4. SITE 409

Shipboard Scientific Party[1]

SITE DATA

Date Occupied: 1500Z 2 August 1976

Date Departed: 0630Z 4 August 1976

Time on Hole: 39.5 hours

Position: Latitude: 62°36.98′N; Longitude: 25°57.17′W

Water Depth (sea level): 832 corrected meters, echo sounding

Water Depth (rig floor): 842 corrected meters, echo sounding

Bottom Felt at: 843 meters, drill pipe

Penetration: 319 meters

Number of Holes: 1

Number of Cores: 32

Total Length of Cored Section: 295.5 meters

Total Core Recovered: 88.43 meters

Percentage Core Recovery: 30 per cent

Oldest Sediment Cored:
Depth sub-bottom: 81.5 meters
Nature: Sandy calcareous mud
Chronostratigraphic unit: Upper Pliocene
Measured velocity: 1.57 km/s

Basement:
Depth sub-bottom: 80 meters[2]
Nature: Vesicular basalt
Velocity range: 3.7-5.75 km/s

Principal Results: Site 409 is on the western crestal region of the Reykjanes Ridge. The site is situated in the Matuyama reversed stripe near the Gauss boundary (anomaly 2′).

A hard sea floor of turbidite sand required washing down to 24.5 meters. We cored continuously from there to 319 meters and recovered 88.43 meters (30%).

From 0 to 59 meters is Pleistocene turbidites, graded muddy calcareous sand to sandy calcareous mud, with erratics to 46 meters, and benthic shell sands and foraminifer sands. This overlies 21 meters of lower Pleistocene to upper Pleistocene sandy calcareous mud, ungraded, with some benthic shell fragments. Beginning at 80 meters, we cored basalt, highly vesicular, phyric and aphyric, with some unaltered olivine, for 239 meters.

Several records were set at this site: the deepest single-bit penetration of basalt (239 m), the youngest crust to be drilled (2.4 m.y.) and the shallowest water for a site (832 m).

BACKGROUND AND OBJECTIVES

Site 409 was selected to be near the crest of the Reykjanes Ridge at the end of the transect of three sites, drilled as 407 (anomaly 13), 408 (anomaly 6), and 409. The idea was that it should be drilled as near the crest of the Reykjanes Ridge as possible, and the means by which the site was finally chosen are set out in the Operations section of this chapter.

There were no particular sedimentary targets at the site, where the sediments were expected to be mixed glacial marine and turbiditic sediments from higher up the ridge toward Iceland. The complete string of dredge hauls down the crest of the Reykjanes Ridge (Schilling, 1973) might seem to make this hole unnecessary, in that they could provide a present-day geochemical background to compare against the holes in older crust; but surface dredging, especially if not carried out in a detailed and systematic way in a small area, may not give results fully representative of the crust in a particular area. Nor, of course, can a single drill hole. But in areas, such as FAMOUS, where both drilling and dredging have been carried out, the two procedures have been complementary. The great variety of basaltic rocks observed subaerially in Iceland, compared with the rather narrow range dredged from the Reykjanes Ridge, suggests that bias in dredging may be a real effect. Also, it is important, in making detailed comparisons on such a transect, that similar methods be used to collect all materials, to reduce systematic bias in sampling.

The hole was designed, then, with two ends in view: to provide a baseline against which Sites 407 and 408 could be tested for geochemical anomalies, and to provide further information about the deeper structure of the Reykjanes Ridge crest.

OPERATIONS

At Site 409 we drilled one hole to a total penetration of 319 meters. Coring was conducted over 295.5 meters, and 88.43 meters (30%; Table 1) was recovered.

Site 409 is within OCP site area 9 on the western crest of the Reykjanes Ridge. Enroute from Aberdeen to Site 407 (OCP 11), we passed over a tentative Site 409 locality selected on the basis of *Meteor* 42B data. We made our profile at 6 knots with tandem 5- and 10-in.[3] airguns. This allowed fairly good resolution of the sediment cover and

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[2]Determined from drilling log.

TABLE 1
Coring Summary, Site 409

Core	Date (August 1976)	Time	Depth From Drill Floor (m)	Depth Below Drill Floor (m)	Length Cored (m)	Length Recovered (m)	Recovery (%)
1	2	2035	842.0- 843.0	0.0- 1.0	1.0	cc	5
Hard turbiditic bottom - washed down 23.5 meters							
2	2	2140	866.5- 876.0	24.5- 34.0	9.5	4.30	45
3	2	2210	876.0- 885.5	34.0- 43.5	9.5	cc	0.1
4	2	2240	885.5- 895.0	43.5- 53.0	9.5	6.75	71
5	2	2310	895.0- 904.5	53.0- 62.5	9.5	6.04	64
6	2	2340	904.5- 914.0	62.5- 72.0	9.5	4.56	48
7	3	0105	914.0- 923.5	72.0- 81.5	9.5	9.53	100
8	3	0150	923.5- 933.0	81.5- 91.0	9.5	0.70	7
9	3	0250	933.0- 942.5	91.0-100.5	9.5	3.25	34
10	3	0419	942.5- 952.0	100.5-110.0	9.5	8.35	88
11	3	0530	952.0- 961.5	110.0-119.5	9.5	4.48	47
12	3	0615	961.5- 971.0	119.5-129.0	9.5	0.95	10
13	3	0702	971.0- 980.5	129.0-138.5	9.5	2.17	23
14	3	0800	980.5- 990.0	138.5-148.0	9.5	1.18	12
15	3	0905	990.0- 999.5	148.0-157.5	9.5	5.91	62
16	3	1000	999.5-1009.0	157.5-167.0	9.5	2.00	21
17	3	1045	1009.0-1018.5	167.0-176.5	9.5	1.28	13
18	3	1150	1018.5-1028.0	176.5-186.0	9.5	3.40	36
19	3	1230	1028.0-1037.5	186.0-195.5	9.5	0.10	1
20	3	1335	1037.5-1047.0	195.5-205.0	9.5	1.00	11
21	3	1455	1047.0-1056.5	205.0-214.5	9.5	3.00	32
22	3	1545	1056.5-1066.0	214.5-224.0	9.5	0.80	8
23	3	1645	1066.0-1075.5	224.0-233.5	9.5	1.90	20
24	3	1800	1075.5-1085.0	233.5-243.0	9.5	7.00	74
25	3	1905	1085.0-1094.5	243.0-252.5	9.5	3.70	39
26	3	2005	1094.5-1104.0	252.5-262.0	9.5	1.10	12
27	3	2045	1104.0-1113.5	262.0-271.5	9.5	0.60	6
28	3	2130	1113.5-1123.0	271.5-281.0	9.5	1.10	12
29	3	2225	1123.0-1132.5	281.0-290.5	9.5	0.50	5
30	3	2330	1132.5-1142.0	290.5-300.0	9.5	0.20	2
31	4	0250	1142.0-1151.5	300.0-309.5	9.5	1.68	18
32	4	0400	1151.5-1161.0	309.5-319.0	9.5	0.90	9
Total					295.5	88.43	30

showed the thinning of the sediments over the crest (Figure 1).

The *Meteor* 40b survey data show that the crestal area is bounded to the west by a series of fault scarps with a net throw of about 500 or 600 meters (Figures 2 and 3). Isolated pockets of sediment, up to 100 ms (DT) thick, can be seen in valleys atop the crestal region. After Site 408 we made a short visit to Reykjavik, then approached our tentative Site 409 location from the northwest on 131°T (Figure 4). At half-speed we steamed up to the crest region, noting where the sediment thinned to less than 100 ms (DT), then came about to port and dropped the beacon at 1352Z, 2 August (Figure 5). Spud-in was at 1900Z, five hours later. The magnetic field over the site shows that we dropped on the east side of anomaly 2'; this is just near the Matuyama-Gauss boundary. In attempting to spud-in at 842 meters, we found the sea floor to be very hard and sandy, and so washed down the interval 1 to 24.5 meters sub-bottom, to allow stability for the bottom hole assembly. We cored continuously from 24.5 to 319 meters sub-bottom. Basalt was first recovered in Core 7 and was continuously cored for about the next 240 meters.

Drilling rates in the hole are discussed in detail elsewhere in this chapter. In the sedimentary overburden, cores could be cut in 5 to 10 minutes, but in the basalt section, cutting time ranged from 10 to 90 minutes, and averaged about 30 minutes. The bit was found to be in good condition, despite this deep penetration into basalt. Several records were set at this site: the deepest single bit penetration of basalt (239 m), the youngest crust to be drilled (2.4 m.y.) and the shallowest water for a site (842 m).

We abandoned this site abruptly on 4 August 1976 because of a fatal accident on board.

SEDIMENT LITHOSTRATIGRAPHY

Introduction

The drilling at Site 409 resulted in approximately 53 per cent recovery (excluding the washed-down interval from 1.0 to 24.5 m) of sediment before basalt bedrock was penetrated at 80 meters below the sea floor. One thin unit of sedimentary rock interlayered with the basalt occurs between 130.0 and 131.6 meters (core recovery depths).

Two major units are distinguished according to lithologic characteristics and, especially, sedimentary structures (Figure 6) (depths quoted are core recovery depths, not corrected with drilling logs).

Unit 1 (24.5 to 58.9 m): lower Pleistocene calcareous muds, with several turbidite units.

Unit 2 (58.9 to 80.1 m): lower Pleistocene to upper Pliocene, mostly structureless calcareous sandy muds.

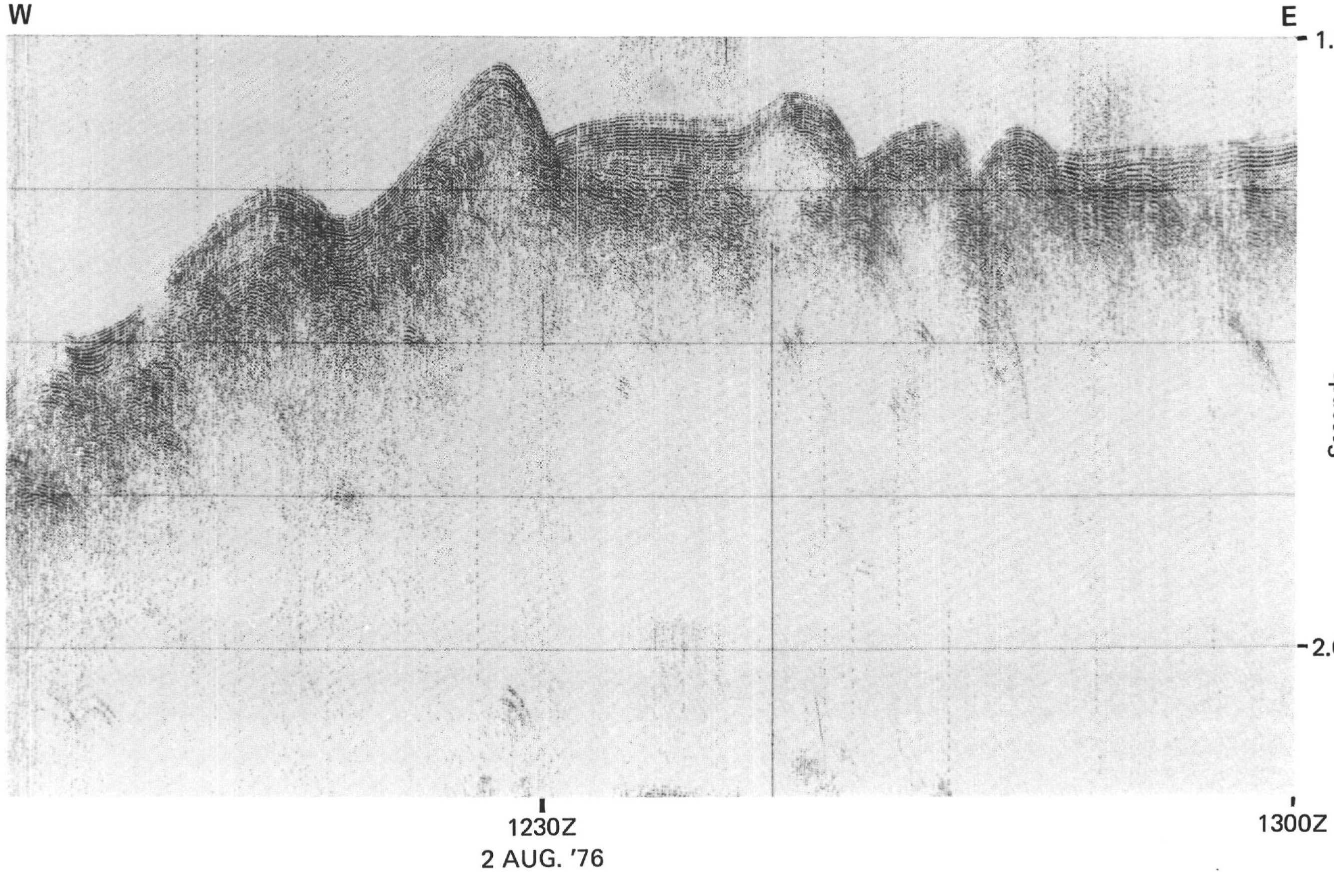

Figure 1. *Reflection profile taken from* Glomar Challenger *in vicinity of Hole 409. Track shown in Figure 4.*

Interlayered Sediments (130 to 131.6 m): Undated limestone with sand- to gravel-size basalt fragments.

Description of Lithologic Units

Unit 1 (Hole 409, Cores 2 to 5, 24.5 to 58.9 m)

Core 1 is not included in this unit, because only a core-catcher sample, representing 0 to 1.0 meters below the sea floor, was recovered. Owing to a hard sandy bottom, recovery of core was not possible until the 23.5 meters below Core 1 was washed down. Although the sediment in the core-catcher sample of Core 1 is calcareous sandy mud similar to that of Cores 2 to 5, it is a mixture of sediment obtained through several attempts to penetrate bottom. This material is lower Pleistocene, according to micropaleontological data.

Cores 2 to 5 are lower Pleistocene, mostly calcareous sandy muds and marly oozes which, except for Core 3 (core-catcher sample only), contain several turbidite units. Most of the turbidite sequences contain, at the base, gray sandy mud which grades upward into light gray to greenish gray calcareous ooze. Some turbidites contain fine foraminiferal sand, and others contain benthic shell fragments of sand to granule size.

Smear-slide analyses (Figure 6) show that coarse detrital grains (>63 μm) are mostly feldspar and quartz grains, with minor amounts of opaque minerals. The total coarse detrital fraction ranges from 5 per cent to over 75 per cent, depending on the sampling position in the turbidite sequence (larger amounts in the basal units). Calcium carbonate (bomb data) constitutes between 0 and 80 per cent, but 8 of 11 measurements in this unit show less than 30 per cent $CaCO_3$. Calcareous nannofossils and foraminifers account for most of the $CaCO_3$. Biogenic silica, mostly sponge spicules, occurs in uniformly small amounts between 1 to 10 per cent throughout the unit. Volcanic ash — as fresh glass, zeolites, and palagonite — varies between 2 to 40 per cent, although most samples contain less than 20 per cent ash. Several rounded basalt and scoria pebbles and two limestone pebbles, all probably ice-rafted, were found scattered through Cores 2 and 4 (down to Core 4, Section 2, 46.0 m).

Sedimentary structures in the unit are limited to the graded bedding of the turbidite sequences. Mottling caused by bioturbation was not apparent.

Unit 2 (Hole 409, Cores 6 and 7, 58.9 to 80.1 m)

This upper Pliocene to lower Pleistocene unit consists of nearly structureless calcareous sandy mud and marly ooze. The major components in smear slides indicate very uniform composition throughout this unit (Figure 6). Calcium carbonate contents (bomb analyses) are grouped around 20 to 30 per cent; coarse detrital minerals (quartz, feldspars, and opaque minerals) range from 5 to 10 per cent; biogenic silica (predominantly sponge spicules) varies between 1 and 15 per cent, but most samples contain less than 10 per cent. Volcanic ash contents (fresh glass and palagonite) are grouped around 5 to 10 per cent.

No mottling was evident in Unit 2, and only rare laminae occur in the cores. Color is uniformly dark gray.

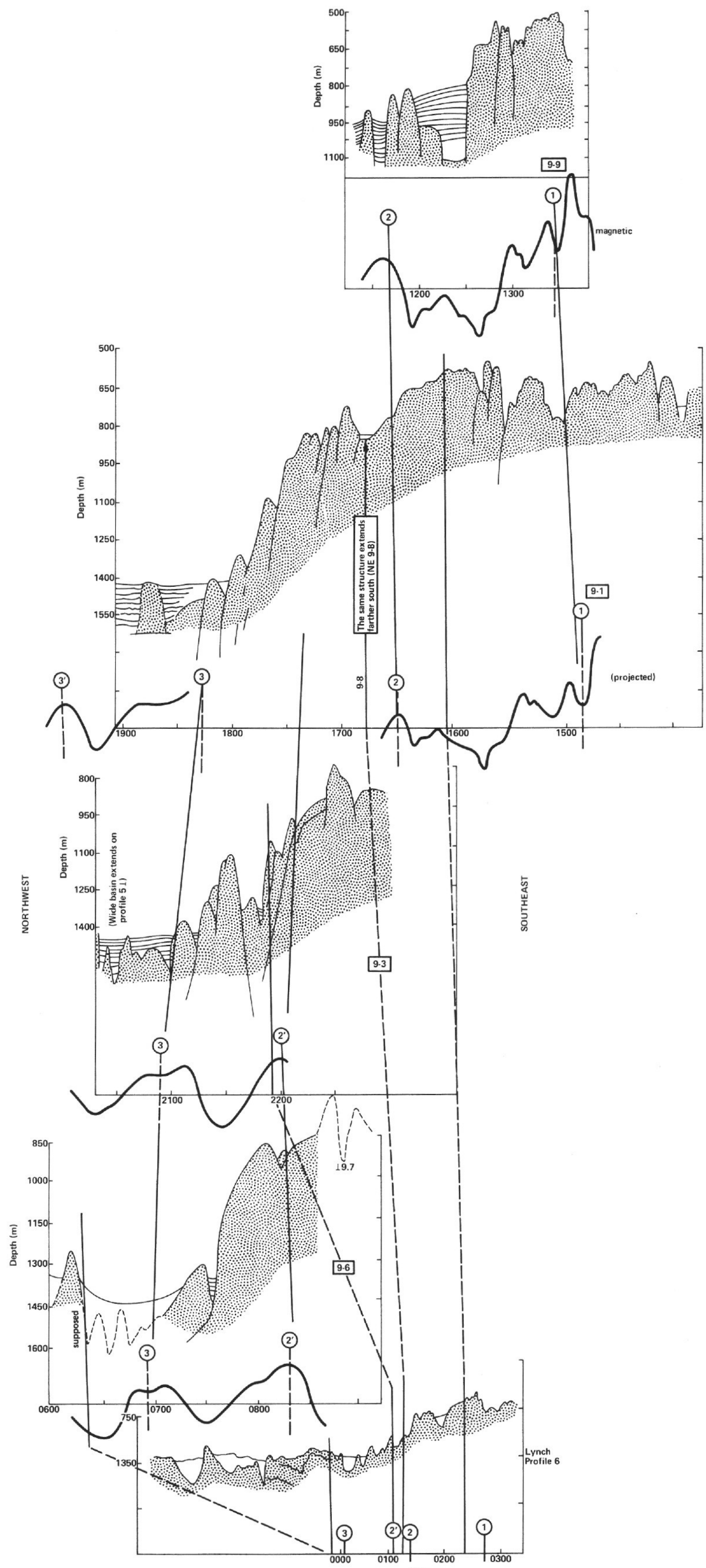

Figure 2. *Seismic and magnetic data taken by* R/V Meteor *near site 409. Tracks shown in Figure 3.*

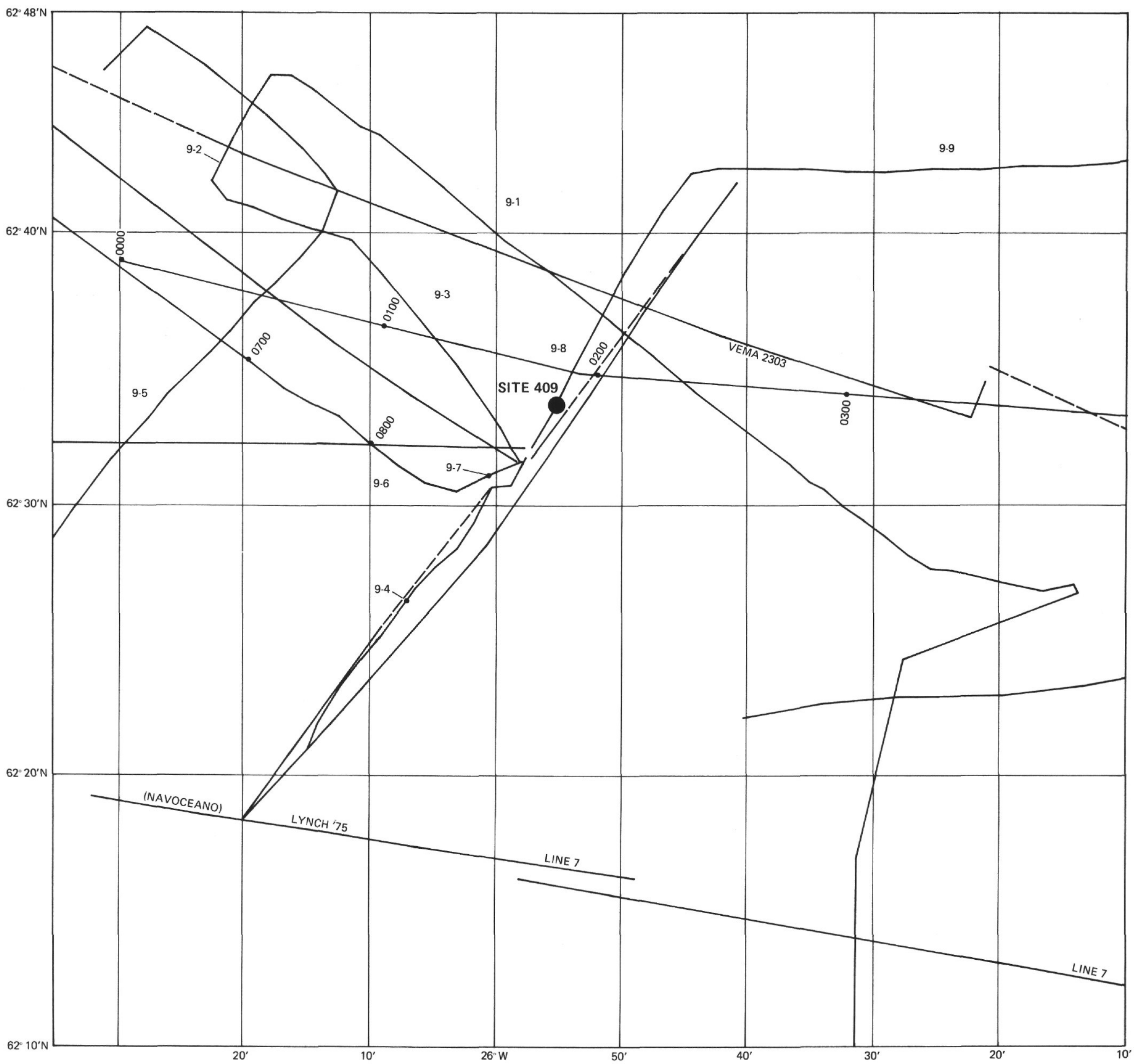

Figure 3. *Ship tracks for IPOD site surveys near Site 409.*

Interlayered Sediments (Core 13, 130 to 131.6 m)

In Core 13, Section 1, several cobbles of limestone occur within the basalt. The limestone contains a mixture of foraminifers, nannofossils, benthic shell fragments, and granule-size basalt particles. The microfossils were too poorly preserved to allow an age assignment.

BIOSTRATIGRAPHY

Sediments recovered at Site 409 range from Pleistocene to uppermost Pliocene. Basalt was encountered at 80 meters sub-bottom (Core 7). Ice-rafted mineral grains are present throughout the sedimentary sequence recovered above basalt. Small amounts of sediment in Core 13 (130 m sub-bottom) do not contain age-diagnostic microfossils. The Pliocene/Pleistocene boundary is placed below Sample 6, CC (67 m sub-bottom) because of the absence of barred *Gephyrocapsa* spp. below this level.

Planktonic Foraminifers

With one exception, Hole 409 samples examined for planktonic foraminifers contain common to abundant *Neogloboquadrina pachyderma*. Other taxa usually present include *Globigerina bulloides*, *Turborotalita quinqueloba*, and *Globorotalia inflata*. The one exception, Sample 2-3, 15-17 cm (27.6 m sub-bottom), which yielded an assemblage containing dominant by *Globigerina bulloides* and *Turborotalita quinqueloba*, together with rare *Globorotalia truncatulinoides* and *Neogloboquadrina dutertrei*, probably represents an interglacial stage. If placement of the Pliocene/Pleistocene boundary is correct,

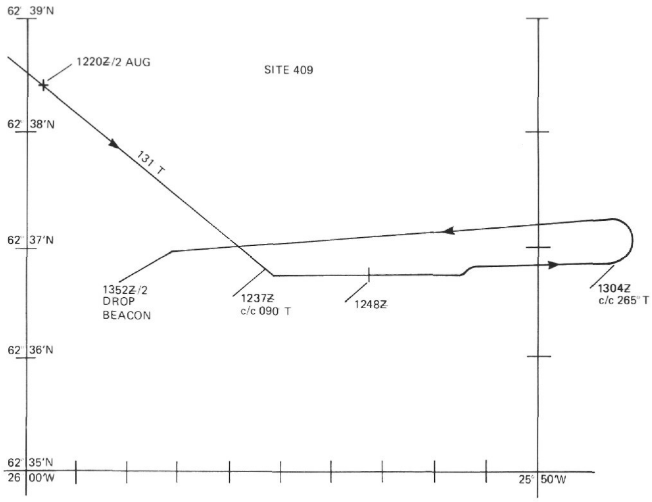

Figure 4. *Track chart of* Glomar Challenger, *Site 409.*

the absence of *Neogloboquadrina atlantica* from Core 7 suggests that the last occurrence of this taxon may be within the upper Pliocene. Estimates of the Pliocene/Pleistocene boundary based on the last occurrence of *N. atlantica* in the previous sites may therefore be slightly too old.

These and other findings are summarized in Table 2.

Nannofossils

Coccolith assemblages ranging from upper Pliocene to lower Pleistocene occur in the 80-meter section (Cores 1 to 7) at Site 409. All observations reported here refer to core-catcher samples unless otherwise noted. All samples except 3, CC contain common to abundant, well-preserved nannofossils; Sample 3, CC is virtually barren of calcareous material.

Samples 1, CC to 6, CC contain an assemblage of nannofossils characteristic of the lower Pleistocene (*Emiliania annula* Zone, NN 19): abundant *Coccolithus pelagicus*, common to abundant *Gephyrocapsa caribbeanica*, *G. doronicoides*, and *G. oceanica*, and occurrences of *Cycloccolithina leptopora*, *Helicopontosphaera kamptneri*, and *Emiliania annula*. Samples 2, CC and 5, CC are peculiar, in that *C. pelagicus* is absent. This species usually dominates all assemblages from Miocene to Recent at the previous sites (407 and 408) at this latitude.

The sample from above basalt (Core 7, Section 6; 80 m sub-bottom) contains an upper Pliocene (*Discoaster brouweri* Zone, NN 18) nannofossil assemblage. Present are abundant *c. pelagicus*, common *E. annula*, and *C. leptopora*. Notably absent are *Gephyrocapsa* spp. The Pliocene/Pleistocene boundary, as established with

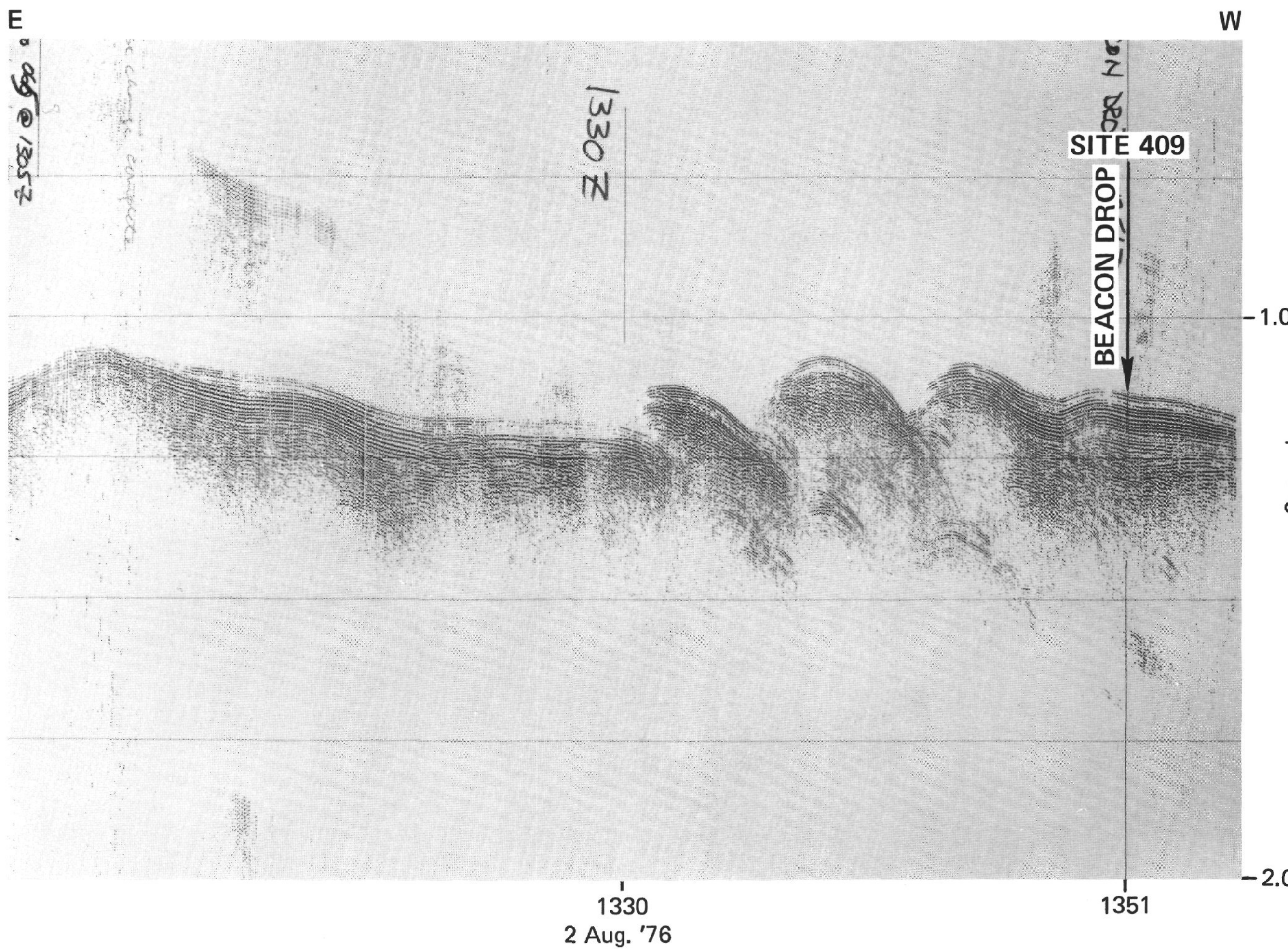

Figure 5. *Reflection profile taken from* Glomar Challenger *on approach to Hole 409.*

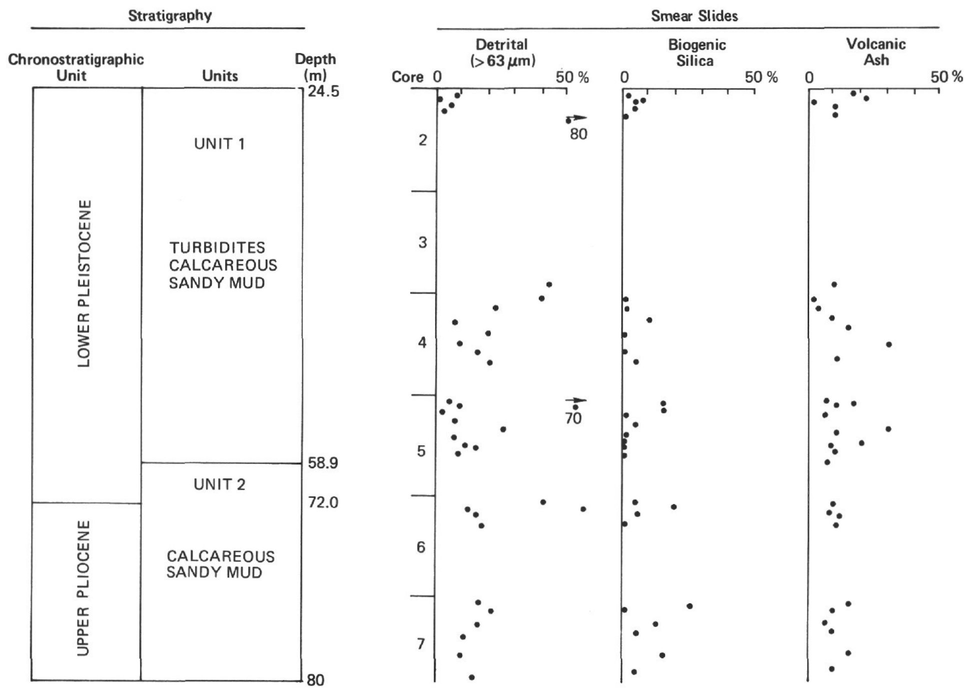

Figure 6. *Stratigraphy and smear-slide analysis of sediments at Hole 409.*

nannofossils, is based on the first occurrence of *Gephyrocapsa* spp. in Sample 6, CC (67.0 m sub-bottom).

These and related findings are summarized in Table 2.

Minor amounts of chalk occur about 50 meters below the first basalt. Samples 13-1, #13 and 13-2, #1 ($\simeq$ 130 m sub-bottom) contain rare occurrences of poorly preserved nannofossils in an ash matrix. No species determinations were possible.

PHYSICAL PROPERTIES OF SEDIMENTS

Hamilton Frame sonic velocity measurements of the drilled sedimentary section are plotted against depth sub-bottom in Figure 7. The data have a sample mean of 1.56 km/s and a sample standard deviation of 0.10. A systematic peak of 1.85 occurs at 63.1 meters sub-bottom, and correlates well with a change in the drilling rate and the lithostratigraphic boundary at the base of Unit 1 (see lithostratigraphy), the Pliocene/Pleistocene boundary. The sample mean sound velocity is also in excellent agreement with the 103-ms acoustic basement detected in the seismic profile records and the 80-meter (sub-bottom) basement established by drilling; 1.56 $\pm$0.1 km/s implies acoustic basement at 80.6 $\pm$5 meters sub-bottom.

The water content and wet-bulk density data are plotted in Figures 8 and 9. Neither shows trends and both have a great deal of scatter.

GEOCHEMISTRY

Only two samples of interstitial pore solutions were analyzed from the approximately 80 meters of sediment recovered from this site. The results are listed in Table 3 and include Ca^{++}, *p*H, alkalinity, chlorinity, and salinity. The sediments consist essentially of a turbidite sequence which has been interpreted as derived from the shallow-water shelf around Iceland.

The two samples do not provide enough information to deduce any meaningful trends in the chemistry of the solutions with depth, but the Ca^{++} concentrations at this site are much higher than previous sites. The significance of the Ca^{++} enrichment of the solutions is unclear, but may be linked with the relatively shallow water environment in which the sediments were deposited, and/or their more calcareous composition. Interesting in this condition is the large amount of aragonite that has been precipitated in parts of the basalt core.

PALEOENVIRONMENTAL INTERPRETATION

The sediments recovered at Site 409 are mainly turbidites with abundant shelf(?) fauna (mainly bivalve fragments) and terrigenous sand, clay, and volcanic ash, probably derived from Iceland. Bryozoan fragments, sponge spicules, foraminifers, and nannofossils are also important constituents.

Turbidites were recovered through Core 5 (Sample 5-4, 115 cm); the base of the lowest identifiable graded unit is at 58.65 meters. Coarse glacial erratics (mainly rounded basalt pebbles) are present as deep as Section 4-2 (46 m sub-bottom). Content of sand- and silt-size detrital grains remains above 10 per cent throughout the entire sedimentary section, indicating ice-rafting or turbidity current activity throughout. The graded turbidites are all Pleistocene, according to the nannofossil assemblages, which indicate that Zone NN 19 is present as deep as Sample 5, CC.

