8. SITE 413

Shipboard Scientific Party[1]

SITE DATA

Date Occupied: 0400 28 August 1976

Date Departed: 1530 30 August 1976

Time on Hole: 3 days, 11.5 hours

Position: Latitude: 36°32.59′N; Longitude: 33°10.50′W

Water Depth (sea level): 2598 corrected meters, echo sounding

Water Depth (rig floor): 2608 corrected meters, echo sounding

Bottom Felt at: 2608 meters, drill pipe

Penetration: 149.5 meters

Number of Holes: 1

Number of Cores: 5

Total Length of Cored Section: 39.5 meters

Total Core Recovered: 2.97 meters

Percentage Core Recovery: 8 per cent

Oldest Sediment Cored:
Depth sub-bottom: 110 meters
Nature: Nannofossil ooze
Chronostratigraphic Unit: Pleistocene

Basement:
Depth sub-bottom: 110 meters
Nature: Basalt
Velocity range: 4.65-4.91 km/s

Principal Results: Site 413 was drilled on the south side of fracture zone B in FAMOUS area, 1.3 miles south of Site 412. Because the reflection profile showed a sedimentary section similar to Site 412, the hole was washed to basement at 110 meters sub-bottom. Basement was cored to 149.5 meters sub-bottom, with 3.0 meters recovery. Recovered rock is olivine-rich basalt with abundant olivine microphenocrysts and quench olivine in variolites. Basalt occurs as cobbles, rarely oriented, often surrounded by a weathered rim. It may form part of a talus pile beneath a fault scarp to the south. The first basement core contains Quaternary basaltic-foraminiferal sand, perhaps *in situ*, but most likely drill cuttings. Deteriorating weather forced our departure.

BACKGROUND AND OBJECTIVES

The reasons for placing sites in fracture zones were discussed in Background and Objectives for Site 412. They are, briefly, to see to what extent fracture-zone sedimentary basins may be used for drilling holes in very young crust, and to investigate fracture zones themselves as important components of the oceanic crust. Site 413 was planned to complement Site 412 in achieving both of these ends. Figure 1 is a topographic map of the region of fracture zone B in the FAMOUS area where both sites were placed (Phillips and Fleming, unpublished). Site 412 was selected on the north side of the fracture-zone valley, to intercept young crust, about 1.6 m.y. old, if possible. On simple transform-fault theory, the crust at this site, having accreted onto the moving part of the African plate, would never have been deformed by transform-fault activity. Site 413, on the other hand, is on the south side of the fracture-zone valley. At this site, simple extrapolation of the trend of the active transform fault that links the two stretches of mid-ocean ridge to the north and south of the fracture zone would indicate that we were on the old side of the fault, on crust that had been formed 3.4 m.y. ago at the ridge crest to the west, as predicted by its situation just on the old side of anomaly 2′ (Phillips and Fleming, unpublished). This crust would have been sheared against crust moving in the opposite direction from the spreading center to the north of the fracture zone for about 2 m.y., before becoming attached to newly created undeformed crust 1.6 m.y. ago. Thus, the simple picture of transform faults would predict asymmetry between Sites 412 and 413, and it was to test this asymmetry that Site 413 was drilled.

More complex models of transform-fault activity are possible. One variant that seems reasonable, in light of the morphology of the intersections between the median valley and the fracture zone at the present time, is that the transform fault is overrun by lavas coming from north of the fault after it ceases to be active (as it migrates past the spreading center). On this picture, the fault would be buried beneath later lavas, and the basement at Sites 412 and 413 would be undeformed lavas of the same age.

OPERATIONS

Our purpose at Site 413 was to sample crust from the side of the fracture zone opposite Site 412. To set the beacon, we moved away northward from Site 412, turned, streamed gear, and came back over the Site 412 beacon while running a seismic profile (see tracks on Figure 1). After altering course to 200°, we crossed the floor of the fracture-zone valley and dropped the beacon just at the south edge of the

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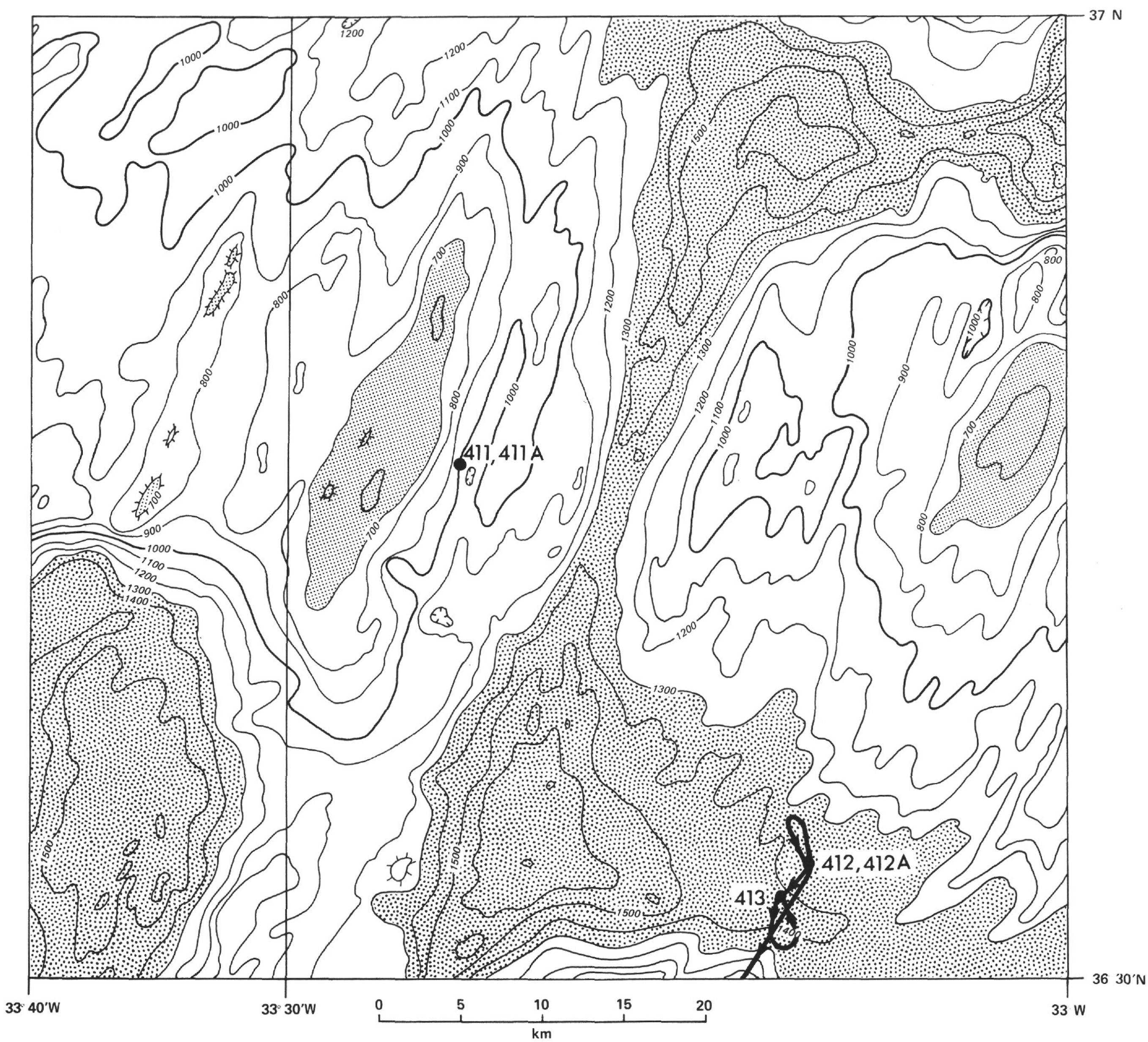


Figure 1. *Bathymetric chart of FAMOUS region (after Phillips and Fleming, unpublished), showing locations of Sites 411, 412, and 412. Also shown is the track of* Glomar Challenger *to and from Site 413.*

flat valley floor (Figure 2), at 0115 hours, 28 August. The seismic reflection profile appeared to show 216 meters of sediment at or just north of the beacon-drop site and, because we had cored the upper part of the sediments at Hole 412, we devised a coring program which included washing down the first 150 meters. This proved unsatisfactory when basalt was encountered after only 110 meters. We cored the basalt for 39.5 meters, and recovered 2.97 meters (Table 1); worsening weather forced us to pull the string, starting at 0500 hours, 29 August.

