4. SITE 599[1]

Shipboard Scientific Party[2]

HOLE 599

Date occupied: 20 March 1983

Date departed: 21 March 1983

Time on hole: 18 hr., 12 min.

Position: 19°27.09'S, 119°52.88'W

Water depth (sea level; corrected m, echo-sounding): 3654

Water depth (rig floor; corrected m, echo-sounding): 3664

Bottom felt (m, drill pipe): 3643.7

Penetration (m): 40.8

Number of cores: 5

Total length of cored section (m): 40.8

Total core recovered (m): 34.76

Core recovery (%): 85.2

Oldest sediment cored:
Depth sub-bottom (m): 40.8
Nature: Clayey nannofossil ooze
Age: late Miocene
Measured velocity (km/s): 1.52

Basement:
Depth sub-bottom (m): 40.8
Nature: Basalt

HOLE 599A

Date occupied: 21 March 1983

Date departed: 21 March 1983

Time on hole: 3 hr., 40 min.

Position: 19°27.09'S; 119°52.88'W

Water depth (sea level; corrected m, echo-sounding): 3654

Water depth (rig floor; corrected m, echo-sounding): 3664

Bottom felt (m, drill pipe): 3643.7

Penetration (m): 22.6

Number of cores: None[3]

HOLE 599B

Date occupied: 21 March 1983

Date departed: 22 March 1983

Time on hole: 1 day, 12 hr., 57 min.

Position: 19°27.09'S, 119°52.88'W

Water depth (sea level; corrected m, echo-sounding): 3654

Water depth (rig floor; corrected m, echo-sounding): 3664

Bottom felt (m, drill pipe): 3643.7

Penetration (m): 49.8

Number of cores: 4[4]

Total length of cored section (m): 23.6

Total core recovered (m): 11.57

Core recovery (%): 49.0

Oldest sediment cored:
Depth sub-bottom (m): 40.8
Nature: Clayey nannofossil ooze
Age: late Miocene

Basement:
Depth sub-bottom (m): 40.8
Nature: Basalt

Principal results: Site 599 is the third site drilled in the Leg 92 hydrogeology transect of the East Pacific Rise at 19°S. At Hole 599 we recovered four hydraulic piston corer (HPC) cores of sediment and one of clay and nannofossil-bearing water and a few basalt glass chips. Hole 599A was devoted to heat flow and *in situ* pore water experiments, as was Core 1 of Hole 599B. All experiments were successful. Core 2 of Hole 599B recovered the lowermost nannofossil clays, and Cores 3 and 4 were drilled into basalt with the extension core barrel (XCB).

Sedimentary Unit I is 40.8 m of very dark clayey nannofossil ooze with abundant red brown to yellow brown semiopaque oxides (RSO) in the clay fraction. Carbonate turbidites and reworked intervals occur in the lower 20 m. The sediments range in age from Pleistocene to late Miocene; the basal nannofossil zone is CN8B. We penetrated 9 m into basalt, recovering 2.1 m of rounded pillow fragments and drilling breccia. The larger pieces show alteration rims and contain minor amounts of iron oxides and brown smectites. Bit torquing and sticking and hole carving forced us to abandon Hole 599B after about 20 hr. of basalt drilling. Heat flow measurements gave a flux of 101 mW/m^2.

BACKGROUND AND OBJECTIVES

Site 599 is about 275 km east of Site 598 and 1700 km east of Tahiti. It lies in about 3650 m of water 650 km west of the axis of the East Pacific Rise (EPR) on crust of middle to late Miocene age.

The exact age of the seafloor at Site 599 was unclear, because the seafloor magnetic anomalies from both the

[1] Leinen, M., Rea, D. K., et al., *Init Repts. DSDP*, 92: Washington (U.S. Govt. Printing Office).

[2] Margaret Leinen (Co-Chief Scientist), The University of Rhode Island, Narragansett, Rhode Island; David K. Rea (Co-Chief Scientist), The University of Michigan, Ann Arbor, Michigan; Keir Becker, Scripps Institution of Oceanography, La Jolla, California (present address: University of Miami, Miami, Florida); Jacques J. Boulègue, University of Paris, Paris, France; Jörg Erzinger, Justus-Liebig University, Giessen, Federal Republic of Germany; Joris M. Gieskes, Scripps Institution of Oceanography, La Jolla, California; Marjorie S. Goldfarb, Scripps Institution of Oceanography, La Jolla, California (present address: University of Washington, Seattle, Washington); Michael A. Hobart, Lamont-Doherty Geological Observatory, Palisades, New York; Miriam Kastner, Scripps Institution of Oceanography, La Jolla, California; Stephen Knüttel, Florida State University, Tallahassee, Florida; Mitchell W. Lyle, Oregon State University, Corvallis, Oregon; Tadashi Nishitani, Akita University, Akita, Japan; Robert M. Owen, The University of Michigan, Ann Arbor, Michigan; Julian A. Pearce, The Open University, Milton Keynes, United Kingdom (present address: The University, Newcastle-upon-Tyne, United Kingdom); Karen Romine, The University of Rhode Island, Kingston, Rhode Island (present address: Exxon Production Research Company, Houston, Texas).

[3] Experimental hole. Two heat flow shoe lowerings, one Barnes/Uyeda pore water/heat flow sampler lowering.

[4] One for pore water sampling and heat flow measurement only, three for samples of sediment or rock.

Conrad-13 and Ariadne II cruises are ambiguous. The age estimates range from 9 to 7 Ma and indicate west-flank seafloor spreading rates of from 72.4 to 93.1 mm/yr. For the past 2.4 m.y., west-flank EPR spreading rates have been 70.4 mm/yr. (Rea, 1978).

The region surveyed for the site was chosen from *Conrad*-13 and *Conrad*-17 air gun records, which showed smooth basement and continuous sediment cover. A detailed survey was completed by the *Thomas Washington* (cruise Ariadne II) in early 1982. Seabeam data from that cruise show linear abyssal hills that trend north-northeast and have about 200 to 300 m of relief. A broader region of low relief 8 km wide and 10 km long occupies the east central portion of the survey area (Fig. 1). The proposed location for Site HY-2 was near the southern end of this flat area, where sediment cover is thickest.

Air gun records show approximately 0.06 s (45 m) of sediment over acoustic basement in the flat areas between the ridges but patchy sediment cover on the slopes of both the abyssal-hill ridges and the valleys (Fig. 2). Acoustic basement is a strong smooth reflector in the flat areas and may be sedimentary or igneous.

Heat flow measurements made during the site survey show low values of heat flow (18 to 41 mW/m^2) in the valley at the western margin of the area and moderate values (31 to 196 mW/m^2) in the flat area covered by sediments (Fig. 3). None of the heat flow gradients showed curvature indicative of the hydrothermal advection of pore water through the sediments. Similarly, the pore water chemistry from the site survey cores showed no evidence of advection. Gravity cores from the area recovered calcareous oozes with sedimentation rates of about 5 mm/10^3 yr. Since there were no indications of vertical advection, the location chosen for Site 599 was the thickest part of the flattest and widest portion of the sediment-covered area.

Our specific objectives were to recover a continuous sedimentary section that would include late Miocene to Recent biogenic and hydrothermal sediments. We wanted to study a site of intermediate age in our evaluation of hydrothermal sediment deposition and alteration with time and the general paleoclimatic and paleoceanographic history of the southeastern Pacific Ocean. We also planned to continue our studies of heat flow and pore water chemistry to verify that hydrothermal advection was not occurring at the site and to determine whether there was pore water evidence of sediment diagenesis at the site. Finally, we hoped to recover basalt basement at this site to compare its petrology, chemistry, and degree

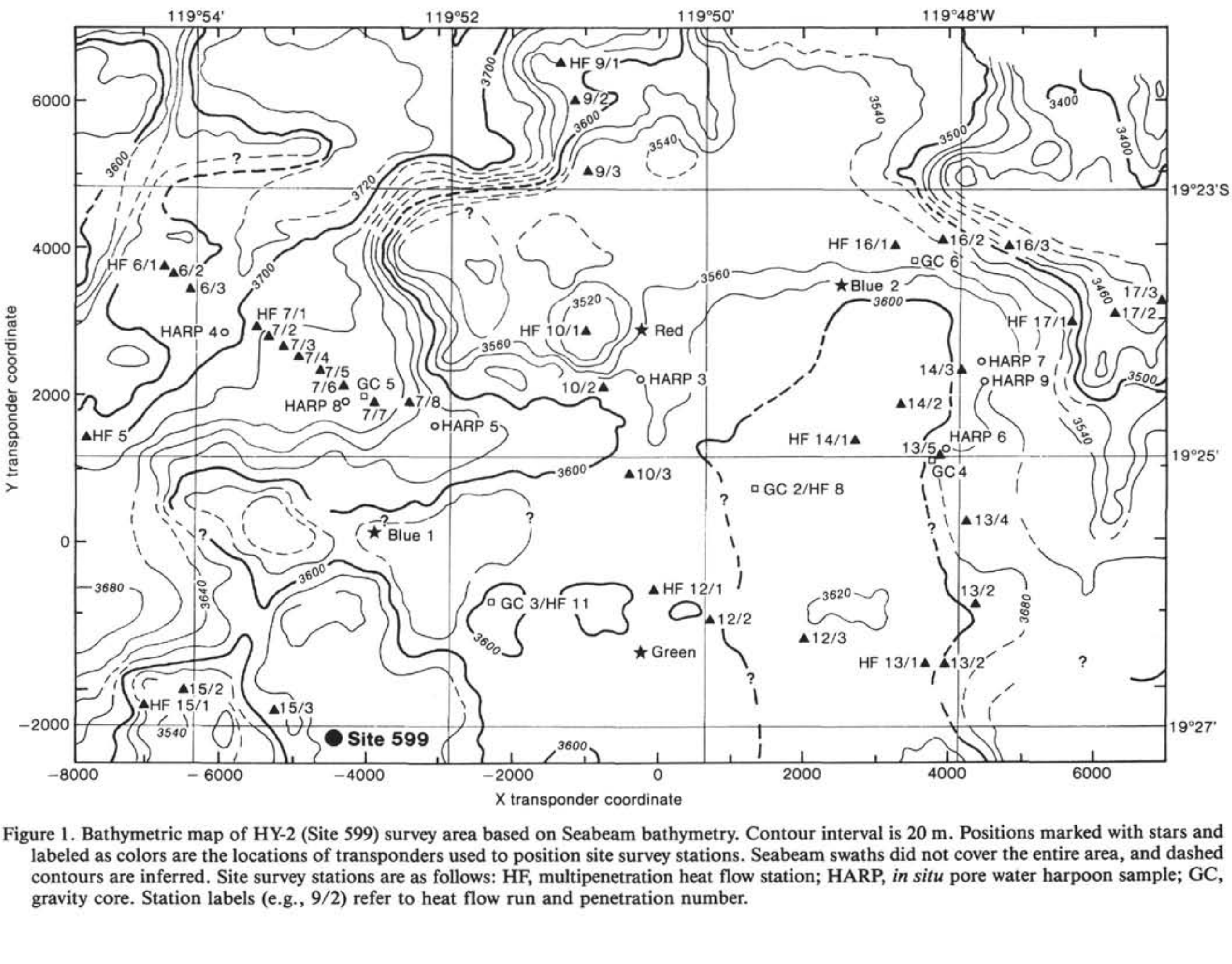


Figure 1. Bathymetric map of HY-2 (Site 599) survey area based on Seabeam bathymetry. Contour interval is 20 m. Positions marked with stars and labeled as colors are the locations of transponders used to position site survey stations. Seabeam swaths did not cover the entire area, and dashed contours are inferred. Site survey stations are as follows: HF, multipenetration heat flow station; HARP, *in situ* pore water harpoon sample; GC, gravity core. Station labels (e.g., 9/2) refer to heat flow run and penetration number.

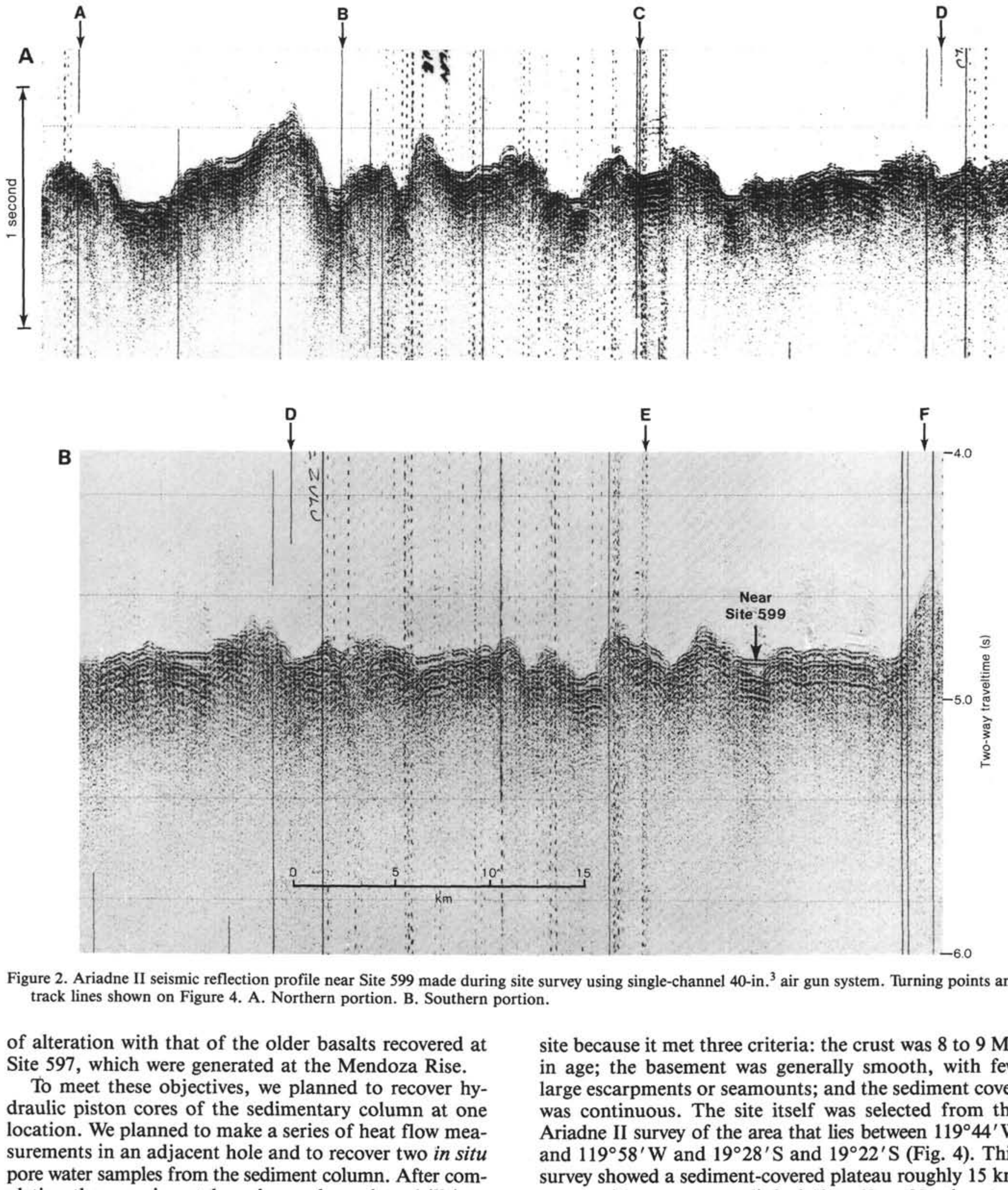


Figure 2. Ariadne II seismic reflection profile near Site 599 made during site survey using single-channel 40-in.^{3} air gun system. Turning points and track lines shown on Figure 4. A. Northern portion. B. Southern portion.

of alteration with that of the older basalts recovered at Site 597, which were generated at the Mendoza Rise.

To meet these objectives, we planned to recover hydraulic piston cores of the sedimentary column at one location. We planned to make a series of heat flow measurements in an adjacent hole and to recover two *in situ* pore water samples from the sediment column. After completing the experimental work we planned to drill into basement rock long enough to allow 25 m of penetration.

