HOLE 459

Date occupied: 25 April 1978
Date departed: 26 April 1978
Time on hole: 15.4 hrs
Position: 17°51.75'N; 147°18.09'E
Water depth (sea level; corrected m, echo-sounding): 4121
Water depth (rig floor; corrected m, echo-sounding): 4131
Bottom felt (m, drill pipe): 4130
Penetration (m): 3.5
Number of cores: 1
Total length of cored section (m): 3.5
Total core recovered (m): 3.28
Core recovery (%): 94
Oldest sediment cored:
Depth sub-bottom (m): 3.5
Nature: vitric mud
Age: Recent
Principal results: See Hole 459B.

HOLE 459A

Date occupied: 26 April 1978
Date departed: 26 April 1978
Time on hole: 9.0 hrs
Position: 17°51.75'N; 147°18.09'E
Water depth (sea level; corrected m, echo-sounding): 4121
Water depth (rig floor; corrected m, echo-sounding): 4131
Bottom felt (m, drill pipe): 4129.5
Penetration (m): 67
Principal results: See Hole 459B.

HOLE 459B

Date occupied: 26 April 1978
Date departed: 4 May 1978
Time on hole: 192 hrs
Position: 17°51.75'N; 147°18.09'E
Water depth (sea level; corrected m, echo-sounding): 4121
Water depth (rig floor; corrected m, echo-sounding): 4131
Bottom felt (m, drill pipe): 4125.5
Penetration (m): 691.5
Number of cores: 73
Total length of cored section (m): 691.5
Total core recovered (m): 182.14
Core recovery (%): 26
Oldest sediment cored:
Depth sub-bottom (m): 559
Nature: silicified claystone
Age: pre-late Eocene
Measured velocity (km/s): 1.77
Basement:
Depth sub-bottom (m): 559
Nature: basalt
Velocity range (km/s): 2.7–4.4
Total basement penetration: 132.5
Principal results: Site 459 is located on the eastern edge of a deep sediment pond immediately above (west of) the trench slope break. Hole 459 was abandoned when the lower half of the core barrel containing the mudline core dropped down the drill string and fishing attempts were unsuccessful. Hole 459A, a pilot hole for potential re-entry, was washed down to 87.0 meters; no cores were taken. In Hole 459B, a total of 691.5 meters was cored with a recovery rate of 26%. The upper 559.0 meters are sediments consisting mainly of vitric mud and ooze with ash layers, late to early Pleistocene in age, over a thick pile of turbidites of late Oligocene through middle Miocene age. These in turn overlie middle Eocene to early Oligocene clayslones. Hiatuses are recognized for 3.0–10.0, 13.4–14.0, 30.0–34.5, and 40.0–42 Ma. The sedimentary sequence shows that the Site 459 area was subjected to active vertical displacement and tectonic stress in the late Oligocene to middle Miocene period.

Below the sediments, 132.5 meters of fine- to medium-grained clinopyroxene-plagioclase pillow basalts, flows, and possible intrusives were cored. Two major chemical types divided into seven subtypes occur, all of them tholeite and quartz tholeite in composition. Low contents of TiO₂, Zr, and V despite generally fractionated compositions indicate that these basalts are island arc, rather than abyssal, tholeites. However, orthopyroxene does not occur in these lavas. Coarser-grained basalts contain quartz–alkali feldspar micrographic intergrowths. The basalts are highly fractured and intensely altered, especially in zones of fractures. Alteration occurred in two stages: (1) an oxidative, probably early, and possibly hydrothermal stage in which dioctahedral smectites, celadonite, iron hydroxides, and palygorskite formed as vesicle and vein fillings, and (2) a nonoxidative, probably later stage of intense replacement of groundmass portions of the lavas with trioctahedral smectite and phillipsite. Stage (1) also affected the lowermost sediments, since they too contain palygorskite.

The stable paleomagnetic inclinations of the sediments become shallower deeper in the hole, indicating a northward movement of the site during the Cenozoic. Inclinations in basement are also shallow and of both normal and reversed polarity. Some changes in inclination occur within chemical subtypes, implying faulting of...
Figure 1. Location of Site 459 (open circle) in the fore-arc region of the Mariana island arc, near the Mariana Trench. Other sites drilled during Leg 60 are shown as closed circles. Sites drilled on Leg 59 are circled dots. Site 290 (Leg 31) is shown by a star.

BACKGROUND AND OBJECTIVES

Site 459 (site survey target SP-3C) is located on the eastern margin of the last deep sediment pond on the island arc side of the trench slope break (Figs. 1 and 2). It is one of a series of Leg 60 holes (458, 459, and 460/461) designed to investigate the portion of the Mariana arc between the trench axis and the active volcanic arc. The overall background and objectives for this series of holes are discussed in a separate chapter (Mariana arc and fore-arc background and objectives, this volume), and will not be repeated here.

A portion of a reflection seismic record (Fig. 3) obtained during the site selection survey less than 5 km south of Site 459 is an example of the character of the trench–slope break where it demarks the abrupt change from the gentle dip of the fore-arc seafloor to the steep (>9°) dip of the trench wall. The top of the inner wall of the trench, where no acoustic layering is observed, is at about 1125Z time on the reflection profile. We assume the lack of sediment reflections is probably the result of tectonic disturbance of the sediments rather than outcropping of basement, because sonobuoy, OBS, and multichannel seismic velocity determinations near the trench–slope break all indicate a substantial thickness of low-velocity material (about 1 km with velocities less than 3 km/s). Normal faulting is predominant in the seafloor and sub-bottom, suggesting that the region is under tension. To the west, toward the volcanic arc, the sediments appear to thicken over a gradually better-defined and deepening acoustic basement. By 1300Z on Figure 3, apparent sediments are approximately 600 ms (500 m) thick, and the degree of disturbance has lessened to the point where the acoustic basement is well defined and some layering can be observed. This is also the thickest part of the sediments on this particular profile. By 1400Z the acoustic basement shoals to where it seems to crop out on the ocean floor.

Another reflection seismic record less than 7 km north of Site 459 (Fig. 4) demonstrates a portion of the trench slope break that has a topographic high rising over 800 meters above the bathymetric trend. No sub-bottom reflectors are observed on the high, which gives it the appearance of an igneous body. However, no magnetic anomalies and only a very subdued gravity anomaly are observed (Hussong and Fryer, this volume). Because these data suggest that the bathymetric high is composed of material with low magnetic susceptibility and low density, it is probably not a volcanic feature.

The primary objectives at Site 459 (SP-3C) were to:
1) determine the nature and origin of the material comprising the acoustic basement at the trench slope break (and, perhaps, by extension the material in the trench–slope break bathymetric high);
2) determine if the wide variety of igneous and metamorphic rocks dredged from lower down the inner wall of the trench (e.g., Dietrich et al., 1978) are derived from the trench slope break;
3) learn, from the recovered sediment, something of the tectonic and volcanic history of the uppermost inner trench wall; and
4) serve as a reference section for comparison with Site 458, on the fore-arc, and Sites 460 and 461, deep on the inner wall of the trench.

OPERATIONS

After a 17-hour stop in Saipan to load supplies, the Glomar Challenger sailed at 0615 on 24 April 1978 for Site 459. During transit to Saipan, and during the run back from Saipan to Site 459, all the normal profiling equipment (3.5-kHz and 12-kHz bathymetry, airgun reflection seismic system and magnetometer) were operational.

Site 459 was chosen very near the flank of a bathymetric high on the trench–slope break (see Background and Objectives). The approach to the target area was made from the west, across a sediment-filled basin onto the lower slope of the bathymetric high. The sediment thinned out very quickly as the high was approached, and, although we suspected that there was still adequate sediment to spud in, the difficult drilling conditions encountered previously reinforced our caution and we moved back west to the large sediment-filled basin. When the Challenger profile records showed well over 300 meters of sediment, a single life 13.5-kHz beacon was dropped (17°51.7’N, 147°18.1’E) in a PDR depth of 4121 meters at 0604 on 25 April (Fig. 5).

A standard (120-meter) bottom hole assembly was rigged with a 9/8-inch F93CK bit and the bit release assembly that had just been picked up in Saipan. The drill string was started down at 0730, and we spudded in at a depth of 4120 meters (4130 m below rig floor) at 1400 on 25 April 1978.

The inner barrel containing the mudline core was brought back up to the derrick floor, and the drill pipe was opened to retrieve the core. As the inner barrel was lifted from the drill pipe it came unscrewed in the middle, and the lower half, including the core catcher and liner with the mudline core, dropped back down the drill
string. (The expletive simultaneously emitted by the drillers and various bystanders will be left to the reader's imagination.) Two attempts to fish the bottom portion of the inner barrel failed, probably because the plastic core liner was the uppermost object in the hole and was difficult to grasp with the fishing tool. At 1750 the fishing attempts were abandoned and the entire drill string was brought back up. The mudline core was brought aboard in the bottom hole assembly at 0030 on 26 April. The well-traveled 3.28-meter core was the total recovery for Hole 459.