The weather remained bad for the rest of the 29th. We planned to drill a hole (413A) when it cleared, offset 1000 feet to the north of the beacon, but, though the string was run to the mud line in the early hours of 30 August, no coring was started, because the weather had not improved. At 1630 hours, 30 August, we were underway for Site 414, hoping to beat the weather by moving away from the FAMOUS area, since the bad weather seemed intent on staying there. On leaving, we made another north-south pass over the beacon, and passed 1000 feet to the west of it (Figure 3). Reflectors on this profile give much more reason for expecting basalt at 110 meters than had the original profile, though neither could be said to be clear.

SEDIMENT LITHOSTRATIGRAPHY

Introduction

The sediment was washed through down to basement. The first section of Core 1 (110.0 to 111.5 m) contained several pieces of basalt and basalt-limestone breccia,

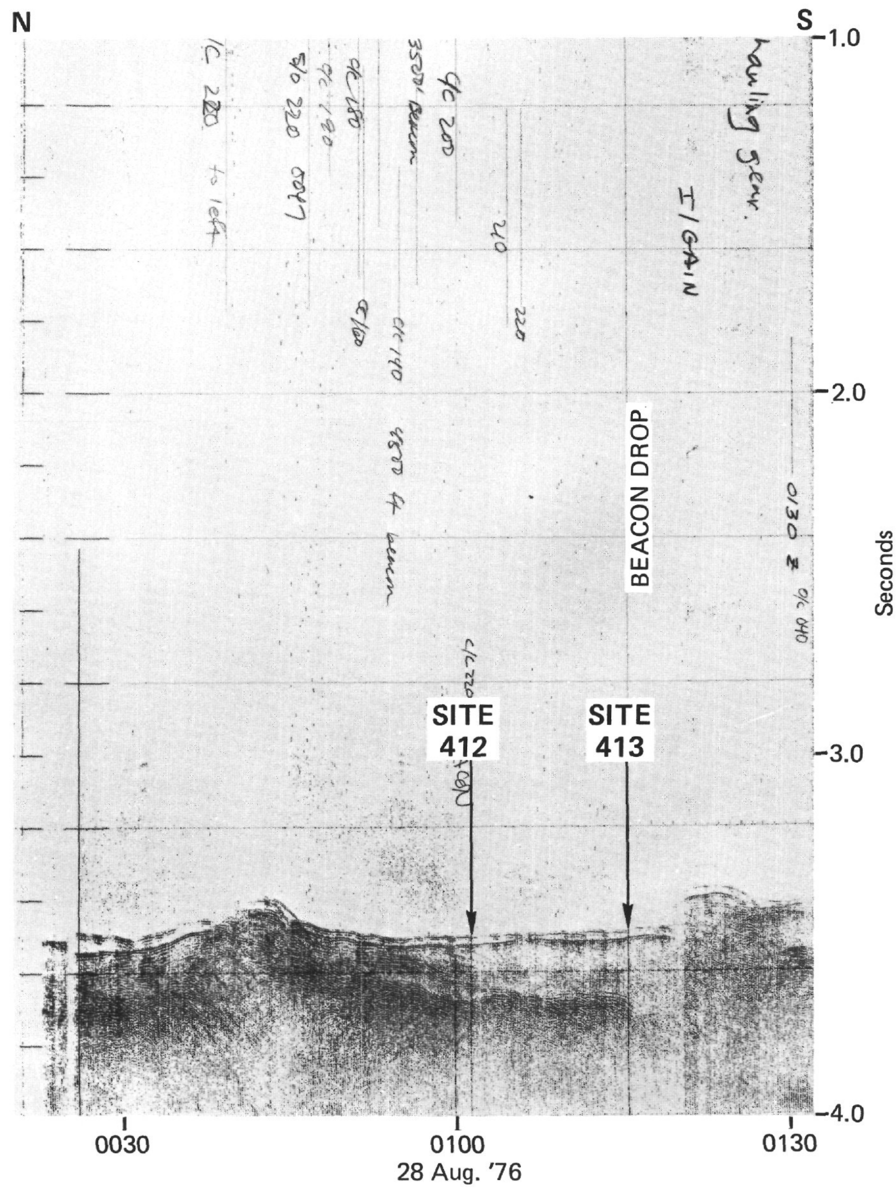


Figure 2. *Seismic reflection profile taken on approach to Site 413.*

TABLE 1
Coring Summary, Site 413

Core	Date (Aug. 1976)	Time	Depth From Drill Floor (m)	Depth Below Sea Floor (m)	Length Cored (m)	Length Recovered (m)	Recovery (%)
1	28	2035	2718.0-2723.0	110.0-115.0	5.0	1.5	30
2	28	2205	2723.0-2732.5	115.0-124.5	9.5	0.4	4
3	28	2350	2732.5-2742.0	124.5-134.0	9.5	0.3	3
4	29	0200	2742.0-2751.5	134.0-143.5	9.5	0.4	4
5	29	1000	2751.5-2756.5	143.5-149.5	6.0	0.37	6
Total					39.5	2.97	8

surrounded by a medium to coarse basaltic sand. Before the core was split, the basalt pieces were removed from the core liner. The exact stratigraphic relationship between the basalt pieces and the sand is therefore unknown. After the core liner of Section 1 had been split, we found a thin, apparently bedded sequence of medium basaltic sand with abundant foraminifers in the upper 10 cm; this was probably overlying the uppermost basalt piece before the basalt was removed from the liner. In view of all this, we will describe the sand separately from the rock, although they occurred together in the first section.

Sediment Descriptions

Basaltic Sand (Core 1, Section 1, 110.0 to 111.5 m)

This is medium to coarse angular basaltic sand. We observed the following constituents under the binocular microscope: basalt, pale yellow limestone, foraminifers, calcite, and minor amount of pteropods, glauconite, pyrite (burrow filling and coatings on foraminifer tests), olivine, and zeolites. The sand shows an increase in foraminifer content upward in the section, and a decrease in grain size upward. Since all rock and mineral particles are angular and the fossils appear to be unabraded and "fresh" (not discolored), it appears that this material represents drilling