Two cores (6 and 7) were recovered below the Pleistocene turbidites. These calcareous clays are similar lithologically to the overlying turbidites (calcareous sandy

TABLE 2
Paleo/Biostratigraphic Summary of Core-Catcher Samples (CC)

Core	Depth (m)	Chronostraitigraphic Unit	Planktonic Foraminifers	Calcareous Nannofossils
1	1.0	Lower Pleistocene	Not examined	*C. pelagicus* *P. lacunosa* *C. leptopora* *Gephyrocapsa* spp. *S. histrica*
2	29.0	Lower Pleistocene	Sample 2-2, 57-54 cm (27.0 m) *Neogloboquadrina pachyderma* (S) *Globigerina bulloides* *Turborotalita quinqueloba* *Globorotalia inflata* *G. scitula*	*C. leptopora* *Gephyrocapsa* spp. *H. kamptneri* no *C. pelagicus*
3	34.0	Lower Pleistocene	Sample 2-13, 15-17 cm (27.5 m) *Globigerina bulloides* *Turborotalita quinqueloba* *Neogloboquadrina pachyderma* (D) *Globorotalia truncatulinoides*	*C. pelagicus* *Gephyrocapsa oceanica*
4	50.0	Lower Pleistocene	Sample 4-2, 100-102 cm (46 m) *Neogloboquadrina pachyderma* (S) *Turborotalita quinqueloba* *Globigerina bulloides*	*C. pelagicus* *C. leptopora* *S. histrica* *Gephyrocapsa* spp.
5	59.0	Lower Pleistocene	Sample 5-3, 21-23 cm (56.0 m) *Neogloboquadrina pachyderma* (S) *Turborotalita quinqueloba* *T.* sp. *Globorotalia inflata* *Globigerina* sp.	*P. lacunosa* *Gephyrocapsa* spp.
6	67.0	Lower Pleistocene	6-1, 24-26 cm (63.0 m) *Neogloboquadrina pachyderma* (S) *Globigerina bulloides* *Turborotalita quinqueloba* *Globorotalia inflata*	*C. pelagicus* *H. sellii* *C. leptopora* *G. oceanica* *G. caribbeanica*
7	80.0	Upper Pliocene	Sediment/basalt contact, Section 7-6 *Neogloboquadrina pachyderma* (D) *Globigerina* sp. *Globorotalia inflata* *G. bulloides* *G. scitula*	Sediment/basalt contact, Section 7-6 *C. leptopora* *C. pelagicus* *P. lacunosa*

muds with abundant sponge spicules, bryozoan fragments, bivalve fragments, ash, and terrigenous sand, silt, and clay). The provenance of those homogeneous gray sandy muds is not entirely clear: they could be "glacial marine" (ice-rafted) deposits or possibly turbidites which have been reworked by bottom currents, slumping, or bioturbation. Coring disturbance may be responsible for at least some of the homogeneity, although Core 6 does not appear to be intensely disturbed.

Sedimentation appears to have been initiated very near the inferred (magnetic) age of formation of 2.4 m.y.; it is perhaps slightly younger than basement, judging by the absence of *N. atlantica*, which ranges very near to the Pliocene/Pleistocene boundary.

SEDIMENT ACCUMULATION RATES

Assuming an age for the basal sediments of 2.0 m.y. (± 0.2), we calculate a sediment accumulation rate of 40 m/m.y. (± 5) for this site.

BASEMENT LITHOSTRATIGRAPHY

Lithostratigraphy of Basement Rocks

Massive basalt was first recovered in Core 7, Section 6 (80.0[3] m). Except for minor fossiliferous, tuffaceous sediment in Core 13, the rest of the recovered material was basalt. The hole bottomed at 319 meters. We recovered 58.5 meters of basalt, for a recovery rate of 24 per cent in the igneous part of the hole.

Macroscopically, nearly the entire basalt section is composed of aphyric, fine-grained basalt with rare microphenocrysts of plagioclase and olivine. Vesicularity is the most striking and variable feature. Modal counts of the most porous samples range from about 14 per cent to as much as 38 per cent vesicularity. Nearly all recovered pieces are at least 5 to 10 per cent vesicular. Since one might expect better recovery from nonvesicular, massive basalt had any been penetrated, it appears that the entire igneous section is composed of relatively frothy lavas.

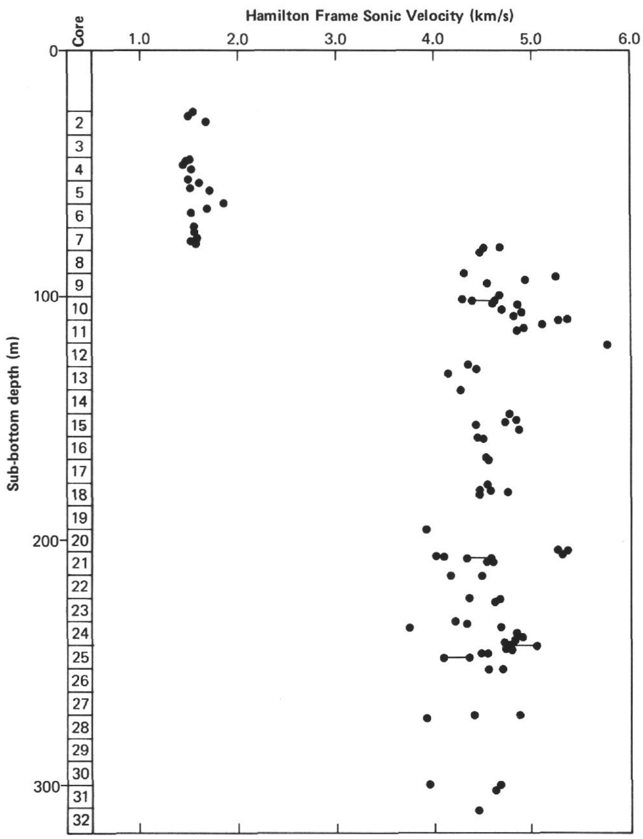

Figure 7. *Sonic velocity versus depth, Hole 409.*

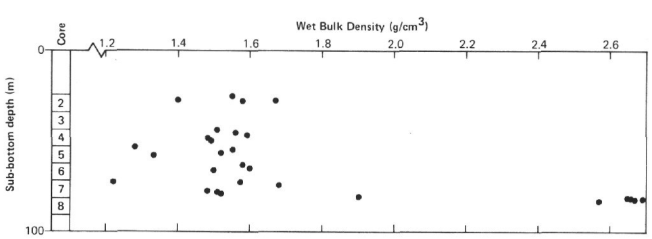

Figure 8. *Wet-bulk density versus depth, Hole 409.*

Individual flows are probably not very thick; this is suggested by the absence of massive degassed flow interiors. The number of flows that the hole penetrated can be estimated from the number of recovered glassy flow margins and from fluctuations in the drilling rate.

The locations of glassy margins, fine-grained margins, and interlayered sediments are summarized in Table 4. Twenty-three basalt fragments have glassy selvages, indicating a quenched skin on a lava flow. Where adjacent fragments are glassy, as for example in Core 13, Section 2, and Core 20, Section 1, it is not known if each fragment comes from a different flow or if several fragments were recovered from the same flow. Assuming that such fragments are from the same flow, a minimum of 18 glassy flow boundaries are indicated. Interbedded sediment in Core 13 and abrupt changes in grain size in Core 8 suggest three more flow boundaries.

Additional flow boundaries may be surmised from fluctuations in drilling rate. Figure 10 summarizes drilling

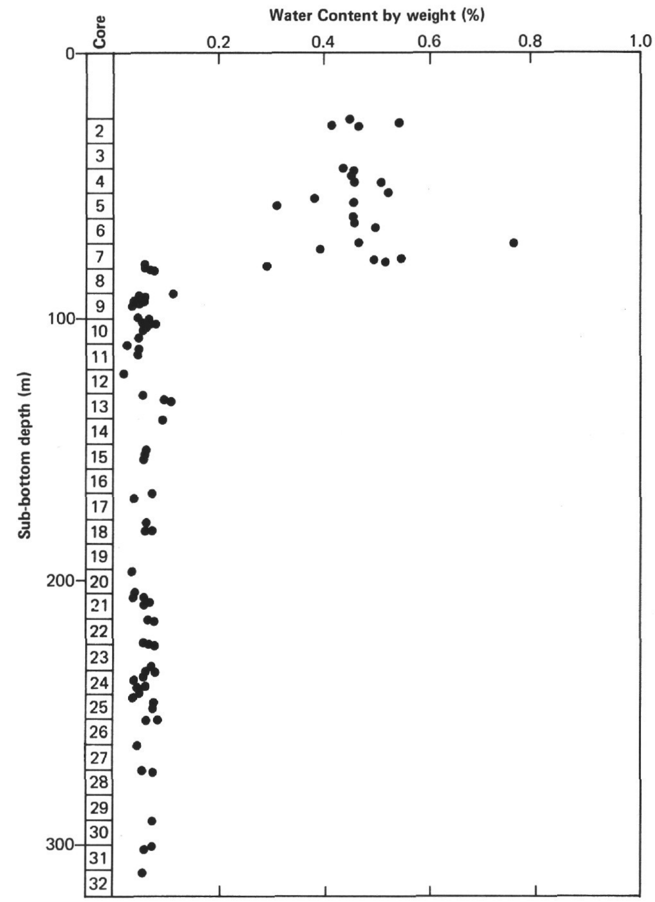

Figure 9. *Water content versus depth, Hole 409.*

rate for the entire hole. Sediments overlying the basalt were drilled at rates from about 20 seconds to 70 seconds per meter, and averaged about 30 seconds per meter. The basalt section was penetrated at an average rate of about 240 seconds per meter; scattered "hard" intervals required as much as 840 seconds per meter, and "soft" intervals were penetrated at less than 60 seconds per meter. The easily drilled intervals within the basalt section may reflect the presence of sediment or tuffaceous or rubbly basaltic debris or some combination of these materials. In view of the degree of vesicularity of the recovered materials, the easily drilled intervals may well reflect even more vesicular, fragile interflow debris with little or no sediment present. Whatever the nature of the easily drilled material, it apparently marks boundaries between flows. Some contrasts in petrographic character (see following section) further define flows or groups of flows.

The stratigraphic section in Figure 11 takes all of the above lines of evidence into account. Apparently we penetrated a minimum of 58 flows or groups of flows, and these average from about 3 to 4 meters thick, depending upon one's interpretation of the easily drilled intervals. If one takes a more conservative estimate of the number of flows, based only on the presence of glass margins, interlayered sediment, and petrographic character, then the average thickness is on the order of 6 to 8 meters. Either estimate is consistent with the results of similar calculations for Sites 407 and 408.

TABLE 3
Summary of Shipboard Geochemical Data

Sample Number	Sample (Interval in cm)	Sub-Depth (m)	pH	Alkalinity (meq/1)	Salinity (°/oo)	Ca^{++} (mmoles/1)	Mg^{++} (mmoles/1)	CL- (°/oo)
	SSW		8.88	2.36	35.5	10.5195	53.8894	19.375
13	2-2, 144-150	876	8.674	1.72	35.8	17.030	48.2192	19.908
14	5-4, 0-10	904.5	9.484	1.02	35.5	16.1988	47.1988	19.8411

TABLE 4
Locations of Glassy Margins, Fine-Grained Margins, and Interlayered Sediments, Hole 409

Core	Section	Piece Number	Interval (cm)	Evidence of Flow Boundary
7	6	2	38-45	Glass
8	1	–	50	Grain-size change
8	1	–	61	Grain-size change
12	1	1	0-10	Glass
13	1	6	44-55	Glass
13	1	9	70-76	Glass
13	1	13-18	100-150	Fossiliferous sediment
13	2	1	0-7	
13	2	13, 14, 15, 16, 18	95-131 and 140-150	Glass
20	1	1	0-10	Glass
20	1	7	51-60	Glass
20	1	12, 13	96-102	Glass
21	1	17	140-150	Glass
21	2	9	75-85	Glass
21	3	2	10-20	Glass
21	3	9	64-70	Glass
25	3	4	31-37	Glass
25	3	14	128-137	Glass
28	1	3	20-26	Glass
28	1	6	45-50	Glass
32	1	14	111-119	Glass
32	1	16	125-140	Glass

Four geochemical units were defined, and are shown in Figure 12. Unit 1, at the top, is variable in composition, with a wide range in Fe/Mg ratio, and is richer in Zr and Ti than Unit 2 below. Unit 2 is fairly constant in composition, and similar to the more basic members of Unit 1. The major geochemical break in the hole occurs between Sections 2 and 3 of Core 13. Unit 3 differs markedly from Unit 2 in its higher content of Ti, Zr, and Ce/Y. Unit 4 was penetrated only at the very bottom of the hole, and is represented by only one sample, which has very low K_2O, TiO_2, and Ce/Y, relative to Unit 3.

IGNEOUS PETROGRAPHY

The 80 meters of sediment that overlies basaltic basement consists of calcareous sandy mud rich in volcanic fragments. We describe briefly here these clastic volcanic products before describing the sequence of basaltic flows.

Volcanic Fragments Recovered in the Sediment

Sediments containing up to 30 per cent ash were recovered in the uppermost 40 meters of the section. All volcanic fragments are pale brown, massive to vesicular, and probably are sideromelane glass. Phenocrysts include plagioclase, olivine, and pyroxene. Colorless glass fragments, presumably of rhyolitic composition, were common at Site 407 and 408, but totally absent at Site 409, suggesting that Site 409 was too far from these silicic eruptions to receive any ash, or that these eruptions predate the formation of oceanic crust at Site 409.

Sequence of Basaltic Flows

A minimum of 58 flow units appear to have been drilled. All lava flows are aphyric to sparsely phyric basalt containing phenocrysts of one or more of the minerals olivine, plagioclase, and augite. Different rock types have been distinguished according to phenocryst assemblages, groundmass mineralogy, and groundmass texture. The different types so defined occur at various levels in the sequence, in apparently random fashion (Figure 12). All the rock types appear to be olivine tholeiites or slightly evolved products.

Olivine Tholeiitic Basalt

Aphyric olivine basalt was recovered from the bottom part of the hole (284 to 320 m), and at 247 to 255 meters, 212 to 220 meters, 202 to 206 meters, 136 to 188 meters, 119 meters, and 104 to 108 meters. Modal olivine content ranges from 3 per cent to 12 per cent, and is generally euhedral; well-formed crystals or skeletal shapes are typical of growing forms. Although relatively large crystals (1 to 5 mm) are present in some varieties, olivine generally is small enough to be considered a groundmass phase.

Plagioclase composition is about An_{80-70} in the most basic varieties, and pyroxene is colorless and late in crystallizing. Opaque minerals are limited to the groundmass, where they dust the residual glass. Textures range from intergranular to intersertal or variolitic toward flow margins.

Evolved varieties are characterized by more sodic plagioclase (An_{65-50}), and frequently by a smaller olivine content. These occur mainly in the lowermost part of the hole — 284 to 320 meters and 247 to 255 meters — and at 104 to 108 meters.

Textures of the evolved rocks range from sub-ophitic to variolitic. Sub-ophitic texture is most common in flow interiors. Olivine is commonly altered to smectite or calcite. Some olivine is completely altered, as at 119 meters, or at 150 to 166 meters, and some is fresh.

Olivine-Plagioclase Phyric Basalts

Plagioclase phyric lavas are common in the section. The phenocryst content rarely exceeds 15 per cent, and is generally between 3 per cent and 10 per cent. We found no evidence for phenocryst resorption.

The uppermost lava of Hole 409 contains An_{80} plagioclase phenocrysts. Plagioclase phyric lavas occur also

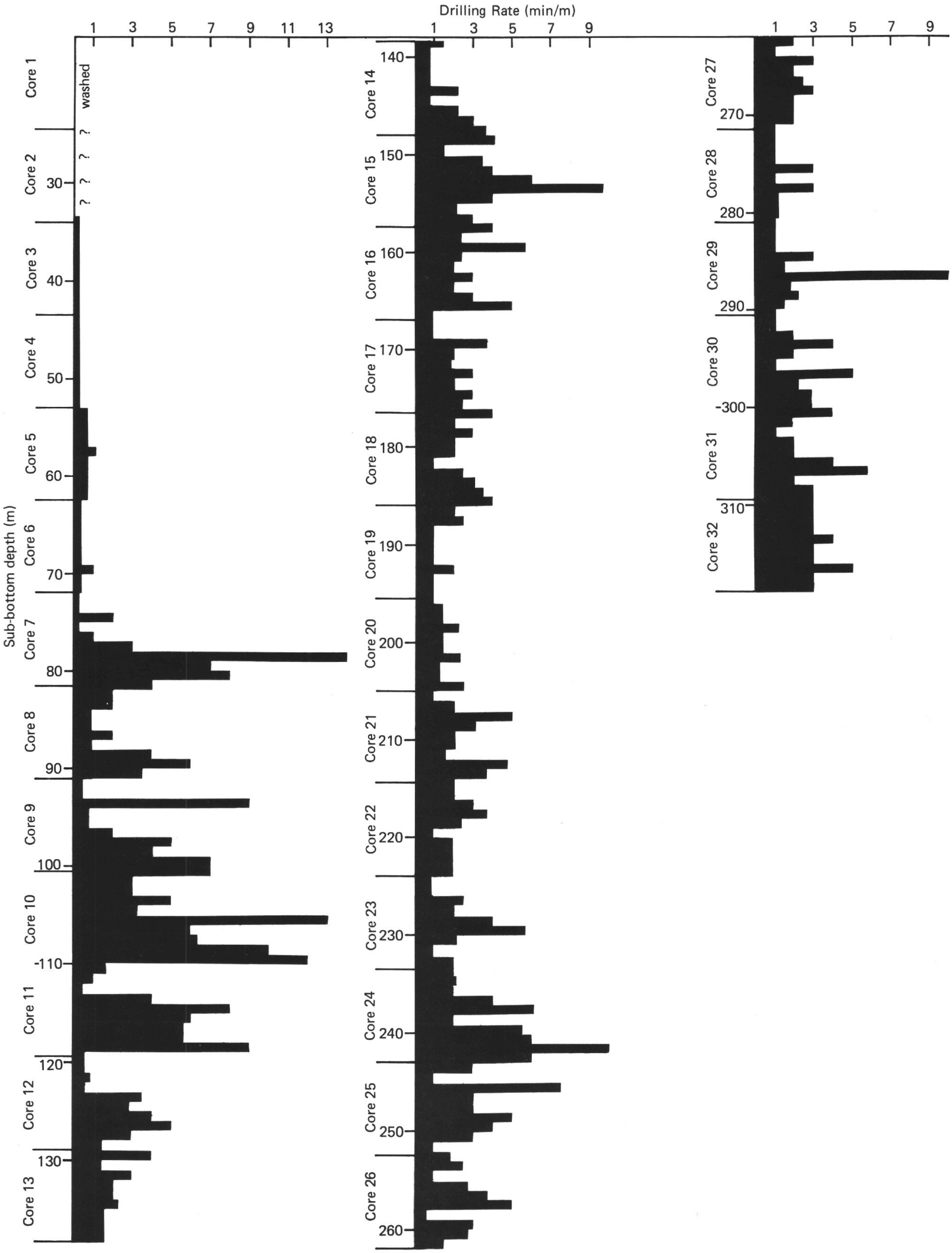

Figure 10. *Drilling rate (min/m) for Hole 409.*

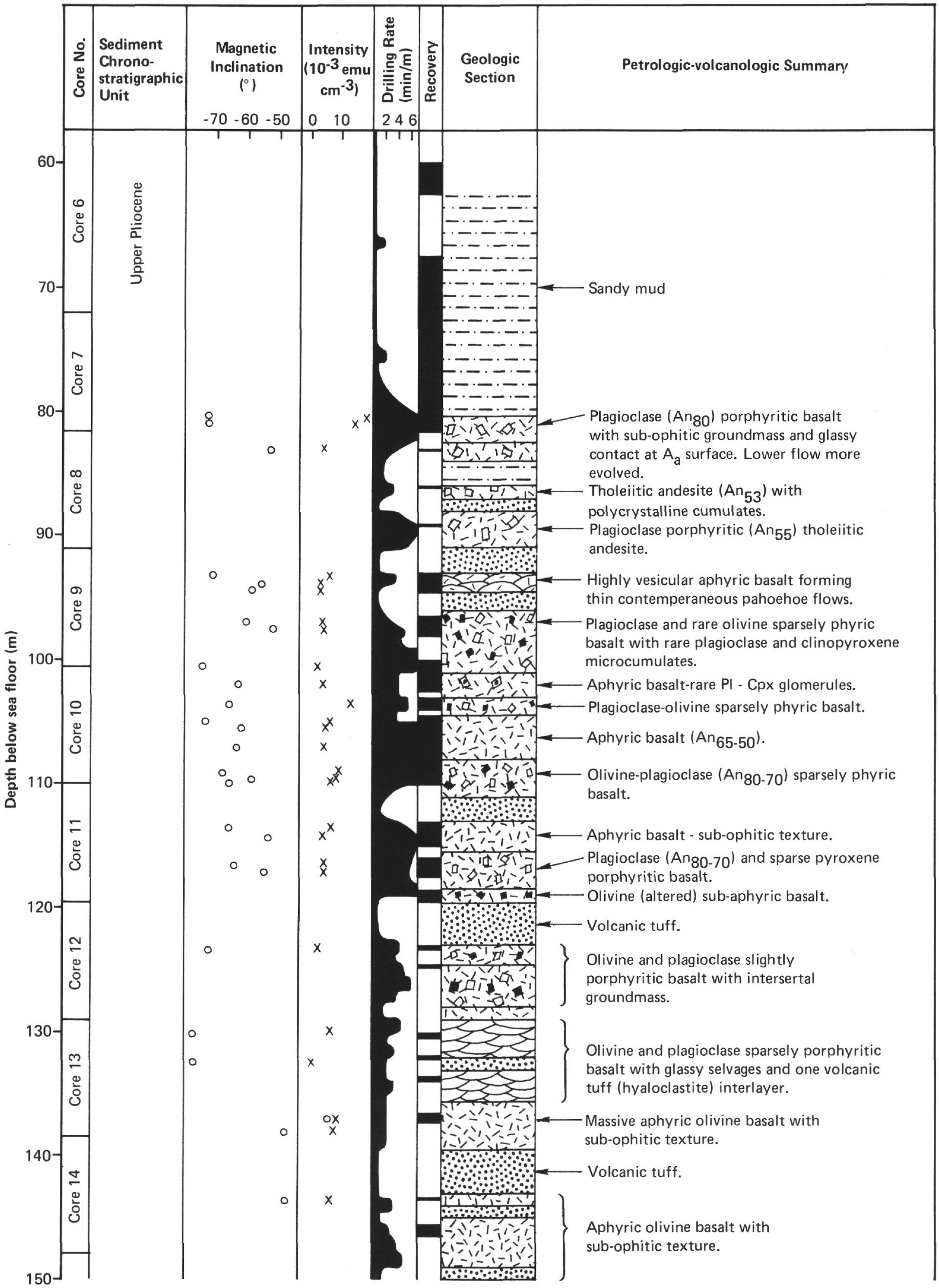

Figure 11. *Stratigraphic section for Hole 409.*

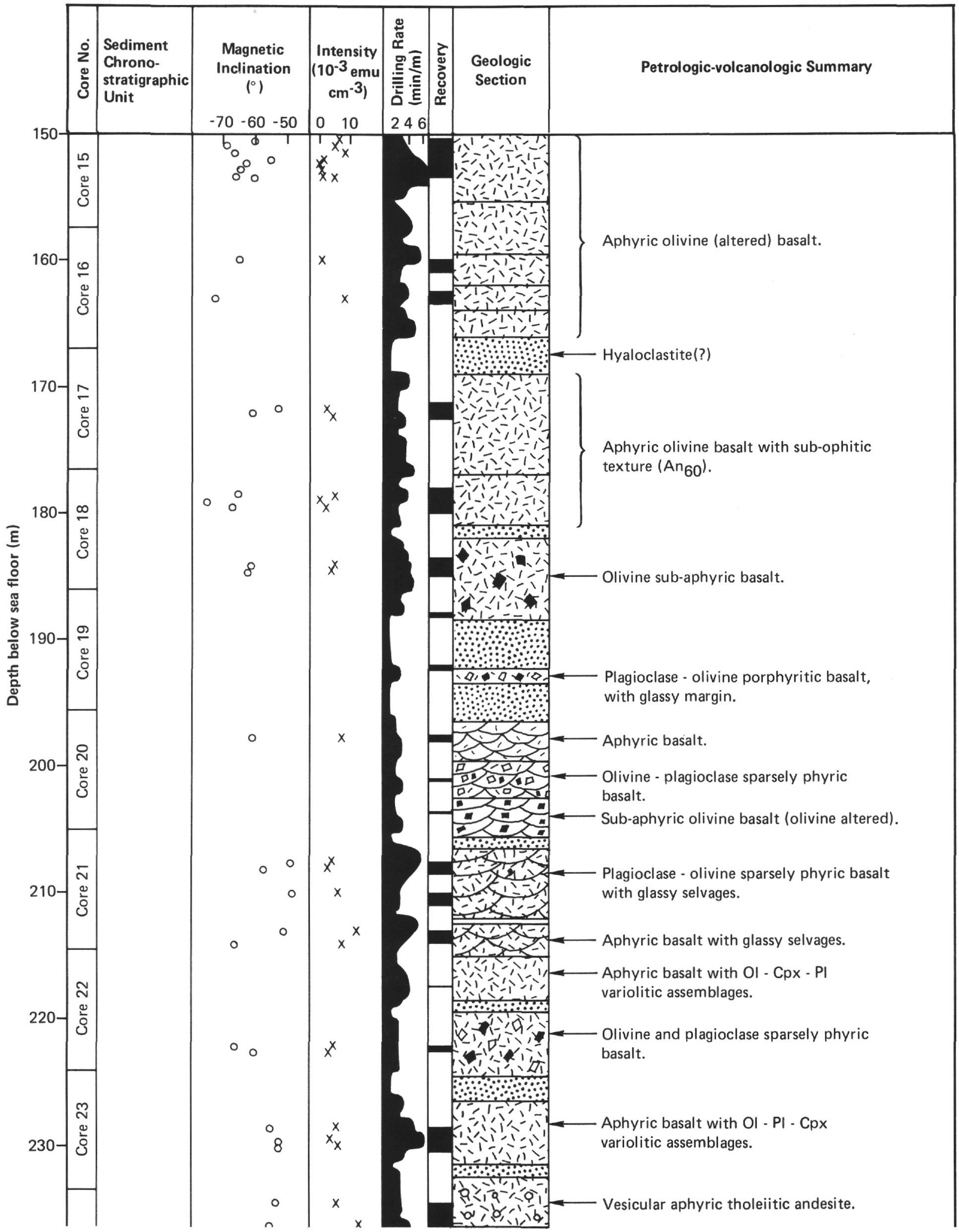

Figure 11. *(Continued).*

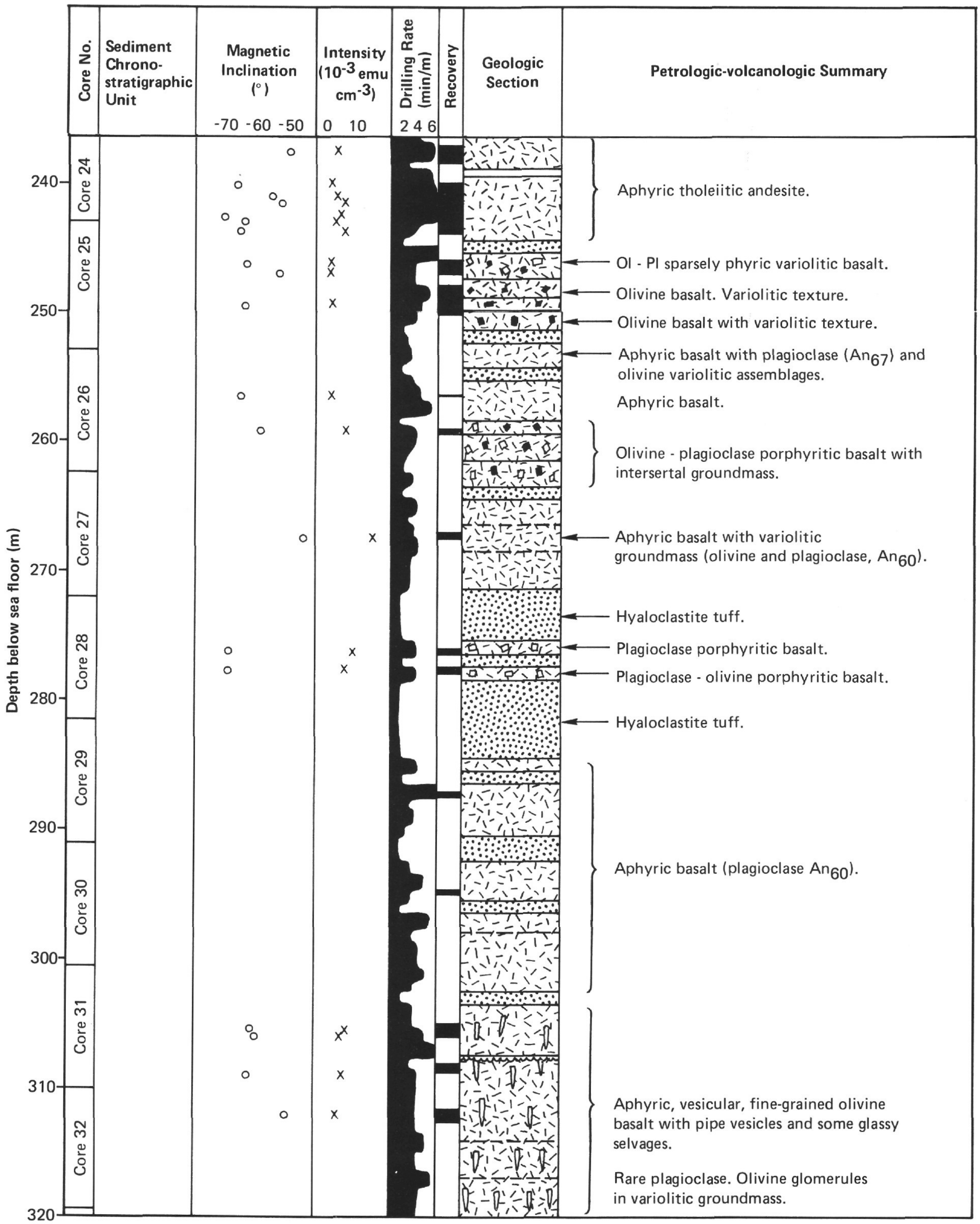

Figure 11. *(Continued).*

at 108 to 112 meters, 123 to 128 meters, 193 meters, 200 to 206 meters, 219 to 225 meters, 245 to 247 meters, 159 to 164 meters and 175 to 179 meters.

It is not always possible to be sure whether a plagioclase phyric lava represents an individual flow or an intra-flow variation. Core recovery was never continuous enough to observe intra-flow variations, but it seems likely that such variation exists, as in other volcanic areas. The presence of plagioclase phenocrysts in some glassy samples indicates that these crystals grew before eruption.

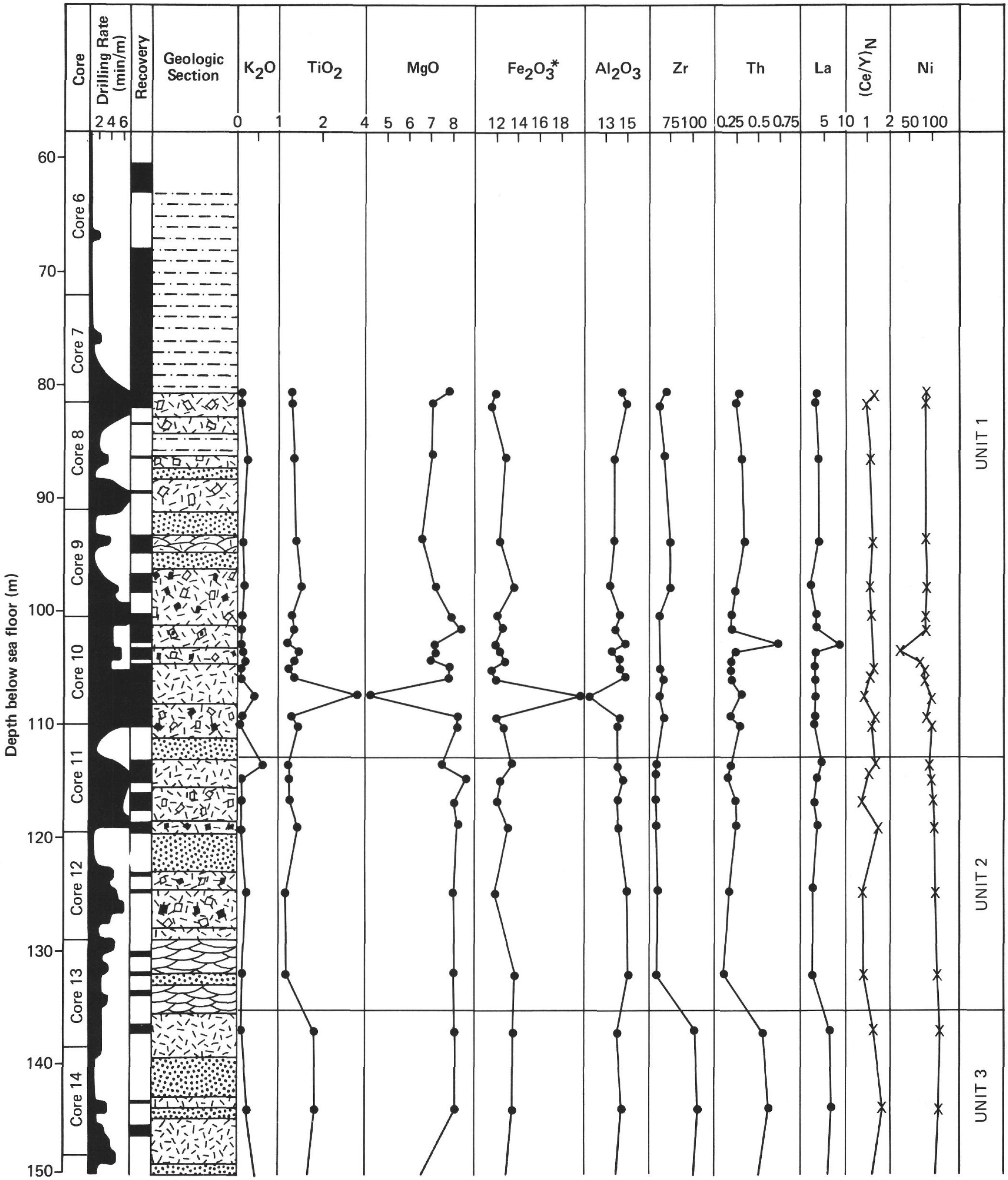

Figure 12. *Geochemical units for Hole 409.*

Evolved Basalts and/or Tholeiitic Andesites

Some of the lavas are characterized by An_{55-45} plagioclase, scarcity or absence of olivine, and common clinopyroxene in microcumulate assemblages with plagioclase. Furthermore, late pyroxene in the groundmass is commonly pleochroic in shades of brown to violet, typical of Fe-Ti enrichment.