At 0310 the pipe was started back down without moving the ship for Hole 459A. Because this was a potential re-entry site, we conducted 459A as a wash-down pilot hole to determine the length of the casing that would be required for the re-entry cone. Spud-in was at 0726 in 4119.5 meters of water. The bit reached a depth of 87.0 meters after 73 minutes of washing down (the center bit was in place, and no rotation was done). At this time we started back out of the hole, clearing the mudline at 0920 on 26 April 1978.

We offset 50 feet to the east, and Hole 459B was begun by spudding in at 1100 in 4115.5 meters of water (4125.5 meters of pipe below rig floor). The coring summary and drilling rate for all three holes at this site are given in Table 1 and the coring rate for Hole 459B is plotted versus depth in Figure 6. Although plenty of sediment was encountered in Hole 459B, as in the case of Site 458, much of the sediment was quite friable and recovery was erratic and generally low. Approximately 560 meters of sediment and 130 meters of igneous rock were penetrated, with a core recovery rate of 26%.

Three Tokyo T-probe downhole temperature measurements were made at depths of 64.5, 131.0, and 197.5 meters (Uyeda and Horai, this volume). After the second measurement (131 m) the lower 200 feet of sandline had to be cut off because it had been badly kinked during the temperature measurement. This line damage could be the result of one or a combination of three factors: (1) water circulation was turned off while lowering the heat probe to minimize temperature disturbance in the hole; (2) the probe was locked in the bit for a particularly long time; and (3) too much sandline slack may have been let out when the probe locked in the bit. The first two conditions did occur; the third is a possibility. The long measurement duration and shutting down of circulation were two of several variations on the Tokyo T-probe technique that were conducted in order to learn more about temperature disturbance and variation in the hole (Uyeda and Horai, this volume).

The only other problems encountered during drilling were when the overshot filled with line tar and failed to grasp the inner barrel, necessitating two extra core recovery trips. This was as a result of having laid on a new tar-saturated sandline between Sites 458 and 459, so that large amounts of line tar were coming off into the hole.
Site 459 is 4 km north of here; Course 270°.

Figure 3. Portion of Hawaii Institute of Geophysics site survey airgun reflection seismic profile obtained on 18 February 1976. Single-channel hydrophone array, filtered 20-80 Hz.

The line tar also showed up in the top of a few core samples, particularly the one taken after the heat flow measurement at 64.5 meters depth. The ship drifted some 180 feet off station during the cutting of Core 17, owing to the uncompensated addition of an engine to the main drive. This excursion does not seem to have affected the recovery of samples in Core 17.

The heave compensator was installed and used for the cutting of the igneous rock Cores 63 through 73. During cutting and retrieval of Core 73 the pipe started sticking and torquing owing to caving and infilling, probably from the fractured rock encountered through most of the basement drilling. We decided to abandon further drilling and proceed with logging the hole at this time. The drill string was raised above the sticking level in the hole, and the bit was released at 1753 on 2 May 1978, at a sub-bottom depth of 663 meters. After circulating seawater to clear the hole (mud was not circulated, because the hole has to be full of salt water for the large-scale resistivity experiment [Francis, this volume]), the heave compensator and Bowen unit were set back and the pipe raised to 4244 meters below the rig floor for logging.

The first Gearhart-Owen (GO) logging tool (temperature and gamma-density) was able to go to a depth of only 4646 meters before being stopped (1410 on 2 May) by bridging of the hole. Unfortunately, this blocking was above basement. The second GO run (gamma-sonic and caliper) did not operate properly. The third run (gamma-neutron and laterolog) operated properly but encountered hole bridging at only 4630 meters (2137 on 2 May). The fourth run (gamma-induction) went to only 4611 meters (0245 on 3 May), and the fifth run (repeat of temperature) could go to only 4602 meters (at 0718 on 3 May).

The caving-in of the hole was progressing rapidly, so we rigged the large-scale resistivity experiment (Francis, this volume) rather than try another sonic run. The resistivity experiment lasted from about 0830 to 1757 on 3 May, during which time current was applied at 55 depths for 10 seconds in each polarity. The measurements were apparently successful. Unfortunately, the hole had infilled to 4593 meters by the time this tool reached bottom (1425 local time).

During and just after the large-scale resistivity run the sonic log was repaired and subsequently run to a depth of 4589 meters at 2223 local time. Although the
sonic tool seemed operational, it behaved erratically and the caliper did not operate, so the measurements are of doubtful quality.

After completion of the logging the drill string was started up at 0200 hrs. and was on deck and secured for transit to the next site at 0930 local time on 4 May 1978.

SEDIMENT LITHOLOGY

At Site 459 (Hole 459B) a 691.5-meter sequence of sediment and igneous rocks was drilled and continuously cored. The total thickness of sediment above the igneous rocks is 559.0 meters. These sediments may be divided into six units, with Unit 3 being further divided into 3 subunits (Fig. 7).

<table>
<thead>
<tr>
<th>Unit</th>
<th>Core</th>
<th>Thickness (m)</th>
<th>Main Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-4</td>
<td>36</td>
<td>Siliceous vitric mud and nannofossil vitric ooze</td>
</tr>
<tr>
<td>2</td>
<td>5-7</td>
<td>28.5</td>
<td>Hiatuses; vitric mud, nannofossil vitric ash</td>
</tr>
<tr>
<td>3</td>
<td>8-57</td>
<td>475</td>
<td>Turbidites; slumping; faulting.</td>
</tr>
<tr>
<td>4</td>
<td>58</td>
<td>9.5</td>
<td>Claystone</td>
</tr>
<tr>
<td>5</td>
<td>59</td>
<td>9.5</td>
<td>Claystone and cherts</td>
</tr>
<tr>
<td>6</td>
<td>60</td>
<td>0.5</td>
<td>Slikensided silicified claystone</td>
</tr>
</tbody>
</table>

**Unit I:** 36 m; 0-36 m, Cores 1 through 4; late Pleistocene (Gephyrocapsa oceanica Zone); 0-0.9 Ma. Dominant lithologies are vitric siliceous and calcareous mud and ooze with muddy to sandy vitric ash layers. The color is mainly dark brown to yellowish brown and is darker in the coarser lithologies. The unit is rich in biogenic sediments. The uppermost 14 meters (Cores 1 and 2) are siliceous with diatoms (up to 75%) and radiolarians (up to 25%). In Cores 3 and 4 nannofossils become predominant (up to 50%) in marly nannofossil ooze. Foraminifers are scarce. Volcaniclastic materials are present either as a minor component in biogenic sediments or as the dominant component in muddy to silty ash layers. They are mainly volcanic glass (25-50%) and feldspars (5-25%). Volcanic glass is generally vesicular, fresh or altered. Clays occur as alteration of volcanic glass and are important components in mud and marly ooze. Reworked pebbles of older claystone and mudstone are common in sandy layers of the two first cores.

The unit is late Pleistocene (Gephyrocapsa oceanica Zone, including both the Ceratolithus cristatus and Emiliana huxleyi subzones); it bottoms at about 0.9 Ma.

**Unit II:** 28.5 m; 36-64.5 m, Cores 5 through 7, several possible hiatuses; early Pleistocene–Pliocene?, and early Pliocene–late Miocene; 3.0-10.0 Ma. Between Cores 4 and 8, a condensed sequence with hiatuses is made of vitric mud, marly nannofossil ooze, muddy to sandy crystal, and/or vitric ash. Dominant colors are grayish olive and olive gray.
A major and/or a highly condensed sequence is suggested in this unit in the early Pliocene and in late Miocene; Core 5, CC can be placed in the late early Pleistocene Gephyrocapsa caribbeana nannofossil Subzone. Four sections of Core 6 are barren. Sample 459B-6, CC may be assigned to the early late Pliocene Discoaster tamalis nannofossil Subzone or older. Only a core catcher sample was recovered from Core 7, and it can be placed in the earliest late Miocene Ommatartus antipenultimus radiolarian Zone (7.8–9.3 Ma).

Another hiatus, 9.3 Ma, may also exist between 7, CC and the cores comprising Unit III, because the top of the unit is assigned to the late middle Miocene by the Catinaster calyculus nannofossil Subzone (11–12 Ma).

Volcaniclastics are more abundant than in Unit I (15–80%), especially in Core 6. Biogenic components, both calcareous and siliceous, are rare. Nannofossils that may be reworked occur in Core 6. This makes it difficult to establish an exact time scale in this unit.

Unit III: 475 m; 64.5–539.5 m; Cores 8 through 57; middle Miocene through late Oligocene; 11–30 Ma. This unit consists of a thick accumulation of typical turbidites, where the sequences (Bouma sequences or cycles, more or less complete) usually show from top to bottom: (1) burrowed marly chalk or mudstone; (2) massive mudstone; (3) laminated mudstone or siltstone; (4) cross-beded siltstone; and (5) graded siltstone or sandstone with erosional contacts at the bottom.

Mass flows (turbidite facies) from nearby sources also occur in the lower cores. Slumping occurs commonly throughout the unit. Extensive normal (tensile) faulting is developed throughout, particularly in Cores 26 to 28 (boundary between early and middle Miocene) and 50 to 54 (late Oligocene). Displacement is commonly of a few centimeters or less but can reach 15 cm. Erosional “minidikes,” probably the traces of dewatering passages, occur generally at the top of turbidite sequences (Cores 46–57) and crosscut burrows. The openings are tensional in origin and can be filled with overlying coarse-graded sand (sandstone).