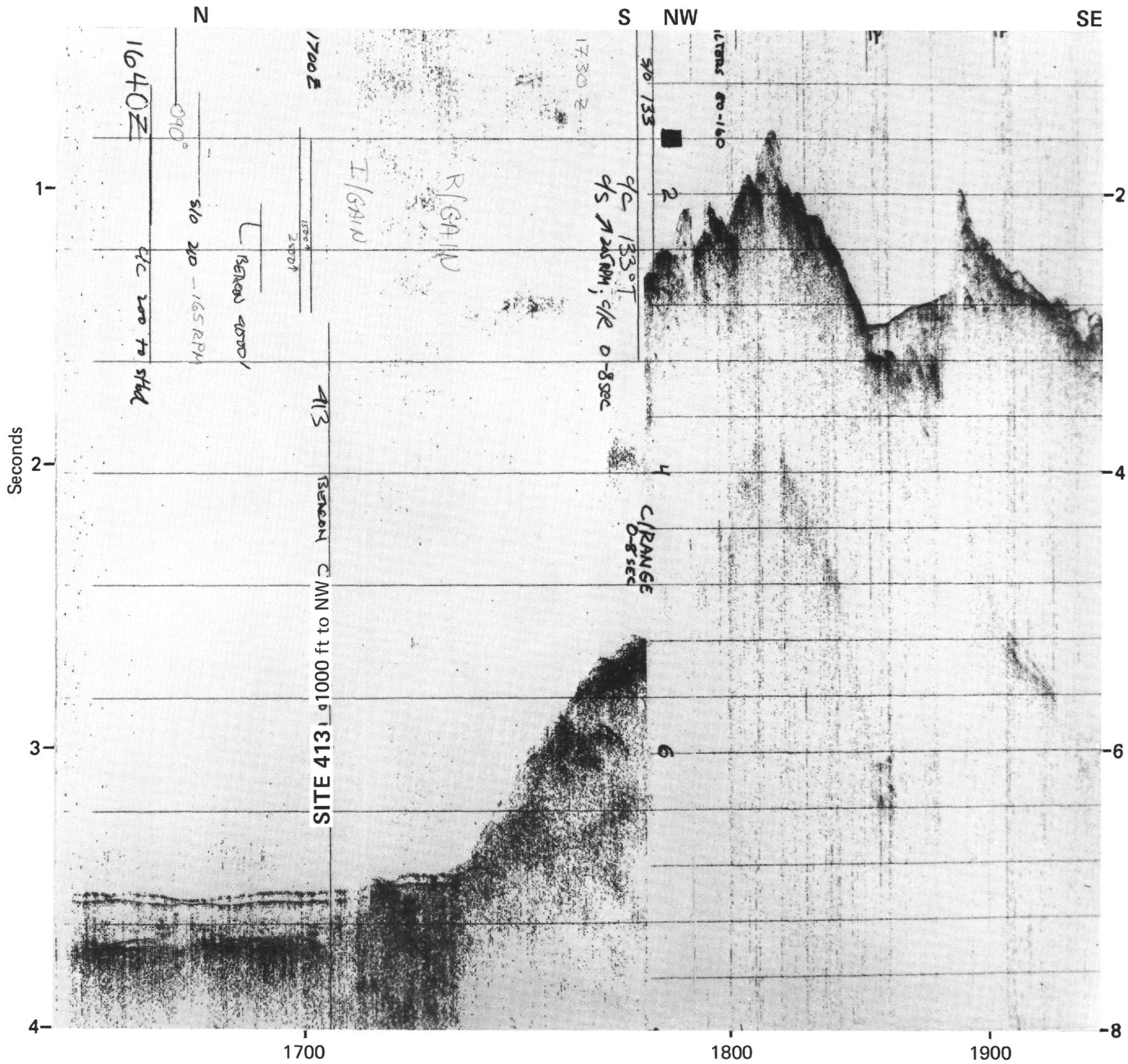


Figure 3. *Seismic reflection profile. Taken after leaving Site 413.*

cuttings in which fossils were introduced while raising the core.

Interlayered Sedimentary Rock

Basalt-Limestone Breccia (Cores 1 through 3, 111.1 to 134.0 m)

This rock consists of angular basalt fragments, from sand to pebble size, floating in pale yellow limestone (micritic) matrix. Some basalt fragments are rimmed with palagonite. The breccia decreases in quantity from top to bottom, until, in Core 3, there is only one piece of breccia. The petrography and origin of this breccia, along with similar interlayered sedimentary rocks recovered at other holes, are discussed in a separate section (Varet and Demange, this volume).

BIOSTRATIGRAPHY

Pleistocene sediments(?) and limestone interlayered with basalt were recovered at Site 413.

Planktonic Foraminifers

Sample 1-1, 10-12 cm (~110 m sub-bottom) contains abundant well-preserved Pleistocene planktonic foraminifers. Common taxa include *Globorotalia truncatulinoides*, *G. crassaformis*, *G. inflata*, *Neogloboquadrina dutertrei*, *N. pachyderma* (dextral), *Orbulina universa*, *Turborotalita quinqueloba*, and *Globigerina bulloides*. The well-preserved foraminifers are most common in the upper part of Core 1, and are associated with abundant angular grains of basalt, glass, and palagonite. Foraminifers are concentrated in the >149 μm size fraction.

It seems likely that the "sediment" recovered in Core 1 represents drill cuttings mixed with foraminifers derived from up-hole.

No foraminifers were reliably identified from interlayered limestones.

Nannofossils

Nannofossils from Hole 413 cores were examined. Core 1, Section 1, 10-11 cm (~110 m sub-bottom) consists of basaltic and carbonate sand and silt. Abundant well-preserved nannofossils occur. The assemblage present indicates the lower Pleistocene (Zone NN 19): *Coccolithus pelagicus*, *Gephyrocapsa* spp., *Helicopontosphaera kamptneri*, *Pontosphaera discopora*, and *Emiliania annula*. Core 2, Section 1, piece #6 (~115 m sub-bottom) consists of limestone indurated on a basalt substrate. Nannofossils are few and poorly preserved. They indicate a Pleistocene date, but taxa are insufficient to suggest a zone: *C. pelagicus*, *Gephyrocapsa* spp., and *P. discopora*. Core 3, Section 1, piece #7 (~124.5 m) is also a limestone on basalt substrate. Nannofossils are few and in very poor condition. Only *Gephyrocapsa* spp. are recognizable, although others are present.

PALEOENVIRONMENTAL INTERPRETATION

We gained no information about depositional environments from the approximately one meter of basalt-limestone sand recovered at Hole 413. We do not know whether the sand is drilling breccia, but the large number of "fresh" (not discolored) foraminifers implies downhole contamination subsequent to washing down to basement.

The interlayered sediments are similar to those recovered at Hole 412 (nannofossil chalk), except that they occur only as thin (<½ cm) coatings on basalt. Drilling rates suggest sediment layers within the basalt rubble, although very little sediment was recovered.

BASEMENT LITHOSTRATIGRAPHY

We encountered basalt at 110 meters sub-bottom depth and drilled for 39.5 meters before bad weather forced us to terminate drilling of the hole. Only 2.97 meters (7.5%) were recovered. Except for 1.50 meters retrieved in Core 1, none of the five cores contained more than 40 cm of basalt.

All recovered material is aphanitic to fine-grained, even-textured aphyric basalt, with rare scattered microphenocrysts of plagioclase and/or olivine. Glass selvages are rare, and occur only in Cores 4 and 5. The upper three cores are finely vesicular (5%, 0.1 to 0.2 mm), but contain occasional larger vesicles (to 8 mm). The lower two cores are essentially non-vesicular. Cores 1 through 3 are fresh, and Cores 4 and 5 are moderately to strongly weathered; some rounded cobbles are completely rimmed with yellow-brown rinds. Several samples in Cores 1 and 2 and one cobble in Core 3 have rinds or veins of limestone breccia containing clasts of palagonitized red-brown glass and basalt.

The basalt can be divided into two groups, an upper unit composed of flows and hyaloclastite, and a lower unit of more massive basalt. Examination of the drilling-rate graph (Figure 4) reveals two periods of slow drilling, separated by an interval of much more rapid drilling; this indicates that these two units are separated by interlayered sediment on a rubble zone (none of which was recovered). Paleomagnetism data from two samples suggest that the upper unit is *in situ*, but the rounded shapes of the cobbles and their complete marginal alteration indicate that the second unit has been reworked and probably represents a talus deposit.

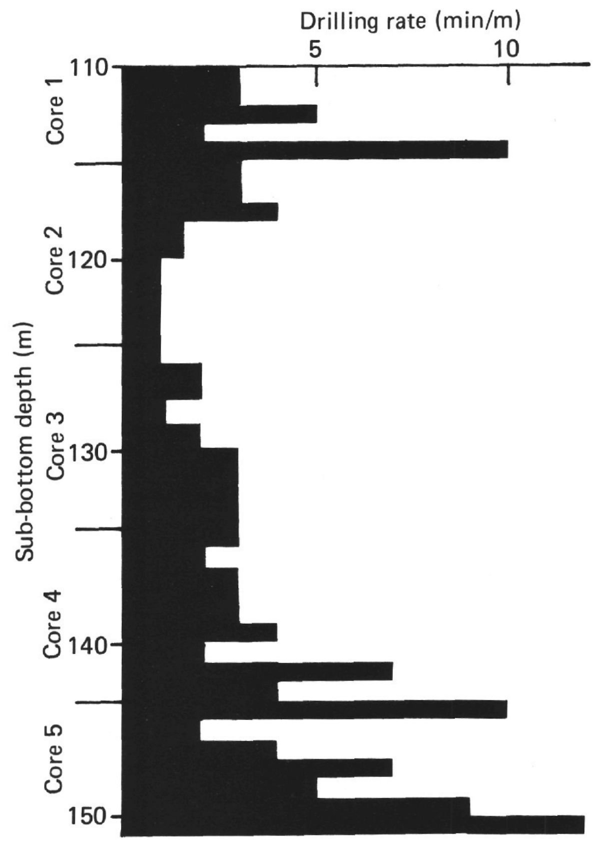


Figure 4. *Drilling rate (min/m), Hole 413.*

The geochemical data suggest no clear chemical stratigraphic break in the hole (Figure 5), but toward the bottom, fragments with high Al_2O_3, low K_2O and TiO_2, and other incompatibles, are present.

IGNEOUS PETROGRAPHY

The two units recovered at Site 413, between 110 and 118 meters and between 126 and 150 meters sub-bottom, are both reworked formations of igneous origin (Figure 6).

The upper unit is reworked volcanic breccia with hyaloclastite and lava fragments cemented by a compacted limestone. Basalt texture ranges from glassy to microcrystalline; relatively well crystallized groundmass has sub-ophitic texture. Olivine is present as microphenocrysts (<0.5 mm diameter) in all samples studied, and averages 10 per cent. In the microcrystalline varieties, olivine is also present in the groundmass, where it coexists with plagioclase, augite, and magnetite. Augite is pale brown, and frequently shows hourglass structures.

