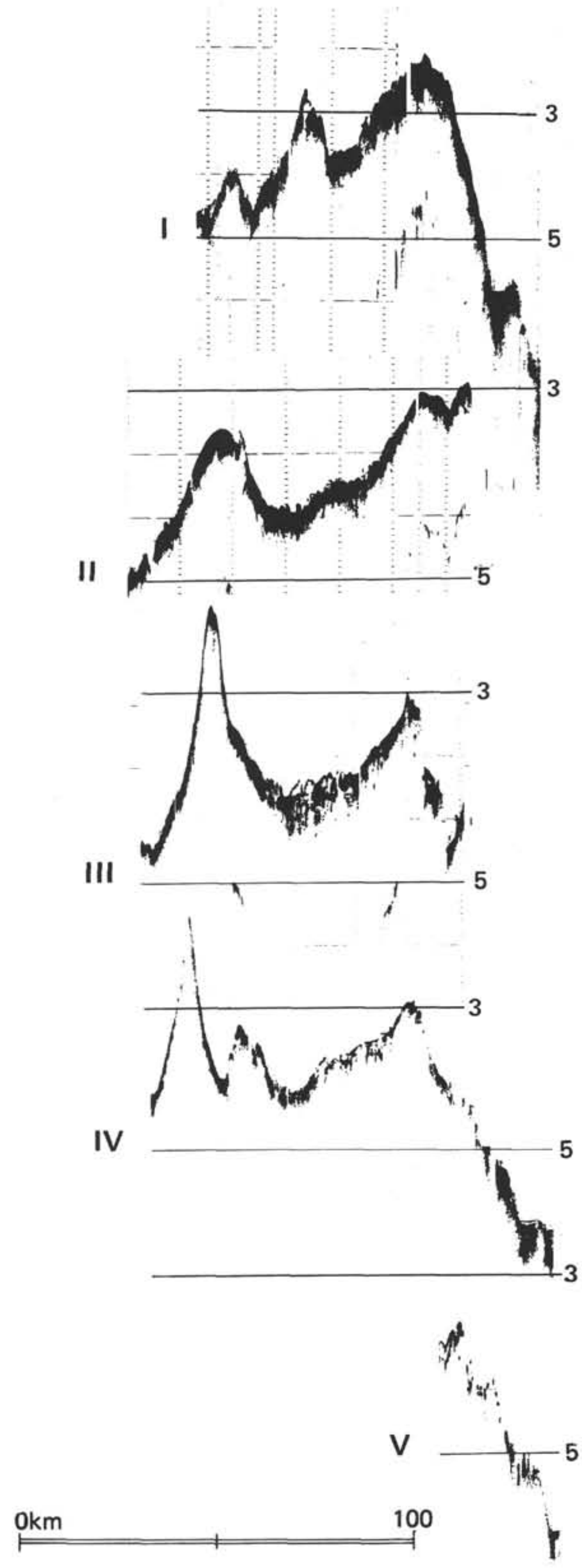


Figure 2. Seismic-reflection profiles (L-DGO Site Survey data) in the vicinity of Site 451. (Profiles I, IV, and V show the steep scarp on the eastern side of the West Mariana Ridge. Ships' tracks for these profiles are shown in Fig. 4. Reflection time is in seconds.)

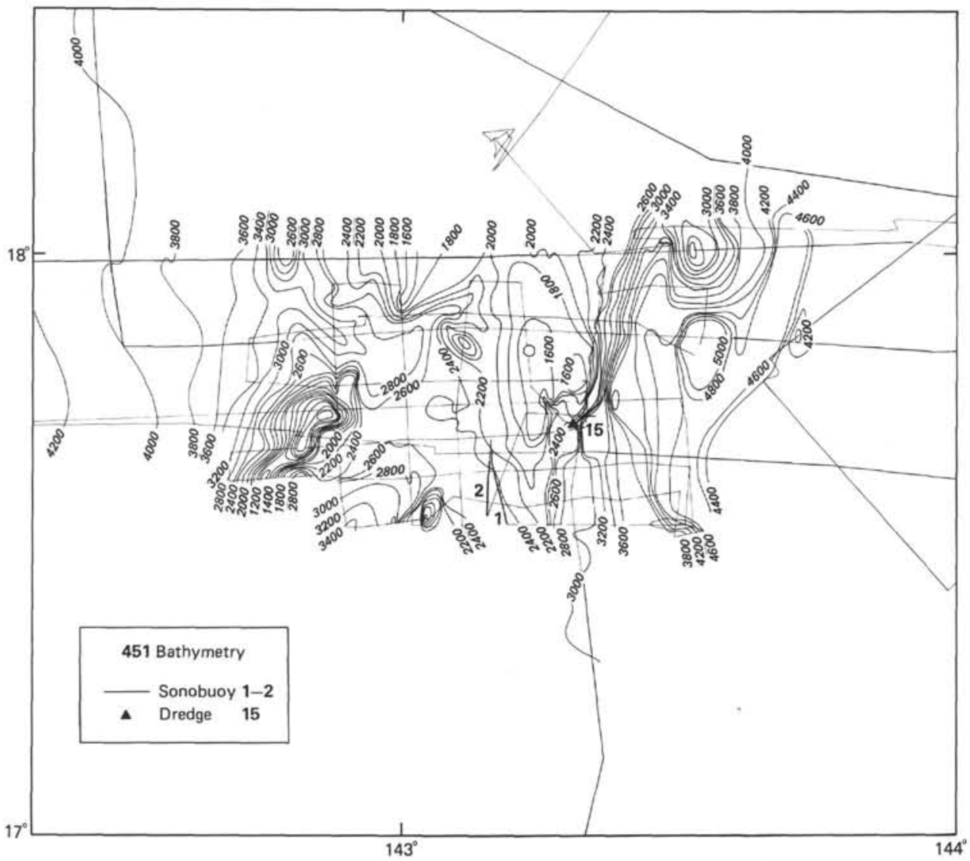


Figure 3. Bathymetry in the vicinity of Site 451 (L-DGO Site Survey data). (Note the steep scarp on the eastern side of the Mariana Ridge. Depths are in corrected meters.)

a considerable distance to the north of Site 451 the ridge is built up mainly of material with a 3.5-km/s velocity, based on the one refraction line across the Honshu Ridge. Dredging (locality shown in Figs. 3 and 4) recovered only weathered mafic rocks and sediments from a massive basement-type block that appears to dip gently to the west.

The broad objective of Site 451 was to compare the drilling results of Site 451 with drilling planned for Leg 60 on the active volcanic Mariana arc in order to determine whether the West Mariana Ridge actually is a remnant arc left behind the Mariana Ridge during back-arc spreading to form the Mariana Trough and to ascertain what the detailed evolution of this process includes. For example, the episodic nature of volcanism within the entire Palau-Kyushu–West Mariana–Mariana remnant arc–arc province was to be investigated, with particular attention to variability of magmas and magma sources in space and time. Timing of volcanic and structural events within the West Mariana Ridge was to be related to sedimentary and structural events in the Parece Vela Basin. Of particular interest was the structural and volcanic control of sedimentation on the West Mariana Ridge. The nature of metallogenesis in immature arc-volcaniclastic sediments and the roles of diagenesis and incipient hydrothermal mechanisms in metallogenesis were especially important in conceptualizing ore formation in island arcs.

The specific objective was to drill through 0.7 to 1 km of sediments on the eastern side of the West Mariana Ridge and to penetrate the 3.9- to 4.2-km/s basement.

OPERATIONS

The final drilling location of Site 451 is situated about 240 km due east of Site 450. At 1130 Local Time (L), 7 March, approximately 17.5 hours after leaving Site 450, a brief seismic-profile survey was begun; at 1326 L the positioning beacon was dropped and normal site operations were begun (Fig. 6).

An attempt to retrieve a mudline punch core was made when the core bit had been lowered to 2081.5 meters. Although the depth was 11.5 meters below the precision depth recorder (PDR) depth, no weight indication of contact with the seafloor was felt. No sediment was recovered. The procedure was repeated with an additional joint of pipe to 2091 meters; on this attempt 4.2 meters of sediment were recovered and the water depth was set at 2086 meters from the rig floor.

The record of drilling operations is summarized in Table 1. At 38 meters sub-bottom, firm volcaniclastic material was encountered, and there was concern for the bottom-hole assembly (BHA) because the lower bumper

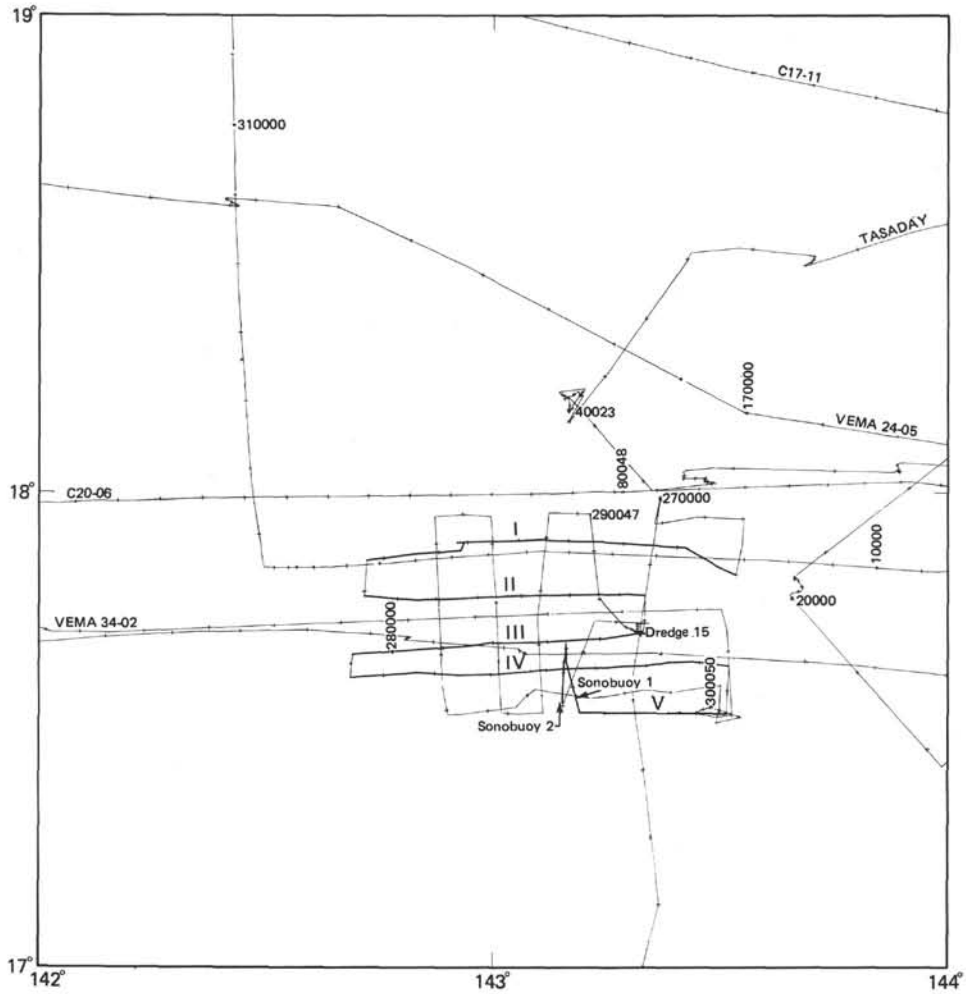


Figure 4. Survey tracks in the vicinity of Site 451 on the West Mariana Ridge (L-DGO Site Survey data). (The heavily drawn east-west lines with Roman numerals correspond to profiles shown in Fig. 2.)

subs were just reaching the seafloor. After a few meters were carefully drilled, somewhat softer material was encountered and the BHA was buried without incident.

Low core recovery from about 55 to 475 meters sub-bottom was attributed to semi-indurated tuff and ash beds; recovery improved as compaction and induration increased with depth.

Minor hole problems occurred at 537 meters and at 641 meters sub-bottom, created by the influx of excessive accumulations of cuttings in the hole. The hole had been kept clean by regular mud flushes in the course of drilling; it was concluded that "avalanches" of cuttings from the seafloor around the hole or from washouts in the upper part of the hole caused these problems. The lower influx (641 m) occurred during attempts to clear a plugged bit. The altered volcaniclastic material encountered showed a tendency to accumulate in a waxy clay-like mass in the core catcher; this caused repeated jamming, which adversely affected core recovery. A similar buildup apparently occurred in the throat and jets of the core bit. The bit deplugger was run and the throat was opened, indicated by mud pump pressure. The next core barrel failed to seat, however, and even more severe plugging resulted from a 3-meter core attempt. Several more wire-line runs were required to clear the bit completely, and a total delay of 7.5 hours resulted.

Normal operations continued until the final operating day of the leg. At a depth of 926.5 meters sub-bottom, core barrel 101 stuck at the bit, and three wire-line runs (two sheared release pins) were required to retrieve it. A small lump of altered basalt was found imbedded in the clay-like material jamming the core catcher.

The penetration rate was much lower on the subsequent core, and it was decided to retrieve the core after 4 meters were cut to maximize basalt recovery. During the cutting of the core, however, the mud pump pressure increased markedly, indicating that the bit was plugging. Core recovery was only 40 cm, some of which was altered basalt. The amount was insufficient to determine whether the basalt was a large clast or part of a flow.

A last-minute attempt was made to clear the bit and cut one additional core. Pump pressure indicated the bit to be almost completely plugged, and the deplugger did not open the throat when it landed at the bit. The overshot was lowered and engaged the deplugger barrel. Sev-

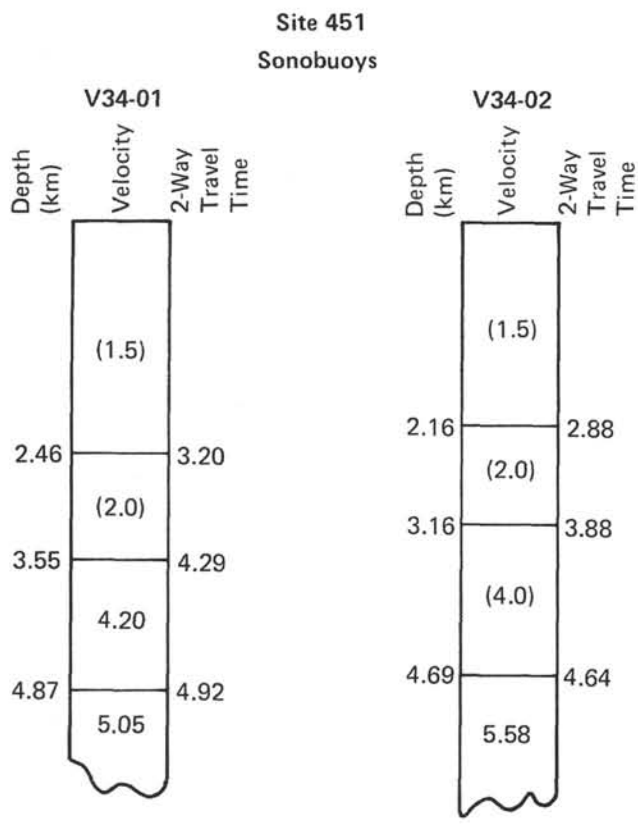


Figure 5. Results of the two sonobuoys shot on the West Mariana Ridge (L-DGO Site Survey data). (Significant topographic slopes along the line of these profiles reduce their accuracy.)

eral attempts were made to break through the obstruction by jarring the wire-line jars, but the deplugger became stuck without reducing the pumping pressure. Attempts to dislodge the deplugger resulted in a sheared release pin.

Operating time had run out and prospects for recovering any additional core were low. The drill string was retrieved, concluding drilling operations for Leg 59. On retrieval, the throat of the bit was found to be solidly packed with pulverized clay and rock for its entire length. The apices of all four cones of the bit had been broken off, leaving only the second row of inserts of two of the cones to trim the diameter of the core.

After the drilling equipment had been secured for sea, the vessel got underway for profile surveying at 1940 L, 13 March. On departure to the west to stream gear, the site was crossed on an easterly profile. The profile was continued 35 km to the east, and then a southerly course was set for Apra, Guam.

SEDIMENTARY LITHOLOGY

At Site 451, 930.5 meters of sediments and volcaniclastic rock were drilled and continuously cored. Basalt fragments recovered from the bottom of the hole may represent the upper surface of a lava flow, but otherwise no flows or igneous intrusions were encountered. Recovery was poor in the interval of poorly consolidated sediments from Cores 11 through 23 and 48 through 51.

The upper Miocene to Quaternary sedimentary section consists of two lithologies that contrast sharply in appearance and genesis, separated by a transition zone of intercalated beds of both lithologies with layers that are intermediate in composition. Thus, the sedimentary column is conveniently separable into three lithologic units (Fig. 7).

At the top, Unit 1 (36.0 m thick) consists of lower Pliocene to Quaternary soft biogenous carbonate oozes. The uppermost two meters of Unit 1 are a grayish brown foraminiferal ooze that grades downward into delicately hued alternations of grayish brown foraminiferal-nannofossil ooze and light yellow-brown and yellow nannofossil-foraminiferal ooze (Core 2). The nannofossil-ooze layers become thicker down-core at the expense of the foraminiferal-nannofossil oozes; Cores 3 and 4 and the upper part of Core 5 are exclusively nannofossil-foraminiferal oozes, and the basal 20 cm of Unit 1 are a light gray nannofossil ooze. A single 20-cm thick, very dark gray bed of ash occurs in Core 3, 20 meters above the base of the unit. Pumice and glass fragments, locally brown or black and covered by manganiferous films, are present in Core 1. Glass (trace to 3%), crystal fragments (trace to 2%),

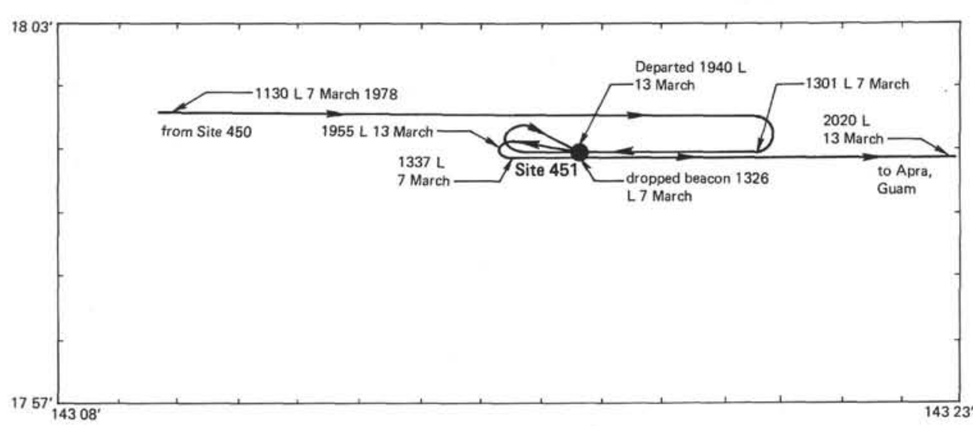


Figure 6. Track of the *Glomar Challenger* between Site 450 and 451 showing details of pre- and postsite surveys. (The ● marks the site position.)

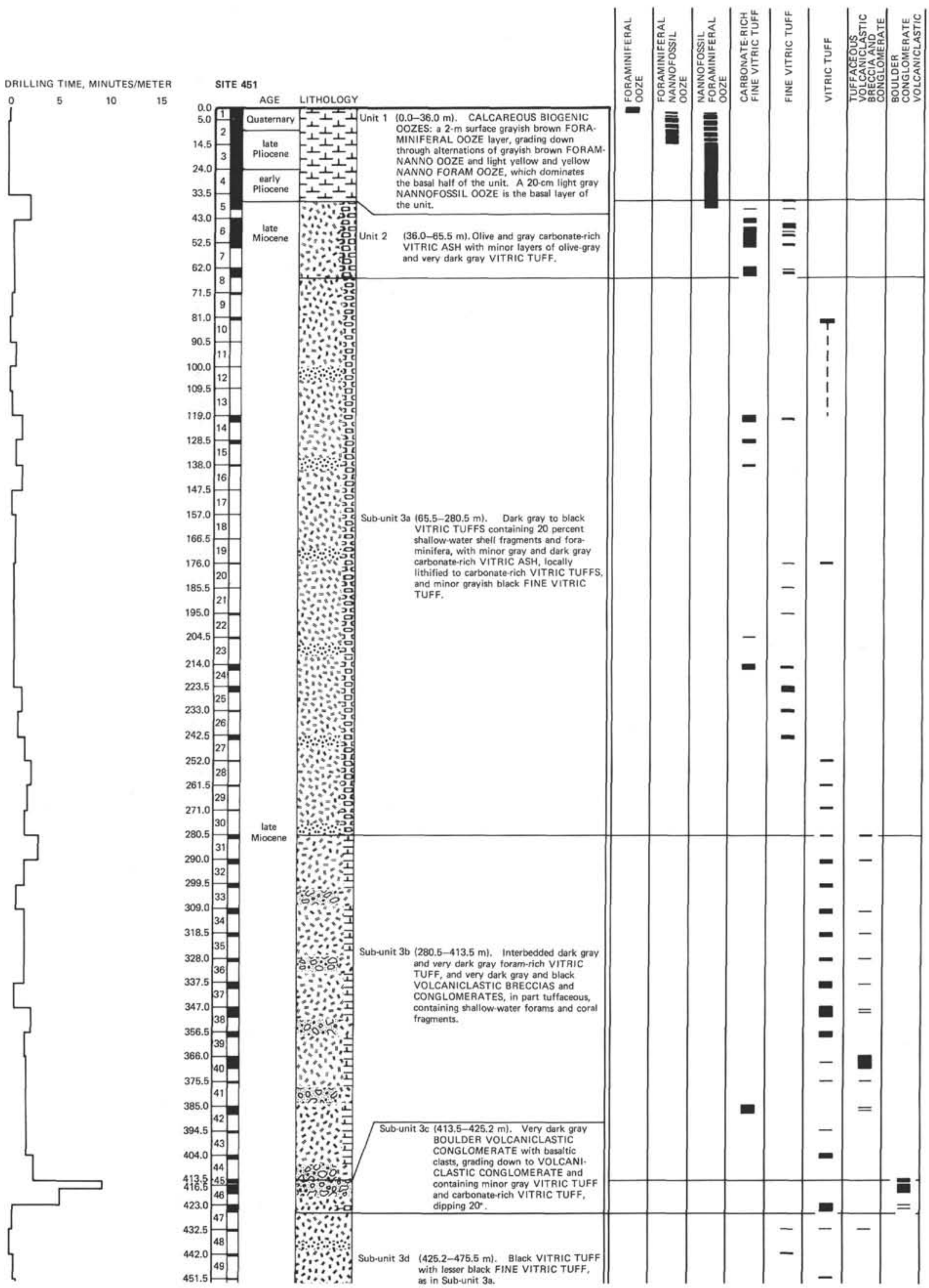


Figure 7. Lithology, age, core recovery, and drilling rate at Site 451. (The drilling rate is included here to show its correlation with lithology and lithologic boundaries. Core recovery is indicated by the solid symbol in the second left column. Lithologic symbols are summarized in the Introduction to this volume. Component percentages derived from smear slides and core descriptions are indicated in the eight columns on the right of the figure.)

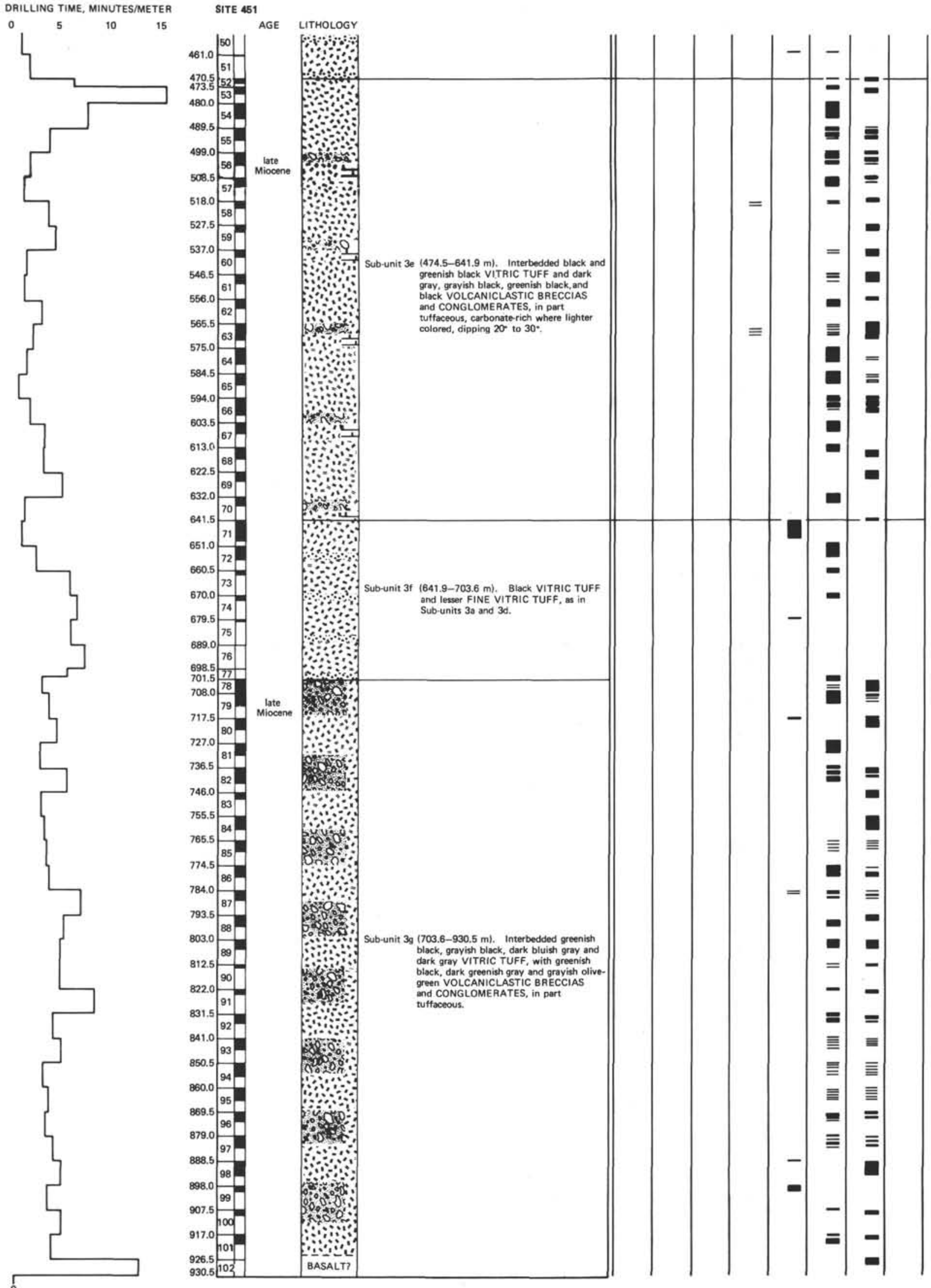


Figure 7. (Continued).

Table 1. Coring summary for Hole 451.

Core No.	Date (March, 1978)	Local Time (L)	Depth from Drill Floor (m, top-bottom)	Depth below Sea Floor (m, top-bottom)	Length Cored (m)	Length Recovered (m)	Recovery (%)
1	7	2138	2086.0-2091.0	0.0- 5.0	5.0	4.2	84
2	7	2216	2091.0-2100.5	5.0- 14.5	9.5	8.8	93
3	7	2258	2100.5-2110.0	14.5- 24.0	9.5	9.5	100
4	7	2332	2110.0-2119.5	24.0- 33.5	9.5	9.1	96
5	8	0037	2119.5-2129.0	33.5- 43.0	9.5	5.9	62
6	8	0121	2129.0-2138.5	43.0- 52.5	9.5	9.5	100
7	8	0208	2138.5-2148.0	52.5- 62.0	9.5	1.4	15
8	8	0255	2148.0-2157.5	62.0- 71.5	9.5	3.7	39
9	8	0335	2157.5-2167.0	71.5- 81.0	9.5	0.4	4
10	8	0426	2167.0-2176.5	81.0- 90.5	9.5	1.2	13
11	8	0515	2176.5-2186.0	90.5-100.0	9.5	0.0	0
12	8	0602	2186.0-2195.5	100.0-109.5	9.5	0.0	0
13	8	0645	2195.5-2205.0	109.5-119.0	9.5	0.0	0
14	8	0739	2205.0-2214.5	119.0-128.5	9.5	2.7	28
15	8	0838	2214.5-2224.0	128.5-138.0	9.5	0.7	7
16	8	0936	2224.0-2233.5	138.0-147.5	9.5	0.1	1
17	8	1030	2233.5-2243.0	147.5-157.0	9.5	0.0	0
18	8	1116	2243.0-2252.5	157.0-166.5	9.5	0.1	1
19	8	1215	2252.5-2262.0	166.5-176.0	9.5	0.0	0
20	8	1340	2262.0-2271.5	176.0-185.5	9.5	0.2	2
21	8	1450	2271.5-2281.0	185.5-195.0	9.5	0.1	1
22	8	1525	2281.0-2290.5	195.0-204.5	9.5	0.2	2
23	8	1620	2290.5-2300.0	204.5-214.0	9.5	0.2	2
24	8	1740	2300.0-2309.5	214.0-223.5	9.5	2.0	21.1
25	8	1805	2309.5-2319.0	223.5-233.0	9.5	1.8	18.9
26	8	1905	2319.0-2328.5	233.0-242.5	9.5	0.5	5.3
27	8	2004	2328.5-2338.0	242.5-252.0	9.5	1.2	12.6
28	8	2106	2338.0-2347.5	252.0-261.5	9.5	0.1	1.1
29	8	2220	2347.5-2357.0	261.5-271.0	9.5	0.2	2.1
30	8	2322	2357.0-2366.5	271.0-280.5	9.5	0.1	1.1
31	9	0040	2366.5-2376.0	280.5-290.0	9.5	1.6	16.8
32	9	0149	2376.0-2385.5	290.0-299.5	9.5	1.8	18.9
33	9	0244	2385.5-2395.0	299.5-309.0	9.5	1.4	14.7
34	9	0352	2395.0-2404.5	309.0-318.5	9.5	1.8	18.9
35	9	0451	2404.5-2414.0	318.5-328.0	9.5	1.0	9.5
36	9	0550	2414.0-2423.5	328.0-337.5	9.5	1.0	10.5
37	9	0645	2423.5-2433.0	337.5-347.0	9.5	2.1	22.1
38	9	0800	2433.0-2442.5	347.0-356.5	9.5	3.6	37.9
39	9	0900	2442.5-2452.0	356.5-366.0	9.5	1.9	20.0
40	9	1010	2452.0-2461.5	366.0-375.5	9.5	4.2	44.2
41	9	1123	2461.5-2471.0	375.5-385.0	9.5	1.5	15.8
42	9	1220	2471.0-2480.5	385.0-394.5	9.5	3.0	31.6
43	9	1323	2480.5-2490.0	394.5-404.0	9.5	0.1	1.0
44	9	1436	2490.0-2499.5	404.0-413.5	9.5	1.2	12.6
45	9	1559	2499.5-2502.5	413.5-416.5	3.0	1.6	53.3
46	9	1725	2502.5-2509.0	416.5-423.0	6.5	3.2	49.2
47	9	1831	2509.0-2518.5	423.0-432.5	9.5	2.5	26.3
48	9	1926	2518.5-2528.0	432.5-442.0	9.5	0.2	2.1
49	9	2017	2528.0-2537.5	442.0-451.5	9.5	0.5	5.3
50	9	2118	2537.5-2547.0	451.5-461.0	9.5	0.1	1.0
51	9	2424	2547.0-2556.5	461.0-470.5	9.5	0.1	1.0
52	9	2326	2556.5-2559.5	470.5-473.5	3.0	1.2	12.6
53	10	0305	2559.5-2566.0	473.5-480.0	6.5	2.5	38.5
54	10	0510	2566.0-2575.5	480.0-489.5	9.5	5.6	58.9
55	10	0625	2575.5-2585.0	489.5-499.0	9.5	4.4	46.3
56	10	0724	2585.0-2594.5	499.0-508.5	9.5	5.2	54.7
57	10	0835	2594.5-2604.0	508.0-518.0	9.5	3.7	38.5
58	10	1000	2604.0-2613.5	518.0-527.5	9.5	2.9	30.5
59	10	1210	2613.5-2623.0	527.5-537.0	9.5	2.4	25.3
60	10	1415	2623.0-2632.5	537.0-546.5	9.5	2.7	28.4
61	10	1515	2632.5-2642.0	546.5-556.0	9.5	3.2	33.7
62	10	1705	2642.0-2651.5	556.0-565.5	9.5	3.2	33.7
63	10	1815	2651.5-2661.0	565.5-575.0	9.5	6.1	64.2
64	10	1921	2661.0-2670.5	575.0-584.5	9.5	5.6	58.9
65	10	2019	2670.5-2680.0	584.5-594.0	9.5	4.2	44.2
66	10	2134	2680.0-2689.5	594.0-603.5	9.5	6.1	64.2
67	10	2245	2689.5-2699.0	603.5-613.0	9.5	3.8	40.0
68	10	2358	2699.0-2708.5	613.0-622.5	9.5	4.1	43.2
69	11	0147	2708.5-2718.0	622.5-632.0	9.5	3.5	37.0
70	11	0325	2718.0-2727.5	632.0-641.5	9.5	3.0	31.5
71	11	0452	2727.5-2737.0	641.5-651.0	9.5	7.4	77.9
72	11	0612	2737.0-2746.5	651.0-660.5	9.5	5.0	52.6
73	11	0800	2746.5-2756.0	660.5-670.0	9.5	1.3	13.7
74	11	0945	2756.0-2765.5	670.0-679.5	9.5	1.6	16.8
75	11	1120	2765.5-2775.0	679.5-689.0	9.5	0.5	5.3
76	11	1330	2775.0-2784.5	689.0-698.5	9.5	Tr.	0.0
77	11	1622	2784.5-2787.5	698.5-701.5	3.0	0.0	0.0
78	11	2213	2787.5-2794.0	701.5-708.0	6.5	6.4	98.5
79	12	0006	2794.0-2803.5	708.0-717.5	9.5	4.5	47.4
80	12	0132	2803.5-2813.0	717.5-727.0	9.5	7.2	43.2
81	12	0241	2813.0-2822.5	727.0-736.5	9.5	4.7	49.5
82	12	0430	2822.5-2832.0	736.5-746.0	9.5	6.0	63.2
83	12	0544	2832.0-2841.5	746.0-755.5	9.5	1.8	18.9
84	12	0710	2841.5-2851.0	755.5-765.0	9.5	4.9	51.6
85	12	0830	2851.0-2860.5	765.0-774.5	9.5	5.0	52.6
86	12	0951	2860.5-2870.0	774.5-784.0	9.5	4.2	44.2
87	12	1142	2870.0-2879.5	784.0-793.5	9.5	3.3	34.7
88	12	1400	2879.5-2889.0	793.5-803.0	9.5	4.1	43.2
89	12	1530	2889.0-2898.5	803.0-812.5	9.5	3.4	35.8
90	12	1701	2898.5-2908.0	812.5-822.0	9.5	1.3	13.7
91	12	1900	2908.0-2917.5	822.0-831.5	9.5	2.0	21.0
92	12	2030	2917.5-2927.0	831.5-841.0	9.5	3.5	36.8
93	12	2202	2927.0-2936.5	841.0-850.5	9.5	4.1	43.2
94	12	2231	2936.5-2946.0	850.5-860.0	9.5	5.2	54.7
95	13	0050	2946.0-2955.5	860.0-869.5	9.5	5.0	52.6
96	13	0203	2955.5-2965.0	869.5-879.0	9.5	3.4	36.0
97	13	0336	2965.0-2974.5	879.0-888.5	9.5	4.4	46.3
98	13	0545	2974.5-2984.0	888.5-898.0	9.5	5.7	60.0
99	13	0657	2984.0-2983.5	898.0-907.5	9.5	2.1	22.1
100	13	0837	2983.5-3003.0	907.5-917.0	9.5	2.1	22.1
101	13	1110	3003.0-3012.5	917.0-926.5	9.5	1.3	14.0
102	13	1302	3012.5-3016.5	926.5-930.5	4.0	0.2	2.1
Total					930.5	280.1	30.1

and feldspar and heavy minerals (trace to 1%) are very minor constituents.

Unit 2, 29.5 meters thick, consists of upper Miocene, carbonate-rich fine vitric tuff, fine vitric tuff, and nannofossil-foraminiferal ooze interbeds. The uppermost interbeds (80 cm thick) are two olive-gray and dark olive-gray ash beds (25 and 40 cm thick), intercalated with a nannofossil–foraminiferal ooze (15 cm thick). Below this intercalated zone are 8.7 meters of light olive-gray carbonate-rich ash layers (each <10 cm thick) interbedded with lithified dark olive-gray vitric tuff layers. In Core 6 the carbonate-rich ash layers increase in thickness to 70 cm, and the tuff layers increase in thickness to 35 cm. This general lithology continues down to a sub-bottom depth of 65.5 meters, the base of Unit 2.

The contact between Units 2 and 3 was not recovered but can be reasonably placed just below the lowermost beds of Unit 2, where core recovery dropped markedly as a consequence of the poorly consolidated vitric tuffs dominating the Unit 3 beds. Unit 3, 865.0 meters thick, extends from 65.5 meters to 930.5 meters sub-bottom and consists of upper Miocene fine vitric tuffs, vitric tuffs, and volcaniclastic conglomerates and breccias. Figure 7 shows the stratigraphic distribution of these rock types and the seven recognizable sub-units. This thickness may represent more than the complete Unit 3 section at Site 451, inasmuch as it is believed that the poorly recovered bottom 4 meters of the hole, where drilling rate slowed sharply, were drilled in igneous rock.

Only about 6% of the 215.0 meters of Sub-unit 3a were recovered in the coring. The predominant rock type is a black to dark gray vitric tuff, with lesser dark gray, very dark gray, and black fine vitric tuffs. The sediments are composed of about 25% glass and 45% clay alteration products. Calcareous material makes up most of the remainder, notably as burrow fillings in the fine tuffs and as shallow-water foraminifers (see the biostratigraphy section of this site report) and coral fragments in the coarser tuffs. Foraminifers commonly occur concentrated in laminae.

Approximately two-thirds of the 133.0-meter-thick Sub-unit 3b is composed of the same vitric tuff as is Sub-unit 3a, but in 3b there are interbeds with conglomerate and breccia layers 10 to 340 cm thick. Typical clast sizes are 0.5 mm in diameter, although rare clasts up to 3 cm occur. The clast:matrix ratio varies between 2:1 and 4:1; aphanitic and vesicular basalt account for more than half (rarely up to 90%) of the clasts, which are angular to subrounded. The matrix consists of fine glass and its alteration products. The sub-unit features laminated intervals of fine sand-sized clasts, graded bedding, load casts, and rare penecontemporaneous normal faulting of small displacement (5 mm) and disharmonic, recumbent folding (Fig. 8). Bioturbation of the finer beds occurs and is intense in one 40-cm-thick layer at the top of the sub-unit. Shallow-water foraminifers, coral fragments, and lignite fragments are present in the coarser layers.

Sub-unit 3c, 11.7 meters thick, features a boulder volcaniclastic conglomerate 4.6 meters thick at its top; the boulders are 20 to 30 cm in size within the core and are composed of plagioclase-olivine-phyric basalt and vesicular plagioclase-phyric basalt. This bed progressively becomes finer down-core, becoming a vitric tuff with intercalations of gray carbonate-rich tuff about 10 cm thick. Two other coarse beds, 40 and 70 cm thick, occur near the base of the sub-unit. Approximately half of the recovery from Sub-unit 3c is breccia and conglomerate.

Sub-unit 3d, 49.3 meters thick, is an interval much like Sub-unit 3a, in which poorly recovered vitric tuff predominates. Biogenic carbonate is present in small amounts as pelagic and benthic foraminifers and nannofossils. Some of the beds are black and structureless; others are dark gray and show lamination and cross-bedding.

Sub-unit 3e, 167.4 meters thick, is an intercalated sequence of vitric tuffs, volcaniclastic breccias, and conglomerates much like those of Sub-unit 3b. Again, coarse beds comprise about one-third of the recovered material. The rock is more indurated and the glassy material more altered to clay. Subangular to subrounded clasts of altered basalts and andesites 3 to 4 mm in diameter occur as minor constituents. Clasts and matrix both contain very small amounts of disseminated pyrite. The clast:matrix ratio is about 4:1. Silicified foraminifers were observed in two of the cores; lignite lenses also are present.

Sub-unit 3f, 61.7 meters thick, is another interval dominated by black vitric tuffs and lesser fine vitric tuffs and characterized by poor core recovery. Andesite clasts occur in the coarser sediments of every core in the sub-unit.

Sub-unit 3g, either 222.9 or perhaps more than 226.9 meters thick, consists primarily of greenish black, dark greenish gray, and grayish olive-green coarse volcaniclastic breccias and conglomerates, in part tuffaceous, in layers 20 cm to 5 meters thick. Interbedded with them, in intervals typically about 1 meter thick, are greenish black, grayish black, dark bluish black, and dark gray vitric tuffs.

The depositional history of Site 451 on the West Mariana Ridge is one of rapid accumulation of great thickness of epiclastic volcanic sediments derived from relatively shallow water during the late Miocene. Many of the coarser clasts in Unit-3 sediments display rounding attributable to reworking in near-surface environments of high wave energy, and it is possible that some of these clasts may even have been rounded in a subaerial setting. Reworked shallow-water carbonate tests were also deposited with the Unit-3 sediments, although carbonate contents are strongly masked and diluted by the volcaniclastic components. Because lignite occurs as lenses and fragments isolated at one stratigraphic horizon, and because lignite does not form in marine environments, the lignite within tuffs was not formed *in situ* but was most probably derived by erosion of nearby volcanic islands.

In the latest Miocene, the supply of volcaniclastic material was reduced enough so that carbonates comprise a significant fraction of the Unit-2 sediments. By the Pliocene, volcanism had ceased altogether, and only carbonate oozes with insignificant ash admixtures were deposited until the present. At no time in the entire period of time recorded by the cored sequence does Site 451 appear to have been below the carbonate compensation depth (CCD).

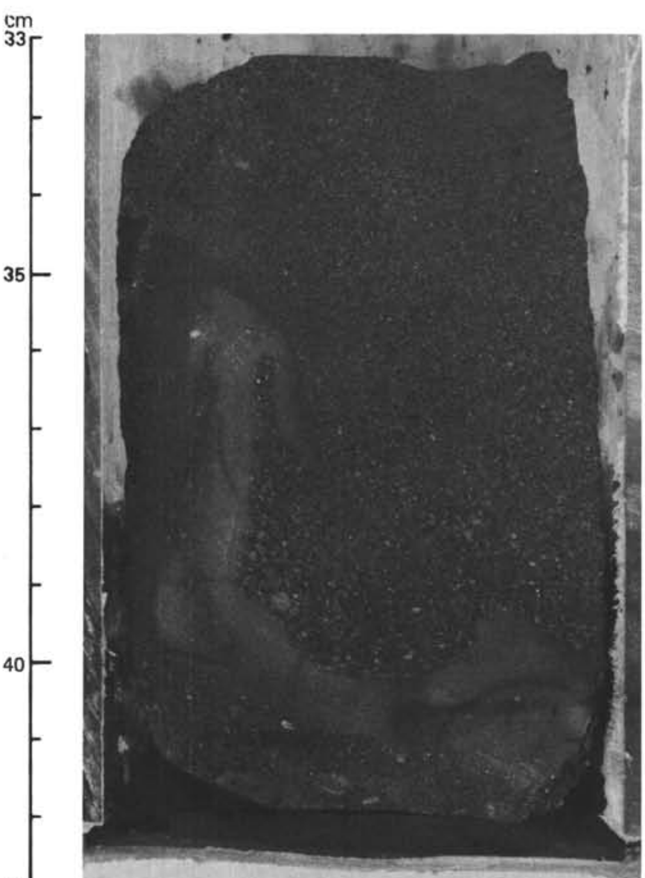


Figure 8. Disharmonic, recumbent folding associated with the base of a graded bed.

BIOSTRATIGRAPHY

At Site 451, at least 926.5, if not 930.5 meters of sediment were cored. Foraminiferal–nannofossil ooze is present in the first five cores, changing to carbonate-rich vitric ash and vitric tuffs downward. Volcaniclastic rocks occur with increasing frequency down-hole and dominate in the lower part of the hole.

In Cores 1 to 3 (0.0–24.0 m), foraminifers, calcareous nannofossils, and radiolarians are present, indicating an age of late Pliocene to late Quaternary. Diatoms occur only in the lower part of Core 1 and in Core 2 and are associated with rare silicoflagellates. Below Core 3 only calcareous nannoplankton and foraminifers remain, and these are common down to Core 14 (24.0–128.5 m), indicating an age of late Miocene to early Pliocene for this interval. Cores 15 to 19 (128.5–176.0 m) are essentially barren or had no recovery. From Core 20 downward, fossil occurrences are restricted to interbedded biogenic horizons in which poorly preserved upper Miocene nannofossils and the planktonic foraminifer *Orbulina* spp. (middle Miocene or younger) are present. Larger foraminifers are occasionally present from Core 31 downward. Coral fragments were also found (e.g., Core 91). The lowest nannofossil occurrence was noted in Core 85 (765.0–774.5 m), which is situated in the basal part of Zone NN 10 (*Discoaster calcaris* Zone, upper Miocene).

