

## 8. SITE 453: WEST SIDE OF THE MARIANA TROUGH<sup>1</sup>

### Shipboard Scientific Party<sup>2</sup>

#### HOLE 453

- Date occupied:** 28 March 1978  
**Date departed:** 4 April 1978  
**Time on hole:** 164 hours, 24 minutes (6.85 days)  
**Position:** 17°54.42' N; 143°40.95' E  
**Water depth (sea level, corrected m, echo sounding):** 4693  
**Water depth (rig floor, corrected m, echo sounding):** 4703  
**Bottom felt at:** 4703 meters, drill pipe  
**Penetration (m):** 605  
**Number of holes:** 1  
**Number of cores:** 64  
**Total length of cored section (m):** 605  
**Total core recovered (m):** 236.83  
**Percentage core recovery:** 39.1
- Oldest sediment cored:**  
Depth sub-bottom (m): 446  
Nature: Sandy vitric tuff (epiclastic)  
Chronostratigraphic unit: Earliest Pliocene  
Measured velocity (km/s): 2.29
- Basement:**  
Depth sub-bottom (m): 455.5  
Nature: Variably altered polymict igneous breccias above intensely sheared gabbro cataclastites. Not considered "true" basement.  
Velocity range (km/s): 3.27–6.82
- Principal results:** Site 453 is the westernmost of the three drilling targets in the Mariana Trough (SP4-D), located in a sediment pond about 20 km long and 3 to 4 km wide striking approximately 030°. The site is about 10 km east of the eastern edge of the West Mariana Ridge. A downhole heat flow of 2.4 HFU was obtained on the first use of the Uyeda/Kinoshita heat probe. The hole was not logged because the drill pipe was bent after taking the final core.

The sediment section consists of 455.5 meters of muds, silts, and sands composed mainly of volcanic debris. The oldest fossils are early Pliocene from the *T. rugosus* nannofossil subzone. The latter provides a minimum "basement" age of over 4.7–5.0 m.y., which is substantiated by paleomagnetic evidence in the sediments. The sediment age implies a maximum half-spreading rate of 2.7

cm/y. in the Mariana Trough, although other evidence suggests that the spreading is considerably slower and also may have been episodic. Sediment accumulation rates are very high, but decrease with time, and average about 7 kg/cm<sup>2</sup>/m.y.

Below sediments, 85.5 meters of coarse, poorly sorted igneous polymict breccia containing mainly large angular gabbro and metagabbro clasts up to a half meter in size with minor basalts overlie 28.5 meters of metamorphosed (lower greenschist facies) polymict breccia containing mainly metavolcanic clasts with no large cobbles and rare gabbros. Beneath these are sheared meta-igneous rocks, including a continuously recovered 1.5-meter interval of highly sheared serpentinite noritic gabbro cataclastite cored before the bit wore out. All of these rocks are geochemically related to arc magma series, hence were apparently derived from the West Mariana Ridge. Metamorphism appears hydrothermal in origin in the lower parts of breccias. Seismic evidence suggests that the top of the cored igneous rock, which may be a slump or avalanche sequence over a possible fault zone associated with the initial opening of the Mariana Trough, is flat-lying and on the order of 500 meters above acoustic basement.

#### BACKGROUND AND OBJECTIVES

Site 453 (site survey target SP-4F) was planned to sample the oldest back-arc basin crust in the still-active extensional Mariana Trough. Based on its position on the western edge of the basin (about 10 km east of the western edge of the West Mariana Ridge; Fig. 1), its depth, and its thick sediment cover, SP-4F was predicted to lie on crust that was formed during the initial rifting that produced the Mariana Trough.

The specific objectives of the SP4-F drilling included:

- 1) determination of the time initiation of the opening of the Mariana Trough through paleontological, paleomagnetic, and radiometric means by penetrating through the sediments and into the igneous basement;
- 2) petrologic study of the basement rock as representative of the upper marginal basin crust formed during the first stage of back-arc extension; and
- 3) determination of the history of tectonic and volcanic activity in the Trough, and possibly the nearby remnant West Mariana Ridge and the Mariana volcanic arc, since the initial stages of back-arc rifting.

IPOD site selection surveys near SP4-F revealed the following general characteristics of this portion of the western edge of the Mariana Trough (for more details see Fryer and Hussong, this volume):

- 1) There are no obviously correlatable sea-floor-spreading type magnetic anomalies;
- 2) The topography is very irregular but has some suggestion of predominant block faulting with the blocks tilted to the west so that the eastern sides of many of the topographic highs are fault scarps (Fig. 2).
- 3) The SP4-F site is about 40 km north of a broad, east-west trending bathymetric low suggestive of a fracture zone (Fig. 1);

<sup>1</sup> Initial Reports of the Deep Sea Drilling Project, Volume 60.

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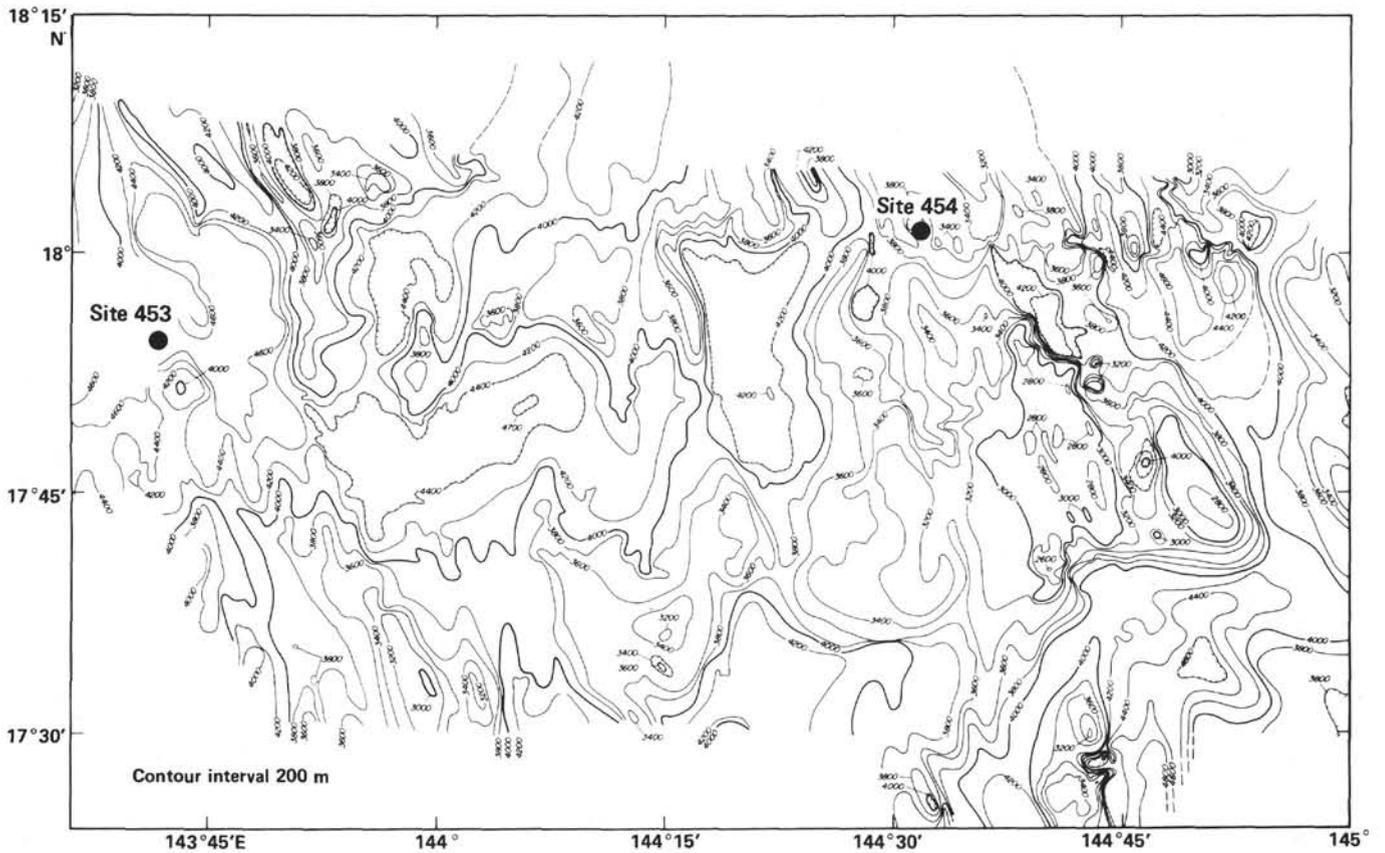


Figure 1. Bathymetry of the Mariana Trough (from Hussong, this volume), in corrected meters at a 200-meter contour interval. Site 453 is at the western edge of the Trough.

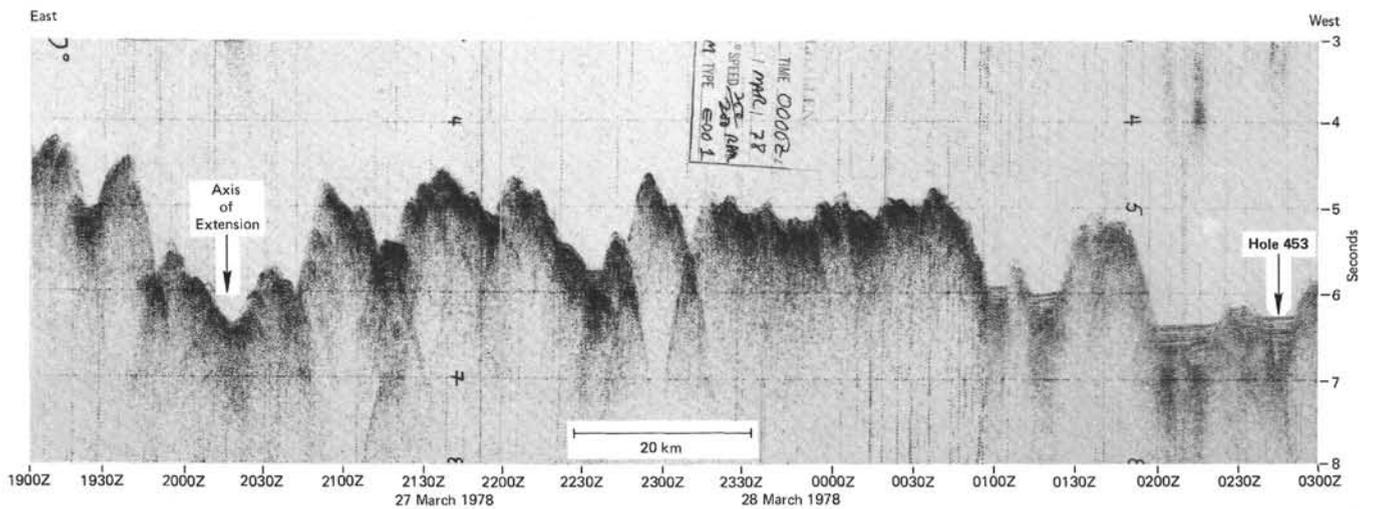


Figure 2. *Glomar Challenger* reflection seismic record across the western portion of the Mariana Trough. This profile extends across the entire Leg 60 drilling area and is discussed in detail by Hussong (this volume).

4) Heat flow is around 0.5–1.5 HFU (later measurements include some >20 HFU; Hobart et al., 1979);

5) From refraction data the crust averages around 5.5 km thick, with an unusually thick (1.5-km) Layer 2A (4–5 km/s) and a Moho averaging 10.5 km beneath sea level;

6) Basement velocities beneath the sediment ponds are characteristically higher than in the bathymetric highs; and

7) SP4-F is approximately 10 km east of the eastern edge of the West Mariana Ridge remnant arc, and 120 km west of the apparent axis of spreading in the Mariana Trough (Fig. 2).

### OPERATIONS

The transit from Hole 452A to Site 453 provided the opportunity to make a geophysical traverse of all the targets between SP-1 and SP-4, which was accomplished using the reflection seismic system with a 120-cu. in. air gun, the 3.5-kHz and 12-kHz PDR's, and the magnetometer. The results of the traverse are described by Hussong (Underway Geophysics, this volume).

The approach to Site 453 was controlled largely by comparison of bottom and sub-bottom structure observed by Hawaii Institute of Geophysics and Lamont-Doherty Geological Observatory site surveys, with the seismic profiles collected on the *Challenger*. The sediment ponds, even in this oldest and deepest western edge of the Mariana Trough, are only a few kilometers across and are not interconnected, so each small pond has a distinctive depth. It is therefore possible to keep track of the ship's location in well-surveyed areas in the Mariana Trough by monitoring sediment-pond depths.

A 16-kHz double-life beacon was dropped at 1318 on 28 March, during the second pass of the ship over the target sediment pond (see Geophysics section, this chapter, for a description of the target sediment pond). The beacon was dropped on the western side of the pond, where the sediment was not as deep as at the center, in order to limit the total sediment thickness that would have to be cored. It was estimated, based on the shipboard reflection records, that the total sediment thickness under the beacon was approximately 600 meters.

No further survey work was conducted until after completion of the drilling.

With plenty of sediment and excellent weather, a standard F94CK bit and 120-meter bottom-hole assembly was rigged. The pipe string was run and bottom felt and cored at a pipe string depth of 4703 meters at 2330, local time.

The first three cores were obtained without rotation, and subsequent drilling of the first 30 cores was rapid (Fig. 3; Table 1).

The Tokyo T-probe was run after Core 9; it obtained a good measurement that yielded a heat flow value of 2.40 HFU at 75.5 meters sub-bottom depth. Deployment of this instrument, which is mounted on the down-hole water sampling device, was accomplished with no problems. The heat flow measurement took a total of 48

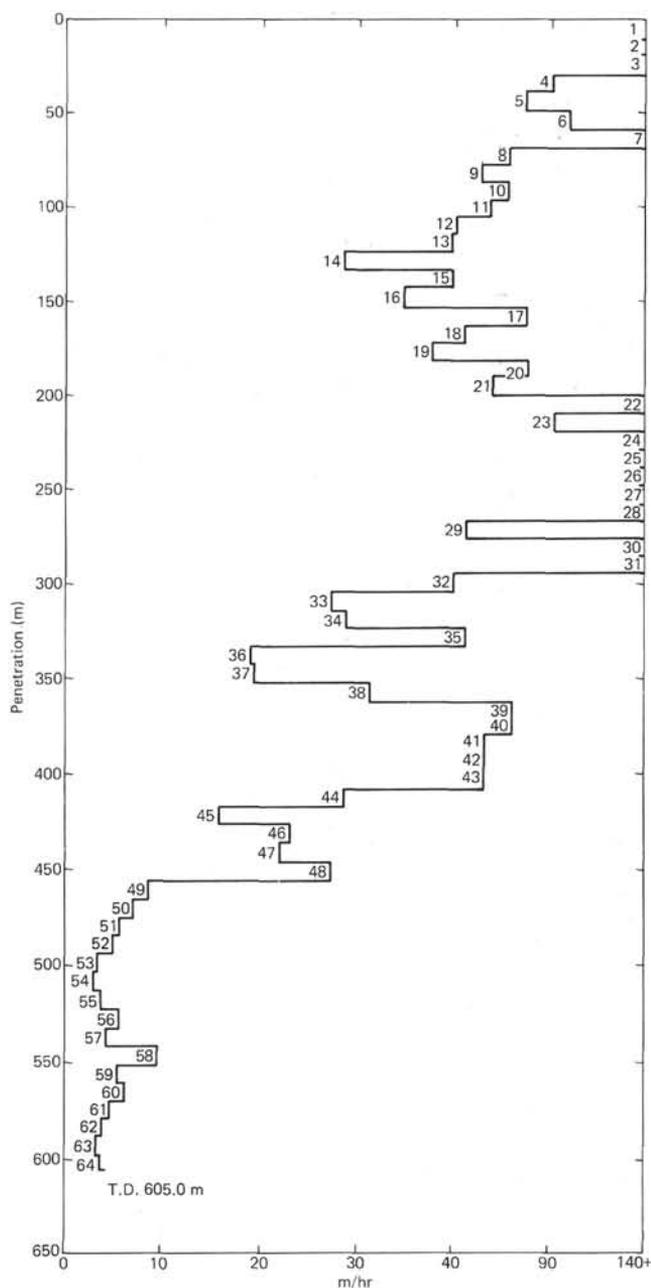


Figure 3. Drilling rate per core, Site 453. T.D. = total depth. Core numbers are indicated on the figure.

minutes in the hole, but in the future the time for measurement could be substantially reduced since the measured values reached equilibrium even more quickly than anticipated (see Uyeda and Horai, this volume).

Drilling rates slowed after Core 31 (294 m sub-bottom), in apparent response to an increase in the degree of lithification of the sediments. Beyond 455.5 meters below the sea floor, the drilling rate slowed to an average of 4.5 meters per hour as the bit penetrated a possible talus pile of igneous rocks, breccias, and deeper metamorphic rocks. Under these severe drilling conditions, bit wear became a concern. Recovery of the igneous rocks from Cores 48 through 57 was 33 per cent, but from Core 58 through Core 64 the recovery dropped

Table 1. Coring summary, Hole 453.

Core	Date (1978)	Time	Depth from Drill Floor (m)	Depth below Sea Floor (m)	Length Cored (m)	Length Recovered (m)	Recovery (%)
1	3/29	0034	4703.0-4712.0	0-9.0	9.0	9.23	100
2	3/29	0157	4712.0-4721.5	9.0-18.5	9.5	6.15	64.7
3	3/29	0315	4721.5-4731.0	18.5-28.0	9.5	3.35	35.3
4	3/29	0440	4731.0-4740.5	28.0-37.5	9.5	8.56	90.1
5	3/29	0558	4740.5-4750.0	37.5-47.0	9.5	2.44	25.7
6	3/29	0717	4750.0-4759.5	47.0-56.5	9.5	1.75	18.4
7	3/29	0838	4759.5-4769.0	56.5-66.0	9.5	0.25	2.6
8	3/29	1004	4769.0-4778.5	66.0-75.5	9.5	6.20	65.2
9	3/29	1334	4778.5-4788.0	75.5-85.0	9.5	0.45	4.7
10	3/29	1503	4788.0-4797.5	85.0-94.5	9.5	3.90	41.4
11	3/29	1623	4797.5-4807.0	94.5-104.0	9.5	9.57	100
12	3/29	1757	4807.0-4816.5	104.0-113.5	9.5	8.71	91.7
13	3/29	1936	4816.5-4826.0	113.5-123.0	9.5	1.55	16.3
14	3/29	2108	4826.0-4835.5	123.0-132.5	9.5	3.03	31.9
15	3/29	2240	4835.5-4845.0	132.5-142.0	9.5	3.90	41.1
16	3/30	0021	4845.0-4854.5	142.0-151.5	9.5	0	0
17	3/30	0144	4854.5-4864.0	151.5-161.0	9.5	0.78	8.2
18	3/30	0312	4864.0-4873.5	161.0-170.5	9.5	9.70	100
19	3/30	0450	4873.5-4883.0	170.5-180.0	9.5	0.87	9.2
20	3/30	0610	4883.0-4892.5	180.0-189.5	9.5	4.5	47.4
21	3/30	0745	4892.5-4902.0	189.5-199.0	9.5	2.2	23.2
22	3/30	0909	4902.0-4911.5	199.0-208.5	9.5	3.5	36.8
23	3/30	1025	4911.5-4921.0	208.5-218.0	9.5	2.23	23.5
24	3/30	1150	4921.0-4930.5	218.0-227.5	9.5	3.39	35.6
25	3/30	1317	4930.5-4940.0	227.5-237.0	9.5	1.99	20.9
26	3/30	1430	4940.0-4949.5	237.0-246.5	9.5	5.66	59.6
27	3/30	1520	4949.5-4959.0	246.5-256.0	9.5	3.86	40.6
28	3/30	1710	4959.0-4968.5	256.0-265.5	9.5	2.18	22.9
29	3/30	1832	4968.5-4978.0	265.5-275.0	9.5	6.37	67.1
30	3/30	1952	4978.0-4987.5	275.0-284.5	9.5	1.25	13.2
31	3/30	2121	4987.5-4997.0	284.5-294.0	9.5	4.62	48.6
32	3/30	2304	4997.0-5006.5	294.0-303.5	9.5	4.23	44.5
33	3/31	0056	5006.5-5016.0	303.5-313.0	9.5	5.28	55.6
34	3/31	0243	5016.0-5025.5	313.0-322.5	9.5	4.94	52.0
35	3/31	0414	5025.5-5035.0	322.5-332.0	9.5	5.91	62.2
36	3/31	0604	5035.0-5044.5	332.0-341.5	9.5	7.67	80.7
37	3/31	0750	5044.5-5054.0	341.5-351.0	9.5	7.08	74.5
38	3/31	0933	5054.0-5063.5	351.0-360.5	9.5	3.47	36.5
39	3/31	1056	5063.5-5073.0	360.5-370.0	9.5	6.92	72.8
40	3/31	1218	5073.0-5082.5	370.0-379.5	9.5	5.5	57.9
41	3/31	1351	5082.5-5092.0	379.5-389.0	9.5	7.55	79.4
42	3/31	1514	5092.0-5101.5	389.0-398.5	9.5	3.06	32.2
43	3/31	1647	5101.5-5111.0	398.5-408.0	9.5	4.38	46.1
44	3/31	1813	5111.0-5120.5	408.0-417.5	9.5	2.99	31.4
45	3/31	2013	5120.5-5130.0	417.5-427.0	9.5	5.79	60.9
46	3/31	2206	5130.0-5139.5	427.0-436.5	9.5	1.70	17.9
47	3/31	2344	5139.5-5149.0	436.5-446.0	9.5	4.18	44.0
48	4/1	0132	5149.0-5158.5	446.0-455.5	9.5	0.74	7.8
49	4/1	0407	5158.5-5168.0	455.5-465.0	9.5	1.73	18.2
50	4/1	0708	5168.0-5177.5	465.0-474.5	9.5	1.44	15.2
51	4/1	1010	5177.5-5187.0	474.5-484.0	9.5	4.11	43.2
52	4/1	1323	5187.0-5196.5	484.0-493.5	9.5	2.21	23.2
53	4/1	1809	5196.5-5206.0	493.5-503.0	9.5	5.91	62.2
54	4/1	2312	5206.0-5215.5	503.0-512.5	9.5	3.51	36.9
55	4/2	0458	5215.5-5225.0	512.5-522.0	9.5	4.82	50.7
56	4/2	0817	5225.0-5234.5	522.0-531.5	9.5	1.85	19.4
57	4/2	1209	5234.5-5244.0	531.5-541.0	9.5	5.06	53.2
58	4/2	1504	5244.0-5253.5	541.0-550.5	9.5	0.40	4.2
59	4/2	1840	5253.5-5263.0	550.5-560.0	9.5	0.24	2.5
60	4/2	2139	5263.0-5272.5	560.0-569.5	9.5	0.12	1.2
61	4/3	0105	5272.5-5282.0	569.5-579.0	9.5	0.2	2.0
62	4/3	0450	5282.0-5291.5	579.0-588.5	9.5	0.21	2.2
63	4/3	0940	5291.5-5301.0	588.5-598.0	9.5	1.43	15.0
64	4/3	1300	5301.0-5308.0	598.0-605.0	7.0	0.06	0.8
Total					605.0	236.83	39.1

to 4.1 per cent, even though the recovered rocks were apparently less dense in the deeper cores.

Various combinations of bit weight and pumping pressure were tried, and the hole was twice flushed with mud, but the percentage of recovery did not improve. After torquing increased dramatically during the cutting of Core 64, we decided that the bit was no longer operational, so drilling was stopped after 7 meters penetration on that cut. On recovery, the single cored rock that was recovered had only about a half of the diameter of a normal core, indicating that the cone bearings on the bit had been destroyed.

The hole reached a total depth of 605 meters below the sea floor, of which 137 meters had penetrated igneous rocks. The bit was rotated for 42 hours and 32 minutes before its apparent destruction. Sample re-

covery was 236.8 meters (39%) of the material penetrated.

After drilling was halted, preparation began for running a full set of downhole logs. We had decided to log the hole filled with salt water, rather than mud, since the water was required for the planned experimental large-scale resistivity log. In preparation, some 150 barrels of mud were circulated through the hole to flush it out, the bit was released, and the pipe was raised to 187 meters below the sea bottom. We had planned to lift all the drill string and leave only the 120-meter bottom-hole assembly in the hole, but heavy lifting loads on the string indicated that the shallow portions of the hole were caving in around the pipe during extraction. With the bottom of the string around 150 meters sub-bottom, lifting was halted. To clear the potential bridging in the upper part of the hole, four joints were replaced and the bottom of the string was pumped down to 186 meters sub-bottom. During this operation a 40,000-lb drop in weight occurred.

Logging commenced at 1930. The first tool to be lowered was to have been the temperature probe. The danger that the drill hole might be bridged prompted replacement of the T-probe with the heavier gamma-neutron activation and laterolog probe which more likely would drop through minor sediment bridges in the hole, and which would also give a continuous data readout on the ship indicating movement through the drill hole.

The probe was lowered to a depth of 4677.5 meters, where it was stopped by an apparent bend in the drill pipe. The rotary shifting tool for the bit release had been run at 1400-1530 and had not become stuck (although it is a larger tool than the log). We concluded therefore that the drill pipe became bent between 1530 and 1930, possibly when the the 40,000-lb drop in weight occurred.

As it was not possible to run the Gearhart-Owen downhole tools, the cause and nature of the bend in the pipe were unknown, and the top of the hole was apparently unstable, we decided to abandon Hole 453 without attempting the Francis large-scale resistivity log. Were the large-scale resistivity log to have encountered an obstruction in the pipe or the hole, it would have been difficult to detect before slacking and possibly snarling the sand line.

The string was pulled and secured at 0942 on 4 April, 1978. The third section of pipe above the bottom-hole assembly was bent.

Before departure for Site SP-4F, a short survey around the Site 453 pond was conducted in order to define the approximate shape of the pond and the surrounding ridges. The results of this work are detailed in the Geophysics section of this chapter.

At 1406 on 4 April the *Challenger* departed from Site 453 on a course of 081° for target Site SP-4E.

## LITHOLOGY

The clastic fill of the sediment pond in which Site 453 was located comprises two units. The upper part (Fig. 4) is a sequence of 455.5 meters of muds, silts, and sands

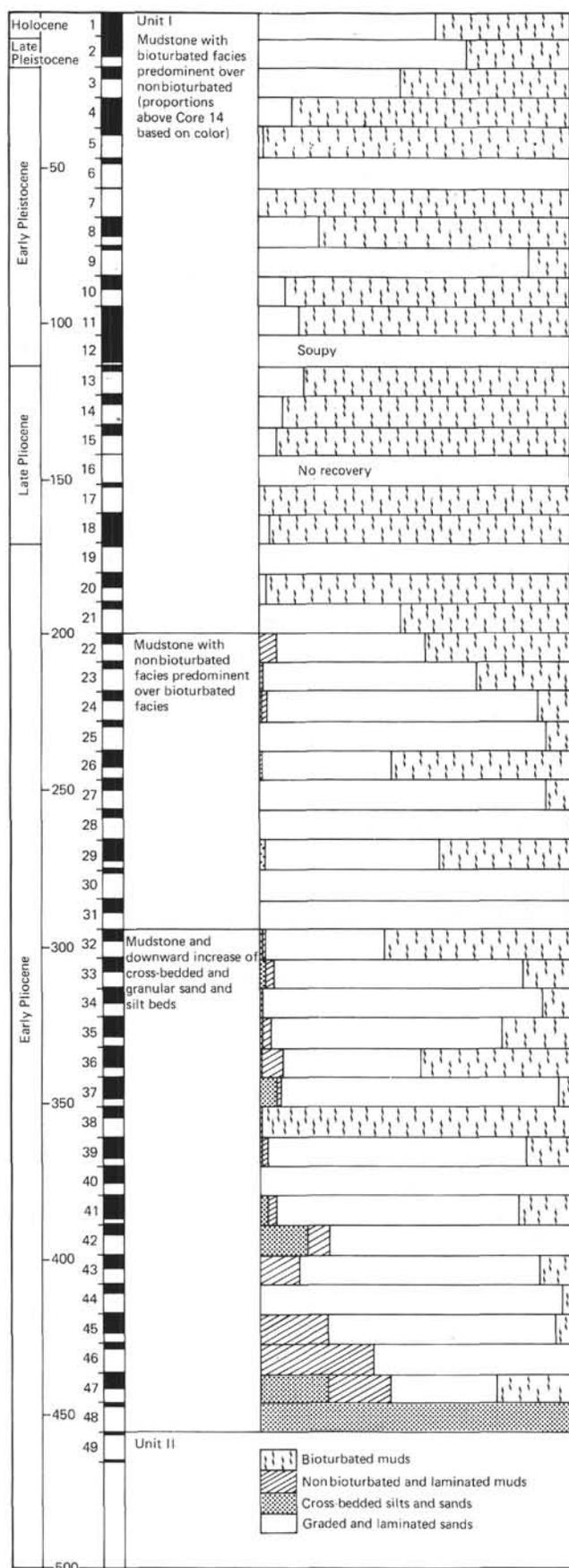


Figure 4. Stratigraphic column for Site 453 showing proportions of lithologies in each core.

(Unit I) composed mainly of volcanogenic detritus overlying a polymict breccia containing gabbro and basalt fragments (Unit II). The seismic reflection record shows Unit I to be flat-lying in the upper 100 meters and slightly undulating in the lower part.

The oldest fossils found are from the early Pliocene nannofossil subzone of *Triquetrorhabdulus rugosus*. The zone is regarded by some authors as uppermost Miocene, but using the scheme of Ellis and Lohman (1979) we place this subzone in its entirety in the early Pliocene; thus, the oldest sediment is 4.7 to 5 m.y. old. A similar age is inferred from paleomagnetic studies on the sediments of the unit.

The sediments are soft and un lithified in the first 12 cores, semilithified for the next eight to 10 cores, and lithified in the lower cores.

### Stratigraphy

Two alternating lithological associations are found in Unit I. They are identified by their sedimentary structures, grain size, bioturbation, and (to a lesser extent) color. In the uppermost 13 cores where sedimentary structures have been destroyed by drilling, identification has been based mainly on color.

#### Strongly Bioturbated Beds

The bioturbated sequence is almost entirely silt and mud, and the color is distinctly more green than the non-bioturbated association. Burrows are generally large (5 mm to 1 cm), and predominantly parallel to the bedding; they are often clearer in the upper parts of the beds, while the lower parts are color-mottled. Indistinct laminations are sometimes found. Burrow fillings are normally paler than the bulk of the sediment, and examination of one very pale infilling revealed a high carbonate content including abundant nannofossil remains. Apart from these minor occurrences, nannofossils are extremely rare in this association.

In the upper part of Unit I, beds of this lithology over 6 meters thick have been recovered (Core 18), but in the basal 100 meters of the unit the thickest bed is 60 cm.

#### Nonbioturbated Beds

Beds of this association are browner in color than the strongly bioturbated beds and are almost always graded although most of each bed is in the mud size range. Coarseness of the beds increases with depth in Unit I. The "typical" bed of this association, from the base up, comprises (1) a graded sand (medium to fine grained at the bottom and very fine grained at the top) with some laminations and an erosional base, (2) a very fine sandy to silty layer with small-scale cross-bedding (ripple lamination), (3) laminated siltstone fining up into mudstone (laminations from 1 mm to 1 cm apart), (4) mudstone with few laminations but usually with regular flat partings, few laminations, and rare narrow (2-4 mm) vertical burrows, (5) a fine laminated zone with laminations up to several centimeters apart containing the greatest (but small) concentration of nannofossils.

On the barrel sheets and in the petrographic discussion that follows, the sediments are classified as tuffs

(indurated) and ashes (non-indurated) if they contain over 50 per cent volcanogenic detritus (see Introductory Chapter, this volume).

The thickest bed recovered belonging to this association is over 8 meters thick, but beds of 1 to 2 meters are more typical. Within the beds the greatest variation occurs in the lowest part, the cross-bedded layer being replaced in many cases by a graded silt-to-very-fine-sand layer or a graded silt layer. The coarsest sand layer is occasionally reduced to a single band or a layer less than 1 cm thick with cross-bedding. The bedding of the cross-bedded layer is suggestive of climbing ripples in Core 47.

Sedimentary structures observed in the lower laminated sequence include small-scale structures, small-scale graded bedding, cross-bedding of interbedded silt laminae and mudstone, and in Core 47 several centimeters of flaser-bedded silt laminae.

The proportions of the various lithologies are shown in the stratigraphic column (Fig. 4). The reliability of the proportions should be judged against the recovery for the core. There is a rapid upward decrease in the proportion of coarser sediment over the basal 80 meters of the unit. The highest cross-bedded unit is in Core 20 (180-189.5 m). Above the top of Core 21 (189.5), just below the early/late Pliocene boundary, there is a sharp increase in the proportion of bioturbated sediments. There is no significant change in the sediment assimilation rate associated with this change in bioturbation. The sediment accumulation rate at this time had slowed to approximately 4.5 kg/cm<sup>2</sup>/m.y. and continues to decrease with time (see Accumulation Rates, this chapter).

Siliceous fossils are present in the first three cores but rapidly decrease in abundance downward.

A single carbonate-rich layer was recovered. It is a graded bed 17 cm thick and strongly burrowed at the top, overlain by bioturbated mudstone with mudstone filling the burrows.

### Sedimentary Petrography

Several mineralogic associations more or less dependent on grain size can be differentiated in Unit I. The sediment supply is almost exclusively volcanic. Siliceous organisms are abundant at the top of the hole but are extremely rare below. In contrast, calcareous remains are found throughout the core, but they are rare.

*Siliceous ooze and siliceous mud.* Siliceous sediments with up to 70 per cent diatoms and radiolarians are present in Cores 1 through 3 in the most recent sediments. The other major components are clay and traces of micronodules, glass, and feldspar.

*Clay and claystone.* These contain 90 to 98 per cent clay plus traces of feldspars, pyroxene, zeolites, volcanic glass, and micronodules. This lithology is found at intervals throughout the unit below Core 3.

*Mud and mudstone.* Up to 10 percent of feldspar, pyroxene, and glass are present in these sediments together with up to 90 per cent clay; their texture is more silty.

*Volcanoclastic-rich layers (vitric-lithic clay, mud, non-indurated ash, indurated tuff).* Volcanoclastic elements are very abundant and dispersed throughout the whole unit. They tend to be more abundant in non-bioturbated sediments when compared with bioturbated sediments of the same grain size. Volcanic components can constitute up to 80 per cent of the silt- and sand-sized sediments. Volcanic glass is the most abundant component, followed by feldspar, heavy minerals, and volcanic rock fragments. Within a single graded sequence of non-bioturbated sediments volcanoclastic components increase markedly downward, simultaneously with grain size (Fig. 5).

The most abundant type of the glass is very pale yellow and angular with closely spaced, thin pipe vesicles. Also present are colorless bubble-wall fragments, and colorless, pale brown and pale green glasses of other morphologies. The colorless ones, including those with pipe vesicles, have a lower index of refraction indicating that their compositions are more silicic. Pale green colored glass occurs in Cores 8 and deeper cores.

Superimposed on the above variability, volcanic glasses become increasingly brownish downward as a result of their alteration into clay minerals, thus making the recognition of the various types more difficult deeper in the unit. Heavy minerals are scanty, clinopyroxene is present in most sandy samples, and orthopyroxene appears in Cores 8, 13, and 39. In Core 13 it is a major component of a muddy vitric crystal tuff layer which is 0.5 cm thick.

*Other minerals.* Opaque "micronodule"-rich layers are often present in Unit I and are often associated with zeolites and pale volcanic glass. Microprobe examination of the "micronodules" has shown them to be very dark, iron-rich basaltic glass fragments. Small amounts of carbonate (dolomite?) occur in some intervals (Cores 18 and 36), as does minor pyrite (Core 44). Unidentified

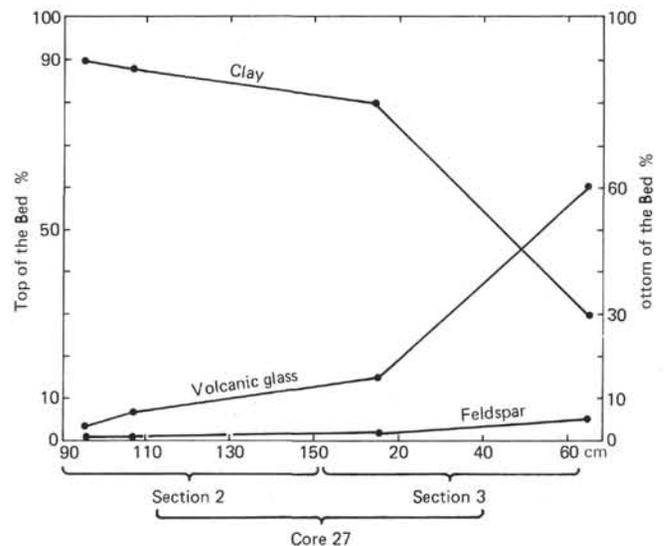


Figure 5. Change in composition within a graded bed of nonbioturbated mudstone estimated from smear slide determinations.

carbonate (dolomite?) in Core 36 constitutes almost all the light-colored burrow fills in the claystone.

### Deposition of the Sediments

Each of the sediment ponds in the region of Site 453 is isolated from adjacent ponds by intervening ridges and hills. The rough ridge and pond topography prevents the direct inflow of sediments from the possibly western source, the West Mariana Ridge, and the more remote Mariana Island arc to the east. The sediment composition indicates that the detritus is almost exclusively of volcanic origin, and the sedimentary structure show that pond fill was mainly laid down by turbidity current deposition with intervening periods of slower pelagic or hemipelagic accumulation during which the sediments were strongly bioturbated. Because of the extremely low abundance of biogenic elements, these sediments are thought to have been deposited close to the carbonate compensation depth (CCD). The turbidites are unusual in that the upper laminated sequence of the idealized turbidite is by far the thickest and the most commonly developed. The ripple-laminated and graded-sand sequences occur frequently only in the basal third of Unit I. There is an overall decrease of grain size up the sedimentary column. No true ash fall layers have yet been identified in the sequence. If they did occur, they may have formed thin bands in the slowly deposited strongly bioturbated layers and their identity has been subsequently lost.

The most abundant volcanic glass in the sediments has a low refractive index and is assumed to be ultimately derived from an island arc, rather than from volcanism within the basin. The more likely source is the Mariana Arc, where currently active volcanoes are located, rather than the West Mariana Ridge which is now entirely submerged. Drilling at Site 451 on the West Mariana Ridge revealed a thin, fine-grained Pliocene-Pleistocene section with no apparent volcanic ash above the early Pliocene (Scott, Kroenke, et al., 1980).

The immediate but not primary sources of the Site 453 sediment are the ridges surrounding the basin. We assume that sediment from Mariana Arc volcanism accumulated on these ridges and was mobilized into turbidity flows triggered by seismicity within the basin, by ash showers, or by slope instability.

## BIOSTRATIGRAPHY

### Summary

Evidence from generally common occurrences of calcareous nannofossils and rare occurrences of radiolarians (in the upper four cores) indicates that the sedimentary interval (Cores 1 through 48) overlying the igneous breccia (Core 49 and below) ranges in age from late Pleistocene to early Pliocene. Cores 1 and 2 are of late Pleistocene age, Cores 3 through 12 are early Pleistocene, Cores 13 through 18 are late Pliocene, and Cores 19 through 48 are early Pliocene. There is no evidence that Miocene sediments have been encountered, based on the comparison of nannofossil assemblages recov-

ered at this site with those recovered from the Messinian (Miocene) stratotype section.

