6. SITE 411

Shipboard Scientific Party[1]

SITE DATA

Date Occupied: 1200 21 August 76

Date Departed: 2359 23 August 76

Time on Hole: 2 days, 12 hours

Position: Latitude: 36°45.97′N; Longitude: 33°23.30′W

Water Depth (sea level): 1935 corrected meters, echo sounding

Water Depth (rig floor): 1945 corrected meters, echo sounding

Bottom Felt at: 1950, 1975 meters, drill pipe

Penetration: 119.5 meters

Number of Holes: 2

Number of Cores: 5 and 3

Total Length of Cored Section: 73.0 meters

Total Core Recovered: 18.65 meters

Percentage Core Recovery: 24.5 per cent

Oldest Sediment Cored:
Depth sub-bottom: 37.0 meters
Nature: Foraminifer sand
Chronostratigraphic Unit: Pleistocene

Basement:
Depth sub-bottom: 74 meters
Nature: Dense basalt
Velocity Range: 5.17-5.9 km/s

Principal Results: Site 411 is on the west terrace in the rift valley of the Mid-Atlantic Ridge crest. The site is in a half-mile-wide basin mapped by multibeam sonar and deep tow during FAMOUS project. Situated on the old side of the Jaramillo anomaly, Site 411 is the youngest site yet drilled by DSDP, just over 1 million years old. The basin was searched for a site to spud into by probing with the drill string on a 500-foot grid, using beacon offsets. The eleventh probe found 74 meters of sediment, and spud-in was completed.

Hole 411 was washed from 74 meters sub-bottom to basalt. The basalt was cored continuously for 45.5 meters, to 119.5 meters sub-bottom. Recovery was only 4 meters. The recovered section is fresh, dense, aphyric and plagioclase and olivine phyric basalt alternating in flows and rubble zones. Caving of the hole necessitated our abandoning it. Hole 411A was offset 50 feet and three cores were cut between the mud line and 37 meters sub-bottom. Pleistocene foraminifer sand caused very unstable hole conditions. We abandoned the site at 2359 hours on 23 August.

BACKGROUND AND OBJECTIVES

A "zero-age" site, to be placed somewhere in the Pacific, has been suggested to the JOIDES Ocean Crust Panel. The scientific community has received this with enthusiasm. The purpose of such a site would be to investigate ongoing geological processes, if not precisely as they happen (technological limitations restrict the possibility of that), then as soon after they happen as possible. For this purpose the mid-ocean ridge crests appear to have advantages over most other geological environments. Igneous, metamorphic, and hydrothermal processes there appear to form a closely linked chain in space and time, and take place not far below the ocean floor. A zero-age hole would thus be placed as near the active zone at the ridge axis as possible, with the aim of sampling newly formed or newly altered rocks, together with the associated solutions, if possible. Site 411 was in many ways a feasibility test for such a zero-age hole.

The chief problem on any such site is the small amount of sediment cover. Even with relatively high pelagic sedimentation rates such as the 40 to 50 m/m.y. that we found on the Reykjanes Ridge, the 80 to 100 meters of sediment necessary for spudding in would take 2 m.y. to accumulate. Some place of abnormally high sedimentation rate is thus required. This may be on a regional scale, as in the Juan de Fuca Ridge, flooded by turbidites from the Columbia River, or on a local scale, where sediment is concentrated from local topographic highs and deposited in local basins. Site 411 is in the latter category. It is situated in the FAMOUS area, just south of the Azores, on the Mid-Atlantic Ridge, in a small valley 10 km west of the axis of the median valley. The particular site was selected to be at the young end of a flow line from Leg 37 Sites 332 through 335.

Detailed topographic surveys of the area in connection with the FAMOUS project (Phillips and Fleming, unpublished) have shown that the median valley is very narrow, with sides that rise to the crestal mountains to the west and to the east. The west side is the steeper, with tall cliffs, broken by a main terrace and two valleys at different levels that run along the back edges of tilted fault blocks or in grabens associated with these (Figure 1). During the FAMOUS project, deep-tow surveys were made in the area (Macdonald and Luyendyk, 1977), and six of the survey lines passed across the west outer wall of the median valley. On one of these a crossing of the upper valley on the west

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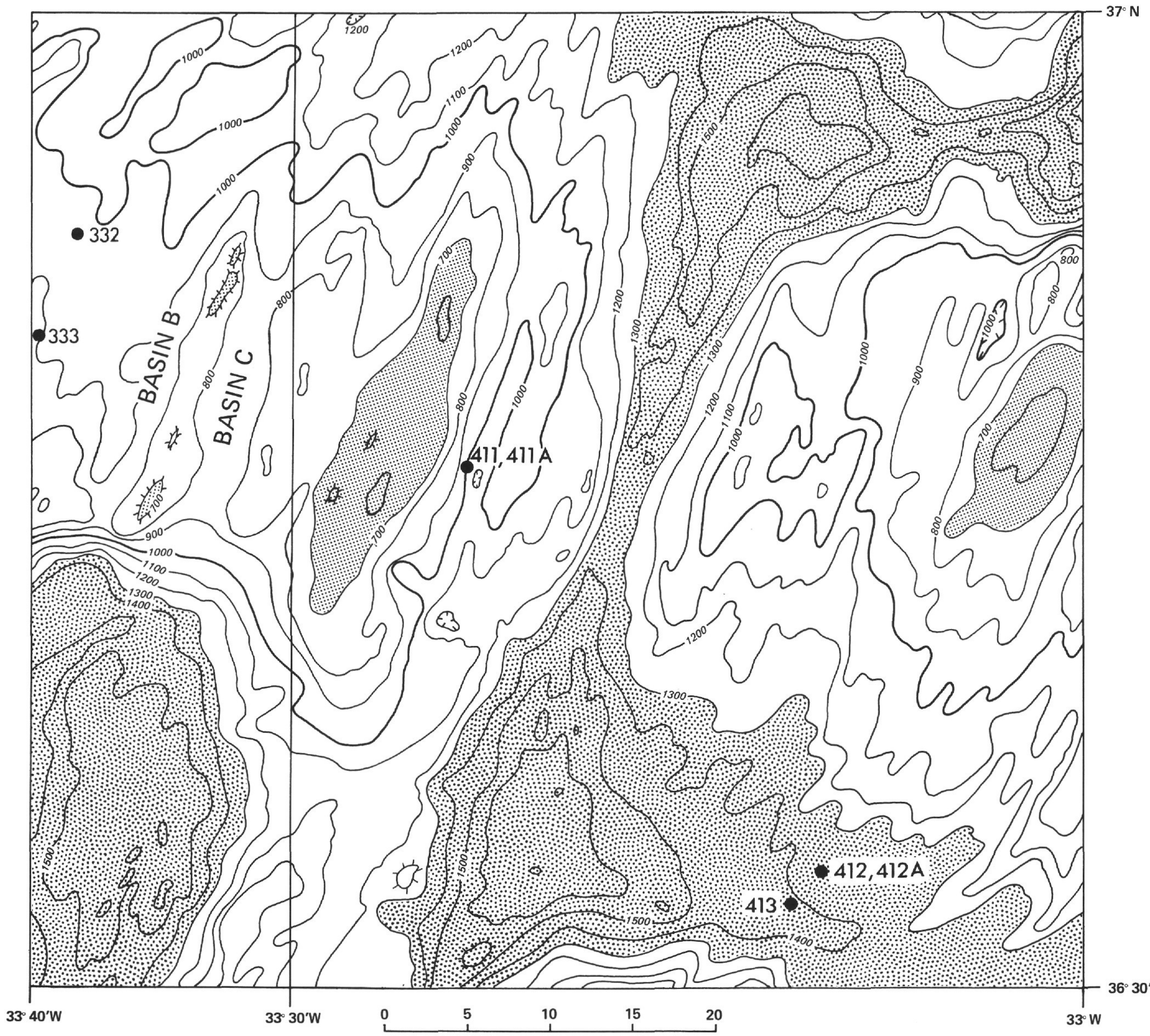


Figure 1. *Topographic chart of the FAMOUS area in uncorrected fathoms; after Phillips and Fleming, unpublished.*

terrace showed sediment filling on a 4.0-kHz near-bottom profiler record, and indicated a sediment depth of more than 50 meters, possibly enough to spud-in (Figure 2). Because of the presence of side echoes and because of the small size of the basin (about half a mile across), such a small pond would not be visible from a surface-ship survey, though it is large enough to spud-in. In addition to the deep-tow survey, we had access to contoured strips from multibeam echo sounder records from the Office of Special Projects, NAVOCEANO (Phillips and Fleming, unpublished).

Two of these strips, taken somewhat to the south of the deep-tow crossing of the valley, showed it to be linear, composed of a chain of small basins separated by saddles (Figure 3). The basins appeared from the contour information to be flat-floored, and so presumably contain sediments. These targets were all small, however, up to about ½ mile square, and it was clear that they would be very difficult to find, and that any sediment in them would not be visible on conventional seismic profiling equipment, so that a different approach from normal was called for (see next section). A very detailed petrographic and geochemical survey in the FAMOUS area has been completed by the FAMOUS project team. Horizontal variation in petrography of surface samples within the rift valley was well documented during this project (Hekinian et al., 1976), and it was clearly of interest to see whether such changes would be found in a vertical section.

Deep-tow magnetometer profiles taken nearby show that the Jaramillo anomaly is on the horst forming the east side of the valley and associated basins. Site 411 is thus just over 1.0 m.y. old. This is less than half the age of the previous youngest basement cored on the project (at Site 409, this

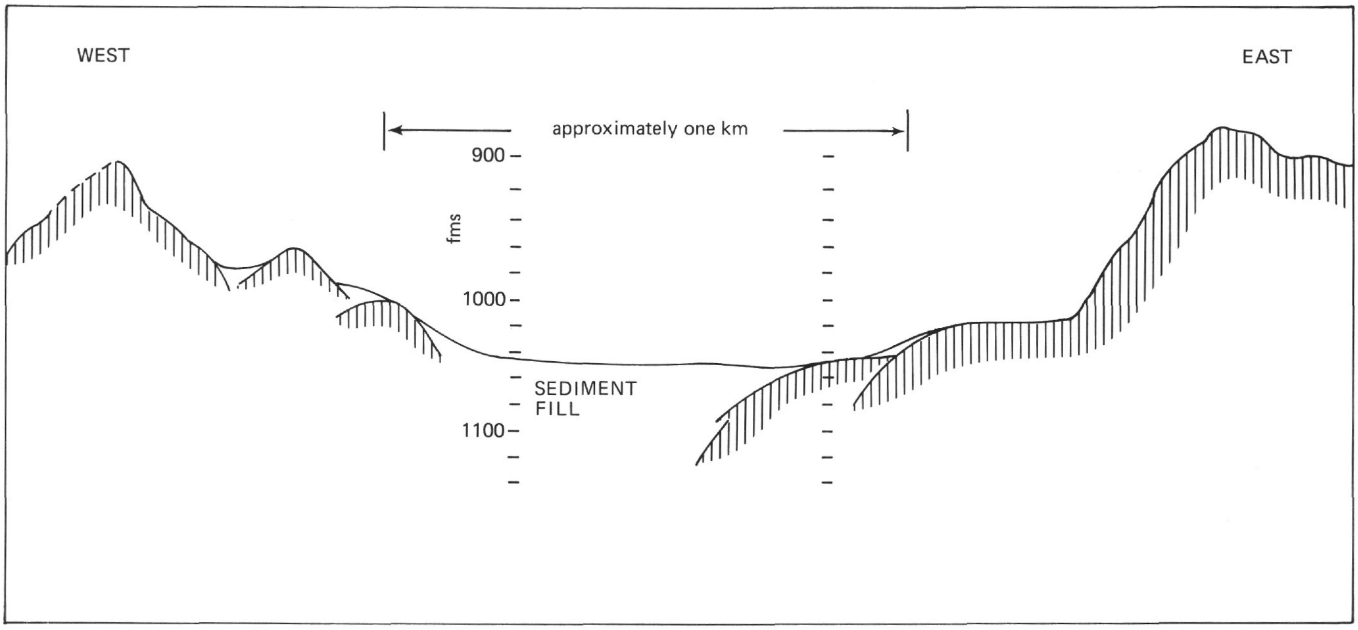


Figure 2. *Deep-tow 4.0-kHz profile just north of Site 411 (see Figure 3).*

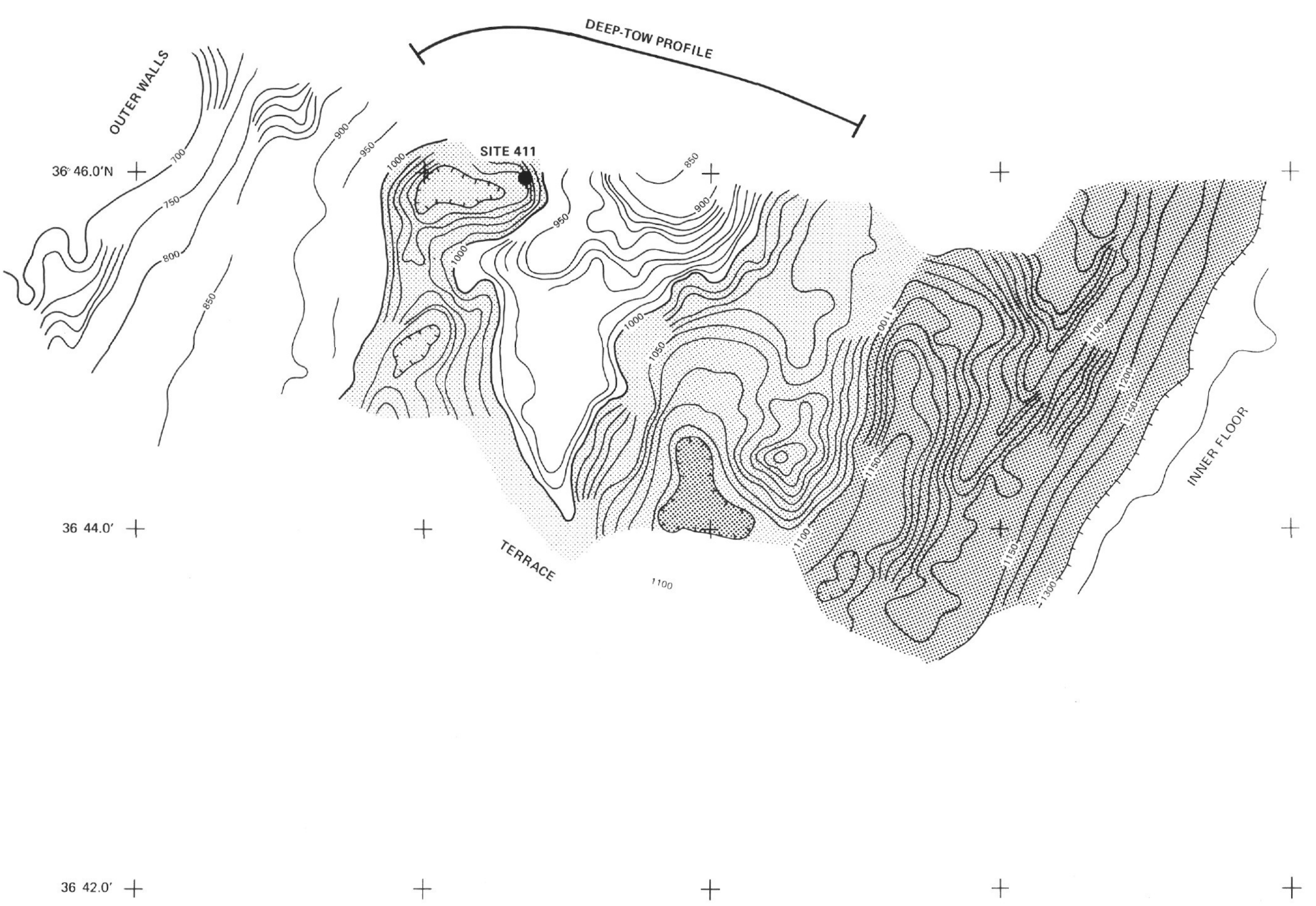


Figure 3. *Topographic chart in the vicinity of Site 411, from a U. S. Navy Office of Special Projects multibeam echo-sounder survey (Phillips and Fleming, unpublished). Soundings in uncorrected fathoms.*

leg, where crust 2.4 m.y. old was cored). Before Leg 49, the youngest basement drilled was at Site 332, Leg 37, also in the FAMOUS area, where the age was 3.5 m.y.