This turbiditic Unit III is divided into 3 subunits on the basis of composition and texture:

Subunit IIIa: 161.5 m; 64.5–226 m; Cores 8 through 24; middle Miocene (Catinaster calyculus Subzone through Sphenolithus heteromorphus Zone); 11–15 Ma. One or more turbidites occur between vitric marly nannofossil chalks and vitric mudstones. The color is dominantly olive gray, with olive black graded or laminated layers (silty and sandy vitric tuff). Volcanic glass (10–70%) is strongly altered; clays, including green clay present all through this subunit, are also a prominent
component (40–80%). Calcareous nannofossils usually represent 10 to 30% of the sediments but decrease in abundance downward.

In this subunit a small hiatus may exist in the early Miocene (15–24 Ma). This subunit consists of turbiditic sequences with the following lithologies, from top to bottom in complete turbidites: claystone, mudstones increase downward through the same interval. The Coccolithus miopelagicus nanno-

Table 1. Coring summary, Site 459.

<table>
<thead>
<tr>
<th>Hole Code</th>
<th>Date (1978)</th>
<th>Time</th>
<th>Depth from Drill Floor (m)</th>
<th>Depth below Seafloor (m)</th>
<th>Length Cored (m)</th>
<th>Length Recovered (m)</th>
<th>Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hole 459</td>
<td>26 Apr.</td>
<td>0001</td>
<td>4125.5-4133.0</td>
<td>0-3.5</td>
<td>3.5</td>
<td>3.28</td>
<td>93.7</td>
</tr>
<tr>
<td>Hole 459A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hole 459B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 6. Coring summary, Hole 459B, showing the coring rate per core versus meters of total penetration.

fossil Subzone (ca. 0.6 Ma) is missing and the S. heteromorphus Zone is rather briefly represented.

Marly nannofossil chalks decrease (Holes 21–25) and mudstones increase downward through the same interval. Mudstones become dominant below Core 24.

Subunit III B: 228 m; 226–454 m; Cores 25 through 48; early Miocene (15–24 Ma). This subunit consists of turbiditic sequences with the following lithologies, from top to bottom in complete turbidites: claystone, mud-
Figure 7. Sediment age, lithology, units, and core recovery versus depth, Hole 459B.

Stone, siltstone, and sandstone. Mudstones are contaminated by volcaniclastics, whereas siltstones and sandstones are generally vitric tuffs (more than 50% of ash-size components). Marly nannofossil chalks are rare in the upper part (Cores 25–30), absent in the middle portion, and rare in the lower cores (46–48).

Subunit IIIC: 85.5 m; 454-539.5 m; Cores 49 through 57; late Oligocene; 23–30 Ma. In this subunit, vitric marly nannofossil chalk and limestone increase downward, giving way to calcareous turbidites in Cores 54 to 57. Large foraminifers are commonly reworked in these turbidites (Cores 54, 56, 57). Volcanic glass is very rare (0–3% at the bottom in Cores 55–57) but is increasingly present upward (53 through 49).

Dominant colors are greenish gray, olive gray, and yellowish gray. Core 56, Section 4 contains a dusky brown uniform clay.

Unit IV: 9.5 m; 539.5–549 m; Core 58; early Oligocene to latest Eocene, 34–40 Ma. Absence of a nannofossil zone and a subzone Sphenolithus predistentus and Reticulofenestra hillae) may indicate a hiatus of ca. 4 m.y. (30–34 Ma) between Units III and IV. Unit IV consists of siliceous claystone and mudstone and silt and sandy vitric tuff organized in graded sequences. Nanno-
fossil limestones are absent; siliceous biogenic components occur (up to 10%). The dominant color is light brown to moderate brown.

Unit V: 9.5 m; 549-558.5 m; Core 59; late Eocene (radiolarian Podocystis chalara Zone which occupies the early-late Eocene at about 44 Ma). A light brown claystone with several pieces of silicified claystone and grayish brown cherts occurs in Core 59. Smear slides of the claystones contain the following: clay (95%), feldspar (5%), rare radiolarians. A hiatus of over 2 m.y. might occur between Thysocystis bromia radiolarian Zone in Core 58 and the Podocystis charara radiolarian Zone in Core 59 (40-42 Ma).

Unit VI: 0.5 m; 558.5-559 m; Core 60; pre-late Eocene. In Core 60, the uppermost basement basalt is overlain by 0.5 meters of soft dusky yellowish brown claystone which is silicified and contains very abundant slickensides (produced by drilling? tectonic?). The surface of the first piece of basalt shows a thin slickensided film of the same dusky yellowish brown material. It is therefore not clear whether the sediment contact is depositional, intrusive, or even tectonic in origin. The uppermost basement basalt is more intrusive (see section on Igneous Rocks, Lithology).

BIOSTRATIGRAPHY

Summary

Diverse calcareous nanoplankton and radiolarian assemblages occur throughout most of the sedimentary interval (Cores 1-60) overlying igneous rocks at Site 459 and range in age from late Pleistocene to late Eocene. Several breaks can be seen in the biostratigraphic interval with major hiatuses occurring in the Pliocene-late Miocene, middle Miocene, early Oligocene, and early Eocene.

Poor recovery and the absence of age-diagnostic nanoplankton species in Cores 6 and 7 make precise zonal determinations impossible, although a discontinuous record is suggested for the early Pleistocene and Pliocene. A minimum gap for the early Pliocene and late Miocene of about 7 m.y. (3.0-10.0 Ma) occurs between Cores 6 and 7.

A nanoplankton subzone representing 0.6 m.y. (13.4-14.0 Ma) is absent between Cores 20 and 21.

Another sizable break occurs between the early and late Oligocene (Cores 57 and 58), representing a minimum of 4.5 m.y. (30.0-34.5 Ma). Still another large gap can be recognized between Cores 58 and 59, since a late Eocene radiolarian assemblage is seen in Core 59. This could represent a minimum of 2.0 m.y. (40.0-42.0 Ma).

Nannoplankton and radiolarian zonations correlate extremely well palaeontologically throughout the intervals where both groups occur; however, absolute age determinations vary slightly. This is to be expected when two different zonation schemes are related to absolute time by different methods and subsequently compared. The major exception to zonation agreement is in the early Miocene, where sizable discrepancies are present. This relationship is also evident when a comparison is made between nanoplankton and radiolarian results in the early Miocene at Site 296 (Ellis, 1975; Ling, 1975) as well as other DSDP sites. It would appear that this is due to a major error in zonal age determinations of one or both of the fossil groups.

The major paleontologic breaks agree very closely with changes noted in the lithology at this site.

Nannoplankton

Nannoplankton assemblages throughout the sedimentary interval in Hole 459B range from good to poor preservation and show wide species diversity. They also contain sufficient age-diagnostic forms to indicate that the biostratigraphic sequence is discontinuous.

The Holocene-late Pleistocene Emiliania huxleyi Zone is recognized in Core 1 of Hole 459. The following Pleistocene zonation can be recognized in samples from Hole 459B: the Ceratolithus cristatus Subzone of the Gephyrocapsa oceanica Zone, sections 1 through 4, Core 1; the Emiliania huxleyi Zone of the G. oceanica Zone, Samples 459B-1-5, 90-91 cm through 459B-4,CC; the Gephyrocapsa caribbeanica Subzone of the Crenolithus doronicoides Zone, Sample 459B-5,CC.

Samples from Sections 1 through 4 of Core 6 are barren. Sample 459B-6,CC contains three rare occurring species of Discoaster. If these are indigenous, then the sample is of early late Pliocene age and the intervening subzones are either missing or represented by the barren interval.

Samples from Cores 8 to 15 are assigned to the late middle Miocene Discoaster hamatus Zone because of the presence of the nominate species D. hamatus. The presence of D. sp. cf. D. quinqueramus in Samples 459B-8-1, 90-91 cm; 459B-9,CC; 459B-11-2, 18-19 cm; 459B-11,CC; and 459B-12,CC suggests that these samples may belong in the early middle Miocene. (This species is discussed by Bukry, 1973; Howe and Ellis, 1977; Ellis and Lohman, 1979.) However, the total absence of other late Miocene key species indicates that these samples probably belong in the middle Miocene. In that case, considerable section is missing. Nannoplankton zones from early Pliocene (3.0 Ma) to the top of the middle Miocene (11.0 Ma) are absent. However, late Miocene radiolarians are noted in Sample 459B-7,CC. Consequently a hiatus representing about 7.0 m.y. (3.0-10.0 Ma) exists between Samples 459B-6,CC and 459B-7,CC.

The two subzones of the Discoaster hamatus Zone, the Catinaster calycus Subzone and the Helicosphaera carteri Subzone, can also be identified. The boundary between them occurs between Samples 459B-15-1, 52-53 cm, and 459B-17,CC.

The Catinaster calycus Zone is determined for Samples 459B-19-1,CC top and bottom. Samples from Core 20 can be assigned to the Discoaster kugleri Subzone of the D. exilis Zone.