### Nannofossils

Nannofossils observed in Pleistocene, late Pliocene, and latest early Pliocene samples (Cores 1 through 21) occur sparsely and are poorly preserved. However, the following zones can be recognized:

Late Pleistocene—the *Gephyrocapsa oceanica* Zone, Samples 1,CC and 2,CC.

Early Pleistocene—the *Gephyrocapsa caribbeanica* Subzone of the *Crenalithus daronicoides* Zone, Samples 3-2, 90-91 cm through 6,CC. The *Emiliana annula* Subzone of the *C. daronicoides* Zone, Samples 8,CC through 12,CC.

Late Pliocene—three of the four subzones of the *Discoaster brouweri* Zone can be recognized: the *Discoaster pentaradiatus* Subzone, Sample 13,CC; the *Discoaster surculus* Subzone, Samples 14-1, 20-21 cm through 14,CC; and the *Discoaster tamalis* Subzone, Samples 15-2, 90-91 cm through 18,CC.

Early Pliocene—the *Discoaster asymmetricus* Subzone of the *Reticulofenestra pseudumbilica* Zone, Samples 19-1, 60-61 cm through 22-2, 90-91 cm.

Nannofossils occur more commonly and are moderately well preserved in early Pliocene samples. The following zones can be recognized in the early Pliocene:

The *Sphenolithus neoabies* Subzone of the *Reticulofenestra pseudumbilica* Zone, Samples 22,CC through 27-1, 90-91 cm.

All three subzones of the *Amaurolithus tricorniculatus* Zone can be recognized: the *Ceratolithus rugosus* Subzone, Samples 27-2, 130-131 cm through 28-1, 50-51 cm or possibly 29-4, 128-129 cm; the *Ceratolithus acutus* Subzone, Samples 29,CC (or possibly 28,CC) through 38-2, 59-60 cm; and the *Triquetrorhabdulus rugosus* Subzone, Samples 38,CC through 48,CC. Samples below 44,CC do not contain early Pliocene zonal index species or any species used to define Miocene zones.

The Pliocene/Miocene boundary is placed at the base of the *Triquetrorhabdulus rugosus* Subzone. A recent study by Ellis and Lohman (1979) of the nannofossil assemblages recovered from the Zanclean (Pliocene) and Messinian (Miocene) stratotype sections in Sicily shows this position to be the most reasonable for the Pliocene/Miocene boundary. No Messinian-age nannofossil species were seen in the samples from Hole 453.

Reworked Miocene nannofossils are not apparent in any of the Hole 453 samples. However, the Oligocene and late Eocene species *Dictyococcites bisectus* and the Oligocene species *Cyclicargolithus abisectus* are seen in Samples 43,CC and 47,CC, respectively. Rare specimens of *Discoaster deflandrei* are also observed in Samples 43,CC and 48,CC.

### Radiolarians

Well-preserved radiolarians occur in Cores 1, 2, and 3. They are rare in the upper half of Core 4; the lower half is barren. Sporadic occurrences in lower cores are

from regions of suspected drilling disturbance and contain no species indicating ages older than those of the first four cores. One exceptional occurrence is in Core 17, where badly altered radiolarians (no age-diagnostic forms recognizable) are filled with an unidentified isotropic crystalline mineral.

The radiolarians of Hole 453 are all of Quaternary age. Species on which Nigrini's (1971) zonation is based are very scarce, but enough can be found in the rich assemblages of the first three cores to permit recognition of the upper three zones: the *Buccinosphaera invaginata* Zone in Core 1, the *Collospira tuberosa* Zone in Cores 1 and 2, and the *Amphirhopalum upsilon* Zone in Cores 2 and 3.

#### Foraminifers (V. A. Krasheninnikov)

Rare foraminifers of Quaternary to Pliocene age occur in Sample 3-1, 50-52 cm.

#### Accumulation Rates

The sediment accumulation curve (Fig. 6) has been calculated in kilograms of water-free sediment per square centimeter. The weight of the sediment has been based on the porosity and grain density measurements. An average has been taken for each core; because the values obtained were a little erratic in the upper part of the core, a moving average over five cores has been used. The time lines are based on an estimate of the ages of the nannofossil zones determined in the cores using the time scale of Bukry (1975).

The total accumulation of detrital sediment is a little over 34 kg/cm<sup>2</sup> for the past 5 m.y. The rate of accumulation has declined with time from the inception of sedimentation, except for an interval between 0.9 and 1.8 m.y.. The sediments are almost entirely volcanogenic, and the organic contribution to the sediment column is significant only in Cores 1 and 2 deposited in the past 0.9 m.y. Smear slide estimates of samples from those cores give an average siliceous organic content of just over 20 per cent.

The stratigraphic column can be divided into three segments on the basis of sediment accumulation rates.

Time Interval	Sub-Sea-Floor Depth (m)	Accumulation Rate (kg/cm <sup>2</sup> /m.y.)
1) Holocene and late Pleistocene (0-0.9 m.y.)	0-19.0	0.9
2) Early Pleistocene (0.9-1.8 m.y.)	19.0-112.7	4.7
3) Pliocene (1.8-5 m.y.)	112.7-446	1.5 - 31

The observed decrease in the rate of sedimentation with time at Site 453 would be predicted from its location if the active Mariana Arc were the sediment source. This site lies near the western edge of the Mariana Trough and west of the spreading center within the Trough. As spreading has taken place in the Mariana Trough, the distance from the pond in which the site is located to the active arc on the Mariana Ridge has in-

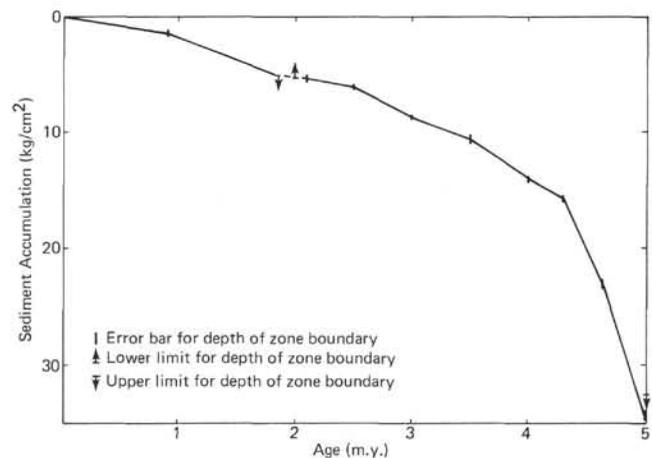


Figure 6. Sediment accumulation (kg/cm<sup>2</sup>) versus age, Site 453.

creased. Deviations of the observed sediment accumulation from a simple curve may be attributed to changes in the level of volcanic activity, to fluctuation in spreading rates, or to imperfections in the dating of the biostratigraphic zonation.

The only significant deviation is the increase in the gradient of the accumulation curve in the early Pleistocene. The most likely explanation is an increase for a short period in the volcanic productivity of the arc. The steady upward decrease in the accumulation rate is reflected in changes in the style of sedimentation. There is an upward decreasing sediment grain size, an increase in the amount of bioturbation, and a decrease in the thickness of turbidite units.

Segment 2 sediments (early Pleistocene), in which more rapid sedimentation took place, are difficult to interpret because of drilling disturbance. The recovered sediment is not significantly coarser than the beds with a slower sedimentation rate immediately above and below. It is not clear whether the increased sedimentation rate applies to part or all of the interval.

#### STRATIGRAPHIC SYNTHESIS

The deposits which fill the pond where Site 453 is located consist of two distinct units:

Unit I—455.5 meters of volcanoclastics of mainly silt size with a minor pelagic component, and Unit II—polymict breccias consisting mainly of fresh to altered and metamorphosed basaltic volcanic and plutonic rocks.

Unit I consists of the following components: pelagic sediments which have a persistent but minor role in the accumulation of the column, and volcanoclastic supplies which are superimposed as discrete contributions. The interplay of slow, continuous pelagic deposition and rapid but episodic volcanic-turbidite deposition generates the bioturbated and non-bioturbated beds (c.f., Lithology section, this chapter).

The entire pelagic-hemipelagic sediment sequence consists of claystone and mudstone or clay and mud (highly burrowed). In the two topmost cores, siliceous ooze containing radiolarians and diatoms are present. Zeolite is frequently well developed in clays. Carbonates are prac-

tically absent from the sequence except in a few layers and in some burrows, where undetermined carbonate (possibly dolomite) occurs. Based on the state of microfossil preservation, it is unlikely that the sediment/water interface has been above the CCD since at least the earliest Pliocene (Ellis, this volume).

Volcaniclastic materials are present in almost all the cored samples. Even the clays contain up to 10 per cent very fine grained volcanic glass and feldspars. The concentration of these products is much higher in the silty and sandy graded beds which have turbidite characteristics—graded bedding, cross-bedding, lamination, etc. Two different modes of transportation and emplacement of these volcaniclastic materials are envisaged: (1) raining through the water column and (2) the flow of turbidity currents over the seafloor.

The deposits raining down through the water column could result from volcaniclastic air falls, ash flows over the sea surface, and the sinking of waterlogged pumice fragments. These volcanic glasses are dispersed through all the bioturbated units. Their sparse yet rather uniform occurrence suggests that they arrived in the vicinity by air fall or floating, originating from distant volcanoes.

The turbidity current deposits result from an instantaneous supply of suspended material to the basin floor. The currents could have been generated from either volcanic eruptions or non-volcanic events such as seismicity or slumping of volcanic debris deposited earlier from the surrounding hills.

The common occurrence of volcanic glasses of low refractive index throughout the unit (except for the three highest cores) and the sporadic presence of hypersthene-bearing tuffs and vitric muds suggest that episodic supply of volcaniclastics from subaerial island arc-type volcanism continued since the earliest Pliocene until the latest early Pleistocene (Core 4). A change in the type of volcanic activity may have taken place at that time.

Small-scale normal faults with the displacement of the order of millimeters occur in the lower portion of the Unit I. On the other hand, no structures have been observed which show horizontal contractional deformation. These may suggest a pervasive extensional tectonic regime in the area during the opening period of the Mariana Trough.

Unit II is a 149.5 meter thick, complex igneous and metamorphic polymict breccia sequence which lies beneath Unit I down to the bottom of the hole. Details of its stratigraphy and petrography are reported in other sections of this report.

### **History of the Region Adjacent to Site 453**

About five or more million years ago the crust in the vicinity of Site 453 was formed. This crust consists of blocks of igneous and metamorphic rocks down-dropped or uplifted from the West Mariana Ridge. The crust formation process and possible subsequent movements resulted in the present horst and graben basement structure of the western part of the Mariana Trough.

Since the initiation of pelagic sedimentation, the area remained close to, but below, the CCD up to the present time. Ashy turbidite layers are frequently interlayered with pelagic clay in the Pliocene, but diminish in abundance up the sequence and are rare by the early Pleistocene. This trend suggests an increased distance between Site 453 and the source volcanoes on the arc and/or a decline in the level of volcanic activity on the arc.

### **INTERSTITIAL WATER GEOCHEMISTRY**

Pore waters were extracted from 12 samples at regular intervals throughout the 450 meters of sediment recovered at Site 453. The data are listed and plotted versus depth in Gieskes and Johnson (this volume). As in many sites where the sediments are rich in volcanic glass, there is a sharp drop in  $Mg^{2+}$  and increase in  $Ca^{2+}$  with depth, apparently a consequence of exchange of sea-water Mg for Ca in glass during alteration to clay (e.g., Balshaw, this volume). However, just above the igneous polymict breccia at the base of the sediments, these trends abruptly reverse, with Mg and Ca values again approaching those of sea water. Gieskes and Johnson (this volume) interprets this to mean that sea water is being drawn down into the breccia sequence, perhaps via nearby basement outcrops, and is reaching the base of the sediment with little modification, perhaps because of hydrothermal circulation. Certainly, the higher but variable heat flow recorded in and near the site (Uyeda and Horai, this volume; Hobart et al., 1979) supports this interpretation.

### **IGNEOUS AND METAMORPHIC ROCKS**

#### **Lithology**

Drilling at Site 453 penetrated 149.5 meters of complex polymict breccia and serpentized rock beneath the sediments. The material recovered may be classified into three general categories based on gross lithologic changes with depth in the hole (Fig. 7). These are: (1) igneous polymict breccia with many small and a number of large (> 10 cm) gabbro clasts (0–85.5 m below the sediment/breccia interface), (2) polymict breccia consisting mainly of metavolcanics and metabreccia without large gabbro clasts (85.5–114 m below the interface), and (3) a sheared mafic gabbro zone (114–149.5 m below the interface).

#### **Upper Polymict Breccia (0–85.5 m below sediments)**

The breccia interval is composed of angular to sub-rounded fragments of gabbro, diabase, and basalt cemented in a varicolored (mainly red-brown) matrix. The gabbro fragments range in proportion to basalt, metabasalt, and diabase in the cores from 54:46 to 95:5, and they average 71:29 (based on counts of clasts > 3 cm longest diameter on flat surfaces of working halves). They include fragments with color indices > 70 (mafic gabbros), < 30 (leucocratic and pegmatitic gabbros), and 30–70 (gabbros per se). The less abundant basaltic rocks include: (1) fine-grained aphyric or sparsely phyrlic basalt, (2) medium-grained aphyric basalt (dia-

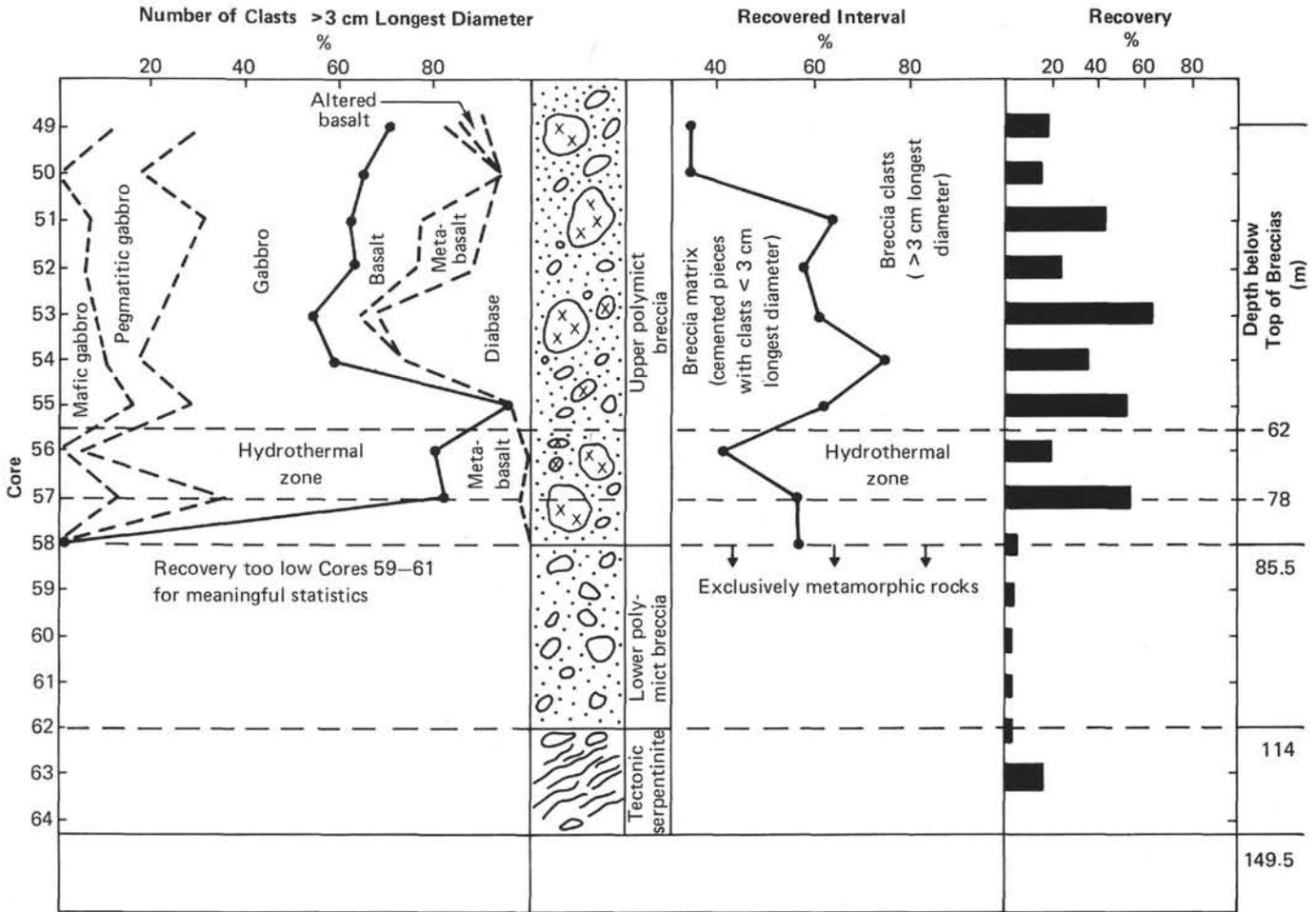


Figure 7. Variation with depth in core of (1) number of gabbro (dashed lines) and basalt (solid line) clasts, (2) lithology, (3) percentage of recovered breccia that is composed of clasts less than 3 cm (left) and greater than 3 cm (right), and (4) percentage of recovery.

base), (3) metabasalts, green in color, and (4) altered basalts, brown or reddish brown.

The rock fragments are cemented in a matrix of quartz, carbonate, iron oxide and hydroxides, and chlorite. The reddish color of the matrix is the result of oxidation of magnetites, or titanomagnetites, and (to a lesser degree) mafic silicate phases, to iron hydroxides, as seen using reflected light microscopy. Angular pebbles and sand-sized grains of igneous and metamorphosed igneous rocks are abundant throughout the matrix. Quartz crystals occur in some cavities and cracks between breccia fragments. Carbonate is most abundant in the upper intervals and diminishes with depth. It does not react readily with hydrochloric acid, hence does not appear to be entirely calcite.

Fragments in the breccia vary considerably in size. They range from sand-sized to clasts as large as 45 cm. A size-frequency diagram for gabbro clasts larger than 3 cm in the longest diameter and basaltic clasts (includes metabasalts and diabases) larger than 2 cm in the longest diameter is presented in Figure 8A. The basaltic

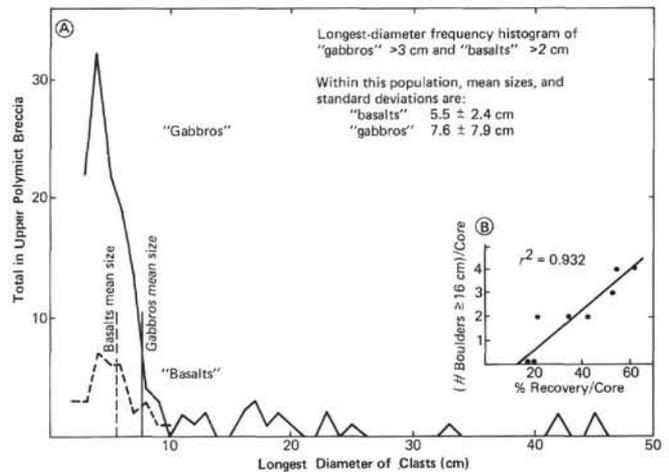


Figure 8. Size frequency diagram for basaltic clasts larger than 2 cm (dashed line) and gabbroic clasts larger than 3 cm (solid line). Vertical lines indicate the mean size of basaltic (dashed line) and gabbroic (solid line) clasts.

rocks average 5.5 cm and the gabbros 7.6 cm in the longest measurable diameter.

There is a strong correlation between percentage recovery and size of gabbro clasts present (Fig. 8B). The correlation coefficient between the percentage recovery in each core and the number of large (16 cm or greater) gabbro clasts is 0.932.

The proportion of various rock types per core versus depth (based on gabbros larger than 3 cm in the longest diameter and basaltic rocks larger than 2 cm in the longest diameter) is plotted on Figure 7. On the basis of this diagram, the upper polymict breccia can be divided into less- and more-gabbroic zones. Above Core 55—that is, to a depth of about 60 meters below the sediment/breccia interface—the gabbro clasts comprise 54–70 per cent of all clasts larger than 3 cm. In the gabbro-rich zone, below 60 meters into the breccia, gabbro clasts comprise 80–95 per cent of the total clasts larger than 3 cm.

The 85.5-meters-thick gabbro-rich rocks include a zone where the breccia cement is green in color and consists mainly of chlorite. This zone starts with Core 55, Section 4, Piece 4, and continues through Core 57, Section 2, Pieces 14 through 16—a depth interval from about 62 to 78 meters below the sediment/breccia interface. Above and below this interval, the breccia matrix is grayish brown. The zone of green matrix contains demagnetized gabbros. Thin sections show that gabbros from this zone are more chloritized than those above or below. In Cores 55 and 56, some gabbros have high-angle fractures with mafic minerals aligned parallel to the fractures, suggesting partial recrystallization. The demagnetized rocks are evidence that the green breccia matrix was probably a zone for flux of hydrothermal fluids at elevated temperatures.

Gabbros in this zone show retrograde metamorphic effects, apparently the result of the hydrothermal conditions they had been exposed to. Many have bleached exterior rinds in which calcic plagioclase has been transformed to K-feldspar (Fig. 9). Accompanying the color change in the matrix is an increasing abundance of quartz-K-feldspar chlorite veins within the rock clasts. Nearly all of the metabasalts and many gabbros in the low-gabbro zone were apparently metamorphosed prior to incorporation within the breccia.

Several zones in the upper polymict breccia have higher abundances of certain clasts than others. Cores 53 and 54 in the low-gabbro zone have a high proportion of medium-grained basalt (“diabase”) as shown on Figure 7. Several of these basalts appear to have disaggregated within the breccia matrix. As a result of this, the breccia matrix surrounding them is a deep brick-red color.

Another zone with a predominant rock type is the green-matrix zone of Cores 55 and 56. Here the proportion of pegmatitic gabbro is low (Fig. 7), and the gabbros have higher color indices than elsewhere (50–70 rather than 30–70).



Figure 9. Gabbro clast with encrusting breccia and K-feldspar alteration rind. Sample 453-57-2 (Piece 14), 83–89 cm.

#### Lower Polymict Breccia (85.5–114 m below sediment)

A principal feature of this interval is its low recovery (Fig. 7). The rock types that were recovered, although brecciated, differ in several respects from those of the upper polymict breccia.

The clast types are primarily metamorphosed andesites and dacites, rather than gabbros. These are pale green and some have veins of quartz or other minerals on or in them. Pyrite is abundant.

There are three types of breccia. One is a gray, semi-lithified mudstone containing coarse fragments of metamorphosed mafic igneous rock (Sample 58-1, Piece 8). The second is a dark green, friable breccia of altered mafic material of uniform color and appearance. The fragments in this breccia are 0.5-to-1-cm angular chips. There are no feldspathic gabbro fragments in this type of breccia, unlike the typical matrix material of the upper polymict breccia. The third breccia type comprises indurated, pale green metavolcanic breccia (Sample 60-1, Piece 1). This appears to be a cemented and metamorphosed, fragmental version of the typical metavolcanic clasts in this interval. It is important to emphasize that none of the breccia types occurs in the upper polymict

breccia, and that here metavolcanics far predominate over gabbros.

The upper polymict breccia contains many large gabbro clasts, and these appear to correlate with recovery (Fig. 8B). Had large clasts of any kind been in the lower polymict breccia, it seems likely that recovery would have been higher. Recovery in the last core of the upper polymict breccia (Core 57) was among the highest in that breccia, and there was no evidence for a decrease in bit diameter at that time. The drilling rate also accelerated with Core 58. It seems likely, then, that the lower polymict breccia comprises predominantly soft breccias which fragmented during drilling. Rather than enter the core barrel, the small fragments were washed out by circulation.

The transition between the upper and lower polymict breccias was abrupt, in terms not only of recovery but also of breccia lithology. The matrix material in the lower part of Core 57 had the typical gray-red color of the upper polymict breccia. With Core 58, breccias are highly chloritic and in this respect are similar to those of the green-matrix zone of the upper breccia. But they do not contain fragments of gabbro. It seems probable that the metamorphism in the lower polymict breccia was caused by the same hydrothermal event that altered the green breccia zone in the upper polymict breccia, since the metamorphic mineral assemblages are so similar (pyrite, chlorite, quartz, etc.).

#### **Sheared Mafic Gabbro (114–149.5 m below basement)**

Only a few fragments of metabreccia and pale green clay—a type of drilling slurry—were recovered in Core 62. The origin of this mud was obscure until retrieval of Core 63, in which 1.5 meters of strongly sheared serpentinite and mafic gabbro were recovered. The outer cored surface of this material was coated with an identical soft green mud produced by the friction of drilling on the serpentinite. Because of the possibility that the few fragments of metabreccia in Core 62 were fragments from the interval from 85.5 to 114 meters below the sediments (Cores 58–61) that fell down the hole, the transition between the lower polymict breccia and the serpentinite zone is placed at the base of Core 61, above the “green mud” interval.

The material in Core 63 is dark gray-green and dark green gabbro with abundant pyrite. The gabbro is in small fragments (typically 1–5 cm) stretched out along a primary rock foliation (Fig. 10). It is mafic to noritic, very dark gray in color, and makes up between 40 and 60 per cent of the rock (varying from place to place). Chloritic material is webbed between these fragments.

### **PETROGRAPHY**

#### **Matrix**

The breccia's matrix consists of sand-sized fragments of various rock types and rock-forming minerals. The proportions of matrix and clastic material are variable. Matrix materials juxtaposed to large rock fragments are

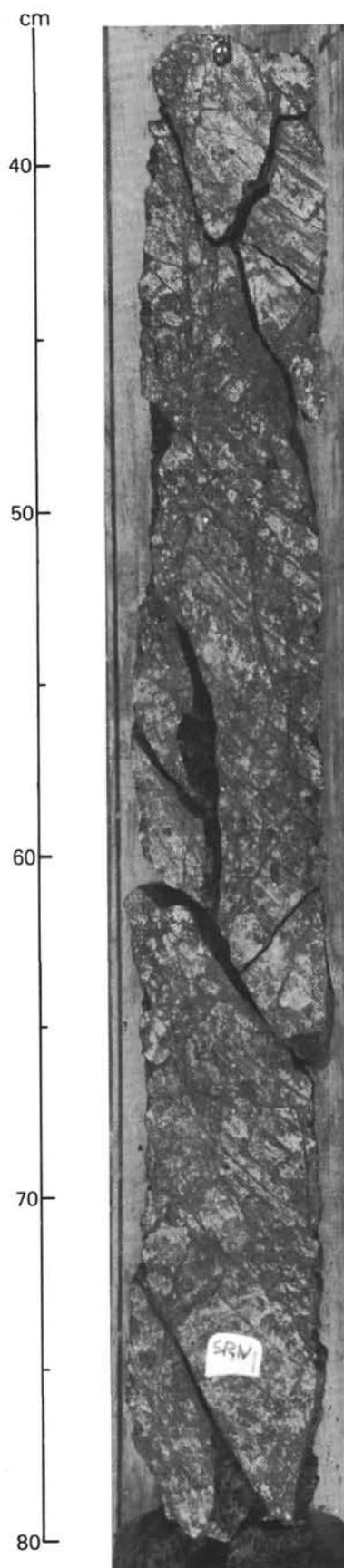


Figure 10. Section 63-1, showing serpentinitized gabbro with fragments stretched out along the primary rock foliation.

typically enriched in small rock clasts of the same composition (the best example is the matrix of Sample 53-3, 79-81 cm. In general the matrix is heterogeneous.

The main components of the matrix are carbonate, chlorite, clay minerals, and iron oxides and hydroxides. Small amounts of epidote, quartz, prehnite, and pumpellyite are present in many cases. These minerals are variable in proportions and form granoblastic, sometimes lepidoblastic, textures in the matrix. Quartz, iron-oxides, and carbonate are more abundant in the uppermost part of the breccia section and beneath the "green-matrix zone." Within the green zone the matrix consists mainly of chlorite, zeolite, and epidote, and is enriched in clastic material.

It is interesting that in Sample 49-2, 64-66 cm, some rock fragments contain up to 70 per cent of andesine-labradorite plagioclase and could be andesitic in composition.

In thin section 54-1, 31-33 cm, one crystal in the matrix displays the optical properties of lawsonite. It is clastic in origin, indicating that one of the possible sources of the breccia matrix could be a high-pressure metamorphosed terrain.

Sample 49-1, 120-123 cm (Piece 8), consists of fine (0.3-to-0.5-cm) carbonate grains (70% by volume) and sparse altered rock fragments cemented by chlorite, clay, and iron-oxide. This sample seems to represent a portion of matrix that is almost free of clastic components.

#### Basalts and Diabase

Diabasic fragments are more abundant than basaltic ones in the breccia. Commonly aphyric or sometimes sparsely phyrlic, they contain 50 to 70 per cent plagioclase ( $An_{50-70}$ ), 30 to 50 per cent clinopyroxene, and accessory magnetite. Typical ground mass textures are ophitic or intersertal. Vesicles are rare (1-2%), small (0.2 to 0.6 mm), or totally absent. All of these rocks are moderately or severely altered, having variable amounts of chlorite, amphibole stilpnomelane, and iron oxides replacing clinopyroxene, and sericite, albite, and clay minerals replacing plagioclase.

In plagioclase or plagioclase-pyroxene phyrlic basalts the euhedral plagioclase phenocrysts ( $An_{55}$ , 0.5 to 5 mm in diameter) comprise up to 30 per cent of the rocks by volume. These, together with rare augite phenocrysts, are set in a subophitic or intersertal matrix formed by intergrown crystallites of the same minerals, plus minute opaques and some altered volcanic glass. A single olivine microphenocryst, altered to iddingsite, is present in thin section 54-3, 106-109 cm.

Alteration of the rocks is moderate to very high. In slightly or moderately altered rocks, chlorite and stilpnomelane replace the matrix and pyroxene grains, and sericite aggregates appear within the plagioclase grains. The metabasalts are amygdaloidal with chlorite, quartz, carbonate, and prehnite filling vesicles and vugs. These minerals also form the granoblastic groundmass together with pumpellyite, clay minerals, and iron hydroxides (see thin section 50-1, 52-56 cm).

#### Gabbros

The gabbros are the most abundant and most variable rock fragments of the breccia. Besides normal gabbros, anorthositic, pegmatitic, noritic, troctolitic, and hornblende varieties are present. The original mineral assemblage includes plagioclase ( $An_{60-97}$ ), clinopyroxene, orthopyroxene(?), olivine, and minor magnetite. One specimen of hornblende anorthositic gabbro (Sample 55-4, 133-135 cm) contains up to 10 per cent green spinel. Hypidiomorphic-granular, ophitic, poikilitic, and cumulus textures are typical of unmetamorphosed gabbros. In metamorphosed varieties granoblastic, nematoblastic, or foliated textures are observed.

Many gabbro fragments in the breccia contain secondary minerals typical of greenschist or amphibolite facies metamorphism. The most widespread is green hornblende. In thin section 55-4, 133-135 cm, it is bluish green and is more aluminous than usual. Chlorite, epidote, sericite, carbonate, clay minerals, accessory zeolite, prehnite, pumpellyite, and stilpnomelane are also present in many, especially in the highly altered gabbros. Core 63 of this site consists mostly of intensively sheared melanocratic and mylonitized gabbros, with abundant secondary green hornblende replacing cataclastic pyroxene grains, and traces of biotite.

#### Tonalite

One piece of foliated tonalite was found within the breccia fragments (Sample 55-3, 63-67 cm). The rock has lepidogranoblastic texture and consists of zoned oligoclase-albite, quartz, biotite, and minor K-feldspar with accessory magnetite, apatite, and zircon.

#### CHEMISTRY OF IGNEOUS AND METAMORPHIC ROCKS

Wood et al. (this volume) report analyses for 24 igneous and metamorphic rocks from the breccias of Site 453. Most of the rocks analyzed are gabbros, metagabbros, and pegmatitic gabbros showing clear evidence in their bulk chemistry of being cumulus rocks rich in either plagioclase or mafic phases. There is indeed a high abundance of mafic gabbros in Cores 55 through 57. Two samples analyzed from the upper polymict breccia are metabasalt. The two samples analyzed from the lower breccia are metamorphosed andesite and dacite. The sheared, serpentinized metagabbro from Core 63 has the composition of a mafic gabbro.

All of these rocks have the basic geochemical characteristics of arc magma types, with high Sr and Ba but low Ti, Cr, and Ni contents. One basalt (Sample 52-1, 30-36 cm) has the composition of a primitive arc tholeiite. The high Sr and Ba contents of the plutonic rocks, in the view of Wood et al. (this volume), are "consistent with an origin in the deep-seated portion of an island arc." The high Ba and Sr in particular, and the somewhat high  $K_2O$  of the biotite-bearing rocks, are certainly more typical of deep-seated arc rocks than gabbros found in exposed sections of ocean crust. This interpre-

tation is complicated in a few rocks by marked enrichments in  $K_2O$  and Ba from alteration processes. Nevertheless, the entire assemblage implies that the ridges surrounding Site 453, from which the breccias must have come, are founder portions of the West Mariana Ridge and are not truly a portion of the Mariana Trough.

## ALTERATION

### Alteration and Metamorphism

Differences in the secondary mineral assemblages observed in the matrix and clasts of the breccias suggest that many of the clasts were metamorphosed to lower greenschist or upper amphibolite facies before their incorporation into the breccia. Furthermore, many of the gabbroic clasts have tectonite fabrics that are generally not reflected in the adjacent matrix. This indicates a pre-breccia metamorphic history for many of the gabbros. The andesite and dacite of the lower polymict breccia also apparently had a pre-breccia metamorphic history, as evidenced by their bulk composition which is more albitized than the gabbros or metabasalts of the upper breccia.

The breccia matrix appears to have been subjected to lower-greenschist-facies metamorphic conditions. This is reflected primarily in the occurrence of chlorite, prehnite, and carbonate in the matrix. In the sections of breccia most affected by metamorphism, the original metamorphic mineralogy of the clasts appears to have retrograded to the lower greenschist facies of the matrix; and the breccia matrix is green, rather than brownish red.

The tentative identification of lawsonite in the matrix of a breccia fragment is intriguing and could have important implications for the origin of the breccia source material. The occurrence of abundant green spinel in several of the gabbro clasts studied in thin section is also noteworthy, since it has so rarely been reported in mafic plutonic rocks (e.g., Deer et al., 1964).

It is difficult at this stage to draw conclusions concerning the origin and history of the breccia and the serpentinite. However, it seems clear that the source areas for the breccia were metamorphosed prior to breccia formation. Based on the rock bulk analyses, the eastern slope of the West Mariana Ridge was the immediate source area. The metamorphism apparently occurred in the volcanic arc and predated the opening of the Mariana Trough.

The lower greenschist facies metamorphism of the breccia matrix may reflect interaction of parts of the breccia section with hydrothermal fluids originating from depths below the breccia. It is difficult to know whether these might be the same fluids which have reversed the Mg and Ca pore fluid gradients at the base of the sediments. Those fluids appear to have the composition of sea water (Gieskes and Johnson, this volume), but the hydrothermal alteration appears to have involved considerable transformation of calcic plagioclase to K-feldspar and occurred under high-temperature (resulting in the formation of chlorite), reducing conditions.

## Origin of the Breccias

The origin of the sheared serpentinite is not clear at present. In Core 64 one rock was recovered—a sheared dark green rock with prominent plagioclase crystals. It could be a metamorphosed mafic gabbro or diabase. Whether it fell down the hole from above the sheared serpentinitized gabbro of Core 63 or represents still another mafic breccia sequence cannot be resolved at present.

Any one of several hypotheses might explain the breccia sequence. The simplest is that the upper breccia, the lower breccia, and the serpentinitized gabbro each represents separate, chaotically slumped masses from sources of restricted composition. The local concentration of mafic gabbros and diabase in the upper polymict breccia would be basically random in origin, only the overall source for the upper breccias was more heterogeneous. It is also probable that the gabbros came from sources closer than the basalts, as evidenced by their greater abundance and large clast size. This could indicate that the basalts might have been derived from higher up on the same fault block, or that the access of basaltic debris to the bottom of the sediment pond was restricted by benches. The location of the breccias in the center of the sediment pond and their low angle of repose (see section on Geophysics, this chapter) suggest they might be flat-lying slump or avalanche debris rather than talus.

An alternative emplacement hypothesis is that only the upper polymict breccia is a slump or avalanche deposit. The lower breccias and sheared mafic gabbro could be a part of a fault zone. The hypothesis, then, links the occurrence of sheared rocks with zones of hydrothermal alteration and with lithologic changes. It is tempting to speculate that the hydrothermal zone in the upper polymict breccias, as well as the hydrothermally altered pyritized greenstones of the lower polymict breccias, formed in zones of shear that were conduits for hydrothermal solutions. Displacement along the shear zone juxtaposed breccias of different igneous and metamorphic rock populations, and of different clast size. The sheared mafic gabbro is the principal evidence for the lower shear zone. Fractured gabbros in the green breccia zone of the upper polymict breccia might be evidence for shear there as well.

A third hypothesis would have the sheared gabbro alone part of a fault zone. The breccias above would have been shed from a block of crust that was gradually faulted relatively upward, exposing deeper and more coarsely crystalline mafic rock assemblages. Thus the lower polymict breccia would consist mainly of metavolcanics derived from the upper part of the fault block before deeper gabbros were exposed. The upper breccia would contain mostly gabbros, with fewer basalts and diabases.

## PALEOMAGNETICS

Paleomagnetic measurements were made in 34 sediment samples and 22 igneous and metamorphic rock samples from the breccia zones (Bleil, this volume). The variation of magnetic inclination with depth and the

paleontological information in the lower sediment layer fit approximately with the current geomagnetic polarity time scales. This fit gives an age of about  $5.0 \pm 0.2$  m.y. for the base of the sediment. The magnetic inclination of sediments, however, is too shallow for the present location of the site (mean stable inclination =  $15.0^\circ \pm 10.0^\circ$ , as against the present inclination of the Earth's field at this latitude of about  $+35^\circ$ ). Rocks from the breccia zone show a stable inclination of  $36.4^\circ \pm 20.3^\circ$ , which agrees with the present inclination. The origin of the remanent magnetization remains unclear. For more details, see Bleil (this volume).

### PHYSICAL PROPERTIES

Compressional wave velocity, wet-bulk density, salt-corrected water content, porosity, acoustic impedance, and thermal conductivity were determined for cores recovered from Site 453. The measurements are tabulated in Table 2.

#### Sonic Velocities

Sonic velocities were measured on the Hamilton Frame. With the exception of one sample, which was checked for anisotropy, measurements were made only for the vertical direction. Many of the sedimentary rock samples obtained from depths greater than 120 meters below the sea floor cleaved easily along bedding planes, making it easy to produce a parallel-sided slab suitable for placing in the Hamilton Frame. Further trimming or sawing of such samples to measure velocities parallel to the bedding planes would in most cases have resulted in their disintegration. Compressional wave velocity in the sediment ranged from 1.50 to 2.45 km/s. In the breccia underlying the sediment the mean seismic velocity of 12 samples was 4.75 km/s, but three gabbro samples from within the breccia had much higher velocities (6.57 to 6.82 km/s). The tectonized serpentinite at the bottom of the hole had highly variable seismic velocities, ranging from 4.21 to 6.10 km/s, probably depending on the amount of shearing within the samples.