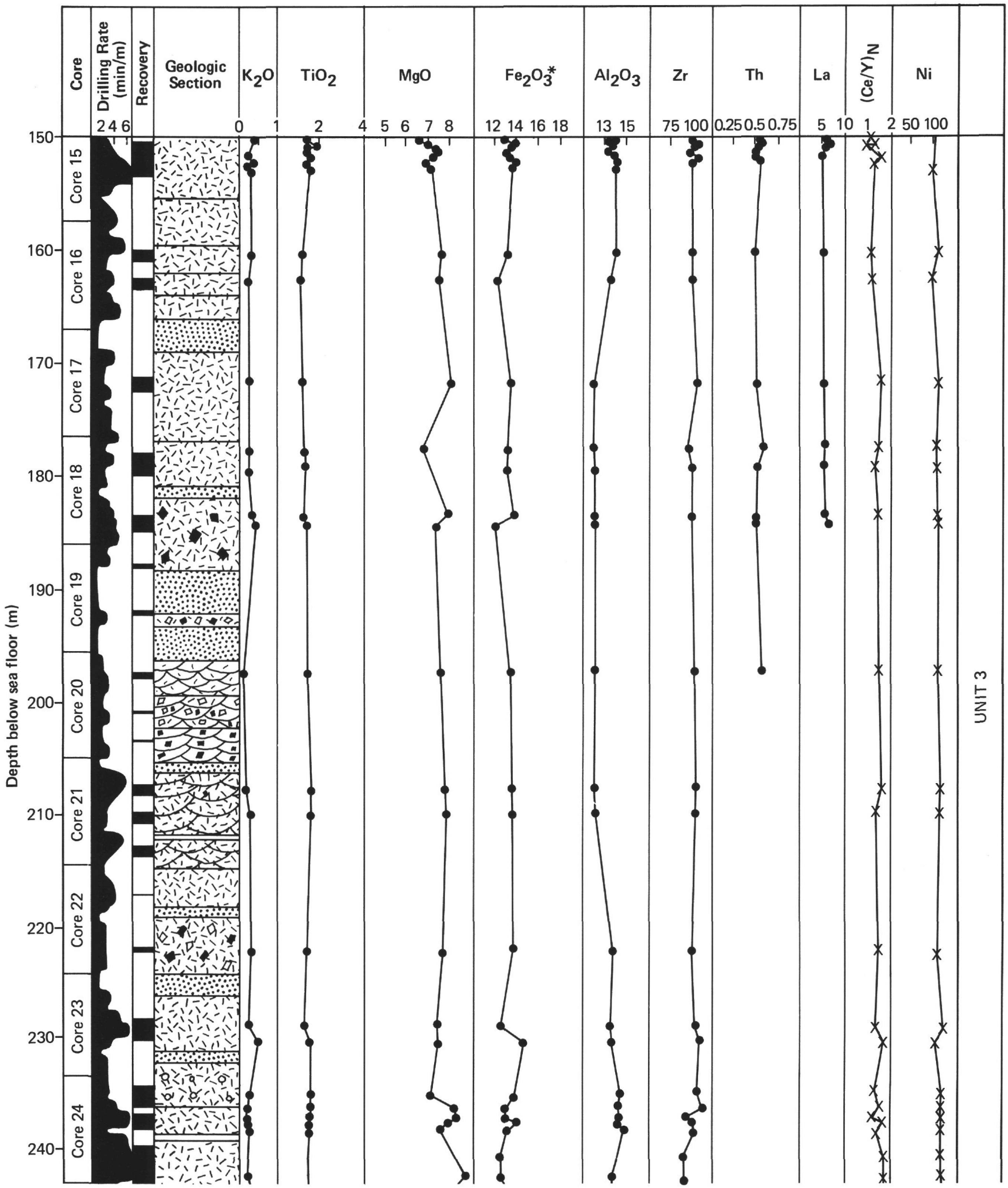

Figure 12. *(Continued).*

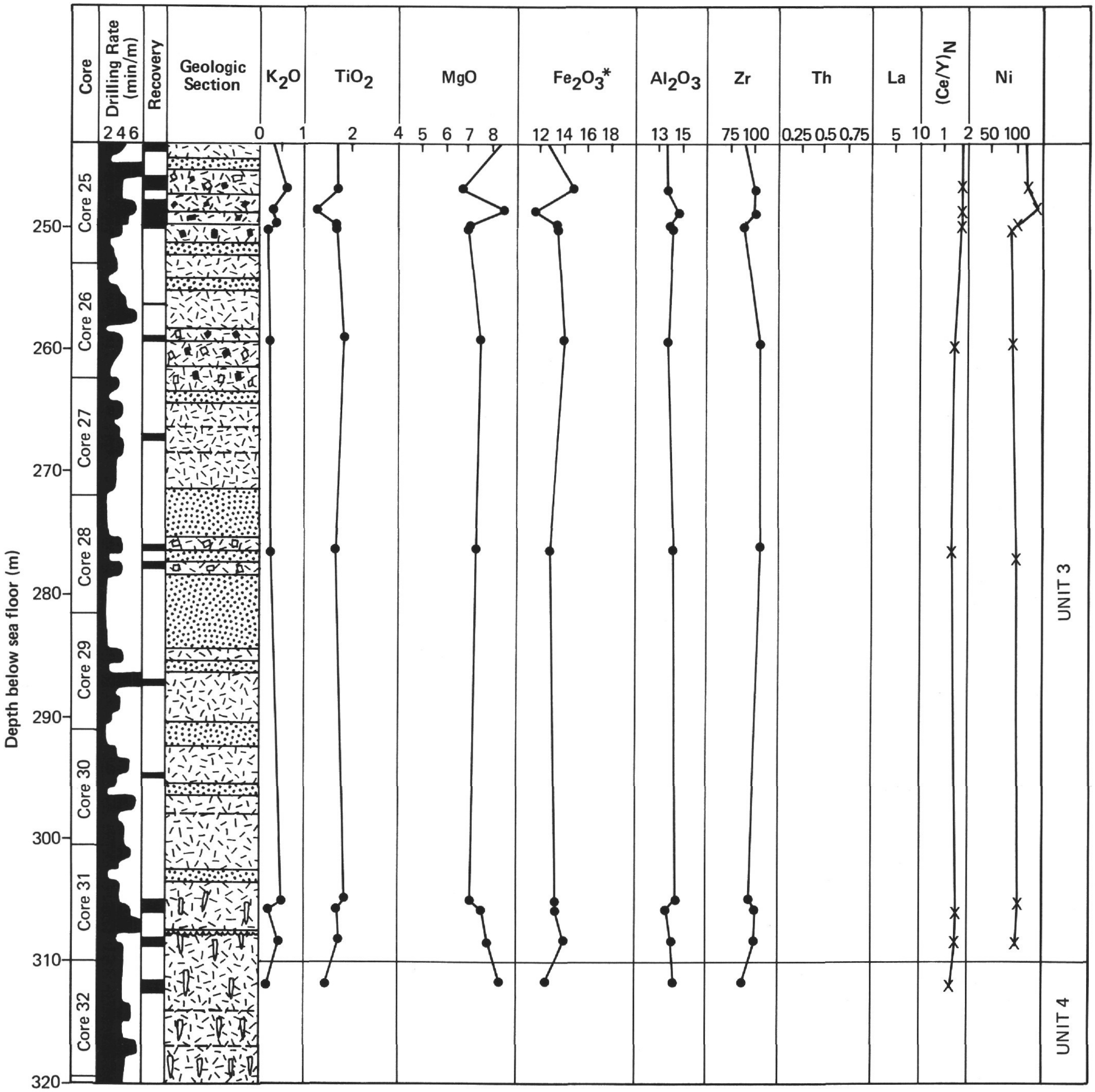

Figure 12. *(Continued).*

Aphyric varieties are present in the intervals 232 to 242 meters and 103 to 106 meters. The groundmass has a sub-ophitic texture in the most crystalline varieties, and flow margins have an intersertal texture. The residual glass is generally rich in iron, and is either black or pale brown with titanomagnetite microcrystals.

Phyric varieties generally contain only plagioclase phenocrysts (An_{55-50}), as in Core 8 (82 to 91 m). But in a few samples, clots of plagioclase and clinopyroxene are present (82 to 84 m, 88 to 91 m, and 96 to 103 m). In the interval between 96 and 103 meters, some olivine is present.

Discussion

Although the basaltic lavas at Site 409 form a rather homogenous aphyric to sparsely phyric sequence, with plagioclase as the dominant phenocryst, by the preliminary petrographic study of nearly one hundred thin sections suggests some variations. Plagioclase composition ranges from An_{80} to An_{50} or less, olivine content is variable, and strongly pleochroic pyroxene is present in some rocks. Geochemical results show that some of the variation results from crystal fractionation, as within Unit 1, but some is a reflection of different primary magmas.

No clear time-related magmatic evolution is evident in the section, in either the nature or the degree of fractionation of the magmas. Hence, no magmatic cycles similar to those reported from Leg 37 are apparent here. Comparison of Site 409 with Sites 408 and 407 gives no indication of a systematic increase in incompatible-element contents or ratios with time. There is, in part, a systematic decrease in such variables with time. In addition, within a single hole, there are marked variations both in degree of fractionation, and in primary magma types.

ALTERATION PETROGRAPHY

One of the most interesting things about the rocks of Site 409 is how little altered they are. At Sites 407 and 408, olivine is consistently altered to smectite or sometimes to carbonate, except where it lies within a glassy rind, and basalt glass is frequently somewhat altered. At Site 409, fresh olivine remains in most specimens, and glass is no more altered than at the other sites.

Alteration minerals do occur at Site 409, usually filling some of the abundant vesicles characteristic of the rocks at the site. Most frequent and abundant are radiating clumps of aragonite attached to the walls of vesicles.

Also present are various clay minerals, ranging from dull dark green to celadon blue to orange-brown, and thus presumably including a range of smectites, celadonites, and pelagonites of different kinds. Sometimes these are abundant enough to fill completely the vesicles of a rock, but usually they form no more than thin coatings around the edges of the vesicles.

Does the small amount of alteration mean that much of the zeolite facies alteration in drilled basalts is produced by low-temperature solutions percolating into the basalt over a period of several million years? Recently, it has been common to suppose that this alteration was produced in the basalts during hydrothermal circulation of sea water in the rocks, driven by the heat of underlying igneous intrusions, and that it was therefore most active very close to the mid-ocean ridge crests. The discovery of greenschist facies metabasalt exposed on the bounding faults of the median valley of the Mid-Atlantic Ridge (Melson and van Andel, 1966), and thus clearly metamorphosed when below the floor of the median valley itself, is taken as evidence of this. Yet at Site 409 we have 239 meters of basalt within which the earliest metamorphic event, the destruction of olivine, has not yet taken place. Very little water, hot or cold, can have passed through this rock since it was formed.

This is more surprising when the vesicularity of the rocks is taken into account. With more than 30 per cent vesicles, many of them pipe vesicles, the permeability of the rock must be rated as high. In massive impermeable basalts of the kind found in normal oceanic crust, one would expect convective hydrothermal flow to be confined to discrete fissures or faults; such restriction of flow would explain the preservation of olivine at Site 409 were it not for the apparently high permeability of the rocks at that site. It seems that there may be some fundamental flaw in our thinking about penetrative hydrothermal convection in the ocean crust.

The occurrence of aragonite at this site, rather than calcite, is also interesting. Aragonite is the metastable $CaCO_3$ polymorph at low pressures in the pure $CaCO_3$ system. It can crystallize metastably in this system, but can crystallize more readily in solutions, such as sea water, that contain high concentrations of Mg. Thus $CaCO_3$ primarily precipitated from sea water at present occurs as aragonite.

Two sources seem possible for the solutions that precipitated aragonite in the basalts of this site. One could have been hydrothermal solutions originating as sea water penetrated deep into hotter regions of the crust. There plagioclase would have become zeolitized or albitized, releasing Ca and Al to the solution. The Al would have immediately been immobilized as Mg silicates such as smectite removed the Mg from the hydrothermal water. The result would have been a Ca-rich, Mg-poor brine, which, as it rose, may have crystallized $CaCO_3$. These would be proper deep-penetrating hydrothermal solutions of the kind usually envisaged. The second source could have been deep ocean water, undersaturated with $CaCO_3$ at its normal temperature, but slightly oversaturated if warmed up by penetration into the oceanic crust. Water of this kind could have penetrated directly downward without becoming involved in hydrothermal circulation patterns. The presence of aragonite in the basalt suggests that the first source is less likely, and that the small amount of alteration here is the product of cool, newly derived sea water.

BASEMENT PALEOMAGNETISM

Seventy-six specimens of basalt were taken from sub-bottom depths between 80 and 310 meters (Cores 7 through 32) in Hole 409, drilled between anomalies 1 and 2, in the Matuyama reversed interval. All the NRM intensities and inclinations were measured on board *Glomar Challenger,* but 12 of the specimens received no further treatment until they were remeasured and demagnetized in the onshore laboratory (see Table 5). For 10 of these specimens the difference between the shipboard and onshore measurements was small and within the experimental uncertainty; in two cases there was a discrepancy of direction of up to 15°, but the onshore direction tended to approach the shipboard result when progressive demagnetization was carried out. The time between the shipboard and onshore measurements was about two months. It would seem, therefore, that viscous magnetic changes during this period were not significant, and we will not distinguish in this report between specimens treated on the ship and on shore.

The NRM intensities ranged from 6×10^{-4} to 1.7×10^{-2} emu cm^{-3}, with a mean value of 5.1×10^{-3} emu cm^{-3}, and showed no systematic variation with depth (Figure 13). Only six of the specimens had intensities greater than 10^{-2} emu cm^{-3}; these include the two uppermost specimens. Although the lithologies sampled differed greatly in vesicularity, there is no obvious correlation between this property and NRM intensity.

All but two of the specimens (13-2, 131.4 m and 15-1, 149.3 m) had reversed initial inclinations between $-10°$ and $-72°$ (Figure 14). The results from specimens 13-2 and 15-1 are ignored as representing not normal excursions but misorientation. This is justifiable for two reasons: each occurs as an isolated ''normal'' specimen only a few tens of centimeters away from its reversed neighbors, and each has

TABLE 5
Paleomagnetism Data, Site 409

Sample (Interval in cm)	Depth Sub-Bottom (m)	NRM Intensity (10^{-3} emu cm^{-3})	Initial Inclination (°)	Stable Inclination (°)	MDF (Oe)	Comments
7-6B, 73-75	80	7.1	-73.1	-72.0	180	Fine-grained basalt
7-7, 1-3	81.1	14.1	-70.8	-71.9	40	Fine-grained basalt
8-1, 112-130	82.7	4.2	-44.0	-52.4	300	Very vesicular
9-1, 4-6	91.1	5.8	-64.7	-70.6	150	Very vesicular
9-1, 130-132	92.3	3.3	-50.5	-54.6	Thermal	Vesicular
9-2, 24-34	92.8	2.5	-53.4	-58.7	220	Vesicular
9-3, 13-17	94.2	3.3	-58.0	-60.2	Thermal	Vesicular
9-3, 119-122	95.2	3.6	-51.1	-67.0	75	Vesicular
10-1, 10-12	100.6	2.2	-32.7	-74.1	60	Fine-grained
10-2, 28-31	102.3	4.1	-53.9	-62.7	480	Not vesicular
10-2, 136-139	103.4	12.3	-62.2	-66.1	Thermal	
10-3, 60-64	104.1	5.5	-65.0	-73.6	180	
10-4, 88-90	105.9	5.1	-61.4	-64.9	Thermal	
10-5, 42-44	106.9	3.7	-41.7	-63.4	80	
10-6, 134-136	109.4	8.4	-67.7	-67.4	80	
10-7, 6-8	109.5	7.9	-58.4			
10-8, 60-62	109.8	6.3	-46.6	-65.6	100	
11-1, 54-56	110.6	6.6	-57.7	-63.2	120	
11-2, 78-80	112.3	3.3	-28.5	-52.9	Thermal	
11-3, 78-80	113.8	3.9	-47.7	-64 1	50	
11-4, 36-38	114.9	4.1	-53.9	-66.5	60	
12-1, 138-140	120.9	2.6	-73.0	-72.7	180	
13-1, 48-50	129.5	5.2	-77.8	-77.9[	200	
13-1, 137-140	130.4	0.001	-71.7	-77.0	300	Very altered
13-2, 84-87	131.4	8.6	? 33.9	? 36.2	280	Ignored
13-3, 37-40	132.4	7.8	-46.0	-47.9	260	
14-1, 48-52	139.0	5.7	-43.7	-48.1	250	
15-1, 26-28	148.3	6.3	-57.2	-59.4	200	
15-1, 132-134	149.3	5.6	? 68.7	? 66.8	150	Ignored
15-2, 35-37	149.9	9.6	-64.0	-66.4	80	
15-2, 140-142	150.9	2.1	-55.0			
15-3, 104-106	152.1	0.7	-54.6	-63.3	Thermal	
15-4, 62-65	153.1	1.0	-54.9	-60.4	450	
15-5, 68-70	154.7	1.6	-66.9	-66.1	7500	
15-6, 30-32	155.8	5.3	-56.3	-59.5	140	
16-1, 122-125	158.7	1.4	-60.8	-65.8	390	
16-2, 16-19	159.2	9.1	-70.5	-72.4	160	
17-1, 36-38	167.4	2.6	-53.0	-60.4	290	Vesicular
17-2, 11-13	168.6	4.7	-57.8	-61.0	130	
18-1, 140-150	178.0	4.7	-64.8	-66.0	170	
18-2, 96-100	179.0	0.9	-52.7	-75.6	420	
18-3, 120-125	180.7	2.1	-42.5	-67.3	Thermal	
18-4, 20-23	181.2	7.1	-58.4	-61.2	100	
18-4, 100-105	182.0	3.6	-62.6	-65.0	260	
20-1, 53-60	196.5	6.7	-58.2	-60.5	200	
21-1, 3-6	205.0	3.4	-37.7	-48.8	310	
21-1, 97-102	206.0	2.4	-32.8	-57.0	250	
21-2, 79-82	207.3	6.7	-48.9	-52.8	320	
21-3, 37-39	208.4	10.9	-46.9	-51.2	Thermal	
21-3, 141-144	209.4	6.4	-67.0	-66.2	190	
21-1, 53-57	215.1	3.1	-61.7	-66.4	200	
21-1, 94-97	215.5	3.2	-55.6	-60.0	220	
23-1, 29-37	224.3	4.9	-52.0	-54.7	Thermal	
23-2, 34-45	225.9	3.2	-47.3	-52.9	180	
23-2, 127-132	226.8	5.4	-52.8	-58.6	430	
24-1, 14-17	233.7	5.0	-42.3	-52.8	120	
24-1, 142-148	235.0	12.2	-52.3	-55.0	140	
24-2, 86-92	235.9	3.6	-33.1	-50.2	70	
24-3, 74-81	237.3	1.4	-10.0	-66.5	70	
24-4, 88-93	238.9	3.3	-55.9	-61.6	75	
24-5, 67-73	240.2	5.0	-53.4			
24-6, 65-71	241.7	3.9	-28.6	-71.6	50	
24-7, 52-59	243.0	2.4	-24.5	-68.4	40	
25-1, 81-85	243.8	5.3	-55.6	-66.6	120	
25-2, 33-36	244.9	0.8	-48.1	-64.5	Thermal	
25-3, 85-90	246.9	0.9	-48.5	-54.7	320	
25-4, 102-105	248.5	1.5	-54.9	-64.3	210	
26-1, 30-32	252.8	1.1	-54.4	-66.1	390	
26-1, 76-79	253.3	6.0	-57.0	-59.7	180	
27-1, 32-35	262.3	14.0	-46.3	-47.3	250	
28-1, 39-42	271.9	7.5	-69.3	-69.9	270	
28-1, 145-148	273.0	5.7	-65.6	-70.9	160	
31-1, 11-14	300.1	5.3	-58.3	-64.5	120	
31-1, 104-151	301.1	3.9	-55.6	-62.2	Thermal	
31-2, 71-74	302.2	4.3	-59.3	-63.8	220	
32-1, 78-89	310.3	2.4	-47.2	-52.0	200	

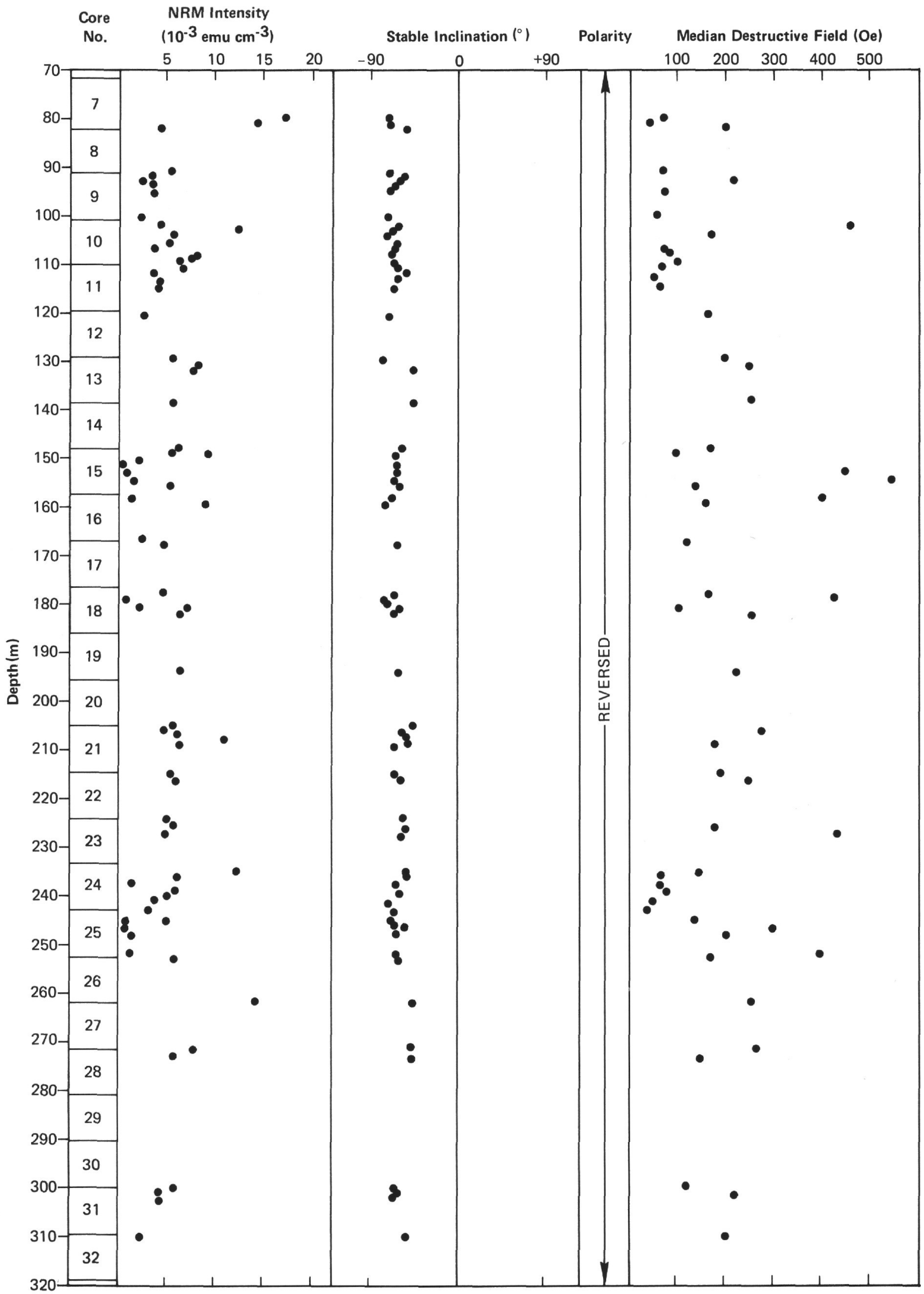

Figure 13. *Downhole plot of paleomagnetism results, Hole 409.*

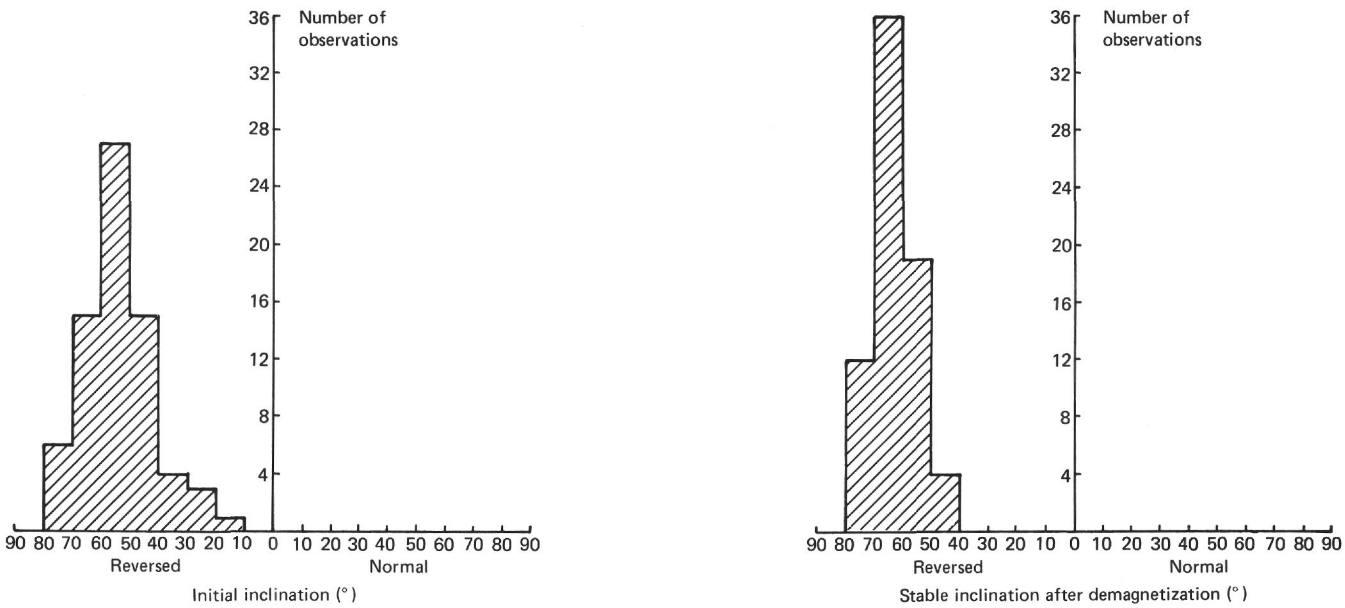

Figure 14. *Histograms showing distribution of inclinations of 71 specimens before and after demagnetization to stable end point.*

AF demagnetization characteristics appropriate to reversely magnetized specimens (see later discussion). After alternating field (AF) or thermal demagnetization, the stable inclinations ranged from −45° to −78°, with a mean value of −63° ±2° (calculated by the method of Briden and Ward, 1966) (Figures 13 and 14). No systematic variation of inclination with depth is evident (Figure 13). But a sudden change in stable inclination, from values around 47° to values around 48°, occurs below specimen 13-1, 137 to 140 cm, which is very altered and close to a petrographic boundary.

AF Demagnetization

We subjected 61 of the specimens to stepwise AF demagnetization, to peak fields up to 800 Oe, most commonly to 500 Oe. About half of these showed great directional stability, and the remainder tended to move to steeper inclinations, especially those with the most shallow initial values (Figure 15). Figure 14 shows the reduction in scatter among the inclinations after demagnetization to a stable end-point. Most of the specimens showed a slight increase in intensity after low-field demagnetization ($J/J_0 > 1$) (Figure 16). This suggests removal of an unstable normal component, possibly acquired during drilling, or a viscous remanence acquired during the subsequent normal (Brunhes) interval of the geomagnetic field. The AF demagnetization characteristics of these specimens are very similar to those of the reversed specimens from Site 407, where the presence of an unstable normal component was also inferred. Both of the isolated specimens which appear to be normally magnetized (13-2 and 15-1) showed great directional stability and also the slight increase in intensity after low-field treatment, which would not be expected for genuinely normal specimens; it is therefore highly probable that they have been misoriented by 180°.

The median destructive fields (MDFs) of the specimens are plotted against depth in Figure 13. Again, this property fluctuates in an unsystematic way with depth, and suggests fluctuation of coercivities. The MDF may not be very useful in the presence of a secondary demagnetization component opposite in sign to the main component, but magnetic stability will be examined in shore-based work on variation in grain size and degree of alteration of the primary magnetic minerals.

Thermal Demagnetization

Ten specimens were demagnetized by the method used at Sites 407 and 408. They included two with unusually high NRM intensity (specimens 10-2 and 21-3, intensity $>10^{-2}$ emu cm^{-3}) and two with low intensity (specimens 15-3 and 25-2, $<10^{-3}$ emu cm^{-3}). Figure 17 shows the normalized remanence intensity as a function of maximum temperature, after stepwise heating in a (nominally) field-free space. The blocking temperatures of the specimens, roughly between 410°C and 430°C, are very similar to each other, for specimen 11-2, which seems to have a lower blocking temperature, around 350°C. Blocking temperatures in the range 410°C to 430°C are close to those obtained from thermal demagnetization experiments at Sites 407 and 408. This may indicate that the ferromagnetic constituents of the specimens from Sites 407, 408, and 409 have essentially similar chemical compositions, including degree of oxidation, although the specimens are of significantly different ages.

Three specimens with relatively weak NRMs (15-3, $J_0 = 6.6 \times 10^{-4}$ emu cm^{-3}; 18-3, $J_0 = 21.3 \times 10^{-4}$ emu cm^{-3}; 25-2, $J_0 = 7.9 \times 10^{-4}$ emu cm^{-3}) showed about a 20 per cent increase in remanence intensity after heating to 250°C through 350°C. This increase might be explained by two coexisting magnetic phases of different blocking temperature and different stability. One would have a higher blocking temperature (410°C to 430°C) and higher stability, the other a lower blocking temperature (350°) and lower stability. The former would hold the

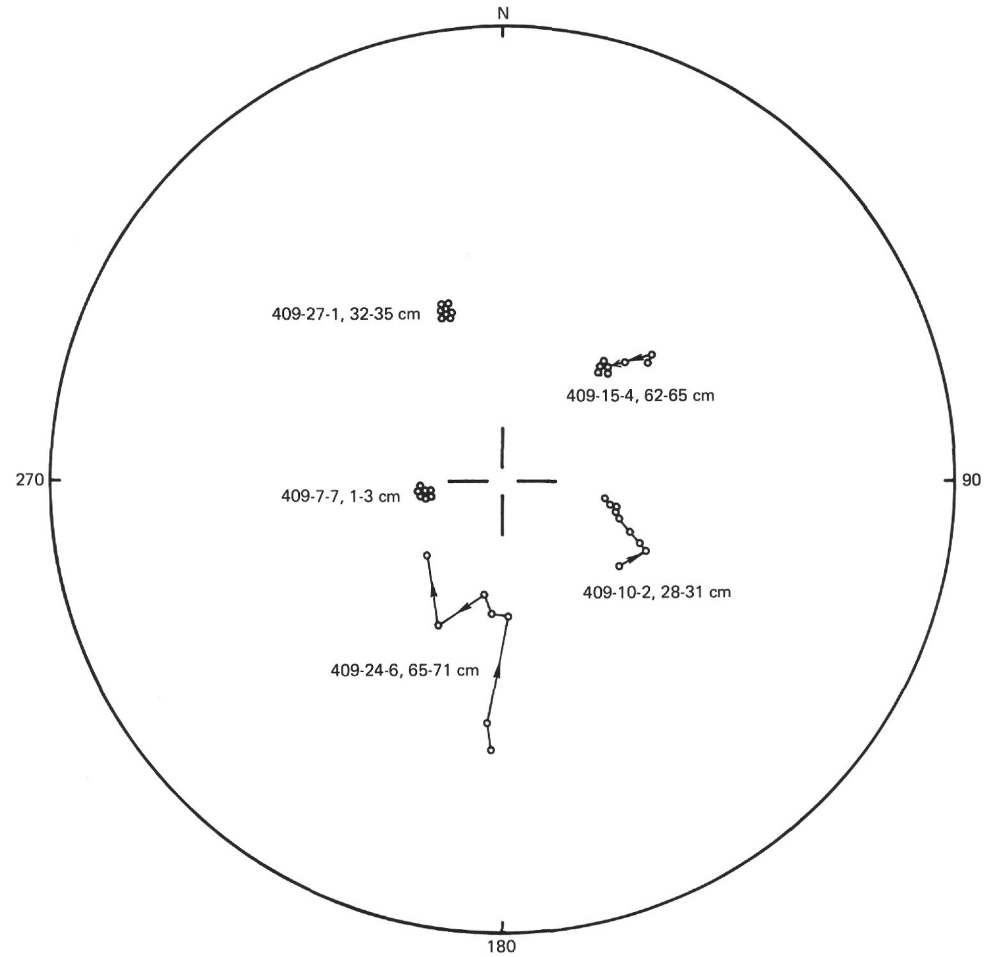

Figure 15. *Stereographic (equal-angle) projection showing examples of changes of paleomagnetic direction on AF demagnetization, Hole 409. Open circles denote upper hemisphere.*

original direction of NRM, parallel to the geomagnetic field at the time of formation of these basalts during the Matuyama reversed interval, and the latter would lose its original direction and acquire viscous or isothermal magnetization close to the present geomagnetic field. This explanation is supported by the results from Site 408, where the specimens are normally magnetized. There, intensity does not increase between 250°C and 350°C, but the weakly magnetized specimens (408-36-2 and 408-36-3) decay in intensity less rapidly with temperature than the other two specimens (compare Figure 17, this chapter, with Figure 22, Site Summary).

The increase of remanence intensity observed in some specimens after heating to 400°C may be a result of a chemical change (e.g., decomposition of titanomagnetite into magnetite and ilmentite) that produces a much higher magnetic intensity and blocking temperature, and so causes appreciable remanence (TRM or CRM) even in the small residual field of the cooling chamber. Changes in direction after thermal demagnetization (Figure 18) indicate that remanence measured above 450°C is erratic and has been acquired on cooling. A more precise explanation of the overall thermal behavior should be possible after shore-based thermomagnetic and X-ray analyses (see Part II).

Summary

The uppermost 230 meters of basalt in Hole 409 has reversed polarity consistent with origin during the Matuyama reversed interval and consistent with the sign of the magnetic anomaly. The mean NRM intensity of 5.1×10^{-3} emu cm^{-3} is slightly higher than the mean values for Sites 407 and 408, but the difference is small. The NRM intensity of basaltic basement drilled at the Reykjanes ridge sites is, on the whole, greater than intensities of oceanic basalts drilled and dredged elsewhere. This may be because of the higher latitude of these sites, about 64°N, where the earth's magnetic field is stronger than at the lower latitudes of previous drilling sites. The mean NRM intensity at Sites 407, 408, and 409 is less than half the value (1.2×10^{-2} emu cm^{-3}) cited by Talwani et al. (1971) for localities off the axis of the Reykjanes Ridge.

At all three Reykjanes Ridge sites the mean inclination is shallower than that predicted by the axial dipole field model (76°). It is not known what intervals of time the sampling represents; in the absence of declination data, the

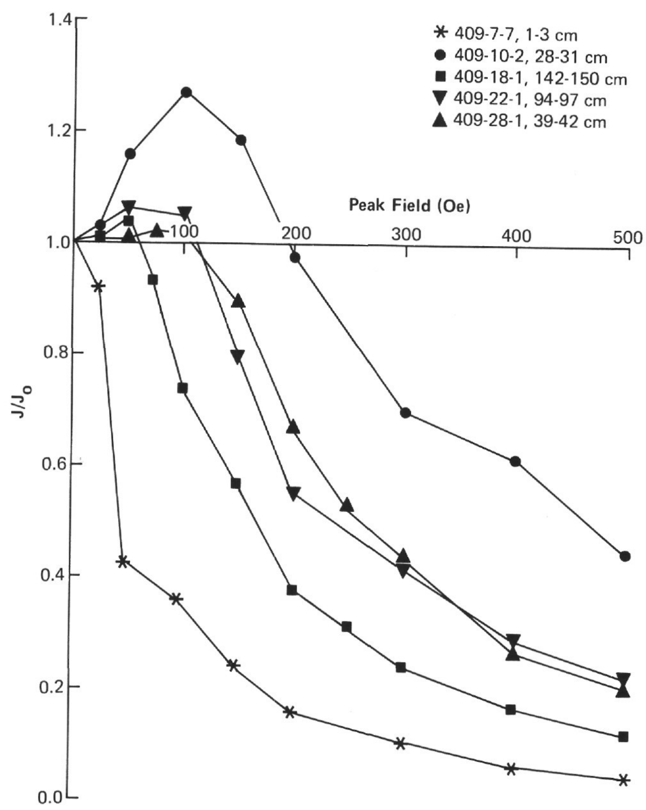

Figure 16. *Examples of intensity changes on AF demagnetization, Hole 409.*

contribution of secular variation to the scatter among the stable inclination values cannot be assessed directly (see Luyendyk, this volume). Reversely magnetized specimens obtained by deep sea drilling elsewhere commonly have inclinations shallower than the predicted value; the discrepancy awaits explanation.

PHYSICAL PROPERTIES OF BASEMENT ROCKS

Hamilton Frame sonic velocity, wet-bulk density, water content, and gamma-ray attenuation were measured on samples of the Site 409 basement rocks, and are plotted in Figures 19 through 22.

The sonic velocities, despite large scatter, again suggest a negative velocity gradient with depth. Velocitics average about 4.8 km/s at 80 meters sub-bottom; at 300 meters they average about 4.6 km/s.

Wet-bulk densities and densities derived from gamma-ray attenuation are in good agreement, considering the scatter of these data. Neither data set shows any trend and both sets have average values of 2.67 to 2.70.

Water content values have a similar scatter and average about 0.06.

CORRELATION OF SEISMIC REFLECTION PROFILE WITH DRILLING RESULTS

The beacon drop for Site 409 was guided by a requirement for a 100-ms (DT) minimum sediment thickness to bury the bottom hole assembly. An on-site sonobuoy profile was run using an 80-in.[3] airgun and an SSQ-41 sonobuoy (Figure 23). This verified that acoustic basement was at 103 ms(DT) below the sea floor.