OPERATIONS

Site Survey

The area in which Site 599 is located was considered appropriate for detailed surveys and as a potential drill site because it met three criteria: the crust was 8 to 9 Ma in age; the basement was generally smooth, with few large escarpments or seamounts; and the sediment cover was continuous. The site itself was selected from the Ariadne II survey of the area that lies between 119°44′W and 119°58′W and 19°28′S and 19°22′S (Fig. 4). This survey showed a sediment-covered plateau roughly 15 km across with an average relief of 40 to 60 m. Northeast of the site there is an abyssal-hill ridge with a maximum relief of 250 m. West of the site there is a flat-floored trough about 100 m deeper than the plateau. Figure 4 shows the Seabeam bathymetric swath map of the surveyed area. A somewhat more interpretive map that includes the locations of all the site survey stations is shown in Figure 1.

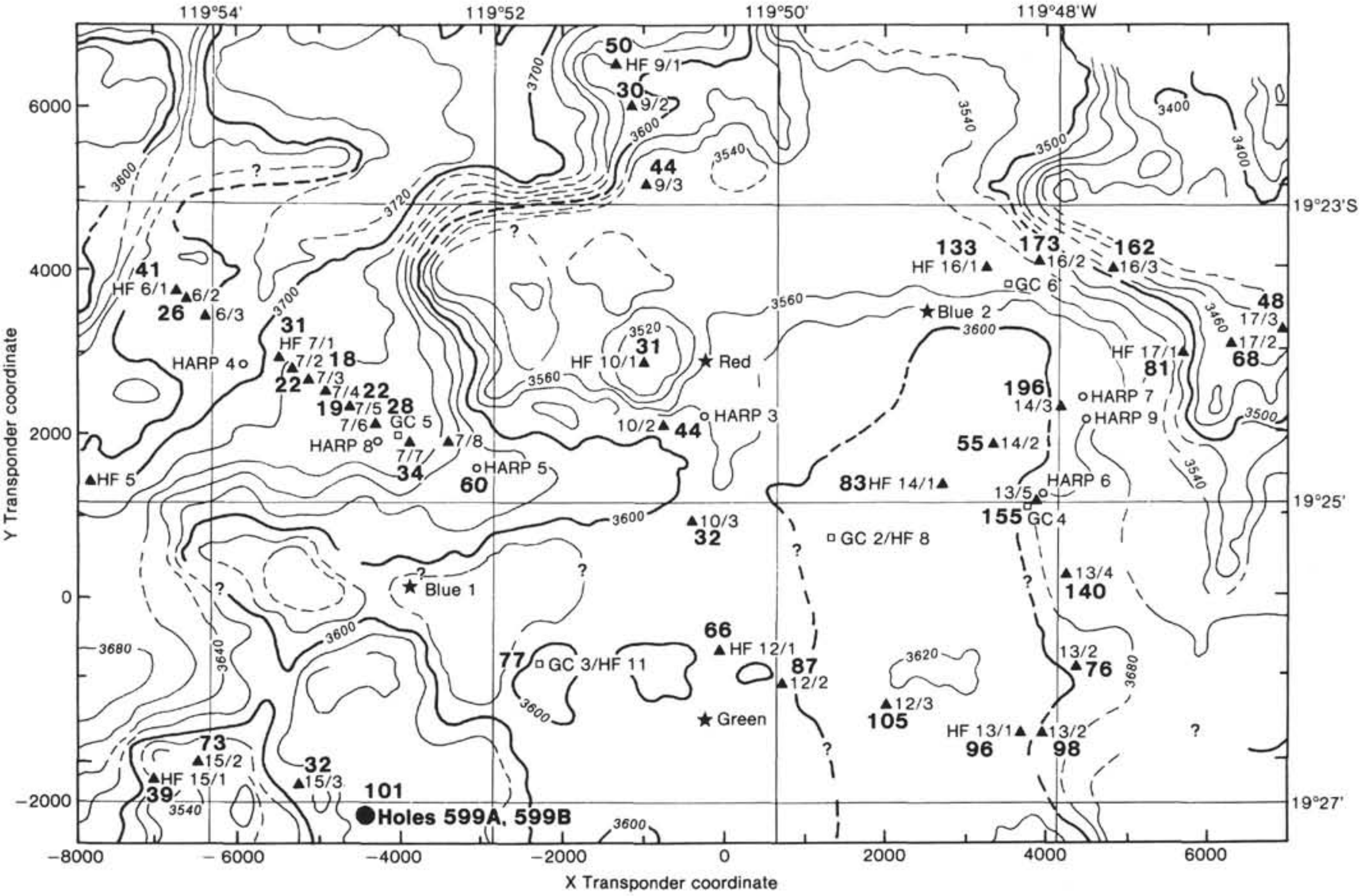


Figure 3. Heat flow values from the site survey for Site 599 and from Holes 599A and 599B. Heat flow site survey was done using a multipenetration heat flow system. All heat flow values are in mW/m^2. HF, HARP, GC, and station labels as defined for Figure 1.

Air gun records from the site survey cruise show that the sediment on the plateau varies in thickness from 0.05 s (about 35 m) in the north to 0.07 s (about 55 m) in the south (Fig. 2). The sediment is acoustically transparent in the Ariadne II profiles (Fig. 2), although the water gun records from the *Glomar Challenger* profile show several internal reflectors (Fig. 5). In addition, the Ariadne II records show a fairly smooth sediment surface, whereas the *Glomar Challenger* records show a more hummocky surface. The basement on the air gun profiles is a strong smooth reflector with an accompanying bubble pulse and was interpreted as sedimentary. The water gun records show no such strong basement reflector, and basement was difficult to differentiate from the disrupted reflectors in the lower half of the sediment column.

The location proposed for Site 599 was the thickest portion of the flat sediment, which would provide the best sedimentary section. In addition, it was hoped that bottom current activity and downslope sediment transport would be minimal, because the area appeared to be quite flat. The heat flow and pore water chemical gradients in the area gave no indication of the pore water advection associated with ridge-flank hydrothermal activity. Heat flow values averaged about 100 mW/m^2 (Stations HF 12/2, 12/3, 13/1, and 13/2; Fig. 3). Gravity cores taken 3 km north of the proposed site, on the sediment-covered plateau, contained light brown to medium brown foraminifer- and clay-bearing nannofossil ooze that contained 75 to 90% $CaCO_3$.

Navigation

In case neither of the two acoustic transponders left in the area by the site survey party was still operating, we planned to drop the navigation beacon as we steamed into the area at the best estimate of the latitude and longitude of HY-2 obtained from the site survey data. We collected water gun records as we approached the area in the *Glomar Challenger*, and it became clear that the sediments were quite different than they had appeared in the air gun records. Specifically, the sediment-covered plateau looked hummocky and did not have flat, continuous sediment reflectors. We decided to make a brief water gun survey in order to re-evaluate the site. After surveying, we decided to drill at a site in the sediment pond west of the plateau, even though we expected to find some redeposited sediment there. We chose this location for two reasons. First, the sediment in the pond had acoustic characteristics (an upper zone containing several acoustic reflectors and a lower more transparent zone) more similar to those of the sediment at Sites 597 and 598 than the sediment on the plateau. Second, the reflectors on the plateau were discontinuous, evidence of erosion and/or reworking.

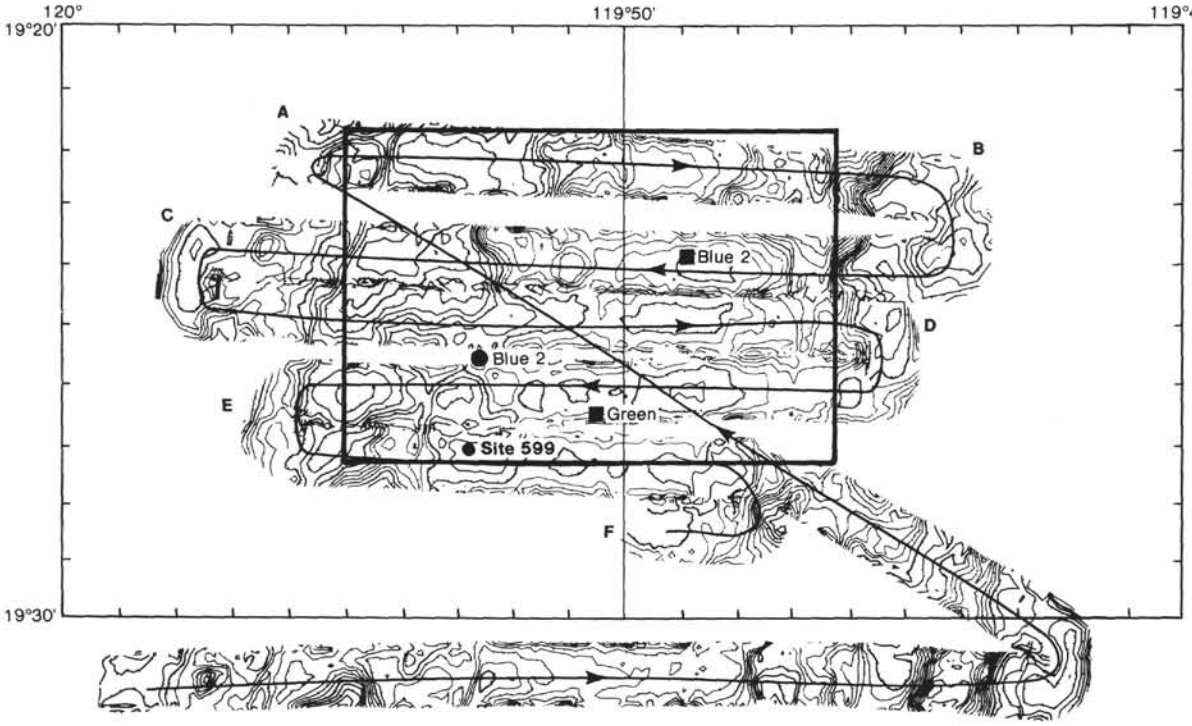


Figure 4. Original Seabeam swath map of the area surveyed for Site 599. Contour interval is 20 m; symbols are the locations of the acoustic transponders used to navigate site survey stations. The box outlines the area of the processed Seabeam map in Figure 1 and of the map area in Lonsdale (this volume). Letters correspond to the course changes indicated in the air gun record in Figure 2.

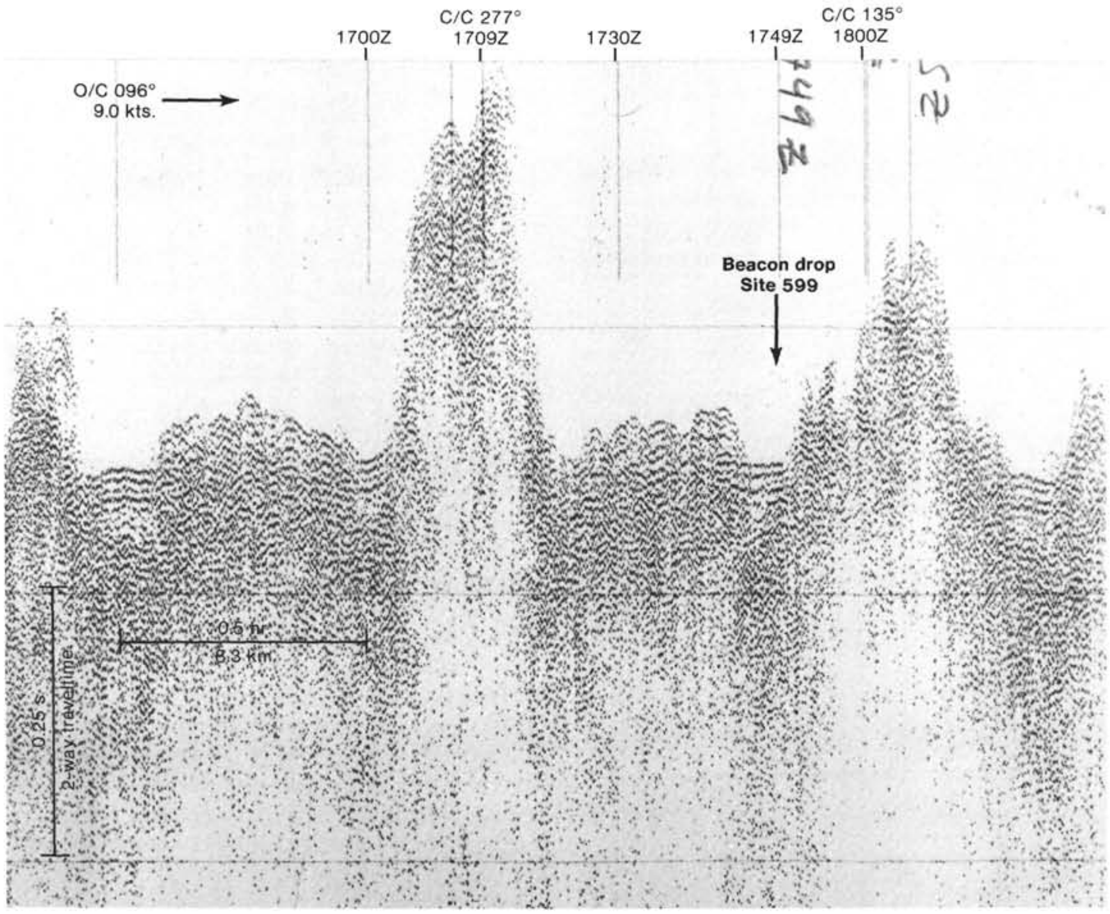


Figure 5. *Glomar Challenger* water gun profile of the approach to Site 599.

A 16.0-kHz beacon was dropped at Site 599 at 0949 hr. on 20 March. The acoustic transponders emplaced during the site survey cruise were interrogated by using the techniques described in the Operations section of the Site 597 chapter (this volume). Both transponders were operating and indicated that the beacon was probably near the margin of the sediment pond. Offsets of 1500 ft. (457.2 m) north and 1500 ft. (457.2 m) east were introduced to the dynamic positioning computer. The ranges of the two transponders were then used to determine the position of the site relative to the Seabeam bathymetric map and the site survey stations.

Drilling Operations

Winds were gusting to 35 knots and there were three sets of swells when the ship was positioned over the beacon. With the bow into the wind, the roll and pitch, which approached 10° on occasion, were unacceptable for handling drill pipe. Operations were delayed until 1320 hr. on 20 March, when the bottom hole assembly was made up and the drill pipe was run into the hole. Hole 599 was spudded at 2110 hr. with the mud line at 3643.7 m, 4.3 m above precision depth recorder (PDR) depth (Table 1). The hole was cored continuously with the variable-length hydraulic piston corer (VLHPC) until Core 599-5 terminated on basement at 3684.5 m (40.8 m below seafloor [BSF]). The pipe was pulled clear of the mud line, ending operations at Hole 599, at 0401 hr. on 21 March.

We decided to make all heat flow measurements and to take all pore water samples in a single, separate hole; this plan of action had worked well at Site 598. Hole 599A was spudded at 0420 hr. with the Von Herzen heat flow shoe connected to the Barnes/Uyeda tool by a separate subassembly. Three successful heat flow measurements and one *in situ* pore water sample were taken. Because of the shallow penetration, the drill string was pulled clear of the mud line at 0800 hr. while the tool was being redressed.

Table 1. Coring summary, Holes 599, 599A, and 599B.

Core	Date (Mar. 1983)	Time (hr.)	Depth from drill floor (m)	Depth below seafloor (m)	Length cored (m)	Length recovered (m)	Recovery (%)
Hole 599							
1	20	2142	3643.7–3651.6	0–7.9	7.9	7.89	100
2	20	2315	3651.6–3661.2	7.9–17.9	9.6	9.43	98
3	21	0035	3661.2–3670.8	17.5–27.1	9.6	9.13	95
4	21	0203	3670.8–3680.4	27.1–36.7	9.6	8.30	86
5	21	0330	3680.4–3684.5	36.7–40.8	4.1	0.01	0.2
Total					40.80	34.76	85.2
Hole 599A							
1W	21	0740	3643.7–3647.1	0–3.4	3.4	a	0
	21		3647.1–3656.7	3.4–13.0	9.6	b	0
	21		3656.7–3666.3	13.0–22.6	9.6	c	0
Hole 599B							
1W	21		3643.7–3675.9	23.6–32.2	8.7	b	0
2	21	1350	3675.9–3684.5	32.2–40.8	8.6	9.49	110
3	21	2240	3684.5–3693.5	40.8–49.8	9.0	1.52	17
4[c]	22	1020	3687.5–3693.5	43.8–49.8	6.0	0.56	9
Total					23.6	11.57	49.0

[a] Heat flow measurement.
[b] Pore water sample and heat flow measurement.
[c] Re-cored fill.