#### Wet-Bulk Density, Water Content, Porosity

A proportion of the sonic velocity samples were subjected to GRAPE special 2-Minute counts for the determination of wet-bulk density. The wet-bulk density, water content, and porosity of the greater number of these same samples were then determined by gravimetric methods. During drilling at this site the GRAPE machine underwent major servicing, including the installation of a new scintillation tube. This resulted in a 7% per cent change in the attenuation coefficient obtained with the 5-cm-thick quartz standard, and a doubling of the air count. The change occurred between Cores 28 and 29 as far as the 2-minute observations are concerned. However, as the comparison of the two methods of measuring density indicates (Fig. 11), no systematic error resulted. The slightly large discrepancies obtained between the two methods at the higher end of the density scale is thought to be due to the igneous rock samples

(particularly the breccia) being inherently more inhomogeneous on the scale of the gamma-ray beam (about the thickness of a pencil) than the sedimentary samples.

The wet-bulk densities of the sedimentary rocks range from 1.2 to 1.9 g/cm<sup>3</sup>. One sample (from Section 29-1) yielded a gravimetric determination of 2.03 g/cm<sup>3</sup> and a GRAPE value of 1.50 g/cm<sup>3</sup>. This was the only major discrepancy between the two methods (too large to show on Fig. 11). The higher density is probably in error.

The igneous rocks had much higher densities, averaging 2.55 g/cm<sup>3</sup> for 12 breccia samples, 2.92 g/cm<sup>3</sup> for three gabbros, 2.93 g/cm<sup>3</sup> for three serpentinites, and 2.63 g/cm<sup>3</sup> for a gabbro pegmatite.

#### Variation of Velocity-Density Parameters with Depth

Sonic velocity, wet-bulk density, and acoustic impedance for the sedimentary sequence are plotted against depth below the sea bed in Figure 12. In general all three parameters increase with depth, although much small-scale variation—particularly in sonic velocity—is apparent. It is important to emphasize that most of this scatter is real, not the result of measurement errors, and is generated by beds with different properties alternating in the sedimentary sequence, often within the same core or section of a core. In an attempt to relate these measurements to the seismic reflection profile, two broad-scale discontinuities have been identified at 120 meters and 290 meters below bottom. These two discontinuities divide the sedimentary column into three layers whose average properties are summarized in Table 3. In terms of the measured samples themselves, the three layers correspond to:

- (1) muds and clays soft enough for samples to be scooped from the cores;
- (2) mudstones and claystones cleaving easily along bedding planes to produce parallel-sided samples; and
- (3) same mudstones and claystones as (2), but which required sawing to prepare a sample for the Hamilton Frame.

The normal reflection coefficient and two-way travel time from the sea bed have been calculated for each discontinuity and are given in Table 3. The correlation between the calculated reflection times and the seismic reflection record is shown in Figure 13. The reflection coefficients increase down the column, but none is large until the sediment/breccia interface is reached. The fact that this does not show up more clearly on the reflection record may be due to the probable rough surface of breccia rubble layer.

Sonic velocity and porosity measurements for the breccia samples are plotted against depth in Figure 14. Both show consistent and compatible trends, with velocity increasing and the porosity decreasing with depth.

#### Thermal Conductivity

Thermal conductivities of core samples recovered at Site 453 were measured, and a profile of thermal conductivity of the uppermost oceanic crust constructed

Table 2. Physical properties measurements, Hole 453.

Sample (interval in cm)	Depth (m)	Sound Velocity (vertical) (km/s)	GRAPE 2-min. Wet-Bulk Density (g/cm <sup>3</sup> )	Wet Water Content (salt corrected) (%)	Porosity <sup>a</sup> (%)	Wet-Bulk <sup>b</sup> Density (g/cm <sup>3</sup> )	Acoustic Impedance (g/cm <sup>2</sup> s × 10 <sup>5</sup> )	Rock Type
1-2, 100-102	2.50	1.52		73.7	87.9	1.22	1.85	Mud
1-3, 80-82	3.80	1.52						Mud
1-4, 114-116	5.64	1.51						Mud
1-5, 100-102	7.00	1.50		68.8	85.4	1.27	1.90	Mud
1-6, 3-5	7.53	1.52						Mud
2-1, 100-102	10.0	1.51						Mud
2-2, 80-82	12.30	1.51		66.2	83.8	1.30	1.96	Mud
2-3, 85-87	12.85	1.51		57.0	77.9	1.40	2.11	Mud
2-4, 10-12	13.60	1.52		47.0	70.5	1.54	2.34	Mud
3-1	18.5	1.51						Mud
3-2, 45-47	20.45	1.50		63.4	82.1	1.33	1.99	Mud
4-2, 105-107	30.55	1.54		74.8	88.7	1.22	1.88	Clay
4-3, 100-102	32.0	1.53						Clay
4-4, 100-102	33.50	1.53		76.3	89.8	1.21	1.85	Clay
4-5, 60-62	34.60	1.53						Clay
4-6, 30-32	35.80	1.57						Clay
5-1, 75-77	38.25	1.54		75.0	89.2	1.22	1.88	Clay
5-2, 35-37	39.35	1.56						Clay
6-1, 100-102	48.0	1.58		74.6	88.9	1.22	1.93	Mud
8-1, 40-42	66.40	1.55						Clay
8-1, 132-134	67.32	1.57						Clay
8-2, 40-42	67.90	1.55		73.4	88.5	1.23	1.91	Clay
8-3, 80-82	69.80	1.55		76.3	90.0	1.21	1.88	Clay
8-4, 90-92	71.40	1.56						Clay
9-1, 21-23	75.71	1.62		54.9	76.8	1.43	2.32	Mud
10-2, 100-102	87.5	1.56		75.3	89.3	1.21	1.89	Clay
10-3, 13-15	88.13	1.62						Clay
11-1, 43-45	94.93	1.55		74.0	88.6	1.23	1.91	Clay
11-2, 43-45	96.43	1.78		50.9	72.3	1.45	2.58	Clay
11-3, 60-62	98.10	1.51						Mud
11-4, 43-45	99.43	1.52		69.7	86.6	1.27	1.93	Mud
11-5, 43-45	100.93	1.56		63.3	82.5	1.33	2.07	Mudstone
11-6, 43-45	102.43	1.55		68.5	85.8	1.28	1.98	Mud
13-1, 83-85	114.33	1.54		52.8	74.0	1.43	2.20	Mud
14-1, 46-48	123.46	1.62						Mudstone
14-2, 76-78	125.26	1.79		57.5	77.3	1.38	1.47	Mudstone
14,CC	126.0	1.92						Mudstone
15-1, 63-65	133.13	1.79	1.31				2.34	Claystone
15-2, 29-31	134.29	1.75	1.36	60.7	80.5	1.36	2.38	Claystone
17-1, 46-48	151.96	1.86	1.37	57.9	78.2	1.38	2.57	Mudstone
18-1, 103-105	162.03	1.72	1.40	51.5	72.7	1.45	2.49	Mudstone
18-5, 137-139	168.37	1.83	1.50	52.0	73.6	1.45	2.65	Claystone
19-1, 28-30	170.78	1.63						Mudstone
20-1, 140-142	181.40	1.61	1.31	66.7	84.4	1.30	2.09	Mudstone
20-2, 40-43	181.90	1.63						Mudstone
21-1, 120-122	190.70	1.81	1.31	66.6	83.6	1.28	2.32	Mudstone
21-2, 13-15	191.13	1.74						Silty tuff
22-1, 148-150	200.48	1.83	1.43	50.0	71.1	1.46	2.67	Claystone
22-2, 63-65	201.13	1.80						Claystone
23-1, 105-107	209.55	1.73	1.41	55.0	75.3	1.40	2.42	Mudstone
24-1, 102-104	219.02	1.73		49.5	70.3	1.45	2.51	Silty tuff
24-1, 140-143	219.40	1.68						Silty tuff
24-2, 72-74	220.22	1.63		53.3	73.0	1.40	2.28	Mudstone
24-2, 141-144	220.91	1.68						Mudstone
25-1, 49-51	227.99	1.67						Mudstone
26-1, 49-51	237.49	1.62		50.1	71.1	1.45	2.35	Claystone
27-1, 8-10	246.58	1.74	1.49	45.9	67.4	1.51	2.63	Claystone
27-1, 130-132	247.8	1.76						Mudstone
27-2, 108-110	249.09	1.71						Claystone
28-1, 5-7	256.05	1.64	1.45	50.6	70.9	1.43	2.35	Claystone
28-2, 29-31	257.79	1.66						Mudstone
29-1, 21-22	265.71	1.99						Claystone
29-1, 89-91	266.39	2.06	1.50	20.4	40.4	2.03	4.18	Claystone
29-2, 33-34	267.33	2.00						Mudstone
29-3, 32-34	268.82	2.43						Mudstone
29-4, 52-55	270.52	1.93						Mudstone
30-1, 103-105	276.03	1.68		49.8	70.4	1.45	2.44	Claystone
31-2, 68-70	286.68	1.76	1.53	48.2	69.5	1.48	2.60	Claystone
32-1, 125-127	295.25	2.16	1.64	43.3	67.3	1.59	3.43	Mudstone
32-2, 38-40	295.88	1.98						Mudstone
32-3, 70-72	297.70	1.97						Mudstone
33-1, 70-72	304.20	1.95	1.52	44.5	66.4	1.53	2.98	Mudstone
33-2, 30-34	305.30	2.09						Mudstone
33-3, 110-112	307.60	2.14						Mudstone
34-1, 72-74	313.72	2.33	1.62	41.7	65.7	1.61	3.75	Mudstone
34-2, 116-119	315.66	2.15						Mudstone
34-3, 89-91	316.89	2.03						Mudstone
35-1, 109-112	323.59	2.02						Mudstone
35-2, 4-6	324.04	2.02	1.63	42.1	66.6	1.62	3.27	Mudstone
35-3, 86-88	326.36	2.19						Mudstone
36-1, 72-74	332.72	1.70						Mudstone
36-2, 82-84	334.32	1.68	1.40	59.2	79.6	1.38	2.32	Mudstone
36-3, 106-108	336.06	1.97						Claystone
36-4, 113-119	337.63	1.98						Mudstone
36-5, 73-74	338.73	2.39	1.90	29.6	53.7	1.86	4.45	Siltstone
37-1, 37-42	341.87	1.95						Mudstone
37-2, 20-22	343.20	2.17	1.73	36.5	60.6	1.70	3.69	Mudstone
37-4, 55-59	346.55	2.25						Siltstone
38-1, 100-103	352.00	2.09						Mudstone
38-2, 54-56	353.04	2.01		41.8	66.3	1.62	3.26	Mudstone
39-1, 72-75	361.22	2.10	1.60	43.9	68.0	1.59	3.34	Claystone

Table 2. (Continued).

Sample (interval in cm)	Depth (m)	Sound Velocity (vertical) (km/s)	GRAPE 2-min. Wet-Bulk Density (g/cm <sup>3</sup> )	Wet Water Content (salt corrected) (%)	Porosity <sup>a</sup> (%)	Wet Bulk <sup>b</sup> Density (g/cm <sup>3</sup> )	Acoustic Impedance (g/cm <sup>2</sup> s × 10 <sup>5</sup> )	Rock Type
39-2, 30-33	362.30	2.12						Claystone
39-4, 54-56	365.54	1.91						Mudstone
40-1, 72-74	370.72	1.90						Mudstone
40-2, 98-100	372.48	1.93	1.49	43.9	65.4	1.53	2.95	Mudstone
40-4, 52-55	375.02	1.90						Siltstone
41-2, 81-83	381.81	2.19						Mudstone
42-1, 105-108	390.05	2.22						Mudstone
42-2, 52-55	391.02	2.26	1.67	38.4	62.7	1.67	3.77	Mudstone
43-3, 30-32	401.80	2.26	1.68	39.6	64.2	1.66	3.75	Mudstone
44-1, 36-38	408.36	2.24	1.59	41.3	63.8	1.58	3.54	Mudstone
44-2, 23-26	409.73	2.22						Mudstone
45-1, 45-47	417.95	2.42	1.62	37.5	61.6	1.67	4.04	Mudstone
45-2, 106-108	420.06	2.45						Siltstone
45-4, 50-52	422.50	2.56V						Mudstone
45-4, 50-52	422.50	2.60H						Mudstone
46-1, 14-16	427.14	2.14	1.70	38.4	62.5	1.67	3.57	Claystone
47-1, 29-31	436.79	2.19	1.80	34.5	59.0	1.75	3.83	Claystone
47-3, 32-34	439.82	2.17						Siltstone
48-1, 21-23	446.21	2.29	1.93	27.3	50.2	1.88	4.31	Very fine sandstone
49-1, 77-80	456.27	5.52	2.83	1.9	5.1	2.83	15.6	Basalt
49-1, 98-100	456.48	6.73	2.87	0.9	2.6	2.87	19.3	Gabbro
49-1, 113-114	456.63	5.70	2.83	1.1	3.1	2.81	16.0	Metabasalt
49-1, 118-126	456.68	2.37						Sandstone
49-2, 41-42	457.41	4.41	2.37	6.3	15.2	2.46	10.8	Breccia
49-2, 105-107	458.05	4.07	2.41	5.6	13.8	2.51	10.2	Breccia
50-1, 42-44	465.42	5.96	2.83	0.7	1.9	2.82	16.8	Altered basalt
50-1, 107-109	466.07	5.70	2.60	3.1	8.1	2.66	15.2	Gabbro
51-1, 5-7	474.55	6.82	2.80	0.3	0.8	2.88	19.6	Gabbro
51-2, 11-13	476.11	4.70	2.77	5.0	12.7	2.59	12.2	Breccia
51-3, 19-25	477.69	4.77	2.46					Breccia
52-1, 12-126	485.20	4.36	2.67					Breccia
53-1, 33-34	493.83	4.84	2.58	4.6	11.3	2.53	12.2	Breccia
53-3, 24-26	496.74	6.57	3.01	0.3	1.0	3.04	20.0	Gabbro
53-5, 123-126	500.73	4.75	2.50	4.2	10.5	2.54	12.1	Breccia
54-1, 24-31	503.24	4.71	2.64					Breccia
55-3, 2-8	515.52	5.01	2.60					Breccia
56-1, 38-40	522.38	4.15	2.58	4.2	10.4	2.56	10.6	Breccia
57-1, 123-125	532.73	5.40	2.48	3.1	7.5	2.48	13.4	Breccia
57-2, 108-113	534.08	5.78	2.73					Breccia
63-1, 25-27	588.75	4.21	2.86	4.4	12.2	2.82	11.9	Serpentinite
63-1, 121-123	589.71	6.10	3.13	1.8	5.3	3.05	18.6	Serpentinite
63-1, 127-130	589.77	5.19	2.77					Serpentinite

<sup>a</sup> Porosity = salt corrected wet water content × wet-bulk density (gravimetric)/1.025.  
<sup>b</sup> Gravimetric method.

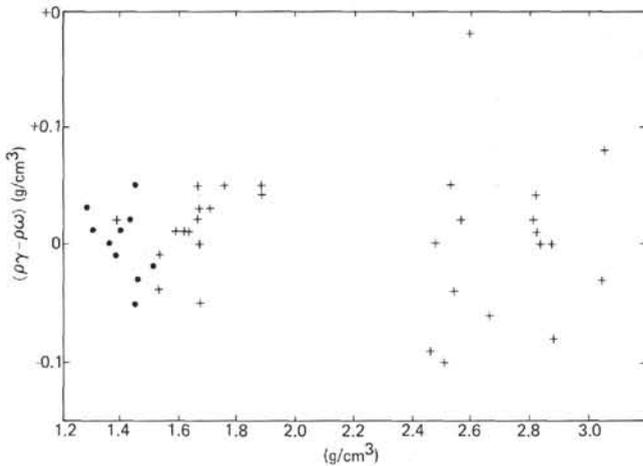


Figure 11. Comparison of GRAPE ( $Q_{GRAPE}$ ) (2-minute) and gravimetric ( $Q_b$ ) determinations of wet-bulk density. Solid circles are determinations of Cores 15 through 28; crosses are Cores 29 through 68.

(Horai, this volume). The results show a thermal conductivity monotonically increasing with depth through the entire sedimentary section. The rate of increase is 0.23 mcal/cm s °C/100 meters. There is no clear relationship between thermal conductivity and depth in the breccia sequence which extended from the depth of 450

meters downward. Details are given in Horai (this volume).

**GEOPHYSICS**

After drilling at Site 452, the easternmost of the Leg 60 drill sites, the *Glomar Challenger* traversed all the other SP1 through SP4 targets on the way to Site 453, the westernmost drill site. The reflection seismic profile along this track is described by Hussong (this volume). The *Challenger* then made one pass over the sediment pond target for SP-4F, and returned and dropped the beacon.

A generalized isopach map of the SP-4F sediment pond in which Hole 453 was drilled was prepared from the ship's tracks approaching and departing the site, supplemented by an L-DGO and two H.I.G. tracks in the area. The map (Fig. 15) shows the pond to be elongated north-northeast-south-southwest, 3-5 km wide, and at least 20 km long. It is flanked by irregular ridges rising only about 400 meters above the pond on the west and 200 meters on the east. Although the north-eastern end of the pond was not crossed by any tracks available to this report, a track along 18°N latitude does not intersect the pond. The sediment thickness in the pond also decreases markedly to the northeast.

The southwest end of the pond is also poorly defined. An east-west H.I.G. track along 17°48'N shows the

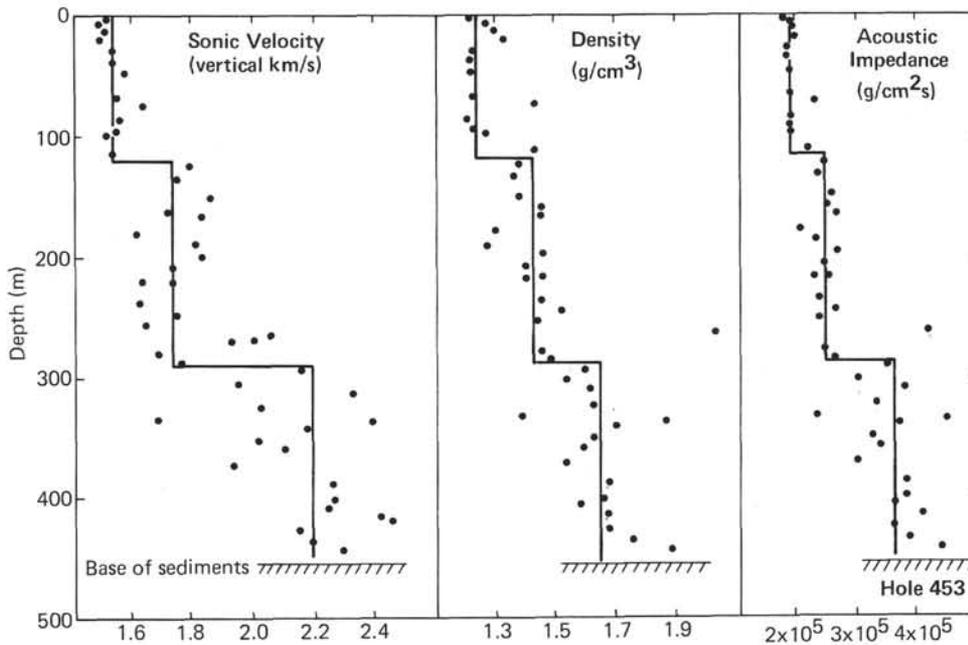


Figure 12. Shipboard density and sonic velocity measurements of Hole 453 sediment core samples used to calculate the acoustic impedance with depth.

Table 3. Summary of velocity-density parameters, Hole 453.

Interval	Sonic Velocity (km/s)	Wet-Bulk Density (g/cm <sup>3</sup> )	Acoustic Impedance (10 <sup>5</sup> g/cm <sup>2</sup> s)	Two-Way Travel Time <sup>a</sup> (millisecond)	Normal Reflection Coefficient at Base of Layer	Predominant Rock Types
Sea water near bottom	1.54 <sup>b</sup>	1.03	1.59	0	0.09	
0-120 m	1.54	1.24	1.91	156	0.13	Mud, clay
120-290 m	1.73	1.42	2.46	352	0.19	Mudstone, claystone
290-455 m	2.19	1.64	3.59	503	0.54	Mudstone, claystone
455- m	4.75	2.55	12.1			Igneous rock breccia

<sup>a</sup> From sea bed to base of layer.

<sup>b</sup> Interpolated from Matthews Tables, Area 42, for a depth of 4693 meters.

sediment pond at the same water depth, but this far south, it is disrupted by large, high-angle faults. This profile is not used in Figure 15. Another Hawaii Institute of Geophysics track, at about 17°46'N, did not intersect the pond.

A cross-section of the pond, through the drill site and along the ship's track, labeled A-B in Figure 15, is presented as Figure 16. This is a true-scale (no vertical exaggeration) depth section based on the reflection times obtained by the Challenger during the crossing of the pond on 0301-0346 28 March (Fig. 13) and velocities of drilled samples as measured aboard ship. The thickness of the sediment layer and depth to the top of the gabbro/breccia are well controlled by the profiling data and the drilling. The depth to basement is calculated from less distinct reflectors and should be considered only a good approximation.

Figure 17 also shows the reflection record from which the pond section is derived. It is interesting that in the adjacent pond to the east, sub-bottom reflectors in the sediment have similar character and depth to those observed at Site 453, suggesting that the sediment char-

acter and sedimentation process found in Hole 453 may extend to adjacent ponds.

When the gabbro/breccia material was first sampled at Site 453, the initial shipboard evaluation was that we had penetrated a talus slope. However, if we assume that the reflector which correlates with the top of the breccia is continuous across the pond, as is apparent on the reflection record, then the scale drawing (Fig. 16) of the Site 453 pond shows the relatively flat upper surface and large volume of the gabbro/breccia material in the pond, particularly when compared to the relative smallness of the ridges surrounding the ponds. It is difficult to consider the ridges as the source of the disturbed crystalline rock in the bottom of the pond when looking at the slopes and transport distances without benefit of vertical exaggeration. Furthermore, the presence of the 4.75-km/s layer throughout the pond, rather than only at its periphery, suggests that the rock fragments comprising it were fractured and deposited essentially *in situ*.

A possible source of the breccia rubble might be crustal faulting that could also be responsible for the

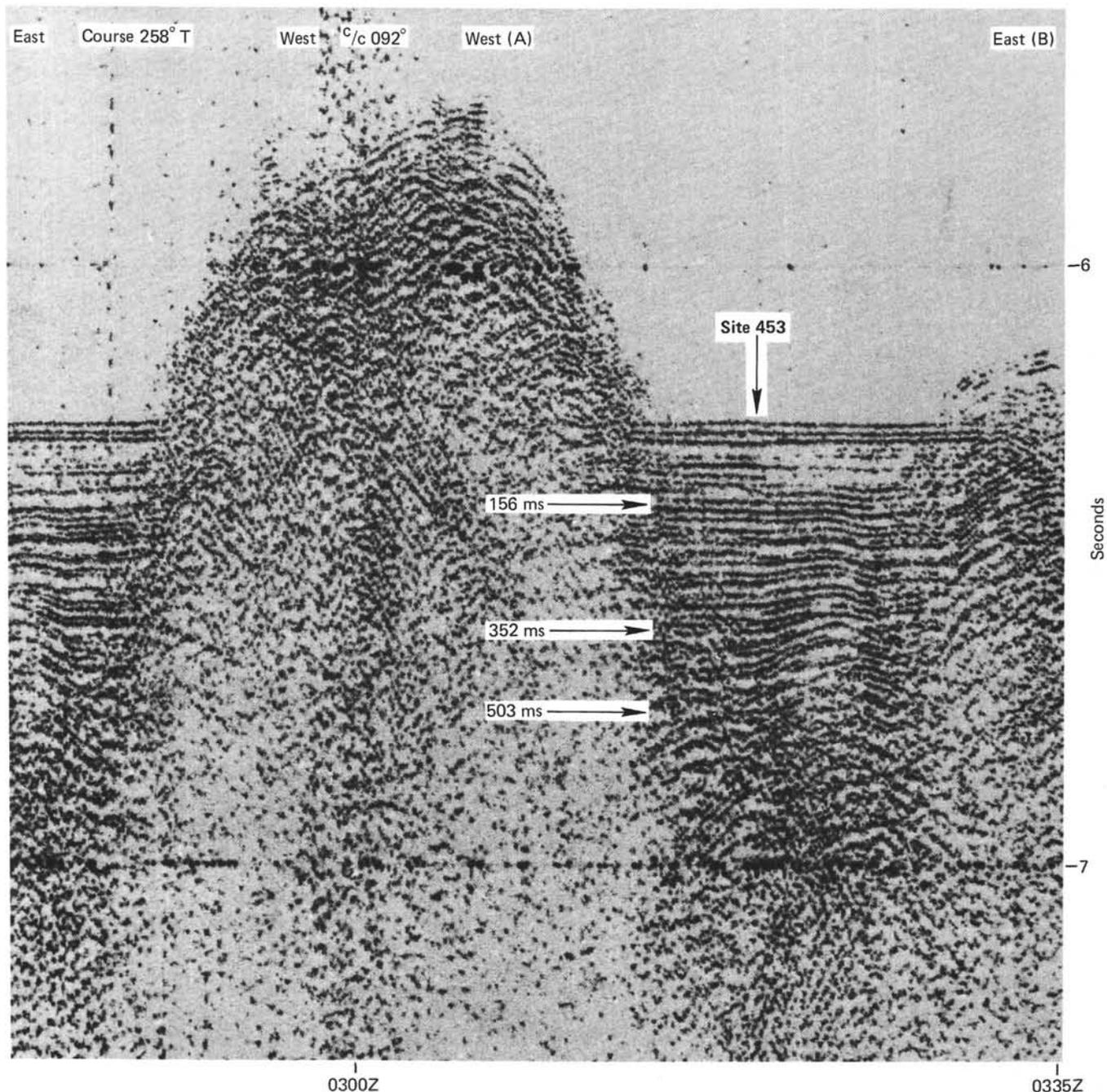


Figure 13. Low frequency (120-cu. in. airgun source) reflection record across the pond at Site 453. The sediment pond at the left is the western side of the same pond before the *Challenger* reversed its course and made the second crossing (west to east; labeled A to B). The reflectors labeled by their two-way seismic travel times beneath the sea floor correspond to the calculated major change in acoustic impedance observed in the core samples (Fig. 12).

elongate north-northeast-south-southwest orientation of the Site 453 sediment pond. This possibility is given more likelihood by the post-cruise determinations that the polymict breccia and the underlying meta-igneous rocks are apparently derived from the West Mariana Ridge. The initial rifting during the onset of spreading of the Mariana Trough may have produced the deep graben-shaped depression at Site 453, and provided the vertical displacement needed to get the arc-derived rocks into their present location.

## HEAT FLOW

At Site 453, a terrestrial heat flow experiment was conducted for the first time using the new Tokyo T-probe developed by Yokota et al. (1980). The downhole temperature measured at a sub-bottom depth of 75.5 meters was 11.9°C. This value and the bottom water temperature (1.7–2.2°C) gave the geothermal gradient value of 12.8–13.5°C/100 meters. The *in situ* thermal conductivity of the sediments was estimated as 1.82

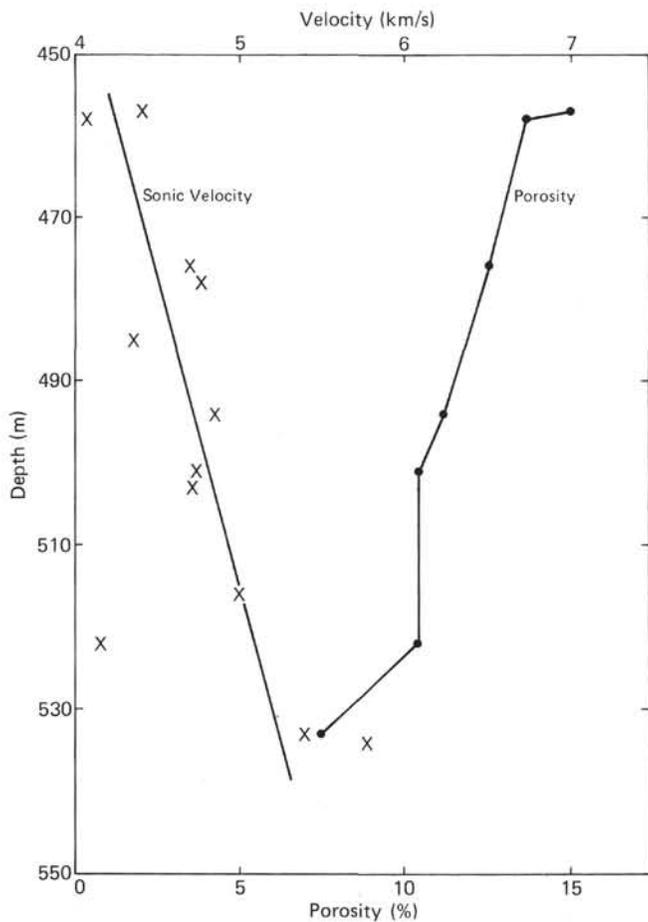


Figure 14. Variation of sonic velocity and porosity of polymict breccia and meta-igneous rock samples versus depth below sea floor from which the cores came in Hole 453. Using the values, an average seismic compressional velocity of 4.75 km/s was assumed for these rocks.

mcal/cm s °C, from measurements on 28 samples recovered (Horai, this volume) between the sea bottom and a depth of 88.3 meters. On the basis of these values of the geothermal gradient and thermal conductivity, the heat flow for the depth interval 0–75.5 meters was estimated at  $2.33\text{--}2.46 \times 10^{-6}$  cal/cm<sup>2</sup> s (HFU), the mean being 2.40 HFU.

The heat flow value of 2.40 HFU obtained here, though estimated from only a single temperature measurement, may be considered reliable. This value is significantly higher than the average oceanic heat flow but is reasonable for young sea floor such as the Mariana Trough (Watanabe et al., 1977). Heat flow measurements taken previously in this area by a conventional oceanic heat flow probe are below 1 HFU (Anderson, 1975). In view of the possibility that the heat transfer in the young crust is largely controlled by hydrothermal circulation, local high variability is expected. An additional series of conventional heat flow stations obtained after Leg 60 did find this expected high variability (Hobart et al., 1979). The igneous rocks sampled from the bottom of Site 453 exhibited both petrologic and paleomagnetic evidence of hydrothermal alteration (see section on petrology and paleomagnetism, this chapter).

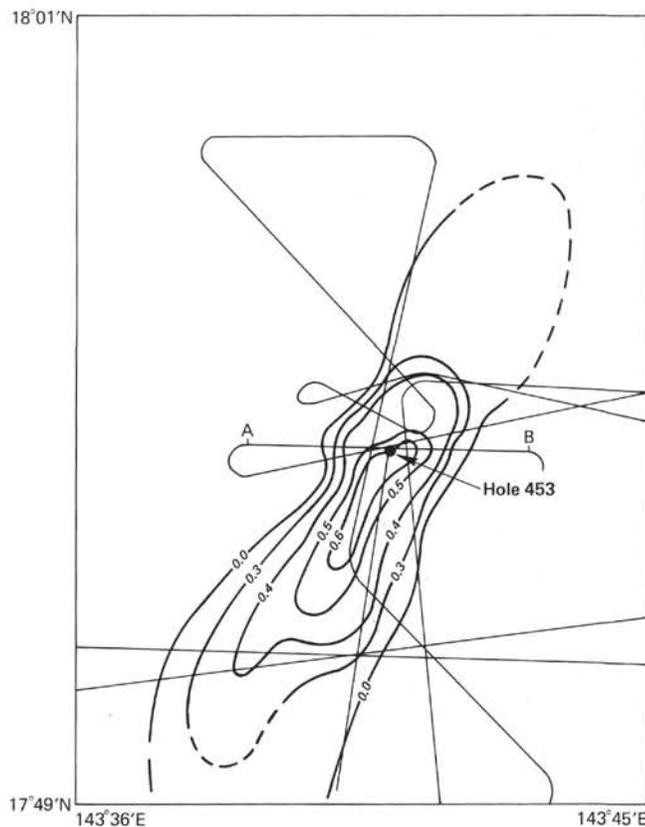


Figure 15. Sediment isopach in seconds of two-way travel time near Site 453. The reflection profile shown as Figure 13 is located along the A-B track line segment. Data from tracks of the *Glomar Challenger*, *Kana Keoki*, and *Conrad*.

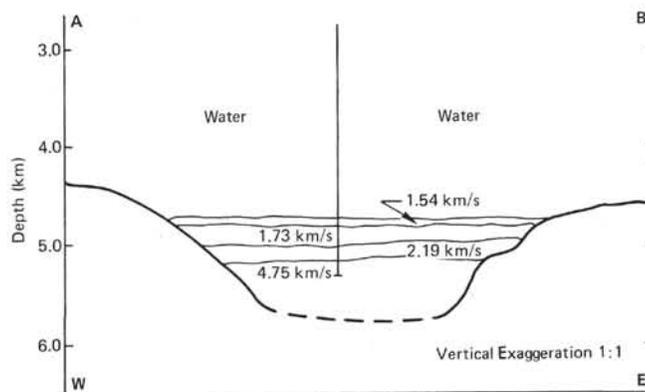


Figure 16. Depth section of the sediment pond at Site 453 showing the position of the drill string at the deepest core. The seismic velocities in each of the layers is averaged from shipboard measurements of core samples.

Details of the heat flow measurements are given in Uyeda and Horai (this volume).

### SUMMARY AND CONCLUSIONS

Any evaluation of the results of the Site 453 drilling in relation to the objectives set forth in the beginning of this chapter must be tempered by the recognition that we can conclude little about the origin of the crust beneath this site. Although we penetrated nearly 150

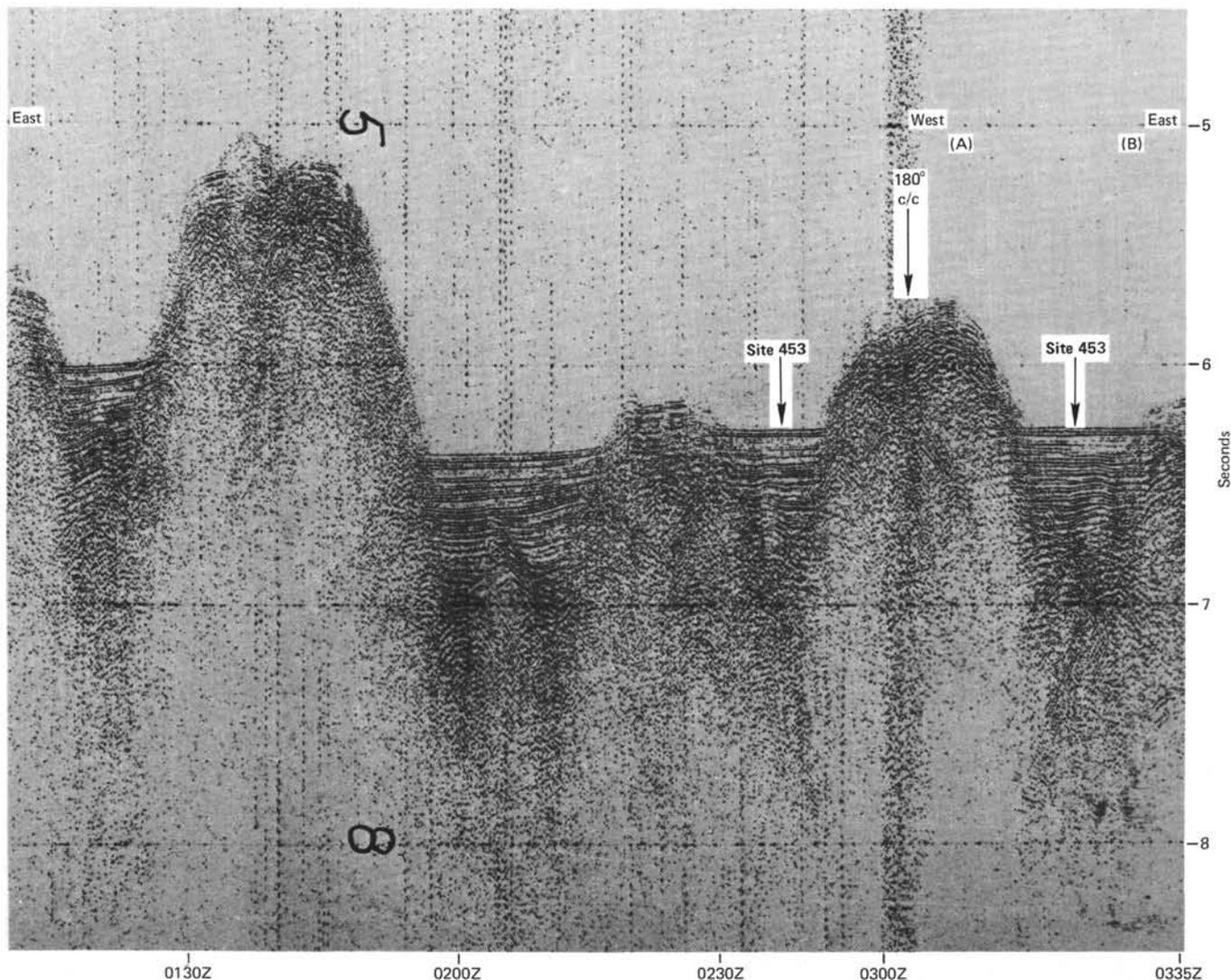


Figure 17. Two crossings of Site 453 and the two sediment ponds east of the drill site. Note that the ponds are at very different depths, demonstrating that there is no sediment transport path between adjacent ponds because of intervening bathymetric relief. Nevertheless, the acoustic character of the reflectors (depth below sea floor and relative amplitude) is highly similar in the ponds, suggesting they both underwent a similar sedimentation history.

meters of igneous and meta-igneous rocks beneath the 455.5 meters of sediment in Hole 453, an evaluation of the seismic reflection profiles over the site indicates that acoustic basement, though poorly defined, is much deeper. Correlation of seismic reflectors with depth, at which major changes of acoustic impedance were calculated from shipboard measurement of the physical properties of the cores, was good in the sediment. Although the top of the breccias produced a less distinct reflection than would be expected (at  $\sim 0.5$ -s reflection time), strong reflectors are observed to sub-bottom depth of over 0.7 s. This indicates that we were still more than 300 meters from acoustic basement when the drill bit apparently failed.

The rocks that were recovered are all derived from an island arc, and we assume that they are tectonically displaced from the West Mariana arc during initial rifting of the Mariana Trough. This would suggest that the crust beneath Site 453 may not be part of the Trough.

However, the rocks have been exposed to a high degree of hydrothermal metamorphism that produces alteration similar to that encountered on other Mariana Trough sites (e.g., Site 454). Extremely high and variable heat flow ( $\sim 0$ - $> 20$  HFU; Hobart et al., 1979) was also measured in the Site 453 sediment pond. These indications of pronounced hydrothermal circulation suggest that the crust beneath Site 453, perhaps at the depth of the acoustic basement, may be part of the Mariana Trough.

Regardless of the nature of the underlying crust at Site 453, we also are at a loss to explain how the large volume of apparently flat-lying breccias were emplaced in the pond. The surrounding ridges seem to be distant and small sources for the voluminous breccias. The breccias are also of two distinct types (86 m of gabbroic breccia with large clasts overlying 29 m of very different volcanic breccia with much smaller clasts), suggesting that two different events and/or sources produced the

breccias at the time of initial back-arc basin formation, after which sedimentation began about 5 m.y. ago. None of the explanations for the breccias suggested in this chapter (talus pile, avalanche deposits, drilling in a fault plane) adequately explains their character.