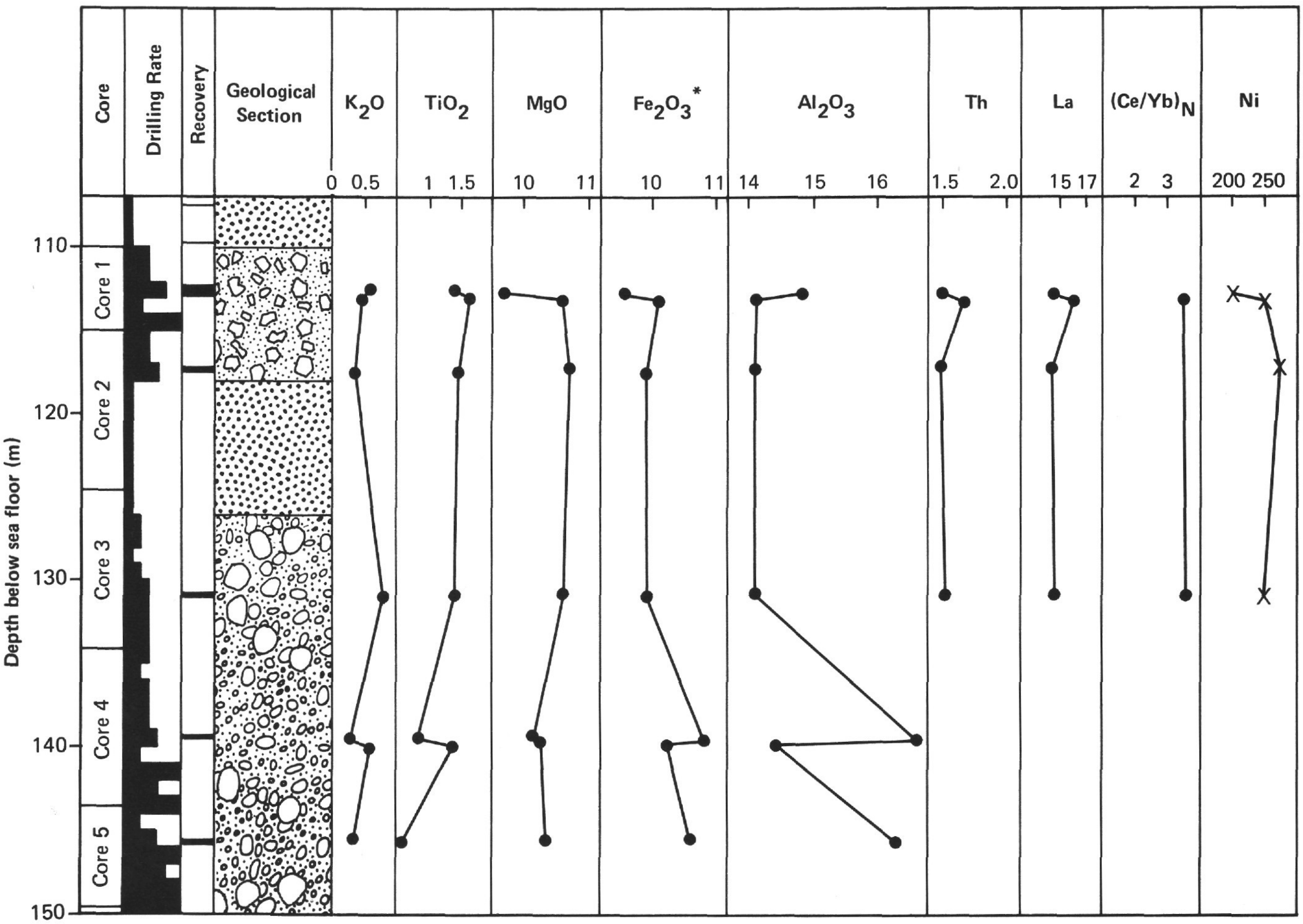


Figure 5. *Geochemical data, Hole 413.*

The lower unit consists of pebbles and boulders of compact basalt. These are clearly rounded and show no preferred orientation. They are, moreover, altered, with clear concentric oxidation and hydration rims. Texture of these basalts ranges from medium grained to glassy, and vesicular as well as compact varieties are present. No limestone or hyaloclastite occurs in this lower unit. Although the petrology of the basalt pieces seems extremely variable in hand specimens, petrographic study of six thin sections from this lower unit shows fairly constant composition. Groundmass ranges from completely glassy to microcrystalline — in that case with an intersertal texture — and olivine phenocrysts are constantly present. They always average around 10 per cent, and frequently have spinel inclusions. Microcrystalline groundmass also contains olivine, together with clinopyroxene, plagioclase, and opaques, with 10 to 20 per cent brown glass.

These two units are separated by an easily drilled layer that was not recovered, and show some geological differences. They probably represent an accumulation of talus in the vicinity of a fault scarp near the foot of the southern fracture-zone wall. It may well be that this does not represent the basement at Hole 413, since none of the rocks recovered seem to be in place.

The recovered rocks, however, provide information on the rocks exposed in the nearby southern scarp of the fracture zone.

Two distinct geochemical types are present in the hole. One, found generally in the upper part of the hole, is relatively enriched in incompatible elements, and has a higher Ce/Yb ratio than is normal in the FAMOUS area. The lower unit has a substantially lower Ce/Yb ratio than the FAMOUS average. This large range in geochemistry is consistent with our having recovered principally talus.

ALTERATION PETROGRAPHY

The alteration at Site 413 is very similar to that at Site 412. Many of the basalts are very fresh, with only traces of smectite, lining vesicles, to mark the onset of alteration. Some are more altered, especially the specimens near the top of basement. The alteration takes the form principally of crystallization of smectite, first as vesicle rims, then replacing glass in the mesostasis, and finally beginning to replace olivine. In no sample is the replacement of olivine more than 10 per cent complete. Calcite occurs in the upper lavas (Core 1, 110-115 m) macroscopically as a rare vesicle filling, but it has only been seen in thin section in Section 4-1, piece 7 (134-143.5 m), again as a vesicle filling.

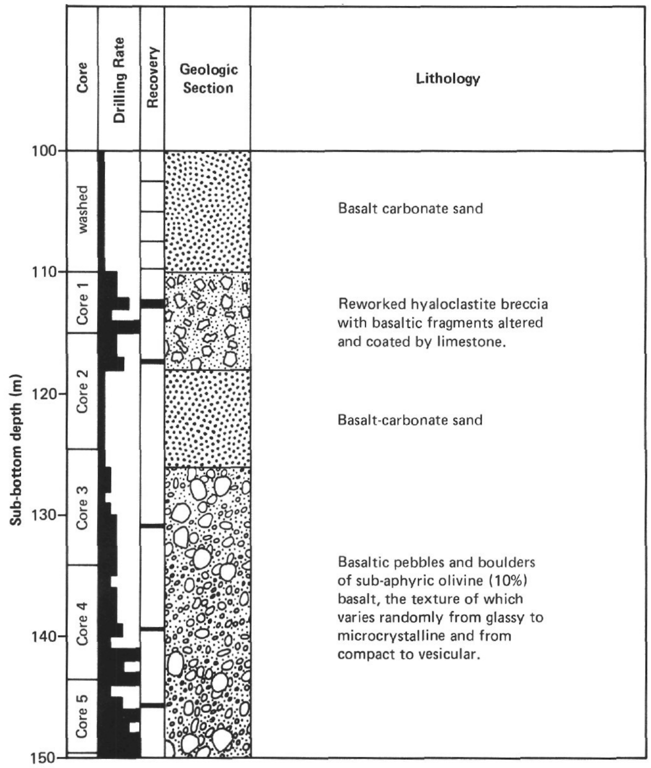


Figure 6. *Stratigraphic section, basement rocks, Hole 413.*

TABLE 2
Paleomagnetism Data

Sample (Interval in cm)	Depth (m)	NRM Intensity (10^{-3} emu cm^{-3})	Initial Inclination (°)	Stable Inclination (°)	(Oe)
413-1-2, 64-67	110.6	7.924	-54.6	-58.7	115
413-1-2, 66	110.6	16.640	-54.0	-54.0	95
413-1-2, 100	111.0	12.344	-60.2	-58.8	235