Hole 599B, the second hole drilled for downhole measurements, was spudded at 0945 hr. One successful pore water sample and one heat flow measurement were taken. One additional VLHPC core was then taken just above basement to recover some of the semilithified sediment overlying the basement contact. Basement was at 3684.5 m (40.8 BSF) in Hole 599B. The extension core barrel (XCB) was then used to drill basement. The first XCB core penetrated 9 m and recovered 1.52 m of basalt cobbles. When the second XCB was lowered there were 6 m of fill in the hole, and it took 8.2 hr. to drill to the depth of the first XCB; torquing and sticking of the drill pipe were severe. The drill pipe got stuck twice; freeing the bit took 10 min. and 75,000 lb of overpull the first time and 18 min. and 125,000 lb of overpull the second time. We decided to abandon the hole. The XCB was recovered with 0.56 m of basalt rubble. The bit was on deck at 1545 hr. on 22 March, and Hole 599B terminated at a total depth of 3693.5 m (49.8 m BSF).

After pulling the drill string we attempted to recall the two acoustic navigation transponders. Both transponders responded to recall commands. The "Green" transponder returned to the surface within 300 m of the ship, but we could not find it. All transponders were equipped with pressure-activated strobes for night recovery, but it seems likely that the strobe was not working when the transponder surfaced. The "Blue" transponder also surfaced, and we recovered it without incident at 2235 hr. We were under way at 2242 hr. on 22 March.

LITHOLOGY

Details of Lithology

The sediment cover at Site 599 consists of a single lithologic unit, 40.8 m of clay-bearing to clayey nannofossil ooze (Fig. 6), very similar in composition to Unit II at Site 597 and Unit I at Site 598. The sediment column is unconsolidated ooze throughout, and it directly overlies basaltic basement. The sediments at Site 599 are composed of two distinct facies, which occur throughout the sediment column as alternating light- and dark-colored zones (about 10 to 100 cm thick) or bands (2 to 5 cm thick). The lighter colored material is a yellowish brown to dark yellowish brown clay-bearing to clayey nannofossil ooze typically containing 70 to 80% calcareous nannofossils, 15 to 25% clay plus RSO (red brown to yellow brown semiopaque oxides), 3 to 5% foraminifers (mostly fragmented), 1% palagonite, 1% zeolite (phillipsite), and trace amounts of volcanic glass, opaque grains, and fish debris. The darker material is a dark reddish brown clayey nannofossil ooze typically containing 55 to 70% calcareous nannofossils, 30 to 40% clay plus RSO, 3 to 5% foraminifers (mostly fragmented), 1 to 2% palagonite, 1 to 2% opaque grains, and trace amounts of volcanic glass, zeolites, and fish debris. The calcareous tests are both slightly dissolved and slightly overgrown; otherwise, there is little postdepositional modification. The clay plus RSO fraction is similar to that at Site 598 but is consistently darker in color than the same fraction at Site 597. Thus, for the same carbonate content, the sediment colors are somewhat darker in shade

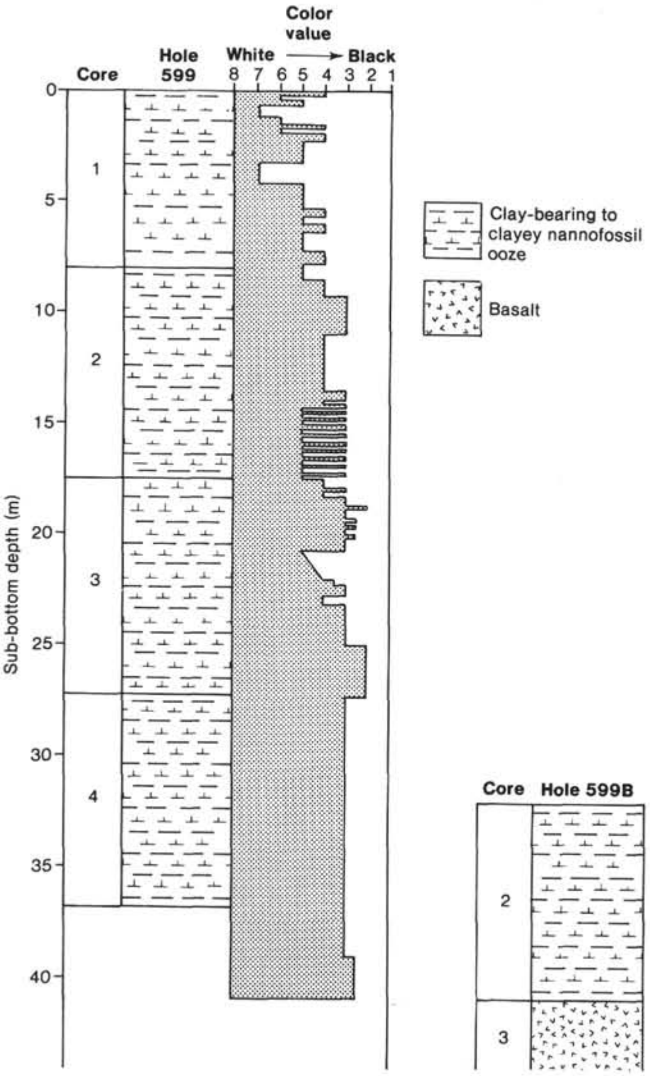


Figure 6. Lithologic sections, Holes 599 and 599B. Color value is a measure of "lightness" used in Munsell soil color charts and all core descriptions.

relative to Site 597. More fish debris and fewer micronodules were noted at Site 599 than at Site 597 or 598.

Sedimentation rate increases from 0.5 to 1.0 m/m.y. in the upper portion of Core 599-1 to an average of 8.5 m/m.y. from Core 599-2 to Core 599-4, and it increases again (to 12.0 m/m.y.) in the lower part of Core 599-4. This increase in sedimentation rates downcore is similar to, but sharper than, that reported for Site 597. Zeolites are most common in the more slowly accumulating sediments in Sections 599-1-1 to -1-4 (Fig. 7). As at Site 598, the clay plus RSO content remains constant or increases slightly downcore despite the increased sedimentation rate.

Discussion

Much of the sediment column (particularly the upper 21 m) appears to be extensively reworked. Some of the large-scale alternating color zones, which have sharp lower contacts and grade upward (e.g., Section 599-3-1; Fig. 6), probably result from bottom transport; the darker zones are coarser than the lighter ones (Rea and Janecek, this volume). Two prominent features of the sediment column are (1) a very sharp dark-over-light sediment erosional contact at 599-3-3, 21 cm; and (2) a series of thin (2- to 5-cm) alternating color bands in Sections 599-2-5, -2-6, -3-1, -3-2, -4-2, and -4-3 (Figs. 6 and 8). In the first of these features, the dark upper layer at the erosional contact is older (CN8B or CN9A nannofossil zones) than the lower light layer (CN9B), suggesting that redeposition has occurred. The origin of the thin color bands is as yet unclear. The bands differ from the large-scale color zones discussed above (and presumed to be turbidites) because both the upper and lower contacts are relatively sharp and the bands lack a basal sand layer, even though the undisturbed sediments contain 3 to 5% sand-sized foraminifers. On the other hand, the lack of bioturbation suggests that the bands were deposited relatively rapidly. The thin color banding might also be caused by cycles of dissolution, dilution, or both.

BIOSTRATIGRAPHY

About 35 m of sediment of Pleistocene to late Miocene age were recovered from the first hole drilled at Site 599. The samples from Core 599-1 (0 to 7.9 m) were Pleistocene through Pliocene in age. Sample 599-1,CC appears to contain Pliocene species together with reworked late Miocene species. Core-catcher Samples 599-2,CC through -5,CC are all latest Miocene in age. Significant amounts of reworking throughout the section are suggested by both the planktonic foraminifers and the calcareous nannofossils. No siliceous microfossils were found.

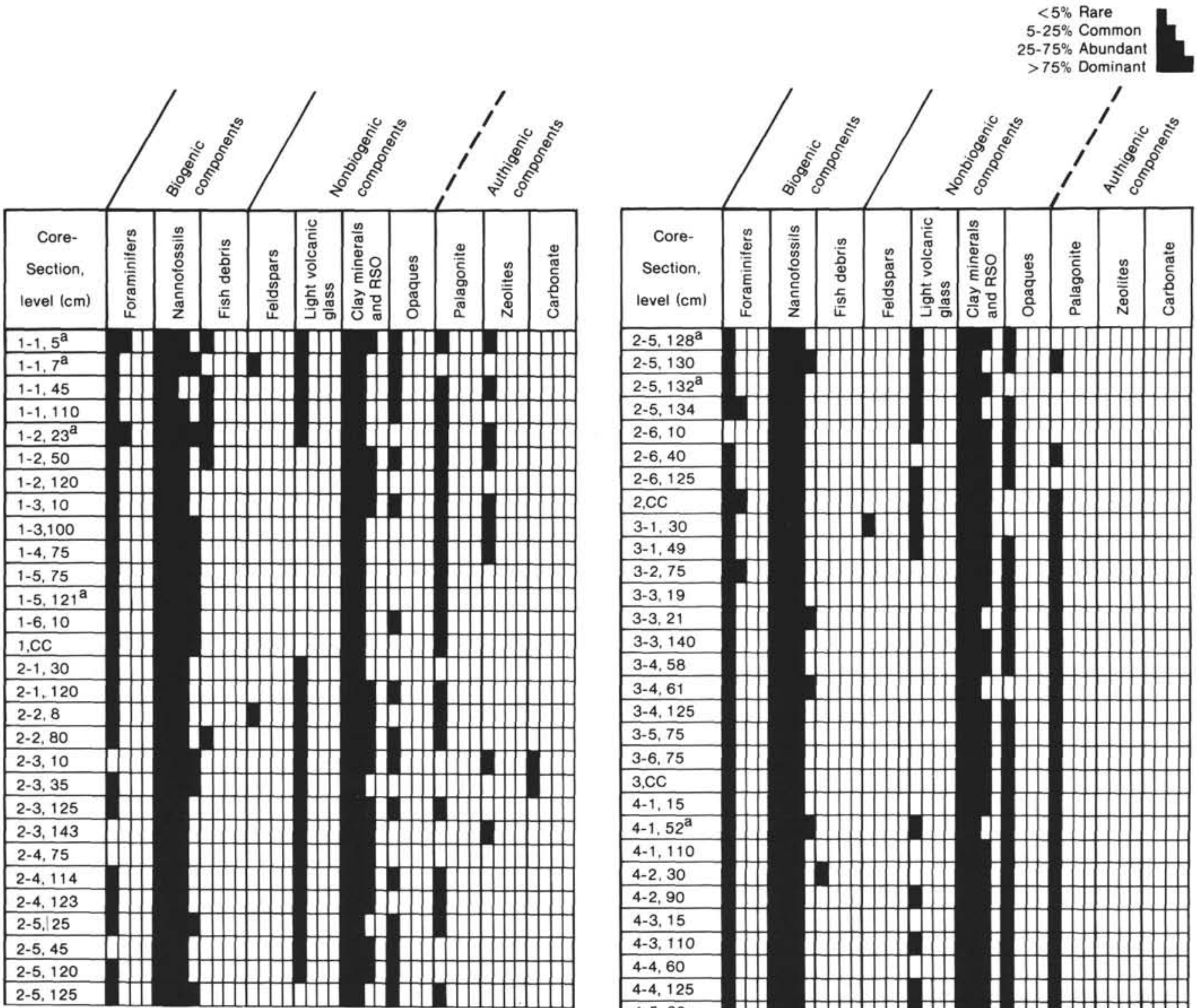
The nannofossils provided a zonation that, particularly for the late Miocene, was more detailed than that provided by the foraminifers. A late Miocene age is indicated by the foraminifers present in all five core-catcher samples; however, Sample 599-1,CC is probably Pliocene in age, although reworked late Miocene fossils are present. The nannofossils were used to subdivide the late Miocene material into three zones, CN9B, 9A, and 8B (Okada and Bukry, 1980). The age of the oldest nannofossil zone present (that in contact with basement) is 8.1 to 8.6 Ma (Haq, 1984), which is older than the magnetic anomaly age of 7.8 Ma. The foraminiferal zonation gives the basal sediments an age of 5.0 to 7.7 Ma.

No sediments were recovered in Core 599B-1. Sediment was recovered in Core 599B-2, and the core-catcher sample (40.8 m BSF) was dated as latest Miocene by the foraminifers and as early late Miocene by the calcareous nannofossils. Sample 599B-3,CC was a basal sediment mixed with basalt gravel. The sample's age could not be determined, because downhole contamination produced a mixed assemblage of common upper Miocene through lower Pleistocene microfossils.

Planktonic Foraminifers

Planktonic foraminifers of late Miocene to Pleistocene age were recovered from the Site 599 sediment column (Fig. 9, Table 2). Foraminifers were generally abundant throughout. Preservation was moderate to poor in most samples (Table 2).

Sample 599-1-1 (0.15 to 0.17 m BSF) was Pleistocene in age (Zone N22; Blow, 1969), with common specimens of *Globorotalia truncatulinoides*; the first appearance



Note: Looked for and not found: (biogenic) radiolarians, diatoms, sponge spicules, silicoflagellates; (nonbiogenic) quartz, heavy minerals, dark volcanic glass, glauconite; (authigenic) amorphous iron oxides, Fe—Mn micronodules, pyrite, recrystallized silica.

[a]Minor lithology.

Figure 7. Smear slide summary, Hole 599.

of this species marks the base of the Pleistocene (and Zone N22). A few specimens of *G. tosaensis* and *Neogloboquadrina dutertrei* were found in the sample, indicating a probable early Pleistocene age. Foraminifers characteristic of upper Pliocene Zone N21 were encountered in the next sample, Sample 599-1-1, 140–150 cm (1.4 to 1.5 m BSF); the species association included *G. tumida flexuosa* (few to common), *G. tosaensis* (few), *G. hirsuta* (rare), and *G. ungulata* (rare). *G. tumida* and *Sphaeroidinella dehiscens* were also common in the sample. Deeper in the section, Sample 599-1-3, 140–150 cm (4.4 to 4.5 m BSF) also appeared to be late Pliocene (Zone N21) in age, with the same species association as in Sample 599-1-1, 140–150 cm (1.4 to 1.5 m BSF), although it also contained numerous reworked specimens of *Globigerina nepenthes, Sphaeroidinellopsis paenedehiscens,* and *S. seminulina kochi*, which were probably from the earliest Pliocene (Zone N19).