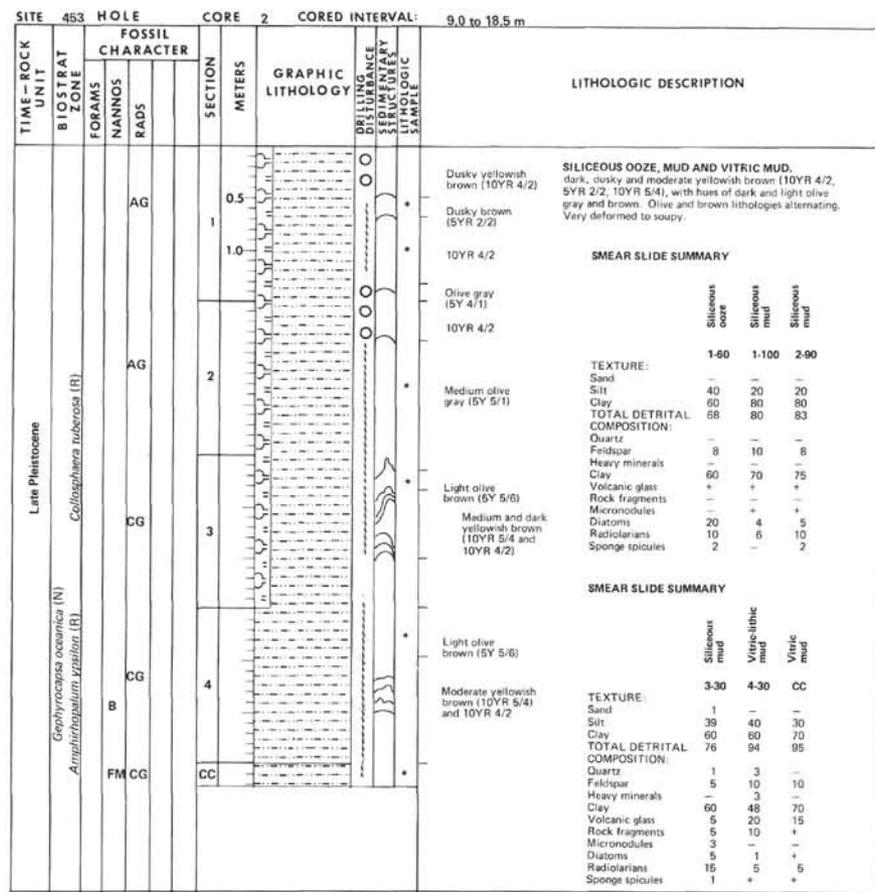
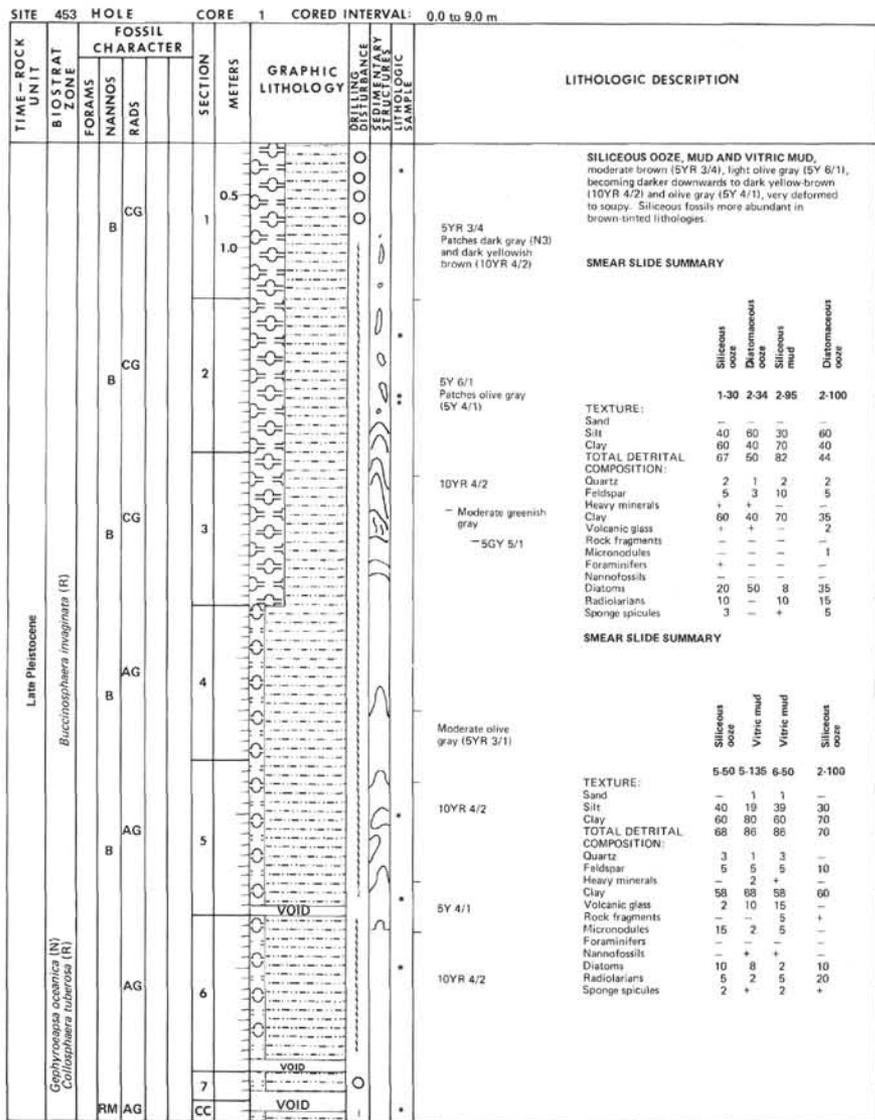
The sediments at Site 453 are of predominant island-arc volcanic origin. By the early Pliocene, volcanism had ceased on the West Mariana Ridge (Site 451; Kroenke, Scott et al., 1980) suggesting that the present Mariana arc volcanoes were the source of the sediments. At first the sedimentation rate was very high ( $\sim 34$  kg/cm<sup>2</sup>/m.y.) at Site 453, but this rate uniformly decreased with time as the trough opened and the arc volcanoes moved away to the east. The progressive filling of the bathymetric lows in the western Mariana Trough would reduce the ratio of the area of the turbidite source to the area of deposition, thereby effectively slowing the sedimentation rate. However, this effect, because of the rugged terrain near Site 453, is minor compared to the dramatic rate of slowing of deposition observed at the site. Only a slight increase in the sedimentation rate in the late Pliocene-early Pleistocene (1.8-0.9 m.y. ago) deviates from this uniform decrease in sedimentation, and may therefore represent an episode of increased volcanism.

On the basis of the paleontologic and paleomagnetic age determination of the basal sediments at Site 453, the half-rate of spreading of the Mariana Trough must be less than 2.4 cm/y. The apparent uniform decrease in

sedimentation rate suggests that this spreading (and then the removal of the volcanic source from Site 453) must have been similarly uniform.

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TIME-ROCK UNIT	SITE 453	HOLE	CORE 3	CORED INTERVAL: 18.5 to 28.0 m	FOSSIL CHARACTER	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
Early Pleistocene <i>Gephyrocapsa caribbeensis</i> (N) <i>Amphirophalum ypsilon</i> (R)	453		3	18.5 to 28.0 m	AG	1	0.5		*	10YR 4/2	LITHIC-CRYSTAL, LITHIC AND VITRIC MUD, moderate olive green (5Y 5/1) and dark yellowish brown (10YR 4/2) moderately deformed. Core-Catcher: As above.
						1.0	5Y 5/1				
						2					
CG	453		3	18.5 to 28.0 m	CG	2			*	5Y 5/1	LITHIC-CRYSTAL, LITHIC AND VITRIC MUD, moderate olive green (5Y 5/1) and dark yellowish brown (10YR 4/2) moderately deformed. Core-Catcher: As above.
						3					
						CC					
RP	453		3	18.5 to 28.0 m	RP	3			*	5Y 5/1	LITHIC-CRYSTAL, LITHIC AND VITRIC MUD, moderate olive green (5Y 5/1) and dark yellowish brown (10YR 4/2) moderately deformed. Core-Catcher: As above.
						4					
						5					

## SMEAR SLIDE SUMMARY

TEXTURE:	Lithic crystal mud	Lithic mud	Crystal-vitric mud	Vitric mud	Mud
Sand	1-70	4-140	2-60	2-90	CC
Silt	40	28	36	30	20
Clay	60	70	65	60	79
TOTAL DETRITAL COMPOSITION:	93	95	97	100	95
Quartz	5	2	2	3	6
Feldspar	20	10	15	10	6
Heavy minerals	5	70	85	57	78
Volcanic glass	10	13	15	10	5
Rock fragments	10	13	15	20	6
Micronodules	-	-	-	-	2
Foraminifers	-	-	-	-	1
Nannofossils	-	-	-	-	1
Diatoms	-	-	-	-	1
Radiolarians	-	-	-	-	1
Sponge spicules	-	-	-	-	1
Fish remains	-	-	-	-	1

TIME-ROCK UNIT	SITE 453	HOLE	CORE 4	CORED INTERVAL: 28.0 to 37.5 m	FOSSIL CHARACTER	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
Early Pleistocene <i>Gephyrocapsa caribbeensis</i> (N)	453		4	28.0 to 37.5 m	RM	1	0.5		*	5Y 5/6	ZEOLITIC-CLAY AND MUD, light olive brown (5Y 5/6) and moderate olive brown (5Y 4/4) with shades of olive gray (5Y 3/2) and moderate brown (5Y 4/4). Moderately disturbed, but with traces of layering. Colors and lithology independent. Core-Catcher: As above.
						1.0	5Y 4/4				
						2					
CG	453		4	28.0 to 37.5 m	RM	2			*	5Y 5/6	ZEOLITIC-CLAY AND MUD, light olive brown (5Y 5/6) and moderate olive brown (5Y 4/4) with shades of olive gray (5Y 3/2) and moderate brown (5Y 4/4). Moderately disturbed, but with traces of layering. Colors and lithology independent. Core-Catcher: As above.
						3					
						4					
RP	453		4	28.0 to 37.5 m	RM	3			*	5Y 5/6	ZEOLITIC-CLAY AND MUD, light olive brown (5Y 5/6) and moderate olive brown (5Y 4/4) with shades of olive gray (5Y 3/2) and moderate brown (5Y 4/4). Moderately disturbed, but with traces of layering. Colors and lithology independent. Core-Catcher: As above.
						4					
						5					
B	453		4	28.0 to 37.5 m	B	4			*	5Y 4/4	ZEOLITIC-CLAY AND MUD, light olive brown (5Y 5/6) and moderate olive brown (5Y 4/4) with shades of olive gray (5Y 3/2) and moderate brown (5Y 4/4). Moderately disturbed, but with traces of layering. Colors and lithology independent. Core-Catcher: As above.
						5					
						6					
B	453		4	28.0 to 37.5 m	B	5			*	5Y 3/2	ZEOLITIC-CLAY AND MUD, light olive brown (5Y 5/6) and moderate olive brown (5Y 4/4) with shades of olive gray (5Y 3/2) and moderate brown (5Y 4/4). Moderately disturbed, but with traces of layering. Colors and lithology independent. Core-Catcher: As above.
						6					
						7					
RP	453		4	28.0 to 37.5 m	B	6			*	5Y 4/4	ZEOLITIC-CLAY AND MUD, light olive brown (5Y 5/6) and moderate olive brown (5Y 4/4) with shades of olive gray (5Y 3/2) and moderate brown (5Y 4/4). Moderately disturbed, but with traces of layering. Colors and lithology independent. Core-Catcher: As above.
						7					
						CC					
VOID	453		4	28.0 to 37.5 m	B	7			*	5Y 4/4	ZEOLITIC-CLAY AND MUD, light olive brown (5Y 5/6) and moderate olive brown (5Y 4/4) with shades of olive gray (5Y 3/2) and moderate brown (5Y 4/4). Moderately disturbed, but with traces of layering. Colors and lithology independent. Core-Catcher: As above.
						8					
						9					

## SMEAR SLIDE SUMMARY

TEXTURE:	Zeolitic clay	Pelagic clay	Mud	Mud	Zeolitic clay	Pelagic clay
Sand	1-65	1-65	3-65	4-65	5-65	6-65
Silt	5	8	15	5	5	5
Clay	95	92	100	85	95	100
TOTAL DETRITAL COMPOSITION:	97	100	100	96	95	100
Feldspar	7	5	10	5	5	3
Clay	90	92	75	85	90	97
Volcanic glass	+	3	15	3	+	+
Rock fragments	-	-	5	-	-	-
Micronodules	-	+	-	1	+	+
Zeolite	-	+	-	1	5	+
Radiolarians	-	-	-	-	-	-
Sponge spicules	-	+	-	-	-	-

SITE 453		HOLE		CORE 5		CORED INTERVAL: 37.5 to 47.0 m		
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
		FORAMS	NANNOS					
Early Pleistocene	<i>Gephyrocapsa caribbeanica</i> (N)	B						<p>MUD, moderate olive brown (5Y 4/4), very deformed with only traces of layering.</p> <p>5Y 4/4</p> <p>Olive gray (5Y 3/2)</p> <p>5Y 4/4</p>
		RP	B					

**SMEAR SLIDE SUMMARY**

	Mud	Mud
	1-75	2-50
TEXTURE:		
Sand	-	-
Silt	10	5
Clay	80	95
TOTAL DETRITAL	92	98
COMPOSITION:		
Quartz	-	?
Feldspar	5	10
Clay	87	87
Volcanic glass	+	+
Rock fragments	-	1
Micro nodules	3	-
Zeolite	5	2

SITE 453		HOLE		CORE 7		CORED INTERVAL: 56.5 to 66.0 m		
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
		FORAMS	NANNOS					
		B						<p>5GY 3/2</p> <p>CLAY, grayish olive green (5GY 3/2), moderately deformed (7).</p>

**SMEAR SLIDE SUMMARY**

	Pelagic clay
	CC
TEXTURE:	
Sand	1
Silt	9
Clay	90
TOTAL DETRITAL	97
COMPOSITION:	
Feldspar	3
Heavy minerals	+
Clay	90
Volcanic glass	2
Rock fragments	2
Micro nodules	3
Fish remains	+

SITE 453		HOLE		CORE 6		CORED INTERVAL: 47.0 to 56.5 m		
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
		FORAMS	NANNOS					
Early Pleistocene	<i>Gephyrocapsa caribbeanica</i> (N)	B						<p>MUD AND LITHIC CRYSTAL MUD, grayish olive (10Y 4/2). Deformation indeterminate ? moderate. Core-Catcher: As above.</p> <p>10YR 4/2</p>
		RP	B					

**SMEAR SLIDE SUMMARY**

	Lithic-crystal mud	Mud
	1-7	1-100
TEXTURE:		
Sand	10	-
Silt	40	10
Clay	50	90
TOTAL DETRITAL	80	85
COMPOSITION:		
Feldspar	15	5
Heavy minerals	+	-
Clay	50	80
Volcanic glass	+	+
Rock fragments	15	-
Micro nodules	15	10
Zeolite	5	5
Foraminifers	5	-
Radiolarians	?	-

SITE 453		HOLE		CORE 8		CORED INTERVAL: 86.0 to 75.5 m	
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION	METERS	GRAPHIC LITHOLOGY	LITHOLOGIC DESCRIPTION
		FORAMS	NANNOS				
Early Pleistocene	<i>Gephyrocapsa caribbeanica</i> (N)	B		1	0.5 1.0		Greenish gray (10GY 5/2)  5GY 2/1  CLAY, CRYSTAL MUD, AND VITRIC MUD, greenish black (5GY 2/1), grayish olive green (5GY 3/2), moderately olive gray (5Y 4/2), dusky yellow green (10GY 3/2) and olive black (5Y 2/1), moderately deformed. No internal layering in each color. Core-Catcher: As above.
				2			5GY 3/2  SMEAR SLIDE SUMMARY  TEXTURE: Sand 2 - - - - Silt 8 10 40 7 45 Clay 90 90 80 93 60 95 TOTAL DETRITAL 90 97 100 98 100 98 COMPOSITION: Quartz - - - - - Feldspar 5 5 10 5 10 3 Heavy minerals - - - - - Clay 85 90 60 91 50 90 Volcanic glass + 2 30 2 40 5 Rock fragments - - - - - Micronodules 7 3 1 2 + - Zeolite 3 - - - -
				3			5Y 4/2  SMEAR SLIDE SUMMARY  Crystal mud Vitric mud Vitric mud 4-117 4-135 CC
				4			10GY 3/2  5GY 3/2  TEXTURE: Sand 5 2 - - - Silt 30 15 20 - - Clay 65 83 80 - - TOTAL DETRITAL 100 98 100 - - COMPOSITION: Quartz - - - - - Feldspar 15 5 8 - - Heavy minerals 1 1 + - - Clay 85 84 72 - - Volcanic glass 10 8 15 - - Rock fragments 10 - 5 - - Micronodules - 2 - - - Zeolite - - - - -
		RP B		CC			5Y 2/1 Olive gray (5Y 4/1)

SITE 453		HOLE		CORE 9		CORED INTERVAL: 75.5 to 86.0 m	
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION	METERS	GRAPHIC LITHOLOGY	LITHOLOGIC DESCRIPTION
		FORAMS	NANNOS				
Early Pleistocene	<i>Emiliana annula</i> (N)?	RP		1	0.5 1.0		5Y 3/2 5GY 5/2 5Y 3/2  CLAY, LITHIC MUD, VITRIC MUD, olive gray (5Y 3/2) and dusky yellow green (5GY 5/2), moderately deformed, color layering.
				2			SMEAR SLIDE SUMMARY  TEXTURE: Sand - - - - - Silt 5 20 - - - Clay 95 80 90 - - TOTAL DETRITAL 100 95 100 - - COMPOSITION: Feldspar 5 5 10 - - Clay 95 80 80 - - Volcanic glass + + 10 - - Rock fragments - + - - - Micronodules + + - - - Zeolite 1 5 - - -

SITE 453		HOLE		CORE 10		CORED INTERVAL: 85.0 to 94.5 m	
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION	METERS	GRAPHIC LITHOLOGY	LITHOLOGIC DESCRIPTION
		FORAMS	NANNOS				
Early Pleistocene	<i>Emiliana annula</i> (N)	B		1	0.5 1.0		Section 1, 0-100 cm: Drilling breccia of green and brown clay fragments. CLAY, VITRIC CLAY, olive gray (5Y 3/2), grayish olive green (5GY 3/2) with SILTY VITRIC ASH (3-30 to 40 cm), dusky olive green (5GY 5/2) in color, moderately deformed with only color layering. Core-Catcher: As above.
				2			VOID  5Y 3/2  SMEAR SLIDE SUMMARY  TEXTURE: Sand - - - - - Silt 8 20 - 5 2 90 8 Clay 92 80 95 96 10 92 TOTAL DETRITAL 100 95 100 100 100 100 COMPOSITION: Feldspar - 5 5 5 2 5 3 Heavy minerals - - - - - Clay 90 70 93 98 10 92 Volcanic glass 5 20 2 + 84 5 Micronodules + + 1 - - - Zeolite - - - - - Diatoms - 5 - - - - Radiolaria - + - - - -
				3			5GY 5/2
				CC			5GY 3/2

SITE 453		HOLE		CORE 11		CORED INTERVAL: 94.5 to 104.0 m	
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION	METERS	GRAPHIC LITHOLOGY	LITHOLOGIC DESCRIPTION
		FORAMS	NANNOS				
Early Pleistocene(?)	B	B	B	1	0.5	[Lithology: Vitric mudstone]	VOID 5Y 4/1
				1.0	VITRIC MUDSTONE, CRYSTAL MUDSTONE, CLAYSTONE, olive gray (5Y 4/1), grayish olive green (5GY 3/2), and grayish green (10GY 5/2). Semi-lithified core shattered by drilling (crumbles).		
				2	1.0	[Lithology: 5GY 3/2]	SMEAR SLIDE SUMMARY
				2	2		5GY 3/2
				3	1.0	[Lithology: 10GY 5/2]	SMEAR SLIDE SUMMARY
				3	3		10GY 5/2
				4	1.0	[Lithology: 5GY 3/2]	SMEAR SLIDE SUMMARY
4	4	5GY 3/2					
5	1.0	[Lithology: 5GY 3/2]	SMEAR SLIDE SUMMARY				
5	5		5GY 3/2				
6	1.0	[Lithology: 5GY 3/2]	SMEAR SLIDE SUMMARY				
6	6		5GY 3/2				
7	1.0	[Lithology: 5GY 3/2]	SMEAR SLIDE SUMMARY				
7	7		5GY 3/2				
CC				7	1.0	[Lithology: 5GY 3/2]	5GY 3/2

SITE 453		HOLE		CORE 12		CORED INTERVAL: 104.0 to 113.5 m	
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION	METERS	GRAPHIC LITHOLOGY	LITHOLOGIC DESCRIPTION
		FORAMS	NANNOS				
Early Pleistocene(?)	B	B	B	1	0.5	[Lithology: Crystal mud]	1.0 cm to 6-95 cm: CRYSTAL MUD, a grayish olive green (5GY 3/2). The core is soupy except Section 6, which is brecciated with fragments in a muddy matrix. Some radiolarian ooze which occurs is downhole contamination.
				1.0	SMEAR SLIDE SUMMARY		
				2	1.0	[Lithology: 5GY 3/2]	SMEAR SLIDE SUMMARY
				2	2		5GY 3/2
				3	1.0	[Lithology: 5GY 3/2]	SMEAR SLIDE SUMMARY
				3	3		5GY 3/2
				4	1.0	[Lithology: 5GY 3/2]	SMEAR SLIDE SUMMARY
4	4	5GY 3/2					
5	1.0	[Lithology: 5GY 3/2]	SMEAR SLIDE SUMMARY				
5	5		5GY 3/2				
6	1.0	[Lithology: 5GY 3/2]	SMEAR SLIDE SUMMARY				
6	6		5GY 3/2				
7	1.0	[Lithology: 5GY 3/2]	SMEAR SLIDE SUMMARY				
7	7		5GY 3/2				
CC				7	1.0	VOID	

SITE 453 HOLE CORE 13 CORED INTERVAL: 113.5 to 123.0 m		FOSSIL CHARACTER		SECTION METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE STRUCTURE LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION																																																																		
TIME-ROCK UNIT	BIOSTRAT ZONE	FORAMS	NANNOS RADS																																																																						
Late Pliocene	<i>Discoaster pentaradiatus</i> (N)			0.5 1.0			<p>CLAYSTONE, grayish olive green (5GY 3/2) and grayish green (10GY 5/2), with olive black (5Y 2/1) bands of SANDY VITRIC ASH AND MICRONODULAR SAND, olive black (5Y 2/1), semi-lithified and crumbly.</p> <p>5GY 3/2</p> <p>10GY 5/2 5Y 2/1 5GY 3/2 5Y 2/1 5GY 3/2 5GY 3/2</p> <p><b>SMEAR SLIDE SUMMARY</b></p> <table border="1"> <tr> <td></td> <td>Vitric mud</td> <td>Sandy vitric ash</td> <td>Micronodular sand</td> <td>Pelagic clay</td> <td>CC</td> </tr> <tr> <td>TEXTURE:</td> <td>1-77</td> <td>1-87</td> <td>1-120</td> <td></td> <td></td> </tr> <tr> <td>Sand</td> <td>50</td> <td>70</td> <td></td> <td></td> <td></td> </tr> <tr> <td>Silt</td> <td>35</td> <td>45</td> <td>20</td> <td>5</td> <td></td> </tr> <tr> <td>Clay</td> <td>65</td> <td>10</td> <td>10</td> <td>95</td> <td></td> </tr> <tr> <td>TOTAL DETRITAL COMPOSITION:</td> <td>100</td> <td>80</td> <td>25</td> <td>99</td> <td></td> </tr> <tr> <td>Feldspar</td> <td>15</td> <td>15</td> <td>10</td> <td>5</td> <td></td> </tr> <tr> <td>Heavy minerals</td> <td></td> <td></td> <td></td> <td>1</td> <td></td> </tr> <tr> <td>Clay</td> <td>65</td> <td>25</td> <td>10</td> <td>90</td> <td></td> </tr> <tr> <td>Volcanic glass</td> <td>20</td> <td>30</td> <td>5</td> <td>2</td> <td></td> </tr> <tr> <td>Micronodules</td> <td></td> <td>20</td> <td>75</td> <td>1</td> <td></td> </tr> </table>		Vitric mud	Sandy vitric ash	Micronodular sand	Pelagic clay	CC	TEXTURE:	1-77	1-87	1-120			Sand	50	70				Silt	35	45	20	5		Clay	65	10	10	95		TOTAL DETRITAL COMPOSITION:	100	80	25	99		Feldspar	15	15	10	5		Heavy minerals				1		Clay	65	25	10	90		Volcanic glass	20	30	5	2		Micronodules		20	75	1	
	Vitric mud	Sandy vitric ash	Micronodular sand	Pelagic clay	CC																																																																				
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Clay	65	25	10	90																																																																					
Volcanic glass	20	30	5	2																																																																					
Micronodules		20	75	1																																																																					

SITE 453 HOLE CORE 14 CORED INTERVAL: 123.0 to 132.5 m		FOSSIL CHARACTER		SECTION METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE STRUCTURE LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION																																																																																																																																																																
TIME-ROCK UNIT	BIOSTRAT ZONE	FORAMS	NANNOS RADS																																																																																																																																																																				
Late Pliocene	<i>Discoaster surculus</i> (N)			0.5 1.0			<p>MUDSTONE AND CLAYSTONE, greenish gray (5GY 2/1) and dark greenish gray (5GY 4/1). The core is semi-lithified and fractured. Unfractured fragments are in the drilling paste. Burrows and mottling also occur.</p> <p>Core-Catcher: As above.</p> <p>5GY 2/1</p> <p>5GY 4/1</p> <p>VOID</p> <p>5GY 2/1</p> <p>5GY 4/1</p> <p><b>SMEAR SLIDE SUMMARY</b></p> <table border="1"> <tr> <td></td> <td>Mud-stone</td> <td>Mud-stone</td> <td>Mud-stone</td> <td>Mud-stone</td> </tr> <tr> <td>TEXTURE:</td> <td>1-20</td> <td>1-24</td> <td>1-65</td> <td>1-121</td> </tr> <tr> <td>Sand</td> <td>2</td> <td>1</td> <td>+</td> <td>0</td> </tr> <tr> <td>Silt</td> <td>8</td> <td>20</td> <td>10</td> <td>10</td> </tr> <tr> <td>Clay</td> <td>90</td> <td>80</td> <td>90</td> <td>90</td> </tr> <tr> <td>TOTAL DETRITAL COMPOSITION:</td> <td>90</td> <td>92</td> <td>100</td> <td>98</td> </tr> <tr> <td>Quartz</td> <td>+</td> <td></td> <td></td> <td></td> </tr> <tr> <td>Feldspar</td> <td>8</td> <td>5</td> <td>5</td> <td>5</td> </tr> <tr> <td>Heavy minerals</td> <td>+</td> <td>+</td> <td>+</td> <td>+</td> </tr> <tr> <td>Clay</td> <td>80</td> <td>80</td> <td>90</td> <td>89</td> </tr> <tr> <td>Volcanic glass</td> <td>2</td> <td>7</td> <td>5</td> <td>3</td> </tr> <tr> <td>Rock fragments</td> <td>+</td> <td></td> <td></td> <td></td> </tr> <tr> <td>Micronodules</td> <td>+</td> <td>10</td> <td>+</td> <td>1</td> </tr> <tr> <td>Zeolite</td> <td>+</td> <td>+</td> <td></td> <td></td> </tr> <tr> <td>Nannofossils</td> <td>+</td> <td>+</td> <td></td> <td></td> </tr> <tr> <td>Sponge spicules</td> <td>+</td> <td></td> <td></td> <td></td> </tr> </table> <p><b>SMEAR SLIDE SUMMARY</b></p> <table border="1"> <tr> <td></td> <td>Clay-stone</td> <td>Mud-stone</td> <td>Mud-stone</td> <td>CC</td> </tr> <tr> <td>TEXTURE:</td> <td>2-10</td> <td>2-45</td> <td></td> <td></td> </tr> <tr> <td>Sand</td> <td></td> <td>10</td> <td>15</td> <td></td> </tr> <tr> <td>Silt</td> <td>5</td> <td>90</td> <td>85</td> <td></td> </tr> <tr> <td>Clay</td> <td>95</td> <td>90</td> <td>85</td> <td></td> </tr> <tr> <td>TOTAL DETRITAL COMPOSITION:</td> <td>99</td> <td>100</td> <td>90</td> <td></td> </tr> <tr> <td>Quartz</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>Feldspar</td> <td>3</td> <td>10</td> <td>5</td> <td></td> </tr> <tr> <td>Heavy minerals</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>Clay</td> <td>95</td> <td>90</td> <td>85</td> <td></td> </tr> <tr> <td>Volcanic glass</td> <td>1</td> <td>+</td> <td></td> <td></td> </tr> <tr> <td>Rock fragments</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>Micronodules</td> <td>1</td> <td>+</td> <td>10</td> <td></td> </tr> <tr> <td>Zeolite</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>Nannofossils</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>Sponge spicules</td> <td></td> <td></td> <td></td> <td></td> </tr> </table>		Mud-stone	Mud-stone	Mud-stone	Mud-stone	TEXTURE:	1-20	1-24	1-65	1-121	Sand	2	1	+	0	Silt	8	20	10	10	Clay	90	80	90	90	TOTAL DETRITAL COMPOSITION:	90	92	100	98	Quartz	+				Feldspar	8	5	5	5	Heavy minerals	+	+	+	+	Clay	80	80	90	89	Volcanic glass	2	7	5	3	Rock fragments	+				Micronodules	+	10	+	1	Zeolite	+	+			Nannofossils	+	+			Sponge spicules	+					Clay-stone	Mud-stone	Mud-stone	CC	TEXTURE:	2-10	2-45			Sand		10	15		Silt	5	90	85		Clay	95	90	85		TOTAL DETRITAL COMPOSITION:	99	100	90		Quartz					Feldspar	3	10	5		Heavy minerals					Clay	95	90	85		Volcanic glass	1	+			Rock fragments					Micronodules	1	+	10		Zeolite					Nannofossils					Sponge spicules				
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SITE 453 HOLE CORE 15 CORED INTERVAL: 132.5 to 142.0 m		FOSSIL CHARACTER		SECTION METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE STRUCTURE LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION																																																																																																																																		
TIME-ROCK UNIT	BIOSTRAT ZONE	FORAMS	NANNOS RADS																																																																																																																																						
Late Pliocene	<i>Discoaster tamalis</i> (N)			0.5 1.0 2.0 3.0			<p>CLAYSTONE, MUDSTONE, VITRIC MUDSTONE, greenish gray, dark greenish gray (5GY 4/1), grayish green (5GY 2/1). Barrowed and mottled, semi-lithified, fragmented to paste in Section 2 and bottom half and upper part of Section 3. Bedding occurs in the lower part of Section 3. A cross-bedded unit is at Section 3; 55-60 cm. It contains coarse mudstone grains to 3 mm.</p> <p>Core-Catcher: Claystone as above.</p> <p>5GY 2/1</p> <p>5GY 4/1</p> <p>Greenish black (5GY 2/1)</p> <p>5GY 4/1</p> <p><b>SMEAR SLIDE SUMMARY</b></p> <table border="1"> <tr> <td></td> <td>Claystone</td> <td>Claystone</td> <td>Claystone</td> <td>Claystone</td> </tr> <tr> <td>TEXTURE:</td> <td>1-30</td> <td>1-140</td> <td>2-113</td> <td>3-33</td> </tr> <tr> <td>Sand</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>Silt</td> <td>5</td> <td>1</td> <td>5</td> <td>5</td> </tr> <tr> <td>Clay</td> <td>95</td> <td>99</td> <td>95</td> <td>95</td> </tr> <tr> <td>TOTAL DETRITAL COMPOSITION:</td> <td>100</td> <td>100</td> <td>100</td> <td>96</td> </tr> <tr> <td>Feldspar</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>Heavy minerals</td> <td>5</td> <td>1</td> <td>5</td> <td>3</td> </tr> <tr> <td>Clay</td> <td>95</td> <td>99</td> <td>95</td> <td>90</td> </tr> <tr> <td>Volcanic glass</td> <td></td> <td></td> <td></td> <td>2</td> </tr> <tr> <td>Micronodules</td> <td></td> <td></td> <td></td> <td>5</td> </tr> <tr> <td>Zeolite</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>Nannofossils</td> <td></td> <td></td> <td></td> <td>1</td> </tr> </table> <p><b>SMEAR SLIDE SUMMARY</b></p> <table border="1"> <tr> <td></td> <td>Vitric mudstone</td> <td>Mudstone</td> <td>Vitric mudstone</td> <td>Claystone</td> </tr> <tr> <td>TEXTURE:</td> <td>3-40</td> <td>3-47</td> <td>3-78</td> <td>CC</td> </tr> <tr> <td>Sand</td> <td>2</td> <td></td> <td></td> <td></td> </tr> <tr> <td>Silt</td> <td>23</td> <td>20</td> <td>15</td> <td>10</td> </tr> <tr> <td>Clay</td> <td>75</td> <td>80</td> <td>85</td> <td>90</td> </tr> <tr> <td>TOTAL DETRITAL COMPOSITION:</td> <td>95</td> <td>92</td> <td>94</td> <td>90</td> </tr> <tr> <td>Feldspar</td> <td>15</td> <td>12</td> <td>2</td> <td>+</td> </tr> <tr> <td>Heavy minerals</td> <td>3</td> <td></td> <td></td> <td>+</td> </tr> <tr> <td>Clay</td> <td>65</td> <td>80</td> <td>82</td> <td>90</td> </tr> <tr> <td>Volcanic glass</td> <td>12</td> <td>+</td> <td>10</td> <td>+</td> </tr> <tr> <td>Micronodules</td> <td>5</td> <td>8</td> <td>5</td> <td>10</td> </tr> <tr> <td>Zeolite</td> <td>+</td> <td>+</td> <td>+</td> <td></td> </tr> <tr> <td>Nannofossils</td> <td>+</td> <td>+</td> <td>+</td> <td></td> </tr> </table>		Claystone	Claystone	Claystone	Claystone	TEXTURE:	1-30	1-140	2-113	3-33	Sand					Silt	5	1	5	5	Clay	95	99	95	95	TOTAL DETRITAL COMPOSITION:	100	100	100	96	Feldspar					Heavy minerals	5	1	5	3	Clay	95	99	95	90	Volcanic glass				2	Micronodules				5	Zeolite					Nannofossils				1		Vitric mudstone	Mudstone	Vitric mudstone	Claystone	TEXTURE:	3-40	3-47	3-78	CC	Sand	2				Silt	23	20	15	10	Clay	75	80	85	90	TOTAL DETRITAL COMPOSITION:	95	92	94	90	Feldspar	15	12	2	+	Heavy minerals	3			+	Clay	65	80	82	90	Volcanic glass	12	+	10	+	Micronodules	5	8	5	10	Zeolite	+	+	+		Nannofossils	+	+	+	
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Site 453, Core 16, 142.0-151.5 m: No recovery.

SITE 453 HOLE CORE 17 CORED INTERVAL: 151.5 to 161.0 m		FOSSIL CHARACTER		SECTION METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE STRUCTURE LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION																																							
TIME-ROCK UNIT	BIOSTRAT ZONE	FORAMS	NANNOS RADS																																											
Late Pliocene	<i>Discoaster tamalis</i> (N)			0.5			<p>MUDSTONE, greenish black (5GY 4/1), semi-lithified, slightly mottled.</p> <p>Core-Catcher: Mudstone as above.</p> <p>5GY 4/1</p> <p><b>SMEAR SLIDE SUMMARY</b></p> <table border="1"> <tr> <td></td> <td>Micronodular mudstone</td> <td>Vitric mudstone</td> </tr> <tr> <td>TEXTURE:</td> <td>1-17</td> <td>CC</td> </tr> <tr> <td>Sand</td> <td></td> <td>1</td> </tr> <tr> <td>Silt</td> <td>75</td> <td>30</td> </tr> <tr> <td>Clay</td> <td>75</td> <td>60</td> </tr> <tr> <td>TOTAL DETRITAL COMPOSITION:</td> <td>85</td> <td>81</td> </tr> <tr> <td>Feldspar</td> <td>5</td> <td>5</td> </tr> <tr> <td>Heavy minerals</td> <td>+</td> <td>1</td> </tr> <tr> <td>Clay</td> <td>75</td> <td>60</td> </tr> <tr> <td>Volcanic glass</td> <td>5</td> <td>15</td> </tr> <tr> <td>Micronodules</td> <td>15</td> <td>20</td> </tr> <tr> <td>Zeolite</td> <td>+</td> <td>+</td> </tr> <tr> <td>Fish remains</td> <td>+</td> <td></td> </tr> </table>		Micronodular mudstone	Vitric mudstone	TEXTURE:	1-17	CC	Sand		1	Silt	75	30	Clay	75	60	TOTAL DETRITAL COMPOSITION:	85	81	Feldspar	5	5	Heavy minerals	+	1	Clay	75	60	Volcanic glass	5	15	Micronodules	15	20	Zeolite	+	+	Fish remains	+	
	Micronodular mudstone	Vitric mudstone																																												
TEXTURE:	1-17	CC																																												
Sand		1																																												
Silt	75	30																																												
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Feldspar	5	5																																												
Heavy minerals	+	1																																												
Clay	75	60																																												
Volcanic glass	5	15																																												
Micronodules	15	20																																												
Zeolite	+	+																																												
Fish remains	+																																													

SITE 453 HOLE		CORE 18		CORED INTERVAL: 161.0 to 170.5 m		
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION METERS	GRAPHIC LITHOLOGY	LITHOLOGIC DESCRIPTION
		FORAMS	NANNOS			
				0.5		5G 4/1 CLAYSTONE, CALCAREOUS, VITRIC AND MICRONODULAR MUDSTONE, mainly greenish gray (5G 6/1) to dark greenish gray (5G 4/1), soft and highly deformed. Semi-lithified 1.0 to 1.30 cm bioturbated mudstone, 1-130 cm to 2-130 cm laminated mudstone with dolomite (?) horizons. 2-130 cm to 5-142 cm: Bioturbated mudstone. 6-0 to 10 cm: Graded bed, fine to medium sand-size (mudstone clasts ?). 6-10 cm to 7-40 cm: Bioturbated (?) mudstone. Core-Catcher: Laminated mudstone.
				1.0		5G 6/1
				2		5G 6/1 beds alternate with 5G 4/1
				3		VOID
				4		VOID
				5		VOID
				6		Greenish black (5G 2/1)
				6		5G 4/1
				7		Medium greenish gray (5G 3/1) to greenish gray (5G 5/1)
				CC		

SITE 453 HOLE		CORE 19		CORED INTERVAL: 170.5 to 180.0 m		
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION METERS	GRAPHIC LITHOLOGY	LITHOLOGIC DESCRIPTION
		FORAMS	NANNOS			
				1		5GY 5/1 VITRIC MUDSTONE, medium greenish gray (5GY 5/1). The core is broken up by drilling, semi-lithified, partings in mudstone every 3.5 mm toward the bottom. Core-Catcher: As above.
				0.5		
				CC		

**SMEAR SLIDE SUMMARY**

Vitric mud  
1-50

TEXTURE:  
Sand -  
Silt 40  
Clay 60  
TOTAL DETRITAL 100  
COMPOSITION:  
Feldspar 5  
Heavy minerals +  
Clay 55  
Volcanic glass 40  
Zeolite ?