The presence of the early middle Miocene Sphenolithus heteromorphus Zone assemblage in the two samples of Core 21 (Samples 21-1, 35-36 cm, and 459B-21,CC) suggests that the lower subzone of the overlying Discoaster exilis Zone, the Cuculithus miopelagius
lapping C. laticonus and O. antepenultimus morphotypes and probably are therefore in the C. petterssoni Zone.

Core 21 represents the Dorcadospirys alata Zone. Cores 22 through the top of Core 24 represent either the same zone or the next earlier C. costata Zone, which is clearly recognizable in the rest of Core 24 through the top of Core 25.

The rest of Core 25 through Core 27 belongs to the Stichocorys woffittii Zone.

No zone-diagnostic assemblages occur below until the lowest two sediment cores (58 and 59). Core 58 assemblages belong to the latest Eocene Thyrsocystis bromia Zone. Separated by an hiatus, Core 59 belongs to the late Eocene Podocystis chalara Zone.

**Foraminifers (V. A. Krasheninnikov)**

Only rare, poorly preserved foraminifers are present in samples from Site 459. Samples 459B-1-1, 44-46 cm and 459B-1-1, 50-52 cm through 459B-2-2, 50-52 cm belong to the undifferentiated Quaternary. Rare benthic forms are present in Samples 459B-20-1, 50-52 cm through 24-2, 91-93 cm. Lower Miocene foraminifers occur in Samples 459B-29-3, 21-23 cm through 459B-43-1, 51-53 cm. Samples 459B-54-1, 81-83 cm through 459B-56-2, 64-66 cm can be assigned to the Oligocene Globorotalia ciperoensis Zone and/or the G. opima Zone.

## ACCUMULATION RATES

For consistency through ages, nanoplankton dates are used for calculation of accumulation rates, except for Lithologic Units IV and V. The accumulation rates are tabulated in Table 2, based on the accumulation curve presented in Figure 8.

The overall rate at Site 459 is higher by a factor of two than that at Site 458, which is geographically nearer to the subaerial detrital source region, the Mariana arc. The difference is easily explained by the abundance of turbidites and occasional mass flows at Site 459 in Lithologic Unit III (see Sediment Synthesis section for discussion).

### Table 2. Accumulation rates, Site 459.

<table>
<thead>
<tr>
<th>Lithologic Unit</th>
<th>Core</th>
<th>Accumulation Rate (kg/cm²/m.y.)</th>
<th>Duration (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1-4</td>
<td>3.0</td>
<td>0.9</td>
</tr>
<tr>
<td>II</td>
<td>5-7</td>
<td>2.0</td>
<td>0.9-3.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.0-10.0 Hiatus</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>A</td>
<td>8-20</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td>13.4-14.0 Hiatus</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>21-24</td>
<td>14.0-24.0</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>25-48</td>
<td>24.0-30.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30.0-34.5 Hiatus</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IV</td>
<td>58</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>59</td>
<td>21.5</td>
</tr>
<tr>
<td></td>
<td>VI</td>
<td>60</td>
<td>742.0-745.0</td>
</tr>
</tbody>
</table>

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Subzone, is missing. This would represent an interval spanning 0.6 m.y. (13.4-14.0 Ma).

The early Miocene-middle Miocene boundary, which corresponds with the boundary between the Sphenolithus heteromorphus Zone and the Helicosphaera ampliaperta Zone, can be placed between Cores 21 and 22.

The top of the early Miocene Sphenolithus belemnos Zone is drawn between Samples 459B-28-1, 42-43 cm, 459B-28-2, 102-103 cm at the first occurrence of S. heteromorphus.

The Discostera druggii Subzone of the basol Miocene and late Oligocene Triquetrorhabdulus carinatus Zone can be recognized in Samples 459B-35-1, 36-37 cm through 459B-46,CC. A few reworked specimens each of several early Oligocene and/or Eocene species occur in Sample 459B-35,CC near the top of the subzone.

The remaining two lower subzones of the Triquetrorhabdulus carinatus Zone cannot be differentiated. Consequently, the Miocene-Oligocene boundary, which coincides with the boundary between these two subzones, cannot be precisely defined. This undifferentiated interval of the T. carinatus Zone is present in samples of Cores 47 and 48.

The late Oligocene Sphenolithus ciperoensis Zone is recognized in Samples 459B-49-1, 8-9 cm through 459B-54-2,66-67 cm. The early late Oligocene Sphenolithus distentus Zone is determined for Samples 459B-54-3,83-84 cm through 459B-57,CC.

Sample 459B-58-1, 28-29 cm can be placed in the early Oligocene Calidiscus formosa Subzone of the Helicosphaera reticulata Zone. This would indicate a hiatus of at least 4.5 m.y. (30.0-34.5 Ma) between Cores 57 and 58. Although the occurrence range of key age-determining species extends into the Eocene, an Eocene hiatus of at least 4.5 m.y. (30.0-34.5 Ma) between Cores 57 and 58. Although the occurrence range of key age-determining species extends into the Eocene, an Eocene age is not considered for this sample because nanoplankton species limited in the occurrence to the Eocene are not found in association.

**Radiolarians**

Radiolarians occur at the top of the sedimentary column and at various intervals separated by barren intervals. Preservation and diversity are reasonably good during the Quaternary, part of the middle and early Miocene, and one zone of the Eocene. Nevertheless, many species with stratigraphic importance are lacking.

Quaternary assemblages are abundant only in Core 1 of Holes 459 and 459B, where the Buccinosphaera invaginata Zone is represented. In Hole 459B radiolarians are sparse in Cores 2 and 3 and absent in Cores 4 and 5; Core 6 contains only sparse assemblages. None of these lower cores contains age-diagnostic forms.

The core catcher sample of Core 7 contains an assemblage representing the late Miocene Ommtatius antepenultimus Zone. Radiolarians are sparse and nondiagnostic in Core 8 and barren in Cores 9 through 14.

In Core 15 assemblages are poorly preserved but contain curved, flat spines of the genus Oroscena, which are restricted approximately to the late middle Miocene Cannartus petterssoni Zone in DSDP Leg 6 material (Kling, 1971). Samples from Core 20 are above the top of Calocycletta costata and in the interval of over-
Within Unit III, the accumulation rate increases upward from 1.9 to 3.2 kg/cm²/m.y. at about Cores 47 and 48 near the boundary of Subunits IIIb and IIIc (between Cores 48 and 49). This change apparently corresponds to the different nature of turbidites in the respective subunits. Limestones and chalks are dominant lithologies in the lower Subunit IIIc with its slower rate, whereas volcaniclastic siltstones and sandstones are dominant lithology in the upper subunit. The still higher sedimentation rate of Subunit IIIa (3.9 kg/cm²/m.y.) may also have resulted from a higher supply rate of volcanic detritus, as shown by the generally upward-increasing abundance of ash in Subunit IIIc.

The rate in the late Pleistocene is unexpectedly high (3 kg/cm²/m.y.). It is 1 kg/cm²/m.y. at Site 458 during the same period. Because the composition of the late Pleistocene sediments at the two sites does not differ greatly according to smear slide examination (volcanic ash 30–70%, calcareous biogenics; 20–40%, siliceous biogenics 5–15%, detritus 10–30%, at both sites), the higher rate at Site 459 may indicate enhanced biogenic productivity and inflow of volcaniclastics.

Two Neogene hiatuses occur at the same general times at the two sites. The younger is from 3 to 7 Ma at Site 458 and although it ended at the same time at Site 459, it commenced 10 Ma. Middle Miocene hiatuses occur at both sites. They are both short and do not quite coincide. The break at Site 458 is from 12 to 13 Ma and at Site 459 it is from 13.4 to 14 Ma.

**SEDIMENT SYNTHESIS**

Site 459 is about 157 km eastward of the active Mariana arc axis (Site 457) and about 52.5 km westward of the Mariana trench axis. The site was located on the upper part of the slope of the Mariana Trench, above the trench–slope break. The relative locations of previous sites in the Mariana arc-trench system are shown on Figures 1 and 2. At Site 459 there was some anticipation that the drill might penetrate acoustically opaque sediments belonging to the uppermost imbricate thrust sheets of an accretionary prism.

The 559 meters of sediment at Site 459 are divided into six units and contain several hiatuses, which have already been described. These nondepositional and/or erosional periods might be related to changes in bottom currents and/or to the formation of significant slopes and/or to tectonic instabilities.

The well-developed late Oligocene–early and middle Miocene sediment sequence in Hole 459B indicates downslope sedimentation in a basin. Common slump features and massive flows occurring in the sequence also indicate sediment transport along slopes. The Oligocene–Miocene paleogeography might have been a relatively deep basin at Site 459 with topographic highs or wide drainage areas as sources of clastic materials transported downslope by slumping and turbidity currents.

**Comparison with Previous Sites**

The sedimentary sequence at Site 459 belongs to the Mariana arc–trench system and is clearly different from the sequence drilled at Site 452 on the Pacific plate, east of the Mariana trench axis.

It is possible to compare the sedimentary evolution through the Cenozoic at Site 459 with that at Site 458, which is located about 31 km to the west, on the same transect:

1) The dominant characteristics of Site 458 are also observed at Site 459, i.e., development of carbonates, similar biogenic components (nannofossil chalks), strong alteration of volcanic debris in older sandstones and siltstones, and the occurrence of reworked material.