OPERATIONS

Since the target we were aiming for was so small, the first step toward finding it was to navigate accurately along the incoming track. We approached the FAMOUS area from Site 410 on a course of 199°, aiming for Sites 332 and 333, 20 miles to the west of the median valley. The weather was good, and the bearing of this track was well controlled by satellite. The speed on the track was not so well controlled, as the ship decreased speed for about an hour just before the final satellite fix. This fix was timed at 0154 hours 21 August, when we were still 17 miles from our turning point, and between there and 0526 hours, when we were just short of the dropping place, we had to rely on dead-reckoning and the bathymetric chart of the FAMOUS area (Figures 1 and 3). This dead-reckoning track, and others we had to make on Leg 49, highlighted the astonishing fact that *Glomar Challenger* has not even the simplest log for measuring speed through the water and distance run.

An hour after turning, we reduced speed, nominally to 3 knots, but in fact only to 4.5 knots, since the sea was calm and the wind from astern. This discrepancy only became apparent shortly before beacon drop. We made the drop at 0558 on 21 August, using the PDR to find the valley and dropping on the deepest point in it (Figure 4). After the drop, the ship steamed on across the median valley to cross another reported sediment pond on the east side. This proved to have only a few meters of sediment in it, as measured by the seismic reflection gear, and the ship returned to the beacon, and was on station by 1300. The tracks on this approach are shown in Figure 5.

Our first estimate of the position of the beacon drop put us ½ to 1 mile south of the deep-tow crossing, and just north of one of the small basins noticed in a multi-beam echo-sounder survey. Our first aim was to reach the deep-tow track, because it was only here that we had definite evidence of sedimentary thickness. Accordingly, we tried to wash down to basement at offsets about 3000 feet north and 1400 feet and 2000 feet east of the beacon. These attempts both gave 26 meters of sediment, and it seemed that we were unable to offset far enough from the beacon to reach the sediment seen on the deep-tow track. Accordingly, we tried the basin to the south that had showed up on the multibeam profile. The points at which we paused, and those at which we tried to spud, are shown on Figure 6. The problem was complicated by the very steep south and west walls of the basin, which showed up as side-echoes whenever we strayed too far in those directions. After some success, with 51 meters on the edge of the basin, it turned out that the deepest parts of the basin had scarcely any sediment at all. We therefore returned to the saddle near the beacon, to see if any more sediment was to be found. It seemed possible that the saddle consisted of a pile of sediment, and that the basins might be places where sediment drifting down from the mountains had not reached. However, attempts to wash down were again unsuccessful; we found only 20 or 30 meters of sediment. In desperation we returned to the slopes into the basin where the greatest thickness to date had been recorded, and tried again 200 feet to the west of it; 74 meters of sediment were found by washing down, and allowed successful spud-in. This was the eleventh attempt in an exercise lasting about 36 hours. It is likely that such techniques would be necessary, but quite workable, in any attempt to drill on a "zero-age" site. Although time-consuming, it is a method that certainly works. It would be made easier by having a seismic transducer in the end of the pipe, so that precise sediment thickness below the bit could be determined.

After spud-in, we began drilling of hard rock at 2200 hours 22 August. Almost immediately we ran into problems. We cut five cores in basement before sticking and plugging caused us to abandon the hole (Table 1). The bit could be freed by raising and pumping, but after a long struggle it proved impossible to regain the depth of the bottom core. We suspected that the nature of the sediment might have been responsible for the trouble we had in drilling; to check this, we offset the ship 50 feet and started a sediment hole nearby. The bottom at this hole was 35 meters deeper than at Hole 411, suggesting that Hole 411 had luckily been placed on a sediment drift. The sediment from Hole 411A was a foraminifer sand, very easily fluidized, and, by the time it had been cored, recovered, and split, quite structureless. It is clear that this is one of the reasons for the difficulties we had at this site, and that at any very young site the geotechnical properties of the overlying sediment will need special consideration.

Essentially, the operations here showed that given rather unorthodox procedures and sufficient care, a site can be found for a hole in very young oceanic crust. If similar care is taken on a non-rifted ridge where regional or local sedimentation is rapid, there is no reason why a hole should not be drilled in as young, or younger, ocean crust. Precautions that seem to be necessary are first, a deep-tow survey of the area, and second, a geotechnical study of surface sediments. For maximum drilling capabilities, casing, plus heavier drilling muds, to maintain hole stability, would be advisable.

SEDIMENT LITHOSTRATIGRAPHY

Introduction

No sediments were cored at Hole 411. The drilling at Hole 411A resulted in the recovery of three cores, with a recovery rate of approximately 53 per cent, to a depth of 37.0 meters. The interval between 18.0 and 27.5 meters was washed (Table 1).

Description of Sediment

Nannofossil-Foraminiferal Ooze (Hole 411A, Cores 1 through 3, 0 to 18.0 m and 27.5 to 37.0 m)

The sediment is soupy, grayish orange, fine to medium sand-sized foraminiferal ooze with a nannofossil ooze matrix. Smear-slide estimates of foraminifer content are low, owing to the bias for clay and silt-size particles inherent in the smear-slide technique. Through a combination of visual core (binocular microscope) and smear-slide estimates, we conclude that 60 to 80 per cent of the sediment is composed of foraminifers. The remainder is mostly nannofossil ooze, with small amounts of transparent to green and brown volcanic glass (5 to 10%), feldspar (2 to 5%), unspecified carbonate particles (2 to 5%), and traces of siliceous sponge spicules and opaque heavy minerals. Some of the unspecified carbonate grains are calcareous spines of undetermined origin.

Two lumps of structureless light gray nannofossil ooze are at the bottom of Core 3, Section 2 (145-150 cm). The lumps have a thin coating of orange foraminifer tests that probably came from above as a result of drilling disturbance and washing. The lumps are composed predominantly of nannofossils (about 70%) and foraminifers (20%), and the remainder is a mixture of feldspar, volcanic glass, calcareous spines, and a trace of siliceous sponge spicules and opaque heavy minerals.

BIOSTRATIGRAPHY

Sediments recovered from both holes at Site 411 are Pleistocene. Hole 411 was washed to basement with a core liner in place. No depth can be confidently assigned to sediment recovered from Hole 411, and it is possible that much of the sediment recovered was picked up during several attempts to spud in at adjacent locations.

The oldest sediment recovered in Hole 411A (Sample 3-2, 1 5-146 cm, ~ 30 m sub-bottom) belongs to nannofossil Zone NN19; this is compatible with the expected age for basement, about 1.0 m.y.

Planktonic Foraminifers

Globorotalia inflata, G. truncatulinoides, and *Neogloboquadrina pachyderma* (dextral) are the most common taxa in samples of the coarse foraminiferal sand recovered at Site 411. Most specimens are larger than 149 μm, fragments are common, and relatively little material smaller than 63 μm was noted during processing. This suggests transportation of coarse material into the basin from adjacent topographic highs, or winnowing, or some combination of the two.

Nannofossils

Hole 411

Hole 411 was sampled for nannofossils only from the material recovered above the basalt in Core 1. Abundant well-preserved nannofossils occur in this foraminifer-pteropod sand. The assemblage present indicates the lower Pleistocene (Zone NN 19): *Gephyrocapsa* spp., *Coccolithus pelagicus, Helicopontospaera kamptneri, Cyclococcolithina leptopora,* and *Emiliania annula.*

Hole 411A

Sampling for nannofossils in 411A material was conducted only in Core-Catcher Samples 1 and 2. Sample 1,CC contains an upper Pleistocene assemblage (Zone NN 20/21) consisting of *Gephyrocapsa* spp., *H. kamptneri, C. pelagicus, C. leptopora,* and *Rhabdosphaera clavigera.* Sample 2,CC contains a lower Pleistocene assemblage (Zone NN 19) consisting of *Gephyrocapsa* spp., *H. kamptneri, C. pelagicus, C. leptopora,* and *E. annula.* These and other findings are summarized in Table 2.

PALEOENVIRONMENTAL INTERPRETATION

The total sediment thickness at Site 411 is 74 meters, found by washing down to basement.

The sediments cored at Hole 411A are entirely Pleistocene. The nannofossil assemblage suggests that the boundary between Zones NN 20 and NN 19 occurs between Samples 1, CC and 2, CC (8.5 and 11.4 m sub-bottom, respectively), indicating an accumulation rate between 27 and 38 m/m.y. during the past 0.3 million years. This rate differs significantly from that calculated using the predicted basement age of 1.0 m.y. (74 m/m.y.). The rapid sediment deposition may have resulted from submarine slumping or turbidity-current deposition in this sediment pond in the median valley of the Mid-Atlantic Ridge, although no evidence of graded bedding was visible in the soupy, structureless sediment. The loosely consolidated foraminiferal sand with only a minor nannofossil ooze matrix may be a result of winnowing of the fine sediment fraction by currents.

BASEMENT LITHOSTRATIGRAPHY

Basalt, underlying pteropod-bearing foraminifer sand, was encountered at 74 meters sub-bottom depth and drilled for 45.5 meters. Only 4.0 meters (8.8%) was recovered, and none of the five cores brought on board contained more than 1.28 meters of hard rock. Macroscopic examination, based on the presence of glass selvages, vesicle-rich zones, and grain-size changes, indicates that parts of as many as 15 flows may have been recovered. Two lithologically distinct basalt types are present. The first three cores are largely fine-grained sparsely olivine phyric basalts with or without plagioclase microphenocrysts. Many of the olivine phenocrysts contain visible inclusions of octahedral spinel. Contents of olivine phenocrysts range up to 10 per cent. The lower cores are characterized by plagioclase phyric basalts with 10 to 20 per cent of plagioclase phenocrysts (up to 4 mm). Despite the low recovery, the drilling record (Figure 7) correlates well with the macroscopic features and also indicates that a maximum of 15 flows or groups of flows (averaging 3 to 4 m thickness) were drilled. Drilling rates were somewhat higher in the plagioclase phyric basalt. Several periods of high drilling rate (1 to 2 min/m) scattered throughout the record indicate that softer rock was penetrated, but since apparently none of this material was recovered, its composition is purely speculative. A stratigraphic column (Figure 8) has been prepared by attempting to correlate drilling rate with macroscopic features. Two units were distinguished geochemically (Figure 9). The boundary between them is in Core 3, Section 1, at 105 cm, where a marked petrographic break occurs, separating predominantly olivine phyric from predominantly plagioclase phyric basalts. The upper unit has lower K_2O, TiO_2, and Zr contents and higher Ni and Mg contents than the lower unit.

IGNEOUS PETROGRAPHY

The upper stratigraphic unit consists predominantly of olivine phyric (or sparsely phyric) basalt interlayered with aphyric basalt (Figure 8). The olivine phenocrysts (0.3 to 2 mm in diameter) contain abundant dark brown spinels (magnesiochromites) and are set in a fine-grained, variolitic/glassy groundmass. Rare plagioclase microphenocrysts are present in parts of this unit. The basalt contains between 5 and 10 per cent vesicles (0.5 to 1 mm in diameter).

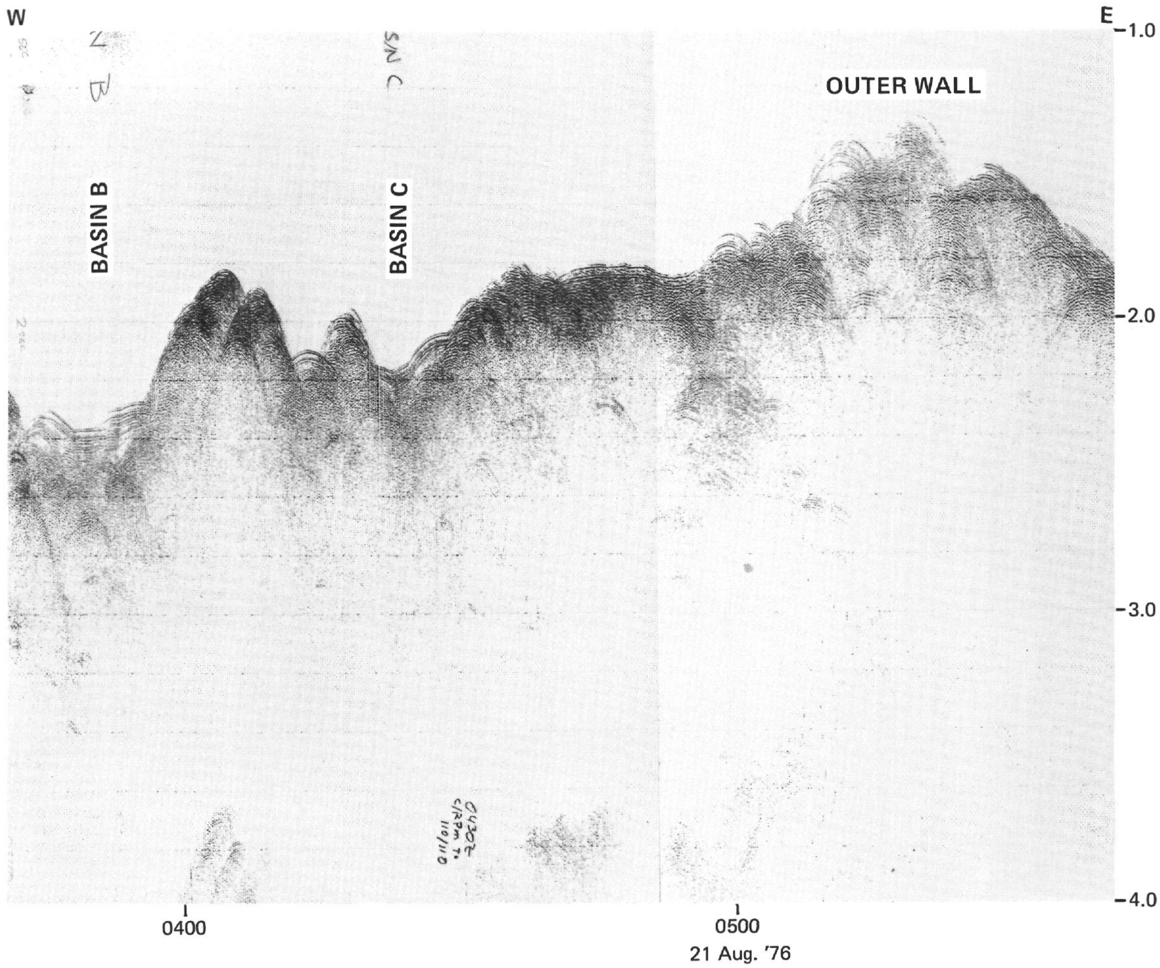


Figure 4. *Seismic profiles taken by D/V* Glomar Challenger *from west to east across Site 411 and back, showing beacon drop. Tracks in Figure 5.*