SITE 453 HOLE		CORE 20		CORED INTERVAL: 180.0 to 189.5 m		
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION METERS	GRAPHIC LITHOLOGY	LITHOLOGIC DESCRIPTION
		FORAMS	NANNOS			
				0.5		MICRONODULAR MUDSTONE, dark greenish gray (5G 4/2), mottled and burrowed, semi-lithified, rock partly pulverized by drilling, with SILTY CHALK (pale blue green (5BG 7/2)   2.7 to 25 cm graded bedded, burrowed at top. Burrows are infiltrated with overlying sediment.
				1.0		5G 4/2
				2		5BG 7/2
				3		5G 4/2

**SMEAR SLIDE SUMMARY**

Silty chalk  
2-23

Micronodular mudstone  
2-70

TEXTURE:  
Sand -  
Silt 60  
Clay 40  
TOTAL DETRITAL 30  
COMPOSITION:  
Feldspar -  
Heavy minerals -  
Clay 30  
Volcanic glass +  
Micronodules -  
Carbonate unsp. 70  
Nano-fossils +



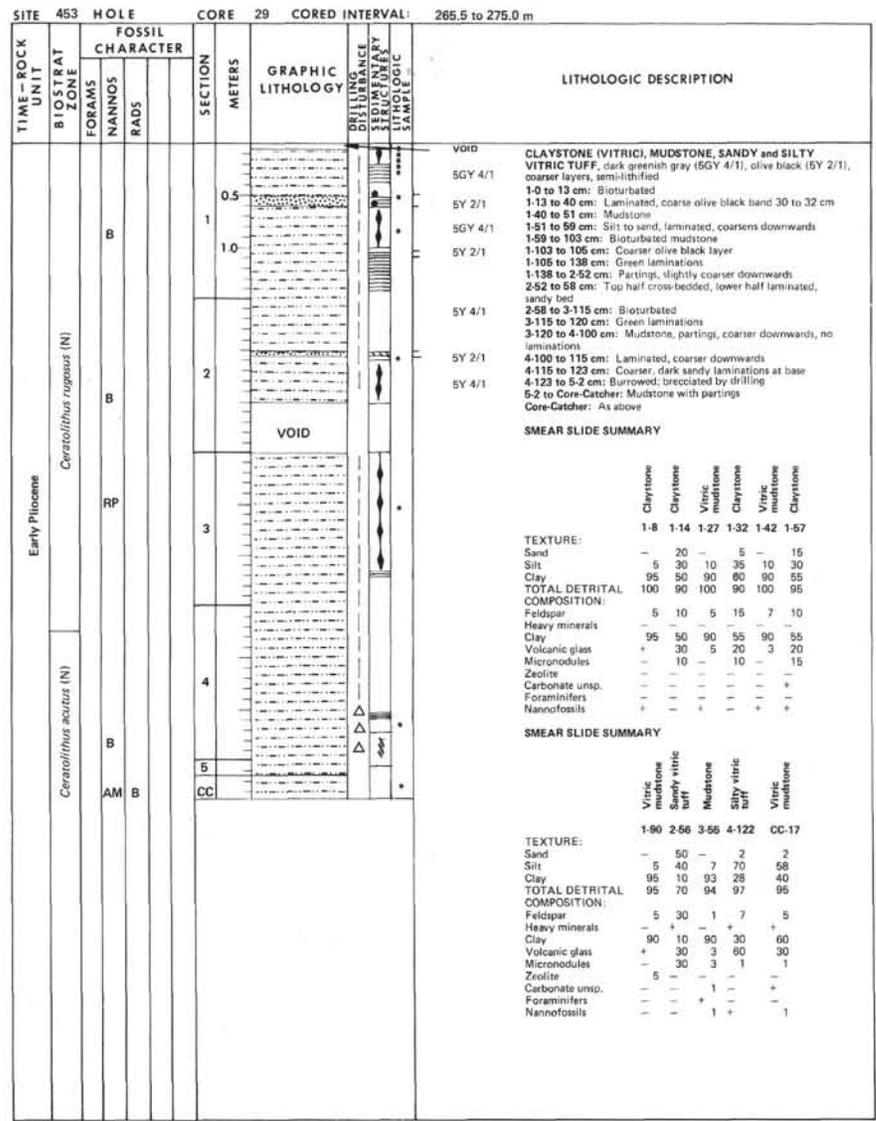
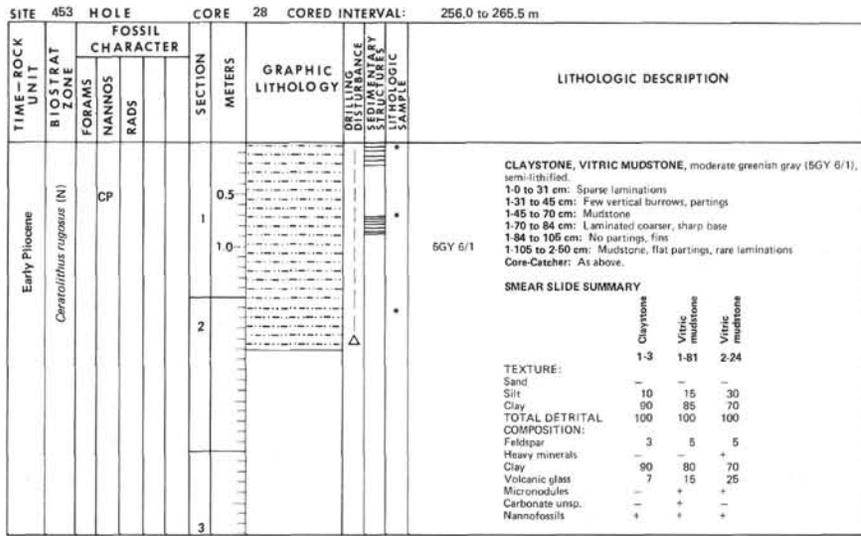
SITE 453		HOLE		CORE 23		CORED INTERVAL: 208.5 to 218.0 m											
TIME-ROCK UNIT	BIOTRAT ZONE	FOSSIL CHARACTER		SECTION	METERS	GRAPHIC LITHOLOGY	LITHOLOGIC DESCRIPTION										
		FORAMS	NANNOS														
Early Pliocene	<i>Sphenolithus neobulbes</i> (N)	AM	B	1	0.5		5GY 4/1: VITRIC MUDSTONE, CLAYSTONE, dark greenish gray (5GY 4/1), dusky green (5G 3/2), grayish green (10GY 5/2), semi-lithified. 1-0 to 18 cm: Bioturbated 1-18 to 23 cm: Cross-bedded 1-23 to 50 cm: Bioturbated 1-50 to 96 cm: Laminated, a few narrow vertical burrows 1-96 to 120 cm: Rare laminations 1-120 to 140 cm: Laminated 1-140 to 2-53 cm: Non-laminated Core-Catcher: Bioturbated										
							Moderate greenish gray (5GY 5/1)										
				2			5GY 4/1										
				CC			5GY 4/1										
<p><b>SMEAR SLIDE SUMMARY</b></p> <table border="1"> <thead> <tr> <th></th> <th>Opaque (F<sub>2</sub> Min) Layer(?)</th> <th>Claystone</th> <th>Claystone</th> <th>Vitric mudstone</th> </tr> </thead> <tbody> <tr> <td>1-81</td> <td>1-81.5</td> <td>1-97</td> <td>1-98</td> <td></td> </tr> </tbody> </table> <p>TEXTURE: Sand - - - - Silt - - 10 5 20 Clay - - 90 95 80 TOTAL DETRITAL 10 100 97 - COMPOSITION: Feldspar - 3 1 2 Clay - 10 90 95 80 Volcanic glass - - 7 3 15 Micronodules - - - 2 1 Zeolite - - - 1 1 Opaque 90 - - - -</p>									Opaque (F <sub>2</sub> Min) Layer(?)	Claystone	Claystone	Vitric mudstone	1-81	1-81.5	1-97	1-98	
	Opaque (F <sub>2</sub> Min) Layer(?)	Claystone	Claystone	Vitric mudstone													
1-81	1-81.5	1-97	1-98														

SITE 453		HOLE		CORE 24		CORED INTERVAL: 227.5 to 237.0 m																													
TIME-ROCK UNIT	BIOTRAT ZONE	FOSSIL CHARACTER		SECTION	METERS	GRAPHIC LITHOLOGY	LITHOLOGIC DESCRIPTION																												
		FORAMS	NANNOS																																
Early Pliocene	<i>Sphenolithus neobulbes</i> (N)	CM	B	1	0.5		Moderate greenish gray (5GY 5/1)																												
							5GY 4/1: CRYSTAL VITRIC MUDSTONE, CLAYSTONE, and SILTY VITRIC TUFF, greenish gray (5GY 4/1), dark greenish gray (5GY 4/1), and olive gray (5Y 4/1), semi-lithified. 1-0 to 35 cm: Mudstone with partings 1 cm 1-35 to 60 cm: Bioturbated 1-60 to 78 cm: Laminated 1-78 to 79 cm: Cross-bedded sand lens 1-78 to 90 cm: Coarsens downwards, burrowed at top, silty laminations at base. 1-89 to 128 cm: Small burrows and flat partings 1-128 to 2-10 cm: More silty, erosional base 2-10 to 30 cm: Laminations, bed, coarsens downwards; erosional base. 2-30 to 47 cm: Mudstone, claystone, laminated faintly near base. 2-47 to 60 cm: Cross-bedded sandy layer 2-60 to 96 cm: Massive mudstone laminations near base. 2-95 to 98 cm: Cross-bedded silt 2-98 to 103 cm: Laminated sandy layer 2-103 cm to Core-Catcher: Massive mudstone Core-Catcher: As above																												
				2			5GY 4/1																												
				3			5GY 6/1																												
				CC			5GY 6/1																												
<p><b>SMEAR SLIDE SUMMARY</b></p> <table border="1"> <thead> <tr> <th></th> <th>Vitric mudstone</th> <th>Claystone</th> <th>Silty-vitric tuff</th> <th>Vitric mudstone</th> <th>Vitric mudstone</th> <th>Silty-vitric tuff</th> </tr> </thead> <tbody> <tr> <td>1-20</td> <td>1-69</td> <td>1-78.5</td> <td>1-82</td> <td>1-87</td> <td>1-100</td> <td></td> </tr> </tbody> </table> <p>TEXTURE: Sand - - - - Silt 30 10 80 35 30 50 Clay 70 90 20 65 70 48 TOTAL DETRITAL 100 97 100 100 100 98 COMPOSITION: Quartz - - - - Feldspar 5 2 5 10 5 2 Heavy minerals + + + - - - Clay 70 83 20 65 70 45 Volcanic glass 25 10 75 25 25 50 Micronodules - 2 + - - 2 Zeolite - 1 - - - 1 Foraminifers - - - - - - Nannofossils + - - - - + Opaque 2 - - - - -</p> <p><b>SMEAR SLIDE SUMMARY</b></p> <table border="1"> <thead> <tr> <th></th> <th>Vitric mudstone</th> <th>Claystone</th> <th>Silty-vitric tuff</th> <th>Crystal-mudstone</th> <th>Vitric mudstone</th> <th>Mudstone</th> </tr> </thead> <tbody> <tr> <td>2-3</td> <td>2-37</td> <td>2-48</td> <td>2-55</td> <td>2-75</td> <td>2-125</td> <td></td> </tr> </tbody> </table> <p>TEXTURE: Sand 10 - 5 - - - Silt 30 5 35 - 15 20 10 Clay 80 95 60 85 80 90 TOTAL DETRITAL 100 100 100 100 100 100 COMPOSITION: Quartz - - - 1 - - - Feldspar - 5 10 5 - 10 10 Heavy minerals + - - - - - Clay 80 90 55 85 75 90 Volcanic glass 35 - 40 5 15 + Micronodules - - - - - - Zeolite - - - - - - Foraminifers - - + - - - Nannofossils - - + - - - Opaque - - 1 - - -</p>									Vitric mudstone	Claystone	Silty-vitric tuff	Vitric mudstone	Vitric mudstone	Silty-vitric tuff	1-20	1-69	1-78.5	1-82	1-87	1-100			Vitric mudstone	Claystone	Silty-vitric tuff	Crystal-mudstone	Vitric mudstone	Mudstone	2-3	2-37	2-48	2-55	2-75	2-125	
	Vitric mudstone	Claystone	Silty-vitric tuff	Vitric mudstone	Vitric mudstone	Silty-vitric tuff																													
1-20	1-69	1-78.5	1-82	1-87	1-100																														
	Vitric mudstone	Claystone	Silty-vitric tuff	Crystal-mudstone	Vitric mudstone	Mudstone																													
2-3	2-37	2-48	2-55	2-75	2-125																														

SITE 453		HOLE		CORE 25		CORED INTERVAL: 227.5 to 237.0 m	
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION	METERS	GRAPHIC LITHOLOGY	LITHOLOGIC DESCRIPTION
		FORAMS	NANNOS				
Early Pliocene	<i>Sphenolithus neobates</i> (N)	CP		1	0.5		5G 4/1 MUDSTONE, SILTY VITRIC TUFF, dark greenish gray (5G 4/1), moderate greenish gray (5G 5/1), semi-lithified. 1-0 to 22 cm: Moderately bioturbated 1-22 to 80 cm: Mudstone with partings; few laminations. 1-80 to 100 cm: Thin dark laminations 1-100 cm to Core-Catcher: Mudstone with a few laminations. Core-Catcher: As above
				1	1.0		5G Y 5/1 <b>SMEAR SLIDE SUMMARY</b>  Silty-vitric tuff 1-86  TEXTURE: Sand 3 Silt 90 Clay 17 TOTAL DETRITAL 90 COMPOSITION: Feldspar 1 Heavy minerals 1 Clay 10 Volcanic glass 79 Micronodules 1 Zeolite 2 Carbonate unsp. 5 Nannofossils 1
		CM	B	2			
				CC			

SITE 453		HOLE		CORE 26		CORED INTERVAL: 237.0 to 246.5 m	
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION	METERS	GRAPHIC LITHOLOGY	LITHOLOGIC DESCRIPTION
		FORAMS	NANNOS				
Early Pliocene	<i>Sphenolithus neobates</i> (N)			1	0.5		Grayish olive green (5GY 3/2) 10GY 5/2 5G Y 5/1 5GR 6/1 5G Y 5/1 5G 4/1
				1	1.0		CLAYSTONE, VITRIC MUDSTONE and SILTY VITRIC TUFF, moderate to dark greenish gray (5G Y 5/1 to 5G 4/1), grayish green (10GY 5/2), etc., lithified, semi-lithified, 3-110 cm onwards brecciated by drilling. 1-0 to 19 cm: Bioturbated 1-19 to 28 cm: Laminated, some burrows 1-28 to 90 cm: Mudstone, erosional contact, laminations close to base. 1-90 to 122 cm: Mudstone sandy layer at base, few laminations in middle. 1-122 to 2-20 cm: Massive mudstone 2-20 to 30 cm: Bioturbated 2-30 to 50 cm: Green laminated mudstone, few burrows 2-50 to 66 cm: Silty; bed fins upwards 2-66 to 75 cm: Laminated mudstone, claystone 2-75 to 3-37 cm: Mudstone, silty from 2-120 cm down 3-37 to 40 cm: Silty to very fine sand, cross-bedded 3-40 to 66 cm: Bioturbated, laminated at base 3-66 to 96 cm: Mudstone, darker graded layer in basal sand 3-96 cm to Core-Catcher: Bioturbated Core-Catcher: As above
				2			5G Y 5/1 <b>SMEAR SLIDE SUMMARY</b>  Claystone 2-67 Vitric mudstone 2-74 Claystone 2-75 Silty vitric tuff 2-107 4-16  TEXTURE: Sand - - - - 10 Silt 8 15 6 7 90 Clay 92 85 94 93 - TOTAL DETRITAL 99 95 96 97 100 COMPOSITION: Feldspar 1 1 1 1 5 Heavy minerals - - - - 5 Clay 90 80 90 89 - Volcanic glass 8 15 5 7 90 Micronodules + 2 1 2 - - Carbonate unsp. - - - 3 + - Nannofossils + 2 - 1 - 1 -
				3			Greenish black (5GY 2/1) 5G Y 4/1 5G Y 5/1
				4			5G Y 4/1
		RP	B	CC			

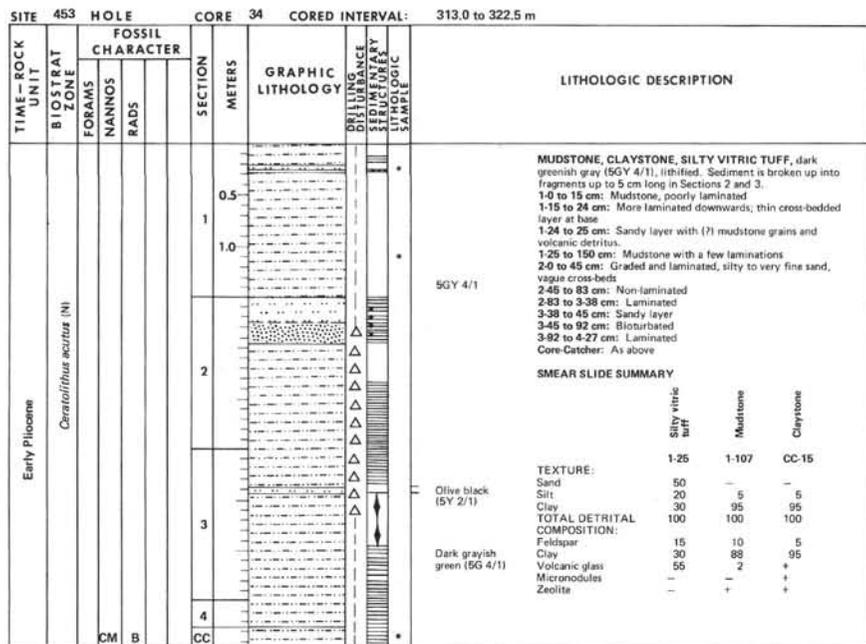
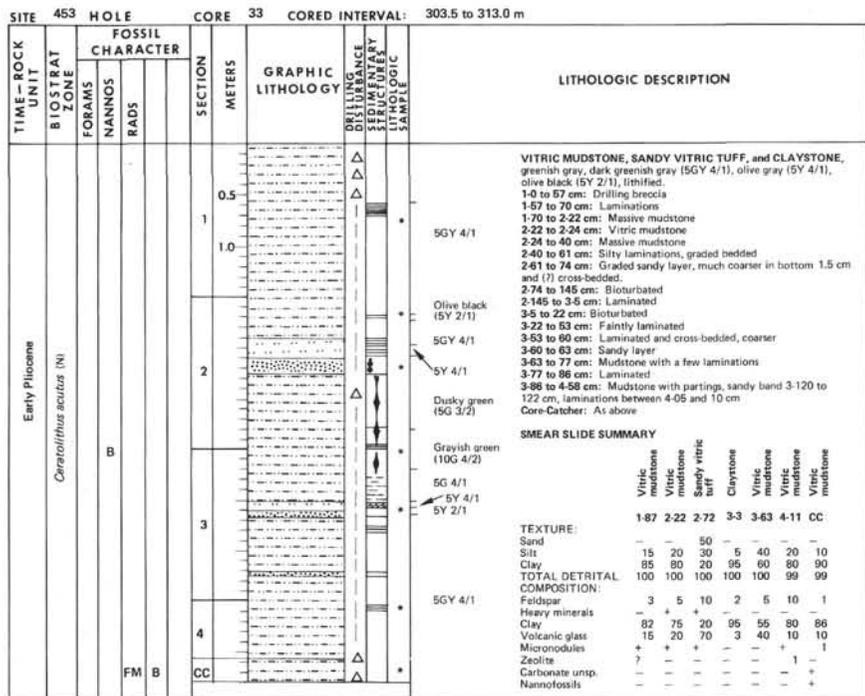
SITE 453		HOLE		CORE 27		CORED INTERVAL: 246.5 to 256.0 m	
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION	METERS	GRAPHIC LITHOLOGY	LITHOLOGIC DESCRIPTION
		FORAMS	NANNOS				
Early Pliocene	<i>Sphenolithus neobates</i> (N)			1	0.5		5G Y 4/1 CLAYSTONE and VITRIC MUDSTONE, dark greenish gray (5G Y 4/1), and greenish black (5G Y 2/1), semi-lithified. 1-0 to 2-60 cm: Claystone, mudstone, laminations at top, coarsest in bottom 10 cm, coarsens downwards. 2-60 to 80 cm: Bioturbated mudstone 2-80 to 3-81 cm: Mudstone and claystone, partings closely spaced, few laminations 3-59 to 66 cm Core-Catcher: As above
				1	1.0		5G Y 4/1 <b>SMEAR SLIDE SUMMARY</b>  Claystone 1-5 Vitric mudstone 1-70 Vitric mudstone 1-145 Vitric mudstone 2-5 Vitric mudstone 2-55 Claystone 2-77  TEXTURE: Sand - - - - 5 Silt 5 20 25 20 40 10 Clay 95 80 70 80 60 90 TOTAL DETRITAL 96 95 100 100 100 98 COMPOSITION: Feldspar 1 5 5 5 5 3 Heavy minerals + - - - + - Clay 90 80 75 80 60 88 Volcanic glass 5 10 20 15 36 5 Micronodules 1 + - - + 3 Zeolite - - - - - + Carbonate unsp. + 5 - - - + Foraminifera 2 - - - - + Nannofossils - + + - - +
				2			5G Y 2/1 <b>SMEAR SLIDE SUMMARY</b>  Claystone 2-85 Claystone 2-96 Claystone 2-107 Silty vitric tuff 3-5 Vitric mudstone 3-65  TEXTURE: Sand - - - - 3 Silt 5 8 5 15 60 Clay 95 92 95 85 37 TOTAL DETRITAL 96 95 96 - 96 COMPOSITION: Feldspar 1 1 1 2 5 Heavy minerals - - - - 1 Clay 92 90 88 80 30 Volcanic glass 3 4 7 15 60 Micronodules 2 1 2 2 1 Zeolite 2 2 - - - Carbonate unsp. + 1 - - - + Foraminifera - - - - + Nannofossils + + + + 1
				3			5G Y 4/1
				4			
				us			



SITE 453		HOLE		CORE 30		CORED INTERVAL: 275.0 to 284.5 m							
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION	METERS	GRAPHIC LITHOLOGY	LITHOLOGIC DESCRIPTION						
		FORAMS	NANNOS RADS										
Early Pliocene	<i>Ceratolithus acutus</i> (N)			1	0.5		VOID CLAYSTONE, greenish gray (SG 6/1) section in fragments to 5 cm, semi-lithified. 1-6 to 125 cm: Claystone with closely spaced partings <b>SMEAR SLIDE SUMMARY</b> <table border="1"> <tr> <td></td> <td>Claystone</td> <td>Claystone</td> </tr> <tr> <td></td> <td>1-4</td> <td>1-89</td> </tr> </table> TEXTURE: Sand - 2 - 5 Silt 98 95 Clay 100 98 <b>TOTAL DETRITAL</b> COMPOSITION: Feldspar 2 1 Clay 98 92 Volcanic glass - 3 Micronodules - 1 Zeolite + - Carbonate unsp. - 1 Nannofossils - 2		Claystone	Claystone		1-4	1-89
	Claystone	Claystone											
	1-4	1-89											
				2	1.0								

SITE 453		HOLE		CORE 31		CORED INTERVAL: 284.5 to 294.0 m							
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION	METERS	GRAPHIC LITHOLOGY	LITHOLOGIC DESCRIPTION						
		FORAMS	NANNOS RADS										
Early Pliocene	<i>Ceratolithus acutus</i> (N)			1	0.5		CLAYSTONE, MUDSTONE, greenish gray (SG 6/1), lithified to Section 3-24 cm. Sections 1 and 2: There are a few fine vertical burrows. 3-24 to 40 cm: Sparse laminations, becomes coarser in bottom of Section 3. Core-Catcher: As above. <b>SMEAR SLIDE SUMMARY</b> <table border="1"> <tr> <td></td> <td>Claystone</td> <td>Claystone</td> </tr> <tr> <td></td> <td>2-80</td> <td>CC</td> </tr> </table> TEXTURE: Sand - 7 - 5 Silt 93 95 Clay 96 100 <b>TOTAL DETRITAL</b> COMPOSITION: Feldspar 2 3 Clay 89 92 Volcanic glass 5 5 Micronodules - 2 - Zeolite - + Carbonate unsp. 1 - Nannofossils 1 +		Claystone	Claystone		2-80	CC
	Claystone	Claystone											
	2-80	CC											
				2	1.0								
				3	1.0								
				CC	VOID								

SITE 453		HOLE		CORE 32		CORED INTERVAL: 294.0 to 303.5 m											
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION	METERS	GRAPHIC LITHOLOGY	LITHOLOGIC DESCRIPTION										
		FORAMS	NANNOS RADS														
				1	0.5		MICRONODULE MUDSTONE and SANDY VITRIC TUFF, lithified. 1-0 to 45 cm: Mudstone, massive 1-45 to 85 cm: Laminated, laminations darker 1-95 to 2-10 cm: Mudstone, slightly coarser downwards 2-10 to 16 cm: Silty laminations 2-16 to 24 cm: Graded sandy unit (?), some cross-bedding 2-24 cm to Core-Catcher: Bioturbated mudstone Core-Catcher: As above <b>SMEAR SLIDE SUMMARY</b> <table border="1"> <tr> <td></td> <td>Sandy vitric tuff</td> <td>Micronodular mudstone</td> <td>Micronodular mudstone</td> <td>Micronodular mudstone</td> </tr> <tr> <td></td> <td>2-24</td> <td>2-41</td> <td>3-37</td> <td>CC</td> </tr> </table> TEXTURE: Sand 30 5 5 5 Silt 30 30 15 15 Clay 40 65 80 80 <b>TOTAL DETRITAL</b> COMPOSITION: Feldspar 15 5 5 3 Heavy minerals 10 + - - Clay 40 65 77 80 Volcanic glass 35 - - - Micronodules + 30 15 17 Zeolite ? + 3 +		Sandy vitric tuff	Micronodular mudstone	Micronodular mudstone	Micronodular mudstone		2-24	2-41	3-37	CC
	Sandy vitric tuff	Micronodular mudstone	Micronodular mudstone	Micronodular mudstone													
	2-24	2-41	3-37	CC													
				2	1.0												
				3	1.0												
				CC													







SITE 453 HOLE		CORE 39		CORED INTERVAL: 360.5 to 370.0 m																																																																																																					
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE STRIP	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION																																																																																																	
		FORAMS	NANNOS						RADS																																																																																																
Early Pliocene	<i>Triquetrorhabdulus rugosus</i> (N)	FP			0.5			Moderate greenish gray (5GY 5/1)	<p><b>CLAYSTONE, VITRIC MUDSTONE, SILTSTONE and SANDSTONE, greenish gray (5G 6/1) lithified.</b></p> <p>1-0 to 20 cm: Massive mudstone</p> <p>1-20 to 35 cm: Laminated siltstone</p> <p>1-35 to 41 cm: Graded silt to fine sand with some cross-bedding</p> <p>1-41 to 70 cm: Burrowed mudstone</p> <p>1-70 to 105 cm: Laminated mudstone and claystone</p> <p>1-105 to 106 cm: Very fine sand</p> <p>1-106 to 2-23 cm: Bioturbated mudstone, very fine sand band 107 to 108 cm</p> <p>2-23 to 3-53 cm: Laminated claystone, few vertical burrows</p> <p>3-53 to 82 cm: Has more closely-spaced laminations than above, becomes silty (siltstone) with a few vertical burrows at top</p> <p>3-82 to 102 cm: Laminated very fine sand, cross-bedded at the base</p> <p>3-102 to 112 cm: Fine sand, laminated, erosional base</p> <p>3-112 to 4-93 cm: Mudstone, bedding wavy, greatly inclined, burrows also wavy</p> <p>4-93 to 98 cm: Siltstone coarsens downwards to a small patch of sand at the base</p> <p>4-98 to 5-74 cm: Laminated mudstone</p> <p>Core-Catcher: As above</p> <p><b>SMEAR SLIDE SUMMARY</b></p> <table border="1"> <thead> <tr> <th></th> <th>Claystone</th> <th>Claystone</th> <th>Claystone</th> <th>Claystone</th> <th>Claystone</th> </tr> </thead> <tbody> <tr> <td>TEXTURE:</td> <td>1-46</td> <td>1-90</td> <td>1-100</td> <td>2-25</td> <td>3-10</td> </tr> <tr> <td>Sand</td> <td>2</td> <td>-</td> <td>5</td> <td>-</td> <td>6</td> </tr> <tr> <td>Silt</td> <td>5</td> <td>2</td> <td>-</td> <td>5</td> <td>-</td> </tr> <tr> <td>Clay</td> <td>93</td> <td>98</td> <td>95</td> <td>95</td> <td>94</td> </tr> <tr> <td>TOTAL DETRITAL</td> <td>100</td> <td>97</td> <td>100</td> <td>93</td> <td>95</td> </tr> </tbody> </table> <p>COMPOSITION:</p> <table border="1"> <thead> <tr> <th></th> <th>Claystone</th> <th>Claystone</th> <th>Claystone</th> <th>Claystone</th> <th>Claystone</th> </tr> </thead> <tbody> <tr> <td>Quartz</td> <td>-</td> <td>-</td> <td>-</td> <td>-</td> <td>-</td> </tr> <tr> <td>Feldspar</td> <td>8</td> <td>5</td> <td>10</td> <td>1</td> <td>1</td> </tr> <tr> <td>Heavy minerals</td> <td>-</td> <td>-</td> <td>-</td> <td>-</td> <td>-</td> </tr> <tr> <td>Clay</td> <td>90</td> <td>90</td> <td>90</td> <td>90</td> <td>90</td> </tr> <tr> <td>Volcanic glass</td> <td>2</td> <td>2</td> <td>4</td> <td>2</td> <td>5</td> </tr> <tr> <td>Micronodules</td> <td>-</td> <td>-</td> <td>-</td> <td>2</td> <td>-</td> </tr> <tr> <td>Zeolite</td> <td>-</td> <td>3</td> <td>+</td> <td>5</td> <td>2</td> </tr> <tr> <td>Carbonate unisp.</td> <td>-</td> <td>-</td> <td>-</td> <td>+</td> <td>+</td> </tr> <tr> <td>Nannofossils</td> <td>+</td> <td>-</td> <td>-</td> <td>-</td> <td>+</td> </tr> </tbody> </table>		Claystone	Claystone	Claystone	Claystone	Claystone	TEXTURE:	1-46	1-90	1-100	2-25	3-10	Sand	2	-	5	-	6	Silt	5	2	-	5	-	Clay	93	98	95	95	94	TOTAL DETRITAL	100	97	100	93	95		Claystone	Claystone	Claystone	Claystone	Claystone	Quartz	-	-	-	-	-	Feldspar	8	5	10	1	1	Heavy minerals	-	-	-	-	-	Clay	90	90	90	90	90	Volcanic glass	2	2	4	2	5	Micronodules	-	-	-	2	-	Zeolite	-	3	+	5	2	Carbonate unisp.	-	-	-	+	+	Nannofossils	+	-	-	-	+
						Claystone	Claystone	Claystone		Claystone	Claystone																																																																																														
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SITE 453 HOLE		CORE 40		CORED INTERVAL: 370.0 to 379.5 m																												
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE STRIP	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION																								
		FORAMS	NANNOS						RADS																							
Early Pliocene	<i>Triquetrorhabdulus rugosus</i> (N)	FP			0.5			<p><b>MUDSTONE and SILTSTONE, greenish gray (5GY 6/1), lithified.</b></p> <p>1-0 to 2-150 cm: Mudstone or claystone with sparse laminations. Long narrow vertical burrows can be traced over 18 cm in places. Flame structures occur at the bases of some silt bands.</p> <p>3-0 to 146 cm: Lamination becomes prominent at about 100 cm and much more fragment from 130 cm to the base of the core, more silty</p> <p>4-0 to 82 cm: Silty, laminated</p> <p>Core-Catcher: As above</p> <p><b>SMEAR SLIDE SUMMARY</b></p> <table border="1"> <thead> <tr> <th></th> <th>Vitric mudstone</th> </tr> </thead> <tbody> <tr> <td>TEXTURE:</td> <td>3-148</td> </tr> <tr> <td>Sand</td> <td>2</td> </tr> <tr> <td>Silt</td> <td>20</td> </tr> <tr> <td>Clay</td> <td>78</td> </tr> <tr> <td>TOTAL DETRITAL</td> <td>100</td> </tr> </tbody> </table> <p>COMPOSITION:</p> <table border="1"> <thead> <tr> <th></th> <th>Vitric mudstone</th> </tr> </thead> <tbody> <tr> <td>Feldspar</td> <td>10</td> </tr> <tr> <td>Clay</td> <td>75</td> </tr> <tr> <td>Volcanic glass</td> <td>15</td> </tr> <tr> <td>Micronodules</td> <td>+</td> </tr> <tr> <td>Nannofossils</td> <td>+</td> </tr> </tbody> </table>		Vitric mudstone	TEXTURE:	3-148	Sand	2	Silt	20	Clay	78	TOTAL DETRITAL	100		Vitric mudstone	Feldspar	10	Clay	75	Volcanic glass	15	Micronodules	+	Nannofossils	+
						Vitric mudstone																										
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Clay	75																															
Volcanic glass	15																															
Micronodules	+																															
Nannofossils	+																															
1																																
2					5GY 6/1																											
3					Void																											
4					Moderate greenish gray (5GY 5/1)																											
CC																																

SITE 453 HOLE		CORE 41		CORED INTERVAL: 379.5 to 389.0 m			
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE SERVICED BY STRUCTURE LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
		FORAMS	NANNOS				
					VOID		
				1	0.5		Dark greenish gray (5G 4/1)
				1	1.0		Medium dark gray (N4)
				2			Moderate greenish gray (5G 5/1)
				3			Dark greenish gray (5G 4/1)
				3			Dusky green (5G 4/1)
				4			5G 4/1
				4			Olive black (5Y 2/1)
				5			5G 4/1
				CC			

**LITHOLOGIC DESCRIPTION**

**ZEOLITIC and VITRIC MUDSTONE, SANDSTONE, greenish gray, olive black, lithified.**  
**1-10 to 55 cm:** Bioturbated mudstone  
**1-55 to 72 cm:** Laminated, green laminae in upper part; paler below  
**1-72 to 92 cm:** Mudstone less laminated  
**1-92 to 94 cm:** Very fine sand, cross-bedded  
**1-94 to 150 cm:** Laminated mudstone  
**2-0 to 107 cm:** Sparse laminations  
**2-107 to 122 cm:** Closely spaced partings  
**2-122 to 3-15 cm:** Closely laminated  
**3-15 to 36 cm:** Silty, non-laminated  
**3-36 to 53 cm:** Very fine sand increasing in grain-size downwards, laminated; some cross-beds 1 cm thick  
**3-53 to 113 cm:** Burrowed mudstone  
**3-113 to 4-70 cm:** Mudstone, few laminations to 4-10 cm, more below; few thin vertical burrows  
**4-70 to 80 cm:** Mudstone, silty laminations  
**4-80 to 87 cm:** Silt grading to very fine sand, some cross-beds  
**4-87 to 93 cm:** Very fine sand grading down to fine sand  
**4-93 to 136 cm:** Laminated mudstone  
**4-136 to 5-150 cm:** Mudstone with few laminations, a few vertical burrows in upper part of Section 5  
**Core-Catcher:** As above

**SMEAR SLIDE SUMMARY**

	Zeolitic mudstone	Zeolitic mudstone	Vitric mudstone	Mudstone
TEXTURE:				
Sand	0.5	1	-	-
Silt	39	34	15	10
Clay	50	65	85	90
TOTAL DETRITAL	60	80	-	100
COMPOSITION:				
Feldspar	2	2	10	10
Heavy minerals	+	1	-	+
Clay	53	67	75	88
Volcanic glass	5	20	15	2
Micronodules	30	5	+	+
Zeolite	10	10	-	-
Opalines	-	5	-	-

SITE 453 HOLE		CORE 42		CORED INTERVAL: 389.0 to 398.5 m			
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE SERVICED BY STRUCTURE LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
		FORAMS	NANNOS				
					VOID		
				1	0.5		5G 4/1
				1	1.0		Medium to dark gray (N4 to N3)
				2			Grayish green (10G 4/2)
				CC			

**LITHOLOGIC DESCRIPTION**

**CLAYSTONE, VITRIC and ZEOLITIC MUDSTONE, SILTSTONE and SANDSTONE, dark gray (N3), greenish gray and dark greenish gray (5G 4/1), lithified.**  
**1-0 to 108 cm:** Mudstone, few laminations  
**1-108 to 129 cm:** Very fine sandstone, some cross-beds  
**1-129 to 2-26 cm:** Sand grading from very fine to medium, some laminations in upper part  
**2-26 to 61 cm:** Mudstone with flat partings, poorly laminated  
**2-61 to 79 cm:** Graded bed, very fine sand at the base, silt at top  
**2-79 to 105 cm:** Laminated silty mud with silty sands  
**2-105 to 128 cm:** Graded bed, very fine sand at the base, silt at the top  
**2-128 to 133 cm:** Bioturbated claystone  
**Core-Catcher:** As above

**SMEAR SLIDE SUMMARY**

	Crystalline mudstone	Vitric mudstone	Zeolitic mudstone	Zeolitic mudstone	Claystone	Claystone
TEXTURE:						
Sand	-	-	2	10	-	-
Silt	20	30	25	25	5	10
Clay	80	70	73	65	95	90
TOTAL DETRITAL	85	95	85	83	100	100
COMPOSITION:						
Feldspar	15	10	7	8	5	10
Heavy minerals	+	+	5	5	+	-
Clay	70	60	70	60	95	90
Volcanic glass	10	25	3	10	-	-
Micronodules	-	-	6	2	-	-
Zeolite	5	5	10	15	+	+
Nannofossils	-	+	+	-	-	-
Diatoms	-	+	+	-	-	-
Radiolaria	-	+	+	-	-	-

SITE 453 HOLE		CORE 43		CORED INTERVAL: 398.5 to 408.0 m			
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE SERVICED BY STRUCTURE LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
		FORAMS	NANNOS				
				1	0.5		MUDSTONE, SILTSTONE and VERY FINE SANDSTONE, dark greenish gray (5G 4/1), lithified.
				1	1.0		1-0 to 3-15 cm: Drilling breccia
				2			3-15 to 28 cm: Silt and very fine sand, cross-bedded and laminated
				2			3-28 to 36 cm: Bioturbated mudstone
				3			5G 4/1
				CC			5G 4/1
				CC			5G 4/1

**LITHOLOGIC DESCRIPTION**

**MUDSTONE, SILTSTONE and VERY FINE SANDSTONE, dark greenish gray (5G 4/1), lithified.**  
**1-0 to 3-15 cm:** Drilling breccia  
**3-15 to 28 cm:** Silt and very fine sand, cross-bedded and laminated  
**3-28 to 36 cm:** Bioturbated mudstone  
**Core-Catcher, 0-50 cm:** Mudstone with good parting