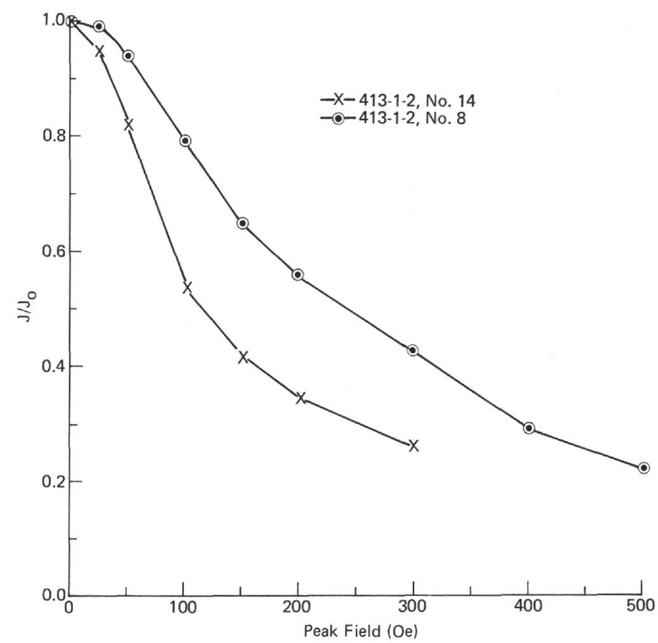


Figure 7. *AF demagnetization, Hole 413.*

Secondary pyrite was found in one sample from Section 1-2, piece 4 (110-115 m). In one sample, too, opaque iron or manganese oxide occurs as spherical blobs forming part of the filling of vesicles (Section 3-1, piece 4; 124.5-134 m).

Through much of the recovered basalt, and particularly in the lower cores, the basalt fragments recovered take the form of cobbles with gray cores almost entirely surrounded by a yellow oxidized rim. This is one of the pieces of evidence taken to show that basement at Site 413 is a talus pile or some similar breccia. Such a contrast between a very oxidized outer rim and a still-reduced inner zone is unusual in dredged basalts. More often, the weathering that produces a yellow color in old ocean floor basalts proceeds slowly enough that there is never so marked a contrast between core and margin.

BASEMENT PALEOMAGNETISM

Very little basalt was recovered at this 3.5-m.y.-old site on anomaly 2′. As a result, only one standard-size specimen and two small cores could be oriented for paleomagnetism at Site 413. As can be seen from Table 2, the NRM intensity of the standard specimen was just less than 8×10^{-3} emu cm^{-3}, and of the small cores, 12 to 16×10^{-3} emu cm^{-3}. All specimens had high directional stability, reversed polarity, and stable inclination around $-58°$. This is very close to the axial dipole value of 56.4° at this latitude (36.5°N), and is in agreement with the sign of the anomaly. The median destructive fields of AF demagnetization ranged from 95 to 235 Oe (Figure 7).

CORRELATION OF SEISMIC REFLECTION PROFILE WITH DRILLING RESULTS

Reflection profiles using tandem 10- and 40-in.^{3} airguns were run approaching and leaving Site 413. The approach profile (Figure 2) shows apparently down-faulted basement beneath the beacon drop. This reflection is very weak at 245 ms (DT). Using a velocity gradient of 1.0 s^{-1} and assuming a bottom water sound velocity of 1500 m/s gives a sub-bottom depth of 216 meters. This figure includes an added 10 per cent based on underestimates for Site 412. Basement was reached at 110 meters, much shallower than any observed reflection could account for. Leaving Site 413, we repeated this profile, passing 1000 feet southeast of the beacon. We carefully monitored the system gain on this crossing to optimize the data. This profile (Figure 3) shows indications of discontinuous reflections at slightly over 100 ms (DT); this correlates reasonably with drilled depths. It appears, then, that the beacon is actually situated over upfaulted basement, against the south wall of fracture zone B. This dissected terrain yields diffuse non-specular returns not readily visible. The 245 ms (DT) reflection seen on the first approach must be a side echo.

A well-developed sub-bottom reflector is apparent at 20 to 30 ms (DT); we also saw this at Site 412, a mile or two north, and it appears to occupy the entire fracture-zone valley. Its appearance is definitely real, as indicated by its variable sub-bottom depth. Coring at Hole 412 did not divulge the nature of this reflector. It could very likely represent a subtle change in consolidation and water content in the nannofossil ooze, or a thin layer of upper Pleistocene turbidites.

SUMMARY AND CONCLUSIONS

Site 413 is in the valley of fracture zone B, about 1.3 nautical miles south of Site 412 on azimuth 200°. This site was meant to be a companion to 412, and was chosen for study of geologic variation across the valley. First of all, we hoped to position the site across the plate-boundary scar onto the older south side of the valley (3.4 m.y., versus 1.6 m.y. on the north side). Also, the south side should have passed through the actual transform shear zone; therefore the rocks here could be much more petrologically variable.

The hole was begun in 2600 meters of water, just at the south edge of the flat valley floor. We washed down 110 meters of sediment and penetrated 39.5 meters of basement before inclement weather forced us to abandon this site and the FAMOUS area.

We recovered no sediments from above basement, but the first core brought up angular basaltic sand, along with basalt cobbles. This sand has constituents of basalt, glass, limestone, calcite, and foraminifers, and is probably a drilling breccia. Foraminifers within this sand place it in the lower Pleistocene.

The basement consists of two basalt units (Figure 8) separated by a soft zone, of unknown lithology, about 10 meters thick. The upper basalts are cobbles from a hyaloclastite-basalt-limestone breccia. Poorly preserved nannofossils are present in the limestone, but are useless for age dating. This unit may be in part reworked. Some of the basalt contains as much as 10 per cent olivine microphenocrysts; most is aphyric. The lower unit consists of pebbles and boulders of compact basalt, with random distribution of various rock textures (glassy to microcrystalline). This basalt has phenocrysts of olivine which are 90 per cent fresh and which sometimes have spinel inclusions. The clasts in this unit are rounded and rimmed with brown alteration zones a few millimeters to a centimeter thick. Geochemical data suggest that the two basalt units come from the same magma type.

Only two specimens were studied for paleomagnetism, owing to the paucity of oriented material. They are from the

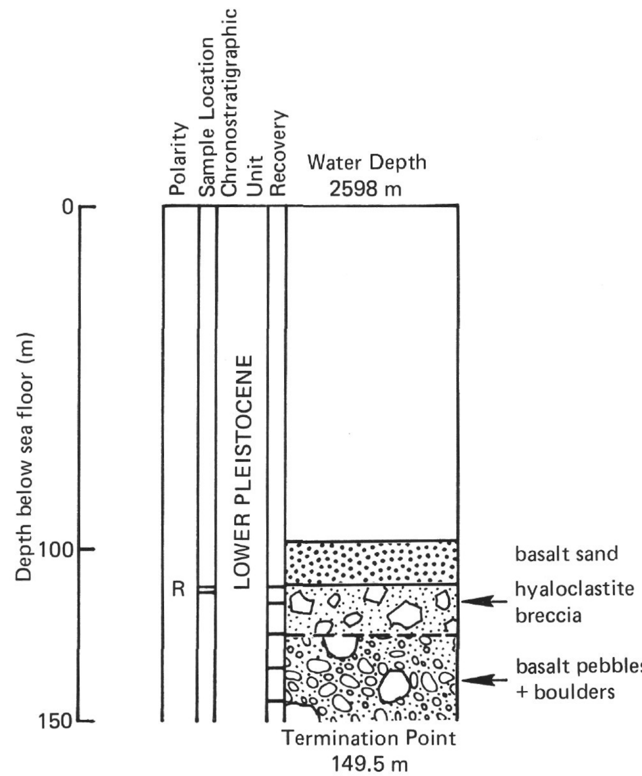


Figure 8. *Stratigraphic section, Hole 413.*

upper unit, and are identical in direction, stable, reversely magnetized, and strongly magnetic (10^{-2} emu cm^{-3}). It is striking that although both basalt units are believed to be reworked talus, the inclinations of these two specimens agree with the dipole value. Either these rocks have been remagnetized after transport, the unit is actually *in situ*, or the agreement is by chance.

Despite this observation, the geologic setting and drilling results imply that Hole 413 has been drilled in a talus pile at the base of the south wall of the fracture zone.