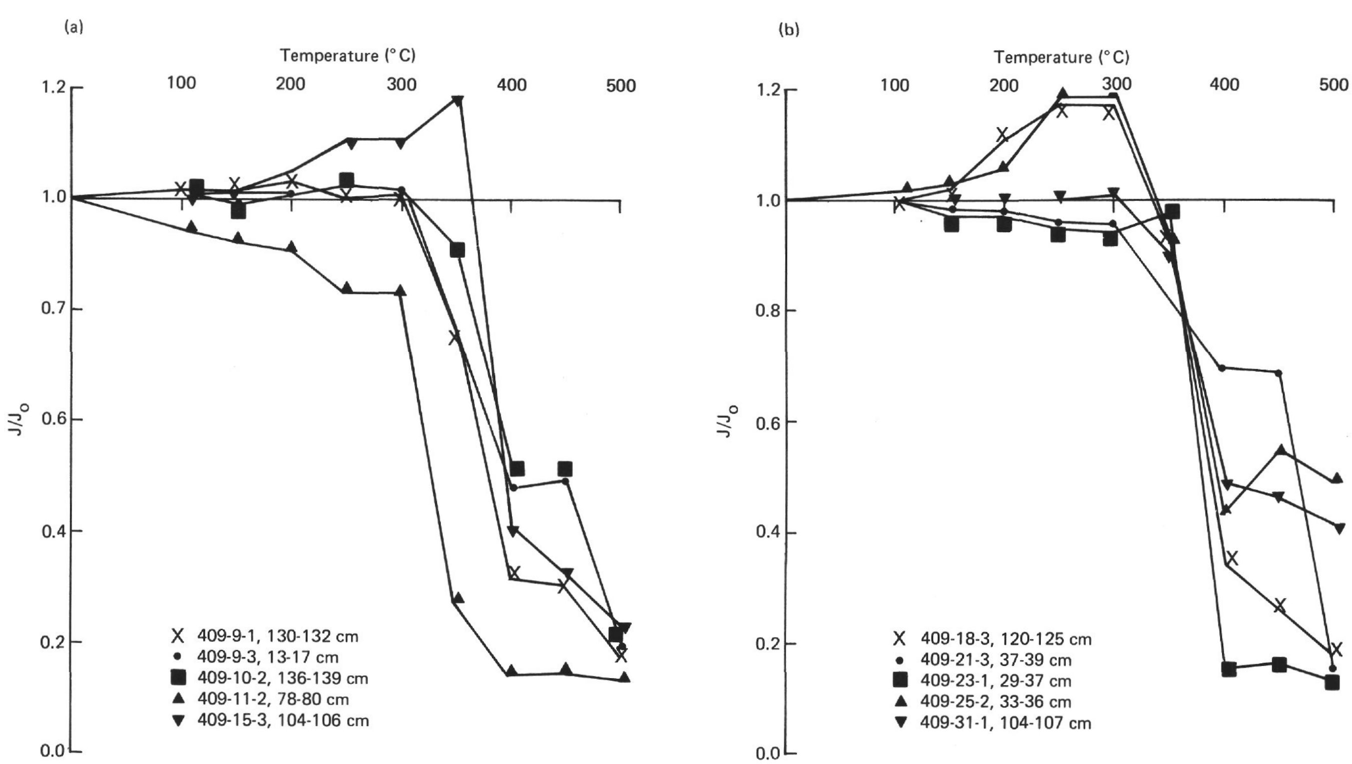

Figure 17. *Changes in intensity on thermal demagnetization, Hole 409.*

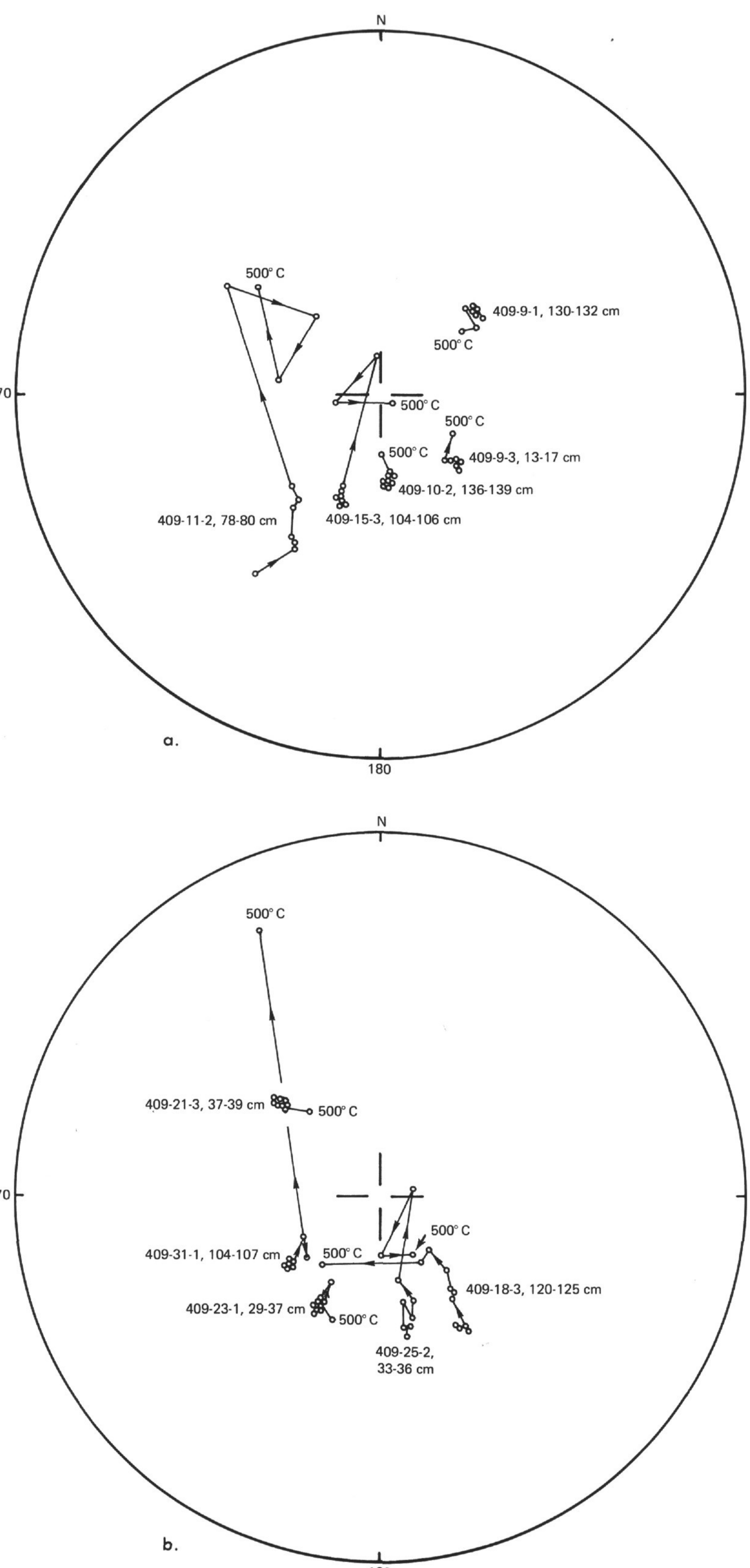

Figure 18. *Stereographic (equal-angle) projections showing examples of changes of paleomagnetic direction on thermal demagnetization, Hole 409. Open circles denote upper hemisphere.*

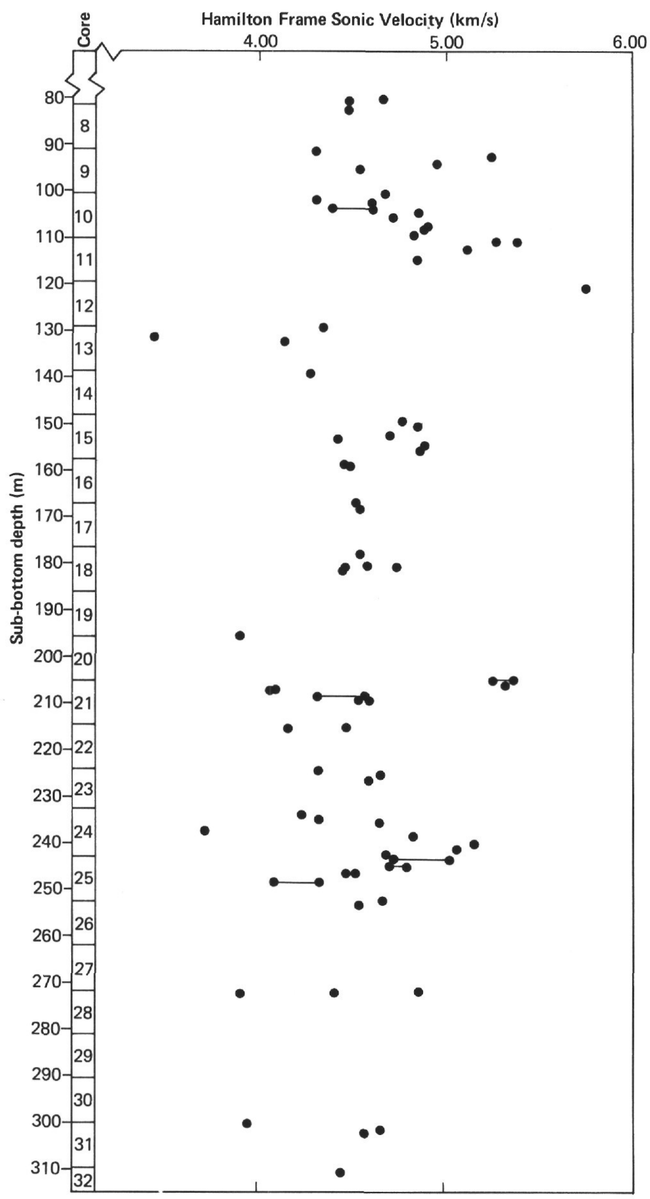

Figure 19. *Sonic velocity versus depth, Hole 409.*

An $x^2 - T^2$ (Figure 24) solution (see 407 Site Summary, Figures 38 through 40) gives an interval velocity in the sediments of 1.31 km/s and basement at 67 meters sub-bottom. Using an assumed velocity gradient of $1.0s^{-1}$ and a bottom water sound velocity of 1500 m/s, basement is calculated at 78 meters. Laboratory velocity measurements of 409 sediments with the Hamilton Frame give 1500 m/s and depth of 76.5 meters sub-bottom for the basement. Again it appears that the gradient method compares most favorably with the sub-bottom depth of 80.5 meters determined from drilling.

A sudden increase in seismic velocities to 1.7-1.8 km/s and decrease in drilling rate occurred at about 62 meters sub-bottom. Presumably this could show as an internal reflector, but our sonobuoy method employed too low an acoustic frequency to resolve this. Reverberation of the sea-floor reflection masks most internal reflectors.

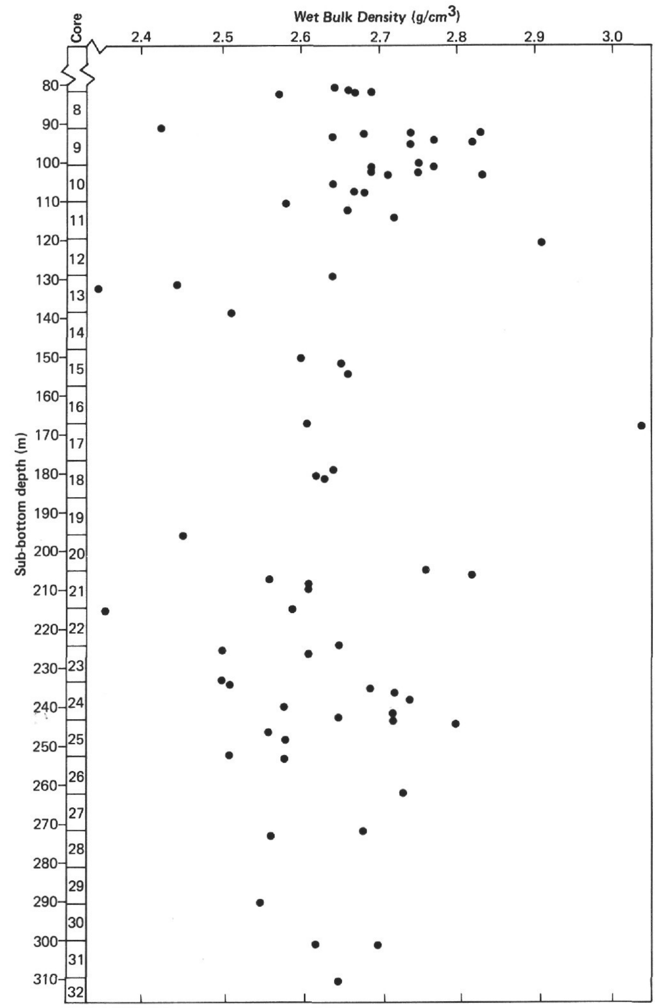

Figure 20. *Wet-bulk density versus depth, Hole 409.*

SUMMARY AND CONCLUSIONS

Penetration into basalt at Site 409 was the deepest with a single bit up to this time. What made this possible was clearly the vesicular nature of the basalt, which allowed a high penetration rate with little wear on the bit. Site 409 had the shallowest water depth of any oceanic site to date: 842 meters from the ocean bottom to the rig floor. The hole here was drilled into very young crust, 2.4 m.y. old, formed near the beginning of the Matuyama reversed epoch. This was possible because sediment has recently been accumulating in the region at a high rate, fed by melting ice and also by turbidity currents from Iceland. The sediment turned out not to be so thick as indicated by the reflection profile at the time we dropped the beacon. The hole reached basement at about 80 meters sub-bottom, but though this slowed the drilling rate, the vesicular basalt did not make for rough drilling, and we continued drilling the hole without problems. Finally, the record number of thin sections of basalt (100) allowed us a very close look at the rocks of the hole, and enabled us to build up a detailed stratigraphy and to achieve a clear view, in the absence of an XRF machine, of magmatic variation.

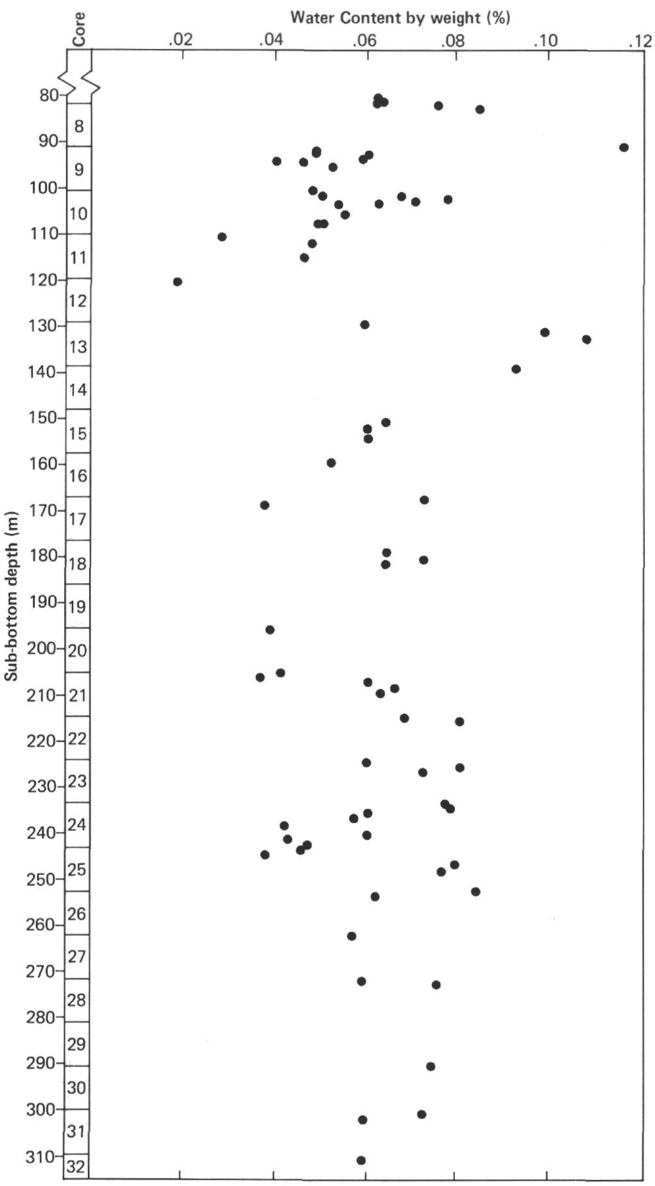

Figure 21. *Water content versus depth, Hole 409.*

We cored the sedimentary section discontinuously because of difficulty in starting the hole. The upper part of the section seemed to be very compacted sands, judging from a core-catcher sample retrieved when we were prodding around, trying to spud in. After washing down to 24.5 meters, coring was continuous to basement. Between 24.5 and 58.9 meters is a unit of lower Pleistocene sandy muds or marly oozes with numerous graded turbidite units. Gravel-size erratics are common down to 46.5 meters, but are not present below this depth. Between 58.9 meters and basement at 80 meters is an upper Pliocene-lower Pleistocene unit of nearly structureless calcareous sandy muds and marly oozes. The provenance of these homogeneous sediments is unclear.

We penetrated the basalt basement for 240 meters. It consists of a rather uniform series of flow units defined by changes in drilling rate, chilled margins, changes in degree of vesicularity, variation in phenocryst mineralogy, and

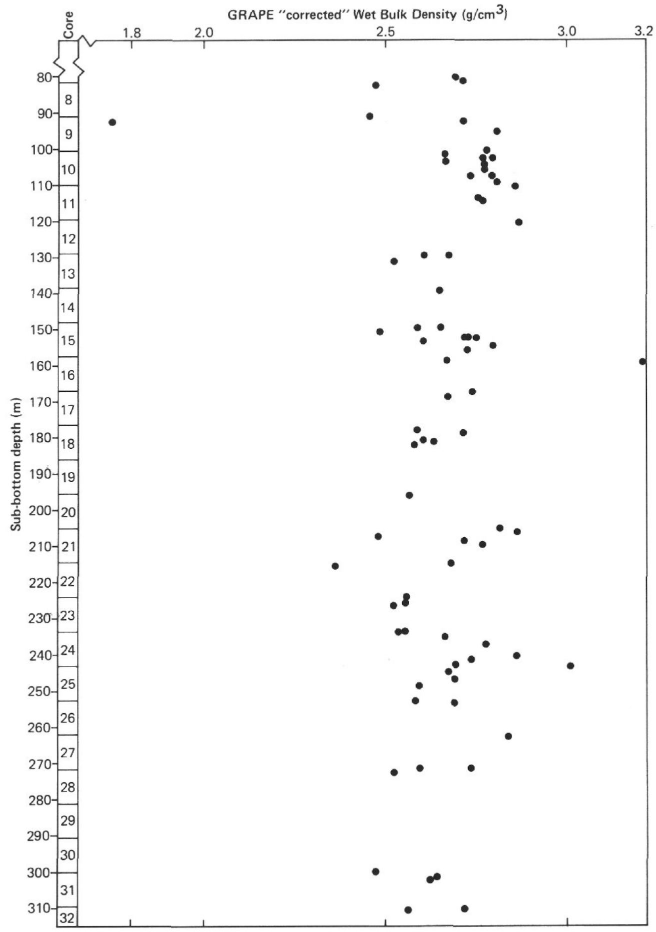

Figure 22. *GRAPE "corrected" wet-bulk density versus depth, Hole 409.*

magnetic inclination. On these bases, we distinguish between 25 and 50 flow units (the number is not entirely certain), each with an average thickness between 3 and 8 meters.

Vesicularity ranges from 5 to 10 per cent (in the least vesicular specimens) up to 38 per cent (in the most vesicular ones). These very vesicular rocks tend to be fine grained or sometimes glassy, and seem to represent flow margins; the less vesicular rock most often represents the interiors of flows, perhaps degassed after eruption, as the presence of pipe vesicles indicates. The degree of vesicularity here is much greater than in the rocks from Sites 407 and 408; Site 407 basalt is less vesicular than that at 408, but the sample from Site 408 is, of course, small.

A high degree of vesicularity could indicate a shallow depth of eruption (Moore, 1965); Moore and Schilling (1973) have demonstrated such a relationship along the Reykjanes Ridge crest. Changing depth of eruption also correlates with changing magma composition, so the Reykjanes Ridge, at the present-day degree of vesicularity, serves as a guide to both lava composition and depth of eruption. Comparison of the chemical compositions of lavas from Sites 407, 408, and 409 indicates that vesicularity should increase from Site 409 to Site 408 to Site 407, if chemistry is the principal control. Since the opposite pattern of vesicularity exists, the site of eruption of the lavas along

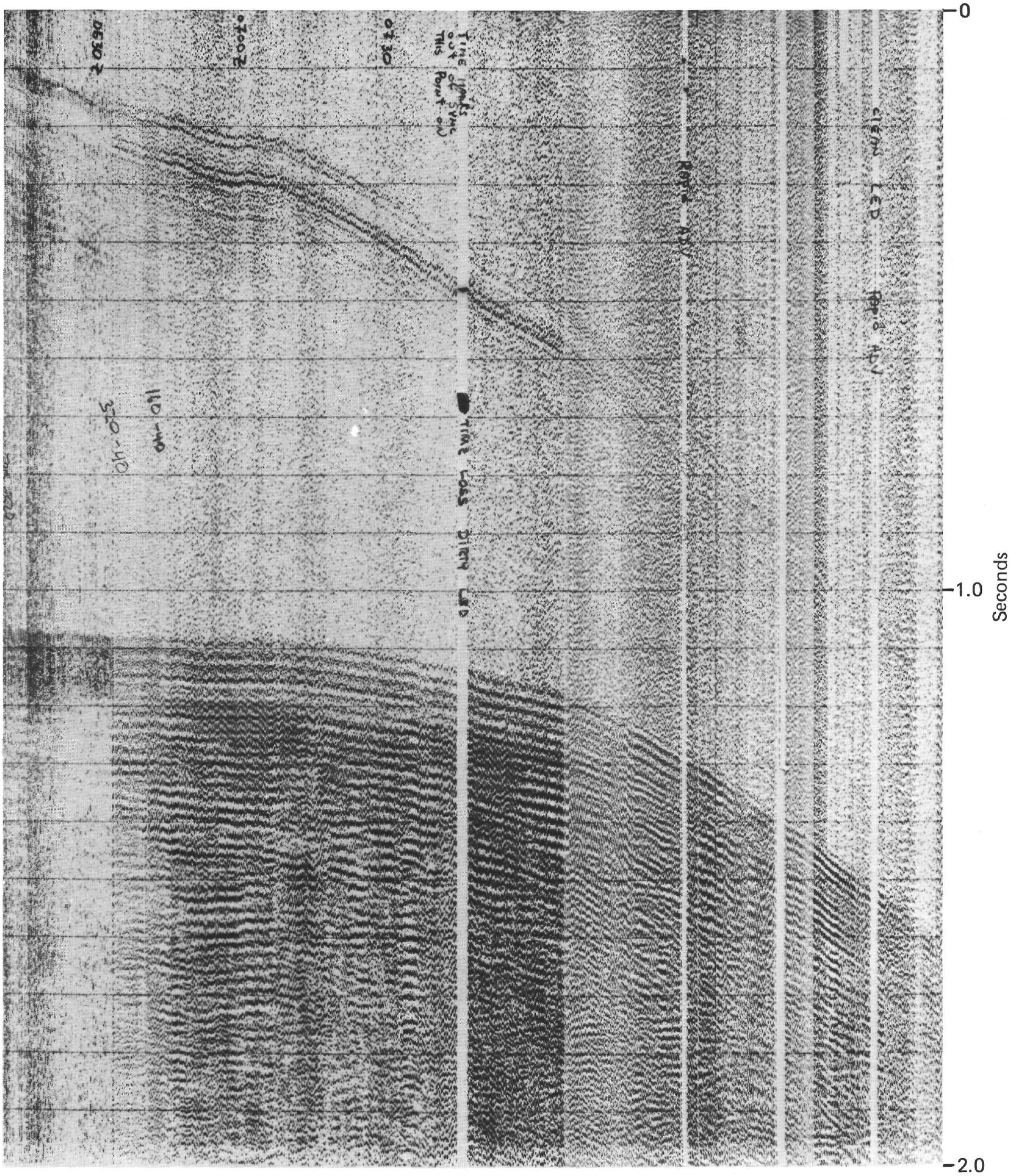

Figure 23. *Sonobuoy profile run at Hole 409.*

the Reykjanes Ridge must have been in successively shallower water from Site 407 time to Site 408 time to Site 409 time. Vesicles thus provide one means of charting the upward growth of the Ridge.

The measurements of paleomagnetism at this site show that the whole section is reversely magnetized, as predicted from the magnetic anomaly data taken as the ship crossed the site. The magnetic anomaly data would put the site near the base of the Matuyama reversed epoch, below the Olduvai event and the Reunion group of short normal events picked up in some parts of the world. This agrees with the age of the lowest sediments in the hole.

The stable inclinations measured after AF and thermal demagnetization are all high ($-45°$ to $-78°$, with a mean of $-63°$), but significantly lower than the axial dipole inclination at these latitudes (76°). The same was true for

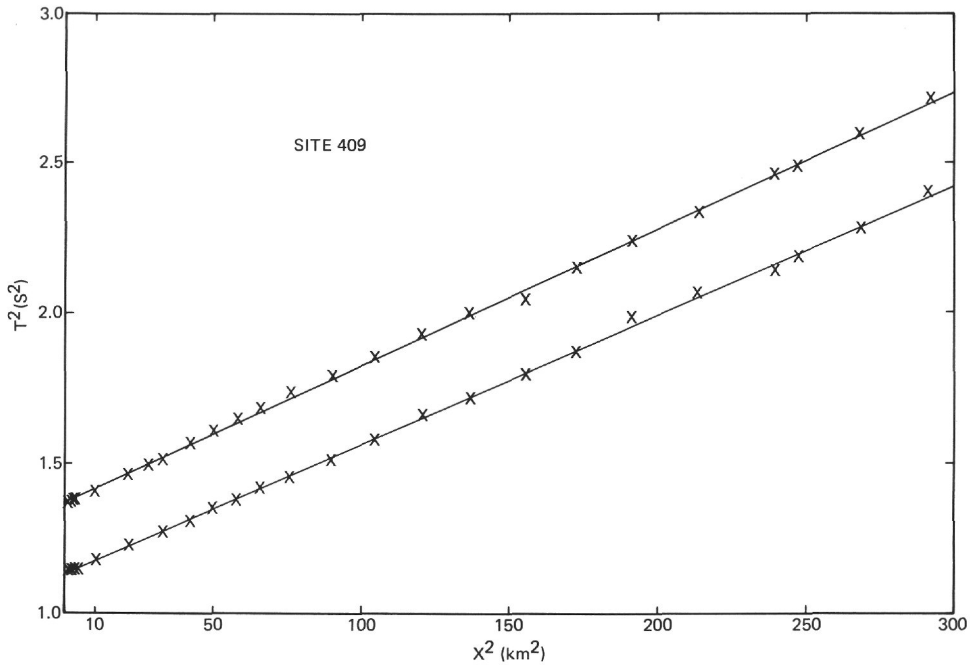

Figure 24. *X^2–T^2 solution for sonobuoy profile run at Hole 409.*

Sites 407 and 408. The reason is not clear, but whatever it is it may well apply to other DSDP sites where similar inclinations, less than the axial dipole inclination, have been observed. Most probably it results from inadequate sampling of secular variation, as discussed elsewhere in this report.

The intensity of magnetization at Site 409 is variable, and correlates with petrography. Only 5 out of 76 specimens show intensities equal to or greater than 1.2×10^{-2} emu cm^{-3} the intensity deduced by Talwani et al. (1971) from magnetic anomalies over topographic irregularities on the RER crest. The mean intensity at Site 409 is 5.1×10 emu cm^{-3}, less than half the value found by Talwani et al. Some of the more highly magnetized parts of the section might be expected to be vesicular chilled flow-boundaries. These might usefully be compared against recovery during drilling; certainly our best recovery was of the more massive, homogeneous flow interiors. It seems likely that the estimate by Talwani et al. (1971) of a 400-meter thickness for the magnetic layer, based on deduced intensities and amplitude of anomalies, may be low, and 6 to 800 meters may be closer to reality.

Demagnetization studies show that the NRM inclinations were mostly very stable. Many of the specimens showed an increase in intensity as AF demagnetization started, attributable to an unstable normal component induced during drilling or to a viscous component acquired during the the Brunhes epoch. Thermal demagnetization shows 9 our of the 10 specimens demagnetized in this way to be very stable in intensity up to a blocking temperature of 410 to 430°C.

Though alteration of basalt glass and olivine to smectite and precipitation of calcium carbonate become important in some parts of the core, the chief impression of the rocks from this site is that they are unaltered. Fresh olivine persists through most of the core, even though it was absent — except in glassy rinds — at Sites 407 and 408. Fresh glass is common, but the lack of pillow structure in the lavas means that it is not abundant. Of the alteration products, smectite is present throughout. The calcium carbonate phase was identified in one sample as aragonite, and the generally developed radiating habit suggests that at this site all of it is probably aragonite. We argue that this implies precipitation from Mg-rich cool sea water, rather than from any kind of hydrothermal solution. Certainly the intensity of hydrothermal circulation at this site must have been very low. In the aphyric basalts, an evolutionary sequence is evident, from basic varieties with rather abundant olivine (up to 10% toward more evolved types with more sodic plagioclase and apparently more Fe- and Ti-rich clinopyroxenes. Varieties corresponding to these aphyric lavas, but containing sparse phenocrysts, show that the phases olivine, plagioclase, and clinopyroxene appear successively, in that order. No cyclicity of eruption is apparent in the core. Geochemical data indicate that Site 409 lavas are, on the average, of the same composition as lavas dredged from nearby parts of the Reykjanes Ridge.

In conclusion, work at this site was extremely successful; records set here have already been enumerated. It is the precursor of what will be a major effort to drill young crust in the later stages of IPOD program, and shows how useful single-bit drilling could be in such a pursuit. In the context of the Reykjanes Ridge transect, it has provided a very fresh, very long section of recently erupted basalt against which both the dredge hauls and the other drilled sites can be evaluated. In addition, the core from this site will be very useful for comparison with cores from normal mid-ocean ridges, toward understanding the volcanology of submarine spreading centers and the kinds of differences that occur between a slow-spreading, non-rifted ridge erupting geochemically anomalous lavas, and normal Mid-Atlantic Ridge.

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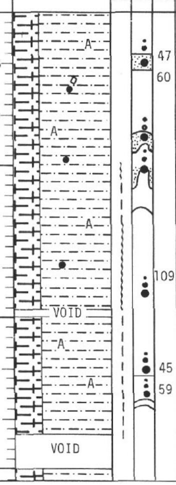
SITE 409 HOLE CORE 1 CORED INTERVAL: 0.0-1.0 m

TIME-ROCK UNIT	BIOSTRAT ZONE	FORAMS	NANNOS	RADS	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE / SEDIMENTARY STRUCTURES / LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
PLEISTOCENE	NN20/21		Cg		CC		(no thickness, symbol only)		SANDY CALCAREOUS MUD Dark gray (5Y 4/1) foram-rich sandy mud with basaltic sand grains scattered throughout. Sample probably not valid representative of the interval as it resulted from repeated attempts to penetrate hard bottom.

SITE 409 HOLE CORE 2 CORED INTERVAL: 24.5-34.0 m

TIME-ROCK UNIT	BIOSTRAT ZONE	FORAMS	NANNOS	RADS	SECTION	METERS
PLEISTOCENE	NN19	Ag			1	0.5, 1.0
					2	
		Ag	Ag		3	
					CC	



dark gray (5Y 4/1)

gray (5Y 5/1)

interlayered dark gray (5Y 4/1) and gray (5Y 5/1)

gray (5Y 6/1)

interlayered gray (5Y 6/1) and gray (5Y 5/1)

greenish gray (5GY 6/1)

very dark gray (5Y 3/1)

gray (5Y 5/1)

CC=10 cm dark gray (5Y 4/1)

LITHOLOGIC DESCRIPTION

SANDY CALCAREOUS MUD
Predominantly gray series of turbidites; individual turbidite units grade from sandy mud at base upward to calcareous mud or nannofossil ooze at top. Large (1 cm long) sponge spicules scattered throughout. Several basalt or scoria pebbles and benthic shell fragments dispersed through sections.

Smear Slides (Major lithology)

	1-47	2-109	3-59
nannos	2	35	5
forams	5	12	--
rads	1	Tr	--
sp. spic.	1	5	Tr
carb. unsp.	2	3	--
fspr.	5	1	40
H. min.	3	3	3
clay	65	35	--
qtz.	--	2	40
volc. glass	15	1	10
palagonite	2	1	--
zeolite	--	1	--
glauconite	--	--	2
diatoms	--	--	--

Smear Slides (Minor lithology)

	1-60	2-109	3-45
nannos	60	45	20
forams	10	25	60
rads	--	--	--
sp. spic.	5	5	5
carb. unsp.	--	--	--
fspr.	--	--	1
H. min.	Tr	2	2
clay	--	15	--
qtz.	--	--	--
volc. glass	20	8	10
palagonite	2	Tr	1
zeolite	--	--	Tr
glauconite	--	Tr	Tr
diatoms	3	--	--

Carbonate Bomb

1-53	24%
2-53	58%
3-53	13%

Explanatory notes in Chapter 1

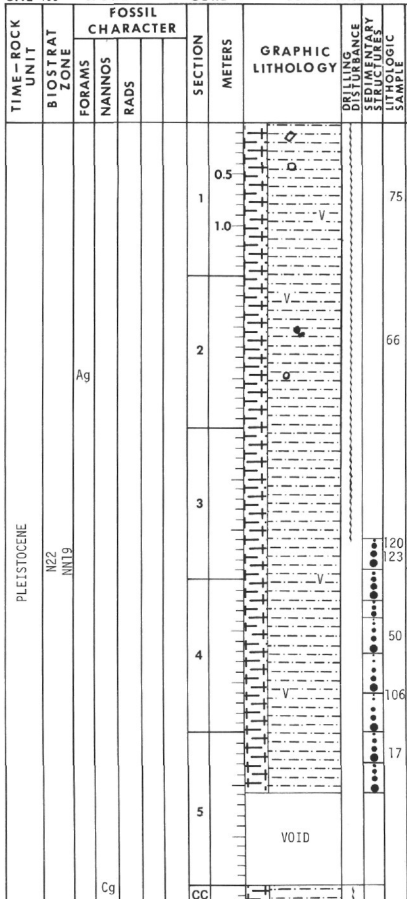
SITE 409 HOLE CORE 3 CORED INTERVAL: 34.0-43.5 m

TIME-ROCK UNIT	BIOSTRAT ZONE	FORAMS	NANNOS	RADS	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE / SEDIMENTARY STRUCTURES / LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
PLEISTOCENE	NN19	Rm			CC		(Small glob only)		SANDY MUD Dark olive gray (5Y 3/2), mostly fine feldspar and quartz sand mixed with clay.

Smear Slides

	CC
fspr.	40
qtz.	
H. min.	3
volc. glass	5
forams	2
nannos	1
carb. unsp.	1
clay	48

SITE 409 HOLE CORE 4 CORED INTERVAL: 43.5-53.0 m



olive (5Y 4/3) to dark olive gray (5Y 3/2)

gray olive green (5GY 3/2)

turbidite sequences grade from very dark gray (5Y 3/1) or olive (5Y 4/3) at base to gray (5Y 4/1) or dark greenish gray (5GY 4/1)

dark greenish gray (5GY 4/1) mixed with very dark gray (5Y 3/1)

LITHOLOGIC DESCRIPTION

CALCAREOUS SANDY MUD

Dominantly dark gray or olive gray. Undeformed part of core consisting of several turbidite sequences, generally grading from terrigenous sand or foram sand up to foram-nanno mud, with color grading from dark gray or olive to lighter gray at the top. Basalt pebbles, benthic shell fragments, two limestone pebbles scattered down to Section 2. Coarse detrital quartz and feldspar, heavy opaque minerals vary from 5-40%. Volcanic ash including zeolite generally 5-15% but up to 30% in some ash-rich horizons. Terrigenous(?) clay 20-60% most sections. Biogenic silica uniformly 2-10%.

Smear Slides (Major lithology)

	1-75	2-66
qtz.	25	20
fspr.	5	
H. min.	10	2
clay	45	64
volc. glass	1	1
palagonite	5	3
glauconite	Tr	--
zeolite	1	3
carb. unsp.	5	2
forams	Tr	3
nannos	2	1
diatoms	--	Tr
rads	--	--
sp. spic.	1	1
silicoflag.	--	Tr

Smear Slides (Minor lithology)

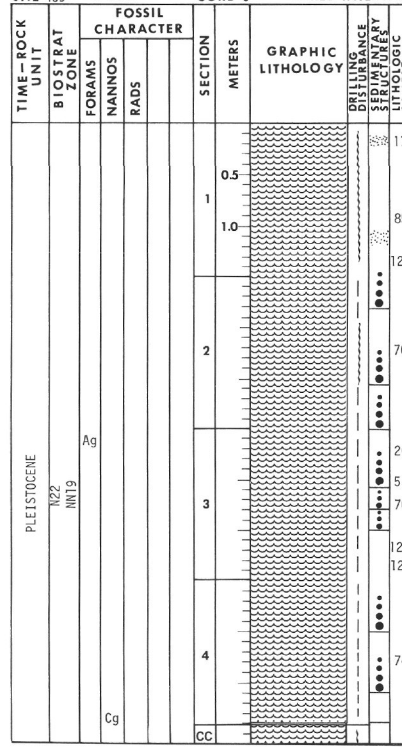
	3-20	3-123	4-50	4-106
qtz.	5	30	10	10
fspr.	2			
H. min.	1	10	5	10
clay	47	10	28	20
volc. glass	1	Tr	1	Tr
palagonite	5	Tr	5	10
glauconite	--	--	Tr	--
zeolite	2	15	15	Tr
carb. unsp.	--	5	5	20
forams	25	50	10	25
nannos	2	Tr	20	Tr
diatoms	Tr	--	--	--
rads	--	--	--	--
sp. spic.	10	Tr	1	5
silicoflag.	--	--	--	--

Carbonate Bomb

1-53	0%
2-53	11%
3-53	18%
4-53	41%
5-22	18%

Explanatory notes in Chapter 1

SITE 409 HOLE CORE 5 CORED INTERVAL: 53.0-62.5 m



variable, generally -ray (5Y 5/1) in coarse units, very dark gray (N3) in fine units

very dark gray (N3)
CC=20 cm

LITHOLOGIC DESCRIPTION

MARLY CALCAREOUS OOZE

Turbidites of variable lithologies ranging from nearly $CaCO_3$-barren sand (1-85) to calcareous ooze (2-70). Most of the variability is in the coarse basal units, while the finer upper units are mainly calcareous mud to marly calcareous sand. A few clam shells and numerous bryozoan fragments are found throughout the core, concentrated in the coarser units. Turbidites may end at 115 cm in Section 4, although the lowermost 45 cm of Core 5 could instead be the upper unit of a turbidite. Forams scattered throughout, some sand-size material in all units. Sponge spicules seen as hair-like mats in some parts.