Calcareous Nannoplankton

In Cores 1 to 3 (0.0–24.0 m), Quaternary to upper-Pliocene calcareous nannoplankton assemblages are present, represented by calcareous nannoplankton Zones NN 21 (*Emiliania huxleyi* Zone) down to NN 16 (*Discoaster surculus* Zone) in successive order, with the exception of Sample 2,CC. Here an NN 21 assemblage was found that obviously represents material caved-in from above. Core 4 and the upper part of Core 5 (24.0–36.5 m) contain the lower Pliocene calcareous nannoplankton Zones NN 12 (*Ceratolithus tricorniculatus* Zone) to NN 15 (*Reticulofenestra pseudoumbilica* Zone), with rather common occurrences of ceratoliths.

The NN 11 assemblage is found in the lower part of Core 5 probably to Core 20 (36.5–185.5 m), although the lower part of this succession is obscured by nonrecovery and barren intervals. In Core 22 and downward to Core 64, several layers contain poorly preserved nannoplankton assemblages, which may belong to Zone NN 10 (*D. calcaris* Zone), because neither *D. quinqueramus* (first occurrence [FO] = base of Zone NN 11) nor *D. hamatus* (last occurrence [LO] = top of Zone NN 9) were found in the volcaniclastic sediment. In Cores 78 and 80 the basal part of Zone NN 10 was reached, in which *Catinaster calyculus* (long-rayed specimens) is present. Some levels contain only solution-resistant forms inadequate for precise age determination. The preservation of calcareous nannofossils in Cores 3 to 14 is fair; and preservation in the two uppermost cores is good.

Foraminifers

Moderately well-preserved planktonic foraminifers are common to abundant in core-catcher samples from Cores 1 to 14, with benthic foraminifers common in the upper cores but rare below Core 5. Below Core 14 all foraminifers occur sporadically because the more abundant volcaniclastic sediments often dilute their presence; preservation is generally poor with increased induration of the sediments.

Mixing of foraminiferal faunas of different age in some of the samples from this site is evident (e.g., Sample 1,CC contains a mixture of foraminifers from Zones N.21 to N.23); this makes it difficult to determine the precise age of these samples.

The following upper Miocene to Quaternary planktonic foraminifer zones were recognized: probably N.23 in the upper portion of Core 1; probably N.22 from Sample 1,CC through Core 2, Section 1; N.21 from Core 2, Section 3 to Core 3, Section 5; N.19 from Core 3, Section 7 to Core 5, Section 1; N.17 from Core 6, Section 1 through Core 8, Section 6 (and Core 10, Section 1[?]).

Rare occurrences of *Candeina* as low as Core 25, Section 1 indicate the presence of Zones N.16/N.17 at least as far down as this. *Orbulina* spp. (middle Miocene or higher) occurs sporadically throughout the lower portion of the sedimentary section.

Reworked larger foraminifers occur sporadically from Core 31 downward. (The following information on these larger foraminifers and associated shallow-water fossils is a personal communication submitted by Dr. J. P. Beckmann, December, 1978.[2])

Samples from Cores 31, 40, 42, 46, 47, 50, 69, 71, and 72 were available for investigation. Fossil remains that are generally regarded as shallow-water indicators were found in all of these cores except Core 69. The best faunas were recovered from Cores 40, 71 and 72, but even in these cores only *Amphistegina* spp. and *Ammonia* cf. *indopacifica* (Thalmann) are fairly common. The remaining taxa are represented in individual samples by only a few specimens (or fragments of specimens). Preservation is usually moderate to poor. Many specimens show signs of breakage or wear, and the material is commonly chalky or recrystallized into clear calcite. A thorough taxonomic study has not been attempted, and an open nomenclature is commonly used in the sample list that follows.

The most significant genera of larger foraminifers at Site 451 are *Lepidocyclina*, *Miogypsina*, *Miogypsinoides*, and *Cycloclypeus*. The group *Operculina-Operculinella-Operculinoides* is also present in most samples, but because of its limited stratigraphic use has not been studied in detail. *Lepidocyclina* is represented in the upper part of the studied interval (mostly Core 40) by *L.* cf. *rutteni* van der Vlerk, whereas in the lower cores (71 and 72) the specimens have broader equatorial chambers and resemble *L. japonica* (Yabe). A few fragments probably belonging to *L. ferreroi* Provale were found in Core 71. *Miogypsina* also occurs very rarely in Core 71. Two specimens of *Miogypsinoides* from the top sample (0–9 cm) of Core 71 seem to be close to *M. complanata* (Schlumberger) and are most probably reworked. The genus *Cycloclypeus* is taxonomically in a confused state, which limits its value for biostratigraphy. In this report, a group named *C.* cf. *eidae/posteidae* (mostly with 7–15 nepionic chambers) is distinguished from a few larger specimens with five or less nepionic chambers, here referred to as *C.* cf. *carpenteri/guembelianus*, following mainly the work of MacGillavry (1962).

The presence of presumably reworked specimens limits the value of the larger foraminiferal faunas for age determination. According to the recent stratigraphic compilations of Adams (1970), Haak and Postuma (1975), and Coleman (1978), the association of Cores 71 and 72 (with *Lepidocyclina* cf. *japonica*, *L.* cf. *ferreroi*, and *Miogypsina* sp.) would suggest the middle Miocene (early Tertiary f). The younger samples (particularly Core 40) with *L.* cf. *rutteni* might be slightly younger (early part of the late Miocene, late Tertiary f). The original life habitat of the fauna, following the models of Henson (1950) and

[2] Dr. J. P. Beckmann, Swiss Federal Institute of Technology, Sonneggstrasse 5, 8006 Zurich, Switzerland.

Chaproniere (1975), was probably a fairly shallow shelf (i.e., a fore-reef shoal). The associated megafossil remains (pelecypod fragments, echinoid spines, some bryozoans) give some further support to this assumption. The rare coral fragments may indicate the vicinity of a reef. The smaller benthic foraminifers (*Lenticulina*, *Bulimina*, *Asterigerina*, and others) in some samples suggest that faunal components of a slightly deeper-water origin may also be present.

The following is a list of larger foraminifers and associated microfossils found in samples from Hole 451. (All listed fossils are rare [one or few specimens], except where otherwise noted. The sections and intervals within each core are indicated.)

Core 31

1, 24–26 cm: *Ammonia* sp.

1, 38–40 cm
1, 50–56 cm
1, 88–90 cm
No distinct shallow-water fossils

Core 40

2, 9–12 cm: *Ammonia* sp., *Cycloclypeus* sp., *Lepidocyclina* sp., *Operculinoides* sp.

2, 37–41 cm: *Ammonia* cf. *indopacifica* (fairly common), *Amphistegina* spp. (fairly common), *Cycloclypeus* cf. *eidae/posteidae*, *Cycloclypeus* spp., *Lepidocyclina* sp., *Operculina* sp.

2, 66–70 cm: *Ammonia* cf. *indopacifica*, *Amphistegina* spp. (fairly common), *Cycloclypeus* cf. *eidae/posteidae*, *Lepidocyclina* cf. *rutteni*, *Operculina* sp.

2, 95–97 cm: *Ammonia* sp., *Amphistegina* sp., *Cycloclypeus* sp.

2, 97–99 cm: *Ammonia* sp., *Amphistegina* sp., *Cycloclypeus* cf. *eidae/posteidae*, *Cycloclypeus* sp., *Lepidocyclina* sp.
(*Lenticulina* sp.)

Core 42

2, 115–120 cm: *Ammonia* sp., *Amphistegina* sp., *Cycloclypeus* sp., (?)*Lepidocyclina* sp., *Operculina* sp.

Core 46

3, 3–6 cm: *Ammonia* sp., *Amphistegina* sp.
(?)coral fragment

3, 10–12 cm: *Operculinoides* sp.

3, 22–24 cm: *Amphistegina* sp., *Operculina* sp.

Core 47

1, 86–88 cm: *Amphistegina* sp., *Ammonia* sp., *Operculina* sp., (?)*Planorbulina* sp.

1, 136–138 cm: *Ammonia* sp., *Amphistegina* sp.

2, 18–22 cm: *Ammonia* sp., *Amphistegina* spp.
(*Bulimina*, *Asterigerina*)

Core 50

Sample 50,CC: *Ammonia* sp., *Amphistegina* sp.
Pelecypod fragments.

Core 69

1, 34–39 cm
2, 118–120 cm
No distinct shallow-water fossils

Core 71

1, 0–9 cm: *Ammonia* cf. *indopacifica* (fairly common), *Amphistegina* spp. (common), *Cycloclypeus* cf. *carpenteri/guembelianus*, *Cycloclypeus* sp., *Lepidocyclina* cf. *japonica*, *Miogypsinoides* cf. *complanata*, *Operculina* cf. *complanata*, *Operculina* sp., *Sphaerogypsina* sp.
Pelecypod fragments, echinoid spines.

1, 143–150 cm: *Ammonia* cf. *indopacifica* (fairly common), *Amphistegina* spp. (fairly common), *Cycloclypeus* sp., *Lepidocyclina* sp.
Pelecypod fragments, echinoid spines.

3, 113–120 cm: *Ammonia* cf. *indopacifica* (fairly common), *Amphistegina* spp (fairly common), *Cycloclypeus* sp., *Heterostegina* sp., *Lepidocyclina* cf. *japonica*, *Miogypsina* sp., *Operculina* cf. *complanata*, *Planorbulina* sp.
Pelecypod fragments, echinoid spines.

4, 122–132 cm: *Ammonia* cf. *indopacifica* (fairly common), *Amphistegina* spp. (fairly common), *Cycloclypeus* spp., *Lepidocyclina* cf. *ferreroi*, *Lepidocyclina* cf. *japonica*, *Miogypsina* sp., *Operculinella* sp.
Pelecypod and gastropod fragments, bryozoans, coral remains.

5, 8–12 cm: *Ammonia* cf. *indopacifica* (fairly common), *Amphistegina* spp. (fairly common), *Cycloclypeus* spp., *Heterostegina* sp., *Lepidocyclina* cf. *japonica*, *Operculinella* sp., *Planorbulina* sp.
Pelecypod fragments, echinoid spines, bryozoans.

5, 93–98 cm: *Ammonia* cf. *indopacifica* (fairly common), *Amphistegina* spp. (fairly common), *Cycloclypeus* cf. *eidae/posteidae*, *Cycloclypeus* sp., *Lepidocyclina* cf. *japonica*, *Operculina* cf. *complanata*, *Operculinella* sp., *Sphaerogypsina* sp.
(*Lenticulina*)
Echinoid spines, bryozoans, coral fragments.

6, 140–145 cm: *Ammonia* cf. *indopacifica* (fairly common), *Amphistegina* spp. (fairly common), *Cycloclypeus* spp., *Lepidocyclina* cf. *ferreroi*, *L.* cf. *japonica*, *Miogypsina* sp., *Operculinella* sp., *Sphaerogypsina* sp.
Echinoid spines.

Core 72

1, 23–28 cm: *Ammonia* cf. *indopacifica* (common), *Amphistegina* spp. (common), *Cycloclypeus* cf. *eidae/posteidae*, *Cycloclypeus* sp., *Lepidocyclina* cf. *japonica*, *Operculina* cf. *complanata*, *Operculinella* sp., *Planorbulinella* sp.
Pelecypod and coral fragments.

1, 60 cm: *Lepidocyclina* sp.

1, 103–105 cm: *Ammonia* cf. *indopacifica* (common), *Amphistegina* spp., *Cycloclypeus* spp., *Lepidocyclina* cf. *japonica*, *Lepidocyclina* sp., *Operculinella* sp.
Pelecypod fragments

1, 136–138 cm: *Ammonia* cf. *indopacifica* (fairly common), *Amphistegina* spp. (fairly common), *Cycloclypeus* cf. *eidae/posteidae*, *Cycloclypeus* sp., *Lepidocyclina* cf. *japonica*, *Lepidocyclina* sp., *Operculinella* sp. (fairly common), *Sphaerogypsina* sp.
(*Lenticulina*)
Pelecypod and (?)coral fragments.

2, 88–95 cm: *Ammonia* cf. *indopacifica* (common), *Amphistegina* spp. (fairly common), *Cycloclypeus* cf. *carpenteri/guembelianus*, *Cycloclypeus* cf. *eidae/posteidae*, *Lepidocyclina* cf. *japonica*, *Operculinella* sp., *Sphaerogypsina* sp.
(*Lenticulina*)
Pelecypod and (?)coral fragments, echinoid spines.

Radiolarians

The core-catcher samples of Cores 1 through 3 contain radiolarians in sufficient numbers to study; in Cores 451-4 and, -10, and Sample 14,CC, traces of this group were found, whereas all other cores appear to lack radiolarians.

The assemblage in Sample 451-1,CC, although belonging to the uppermost Pleistocene *Buccinosphaera invaginata* Zone (Nigrini, 1971), is mixed with elements of Pliocene to early Pleistocene and, in addition, contains a few Miocene orosphaerids. In Samples 2,CC and 3,CC the few species that are present do not allow a zonation; they do, however, indicate an age range from the late Pliocene to the early Pleistocene for the sediments.

Diatoms and Silicoflagellates

Diatoms occur only in the lower part of Core 1, in Core 2, and in the upper of Core 4. They are associated with rare silicoflagellates, sponge spicules, and endoskeletal dinoflagellates and were probably deposited during the late Pleistocene.

PALEOENVIRONMENT

In general, at Site 451, Cores 1 to 14 (except Cores 11–13, which had no recovery) contain common to abundant, moderately well-preserved calcareous nannofossils and planktonic and benthic foraminifers, suggesting deposition above the CCD. Cores 15 to 19 are either essentially barren, or there was no recovery. Below this level, planktonic foraminifers and nannofossils occur sporadically, possibly because of the dilution effect of the ash; preservation is often poor and seems to be associated with increasing induration of these sediments. Both of these fossil groups, however, were occasionally noted nearly to the bottom of the hole.

Benthic foraminifers are rare compared to the planktonic at Site 451, as is typical for sediments deposited at deep bathyal to abyssal depths above the CCD. The rare specimens that were observed in these samples include *Cibicides wuellerstorfi*, *Bulimina alazanensis*, *Gyroidina broeckhiana*, and other indicators of deep bathyal to abyssal waters.

From Core 31 downward, larger foraminifers occur sporadically. These shallow-water forms are reworked.

ACCUMULATION RATES

The depositional history of the sediments drilled at Site 451 can be broken down into four major phases, each characterized by a distinct average sediment accumulation rate (Fig. 9). The phases are gradational, and their boundaries are obviously influenced by the biostratigraphic data that control the overall curve of Figure 9.

In the first phase of deposition (above the bottom of the hole at 930.5 meters sub-bottom), over a span of only about 1.5 m.y. (until the early late Miocene), about 740 meters of volcanic debris consisting of ashes, tuffs, conglomerates, and breccias accumulated at a rate well over 400 m/m.y. On a fine scale, sedimentary structures such as graded bedding, slump features, channel cuts, and sharp fluctuations in size and lithologic character of clasts require that this deposition must have been episodic. In the early late Miocene, a decrease in the influx of volcaniclastic debris resulted in the second phase, during which depositional rates averaged 35 m/m.y. These rates prevailed until the early Pliocene, when a further decline occurred, during which predominantly biogenic sediments accumulated at about 10 m/m.y. It was finally during the Pleistocene that rates decreased to 5 m/m.y.

ORGANIC GEOCHEMISTRY

No gas shows were observed in the sediments of Site 451. The absence of significant hydrocarbon-gas generation within these sediments suggests that they are probably lean in organic matter.

The organic carbon and nitrogen contents were analyzed by methods discussed in the Introduction (this volume). These results, obtained from carbonate-free sediments, are given in Table 2 and plotted against depth in Figure 10. The erratic values of organic carbon

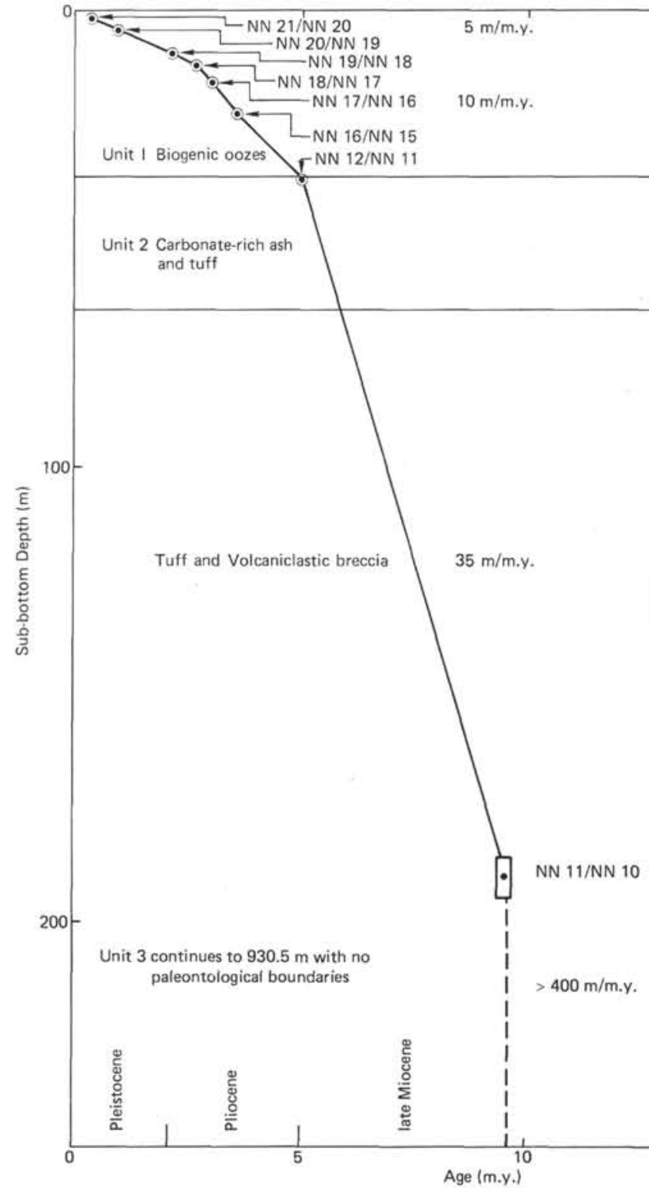


Figure 9. Accumulation rates estimated for the sediments drilled at Site 451. (The time scale and the calibration of the biostratigraphic zonal boundaries to this scale follow Schlanger et al. [1976]. The definition of the nannofossil zones is after Martini [1971]; that of the foraminiferal zones is after Blow [1969]. The horizontal bar shows the chronologic range of Zone NN 10 and the lowest level in Hole 451 at which an NN 10 assemblage was found. At this level in the hole, the fossils indicated that the base of Zone NN 10 was near. Between the NN 10/NN 11 boundary and the bottom of the hole a minimum depositional rate is shown by arbitrarily intersecting the horizontal bar at its oldest end. The dashed line indicates a minimum rate based upon an extrapolation to the lowest NN 10 assemblage.)

and nitrogen in Unit 1, a foraminifer–nannofossil ooze, cannot be readily explained, although it is perhaps significant that the C:N ratio remains roughly constant throughout Unit 1. The values of organic carbon and nitrogen for the vitric tuffs (Units 2 and 3) are low, resembling those of the same lithologies at Site 450. At one stratigraphic horizon, several brown-black seams

Table 2. Organic carbon and nitrogen contents (after carbonate dissolution).

Lithologic Unit or Sub-unit	Sample (intervals in cm)	Organic Carbon (wt. %)	Nitrogen (wt. %)	C:N (atomic ratio)
1	1-2, 31-32	0.22	0.015	17.2
1	1-3, 27-28	0.21	0.021	11.7
1	2-2, 126-127	0.19	0.019	11.7
1	2-5, 97-98	0.22	0.018	14.3
1	3-1, 40-41	0.10	0.009	13.0
1	3-4, 40-41	0.52	0.042	14.5
1	4-1, 130-131	0.35	0.030	13.7
1	4-4, 70-71	1.01	0.82	14.4
1	5-1, 88-89	0.44	0.032	16.1
2	5-4, 21-22	0.05	0.002	29.3
2	6-1, 106-107	0.05	0.004	14.6
2	6-4, 33-34	0.11	0.005	25.7
3a	14-1, 63-64	0.12	0.009	15.6
3e	56-3, 5-7	21.4[a]		
		34.6[a]		
		56.18[b]	0.47	119.0

[a] Shipboard measurements using two different standards (whole rock).
[b] Shore-based measurement on kerogen concentrate.

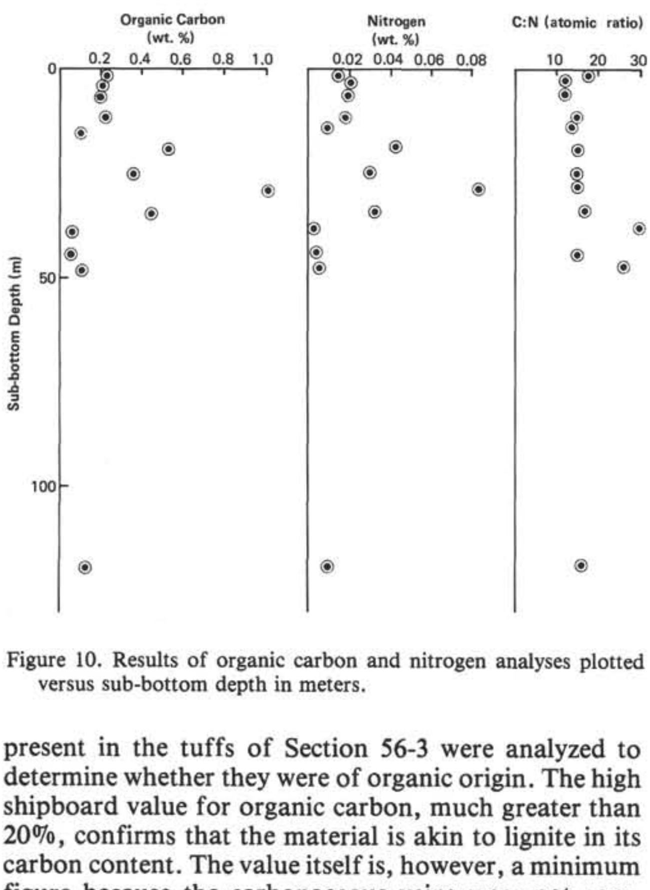


Figure 10. Results of organic carbon and nitrogen analyses plotted versus sub-bottom depth in meters.

present in the tuffs of Section 56-3 were analyzed to determine whether they were of organic origin. The high shipboard value for organic carbon, much greater than 20%, confirms that the material is akin to lignite in its carbon content. The value itself is, however, a minimum figure because the carbonaceous veins were not completely separated from their interbedded tuff. Two shipboard standards were used to calibrate the analysis of the lignite; one produced a calibration curve that gave 21 wt. % organic carbon for the sample, and the other gave 35 wt. % for the sample. Despite the imprecision of these shipboard analyses, the sample is thought to be of terrestrial origin because of its high C:N ratio (>44).

Subsequent shore-based analysis of the separated kerogen gives a much higher organic carbon value (56.18 wt. %) with a higher C:N ratio of 119, confirming that the material is carbonaceous and of terrestrial origin.

Methods used in Rock Eval analyses are presented in the Introduction (this volume). The results of these analyses are summarized in Table 3. Sediments from Units 1, 2, and 3 all have undetectable S_2 responses, except for the lignite seams, which have a broad flat S_2 peak maximizing at 425°C on the boundary of the oil zone of maturation. The small S_3 peak suggests that the sediments consist of mature organic matter. They have a low hydrocarbon potential, characteristic of Type III kerogens of terrestrial original (Tissot and Welte, 1978).

Unfortunately, only about 5 mg of kerogen concentrate were recovered; this amount is insufficient for detailed analysis to obtain further information on the characteristics and origin of this lignite. Attempts to investigate its pyrolysis-GC, the best geochemical tool for dealing with such small amounts of material, were unsuccessful. Its organic-carbon content, C:N ratio, and Rock Eval response all suggest that it is of terrestrial origin. It could represent a distal input to the sedimentary sequence (e.g., by rafting), but a local origin seems more appropriate, because the interbedded tuff contains a locally derived volcanic input. The formation of lignite is thought to occur only in terrestrial or deltaic environments, so that its occurrence nearly 300 meters sub-bottom in a volcaniclastic-breccia sequence seems to indicate the presence of a nearby land mass when the sediment was deposited. The form of the lignite, as oriented lenses within the tuff, suggests that it was deposited by slumping or a similar phenomenon.

The high organic carbon and nitrogen values of some of the nannofossil oozes cannot be attributed to pipedope contamination, because they have no significant S_2 response in Rock Eval analysis. One possibility is that their carbonate was incompletely dissolved during sample preparation, although the consistency in their C:N ratios then becomes rather surprising. Misweighing is a further possibility, because these analyses were not duplicated (as were those for Sites 447, 448, and 449). Sputtering in the combustion furnace could also result in anomalously high values.

Table 3. Qualitative estimate of the relative amount of free hydrocarbons, bound hydrocarbons, and CO_2 from kerogen (and carbonate-rich sediments) based upon sizes of S_1, S_2, and S_3 peaks, respectively, from Rock-Eval analyses.

Lithologic Unit or Sub-unit	No. of Samples	Free Hydrocarbon (S_1)	Bound Hydrocarbon (S_2)	CO_2 from Kerogen (S_3)
1	9	+	–	–
2	3	+	–	–
3a	1	+	–	–
3e (lignite)	1	+	++	+

Note: – = undetectable, + = minor, ++ = moderate relative amounts.

INORGANIC GEOCHEMISTRY OF INTERSTITIAL WATER

Samples for interstitial-water analysis were taken from four cores (451-2-4, 5-3, 14-1, and 34-1) and analyzed according to procedures outlined in the Introduction (this volume). The *p*H and alkalinity of Core 34, Section 1 could not be determined because its total pore-water content was too low. The data are plotted in Figure 11. The increase in Ca^{2+} content and parallel decrease in Mg^{2+} content with depth probably reflects basalt alteration within the vitric tuffs and ashes, as discussed for Sites 450 and 448. The enhanced alkalinity at 38 meters depth (Section 5-3) suggests that there may be a minor zone of sulphate reduction in the sedimentary sequence at that level. The increase in *p*H with depth indicates that the CO_2 content of the pore water is decreasing and that the samples may therefore be saturated with calcite.

IGNEOUS PETROGRAPHY

Hole 451 was cored continuously to a total depth of 930.5 meters; predominantly volcaniclastic conglomerates and breccias and interbedded tuffs were recovered. Basalt fragments recovered from the bottom 4 meters of the hole, where the drilling rate appreciably slowed, may represent the brecciated upper surface of a lava flow; otherwise no lava flows or igneous intrusions were penetrated.

The volcaniclastic conglomerates and breccias generally contain clasts of devitrified and/or altered pumice, glass, basalts, and andesites. Rare clasts of relatively fresh igneous rock are found throughout the section. These range in size from 1 to 15 cm (average, 5 cm). Twenty of the least-altered clasts were studied in thin section and subdivided according to phenocryst assemblages. The total abundance of phenocrysts and groundmass constituents are given as percentages of the whole rock (e.g., the rock consists of 10% phenocrysts, 5% vesicles, and 85% groundmass), whereas the abundance of individual phenocrysts or groundmass constituents are given as percentages of the total phenocrysts or total groundmass constituents (e.g., the phenocrysts consist of plagioclase [60%, 0.8 mm] and olivine [40%, 0.4 mm, altered to green smectite]; the groundmass consists of plagioclase [50%], both pyroxenes [20%], opaques [5%], and glass [25%]).

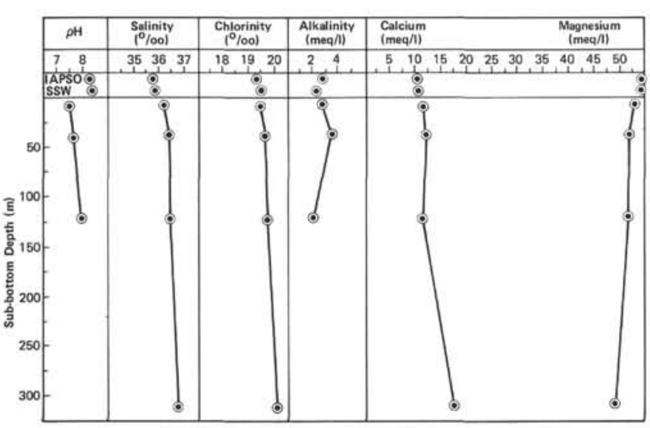


Figure 11. Results of analyses of interstitial water samples plotted versus sub-bottom depth in meters. (IAPSO standard and surface seawater [SSW] analyses are shown for comparison.)

Five petrologic types are recognized:

1) aphyric or sparsely phyric basalt (2 clasts);
2) plagioclase-clinopyroxene-phyric basalt (3 clasts);
3) clinopyroxene-plagioclase-phyric basalt (1 clast);
4) plagioclase-clinopyroxene-magnetite-(olivine)-phyric andesite (6 clasts); and
5) plagioclase-clinopyroxene-orthopyroxene-magnetite-(olivine)-phyric andesite (8 clasts).

Aphyric or sparsely phyric basaltic clasts contain very rare microphenocrysts of plagioclase (0.2–0.3 mm, subhedral) and clinopyroxene (0.3–0.5 mm, subhedral) set in hyalopilitic groundmass consisting of glass (60%) and flow-aligned microlites of plagioclase (40%). Microphenocrysts of olivine are found in a few cases as smectite pseudomorphs.

Plagioclase-clinopyroxene-phyric basaltic clasts contain 12% to 45% phenocrysts of plagioclase (80–95%, 0.1–4 mm, sub- to anhedral, glomerophyric, complex twinning and zoning) and scattered phenocrysts of green clinopyroxene (5–20%, 0.3–2 mm, eu- to subhedral, glomerophyric). The groundmass is vitriophyric to hyalopilitic and is 25% to 75% crystalline.

The one clinopyroxene-plagioclase-phyric basaltic clast contains 35% phenocrysts of clinopyroxene (60%) and plagioclase (40%) set in a vitriophyric groundmass, similar to the second type.

Plagioclase-clinopyroxene-magnetite-(olivine)-phyric andesitic clasts contain 20% to 55% phenocrysts of plagioclase (65–90%, 0.3–5 mm, An_{50-60}, sub- to euhedral, glomerophyric), scattered clinopyroxene (5–20%, 0.1–2 mm, rounded to euhedral, some partially resorbed), scattered magnetite (5–10%, 0.2–0.5 mm, subrounded octahedral), and rare olivine (0–10%, 0.1–2 mm, pseudomorphed by green and brown smectites). The clasts have 45% to 80% groundmass that is typically hyalopilitic, containing glass (40–60%) and flow-banded plagioclase microlites. Many petrographic features of these rocks suggest an andesitic composition (e.g., impoverishment of mafic constituents coupled with a plagioclase-phenocryst core composition of An_{50-60}, pronounced oscillatory zoning, repeated resorption followed by overgrowth, and strongly zoned glass inclusions).

Plagioclase-clinopyroxene-orthopyroxene-magnetite-(olivine)-phyric andesitic clasts are identical to those just described but contain othopyroxene as an additional phenocryst phase. These orthopyroxene phenocrysts are euhedral (4–10%, 0.2–1 mm, En_{80-70}) and contain common inclusions of magnetite. Orthopyroxene phenocrysts are sometimes partially or wholly replaced by smectites.

Preliminary comparison of volcanic sequences from Sites 451 and 448 identifies differences between the geologic evolution of the West Mariana and Palau-Kyushu Ridges. First, extensive deposits of late-Miocene(?) volcaniclastic breccias, conglomerates, and lithic and vitric tuffs encountered on the West Mariana Ridge are not characteristic of the Palau-Kyushu Ridge; during this same time interval about 100 meters of nannofossil ooze were deposited on the Palau-Kyushu ridge. The volcaniclastic sequence recovered at the Palau-Kyushu Ridge is older (middle Oligocene) and consists of alternations of volcaniclastic units with lava flows. Flows may be absent in the Miocene sequence of the West Mariana Ridge, with the possible exception of some brecciated basalts with nondiagnostic features at the bottom of Hole 451.

Although the volcanic suites of the Palau-Kyushu and the West Mariana Ridges are both arc-type volcanic suites and thus differ significantly from Layer 2 of typical oceanic crust, distinct differences between the basalts from the two ridges also exist: mineralogic evidence suggests that the proportion of high-alumina basalts, basaltic andesites, and andesites on the West Mariana Ridge is much higher than on the Palau-Kyushu Ridge. The West Mariana Ridge volcanic rocks are more similar to the Miocene volcanic rocks of Guam and Saipan (Larson et al., 1974; Tracey et al., 1964; Schmidt, 1957). In some basaltic andesites and andesites of the West Mariana Ridge, the presence of magnetite as a liquidus phase is noteworthy. This might be indicative of high oxygen and water fugacities in parental magmas characteristic of calc–alkalic volcanism.

The differences in the geologic evolution of the West Mariana and Palau-Kyushu Ridges are in good accordance with the hypothesis that the Parece Vela Basin formed as a result of inter-arc spreading from the middle Oligocene to the middle Miocene, with the West Mariana Ridge behaving as the active volcanic arc and the Palau-Kyushu Ridge as the remnant arc during that period of spreading.

METAMORPHIC PETROGRAPHY

Although no regional metamorphic rocks were observed in the 930.5 meters drilled at Site 451 on the West Mariana Ridge, much of the upper Miocene volcanic debris has been affected by low-grade hydrothermal activity over small stratigraphic intervals, marked by pyrite, zeolites, and clays. In a few cases, fine native copper veinlets were observed in a situation similar to those occurrences at Site 448, except the degree of alteration and abundance of alteration is much lower. There seems to be two types of alteration present: one is a very low-grade, gradual, pervasive increase in degree of alteration down-hole; the other seems to be relatively higher-temperature hydrothermal metamorphism of some parts of the sediment provenance unrelated to the present environment. Apparently this part of the provenance was more extensively altered because clasts of pyrite, clasts of rocks containing pyrite, and clasts of epidote(?) are fairly common.

PALEOMAGNETISM

No paleomagnetic samples were collected from Hole 451. The rock units at this site consisted of coarse to fine volcaniclastic rocks, for the most part. We encountered penecontemporaneous faults, folds, and slumps, as well as rigid-body faulting and uniform tilting, which make the hole unsuitable for paleomagnetic study. Rock magnetic studies of volcaniclastic breccias from Hole 448A (similar to those found in this hole) are described in a later chapter on paleomagnetism (Keating, this volume).

PHYSICAL PROPERTIES

Physical properties measured on the sediments recovered from Hole 451 include sonic velocity (horizontal and vertical), wet-bulk density, water content, porosity, and acoustic impedance. Methods and procedures are briefly summarized in the Introduction (this volume). Results are listed in Table 4 and are shown graphically in Figure 12.

Sonic velocities were measured on the least-disturbed sections of split cores from Unit 1 and on samples of the consolidated sediments of Units 2 and 3 in both vertical and horizontal directions. Velocities in calcareous oozes and tuffs of Units 1 and 2 range from 1.59 to 1.62 km/s. A significant increase in sonic velocity occurs in the more lithified tuffs and coarser volcaniclastic breccias of Unit 3. Velocities in Unit 3 range from 1.97 to more than 3.1 km/s, with no apparent increase with depth. The scattered values appear to correlate with the alternating lithologies. Although velocity anisotropy appears to be present, vertical velocity is not always lower than horizontal. This presumably reflects the unsorted, unoriented fabric of the coarse detritus. The velocity of one basalt cobble was measured at 4.75 km/s (Core 45, Section 1).

Wet-bulk density, porosity, and water content were measured on samples from Core 14 to the bottom of the hole. Poor core recovery precluded a continuous sequence of measurements between Cores 9 to 30. Core-catcher samples from this interval were used, however, to obtain supplemental values. Wet-bulk densities of 1.91 and 1.75 g/cm^3 from Cores 14 and 15, respectively, correspond to the uppermost semiconsolidated sediments (vitric tuffs of Sub-unit 3a). Porosity is about 47%, and water content ranges from 24% to 27% for Cores 14 and 15.

The wet-bulk density of the series of alternating coarse and fine volcaniclastic sediment comprising Sub-units 3b to 3g (from 280.5 m sub-bottom to the bottom of the hole) average only slightly higher than those of Sub-unit 3a, ranging from 1.89 to 2.2 g/cm^3. In this interval, water contents range from 15.8% to 24.24% and porosity values from about 34% to about 50%. In general, the density of coarse volcaniclastics is higher than that of the tuffs (Table 4). Acoustic impedance in Unit 3 ranges from 4.49 to 7.14×10^5 $g/(cm^2s)$, with no pronounced contrast present to indicate a strong reflector.

GEOPHYSICS

Site 451 is located on a terrace on the east face of the West Mariana Ridge. The site is located in about 2000 meters of water (Fig. 3), approximately 6 km west of the site originally selected. Because single-channel seismic-reflection data showed no obvious sediment overburden, we approached the site with some misgivings. Dur-

Table 4. Physical properties of sedimentary and igneous rocks from Hole 451.

Sample (hole-core-section)	Sub-bottom Depth (m)	Sonic Velocity Horizontal		Sonic Velocity Vertical	Wet-Bulk Density Gravimetric (g/cm³)	Wet-Bulk Density Continuous GRAPE (section averages) (g/cm³)b	Wet-Bulk Density Special 2-min GRAPE (g/cm³)b	Water Content (%)	Porosity (%)	Calculated Grain Density (g/cm³)	Acoustic Impedance [× 10⁵ g/(cm²s)]
451-2-1	5.75	—	—	—	—	1.51	—	—	—	—	—
451-2-3	8.75	—	—	—	—	1.56	—	—	—	—	—
451-2-4	10.95	—	—	—	—	—	—	47.63	—	—	—
451-2-5	11.81	1.595	—	—	—	—	—	—	—	—	—
451-3-3	18.25	—	—	—	—	1.51	—	—	—	—	—
451-3-6	23.34	1.608	—	—	—	—	—	—	—	—	—
451-4-3	27.24	1.587	—	—	—	—	—	—	—	—	—
451-4-3	27.75	—	—	—	—	1.49	—	—	—	—	—
451-5-2	35.75	—	—	—	—	1.51		—	—	—	—
451-5-3	37.70	1.639	—	—	—	—	—	—	—	—	—
451-5-3	37.95	—	—	—	—	—	—	31.88	—	—	—
451-5-4	38.75	—	—	—	—	1.72		—	—	—	—
451-5-4	38.96	1.634	—	—	—	—	—	—	—	—	—
451-6-1	44.08	1.608	—	—	—	—	—	—	—	—	—
451-6-3	46.17	1.616	—	—	—	—	—	—	—	—	—
451-7-1	53.25	—	—	—	—	1.50	—	—	—	—	—
451-14-1	119.77	1.974	—	—	—	—	—	—	—	—	3.77
451-14-1	119.78	—	—	—	1.911	—	—	24.61	47.03	2.720	—
451-14-1	120.45	—	—	—	—	—	—	29.16	—	—	—
451-15-1	128.90	3.077	—	—	—	—	—	—	—	—	5.38
451-15-1	128.91	—	—	—	1.747	—	—	27.15	47.43	2.421	—
451-20,CC	176.10	2.373	—	—	—	—	—	—	—	—	—
451-21,CC	185.60	2.850	—	—	—	—	—	—	—	—	—
451-23,CC	204.60	2.840	—	—	—	—	—	—	—	—	—
451-24-1	214.01	—	—	2.414	—	—	—	—	—	—	—
451-24-1	214.10	2.283	—	—	——	—	—	—	—	—	4.96
451-24-1	214.11	—	—	—	2.172	—	—	15.45	33.54	2.763	—
451-24-1	214.12	2.410	—	—	—	—	—	—	—	—	5.23
451-25-1	223.73	2.385	—	—	—	—	—	—	—	—	—
451-25-1	224.44	2.616	—	2.620	—	—	—	—	—	—	4.95
451-25-1	224.45	—	—	—	1.888	—	—	28.31	53.46	2.908	—
451-26-1	233.05	2.978	—	3.057	—	—	—	—	—	—	6.77
451-26-1	233.06	—	—	—	2.214	—	—	16.67	36.90	2.925	—
451-27-1	243.28	2.876	—	—	—	—	—	—	—	—	—
451-28,CC	252.10	2.786	—	—	—	—	—	—	—	—	—
451-29,CC	261.60	2.929	—	—	—	—	—	—	—	—	—
451-31-1	281.69	3.375	—	3.332	—	—	—	—	—	—	7.14
451-31-1	281.71	—	—	—	2.144	—	—	17.58	37.70	2.837	—
451-32-1	291.17	3.138	—	—	—	—	—	—	—	—	—
451-34-1	310.45	—	—	—	—	—	—	22.97	—	—	—
451-34-2	310.59	2.863	—	—	—	—	—	—	—	—	—
451-34-2	310.61	—	—	—	2.091	—	—	20.46	42.78	2.907	—
451-34-2	310.62	—	—	2.918	—	—	—	—	—	—	6.10
451-36-1	328.27	2.830	—	—	—	—	—	—	—	—	—
451-36-1	328.31	—	—	—	—	—	2.006	—	—	—	—
451-37-1	337.55	2.676	—	—	—	—	—	—	—	—	—
451-37-1	337.60	—	—	—	—	—	1.922	—	—	—	—
451-38-2	349.69	2.860	—	2.865	—	—	—	—	—	—	5.82
451-38-2	349.70	—	—	—	2.030	—	—	22.28	45.21	2.880	—
451-38-2	349.71	—	—	—	—	—	2.024	—	—	—	—
451-39-1	357.23	—	—	—	—	—	2.118	—	—	—	—
451-39-1	357.25	2.523	—	2.545	—	—	—	—	—	—	5.17
451-39-1	357.27	—	—	—	2.030	—	—	22.68	46.05	2.910	—
451-41-1	376.22	2.969	—	2.996	—	—	—	—	—	—	5.81
451-41-1	376.23	—	—	—	1.956	—	—	23.85	46.66	2.792	—
451-41-1	376.26	—	—	—	—	—	1.948	—	—	—	—
451-42-2	387.50	2.697	—	—	—	—	—	—	—	—	—
451-42-2	387.55	—	—	—	—	—	1.979	—	—	—	—
451-44-1	404.74	2.586	—	—	—	—	—	—	—	—	—
451-44-1	404.76	—	—	—	—	—	1.888	—	—	—	—

Table 4. (Continued).