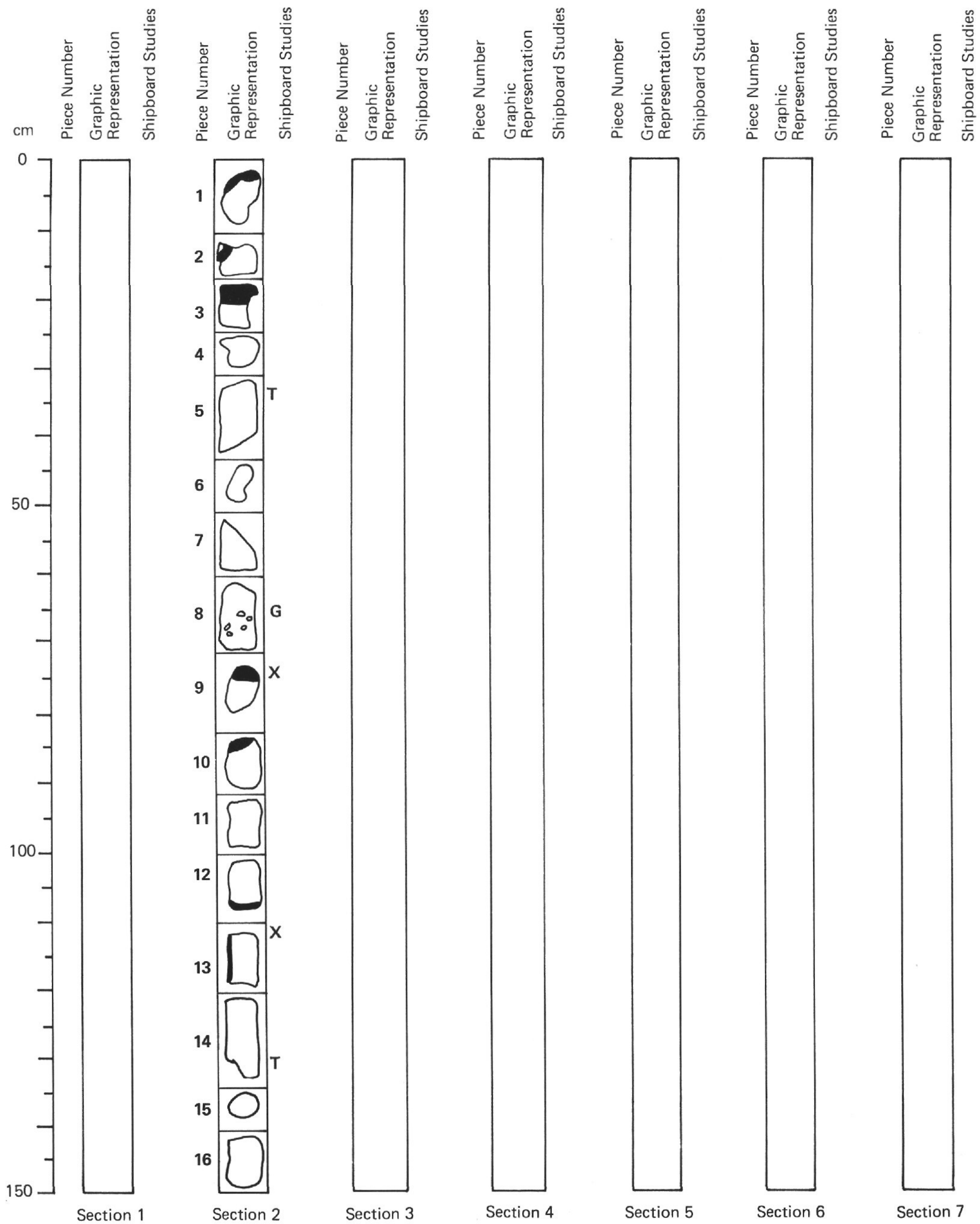
Our few days' work in fracture zone B have focused us on the significant problems associated with fracture zones and the applicability of deep-sea drilling to their study. Ideally, a closely spaced (1-km) profile of holes across a fracture valley would aid greatly in understanding the nature of the ocean crust and the structure of these zones.

SITE 413 HOLE CORE 1 CORED INTERVAL: 110.0-115.0 m

TIME-ROCK UNIT	BIOSTRAT ZONE	FOSSIL CHARACTER: FORAMS	NANNOS	RADS			SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
PLEISTOCENE	N22 NN19	Ag	Ag				1	0.5 1.0	VOID				Basaltic sand surrounded the basalt pieces prior to their removal from core liner. Sand is angular, medium- to coarse-grained, composed of basalt, limestone, calcite, with small amounts of zeolites, glass, and olivine. Unbroken foraminifera common throughout but more abundant in upper 10 cm. Sand slightly finer at top than at bottom. Sand may be drill cuttings.

Explanatory notes in Chapter 1

LEG **49** SITE **413** HOLE CORE **1** DEPTH **110.0-115.0 m**



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

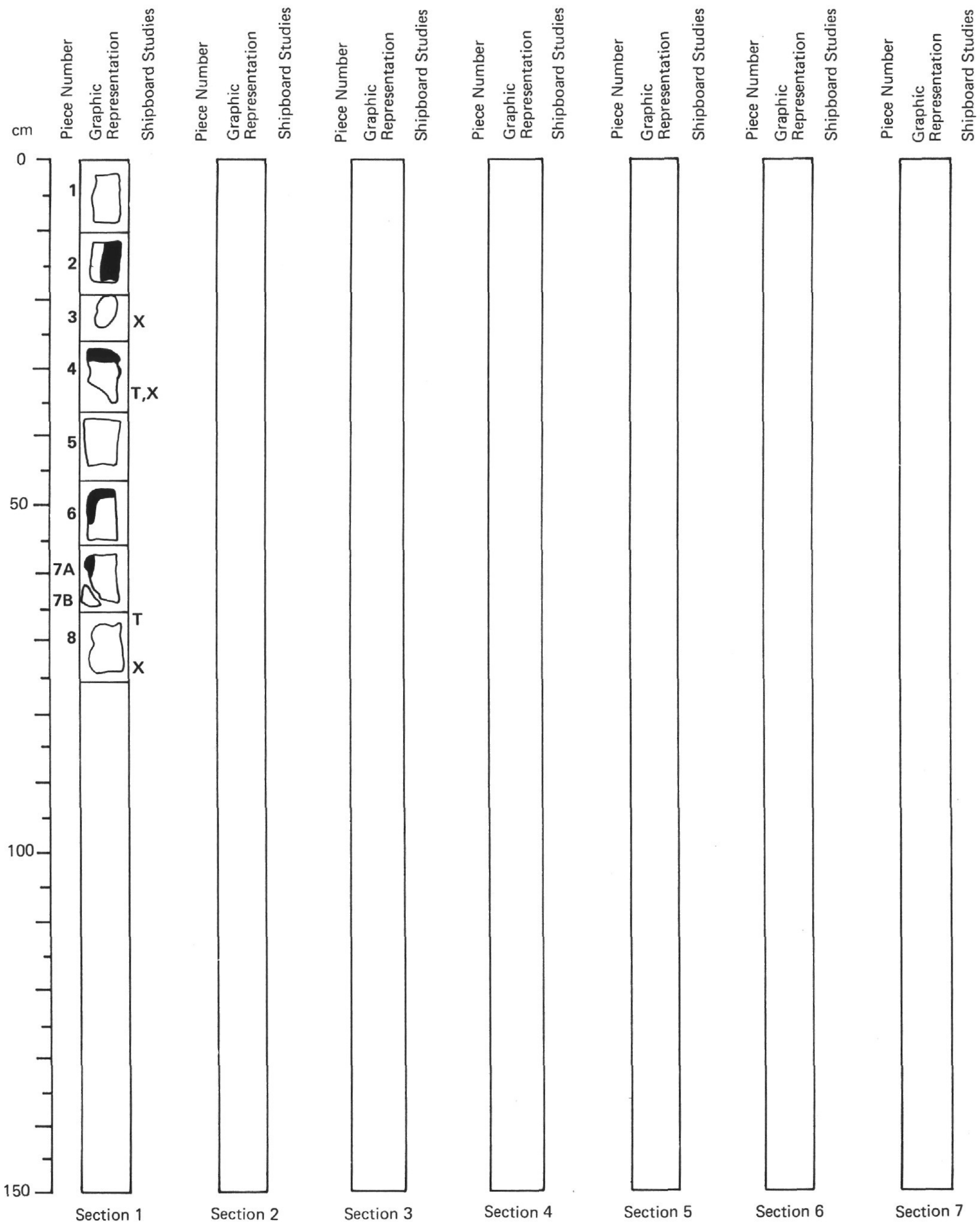
Fine-grained, sparsely microphyric basalt to basalt limestone breccia. Rare microphenocrysts of olivine and plagioclase. Up to 5% vesicles, 0.1 to 0.2 mm in size. Some vesicles filled with carbonate or lined with basaltic glass.