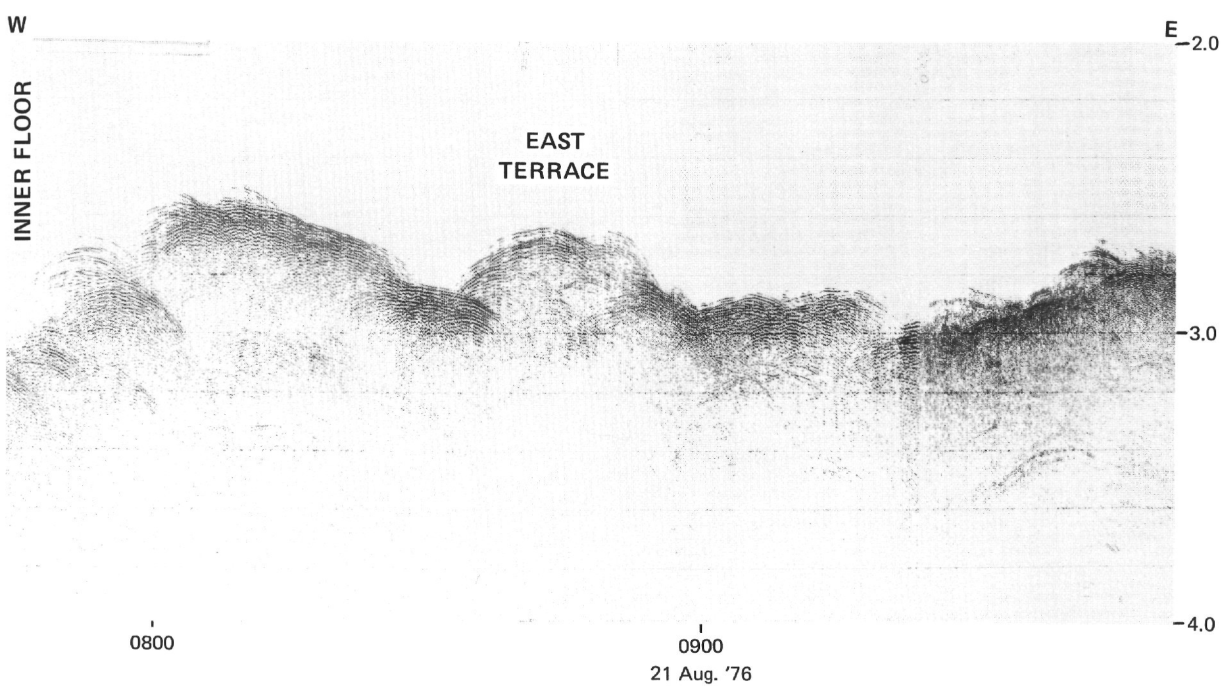
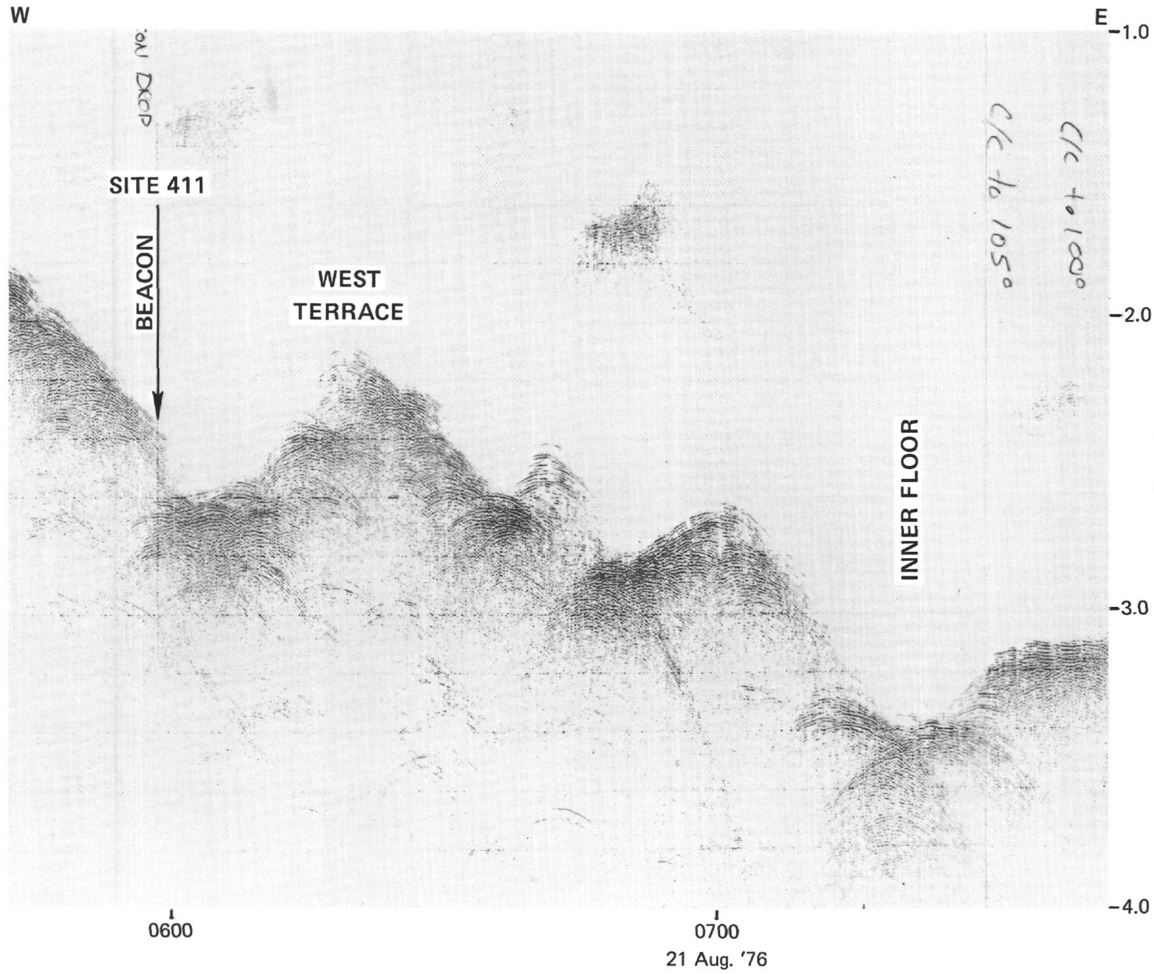


Figure 4. *Continued.*



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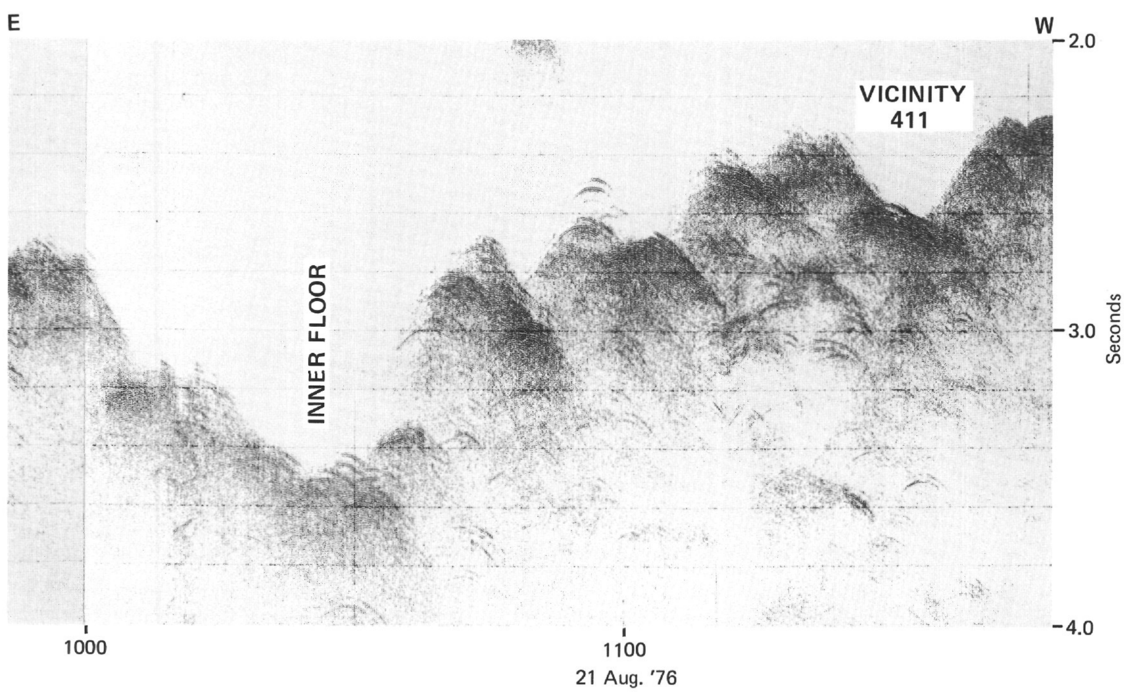

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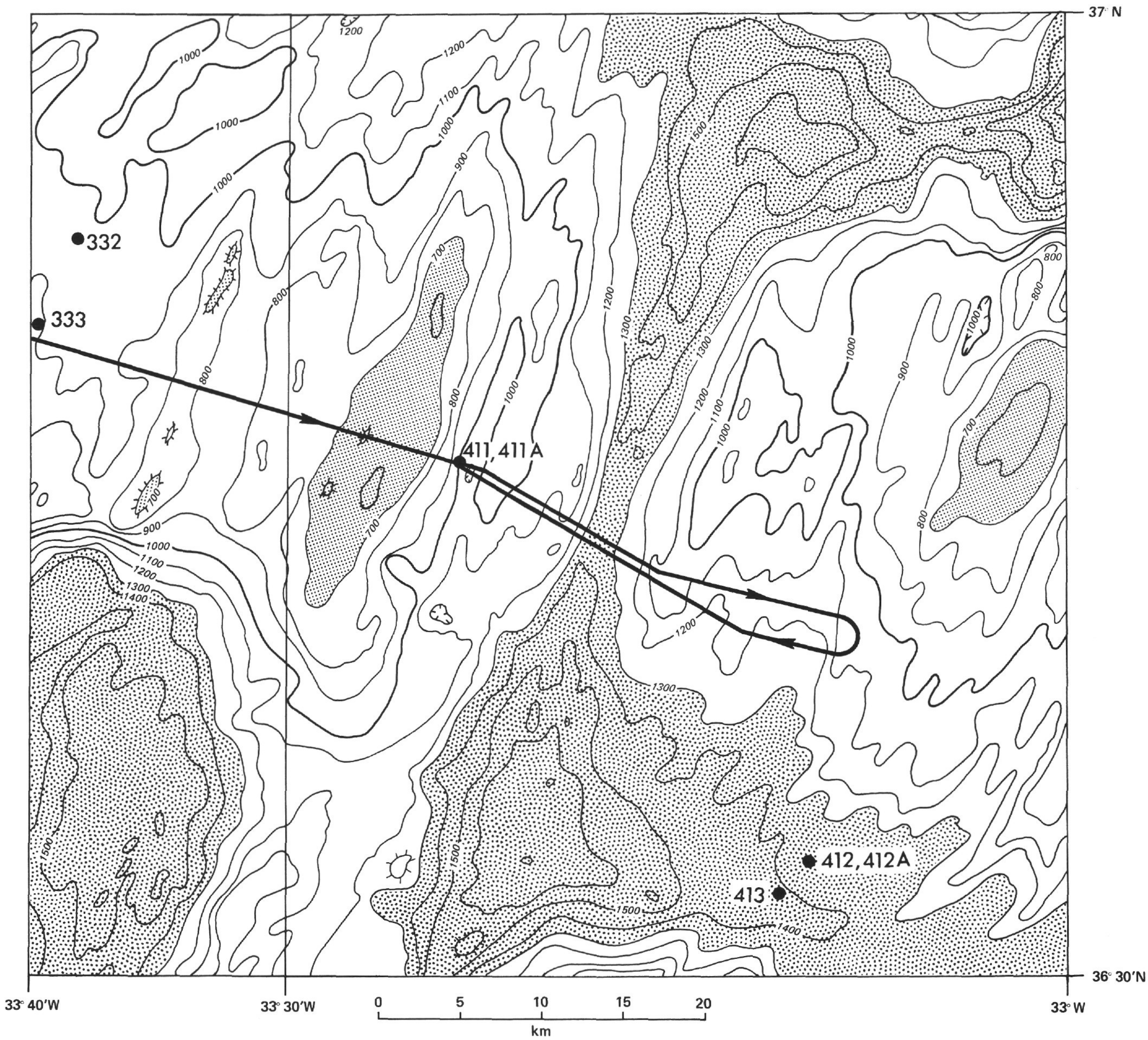

Figure 5. *Track of* Glomar Challenger *in vicinity of Site 411.*

The lower stratigraphic unit is plagioclase phyric and contains strongly zoned plagioclase megacrysts (2 to 4 mm in diameter). The zoning in the plagioclase phenocrysts is normal from calcic cores to more sodic margins. Rare (less than 1%) olivine microphenocrysts (less than 0.5 mm in diameter) are present throughout the unit. The groundmass is predominantly variolitic/glassy, as in the upper unit.

Phyric basalts similar to both the units recovered at this site have been previously reported for the FAMOUS area (Hekinian et al., 1976) and the Leg 37 sites (Robinson et al., 1977). The apparent predominance of highly magnesian phyric basalts at this latitude of the Atlantic for at least 20 m.y. contrasts with other areas of the Atlantic sampled to date.

ALTERATION PETROGRAPHY

The basement rocks recovered at Site 411 are most notable for their freshness. The only alteration product is a green smectite which lines vesicles in some of the rocks, and in one sample (Section 3-1, piece 16, 91.1 m) has partly replaced olivine. Carbonate minerals are entirely absent, and no zeolites are evident. It is possible that the carbonate minerals, which have been found at every other site so far, and have always appeared to crystallize late, only form sometime after the rest of the alteration. These rocks may be too young for this yet to have happened. The rocks from this site are less altered than those from Site 409, the next youngest site drilled, and this relationship again suggests that most of the alteration seen at older sites is the result of slow reaction of the basalt with cold seawater, rather than rapid reaction with hydrothermal solutions.