Sample (hole-core-section)	Sub-bottom Depth (m)	Sonic Velocity Hori-zontal		Sonic Velocity Vertical	Wet-Bulk Density Gravi-metric (g/cm³)	Wet-Bulk Density Continuous GRAPE (section averages) (g/cm³)[b]	Wet-Bulk Density Special 2-min GRAPE (g/cm³)[b]	Water Content (%)	Poros-ity (%)	Calcu-lated Grain Density (g/cm³)	Acoustic Impedance [× 10⁵ g/(cm²s)]
451-45-1	414.24	—	4.751[a]	—	—	—	—	—	—	—	12.88
451-45-1	414.25	—	—	—	2.710	—	—	3.61	9.78	2.895	—
451-46-2	418.88	—	—	—	—	—	2.180	—	—	—	—
451-46-2	418.89	2.927	—	2.860	—	—	—	—	—	—	5.90
451-46-2	418.90	—	—	—	2.064	—	—	20.05	41.38	2.814	—
451-49,CC	442.40	—	—	—	—	—	1.914	—	—	—	—
451-49,CC	442.60	2.628	—	—	—	—	—	—	—	—	—
451-52-1	470.60	2.819	—	—	—	—	—	—	—	—	—
451-52-1	470.63	—	—	—	—	—	1.924	—	—	—	—
451-53-2	475.38	3.129	—	3.115	—	—	—	—	—	—	—
451-53-2	475.40	—	—	—	2.169	—	—	15.80	34.27	2.778	—
451-55-3	492.62	2.706	—	—	—	—	—	—	—	—	—
451-55-3	492.64	—	—	—	—	—	2.061	—	—	—	—
451-56-1	499.34	2.614	—	2.569	—	—	—	—	—	—	5.22
451-56-1	499.35	—	—	—	2.031	—	—	21.65	43.96	2.839	—
451-56-2	500.83	—	—	—	—	—	2.530	—	—	—	—
451-57-2	511.11	—	—	—	—	—	2.083	—	—	—	—
451-57-2	511.15	2.661	—	2.711	—	—	—	—	—	—	5.45
451-57-2	511.16	—	—	—	2.010	—	1.954	22.57	45.36	2.848	—
451-58-2	520.40	2.468	—	—	—	—	—	—	—	—	—
451-58-2	520.41	—	—	—	—	—	1.933	—	—	—	—
451-59-1	528.42	—	—	—	—	—	2.175	—	—	—	—
451-59-1	528.45	2.926	—	2.846	—	—	—	—	—	—	6.21
451-59-1	528.46	—	—	—	2.124	—	—	18.08	38.41	2.826	—
451-60-1	537.56	2.797	—	—	—	—	—	—	—	—	—
451-60-1	537.89	—	—	—	—	—	2.032	—	—	—	—
451-61-2	549.14	2.927	—	2.637	—	—	—	—	—	—	5.37
451-61-2	549.15	—	—	—	2.038	—	—	16.71	34.07	2.575	—
451-61-2	549.19	—	—	—	—	—	1.988	—	—	—	—
451-62-2	558.73	—	—	—	—	—	2.063	—	—	—	—
451-62-2	558.76	2.763	-	2.808	—	—	—	—	—	—	5.71
451-62-2	558.77	—	—	—	2.032	—	—	20.11	40.86	2.745	—
451-64-3	578.80	2.701	—	2.557	—	—	—	—	—	—	5.37
451-64-3	578.81	—	—	—	2.102	—	—	19.10	40.15	2.842	—
451-64-3	579.30	—	—	—	—	—	2.053	—	—	—	—
451-65-1	585.21	—	—	—	—	—	1.930	—	—	—	—
451-66-1	594.21	3.029	—	2.033	—	—	—	—	—	—	4.49
451-66-1	594.22	—	—	—	2.210	—	—	18.02	39.83	3.011	—
451-66-1	594.89	—	—	—	—	—	2.115	—	—	—	—
451-67-1	604.04	2.480	—	—	—	—	—	—	—	—	5.29
451-67-1	604.05	—	—	—	2.134	—	—	23.16	49.42	3.242	—
451-70-2	633.65	2.697	—	—	—	—	—	—	—	—	—
451-70-2	633.67	—	—	—	—	—	1.969	—	—	—	—
451-70-2	633.72	2.622	—	—	—	—	—	—	—	—	5.44
451-70-2	633.73	—	—	—	2.074	—	—	24.24	50.27	3.160	—
451-71-1	642.33	—	—	—	—	—	2.038	—	—	—	—
451-71-1	642.40	2.539	—	2.539	—	—	—	—	—	—	—
451-71-1	642.42	—	—	—	2.104	—	—	21.26	44.73	2.997	—
451-72-2	653.06	2.753	—	2.646	—	—	—	—	—	—	5.95
451-72-2	653.08	—	—	—	2.247	—	—	18.52	41.62	3.136	—
451-72-2	653.09	—	—	—	—	—	2.151	—	—	—	—
451-74-1	670.12	2.916	—	—	—	—	—	—	—	—	—
451-74-1	670.13	—	—	—	—	—	2.202	—	—	—	—
451-75,CC	679.90	3.069	—	—	—	—	2.222	—	—	—	—
451-79-1	708.30	2.480	—	2.413	—	—	—	—	—	—	5.12
451-79-1	708.31	—	—	—	2.120	—	—	20.34	43.12	2.970	—
451-79-1	708.50	—	—	—	2.081	—	—	23.55	49.00	3.119	
451-79-7	717.33	—	—	—	—	—	2.232	—	—	—	—
451-80-1	718.03	—	—	—	—	—	2.134	—	—	—	—
451-81-1	728.21	2.612	—	2.551	—	—	—	—	—	—	5.39

Table 4. (Continued).

Sample (hole-core-section)	Sub-bottom Depth (m)	Sonic Velocity Hori-zontal		Vertical	Wet-Bulk Density Gravi-metric (g/cm^3)	Continuous GRAPE (section averages) (g/cm^3)[b]	Special 2-min GRAPE (g/cm^3)[b]	Water Content (%)	Poros-ity (%)	Calcu-lated Grain Density (g/cm^3)	Acoustic Impedance [$\times 10^5$ $g/(cm^2s)$]
451-81-1	728.22	—	—	—	2.113	—	—	21.13	44.66	3.012	—
451-84-4	760.27	2.737	—	—	—	—	—	—	—	—	—
451-86-1	775.29	—	—	—	—	—	2.155	—	—	—	—
451-86-2	776.13	2.484	—	2.376	—	—	—	—	—	—	4.89
451-86-2	776.14	—	—	—	2.057	—	—	20.66	42.51	2.839	—
451-88-2	795.56	2.679	—	2.620	—	—	—	—	—	—	5.41
451-88-2	795.58	—	—	—	2.066	—	—	20.52	42.39	2.850	—
451-90-1	812.68	—	—	—	—	—	2.167	—	—	—	—
451-92-1	832.85	2.678	—	—	—	—	—	—	—	—	—
451-94-2	852.75	2.805	—	—	—	—		—	—	—	—
451-94-2	852.76	—	—	—	—	—	2.247	—	—	—	—
451-95-1	861.05	2.734	—	—	—	—	—	—	—	—	—
451-99-1	898.64	2.973	—	—	—	—	—	—	—	—	—
451-99-1	898.65	—	—	—	—	—	2.222	—	—	—	—
451-100-1	907.53	2.531	—	—	—	—	—	—	—	—	—
451-102,CC	926.6	—	3.616[a]	—	—	—	—	—	—	—	—

[a] Basalt average velocity.
[b] Based on an assumed grain density of 2.75 g/cm^3.

ing the approach, no discernible reflectors were observed in the reflection profile recorded on board the *Glomar Challenger* (Fig. 13). After crossing the objective site, the vessel came about on a reciprocal course, and the beacon was dropped over what appeared to be a "soft" seafloor reflector. We experienced initial concern, however, as to whether a hard basement was present near or at the surface and whether or not a sufficient thickness of soft sediment was present to facilitate burying the bottom-hole assembly. Thus, in spudding-in we exercised more than the usual amount of caution.

After a considerable depth had been penetrated in the drilling at Hole 451, the reason for the absence of discernible sub-bottom reflectors became obvious. No sharp contrast in acoustic impedance was encountered down-hole (see the section on Physical Properties, this chapter), which explains the lack of any strong reflector. Furthermore, the laboratory measured velocity of the highly altered basalt encountered at the bottom of Hole 451 at a depth of 926.5 meters sub-bottom is only about 3.6 km/s and thus is in the range of the basement velocities mentioned earlier.

SUMMARY AND CONCLUSIONS

Site 451, at 18°00.88'N and 143°16.57'E on the eastern side of the West Mariana Ridge, was drilled with the primary objective of determining the petrologic character of this formerly active volcanic arc as well as the timing of cessation of volcanism, particularly with reference to the age of the spreading of the Mariana Trough and the creation of the active volcanic arc—the Mariana Ridge—east of Site 451 (Fig. 1). Continuous coring at Hole 451 resulted in a total recovery of 280.1 meters out of 930.5 meters drilled. Hole 451 was terminated at 930.5 meters because of severe plugging of the bit and scheduling considerations. Sediments and sedimentary rocks were cored to a depth of 926.5 meters. Below that level, a decrease of drilling rate and recovery of altered basalt pieces suggest that 4.0 meters of basalt were encountered. A total of three major biogenous and volcaniclastic sedimentary units range in age from the late Miocene to the Quaternary. No unit is assigned to the small interval (4.0 m) of basalt at the bottom of the hole, because insufficient basalt was recovered to refute the possibility that the basalt is only a large clast.

The sedimentary section consists of:

Unit 1 (0.0–36.0 m), lower Pliocene to Quaternary calcareous biogenic oozes consisting of grayish brown foraminifer ooze, grayish brown foraminifer–nannofossil ooze, light yellow nannofossil–foraminifer ooze, and a light gray nannofossil ooze.

Unit 2 (36.0–65.5 m), upper Miocene to lower Pliocene olive-gray, carbonate-rich vitric ash with minor vitric tuff.

Unit 3 (65.5–930.5 m), upper Miocene volcaniclastic rocks consisting of seven sub-units:

Sub-unit 3a (65.5–280.5m), upper Miocene, dark gray to black vitric tuffs, vitric ash, and carbonate-rich vitric ash;

Sub-unit 3b (280.5–413.5 m), upper Miocene, interbedded dark gray vitric tuff and dark gray volcaniclastic breccias and conglomerates containing organic carbonate grains;

Sub-unit 3c (413.5–425.2 m), upper Miocene, dark gray boulder volcaniclastic conglomerate grading to carbonate-rich vitric tuff;

Sub-unit 3d (425.2–474.5 m), upper Miocene, black vitric tuff;

Sub-unit 3e (474.5–641.9 m), upper Miocene, interbedded black and greenish black vitric tuff and volcaniclastic breccias and conglomerates;

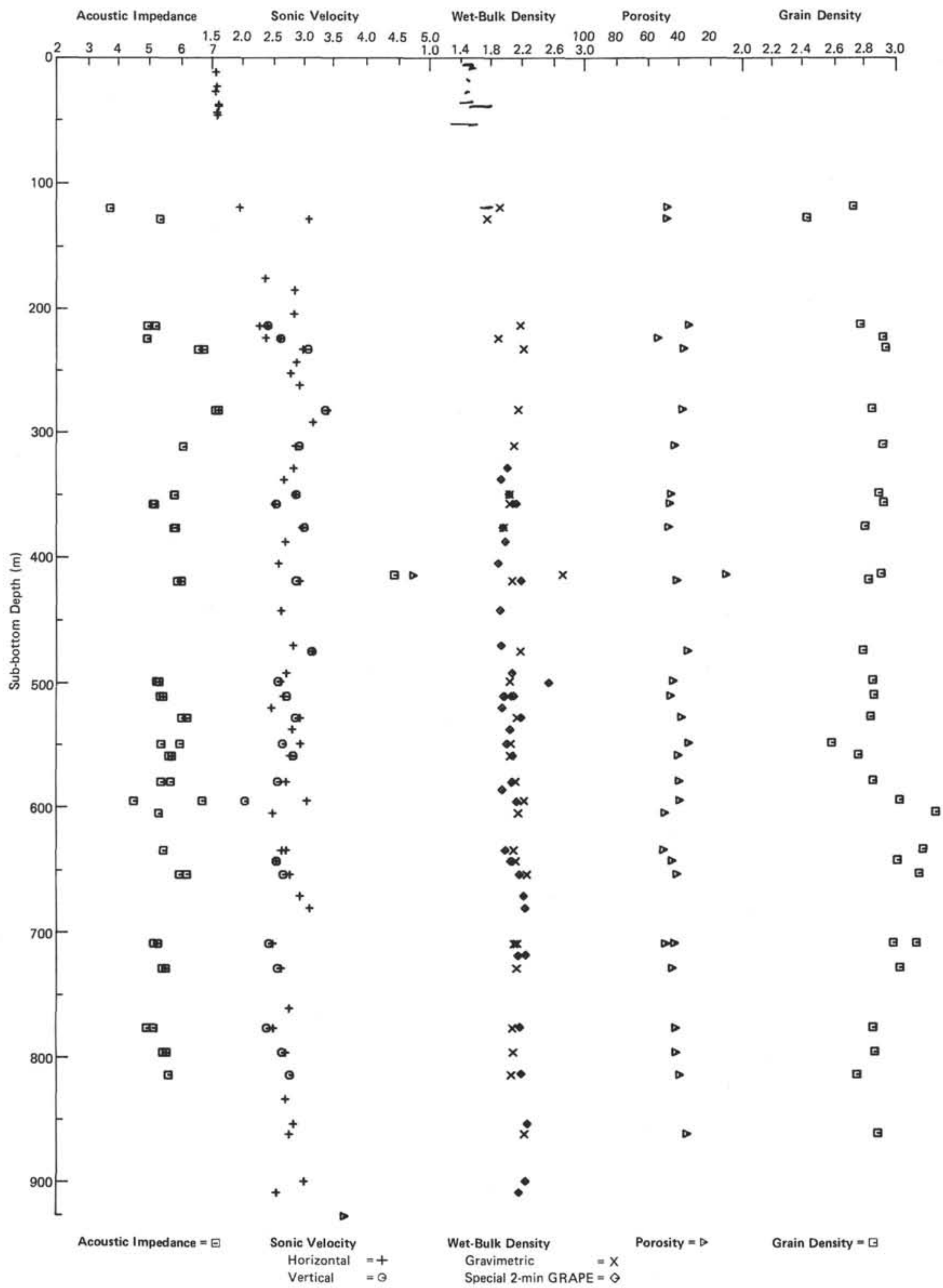


Figure 12. Physical properties of sedimentary and igneous rocks from Hole 451 plotted versus sub-bottom depth in meters. (Acoustic impedance is the product of velocity and bulk density. Sonic velocity measurements include horizontal and vertical velocity of sediments and average velocity of basalts. Gravimetric determinations of wet-bulk density are shown. Special 2-minute and continuous GRAPE determinations of wet-bulk density are also shown, based on an assumed grain density of 2.75 g/cm^3. Porosity was determined gravimetrically, and grain density was calculated from porosity and bulk density.)

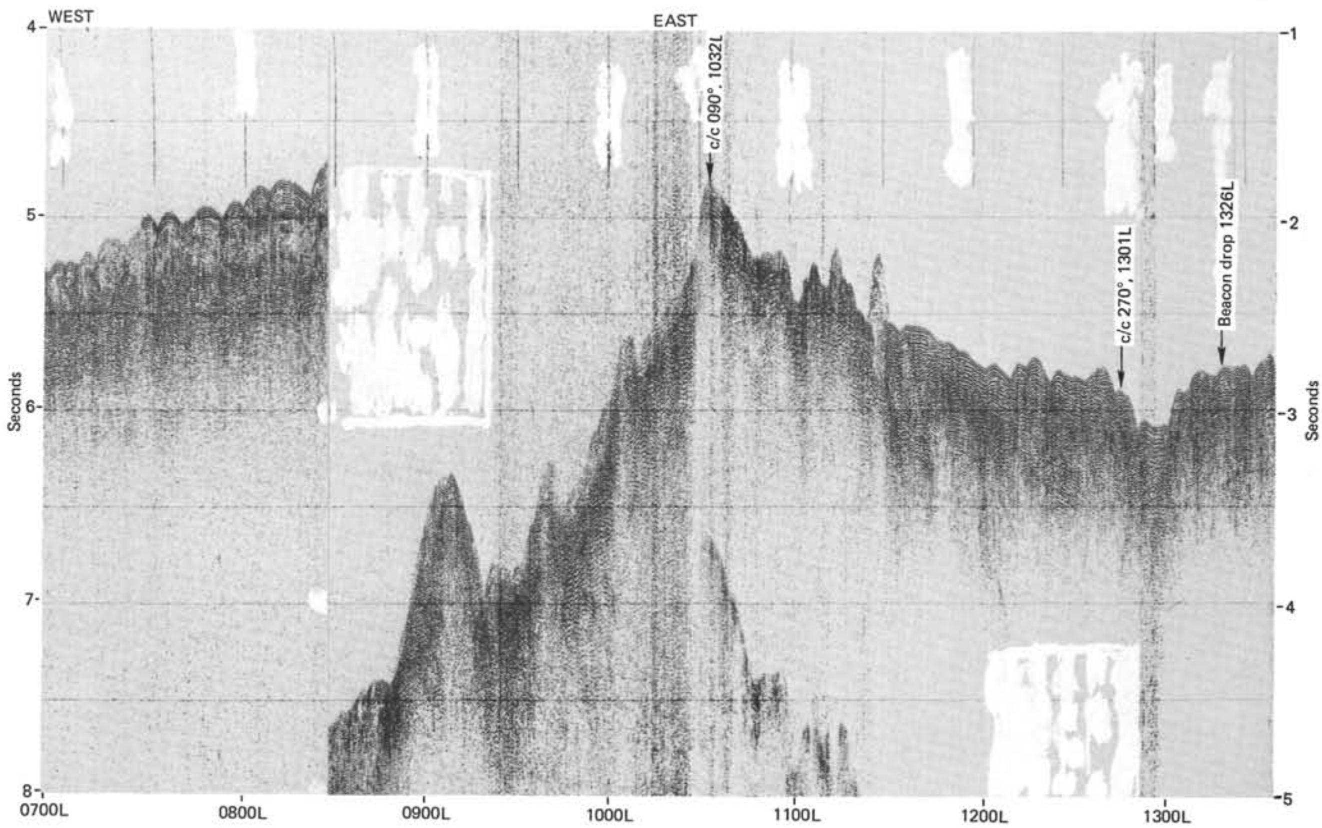


Figure 13. Reflection profile across Site 451 recorded during the approach to the site aboard the *Glomar Challenger*.

Sub-unit 3f (641.9–703.6 m), upper Miocene, black vitric tuff; and

Sub-unit 3g (703.6–930.5 m), upper Miocene, interbedded greenish black vitric tuff with greenish black volcaniclastic breccias and conglomerates.

The recovery of thick sequences of coarse, massive volcaniclastic sediments at Site 451 provides a unique opportunity to investigate tectonic, volcanic, and sedimentologic interrelationships. The repetitious sequences of coarse angular debris grading upward into fine bioturbated layers represent spasmodic deposition probably controlled by tectonic events, because sedimentologic evidence suggests that this debris was deposited in shallow-water to subaerial conditions and was not controlled by direct pulses of volcanic activity. Fragments of corals, gastropods, and larger foraminifers suggest significant reworking of shallow-water deposits. In addition, lenses of lignite in the tuffs are proof that a nearby vegetated land surface on the West Mariana Ridge existed. Scattered pumiceous layers may record local explosive andesitic volcanic events.

To elaborate on the previous discussion, in the last 4 meters of drilling (926.5–930.5 m), the drilling record shows that we encountered a unit resistant to drilling, which behaved in a manner similar to basalts encountered in previous sites. The drilling rate slowed in the unit from 4 minutes per meter to nearly 12 minutes per meter (Fig. 7). Although no clear evidence exists to determine absolutely that the rock recovered is a flow or sill and not a clast, there is considerable circumstantial evidence that points in this direction: (1) the drilling record; (2) a green clay surrounding the crystalline rock that may be altered glass; (3) small fragments of the crystalline rock that are isolated in a green clay; (4) a 3.9-km/s basement was predicted close to this level, and the altered basalt has a velocity of 3.6 km/s; and finally (5) the unit above consists of coarse volcaniclastic debris, yet no coarse sedimentary debris surrounds the basalt itself. The basalt is extremely altered to green clays and is riddled with disseminated native copper (up to 5% or 10% in small pockets). Whether the basalt is only a boulder in the sedimentary sequence, an isolated intrusive body, or the uppermost section of the volcanic-arc basement, it is aphyric and very highly altered.

Within the volcaniclastic sediments five petrographic groups of volcanic clasts were found:

1) aphyric or sparsely phyric basalt;
2) plagioclase-clinopyroxene-phyric basalt;
3) clinopyroxene-plagioclase-phyric basalt;
4) plagioclase-clinopyroxene-magnetite-(olivine)-phyric andesite; and
5) plagioclase-clinopyroxene-orthopyroxene-magnetite-(olivine)-phyric andesite.

Groups 4 and 5 are most abundant, and their two-pyroxene-plus-magnetite phenocryst assemblage in an andesite definitely suggests a calc-alkalic volcanic suite. This greater abundance of calc-alkalic rocks from the West Mariana Ridge compared to the Palau-Kyushu

Ridge indicates a progression to more calc-alkalic and more siliceous rocks with time toward the active Mariana arc.

Although these sedimentary units consist predominately of volcaniclastic debris, calcareous fossils are present. Nannofossils give no indication of hiatuses; apparently a continuous upper-Miocene to Quaternary sequence exists. Although radiolarians, diatoms, and silicoflagellates, in addition to nannoplankton and foraminifers, are present above Core 3, only calcareous nannoplankton and foraminifers occur below this level. The nannofossil boundary NN 10/NN 11 is the only boundary found below the Pliocene/Miocene boundary (between 176.0 and 195.0 m), and no foraminifer boundaries were observed. However, in the 765.0 to 774.5 meter sub-bottom interval, the nannoplankton assemblage characterizes the base of NN 10 (upper Miocene). Below Core 31 (>282.0 m) larger foraminifers, coral fragments (Fig. 14), and gastropod fragments are present; this evidence suggests that the sediments were originally deposited in shallow waters (less than 100 m) and then were transported into deeper environments. Fragments of lignite within tuffs probably were not formed *in situ* because of the local occurrence of numerous isolated lenses, typically only 1 cm in diameter. A more likely origin would be the erosion of nearby existing lignite beds in the landmasses of the volcanic arc itself.

Accumulation rates were very high—400 m/m.y. during late Miocene volcanic activity, decreasing to 35 m/m.y. during late Miocene and early Pliocene. By late Pliocene, the rate was as low as 5 m/m.y. These changes reflect only cessation of volcanic activity, because the region stayed above the CCD throughout its history.

The most impressive feature of the physical properties data is the relative uniformity of acoustic-impedance values. Without differences in acoustic impedance, no reflecting horizons would be detected; this explains why no obvious transparent sediment over-burden could be seen at Site 451.

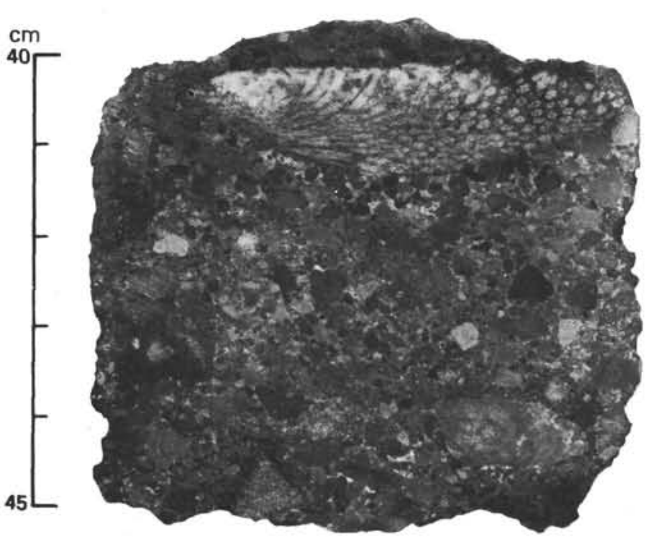


Figure 14. Coral fragment in Sub-unit 3g, indicating a shallow-water source for some of the sediment provenance.

The sequence of events at Site 451 from oldest to youngest can be summarized as follow:

1) A volcanic-arc basement (3.5–4.2 km/s, ~1.5 km thick) was constructed (by 11 m.y. ago) on oceanic(?) basement (5–6 km/s).

2) In the next 2 m.y., about 850 meters of volcaniclastic debris accumulated at a rate of about 400 m/m.y. Locally, the arc was emergent.

3) Tilting (up to 25°) and normal faulting in these sediments occurred both penecontemporaneously by soft-sediment deformation and after induration by rigid-body deformation (Fig. 15, A-D).

4) A dramatic decrease in accumulation rate of volcanic ash marked the end of intense West Mariana Arc volcanism (at 9 m.y. ago).

5) Sporadic volcanism continued, however, for another 4 m.y. (9–5 m.y. ago). The source of the ash may have been waning volcanism of the West Mariana Arc, but the timing of initiation of rifting to form the Mariana Trough and of activation of the modern Mariana Arc is not very well known; the source of the ash may have been early volcanism from the Mariana Arc, windblown across the young, narrow Mariana Trough.

6) Only calcareous biogenous sediments accumulated from 5 m.y. ago to present.

Now that both arcs on either side of the basin and the basin itself have been drilled, a strong case for symmetric spreading can be built for the Parece Vela Basin using several lines of evidence: (1) The time of cessation of volcanism on the Palau-Kyushu Ridge, determined by paleontology, dates the probable initiation of the Parece Vela Basin formation by back-arc spreading (29–32 m.y.). (2) The identification of magnetic anomalies (Langseth, Mrozowski, this volume) in the Western Parece Vela Basin also dates the initiation of spreading (this date coincides with the cessation of volcanism). These anomalies give the time of extinction of the Parece Vela spreading system (about 14–18 m.y.). The Parece Vela Rift bisects the basin. (3) The age of the basement under Site 449 (24 m.y.), determined by paleontology, confirms the magnetic-age estimate; more important, all three dates fall close to a straight line on a time-versus-distance plot (Fig. 16); this requires a rather constant spreading rate (~3.0 cm/yr) and makes the strong case for spreading from the Parece Vela Rift to form the western side of the Parece Vela Basin. More circumstantial evidence must be used for the eastern side, because extrusive basement was never reached and the magnetic-anomaly pattern was not identified. (4) Sites 450 and 53 were drilled into intrusive igneous rocks rather than into extrusive basement; the ages of the oldest sediments encountered are approximately 17 and 18 m.y., respectively, and are several million years younger than basement ages predicted from the symmetrical spreading model (Fig. 16). (5) Site 54 was drilled in the eastern Parece Vela Basin closer to the IPOD Trough over a structure that is similar to the intrusive structures at Sites 450 and 53. Although evidence of the intrusive nature of Site 54 is absent (Karig, Ingle,

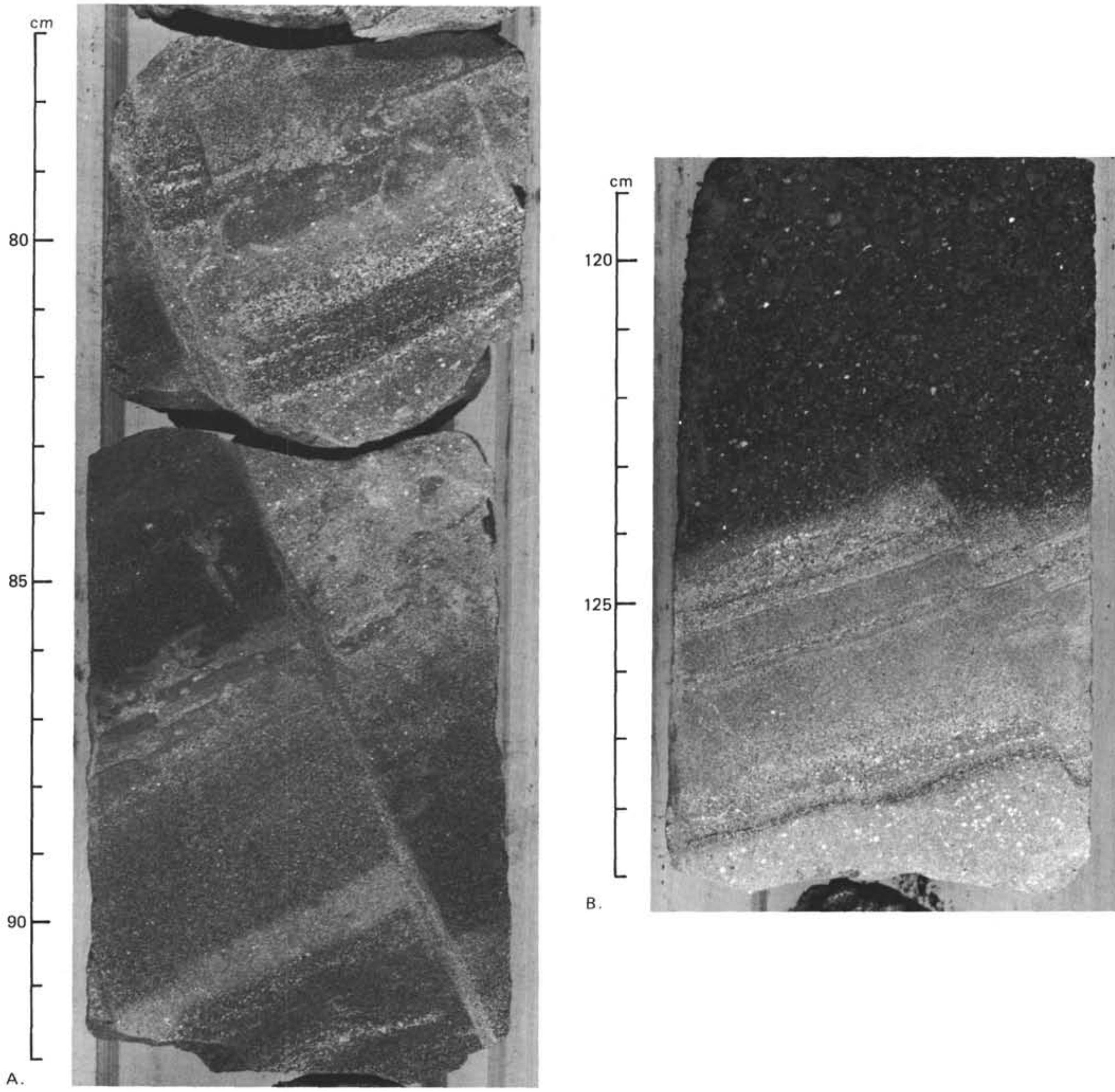


Figure 15. Rigid-body determination of lithified volcaniclastic debris in (A) Sub-unit 3b, Core 42, Section 1, in (B) Sub-unit 3b, Core 42, Section 2, in (C) Sub-unit 3c, Core 46, Section 2, and (D) Sub-unit 3e, Core 60, Section 2. (All of these appear to be normal faults with several centimeters of displacement except A, which must have greater than 15 cm of displacement.)

et al., 1975), it is possible that this site is also intrusive, particularly in light of the intrusions encountered in the northern extension of the Parece Vela Basin—the Shikoku Basin (Klein, Kobayashi, et al., in press)—on Leg 58. (6) The volcanism of the West Mariana Ridge ended intense activity about 11 m.y. ago and sporadic activity about 5 m.y. ago; that is, volcanism (and presumably subduction) continued for at least 8 m.y. after the end of spreading in the Parece Vela Basin. Careful measurement of the dimensions of the Parece Vela Basin (Fig. 17) shows that the eastern side is about 50 km closer to the IPOD Trough than is the western side. Rather than attribute this phenomenon to asymmetrical spreading, a more probable explanation may be that the western side of the West Mariana Ridge had been extended over the oldest marginal-basin crust during construction of the new arc; that is, not only was the arc side of a marginal basin affected by tectonism, off-axis intrusion, and inundation by arc-derived sediments, but it was also the platform upon which the arc grew.

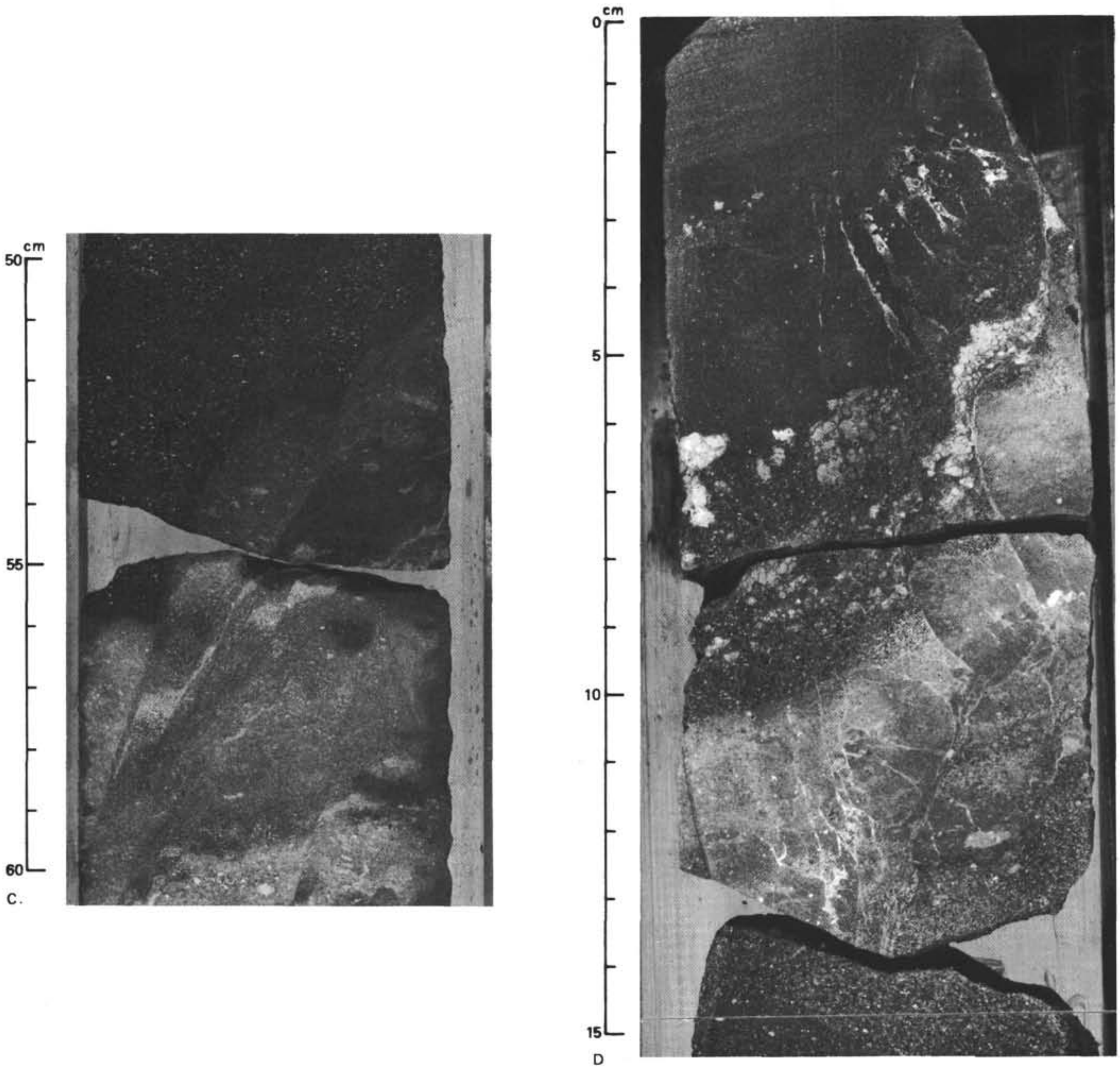


Figure 15. (Continued).

After rifting of the subduction side of the arc away from the remnant portion,a new "rear end" of the arc was rebuilt over the new basin floor.

REFERENCES

Adams, C. G., 1970. A reconsideration of the East Indian letter classification of the Tertiary. *Bull. British Mus. (Nat. Hist.), Geol.*, 19:87.

Blow, W. H., 1969. Late middle Eocene to Recent planktonic foraminiferal biostratigraphy. *Proc. First Conference Planktonic Microfossils, Geneva, 1967*, 1:199–422.

Chaproniere, G. C. H., 1975. Paleoecology of Oligo-Miocene larger foraminiferida, Australia. *Alcheringa*, 1:37.

Coleman, P. J., 1978. Reflections on outer Melanesian Tertiary larger foraminifera. *Bull. Min. Res. Geol. Geoph.*, 192:31.

Haak, R., and Postuma, J. A., 1975. The relation between the tropical planktonic foraminiferal zonation and the Tertiary Far East letter classification. *Geol. en Mijnb.*, 54:195.

Henson, F. R. S., 1950. Cretaceous and Tertiary reef formations and associated sediments in Middle East. *Bull. Am. Assoc. Petrol. Geol.*, 34:215.

Ingle, J. C., 1975. Summary of late Paleogene-Neogene insular stratigraphy, paleobathymetry, and correlations in the Philippine Sea and Sea of Japan region. *In* Karig, D. E., Ingle, J. C., Jr., et al., *Init. Repts. DSDP*, 31: Washington (U.S. Govt. Printing Office), 837–855.

Karig, D. E., 1975. Basin genesis in the Philippine Sea. *In* Karig, D. E., Ingle, J. C., Jr., et al., *Init. Repts. DSDP*, 31: Washington (U.S. Govt. Printing Office), 857–879.

Karig, D. E., and Glassley, W. E., 1970. Dacite and related sediment from the West Mariana Ridge, Philippine Sea. *Bull. Geol. Soc. Am.*, 81:2143-2146.

Karig, D. E., Ingle, J. C., Jr., et al., 1975. *Init. Repts. DSDP*, 31: Washington (U.S. Govt. Printing Office).

Klein, G. deV., Kobayashi, K., et al., in press. *Init. Repts. DSDP*, 58: Washington (U.S. Govt. Printing Office).

Larson, E. C., Reynolds, R. L., Merrill, R., et al., 1974. Major elements of petrochemistry of some extrusive rocks from the volcanically active Mariana Islands. *Bull. Volcanol.*, 38:361-377.

MacGillavry, H. J., 1962. Lineages in the genus *Cycloclypeus* Carpenter (Foraminifera). *Koninkl. Ned. Akad. Wetenschap. Proc., B*, 65:429.

Martini, E., 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. *Proc. Second Planktonic Conference, Rome, 1970*, 2:739–785.

Murauchi, S., Den, N., Asano, S., et al., 1968. Crustal structure of the Philippine Sea. *J. Geophys. Res.*, 73:3143–3171.

Nigrini, C. A., 1971. Radiolarian zones in the Quaternary of the equatorial Pacific Ocean. *In* Funnel, B. M., and Riedel, W. R. (Eds.), *The Micropaleontology of Oceans:* New York (Cambridge Univ. Press), pp. 443–461.

Schlanger, S. O., Jackson, E. D., et al., 1976. *Init. Repts. DSDP*, 33: Washington (U.S. Govt. Printing Office).

Schmidt, D. G., 1957. Geology of Saipan: petrology of the volcanic rocks. *U.S. Geol. Survey Prof. Paper 280-B:* Washington (U.S. Govt. Printing Office), b127–b174.

Tissot, B. P., and Welte, D. H., 1978. *Kerogen. Petroleum Formation and Occurrence:* Berlin (Springer-Verlag), pp. 142-147.

Tracey, J. I., Schlanger, S. O., Stark, J. T., et al., 1964. General geology of Guam. *U.S. Geol. Survey Prof. Paper 403-A:* Washington (U.S. Govt. Printing Office).

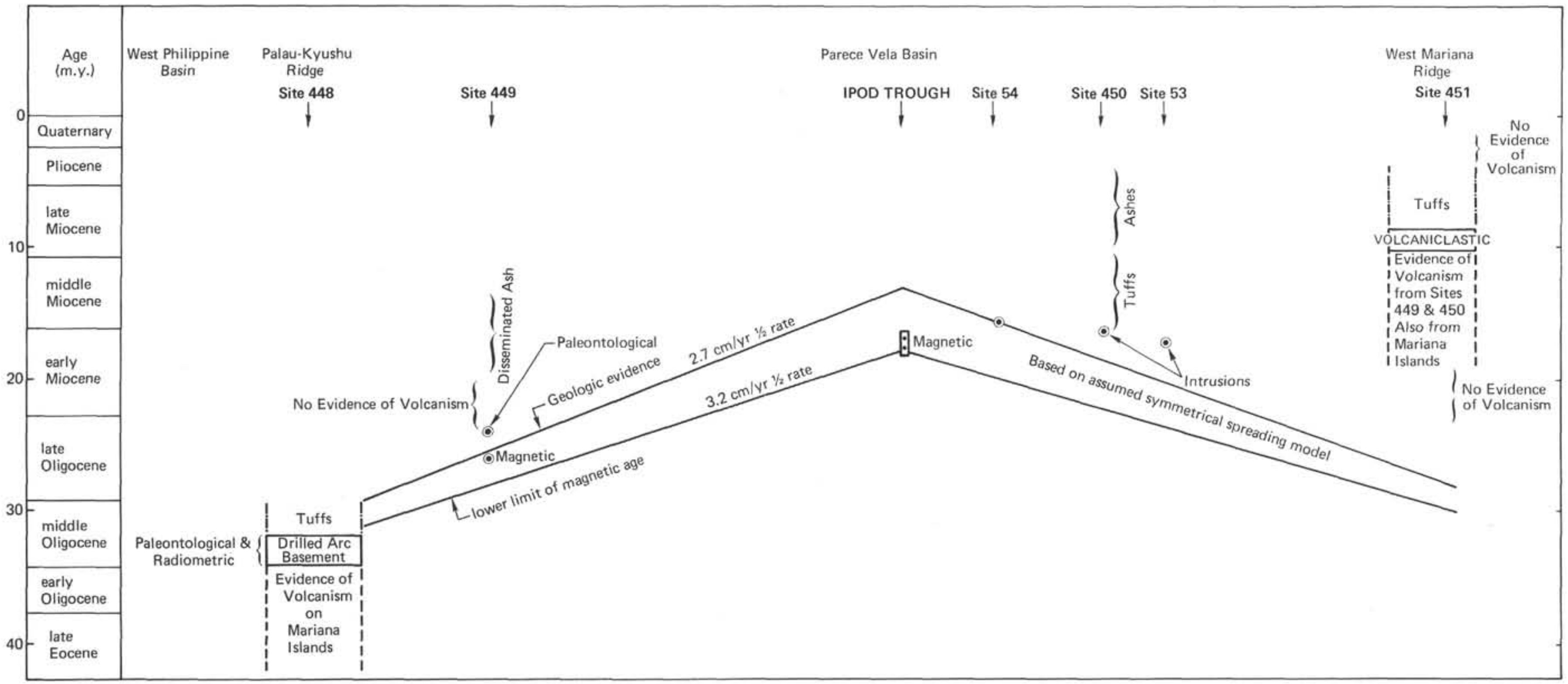


Figure 16. Time-versus-distance plot of the Parece Vela Basin along a profile drawn perpendicular to the IPOD Trough at 18°N. (Solid lines on ridges indicate periods that have direct evidence of abundant volcanism, dashed lines are inferred volcanism based on indirect evidence, and dash-dot lines show periods of waning volcanism. The sloping lines indicate periods of back-arc spreading of the Parece Vela Basin—a line based upon geologic evidence and one on magnetic evidence are both drawn. Periods of lack of volcanism or presence of volcanism in the sedimentary record are depicted by braces.)

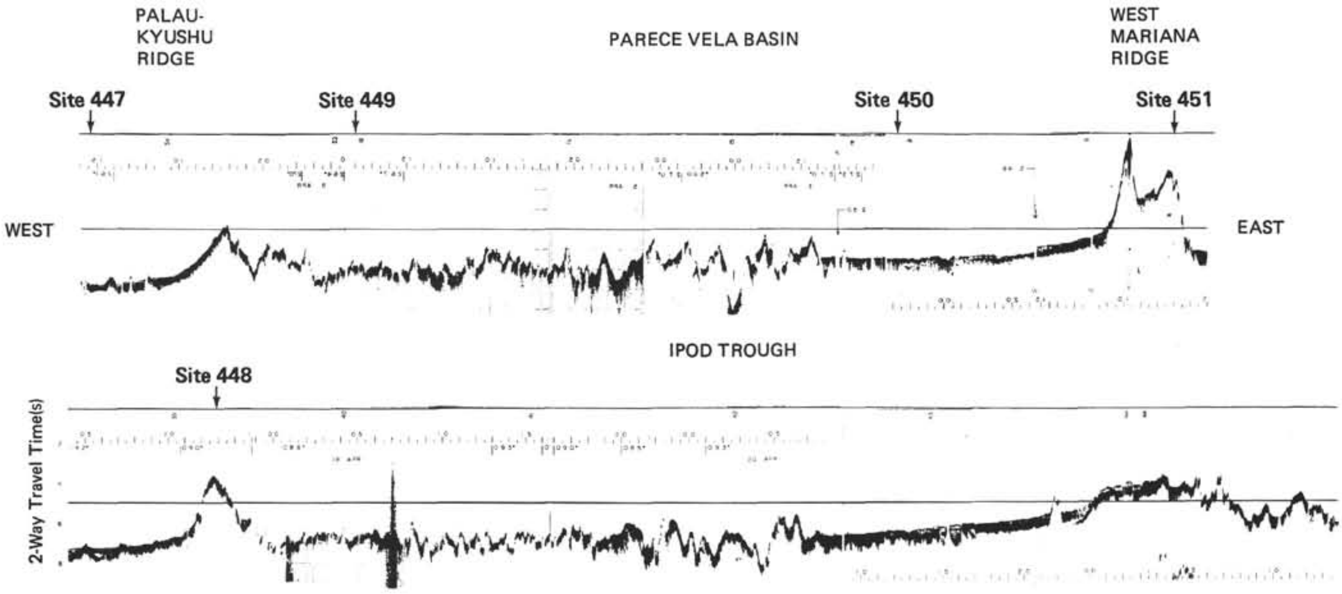
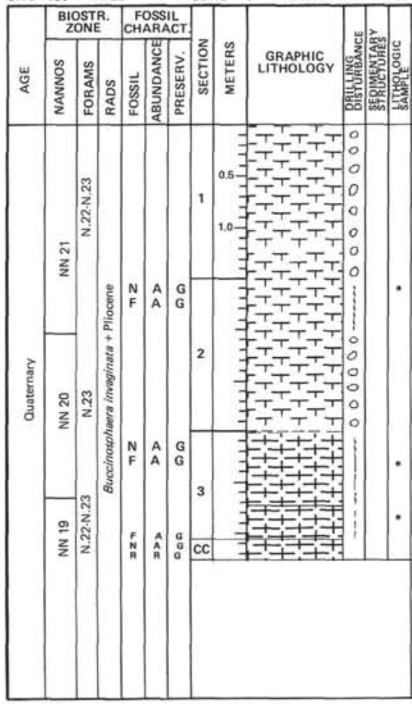


Figure 17. Seismic-reflection profiles across the Parece Vela Basin (L-DGO Site Survey data) along about the 17°60′ parallel (above) and about the 15°70′ parallel (below).