Smear Slides

	1-17	1-85	1-124	2-70	3-20	3-53	3-70	3-123	4-74
fspr. & qtz.	5	60	9	3	5	15	5	10	6
H. min.	2	10	1	1	2	10	2	Tr	2
clay	35	13	40	20	35	15	14	65	20
volc. glass	1	Tr	Tr	1	1	5	Tr	2	1
palagonite	5	5	10	5	25	2		5	3
glauconite		1							
zeolite	1	10	Tr	Tr	5	3	20	3	3
unsp. carb.	3	1	5	60	2	25	15	5	25
forams	10	Tr	15	10	10	20	Tr	5	30
nannos	5	Tr	5	Tr	10	5	14	5	10
silic. micro.	15		15	Tr	5		Tr	Tr	Tr
shell (mollusc?) fragments							30		

Carbonate Bomb

1-53	29%
2-53	39%
3-53	42%
4-63	78%

SITE 409 HOLE CORE 6 CORED INTERVAL: 62.5-72.0 m

TIME-ROCK UNIT: PLEISTOCENE
BIOSTRAT ZONE: NN19
FOSSIL CHARACTER: FORAMS Ag (top), Cg (CC)
SECTIONS: 1, 2, 3, CC
LITHOLOGIC SAMPLE: 69 (Sec. 1), 69 (Sec. 2), 70 (Sec. 3), 2 (CC)

dark greenish gray (5GY 3/1)

dark greenish gray (5G 4/1)

5Y 4/1 to dark gray (N4)

CC=20 cm olive (5Y 5/3)

LITHOLOGIC DESCRIPTION

CALCAREOUS SANDY MUD

Homogeneous unit, composed mainly of gray sandy mud ranging in carbonate content from approximately 10-50%. Occasional ash units (distorted 2-130) and scattered ash throughout. Siliceous microfossils variable, mainly sponge spicules.

Smear Slides

	1-69	2-69	3-70	CC-2
qtz. & fspr.	30	2	10	20
H. min.	10	10	5	2
clay	21	34	56	18
volc. glass	3	2	Tr	10
palagonite	5	5	10	
glauconite	Tr	Tr	--	Tr
zeolite	1	--	2	5
unsp. carb.	Tr	5	5	15
forms	Tr	3	5	30
nannos	25	15	2	Tr
silic. micro.	5	24	5	Tr

Carbonate Bomb

1-60	24%
2-72	34%
3-65	18%

Explanatory notes in Chapter 1

SITE 409 HOLE CORE 7 CORED INTERVAL: 72.0-81.5 m

TIME-ROCK UNIT: late PLIOCENE
BIOSTRAT ZONE: ?N21 NN18
FOSSIL CHARACTER: FORAMS Am, NANNOS Ag
SECTIONS: 1, 2, 3, 4, 5, 6, 7, CC
LITHOLOGIC SAMPLE: 70 (Sec. 1), 70 (Sec. 2), 70 (Sec. 3), 73 (Sec. 4), 70 (Sec. 5), 31 (Sec. 6)

gray (5Y 4/1) with occasional mottles of gray (5Y 5/1)

LITHOLOGIC DESCRIPTION

CALCAREOUS SANDY MUD

Highly disturbed gray sandy mud containing abundant bryozoan and bivalve fragments, forams and sponge spicules down to basalt contact at 6-56. Similar to Core 6, but more disturbed. Sponge spicules abundant in some smear slides, not in others.

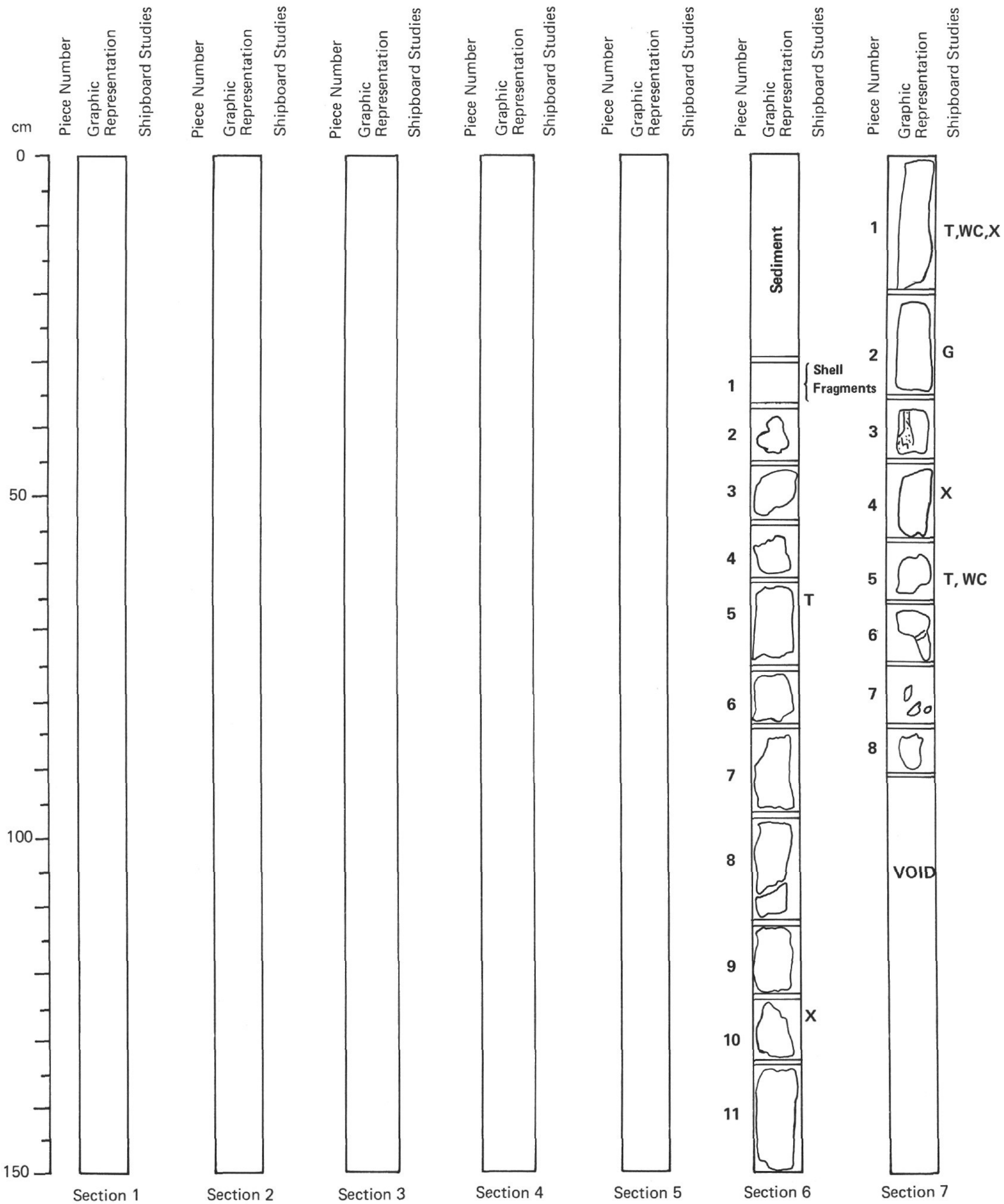
Smear Slides

	1-70	2-70	3-70	4-73	5-70	6-31
fspr. & qtz.	10	15	10	3	2	8
H. min.	5	5	5	7	5	5
clay	25	58	40	48	31	55
volc. glass	1	2	1	2	5	2
palagonite	15	5	5	7	10	5
glauconite		Tr				
zeolite	Tr	1	Tr	Tr	Tr	1
unsp. carb.	12	2	10	10	10	10
forams	5	1	3	2	2	1
nannos	2	10	15	15	20	10
sp. spic.	25	1	10	5	15	3
other silic. micro.	Tr	Tr	1	1	Tr	Tr

Carbonate Bomb

1-70	29%
2-108	36%
3-37	29%
4-110	27%
5-131	15%
6-20	22%

LEG **49** SITE **409** HOLE CORE **7** DEPTH **72.0-81.5 m**



Original basalt recovery was 1.0 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

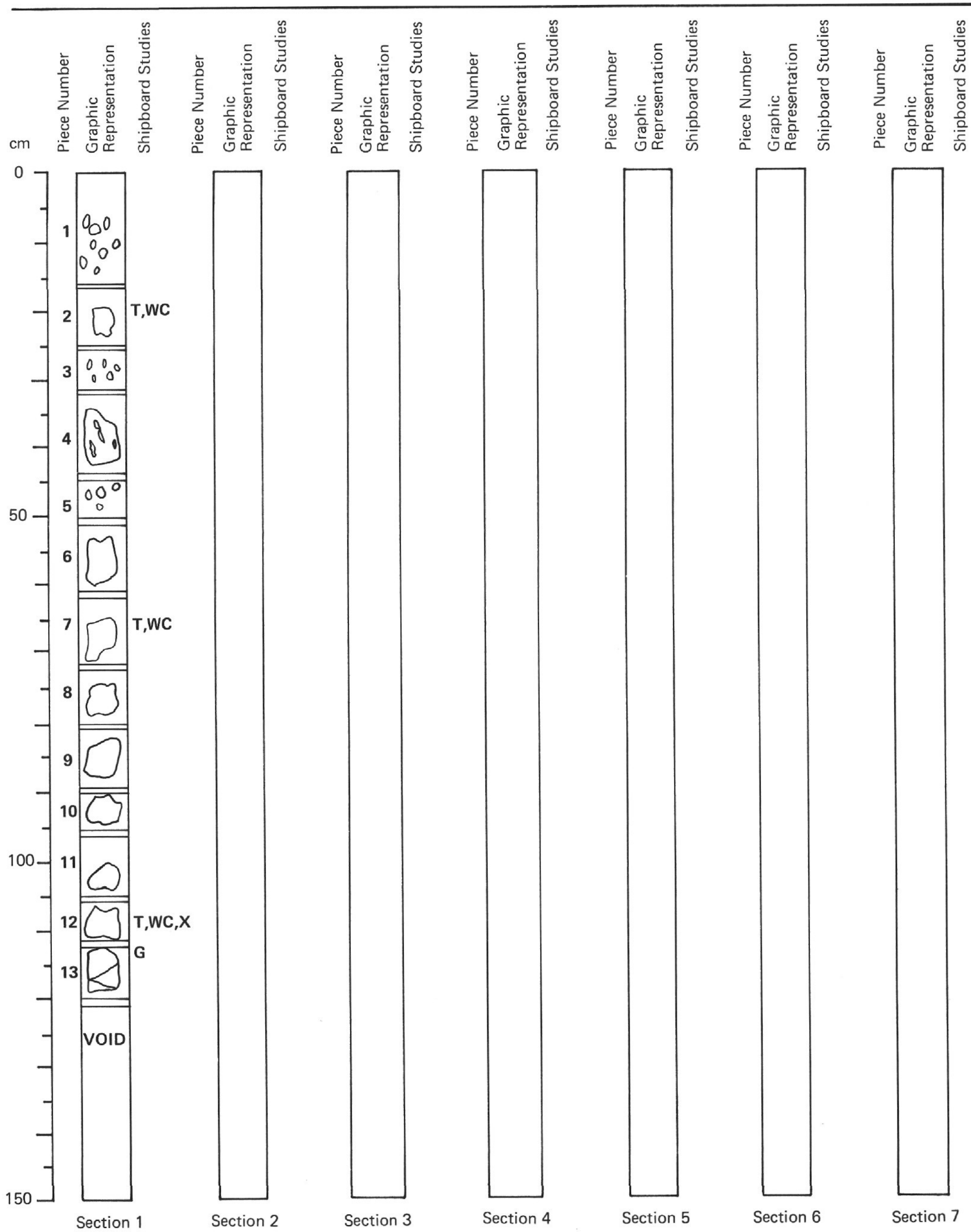
Petrography: plagioclase microphenocrysts (<5%) in a fine-grained vesicular basalt with up to 10% altered glass in groundmass. Traces of olivine in groundmass – some partially altered to smectite.

Basalt (from Core 7, Section 6, 55 to 150 cm plus 90 cm in Core 7 and Core-Catcher). Fine- to medium-grain wtih up to 5% vesicles and plagioclase phenocrysts to 5 mm vesicles empty or lined with smectite, pyrite or platy zeolites(?). Heulandite(?) in cavity at 7-6 (10). Glass zone 7-6 (57-59), nonvesicular zone 7-6 (59-60). Slight hydrothermal alteration.

Shipboard Data

	Vp	NRM	Inc.
Sect. 7, 10 cm:	4.66	––	Reversed
Sect. 7, 50 cm:	4.49	4361	-72°

LEG **49** SITE **409** HOLE CORE **8** DEPTH **81.5-91.0 m**



Original basalt recovery was 0.7 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

Interval 0-60 cm: fine-grained plagioclase phyric basalt with up to 50% plagioclase phenocrysts to 4 mm, up to 5% vesicles (1 mm). Scattered olivine microphenocrysts at 55 cm. Flow banding(?) at 50 cm and 60 cm.

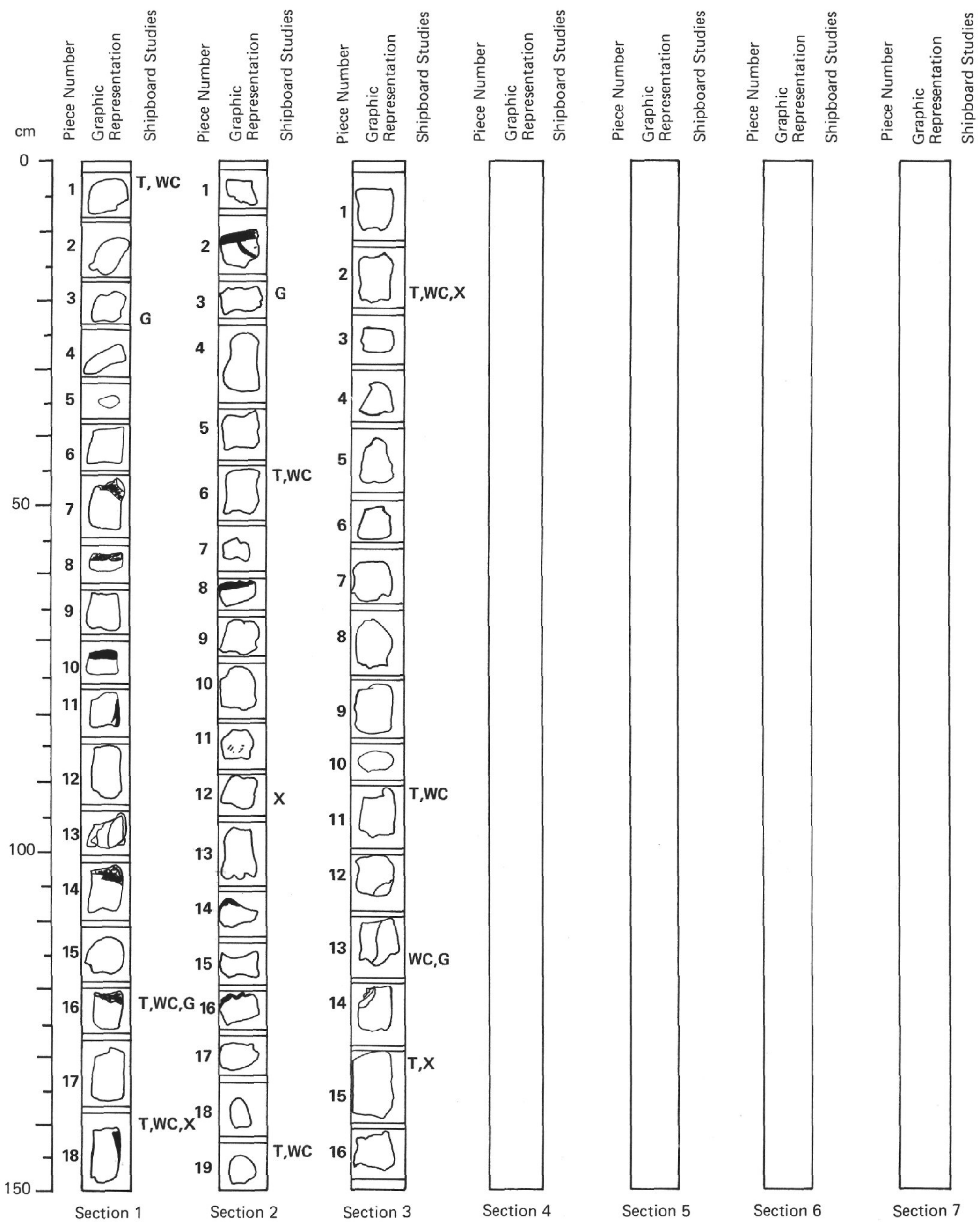
Interval 60-120 cm: Aphyric fine-grained basalt with > 10% vesicles (3-4 mm), some lined with smectite. Entire section relatively unaltered.

Petrography: plagioclase (< 5%) and in places clinopyroxene and olivine (< 1%) microphenocrysts in a fine-grained basalt containing up to 10% glass (altered). The glass is concentrated around vesicles.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 115 cm:	448	984	-52°

LEG 49 SITE 409 HOLE CORE 9 DEPTH 91.0-100.5 m



Original basalt recovery was 3.25 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

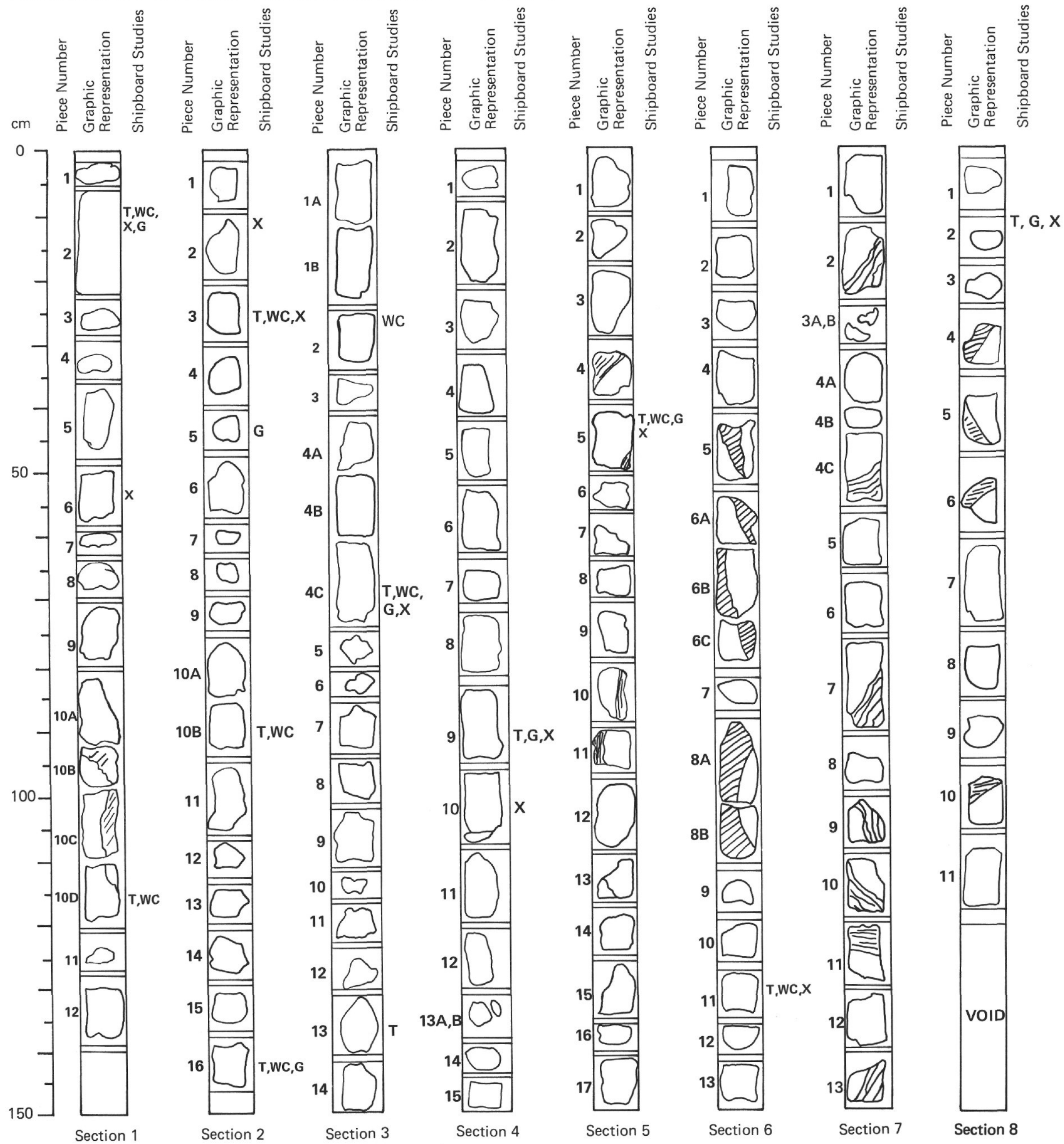
Highly vesicular aphyric fine-grained basalt. Vesicles 1-5 mm, Section 1 - 30-35%; Section 2, 0-70 and 125-150 - 20%, 70-125 - 30%; Section 3, 0-55 - 10%, 55-base - < 2%. Vesicles empty or filled or lined with celadonite and calcite. Oxidized zones (smectite, brown Fe-oxides, and calcite in veins and vesicles) at Section 1, 50, 58, 72, 80, 90, 122, 140; Section 3, 105, 115, and 145. Remainder of rock relatively fresh. Scattered microphenocrysts of plagioclase and olivine. Coarser-grained zone with concentration of plagioclase and olivine microphenocrysts at Section 3, 75-90.

Petrography: Aphyric basalt with intersertal and sub-ophitic texture. Up to 10-15% altered glass and < 5% olivine. Sparse aggregates of plagioclase, clinopyroxene and olivine microphenocrysts.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 10 cm:	4.30	1579	-71°
Sect. 1, 145 cm:	--	--	Reversed
Sect. 2, 30 cm:	5.06	769	-59°
Sect. 3, 15 cm:	4.95	1679	-60°
Sect. 3, 130 cm:	4.53	--	Reversed

LEG **49** SITE **409** HOLE CORE **10** DEPTH **100.5-110.0 m**



Original basalt recovery was 8.35 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

Fine-grained aphyric vesicular basalt with local microphenocrysts of plagioclase (to 5 mm) and olivine (1 mm). Some olivine appears fresh but rock is more altered where olivine present. Vesicles average 5-7% and 0.2-1.0 mm. Numerous vesicle enriched zones (10% to 3 mm). Lined or filled with smectite and/or calcite and traces of pyrite. Pyrite and calcite in veins.

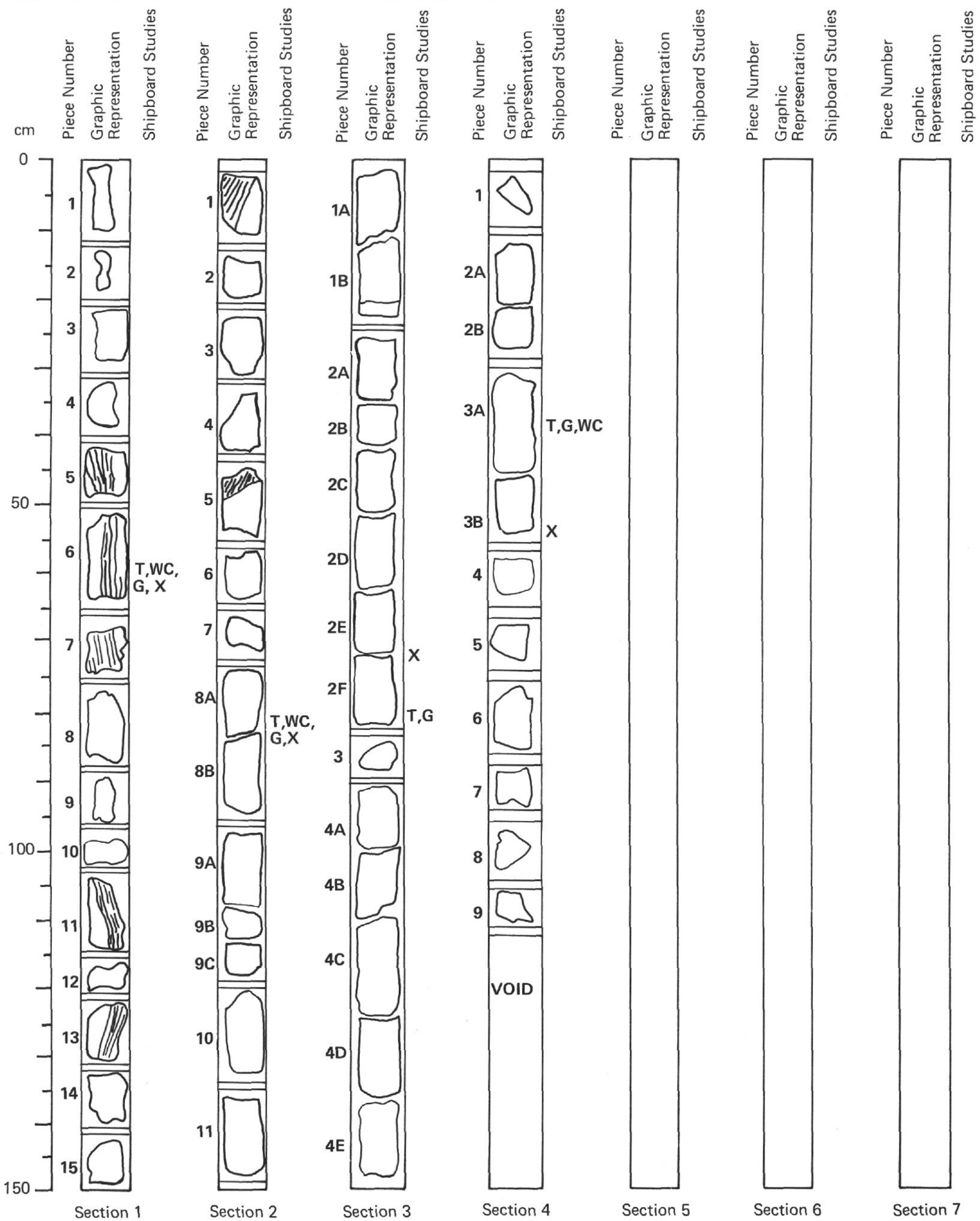
Petrography: Aphyric basalt with a sub-ophitic texture containing glomeroporphyritic aggregates of plagioclase and clinopyroxene (< 1%) microphenocrysts. Olivine content in the groundmass varies from zero to 1 or 2%. The basalt may contain up to 10% altered glass.

The last 2 meters of this core consist of aphyric olivine basalt with up to 10% altered glass. A late stage plagioclase phase engulfing earlier plagioclase is present in the last thin section.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 10 cm:	4.67	681	-74°
Sect. 2, 45 cm:	4.30	2390	-63°
Sect. 2, 140 cm:	4.60	——	Reversed
Sect. 3, 65 cm:	4.38	2050	-74°
Sect. 4, 85 cm:	4.78	——	——
Sect. 5, 45 cm:	4.73	1474	-63°
Sect. 6, 120 cm:	4.89	6415	-67°
Sect. 7, 10 cm:	4.86	——	——
Sect. 8, 10 cm:	4.82	3152	-66°

LEG 49 SITE 409 HOLE CORE 11 DEPTH 110.0-119.5 m



Original basalt recovery was 4.48 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

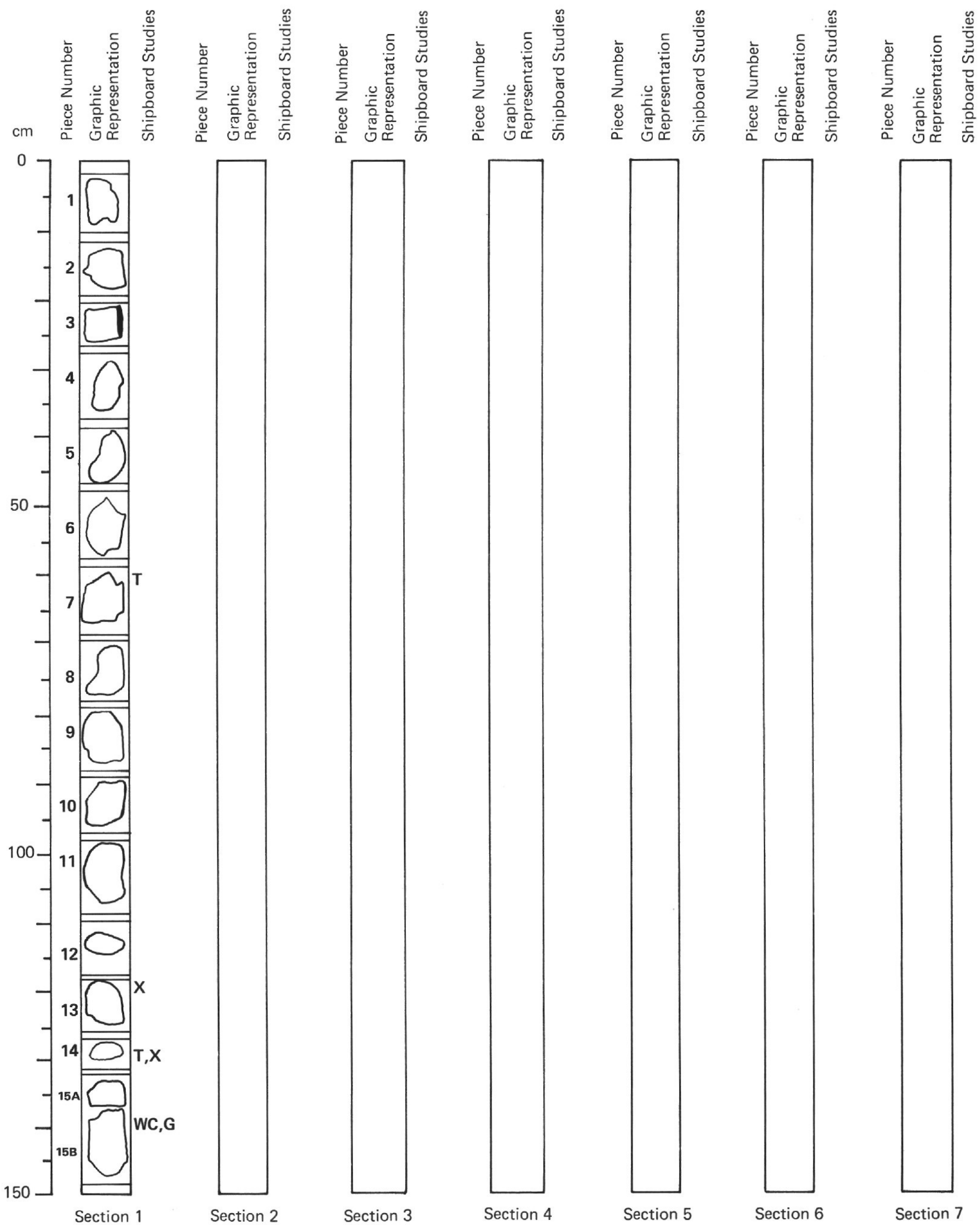
Uniform fine-grained vesicular aphyritic basalt with rare microphenocrysts of plagioclase and fresh olivine (1 mm). Vesicles ≤ 1 mm, 5-10%, lined with smectite. Vertical bands sometimes adjacent to veins are filled vesicles. Scattered calcite veins.

Petrography: Aphyric olivine basalt with intersertal to sub-ophitic texture. Olivine content varies but averages about 5% and is replaced by smectite in some sections. Glomeroporphyritic aggregates of plagioclase, clinopyroxene and olivine microphenocrysts, in that order of abundance, form ~ 1% of the rock. Up to 20% altered glass.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 55 cm:	5.26	2771	-63°
Sect. 2, 80 cm:	5.11	2771	-53°
Sect. 3, 85 cm:	4.92	909	-64°
Sect. 4, 55 cm:	5.10	1608	-66°

LEG **49** SITE **409** HOLE CORE **12** DEPTH **119.5-129.0 m**



Original basalt recovery was 0.95 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

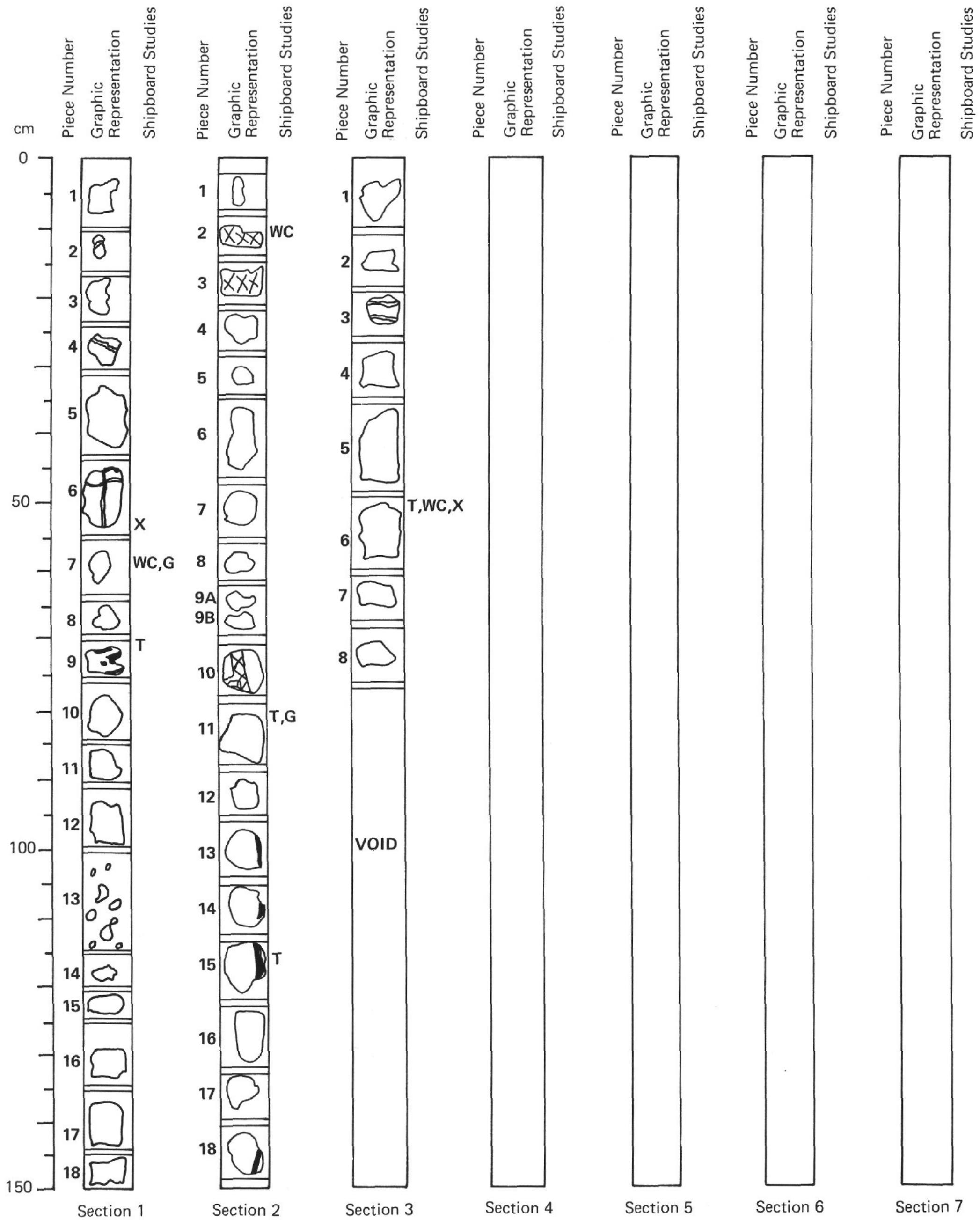
Fine-grained vesicular glassy to aphyric basalt with rare microphenocrysts of plagioclase and olivine (altered). Vesicles average 5% and 0.1-1.0 mm, locally increase to 20% and 4 mm, filled or lined with smectite and/or calcite. Scattered calcite veins.

Petrography: aphyric basalt with an intersertal texture with glomeroporphyritic aggregates of plagioclase, clinopyroxene and olivine (rare) microphenocrysts forming 1-5% of the rock. Up to 20% altered glass.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 35 cm:	5.75	1221	-73°

LEG 49 SITE 409 HOLE CORE 13 DEPTH 129.0-138.5 m



Original basalt recovery was 2.17 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

Section 1, 0-70 and 75-100: vesicular aphyric basalt with glassy groundmass and clots of olivine and plagioclase microphenocrysts. Vesicles (15%) average 1 mm. Fresh glass selvage at 50 cm. Calcite veins. 70-75 cm: breccia, glassy basalt fragments and indurated fossiliferous sediments.

Section 1, 100 cm to Section 2, 20 cm: tuffaceous and fossiliferous sedimentary breccia (5Y 6/4). Fragments of altered glassy vesicular basalt, palagonitized glass in a matrix of forams, clam shells, clay and carbonate.

Section 2, 20 cm to Section 3, 77 cm: highly vesicular glassy to fine-grained aphyric basalt. Vesicles to 25%, average 2 mm, maximum 1 cm, almost all are lined or filled with calcite. Pipe vesicle Section 3, 40-43. Partially palagonitized glass selvages Section 2, 95-125 and 140-150.