Upper Miocene material was recovered in all the core-catcher samples examined (599-1,CC, 7.9 m; 599-2,CC, 17.9 m; 599-3,CC, 27.1 m; 599-4,CC, 36.7 m; and 599-5,CC, 40.8 m). However, Sample 599-1,CC may be lower Pliocene, and the upper Miocene species present may be reworked. Species generally important in these samples include *Globorotalia tumida, G. merotumida, G. plesiotumida, Globigerina nepenthes, Globoquadrina baramoensis, S. seminulina seminulina*, and *S. seminulina kochi*. Sample 599-2,CC is from the uppermost Miocene Zone

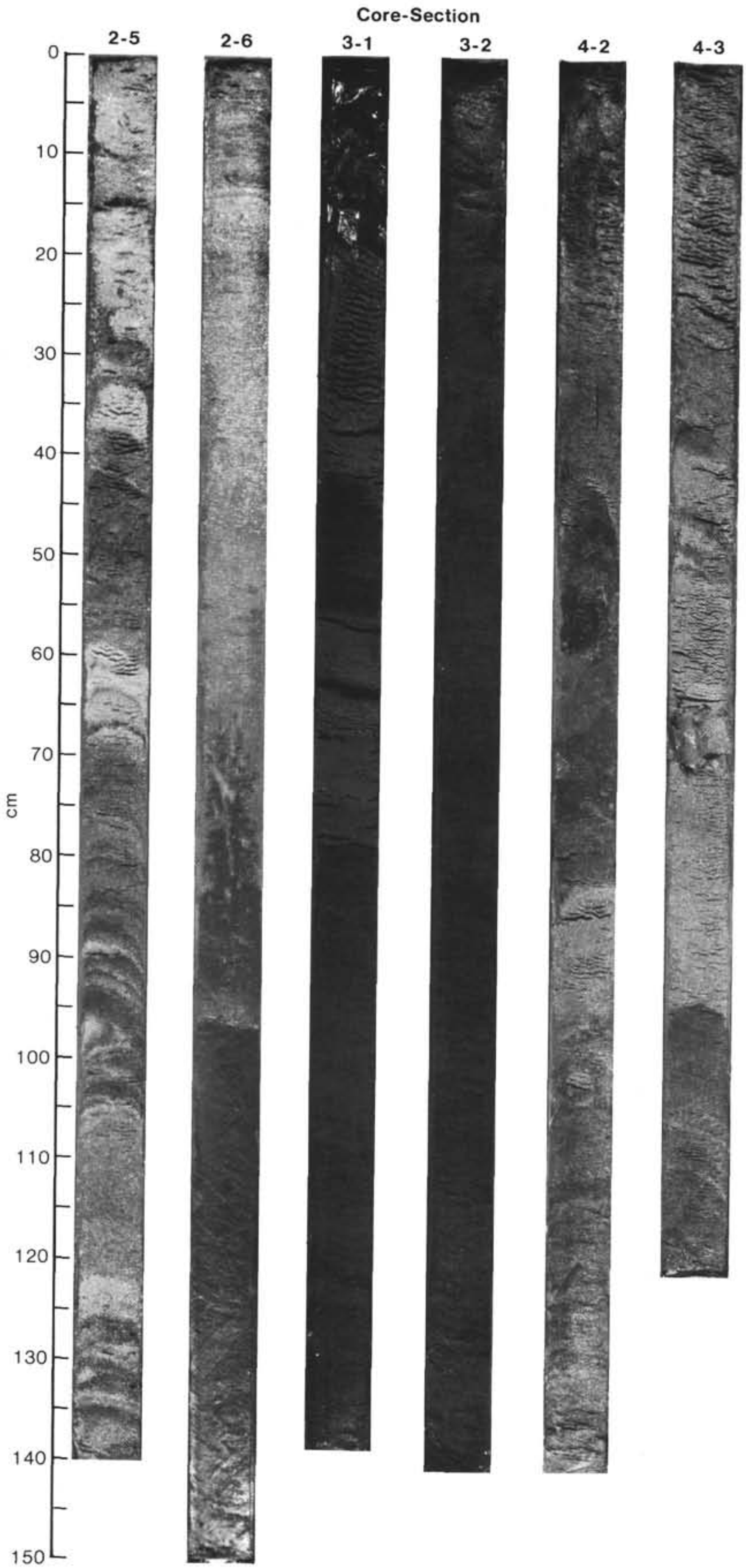


Figure 8. Sections from Hole 599 illustrating bands of alternating color.

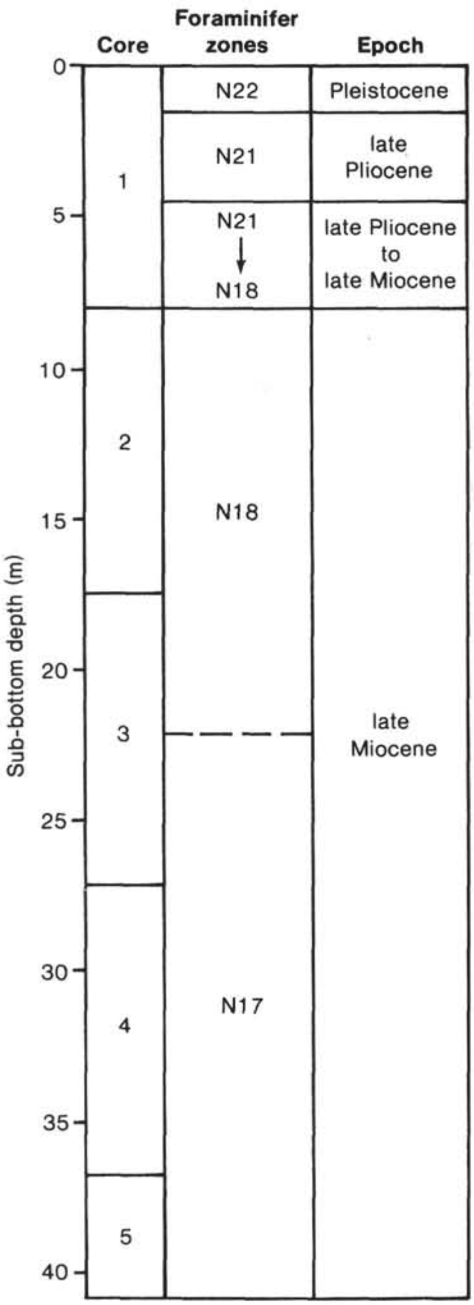


Figure 9. Planktonic foraminifer zones, Hole 599. For Hole 599, significant reworking occurs between depths of 2.8 and 34.8 m.

Table 2. Foraminifer zonation, abundance, and preservation, Site 599.

Sample (interval in cm)	Sub-bottom depth (m)	Age, Zone	Preservation
599-1-1, 15-17	0.15-1.17	Pleistocene, N22	Moderate
599-1-1, 140-150	1.40-1.50	late Pliocene, N21	Moderate
599-1-3, 140-150	4.40-4.50	late Pliocene, N21	Moderate to poor
599-1,CC	7.9	late Miocene, N18	Moderate to poor
599-2,CC	17.5	late Miocene, N18	Moderate to poor
599-3,CC	27.1	late Miocene, N17	Moderate to poor
599-4,CC	36.7	late Miocene, N17	Moderate to poor
599-5,CC	40.8	late Miocene, N17	Moderate

Note: Foraminifers were abundant in all samples.

N18. The absence of *Globorotalia tumida* in Samples 599-3,CC, -4,CC, and -5,CC places those samples in Zone N17.

A second hole, Hole 599B, was washed to 32.2 m above basement and then cored to recover the sediment/basement interface. One sediment core was recovered, and the core-catcher sample from this core and from the basal rubble below it were examined. Sample 599B-2,CC had a late Miocene age (within Zones N17B and N18). Preservation was poor, and no identifiable fragments of *G. tumida* were found; if present, that species would have marked the later zone (N18). Sample 599B-3,CC contained abundant foraminifers mixed in with bits of basalt gravel. The age of this sample could not be determined, however, since the fossil assemblage included common specimens of a number of late Miocene to Pleistocene species, suggesting downhole contamination due to coring.

Nannofossils

Two holes at Site 599 were examined for calcareous nannofossils. The sediment from Hole 599 was dated as being Pleistocene to early middle Miocene. The basal sediments from Hole 599B (599B-2,CC) were within the CN8B Subzone (Okada and Bukry, 1980). The fine fraction of Sample 599B-3,CC, which was from a core of "drilling breccia," was also examined and found to contain a mixed assemblage of Pleistocene to late Miocene nannofossils; the oldest forms were from Zone CN8B.

Samples 599-1-1, 18-19 cm and 56-57 cm are tentatively placed within the Pleistocene Zones CN13 through CN15 (Fig. 10); reworking makes this zonal assignment uncertain. Specimens from the genus *Gephyrocapsa* seem to be present; however, the individuals lack the characteristic central bar (may be *Crenalithus doronicoides*).

A sedimentary clast at about 7 to 9 cm BSF (Section 599-1-1) was also examined, and it contained, for the most part, early Pliocene nannofossils.

Samples 599-1-1, 140-150 cm and -1-2, 56-57 cm are assigned to the *Discoaster brouweri* Zone, CN12, and the *Reticulofenestra pseudoumbilica* Zone, CN11. The criteria used for zone assignment were the absence of the genera *Amaurolithus* and *Gephyrocapsa*, the presence of *Pseudoemiliania lacunosa*, and common to abundant specimens of *D. brouweri, D. pentaradiatus, D. tamalis*, and *D. surculus*. Additional species present are *Ceratolithus cristatus, C. rugosus, R. pseudoumbilica, Sphenolithus* sp., and *D. variabilis. R. pseudoumbilica* was recorded in both samples and in the overlying Sample 599-1-1, 56-57 cm; its presence is assumed to be mostly due to reworking.

The observation of *Amaurolithus amplificus* in Samples 599-1-3, 140-150 cm through 599-1,CC indicates an age of latest Miocene to early lower Pliocene for these samples (Gartner and Bukry, 1974). The presence of *A. primus* and *A. delicatus* in Sample 599-1-3, 56-57 cm places the sample within the range of Zones CN9B and CN10 but indicates the upper boundary of Zone CN10. The amount of reworking within the sample is uncertain; however, specimens of *D. neohamatus* are present. The presence of this species and the poor preservation

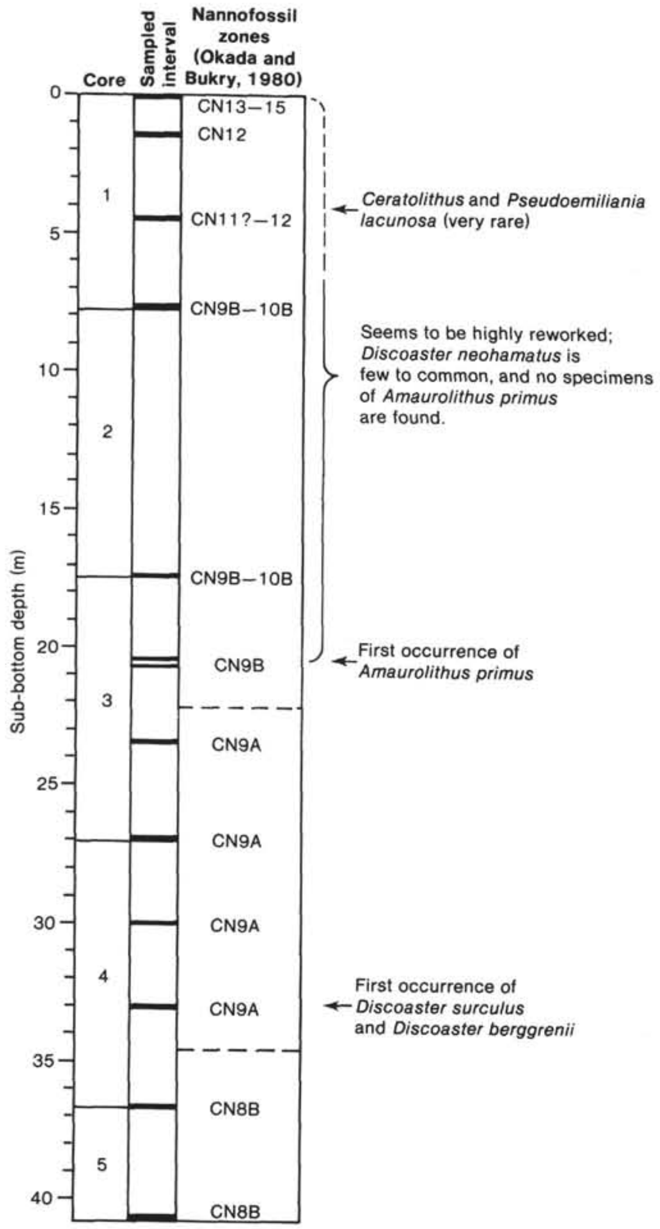


Figure 10. Nannofossil zones, Hole 599. The first occurrence of *Amaurolithus primus* takes place in Sample 599-3-3, 27–28 cm, which lies directly below a sharp lithologic break. No specimens of *Discoaster neohamatus* were found in that sample, and reworking was assumed to be minimal. For Hole 599, significant reworking occurs between depths of 2.8 and 34.8 m.

of *D. quinqueramus* made the placement of the Miocene/Pliocene boundary difficult. The boundary has been placed tentatively between Samples 599-2-1, 56–57 cm and 599-2-2, 56–57 cm. *C. rugosus*, which indicates the upper CN10C Subzone, is recorded only in Samples 599-1-3, 56–57 cm and 140–150 cm.

Samples examined between 599-2-2, 140–150 cm and -3-3, 18–20 cm were originally thought to be below the CN9B/CN9A boundary because of the absence of *A. primus* in all samples examined and the occurrence of *D. neohamatus*. Specimens of *A. primus*, however, were found to be present in Sample 599-3-3, 21–23 cm. This sample was obtained in a light brown layer directly underlying a dark brown layer; the contact between the two was sharp. No specimens of *D. neohamatus* were recorded within the sample (599-3-3, 21–23 cm); and therefore, those materials are assumed to be deposited without significant reworking. The interval (599-2-2, 56–57 cm through -4-3, 56–57 cm) is assigned to the *D. quinqueramus* Zone, *A. primus* Subzone, CN9B. The species present include *D. surculus, D. quinqueramus, D. variabilis, D. challengeri, D. brouweri, D. pentaradiatus, Cyclococcolithina macintyrei, C. leptopora, Coccolithus pelagicus*, and *Triquetrorhabdulus rugosus*. Preservation is moderate; some discoasters are overgrown, and the rest of the assemblage shows signs of dissolution. Specimens of *A. primus* below Sample 599-3-3, 18–20 cm are rare and heavily overgrown; positive identification was difficult.

Samples 599-4-4, 56–57 cm and 140–150 cm are within the *D. berggrenii* Subzone, CN9A. Zone assignment was based on the absence of *A. primus* and the presence of both *D. berggrenii* and *D. surculus*. Specimens of *D. surculus* were easier to identify, because the assemblage was overgrown, and it was difficult to verify the identification of *D. berggrenii* in the lower samples. Other species present were similar to those listed for Sample 599-3-3, 21–23 cm. *D. neohamatus* was also present.

The oldest sediments recovered from Hole 599 (599-4,CC and -5,CC) were assigned to upper subzone of the *D. neohamatus* Zone, CN8B. This zone assignment was based on the presence of *D. neohamatus* and the absence of both *D. surculus* and *Catinaster coalitus*. *D. bellus* also becomes few to common. Preservation was moderate, with most discoasters showing slight overgrowth.

SEDIMENTATION RATES

Sedimentation rates were calculated by using nannofossil zone boundaries (Table 3; Fig. 11).

The rate of sediment accumulation is relatively high in the oldest sediment (approximately 8.1 to 8.6 Ma; nannofossil age determination), 12.0 m/m.y. A decrease to 2.9 m/m.y. occurs between 6.7 and 8.1 Ma; it is followed by a large increase in rates to 14.5 m/m.y. The interval of high rates (5.4 to 6.7 Ma) also appears to be extensively reworked; lateral influx of sediment appears to be the cause of the high rate.

The calcium carbonate compensation depth (CCD) in the Pacific Ocean shoals in the Miocene. However, the basement depth at Site 599 (3695 m) has apparently been shallower than the CCD throughout the site's his-

Table 3. Sedimentation rates, Site 599.

Depth interval (m)	Age (Ma)	Sedimentation rate (m/m.y.)
0–1.0	0–1.88	0.53
1.0–2.8	1.88–3.70	0.99
2.8–11.9[a]	3.7–5.4	5.35
11.9–30.8[a]	5.4–6.7	14.54
30.8–34.8[a]	6.7–8.1	2.86
34.8–40.8	8.1–8.6	12.00

[a] Depths where reworking occurred.