SITE 451 HOLE CORE 1 CORED INTERVAL: 0.0-5.0 m



2.5Y 6/4
2.5Y 6/4

LITHOLOGIC DESCRIPTION

FORAMINIFERAL OOZE, grayish brown (10YR 5/2) passing gradually in Section 3 to **FORAMINIFERAL-NANNOFOSSIL OOZE,** light yellowish brown (10YR 6/4). The grayish-brown sediment contains numerous sand-sized brown pumice and glass fragments, and gravel-sized (0.4-1.5 cm) black Mn-coated pumice clasts. These components are absent near the bottom of Section 3 and in the Core-Catcher. The sediment is uniformly soft; drilling disturbance is moderate to very intense, with soupy intervals.

SMEAR SLIDE SUMMARY

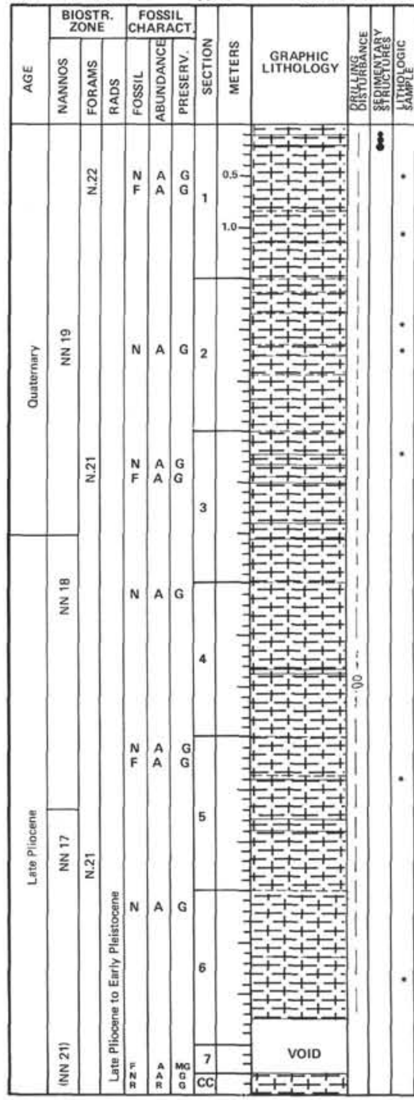
	2-20 (D)	3-42 (D)	3-90 (D)
TEXTURE:			
Sand	60	32	4
Silt	35	67	86
Clay	5	1	0
TOTAL DETRITAL	11	2	TR
COMPOSITION:			
Feldspar	2	1	TR
Heavy minerals	1	TR	TR
Clay minerals	5	1	–
Volcanic glass	3	TR	TR
Micronodules	7	12	3
Zeolites	2	1	TR
Amorph Fe agg.	TR	TR	1
Carbonate unspec.	20	5	5
Foraminifers	57	20	25
Nannofossils	3	60	65
Radiolaria	TR	TR	1
Fish remains	–	–	TR

GRAIN-SIZE:
2-7 (75.6, 17.1, 7.3)
3-7 (48.3, 38.6, 13.2)

CARBON/CARBONATE:
2-14 (0.1, 50.1, 6.1)
3-90 (0.0, 58.5, 7.1)

CARBONATE BOMB:
2, 14-15 (52)
3, 90-91 (61)

SITE 451 HOLE CORE 2 CORED INTERVAL: 5.0-14.5 m



2.5Y 5/2
2.5Y 5/2 and 2.5Y 6/4
2.5Y 6/4
2.5Y 5/2
2.5Y 6/4
2.5Y 5/2
2.5Y 6/4
2.5Y 6/5
2.5Y 5/2
2.5Y 7/4
2.5Y 5/2
2.5Y 7/4
2.5Y 6/2
2.5Y 6/4
2.5Y 6/2
2.5Y 4.5/2
2.5Y 6/2
2.5Y 4.5/2
2.5Y 6/2
2.5Y 7/4
2.5Y 6/2
2.5Y 7/4
scoriaceous lapilli 2x3.5 cm
2.5Y 6/4
2.5Y 4.5/2
2.5Y 6/4
2.5Y 5/2
2.5Y 6/4
2.5Y 6/2
2.5YG 5/2
2.5YG 5/2

LITHOLOGIC DESCRIPTION

NANNOFOSSIL-FORAMINIFERAL OOZE, mainly alternating grayish-brown and light yellowish-brown, with numerous intercalations of very pale brown and light brownish-gray intervals. Pumice and glass fragments, brown or black where Mn-coated, are present mainly in the grayish brown intervals. One scoriaceous lapilli occurs in Section 4. The sediment is uniformly soft; drilling disturbance is moderate in all sections.

SMEAR SLIDE SUMMARY

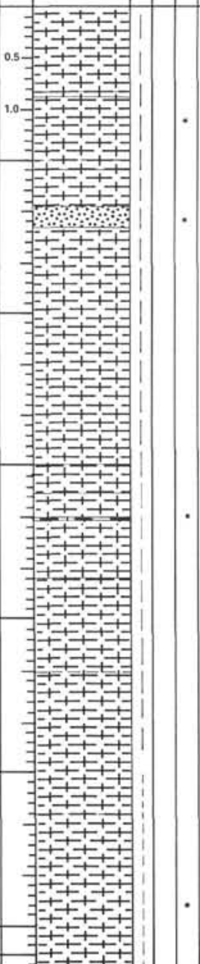
	1-52 (D)	1-107 (D)	2-51 (D)	2-75 (D)	3-30 (M)	5-48 (M)	6-92 (M)
TEXTURE:							
Sand	46	45	44	40	35	45	2
Silt	54	55	52	60	60	55	98
Clay	TR	TR	2	TR	5	TR	0
TOTAL DETRITAL	2	3	TR	1	1	1	2
COMPOSITION:							
Feldspar	1	1	TR	1	TR	1	1
Heavy minerals	1	1	TR	TR	TR	TR	1
Clay minerals	TR	TR	TR	TR	–	–	–
Volcanic glass	TR	1	–	TR	1	TR	TR
Micronodules	4	6	4	4	3	4	10
Zeolites	TR	–	TR	1	TR	–	1
Amorph Fe agg.	–	1	1	1	TR	3	1
Carbonate unspec.	4	5	15	5	20	5	5
Foraminifers	40	30	30	40	20	40	35
Nannofossils	50	55	50	48	55	47	46
Radiolaria	TR	TR	TR	–	1	TR	TR
Sponge spicules	–	–	–	–	–	TR	–

GRAIN-SIZE:
2-49 (70.9, 20.5, 8.7)

CARBONATE BOMB:
5, 74-75 (66)

SITE 451 HOLE CORE 3 CORED INTERVAL: 14.5-24.0 m

AGE	NANNOS	FORAMS	FOSSIL	ABUNDANCE	PRESERV.	SECTION
Late Pliocene	NN 17	N.21	N / F	A / A	G / G	1
	NN 16		N	A	G	2
			N	A	G	3
			N	A	G	4
		N.21	N / F	A / A	G / G	5
Late Pliocene to Early Pleistocene			N / F	A / A	G / G	6
	NN 16	N.19	F N R	A A R	MG M G	7, CC



general color 2.5Y 6/4
2.5Y 5/2 mottles
2.5Y 3/2 layer
2.5Y 5/2 mottles
2.5Y 5/2 mottles
2.5Y 5/2
10YR 3.5/2 ash layer
pumice 1 cm diameter
2.5Y 5/2 mottles
2.5Y 5/2 mottles
pumice lump
2.5Y 5/2 mottles
2.5Y 5/2
10YR 5/4 layer
2.5Y 5/2 with 10YR 3/1 mottles
2.5Y 5/2 mottles
general color 2.5Y 7/4
2.5Y 5/2 mottles

LITHOLOGIC DESCRIPTION

FORAMINIFERAL-NANNOFOSSIL OOZE, light yellowish brown, in Sections 1 through upper portion of 6. Grayish brown and very dark gray mottles are frequent. Main features are: one very dark grayish brown layer of volcanic ash in Section 2; one yellowish brown layer of foraminiferal ooze in Section 4; rare pumice fragments in Sections 2 and 3. From upper part of Section 6 to Core-Catcher the sediment is **NANNOFOSSIL-FORAMINIFERAL OOZE,** pale yellow, with rare grayish brown mottles. The sediment is uniformly soft; drilling disturbance is moderate in Sections 1 to 5, slight in the remaining ones.

SMEAR SLIDE SUMMARY

	1-119 (D)	2-60 (M)	4-50 (M)	6-134 (D)
TEXTURE:				
Sand	55	20	65	43
Silt	45	70	35	47
Clay	0	10	0	10
TOTAL DETRITAL	TR	83	TR	2
COMPOSITON:				
Feldspar	TR	3	TR	–
Heavy minerals	–	1	–	–
Clay minerals	TR	10	TR	2
Volcanic glass	TR	69	–	–
Micronodules	2	6	TR	2
Zeolites	3	1	–	1
Amorph Fe agg.	1	6	TR	2
Carbonate unspec.	25	–	5	20
Foraminifers	20	2	60	43
Nannofossils	50	2	35	30
Radiolaria	–	–	TR	TR

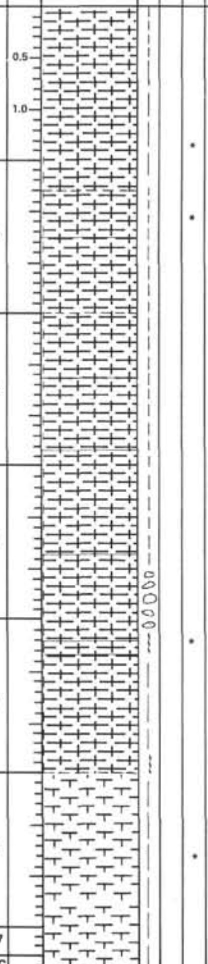
GRAIN-SIZE:
3-100 (44.6, 32.3, 23.1)

CARBON/CARBONATE:
3-104 (0.0, 74.1, 8.9)

CARBONATE BOMB:
3, 104-105 (78)

SITE 451 HOLE CORE 4 CORED INTERVAL: 24.0-33.5 m

AGE	NANNOS	FORAMS	FOSSIL	ABUNDANCE	PRESERV.	SECTION
Early Pliocene	NN 15		N	A	M	1
		N.19				2
			F	A	M	3
			N	A	M	4
	NN 15	N.19	N / F	A / A	M / M	5
	NN13/14		N	A	M	6
			F N R	CA C –	MG M –	7, CC



Mn-coated pumice clasts
2.5Y 5/2 mottles
2.5Y 7/4
10YR 8/4
2.5Y 7/4
10YR 8/4
2.5Y 7/4
10YR 8/4
2.5Y 7/4
10YR 5/1
10YR 8/4
Mn-coated pumice
2.5Y 6/4

LITHOLOGIC DESCRIPTION

NANNOFOSSIL-FORAMINIFERAL OOZE, alternately pale yellow and very pale brown. Sections 1 to 5; light yellowish brown **FORAMINIFERAL OOZE** in Section 6. Slight grayish brown mottles in Section 1. Some black pumice fragments (<2 cm) covered by "cauliflower" Mn occur in Sections 1 and 6. The sediment is uniformly soft; drilling disturbance is slight in Sections 1 to 4, moderate to intense in others.

SMEAR SLIDE SUMMARY

	1-140 (D)	2-60 (D)	5-25 (M)	6-83 (D)
TEXTURE:				
Sand	40	30	20	55
Silt	60	58	72	45
Clay	0	2	8	0
TOTAL DETRITAL	TR	2	9	2
COMPOSITION:				
Feldspar	TR	1	TR	1
Heavy minerals	–	TR	–	–
Clay minerals	TR	TR	8	TR
Volcanic glass	TR	1	1	1
Micronodules	5	3	10	3
Zeolites	TR	–	–	–
Amorph Fe agg.	–	2	1	–
Carbonate unspec.	–	5	10	10
Foraminifers	40	40	30	55
Nannofossils	55	48	40	30
Radiolaria	–	–	TR	–
Fish remains	–	–	–	TR

GRAIN-SIZE:
3-70 (23.9, 44.8, 31.3)

CARBON/CARBONATE:
3-74 (0.0, 84.1, 0.1)

CARBONATE BOMB:
3, 74-75 (85)

SITE 451 HOLE CORE 5 CORED INTERVAL: 33.5-43.0 m

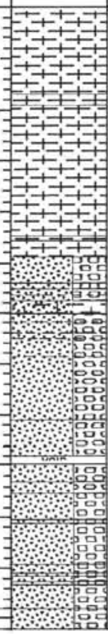
AGE: Early Pliocene (upper part); Late Miocene (lower part)

BIOSTR. ZONE — NANNOS: NN 13/14; NN 12; NN 11 — FORAMS: N.19; N.17-N.19; N.17-N.19

FOSSIL CHARACT. (FOSSIL / ABUNDANCE / PRESERV.):
N A M; F A M (Section 1)
N A M; F A M (Section 2)
N A M; F A M (Section 3)
N A M; F A M (Section 4)
F N R / A A – / MG M – (CC)

SECTION: 1, 2, 3, 4, CC — METERS: 0.5, 1.0

GRAPHIC LITHOLOGY



LITHOLOGIC DESCRIPTION

2.5Y 6/2
2.5Y 7/4
2.5Y 6/2
2.5Y 5/0
2.5Y 7/0
2.5Y 8/8
2.5Y 2.0
5Y 5/6
5Y 4/4
5Y 6/2
5Y 7/3
5Y 4/3
5Y 6/1
5Y 7/1
5Y 4/2
5Y 3/2 +
5Y 5/2
mottles
5Y 5/2
5Y 5/2
5Y 5/2
5Y 3/2 lithified
5Y 4/2
5Y 3/2 lithified
5Y 5/2
5Y 4/2
5Y 3/2 lithified
5Y 3/2 lithified
5Y 6/2
5Y 6/2
volcanic ash cuttings

FORAMINIFERAL-NANNOFOSSIL OOZE, light brownish gray to pale yellow in Sections 1 and upper part of Section 2, gray to light gray in middle Section 2. Some black, Mn-coated pumice fragments (up to 3 cm) are present. From middle Section 2 downward, silt-sized, carbonate-rich **VOLCANIC ASH,** with various tones of olive and gray. Color becomes gray or white in intervals enriched in fresh pumice fragments, (up to 3x4 cm), to olive gray to dark olive gray in some more lithified layers of Section 4. Rare layers of white foraminiferal-nannofossil ooze are interbedded with the ash. Olive-gray and dark olive-gray mottles occur in lower Section 3 and upper Section 4. The sediment is soft except for some thin more lithified ash intervals in Section 4; drilling disturbance is moderate in Sections 1 and 4, slight elsewhere.

SMEAR SLIDE SUMMARY

	1-140 (D)	2-83 (D)	1-45 (D)	3-94 (D)	3-123 (D)
TEXTURE:					
Sand	10	10	1	15	7
Silt	70	85	84	85	89
Clay	20	5	15	10	4
TOTAL DETRITAL	26	5	21	91	52
COMPOSITION:					
Feldspar	1	TR	1	4	3
Heavy minerals	TR	TR	TR	TR	TR
Clay minerals	20	5	15	10	4
Volcanic glass	5	TR	5	77	45
Micronodules	3	2	TR	3	3
Zeolites	–	TR	–	–	TR
Carbonate unspec.	20	10	5	–	10
Foraminifers	25	15	5	1	10
Nannofossils	29	67	69	5	25
Radiolaria	–	1	TR	–	TR
Sponge spicules	–	TR	TR	–	–
Fish remains	–	–	TR	–	–

GRAIN-SIZE:
4-72 (39.1, 47.6, 13.2)

CARBON/CARBONATE:
4-75 (0.0, 18.1, 2.2)

CARBONATE BOMB:
4, 75-76 (17)

SITE 451 HOLE CORE 6 CORED INTERVAL: 43.0-52.5 m

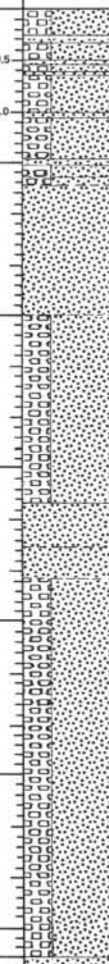
AGE: Late Miocene

BIOSTR. ZONE — NANNOS: NN 11 — FORAMS: N.17; N.17; N.17

FOSSIL CHARACT. (FOSSIL / ABUNDANCE / PRESERV.):
N A M; F A M (Section 1)
F A M (Section 3)
F A M (Section 5)
F N R / CA A – / MG M – (CC)

SECTION: 1, 2, 3, 4, 5, 6, 7, CC — METERS: 0.5, 1.0

GRAPHIC LITHOLOGY



LITHOLOGIC DESCRIPTION

5Y 5/2
5Y 3/2 lithified
5Y 6/2
5Y 3/2 lithified
5Y 6/2
5Y 3/2 lithified
5Y 4/2
5Y 3/2 lithified
5Y 6/2
5Y 5/1
5Y 7/1 pumice layer
General color 5Y 6/1
5Y 5/3 lithified
5Y 3/1

VOLCANIC ASH, carbonate-rich, gray to light olive gray, interbedded with **VOLCANIC ASH and TUFF,** dark olive gray to very dark gray, more lithified. Ash layers are thin and frequent in Section 1, whereas from Section 3 downward only one thick layer occurs. Section 2 is ash containing large (up to 3x5 cm), light gray, angular pumice clasts with numerous Mn blebs. Gray and black, sometimes large, pumice fragments are also present in the ooze. The ooze is soft and the ash and tuff layers are more lithified; drilling disturbance is slight in Sections 1 and 3, very intense in Sections 2 and 4 to 7.

SMEAR SLIDE SUMMARY

	1-30 (M)	1-87 (D)	3-40 (D)	4-68 (D)
TEXTURE:				
Sand	20	7	10	2
Silt	70	83	85	47
Clay	10	10	5	51
TOTAL DETRITAL	75	14	9	92
COMPOSITION:				
Feldspar	5	3	2	1
Heavy minerals	1	1	TR	–
Clay minerals	10	10	5	51
Volcanic glass	69	TR	2	40
Micronodules	4	3	3	1
Zeolites	1	–	1	2
Carbonate unspec.	3	10	10	–
Foraminifers	2	20	5	–
Nannofossils	5	53	72	4
Radiolaria	–	TR	TR	–
Fish remains	–	–	–	1

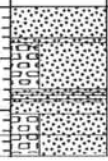
GRAIN-SIZE:
1-71 (22.7, 59.6, 17.7)

CARBONATE BOMB:
1, 70-71 (31)

SITE 451 HOLE CORE 7 CORED INTERVAL: 52.5-62.0 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS
Late Miocene	NN 11	N.17		F	A	M	1	0.5, 1.0
				F N R	CA C –	MG M –	CC	

GRAPHIC LITHOLOGY



5Y 6/2 + 5Y 2/1 + 5Y 3/2
5Y 6/2
5Y 5/1
10G 6/2
5Y 4/1
10G 8/2
10G 6/2
5Y 3/1
5Y 4/1
5Y 4/1

LITHOLOGIC DESCRIPTION

TUFF, carbonate-rich, gray and dark gray, interbedded with fine **VOLCANIC ASH**, pale green and very pale green, in thin layers. Upper 30 cm of Section 1 are a drilling breccia of: ~85% light olive pumice with Mn blebs; ~10% black, Mn-coated pumice; ~5% very dark gray fine tuff. The sediments are uniformly soft; drilling disturbance is very intense in upper Section 1, moderate downcore.

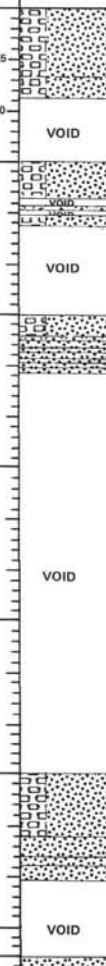
SMEAR SLIDE SUMMARY

	1-30 (M)	1-65 (D)	1-90 (M)
TEXTURE:			
Sand	4	8	4
Silt	86	90	91
Clay	10	2	5
TOTAL DETRITAL	88	5	98
COMPOSITION:			
Feldspar	4	1	3
Heavy minerals	TR	–	TR
Clay minerals	10	2	5
Volcanic glass	74	2	90
Micronodules	2	4	1
Zeolites	–	1	1
Carbonate unspec.	3	2	–
Foraminifers	2	16	–
Nannofossils	4	72	TR
Radiolaria	–	TR	–
Fish remains	1	–	–

SITE 451 HOLE CORE 8 CORED INTERVAL: 62.0-71.5 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS
Late Miocene	NN 11	N.17		F	A	M	1	0.5, 1.0
							2	
							3	
							4	
							5	
							6	
				F N R	RF C –	M M –	7	
							CC	

GRAPHIC LITHOLOGY



5Y 5/1
ash and pumice
5Y 5/1
5Y 5/1
ash and pumice
5Y 5/1
5Y 4/1
5G 4/2 + 5G 5/2
lithified
5Y 4/1
5G 4/2
5Y 4/1
5Y 3/2 + 5Y 3/1
5Y 3/2, 5GY 5/1, 5Y 2/1

LITHOLOGIC DESCRIPTION

TUFF, carbonate-rich, gray to dark gray, and fine **VITRIC TUFF**, dark greenish gray to greenish gray in Section 2, very dark gray to dark olive gray in Section 6. The tuff occurs as thin lithified layers in the calcareous layers which derives from alteration of volcanic glass. Abundant, rounded, well-sorted, gray pumice clasts, (<1 cm) occur in drilling breccias in Sections 1 and 2. The lowermost tuff level contains abundant individual and composite gray burrows. The calcareous tuff is soft; the tuff lithified and hard, has been fractured during drilling; disturbance is very intense throughout the core.

SMEAR SLIDE SUMMARY

	1-80 (D)	3-28 (M)	6-98 (M)
TEXTURE:			
Sand	14	15	1
Silt	25	75	89
Clay	61	10	10
TOTAL DETRITAL	81	94	96
COMPOSITION:			
Feldspar	5	7	1
Heavy minerals	TR	2	1
Clay minerals	61	10	10
Volcanic glass	15	75	84
Micronodules	4	5	1
Zeolites	–	1	1
Foraminifers	5	–	–
Nannofossils	10	–	1
Fish remains	–	–	1

GRAIN-SIZE:
6-31 (14.9, 62.8, 22.4)

CARBON/CARBONATE:
6-30 (0.0, 24.6, 3.0)

CARBONATE BOMB:
6, 30-31 (26)

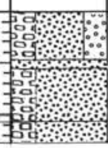
SITE 451 HOLE CORE 9 CORED INTERVAL: 71.5-81.0 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
Late Miocene	NN 11			N F	F C	M P	1	0.5 1.0		O O		

LITHOLOGIC DESCRIPTION

Cuttings of the following lithotypes:
~60% fresh white **PUMICE**; ~35% black, Mn-coated **PUMICE**;
~5% olive fine **VITRIC TUFF**.

SITE 451 HOLE CORE 10 CORED INTERVAL: 81.0-90.5 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
Late Miocene	NN 11	N.17		F	A	M	1	0.5 1.0				• •
				F N R	CA A –	MG M –	CC					

LITHOLOGIC DESCRIPTION

general color
5Y 6/1

5Y 3/1

5Y 4/1 +
5Y 6/1 mottles
5Y 6/1

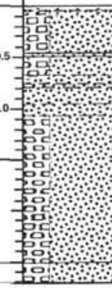
TUFF, carbonate-rich, gray to dark gray, with interbedded very dark gray **VOLCANIC ASH**. Pumice is abundant near the top of Section 1 as small (0.5-1 cm) rounded fragments. Rare dark gray mottles are also present. The sediment is uniformly soft; drilling disturbance is moderate to intense.

SMEAR SLIDE SUMMARY

	1-30 (D)	1-80 (D)
TEXTURE:		
Sand	14	7
Silt	81	88
Clay	5	5
TOTAL DETRITAL	31	24
COMPOSITION:		
Feldspar	3	4
Clay minerals	5	5
Volcanic glass	23	15
Micronodules	4	3
Zeolites	TR	TR
Amorph Fe agg.	TR	–
Recrystallized carb.	5	4
Foraminifers	–	7
Nannofossils	51	68
Diatoms	TR	–
* Radiolaria	1	1
Sponge spicules	TR	TR
Fish remains	1	–

Site 451, Core 11 (90.5-100.0 m), Core 12 (100.0-109.5 m), and Core 13 (109.5-119.0 m): NO RECOVERY.

SITE 451 HOLE CORE 14 CORED INTERVAL: 119.0-128.5 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
Late Miocene	NN 11			F	C	P	1	0.5 1.0				• •
							2					•
				F N R	C C –	M M –	CC					

LITHOLOGIC DESCRIPTION

5Y 3/1
general color
5Y 4/1
5G 4/2 laminae
5Y 6/1
5Y 4/2 lithified
5YR 3/3
5Y 6/1
General color
5Y 5/1
5Y 4/2 mottle
5Y 2/1 mottles
5Y 5/1

TUFF, carbonate-rich, dark gray to gray down core, with intercalated thin layers of sand- and silt-sized very dark gray and olive-gray **VOLCANIC ASH** in Section 1. The thickest intercalation contains also numerous gray, angular, gravel-sized pumice clasts up to 1 cm. The tuff has dark gray and black mottles, made of volcanic glass, in Section 2, and a thin dark brown lamina of nannofossil-bearing vitric ash in Section 1. The sediment is soft except for two more lithified ash intervals in Section 1; drilling disturbance is slight.

SMEAR SLIDE SUMMARY

	1-81 (M)	1-130 (D)	2-76 (M)
TEXTURE:			
Sand	5	10	50
Silt	72	75	40
Clay	23	15	10
TOTAL DETRITAL	94	48	89
COMPOSITION:			
Feldspar	2	2	7
Heavy minerals	1	1	7
Clay minerals	23	15	10
Volcanic glass	69	30	65
Micronodules	1	2	–
Zeolites	1	1	1
Amorph Fe agg.	–	1	–
Carbonate unspec.	–	3	–
Foraminifers	1	5	1
Nannofossils	3	40	7
Radiolaria	–	–	2

GRAIN-SIZE:
2-53 (42.6, 44.6, 12.7)

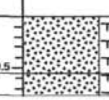
CARBONATE BOMB:
2, 49-50 (14)

CARBON/CARBONATE:
2-61 (0.0, 14.8, 1.8)

PHYSICAL PROPERTIES:

	Section 1 78 cm
Wet bulk density	1.91
Porosity (%)	47.0
Grain density	2.72

SITE 451 HOLE CORE 15 CORED INTERVAL: 128.5-138.0 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
							1	0.5				•
				F N R	F – –	P – –	CC					

LITHOLOGIC DESCRIPTION

5Y 3/1

5Y 3/1

VOLCANIC TUFF, rich in foraminifers, very dark gray, consisting of 80% vitric tuff and 20% carbonate and bioclasts of planktonic foraminifers (mainly *Orbulinae*), which are often concentrated in thin (mm) parallel laminae. Angular, dark olive gray, fine tuff without foraminifers is also present as fragments among the dominant lithology. The sediment is hard and fractured in pieces 2 to 6 cm thick; drilling disturbance is moderate.

SMEAR SLIDE SUMMARY

	1-30 (D)
TEXTURE:	
Sand	10
Silt	90
Clay	TR
TOTAL DETRITAL	76
COMPOSITION:	
Feldspar	2
Heavy minerals	2
Clay minerals	TR
Volcanic glass	20
Micronodules	1
Carbonate unspec.	69
Foraminifers	1
Nannofossils	5

PHYSICAL PROPERTIES:

	Section 1 41 cm
Wet bulk density	1.75
Porosity (%)	47.4
Grain density	2.42

SITE 451 HOLE CORE 16 CORED INTERVAL: 138.0-147.5 m

AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
				N R	– –	– –	CC					•

LITHOLOGIC DESCRIPTION

general color
5Y 7/1 matrix

VITRIC TUFF, carbonate-rich, matrix is light gray with 7 mm diameter clasts of medium dark gray vitric tuff (containing foraminifers), 3 to 6 mm diameter clasts of white pumice, and minor (~2%) black ash flecks.

SMEAR SLIDE SUMMARY

	CC (D)
TEXTURE:	
Sand	3
Silt	80
Clay	17
TOTAL DETRITAL	50
COMPOSITION:	
Feldspar	2
Heavy minerals	1
Clay minerals	17
VOlcanic glass	30
Micronodules	7
Recrystallized carb.	5
Nannofossils	40

Site 451, Core 17, 147.5-157.0 m: NO RECOVERY.

SITE 451 HOLE CORE 18 CORED INTERVAL: 157.0-166.5 m

AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
							CC					

LITHOLOGIC DESCRIPTION

5Y 8/2

PUMICE fragments, white; probably washed hole cavings; clasts range in size from 1 to 8 cm diameter.

Site 451, Core 19, 166.5-176.0 m: NO RECOVERY.

SITE 451 HOLE CORE 20 CORED INTERVAL: 176.0-185.5 m

AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
Late Miocene	NN 11?			F N R	R F –	M P –	CC					• •

LITHOLOGIC DESCRIPTION

5Y 4/1, 5Y 3/1,
5G 2/1 burrow

VITRIC TUFF, dark gray, underlain by very dark gray devitrified glass-rich **CLAY**. This grades downward through a 1.5 cm coarser black **VITRIC TUFF** to a greenish-black **FINE VITRIC TUFF** with a 3 mm wide calcareous burrow and 1 mm diameter pumice fragments.

SMEAR SLIDE SUMMARY

	CC-11 (D)	CC-17 (D)	CC-19 (M)
TEXTURE:			
Sand	9	6	6
Silt	51	44	28
Clay	40	50	66
TOTAL DETRITAL	90	95	82
COMPOSITION:			
Feldspar	4	6	5
Heavy minerals	1	TR	1
Clay minerals	40	50	66
Volcanic glass	45	39	10
Micronodules	4	3	–
Zeolites	1	1	1
Recrystallized carb.	–	–	4
Foraminifers	–	–	4
Nannofossils	5	–	8
Radiolaria	–	–	1
Fish remains	–	1	–

SITE 451 HOLE CORE 21 CORED INTERVAL: 185.5-195.0 m

AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
Late Miocene	?			F N R	C R –	P F –	CC					• •

LITHOLOGIC DESCRIPTION

2.5Y 2.5/0
general color
2.5Y 2.5/0

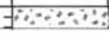
TUFF, carbonate-rich, black and spottled black and whtie, containing altered glass in Section 1.

SMEAR SLIDE SUMMARY

	CC (D)	1-23 (D)
TEXTURE:		
Sand	10	10
Silt	80	60
Clay	10	30
TOTAL DETRITAL	14	57
COMPOSITION:		
Feldspar	3	6
Heavy minerals	1	1
Clay minerals	10	30
Volcanic glass	TR	20
Micronodules	7	1
Zeolites	–	1
Recrystallized carb.	15	5
Foraminifers	1	15
Nannofossils	63	20
Radiolaria	–	1

SITE 451 **HOLE** **CORE** 22 **CORED INTERVAL:** 195.0-204.5 m (Hole deviation of 2.0° at 195.0 m)

AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS
Late Miocene	NN 10?			F N R	RF F –	P P –	CC	



5GY 2/1 clast
5G 2/1 general color
5B 6/1 bioturbation

FINE VITRIC TUFF, greenish black, with 6 mm clast of greenish black glass-rich clay (altered pumice) and a 3 cm thick intensely bioturbated light bluish gray carbonate-rich tuff.

SMEAR SLIDE SUMMARY

	CC-7 (M)	CC-9 (D)	CC-15 (M)
TEXTURE:			
Sand	15	9	6
Silt	70	25	89
Clay	15	66	5
TOTAL DETRITAL	88	95	8
COMPOSITION:			
Feldspar	3	4	1
Clay minerals	15	66	5
Volcanic glass	70	25	2
Micronodules	5	2	3
Zeolites	2	2	2
Recrystallized carb.	2	–	5
Foraminifers	3	–	5
Nannofossils	–	TR	77
Radiolaria	–	–	TR
Sponge spicules	–	–	TR
Fish remains	–	1	–

SITE 451 **HOLE** **CORE** 23 **CORED INTERVAL:** 204.5-214.0 m

AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS
Late Miocene	NN 10?			F N R	F F –	P P –	CC	

general color
2.5Y 2.5/0

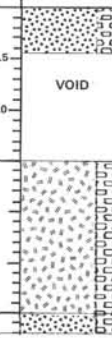
TUFF, carbonate-rich, black, containing glass fragments and nannofossils. Grades into black, fine-grained, glass-rich **CLAY** (altered glass) with traces of large foraminifers.

SMEAR SLIDE SUMMARY

	CC-6 (D)	CC-19 (D)
TEXTURE:		
Sand	11	13
Silt	64	47
Clay	25	40
TOTAL DETRITAL	45	80
COMPOSITION:		
Feldspar	3	5
Heavy minerals	2	–
Clay minerals	25	40
Volcanic glass	15	35
Micronodules	10	8
Zeolites	2	5
Amorph Fe agg.	–	2
Recrystallized carb.	5	–
Foraminifers	6	–
Nannofossils	33	10
Fish remains	1	–

SITE 451 **HOLE** **CORE** 24 **CORED INTERVAL:** 214.0-223.5 m

AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS
Late Miocene	NN 10?	N.16/17					1	0.5, 1.0
							2	
				F N	F R	MG P	CC	



general color
5Y 4/1

general color
5Y 2/1
tuff fragments
5Y 2/1, 5Y 6/1

5Y 2/1
drilling gouge

TUFF, carbonate-rich, dark gray, in Section 1. It contains a clast ratio of 4:6, bioclasts: volcaniclasts; the bioclasts are foraminifers; the volcanic clasts are mainly glass. Some minor very dark gray burrows and mottles. Section 2 contains black **FINE VITRIC TUFF** drilling breccia. The sediment is firm; drilling disturbance is intense.

PHYSICAL PROPERTIES:

	Section 1 11 cm
Wet bulk density	2.17
Porosity (%)	33.5
Grain density	2.76

SITE 451 **HOLE** **CORE** 25 **CORED INTERVAL:** 223.5-233.0 m

AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS
Late Miocene	NN 10	N.16-N.19		F	F	M	1	0.5, 1.0
							2	
				F N R	F F –	P M –	CC	

pumice foraminifer-poor
general color 5Y 4/1
foraminifer-poor

composite
burrow 5Y 4/1

Zoophycus burrow
5Y 6/1
laminations 5YR 3/3

5Y 4/1

FINE VITRIC TUFF, altered, carbonate-bearing, dark gray, rich in large foraminifers; moderately burrowed with localized zones of intense burrowing and mottling. The burrows are gray and filled with foraminifers. From 148 to 164 cm, is coarser due to increased foraminifer content.

SMEAR SLIDE SUMMARY

	1-25 (D)
TEXTURE:	
Sand	10
Silt	12
Clay	78
TOTAL DETRITAL	91
COMPOSITION:	
Feldspar	2
Heavy minerals	1
Clay minerals	78
Volcanic glass	10
Micronodules	7
Zeolites	1
Fish remains	1

PHYSICAL PROPERTIES:

	Section 1 95 cm
Wet bulk density	1.89
Porosity (%)	53.5
Grain density	2.91

CARBONATE BOMB:
1, 81-82 (13)

CARBON/CARBONATE:
1-80 (0.0, 13.4, 1.6)

SITE 451 HOLE CORE 26 CORED INTERVAL: 233.0-242.5 m

Age: Late Miocene; Nannos: ?; Fossil: N R; Abundance: R –; Preserv.: P –; Sections: 1, CC; Meters: 0.5

5G 6/2
5Y 3/1 general color

5Y 7/1,
5GY 7/1

FINE VITRIC TUFF, very dark gray, moderately burrowed with localized foraminifer-enriched zones which locally enhance parallel bedding. Very fine grading in 20 to 28 cm interval. Top 10 cm of greenish-gray altered fine vitric tuff is derived from the altered volcanic glass, is enriched in foraminifers, is moderately to intensely burrowed, and contains a clast (3x6 cm) of unburrowed fine vitric tuff. The Core-Catcher contains moderately-burrowed fine vitric tuff with fine laminations outlined by thin concentrations of slightly coarser volcanic glass. The sediment is uniformly firm with slight drilling disturbance.

SMEAR SLIDE SUMMARY

	1-7 (D)	1-16 (D)	CC-15 (D)
TEXTURE:			
Sand	5	10	1
Silt	23	60	94
Clay	72	30	5
TOTAL DETRITAL	79	91	94
COMPOSITION:			
Feldspar	2	5	1
Heavy minerals	TR	1	–
Clay minerals	72	30	5
Volcanic glass	5	55	88
Micronodules	2	4	1
Zeolites	1	1	5
Amorph Fe agg.	TR	TR	–
Foraminifers	–	1	–
Nannofossils	7	2	–
Fish remains	1	1	TR

PHYSICAL PROPERTIES:

	Section 1 6 cm
Wet bulk density	2.21
Porosity (%)	36.9
Grain density	2.93

SITE 451 HOLE CORE 27 CORED INTERVAL: 242.5-252.0 m

Age: Late Miocene; Nannos: ?; Fossil: N (F N); Abundance: R (R R); Preserv.: P (P P); Sections: 1, CC; Meters: 0.5, 1.0

5Y 2/1 general color

5Y 4/1 general color
composite burrow
5Y 2/1 faulted laminations
5Y 3/1 laminations

5Y 4/1

FINE VITRIC TUFF, black, generally enriched in foraminifers down to 74 cm. The upper 30 cm intensely disturbed by drilling and contain pieces of the tuff with minor foraminifer-enriched areas and up to 2 mm thick zones of coarser glass. Down section are zones of intense bioturbation with olive gray and black fillings. From 74 to 95 cm contains only minor scattered foraminifers; from 95 to 115 cm contains abundant foraminifer concentrations enhancing laminations. Basal 5 cm are normally graded from silt to medium sand-sized vitric tuff. The sediment is uniformly hard and intensely to moderately disturbed by drilling.

SMEAR SLIDE SUMMARY

	1-60 (D)
TEXTURE:	
Sand	4
Silt	73
Clay	13
TOTAL DETRITAL	85
COMPOSITION:	
Feldspar	2
Heavy minerals	TR
Clay minerals	13
Volcanic glass	70
Micronodules	2
Zeolites	2
Nannofossils	10
Fish remains	1

CARBONATE BOMB:
1, 52-53 (6)

CARBON/CARBONATE:
1-51 (0.0, 6.8, 0.8)

SITE 451 HOLE CORE 28 CORED INTERVAL: 252.0-261.5 m

Section: CC

5Y 4/1 and
5Y 3/1

VITRIC TUFF, with foraminifers, dark gray; intervals of very dark gray vitric tuff low in foraminifers. The sediment is hard and consists of several fractured pieces in the Core-Catcher.

SITE 451 HOLE CORE 29 CORED INTERVAL: 261.5-271.0 m

Section: CC

5Y 3/1

VITRIC TUFF, rich in foraminifers, very dark gray; black and gray bioturbation, and one black, coarse layer (~0.5 cm) of vitric tuff poor in foraminifers.

SMEAR SLIDE SUMMARY

	CC-7 (M)
TEXTURE:	
Sand	1
Silt	33
Clay	66
TOTAL DETRITAL	78
COMPOSITION:	
Feldspar	1
Heavy minerals	1
Clay minerals	66
Volcanic glass	10
Micronodules	1
Zeolites	1
Recrystallized carb.	10
Nannofossils	10

SITE 451 HOLE CORE 30 CORED INTERVAL: 271.0-280.5 m

Age: Late Miocene; Nannos: ?; Fossil: N; Abundance: R; Preserv.: P; Section: CC

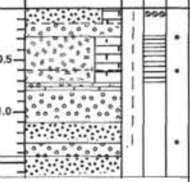
5Y 3/1

VITRIC TUFF, rich in foraminifers, very dark gray where fine-grained, black where coarser. Strongly bioturbated; gray burrows.

SITE 451 HOLE CORE 31 CORED INTERVAL: 280.5-290.0 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS
Late Miocene	?			N	F	P	1	0.5, 1.0
				N	–	–	CC	

GRAPHIC LITHOLOGY / DRILLING DISTURBANCE / SEDIMENTARY STRUCTURES / LITHOLOGIC SAMPLE



LITHOLOGIC DESCRIPTION

5GY 4/1
5GY 4/1
5GY 5/1
5Y 4/1
5Y 3/1
5Y 4/1
5Y 2/1
5Y 3/1

VITRIC TUFF, *rich in foraminifers, dark gray to very dark* gray, intensely bioturbated, in Section 1 and in the Core-Catcher. Intercalated in Section 1 are:
a) an interval of carbonate-rich fine vitric tuff, gray to dark gray, with parallel grayish-green lamination affected by normal faulting with 5 cm displacement;
b) four intervals of volcaniclastic conglomerate, very dark gray to black, containing a few white reworked debris of shallow water organisms such as corals and large benthonic foraminifers (*Lepydocycline?*) with silica replacing the original carbonate skeletons. The sediment is hard, bedding and laminae dip ~40°; drilling disturbance is slight.

SMEAR SLIDE SUMMARY

	1-32 (D)	1-65 (D)	1-142 (M)
TEXTURE:			
Sand	1	5	7
Silt	99	75	53
Clay	0	20	40
TOTAL DETRITAL	1	30	91
COMPOSITION:			
Feldspar	1	5	7
Heavy minerals	–	–	TR
Clay minerals	–	20	40
Volcanic glass	TR	5	44
Micronodules	3	5	7
Zeolites	TR	TR	1
Amorph Fe agg.	1	TR	1
Recrystallized carb.	25	15	TR
Foraminifers	2	5	–
Nannofossils	68	45	TR

PHYSICAL PROPERTIES:

	Section 1 121 cm
Wet bulk density	2.14
Porosity (%)	37.7
Grain density	2.84

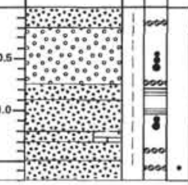
CARBON/CARBONATE:
1-31 (0.1, 48.2, 5.8)

CARBONATE BOMB:
1, 30-31 (47)

SITE 451 HOLE CORE 32 CORED INTERVAL: 290.0-299.5 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS
Late Miocene	?						1	0.5, 1.0
				N	R	P	CC	

GRAPHIC LITHOLOGY / DRILLING DISTURBANCE / SEDIMENTARY STRUCTURES / LITHOLOGIC SAMPLE



LITHOLOGIC DESCRIPTION

5GY 4/1
5Y 2/1
5Y 4/1
5Y 3/1
5Y 3/1
5GY 4/1
2.5Y 3/2

VITRIC TUFF, foraminifer-rich at places, dark gray to black. The rock is fine to medium sand-sized, with three intervals containing abundant gray burrows. Parallel lamination is frequent, sometimes enhanced by alignments of planktonic foraminifers. Section 1 contains also a black **LITHIC and VITRIC VOLCANICLASTIC CONGLOMERATE** interval. The matrix is a fine tuff and the abundant (85%) clasts consist of: ~30% basalt (plagioclase-phyric); ~30% glass; ~30% pumice; ~5% zeolite; and ~5% silicic volcanic rocks. The whole core is hard rock, the drilling deformation is slight.

SMEAR SLIDE SUMMARY

	CC-24 (D)
TEXTURE:	
Sand	10
Silt	28
Clay	72
TOTAL DETRITAL	87
COMPOSITION:	
Feldspar	10
Heavy minerals	TR
Clay minerals	72
Volcanic glass	5
Micronodules	7
Zeolites	1
Amorph Fe agg.	TR
Recrystallized carb.	1
Nannofossils	3
Fish remains	1

CARBON/CARBONATE:
1-122 (0.1, 0.1, 0.1)

CARBONATE BOMB:
1, 124-125 (1)

SITE 451 HOLE CORE 33 CORED INTERVAL: 299.5-309.0 m

AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY
							1	0.5, 1.0	VOID
							2		
				F N	R –	G –	CC		

5Y 5/1 burrows
5Y 2/1
5YR 3/2
5Y 2/1
5YR 3/3 band
5Y 3/1
5Y 3/1

LITHOLOGIC DESCRIPTION

VITRIC TUFF, massive, black and very dark gray; graded interval in top 5 cm, from medium sand- to silt-sized. Planktonic foraminifers rare; gray burrows locally present. Thin, dark reddish brown, deformed layers of calcareous clay rich in iron oxides occur at 50 and 75 cm. The rock is hard; the drilling deformation is intense.