BASEMENT PALEOMAGNETISM

Because of the low recovery, only five standard-size paleomagnetic specimens could be taken from the basalt cored at Hole 411. These came from Cores 1 through 4,

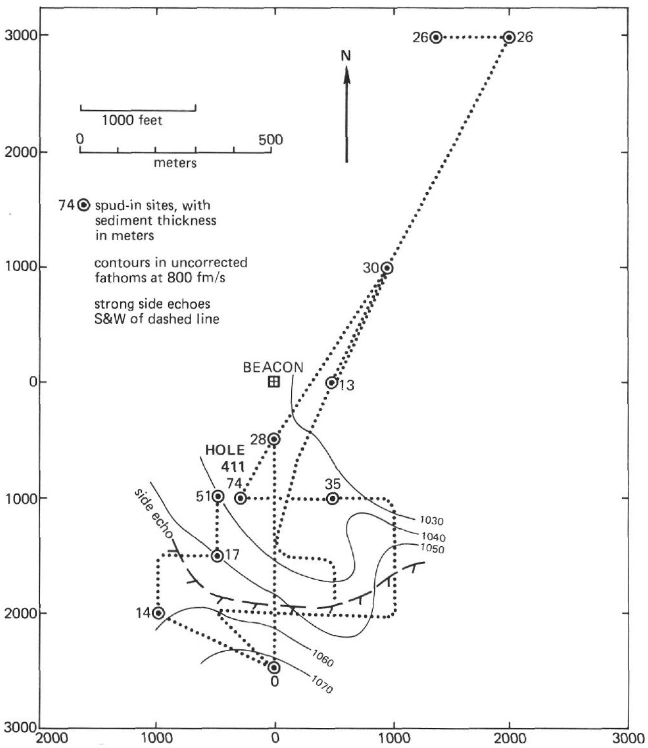

Figure 6. *Bottom contours and sediment thickness around Site 411, determined during spud-in attempts.*

sub-bottom depth 65 to 101 meters. A small core (1 cm length, 1 cm diameter) was taken from the lower half of Section 1, Core 2, three from Section 1, Core 4, and two from very near the top of the only section of Core 5, extending the sampling to 110 meters depth. The first of these in Section 5-1 was taken from piece 2, which had been dropped upon removal from the core barrel, with the hope of orienting it from the magnetic inclination. The small cores were measured using the method devised at Site 410. A change in magnetic directions and properties occurs at about 100 meters depth, consistent with petrographic observations of a change in igneous properties at the same depth. A series of pillow basalts form Cores 1 through 3, and Cores 4 and 5 are more coarsely crystalline flows.

The stable demagnetized inclinations (Figure 10, Table 3) for the samples from above 100 meters depth (Cores 1 through 3) lie between $-54°$ and $-46°$ (Figure 10), with an arithmetic mean value of $-50.2°$ ($\sigma = 3.9°$; the uncertainty quoted is the unbiased estimate of the standard deviation). In contrast, the samples from Cores 4 and 5 are not consistent in polarity, two (side by side) in the bottom of Core 4, Section 1, are normal; and the scatter among all samples from Cores 4 and 5 is considerable. The values range from $+42°$ to $-68°$, with an arithmetic mean (changing all to one polarity and averaging together the two in the bottom of Section 4-1) of $-41.6°$ ($\sigma = 18.7°$).

The inclination value predicted by the axial dipole model for this site at 36°46'N latitude is 56.2°. The discrepancy between an overall mean of 44.2° (σ=12.7°) and the predicted value of 56.2°, in light of the correlation between magnetic and petrographic units, can be attributed to secular variation. The high scatter between inclinations in the lower, coarser unit suggests that an additional variable, related to the formation of this unit, might be responsible not only for the scatter, but also the discrepancy between the predicted and observed inclinations.

The reversed inclinations of the pillow basalts of the upper cores, and the generally reversed inclinations of the lower coarser flows, are consistent with the sign of the magnetic anomaly (and with the early Pleistocene micropaleontological date of the oldest sediments in Hole 411A), which indicates that the basement was formed in the Matuyama reversed epoch.

NRM intensities range from 2×10^{-3} emu cm^{-3} to 11×10^{-3} emu cm^{-3}, averaging 4.9×10^{-3} emu cm^{-3} (Figure 10). Low intensities occur in the specimens from Cores 4 and 5. The magnitudes and spread of these NRM intensities seem fairly typical of basaltic basement as sampled at the other sites on this leg and others, consistent with Macdonald's (1977) analysis of magnetization versus

TABLE 1
Coring Summary, Site 411

Core	Date (Aug. 1976)	Time	Depth From Drill Floor (m)	Depth Below Sea Floor (m)	Length Cored (m)	Length Recovered (m)	Recovery (%)
Hole 411							
1	22	2323	2024.0-2031.5	74.0- 81.5	7.5	0.60	8
2	23	0304	2031.5-2041.0	81.5- 91.0	9.5	1.28	13
3	23	0500	2041.0-2050.5	91.0-100.5	9.5	1.10	12
4	23	0720	2050.5-2060.0	100.5-110.0	9.5	0.80	8
5	23	0910	2060.0-2069.5	110.0-119.5	9.5	0.22	2
6	23	1230	2031.5-2060.0 (est. depths)	81.5-110.0	?	CC	-
Total					45.5	4.0	9
Hole 411A							
1	23	1615	1985.0-1993.5	0.0- 8.5	8.5	8.7	102
2	23	1735	1993.5-2003.0	8.5- 18.0	9.5	2.95	31
Washed 18.0-27.5 meters							
3	23	1845	2012.5-2022.0	27.5- 37.0	9.5	3.0	32
Total					27.5	14.65	53

TABLE 2
Paleo/Biostratigraphic Summary of Core-Catcher Samples (CC), Leg 49, Hole 411A

Core	Depth (m)	Chronostratigraphic Unit	Planktonic Foraminifers	Calcareous Nannofossils
1	8.5	Pleistocene	*Globorotalia inflata* *G. truncatulinoides* *G. crassaformis* *G. scitula* *G. hirsuta* *Neogloboquadrina dutertrei* *N. pachyderma* (D) *Globigerinoides ruber* *G. sacculifer* *G. conglobatus* *Globigerina bulloides*	*Helicopontosphaera kamptneri* *Pontosphaera discopora* *Coccolithus pelagicus* *Cyclococcolithina leptopora* *Gephyrocapsa* spp. *Rhabdosphaera clavigera* *Syracosphaera histrica*
2	11.4	Pleistocene	As above	As above
3	–	Pleistocene	Sample 3-2, 100-102 cm (20.5 cm) As above	–

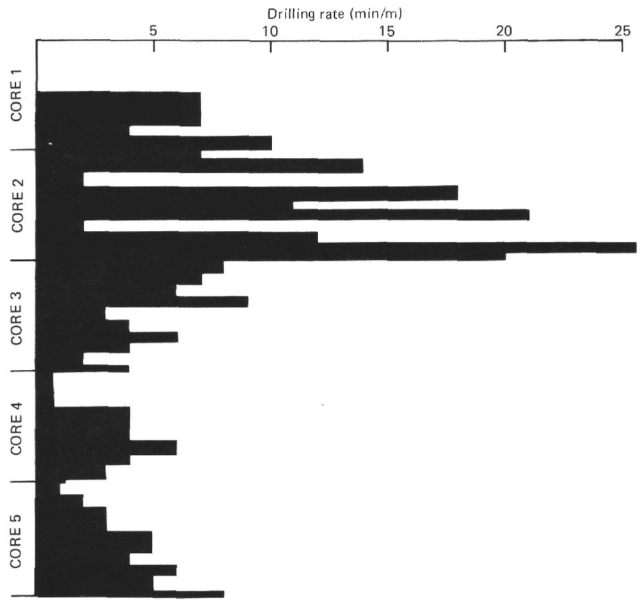

Figure 7. *Basalt drilling rate, Hole 411.*

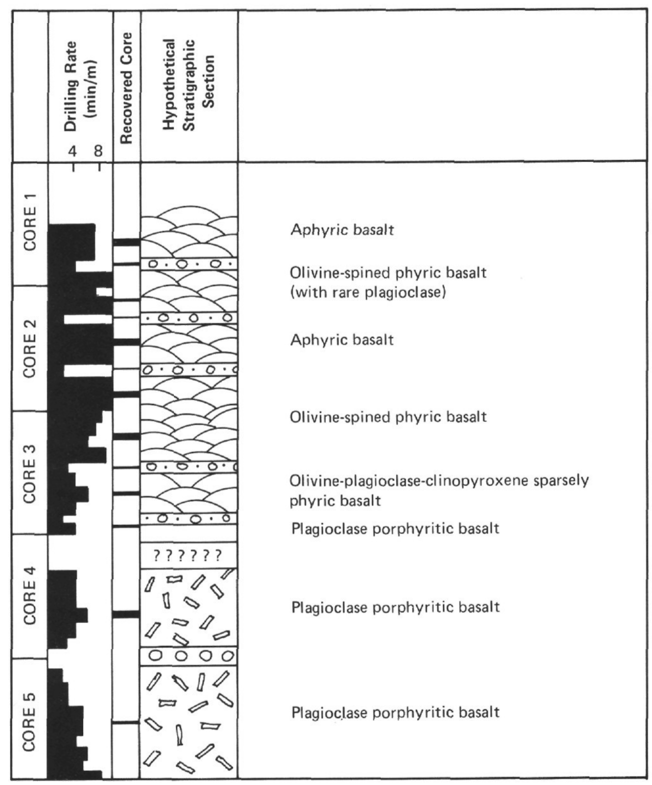

Figure 8. *Stratigraphic column, Cores 1 through 5, and drilling rate, Hole 411.*

distance from the plate boundary. According to Macdonald's estimates of magnetic intensity, obtained by modeling the deep tow near bottom magnetic anomalies, magnetic intensity falls to l/e of the central anomaly value in less than 0.6 m.y. in this area (see fig. 11 of Macdonald, 1977). Site 411 was drilled on the old side of the Jaramillo anomaly, which has an age of roughly 0.95 m.y. Macdonald's data predict magnetic intensity between 4.5 and 8×10^{-3} emu cm^{-3}. Our own sparse data are in good agreement: between 2 and 11×10^{-3} emu cm^{-3}.

Figures 11 and 12 show the results of AF demagnetization. Specimens 1-1 and 2-2 had very high directional stability. Specimen 4-1 changed from initially normal to reversed, to agree with the predominant inclination and the sign of the magnetic anomaly. The small core from Section 4-1 moved from initial inclination +28° to the shallow value of +8° at 500 Oe. Both the small cores from Section 5-1 showed high directional stability; the similarity in their inclination values make it seem more likely that the upper one had been misoriented. Remanence decay curves (Figure 12) show specimens from Cores 1 through 3 (which had the smallest directional change) to have lower AF stability than those from Cores 4 and 5; the upper specimens have median destructive fields around 100 Oe, compared with >150 Oe for the lower ones (see also Figure 10 and Table 3). The directional stability and resistance to AF demagnetization suggest a difference between specimens from the upper and lower parts of the hole. Both the small cores from Core 5 show the initial increase in intensity at low fields that we have come to associate with reversely magnetized specimens; this may be

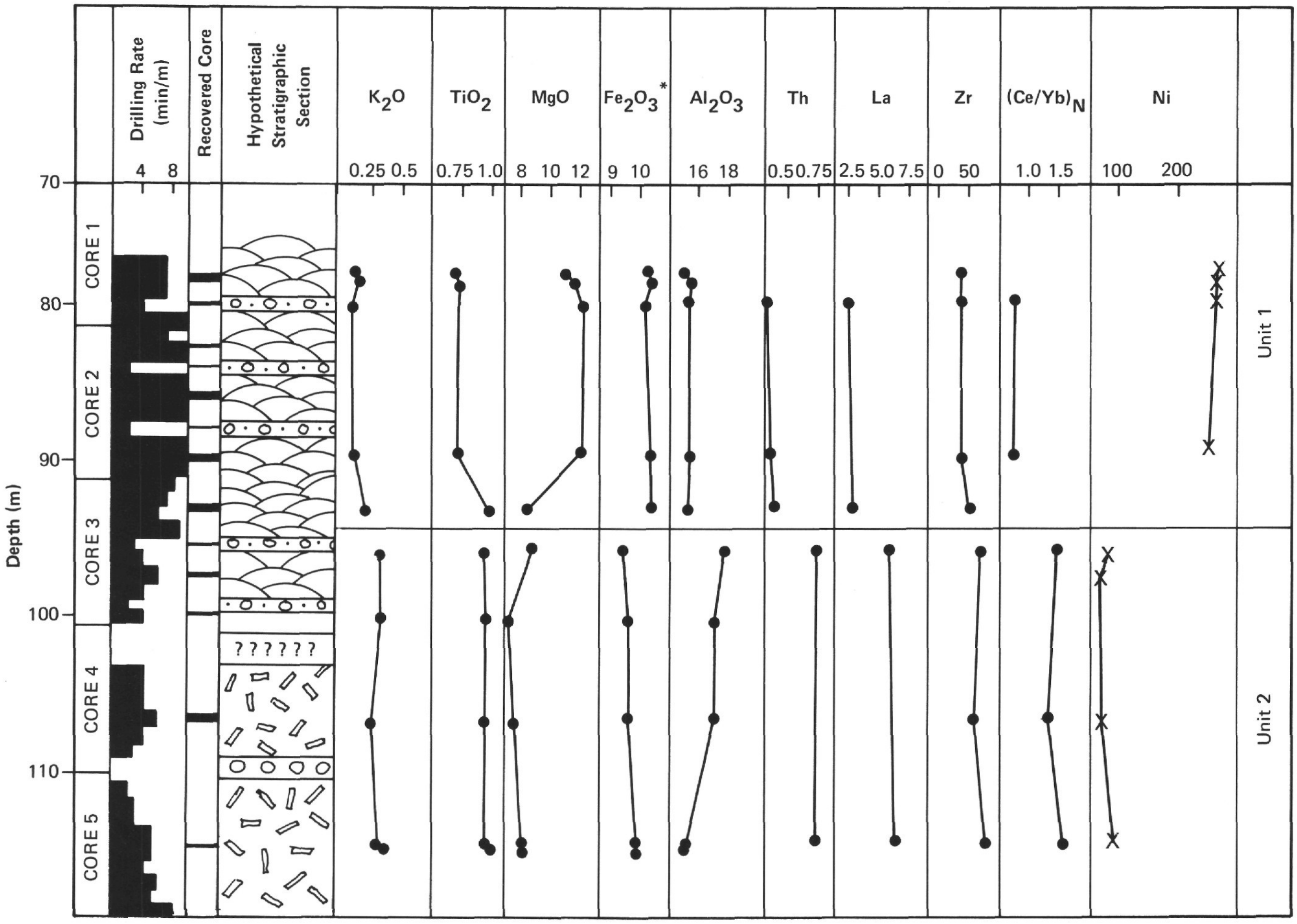

Figure 9. *Geochemically defined units, Hole 411.*

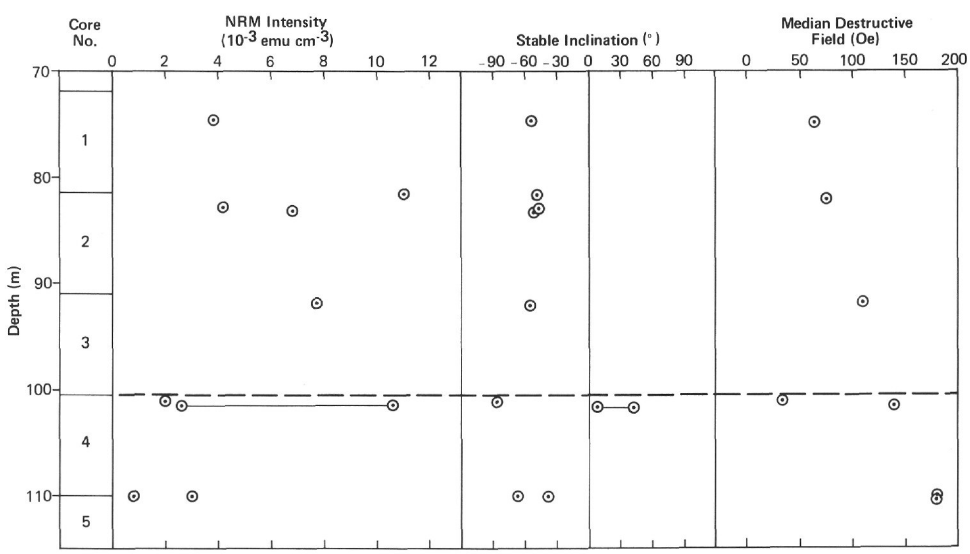

Figure 10. *Downhole plot of paleomagnetism data, Hole 411. Dashed line indicates petrographic break.*