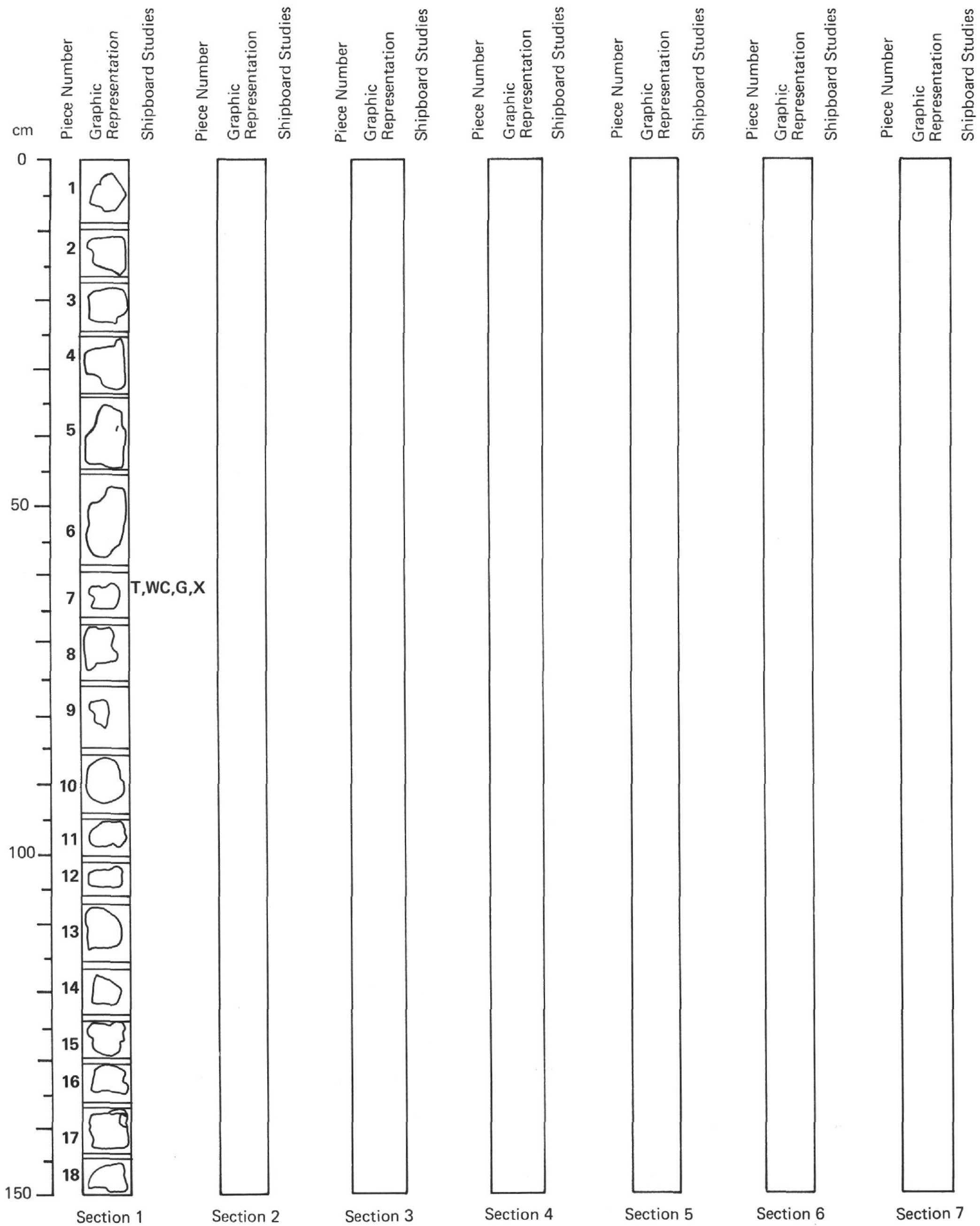
Section 2, 70-80: breccia: fragements of altered highly vesicular aphyric basalt in carbonate matrix.

Petrography: some of the volcanic glass at contact between sediment and basalt is unaltered and contains crystals of plagioclase, olivine and pyroxene in that order. The basalt is aphyric with a subvariolitic texture containing ~ 5% olivine and up to 20% glass (altered) opaque phases restricted to glass.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 50 cm:	4.34	4220	78°
Sect. 1, 145 cm:	—	—	Reversed
Sect. 2, 80 cm:	3.43	—	—
Sect. 3, 45 cm:	4.13	1908	-48°

LEG **49** SITE **409** HOLE CORE **14** DEPTH **138.5-148.0 m**



Original basalt recovery was 1.18 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

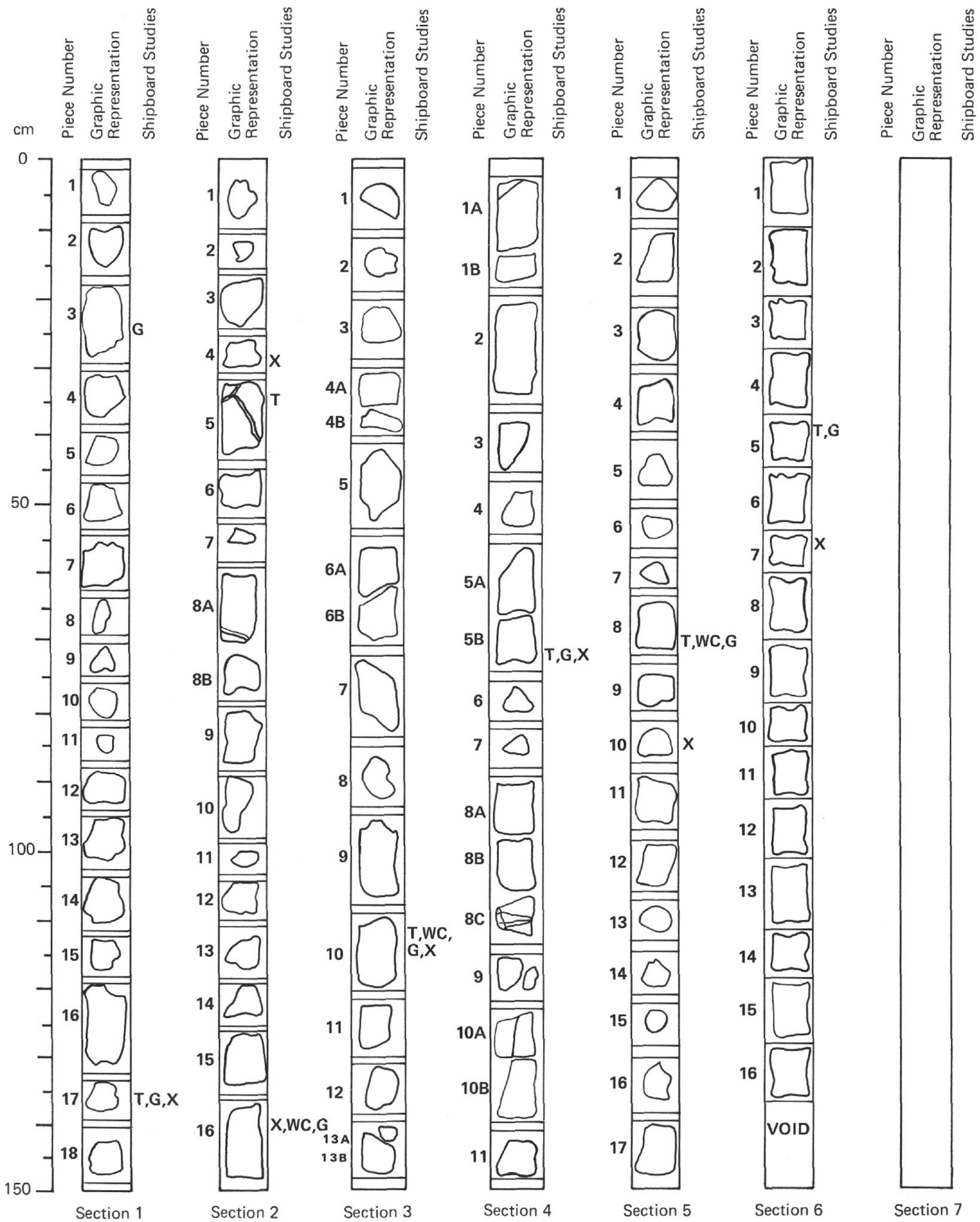
Fine-grained to glassy vesicular aphyric basalt with scattered fresh plagioclase and olivine microphenocrysts. Vesicularity ranges 20-30%. Most vesicles are ≤ 1.5 mm, all are lined with light-colored secondary minerals, a few are completely filled. Rare calcite veins.

Petrography: Aphyric basalt with intersertal to variolitic texture containing ~ 10% altered glass and up to 5% olivine.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 60 cm:	4.27	2349	-48°

LEG **49** SITE **409** HOLE CORE **15** DEPTH **148.0-157.5 m**



Original basalt recovery was 5.91 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

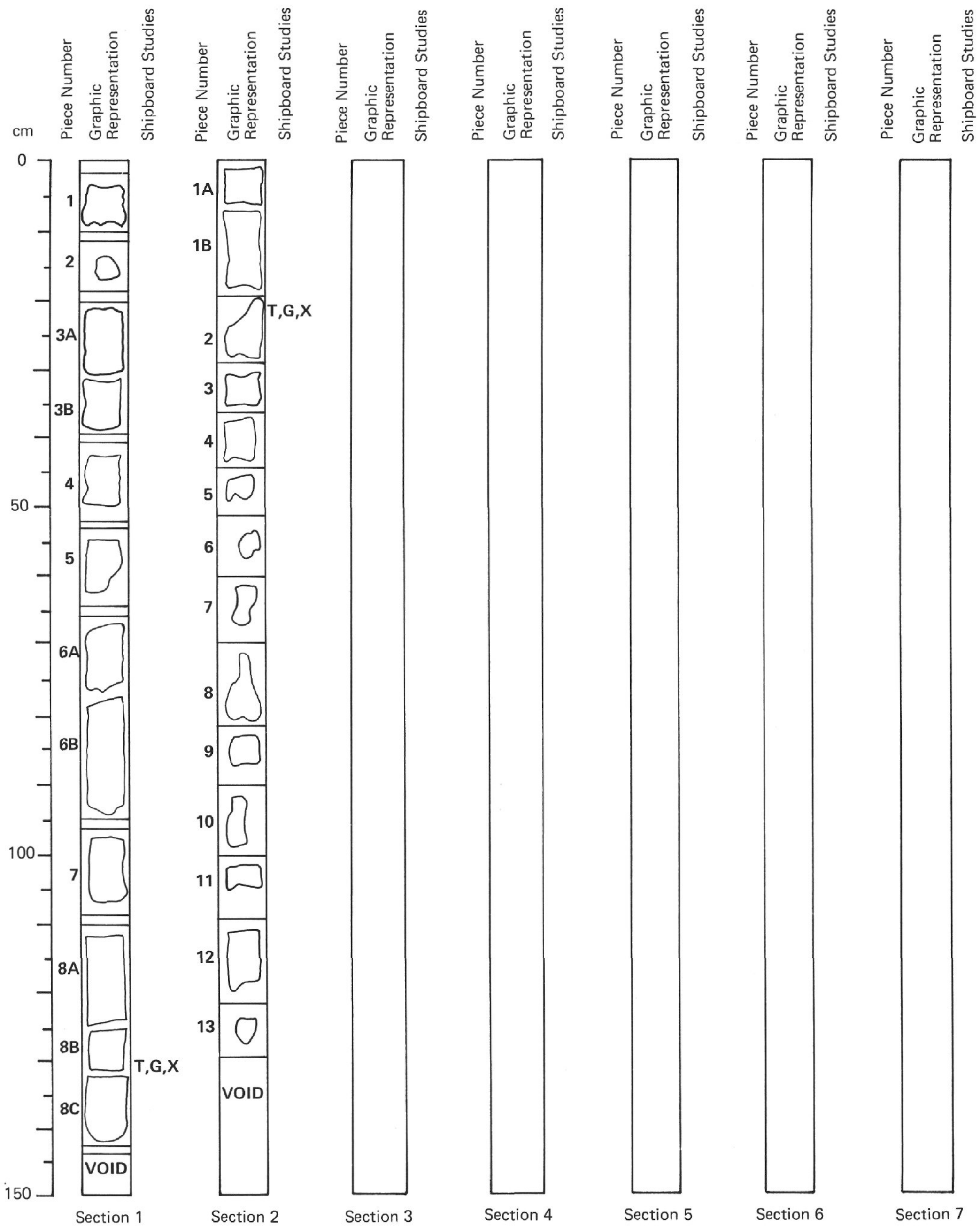
Highly vesicular fine-grained basalt with scattered and unevenly distributed olivine (fresh and altered) microphenocrysts (≈ 1 mm). Vesicles unevenly distributed, range 5-30%, .25 to 6 mm, average 2-2.50 mm. Almost all are lined with calcite, smectite, celadonite and/or rare zeolites (?-base Section 6). Rare fractures lined with smectite and carbonate. Entire core very uniform and relatively fresh.

Petrography: sparsely phyric highly glassy (25-30% in places) basalt with variolitic texture. Up to 10% olivine. Microphenocrysts of olivine and plagioclase. Magnetite found in the altered glass.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 35 cm:	––	1605	-57°
Sect. 2, 35 cm:	4.63	2016	-66°
Sect. 2, 140 cm:	4.88	––	––
Sect. 3, 115 cm:	4.70	777	-63°
Sect. 4, 70 cm:	4.42	497	-60°
Sect. 5, 80 cm:	4.87	1652	-66°
Sect. 6, 40 cm:	4.86	2402	-60°

LEG 49 SITE 409 HOLE CORE 16 DEPTH 157.5-167.0 m



Original basalt recovery was 2.00 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

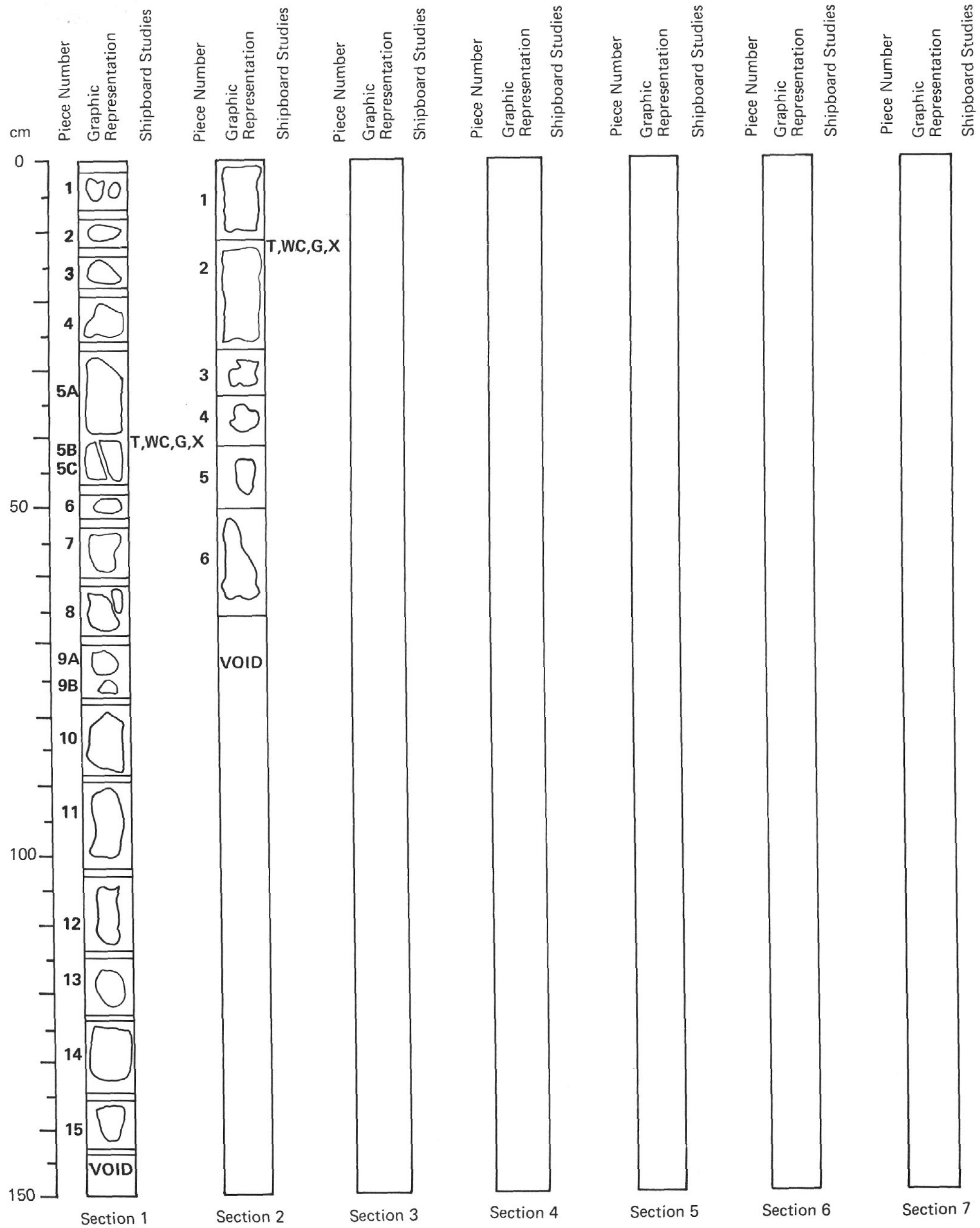
Highly vesicular fine-grained aphyric basalt with scattered plagioclase and fresh olivine microphenocrysts. Vesicles unevenly distributed, range 5-20%, 0.2-8 mm, average 2 mm, empty or thinly lined with smectite or calcite. Core very uniform and relatively fresh.

Petrography: aphyric holocrystalline basalt with a sub-ophitic texture. Traces of olivine which has been replaced by calcite and smectite.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 130 cm:	4.45	671	-66°
Sect. 2, 20 cm:	4.48	2070	-72°

LEG 49 SITE 409 HOLE CORE 17 DEPTH 167.0-176.5 m



Original basalt recovery was 1.28 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

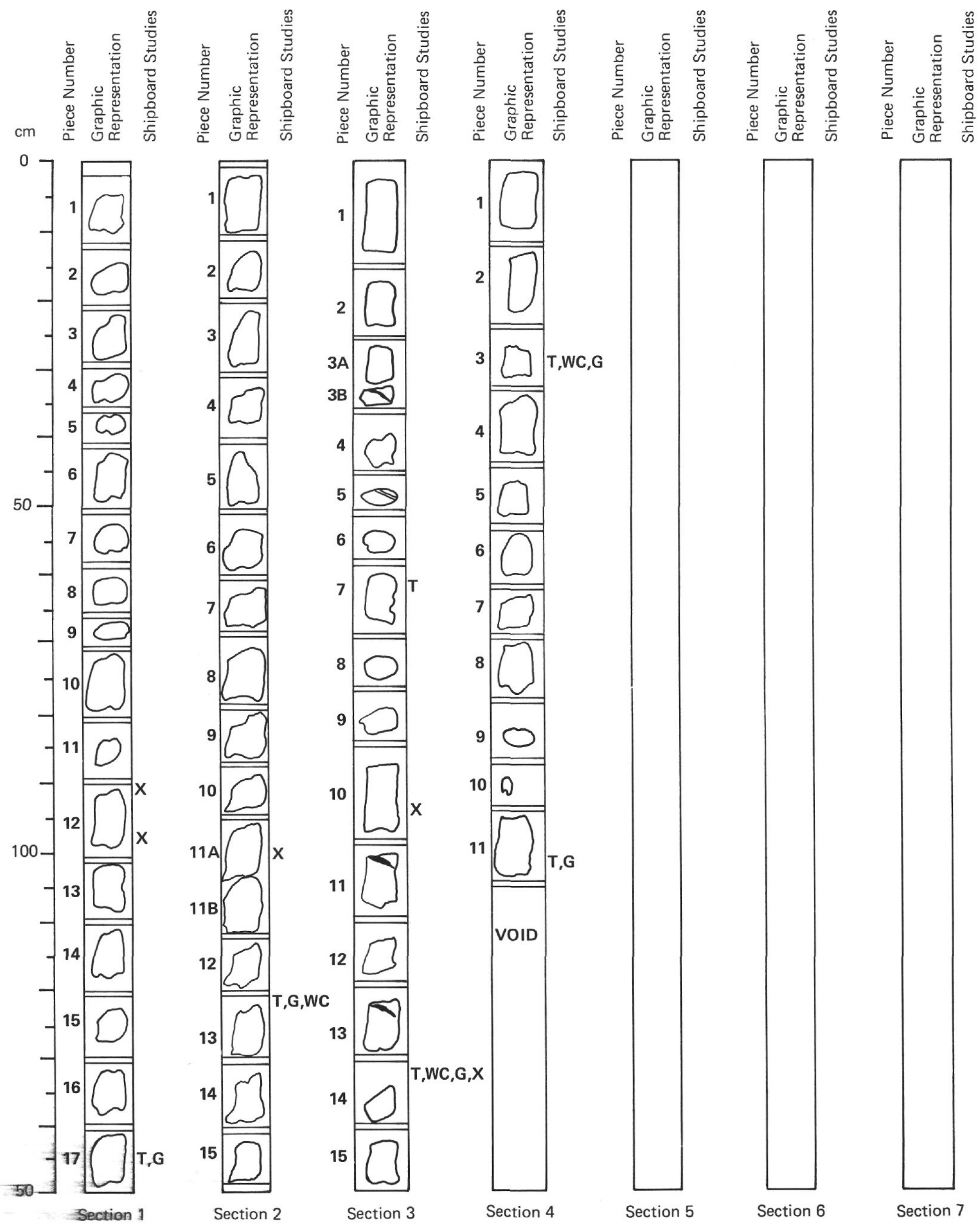
Vesicular fine-grained aphyric to phyric basalt with rare microphenocrysts, plagioclase, and olivine (to 2 mm). Vesicles range 2-20%, 0.2-10 mm, empty, thinly lined with blue-green smectite or celadonite or rarely filled with calcite. Rare veins of carbonate.

Petrography: aphyric olivine basalt with sub-ophitic texture and up to 10% altered glass. Olivine (~5%) altered to calcite and smectite in places.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 50 cm:	4.52	2792	-66°
Sect. 2, 10 cm:	4.53	1949	-61°

LEG 49 SITE 409 HOLE CORE 18 DEPTH 176.5-186.0 m



Original basalt recovery was 3.40 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

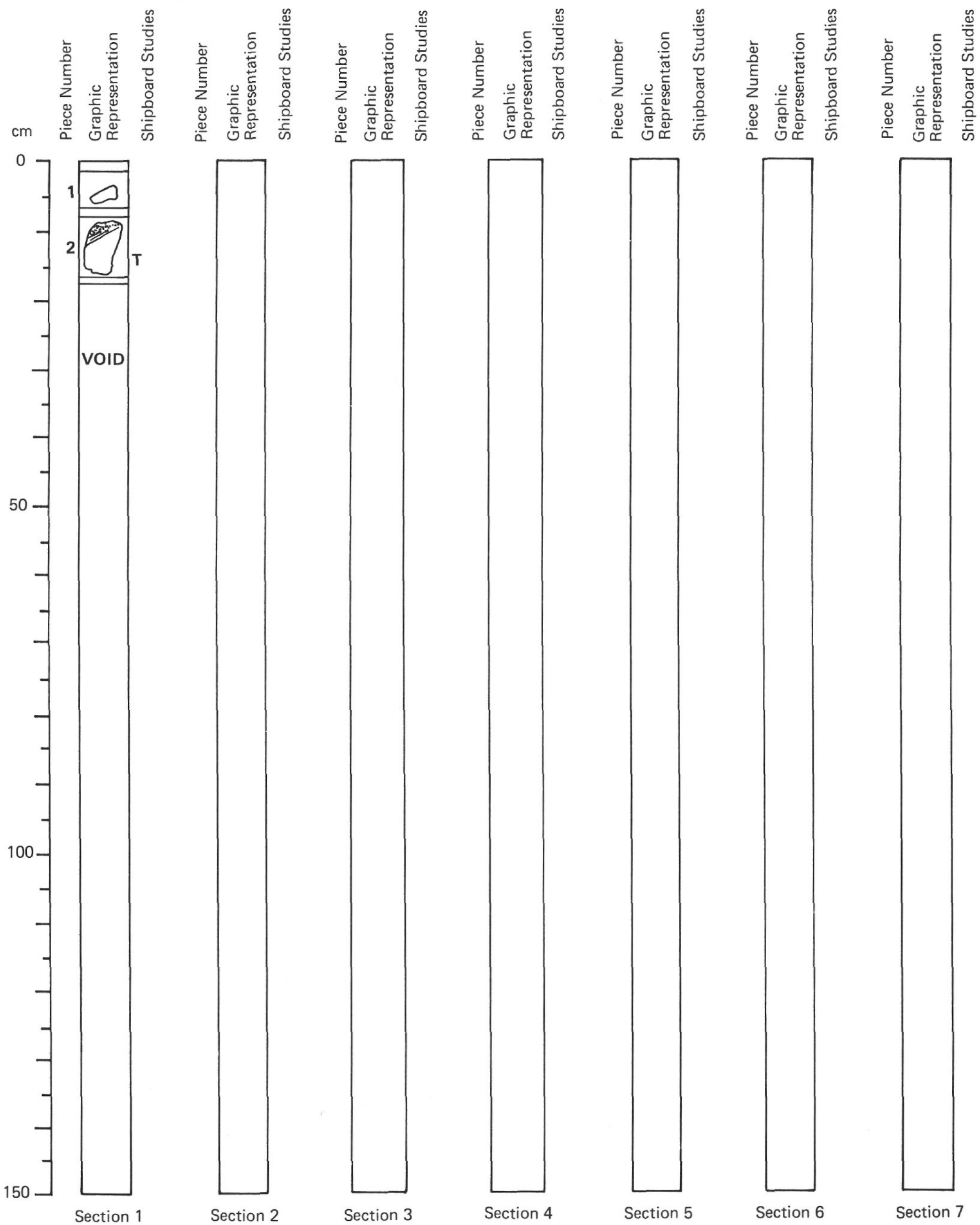
Vesicular aphyric to phyric olivine basalt with up to 10% olivine microphenocrysts (1-2 mm). Both fresh and altered. Olivine often concentrated in layers (the least vesicular ones). Is this crystal settling in a series of compound flows? Vesicles Section 1, 10-20%, rest of core < 10% and mostly ≤ 1 mm. Most vesicles lined with blue-green smectite or lesser amounts of calcite. Section 2 slightly coarser-grained than rest of core.

Petrography: aphyric basalt with sub-ophitic texture with up to 10% altered glass and 5% olivine.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 145 cm:	4.53	2792	66
Sect. 2, 100 cm:	4.74	489	76
Sect. 3, 125 cm:	4.57	778	67
Sect. 4, 30 cm:	4.45	2608	61
Sect. 4, 100 cm:	4.44	––	Reversed

LEG **49** SITE **409** HOLE CORE **19** DEPTH **186.0-195.5 m**

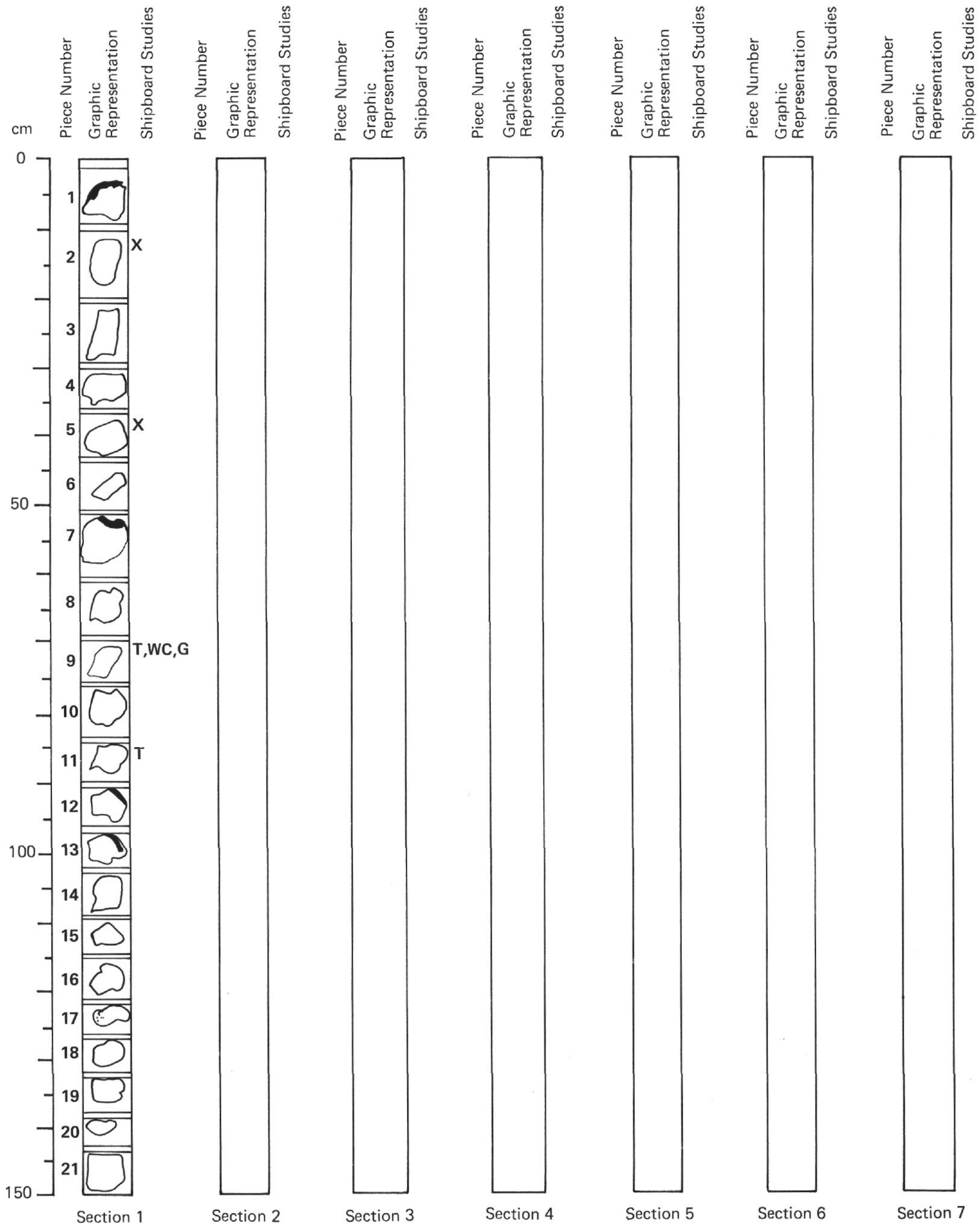


Original basalt recovery was 0.10 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

Two pieces aphyric vesicular olivine basalt. Olivine-rich layer altered brown. Gas bubble trails in piece two.

Petrography: glassy basalt with microphenocrysts of plagioclase and olivine (altered to carbonate).

LEG **49** SITE **409** HOLE CORE **20** DEPTH **195.5-205.0 m**



Original basalt recovery was 1.00 meter. Styrofoam spacers make the length shown here greater than the amount recovered.

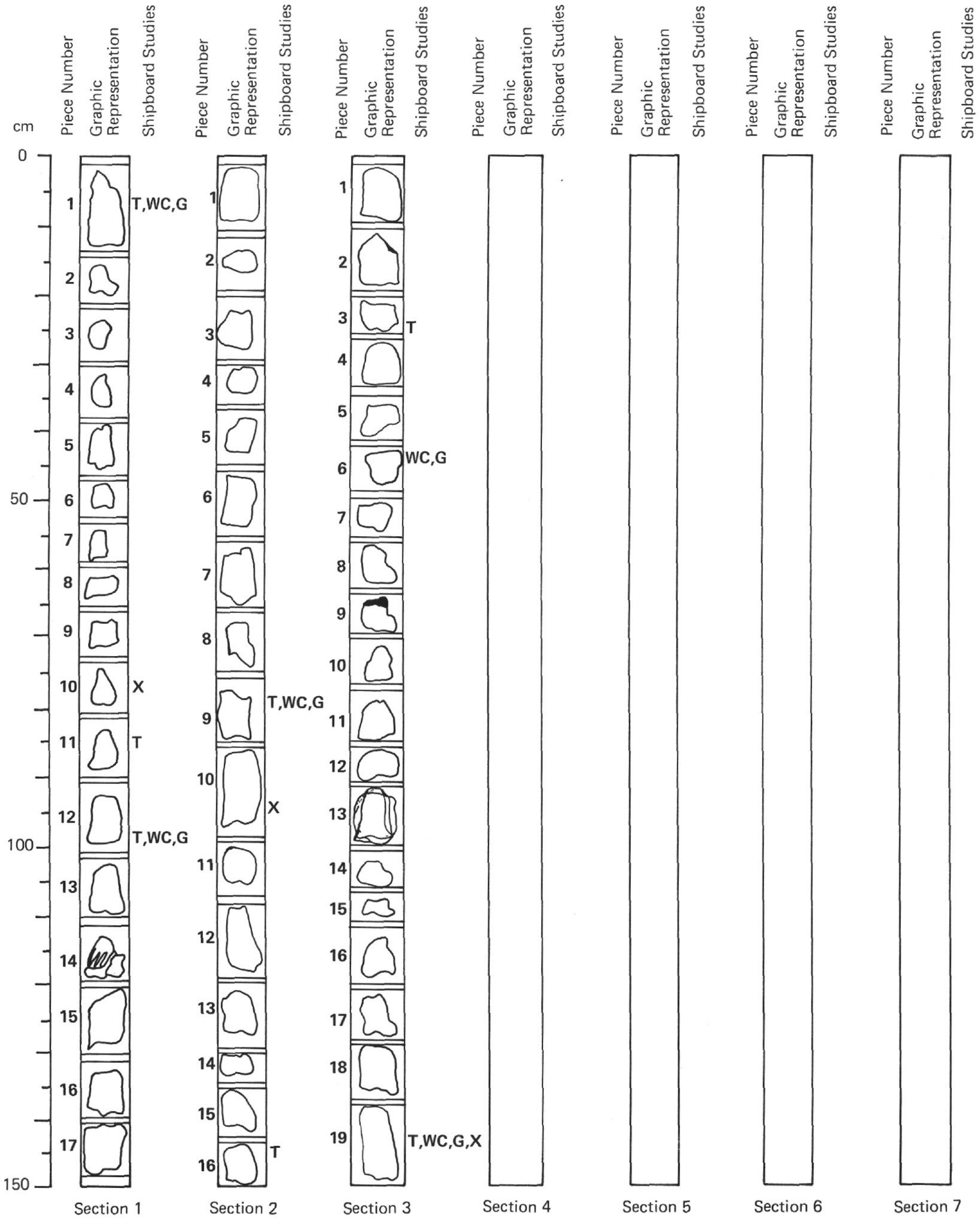
Aphyric basalt with few if any olivine microphenocrysts. Several glass selvages. Vesicles 0-115 cm, > 10%, ≤ 1 mm-4 mm, 115-148 cm, 1%, ≤ 1 mm. Filled with zeolites(?) and lessor amounts of smectite.

Petrography: texture variolitic. Microphenocrysts of plagioclase (An_{60}) and altered olivine. Glass altered and contains "barbed" opaques.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 70 cm:	3.89	2580	-60°

LEG 49 SITE 409 HOLE CORE 21 DEPTH 205.0-214.5 m



Original basalt recovery was 3.00 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

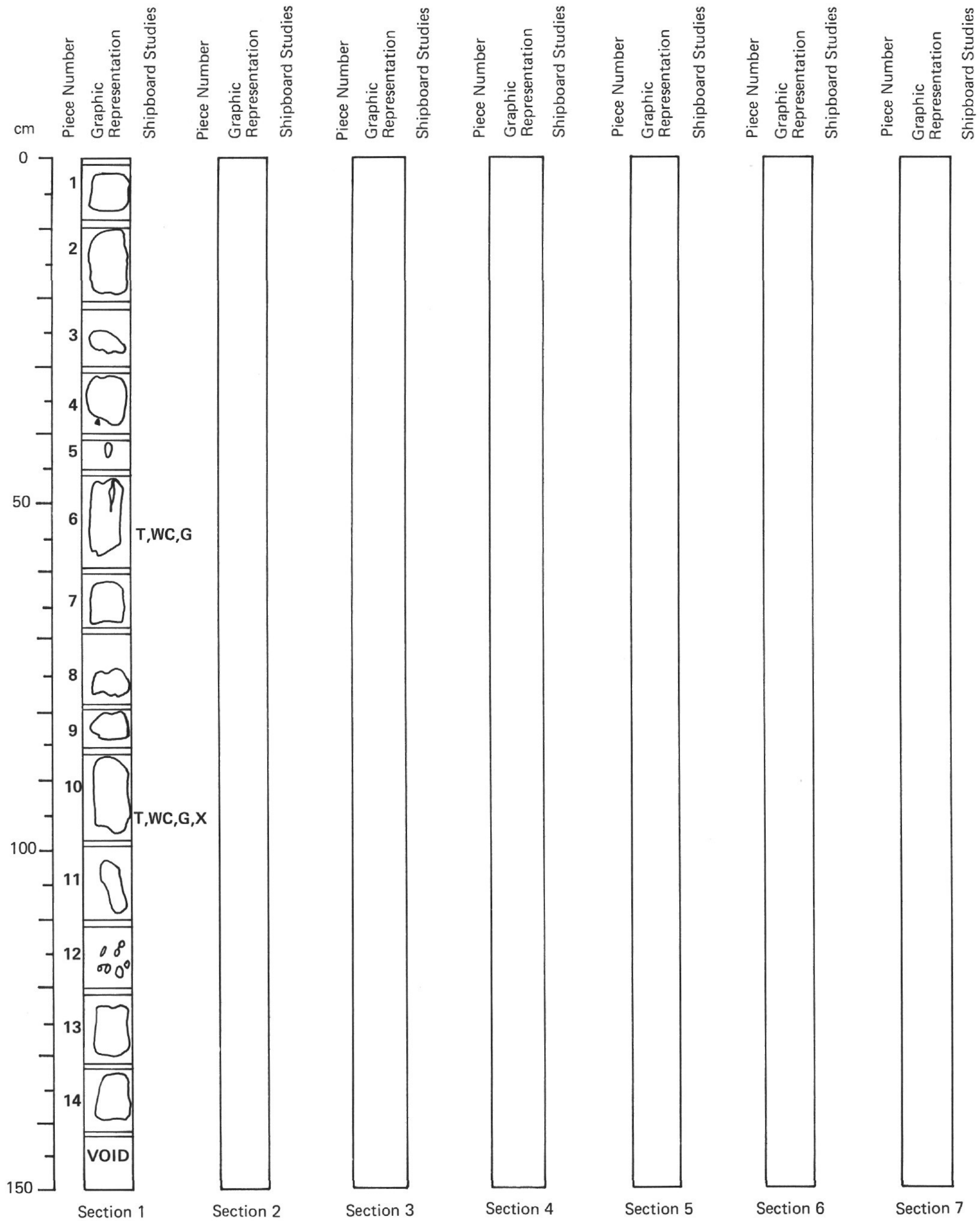
Section 1 (0-140 cm) nonvesicular aphyric basalt. Very fine-grained at top, coarsens downward. Olivine (altered) phenocrysts to 6 mm in interval 90-140 cm. Flow boundary 140 cm. Section 1 (140 cm) - Section 3 (base) aphyric vesicular basalt with visible olivine microphenocrysts in Section 3 (40-150 cm). Local altered glass selvages. Flow boundary Section 2 (75 cm). Coarser-grained zone Section 2 (130-150 cm). Degree of vescularity and oxidation varies. Vesicles 0-10%, 1-4 mm. Filled with smectite and calcite, vertical vesicle trail at Section 2 (95 cm).