SMEAR SLIDE SUMMARY

	1-50 (M)	2-17 (D)
TEXTURE:		
Sand	16	8
Silt	40	61
Clay	44	31
TOTAL DETRITAL	67	89
COMPOSITION:		
Feldspar	7	7
Heavy minerals	1	1
Clay minerals	44	31
Volcanic glass	15	50
Micronodules	9	8
Zeolites	1	1
Amorph Fe agg.	1	1
Nannofossils	20	–
Fish remains	2	1

CARBON/CARBONATE: 2-19 (0.1, 0.0, 0.1)
CARBONATE BOMB: 2, 20-21 (1)

SITE 451 HOLE CORE 34 CORED INTERVAL: 309.0-318.5 m

AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY
							1	0.5, 1.0	
							2		VOID
				N	–	–	CC		

5Y 6/1
5Y 2/1
general color
5Y 4/1
basalt clasts
burrows
5Y 5/1
5GY 4/1

LITHOLOGIC DESCRIPTION

VITRIC TUFF, alternating black coarser and very dark gray to gray finer intervals, the latter with either parallel lamination or gray bioturbation; some vesicular basalt fragments at 80 cm in Section 1. Coarser levels show rare cross-lamination and load-casts. A 10-cm thick, black **LITHIC and VITRIC VOLCANICLASTIC CONGLOMERATE** interval, with rounded fragments (averaging 0.5 cm) of basalt, glass, pumice, and rare acid volcanic rocks in a matrix of finer tuff. Bedding dips 26°.

SMEAR SLIDE SUMMARY

	1-74 (M)	2-8 (D)
TEXTURE:		
Sand	7	6
Silt	38	69
Clay	35	25
TOTAL DETRITAL	95	92
COMPOSITION:		
Feldspar	5	5
Heavy minerals	TR	1
Clay minerals	35	25
Volcanic glass	55	61
Micronodules	2	5
Zeolites	3	2
Fish remains	–	1

PHYSICAL PROPERTIES:

	Section 2 11 cm
Wet bulk density	2.09
Porosity (%)	42.8
Grain density	2.91

CARBON/CARBONATE: 1-135 (0.0, 0.7, 0.1)
CARBONATE BOMB: 1, 136-137 (1-2)

SITE 451 HOLE CORE 35 CORED INTERVAL: 318.5-328.0 m

AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY
							1	0.5	
				N	–	–	CC		

5Y 2/1
5GY 4/1
5GY 4/2

LITHOLOGIC DESCRIPTION

VITRIC TUFF, black, grading down core to **LITHIC and VITRIC VOLCANICLASTIC CONGLOMERATE**, dark greenish gray. Fragments of basalt, glass, and pumice average 2 cm in diameter, in the Core-Catcher some of them exceed 4 cm.

SMEAR SLIDE SUMMARY

	1-25 (D)
TEXTURE:	
Sand	10
Silt	70
Clay	20
TOTAL DETRITAL	74
COMPOSITION:	
Feldspar	5
Clay minerals	20
Volcanic glass	49
Micronodules	3
Zeolites	1
Recrystallized carb.	3
Foraminifers	2
Nannofossils	15
Fish remains	2

CARBON/CARBONATE: 1-14 (0.0, 0.2, 0.1)
CARBONATE BOMB: 1, 10-12 (~1)

SITE 451 HOLE CORE 36 CORED INTERVAL: 328.0-337.5 m

AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY
Late Miocene	?			N	R	P	1	0.5	
				N	–	–	CC		

5Y 2/1
5GY 5/1
5Y 2/1
5GY 4/1
5Y 5/1 +
5Y 2/1

LITHOLOGIC DESCRIPTION

VITRIC TUFF, black, interbedded with **LITHIC and VITRIC VOLCANICLASTIC CONGLOMERATE**, dark greenish gray, with rounded pumice, glass, and basalt fragments as in the previous cores. The Core-Catcher contains admixtures of these lithologies. Bedding dips 34°.

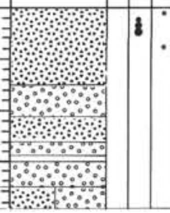
SMEAR SLIDE SUMMARY

	1-30 (D)
TEXTURE:	
Sand	18
Silt	72
Clay	10
TOTAL DETRITAL	92
COMPOSITION:	
Feldspar	6
Heavy minerals	4
Clay minerals	10
Volcanic glass	72
Micronodules	4
Zeolites	3
Fish remains	1

CARBON/CARBONATE: 1-51 (0.0, 0.2, 0.1)
CARBONATE BOMB: 1, 53-55 (~1)

SITE 451 HOLE CORE 37 CORED INTERVAL: 337.5-347.0 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
							1	0.5, 1.0				
							2					
							CC					



general color 5Y 2/1

5GY 2/1 fragments

5Y 2/1

LITHOLOGIC DESCRIPTION

VITRIC TUFF, black, interbedded with **LITHIC and VITRIC VOLCANICLASTIC CONGLOMERATE.** Vitric tuff graded in top 75 cm. In the conglomerate the clasts:matrix ratio is about 4:1. The average clasts size is 4 mm, maximum 3 cm. Clasts petrography includes: plagioclase-phyric basalts with groundmass altered and replaced with smectite; aphyric, aphanitic basalts or basaltic andesite; altered pumice; and basalts with variolitic groundmass. Almost all the clasts are highly vesicular (~15%); some of them are extremely altered with disseminated pyrite. Contacts dip about 20°.

SMEAR SLIDE SUMMARY

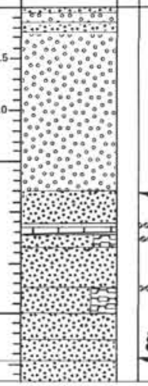
	1-10 (D)	1-40 (D)
TEXTURE:		
Sand	17	60
Silt	53	30
Clay	30	10
TOTAL DETRITAL	91	75
COMPOSITION:		
Feldspar	7	8
Heavy minerals	1	10
Clay minerals	30	10
Volcanic glass	53	47
Micronodules	9	25

CARBON/CARBONATE: 1-5 (0.0, 0.5, 0.1)

CARBONATE BOMB: 1, 3-5 (−1)

SITE 451 HOLE CORE 38 CORED INTERVAL: 347.0-356.5 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
Late Miocene	NN 10?						1	0.5, 1.0				
				N	F	P	2					
							3					
							CC					



general color 5Y 2/1

2.5YR 3/2

2.5Y 4/0 + 5GY 4/1

5GY 4/1 + 5YR 5/1

2.5Y 4/0

5Y 2/1

LITHOLOGIC DESCRIPTION

VITRIC TUFF, black, and **VOLCANICLASTIC CONGLOMERATE**, black, in Section 1 and upper Section 2. In the conglomerate, the clasts:matrix ratio is about 3:1. Clasts average 0.5 cm, but much larger clasts do occur. Their composition is: ~50-60% fine-grained to aphanitic basalt or basaltic andesite; ~30% aphyric vesicular altered variolitic basalt; and ~10% altered pumice clasts. Small pieces of highly oxidized volcanic rocks are present in the matrix, altered andesites? Below 200 cm, the vitric tuff contains intercalations of carbonate-rich tuff, gray to dark gray and dark greenish gray, containing altered glass, burrows, and a few planktonic foraminifera. One of the burrows comprises **NANNOFOSSIL CHALK.** The dip is about 20°.

SMEAR SLIDE SUMMARY

	2-73 (M)	2-77 (M)	2-150 (M)	3-30 (D)
TEXTURE:				
Sand	6	5	5	6
Silt	94	54	54	84
Clay	TR	41	41	10
TOTAL DETRITAL	4	59	54	96
COMPOSITION:				
Feldspar	3	2	2	6
Heavy minerals	–	1	1	TR
Clay minerals	TR	46	41	10
Volcanic glass	1	10	10	80
Micronodules	3	3	3	4
Zeolites	–	–	1	TR
Recrystallized carb.	30	10	10	–
Foraminifers	3	3	3	–
Nannofossils	60	25	30	–
Fish remains	–	TR	TR	–

CARBON/CARBONATE: 2-142 (0.0, 26.2, 3.2)

CARBONATE BOMB: 2, 140-142 (−1)

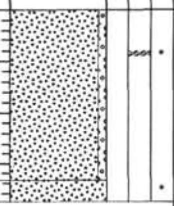
BULK ANALYSIS:	1-137	2-27
SiO_2	50.3	49.7
TiO_2	0.70	0.63
Al_2O_3	19.0	19.0
Fe_2O_3	1.24	1.27
FeO	8.16	8.38
MnO	0.18	0.19
MgO	4.31	4.41
CaO	10.83	11.16
Na_2O	2.16	2.42
K_2O	0.72	0.46
P_2O_5	0.06	0.11

PHYSICAL PROPERTIES:	Section 2 120 cm
Wet bulk density	2.03
Porosity (%)	45.2
Grain density	2.88

SITE 451 HOLE CORE 39 CORED INTERVAL: 356.5-366.0 m

AGE | BIOSTR. ZONE: NANNOS, FORAMS, RADS | FOSSIL CHARACT.: FOSSIL N, ABUNDANCE –, PRESERV. – | SECTION 1, 2, CC | METERS 0.5, 1.0

GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | LITHOLOGIC SAMPLE



general color
5Y 2/0

5Y 2/0

LITHOLOGIC DESCRIPTION

VITRIC and LITHIC TUFF, black, with a few lithic gravel fragments, consisting mainly of vesicular aphanitic to aphyric basalt and basaltic andesite. The tuff also contains small grains of ?epidote pyrite, hydrothermally altered basalt, and rare burrows filled with calcareous clay. Dip is about 20°.

SMEAR SLIDE SUMMARY

	1-45 (M)	CC (D)
TEXTURE:		
Sand	8	8
Silt	36	57
Clay	56	35
TOTAL DETRITAL	81	96
COMPOSITION:		
Feldspar	5	5
Heavy minerals	TR	1
Clay minerals	56	35
Volcanic glass	20	55
Micronodules	3	2
Zeolites	1	2
Recrystallized carb.	10	–
Nannofossils	5	–

PHYSICAL PROPERTIES:

	Section 1 77cm
Wet bulk density	2.03
Porosity (%)	46.1
Grain density	2.91

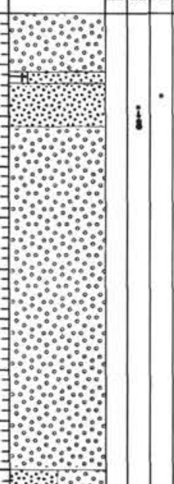
CARBON/CARBONATE:
CC-9 (0.0, 0.0, 0.0)

CARBONATE BOMB:
1, 45-47 (10)
CC, 9-12 (~1)

SITE 451 HOLE CORE 40 CORED INTERVAL: 366.0-375.5 m

AGE | BIOSTR. ZONE: NANNOS, FORAMS, RADS | FOSSIL CHARACT.: FOSSIL N, ABUNDANCE –, PRESERV. – | SECTION 1, 2, 3, CC | METERS 0.5, 1.0

GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | LITHOLOGIC SAMPLE



general color
5Y 2/1

2.5Y 4/0
5Y 2.5/0

5Y 2/1

LITHOLOGIC DESCRIPTION

LITHIC and VITRIC VOLCANICLASTIC CONGLOMERATE, black. Clasts:matrix 4:1; maximum clast size is 2 cm. White, reworked debris of shallow water organisms (corals[?] and large benthonic foraminifers) present. Other clasts include vesicular basalt or basaltic andesite (65%), glass (20%), subaerially weathered basalt (5%), and pumice (10%). In Section 1 is a 60 cm thick layer of black **VITRIC TUFF**, well bedded, with graded bedding and a carbonate-rich top layer. Dip is 25 to 30°.

SMEAR SLIDE SUMMARY

	1-88 (D)
TEXTURE:	
Sand	5
Silt	75
Clay	20
TOTAL DETRITAL	90
COMPOSITION:	
Feldspar	5
Heavy minerals	1
Clay minerals	20
Volcanic glass	64
Micronodules	6
Zeolites	2
Recrystallized carb.	2

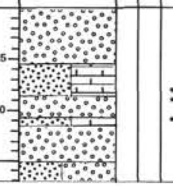
CARBON/CARBONATE:
1-56 (0.1, 6.1 0.8)
1-90 (0.0, 0.2, 0.1)

CARBONATE BOMB:
1, 91-93 (~1)

SITE 451 HOLE CORE 41 CORED INTERVAL: 375.5-385.0 m

AGE | BIOSTR. ZONE: NANNOS, FORAMS, RADS | FOSSIL CHARACT.: FOSSIL, ABUNDANCE, PRESERV. | SECTION 1, CC | METERS 0.5, 1.0

GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | LITHOLOGIC SAMPLE



general color
5Y 2/1

5Y 2/1

5Y 4/4

5Y 2/1 +
5Y 4/0

LITHOLOGIC DESCRIPTION

LITHIC and VITRIC VOLCANICLASTIC CONGLOMERATE, interbedded with black-olive carbonate-bearing **VITRIC TUFF**. The conglomerate has a clasts:matrix ratio of 2:1, and contains basalt (20%), glass, andesite (? 15%), pumice (60%), and a few shallow water large benthic foraminifers. The tuffs show alternating coarse and fine, 2-3 mm beds, and contain disseminated planktonic foraminifers, and penecontemporaneous recumbent folding.

SMEAR SLIDE SUMMARY

	1-84 (D)	1-85 (M)	1-110 (M)
TEXTURE:			
Sand	3	6	3
Silt	87	93	87
Clay	10	1	10
TOTAL DETRITAL	77	38	36
COMPOSITION:			
Feldspar	1	2	1
Heavy minerals	TR	TR	–
Clay minerals	10	1	10
Volcanic glass	66	35	25
Micronodules	2	4	2
Zeolites	–	–	1
Recrystallized carb.	10	10	10
Foraminifers	1	3	2
Nannofossils	10	45	49

PHYSICAL PROPERTIES:

	Section 1 73 cm
Wet bulk density	1.96
Porosity (%)	46.7
Grain density	2.79

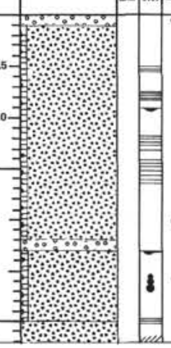
CARBON/CARBONATE:
1-84 (0.0, 2.2, 0.3)

CARBONATE BOMB:
1, 85-86 (3)

SITE 451 HOLE CORE 42 CORED INTERVAL: 385.0-394.5 m

AGE: Late Miocene ? | BIOSTR. ZONE: NANNOS ?, FORAMS, RADS | FOSSIL CHARACT.: FOSSIL N, ABUNDANCE R, PRESERV. P | SECTION 1, 2, CC | METERS 0.5, 1.0

GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | LITHOLOGIC SAMPLE



5Y 2/1

N6 + N3

5Y 5/1
5Y 4/1
5Y 2/1 +
5Y 6/1

5Y 3/1

5Y 5/1

5Y 2/1
5Y 4.5/1
5Y 6/1

5Y 6/1

5Y 2/1 +
5Y 6/1

LITHOLOGIC DESCRIPTION

VITRIC TUFF, carbonate-rich, gray to dark gray to black with thin beds of black **VOLCANICLASTIC CONGLOMERATE**. The vitric tuff is disturbed and displaced by normal faulting, is rich inplanktonic foraminifers, and shows frequent parallel lamination and bedding. Grain size ranges from silt to medium sand; load casts and direct or inverse graded bedding occur. The conglomerate is analogous to that described in the previous core.

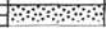
SMEAR SLIDE SUMMARY

	1-9 (M)	2-56 (D)	2-114 (D)
TEXTURE:			
Sand	9	50	25
Silt	61	25	55
Clay	30	25	20
TOTAL DETRITAL	91	74	73
COMPOSITION:			
Feldspar	4	7	9
Heavy minerals	1	1	2
Clay minerals	30	25	20
Volcanic glass	54	51	42
Micronodules	4	5	10
Zeolites	5	10	5
Amorph Fe agg.	–	1	2
Recrystallized carb.	–	10	10
Nannofossils	–	–	TR
Fish remains	2	–	–

CARBON/CARBONATE:
1-61 (0.0, 15.3, 1.9)

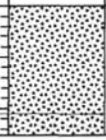
CARBONATE BOMB:
1, 61-67 (17)

SITE 451 HOLE CORE 43 CORED INTERVAL: 394.5-404.0 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
							CC						5Y 2/1 + 5Y 7/1

VITRIC TUFF, massive where coarse grained; carbonate-bearing and with intense light gray bioturbation where fine-grained.

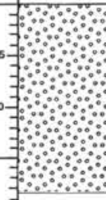
SITE 451 HOLE CORE 44 CORED INTERVAL: 404.0-413.5 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
							1	0.5, 1.0				•	general color 5Y 2/1; 5Y 3/2 burrows
							CC						5Y 2/1

VITRIC TUFF, black. Intervals with dark olive-gray burrow, rich in planktonic foraminifers alternate with massive, foraminifer-poor intervals.

CARBONATE BOMB:
1, 85-86 (2)

SITE 451 HOLE CORE 45 CORED INTERVAL: 413.5-416.5 m

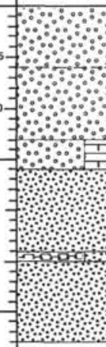
AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
							1	0.5, 1.0				T	general color 5Y 3/1; 5BG 7/2 tuff boulder
							2						
							2						

BOULDER VOLCANICLASTIC CONGLOMERATE, with very dark gray matrix of volcanic tuff and coarser clasts. Epidote and hydrothermal pyrite are diffuse in the matrix. Boulders are 20 to 30 cm thick, composed of plagioclase-phyric vesicular basalt, plagioclase-olivine-phyric amydaloidal basalt, and by a pale blue-green volcanic tuff hydrothermally altered.

BULK ANALYSIS:	1-29	1-70
SiO_2	48.1	48.3
TiO_2	0.59	0.60
Al_2O_3	19.8	19.8
Fe_2O_3	1.20	1.21
FeO	7.91	7.97
MnO	0.18	0.18
MgO	4.86	5.05
CaO	12.60	12.46
Na_2O	2.37	2.13
K_2O	0.26	0.22
P_2O_5	0.10	0.11

PHYSICAL PROPERTIES:	Section 1 75 cm
Wet bulk density	2.71
Porosity (%)	9.78
Grain density	2.90

SITE 451 HOLE CORE 46 CORED INTERVAL: 416.5-423.0 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
							1	0.5, 1.0				•	5Y 3/1; 5Y 2/1
							2					• •	general color 5Y 5/1; 2.5Y 2/1; 5GY 4/1 lamina; 5Y 2/1; 5Y 2/1; 5Y 6/1; 5Y 2/1; 5Y 2/1; 5Y 2/1
				N	–	–	3						
							3						
							4						

BOULDER VOLCANICLASTIC CONGLOMERATE, very dark gray, grading down core to less coarse conglomerate, very dark gray, to foraminifer-rich conglomerate, black, to gray **VITRIC TUFF** with intercalations of gray clay- and carbonate-rich tuff. The boulders consist mainly of plagioclase-olivine-phyric basalt. The vitric tuff is faulted and shows alternating silt- and sand-sized intervals, carbonate-rich and carbonate-poor respectively. Other structures include clay flumes, bioturbation, gradation, and some large pumice clasts and large benthic foraminifers near the bottom of Section 3. The carbonate-rich tuff is sand-sized and rich in foraminifers. Beds dip about 20°.

SMEAR SLIDE SUMMARY

	2-45 (M)	2-91 (M)
TEXTURE:		
Sand	10	9
Silt	70	71
Clay	20	20
TOTAL DETRITAL	45	23
COMPOSITION:		
Feldspar	3	2
Heavy minerals	2	1
Clay minerals	20	20
Volcanic glass	20	7
Micronodules	4	6
Zeolites	TR	2
Amorph Fe agg.	1	–
Recrystallizee carb.	50	61
Foraminifers	TR	–
Nannofossils	TR	1

Smear Slides (Minor): 1-140

CARBON/CARBONATE:
2-76 (0.0, 17.4, 2.1)

CARBONATE BOMB:
2, 76-78 (15)
2, 97-100 (~1)

BULK ANALYSIS:	1-24
SiO_2	50.6
TiO_2	0.77
Al_2O_3	15.8
Fe_2O_3	1.34
FeO	8.81
MnO	0.17
MgO	6.70
CaO	9.58
Na_2O	2.52
K_2O	0.62
P_2O_5	0.23

PHYSICAL PROPERTIES:	Section 2 90 cm
Wet bulk density	2.06
Porosity (%)	41.4
Grain density	2.81

SITE 451 HOLE CORE 47 CORED INTERVAL: 423.0-432.5 m (Hole deviation of 3.0° at 423.0 m)

AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
							1	0.5, 1.0	Void			•
							2					•
							CC					

LITHOLOGIC DESCRIPTION

5Y 6/1 clasts

general color 5Y 2/1

5Y 6/1 and 5BG 5/1 clasts

N4, N6, 5Y 2/1

VITRIC TUFF, black, with coarser layers and scattered clasts which are mainly gray and grayish-blue gray, rounded to subrounded pumice fragments, often almost completely altered to soft clay. Also minor glass and basalt clasts occur. At places, some tabular clasts show crude orientation. Trace components are white fragments of shallow water large benthonic foraminifers, consisting of recrystallized carbonate or silica. The tuff is locally foraminifer-bearing, and is either silt-sized and bioturbated or sand-sized and massive. Bedding dips 20°.

SMEAR SLIDE SUMMARY

	1-62 (M)	2-33 (M)
TEXTURE:		
Sand	0	10
Silt	50	87
Clay	50	3
TOTAL DETRITAL	80	8
COMPOSITION:		
Feldspar	TR	TR
Heavy minerals	TR	–
Clay minerals	50	3
Volcanic glass	30	5
Micronodules	TR	1
Zeolites	20	–
Recrystallized carb.	–	89
Foraminifers	–	2
Nannofossils	–	TR
Fish remains	TR	–

SITE 451 HOLE CORE 48 CORED INTERVAL: 432.5-442.0 m

AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
							CC					

LITHOLOGIC DESCRIPTION

N5

VOLCANICLASTIC CONGLOMERATE, light to medium gray **FINE VITRIC TUFF**, and large medium gray **FINE VITRIC TUFF**, all drilling fragments, with approximately 30% biogenic material and minor bioturbation. This fine vitric tuff grades downward into a coarser dark gray **VITRIC TUFF** with one erosional contact visible in the transition zone.

SITE 451 HOLE CORE 49 CORED INTERVAL: 442.0-451.5 m

AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
Late Miocene	NN 10?			N	F	P	1			O O O		
							CC	0.5				

LITHOLOGIC DESCRIPTION

5Y 2/1 general color

N4

FINE VITRIC TUFF, black, with moderately fine laminations and cross-bedding and ~10% biogenic component in Section 1. The Core-Catcher contains three fragments of medium dark gray bioturbated **FINE VITRIC TUFF** with 20-25% biogenic component (pelagic foraminifers and nannofossils).

SITE 451 HOLE CORE 50 CORED INTERVAL: 451.5-461.0 m

AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
							CC					

LITHOLOGIC DESCRIPTION

5Y 2/1

VITRIC TUFF, black, massive and structureless, contains 2% white biogenic grains which include benthonic foraminifers.

SITE 451 HOLE CORE 51 CORED INTERVAL: 461.0-470.5 m

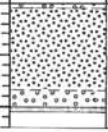
AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
							CC			O O		

LITHOLOGIC DESCRIPTION

general color 5Y 2/1

FINE VITRIC TUFF, black, drilling breccia, moderately burrowed with thin laminations and approximately 10% foraminifers *(Orbulina)*. One clast of black **VITRIC TUFF** present.

SITE 451 HOLE CORE 52 CORED INTERVAL: 470.5-473.5 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
		No older than Middle Miocene		N	–	–	1	0.5, 1.0				*
				F	R	P	CC					

LITHOLOGIC DESCRIPTION

5Y 2/1
5G 2/1

5B 4/1
5Y 2/1

VOLCANICLASTIC CONGLOMERATE, black matrix, the majority of clasts are coarse sand-sized, subangular to subrounded, blue-gray tuff with a gravel-sized clasts of medium gray tuff and black aphanitic basalt. It grades downward into 80 cm of dark green-black **VITRIC TUFF** which contains scattered small granules of blue-gray glass and white pumice; faint laminations dip 30°. Fifteen cm of medium gray conglomerate underlies the tuff; it contains: 15% matrix, 65% tuff clasts, and 20% basalt clasts. In Core-Catcher a piece of black to dark gray calcareous **FINE VITRIC TUFF** with faint laminations dipping 20° and minor bioturbation. The sediment is uniformly hard; drilling disturbance moderate.

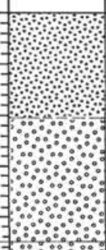
SMEAR SLIDE SUMMARY

	1-28 (D)
TEXTURE:	
Sand	5
Silt	70
Clay	25
TOTAL DETRITAL	86
COMPOSITION:	
Feldspar	1
Heavy minerals	TR
Clay minerals	25
Volcanic glass	55
Palagonite	5
Micronodules	1
Zeolites	1
Recrystallized carb.	5
Nannofossils	2

CARBON/CARBONATE: 1-72 (0.0, 3.1, 0.4)

CARBONATE BOMB: 1, 71-72 (3)

SITE 451 HOLE CORE 53 CORED INTERVAL: 473.5-480.0 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
							1	0.5, 1.0				
							2					
							CC					

LITHOLOGIC DESCRIPTION

5GY 2/1
general color

5BG 5/1
clasts

5G 2/1

VITRIC TUFF, greenish black, massive, coarsens below 80 cm to 103 cm with clasts up to 3 mm diameter of greenish-gray pumice and tuff. Below 103 cm **VOLCANICLASTIC CONGLOMERATE** the matrix of which is greenish black, has clasts up to 1 cm of greenish-gray tuff, black basalt, and rare pumice with diameters of 2 cm. Scattered, 8 cm diameter, medium dark gray, basalt clasts with altered rims are present in Sections 1, 2, and the Core-Catcher. The sediment is uniformly hard; drilling disturbance slight.

CARBON/CARBONATE: 1-0 (0.0, 1.5, 0.2)

CARBONATE BOMB: 1, 1-2 (~2)

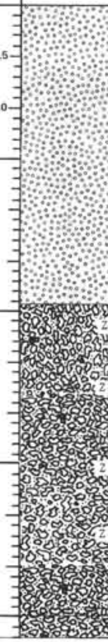
BULK ANALYSIS:

	2-3
SiO_2	48.2
TiO_2	0.76
Al_2O_3	19.4
Fe_2O_3	0.99
FeO	0.55
MnO	0.11
MgO	7.02
CaO	11.76
Na_2O	2.26
K_2O	0.93
P_2O_5	0.25

PHYSICAL PROPERTIES:

	Section 2 40 cm
Wet bulk density	2.17
Porosity (%)	34.3
Grain density	2.78

SITE 451 HOLE CORE 54 CORED INTERVAL: 480.0-489.5 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
							1	0.5, 1.0				T, T
							2					T
							3					
							4					
							CC					*

LITHOLOGIC DESCRIPTION

5G 2/1
general color

basalt clast with
chalcedonic vein

5G 2/1

VITRIC TUFFACEOUS VOLCANICLASTIC CONGLOMERATE, greenish-black matrix, with clasts, (3 mm) of tuff (with 80% zeolite and 20% carbonate cement), minor 1 mm olivine clasts, and large black phyric basalt clasts up to 13 cm. An 8 by 70 mm chalcedony vein filling with discontinuous calcite margins cuts a basalt clast from 113 to 120 cm in Section 1. Below 142 cm in Section 2 the rock is altered and contains approximately 20% zeolites and calcite in the matrix (except for a 30 cm segment in Section 3, from 35 to 65 cm, which has less than 1% zeolites and calcite). The rock is uniformly hard.

SMEAR SLIDE SUMMARY

	CC (D)
TEXTURE:	
Sand	7
Silt	68
Clay	25
TOTAL DETRITAL	100
COMPOSITION:	
Feldspar	TR
Heavy minerals	1
Clay minerals	24
Volcanic glass	75
Micronodules	TR

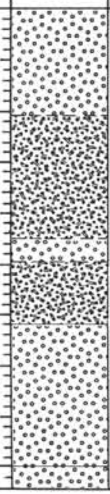
CARBON/CARBONATE: 3-45 (0.0, 4.0, 0.5)

CARBONATE BOMB: 3, 46-47 (3)

BULK ANALYSIS:

	1-22
SiO_2	48.4
TiO_2	0.78
Al_2O_3	18.4
Fe_2O_3	1.07
FeO	7.05
MnO	0.13
MgO	7.76
CaO	10.99
Na_2O	2.40
K_2O	0.85
P_2O_5	0.11

SITE 451 HOLE CORE 55 CORED INTERVAL: 489.5-499.0 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
							1 2 3 CC	0.5 1.0					

general color
5GY 2/1

VITRIC TUFF, black interbedded with **VOLCANICLASTIC CONGLOMERATE.** Gradational contacts common. The clasts:matrix ratio is ~2:1. Angular to rounded clasts of plagioclase-phyric basaltic andesite, aphyric basalt, and red andesite occur in matrix of smaller lithic clasts and altered glass often replaced by green smectite, and intergranular and cavity-filling zeolitic and carbonate cement. Hydrothermal pyrite occurs sporadically in altered fragments of volcanic rocks. The tuff ranges from silt to very coarse sand-sized, and shows in places, graded bedding.

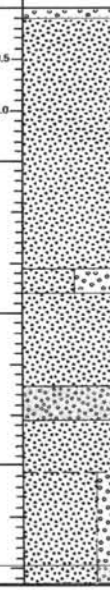
CARBON/CARBONATE:
2-25 (0.0, 1.3, 0.2)

CARBONATE BOMB:
2, 24-25 (2)

10R 4/2

5GY 2/1

SITE 451 HOLE CORE 56 CORED INTERVAL: 499.0-508.5 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
Late Miocene	NN 10?			N	R	P	1 2 3 4 CC	0.5 1.0					

general color
5Y 2/1

VITRIC and LITHIC TUFF and TUFFACEOUS VOLCANICLASTIC CONGLOMERATE, black. These lithotypes form cm-thick interbedded layers in lower Section 2, and thicker layers elsewhere. In lower Section 3 and Core-Catcher scattered granules occur, floating in a tuffaceous groundmass. Clast composition includes basaltic andesite, basalt, altered glass, and pumice. Diffuse grains of hydrothermal pyrite are present. Graded bedding is common. Black lignite fragments occur near the top of Section 3. Dip is ~25°.

black lignite stripes

SMEAR SLIDE SUMMARY

	3-2 (M)
TEXTURE:	
Sand	3
Silt	97
Clay	0
TOTAL DETRITAL	10
COMPOSITION:	
Feldspar	1
Heavy minerals	2
Volcanic glass	7
Organic carbon	90

CARRON/CARBONATE:
1-83 (0.0, 1.1, 0.2)

CARBONATE BOMB:
1, 82-83 (1-2)

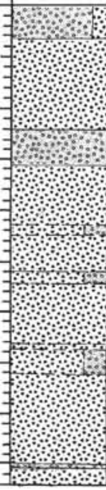
PHYSICAL PROPERTIES:	Section 1 35 cm
Wet bulk density	2.03
Porosity (%)	43.9
Grain density	2.84

5Y 2/1

SITE 451 HOLE CORE 57 CORED INTERVAL: 508.5-518.0 m

AGE | BIOSTR. ZONE: NANNOS, FORAMS, RADS | FOSSIL CHARACT.: FOSSIL ABUNDANCE, PRESERV. | SECTION | METERS | GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | LITHOLOGIC SAMPLE | LITHOLOGIC DESCRIPTION

Sections: 1, 2, 3, CC (meters 0.5, 1.0)



general color
5Y 2/1

VITRIC and LITHIC TUFF and TUFFACEOUS VOLCANICLASTIC CONGLOMERATE, black. The tuff is very fine to coarse sand-sized, conglomerate occurs as discrete layers, containing a few coarse lithic clasts, scattered or clustered in intervals among the tuff layers. Their composition is the same as in the previous core.

SMEAR SLIDE SUMMARY

	2-55 (M)
TEXTURE:	
Sand	25
Silt	60
Clay	15
TOTAL DETRITAL	95
COMPOSITION:	
Feldspar	15
Heavy minerals	10
Clay minerals	15
Volcanic glass	55
Micronodules	3
Zeolites	2

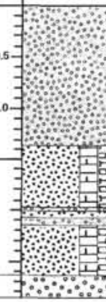
PHYSICAL PROPERTIES	Section 2 116 cm
Wet bulk density	2.01
Porosity (%)	45.4
Grain density	2.85

5Y 2/1

SITE 451 HOLE CORE 58 CORED INTERVAL: 518.0-527.5 m

AGE | BIOSTR. ZONE: NANNOS, FORAMS, RADS | FOSSIL CHARACT.: FOSSIL ABUNDANCE, PRESERV. | SECTION | METERS | GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | LITHOLOGIC SAMPLE | LITHOLOGIC DESCRIPTION

Sections: 1, 2, CC (meters 0.5, 1.0)



general color
5G 2/1

general color
5Y 6/1
5Y 4/1 mottles
N4.5/
N4.5/

5Y 3/1

loose basalt clasts

TUFFACEOUS VOLCANICLASTIC BRECCIA, greenish black, in Section 1 and in two thin intervals in Section 2. Clasts:matrix ratio is 2:1. Clasts are angular to subangular and consist of basalt (45%), pumice (15%), glassy basalt and glass (30%), oxidized andesites (5%), and gray fine vitric tuff (5%). The matrix also secondary zeolites and carbonates. From bottom of Section 2 downcore, alternating intervals of **VITRIC TUFF, CALCAREOUS and CLAY-RICH VITRIC TUFF, NANNOFOSSIL-RICH VITRIC TUFF,** gray to very dark gray. These layers *often show parallel lamination, burrowing and* mottling; some bear planktonic foraminifers. The Core-Catcher contains pieces of fine-grained, slightly hydrothermally altered microplagioclase olivine-phyric basalt, probably representing washed out clasts of an original breccia interval. Dip is 20 to 30°.

SMEAR SLIDE SUMMARY

	2-28 (D)	2-36 (D)	2-91 (D)
TEXTURE:			
Sand	5	5	10
Silt	93	85	65
Clay	2	10	25
TOTAL DETRITAL	9	90	68
COMPOSITION:			
Feldspar	2	25	6
Heavy minerals	2	5	5
Clay minerals	2	10	25
Volcanic glass	3	50	32
Micronodules	1	TR	1
Zeolites	–	5	5
Recrystallized carb.	5	5	5
Foraminifers	5	–	1
Nannofossils	80	–	25

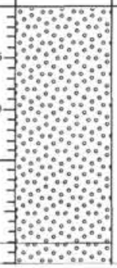
CARBON/CARBONATE: 2-54 (0.0, 1.5, 0.2)

CARBONATE BOMB: 2, 14-16 (47)

SITE 451 HOLE CORE 59 CORED INTERVAL: 527.5-537.0 m (Hole deviation of 3.0° at 537.0 m)

Columns: AGE | BIOSTR. ZONE (NANNOS, FORAMS, RADS) | FOSSIL CHARACT. (FOSSIL, ABUNDANCE, PRESERV.) | SECTION | METERS | GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | LITHOLOGIC SAMPLE | LITHOLOGIC DESCRIPTION

Sections: 1, 2, CC; Meters: 0.5, 1.0



general color 5GY 2/1

boulder basaltic andesite

5GY 2/1

VOLCANICLASTIC CONGLOMERATE, greenish black. The clasts:matrix ratio is 4:1 in Section 1, 5:1 in Section 2. The clasts are subangular to subrounded, some exceeding 20 cm diameter. Their composition is:

Section 1	Section 2	
70%	40%	altered aphyric basalt + glass
10%	30%	plagioclase-phyric basalt
10%	20%	basaltic andesite with oxidized groundmass
10%	10%	altered pumice

The matrix contains small fragments partly cemented by carbonate and zeolite.

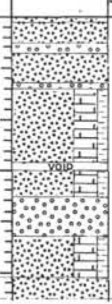
BULK ANALYSIS:	1-54
SiO_2	57.2
TiO_2	0.65
Al_2O_3	17.7
Fe_2O_3	0.86
FeO	5.69
MnO	0.15
MgO	3.03
CaO	8.60
Na_2O	3.27
K_2O	2.13
P_2O_5	0.14

PHYSICAL PROPERTIES:	Section 1 95 cm
Wet bulk density	2.12
Porosity (%)	38.4
Grain density	2.83

SITE 451 HOLE CORE 60 CORED INTERVAL: 537.0-546.5 m

Columns: AGE | BIOSTR. ZONE (NANNOS, FORAMS, RADS) | FOSSIL CHARACT. (FOSSIL, ABUNDANCE, PRESERV.) | SECTION | METERS | GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | LITHOLOGIC SAMPLE | LITHOLOGIC DESCRIPTION

Sections: 1, 2, CC; Meters: 0.5, 1.0



N4 + N2
general color 5YR 2/1
basalt pebble
N3

5Y 5/1

5Y 4/1

5Y 5/1

5YR 2/1

VOLCANICLASTIC CONGLOMERATE, black, interbedded with **NANNOFOSSIL and CLAY-BEARING VITRIC TUFF**, black to dark gray and gray. The conglomerate contains rare oxidized andesite clasts. The tuff is fine to coarse sand-sized, contains patches completely transformed to clay, complex bioturbation and individual burrows, graded beds, intervals with normal faulting.

SMEAR SLIDE SUMMARY

	2-5 (M)	2-6 (M)	2-7 (M)
TEXTURE:			
Sand	5	3	12
Silt	67	1	63
Clay	28	96	25
TOTAL DETRITAL	84	99	33
COMPOSITION:			
Feldspar	4	1	3
Heavy minerals	1	TR	–
Clay minerals	28	96	25
Volcanic glass	51	2	25
Micronodules	2	TR	4
Zeolites	1	1	3
Recrystallized carb.	2	–	5
Foraminifers	1	–	1
Nannofossils	10	–	5

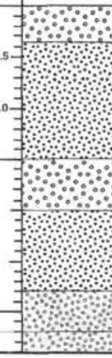
CARBON/CARBONATE: 1-47 (0.1, 12.4, 1.6)

CARBONATE BOMB: 1, 47-48 (12)

SITE 451 HOLE CORE 61 CORED INTERVAL: 546.5-556.0 m

Columns: AGE | BIOSTR. ZONE (NANNOS, FORAMS, RADS) | FOSSIL CHARACT. (FOSSIL, ABUNDANCE, PRESERV.) | SECTION | METERS | GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | LITHOLOGIC SAMPLE | LITHOLOGIC DESCRIPTION

Sections: 1, 2, 3, CC; Meters: 0.5, 1.0



general color 5Y 2/1

basalt clast 3x6 cm

5Y 2/1

Interbedded black **TUFFACEOUS VOLCANICLASTIC BRECCIA, VOLCANICLASTIC BRECCIA, and VITRIC TUFF.** The breccia has a clasts:matrix ratio of 3:1 in Sections 1 and 2, of 1:2 in Section 3. Clasts are angular to subangular basalt, basaltic-andesite(?), pumice and glass. Zeolite is present in the matrix. The vitric tuff contains rare bioturbation, parallel lamination, and beds grading from medium-coarse sand-size to silt-size.

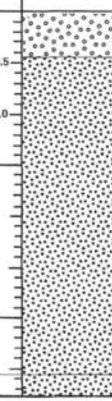
PHYSICAL PROPERTIES:	Section 2 115 cm
Wet bulk density	2.04
Porosity (%)	34.1
Grain density	2.58

SITE 451 HOLE CORE 62 CORED INTERVAL: 556.0-565.5 m

Columns: AGE | BIOSTR. ZONE (NANNOS, FORAMS, RADS) | FOSSIL CHARACT. (FOSSIL, ABUNDANCE, PRESERV.) | SECTION | METERS | GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | LITHOLOGIC SAMPLE | LITHOLOGIC DESCRIPTION

Sections: 1, 2, 3, CC; Meters: 0.5, 1.0

CC: FOSSIL N, ABUNDANCE –, PRESERV. –



5G 2/1

N3 and 5G 2/1

5GY 2/1

VOLCANICLASTIC BRECCIA, greenish black to black, in upper Section 1. Clasts:matrix ratio is 3:1; clasts are ~1:1 lithic:vitric, unsorted and unoriented. The matrix is fine tuff. The largest clasts occur at the bottom of the interval.
VITRIC TUFF, dark gray to greenish gray, underlies the breccia; grain-size ranges from silt to sand.

CARBON/CARBONATE:
2-54 (0.0, 0.9, 0.1)

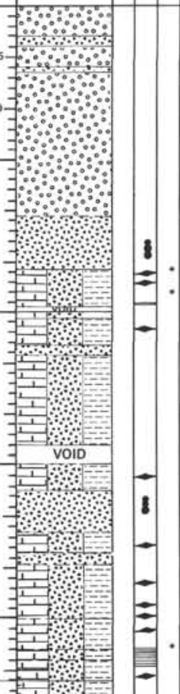
CARBONATE BOMB:
2, 56-57 (1-2)

PHYSICAL PROPERTIES:	Section 2 127 cm
Wet bulk density	2.03
Porosity (%)	40.9
Grain density	2.75

SITE 451 HOLE CORE 63 CORED INTERVAL: 565.5-575.0 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS
Late Miocene	NN 10?			N	C	P	2	0.5, 1.0
				N	F	P	1, 2, 3, 4, 5, CC	

GRAPHIC LITHOLOGY / DRILLING DISTURBANCE / SEDIMENTARY STRUCTURES / LITHOLOGIC SAMPLE



LITHOLOGIC DESCRIPTION

5GY 2/1

N4
N3
N2
5G 6/1
5G 2/1
N5
5G 2/1

5Y 4/1 +
5Y 6/1 burrows
5G 7/2
pumice
5Y 3/1
5YR 5/2
burrows
5YR 4/1
5YR 5/2 +
5Y 3/1
burrows
5YR 4/1
5YR 3/2
5YR 4/2
burrows
5YR 4/1 +
5YR 3/1

Greenish-black **VOLCANICLASTIC BRECCIA and VITRIC TUFF**, as in Core 62. Below lower Section 2, the core contains several layers of very dark reddish-brown clay-rich **VITRIC TUFF** and of carbonate-rich **VITRIC TUFF**, dark gray to gray, intensely bioturbated in red gray and dark red gray. These lithotypes contain intervals with parallel laminations, and are affected by normal faulting and penecontemporaneous deformation. Planktonic foraminifers are present in many levels in Sections 2 to 5, in place as enrichments along laminae. Dip is ~20°.

SMEAR SLIDE SUMMARY

	2-110 (D)	2-130 (M)	5-30 (M)
TEXTURE:			
Sand	13	5	15
Silt	85	75	62
Clay	2	20	23
TOTAL DETRITAL	46	94	94
COMPOSITION:			
Feldspar	6	3	10
Heavy minerals	3	2	5
Clay minerals	2	20	23
Volcanic glass	35	69	57
Micronodules	4	2	4
Zeolites	1	2	1
Recrystallized carb.	3	–	–
Foraminifers	5	–	–
Nannofossils	41	2	–
Fish remains	TR	–	1

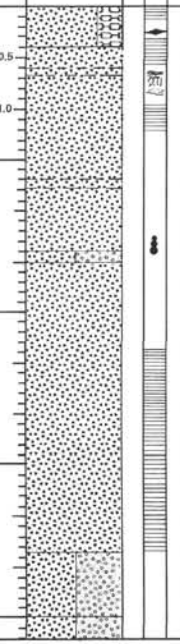
CARBON/CARBONATE:
4-99 (0.1, 10.6, 1.3)
5-37 (0.0, 0.3, 0.1)

CARBONATE BOMB:
4, 99-103 (8)
5, 37-40 (1)

SITE 451 HOLE CORE 64 CORED INTERVAL: 575.0-584.5 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS
Late Miocene	NN 10?			N	F	P	1, 2, 3, 4, CC	0.5, 1.0

GRAPHIC LITHOLOGY / DRILLING DISTURBANCE / SEDIMENTARY STRUCTURES / LITHOLOGIC SAMPLE



LITHOLOGIC DESCRIPTION

5YR 4/1
5Y 2/1
5Y 3/2
5GY 7/1
5G 5/2 celadonite
5Y 2/1 +
5B 7/1
5YR 4/1
5G 4/1
5YR 4/1
5G 5/2 celadonite
5G 4/1
5BG 4/1
pumice
5Y 3/1
5Y 2/1 +
5B 7/1
5Y 2/1
5Y 2/1

VITRIC TUFF, dark gray to very dark gray to black, fine to coarse sand-sized. Often very well laminated in alternating black and light bluish-gray colors. *In* Section 1 occur ripple, festoon, and convolute laminations. Dark gray bioturbation is limited to the upper part of Section 1. Two grayish-green irregular intervals of smectite occur in Sections 1 and 2. Some intervals consist almost entirely of sand- and gravel-sized greenish-gray and light bluish-gray pumice and glass fragments. The lower part of Section 4 and the Core-Catcher contain numerous, 1-2 cm, alternate beds of black vitric tuff and of medium bluish-gray conglomerate, composed of rounded glass and pumice fragments.