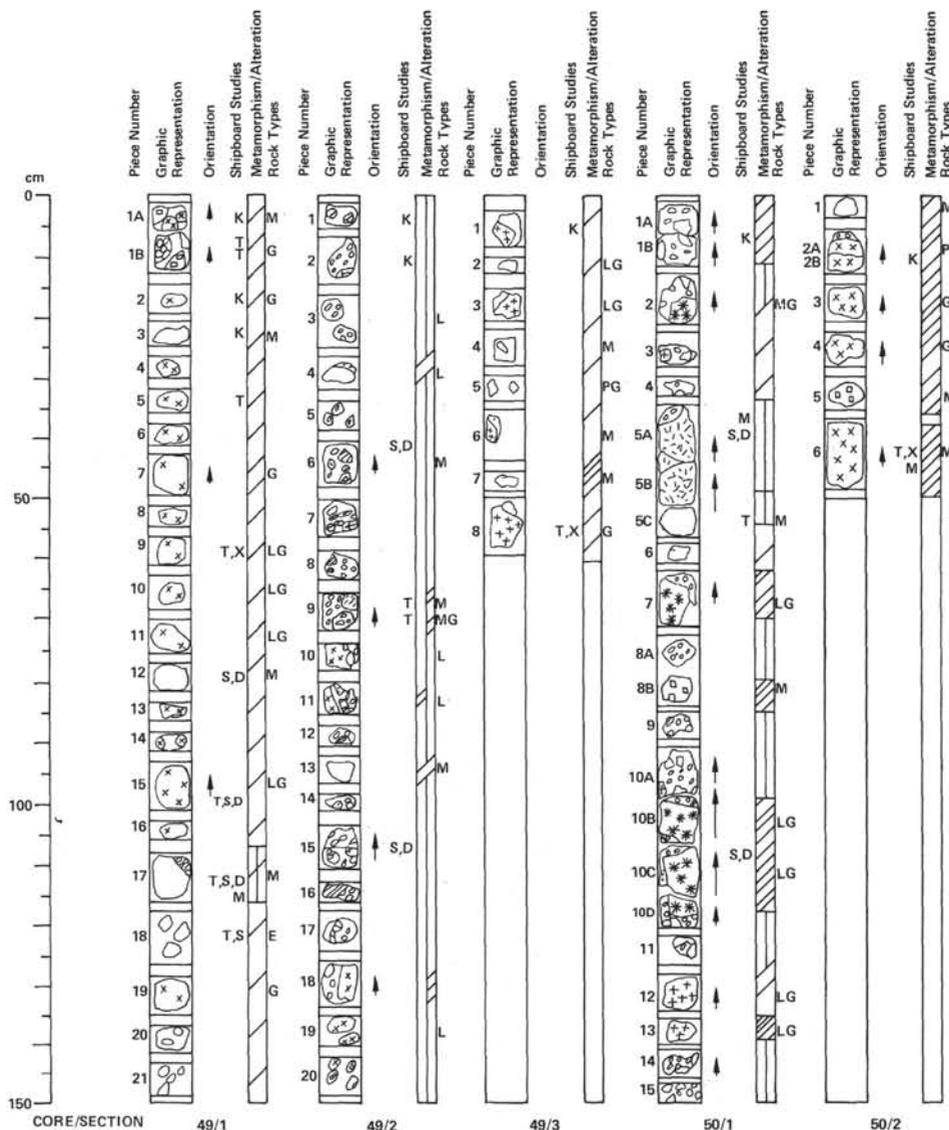
SITE 453 HOLE		CORE 44		CORED INTERVAL: 408.0 to 417.5 m														
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION										
		FORAMS	NANNOS						RADS									
				0.5				ZEOLITIC and VITRIC MUDSTONE and CLAYSTONE, dark greenish gray (5G 4/1), lithified. 1.0 to 2.80 cm: Mudstone dip at top about 5°, suggestion of cross-bedding 1-48 to 50 cm. 1.90 to 94 cm pyrite nodules about 2 cm in diameter on burrow, but cut across layering in mudstone. 2.20 to 90 cm closely-spaced partings. 2.80 to 102 cm: Silty but broken up by drilling 2.102 to 114 cm: Bioturbated mudstone Core-Catcher: Claystone, conchoidal fracture										
				1														
				1.0				5G 4/1 <b>SMEAR SLIDE SUMMARY</b> <table border="1"> <thead> <tr> <th></th> <th>Vitric mudstone</th> <th>Zeolitic vitric claystone</th> <th>Pyrite</th> <th>Mudstone</th> </tr> </thead> <tbody> <tr> <td>Dusky green (5G 3/2)</td> <td>1-42</td> <td>1-85</td> <td>1-93</td> <td>2-105</td> </tr> </tbody> </table> TEXTURE: Sand 2 - - - 2 Silt 15 5 - - 10 Clay 83 95 - - 88 TOTAL DETRITAL 100 90 - - 98 COMPOSITION: Feldspar 5 - - - 10 Heavy minerals + - - - - Clay 80 80 - - 86 Volcanic glass 15 10 - - 2 Micronodules - - - - - Zeolite + 5 - - 2 Carbonate unsp. - - + - - Pyrite - - - 100 - -		Vitric mudstone	Zeolitic vitric claystone	Pyrite	Mudstone	Dusky green (5G 3/2)	1-42	1-85	1-93	2-105
	Vitric mudstone	Zeolitic vitric claystone	Pyrite	Mudstone														
Dusky green (5G 3/2)	1-42	1-85	1-93	2-105														
				2														
				CC														

SITE 453 HOLE		CORE 45		CORED INTERVAL: 417.5 to 427.0 m				
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER		SECTION METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
		FORAMS	NANNOS					
				0.5				MUDSTONE, SILTSTONE and SANDSTONE, dark greenish gray (5G Y 4/1), lithified. 1.0 to 2.85 cm: Laminated silty mudstone, laminations thicken downwards to 1.2 mm 2.85 to 3.60 cm: Cross-bedded increasing in grain-size from silt to fine sand at the base 3.60 to 67 cm: Bioturbated mudstone 3.67 to 93 cm: Laminated silty mudstone, coarsens downwards 3.93 to 102 cm: Cross-bedded sandy layer 3.102 to 115 cm: Bioturbated mudstone 3.115 to 149 cm: Laminated silty mudstone, coarsens downwards 3.149 to 4.4 cm: Cross-bedded very fine sand 4.4 to 9 cm: Bioturbated mudstone 4.9 to 48 cm: Mudstone with increasing silt bands downwards 4.49 to 59 cm: Mudstone with cross-bedded silts, basal silt layer 4.59 to Core-Catcher: Mudstone with silt bands flaser bedding at 73 to 77 cm, flame structure 97 cm, abundant laminae in Core-Catcher Core-Catcher: As above
				1				
				1.0				5G Y 4/1
				2				
				3				Dusky green (5G 3/2) Dark greenish gray (5G 4/1) Dusky green (5G 3/2) Dark greenish gray (5G 4/1)
				4				
				CC				

SITE 453		HOLE			CORE 46		CORED INTERVAL: 427.0 to 436.5 m						
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER			SECTION METERS	GRAPHIC LITHOLOGY	DISTURBANCE SEDIMENTARY STRUCTURES	LITHOLOGIC DESCRIPTION					
		FORAMS	NANNOS	RADS									
					0.5			MUDSTONE, SILTSTONE and SANDSTONE, dark greenish gray (5GY 4/1), lithified. 1-0 to 106 cm: Mudstone and siltstone. Siltstone with cross-beds and laminations. 1-106 to 150 cm and Core-Catcher: Cross-bedded siltstone grading to very fine sandstone.					
		B			1.0		SMEAR SLIDE SUMMARY <table border="1"> <tr> <td></td> <td>Claystone</td> <td></td> </tr> <tr> <td></td> <td>1-1</td> <td>1-125</td> </tr> </table>			Claystone			1-1
	Claystone												
	1-1	1-125											
		B			CC			TEXTURE: Sand - 1 Silt 3 2 Clay 97 97 TOTAL DETRITAL 98 94 COMPOSITION: Feldspar + 2 Clay 99 91 Volcanic glass + 1 Micronodules - + Zeolite - 5 Carbonate unsp. - +					

SITE 453		HOLE			CORE 48		CORED INTERVAL: 446.0 to 455.5 m						
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER			SECTION METERS	GRAPHIC LITHOLOGY	DISTURBANCE SEDIMENTARY STRUCTURES	LITHOLOGIC DESCRIPTION					
		FORAMS	NANNOS	RADS									
Early Pliocene	<i>Triquetrorhabdulus rugosus</i> (N)				1			VERY FINE SANDSTONE 1-0 to 94 cm: Laminated and cross-bedded Core-Catcher: As above					
		B			CC		SMEAR SLIDE SUMMARY <table border="1"> <tr> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> </tr> </table>						
		RP						TEXTURE: Sand 30 Silt 30 Clay 40 TOTAL DETRITAL - COMPOSITION: Feldspar 10 Clay 40 Volcanic glass 50					

SITE 453		HOLE			CORE 47		CORED INTERVAL: 436.5 to 446.0 m										
TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER			SECTION METERS	GRAPHIC LITHOLOGY	DISTURBANCE SEDIMENTARY STRUCTURES	LITHOLOGIC DESCRIPTION									
		FORAMS	NANNOS	RADS													
Early Pliocene	<i>Triquetrorhabdulus rugosus</i> (N)				0.5			SILTSTONE, MUDSTONE, SANDSTONE, grayish green (10G 4/2), dusky green (5G 3/2), lithified. 1-10 to 22 cm: Mudstone with silt bands, thin bioturbated layers 1-22 to 50 cm: Bioturbated mudstone 1-50 to 65 cm: Laminated siltstone 1-65 to 76 cm: Siltstone with small-scale cross-bedding, units 0.5 to 1.5 cm 1-76 to 130 cm: Bioturbated mudstone 1-130 to 2-24 cm: Cross-bedded in small units, coarsens from siltstone to fine sand 2-24 to 36 cm: Mudstone with silt bands, coarsens downwards 2-36 to 49 cm: Bioturbated mudstone 2-49 to 130 cm: Mudstone, laminated with silty bands, coarsens downwards 2-130 to 3-13 cm: Silt, laminated 3-13 to 3-40: Silt grading into very fine sand, complex cross-bedded units 1 cm thick 3-40 to 69 cm and Core-Catcher: Very fine sand and fine sand, laminated Core-Catcher: As above									
		B			1.0		SMEAR SLIDE SUMMARY <table border="1"> <tr> <td></td> <td>Claystone</td> <td>Claystone</td> <td>Claystone</td> <td>Mudstone</td> </tr> <tr> <td></td> <td>1-25</td> <td>1-38</td> <td>2-19</td> <td>2-147</td> </tr> </table>			Claystone	Claystone	Claystone	Mudstone		1-25	1-38	2-19
	Claystone	Claystone	Claystone	Mudstone													
	1-25	1-38	2-19	2-147													
		RP			2			TEXTURE: Sand 10 - 1 5 Silt 10 2 5 7 Clay 90 98 94 88 TOTAL DETRITAL 100 100 100 100 COMPOSITION: Feldspar 7 2 6 12 Heavy minerals 3 - - - Clay 90 98 94 88 Micronodules - - - +									
		B			3												
					CC												



60-453-49 5148.5-5158.0 m (455.5-465.0 m, BSF)

**Coarse gabbro-metabasalt polymict breccia**

All pieces are either breccias, or angular fragments of rocks broken out of breccias, but still with thin crusts of gabbro on them. Letters to right of metamorphism/alteration column indicate rock types of larger clasts as follows: G = gabbro; LG = leucocratic gabbro; MG = mafic gabbro; PG = pegmatitic gabbro; M = metabasalt; E = epidosite. Many gabbros are meta-gabbros.

Cementing material consists of quartz, carbonate, and clays at the top of Section 49-1. Quartz is absent in lower breccias, and abundance of carbonate decreases downward in breccia matrix. Matrix consists mainly of sand- and pebble-sized pieces of gabbros and metabasalts. Plagioclases in breccia matrix and along rims of larger clasts are bleached to whiter color. Olivines and pyroxenes in gabbros are altered to reddish iron oxides(?) and clay minerals. XRD data indicates chlorite is principal cementing mineral in breccia matrix except for local carbonate and quartz. Bleached plagioclases are now mainly K-feldspar. Matrix stained pink to red by iron oxhydroxides.

**Thin Section Data**

**Gabbros: 49-1, 60-61 cm No. 9 Meta-gabbro.** Large plag fractured and veined with tremolite-actinolite, some in 1 cm radiating clusters. Minor plag granulation at boundaries.

**49-1, 100-101 cm No. 15 Mafic gabbro.** Oliv = 25%, cpx = 30%, plag An<sub>50</sub> = 40%, magnetite = 1%. Chlorite and serpentine replace olivine and opx. Sericite, pumpellyite, chlorite after plag. Texture hypidiomorphic granular.

**49-1, 104-107 cm No. 17 Pegmatitic gabbro.** Originally anorthositic gabbro. Now granoblastic aggregate of prehnite, pumpellyite, chlorite, epidote and clay minerals, with minor relict plag.

**49-1, 33-35 cm No. 6 Altered recrystallized gabbro.** Tectonized fabric. Plag partly granulated, lepidoblastic texture. Plag partly altered to sericite. Pyroxene (opx?) altered to hematite, chlorite along exsol. lamellae. Fe-Ti oxides associated with biotite, chlorite. Minor epidote, clays also present.

**49-3, 52-58 cm No. 8 Hornblende gabbro.** Plag (An<sub>50-52</sub>) = 70%. Hblid (green) = 27%, Fe-Ti oxide = 3%. Ophitic texture. Sericite replaces about 25% of plag.

**Metabasalts: 49-1, 11-13 cm No. 1B Plagioclase-phyric metabasalt.**

Relict plag phenos 0.5-2 mm = 30% of rock, partially altered to sericite and clays. Minor relict cpx. Groundmass now carbonate, chlorite, clays.

**49-2, 68-69 cm No. 9.** Plag = 60%, 0.3-2 mm; Cpx = 48%, 0.3-1.2 mm; Fe-Ti oxides = 2%. Vesicles 1-2% lined with chlorite, clay, prehnite. Groundmass has albite, pumpellyite after plag, biotite and hornblende after cpx.

**Breccia Cements: 49-1, 9-10 cm No. 1B.** Rock fragments = 15%; matrix = 85%. Fragments are metabasalts. Matrix has carbonate = 70%, clay minerals (vermiculite), Fe-hydroxides, chlorite, prehnite, epidote together = 30%. Texture: granoblastic.

**49-2, 64-66 cm No. 9.** Rock and mineral fragments: altered amphibole-biotite gabbro, metabasalts, plagioclase, K-feldspar (after plag), biotite, Fe-Ti oxides. Matrix: carbonate, chlorite, pumpellyite, prehnite, vermiculite, hematite (?), epidote, Fe-hydroxides. Proportions are variable. Texture: blastoclastic.

**Epidosite: 49-1, 120-123 cm No. 18.** Granular, subangular grains cemented by chlorite, clay, Fe-hydroxides. Rock has 1% chloritized rocks and totally altered plag (?) grains same size as epidote grains. Rock is about 70% epidote grains.

	<sup>4</sup> JNRM	MDF	Inc.	S	D	Rock Type
49-1, 77-80 cm	---	---	---	5.52	2.83	MB
49-1, 98-100 cm	---	---	---	6.73	2.87	G
49-1, 110-113 cm	7x10 <sup>-6</sup>	48	No	---	---	M
49-1, 113-114 cm	---	---	---	5.70	2.81	M
49-1, 118-128 cm	---	---	---	2.37	---	E
49-2, 41-42 cm	---	---	---	4.41	2.46	Brec.
49-2, 105-107 cm	---	---	---	4.07	2.51	Brec

60-453-50 5158.0-5167.5 m (465.0-474.5 m, BSF)

**Coarse gabbro-metabasalt polymict breccia**

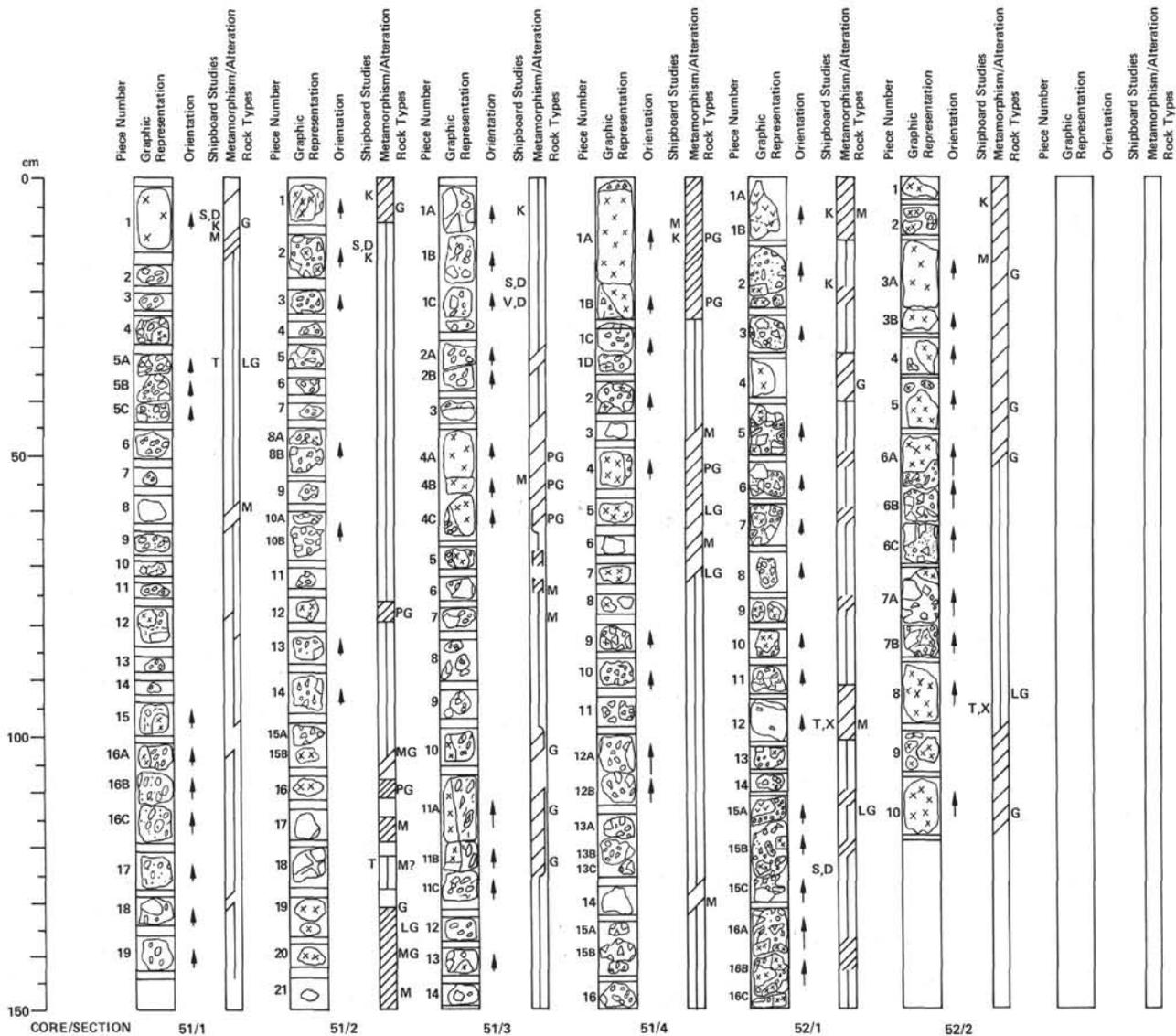
Description and rock types very similar to Core 49. Rock type identification letters to right of metamorphism/alteration column as in Core 49. Cement mainly carbonate and clays, with minor quartz. Sand and pebble-sized rock and mineral grains make up most of breccia matrix. Plag in matrix bleached white, to K-feldspar. Piece 5, Section 1, is altered microbreccia after hyaloclastite(?). Minor sedimentary rocks (mudstones?) in matrix.

**Thin Section Data**

**Metabasalt: 50-1, 52-56 cm No. 5C.** Very badly altered, previously vesicular with trachytic texture. Texture granoblastic, anagda-loidal. Amygdules = 5%, consisting of chlorite, prehnite, qtz, and carbonate. Groundmass = 95%, consisting of prehnite(?), pumpellyite, zoisite, chlorite, quartz, clay minerals.

**Gabbro: 50-2, 39-42 cm No. 6.** Pegmatitic olivine gabbro. Cpx = 60%, olivine = 15%, plagioclase = 25%. Texture: poikilitic. Olivine totally altered to serpentine, chlorite, Fe-Ti oxide. Two generations of cracks, the first filled with actinolite, the second with serpentine-chlorite.

	<sup>4</sup> JNRM	MDF	Inc.	S	D	Rock Type
50-1, 39-42 cm	23x10 <sup>-6</sup>	125	-8.4°	---	---	Brec.
50-1, 42-44 cm	---	---	---	5.96	2.82	Brec.
50-1, 107-109 cm	---	---	---	5.70	2.66	G
50-2, 40-43 cm	2.18x10 <sup>-3</sup>	361	+24.4°	---	---	MG



60-453-51 5177.5-5187.0 m (474.5-484.0 m, BSF)

**Gabbro-metabasalt polymict breccia**

The core consists of fragments of polymict breccia containing mainly pebble-sized angular clasts of igneous and metamorphic rocks, largely feldspathic gabbro. Larger clasts include G = gabbro, MG = mafic gabbro, PG = pegmatitic gabbro, LG = leucocratic gabbro, and M = metabasalt as indicated to the right of the metamorphism/alteration column. Cementing minerals in the breccia matrix are carbonate chlorite, and reddish iron oxyhydroxides. Mafic minerals in gabbro clasts have been altered in two or more stages. Olivines have been replaced by brick-red iron oxyhydroxides, but relict serpentine "sagenitic" web structures can still be seen. Thin bleached rims around larger clasts are K-feldspar replacing plagioclase. In the matrix, larger chips of plagioclase are wholly replaced by K-feldspar. Piece 4 in Section 51-3 is a continuously cored fairly large piece of pegmatic gabbro with some wholly feldspathic portions, and some very mafic portions.

**Thin Section Data**

**Gabbro (norite): 51-1, 30-33 cm No. 5A.** Plagioclase = 80%, opx = 3-5%, cpx = 13%, magnetite = 1-2%, minor brown mica. Texture: hypidiomorphic-granular. Brown mica is probably stilpnomelane after cpx. It is associated with chlorite which, with minor serpentine, also replaces opx.

**Metabasalt(?): 51-2, 123-127 cm No. 18.** Texture: granoblastic and lepidoblastic. Minerals: quartz, epidote, chlorite, minor sphene, opaques (ilmenite?), clinozoisite(?). May originally have been sedimentary.

	J <sub>NRM</sub>	MDF	Inc.	S	D	Rock Type
51-1, 5-7 cm	---	---	---	6.82	2.88	G
51-1, 8-11 cm	1.85x10 <sup>-3</sup>	538	-11.3°	---	---	G
51-2, 11-13 cm	---	---	---	4.70	2.59	Brec.
51-3, 19-25 cm	---	---	---	4.77	(2.46)	Brec.
51-3, 50-52 cm	2.41x10 <sup>-3</sup>	281	+23.9°	---	---	PG
51-4, 7-10 cm	7.50x10 <sup>-3</sup>	548	-8.2°	---	---	PG

60-453-52 5187.0-5196.5 m (484.0-493.5 m, BSF)

**Gabbro-metabasalt polymict breccia**

Description similar to that for 453-51. Clast identification symbols (to right of metamorphism/alteration column) are the same. Several large gabbro cobbles were recovered, plus some large metabasalt fragments. Cement and alteration characteristics as in 453-51, except K-feldspar replacement of plagioclase in the lower part of Section 52-1 is more pervasive.

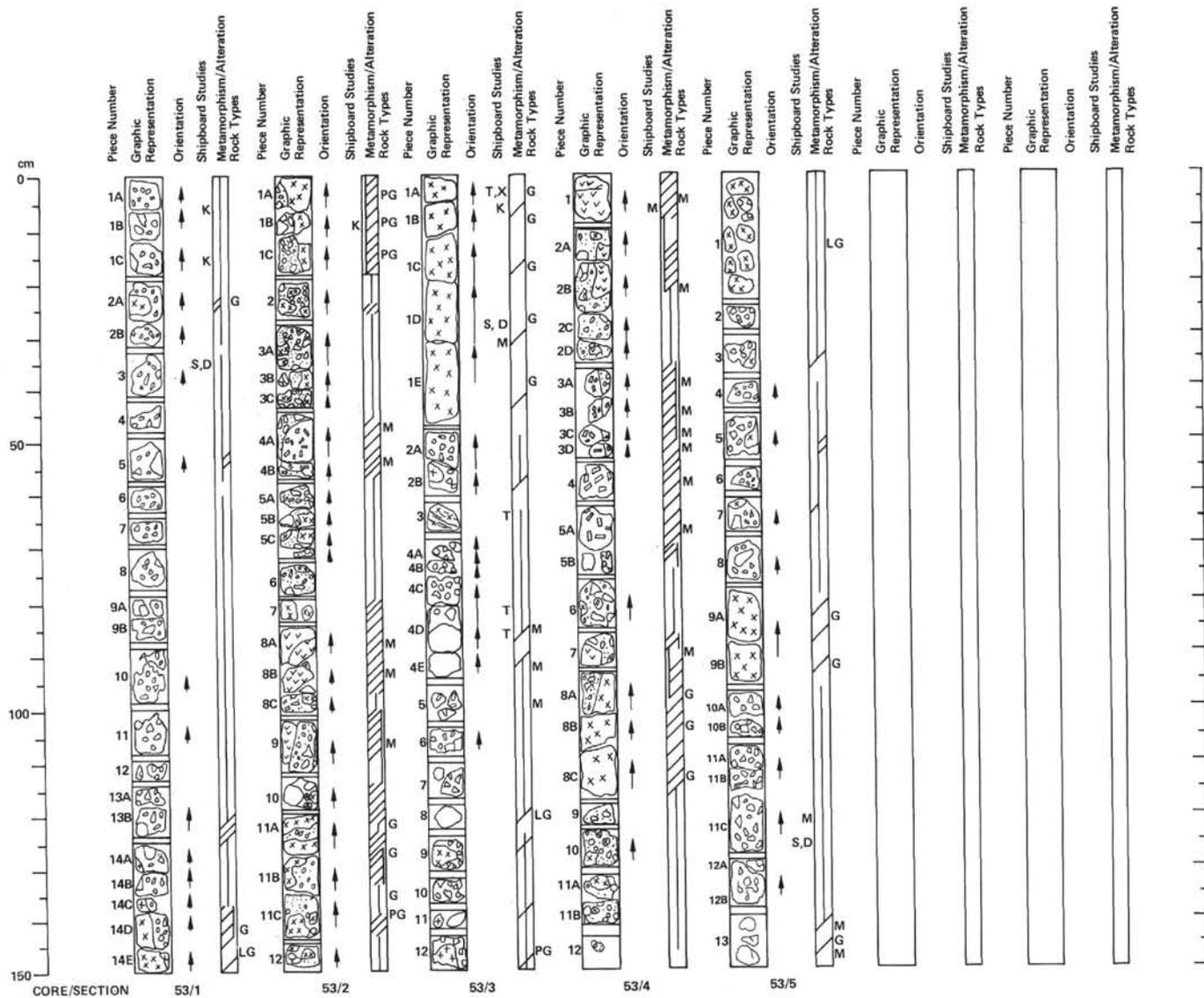
**Thin Section Data**

**Metabasalt: 52-1, 99-102 cm No. 12, Plagioclase-phyric metabasalt.**

Plagioclase phenocrysts 0.7-4.0 mm, An<sub>62</sub>, normally zoned, moderately altered to clays, = 15% of the rock. Groundmass (85% of rock) has altered plag (20%), cpx (65%), and magnetite (15%). Traces of vesicles are filled with chlorite. Groundmass alteration is pervasive, to chlorite, prehnite, sericite, actinolite, and epidote.

**Gabbro: 52-2, 94-97 cm No. 8, Hornblende.** Minerals are labradorite (50%) and hornblende (50%). Texture: hypidiomorphic-granular. Hblid replaces pyroxene; some pyroxene grains replaced by chlorite-actinolite aggregates. Plag is largely replaced by sericite.

	J <sub>NRM</sub>	MDF	Inc.	S	D	Rock Type
52-1, 120-126 cm	---	---	---	4.36	(2.67)	Brec.
52-2, 13-16 cm	.442x10 <sup>-3</sup>	270	+23.9°	---	---	G



60-453-53 5196.5-5206.0 m (493.5-503.0 m, BSF)

**Coarse gabbro-metasalt polymict breccia**

The core consists of fragments of polymict breccia ranging in size from coarse gabbro cobbles tens of centimeters long to pebble-sized angular to subrounded clasts of igneous and metamorphic rocks, mainly gabbros and metabasalts. Larger clasts include G = gabbro, LG = leucocratic gabbro, PG = pegmatitic gabbro, and M = metabasalt as indicated to the right of the metamorphism/alteration column. Cementing minerals are carbonate, chlorite, and reddish iron oxyhydroxides. The red color is especially pronounced in the matrix material cementing metabasalt pieces in the middle of Section 53-3. Ferromagnesian minerals (olivine, opx) in gabbros have been replaced by clays and reddish iron oxyhydroxides. Feldspars in the matrix and along edges of larger gabbro pieces have a bleached appearance (replaced by K-feldspar). A similar type of replacement can be seen in the outer few centimeters of the larger metabasalt pieces. Piece 3 of Section 53-3 is a foliated tonalite.

**Thin Section Data**

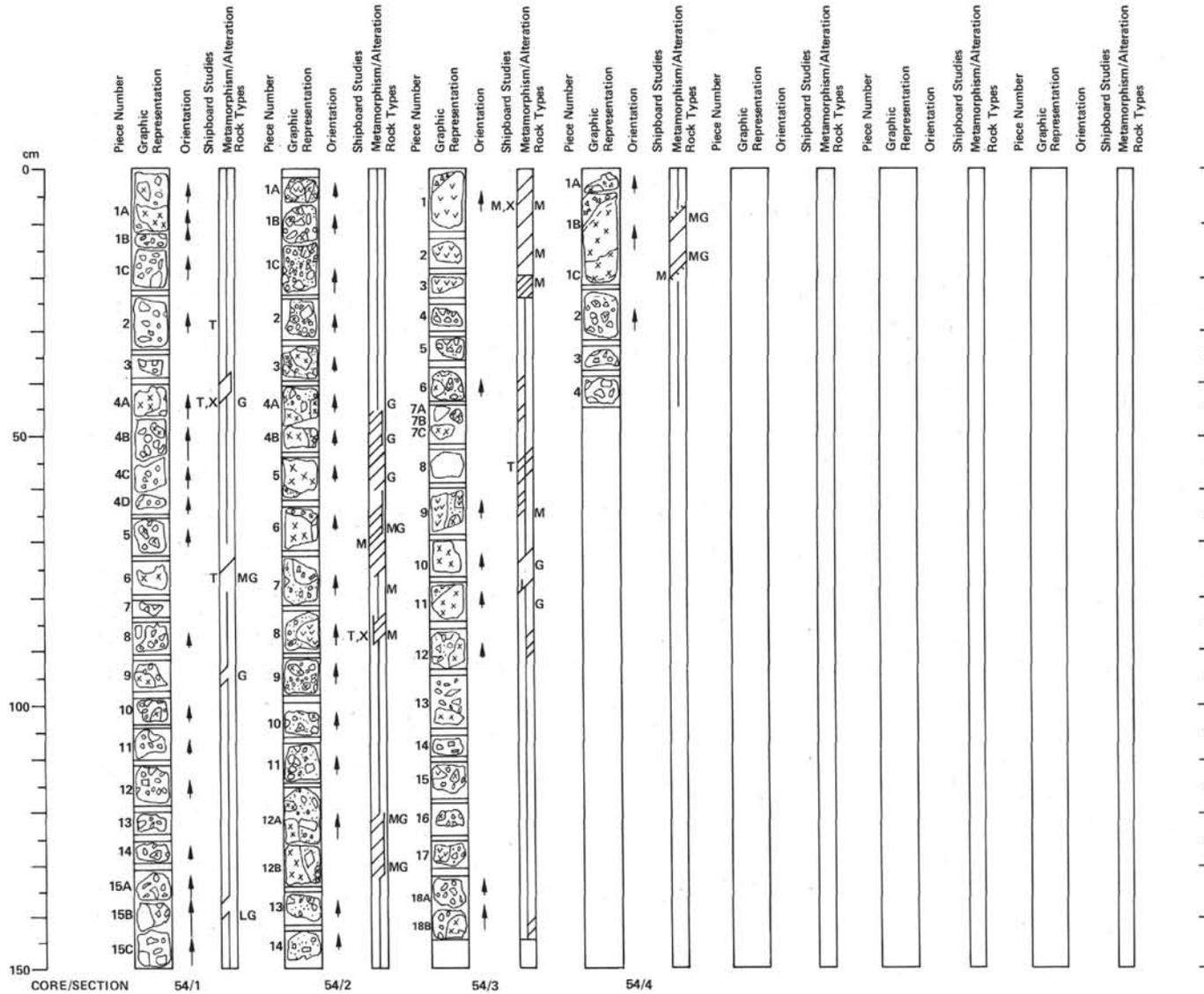
**Gabbro: 53-3, 0-5 cm No. 1, Pegmatitic olivine gabbro.** Texture: granular, poikilitic. Composition: plagioclase = 75%; olivine = 10%; cpx = 10%; opx = 10%. Alteration: olivine to opaques and reddish iron oxides; pyroxenes to chlorite and green hornblende; plagioclase to sericite and clay minerals.

**Tonalite: 53-3, 63-67 cm No. 3.** Texture: lepidogranoblastic (foliated). Composition: plagioclase An<sub>25</sub>An<sub>75</sub> (oligoclase-albite) = 50%; quartz = 40%; hornblende = 7-10%; magnetite = 1-2%. Subordinate biotite, apatite, zircon, and K-feldspar.

**Breccia (basaltic): 53-3, 70-81 cm No. 4D.** Texture: clastic, cemented. Composition: subangular metabasalt and mineral clasts = 65%; cement = 35%. Clasts originally had plag = 70%, cpx = 27%, magnetite = 3%, now almost totally replaced by chlorite, epidote, biotite, magnetite after cpx, and chlorite, pumpellyite, clays after plag. Cement has lepidogranoblastic texture, and is mainly carbonate and red clays, with grains of chlorite, epidote, prehnite, pumpellyite.

**Metabasalt: 53-3, 81-83 cm No. 4D, Altered diabase.** Texture: interstitial. Composition: plagioclase = 50%, interstitial amphibole + chlorite + Fe-Ti oxide + minor euhedral biotite = 50%. Plag 0.1-2.0 mm, zoned rims, partially altered to sericite.

	J-NRM	MDF	Inc.	S	D	Rock Type
53-1, 33-34 cm	—	—	—	4.84	2.53	Brec.
53-3, 24-26 cm	—	—	—	6.57	3.04	G
53-3, 28-31 cm	1.44x10 <sup>-3</sup>	58	(+62.6°)	—	—	G
53-4, 5-8 cm	.442x10 <sup>-3</sup>	64	-49.6°	—	—	M
53-5, 121-123 cm	34x10 <sup>-6</sup>	55	(-9.8)	—	—	Brec.
53-5, 123-126 cm	—	—	—	4.75	2.54	Brec.



**Coarse gabbro-metabasalt polymict breccia**

The core consists of fragments of polymict breccia containing mainly pebble-sized angular clasts of igneous and metamorphic rocks, largely mafic gabbro and metabasalt. Larger clasts include G = gabbro, MG = mafic gabbro, LG = leucocratic gabbro, and M = metabasalt. Cementing minerals in the breccia matrix are carbonate, chlorite, and reddish iron oxyhydroxides. Mafic minerals in the gabbros have been replaced largely by clays and reddish iron oxides. Mafic gabbros are more abundant in this core than in cores above. Plagioclase chips in the breccia matrix have a bleached appearance, having been replaced by K-feldspar. Prominent bleached coronas surround many gabbro clasts.

**Thin Section Data**

**Gabbros: 54-1, 40-47 cm No. 4A, Anorthositic gabbro.** Composition: labradorite 80-85%, altered pyroxenes = 15-20%. Texture: poikilitic. Opx replaced by chlorite and green hornblende. Patches of chlorite in cpx crystals. Plag replaced by sericite. Many narrow cracks filled by chlorite-actinolite aggregates.

**54-1, 75-77 cm No. 6, Amphibole gabbro.** Composition: hornblende = 70%, secondary minerals after plagioclase (prehnite-pumpellyite?) = 30%. Texture: hypidiomorphic granular.

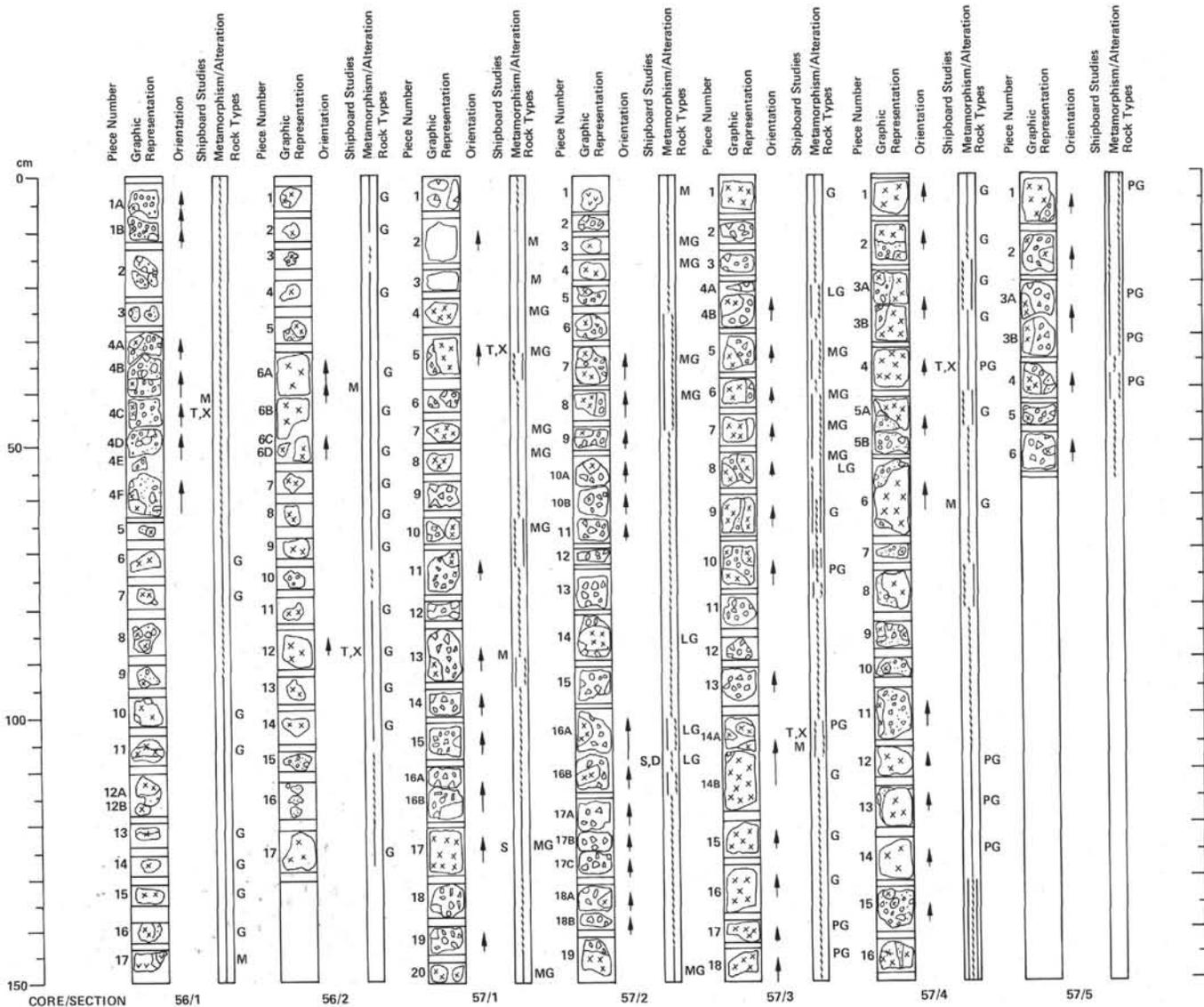
**54-4, 18-20 cm No. 1C, Anorthositic gabbro (altered).** Original composition: labradorite-bytownite = 85%, pyroxene = 15%, magnetite = trace. Texture: originally panidiomorphic granular. Now all pyroxene grains converted into lepidoblastic aggregates of actinolite, chlorite, minor carbonate, and Fe-oxyhydroxides. Plag partly replaced by clay minerals and sericite.