TABLE 3
Paleomagnetism Data

Sample (Interval in cm)	Depth in Hole (m)	NRM Intensity (10^{-3} emu cm^{-3})	Initial Inclination (°)	Stable Inclination (°)	MDF (Oe)	Blocking Temp. in Air (°C)
411-1-1, 78-80	74.8	3.828	-47.2	-52.4	65	
411-2-1, 19-22	81.7	10.982	-48.1	-48.8		∿380 (Leeds)[c]
411-2-1,132-133	82.8	4.186[a]	-46.8	-46.6		375
411-2-2, 6-9	83.1	6.784	-45.8	-49.5	75	
411-3-1, 98-102	92.0	7.791	-52.0	-53.7	110 (Leeds)[c]	
411-4-1, 63-66	101.1	2.049	+18.8	-35.9	35	
411-4-1,117-118	101.7	2.560[a]	+27.7	+8.3[b]	140	
411-4-1,117-118	101.7	1.330[a]	+43.2	41.8[b]		430
411-5-1, 10-12	110.1	1.848[a]	-31.7	-37.0	180	
411-5-1, 21-23	110.2	1.824[a]	-59.6	-68.4	180	

[a] Extrapolated intensity value from a 1 cm × 1 cm core to a 2.4 cm × 2.5 cm core.
[b] Not stable end point
[c] (Leeds) = specimens measured at Leeds University, not on shipboard.

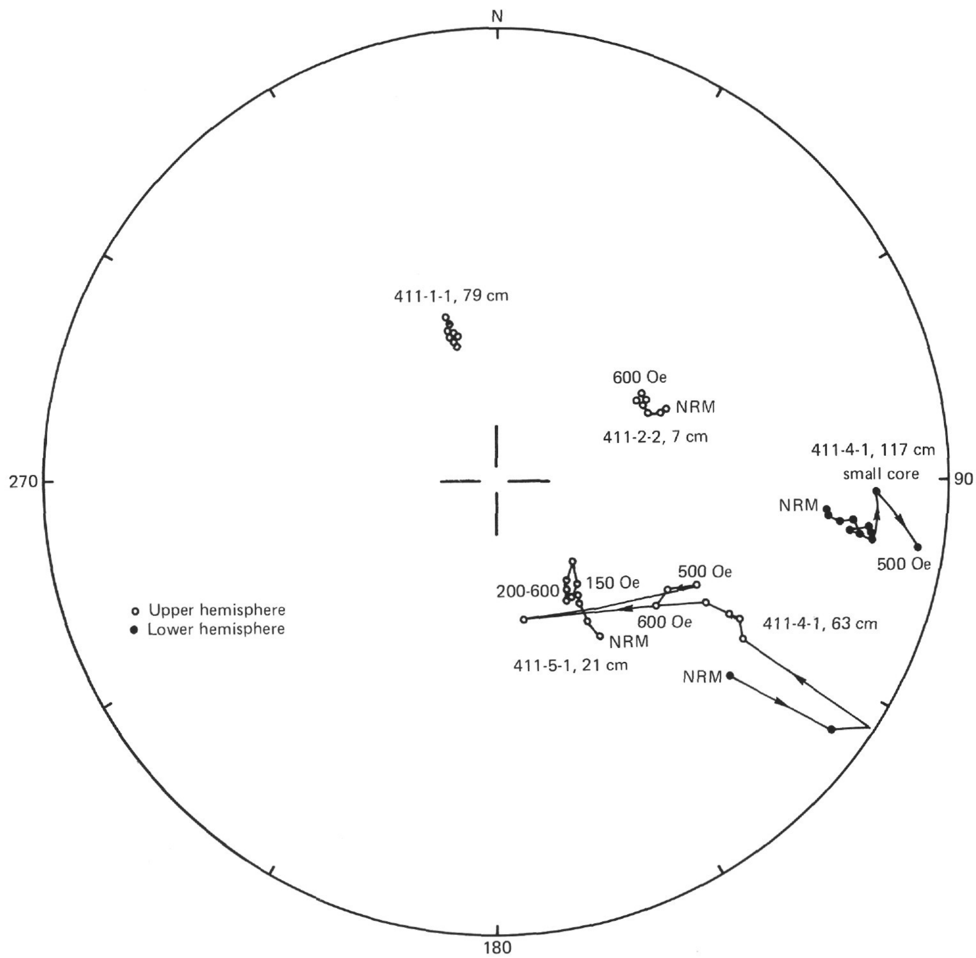

Figure 11. *Directional changes upon AF demagnetization, Hole 411.*

further evidence that piece 2 of Section 5-1 had probably been inverted in handling.

Two small cores (from Sections 2-1 and 4-1) were subjected to thermal demagnetization. Specimen 2-1, piece 13B (83 m) had an NRM intensity and a reversed inclination similar to the other specimens from this site (4.2×10^{-3} emu cm^{-3} and -47°). From the intensity decay curve (Figure 13), this specimen is deduced to have a blocking temperature of about 375°C, which is lower than that obtained at the previous sites on this leg. The result indicated that a constituent ferromagnetic mineral is either less oxidized or richer in titanium.

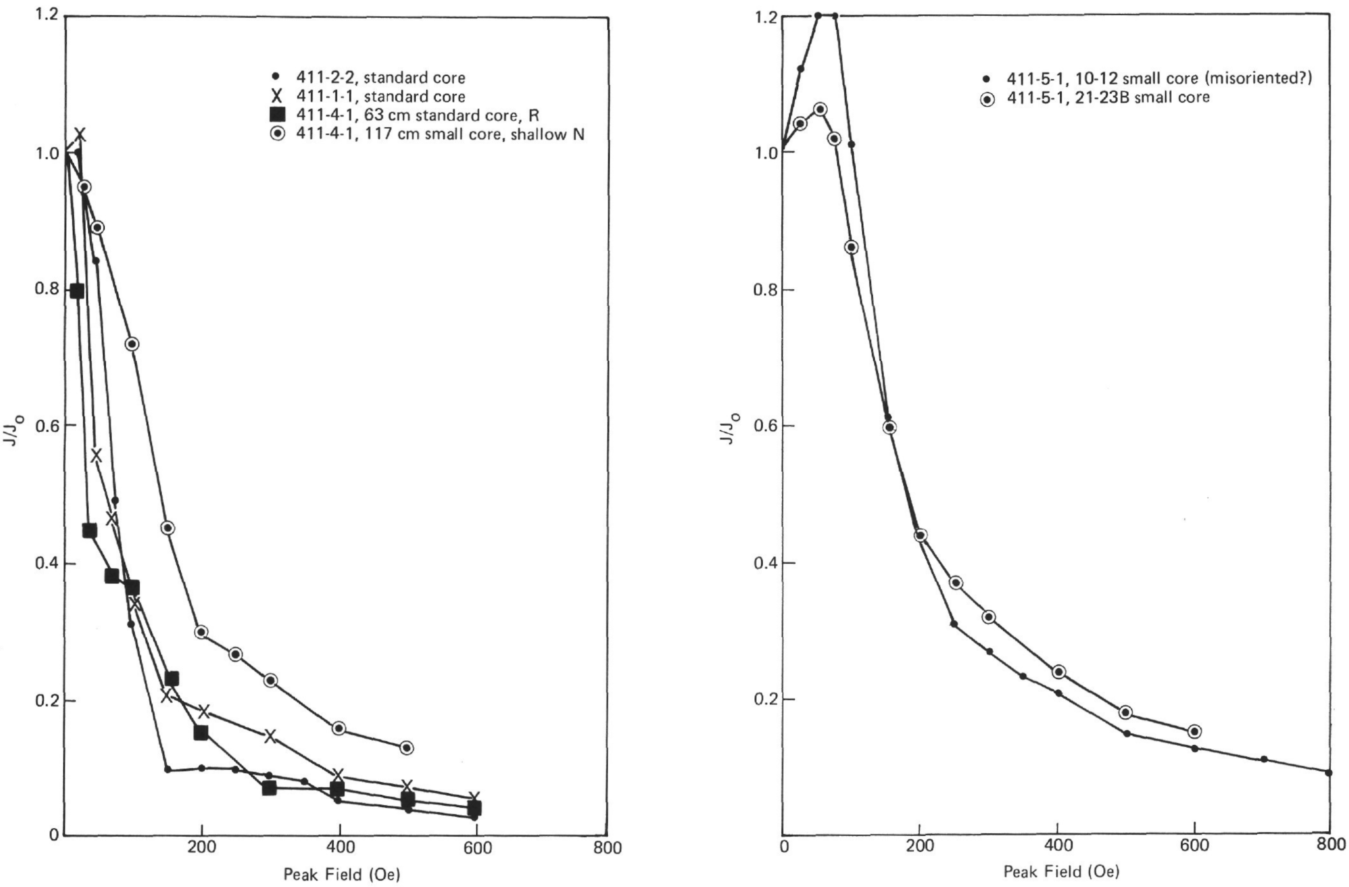

Figure 12. *AF demagnetization, Hole 411.*

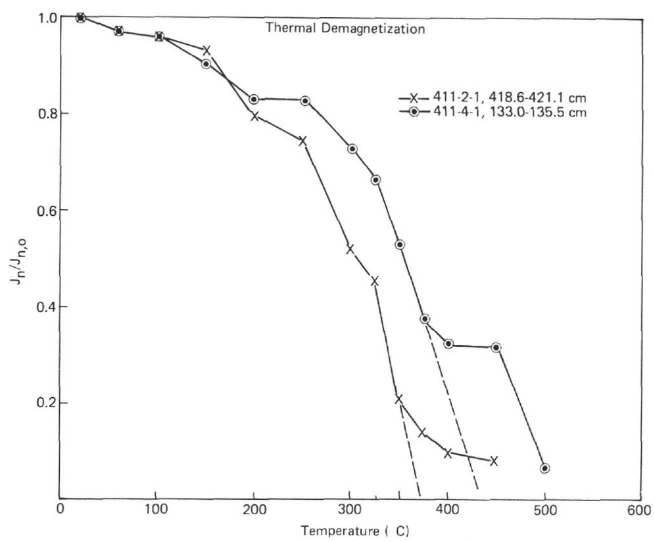

Figure 13. *Thermal demagnetization, Hole 411.*

Since the blocking temperature is lower than the temperature at which oxidation or chemical decomposition of titanomaghemite proceeds rapidly, the specimen can be heated to form an artificial thermoremanent magnetization (TRM). The small core from Section 2-1 was heated to 400°C and cooled to room temperature in laboratory field space. As Figure 14 shows, the TRM thus acquired has almost identical stability to AF demagnetization as the NRM of specimen 2-2. This result clearly indicates that the NRMs originate as TRMs. Since the laboratory field strength is unknown and may vary with the ship's position, it was not possible to compare the TRM and NRM intensities.

Specimen 4-1, piece 14B (102 m) has apparently normal polarity and shows little change on thermal demagnetization, although there is some movement to shallower inclinations. Its neighbor from piece 14A also showed normal polarity and a shallowing inclination upon AF demagnetization. Specimen 4-1 has a higher blocking temperature than Specimen 2-1: around 440°C (Figure 13). The intensity decay curve suggests coexistence of one magnetic phase with a lower blocking temperature similar to Specimen 2-1 and one with a blocking temperature higher than 450°C. It seems likely that the ferromagnetic mineral in this specimen is slightly more oxidized than in specimen 2-1. But it is uncertain whether the apparent normal polarity and rather strange magnetic behavior of Specimen 4-1 is caused by oxidation.

The magnetic inclinations, intensities, and stability to alternating fields are consistent with the deduction, on petrology, of two petrologic units. Cores 1 through 3 (5 specimens), aphyric olivine basalts, have very consistent inclinations of approximately 50°, intensities around 7.7×10^{-3} emu cm^{-3}), and median destructive fields less than 100 Oe. Cores 4 and 5, high aluminum plagioclase phyric basalts, have more scattered inclinations and some normal specimens, lower intensities (2 to 3×10^{-3} emu

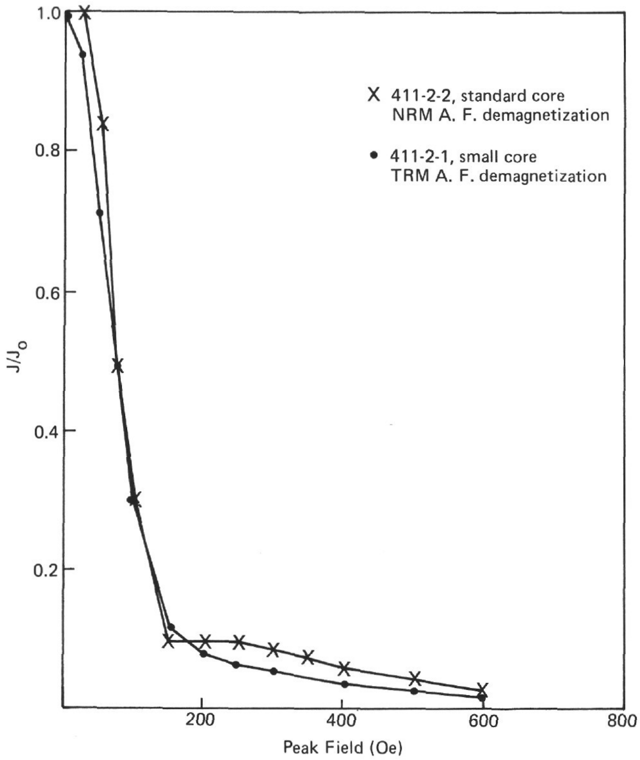

Figure 14. *Comparison of AF demagnetization of NRM of specimen 2-2 with AF demagnetization of TRM acquired by small core from Section 2-1 in laboratory field.*

cm), and higher MDFs, above 150 Oe. Apparent blocking temperature results are also consistent with a change in magnetic and petrologic properties near 100 meters sub-bottom depth (about 28 m into basaltic basement).