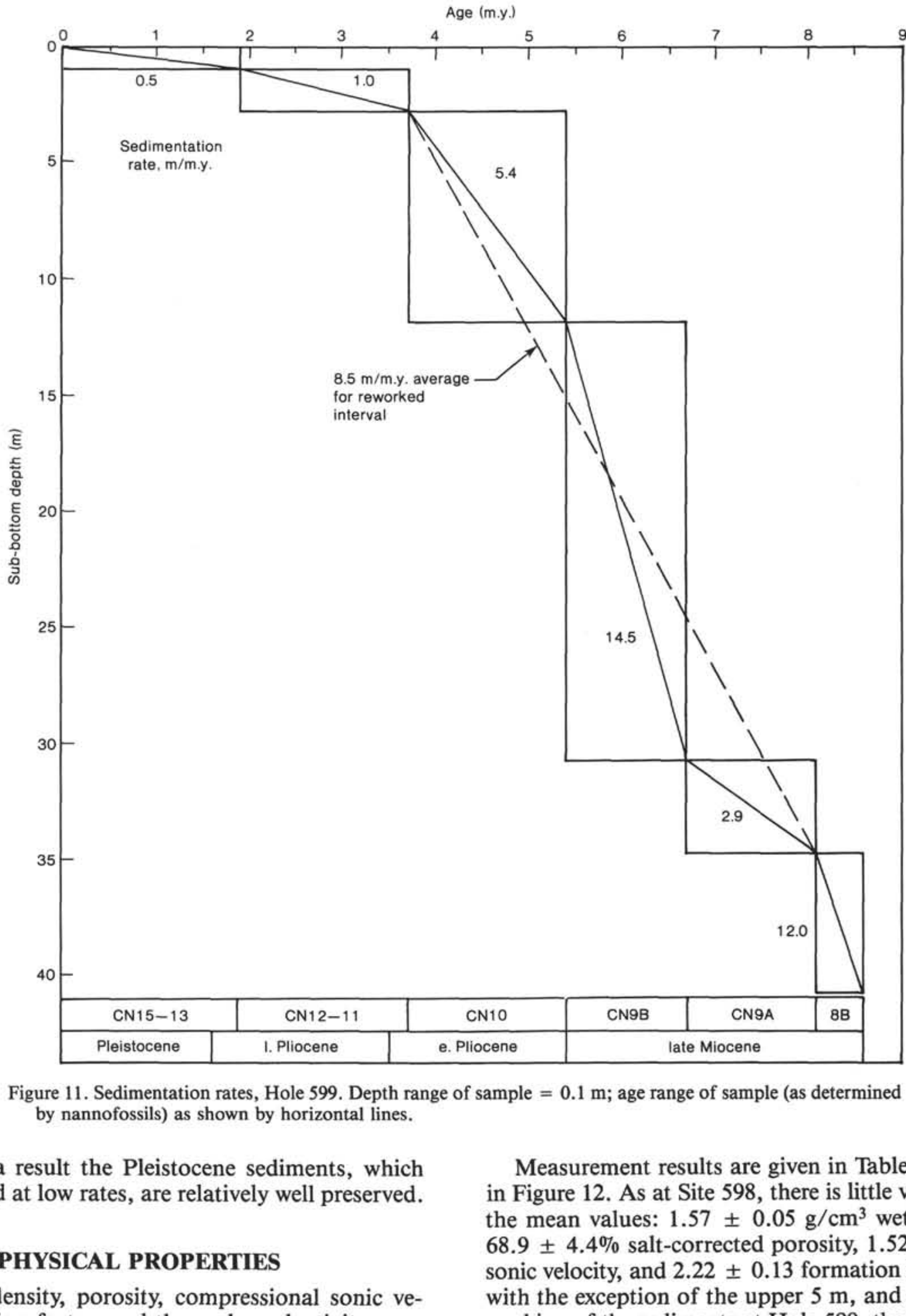


Figure 11. Sedimentation rates, Hole 599. Depth range of sample = 0.1 m; age range of sample (as determined by nannofossils) as shown by horizontal lines.

tory, and as a result the Pleistocene sediments, which were deposited at low rates, are relatively well preserved.

PHYSICAL PROPERTIES

Wet bulk density, porosity, compressional sonic velocity, formation factor, and thermal conductivity were measured once per section in Hole 599. As at Holes 597A and 598, all these measurements were made within the same 5- to 10-cm interval in each section and at ambient laboratory temperatures of 25 to 26°C. In addition, samples for the measurement of density and porosity were taken once per section in Core 599B-2. This core overlaps and extends the penetration of the deepest core in Hole 599.

Measurement results are given in Table 4 and plotted in Figure 12. As at Site 598, there is little variation about the mean values: 1.57 ± 0.05 g/cm^3 wet bulk density, 68.9 ± 4.4% salt-corrected porosity, 1.52 ± 0.01 km/s sonic velocity, and 2.22 ± 0.13 formation factor. In fact, with the exception of the upper 5 m, and despite the reworking of the sediments at Hole 599, the physical properties of the Hole 599 sediments are not significantly different from those of the Hole 598 sediments. In the upper 5 m, the physical properties of the Hole 599 sediments show no deviation from the general trend. There is no evidence of thin zone of lesser density and greater porosity, as there is at Hole 598. The general trend at both Holes 598 and 599 is somewhat surprising—porosity increases with depth and density and the other prop-

Table 4. Sediment physical properties, Site 599.

Core-Section	Sub-bottom depth (m)	Wet bulk density (g/cm^3)	Uncorrected for salt		Corrected for salt		Sonic velocity (km/s)	Acoustic impedance ($Gg/m^2 \cdot s$)	Formation factor
			Porosity (%)	Grain density (g/cm^3)	Porosity (%)	Grain density (g/cm^3)			
Hole 599									
1-1	0.77	1.54	62.6	2.46	63.3	2.44	1.532	2.36	2.33
1-2	2.27	1.65	63.3	2.76	64.0	2.75	1.530	2.52	2.50
1-3	3.77	1.64	60.7	2.62	61.4	2.61	1.536	2.52	2.28
1-4	5.27	1.63	63.6	2.74	64.3	2.73	1.522	2.48	2.28
1-5	6.77	1.65	61.4	2.69	62.1	2.69	1.537	2.54	2.42
2-1	8.67	1.59	64.1	2.65	64.8	2.64	1.526	2.43	2.33
2-2	10.17	1.53	72.8	2.93	73.6	2.93	1.508	2.31	2.05
2-3	11.67	1.54	69.9	2.80	70.7	2.79	1.509	2.32	2.15
2-4	13.17	1.60	64.2	2.66	65.0	2.65	1.524	2.44	2.37
2-5	14.67	1.56	67.6	2.73	68.4	2.72	1.519	2.37	2.26
2-6	16.17	1.58	69.0	2.87	69.8	2.86	1.509	2.38	2.23
3-1	18.27	1.49	74.7	2.92	75.6	2.92	1.505	2.24	2.12
3-2	19.77	1.50	72.8	2.84	73.7	2.83	1.510	2.27	1.99
3-3	21.27	1.63	65.3	2.81	66.0	2.80	1.524	2.48	2.29
3-4	22.77	1.54	69.3	2.77	70.1	2.76	1.512	2.33	2.07
3-5	24.27	1.52	72.8	2.89	73.6	2.89	1.501	2.28	2.08
3-6	25.77	1.54	70.5	2.82	71.3	2.81	1.520	2.34	2.11
4-1	27.87	1.52	72.5	2.88	73.4	2.87	1.501	2.28	2.18
4-2	29.37	1.56	71.0	2.93	71.8	2.92	1.508	2.35	2.11
4-3	30.87	1.59	66.8	2.77	67.6	2.76	1.514	2.41	2.29
4-4	32.37	1.53	73.3	2.97	74.1	2.97	1.508	2.31	2.12
4-5	33.87	1.58	69.7	2.91	70.5	2.90	1.510	2.39	2.21
		1.57			68.9	2.78	1.517		2.22
		±0.05			±4.4	±0.13	±0.011		±0.13
Hole 599B									
2-1	32.97	1.54	71.2	2.89	73.7	3.17			
2-2	34.47	1.54	72.5	2.96	75.1	3.28			
2-3	35.97	1.64	62.5	2.71	64.8	2.89			
2-4	37.47	1.52	71.8	2.83	74.4	3.12			
2-5	38.97	1.41	76.9	2.78	79.7	3.16			
2-6	40.47	1.41	79.8	3.00	82.7	3.50			

erties decrease, showing no evidence of increasing compaction with depth.

IGNEOUS PETROLOGY

Recovery

Igneous basement rocks were recovered from Holes 599 and 599B. A few small altered glassy basalt chips were recovered from Hole 599, and 2.08 m were recovered from Hole 599B (0.75 m of drilling breccia and 1.33 m of rounded basalt fragments).

Hole 599

Core 599-5 contained watery sediment and a few glassy basalt chips. The highly altered basalt glass fragments have an outer rim of palagonite, red brown smectite, iron oxyhydroxides, and some calcite. The total amount of glass is about 50 cm^3; the largest fragments are about 1 cm across.

Hole 599B

Cores 599B-3 and -4, which were drilled with the extended core barrel, penetrated 9 m into basement. Section 599B-3-1 contains 0.75 m of drilling breccia; Section 599B-3-2 contains 0.77 m of round basalt fragments; and Section 599B-4-1 contains 0.52 m of basalt and pillow fragments. All pieces are unoriented. In total, 2.08 m were recovered.

Lithology

The main rock type is a glassy to fine-grained, gray, slightly altered, almost nonvesicular basalt. Two pieces have a glassy margin about 1 mm in thickness and represent pillow fragments. Some pieces show radial fractures. Almost all fragments contain outer oxidative alteration zones 1 to 2 cm wide. The drilling breccia ("gravel") contains about 5% basaltic glass and palagonite.

Mineralogy

All rocks are olivine-poor tholeiites containing 40 to 50% plagioclase, 45 to 55% clinopyroxene, about 5% magnetite, and less than 1% olivine. All the rocks recovered are aphyric, and their texture is subspherulitic to intergranular. The spherulites consist of acicular crystals of plagioclase and granular to dendritic clinopyroxene; magnetite is disseminated mainly within and around the clinopyroxene grains. The grain size ranges from less than 0.05 to 0.1 mm for olivine, 0.1 to 0.4 mm for plagioclase and clinopyroxene, and less than 0.01 mm for magnetite.

Piece 3 in Section 599-3-2 has an outer rim of palagonite and thin calcite veins in contact with fresh glass.

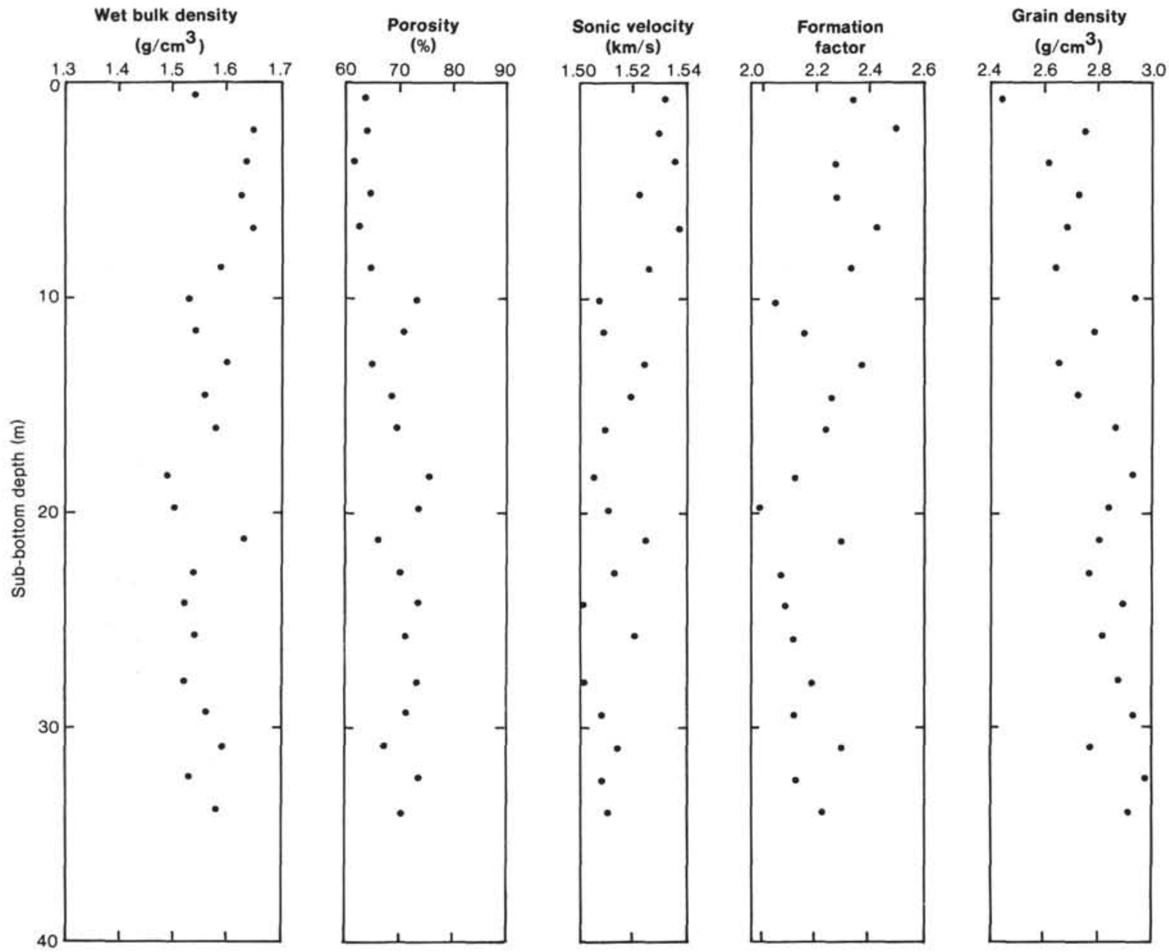


Figure 12. Physical properties, Site 599.

The other fragments contain an outer oxidative alteration zone about 1 to 2 cm wide. These altered zones are dark gray or brownish gray; the interiors are lighter gray.

In the altered zones the vesicles are sparse, small, and filled with a brown smectite and/or iron oxyhydroxides. Some clinopyroxene may be replaced by red brown clays. Iddingsite partially to completely replaces the olivine, and magnetite is replaced by hydrated Fe (III) oxides.

The interiors of the fragments are almost fresh. Most vesicles are empty, but some are filled with blue and brown smectites. Some olivine is replaced by iddingsite.

INTERSTITIAL WATER STUDIES

At Site 599, as at Site 597, we squeezed the interstitial water samples at room temperature immediately after the sediment was recovered. Our data from previous sites indicated that the effect of squeezing the samples at about 4° to 8°C would result in less realistic values for dissolved calcium (see Site 597 chapter, this volume).

The overall results are much the same as for Sites 597 and 598. Downcore alkalinity changes do not appear to be significant (Fig. 13; Table 5).

Nitrate concentrations in squeezed samples agree well with *in situ* values. The profile indicates greater production in the upper 10 to 15 m than lower in the sediment. Similarly, the dissolved ammonia profile suggests greater production in the upper few meters (Fig. 13, Table 5).

The dissolved silica values vary from 250 to 500 μM, higher than the values for Sites 597 and 598 (Fig. 13, Table 5). These values suggest that silica is present in the sediments and is available for dissolution even though no siliceous microfossils were observed.

There is little downhole variation in magnesium and potassium except for changes due to the temperature-of-squeezing effect, and the *in situ* concentrations are, within the accuracy of the methods, the same as in the overlying bottom water (Fig. 13; Table 5).

In both the squeezed and *in situ* samples, dissolved calcium increases downhole, and the divergence between "squeezer" and *in situ* values may also increase downcore. We conclude (as for Sites 597 and 598) that carbonate dissolution is the most logical explanation for the general trends. Alkalinity does not reflect the increase in bicarbonate concentration, perhaps because of the different rates of diffusion of HCO_3^- and Ca^{2+} ions.

In conclusion, the constituents of the interstitial water at this site, with the exception of ammonia, nitrate, and calcium, show conservative behavior (concentrations do not vary with increasing depth). No flux of water through the sediment column is apparent from the data.

HEAT FLOW

Three temperature measurements were made in the sediments at Hole 599A, and one temperature measure-

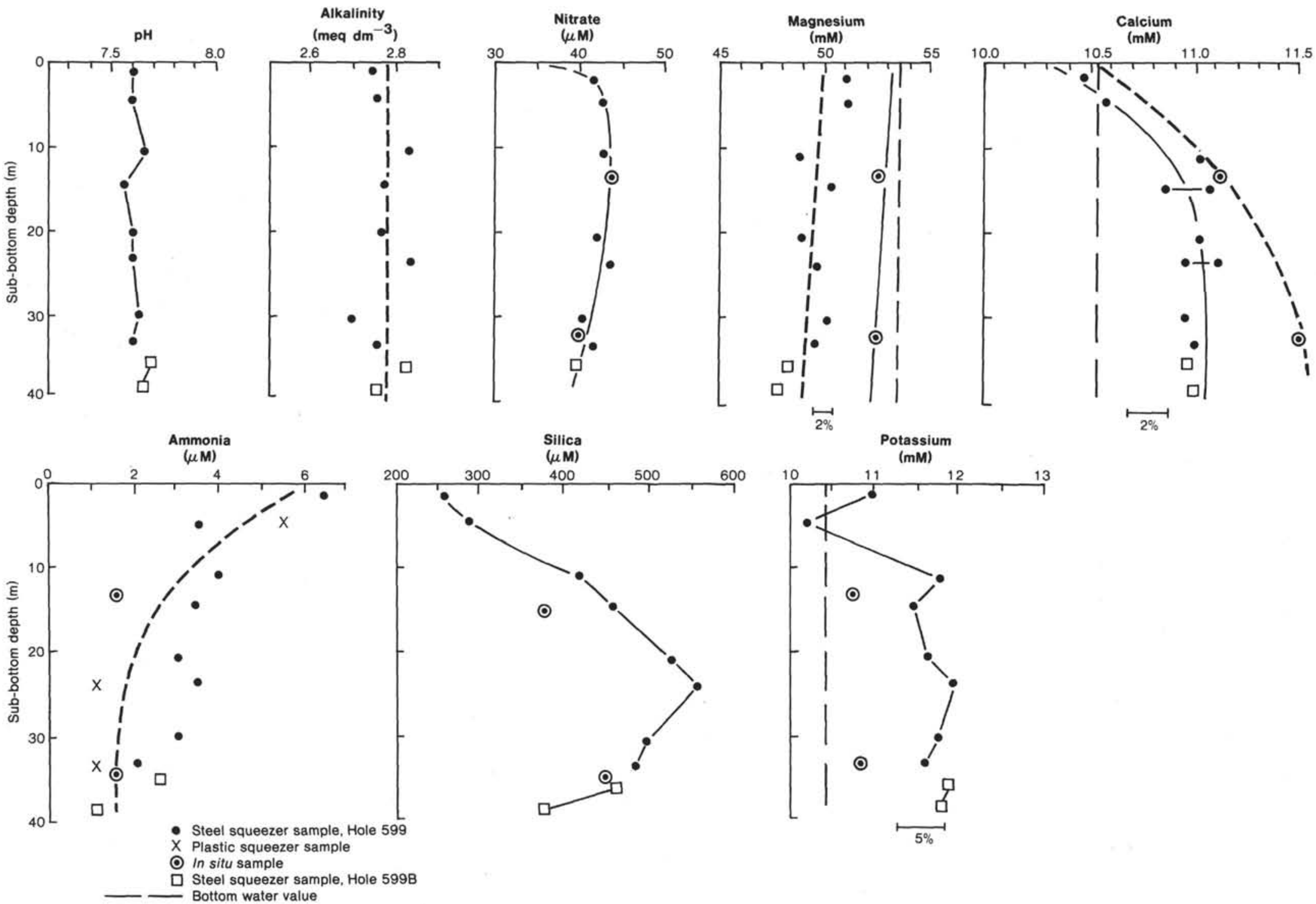


Figure 13. Interstitial water data, Site 599.