Petrography: textures vary: variolitic to intergranular, locally sub-ophitic. Microphenocrysts plagioclase (An_{80-60}), clinopyroxene, olivine. Clinopyroxene locally Fe-rich. Olivine in groundmass. Glass altered to smectite and chlorophaeite.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 10 cm:	5.25	1049	-57°
Sect. 1, 100 cm:	5.31	––	Reversed
Sect. 2, 80 cm:	407	––	Reversed
Sect. 3, 45 cm:	4.32	7493	-51°
Sect. 3, 145 cm:	4.52	––	Reversed

LEG 49 SITE 409 HOLE CORE 22 DEPTH 214.5-224.0 m



Original basalt recovery was 0.80 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

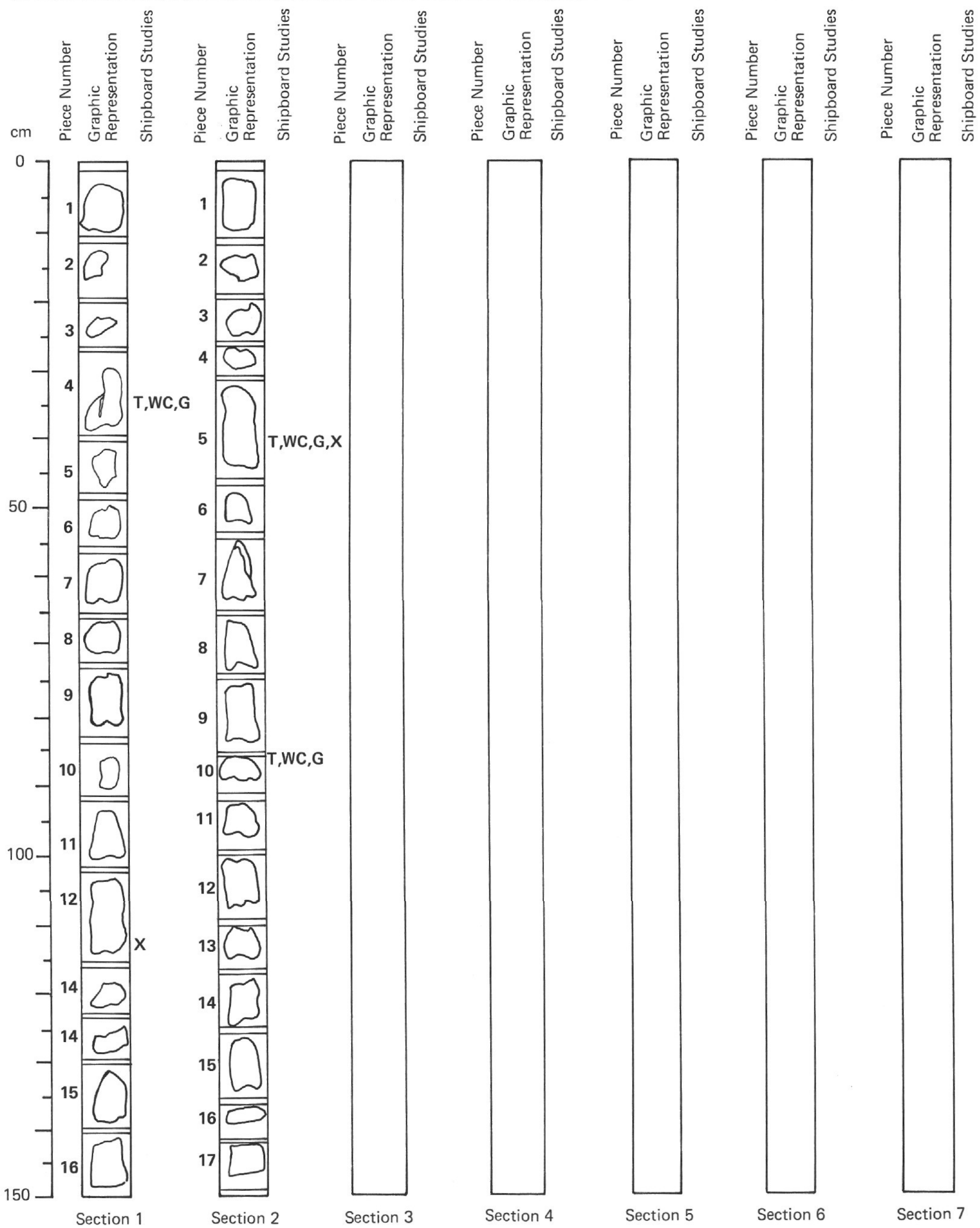
Medium-grained aphyric olivine basalt. Degree of vesicularity varies, 0-10%, maximum 2 mm. Verticle vesicle trails 50-60 cm.

Petrography: variolitic to intergranular texture. Plagioclase, clinopyroxene, and olivine microphenocrysts. Olivine altered to smectite and carbonate. Glass altered to smectite and carbonate. Plagioclase laths locally hollow hopper crystals.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 50 cm:	4.47	1485	-66°
Sect. 1, 100 cm:	4.15	––	Reversed

LEG **49** SITE **409** HOLE CORE **23** DEPTH **224.0-233.5 m**



Original basalt recovery was 1.90 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

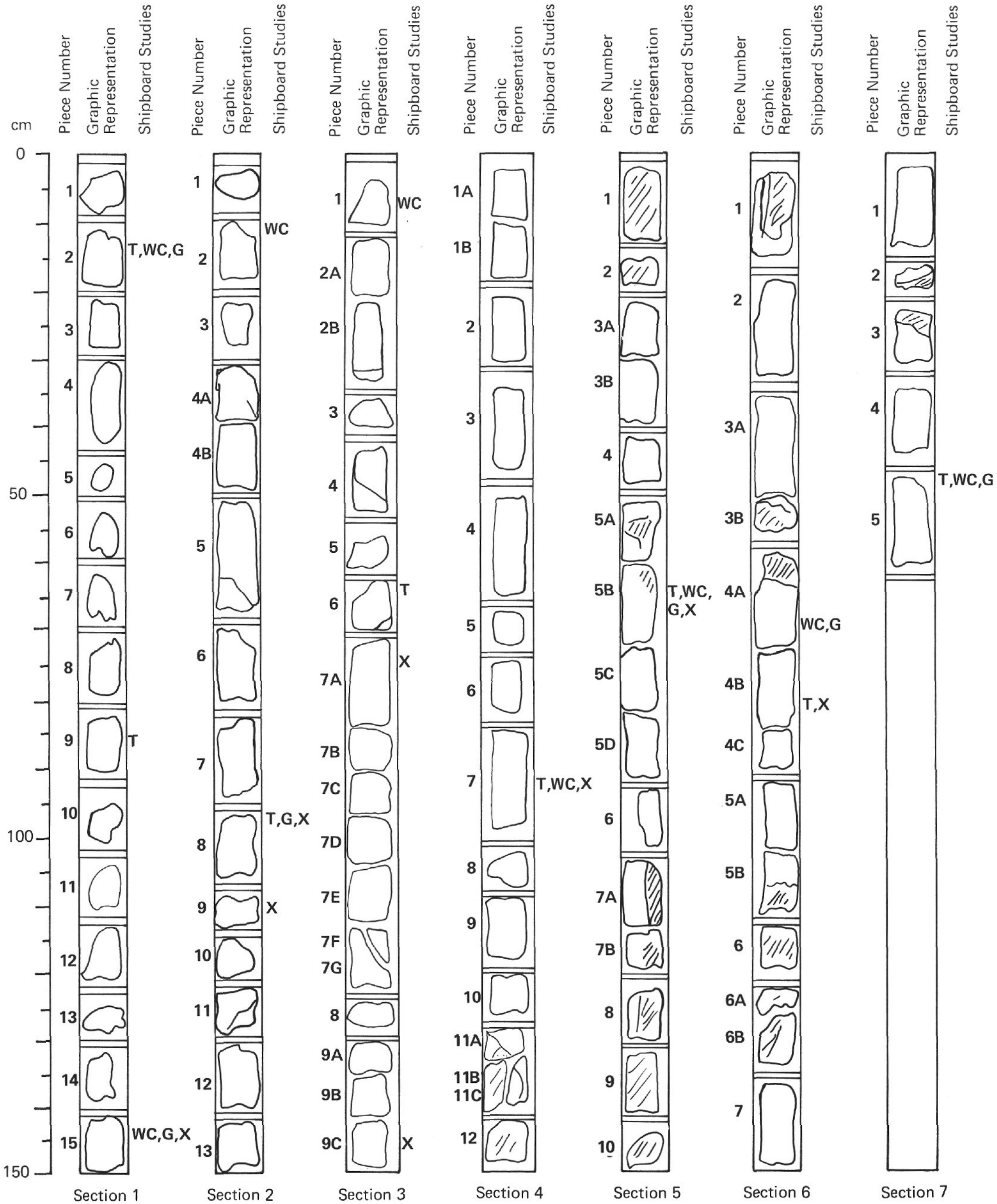
Aphyric basalt. Weathered brown olivine scattered throughout Section 2. Vesicularity varies 1-10%. Most vesicles lined with smectite or calcite. Zeolite in vesicle at Core 2, 105 cm.

Petrography: variolitic texture. Microphenocrysts of plagioclase, clinopyroxene, and olivine. Glass altered to chlorophaeite.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 35 cm:	4.32	821	-55°
Sect. 2, 40 cm:	4.65	1428	-53°
Sect. 2, 90 cm:	4.60	––	Reversed

LEG 49 SITE 409 HOLE CORE 24 DEPTH 233.5-243.0 m



Original basalt recovery was 7.00 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

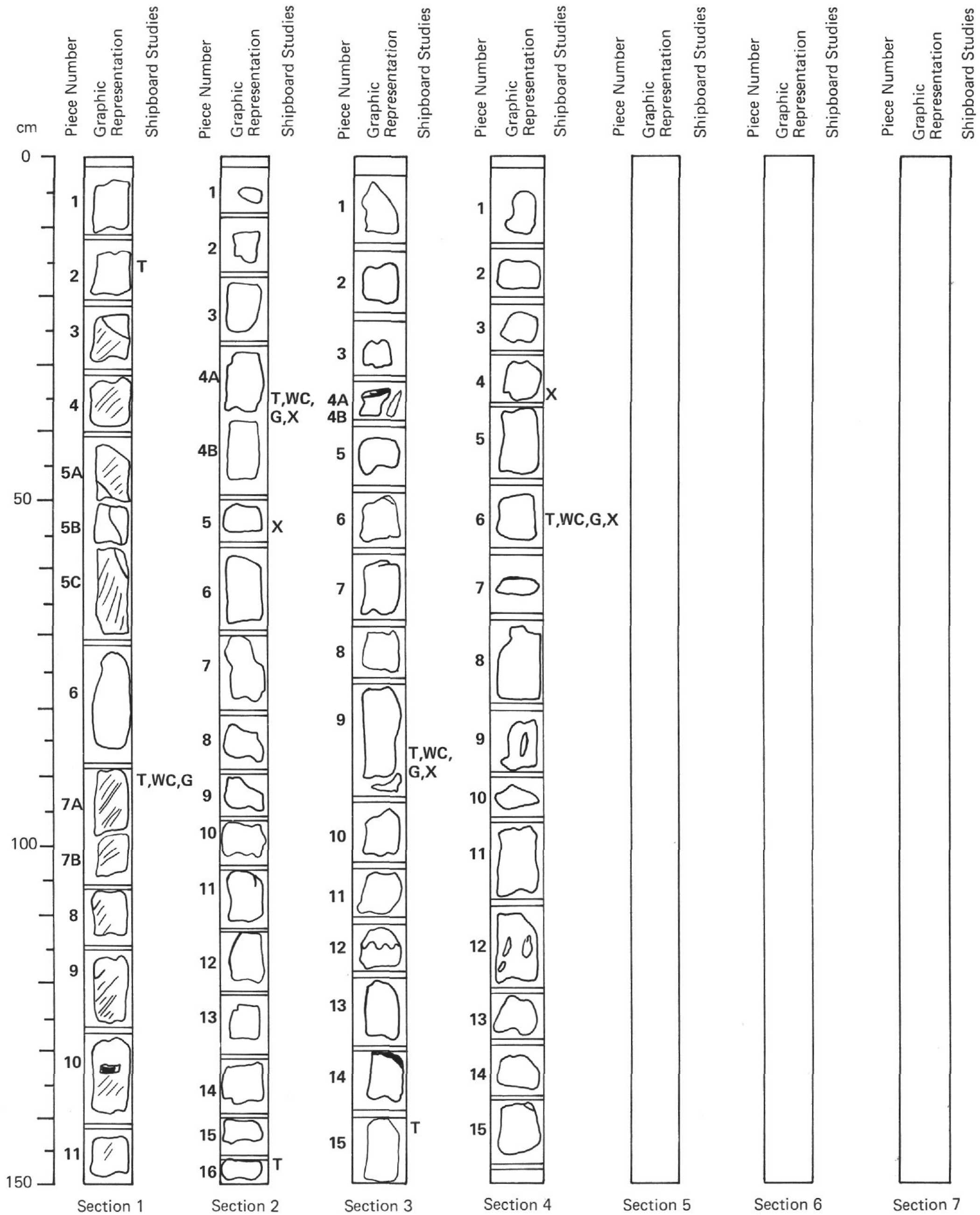
Aphyric vesicular basalt with widely scattered olivine. Degree of hydrothermal alteration varies (weak to strong). Vesicularity varies .50-10%, 1-5 mm. Vesicles and veins filled with smectite brown from oxides, zeolites, epidote, and pyrite. These alteration products suggest these rocks are just below the zeolite-greenschist facies alteration zone (≈ 250° C).

Petrography: texture varies - subvariolitic, intersertal, sub-ophitic. Trace olivine. Glass altered to smectite and leucoxene(?). "Barbed" opaques in glassy zones.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 15 cm:	4.24	1506	-53°
Sect. 1, 145 cm:	4.31	––	Reversed
Sect. 2, 140 cm:	4.65	1054	-50°
Sect. 3, 80 cm:	3.71	372	-66°
Sect. 4, 60 cm:	4.80	––	––
Sect. 4, 90 cm:	4.82	1820	-62°
Sect. 5, 60 cm:	4.90	––	––
Sect. 6, 70 cm:	––	855	-72°
Sect. 7, 50 cm:	4.63	––	––

LEG 49 SITE 409 HOLE CORE 25 DEPTH 243.0-252.5 m



Original basalt recovery was 3.70 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

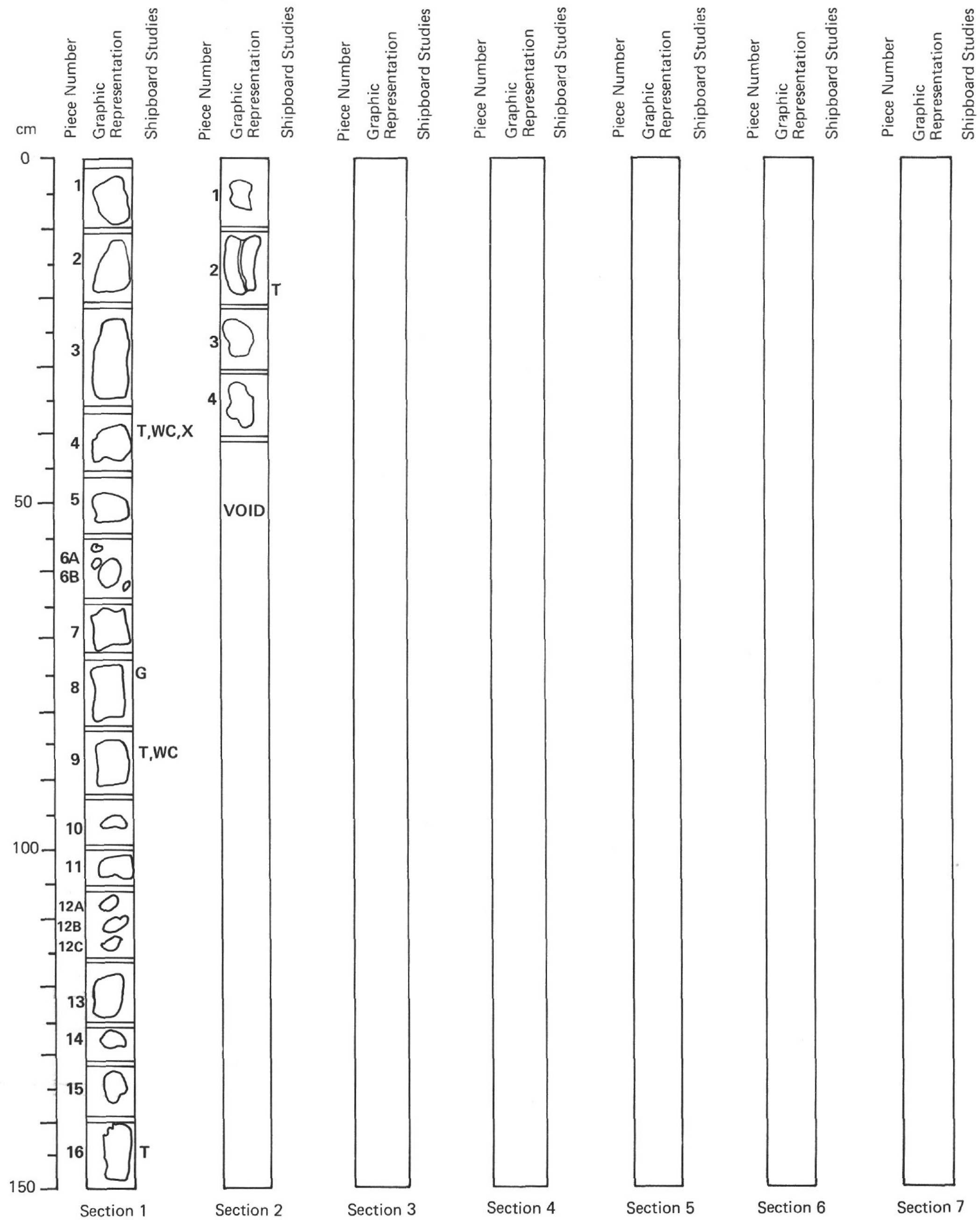
Aphyric vesicular basalt. Hydrothermal alteration has turned rock green and/or brown throughout core. Vesicularity varies < 1-10%, up to 7 mm. Vesicle-rich zone (20%) Section 2, 45-55 cm. Vesicles filled with zeolites and epidote. Glass selvages Section 3, 30 and 130 cm. Flow boundaries Section 2, 70 cm, Section 3, 30 and 125 cm.

Petrography: texture varies - sub-ophitic, intergranular, variolitic, locally intersertal plagioclase, augite (to 10%) and olivine microphenocrysts. Clinopyroxene shows faint brown pleochrosium and sector zoning. Plagioclase laths show slight resorption. Skeletal opaques in glass. Glass altered to smectite and chlorophaeite. Local zeolites in vesicles.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 90 cm:	5.02	784	-67°
Sect. 2, 40 cm:	4.78	746	-65°
Sect. 3, 80 cm:	4.47	482	-55°
Sect. 4, 50 cm:	4.32	909	-64°

LEG **49** SITE **409** HOLE CORE **26** DEPTH **252.5-262.0 m**



Original basalt recovery was 1.10 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

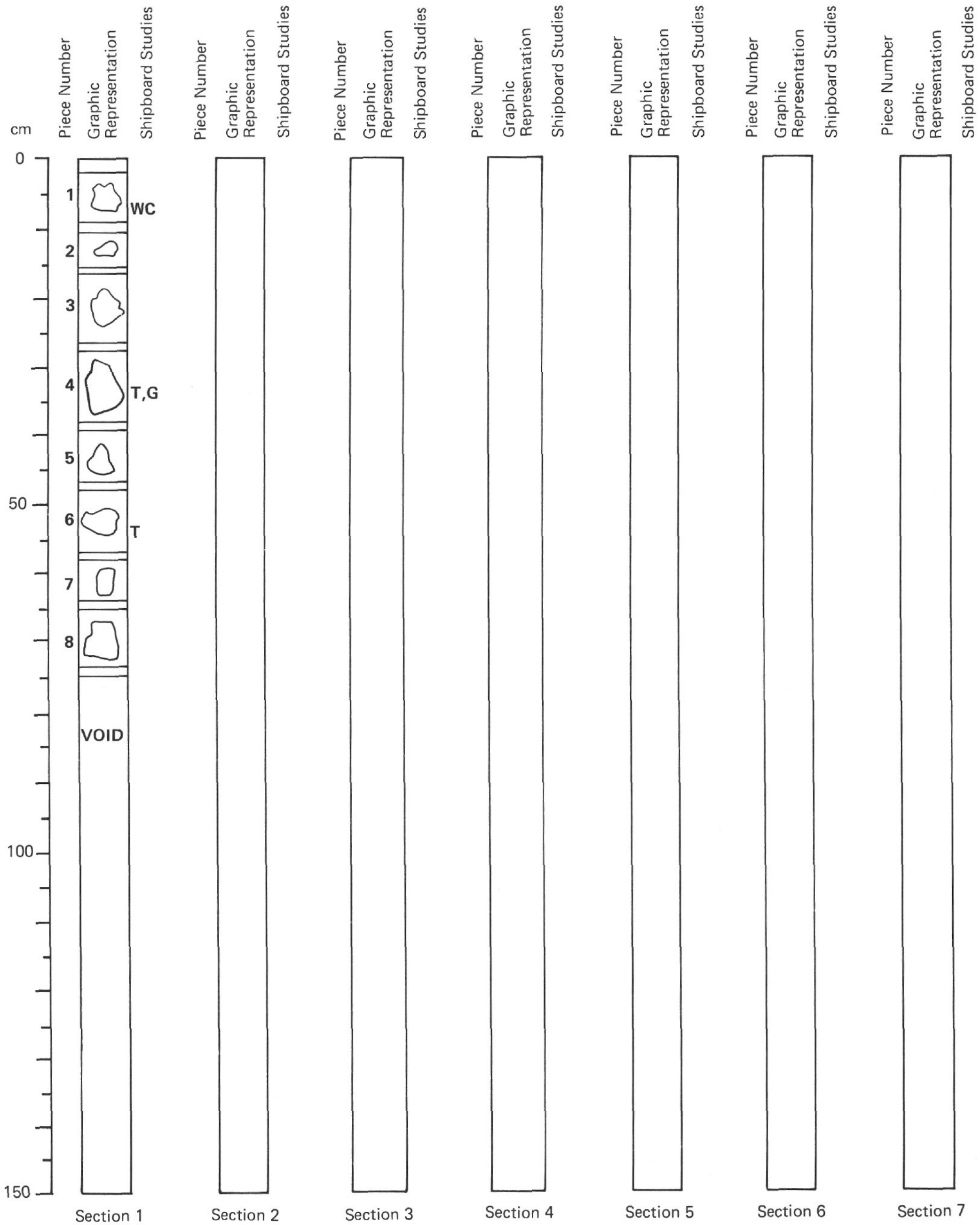
Highly vesicular fine-grained aphyric basalt, 15-20% vesicles, .50-2 mm, rare to 5 mm. Lined with calcite and other secondary minerals. Rare calcite veins.

Petrography: texture variable: variolitic-intersertal-intergranular to locally glassy. Glass altered to chlorophaeite. Scattered plagioclase and olivine microphenocrysts. Groundmass dominantely plagioclase and clinopyroxene with opaques, glass and olivine. Olivine fresh or altered to carbonate.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 40 cm:	4.67	5.48	-66°
Sect. 1, 90 cm:	4.53	—	—

LEG 49 SITE 409 HOLE CORE 27 DEPTH 262.0-271.5 m



Original basalt recovery was 0.60 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

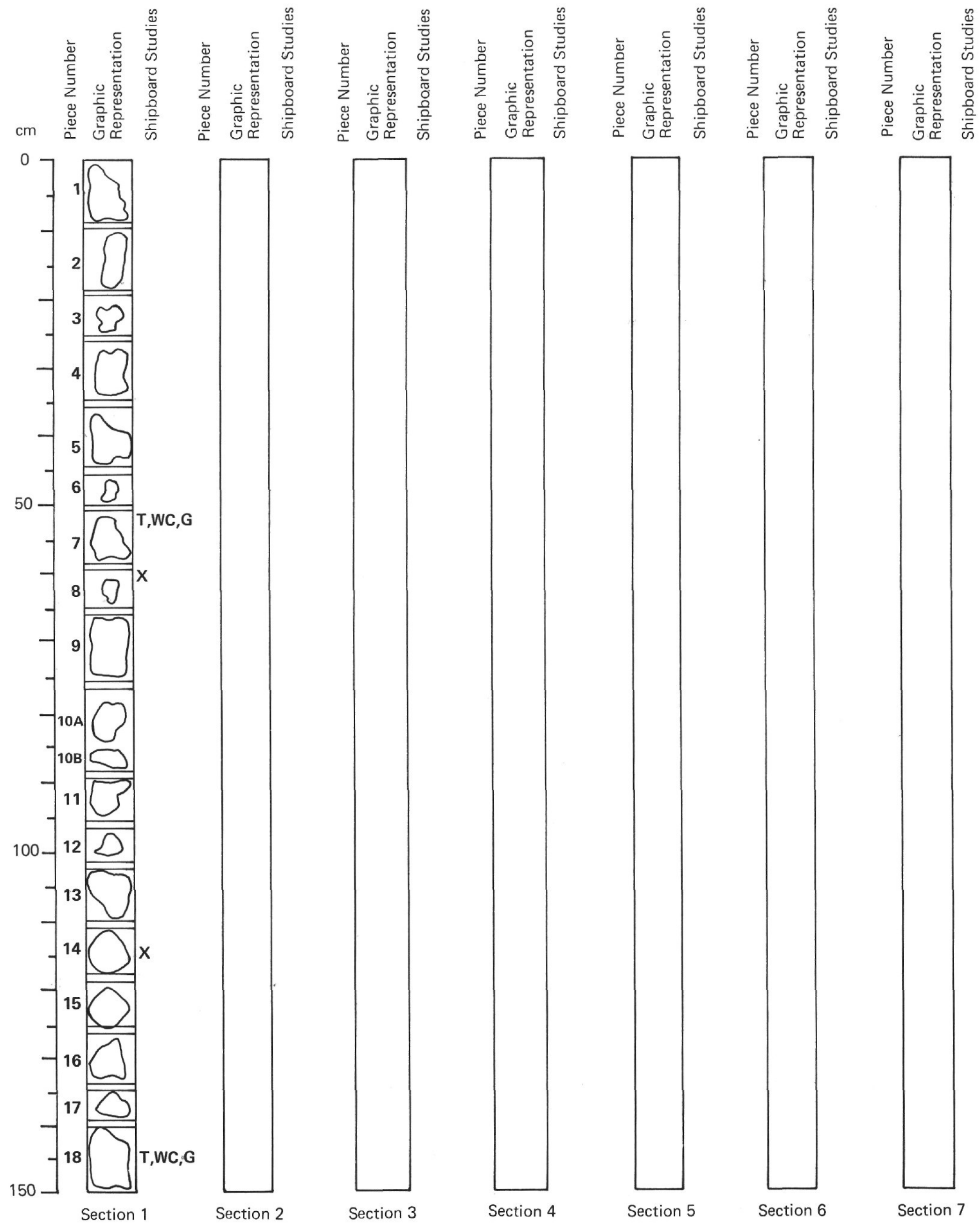
Vesicular fine-grained aphyric basalt. Twenty per cent vesicles (0.5-3.0 mm) at top of core decreases downward to 1-3% and 0.1-0.5 mm at base. Lined with calcite and other secondary minerals.

Petrography: texture varies: variolitic-intersertal-intergranular. Five per cent fresh olivine. Glass altered to smectite. Swallowtail plagioclase laths show some resorption. Sheaf-like varioles of clinopyroxene in groundmass.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 40 cm:	––	9083	-47°

LEG **49** SITE **409** HOLE CORE **28** DEPTH **271.5-281.0 m**



Original basalt recovery was 1.10 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

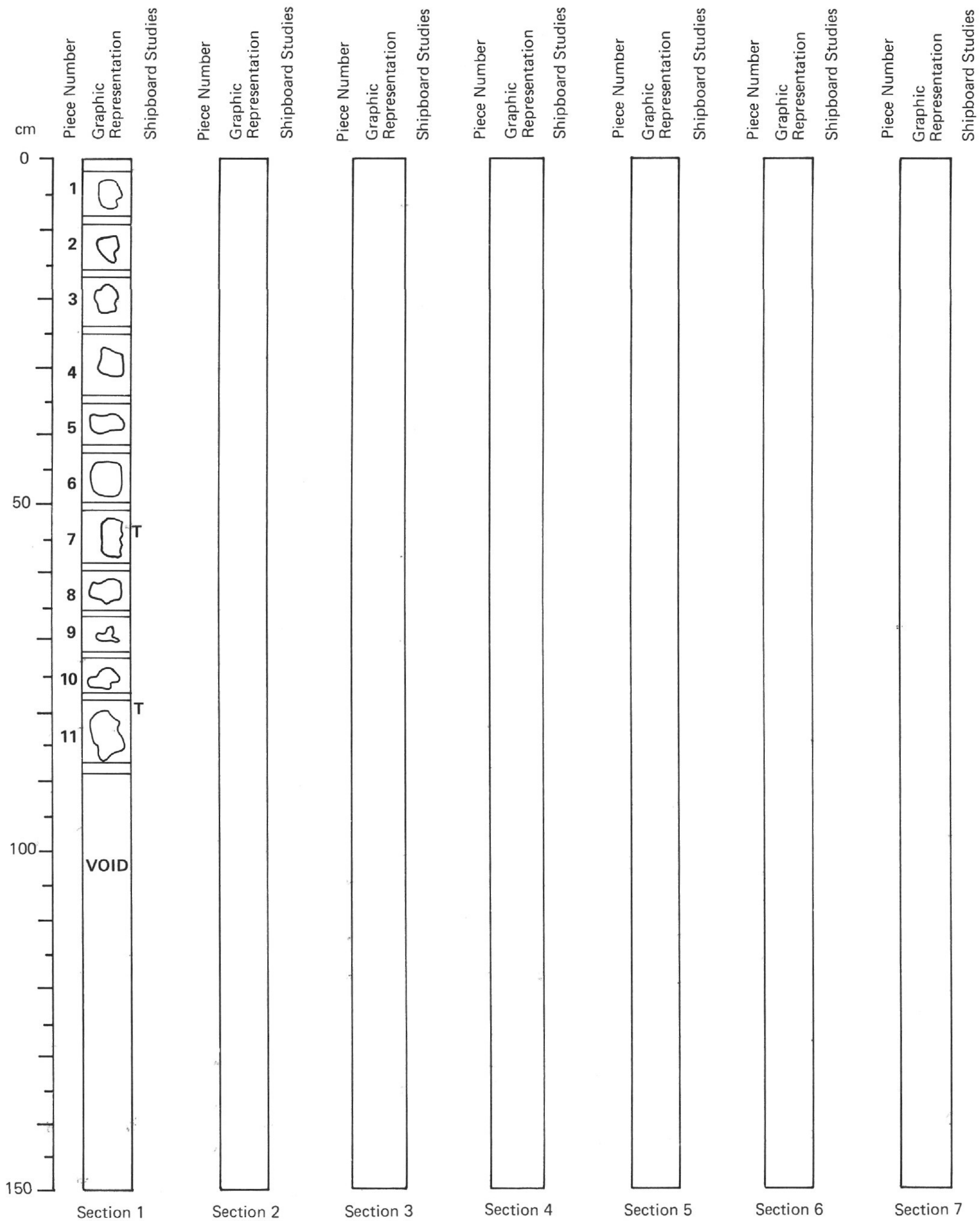
Fine-grained vesicular aphyric basalt. Vesicles average 25-30%, 1-2 mm, maximum 4-5 mm. Local concentrations of pipe vesicles. Breccia of vesicular palagoritized glass and fine-grained basalt at 20-26 and 45-50 cm.

Petrography: variolitic texture. Plagioclase and fresh olivine (< 1%). Microphenocrysts in variolitic and glassy groundmass. "Barbed" opaques in the glass zones only. Glass altered to smectite and chlorophaeite. Vesicles filled with smectite, carbonate and chlorophaeite.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 35 cm:	4.86	––	––
Sect. 1, 50 cm:	4.40	2966	-70°
Sect. 1, 135 cm:	3.90	––	Reversed

LEG **49** SITE **409** HOLE CORE **29** DEPTH **281.0-290.5 m**

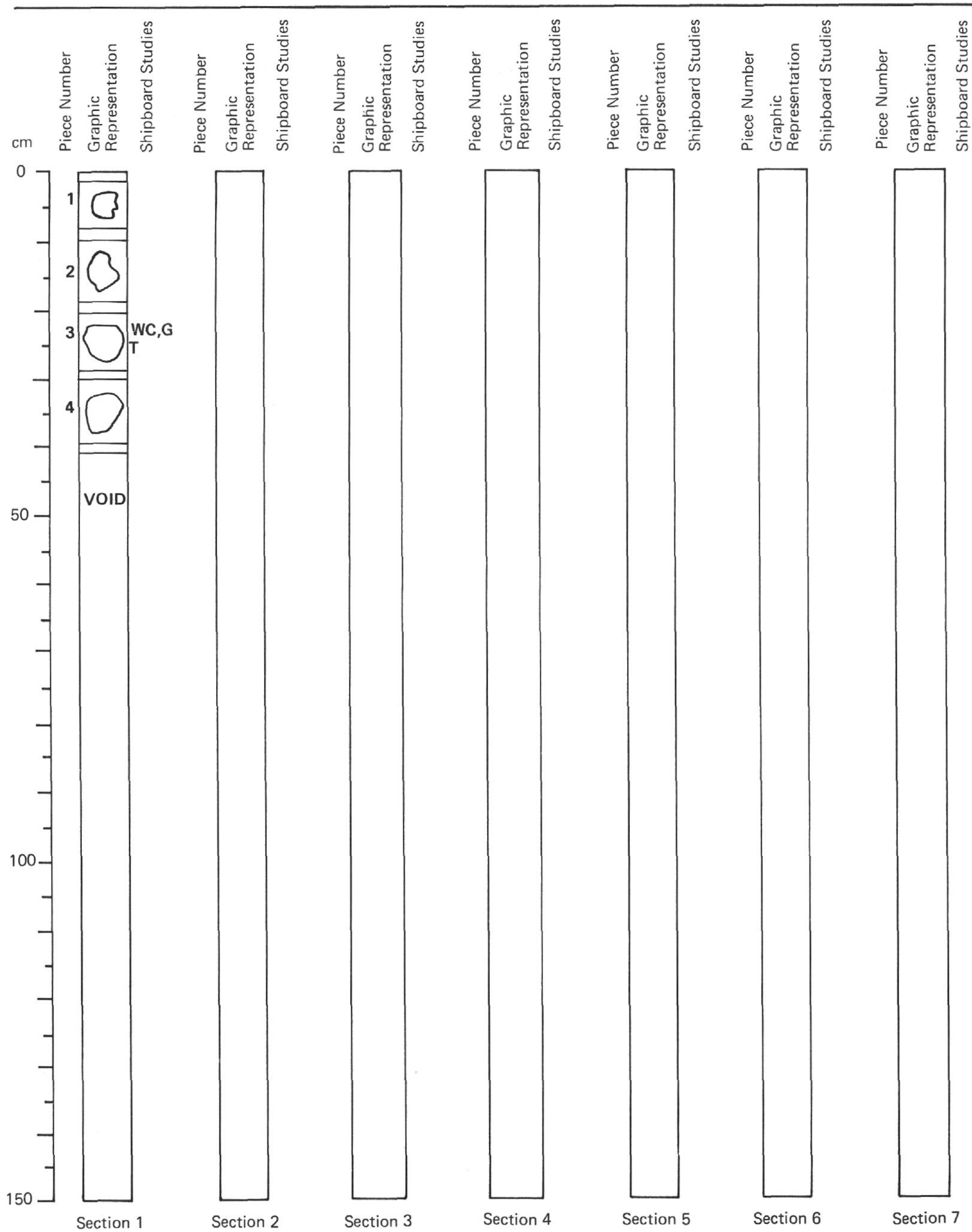


Original basalt recovery was 0.50 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

Highly vesicular fine-grained aphyric basalt with rare olivine microphenocrysts. Vesicles average 10-20%, .50-1.50 mm, lined with smectite, celadonite and calcite.