**Metabasalts: 54-3, 55-58 cm No. 8, Sparsely-phyric metamorphosed diabase.** Phenocrysts all plagioclase = 2% of rock. Composition = An50-gg. Groundmass: plagioclase = 67%, 0.2-1.0 mm. Angg. Magnetite = 3%; rest are secondary minerals, prehnite = 1-2%, biotite = 5%, and chlorite = 25%. Prehnite after plagioclase, chlorite after cpx.

**54-3, 106-109 cm No. 14, Plagioclase-clinopyroxene-olivine metabasalt.** Phenocrysts = 30%, of which plagioclase = 98% up to 5 mm, cpx = 2%, magnetite = trace. Groundmass = 70% of rock, of which plagioclase = 60% 0.3-0.7 cm, An50, cpx = 5%, magnetite = 5%, biotite = 3%, and chlorite = 27%. Alteration = 30% of groundmass, mainly biotite and chlorite after cpx. Iddingsite after olivine phenocrysts.

	NRM	MDF	Inc.	S	D	Rock Type
54-1, 24-31 cm	—	—	—	4.71	(2.64)	Brec.
54-2, 67-69 cm	1.28x10 <sup>-3</sup>	278	+55.0°	—	—	MG
54-3, 5-8 cm	.765x10 <sup>-3</sup>	61	(+22.2°)	—	—	M
54-4, 16-19 cm	1.28x10 <sup>-3</sup>	256	(+57.3°)	—	—	MG





60-453-56 5226.0-5234.5 m (522.0-531.5 m, BSF)

**Coarse gabbro-metabasalt polymict breccia, retrograde metamorphosed**

Polymict breccia containing pebble- to boulder-sized angular clasts of igneous and metamorphic rocks, mainly mafic gabbros. The entire core has been hydrothermally retrograde metamorphosed to chlorite-rich pyritic secondary mineral assemblages. Larger clasts include G = gabbro, and M = metabasalt, listed next to metamorphism/alteration column. Identification of the types of gabbro is hindered by retrograde metamorphism. The Matrix is gray-green in color with numerous smaller bleached plagioclase-rich gabbro chips and pebbles.

**Thin Section Data**

**Gabbros: 56-2, 33-35 cm No. 6A, Altered anorthositic gabbro.** Composition: plagioclase = 90%, secondary chlorite, actinolite and magnetite = 10%. Texture: granular.

**56-2, 85-87 cm No. 12A, Altered gabbro.** Plagioclase partly converted to sericite, chlorite, clay minerals, and probably prehnite and pumpellyite. Mafic minerals replaced by chlorite, actinolite, and epidote.

	J <sub>NRM</sub>	MDF	Inc.	S	D	Rock Type
56-1, 38-40 cm	---	---	---	4.15	2.56	Brec.
56-1, 42-44 cm	< 10 <sup>-7</sup>	---	---	---	---	Brec.
56-2, 36-39 cm	< 10 <sup>-7</sup>	---	---	---	---	G

Note: Samples in this core have been almost completely demagnetized by hydrothermal alteration.

60-453-57 5234.5-5244.0 m (531.5-541.0 m, BSF)

**Coarse gabbro-metabasalt polymict breccia, retrograde metamorphosed**

The core consists of indurated polymict breccia containing pebble- to boulder-sized clasts of igneous and metamorphic rocks, mainly mafic gabbros. All of the core but a portion of the lower two sections has been retrograde hydrothermally metamorphosed to chlorite-rich, pyrite-bearing mineral assemblages. Larger clasts include G = gabbro, MG = mafic gabbro, LG = leucocratic gabbro, and PG = pegmatitic gabbro. Metabasalts are minor, making the breccia virtually monomict in places. The chlorite-rich matrix is gray-green in color with numerous smaller bleached plagioclase rich gabbro chips and pebbles. Mafic minerals in the gabbros are altered to chloritic assemblages. Traces of the originally brown-colored breccia matrix still persist in Sections 4 and 5.

**Thin Section Data**

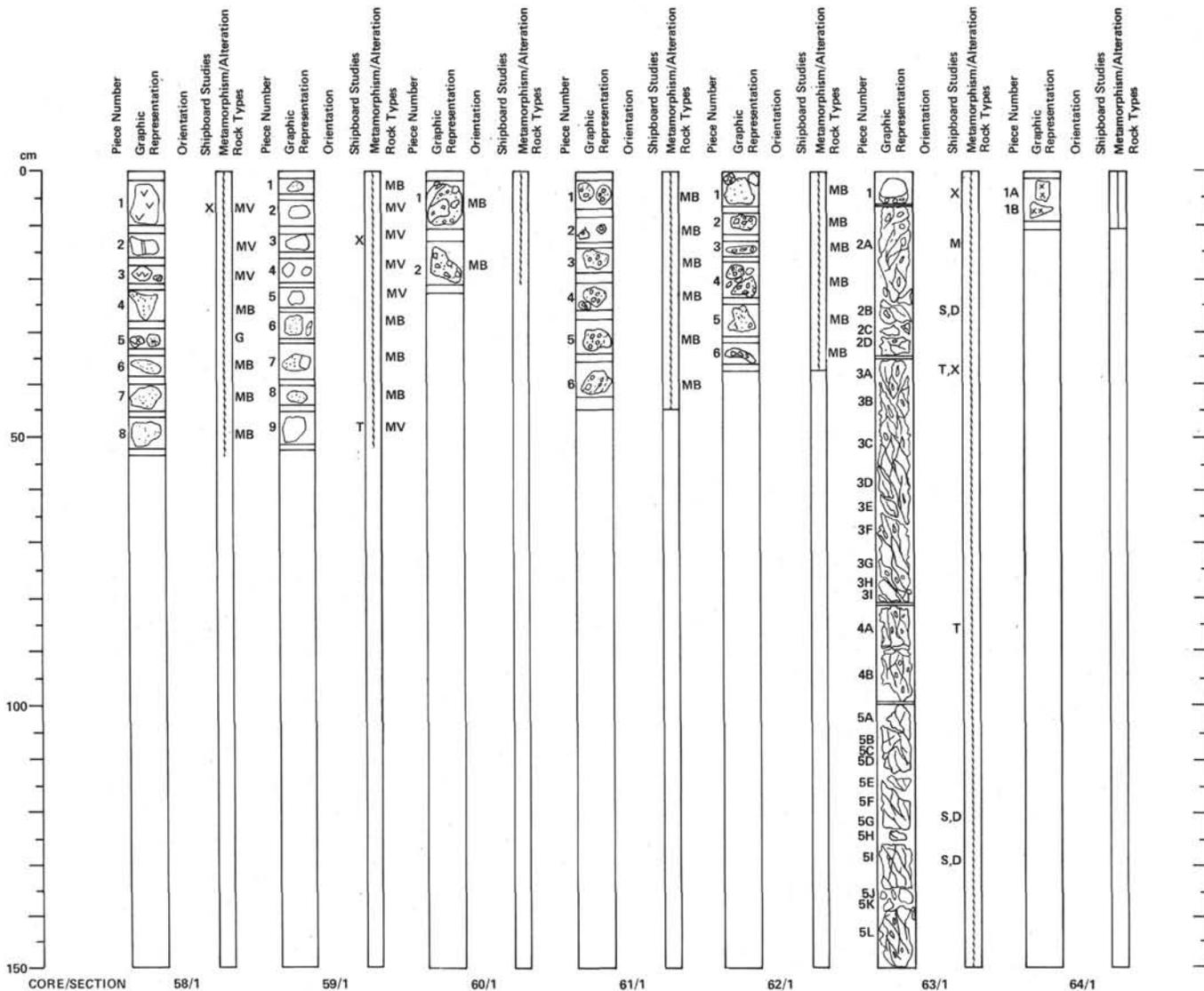
**Gabbros: 57-3, 10-12 cm No. 2, Troctolite.** Composition: Bytownite = 85%, altered intercumulus olivine + magnetite = 15%. Texture: equigranular, cumulate. Alteration: olivine replaced by serpentine, chlorite and magnetite, plagioclase by sericite and clay minerals.

**57-4, 33-36 cm No. 3A, Pegmatitic olivine anorthositic gabbro.** Composition: plagioclase = 90%, cpx = 5%, olivine = 3%, magnetite = 2%. Texture: poikilitic, granular. Alteration: Mafic minerals altered to chlorite, serpentine, magnetite, actinolite. Plagioclase to sericite, chlorite, clay minerals.

**57-4, 106-109 cm No. 11, Coarse pegmatitic olivine gabbro.** Composition: cpx = 70%, olivine = 10%, plagioclase = 18%, magnetite = 2%. Texture: poikilitic. Alteration: moderate; serpentine after olivine, chlorite and actinolite after pyroxene, sericite after plagioclase.

**57-4, 127-131 cm No. 14, Altered troctolite.** Composition: serpentinized olivine = 50%, bytownite = 50%, minor green spinel. Texture: equigranular. Alteration: ol nearly replaced by serpentine, magnetite, chlorite, brucite, only relict grains left. Plagioclase partly replaced by chlorite, clay minerals, prehnite(?).

	J <sub>NRM</sub>	MDF	Inc.	S	D	Rock Type
57-1, 88-91 cm	1.03 x 10 <sup>-3</sup>	77	+49.0°	---	---	Brec.
57-1, 123-125 cm	---	---	---	5.40	2.48	Brec.
57-2, 108-113 cm	---	---	---	5.78	(2.73)	Brec.
57-3, 111-113 cm	1.29 x 10 <sup>-3</sup>	507	+57.2°	---	---	G
57-4, 59-62 cm	.919 x 10 <sup>-3</sup>	133	-45.6°	---	---	G



60-453-58	5224.0-5255.5 m (541.0-550.5 m, BSF)
60-453-59	5253.5-5263.0 m (550.5-560.0 m, BSF)
60-453-60	5265.5-5272.5 m (560.0-569.5 m, BSF)
60-453-61	5275.5-5282.0 m (569.5-579.0 m, BSF)
60-453-62	5282.0-5291.5 m (579.0-588.5 m, BSF)

Metavolcanic, minor metagabbro polymict breccia, hydrothermally altered

These cores, all of which had low recovery, consist largely of cobbles of metavolcanic rocks with minor metagabbros, and either friable or indurated green metabreccias. The cobbles and breccias have been hydrothermally altered to chlorite-rich pyritic mineral assemblages. Clasts include MV = metavolcanic rock (unspecified metamorphosed basalt, andesite, or dacite), MB = micro-breccia, metamorphosed, G = gabbro. Microbreccias in Cores 58-61 include softer, dark green or gray-brown breccias (58-1, Nos. 3, and 5-7), and indurated, lighter green breccias (MB pieces in 59-61). The former may have been hyaloclastites, the latter pyroclastic in origin. Breccias in Core 62 are probably drilling breccias. A prominent vein cuts Piece 58-1, No. 2.

**Thin Section Data**  
 59-1, 47.49 cm No. 9, Totally altered pyroclastic volcanic rock. Texture: amygdaloidal, grano- and lepidogranoblastic. Amygdules: 7% of rock volume, filled by carbonate, quartz, zeolite(?). The same minerals are in cracks together with chlorite and clays. Matrix: very fine-grained aggregate of clays, quartz, chlorite, carbonate, and opaques.

60-453-63	5291.5-5301.0 m (588.5-598.0 m, BSF)
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Metabasalt and sheared serpentized gabbro-norite

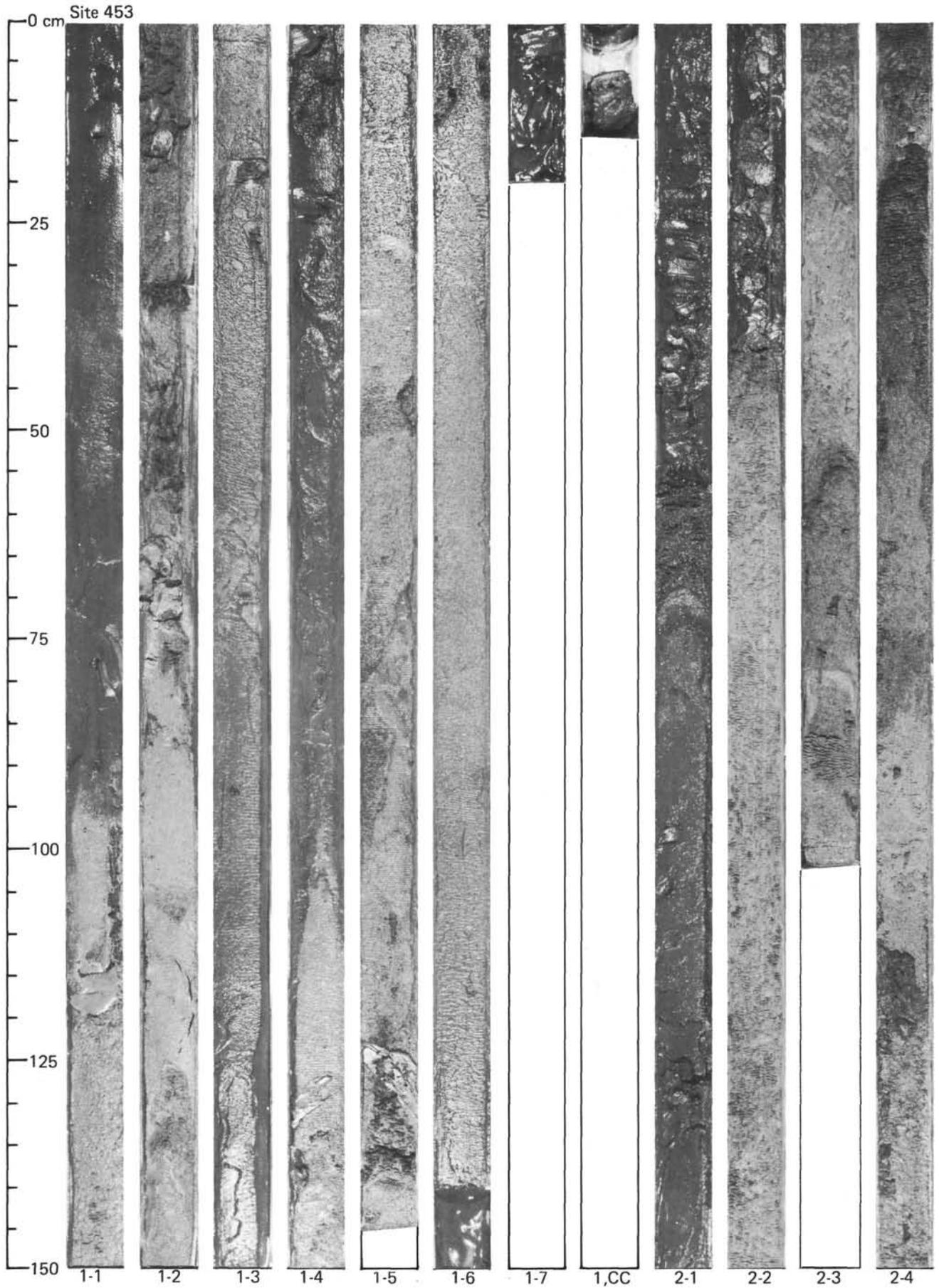
Piece No. 1 is a fragment of medium bluish gray metabasalt, with greenish gray breccia cement on one edge. All other pieces are highly sheared greenish black serpentized gabbro-norite. Originally, the rock was coarse grained, probably with cumulus texture, but now it has a tectonized fabric. Many fracture surfaces have slickensides and are cemented by serpentized "mylonite". Pyrite veins the lower portions of the core.

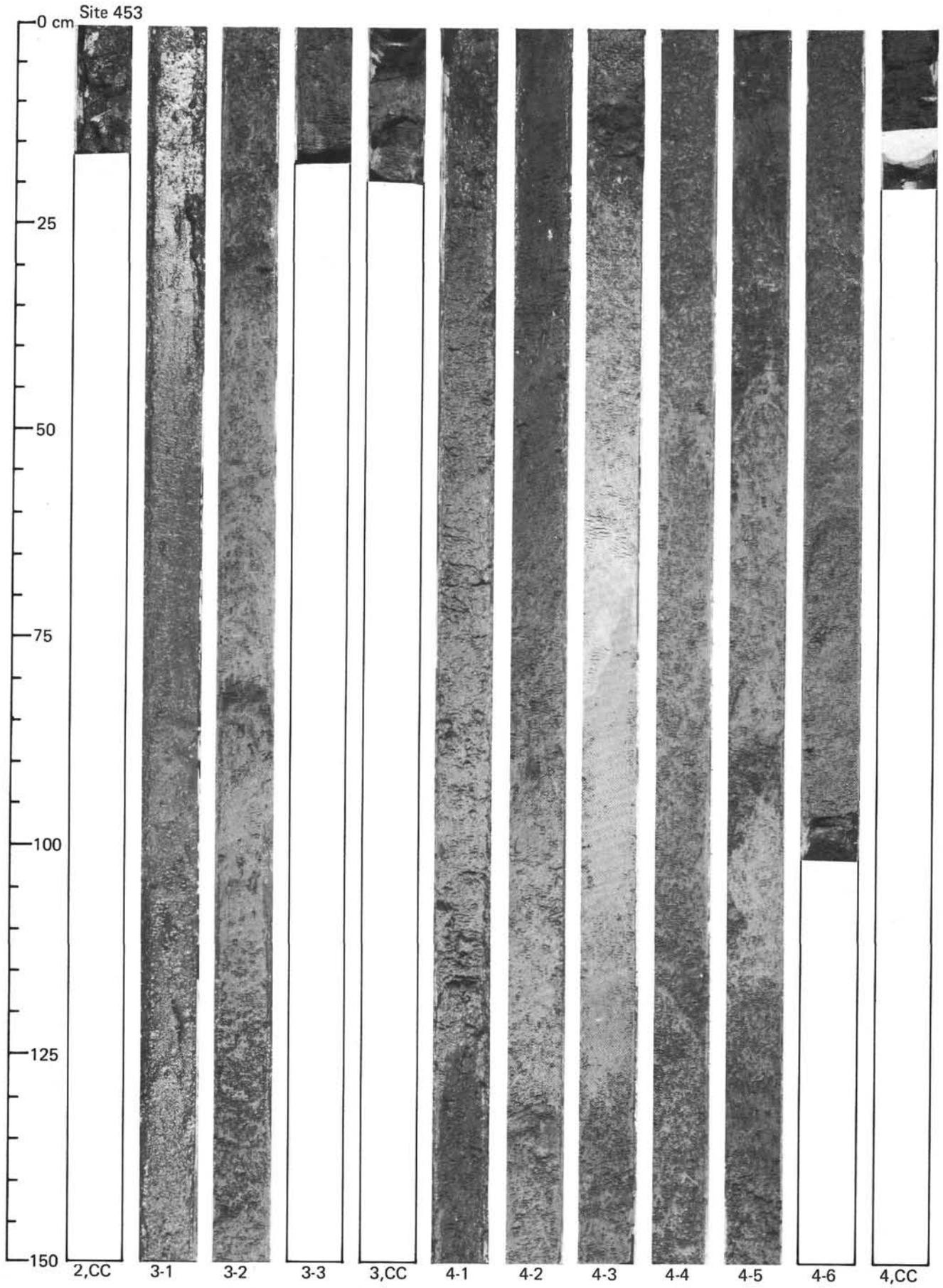
**Thin Section Data**  
 Gabbro-norite: 63-1, 80-83 cm No. 4A. Composition: clasts of deformed gabbro with abundant green hornblende (secondary after pyroxene) cemented by a serpentized matrix. Originally had cpx = 80-85%, plagioclase = 15-18%, opaques = 2-5%, minor stibiomelane or biotite. Texture: clastic, foliated.

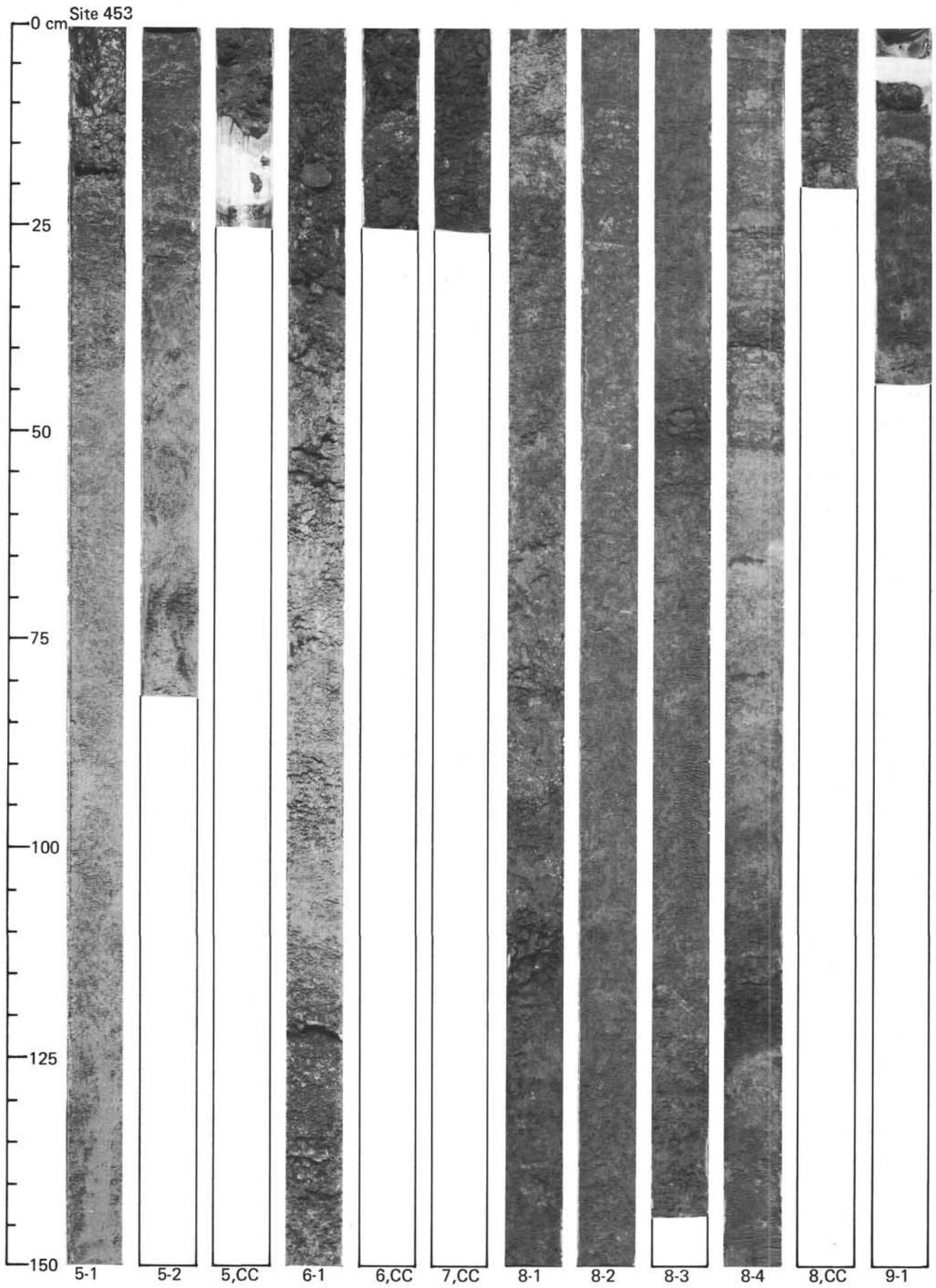
	J-NRM	MDF	Inc.	S	D	Rock Type
63-1, 11-13 cm	.878x10 <sup>-3</sup>	49	No	---	---	Serp. gabbro
63-1, 25-27 cm	---	---	---	4.21	2.82	Serp. gabbro
63-1, 121-123 cm	---	---	---	6.10	3.05	Serp. gabbro
63-1, 127-130 cm	---	---	---	5.19 (2.77)	---	Serp. gabbro

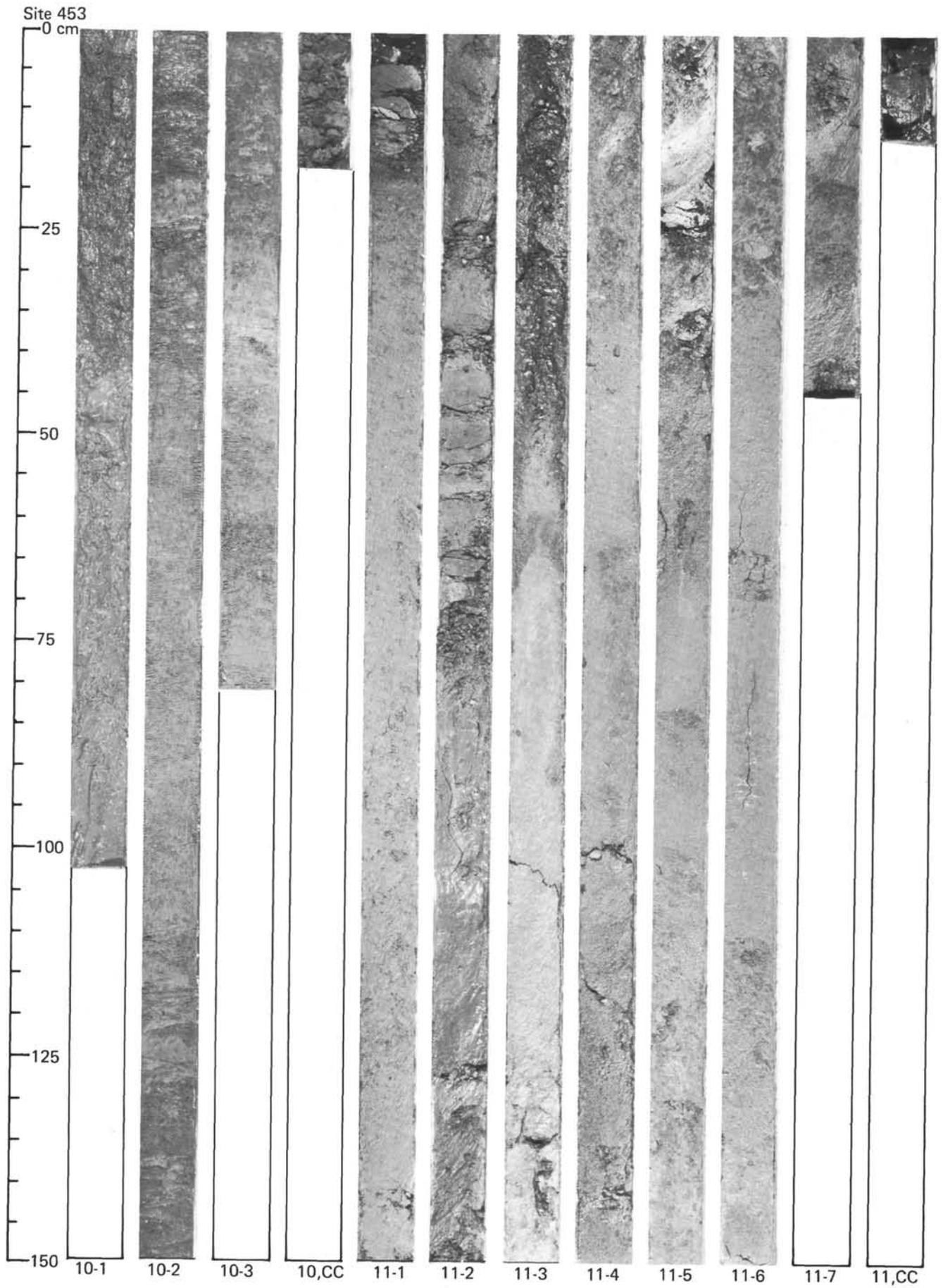
60-453-64	5301.0-5308.0 m (598.0-605.0 m, BSF)
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Possible metagabbro, medium grained, grayish green, foliated texture, with abundant chlorite-albite(?) veins. Rock may have fallen down the hole from above the serpentized norite-gabbro cataclastite of Core 63.