Table 5. Interstitial water chemistry, Site 599.

Sample (interval in cm)	Sub-bottom depth (m)	pH	Alkalinity ($meq \cdot dm^{-3}$)	Ca (mM)	Mg (mM)	K (mM)	Cl (mM)	SO_4 (mM)	NO_3 (μM)	NH_4 (μM)	SiO_2 (μM)
Hole 599											
1-1, 140–150	1.5	7.61	2.75	10.49	51.1	11.0	552	26.2	42	6.5	259
1-3, 140–150	4.5	7.60	2.76	10.57	51.2	10.2	550	27.6	43	3.5	286
2-2, 140–150	10.9	7.66	2.84	11.03	48.85	11.8	558	27.6	43	4.0	420
2-5, 140–150	14.4	7.56	2.78	10.85	50.4	11.5	556	28.0		3.5	456
3-2, 140–150	20.5	7.61	2.77	11.03	49.0	11.7	557	28.3	42.5	3.0	525
3-4, 140–150	23.5	7.60	2.84	11.11	49.8	12.0	559	27.6	44	3.5	556
4-2, 140–150	30.1	7.63	2.69	10.95	50.2	11.8	556	27.5	41.5	3.0	497
4-4, 140–150	33.1	7.60	2.76	11.00	49.7	11.6	557	26.7	42	2.0	487
Hole 599A											
In situ 1	15.0			11.11	52.6	10.8	558	29.3	44	1.5	376
Hole 599B											
In situ 2	34.3			11.50	52.6	10.9	556	29.2	40.5	1.5	451
2-2, 140–150	35.2	7.68	2.83	10.95	48.1	12.0	559	27.1	40	2.5	459
2-4, 140–150	38.2	7.65	2.76	10.99	47.8	11.8	553	27.1		1.0	375

ment was made in the adjacent Hole 599B (Fig. 14). The measurements were made with the Von Herzen VLHPC temperature tool. The Barnes/Uyeda/Kinoshita pore water/heat flow sampler was used simultaneously with the VLHPC tool by using a special connecting subassembly. The pore water/heat flow device failed to obtain a temperature value because of mechanical damage.

The temperature measurements were made at depths of 3.4, 13.0, 22.6, and 32.4 m BSF. The record at 3.4 m indicated that the probe started to sink farther into the mud after about 5 min. at the 3.4-m depth, so we used only the first portion of the record to extrapolate a temperature. Nevertheless, the temperature measured at this depth lies above the slope of the line that best fits the deeper temperature measurements, as at Hole 598A. Very shallow DSDP temperature measurements are often high, a behavior that is not well understood. All of the measurements were good, with little sign of disturbance due to drill pipe motion. A temperature gradient of 106 m°C/m was calculated from the bottom water temperature and the three deepest temperature measurements.

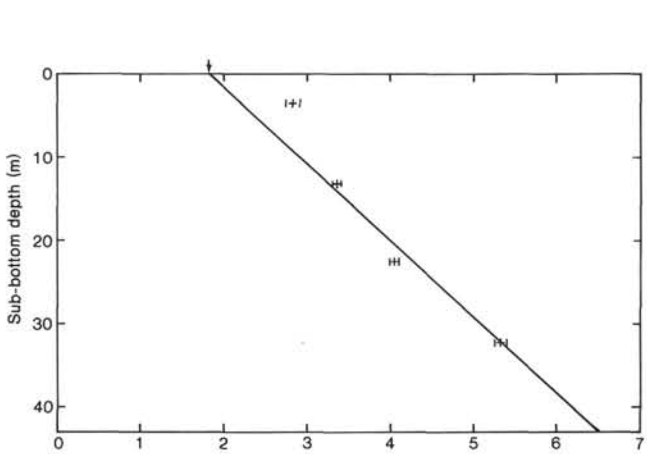


Figure 14. Temperature versus depth, Holes 599A and 599B. The chosen temperature gradient of 106 m°C/m is shown by the line.

Thermal conductivity was measured on every section of core recovered from Hole 599, but the data were not reduced at sea. If we use the value of 0.95 W/m-K obtained during the site survey, the heat flow resulting from our measured gradient is 101 mW/m². The theoretical value is 171 mW/m² for crust of 8-Ma age.

The heat flow results from Holes 599A and 599B and the site survey results are shown in Figure 3. The value of 101 mW/m² from Holes 599A and 599B is higher than the other values in the holes' immediate vicinity, although the value is not very different from the values of 77 and 73 mW/m² found not far away. The average of the site survey values was 70 mW/m², with a standard deviation of 47 mW/m².

The temperature gradient of 106 m°C/m (Fig. 14) and the sediment thickness of about 41 m extrapolate to a basement temperature of 6.2°C, if thermal conductivity is assumed to be constant with increasing depth.

SUMMARY AND CONCLUSIONS

Site 599 was drilled to provide a continuous record of late Miocene to Recent sedimentation for the evaluation of past hydrothermal activity, paleoceanography, and paleoclimate, to obtain data appropriate for the constraint of models of ridge-flank hydrothermal convection, and to collect basalt generated at the fast-spreading East Pacific Rise for comparison with basalt collected at Site 597, which was generated at the Mendoza Rise. Magnetic anomalies from *Conrad*-13, Ariadne II, and Leg 92 underway magnetics indicate a basement age of about 7.8 Ma (Anomaly 4A) for Site 599, about 0.5 Ma younger than the age of the basal nannofossil zone. Three holes were drilled. Hole 599 was cored to a depth of 40.8 m using the VLHPC, and 34.76 m of sediment were recovered. Hole 599A was drilled solely to obtain heat flow measurements and *in situ* pore water samples; three heat flow measurements and one pore water sample were acquired. Hole 599B was washed to 23.6 m, where a temperature measurement was made for heat flow determination and an *in situ* pore water sample was taken. We recovered one VLHPC core between 32.2 and 40.8 m so we could examine the basal sediments at the site. Then the XCB was used to drill basement rock to a total depth of 49.8 m.

Sediment Studies

The sediments recovered in Holes 599 and 599B are clayey and clay-bearing nannofossil oozes. Only one lithologic unit is present. The sediments show alternating light- and dark-colored zones (generally 10 cm to 1 m thick) and bands (2 to 5 cm thick). The color variations are the result of differences in the sediment's calcium carbonate content (70 to 80% in the light-colored sediments, 55 to 70% in the dark sediments). The noncarbonate fraction is made up primarily of clays and RSO. The sediments are significantly darker than those of equal carbonate content at Site 597 and are similar to those from Site 598.

Most of the sediment column, particularly the upper 21 m, appears to be extensively reworked. Some of the color zones have sharp lower contacts, and at one level (599-3-3, 21 cm), the nannofossils in the upper, darker sediments are 1 to 2 m.y. older than those in the underlying lighter material. In addition, the changes in grain size across the contacts are indicative of turbidity current deposition. The extensive mottling of the sediments above the contact at 599-3-3, 21 cm suggests that the redeposition of these sediments was complex and probably intermittent, however. Many parts of the sediment column (e.g., Sections 599-2-5, -2-6, -3-1, -3-2, -4-2, and -4-3) have many alternating color bands with fairly sharp upper and lower contacts. The bands may be caused by cycles of redeposition, dissolution, dilution, or some combination of the three.

Foraminifers were abundant in the sedimentary section, but the age indicated by the foraminifer zonation was substantially different from that indicated by the nannofossil zonation, probably because the nannofossils were better preserved. A basement age of 5.2 to 6.4 Ma is indicated by the foraminifers, whereas a basement age of 8.1 to 8.6 Ma is indicated by the nannofossils. Because of the approximate agreement between the latter and the magnetic anomaly age and because the nannofossils were well enough preserved to permit a fairly detailed zonation, we based our sediment ages and deposition rates on the nannofossils.

The upper 1.0 m of sediment was dated as Pleistocene and was deposited at a rate of 0.5 m/m.y. Pliocene age (CN12 and CN11) was assigned to the sediments below 1.0 m in Core 599-1 (for a sedimentation rate of 1.0 m/m.y.). The Miocene/Pliocene boundary is at about 11.9 m BSF. The sediments at the base of the section were of late Miocene age, and sedimentation rate ranged from 2.9 to 12.0 m/m.y.

The physical properties of the sediments showed little variation from mean values of 1.57 g/cm^3 for wet bulk density, 69% for porosity, 2.78 g/cm^3 for grain density, 1.52 km/s for sonic velocity, and 2.22 for formation factor. By using dry bulk densities calculated from the wet bulk densities and porosities, we calculated mass accumulation rates for the sediments. They ranged from 0.05 g/(cm^2 $\times$ 10^3 yr.) in the Pleistocene sediments near the surface to 0.93 g/(cm^2 $\times$ 10^3 yr.) in the clayey nannofossil ooze near the sediment/basalt contact. The mass accumulation rate of the hydrothermal component, clays and RSO, varies from 250 to 500 mg/(cm^2 $\times$ 10^3 yr.) in the lower half of the core and decreases toward the top.

Igneous Rocks

Igneous basement rocks were recovered from Holes 599 and 599B. Only a few small, altered, glassy basalt chips were recovered from Hole 599, but 2.08 m of drilling breccia and basalt cobbles were recovered from Hole 599B. The basalt cobbles may all be fragments of pillows, but only two pieces have glassy rims. All the pieces have an altered outer zone and a relatively fresh interior. They are almost nonvesicular, spherulitic to intergranular basalts that are olivine-poor tholeiites.

Experimental Studies

Two interstitial water samples were squeezed from each core, and two *in situ* water samples were taken, one each from Holes 599A and 599B. Only Ca^{2+} showed any deviation from conservative behavior downcore, and the Ca^{2+} profile appear to reflect the dissolution of carbonate in the sediments. There was no evidence of advective pore water flux at the site.

Three temperature measurements were made with the VLHPC heat flow shoe at Hole 599A; one was made at Hole 599B. The temperature gradient measured at Hole 599A was 106 m°C/m. If the value of sediment thermal conductivity recovered during the site survey cruise is used, the heat flow is 101 mW/m^2, a value about half the theoretical heat flow for 8-Ma crust.

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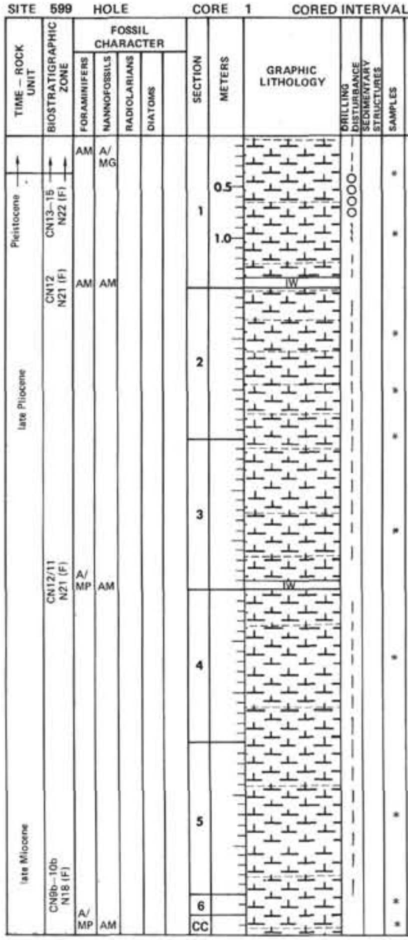
SITE 599 HOLE CORE 1 CORED INTERVAL 0.0–7.9 m



LITHOLOGIC DESCRIPTION

Section 1: CLAY-BEARING NANNO OOZE
0–60 cm: Yellowish brown (10YR 5/4)
60–120 cm: Yellow (10YR 7/6)
120–140 cm: Light yellowish brown (10YR 6/4)
5–7 cm: Turbidite

Section 2: CLAYEY NANNO OOZE
0–19 cm: Brown (7.5YR 4/4)
19–24 cm: Reddish yellow (7.5YR 6/6), possible turbidite
24–70 cm: Strong brown (7.5YR 4/6)
70–117 cm: Strong brown (7.5YR 5/6)
117–158 cm: Strong brown (7.5YR 5/8)

Section 3: CLAY-BEARING NANNO OOZE
0–20 cm: Yellowish brown (10YR 5/8)
20–128 cm: Very pale brown (10YR 7/4)
128–140 cm: Yellowish brown (10YR 5/6)

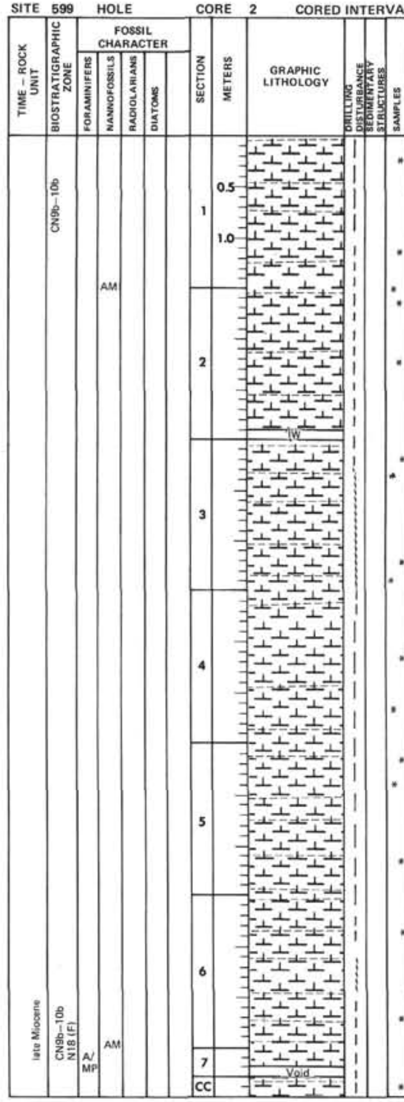
Section 4: CLAY-BEARING NANNO OOZE
0–88 cm: Yellowish brown (10YR 5/6)
88–120 cm: Dark yellowish brown (10YR 4/4)
120–150 cm: Yellowish brown (10YR 5/4)

Section 5: CLAY-BEARING NANNO OOZE
0–19 cm: 10YR 4/4
19–119 cm: 10YR 5/4
119–150 cm: 10YR 4/3

Section 6: CLAY-BEARING NANNO OOZE
0–21 cm: Dark yellowish brown (10YR 4/4)

Core Catcher:
0–18 cm: CLAY-BEARING NANNO OOZE

SITE 599 HOLE CORE 2 CORED INTERVAL 7.9–17.5 m



LITHOLOGIC DESCRIPTION

Section 1: CLAY-BEARING NANNO OOZE
0–80 cm: Light olive brown (2.5Y 5/4)
80–150 cm: Olive brown (2.5Y 4/4)

Section 2: CLAYEY NANNO OOZE
0–12 cm: Dark yellowish brown (10YR 4/4)
12–52 cm: Dark reddish brown (5YR 3/3)
52–56 cm: Dark yellowish brown (10YR 4/4)
56–101 cm: Dark reddish brown (5YR 3/3)
101–104 and 108–113 cm: Dark yellowish brown (10YR 4/4)
104–108 and 113–125 cm: Dark reddish brown (5YR 3/3).