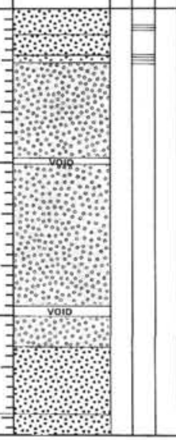
CARBON/CARBONATE:
3-98 (0.0, 0.6, 0.1)

CARBONATE BOMB:
3, 97-98 (1)

PHYSICAL PROPERTIES:	Section 3 31 cm
Wet bulk density	2.10
Porosity (%)	40.2
Grain density	2.84

SITE 451 HOLE CORE 65 CORED INTERVAL: 584.5-594.0 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
							1	0.5 1.0	VOID				N3
							2		VOID				N3 + 5BG 4/1
							3						N1 N2
							CC						N1



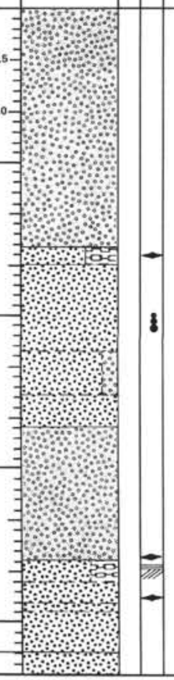
VITRIC TUFF, black to dark gray, and **TUFFACEOUS VOLCANICLASTIC BRECCIA**, dark gray with dark greenish-gray clasts. The vitric tuff is either massive or laminated, fine or coarse sand-sized. The breccia has clasts:matrix ratio of 2:3 and unsorted, angular to subangular. Glass and pumice fragments up to 3 cm in diameter, rarely with crude orientation parallel to the bedding. Dip is ~30°.

CARBON/CARBONATE:
2-43 (0.0, 0.0, 0.0)

CARBONATE BOMB:
2, 41-43 (>1)

SITE 451 HOLE CORE 66 CORED INTERVAL: 594.0-603.5 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
							1	0.5 1.0					N1 + 5B 4/1 clasts
							2						N4 N3
							3						N1 N4 N4 N1+ 5B 4/1 clasts
							4						5BG 4/1 N5 5BG 4/1
							5						
							CC						N1

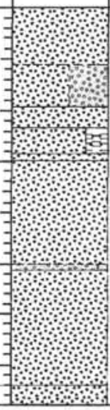


TUFFACEOUS VOLCANICLASTIC BRECCIA, black, interbedded with **VITRIC TUFF**, dark gray to grayish-black to black. The breccia has a clasts:matrix ratio of 1:3 or 4. Blue-gray clasts up to 3 cm (and rare cobbles) are angular to subrounded and the vitric:lithic ratio is 5 or 6:1. The matrix is black coarse tuff. The vitric tuff is often calcareous, medium dark gray and bioturbated, ranging from coarse to fine sand-sized, sometimes in graded beds, and containing rare pumice clasts and local faint cross and parallel lamination. Dip is 30-35°.

PHYSICAL PROPERTIES:	Section 1 22 cm
Wet bulk density	2.21
Porosity (%)	39.8
Grain density	3.01

SITE 451 HOLE CORE 67 CORED INTERVAL: 603.5-613.0 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
						1, 2, 3, CC	0.5, 1.0				



LITHOLOGIC DESCRIPTION

N1
N2
5BG 4/1 clasts
N1
N3
5Y 6/1
5YG 2/1
N3
N3

VITRIC TUFF, black and grayish black, fine to medium sand-sized with graded beds. In several intervals are dark blue-green vitric clasts. From 112 to 140 cm, Section 1, the rock is calcareous and bioturbated. Dip is ~20°.

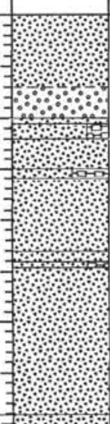
CARBON/CARBONATE:
1-26 (0.0, 0.3, 0.1)

CARBONATE BOMB:
1, 27-28 (1)

PHYSICAL PROPERTIES:	Section 1 55 cm
Wet bulk density	2.15
Porosity (%)	49.4
Grain density	3.24

SITE 451 HOLE CORE 68 CORED INTERVAL: 613.0-622.5 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
						1, 2, 3, CC	0.5, 1.0				



LITHOLOGIC DESCRIPTION

N4
5B 5/1
N3
N4
N3
5BG 4/1
N2
N3
5GY 2/1
N3

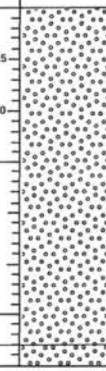
VITRIC TUFF, medium dark gray to dark gray and to grayish black. In upper Section 1 it grades downward to a **VOLCANICLASTIC BRECCIA,** medium bluish gray, with clasts:matrix ratio of 4:1 and vitric:lithic ratio of 5:1. Other features include calcareous bioturbated intervals, faint parallel and lenticular lamination, graded bedding, drag faulting. Dip is 25-30°.

CARBON/CARBONATE:
2-65 (0.0, 0.4, 0.1)

CARBONATE BOMB:
2, 64-65 (>1)

SITE 451 HOLE CORE 69 CORED INTERVAL: 622.5-632.0 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
						1, 2, 3, CC	0.5, 1.0				



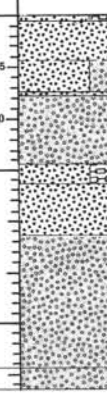
LITHOLOGIC DESCRIPTION

5G 2/1
5G 2/1

VITRIC and LITHIC VOLCANICLASTIC BRECCIA, greenish black, massive; clasts:matrix ratio is 5:1; vitric:lithic ratio ranges from 1:1 to 1:4. Angular to subangular, unsorted, unoriented clasts of dark gray and red-brown basalt, of medium blue-gray glass and pumice are the main components. The matrix is vitric and lithic tuff with trace debris of shallow water benthonic foraminifers. Largest fragments occur in Sections 2 and 3, rounded and with alteration rims.

SITE 451 HOLE CORE 70 CORED INTERVAL: 632.0-641.5 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
						1, 2, 3	0.5, 1.0				
				N	–	–	CC				



LITHOLOGIC DESCRIPTION

N5
N2-N3
5BG 5/1 clasts
N2
5BG 5/1 clasts
N3
N2-N3
5B 5/1
5B 5/1

VITRIC TUFF, medium gray to dark gray and to grayish black in Sections 1 and 2; ranging from silt to coarse sand-size, with some medium blue gray granule-sized fragments; locally calcareous with *Orbulina*; parallel and cross lamination, penecontemporaneous deformation, occasional thin and very fine dusky blue-green laminae are common.

VITRIC VOLCANICLASTIC BRECCIA, black with blue-gray clasts, occurs in Sections 1 to 3 and in the Core-Catcher. The clasts:matrix ratio is 4:1, the vitric clasts account for 95% of the total; they are mostly devitrified pumice with some pyroxene. The matrix is fine tuff. Dip is ~30°.

SMEAR SLIDE SUMMARY	1-75 (M)
TEXTURE:	
Sand	3
Silt	92
Clay	5
TOTAL DETRITAL	88
COMPOSITION:	
Feldspar	2
Heavy minerals	1
Clay minerals	5
Volcanic glass	80
Micronodules	5
Zeolites	1
Amorph Fe agg.	1
Recrystallized carb.	5
Fish remains	TR

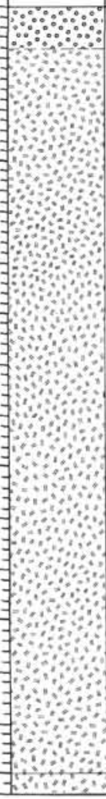
PHYSICAL PROPERTIES:	Section 2 23 cm
Wet bulk density	2.07
Porosity (%)	50.2
Grain density	3.16

CARBON/CARBONATE:
1-29 (0.0, 5.5, 0.7)

CARBONATE BOMB:
1, 28-29 (5)

SITE 451 HOLE CORE 71 CORED INTERVAL: 641.5-651.0 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
						1	0.5, 1.0				
						2					
						3					
						4					
						5					
						CC					



LITHOLOGIC DESCRIPTION

5B 5/1

VOLCANICLASTIC BRECCIA, black with blue gray, 4 mm clasts in the upper 40 cm of Section 1. The clast:matrix ratio is 4:1; clasts consist of devitrified pumice with minor pyroxene inclusions. The matrix is fine tuff. Dip is 30°. Matrix content increase to ~95% near the base of the unit. Color becomes grayish black with ~5% .2 mm diameter white clasts (possibly foraminifers) in this transition layer. Below this is fine **VITRIC TUFF;** a continuous normally graded unit through Section 5 and the Core-Catcher, becoming coarser downward. The entire unit contains abundant fragments of coral and large foraminifer, and rare scattered lithic and vitric clasts (<5 mm diameter).

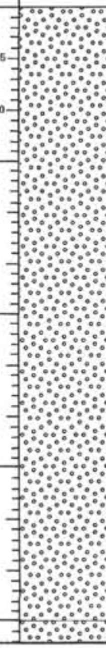
CARBON/CARBONATE:
1-62 (0.0, 3.8, 0.5)

CARBONATE BOMB:
1, 62-64 (4)

PHYSICAL PROPERTIES:	Section 1 92 cm
Wet bulk density	2.10
Porosity (%)	44.7
Grain density	2.99

SITE 451 HOLE CORE 72 CORED INTERVAL: 651.0-660.5 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
						1	0.5, 1.0				
						2					
						3					
						4					
						CC					



LITHOLOGIC DESCRIPTION

5GY 2/1
general color

VOLCANICLASTIC CONGLOMERATE, greenish black; clasts are angular to subrounded, ~.5 cm diameter, consisting of vesicular aphyric basalts, basaltic andesites, hydrothermally altered glass, and altered andesites with an oxidized groundmass containing fragments of olivine, pyroxene, and carbonate. The glass matrix is cemented with carbonate. Clasts:matrix ratio is 2:1. Drilling disturbance is moderate.

CARBON/CARBONATE:
3-56 (0.0, 3.4, 0.4)

CARBONATE BOMB:
3, 56-58 (3.5)

PHYSICAL PROPERTIES:	Section 2 58 cm
Wet bulk density	2.25
Porosity (%)	41.6
Grain density	3.14

SITE 451 HOLE CORE 73 CORED INTERVAL: 660.5-670.0 m

AGE	BIOSTR. ZONE: NANNOS	BIOSTR. ZONE: FORAMS	BIOSTR. ZONE: RADS	FOSSIL CHARACT.: FOSSIL ABUNDANCE	FOSSIL CHARACT.: PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
						1	0.5, 1.0				• • •
						CC					

LITHOLOGIC DESCRIPTION

5GY 2/1,5YR 2/1
5GY 2/1
general color
5GY 2/1, 5YR 2/1
5GY 2/1
general color
5GY 2/1

TUFFACEOUS VOLCANICLASTIC CONGLOMERATE, greenish black and brownish black. The greenish-black conglomerate contains subangular to subrounded 0.5 cm clasts of vesicular aphyric basalts, basaltic andesites, hydrothermally altered glass, and altered andesites with oxidized groundmass containing fragments of olivine, pyroxene, and carbonate. The matrix is mainly altered glass with carbonate cement. This greenish black tuff is interbedded with a massive brownish-black tuff of fine sand-size.

SMEAR SLIDE SUMMARY

	1-15 (D)	1-69 (D)	1-87 (M)
TEXTURE:			
Sand	20	9	4
Silt	75	81	96
Clay	5	10	0
TOTAL DETRITAL	82	91	5
COMPOSITION:			
Feldspar	15	5	3
Heavy minerals	4	1	1
Clay minerals	5	10	–
Volcanic glass	58	75	1
Micronodules	10	3	1
Zeolites	1	1	79
Amorph Fe agg.	1	–	–
Recrystallized carb.	6	5	–
Foraminifers	–	–	TR
Nannofossils	–	–	15

CARBON/CARBONATE:
1-41 (0.0, 11.1, 1.4)
1-119 (0.1, 0.8, 0.1)

CARBONATE BOMB:
1, 40-41 (11)
1, 119-120 (1)

SITE 451 HOLE CORE 74 CORED INTERVAL: 670.0-679.5 m

AGE	BIOSTR. ZONE: NANNOS	BIOSTR. ZONE: FORAMS	BIOSTR. ZONE: RADS	FOSSIL CHARACT.: FOSSIL ABUNDANCE	FOSSIL CHARACT.: PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
						1	0.5, 1.0				
						2					

LITHOLOGIC DESCRIPTION

N1/N2
general color
altered andesite clast

VITRIC, LITHIC, and CRYSTALLINE CONGLOMERATIC TUFFS, black to dark gray, grade into one another throughout core. The clasts are subangular to subrounded with an average diameter of 3-4 mm and occasional clasts of 5-6 cm; no sorting or orientation. Clasts consist mainly of hydrothermally altered plagioclase-phyric and aphyric andesites, and basalts, with fragments of olivine, plagioclase, and carbonate. Both clasts and matrix contain small grains of disseminated pyrite. The sediment is uniformly hard; drilling disturbance is slight.

CARBON/CARBONATE:
2-22 (0.0, 0.7, 0.1)

CARBONATE BOMB:
2, 23-24 (1)

SITE 451 HOLE CORE 75 CORED INTERVAL: 679.5-689.0 m

AGE	BIOSTR. ZONE: NANNOS	BIOSTR. ZONE: FORAMS	BIOSTR. ZONE: RADS	FOSSIL CHARACT.: FOSSIL ABUNDANCE	FOSSIL CHARACT.: PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
						1					
						CC	0.5				

LITHOLOGIC DESCRIPTION

N1/N2
general color
N1/N2

VITRIC and LITHIC and TUFFACEOUS CONGLOMERATE TUFFS, black to dark gray, interbedded and coarsening down section. The clast:matrix ratio is ~5:1. Clasts range from <0.3 mm to 2.5 mm downsection and consist of altered vitric volcanics (with olivine and plagioclase phenocrysts), altered andesite, and volcanic glass.

SITE 451 HOLE CORE 76 CORED INTERVAL: 689.0-698.5 m

AGE	BIOSTR. ZONE: NANNOS	BIOSTR. ZONE: FORAMS	BIOSTR. ZONE: RADS	FOSSIL CHARACT.: FOSSIL ABUNDANCE	FOSSIL CHARACT.: PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
						1	0.5, 1.0				

LITHOLOGIC DESCRIPTION

N1/N2

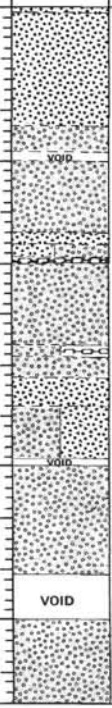
VITRIC TUFF, black to dark gray; one piece recovered.

NOTE: Site 451, Core 77, 698.5-702.5 m: NO RECOVERY.

SITE 451 HOLE CORE 78 CORED INTERVAL: 702.5-708.0 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS
Late Miocene	basal NN 10?			N	R	P	1, 2, 3, 4, 5	0.5, 1.0
				N	F	P		

GRAPHIC LITHOLOGY



LITHOLOGIC DESCRIPTION

N1-5G 2/1
5G 2/1
general color

5G 4/1
general color

5Y 4.5/1
10YR 3.5/1
5Y 4.5/1, 5G 4.5/1
10YR 6.5/1

5G 4.5/1

7.5YR 5/2 bioturbation
7.5YR 4/2 mottle
10YR 5.5/2

black glass-rich layer

5G 5/1

5BG 4/1

VITRIC TUFF, greenish black; containing angular vitric and lithic clasts increasing in size down section to a gradational boundary at 115 cm with **TUFFACEOUS VOLCANICLASTIC BRECCIA.** The clasts:matrix ratio in the breccia is 1:1. Clasts are angular, unsorted, and unoriented. The unit is blue gray and the clasts consist of vitric and lithic components in a 5:1 ratio. The unit is interbedded with vitric tuffs in the center of Section 2 and the lower portion of Section 3. Section 3 also contains intensely bioturbated zones of chalk. Normal and reversely graded beds occur in the lower 50 cm of Section 3. The breccia coarsens below 40 cm in Section 4. Clasts are unsorted and unoriented; dip on bedding is 35-40°.

SMEAR SLIDE SUMMARY

	3-12 (M)	3-36 (M)	3-60 (M)
TEXTURE:			
Sand	3	4	1
Silt	96	96	97
Clay	1	0	2
TOTAL DETRITAL	98	52	96
COMPOSITION:			
Feldspar	2	3	1
Heavy minerals	1	1	–
Clay minerals	1	–	1
Volcanic glass	94	48	93
Micronodules	–	5	1
Zeolites	TR	3	1
Recrystallized carb.	2	40	1
Nannofossils	–	–	TR
Fish remains	–	–	1

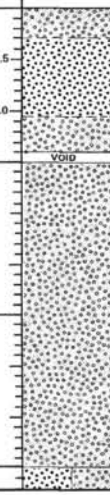
CARBON/CARBONATE:
1-85 (0.0, 5.7, 0.7)
2-101 (0.1, 38.6, 4.7)

CARBONATE BOMB:
1, 86-87 (5)
2, 102-103 (34)

SITE 451 HOLE CORE 79 CORED INTERVAL: 708.0-717.5 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS
							1, 2, 3, CC	0.5, 1.0

GRAPHIC LITHOLOGY



LITHOLOGIC DESCRIPTION

5BG 4/1

5B 4/1,
5BG 4/1

5BG 4/1
general color

N1, 5G 2/1

TUFFACEOUS VOLCANICLASTIC BRECCIA, upper 30 cm same as in previous core, is interbedded with **VITRIC TUFF,** 80 cm thick, that coarsens downward. Clasts average 2 mm in diameter. Dip of 15° is visible in faint laminations. The breccia coarsens below Section 1 to the base of Section 3. Size averages 2 to 4 mm, 50% vitric clasts/50% lithic). The clasts: matrix ratio is 1:1. Clasts are unsorted and unoriented with <1% andesite fragments. There is a coarsening trend in Section 3 downcore.

CARBON/CARBONATE:
CC-30 (0.1, 1.4, 0.2)

CARBONATE BOMB:
CC, 29-30 (1)

PHYSICAL PROPERTIES:	Section 1 31 cm	Section 1 50 cm
Wet bulk density	2.12	2.08
Porosity (%)	43.1	49.0
Grain density	2.97	3.12

SITE 451 HOLE CORE 80 CORED INTERVAL: 717.5-727.0 m

AGE: Late Miocene — NANNOS: basal NN 10 — FOSSIL CHARACT.: N (Fossil), F (Abundance), P (Preserv.)

Sections: 1, 2, 3, CC (VOID at base of Section 1 and Section 2)

N3, 5G 3/1 large foraminifer zone	
N2, N5 burrows	
N3 faulted	
N5, N6	
N3, 5G 3/1	
N3, 5G 2/1	
N4 calcareous tuff	
N3, 5G 2/1	
N2, 5G 2/1	

LITHOLOGIC DESCRIPTION

TUFFACEOUS VOLCANICLASTIC BRECCIA, medium dark gray to greenish-black; clasts average 3 to 5 mm, unsorted or unoriented. Clast:matrix ratio decreases from 1:1 to 1:5 down section, in Section 1. Bedding dips 30-35°. The lower half of this section is dark gray **FINE VITRIC TUFF** containing medium-gray calcareous burrow fillings. Two sharp contacts at 92 and 116 cm delineate a laminated zone of the tuff that has visible step faults. Below this the tuff contains recrystallized foraminifers and angular vitric clasts which increase down to the breccia transition in the top of Section 2. Clast size in the breccia ranges from 2 mm to 2 cm. Fine vitric tuff reappears in Section 3 with faint laminations dipping 30°. The tuff is carbonate-rich from 30 to 70 cm in Section 3.

CARBON/CARBONATE:
3-88 (0.0, 0.9, 0.2)

CARBONATE BOMB:
3, 77-78 (1)

SITE 451 HOLE CORE 81 CORED INTERVAL: 727.0-736.5 m

Sections: 1, 2, 3, 4, CC (VOID at base of Section 1)

general color N2 and 5G 2/1

5B 5/1 clasts

N6

5B 4/1 clasts

5B 4/1 clasts

N6

N2-N3

LITHOLOGIC DESCRIPTION

VITRIC TUFF, grayish black to black, fine-grained throughout. It contains faint and regular parallel lamination, intervals with scattered or aligned coarse medium bluish-gray vitric clasts and gray bioturbated, carbonate-rich layers with some planktonic foraminifers. Dip is 20-30°.

CARBON/CARBONATE:
1-114 (0.0, 0.4, 0.1)

CARBONATE BOMB:
1, 112-114 (1)

PHYSICAL PROPERTIES:	Section 1 122 cm
Wet bulk density	2.11
Porosity (%)	44.7
Grain density	3.01

SITE 451 HOLE CORE 82 CORED INTERVAL: 736.5-746.0 m

Sections: 1, 2, 3, 4, 5, CC (VOID in Section 4)

general color 5G 2/1

5G 2/1

LITHOLOGIC DESCRIPTION

VITRIC TUFF, black, and **VOLCANICLASTIC BRECCIA.** The lithotypes are interbedded and show transitional contacts through graded beds. The tuff is massive except for some contorted lamination and for scattered coarser fragments, sometimes occurring as thin layers. The breccia has a clasts:matrix ratio of 2 to 4:1, the vitric:lithic ratio is 2:1. Clasts are unsorted and unoriented, medium bluish-gray glass and pumice.

CARBON/CARBONATE:
3-35 (0.0, 0.2, 0.1)

CARBONATE BOMB:
3, 34-35 (1)

SITE 451 HOLE CORE 83 CORED INTERVAL: 746.0-756.5 m

FOSSIL CHARACT.: RADS: N, —, —

Sections: 1, 2, CC

general color 5G 2/1

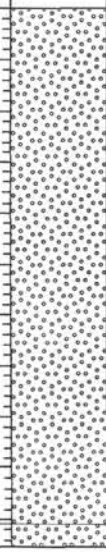
5G 2/1

LITHOLOGIC DESCRIPTION

VOLCANICLASTIC BRECCIA, greenish black. Angular to subangular, unsorted, unoriented clasts of *maximum size 3 cm in a matrix of fine tuff.* The clasts:matrix ratio is 4:1, the vitric:lithic ratio is 5:1. Some large medium-light-gray bioturbate clasts of carbonate-rich vitric tuff occur among the lithic fraction.

SITE 451 HOLE CORE 84 CORED INTERVAL: 755.5-765.0 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
						1	0.5, 1.0					
						2						
						3						
						4						
						CC						



general color
5G 2/1

VOLCANICLASTIC BRECCIA, greenish black. The clasts:matrix ratio is 3:1, the vitric:lithic ratio is 1:3, the maximum clast size commonly is 1.5 cm, with rare 3 cm fragments. The clasts are unsorted and unoriented except for intervals with crude parallel orientation of tabular clasts. The dip is ~30°. Trace amounts of biogenous carbonate debris are also present (large benthonic foraminifers).

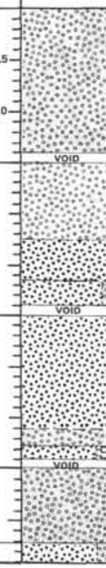
CARBON/CARBONATE:
2-71 (0.0, 0.9, 0.1)

CARBONATE BOMB:
2, 72-73 (1)

5G 2/1

SITE 451 HOLE CORE 85 CORED INTERVAL: 765.0-774.5 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
Late Miocene	basal NN 10					1	0.5, 1.0	VOID				
						2		VOID				N2
						3		VOID				N1, N4
						4						
	N	R	P			CC						



general color
5G 2/1

Interbedded **TUFFACEOUS VOLCANICLASTIC BRECCIA,** greenish black, and **VITRIC TUFF,** black to grayish black. The breccia has a clasts:matrix ratio of 2:1 and a vitric:lithic ratio of 1:3 to 4. Clasts have maximum size of 1.3 to 1.5 cm, are unsorted and unoriented. The tuff is generally massive and rarely contains 10 to 15% scattered fragments up to 5 cm, sometimes in concentrations featuring bedding. One interval near the bottom of Section 3, medium dark gray, is carbonate-rich and bioturbated. Dip is ~25°.

CARBON/CARBONATE:
2-94 (0.0, 0.2, 0.1)

CARBONATE BOMB:
2, 95-96 (>1)

N2

N1

N4

SITE 451 HOLE CORE 86 CORED INTERVAL: 774.5-784.0 m

AGE | BIOSTR. ZONE: NANNOS, FORAMS, RADS | FOSSIL CHARACT.: FOSSIL ABUNDANCE, PRESERV. | SECTION | METERS | GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | LITHOLOGIC SAMPLE

Sections: 1, 2, 3, CC (meters 0.5, 1.0)

LITHOLOGIC DESCRIPTION

general color
5G 4/1

5G 4.5/1

N4

N4

VITRIC and LITHIC TUFF, interbedded with dark greenish gray to medium dark gray interbedded with **VOLCANICLASTIC CONGLOMERATE,** dark greenish gray. The rock has clasts:matrix ratio of 5:1, and subrounded to subangular clasts of altered glassy basalt and oxidized andesite. The matrix is a lithic tuff with some zeolite and carbonate cement; it is generally massive and consists of silt to granule-sized fragments of aphyric basalt, oxidized andesite, altered volcanic glass, and glassy volcanic rocks.

CARBON/CARBONATE:
3-58 (0.1, 23.3, 2.8)

PHYSICAL PROPERTIES:	**Section 2 14 cm**
Wet bulk density	2.06
Porosity (%)	42.5
Grain density	2.84

SITE 451 HOLE CORE 87 CORED INTERVAL: 784.0-793.5 m

AGE | BIOSTR. ZONE: NANNOS, FORAMS, RADS | FOSSIL CHARACT.: FOSSIL ABUNDANCE, PRESERV. | SECTION | METERS | GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | LITHOLOGIC SAMPLE

Age: Late Miocene; Nannos: ?; Fossil: N; Abundance: R; Preserv.: P

Sections: 1, 2, CC (meters 0.5, 1.0)

LITHOLOGIC DESCRIPTION

general color
5G 2/1

5GY 4.5/1

andesite clast

5G 2/1

TUFFACEOUS VOLCANICLASTIC CONGLOMERATE black; interbedded with dark greenish-gray carbonate-rich **TUFF.** The rock has clasts:matrix ratio of 2:1. Unsorted, unoriented clasts are subrounded to subangular altered tuff, vitrophyric basalt, and oxidized andesite. The matrix consists of smaller clasts of the same lithologies with some low-temperature hydrothermal calcite and zeolite cement. The tuff shows some gradation and parallel lamination; the carbonate-rich tuff is intensely bioturbated.

CARBON/CARBONATE:
1-81 (0.0, 38.4, 4.7)

SITE 451 HOLE CORE 88 CORED INTERVAL: 793.5-803.0 m

AGE | BIOSTR. ZONE: NANNOS, FORAMS, RADS | FOSSIL CHARACT.: FOSSIL ABUNDANCE, PRESERV. | SECTION | METERS | GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | LITHOLOGIC SAMPLE

Fossil: N; Abundance: —; Preserv.: —

Sections: 1, 2, 3, CC (meters 0.5, 1.0)

LITHOLOGIC DESCRIPTION

5GY 3/1
tuff clast

5GY 4/1
5GY 2/1

5GY 3/1

5GY 3/1

5GY 3/1

5GY 3/1

Graded beds of **VOLCANICLASTIC CONGLOMERATE,** grayish olive green; passing to **VITRIC TUFF,** greenish black. The top of one of the graded intervals is dark greenish gray, carbonate-rich, and bioturbated; elsewhere it is massive. The rock has clasts:matrix ratio of 4:1. Clasts are rounded pumice (up to 1.5 cm in size), glassy basalt and rare andesite. Some imbricate-oriented clasts are apparent in the vitric tuff.

Smear Slides (Minor): 1-30, 1-105

CARBON/CARBONATE:
2-0 (0.0, 1.2, 0.2)
3-40 (0.0, 0.4, 0.1)

CARBONATE BOMB:
2, 2-3 (1)
3, 43-45 (1)

PHYSICAL PROPERTIES:	**Section 2 58 cm**
Wet bulk density	2.07
Porosity (%)	42.4
Grain density	2.85

SITE 451 HOLE CORE 89 CORED INTERVAL: 803.0-812.5 m

AGE | BIOSTR. ZONE: NANNOS, FORAMS, RADS | FOSSIL CHARACT.: FOSSIL ABUNDANCE, PRESERV. | SECTION | METERS | GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | LITHOLOGIC SAMPLE

Sections: 1, 2, CC (meters 0.5, 1.0)

LITHOLOGIC DESCRIPTION

5G 3/1

5G 3/1

5GY 2/1

5G 3/1

5G 3/1

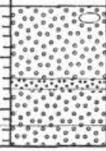
VITRIC TUFF, greenish black, interbedded with **VOLCANICLASTIC CONGLOMERATE,** dark greenish gray. The lithological characters are as described for the previous core, including some imbrication of the clasts. The conglomerateintervals display the following characters:

Section 1	Section 2	
5 to 6:1	1 to 3:1	clasts:matrix ratio
55%	14%	pumice
40%	25%	altered basalt
55%	—	fresh basalt
5%	6%	oxidized andesite

CARBON/CARBONATE:
1-129 (0.0, 0.2, 0.1)

CARBONATE BOMB:
1, 129-132 (1)

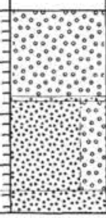
SITE 451 **HOLE** **CORE** 90 **CORED INTERVAL:** 812.5-822.0 m

AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
							1	0.5, 1.0					N3
							CC						

VITRIC TUFF, dark gray, interbedded with **VOLCANICLASTIC CONGLOMERATE.** Same lithology as in previous cores. Some pyrite clusters are present in the topmost core segment. The clasts:matrix ratio is 5:1; the vitric:lithic ratio is 1:1.

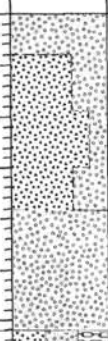
PHYSICAL PROPERTIES:	Section CC
Wet bulk density	2.04
Porosity (%)	40.1
Grain density	2.73

SITE 451 **HOLE** **CORE** 91 **CORED INTERVAL:** 822.0-831.5 m

AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
							1	0.5, 1.0					N3 + 58 4/1 coral debris; N3
							2						
							CC						N3, 5G 2/1

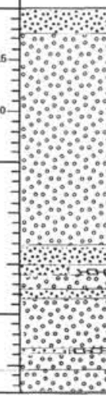
VITRIC TUFF, dark gray, and **VOLCANICLASTIC CONGLOMERATE,** dark grav to medium bluish gray. Some lithology as in previous cores. The rock contains a large (5.5 x 1.2 cm) white fragment of hermatypic coral. The tuff is very fine-grained and massive or coarse-grained with 10 to 20% granule-sized clasts and vitric:lithic ratio of 1:1.

SITE 451 **HOLE** **CORE** 92 **CORED INTERVAL:** 831.5-841.0 m

AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
							1	0.5, 1.0					N3, 5G 3/1 basalt cobble
							2						
							3						
				N	–	–	CC						N3, 5G 2/1, 5G 4/1

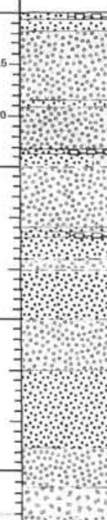
TUFFACEOUS VOLCANICLASTIC CONGLOMERATE, dark gray to dark greenish gray; and **VITRIC TUFF,** greenish black. Same lithology as in the previous cores. The clasts:matrix ratio is 1:1 to 3:1; the vitric: lithic ratio is 1:3 to 1:1. One cobble-sized piece of fine-grained vesicular basalt is present at 13 to 33 cm. The tuff contains 10 to 25% of gravel-sized, grayish blue-green vitric clasts. Among the fragments in the Core-Catcher is a piece containing a disrupted, gray, bioturbated calcareous layer.

SITE 451 **HOLE** **CORE** 93 **CORED INTERVAL:** 841.0-850.5 m

AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
							1	0.5, 1.0					N3 + 5G 2/1
				N	–	–	2						N4
				N	–	–	3						N4
							CC						N3 + 5G 2/1

VITRIC TUFF, dark gray, and **VOLCANICLASTIC CONGLOMERATE,** dark black to gray. Same lithology as in previous cores. The clasts:matrix ratio is 3:1, the vitric:lithic ratio is 1:1; rare clasts reach 4 cm. Two thin levels of gray, bioturbated carbonate-rich vitric tuff are present, and parallel lamination is found in lower Section 2.

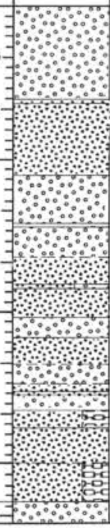
SITE 451 **HOLE** **CORE** 94 **CORED INTERVAL:** 850.5-860.0 m (Hole deviation of 2.0° at 850.5 m)

AGE	NANNOS	FORAMS	RADS	FOSSIL	ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
							1	0.5, 1.0					N3 general color
				N	–	–							N4
				N	–	–	2						N4
							3						
							4						
							CC						N3

VITRIC TUFF, dark gray; interbedded with **TUFFACEOUS VOLCANICLASTIC CONGLOMERATE.** Same lithology as in previous cores. Atop of some tuff intervals there are dark gray levels of carbonate-rich **VITRIC TUFF,** bearing silicified *Orbulinae* and showing no bioturbation except for small individual burrows near the levels bottom. The change to conglomerate has clasts:matrix ratio ranging from 1:1 to 6:1, even in the same depositional unit, generally increasing downward. The vitric:lithic ratio is constantly 4:1 and the clasts are basalt (65%), andesite (10%), pumice and glass (30%). The top of one of the conglomerate intervals shows patches of neomorphic carbonate either on grains or on matrix.

SITE 451 HOLE CORE 95 CORED INTERVAL: 860.0-869.5 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
						1	0.5, 1.0				
						2					
						3					
						4					
						CC					



LITHOLOGIC DESCRIPTION

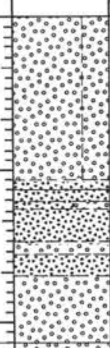
N3 general color
5GY 2/1
5GY 2/1
N2
lamina 5YR 2/1
5YR 2/1
5YR 2/1
N3

VITRIC TUFF, dark gray and greenish black; interbedded with **VOLCANICLASTIC BRECCIA.** Same lithologies as in previous core. Two massive brownish-black fine vitric tuff intervals are carbonate-rich. The breccia has clasts:matrix ratio fo 3:1 and vitric:clastic ratio of 1:1. The clasts are unoriented, unsorted, subangular, and are composed of basalt (50%), andesite (5%), and pumice + glass (45%).

PHYSICAL PROPERTIES:	Section 1 107 cm
Wet bulk density	2.20
Porosity (%)	35.4
Grain density	2.87

SITE 451 HOLE CORE 96 CORED INTERVAL: 869.5-879.0 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
						1	0.5, 1.0				
						2					
						3					
						CC					



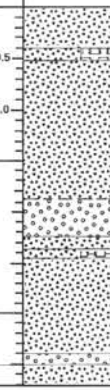
LITHOLOGIC DESCRIPTION

5GY 2/1
general color
N2
5Y 2/1 clasts
5GY 2/1

VITRIC TUFF, grayish black, massive; and **VOLCANICLASTIC BRECCIA**, greenish black; lithotypes as in previous core, and show transitional passages through direct and inverse gradation. The breccia contains 15% of angular cobble-sized fragments of brownish-black fine vitric tuff and 5% cobble-sized basalt. The clasts:matrix ratio is 4:1, the vitric:lithic ratio is 1:1. The clasts are subangular to subrounded, and contain basalt (50%), pumice + glass (95%), vitric tuff (5%).

SITE 451 HOLE CORE 97 CORED INTERVAL: 879.0-888.5 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
						1	0.5, 1.0				
						2					
						3					
						CC					



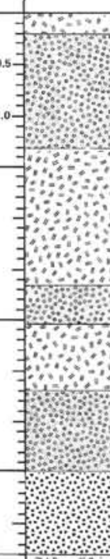
LITHOLOGIC DESCRIPTION

N3 general color
5YR 4/2
N4
5YR 4/1
5G 4/1
5YR 4/1
5G 2/1 +
5G 4/1
5G 2/1
N2
N3
5G 2/1
5YR 4/1
5GY 2/1
N3

VITRIC TUFF, dark gray, alternating with **VOLCANICLASTIC BRECCIA**, greenish black. The tuff contains cross, rippled, undulations and parallel laminations displaying a variety of colors from brownish gray to dark greenish gray to dark gray. Rare bioturbation by individual burrows. Bears either planktonic foraminifers replaced by silica or massive medium dark gray calcareous intervals. Sometimes it grades into breccia, which has a clasts:matrix ratio of 3:1, a vitric:lithic ratio of 5:1, and contains mostly pumice and glass fragments, some of which are crudely orientated parallel to the bedding. Dip is 28 to 30°.

SITE 451 HOLE CORE 98 CORED INTERVAL: 888.5-898.0 m

AGE	BIOSTR. ZONE: NANNOS	FORAMS	RADS	FOSSIL CHARACT.: FOSSIL ABUNDANCE	PRESERV.	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE
						1	0.5, 1.0				
						2					
						3					
						4					
						CC					



LITHOLOGIC DESCRIPTION

5B 4/1
5B 4/1,
5G 2/1
N1, 5G 2/1
N2 calcareous
5B 4/1
5BG 4/1
5YR 2/1, N3, N1
burrowing
5G 2/1, N3
N3, 5G 2/1
N3, 5G 2/1

FINE VITRIC TUFF, dark bluish gray, with rounded lithic:clasts up to 3 mm in diameter. Bedding dips 35 to 40°. This grades into **TUFFACEOUS VOLCANICLASTIC CONGLOMERATE**, below 20 cm in Section 1: average clast size is 3 to 4 mm, with a maximum diameter of 1.5 cm. Clasts:matrix ratio is 1:5 decreasing to 1:1 down section. Clasts consist of 50% lithic, 50% vitric compositions. Minor bioturbation occurs in the tuff at the bast of Section 1. Faint laminations and slump structures appear in the tuff in Section 2 which coarsens to conglomerate at 117 cm similar to previously described with bedding dipping 35°. The tuff in Section 3 grades from ultra fine, through fine to coarse approaching the conglomerate. Minor bioturbation and burrowing occur at the base of the ultra fine tuff. Clast size decreases in Section 4 to **VITRIC TUFF.**

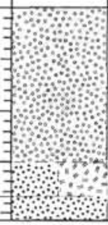
CARBON/CARBONATE:
3-6 (0.0, 0.4, 0.1)

CARBONATE BOMB:
3, 7-8 (1)

SITE 451 HOLE CORE 99 CORED INTERVAL: 898.0-907.5 m

AGE | BIOSTR. ZONE: NANNOS, FORAMS, RADS | FOSSIL CHARACT.: FOSSIL, ABUNDANCE, PRESERV. | SECTION | METERS | GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | LITHOLOGIC SAMPLE | LITHOLOGIC DESCRIPTION

Sections: 1, 2, CC; Meters: 0.5, 1.0



N3, 5YR 2/1
5B 4/1
N3, 5G 2/1
5G 4/1
5GY 2/1
N3, 5YR 2/1
N2, 5YR 2/1
N2, 5YR 2/1

TUFFACEOUS VOLCANICLASTIC CONGLOMERATE and FINE VITRIC TUFF, generally brownish black, containing vitric clasts with a clast:matrix ratio of 4:1. Clast size increases downcore in Section 1 averaging 2 to 3 mm at the base of the section. Section 2 plus the lower 24 cm of Section 1 contain faintly laminated fine vitric tuff and very fine vitric tuff.

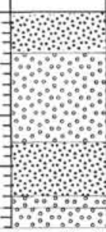
CARBON/CARBONATE:
1-34 (0.0, 21.9, 2.7)
2-8 (0.0, 0.2, 0.1)

CARBONATE BOMB:
1, 36-39 (22)

SITE 451 HOLE CORE 100 CORED INTERVAL: 907.5-917.0 m

AGE | BIOSTR. ZONE: NANNOS, FORAMS, RADS | FOSSIL CHARACT.: FOSSIL, ABUNDANCE, PRESERV. | SECTION | METERS | GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | LITHOLOGIC SAMPLE | LITHOLOGIC DESCRIPTION

Sections: 1, 2, CC; Meters: 0.5, 1.0



N5
general color

N5

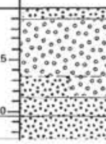
VITRIC and LITHIC TUFF, dark gray subangular to subrounded grains cemented with zeolites. Clasts average 3 mm in diameter increasing down section. They consist of aphyric and phyric basalt, altered glass, and extrusive rocks with glassy matrix. The underlying **VOLCANICLASTIC CONGLOMERATE** has an average clast size of 1 cm. Clasts consist of subangular to subrounded phyric and aphyric basalt with a clast:matrix ratio of 5:1. A 5x3 cm andesite clast is present between 44 and 49 cm in Section 1. Hydrothermally altered andesite and basalt clasts contain epidote and disseminated pyrite. The matrix contains zeolite cement. The vitric and lithic tuff beneath this resembles its counterpart at the top of the core and contains two altered andesite clasts between 126 and 135 cm in Section 1. The lower volcaniclastic conglomerate also resembeles the upper one.

CARBON/CARBONATE:
1-149 (0.0, 5.8, 5.7)

SITE 451 HOLE CORE 101 CORED INTERVAL: 917.0-926.5 m

AGE | BIOSTR. ZONE: NANNOS, FORAMS, RADS | FOSSIL CHARACT.: FOSSIL, ABUNDANCE, PRESERV. | SECTION | METERS | GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | LITHOLOGIC SAMPLE | LITHOLOGIC DESCRIPTION

Sections: 1, CC; Meters: 0.5, 1.0



5YR 2/2
5G 5/2
5YR 2/2
5G 2/1 +
5G 4/1

VITRIC TUFF, dusky brown, and **VOLCANICLASTIC CONGLOMERATE**, grayish green. Same lithology of previous cores. The rock has clasts:matrix ratio of 5:1. The clasts are subangular to subrounded and consist of: 80% altered aphyric to aphanitic basalt and andesites, tuff; 10% oxidized andesites; and 10% hydrothermally altered volcanic rocks with epidote and pyrite + holocrystalline fragments of shallow intrusive rocks, gabbro, gabbro-diorite.