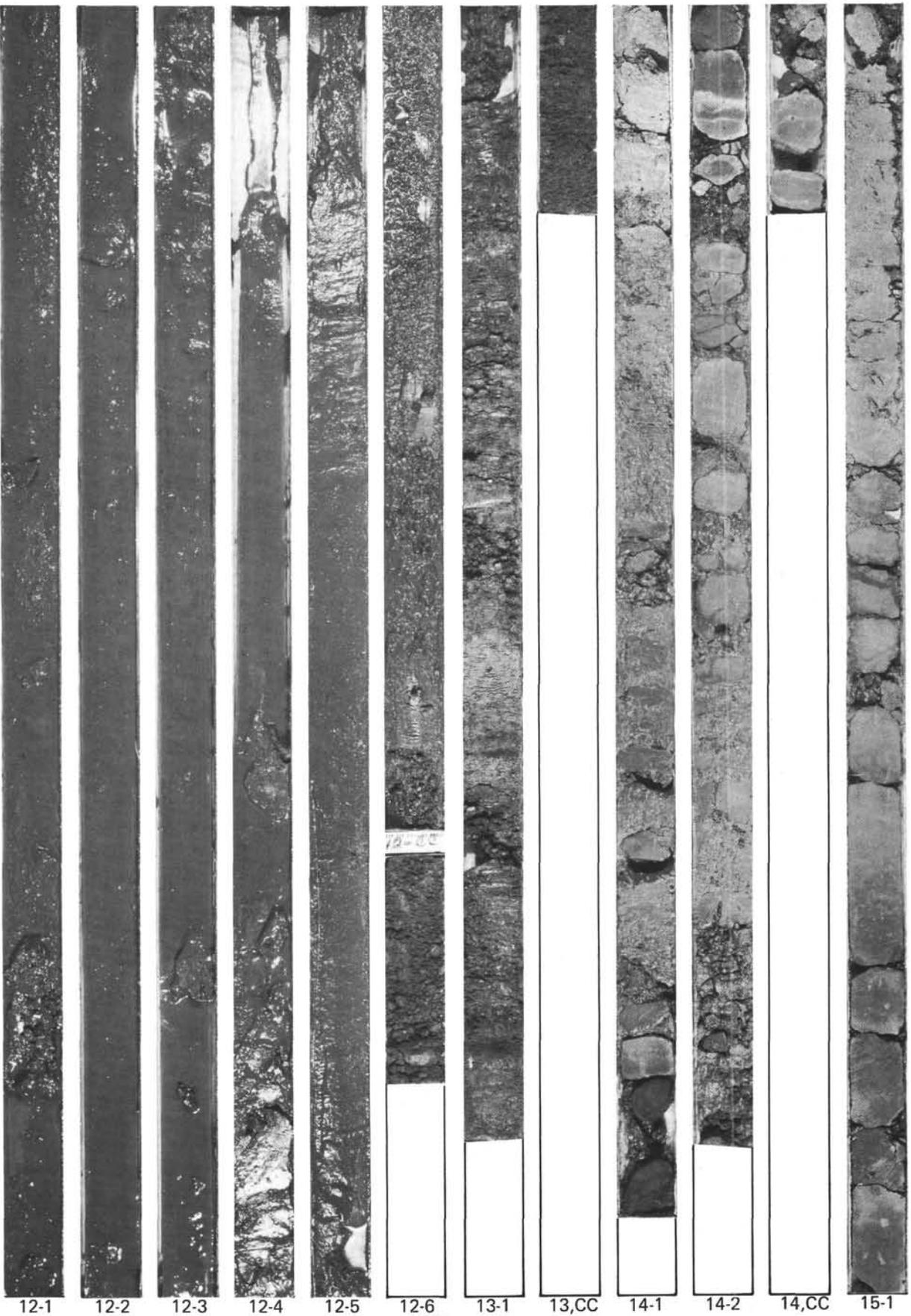


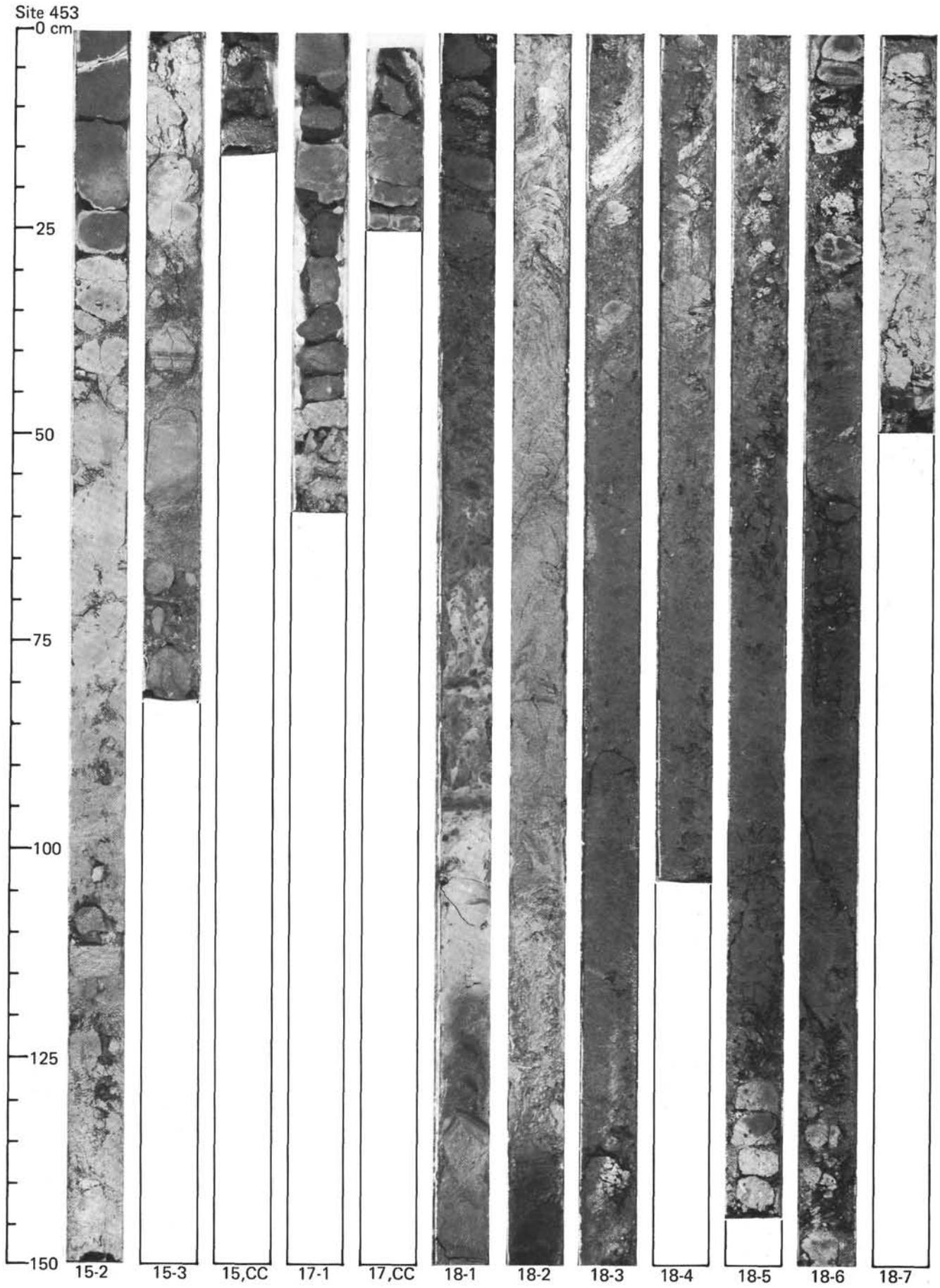




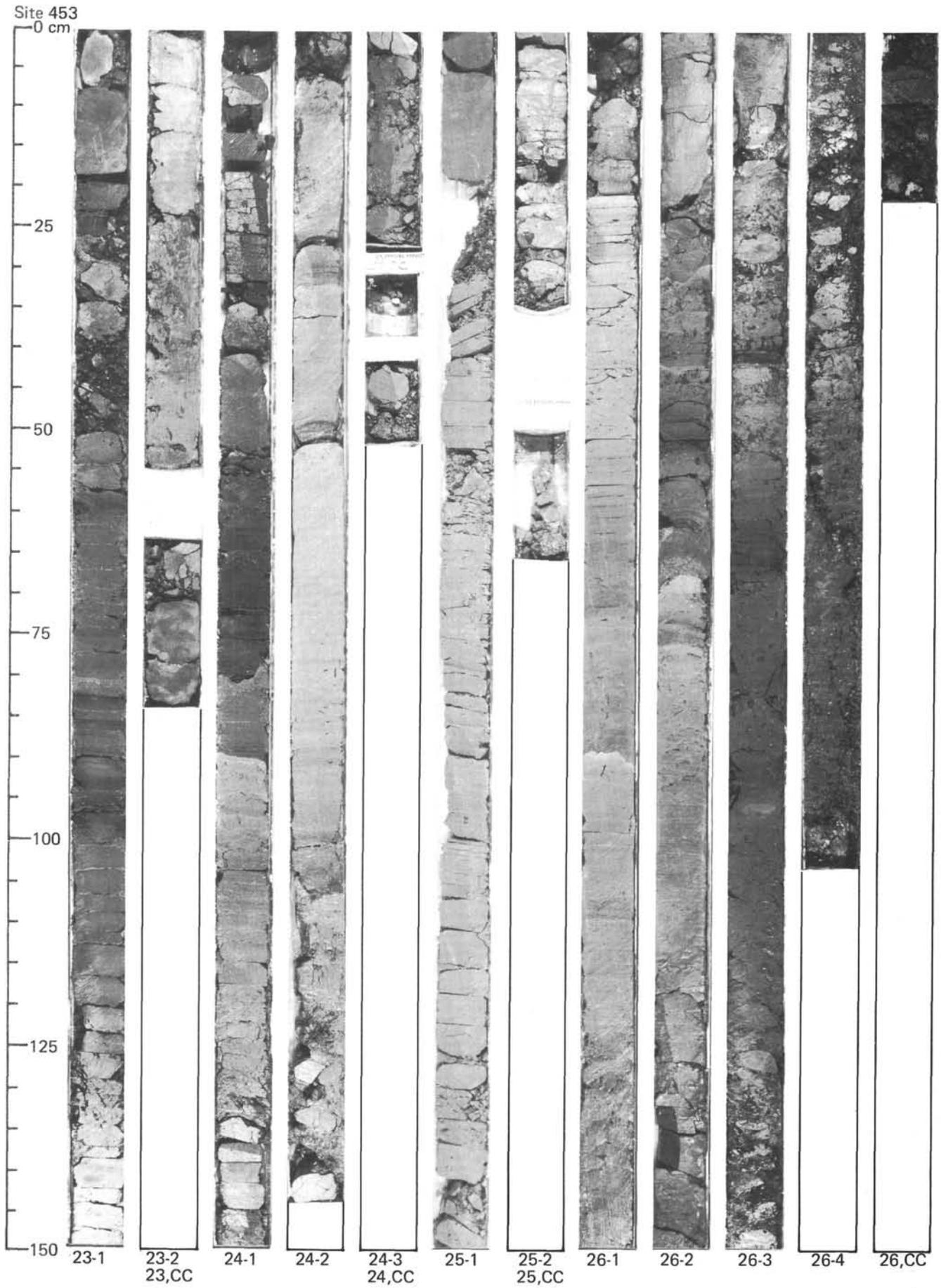
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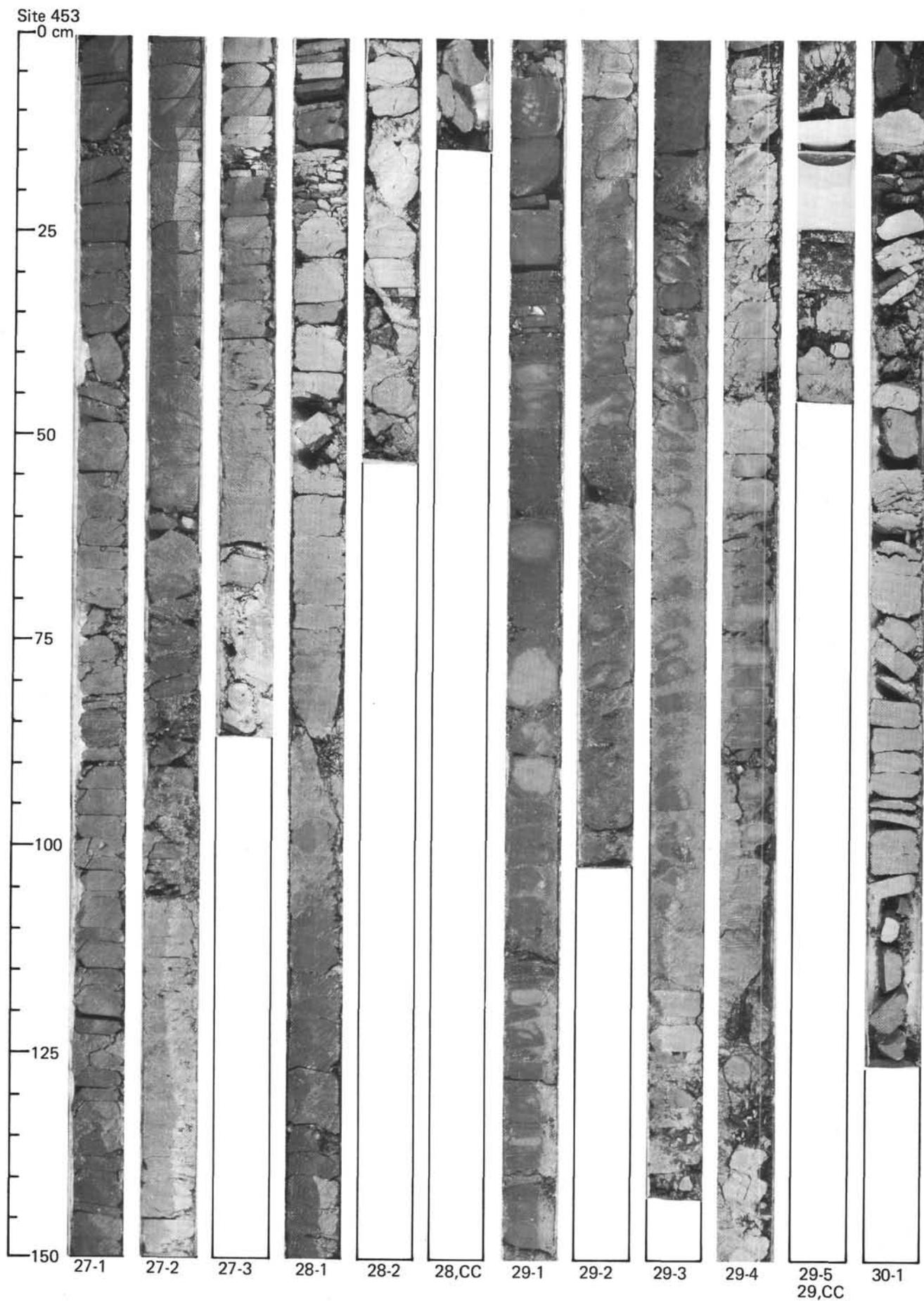
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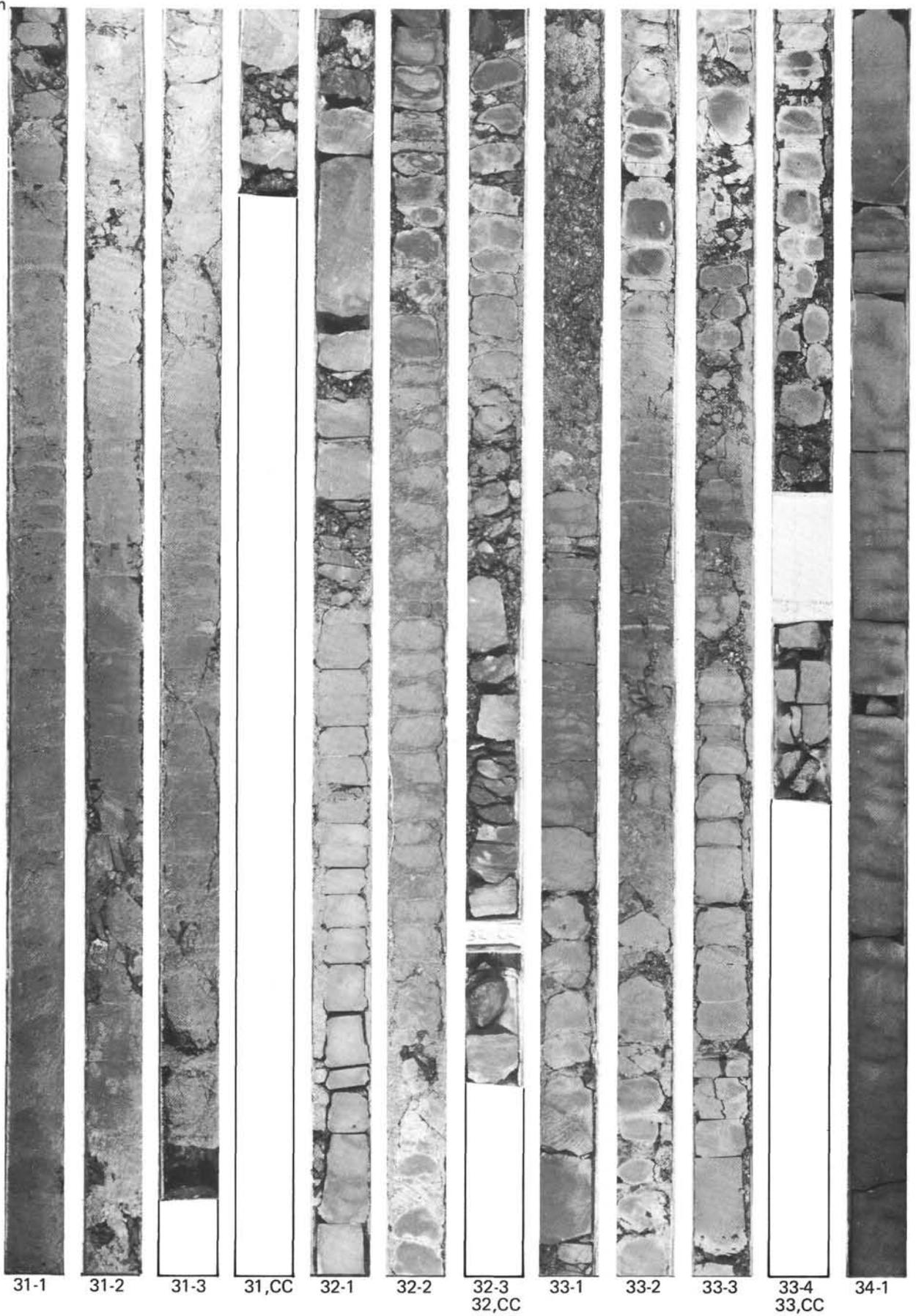
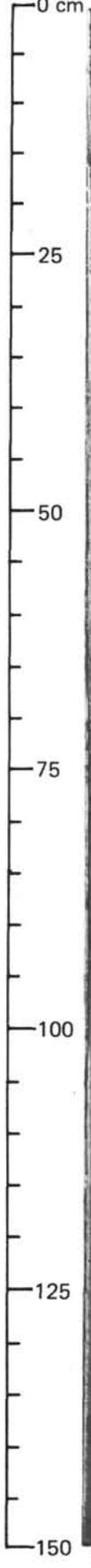




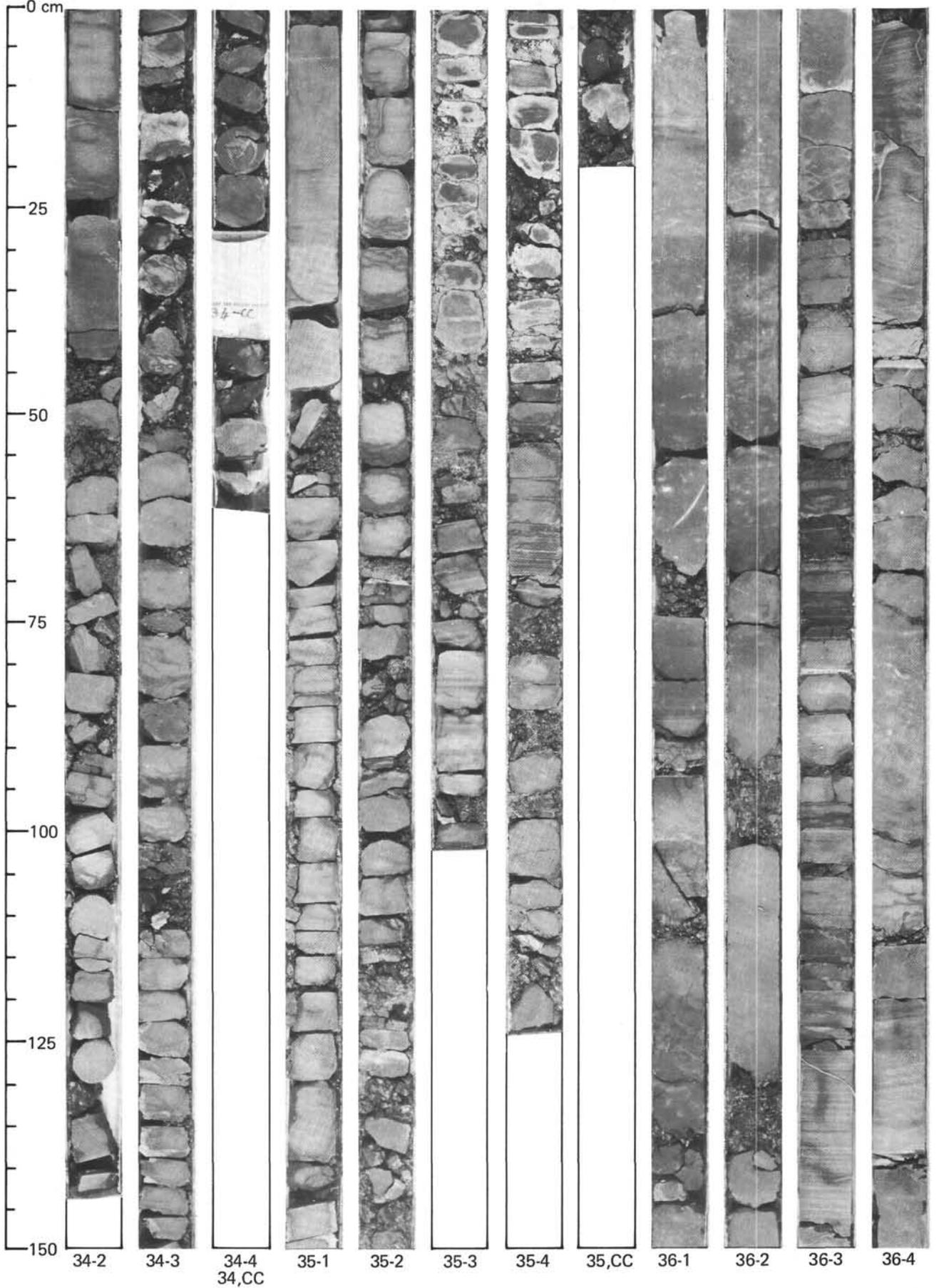


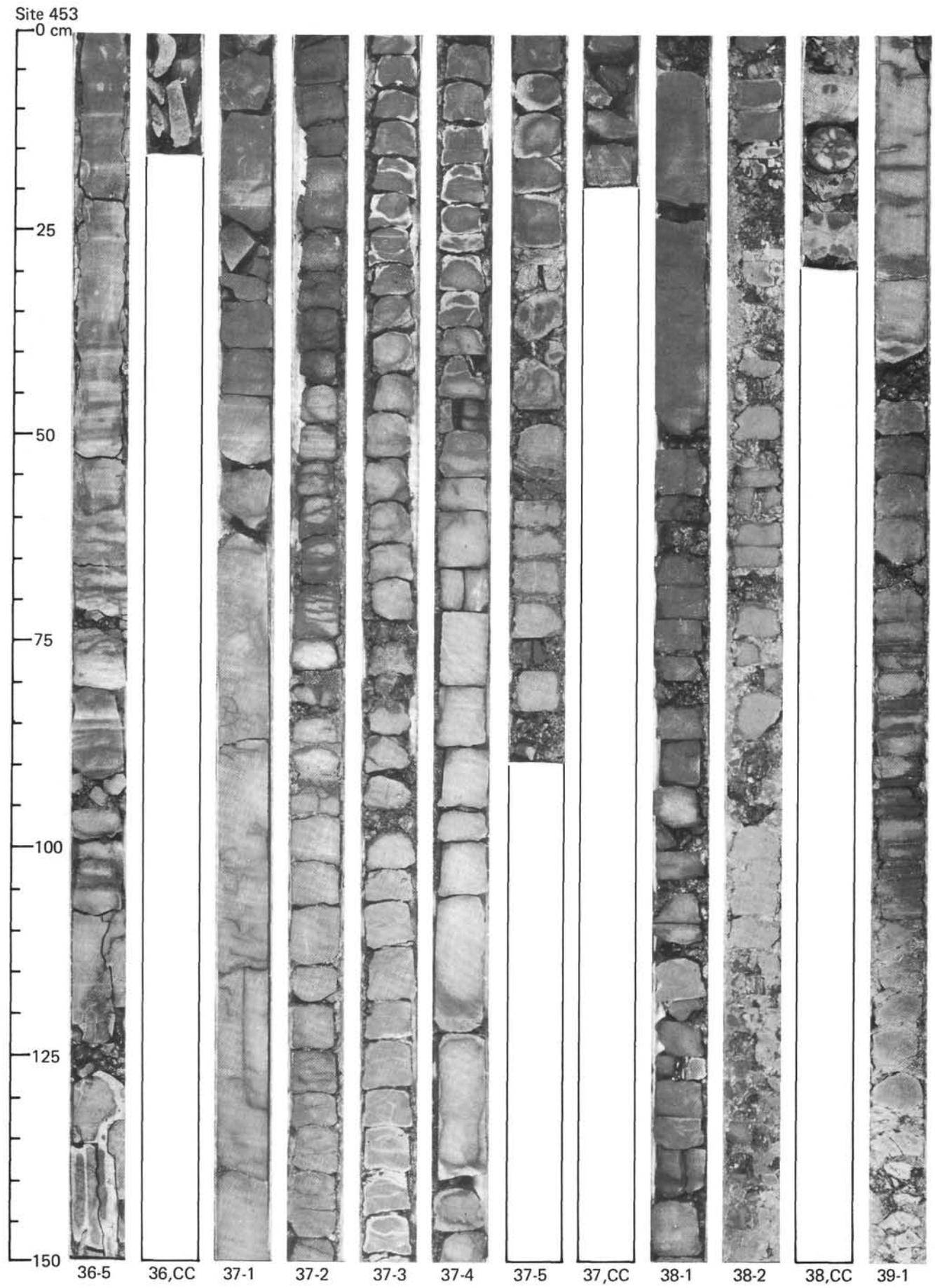


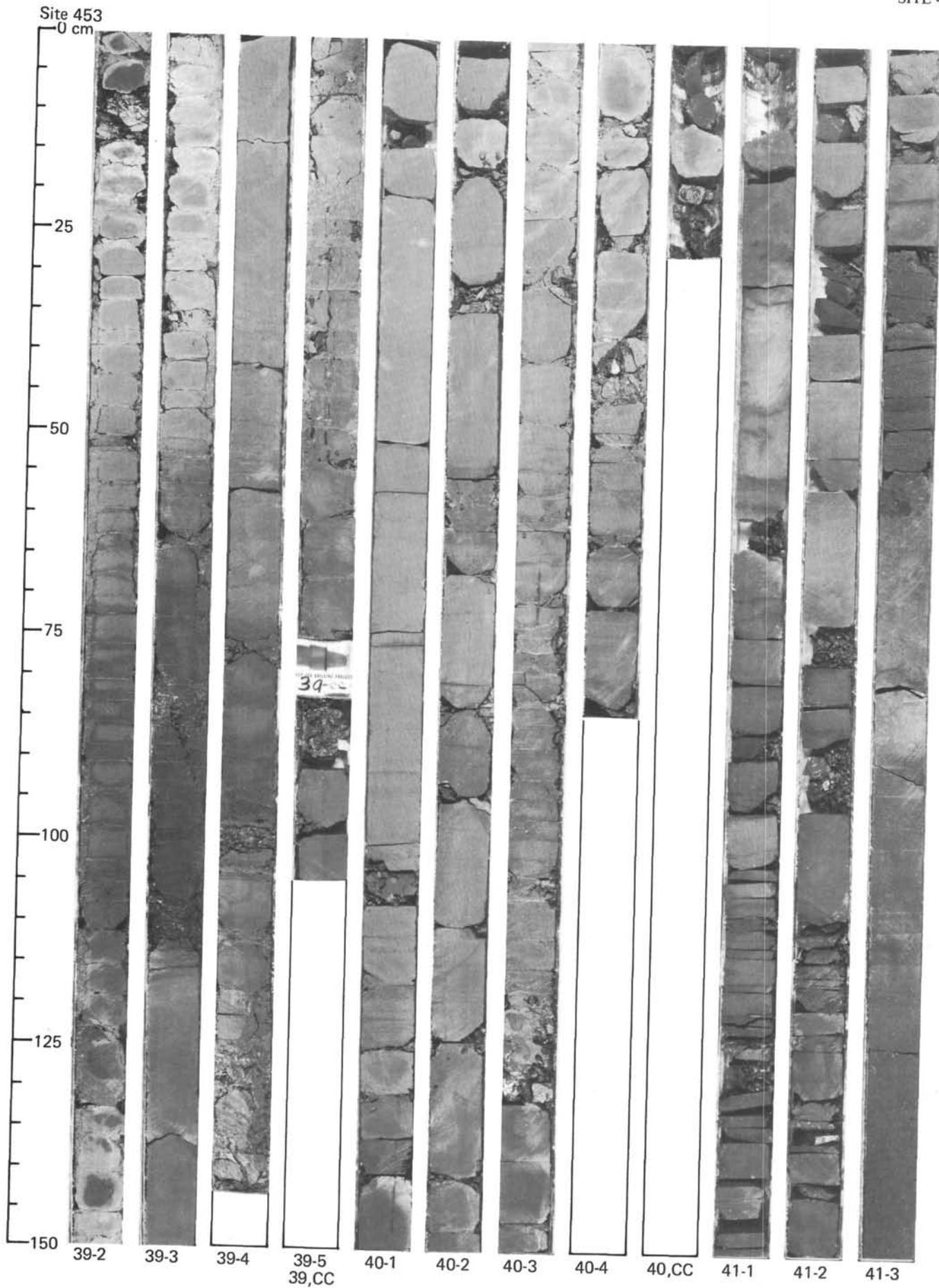
Site 453

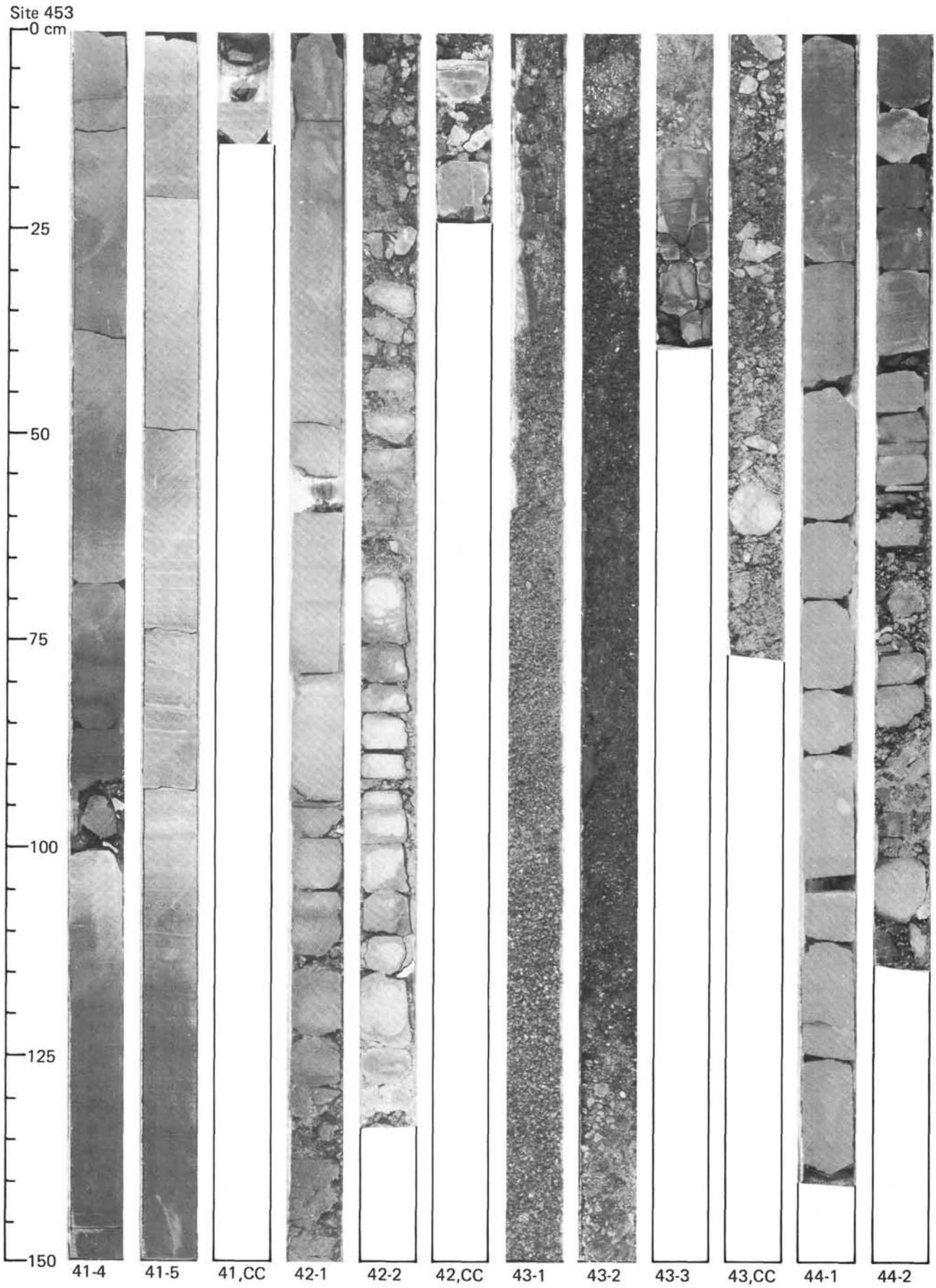


Site 453

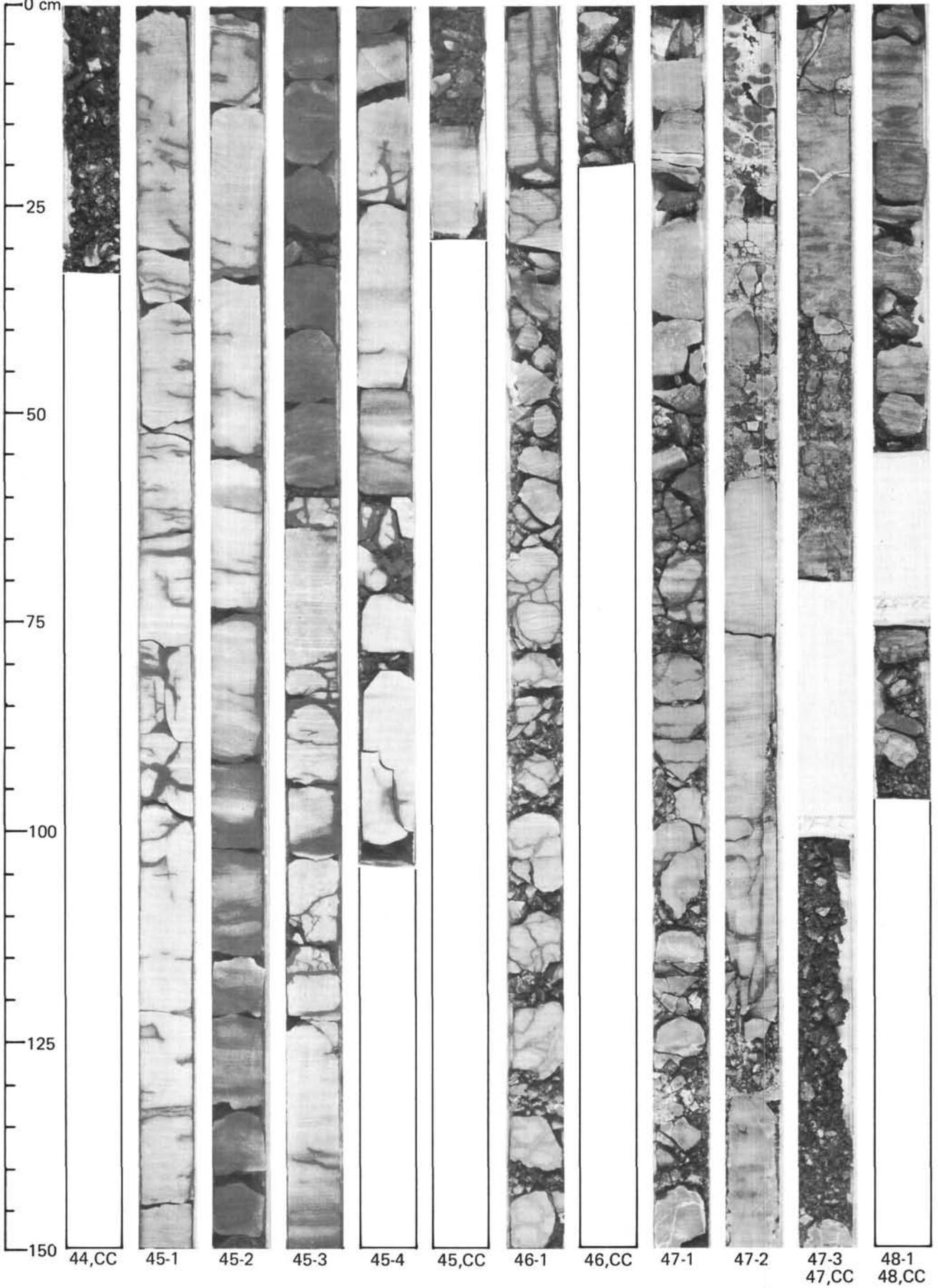




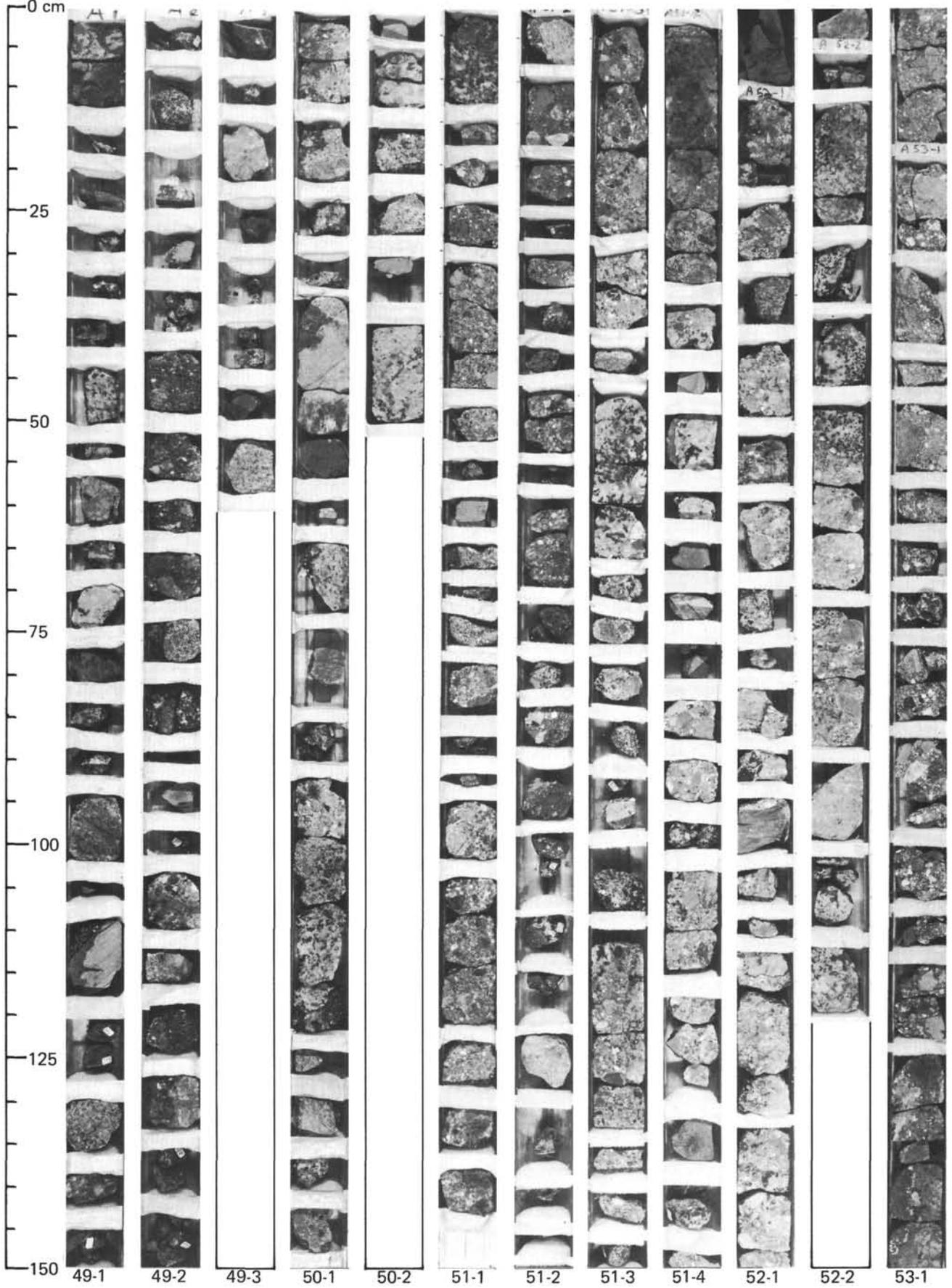




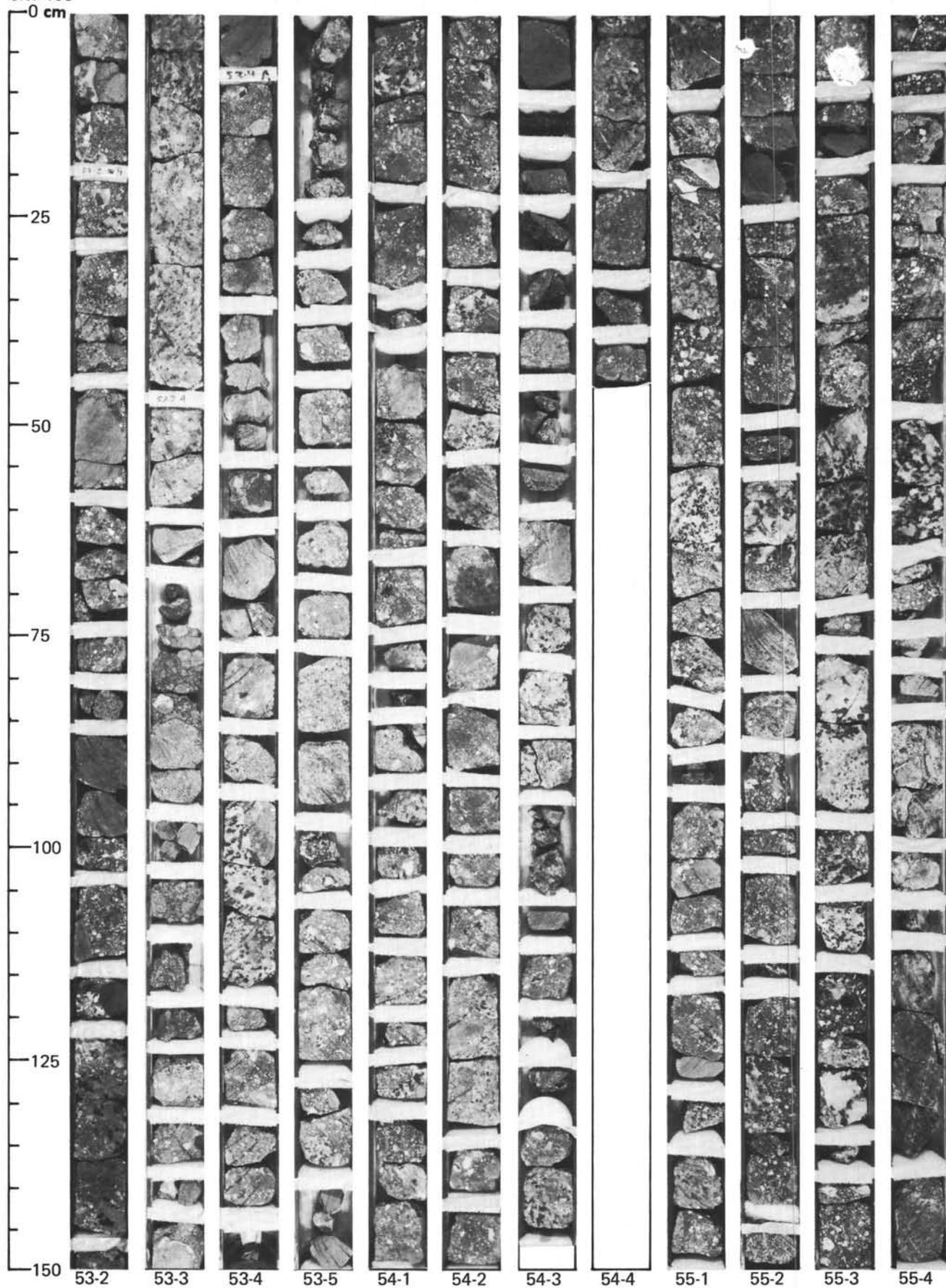
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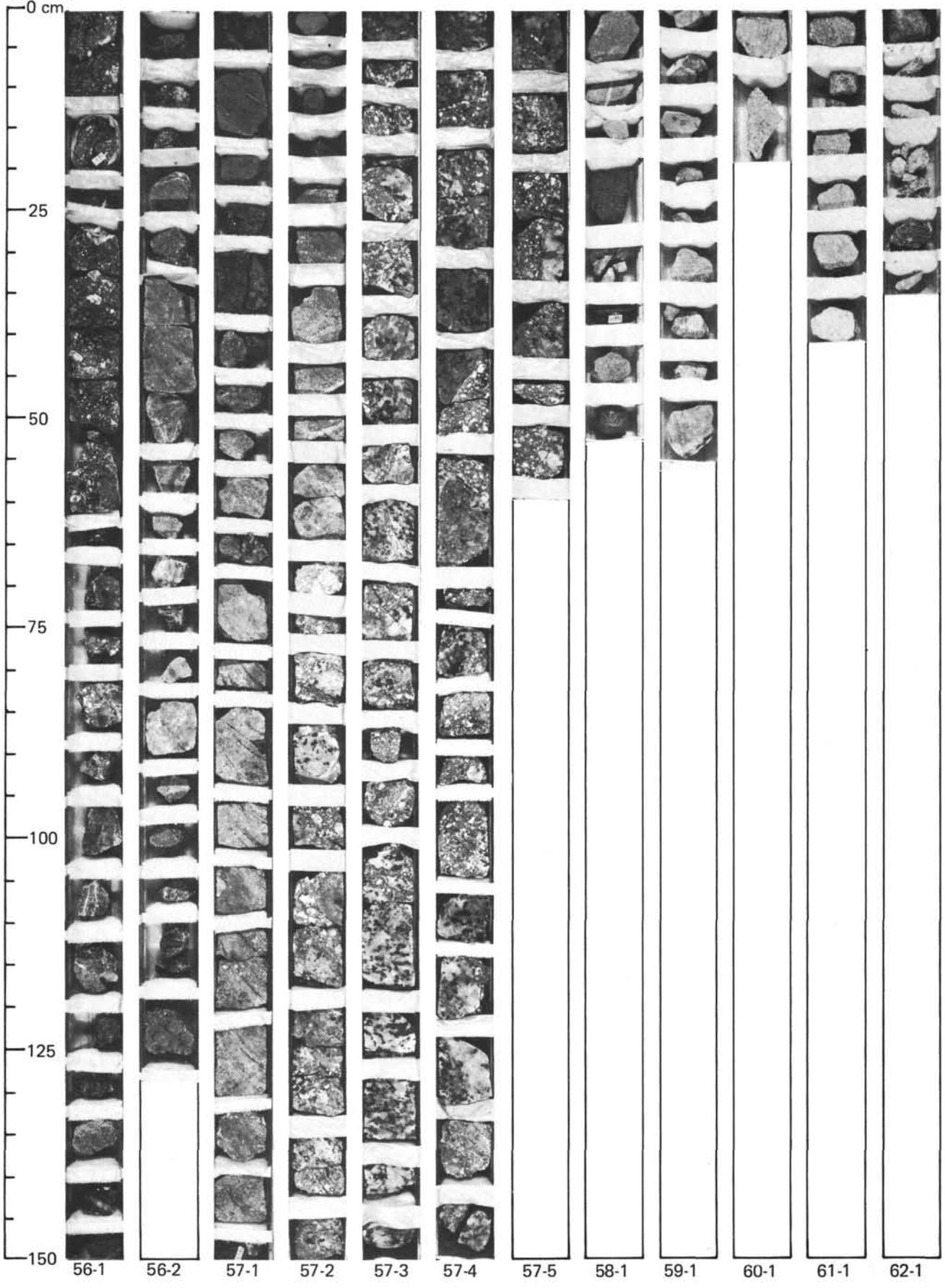
Site 453



Site 453



Site 453



Site 453