Section 3: CLAY-BEARING TO CLAYEY NANNO OOZE
0–22 cm: Dark reddish brown (5YR 3/3)
22–150 cm: Dark yellowish brown (10YR 4/4)

Section 4: CLAY-BEARING TO CLAYEY NANNO OOZE
0–118 cm: Dark yellowish brown (10YR 4/4)
118–130 cm: Dark reddish brown (5YR 3/3)
130–150 cm: Same as 0–118 cm

Section 5: CLAY-BEARING TO CLAYEY NANNO OOZE
Alternate bands: Dark yellowish brown (10YR 5/4) and dark reddish brown (5YR 3/3), see core sheet for detail

Section 6: CLAYEY NANNO OOZE
Alternate bands: Dark yellowish brown (10YR 5/4) and dark reddish brown (5YR 3/3), see core description for details

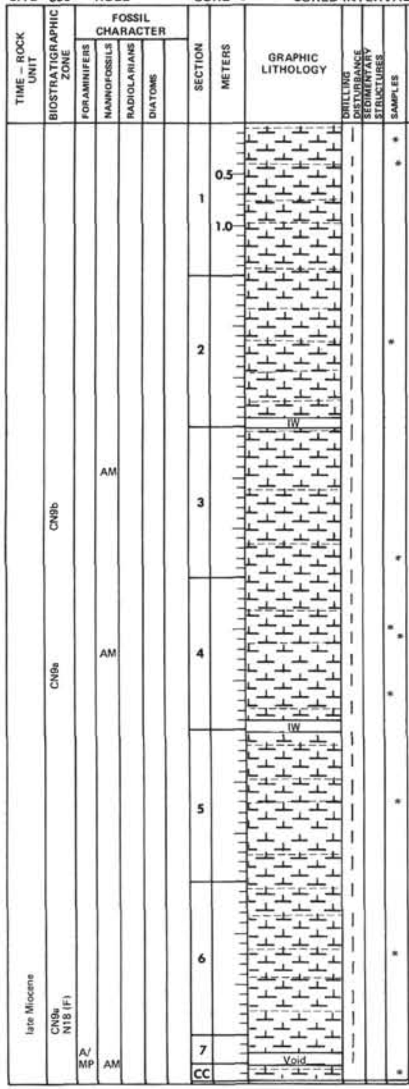
Section 7: CLAYEY NANNO OOZE

Core Catcher: CLAYEY NANNO OOZE

SMEAR SLIDE SUMMARY (%):

	2, 8	4, 114	6, 40
Texture:			
Sand	–	5	–
Silt	70	70	–
Clay	30	25	–
Composition:			
Feldspar	TR	–	–
Clay	25–30	25	30
Volcanic glass	~3	5	–
Palagonite	TR	~1	~2
Foraminifers	~1	4	2
Calc. nannofossils	70	~70	70
Opaques	–	~2	~2

SITE 599 HOLE CORE 3 CORED INTERVAL 17.5–27.1 m



LITHOLOGIC DESCRIPTION

Section 1: CLAY-BEARING TO CLAYEY NANNO OOZE
0–41 cm: Dark yellowish brown (10YR 4/4)
41–55 cm: Dark brown (7.5YR 3/2)
55–78 cm: Brown (7.5YR 4/4)
78–119 cm: Dark brown (7.5YR 3/2)
119–121 cm: Very dark brown (7.5YR 2/2)
121–139 cm: Dark reddish brown (5YR 3/2)

Section 2: CLAYEY NANNO OOZE
Vaguely banded. Base color is dark brown (7.5YR 3/2). Bands are of very dark brown (7.5YR 2.5/2).

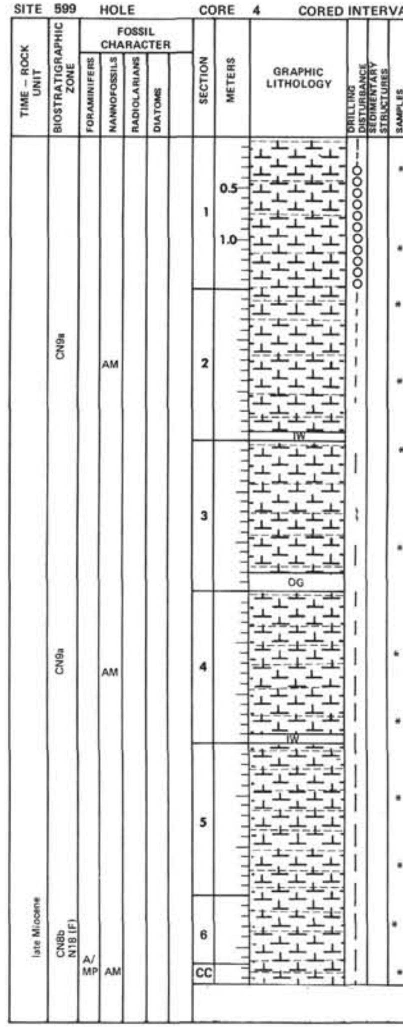
Section 3: CLAYEY TO CLAY-BEARING NANNO OOZE
0–21 cm: Dark brown (7.5YR 3/2)
21–150 cm: 7.5YR 5/4 grading to 7.5YR 4/4

Section 4: CLAYEY TO CLAY-BEARING NANNO OOZE
0–19 cm: 7.5YR 3.5/4
19–59 cm: 5YR 3/2 sharp lower contact
59–108 cm: 7.5YR 4/4
108–140 cm: 7.5YR 3/2

Section 5: CLAYEY NANNO OOZE
Dark brown (7.5YR 3/2)

Section 6: CLAYEY NANNO OOZE
Very dusky red to dark reddish brown (2.5 to 5YR 2/2)

SITE 599 HOLE CORE 4 CORED INTERVAL 27.1–36.7 m



LITHOLOGIC DESCRIPTION

Section 1: CLAYEY NANNO OOZE TO NANNO CLAY
0–31 cm: Dark reddish brown (5YR 7/4)
29–33 cm: Brown (7.5YR 4/4)
33–150 cm: Dark reddish brown (5YR 3/3)

Section 2: CLAYEY NANNO OOZE
0–82 cm: Dark reddish brown (5YR 3/3)
82–110 cm: Dark yellowish brown (10YR 3/4)
110–130 cm: Same as 0–82 cm
130–134 cm: Same as 82–110 cm
134–137 cm: Same as 0–82 cm
137–140 cm: Same as 82–110 cm

Section 3: CLAYEY NANNO OOZE
0–24 cm: Dark yellowish brown (10YR 3/4)
24–39 cm: Dark reddish brown (5YR 3/3)
39–44 cm: Same as 0–24 cm
44–46 cm: Same as 24–39 cm
46–48 cm: Same as 0–24 cm
48–50 cm: Same as 24–39 cm
50–94 cm: Same as 0–24 cm
94–120 cm: Same as 24–39 cm

Section 4: CLAYEY NANNO OOZE
0–105 cm: Dark reddish brown (5YR 3/3)
105–127 cm: Dark yellowish brown (10YR 3/4)
127–140 cm: Same as 0–105 cm

Section 5: CLAYEY TO CLAY-BEARING NANNO OOZE
0–5 cm: Dark reddish brown (5YR 3/3)
5–12 cm: Dark yellowish brown (10YR 3/4)
12–25 cm: Same as 0–5 cm
25–35 cm: Same as 5–12 cm
35–125 cm: Same as 0–5 cm and light bands
125–135 cm: Same as 5–12 cm and dark bands

Section 6: CLAYEY NANNO OOZE
0–7 cm: Dark reddish brown (5YR 3/3)
7–38 cm: Dark yellowish brown (10YR 3/4)
38–64 cm: Same as 0–7 cm

Core Catcher: CLAYEY NANNO OOZE
Dark reddish brown (5YR 3/3)

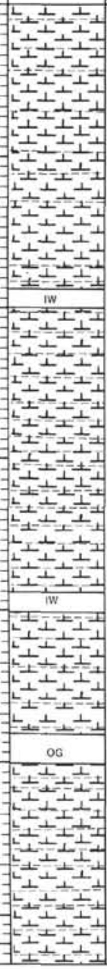
SMEAR SLIDE SUMMARY (%):

	2, 90	4, 60	6, 30
Texture:			
Sand	2–4	5	–
Silt	65	55	–
Clay	30	40	–
Composition:			
Clay	< 30	≤ 40	> 30
Volcanic glass	TR	–	–
Palagonite	> 2	> 2	~1
Foraminifers	~2	< 2	~2
Calc. nannofossils	~70	55	65
Fish remains	–	–	TR
Opaques	1–2	~2	~1

SITE 599 HOLE B CORE 2 CORED INTERVAL 32.2–40.8 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS
?	CN9a/8b		AM			1	0.5, 1.0
						2	
						3	
						4	
						5	
						6	
late Miocene	CN8b (N) N18 (F)	CP	AM			7	
						CC	

GRAPHIC LITHOLOGY



DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | SAMPLES

LITHOLOGIC DESCRIPTION

Section 1: CLAYEY NANNO OOZE
0–150 cm: Dark reddish brown (5YR 3/3)

Section 2: CLAYEY NANNO OOZE
0–140 cm: Dark reddish brown (5YR 3/3)

Section 3: CLAY-BEARING TO CLAYEY NANNO OOZE
Alternating color bands:
0–7, 32–37, and 82–150 cm: Dark reddish brown (5YR 3/3) with occasional faint light bands
7–32 and 37–82 cm: Olive brown (2.5YR 4/4) with occasional faint dark bands

Section 4: CLAYEY NANNO OOZE
0–140 cm: Dark reddish brown (5YR 3/3)

Section 5: CLAYEY NANNO OOZE
0–120 cm: Dark reddish brown (5YR 3/2)

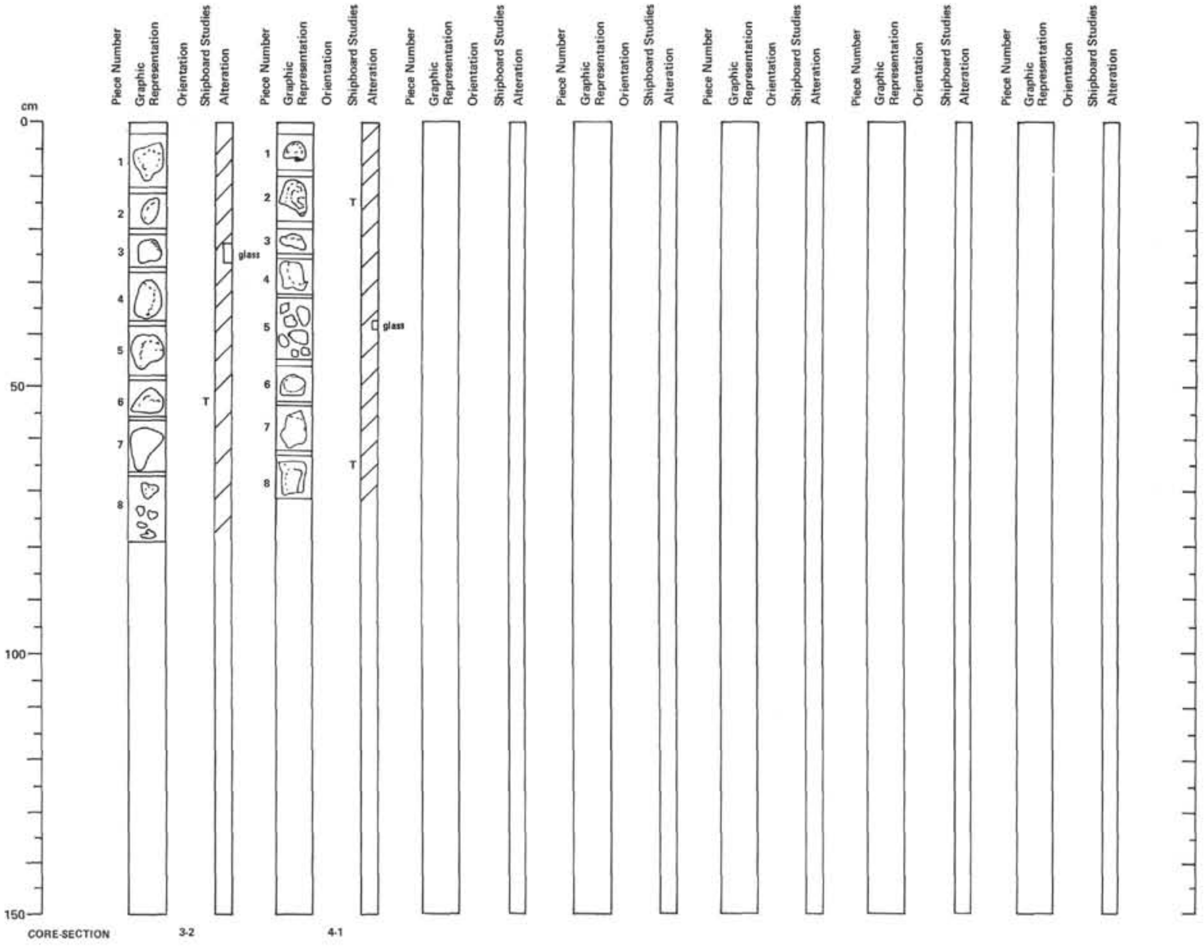
Section 6: CLAYEY NANNO OOZE
0–150 cm: Dark reddish brown (5YR 2.5/4)

Section 7: CLAY-BEARING NANNO OOZE
0–38 cm: Dark reddish brown (5YR 2.5/3)

Core Catcher: NANNO CLAY
0–12 cm: Dark reddish brown (5YR 2.5/2)

SMEAR SLIDE SUMMARY (%):

	2, 75	4, 75	6, 75
Composition:			
Clay	40–45	40–45	40–45
Volcanic glass	–	–	TR
Palagonite	~1	~1	1–2
Foraminifers	5	~3	2–3
Calc. nannofossils	50–55	50–55	50–55
Opaques	TR	TR	TR



92-599B-3 Depth: 40.8–49.8 m

Section 2:

Macroscopic description

Rounded unorientated fragments of basalt ranging from glassy through aphanitic to fine-grained. Color: gray to brownish-gray. Piece 3 is a pillow fragment containing a glassy selvage (~1 mm fresh glass with an outer rim of palagonite and thin veins of zeolite and calcite) with an inner spherulitic zone and radial fractures. The other fragments contain outer oxidative alteration zones ~1 cm wide but show no pillow structures. Likely mineralogy is plagioclase and clinopyroxene (?clinopyroxene microphyritic) and pseudomorphed olivine and magnetite. Alteration slight to moderate. Vesicles sparse and small and sometimes filled by brown smectite. 'Gravel' accompanying core contains ~5% basaltic glass and palagonite.

Thin section description

Piece 6, 48–51 cm: Aphyric basalt. Groundmass consists of 1–5% olivine in equant grains ~0.1 mm square, acicular plagioclase crystals 0.1–0.2 mm long (45–50%), granular and feathery clinopyroxene 0.1–0.2 mm long (45–50%), and magnetite grains 0.005–0.01 mm across (1–5%). Magnetite is disseminated within and between clinopyroxene grains. Olivine is rimmed by iddingsite near the outer altered rim of the piece. In the outer rim olivine is completely replaced and pseudomorphed by iddingsite.

92-599B-4 Depth: 43.8–49.8 m

Section 1:

Macroscopic description

Rounded unoriented fragments of basalt ranging from aphanitic to fine-grained. Colors from light gray to brownish gray. Fragments in Piece 5 have thin glassy rims with palagonite coatings, and may be pillow fragments. The other pieces contain outer zones of oxidative alteration, but no apparent pillow structures. A lesser degree of alteration extends into the interiors of the pieces. Pieces 1 and 3 show a spherulitic texture. The most likely mineralogy is plagioclase (forming spherules in Pieces 1 and 3), clinopyroxene, and altered and pseudomorphed olivine and magnetite. Vesicles sparse and small, most abundant in Pieces 2 and 6, sometimes filled with blue or brown smectite. Alteration slight to moderate. Piece 2 contains 2 to 3 zones of alteration inside the prominent outer oxidized zone. The outer oxidized zone on the pieces is up to 1 cm thick, and a darker gray or brownish gray compared to the interiors of the pieces.