2) At Site 459 the series is mostly replaced by turbiditic sedimentation that invaded the sedimentary basin during the late Oligocene and the early and middle Miocene; when detrital turbidites decrease at Site 459, marly nannofossil chalks occur. This happens on quite different scales: at the bottom and at the top of the whole turbiditic sequence (Unit III) marly nannofossil chalks are well expressed, and at the top of individual turbidites burrowed marly nannofossil chalks are generally present.

3) Finally, the leading sedimentation in the basin during the late Oligocene and early Miocene seems to have been biogenic chalk; turbidites are superposed. They episodically invaded a relatively quiet basin. Nevertheless, Site 459 chalks have a high percentage of clay (marly chalks), and mudstones are well developed.

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**Figure 8.** Sediment accumulation (kg/cm²) versus age, Hole 459B.
the other hand, Site 458 had volcanioclastic sandy layers interbedded in chalks, always thin, and without typical and complete turbiditic sequences.

Sites 458 and 459 belonged to the same general paleoceanographic realm during the Cenozoic. Both sites have an island-arc-type igneous basement shown as pre-middle Eocene at Site 459 (quartz dolerite and basalt) and as pre-early Oligocene at Site 458 (high-MgO bronzite andesite and basalt). During the middle-late Eocene and early Oligocene silicified claystone and claystone were deposited, probably as a result of strong alteration (subaerial? submarine?) of island arc volcanic products. The turbidite regime began slowly during the early late Oligocene, first giving calcareous turbidites with reworked large foraminifers (accumulation rate 1.9 kg/cm$^2$/m.y., Subunit Illb). During the early Miocene and turbidites and slumps became general, and volcanioclastics and clays increased markedly (accumulation rate 3.2 kg/cm$^2$/m.y., Subunit IIIb). During the middle Miocene (Subunit IIIa) marly nannofossil chalks increased in the turbidite sequence, yet with still higher accumulation rate, 3.9 kg/cm$^2$/m.y., giving calcareous turbidites. These are generally thinner as individual turbidite sequences and have a finer grain size than the underlying Subunit IIIb.

During the same period, nannofossil chalks and oozes with thin interbedded ash layers were deposited at Site 458.

The sedimentary evolution of Site 458 lacks the major influence of turbidites when compared with Site 459. Therefore the sources for detrital components may be sought, at least partially, to the east (northeast to southeast?) of Site 459. However, western turbidite sources may also be considered, assuming Site 458 was a bathyal area.

Major hiatuses occur during the late Miocene and the early Pliocene (approximately between 10 and 3 Ma at Site 459 and between 3 and 7 Ma at Site 458).

The Plio-Pleistocene sediment lithologies are rather uniform at both sites: vitric siliceous and vitric calcareous mud and ooze with abundant volcanioclastic materials and more abundant siliceous biogenic components in the uppermost sediments. Plio-Pleistocene accumulation rates were higher by a factor of three at Site 459.

Accumulation rates and the thickness of sediments during the Oligocene and Miocene at Site 459 are about two times greater than at Site 458. Dewatering traces, resulting from compaction, are abundant. The accumulation rates and thickness with the overall vertical evolution of turbidites (coarser at the bottom, finer at the top) may indicate that active relative subsidence at Site 459 (or uplift of the source region) occurred during the late Oligocene and early and middle Miocene. Alternatively, the pattern of sediment transport and deposition may have changed. The occurrence of extensive normal faults and elastic minikides in the sediments of this age, however, implies vertical tectonic movement.

Based on the cores and the site survey geophysical profiles (Hussong and Fryer, this volume) near Site 459, the general tectonic regime seems to have been mainly tensional since the late Oligocene in this upper part of the Mariana trench-slope region.

**GEOCHEMISTRY**

Thirteen samples were taken for porewater chemistry at Site 459, one in Hole 459, the rest in Hole 459B. The results are given in Gieskes and Johnson (this volume). Ca$^{2+}$ increases, and Mg$^{2+}$ decreases steadily to just above basement (559 m sub-bottom), where it is almost entirely depleted. Alkalinity drops sharply in the topmost 50 meters of sediments to a fairly steady range of 0.5 to 1.0 meq/kg. There are modest reversals of the Mg$^{2+}$ and Ca$^{2+}$ gradients just above basement that are evidently a consequence of seawater contamination. The major gradients are evidently produced by reaction of pore fluids with the abundant volcanic glass in the sediments, and perhaps with the basement.

**IGNEOUS ROCKS**

**Lithology**

Igneous rocks were cored at Hole 459B from 559 to 691.5 meters sub-bottom. The rocks recovered are mainly fine to medium grained, clinopyroxene-plagioclase basalts. Primarily on the basis of differences in grain size and degree of crystallinity, four lithologic units were delineated within the igneous section (Fig. 9). These are:

- **Unit 1:** 559-587.0 m; Cores 60 through 62. Generally medium-grained aphyric, vesicular ($x = 20\%$), clinopyroxene-plagioclase basalts. Textures range from intersertal to subophitic in all thin sections except Sample 459B-60-1, 44-47 cm), which has a spherulitic texture. Although crystalline phases are generally little altered, the mesostasis of most samples is altered to clays and palygorskite and is often substantially oxidized (Natland and Mahoney, this volume). The fragments recovered in the core contain very few penetrative fractures or veins. Individual pieces are generally bounded by rounded edges, unlike those of the lower cores. The external surfaces of the pieces are commonly free of clay coatings. This unit could represent a relatively thick (i.e., 30 m) lava flow of which the upper contact was not recovered or a sill intruded along the sediment/basement contact.

- **Unit 2:** 587.0-615.5 m; Cores 63 through 65. Fine-grained, sparsely phryic, highly vesicular ($x = 25\%$), clinopyroxene-plagioclase basalts with low (i.e., 10-20% vol.) degrees of crystallinity. The vesicularity of the thin-sectioned samples ranges from 10 to 35 vol.%. As in Unit 1, the mesostasis in these rocks is largely altered to clay minerals. This alteration extends to the pyroxene microlites as well in the lower portions of the unit. The fracturing observed in Cores 63 and 64 is generally similar to that observed in Unit 1, but Core 65 is highly fractured by drilling. This unit probably represents a sequence of pillow lavas, even though few pillow rinds were found.

- **Unit 3:** 615.5-644.0 m; Cores 66 through 68. Medium- to coarse-grained, sparsely vesicular, clinopyrox-
ene–plagioclase diabase. These rocks are generally similar to those of Unit I except for their lower vesicularity (0–10 vol.%), coarser grain size, and higher fracture density. This unit may represent a sill intruded into the finer-grained basalts.

Unit 4: 644.0–691.5 m; Cores 68 through 73. Fine-grained, sparsely phyllic, moderately vesicular (F = 15 vol.%) clinopyroxene–plagioclase basalt. This unit is similar to Unit II except for its lower vesicularity, higher degree of alteration, and greater fracture density. The fracture density increases substantially with depth, and zones of intense fracturing occur at several levels within the unit. This unit also appears to be a sequence of relatively thin flows of pillow basalt.

The mineralogy and textures of the thin-sectioned samples are discussed in detail in the petrography section. Several points of general significance will be discussed here.

An important mineralogic feature of these basalts is their lack of orthopyroxene as a phenocrystic or groundmass phase. This distinguishes them from the volcanic section drilled at Site 458 just 30 km to the west.

Another important feature of these rocks is the occurrence of micrographic intergrowths of quartz and feldspar in the mesostasis of the diabasic rocks in Unit 3. Intergrowths of this type are a common feature of diabase sills and imply a slow cooling history for the body in which they occur. This would suggest Unit 3 is a sill and not a "thick" (i.e., 30-m) flow. Other data also favor a sill interpretation, including (1) the low magnetic intensities of Unit 3 rocks (see Bleil, this volume),

Figure 9. Lithology of igneous basement recovered in Hole 459B. Zones of normal and reversed polarity, intensity of magnetization, and vesicle abundance are also shown.
(2) the constancy of grain size with depth within the unit, (3) the restriction of vesicles to the upper and lower portions of the unit, and (4) the lack of chilled (i.e., glassy) flow tops. A pillow fragment found in Core 67, Section 2, appears to have been displaced from higher levels in the hole.

Vesicles occur in most of the basalts at this site. The approximate vesicle volumes in rocks that were thin-sectioned are given in Figure 9. Clearly the fine-grained units are more vesicular than the diabasic units. If only the fine-grained flow rocks are considered, vesiculality appears to decrease with depth, although this is obviously only a first-order approximation. The variation in vesiculality within each of the fine-grained flow units suggests the existence of separate flows, each with a vesicular top and a less vesicular interior.

Trains of vesicles are evident in numerous fragments within Units 2 and 4. The orientation of these vesicle trains relative to the vertical plane varies from zero (Core 69, Section 3) to 90° (Core 65, Section 1), often showing angular differences of up to 45° within a single core. If it is assumed that these features formed at near-horizontal orientation, these angles would suggest substantial post depositional rotation of rocks within the units. At present, the cause and timing of such rotations are not known.