PHYSICAL PROPERTIES OF BASEMENT ROCKS

Even more than for Site 410, interpretation of the results here must be based on a very small statistical sample. All physical properties for Site 411 — Hamilton Frame sonic velocity, wet bulk density, both by weight and gamma-ray attenuation, and water content — are plotted against depth in Figure 15.

The mean sonic velocity for these data, 5.52 km/s (s = 0.28), is considerably higher than those measured for basement samples at previous sites.

The wet bulk densities determined by the two methods agree reasonably well and suggest a decrease in density with depth from 3.0 at the basement/sediment interface to 2.9 at 100 meters sub-bottom.

CORRELATION OF SEISMIC REFLECTION PROFILE WITH DRILLING RESULTS

The seismic profile approaching Site 411 showed at the most 50 ms (DT) of penetration, which would have not been believed were it not for a deep-tow profile across this valley on the west inner wall. This profile was taken on the *Knorr* 31 cruise during project FAMOUS. It shows this valley to contain a basin fill of sediments greater than 50 ms (DT) thick. The 4-kHz reflection system on the deep-tow

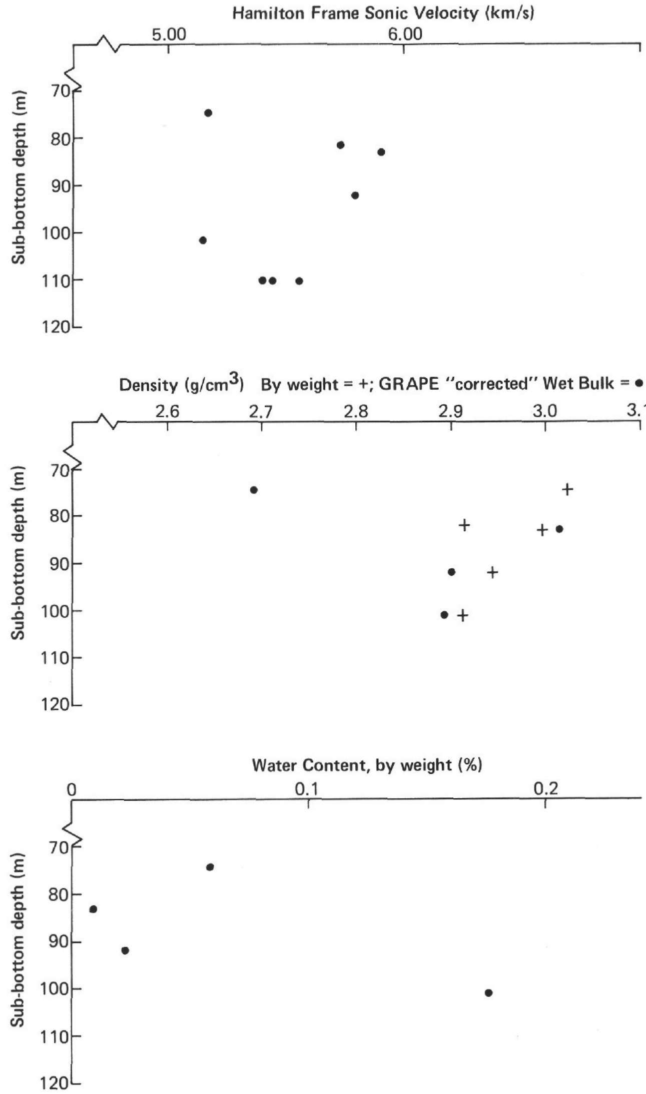

Figure 15. *Physical properties (sonic velocity, density, and water content) versus depth, Hole 411.*

instrument has an effective penetration limit of this order. Our actual probing operation showed highly variable sediment cover in the floor of 14 to 74 meters, which would generally agree with the limits of the deep-tow profile, except that thicknesses less than 50 ms (DT) (40 m?) were more frequent than thicknesses above. The deep-tow profile was probably taken a mile or so north of Site 411, in a different sedimentary basin. Therefore, these results are not immediately applicable.

SUMMARY AND CONCLUSIONS

At Site 411 we drilled two holes in the rift valley of the Mid-Atlantic Ridge, within the project FAMOUS study area. Leg 37 had already drilled two sites on the high fractured plateau on 3.5-m.y.-old crust. Our goal was to move as close as possible toward the crustal accretion zone and "zero-age" crust. From previous deep-tow and multibeam sonar mapping within the rift valley, we located a small half-mile-wide sedimented valley on the western terrace. Sediment thickness was thin and highly variable here. For 36 hours we conducted a systematic probing of the basin with the drill string until we found 74 meters of sediment cover on the eleventh spud-in attempt. The site was positioned just on the older side of the Jaramillo anomaly (about 1 m.y.), and thus basement here is the youngest so far drilled by the Deep Sea Drilling Project. We drilled Hole 411 45.5 meters into basement before hole caving required abandonment of the hole. Hole 411A was offset 50 feet and we cored 37 meters (3 cores) of sediment from the mud line.

Coring at Hole 411A showed the sedimentary section to be unconsolidated sand-size foraminifer ooze within a matrix of nannofossil ooze. Pteropods are common. The (unconsolidated) nature of the sediment section contributed to the bad hole conditions which caused us to abandon the site. The oldest date from the sediments is Pleistocene (NN 19), from 30 meters sub-bottom in Hole 411A. The sedimentation rate indicated here was a maximum of 74 m/m.y. Transport must have been downslope from surrounding highs, resulting in size segregation and removal of nannofossils and clays by bottom currents.

About 15 basalt flow units were penetrated at Site 411, judging by drilling rates and the occurrence of vesicular and glassy zones. Soft zones — indicated by rapid drilling — of either fine rubble or sediment layers were encountered frequently. The basaltic rocks recovered are very fresh and dense. Alteration products are generally absent and no growth of zeolite is apparent, whereas calcite occurs only exceptionally. Two basalt units were penetrated. The upper unit (about 22 m) is fine-grained sparsely olivine phyric basalt with occasional plagioclase microphenocrysts. Olivine phenocrysts sometimes exceed 10 per cent and have spinel (picotite) inclusions. The lower unit (about 19.5 m) is 10 to 20 per cent plagioclase olivine phyric basalt. This twofold basalt stratigraphy is also apparent in geochemical data.

NRM intensities in the basalts are high and range between 10^{-3} and 10^{-2} emu cm^{-3}. This generally agrees with intensity estimates made by inversion of near-bottom magnetic anomaly profiles. The magnetization is also reversed, as it should be for the Matuyama epoch. Specimens from the lower basalt unit show comparatively lower intensities and higher stabilities.

Despite the low recovery at this site, our program here stands as a major drilling accomplishment. Our approach showed that drilling in regions with doubtful or uneven sediment cover can be accomplished with the correct strategy. Basically, this includes near-bottom (deep-tow) site surveying and imaginative use of *Glomar Challenger*'s unique capabilities. For future drilling in these settings, we would also recommend a study of sediment stability at the spud-in site, and of whether it will be possible to run an adequate amount of casing.

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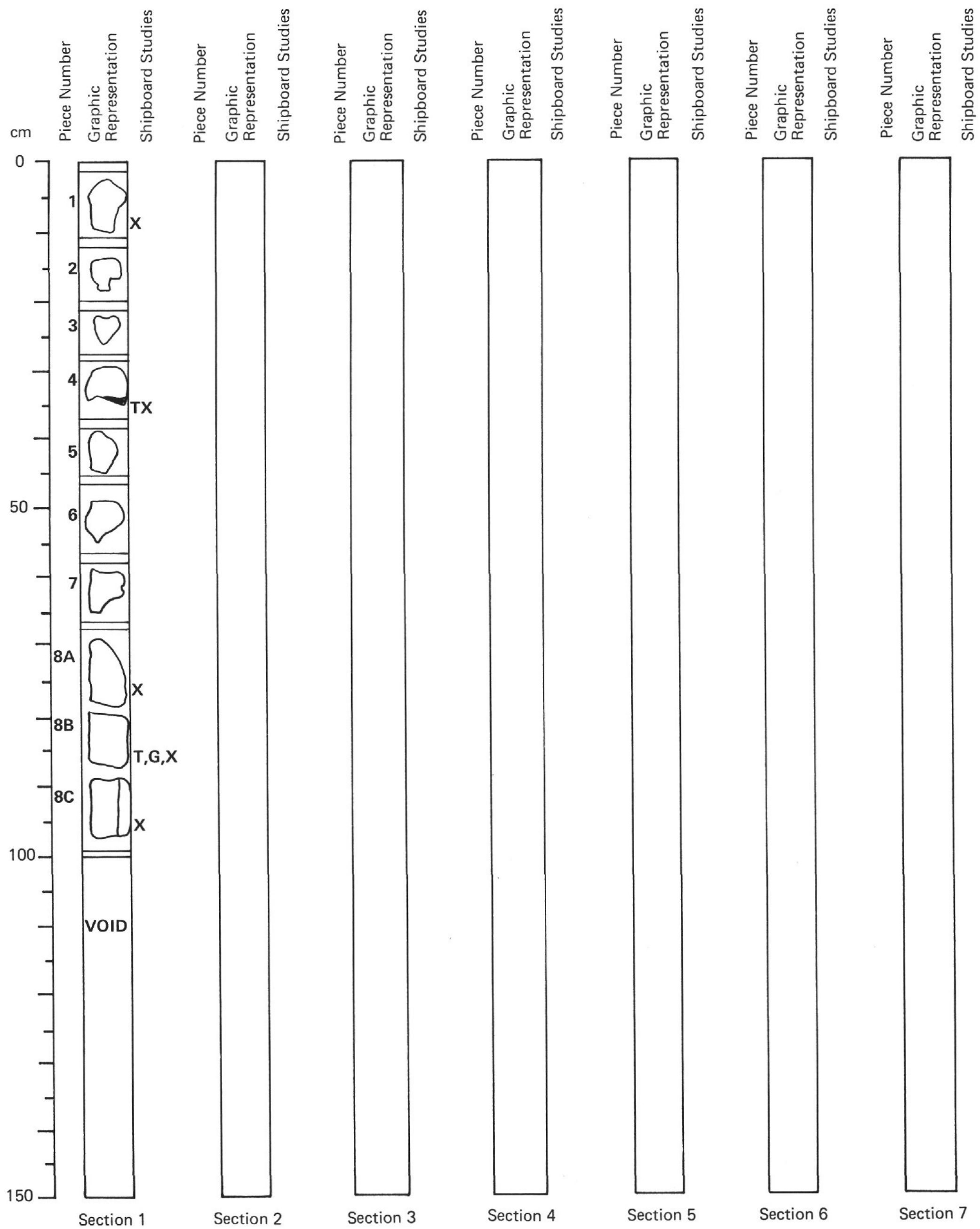
LEG **49** SITE **411** HOLE CORE **1** DEPTH **74.0-81.5 m**



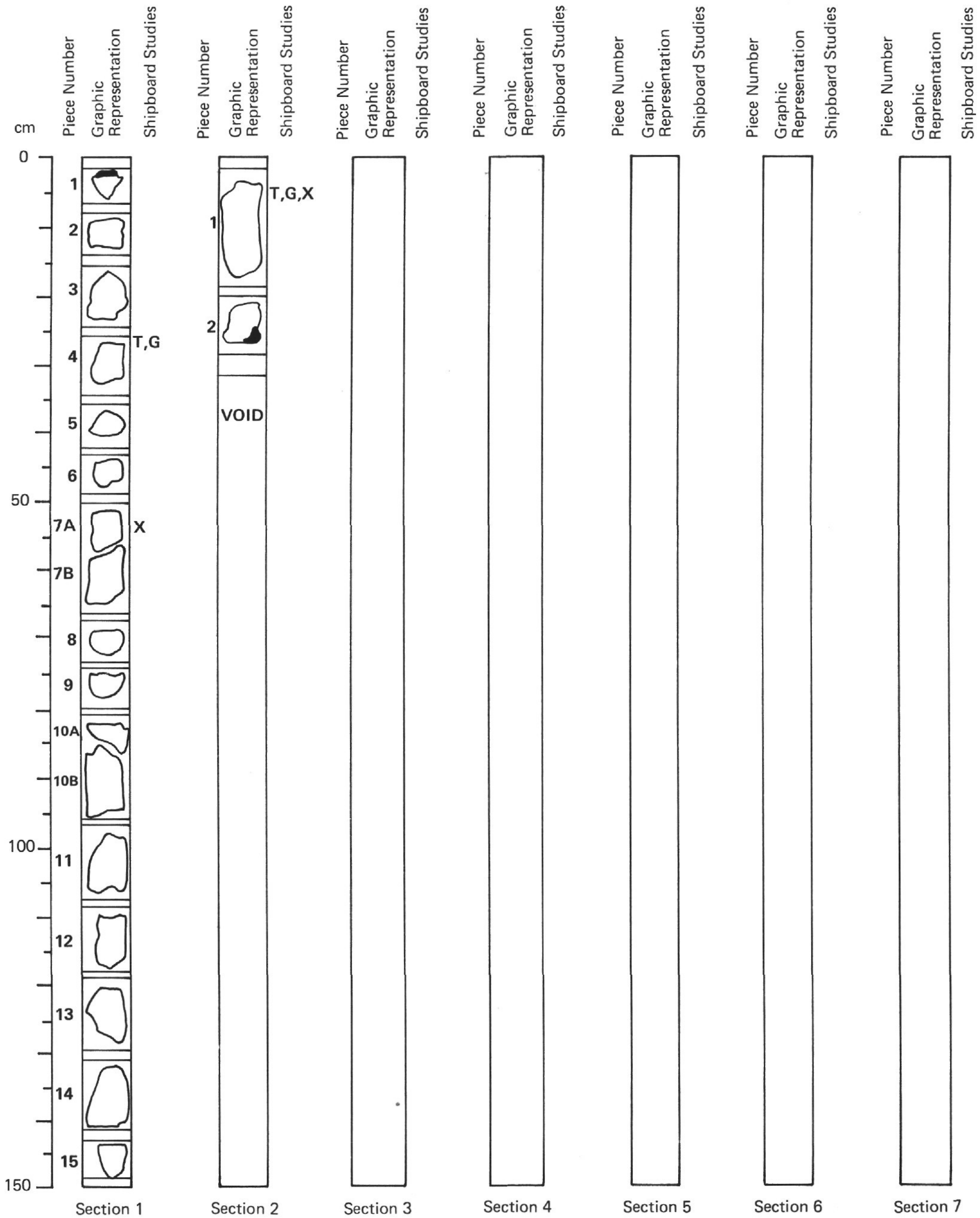
Original basalt recovery was .60 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

Upper unit: sparsely microphyric olivine basalt contains about 1% of 0.5 mm olivine. As much as 5% vesicles, about 0.2 to 0.5 mm diameter, with some partly lined with smectite(?). One fragment has a glassy rind.