Thin section description

Piece 2, 12–15 cm: Aphyric basalt. One plagioclase phenocryst, 1.3 × 0.4 mm. Groundmass consists of plagioclase (40–45%) in acicular crystals 0.1–0.2 mm long, clinopyroxene (50–55%) in granular to dendritic crystals 0.15 mm long, magnetite in possibly skeletal grains less than 0.1 mm long (1–5%), and <1% olivine. Some of the plagioclase and clinopyroxene form subspherical clusters. Some clinopyroxenes are cloudy; olivine is almost entirely altered, magnetite is disseminated in and around clinopyroxene. Scattered vesicles more abundant towards the interior of the piece, are 0.3–1.5 mm in diameter, squared to oblong and rounded, and empty. They form ≤1% of the groundmass.

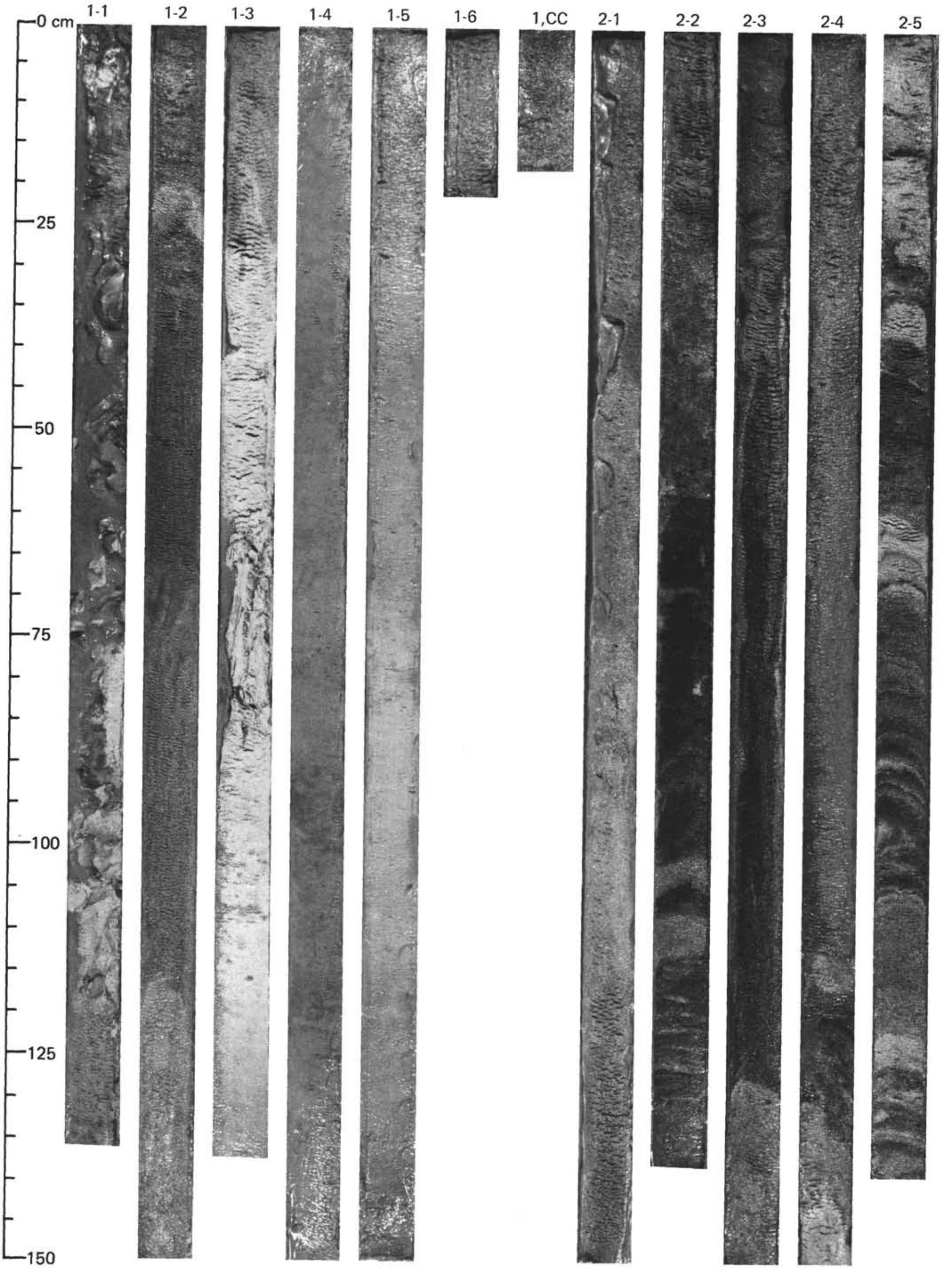
Concentric bands within the piece and an exterior altered rim contain 5–7% pseudomorphs after olivine, now iddingsite.

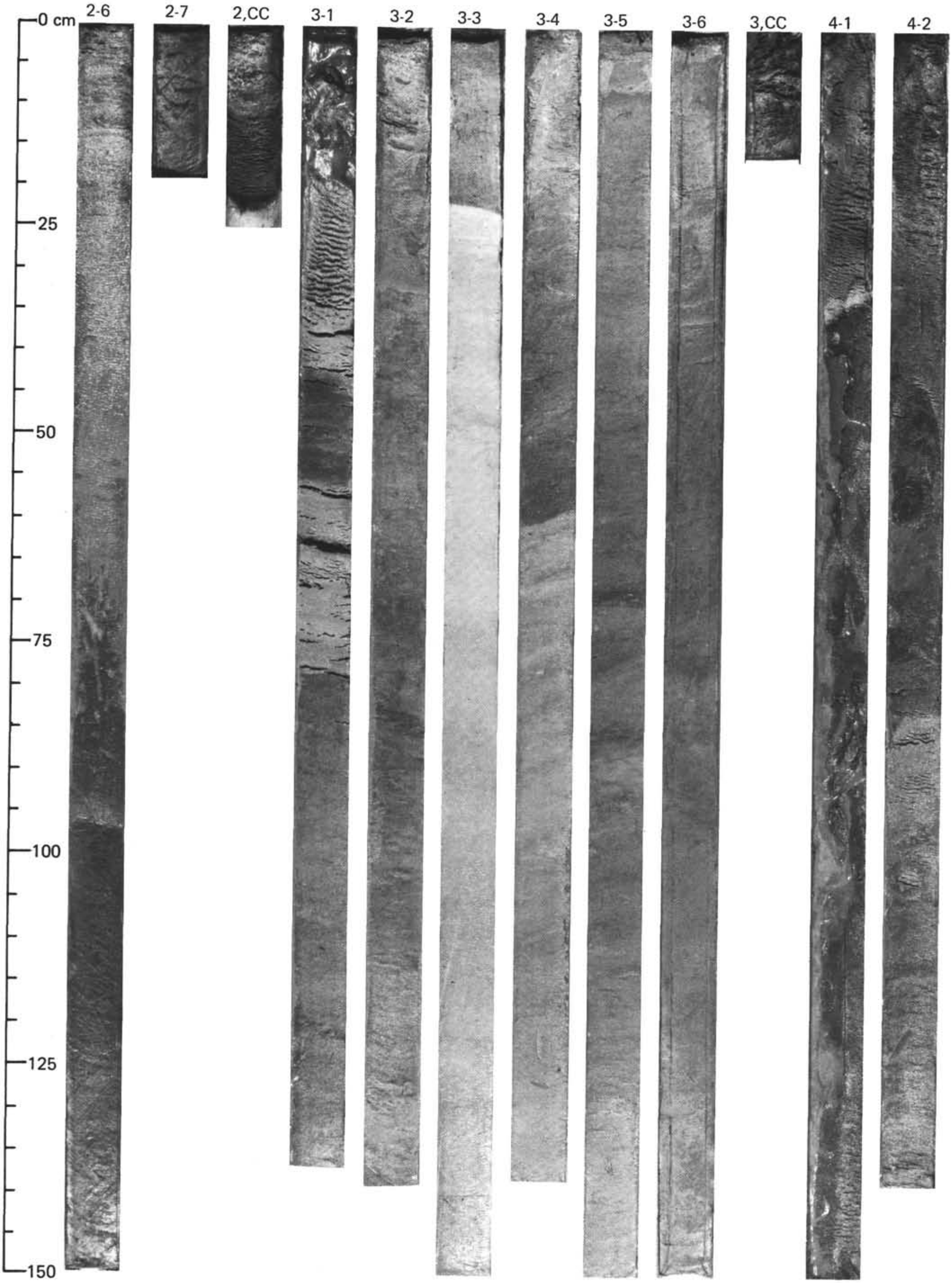
Intergranular to subspherulitic texture.

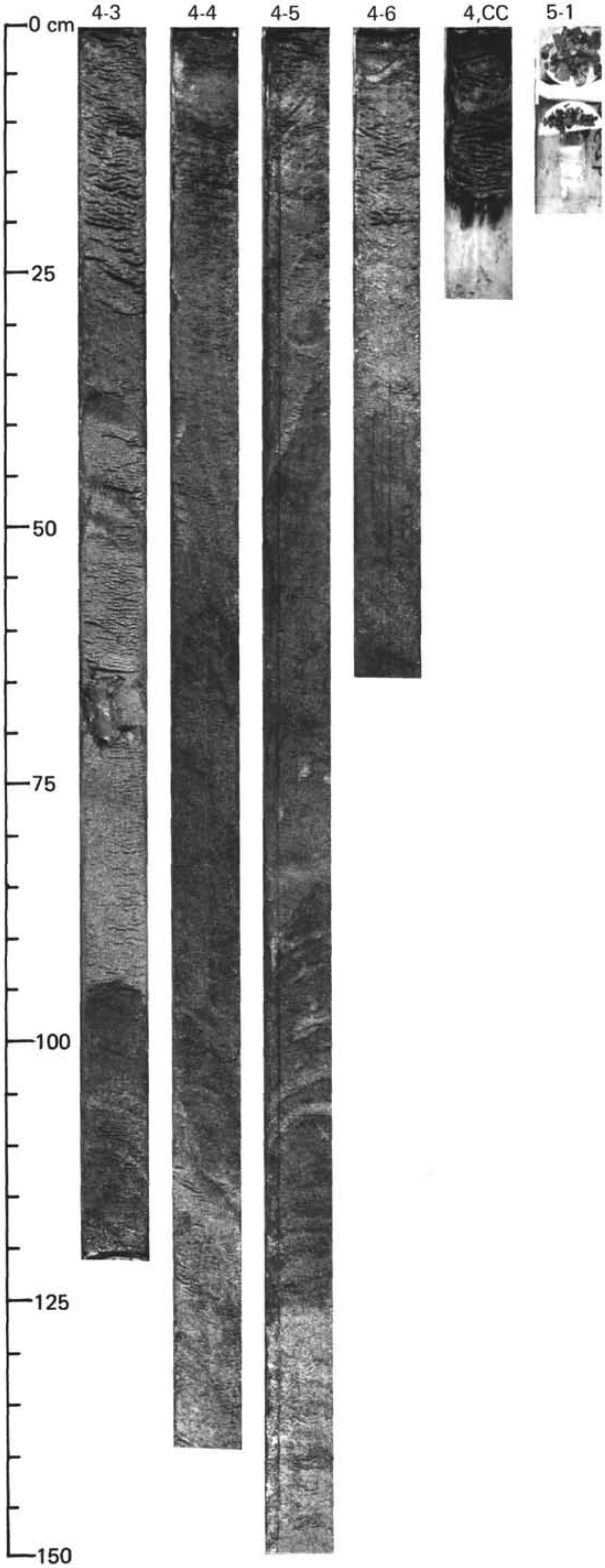
Thin section description

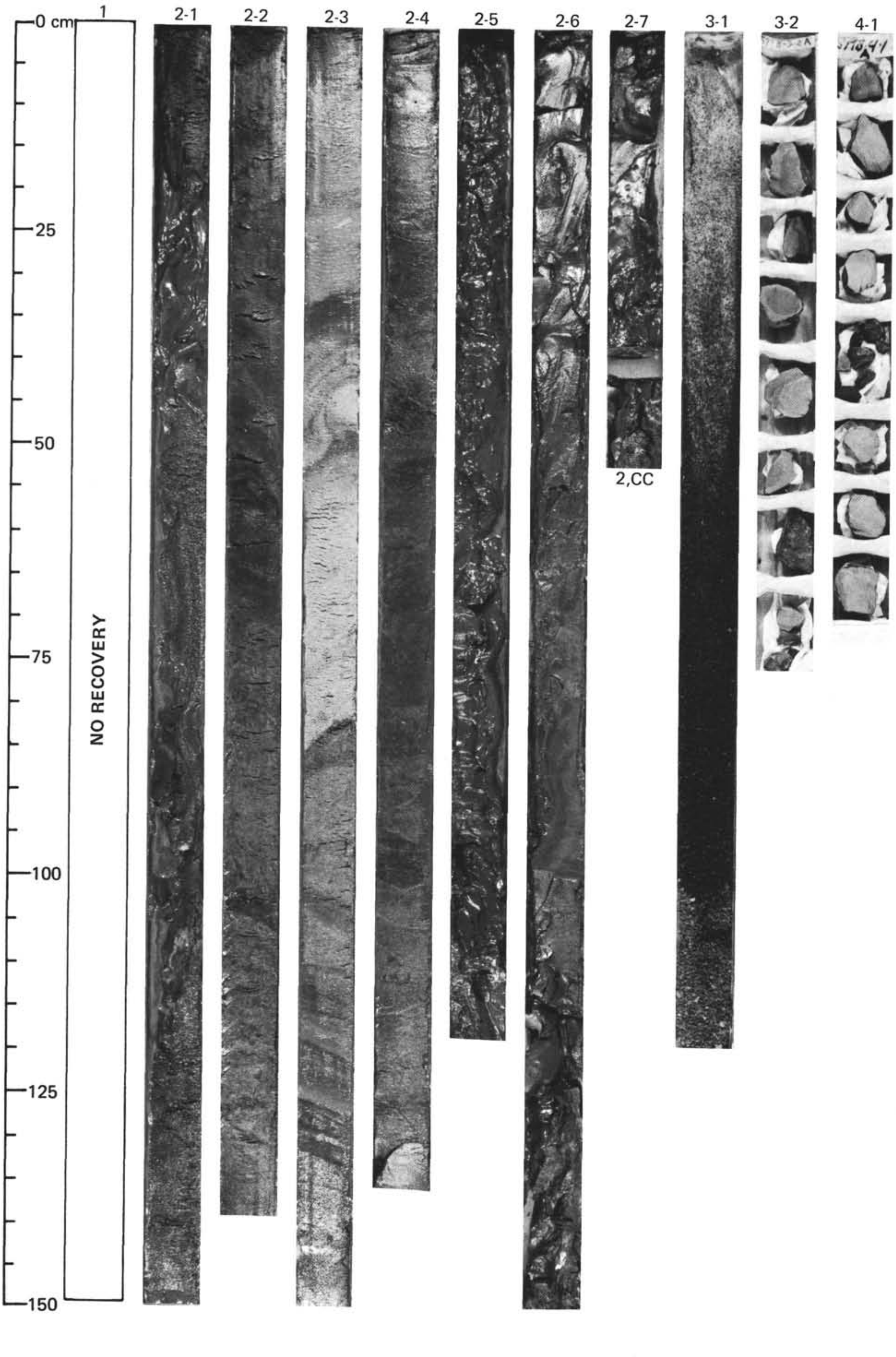
Piece 8, 64–68 cm: Aphyric basalt, subspherulitic to intergranular texture. The groundmass is composed of 50–55% clinopyroxene, in grains about 0.1 mm across, 40–45% plagioclase in acicular crystals 0.1–0.15 mm long, about 5% magnetite in possibly skeletal grains ≤0.01 mm across, and about 1% olivine in grains 0.05 mm across. Plagioclase and clinopyroxene form subspherical clusters. Magnetite is disseminated, mostly between and in clinopyroxene grains. Olivine is mostly replaced by iddingsite.

An outer oxidized zone contains 1–5% iddingsite forming pseudomorphs after olivine, and some brown clay as alteration of clinopyroxene-plagioclase clumps.


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


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


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


0 cm
25
50
75
100
125
150
1
NO RECOVERY
2-1
2-2
2-3
2-4
2-5
2-6
2-7
2,CC
3-1
3-2
4-1