Some fragments have attached pieces of basalt-limestone breccia. Breccia includes palagonite and fine-grained basalt in a dense, creamy white limestone matrix.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 65 cm:	4.65	4288	-59°
Sect. 1, 80 cm:	4.90	––	––

LEG **49** SITE **413** HOLE CORE **2** DEPTH **115.0-124.5 m**

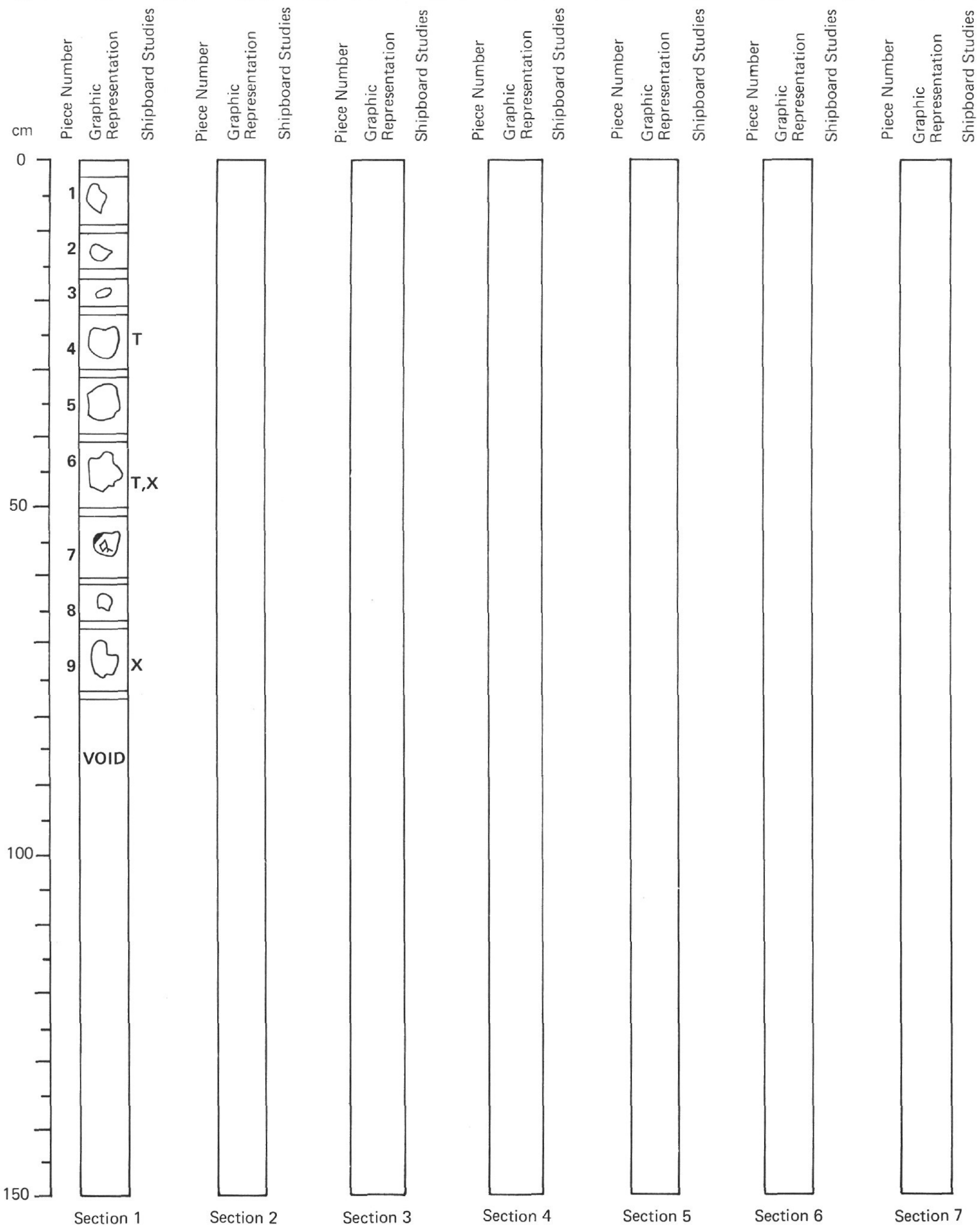


Original basalt recovery was 0.4 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

Fine-grained to aphyritic microphyric basalt, plus basalt-limestone breccia. Rare microphenocrysts of olivine and plagioclase. Up to 5% vesicles, 0.1 to 0.2 mm in size. Some vesicles filled with carbonate or lined with basaltic glass.

Some fragments have attached pieces of basalt-limestone breccia. Breccia includes palagonite and fine-grained basalt in a dense, creamy white limestone matrix.

LEG 49 SITE 413 HOLE CORE 3 DEPTH 124.5-134.0 m

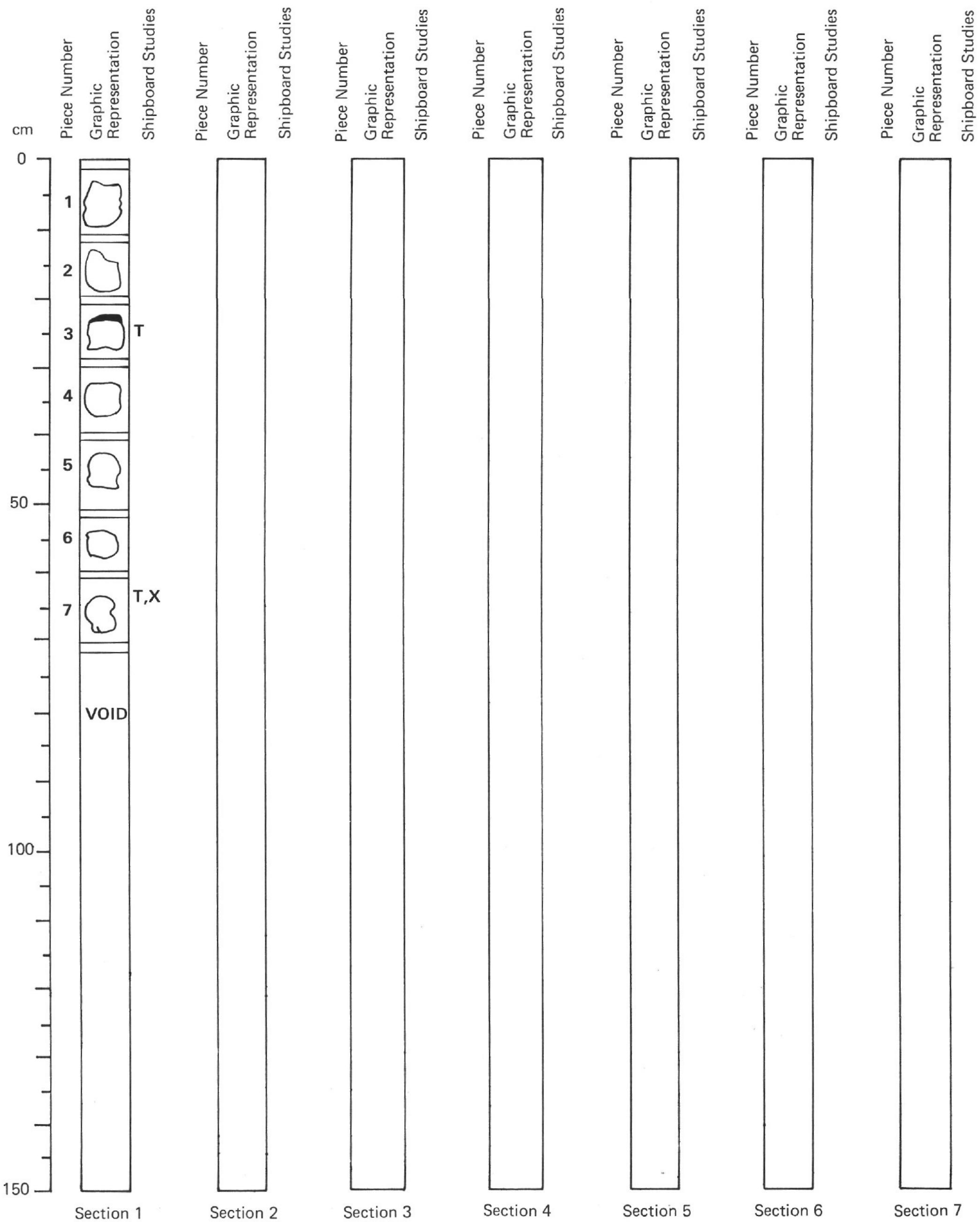


Original basalt recovery was 0.3 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

Type 1: fine-grained, aphyric basalt, relatively fresh to very altered. Rare vesicles from 0.1 to 0.5 mm.