Lower unit: sparsely (< 1%) microphyric olivine, plagioclase basalt. Plagioclase about 1 mm and olivine 1 to 1.5 mm. Less than 1% vesicles (≤ 0.5 mm), all partly filled by smectite(?) and calcite(?).

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 85 cm:	5.80	809	-52°



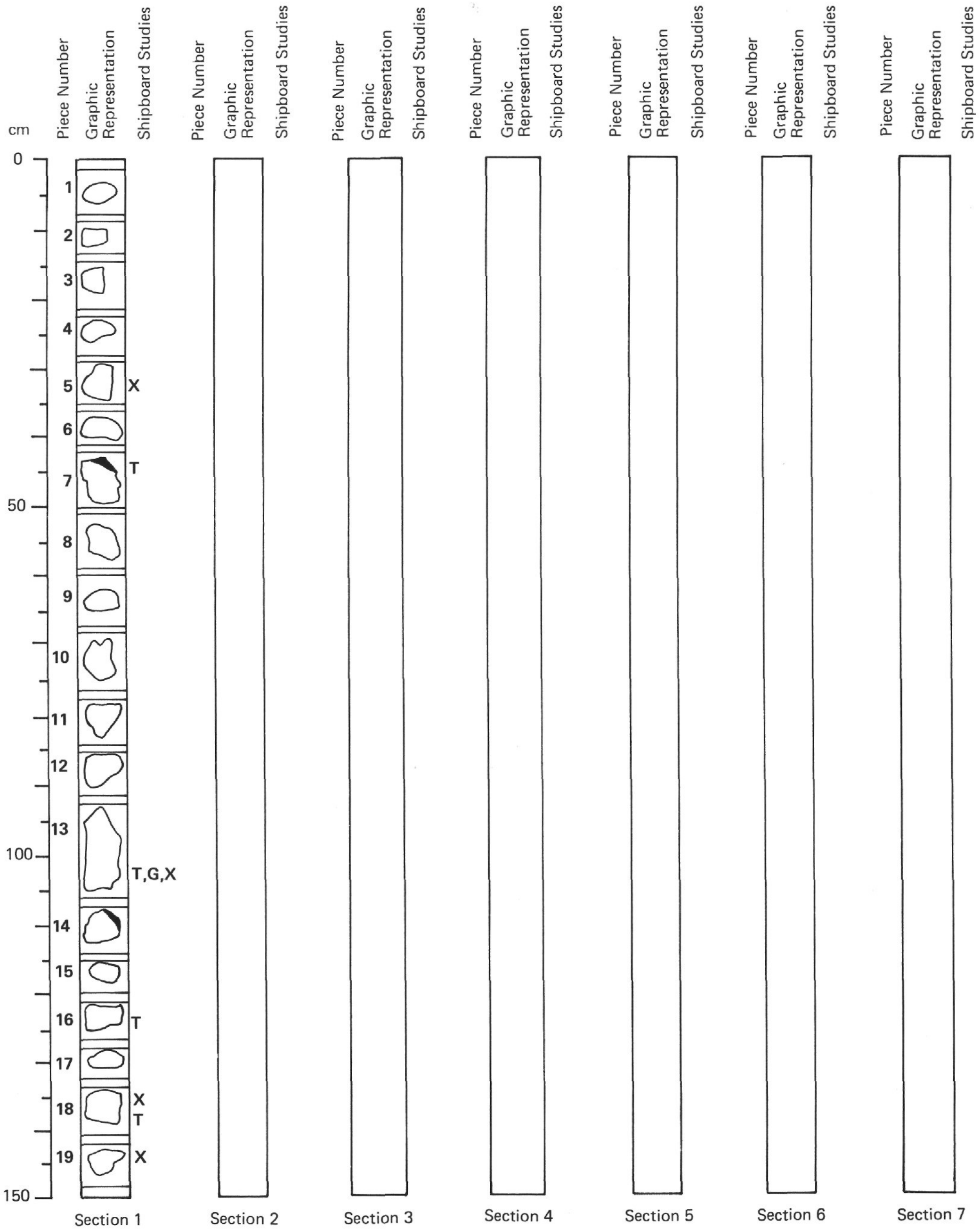
Original basalt recovery was 1.28 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

Sparsely microphyric olivine, plagioclase basalt. Most pieces contain less than 1% microphenocrysts; these range from 0.5 to 1 mm in diameter. The bottom-most piece contains about 5% of 0.1 to 0.5 mm microphenocrysts. Vesicularity is mostly < 1% with some pieces up to 5%. Vesicles 0.1 to 0.5 mm in diameter, some partly filled with smectite(?). Upper-most and lowermost pieces have partly glassy rinds.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 20 cm:	5.73	––	Reversed
Sect. 1, 85 cm:	––	––	Reversed
Sect. 2, 10 cm:	5.90	666	-50°

LEG **49** SITE **411** HOLE CORE **3** DEPTH **91.0-100.5 m**



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

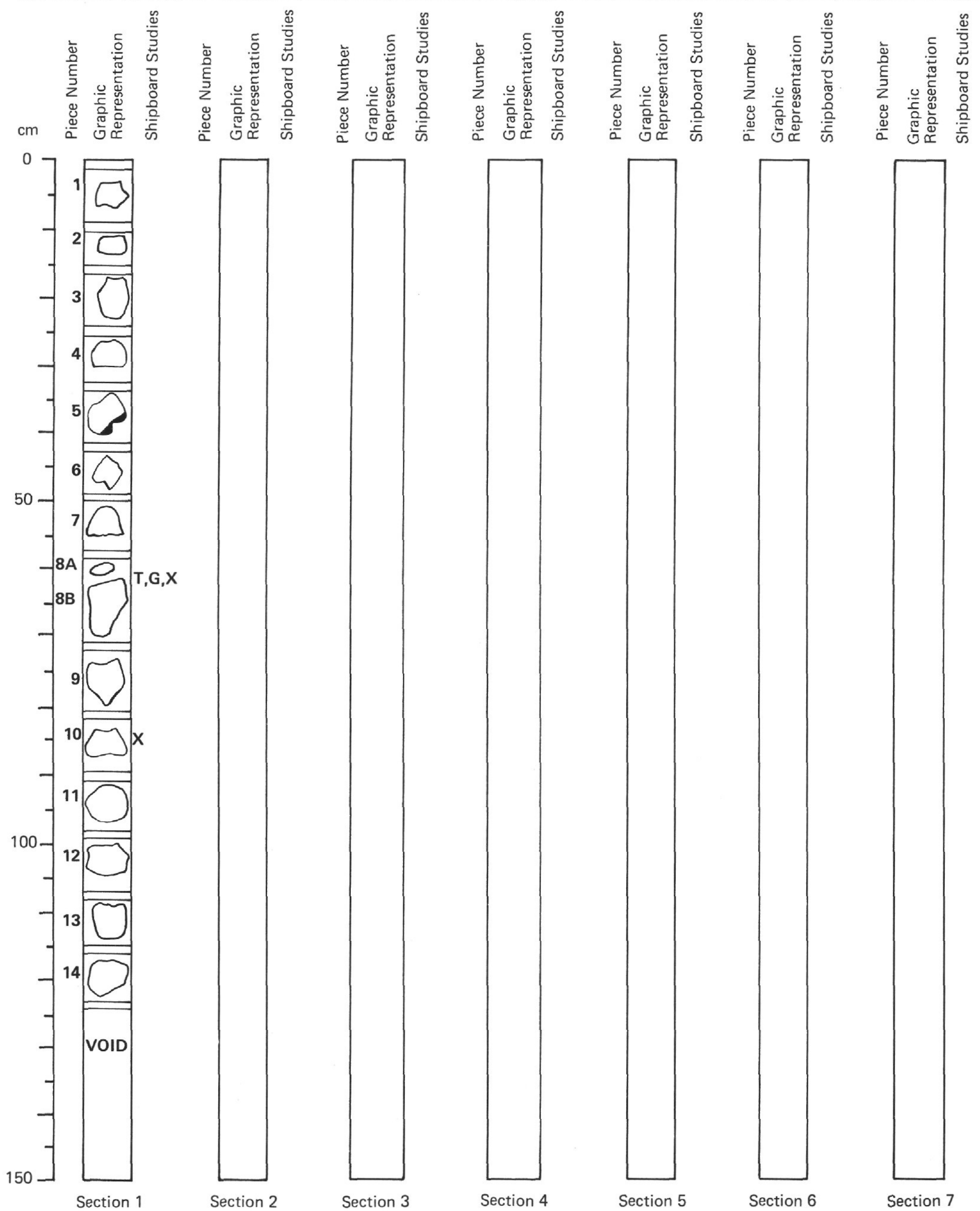
Upper unit: sparsely microphyric olivine, plagioclase basalt. Olivine and plagioclase crystals range from 0.3 to 1.5 mm in diameter and make up 1 to 7% by volume. Vesicularity up to 15% but mostly much less; some vesicles partly filled with carbonate and smectite(?). Glassy margins on two pieces.

Lower unit: plagioclase-olivine phyric basalt. About 15-20% plagioclase crystals, 3-4 mm in diameter. Olivine < 1%, 2-3 mm in diameter. As many as 5-10% vesicles.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 110 cm:	5.79	4317	-54°

LEG **49** SITE **411** HOLE CORE **4** DEPTH **100.5-110.0 m**



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

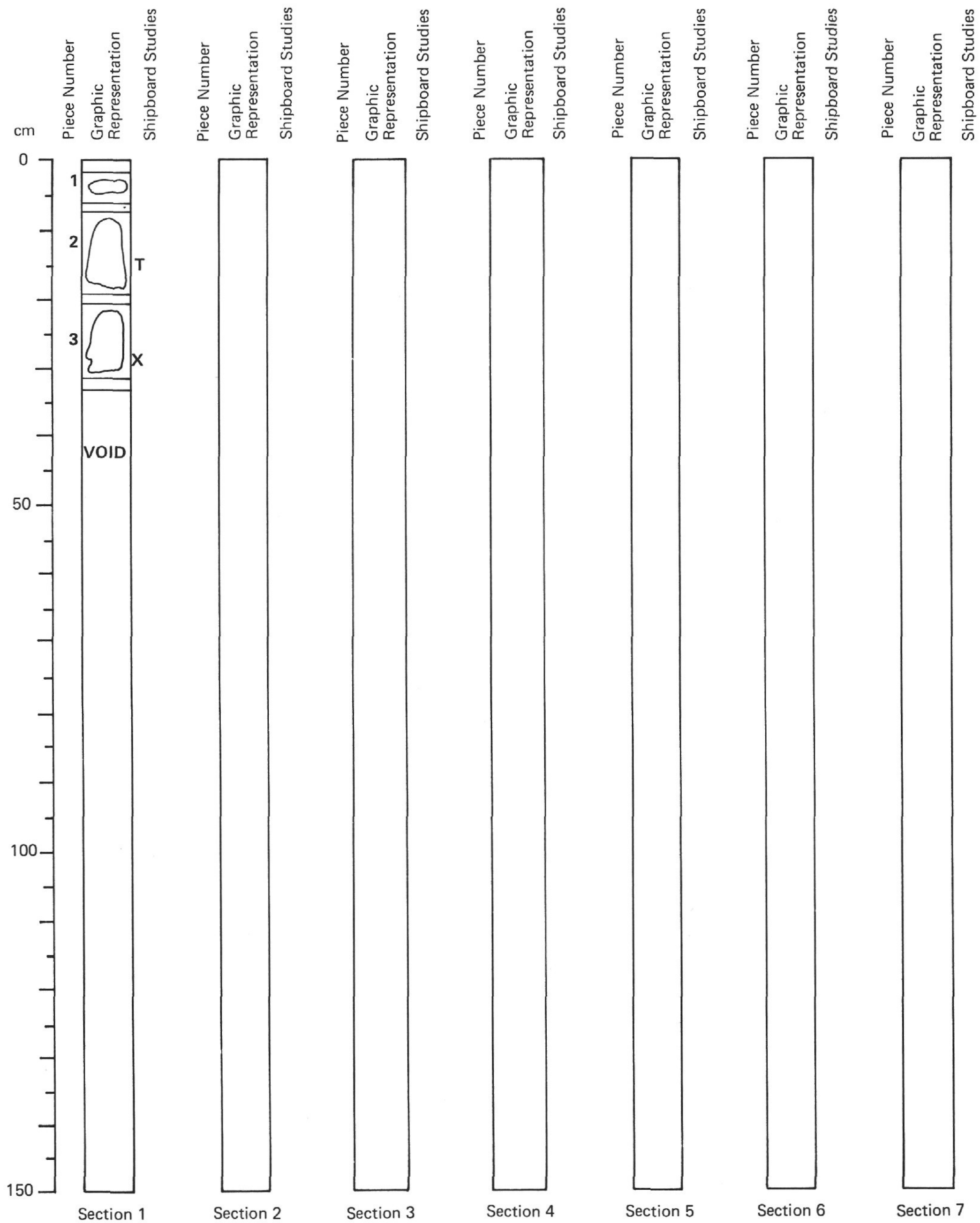
Upper unit: sparsely microphyric plagioclase basalt, 2-3% plagioclase crystals 0.2 to 0.5 mm in size. About 5% of 0.2 to 0.5 mm vesicles.

Lower unit: plagioclase-olivine phyric basalt, 10 to 20 % plagioclase crystals, 2-4 mm in size. About 1% or less of olivine, up to 2 mm in size. A few per cent vesicles, some partly filled with smectite(?). One piece has a partly glassy rind.

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 65 cm:	5.15	321	-36°
Sect. 1, 115 cm:	—	—	Normal

LEG **49** SITE **411** HOLE CORE **5** DEPTH **110.0-119.5 m**



Original basalt recovery was 0.22 meters. Styrofoam spacers make the length shown here greater than the amount recovered.