As noted, the fracture densities in the basement rocks cored at this site generally increase with depth. The fractures are generally at high angles to the horizontal plane (50-70°), although in actuality a wide range of angles occur. The fact that the fracture surfaces are generally coated with clays and other secondary minerals, which could only have formed before the rocks were drilled, makes it clear that most of the fractures developed in the larger fragments predate the drilling event. The occurrence in the lower parts of the hole of drilling “rubble” and pea-sized drilling breccias with clay-coated surfaces suggests these rocks were penetratively fractured or strained at some point in their history with the ubiquitous development of clay minerals along the strain directions.

Petrography

Unit 1: Cores 60 through 62

The rocks from the upper portion (from Section 60-1 to the lower part of 60-2) of Unit 1 are fine-grained basalts. They vary in texture from spherulitic to microlitic and intersertal. Although there is some unaltered glass present in the mesostasis, most of it is devitrified or totally altered to brown clays. Plagioclase varies in abundance from 15 to 50% in these rocks and occurs in spherulitic patches or lath-shaped microlites and skeletal crystals. Fe-Ti ore is present in minor amounts (1-3%), but individual crystals are as large as 1 mm and are generally skeletal in form (acicular in intersertal patches). The diabases contain some interstitial glass, most of which is either devitrified or totally altered to brown clays. Zeolites are present as small radial patches in vesicles of the diabase in the lower part of Section 61-1. The rocks are generally less vesicular (13-15%) and the vesicles are very small and irregular in shape. The estimate of the volume of vesicles in the rocks may be somewhat low, since most of them are lined with or entirely filled by secondary minerals (brown clays, carbonate, and in one instance zeolite).

Unit 2: Cores 63 through 65

The rocks of Unit 2 are glassy, aphyric basalts. The glass makes up 25 to 90% of the rocks and is generally altered to brown or green smectite, pyrophyllite, and iron hydroxides (Natland and Mahoney, this volume). The texture of the rocks varies from spherulitic to hyalopilitic with microlites or skeletal laths of acicular plagioclase making up 3 to 20% of the rock and very small granular pyroxene making up 3 to 15% of the rocks. Very minute grains of Fe-Ti oxides (1-3%) are scattered throughout the mesostasis of the rocks. Secondary minerals in these rocks are brown clays and minor zeolites. No carbonate occurs in these rocks. Vesicles make up to 10 to 35% of the rock volume. They are small, less than 1.0 mm and ranging to 5 mm in diameter, and irregular in shape. They are scattered throughout the groundmass and are lined or occasionally completely filled with brown clay and zeolite (zeolite only in Cores 63 and 64). Green clays occur as pseudomorphs after pyroxene in Sample 459B-65-1, 58-60 cm.

Unit 3: Cores 66 through 68

The rocks of this unit are coarser-grained than Unit 2. Although similar petrographically to the diabase of Unit 1, quartz occurs in the diabase of Unit 3. The rocks have subophitic to intersertal texture and contain quartz and alkali feldspar micropagmatic patches. The rocks contain no phenocrysts and are made up of labradorite (30-60%) and clinopyroxene (10-15%) that ranges from augite to subcalcic augite in composition. The pyroxene grains are zoned slightly with maximum variation in 2V of about 5° (decreasing from about 45 in the cores to 40 in the rims). Fe-Ti oxides vary in abundance from 2 to 7% and occur as small (0.1 mm) euhedral crystals and as larger (up to 0.4 mm) skeletal forms. There are rare needle-like crystals or crystal aggregates of Fe-Ti oxides in the finer-grained portions of the groundmass. These occur most frequently near vesicles. The vesicles in these rocks are sparse (1-15%) and small (0.1-2.0 mm), irregular in shape and scattered throughout the ground-
mass. As in the previous units the vesicles are lined or completely filled with secondary minerals (blue green celadonite, trioctahedral smectite, mixed layer clays; Natland and Mahoney, this volume). Carbonate is absent. The same secondary minerals are present in the mesostasis (which comprises 10 to 30%) of these rocks, as alteration products of glass. Very small amounts of brown, nearly fresh glass are present in almost all of the thin sections, but generally the mesostasis is completely altered. The grain size of the rocks from the bottom of the unit is slightly less than that of the diabase higher in the unit. The glass content of the sample from Section 68-1, 23 cm is very high (53%), although it is extremely altered. This rock may be close to a cooling boundary of the unit.

Unit 4: Cores 68 through 73

The rocks of Unit 4 are fine-grained aphyric to sparsely microphyric basalt that is heavily altered to clays and zeolite with minor carbonate as vein fillings. The rocks have hyalo-ophitic, hyalopilotic, and interstitial textures. The microphenocrysts, which occur only very rarely in these rocks, are either plagioclase (elongate crystals or labradorite showing some resorption and either normal or oscillatory zoning) or pyroxene (anhedral to subhedral grains). The groundmass of the rocks is composed of lath-shaped and skeletal plagioclase crystals (roughly 30% of the rock volume) and granular pyroxene (20% rock volume). Disseminated throughout the groundmass are small (0.01-0.13 mm) crystals of Fe-Ti oxides, either euhedral or skeletal. Occasionally there are fine needle-like oxides which seem to be concentrated in patches of finer-grained groundmass surrounding vesicles. Generally the vesicles of these rocks are small (0.01-0.5 mm), scattered throughout the groundmass, and irregular in shape. They occasionally show alignment as described in the previous section. The vesicles are commonly lined or filled with diotahedral smectite (the brown clays occur in Samples 459B-71-1, 30 cm and 459B-71-2, 15 cm), mixed layer clays (Sample 459B-73-1, 6 cm), and phillipsite (Natland and Mahoney, this volume). The phillipsite occurs as radiating patches on the vesicle walls and in the mesostasis of the rocks. Secondary vein fillings in these rocks are primarily clays, but in the upper portion of Sample 459B-71-2 (15 cm) carbonate is present as a vein filling.

The mesostasis of the rocks is composed of abundant glass, most of which is altered to green and brown clays. There is some relatively fresh glass present in some of the rocks, but in general that glass which is not totally altered is at least somewhat devitrified.

Alteration

All of the igneous rocks recovered at Site 459 show some degree of alteration. In general, the extent of alteration depends on the rock texture, since their glassy or devitrified mesostasis is the most unstable component. In some cases the alteration also affects the groundmass microlites, but it very rarely affects the relatively well-developed crystal phases. The degree of fracturing of the rocks is another factor with which the intensity of alteration is positively correlated. The dominant alteration products are clay minerals and palygorskite, although carbonate, phillipsite, Fe-hydroxides, and opal are present locally (Natland and Mahoney, this volume). Palygorskite occurs only in veins.

Clay minerals replace from 10 to 70% of the rock volume and are spread throughout the igneous section. They are green or brown and are predominantly dioctahedral smectites and mixed-layer clays. Colorless varieties were detected only in the uppermost part of Lithologic Unit I. K-Fe smectites are pale brown and usually associated with Fe-oxyhydroxides. They are more abundant higher in the basement section.Replacing glassy material in the rock mesostasis, clay minerals form chaotic masses and sometimes nearly opaque aggregates when they are intermixed with magnetite, Fe-oxyhydroxides, and remnants of the original minerals or glass. Spherulitic or oolitic textures are characteristic of clay aggregates filling vesicles. The latter are more crystalline and may represent partial recrystallization to mixed-layer clays. A dark green clay appears in pseudomorphs after pyroxene microphenocrysts in thin sections in Sample 459B-65-1, 58-60 cm.

Carbonate occurs within several zones randomly located along the cored interval. Usually it fills the veins and vesicles together with clay minerals and is rarely observed replacing matrix minerals.

Zeolites (mainly phillipsite) are present in low abundance. They usually form small (up to 0.1 mm) radial clusters attached to vesicle walls and are usually covered with rinds of green smectite. They are located mainly in the lower part of the penetrated sequence (Cores 68-71), but phillipsite also occurs in some thin sections above and below this zone.

In the rocks of Unit 3 which have interstitial quartzfeldspar intergrowths, some of the quartz grains are connected with vesicles and the clay aggregates (largely celadonite) filling them. These grains may be considered recrystallized and secondary. Some of the quartz in the mesostasis may also be secondary. Quartz does not occur in other rock types.

In Cores 60 and 61 there are a number of pieces with alteration/oxidation features which resemble Liesegang rings. Their origin is problematic. At several horizons within the cored sequence, tan bands of altered basalt occur which appear to be oxidized/alterred equivalents of the olive gray basalts above and below them. Whether or not these bands are related to flow tops or bottoms is not clear.