SITE 451 HOLE CORE 102 CORED INTERVAL: 926.5-930.5 m

AGE | BIOSTR. ZONE: NANNOS, FORAMS, RADS | FOSSIL CHARACT.: FOSSIL, ABUNDANCE, PRESERV. | SECTION | METERS | GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | LITHOLOGIC SAMPLE | LITHOLOGIC DESCRIPTION

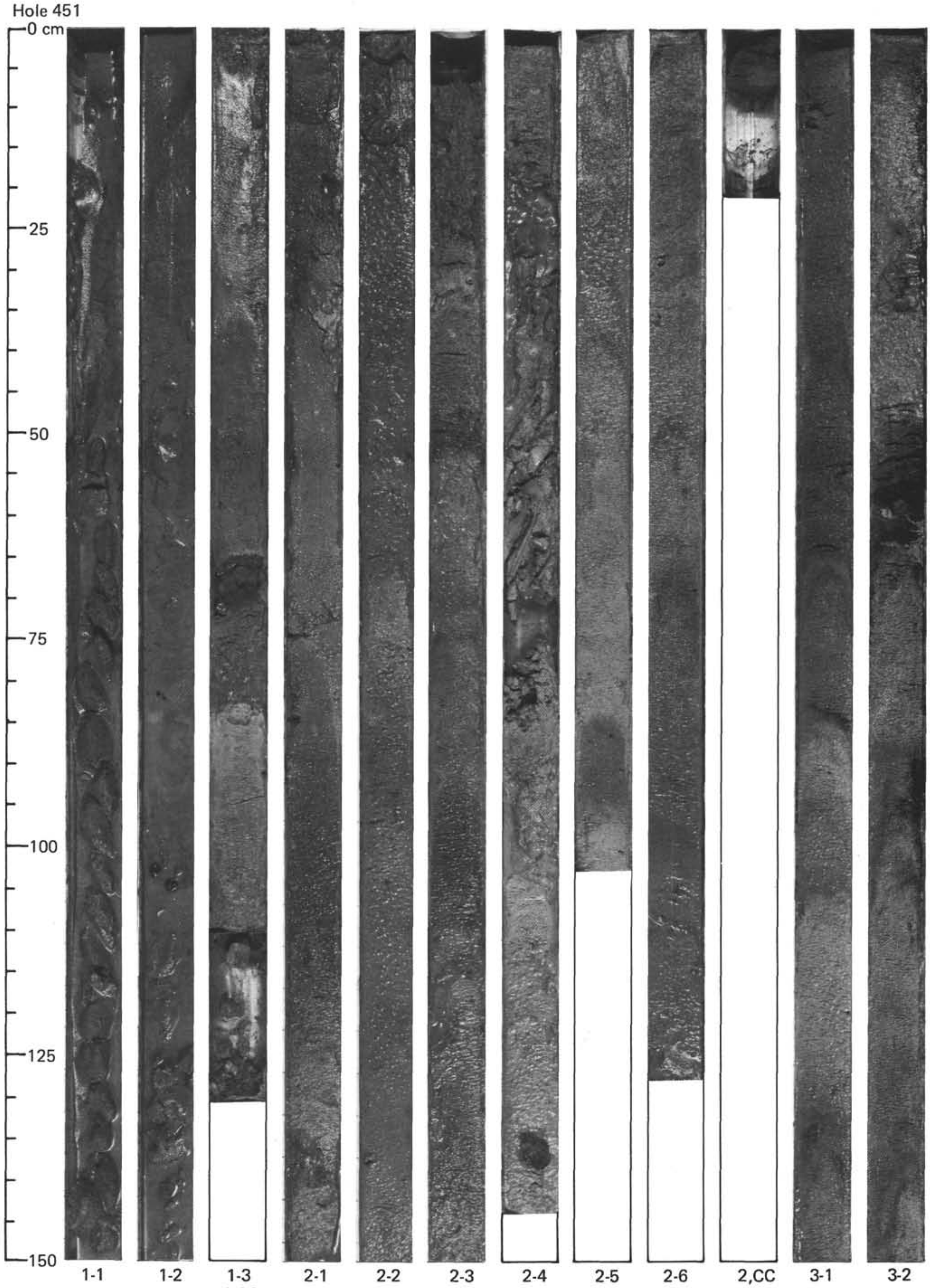
Section: CC

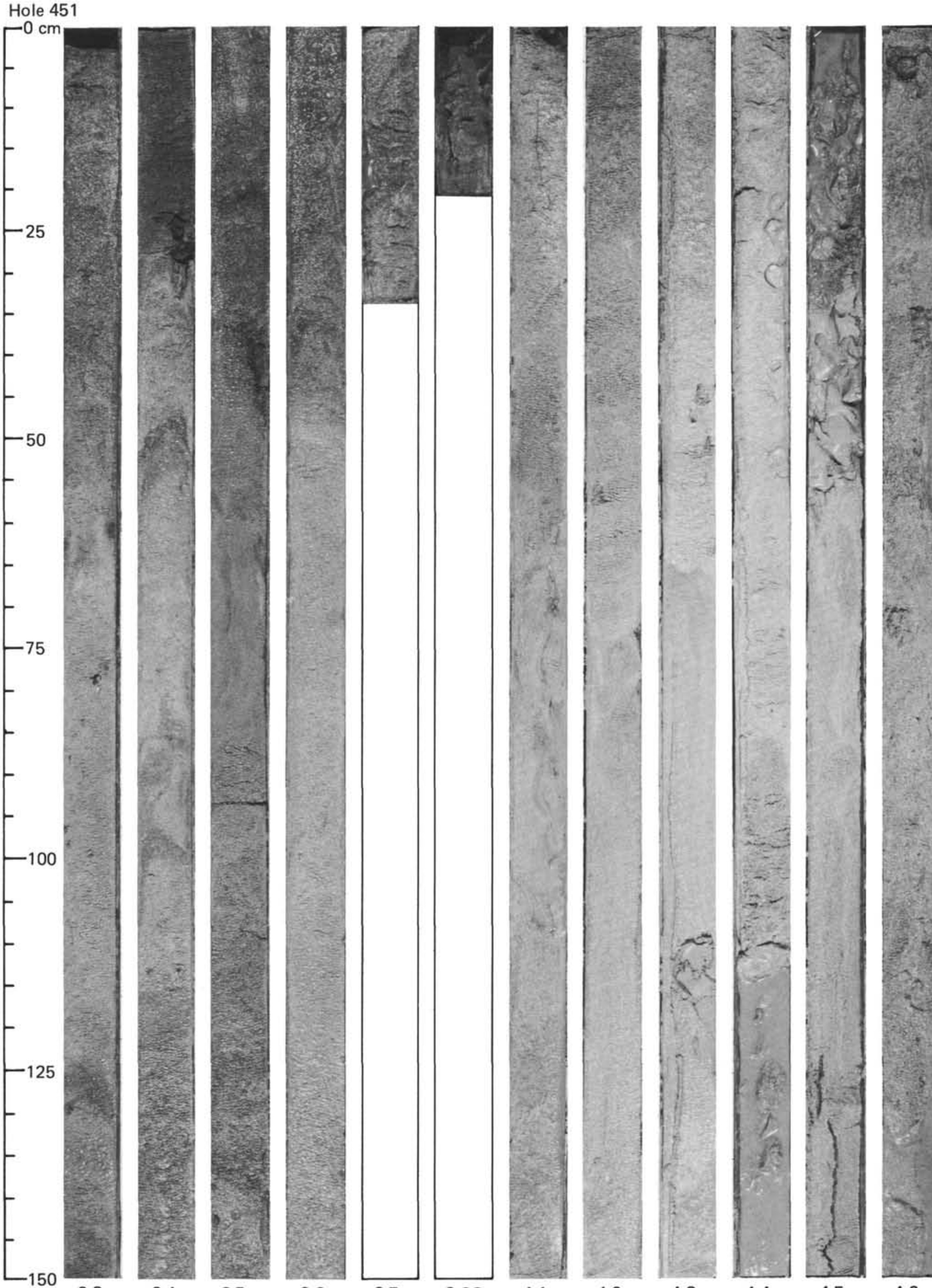
5G 4/1

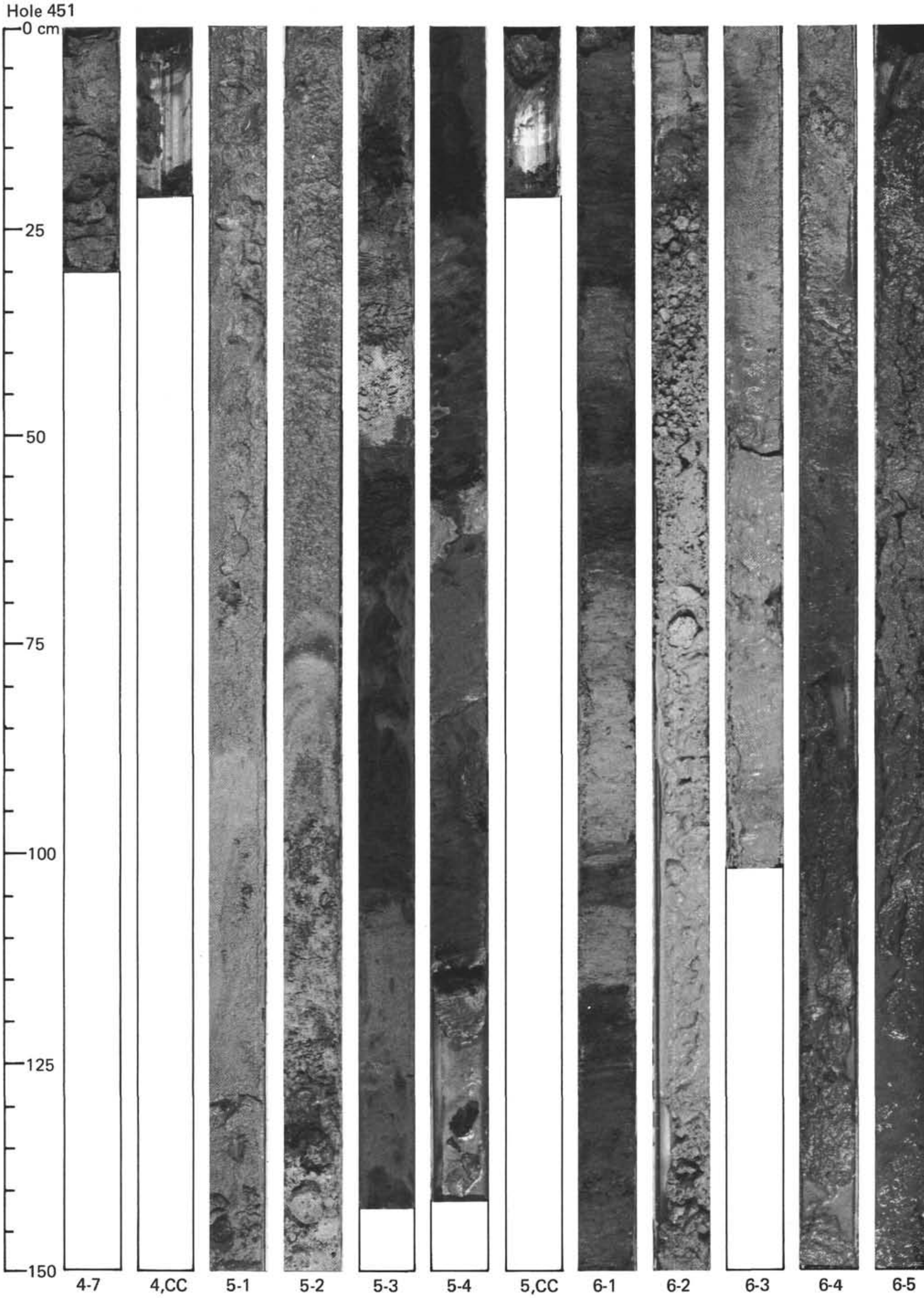
Hydrothermally altered aphyric basalt, light greenish-gray color, with vesicles filled by smectite.

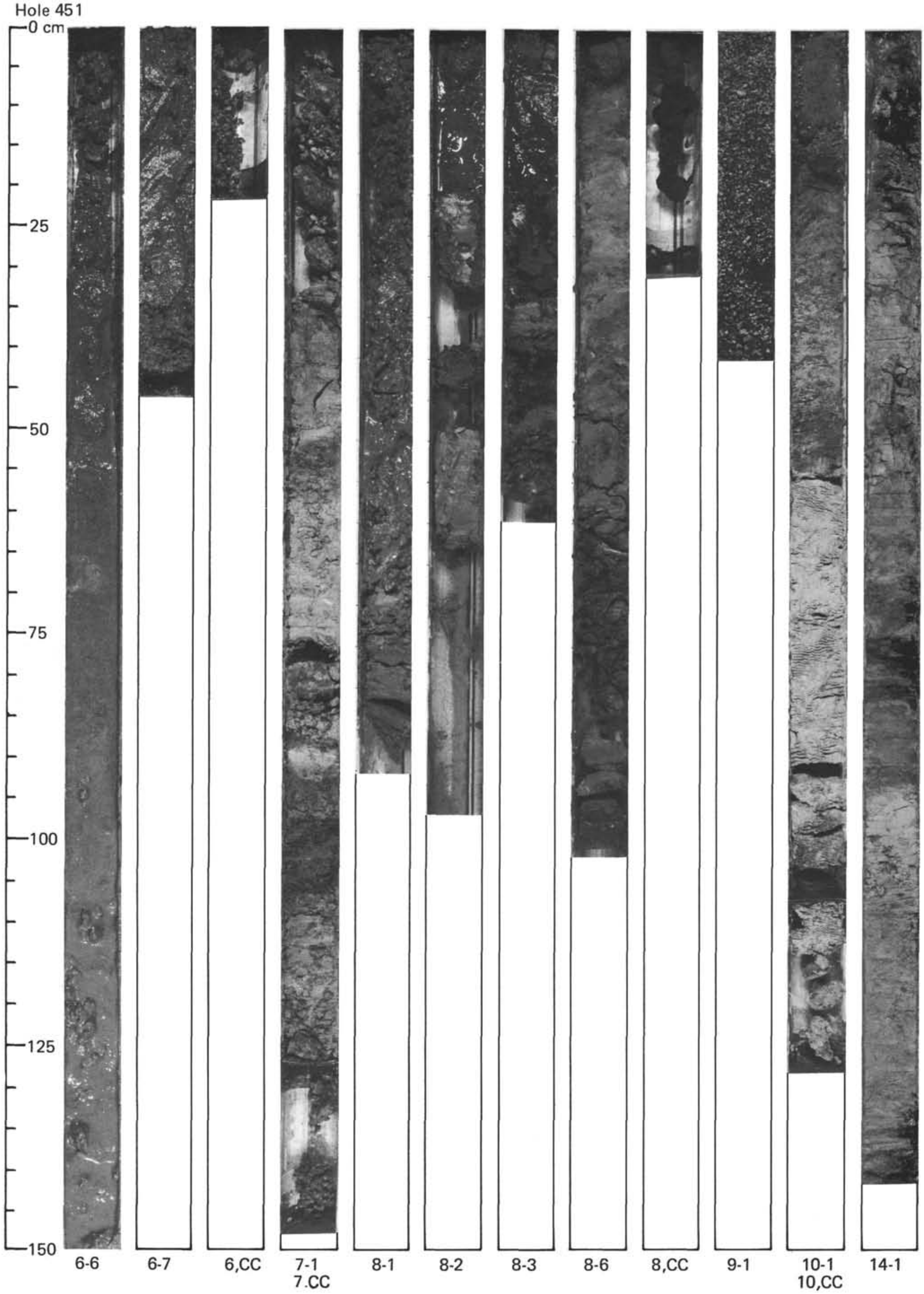
THIN SECTION DESCRIPTION:
Name: olivine-clinopyroxene-plagioclase-phyric basalt
Texture: hyalopilitic
Phenocrysts: plagioclase 2%, 0.4-0.6 mm, euhedral; olivine 4%, 0.4-0.5 mm, subhedral; clinopyroxene 3%, 0.3-0.7 mm, subhedral
Groundmass: plagioclase 15%, An_{63}, laths; olivine 4%; clinopyroxene 3%; magnetite/ilmenite 10%; glass 60%
Vesicles: 10%, 0.5-3 mm, elongate, filled with clay

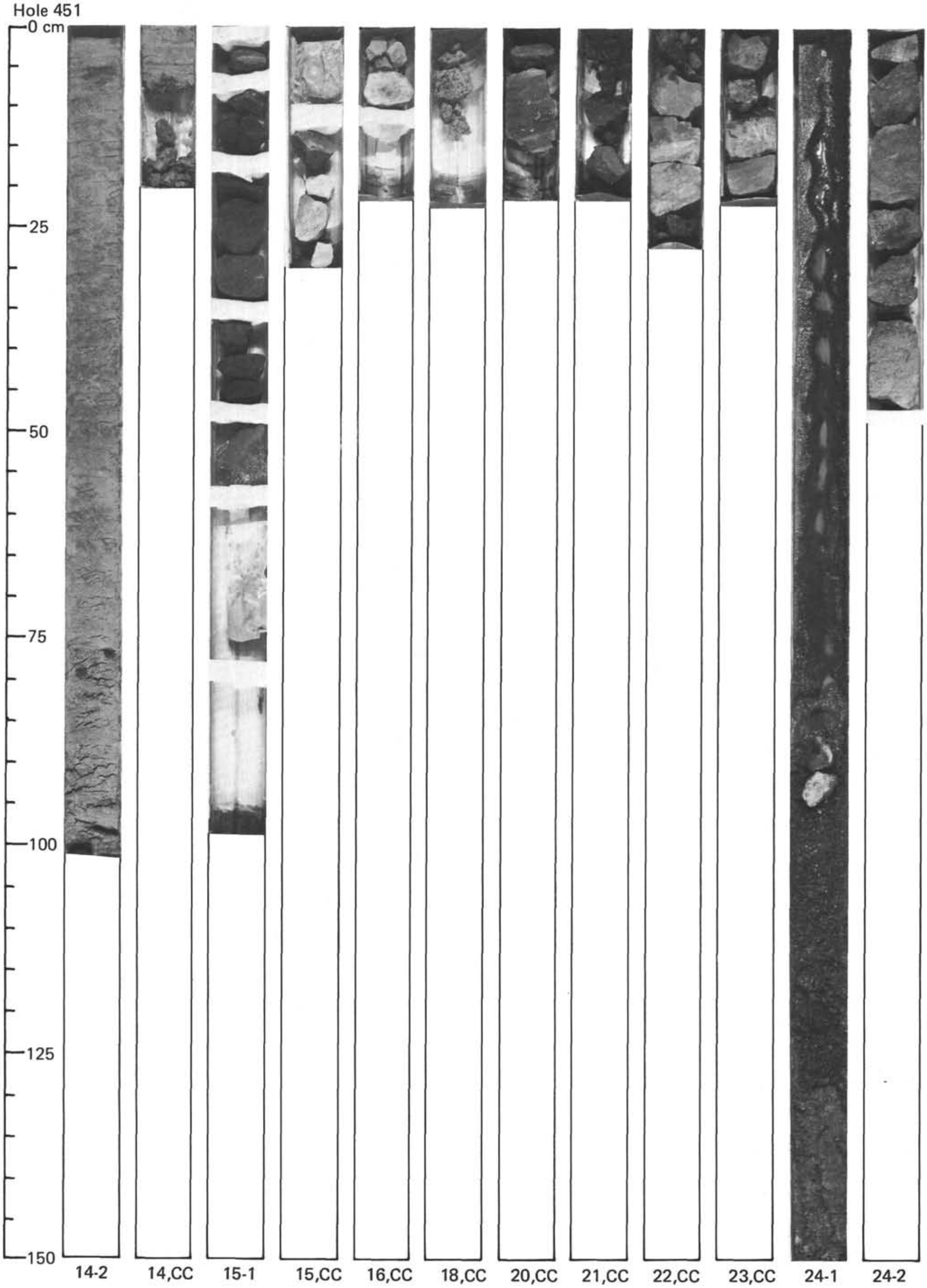
BULK ANALYSIS:	CC-11
SiO_2	48.6
TiO_2	0.94
Al_2O_3	15.3
Fe_2O_3	1.28
FeO	8.47
MnO	0.28
MgO	8.58
CaO	9.97
Na_2O	2.49
K_2O	0.38
P_2O_5	0.17

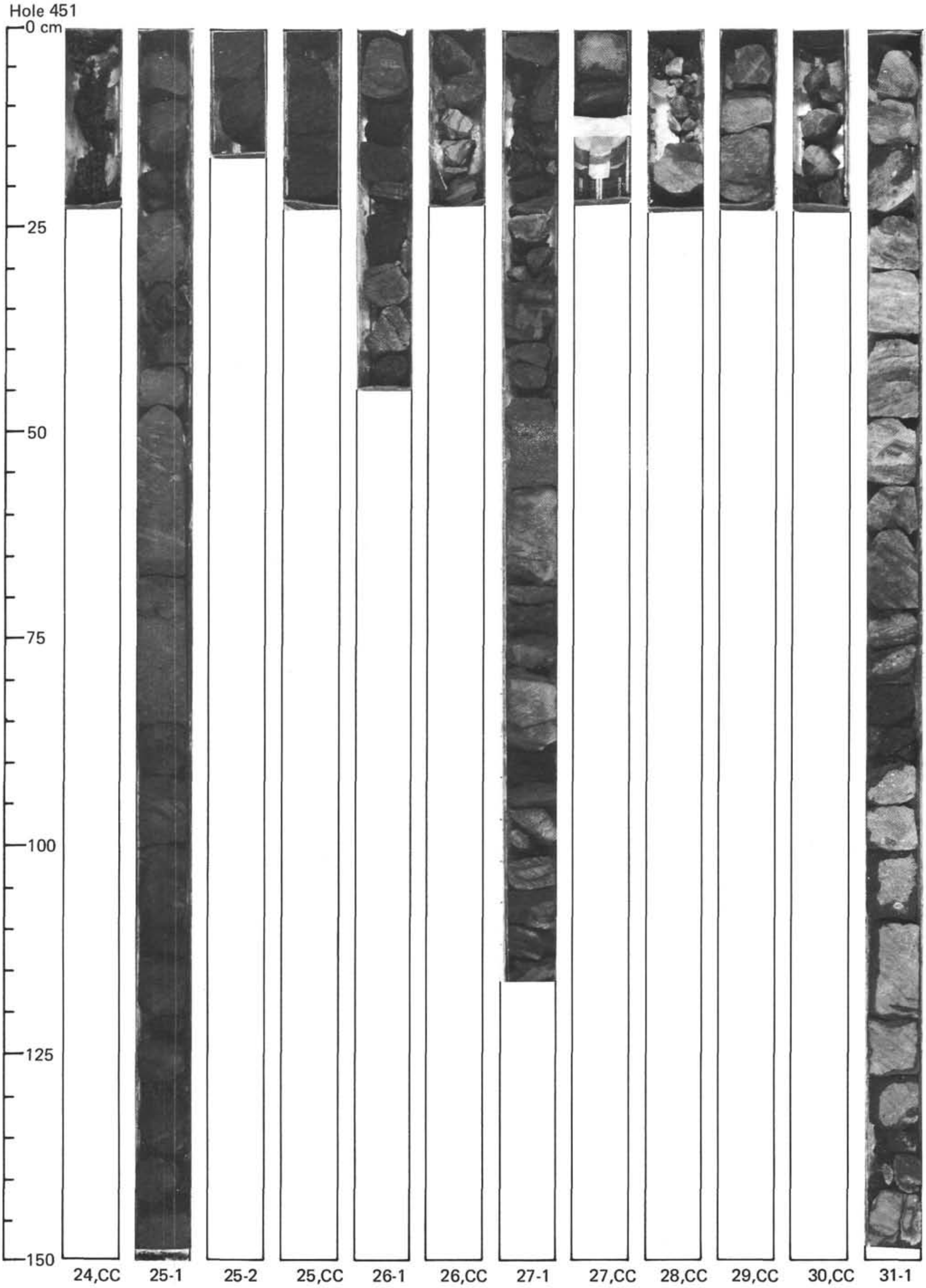

Hole 451
0 cm
25
50
75
100
125
150
1-1
1-2
1-3
1,CC
2-1
2-2
2-3
2-4
2-5
2-6
2,CC
3-1
3-2

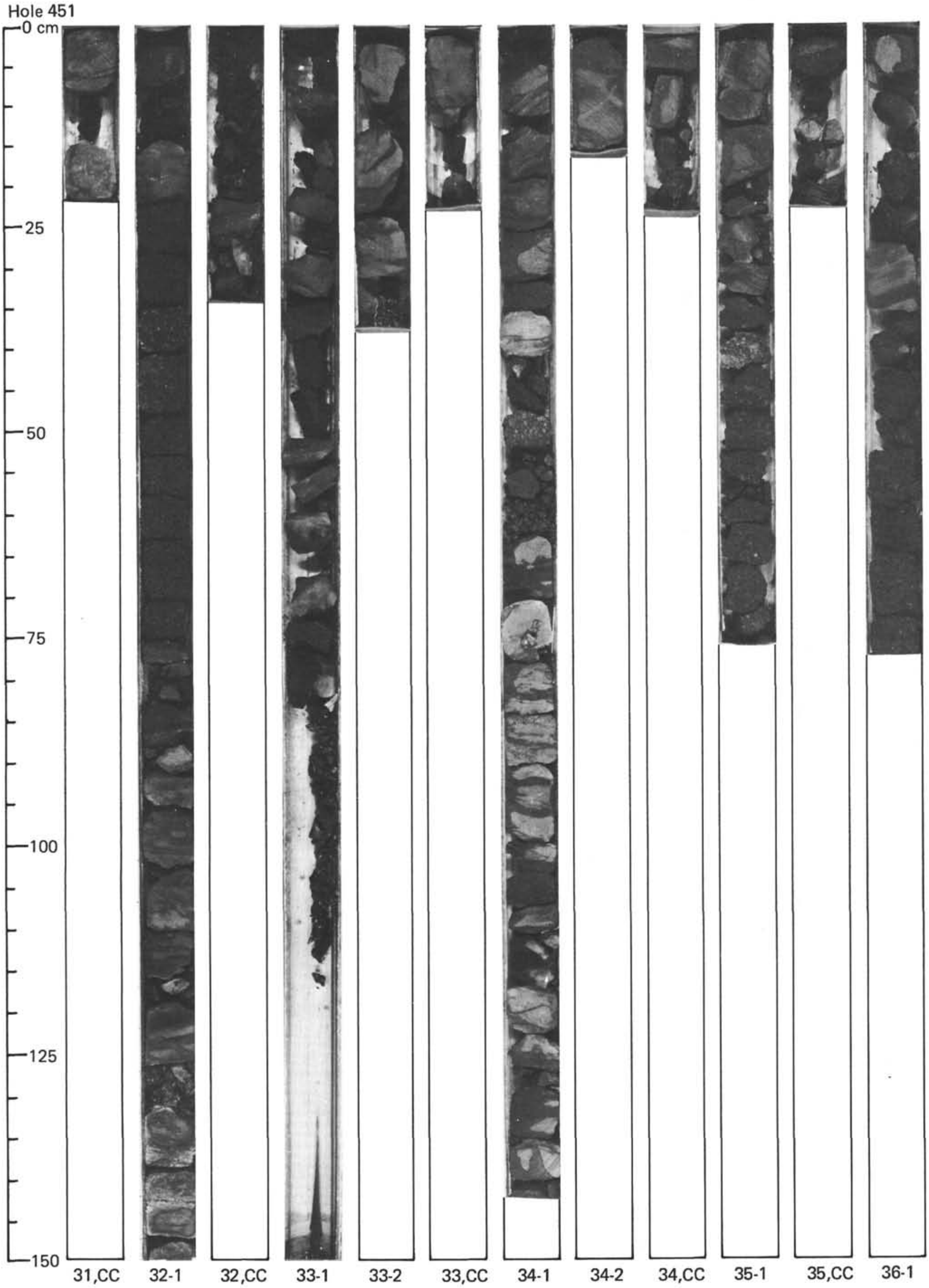

Hole 451
0 cm
25
50
75
100
125
150
3-3
3-4
3-5
3-6
3-7
3,CC
4-1
4-2
4-3
4-4
4-5
4-6

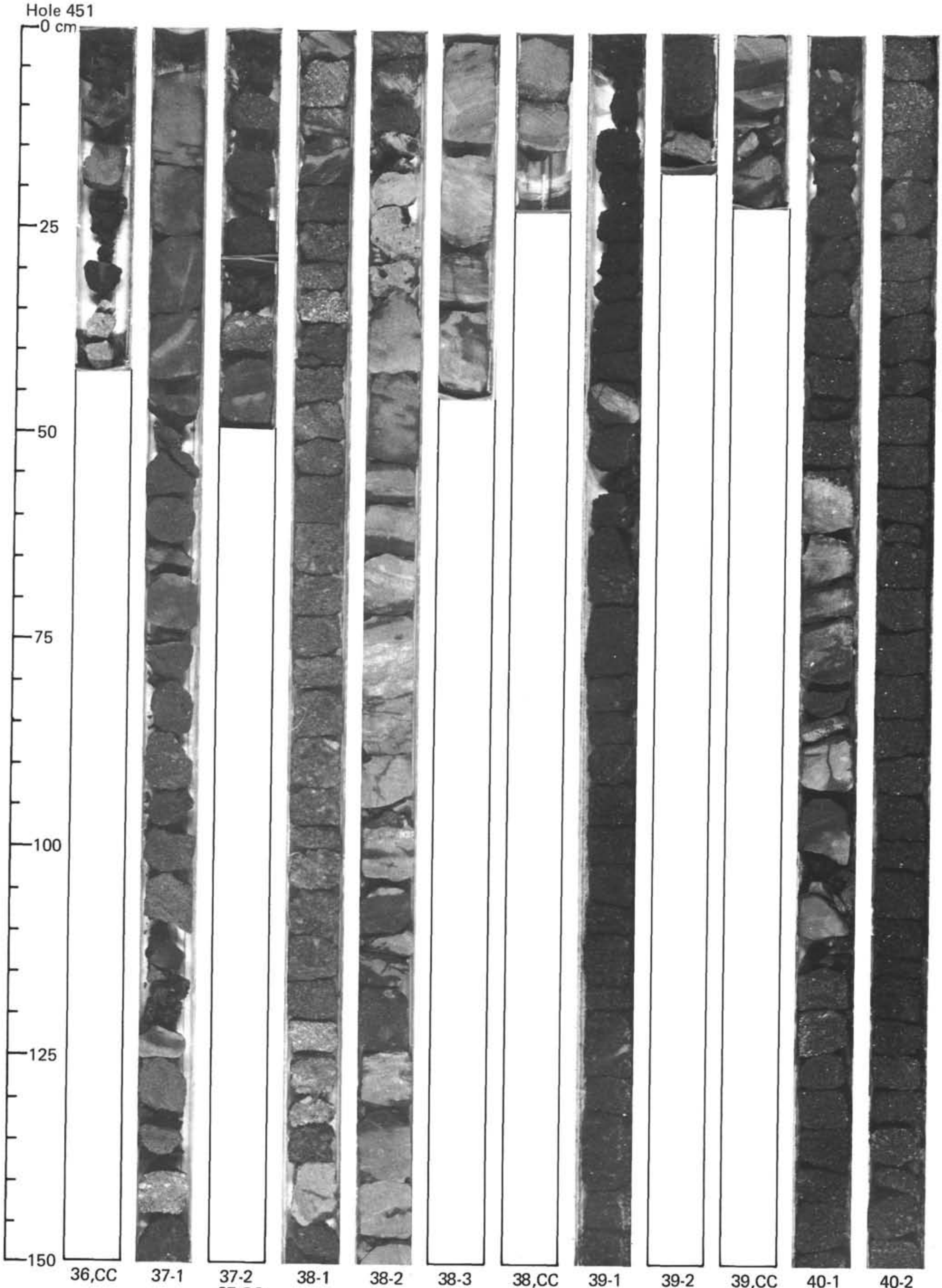

Hole 451
0 cm
25
50
75
100
125
150
4-7
4,CC
5-1
5-2
5-3
5-4
5,CC
6-1
6-2
6-3
6-4
6-5

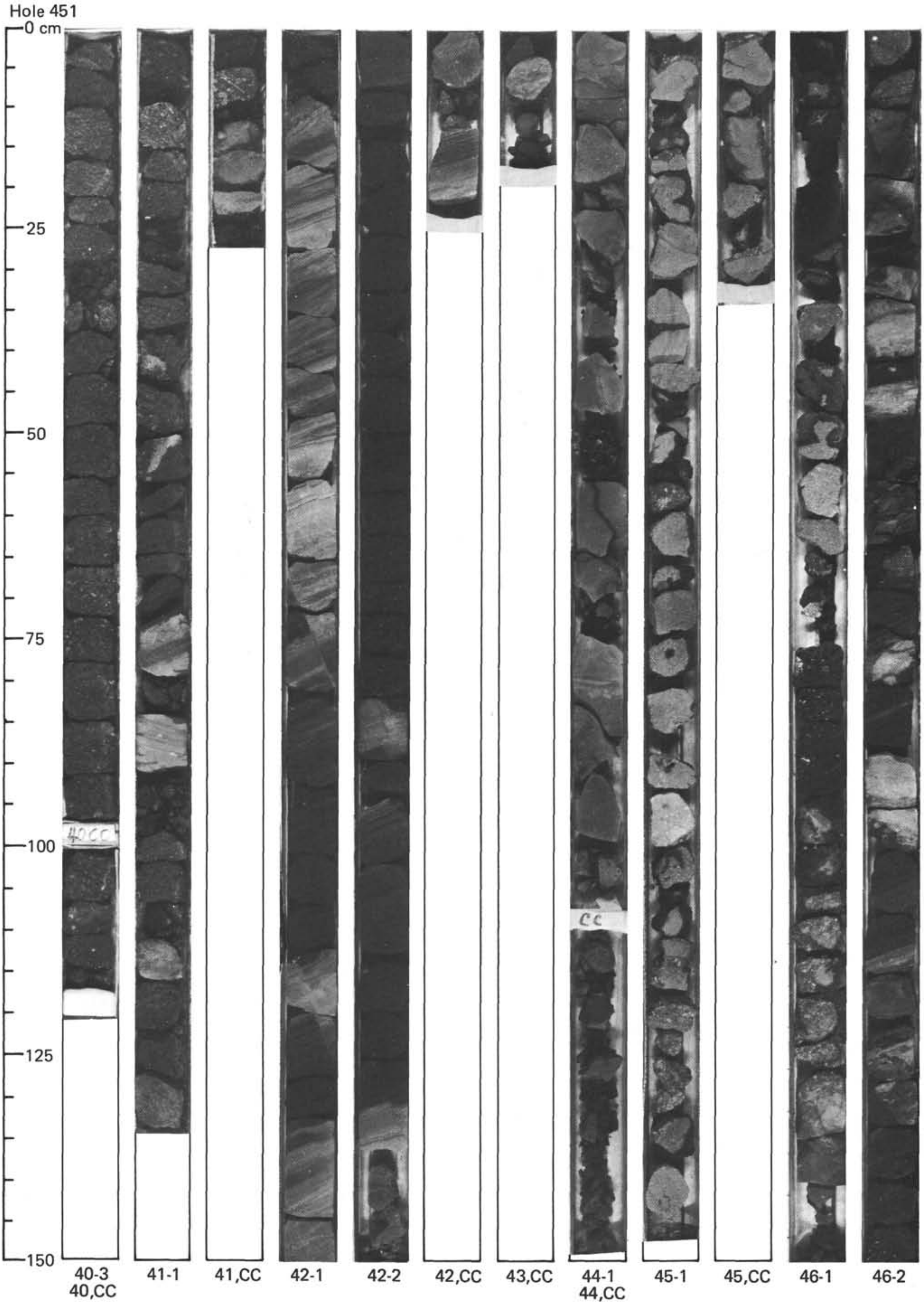

Hole 451
0 cm
25
50
75
100
125
150
6-6
6-7
6,CC
7-1
7.CC
8-1
8-2
8-3
8-6
8,CC
9-1
10-1
10,CC
14-1

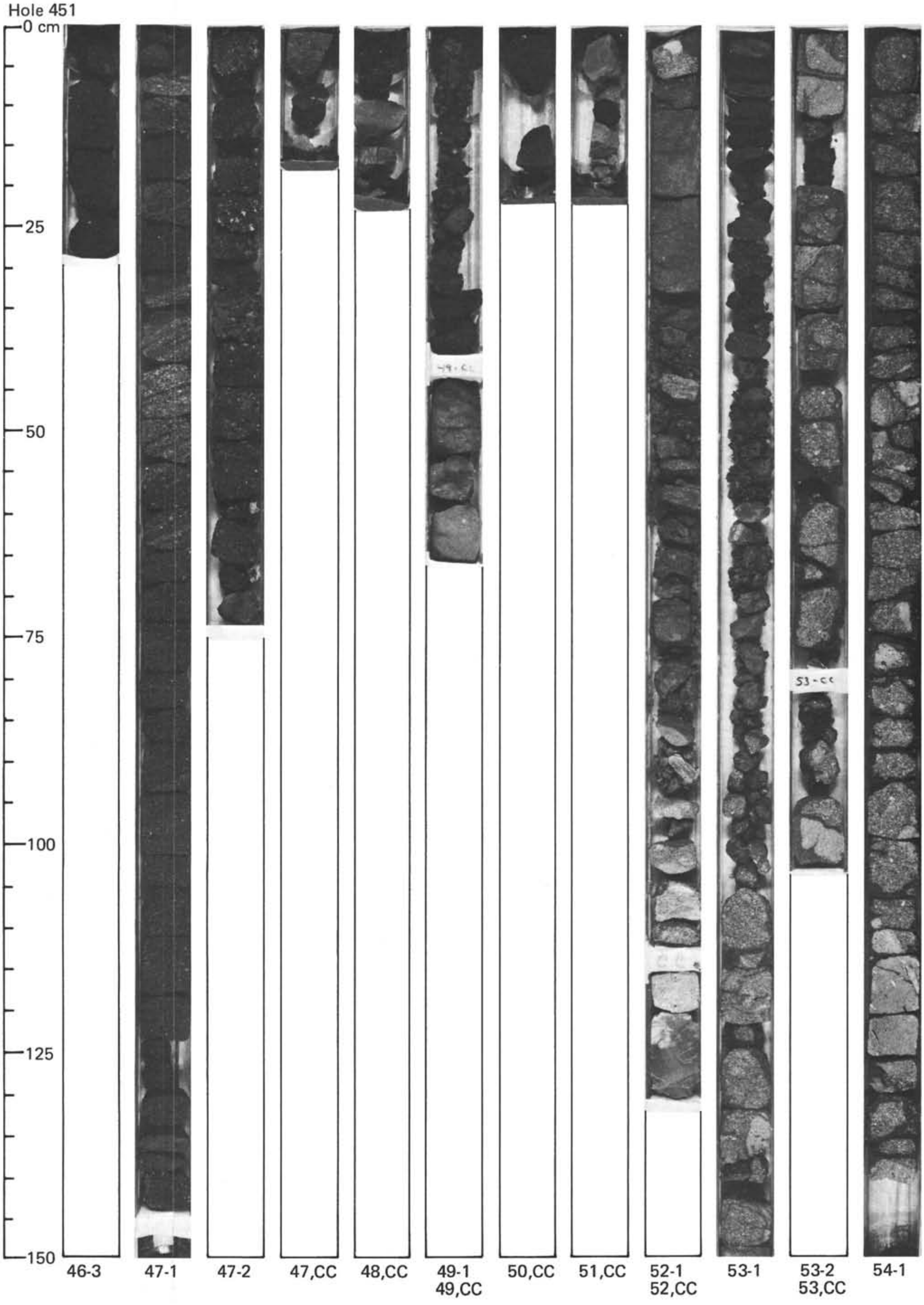

Hole 451
0 cm
25
50
75
100
125
150
14-2
14,CC
15-1
15,CC
16,CC
18,CC
20,CC
21,CC
22,CC
23,CC
24-1
24-2

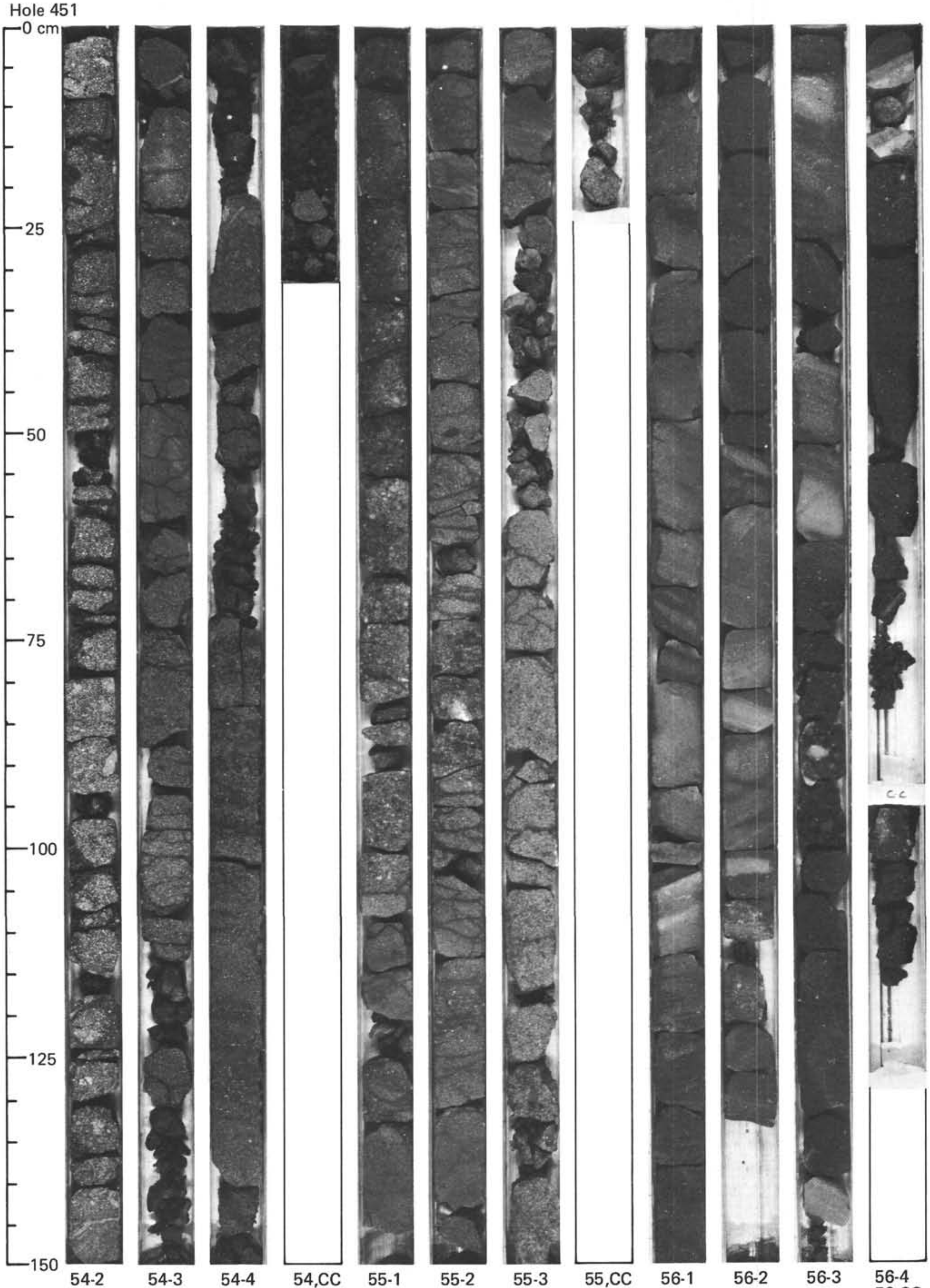

Hole 451
0 cm
25
50
75
100
125
150
24,CC
25-1
25-2
25,CC
26-1
26,CC
27-1
27,CC
28,CC
29,CC
30,CC
31-1

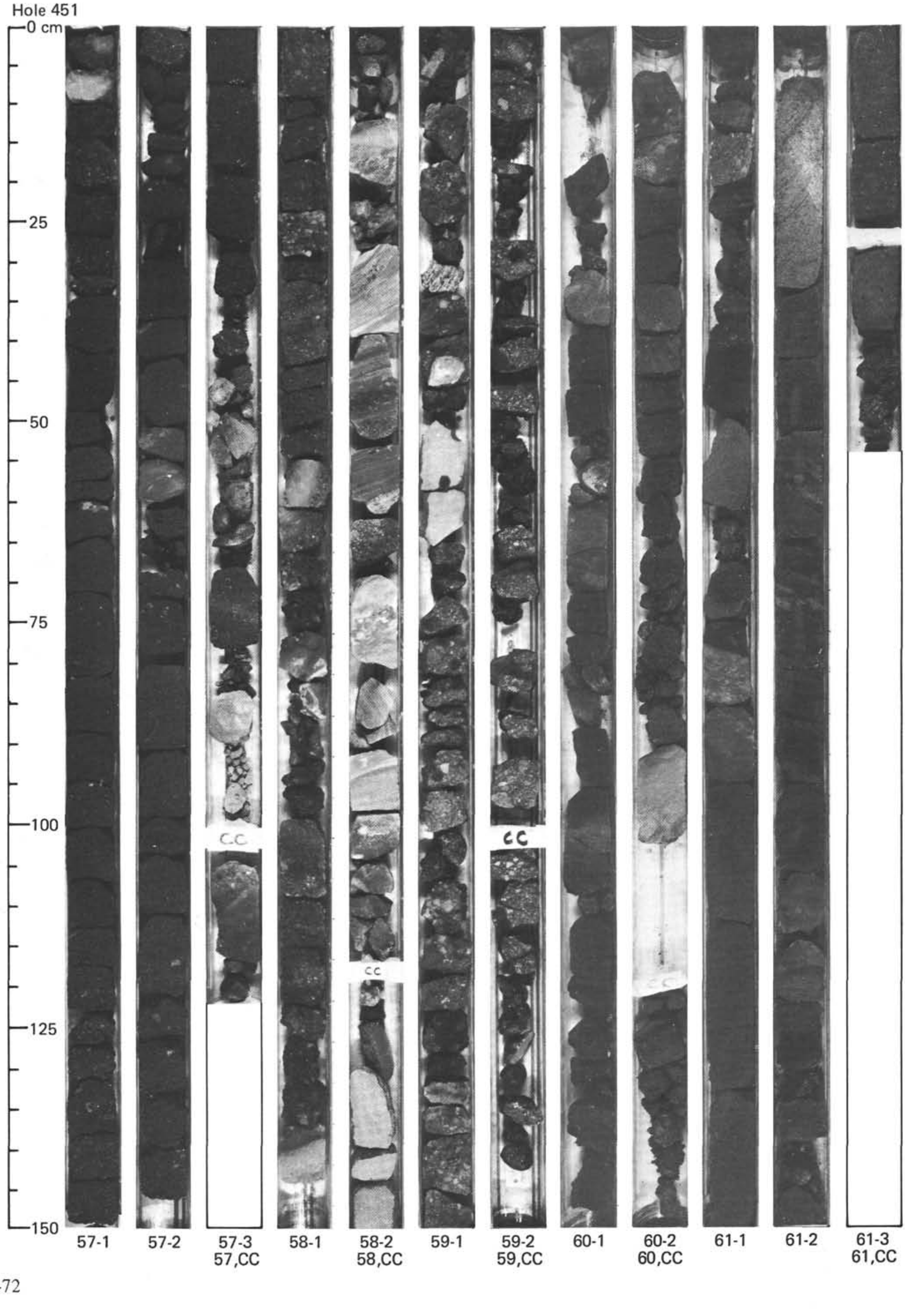

Hole 451
0 cm
25
50
75
100
125
150
31,CC
32-1
32,CC
33-1
33-2
33,CC
34-1
34-2
34,CC
35-1
35,CC
36-1