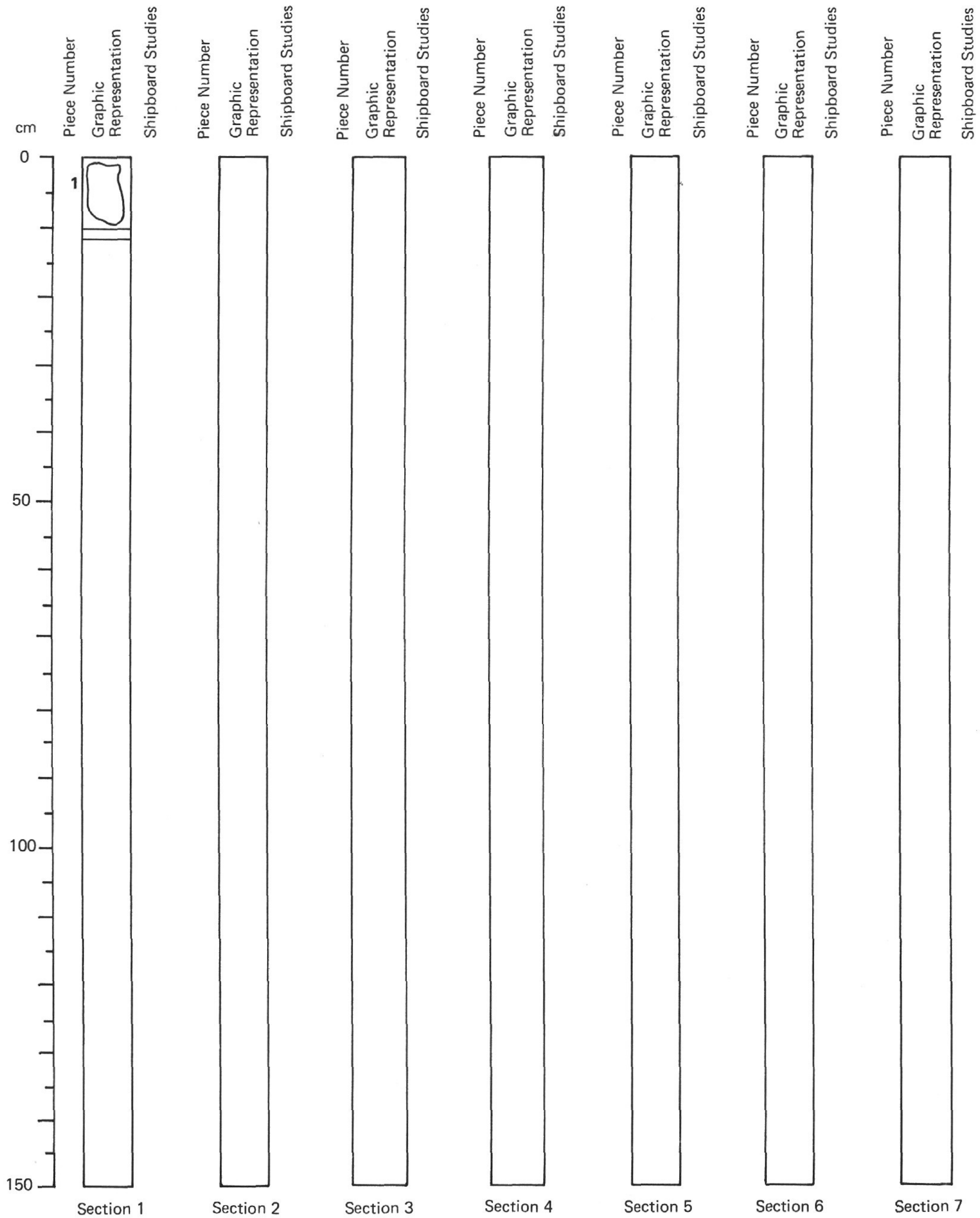
Upper unit: plagioclase phyric basalt. About 10% plagioclase crystals, 1 to 3 mm in size. Also rare olivine, 1 to 1.5 mm in size, 5 to 7% vesicles, about 0.1 to 0.3 mm in size.

Lower unit: olivine phyric basalt. About 5 to 70% olivine, from 0.5 to 3.00 mm in size. Olivine has spinel inclusions. Rare phenocrysts of plagioclase, 1 to 2 mm in size. Also 5-10% vesicles, .2 to 0.8 mm in size, some partly filled with smectite(?).

Shipboard Data

	Vp	NRM	Inc.
Sect. 1, 15 cm:	5.40	61	-37°
Sect. 1, 30 cm:	5.44	––	Reversed

LEG **49** SITE **411** HOLE CORE **6** DEPTH **81.5-110.0 m**



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

One piece of rock. Level of recovery not certain, because drill string was raised and lowered in hole between 81.5 and 119.5 m sub-bottom during coring.

Olivine-plagioclase phyric basalt, 2 to 3% olivine crystals, 1-2 mm in size, with spinel inclusions. Rare plagioclase crystals < 1 mm, 5 to 10% vesicles, about 0.4 mm in size. Some partly filled with smectite.

SITE 411 **HOLE** A **CORE** 1 **CORED INTERVAL:** 0.0-8.5 m

TIME-ROCK UNIT	BIOSTRAT ZONE	FORAMS	NANNOS	RADS	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
PLEISTOCENE	N22/N23 NN20/21	Ag	Cg		1, 2, 3, 4, 5, 6	0.5, 1.0	V			70 (Sec. 1), 70 (Sec. 3), 70 (Sec. 5)	grayish orange (10YR 7/4)

NANNOFOSSIL-FORAMINIFERA OOZE
Grayish orange medium to fine sand, mostly foraminifera with pteropod fragments (5%). Smear slides estimates low in forams owing to bias in smear slide technique for clay- and silt-size material. Volcanic glass angular, silt-size, mostly transparent, *some green and brown*. Thin silt-size calcareous spines included as "carbonate unspecified".

Smear Slides	1-70	3-70	5-70
forams	15	40	25
nannos	50	34	48
carb. unsp.	10	10	10
rads	1	--	--
sp. spic.	2	2	1
fspr.	2	3	5
volc. glass	15	10	10
H. min.	Tr	--	1
palagonite	Tr	--	--

Explanatory notes in Chapter 1

SITE 411 **HOLE** A **CORE** 2 **CORED INTERVAL:** 8.5-18.0 m

TIME-ROCK UNIT	BIOSTRAT ZONE	FORAMS	NANNOS	RADS	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
PLEISTOCENE	N22/N23	Ag	NN19 Ag		1, 2, CC	0.5, 1.0	V; VOID			70 (Sec. 2)	grayish orange (10YR 7/4)

NANNOFOSSIL-FORAMINIFERAL OOZE
Fine- to medium-size foraminifera predominate although smear slide estimate low owing to bias for clay-silt sizes. Volcanic glass angular, silt-size, mostly transparent with some brown and green.

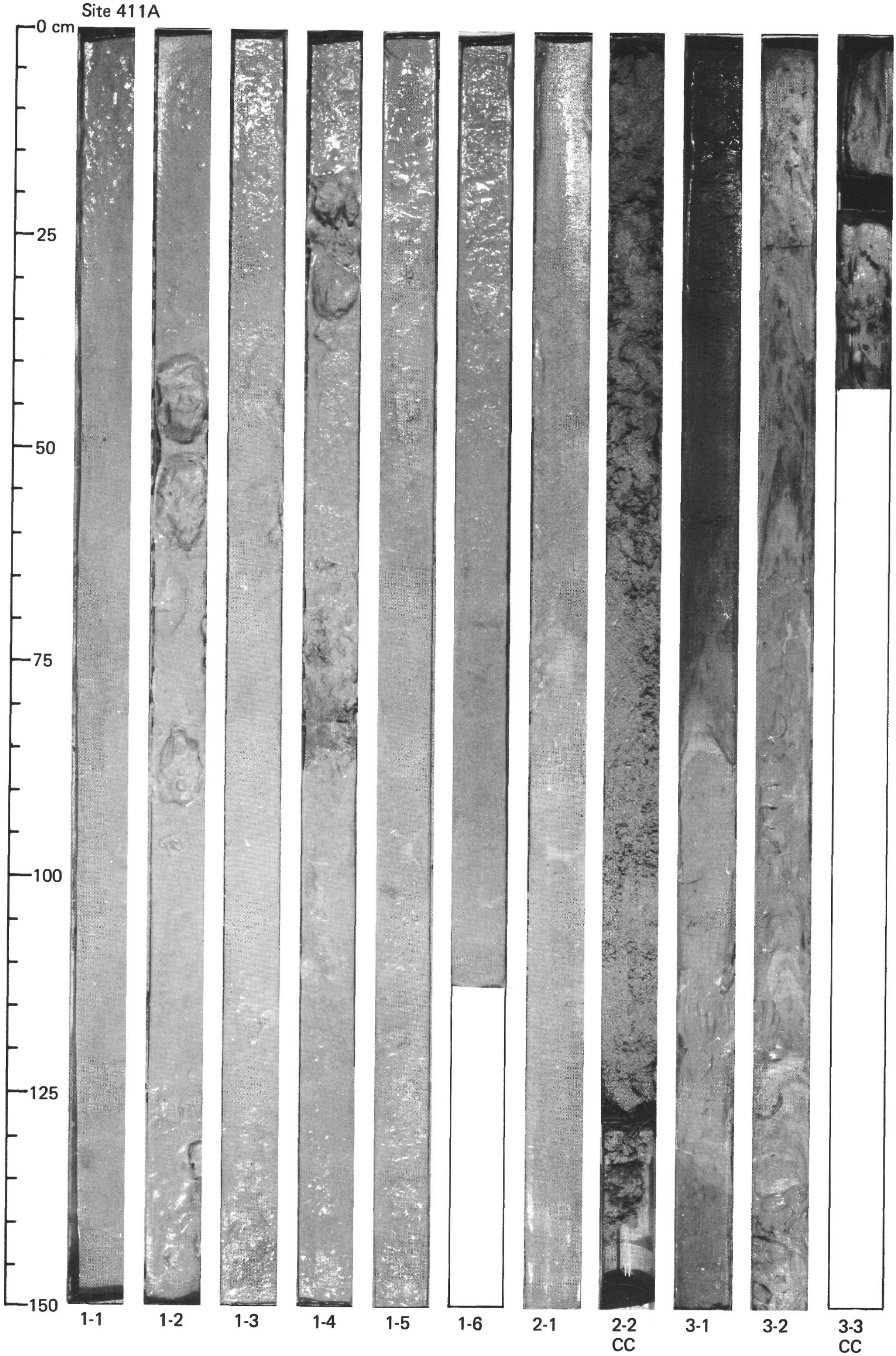
Smear Slides	2-70
forams	40
nannos	41
carb. unsp.	10
sp. spic.	2
volc. glass	5
palagonite	Tr
fspr.	2

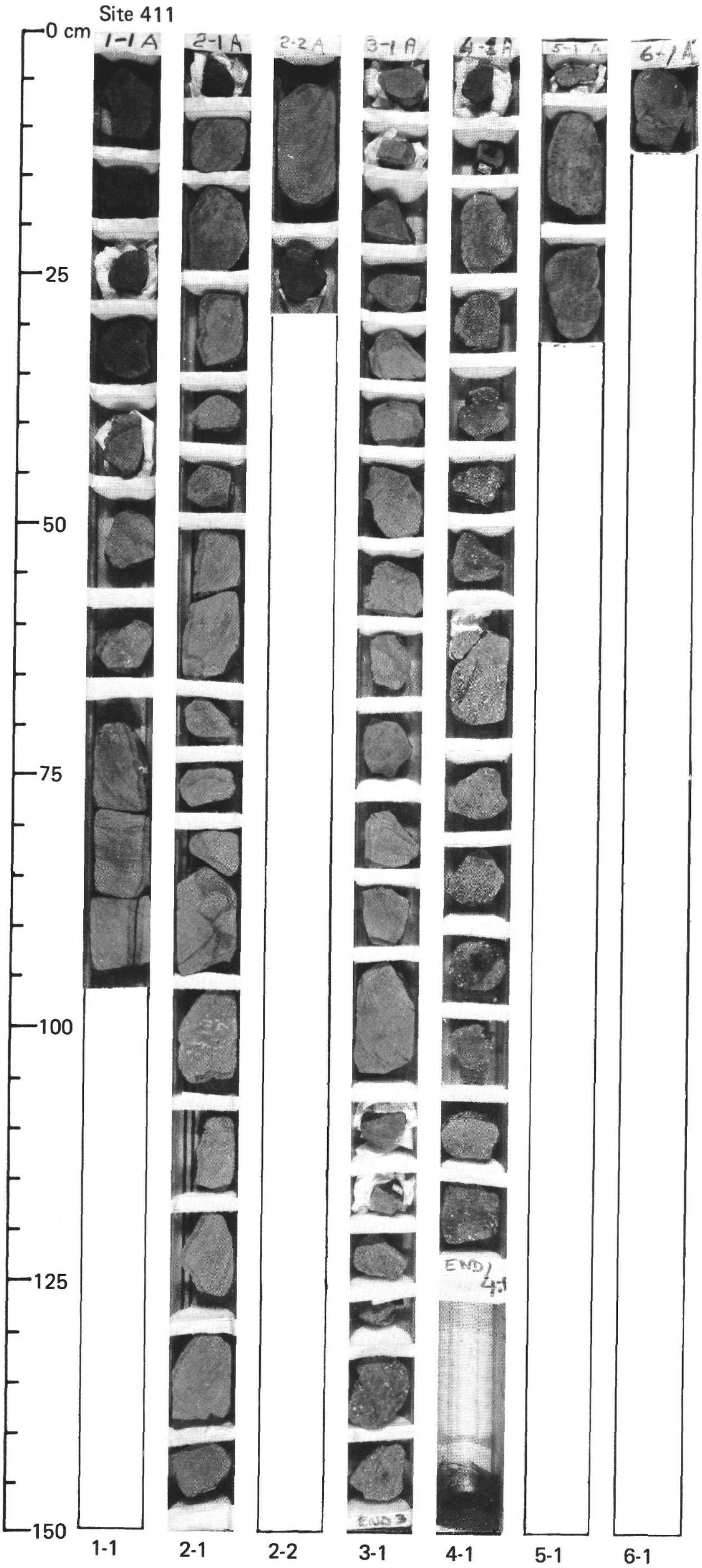
SITE 411 **HOLE** A **CORE** 3 **CORED INTERVAL:** 18.0-27.5 m

TIME-ROCK UNIT	BIOSTRAT ZONE	FORAMS	NANNOS	RADS	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	LITHOLOGIC SAMPLE	LITHOLOGIC DESCRIPTION
PLEISTOCENE	N22/N23	Ag			1, 2	0.5, 1.0					grayish orange (10YR 7/4); very light gray (N8)

NANNOFOSSIL-FORAMINIFERA OOZE
Mostly fine-medium sand-size *foraminifera, some pteropod(?)* fragments. Foraminifera content underestimated in smear slides. Thin zone (145-150) of very light gray nannofossil ooze at bottom of Section 3.

Smear Slides	2-70 (Major lith.)	1-70 (Major lith.)	2-144 (Minor lith.)
nannos	41	36	70
forams	40	50	20
carb. unsp.	10	5	5
sp. spic.	2	--	1
volc. glass	5	2	2
palagonite	Tr	--	--
fspr.	2	2	2
micronodules	--	5	--
H. min.	--	Tr	Tr


Site 411A
0 cm
25
50
75
100
125
150
1-1
1-2
1-3
1-4
1-5
1-6
2-1
2-2
CC
3-1
3-2
3-3
CC


Site 411
0 cm
25
50
75
100
125
150
1-1A
2-1A
2-2A
3-1A
5-1A
6-1A
END 4-1
END 3
1-1
2-1
2-2
3-1
4-1
5-1
6-1