Igneous Rock Chemistry

Combining the data of Wood et al., Bougault et al., and Sharaskin (all in this volume), the igneous rocks of Hole 459B can be divided into two major chemical types and seven subtypes (Fig. 10). All are basalts with the geochemical characteristics of island arc tholeiites—namely, low TiO₂ (0.67-1.11%) and Zr (36-75 ppm) despite high SiO₂ (51.1-58.6%) and moderate to high enrichment in iron (TFe₂O₃ range 9.83-13.63%). Wood et al. (this volume) observe a depletion in Ta relative to
Figure 10. Basement lithologic and chemical stratigraphy, Hole 459B.
...La and Th. Despite the low Ti and Zr, Bougault et al. (this volume) observe that these elements and Y are more enriched than geochemically similar rare earth elements compared with seafloor basalts. Hickey and Frey (this volume) note the light rare earth element depletion of the basalts and the exceptionally low rare earth element abundances observed in some of them (2–6× chondrites) compared with mid-ocean ridge basalts. All of these geochemical features imply that obducted ocean crust from the Pacific Plate was not cored at this site near the eastern edge of the Mariana fore-arc region.

The two major chemical types can be distinguished primarily on the basis of TiO$_2$ and trace elements. The principal division occurs between Cores 64 and 65, within Lithologic Unit 4 (Fig. 10). Above this division, there are two chemical types, B$_{1A}$ and B$_{1B}$, both with low TiO$_2$ contents (0.62–0.83‰) and moderately high Ni (43–68 ppm) and Cr (56–159 ppm). Subtype B$_{1A}$ corresponds to Lithologic Unit 1, a single flow or intrusive body 28.5 meters thick. Below Core 64 are five very similar but nevertheless distinct chemical subtypes (B$_{2A}$–B$_{2E}$) in increasing order of depth (Fig. 10). Compared with the two B$_1$ subtypes, these have generally higher TiO$_2$ (up to 1.21%), and considerably lower Ni (11–24 ppm) and Cr (14–55 ppm). Both principal Types B$_1$ and B$_2$ are mostly quartz normative, but Type B$_2$ basalts include some samples with quite high normative quartz (up to 9.9%). Cores 66 and 67 (Lithologic Unit 3, Chemical Subtype B$_{3B}$), where samples have high normative quartz, contain rocks with the quartz-alkali feldspar micrographic intergrowths mentioned earlier.

Despite the general contrast between Types B$_1$ and B$_2$, which broadly represent a trend of iron, silica, and incompatible trace element enrichment as MgO decreases, the subtypes do not appear to represent a single "liquid" line of descent. Subtype B$_{1A}$, for example, has 3 to 4% lower MgO than Subtype B$_{1B}$, despite higher Ni and Cr. It has lower TiO$_2$ and Zr but higher SiO$_2$. In fact, it differs very little geochemically from the Type A$_2$ high-MgO andesites of Site 458, 31 km to the west. Evidently, the same type of compositional and/or melting variations occurred in the mantle source of lavas at both sites, although perhaps to less of an extreme beneath Site 459.

The "fractionated" B$_2$ subtypes all evidently had parental compositions similar to Subtype B$_{1B}$, but in these subtypes different levels of TiO$_2$ and Zr enrichments occur at comparable MgO and Ni abundances. The single sample analyzed of Subtype B$_{2A}$ has the highest TiO$_2$ and TFe$_2$O$_3$ of all Site 459 samples analyzed, yet it has the lowest SiO$_2$ of all the B$_2$ subtypes. The simplest interpretation of these variations is that different fractionation trends, and probably slightly but distinctly different parental compositions, were involved. Wood et al. (this volume) argue that a mantle phase such as rutile or sphene retained Ti, Ta, and Nb during melting of magmas parental to these arc tholeiites. But they did not reconcile this with the general relative enrichment of Ti (and Zr) compared with rare earth element abundances observed by Bougault et al. (this volume) or with the general highly fractionated compositions of the basalts, which indicate that most do not represent melt compositions. The lavas are highly vesicular and have extremely high intensities of magnetization (Fig. 9). This suggests that conditions of elevated water and oxygen partial pressures may have enhanced the stability of titanomagnetite in the lavas (e.g., Osborne, 1959, 1962). Varying the extent of the fractionation of this mineral along with the primary silicate phases could explain the variable abundances of TiO$_2$ and SiO$_2$ among the Type B$_2$ basalts and perhaps some of the other geochemical "anomalies" of these lavas as well. How early in a fractionation sequence such an effect might occur is difficult to say, but we note that the TiO$_2$ abundances of the most primitive (highest MgO) Site 459 basalts (Subtype B$_{1B}$) are not particularly lower than in all mid-ocean ridge basalts with comparable MgO (e.g., FAMOUS area basalts from the Mid-Atlantic Ridge; Langmuir et al., 1977; Bryan, 1979, and Costa Rica Rift basalts; Srivastava et al., 1980; Fodor et al., 1980; CRRUST, in press).

The effect of alteration on these basalts has been considerable, but the geochemical effects are difficult to evaluate systematically. There are about 50% variations in K$_2$O and twofold variations in Rb within individual chemical subunits in the upper half of the cored basement section, where oxidative alteration is most prominent. In the lower part of the basement section, these variations are much less marked. The two most prominent secondary minerals in the finer-grained basalts are (1) palygorskite in the upper part of basement and (2) dioctahedral smectite, probably saponite, in the lower part of the hole. Both are Mg-rich secondary minerals. Within chemical subtypes, MgO can vary by as much as 1% by weight, but in some samples, reduced MgO correlates with enrichment in K$_2$O, implying that K-rich, Mg-poor clay minerals have partially replaced the rock. Needless to say, alteration effects can make quantitative evaluation of primary geochemistry difficult indeed.

**PALEOMAGNETISM**

We took sediment cores suitable for paleomagnetic study (109 samples from Cores 1–57, Hole 459B), encompassing the last 30 m.y. and obtained a polarity reversal pattern in general agreement with the established paleomagnetic time scale since the early Oligocene. The stable inclination of the sediments is shallower deeper in the hole, indicating a northward movement of the site during the Cenozoic. For the igneous rocks (26 samples) from Hole 459B, there is a clear correspondence between lithologic and magnetic units. The stable inclinations of the igneous rocks are also shallow and of mixed polarity (Fig. 9). For more complete exposition of these points, see Bleil (this volume).

**PHYSICAL PROPERTIES**

Compressional wave velocity, wet-bulk density, salt-corrected water content, porosity, acoustic impedance, and thermal conductivity were determined for cores recovered from Hole 459B. The measurements are tabulated in Table 3. Velocity–density parameters are plotted against depth in Figure 11.
<table>
<thead>
<tr>
<th>Sample Core, Section, Interval (cm)</th>
<th>Depth (m)</th>
<th>Sound Velocity (km/s)</th>
<th>GRAPE (\rho_g)</th>
<th>Wet Bulk Density (\rho_g') (g/cm³)</th>
<th>Water Content (C%)</th>
<th>Porosity (\phi%)</th>
<th>Wet Water Density (\rho_w') (g/cm³)</th>
<th>Acoustic Impedance ((\text{g/cm}^2\times\text{s}))</th>
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<td>1.57</td>
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<td>Very stiff mud</td>
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The igneous basement at about 550 meters depth. One of velocities in the range 2.20 to 2.42 km/s. The only rocks with higher velocities in the sedimentary column were about 500 to 525 meters, limestones were recovered with depth, probably reflecting the greater degree of alteration of the deeper rocks. The overall trend was for the sonic velocity to decrease altered to some degree, ranged from 2.52 to 4.43 km/s. For example, the low velocities encountered at about 200 meters depth were all measured in chalks. However, it is difficult to understand why the small peak in the velocity–depth curve at 45 meters. A proportion of these samples were then subjected to gravimetric measurement of density, water content, and porosity. Although the density–depth plot shows more scatter than the velocity–depth plot, it reflects some of the features of the latter. The shallow peak in the velocities at 260 meters also appears to be present in the density plot. The highest densities in the sedimentary rocks occur in the limestone between 500 and 525 meters sub-bottom. These range from 1.9 to 2.3 g/cm³. The top part of this limestone formation was reached by the Gearhart-Owen density log, yielding a density of 2.02 g/cm³ and placing its upper contact at 504.5, 506.0, and 504.2 meters sub-bottom on three consecutive passes of the tool. Subsequent logs failed to reach this depth because the hole was gradually filling up.

The densities of the basalts ranged from 2.1 to 2.6 g/cm³, showing an overall tendency to decrease with depth (Fig. 11). Sonic velocity and density show a reasonable correlation (Fig. 12), though not so marked as for Hole 458. The porosities of the basalts ranged from 16 to 41%. The highest porosities were clearly associated with the most altered samples. It is likely that some of this porosity is not real but due to water being driven from clay minerals while drying for 24 hours at 110°C. The best indication of the initial porosity of the basalts is therefore the minimum observed—about 16%.

Thermal Conductivity

Thermal conductivities of both sedimentary and igneous core samples recovered from Hole 459B were measured and a thermal conductivity profile was constructed to a sub-bottom depth of 690 meters. The data show that the increase of sediment thermal conductivity with depth is very gradual—i.e., 0.18 mcal/cm s °C/100 m. Below 511 meters, however, some lithified sediments, mostly limestone, show an unusually high thermal conductivity, an average of 11 samples being 5.32 ± 0.24 mcal/cm s °C. Data also show a remarkable correlation between the thermal conductivity of basement rocks and their lithology. For a detailed synopsis of these results, see Horai (this volume).