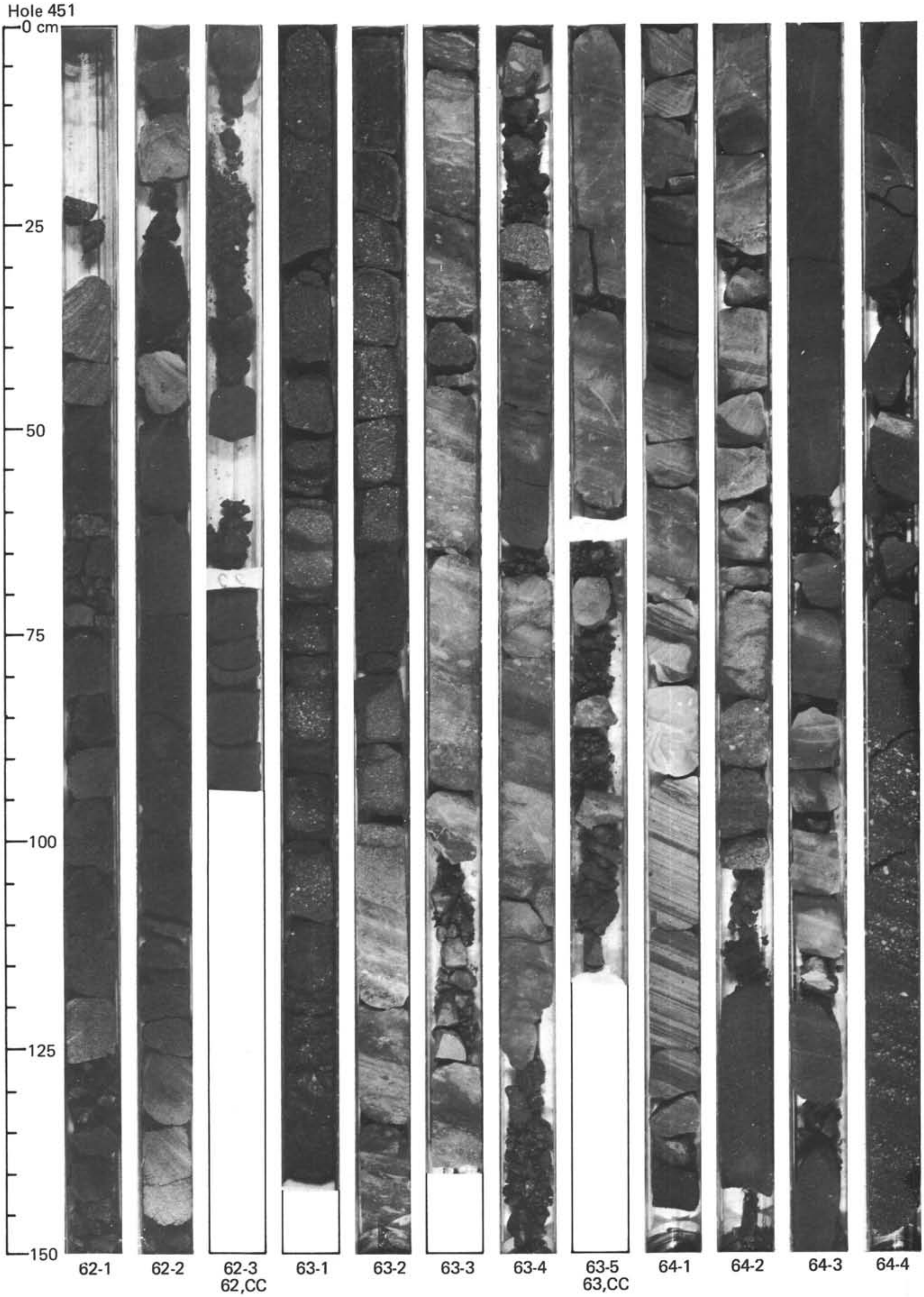

Hole 451
0 cm
25
50
75
100
125
150
36,CC
37-1
37-2
37,CC
38-1
38-2
38-3
38,CC
39-1
39-2
39,CC
40-1
40-2

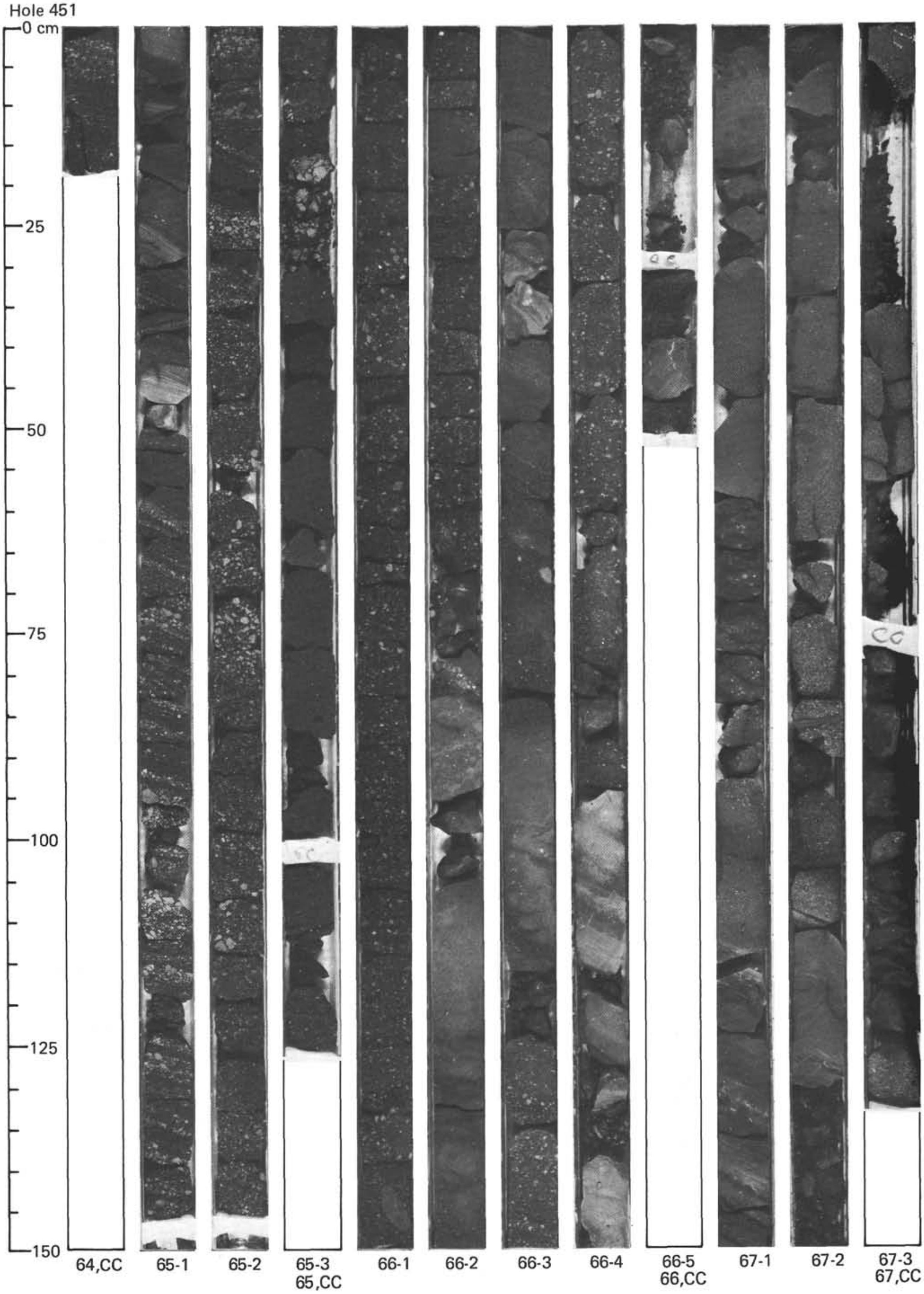

Hole 451
0 cm
25
50
75
100
125
150
40-3
40,CC
41-1
41,CC
42-1
42-2
42,CC
43,CC
44-1
44,CC
45-1
45,CC
46-1
46-2

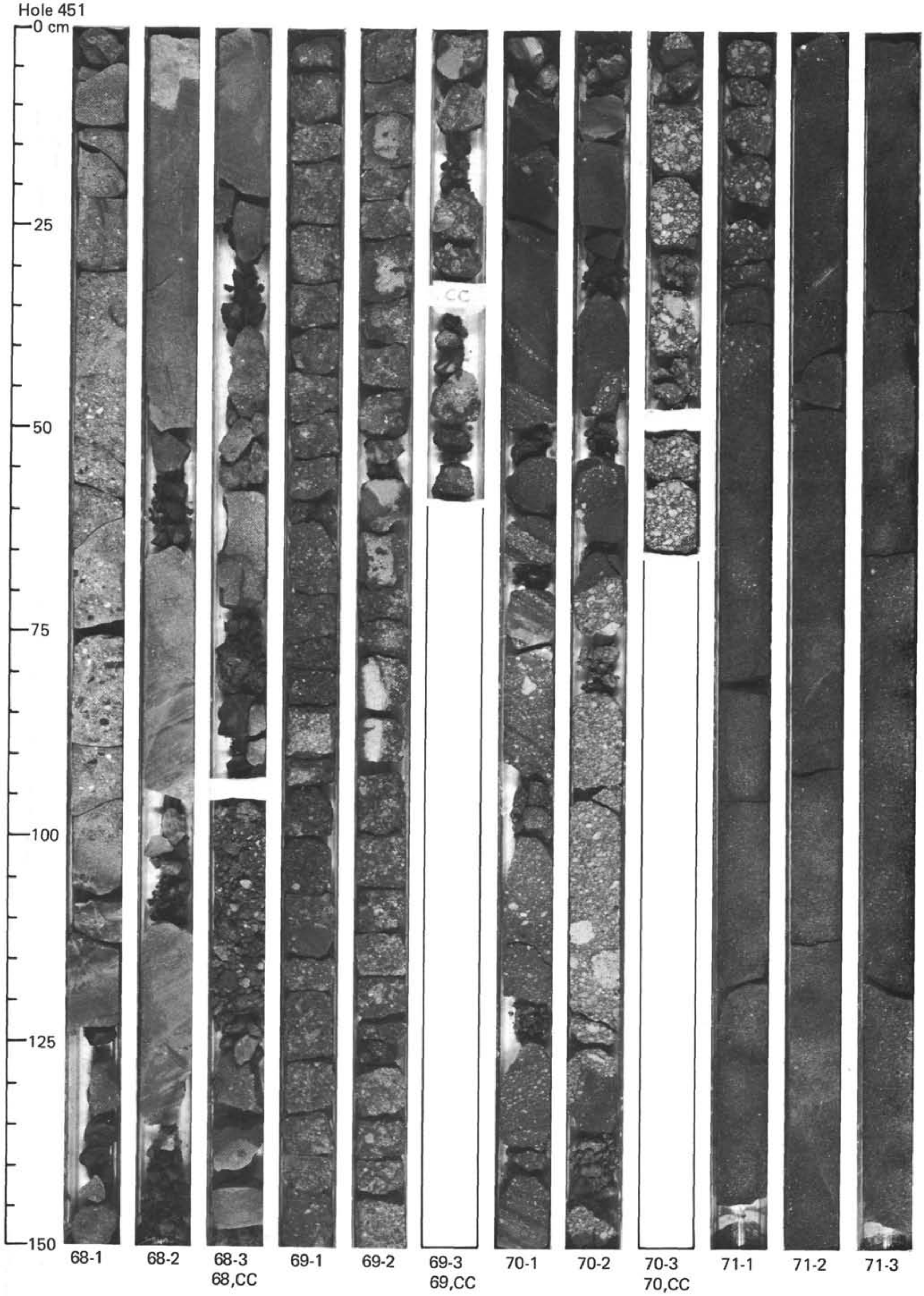

Hole 451
0 cm
25
50
75
100
125
150
46-3
47-1
47-2
47,CC
48,CC
49-1
49,CC
50,CC
51,CC
52-1
52,CC
53-1
53-2
53,CC
54-1
49-CC
53-CC

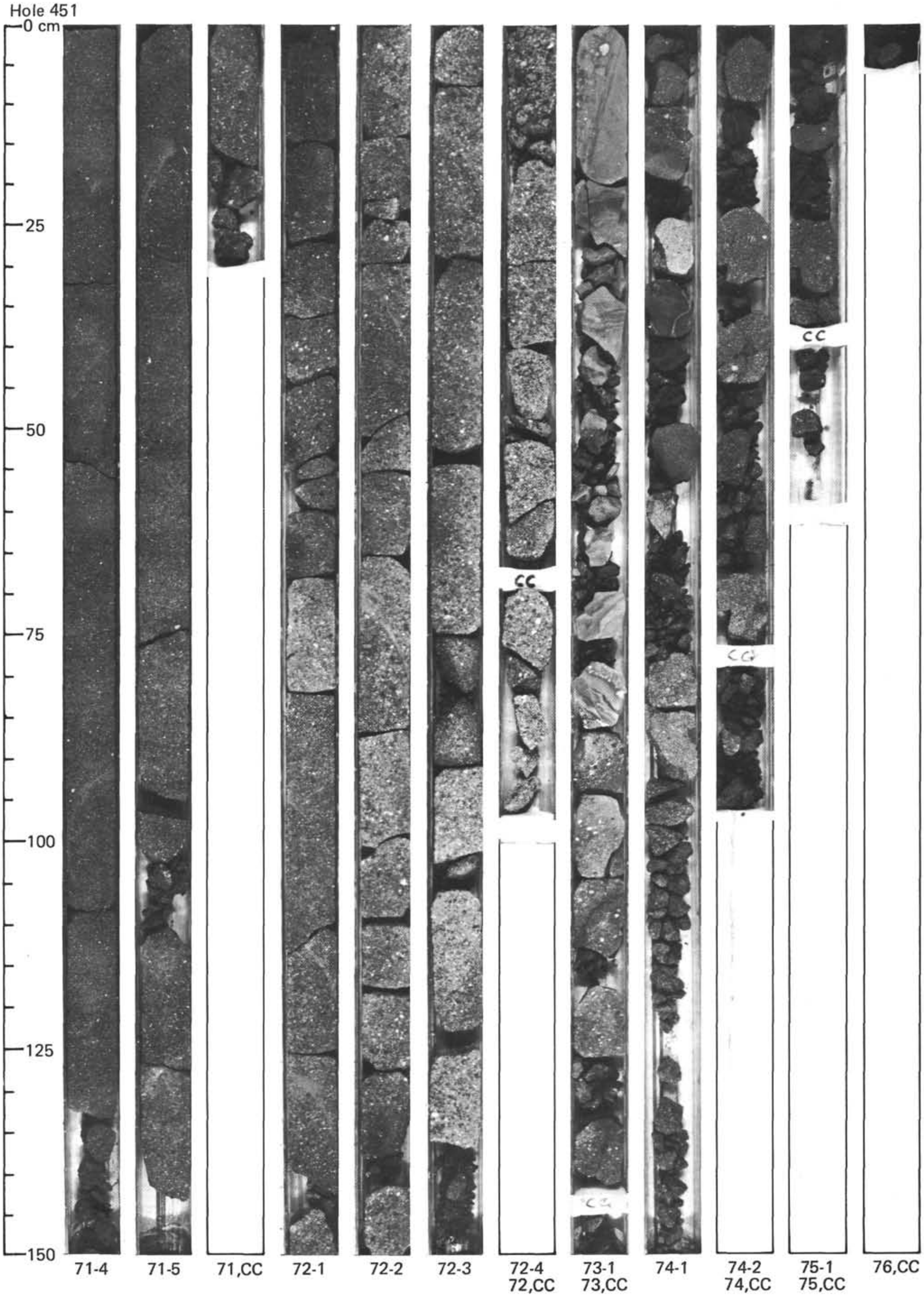

Hole 451
0 cm
25
50
75
100
125
150
54-2
54-3
54-4
54,CC
55-1
55-2
55-3
55,CC
56-1
56-2
56-3
56-4
56,CC

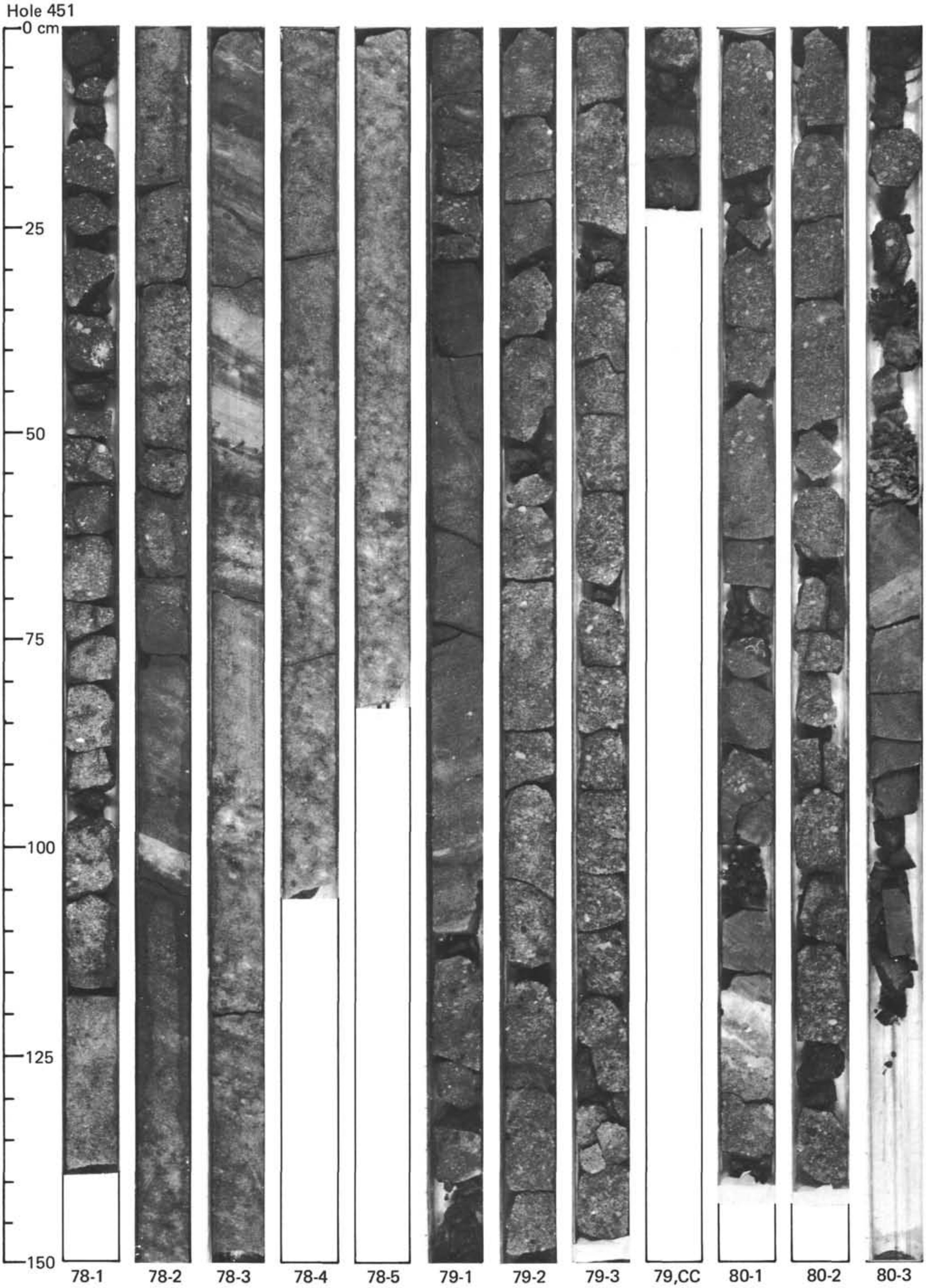

Hole 451
0 cm
25
50
75
100
125
150
CC
CC
CC
CC
57-1
57-2
57-3
57,CC
58-1
58-2
58,CC
59-1
59-2
59,CC
60-1
60-2
60,CC
61-1
61-2
61-3
61,CC

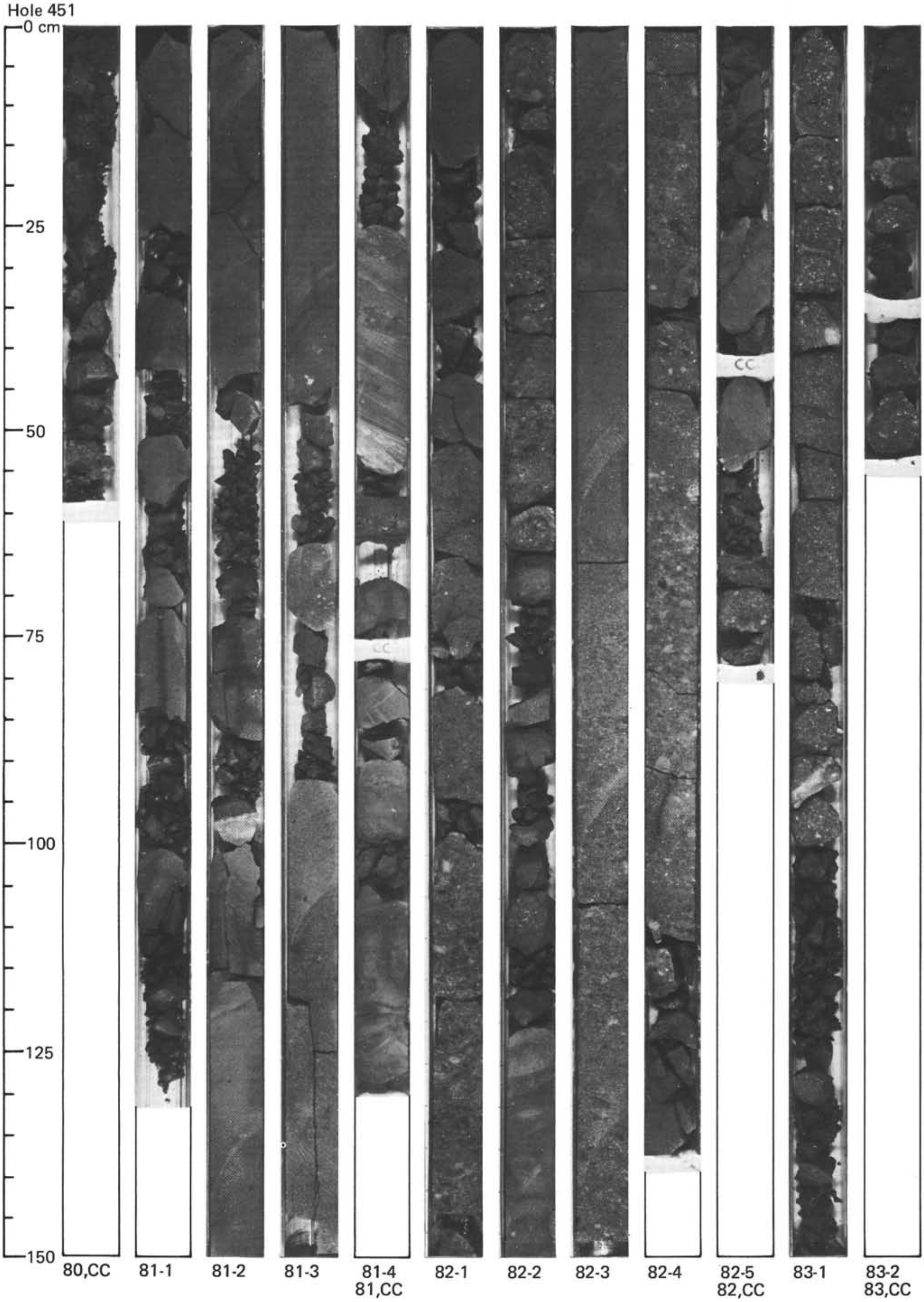

Hole 451
0 cm
25
50
75
100
125
150
62-1
62-2
62-3
62,CC
63-1
63-2
63-3
63-4
63-5
63,CC
64-1
64-2
64-3
64-4

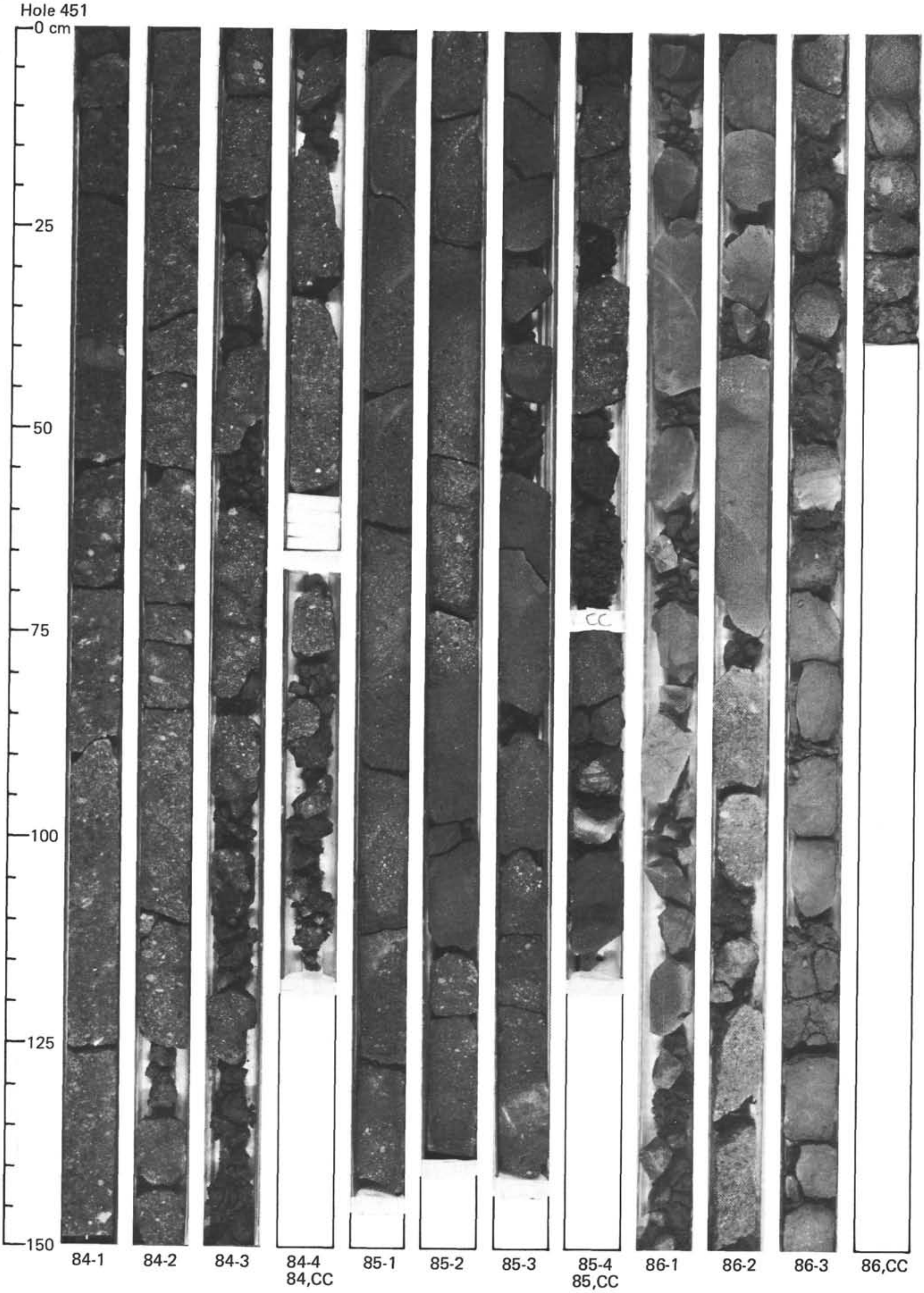

Hole 451
0 cm
25
50
75
100
125
150
64,CC
65-1
65-2
65-3
65,CC
66-1
66-2
66-3
66-4
66-5
66,CC
67-1
67-2
67-3
67,CC

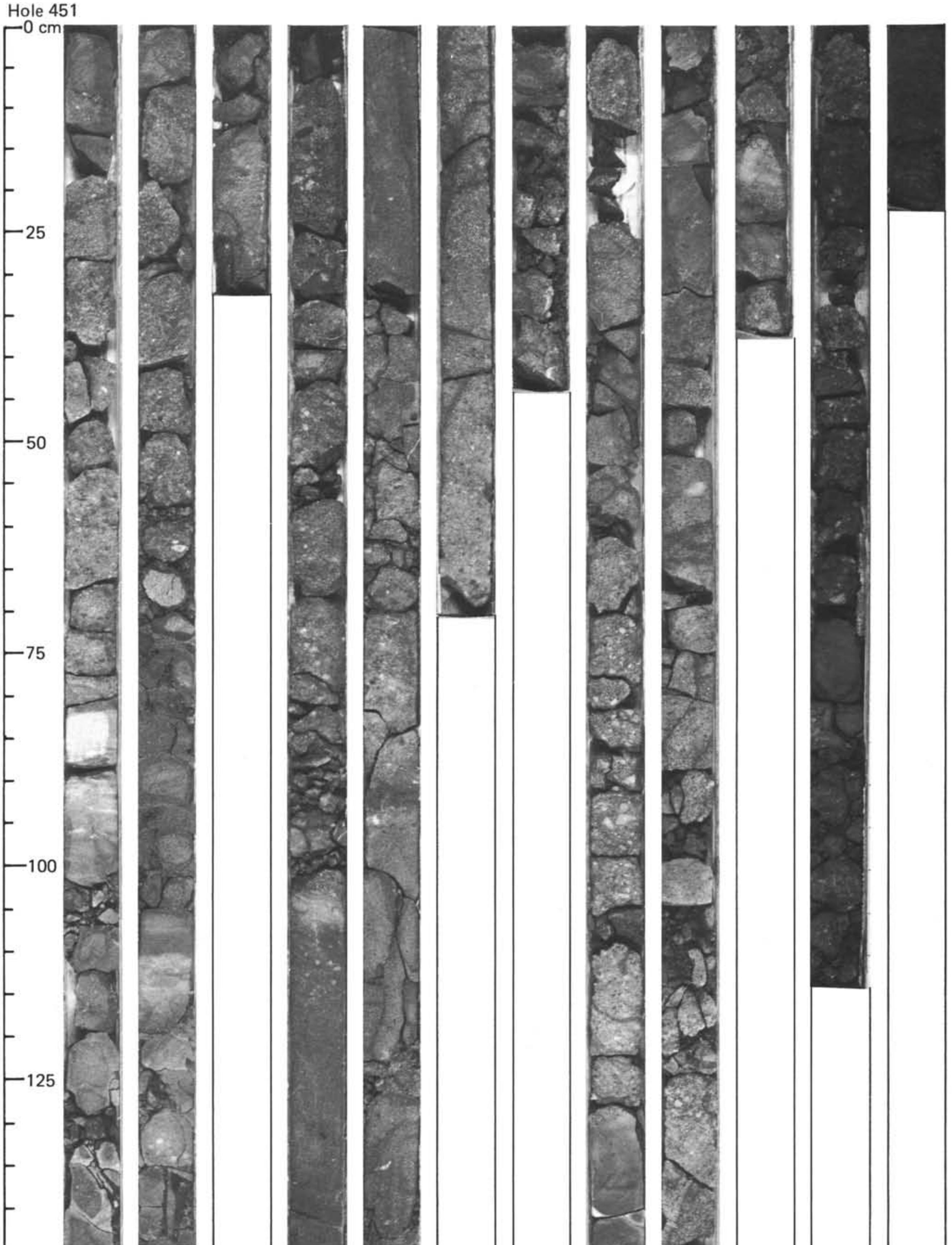

Hole 451
0 cm
25
50
75
100
125
150
68-1
68-2
68-3
68,CC
69-1
69-2
69-3
69,CC
CC
70-1
70-2
70-3
70,CC
71-1
71-2
71-3

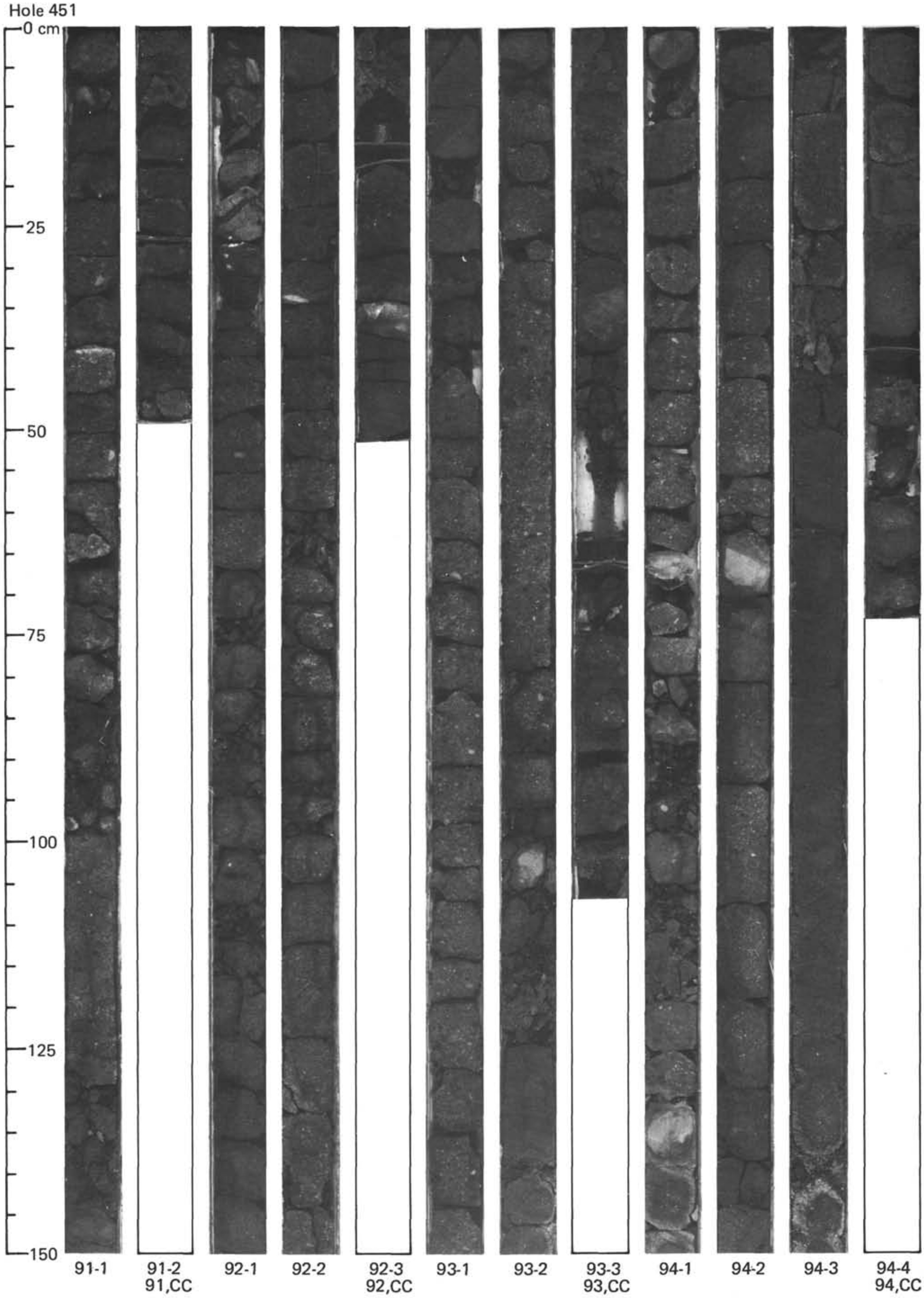

Hole 451
0 cm
25
50
75
100
125
150
71-4
71-5
71,CC
72-1
72-2
72-3
72-4
72,CC
73-1
73,CC
74-1
74-2
74,CC
75-1
75,CC
76,CC
CC
CC
CC
CC

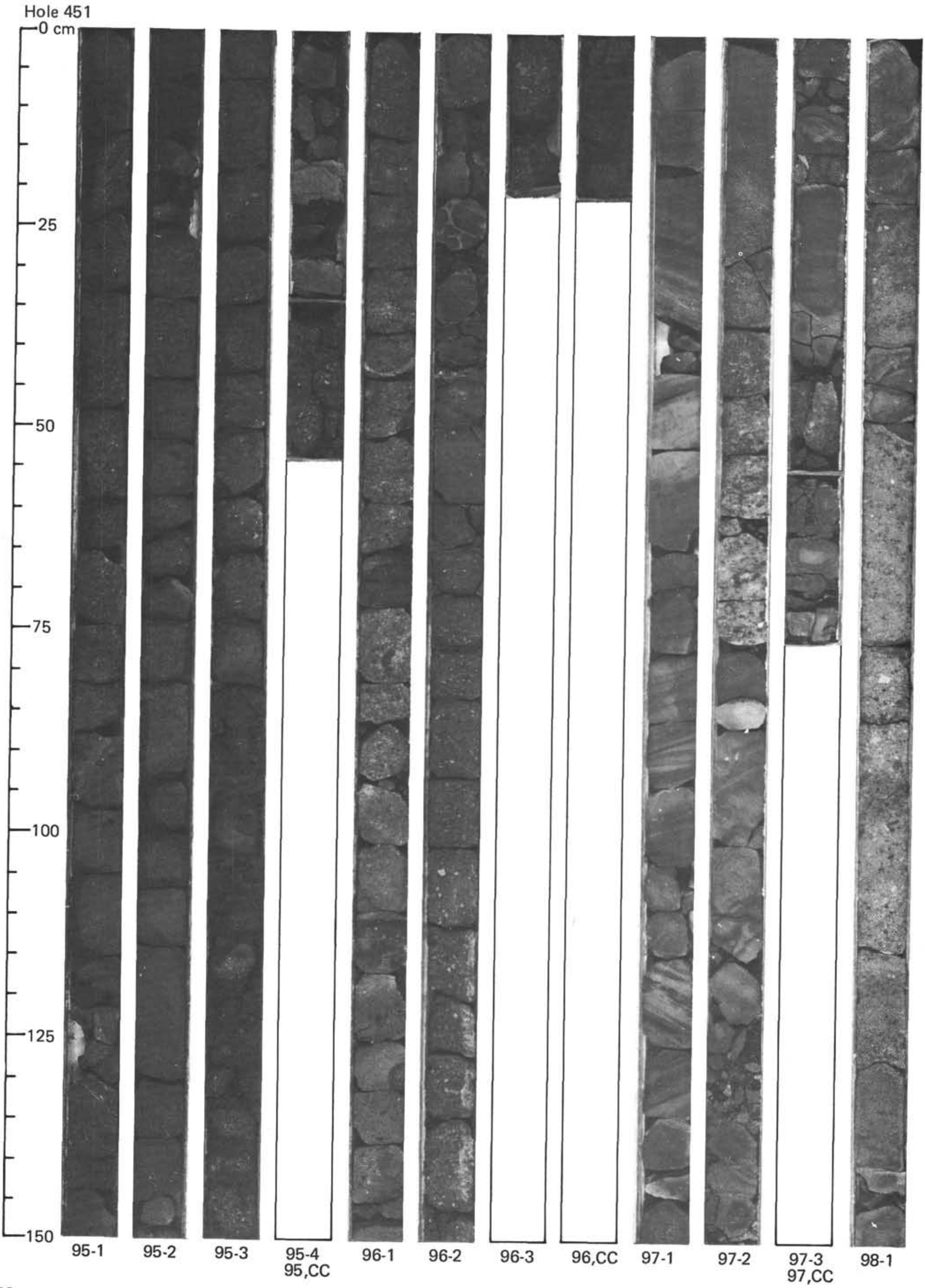

Hole 451
0 cm
25
50
75
100
125
150
78-1
78-2
78-3
78-4
78-5
79-1
79-2
79-3
79,CC
80-1
80-2
80-3

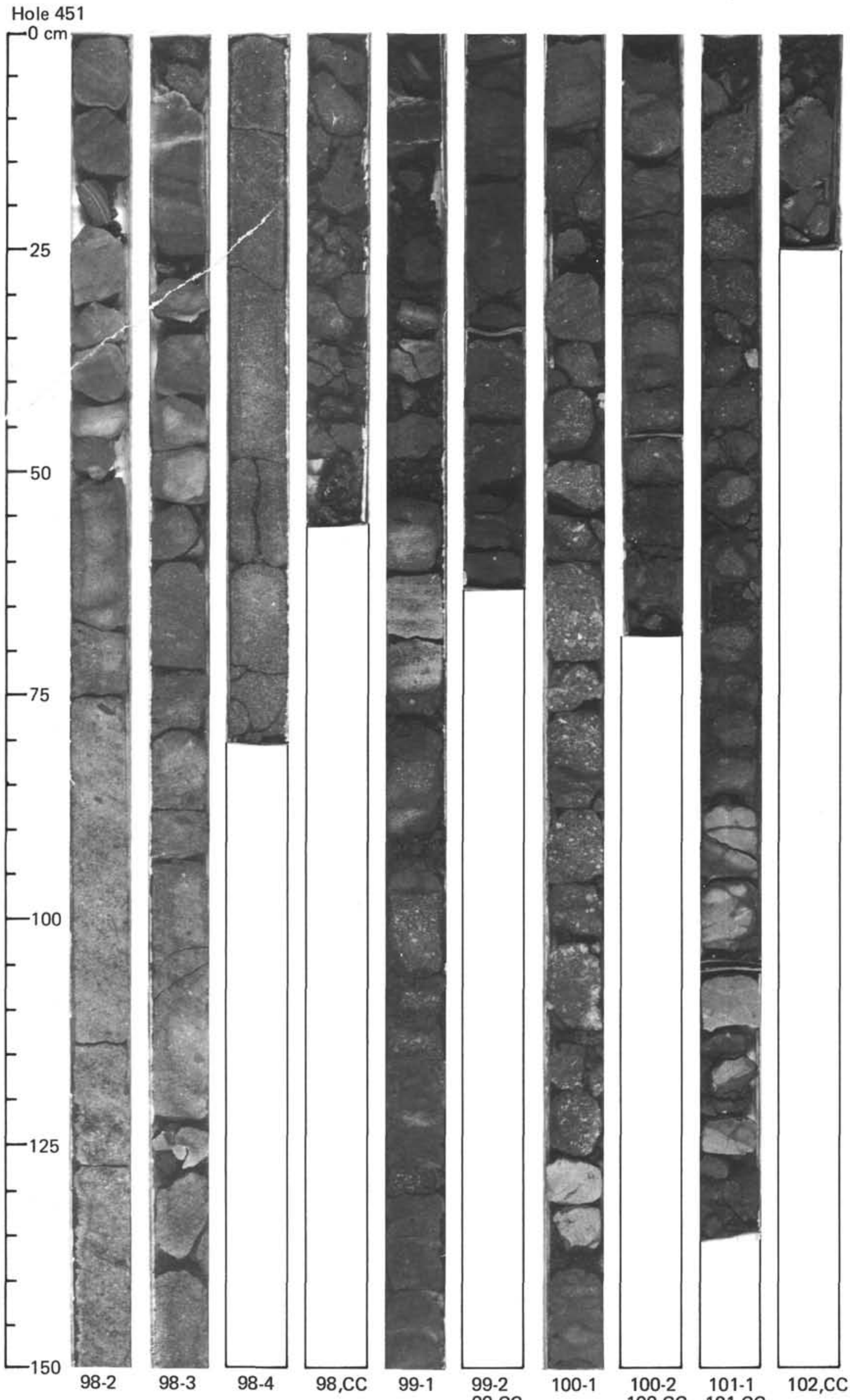

Hole 451
0 cm
25
50
75
100
125
150
80,CC
81-1
81-2
81-3
81-4
81,CC
82-1
82-2
82-3
82-4
82-5
82,CC
83-1
83-2
83,CC
CC
CC


Hole 451
0 cm
25
50
75
100
125
150
CC
84-1
84-2
84-3
84-4
84,CC
85-1
85-2
85-3
85-4
85,CC
86-1
86-2
86-3
86,CC


Hole 451
0 cm
25
50
75
100
125
150
87-1
87-2
87,CC
88-1
88-2
88-3
88,CC
89-1
89-2
89,CC
90-1
90,CC


Hole 451
0 cm
25
50
75
100
125
150
91-1
91-2
91,CC
92-1
92-2
92-3
92,CC
93-1
93-2
93-3
93,CC
94-1
94-2
94-3
94-4
94,CC


Hole 451
0 cm
25
50
75
100
125
150
95-1
95-2
95-3
95-4
95,CC
96-1
96-2
96-3
96,CC
97-1
97-2
97-3
97,CC
98-1


Hole 451
0 cm
25
50
75
100
125
150
98-2
98-3
98-4
98,CC
99-1
99-2
99,CC
100-1
100-2
100,CC
101-1
101,CC
102,CC