Type 2: basalt-limestone breccia: fragments of very altered, fine-grained basalt and fresh to palagonitized basalt glass in a limestone matrix.

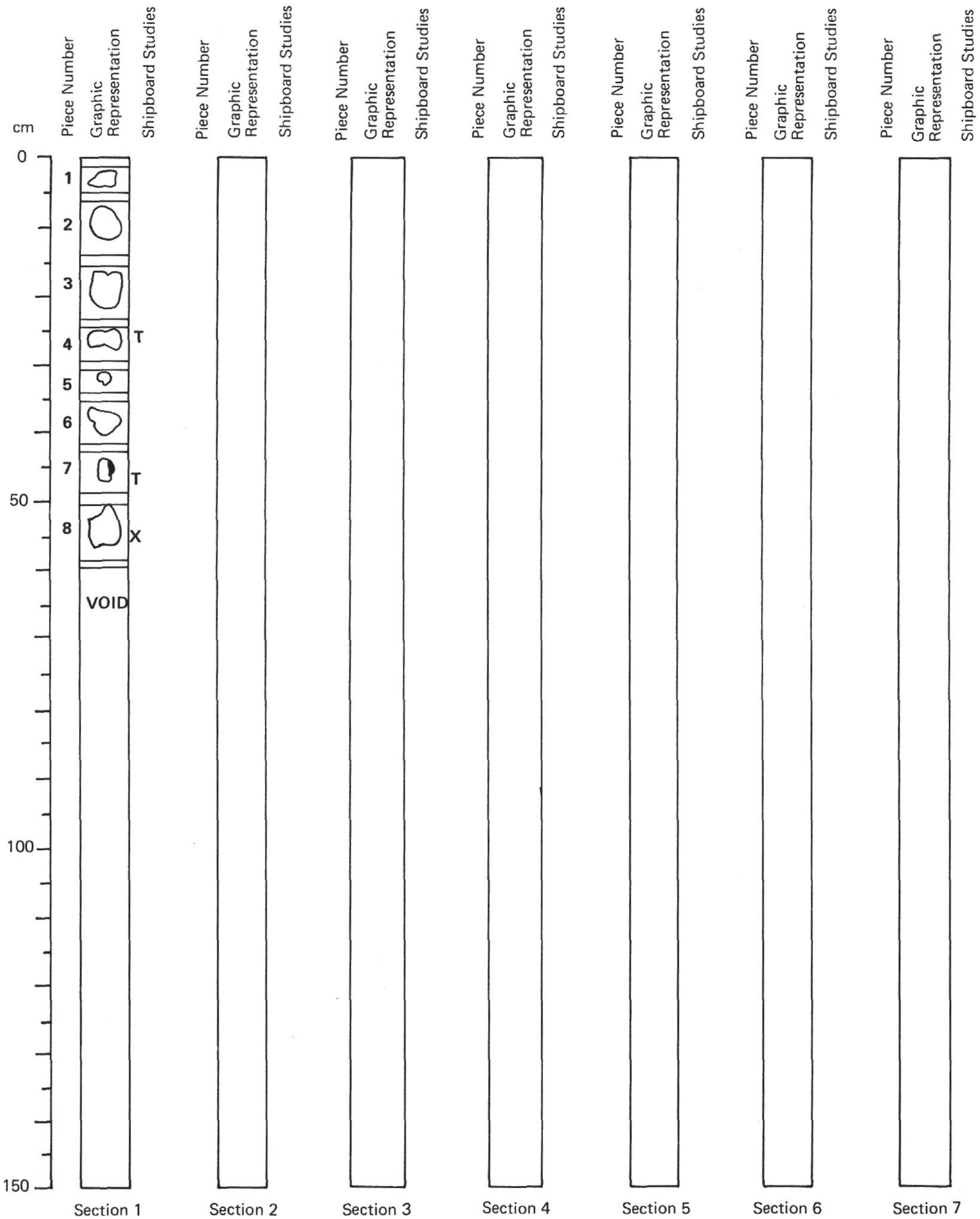
LEG 49 SITE 413 HOLE CORE 4 DEPTH 134.0-143.5 m



Original basalt recovery was 0.4 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

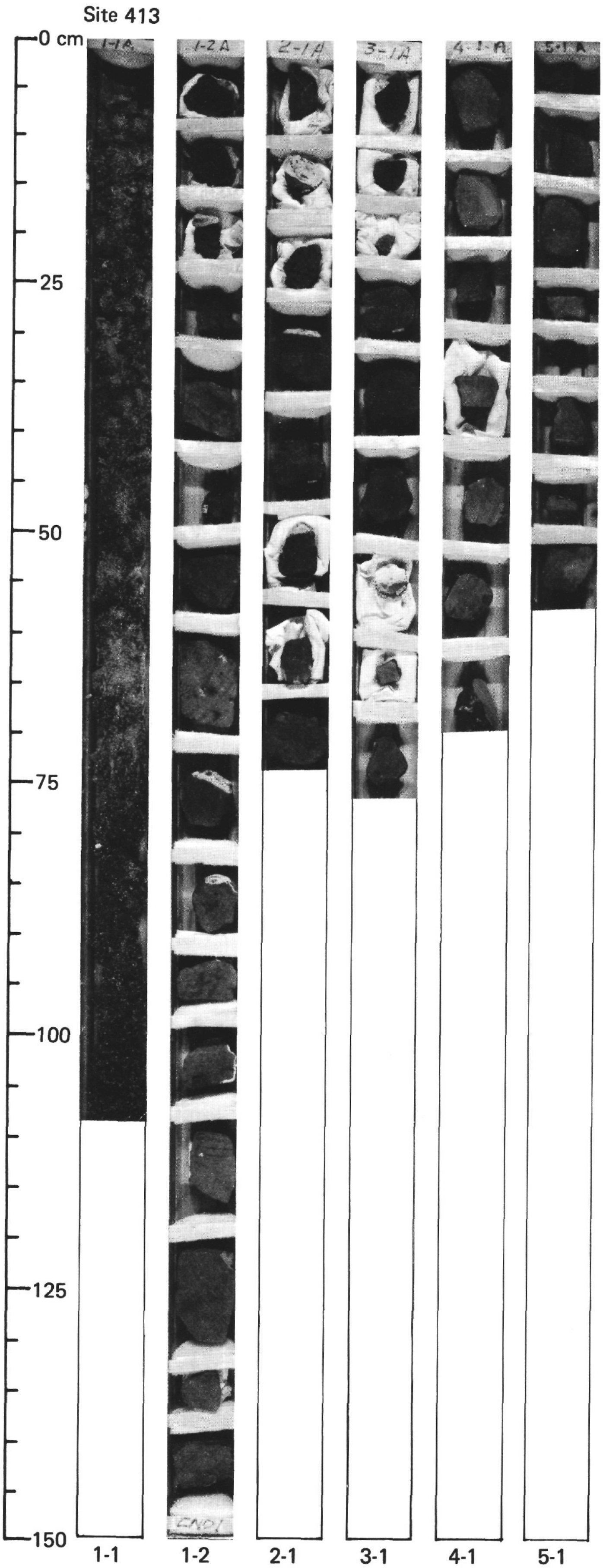
Fine-grained, sparsely microphyric basalt. Rare microphenocrysts of olivine < 5% vesicles, 0.1 to 0.5 mm in size. Moderately to intensely altered. One fragment has a glass selvage.

LEG 49 SITE 413 HOLE CORE 5 DEPTH 143.5-149.5 m



Original basatl recovery was 0.37 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

Fine-grained, aphyric basalt, moderately to intensely altered. One fragment has a glass selvage.


Site 413
0 cm
25
50
75
100
125
150
1-1A
1-2 A
2-1A
3-1A
4-1-A
5-1 A
END
1-1
1-2
2-1
3-1
4-1
5-1