Petrography: intersertal texture. Glass fresh (black) or altered. Plagioclase varies An_{80-55}. Olivine pseudomorphed by calcite or iddingsite. Vesicles filled with smectite, carbonate, chlorite and sulfide.

LEG 49 SITE 409 HOLE CORE 30 DEPTH 290.5-300.0 m

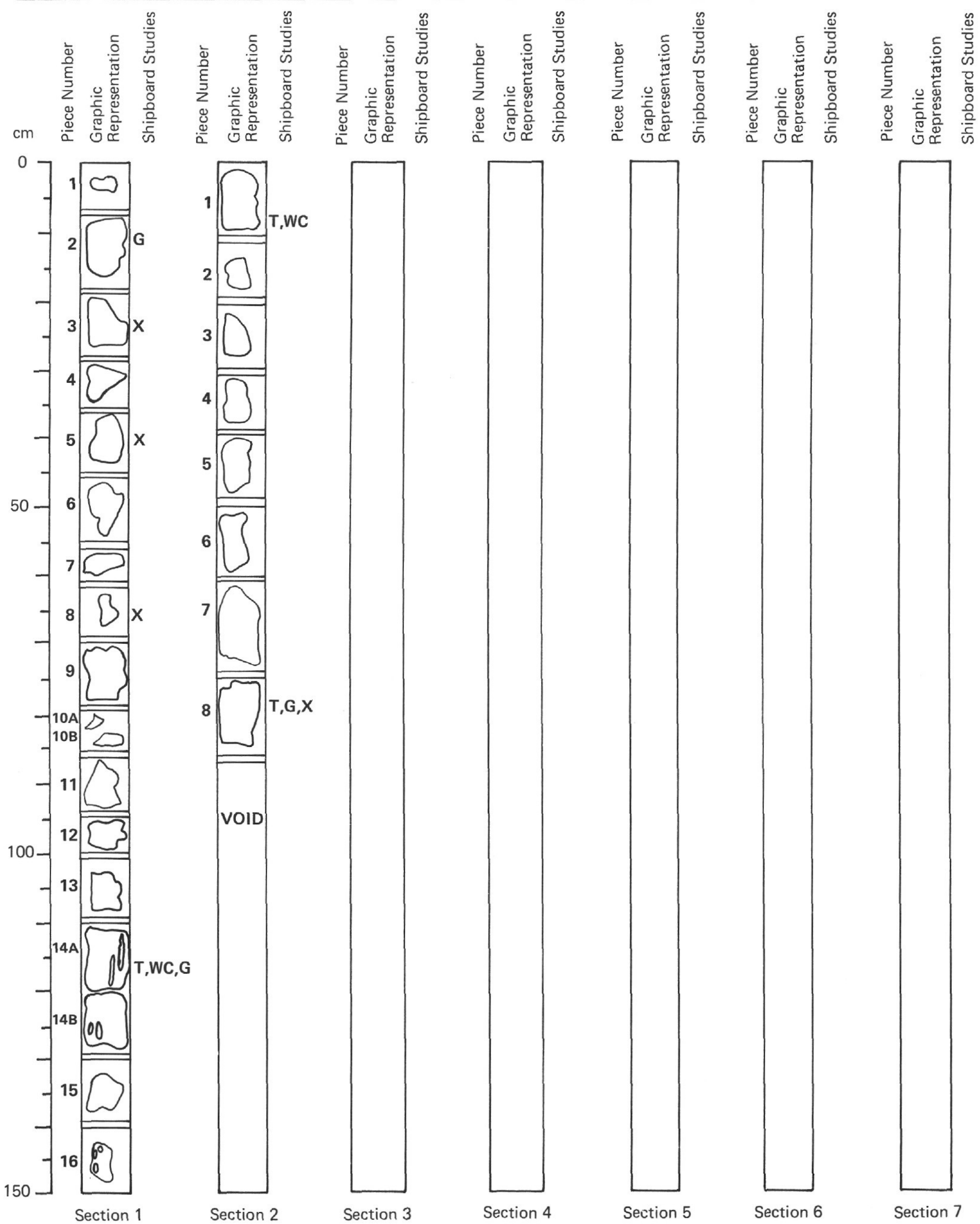


Original basalt recovery was 0.20 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

Vesicular fine-grained aphyric basalt with rare olivine microphenocrysts. Uneven vesicle distribution, 5-20%, average 0.3-1.0, rare to 4 mm, lined with calcite and celadonite.

Petrography: intersertal texture, 5-10% fresh olivine in groundmass. Vesicles filled with carbonate.

LEG 49 SITE 409 HOLE CORE 31 DEPTH 300.0-309.5 m



Original basalt recovery was 1.68 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

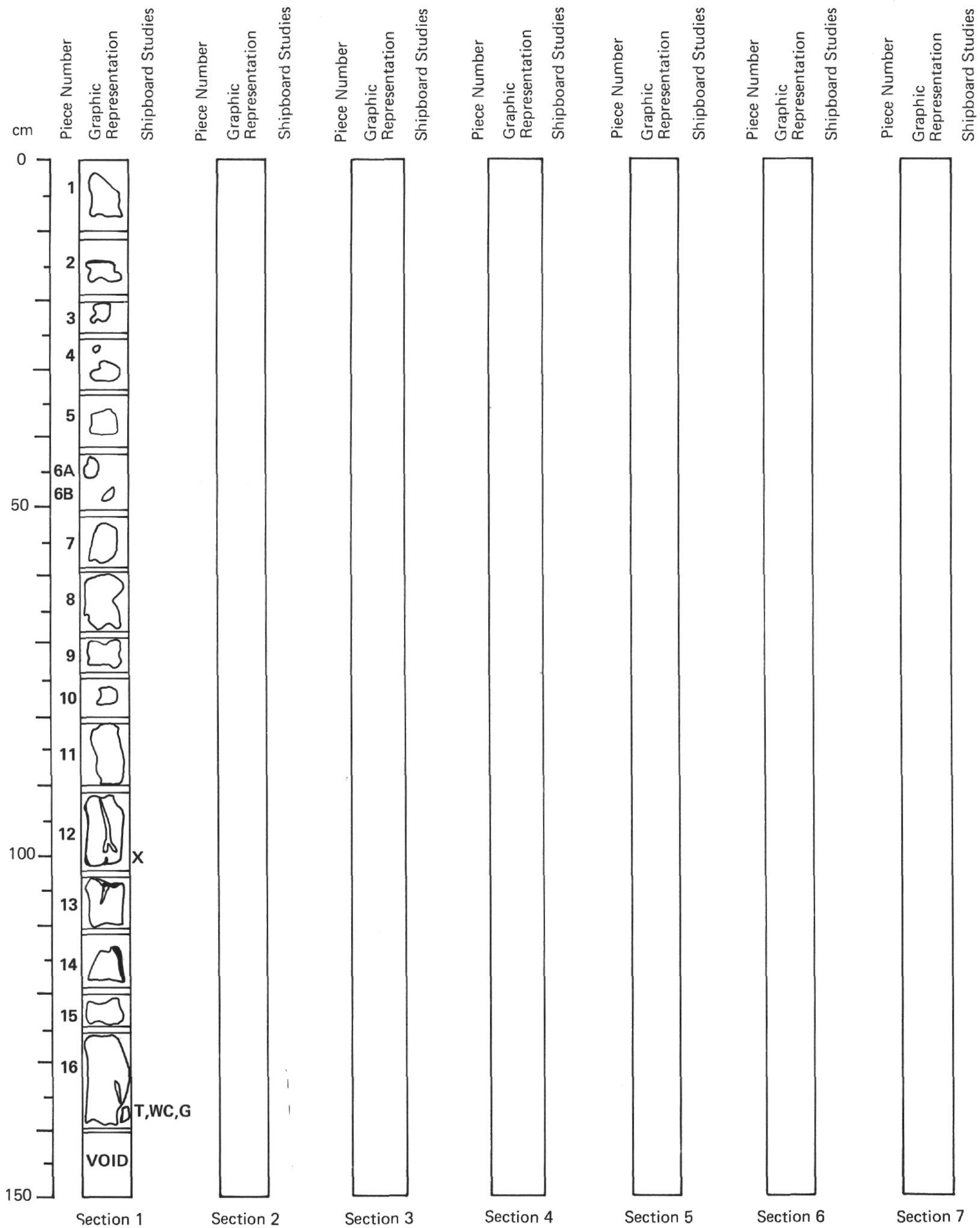
Highly vesicular fine-grained aphyric basalt. Vesicles 30-50% at 1-2 mm. Lined with calcite and smectite. Local concentration of pipe vesicles up to 15 cm long.

Petrography: intergranular basalt, 1-5% plagioclase microphenocrysts < 1% augite microphenocrysts. Smectite and minor olivine in groundmass.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 100 cm:	4.66	1867	- 62°
Sect. 2, 70 cm:	4.57	1776	- 64°

LEG **49** SITE **409** HOLE CORE **32** DEPTH **309.5-319.0 m**



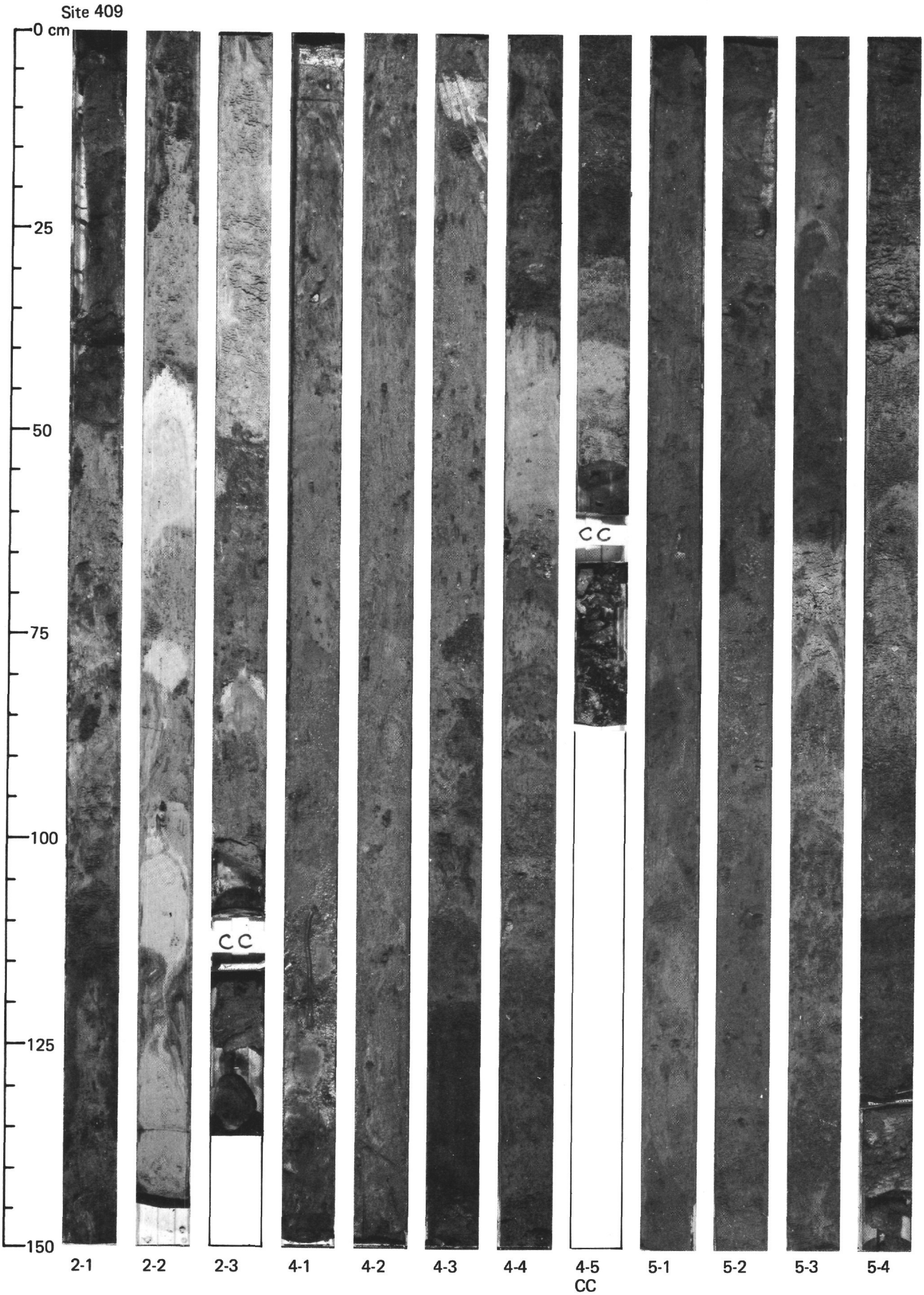
Original basalt recovery was 0.90 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

Aphyric vesicular fine-grained basalt. Vesicles 30% at 1-2 mm. Pipe vesicles concentrated in interval 50-110 cm. Glass selvages at 115 and 125 cm.

Petrography: variolitic texture. Plagioclase crystals have length to width ratio of 25:1 and some are hollow hopper crystals. Groundmass contains smectite and carbonate, but is mostly feathery or sheaf-like bundles of clinopyroxene.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 145 cm:	4.44	1868	-52°


Site 409
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125
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2-2
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4-1
4-2
4-3
4-4
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5-1
5-2
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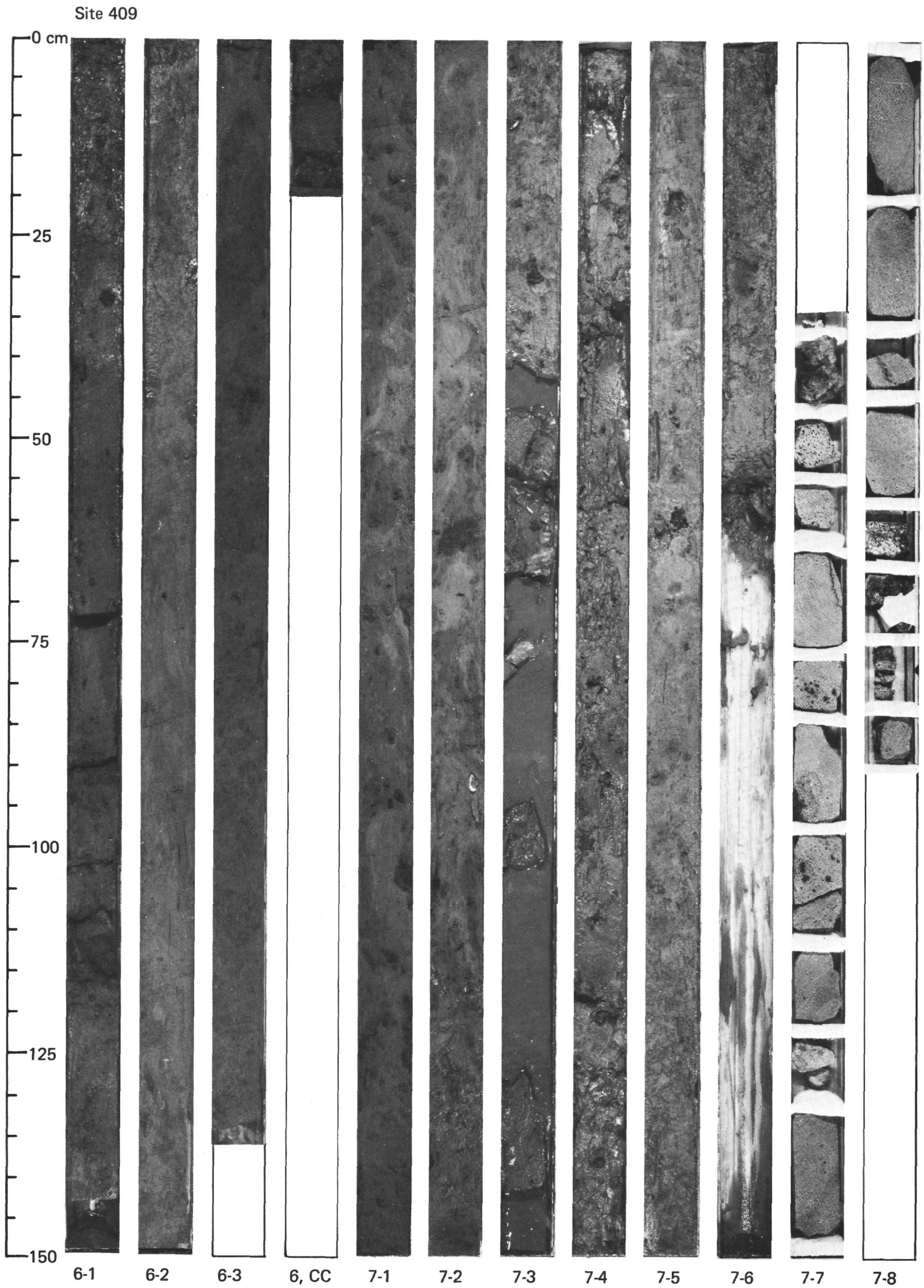
5-4


Site 409
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6-1
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7-5
7-6
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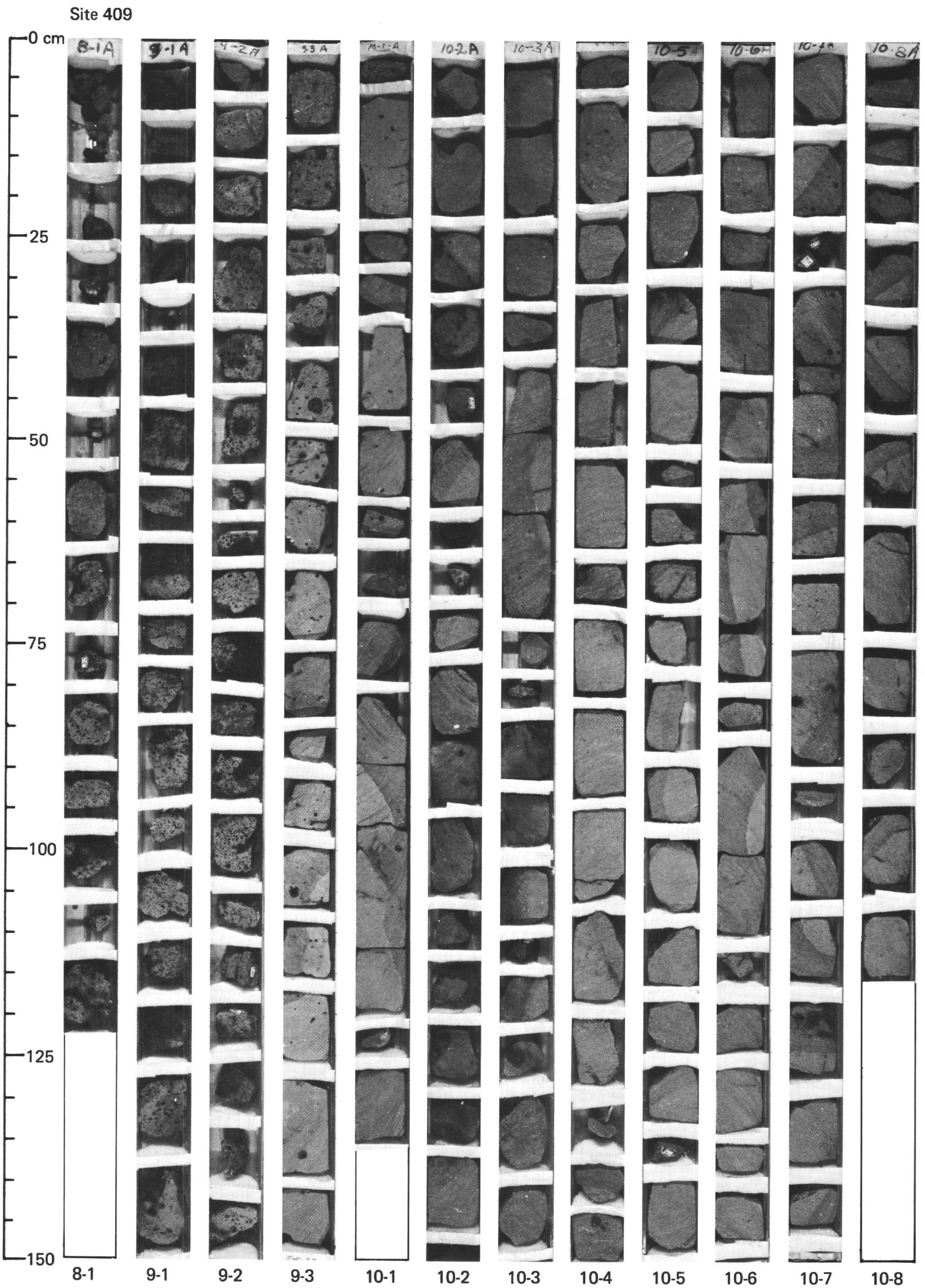
Site 409
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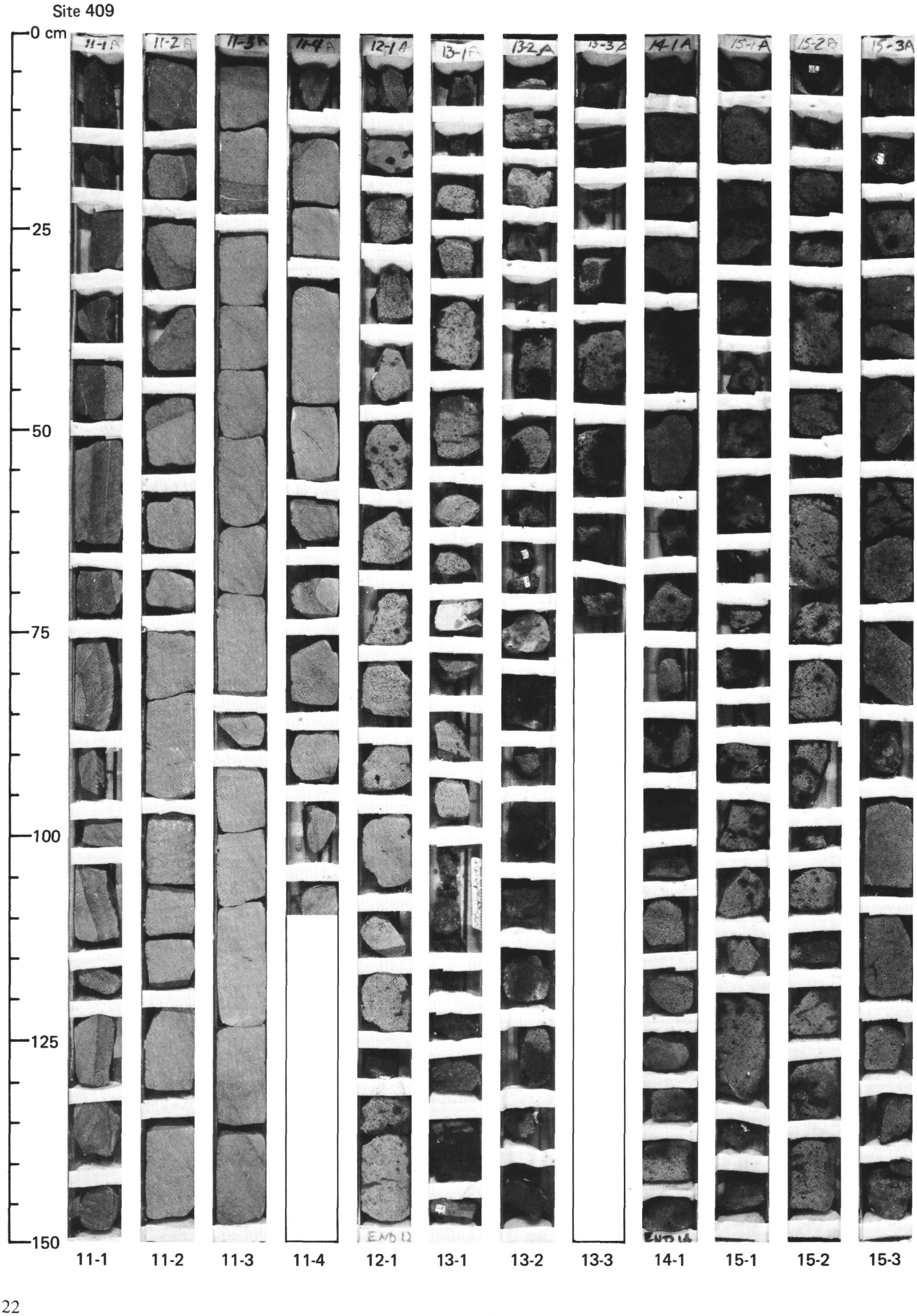
10-8


Site 409
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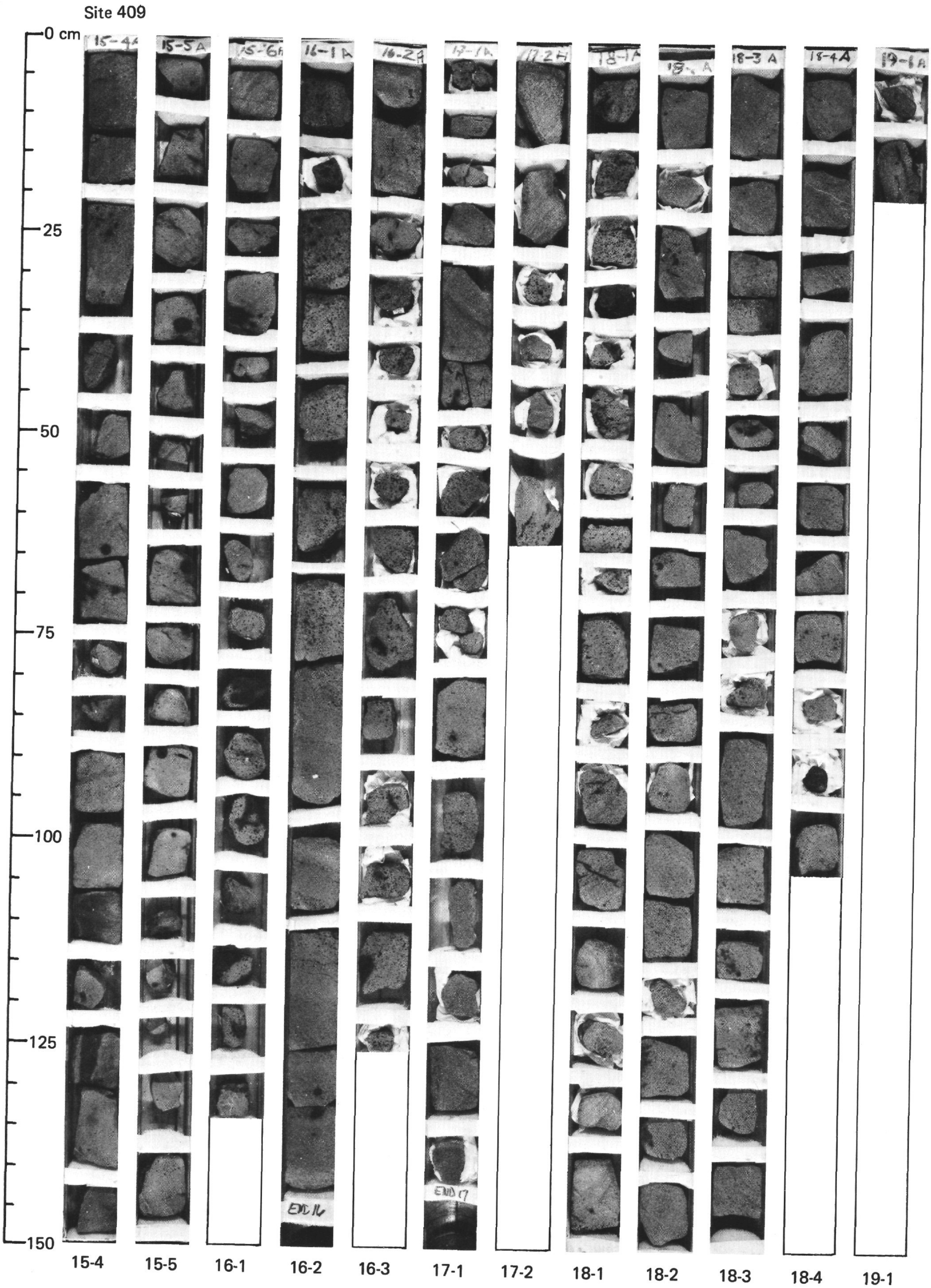
11-4
12-1
13-1
13-2
13-3
14-1
15-1
15-2
15-3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17-1
17-2
18-1
18-2
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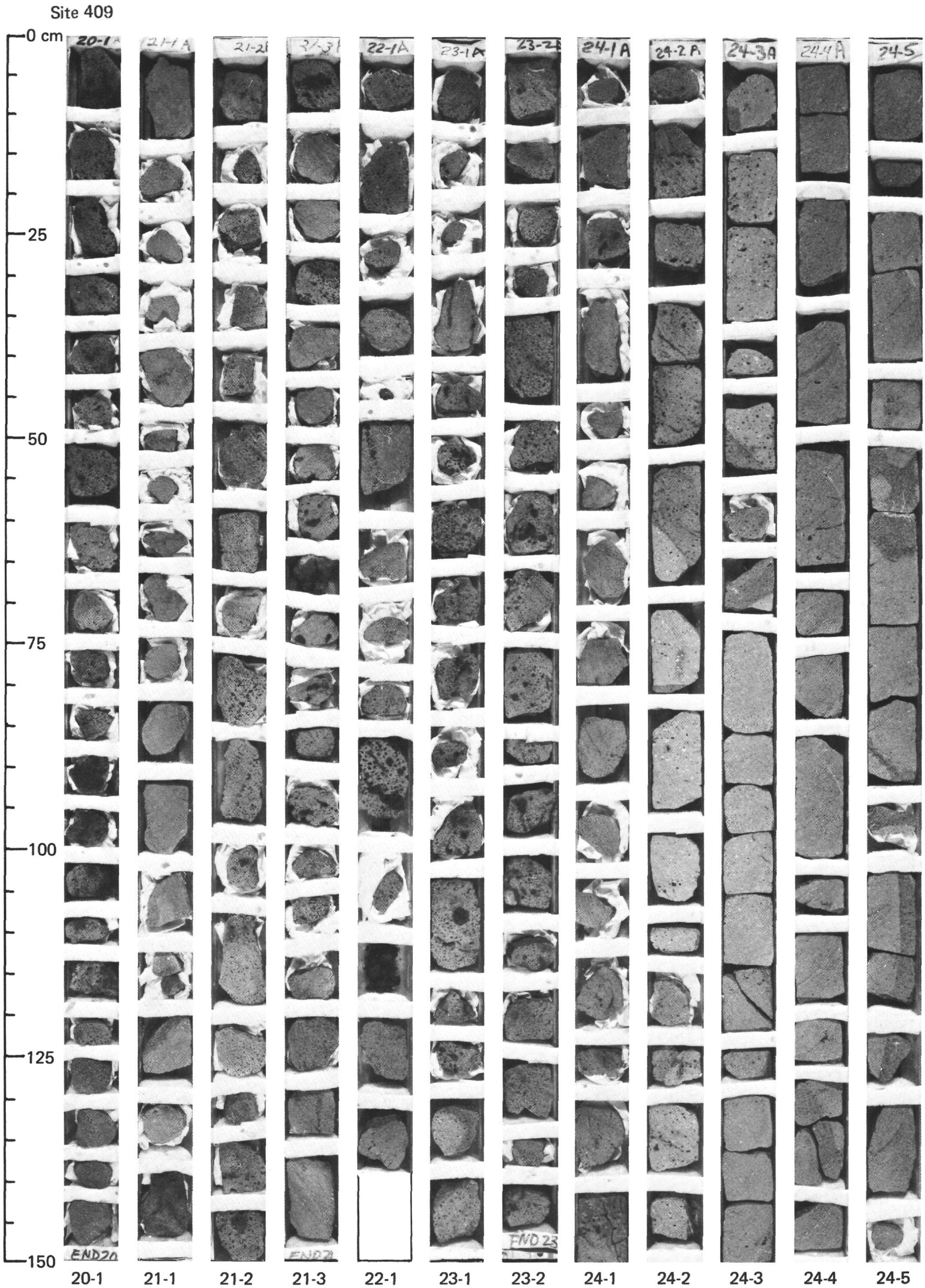
18-4
19-1


Site 409
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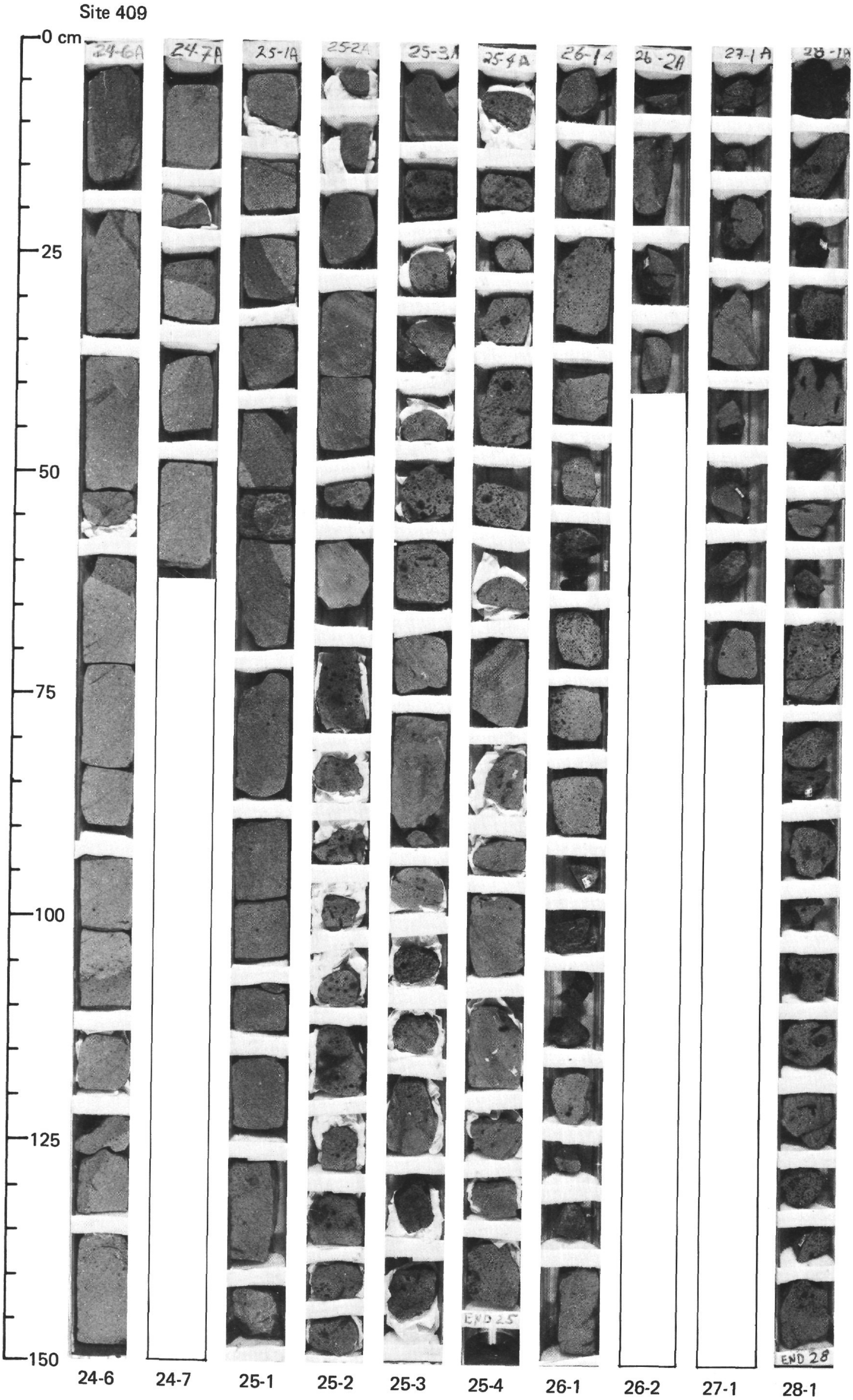
24-3
24-4
24-5


Site 409
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25-4
26-1
26-2
27-1
28-1