Heat Flow

Heat flow estimated from one sediment temperature measurement at 64.5 meters sub-bottom depth in Hole

Table 3. (Continued).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Core, Section, Interval (cm)</th>
<th>Depth (m)</th>
<th>Sound Velocity (km/s)</th>
<th>GRAPE Wet Bulk Density (g/cm³)</th>
<th>Wet Water Content (%)</th>
<th>Porosity (%)</th>
<th>Wet Bulk Density (g/cm³)</th>
<th>Acoustic Impedance (g/cm² x 10⁶)</th>
<th>Rock Type</th>
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<td>65-1, 84-86</td>
<td>606.84</td>
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<td>2.14</td>
<td>19.5</td>
<td>40.6</td>
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<td>2.54</td>
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<td>66-2, 61-68</td>
<td>617.61</td>
<td>2.87</td>
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<td>67-1, 106-108</td>
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<td>69-1, 126-128</td>
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<td>69-2, 28-32</td>
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<td>6.08</td>
<td>Very altered basalt</td>
<td></td>
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</tbody>
</table>

a From 2-min. counts.  
b Salt-corrected.  
c Porosity = (salt-corrected wet-water content) x [wet-bulk density (gravimetric)]/1.025.  
d Gravimetric method.

Sonic Velocity

Sonic velocities for the vertical direction were measured in the Hamilton Frame. The first 8 cores, to 74 meters depth, were un lithified except for some minor bands in Core 6. These minor lithified bands give rise to the spike in the velocity–depth curve at 45 meters. A wide range of rock types was recovered from the lithified part of the sedimentary column, ranging in grain size from claystones to sandstones and in composition from calcareous to siliceous to vitric ash, but predominantly mixtures of these three components. The plot of velocity against depth (Fig. 11), although showing an overall trend of increasing velocity with depth, also shows a large-scale waviness which may be related to comparable changes in composition or grain size. For example, the low velocities encountered at about 200 meters depth were all measured in chalks. However, it is difficult to understand why the small peak in the velocity–depth plot occurs at about 260 meters.

Toward the base of the sedimentary column, from about 500 to 525 meters, limestones were recovered with velocities in the range 2.20 to 2.42 km/s. The only rocks with higher velocities in the sedimentary column were cherts, two thin bands of which were found just above the igneous basement at about 550 meters depth. One of these cherts gave a velocity of 3.18 km/s.

Sonic velocities in the basalts, all of which were altered to some degree, ranged from 2.52 to 4.43 km/s. The overall trend was for the sonic velocity to decrease with depth, probably reflecting the greater degree of alteration of the deeper rocks.

Density, Porosity, and Water Content

Wet bulk densities were determined by 2-minute GRAPE counts on the same parallel-sided chunks for which velocity determinations had previously been made. A proportion of these samples were then subjected to gravimetric measurement of density, water content, and porosity. Although the density–depth plot shows more scatter than the velocity–depth plot, it reflects some of the features of the latter. The shallow
459B is 0.7 HFU. Owing to a change in recorded temperature during the measurement, however, this value is not very reliable. Water temperature in the hole, measured at various subsequent stages of drilling and during Gearhart-Owen logging, showed the effect of drilling disturbance but could be correlated enough to help substantiate the calculated heat flow value (Uyeda and Horai, this volume).

**SUMMARY AND CONCLUSIONS**

Site 459 is on the easternmost edge of the thickly sedimented fore-arc basin just above the Mariana trench-slope break. The main objective of drilling at this site was to investigate the sedimentary history of the forearc region and the nature of its basement. We hoped also to learn more about the volcanic and tectonic history of the Mariana arc–trench system.

The site was located where the Glomar Challenger air-gun profile showed well over 300 meters of sediment. Three holes were drilled at Site 459. The first failed because of mechanical failure, and the second was a washdown pilot hole in the event of re-entry.

A total of 691.5 meters of sediments and igneous rocks was cored in Hole 459B. This included 559 meters of sediments in 6 lithologic units, and 132.5 meters of igneous rocks in 4 lithologic units. The igneous rocks are mainly fine- to medium-grained vesicular clinopyroxene-plagioclase basalts.

Well-developed late Oligocene and early and middle Miocene turbidite sequences attest to rapid sedimentation and significant topographic relief in the area of Site 459 during those epochs. The environment seems to contrast with that near Site 458 (which is 670 m shallower and about 31 km to the west, closer to the Mariana arc). At the latter, nannofossil chalk and oozes with thin ash layers were deposited during the same period. Accumulation rates of sediments during the Oligocene and Miocene at Site 459 are about twice as high as at Site 458.

Sites 458 and 459 belonged to the same general paleoceanographic realm during the Cenozoic. Both have island-arc-type igneous basement which is at least pre-middle Eocene at Site 459 and early Oligocene at Site 458. No substantial turbidites were recovered at Site 458. If the source of the dominant turbidites at Site 459 was the volcanic arc to the east, then one must argue that these turbidites somehow bypassed the intervening Site 458. Alternatively, a much closer source of turbidites may have influenced sedimentation at Site 459. In either case, large relative subsidence of Site 459 or uplift of its turbidite source regions during the late Oligocene as well as in the early and middle Miocene may explain fluctuations in sediment accumulation rate at the site. Extensive normal faulting and clastic mini-dikes in the cores from the same period further indicate that the fore-arc regional stress pattern was dominantly tensional.

As at Site 458, it is important to note that both the sediments and igneous rocks in Hole 459B show many signs of small-scale disruption (fractures and slickensides). Based on the consistent paleomagnetic trends, a fairly continuous sedimentation history, and the absence of repeated intervals, however, we may discount the occurrence of larger-scale tectonic deformation. What disruption does occur in the sedimentary column (the major hiatuses) seems to correlate between Sites 458 and 459, suggesting that it may be caused by a phenomenon more widespread than local tectonics.

Igneous rocks recovered in Hole 459B consist of pillows, flows, and possible intrusions of arc-related tholeiitic basalt. Two major chemical types comprising seven subtypes were recovered, most of them considerably fractionated from parental compositions. At least one of the subtypes appears to be at least transitional in composition to such high-MgO andesites as those recovered only 31 km away at Site 458. In any case, a spec-
trum of differences in parental compositions such as source composition and perhaps depth, phase control, degree of melting, and pathways of shallow fractionation can be inferred from the basalt compositions.

Alteration in basement of Hole 459B is of a type heretofore unobserved either in the deep ocean or on land. The striking feature of the alteration is the abundant development of palygorskite as a vein-filling mineral. It is associated in the cores with celadonite and iron hydroxides and hence probably represents an early, possibly hydrothermal oxidative stage of alteration. Late alteration, concentrated along the zones of intense fracturing, particularly deeper in the hole, was nonoxidative and led to the formation of dioctahedral smectite and phillipsite. Palygorskite also occurs in the lowermost sediments (Desprairies, this volume), which are brown and look oxidized. It probably formed at the same time as the palygorskite in the igneous basement, when there were only a few meters of sediments on the basalts.

Of the reversals that would be expected for the time covered, paleomagnetic measurements in the sediments reveal 32 reversals out of 97, in spite of several hiatuses, core disturbance, and a 36% recovery rate (Bleil, this volume). Inclinations are generally shallower deeper in the hole. Basement rocks, which have an exceptionally wide range in NRM intensity ($10^{-5}$ to $10^{-1}$ emu/cm$^3$), have shallow inclinations, implying for Site 459 a lower paleolatitude (~5°) at the time of basalt extrusion than at present.

Logging and the large-scale resistivity experiment were successfully conducted in Hole 459B, although caving of sediments prevented these measurements in basement. Heat flow at the site is estimated at 0.7 HFU. The laboratory-measured sonic velocity of the basement basalts decreased with depth in the 134.5 meters of basement cored, from an average of about 4 km/s to about 3 km/s. The higher-velocity rocks appear to be from massive flows that are less altered than the lower-velocity rocks, which are mostly pillow lavas. As at other sites drilled during Leg 60, the thermal conductivity is very dependent on the lithology and degree of lithification of the sediments and on the vesicularity of the igneous rocks.

REFERENCES


### Lithologic Description

**Section 1, 0.20 m:** Shelly with sandy iron flake from pit.
- Olive gray ash (5Y 4/2)
- Olive black (5Y 2.5/2) sandy vitric ash
- Dark grayish brown (2.5Y 4/2), mud, silt
- Olive black
  - Very dark grayish brown (2.5Y 3/2) with a black patch
  - Very dark gray (5Y 2.5/3)
  - Dark brown (7.5YR 3/2)
  - Very dark gray (5Y 3/1)
- Dark grayish brown (2.5Y 4/2) ash layers
- Very dark grayish brown (2.5Y 3/2)
- Dark grayish brown (2.5Y 4/2) sandy vitric ash

**Section 3 and Core-Catcher:**
- Sandy vitric nannofossil mud with traces of foraminifers
- Mottled with darker sandy mud.

**SMEAR SLIDE SUMMARY**

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<th>Clay</th>
<th>Mica</th>
<th>Carbonate</th>
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### Site 459 Holecore

**Core 1:**
- Cored Interval: 0.0 to 3.5 m
- Lithologic Description
  - Olive gray ash (5Y 4/2)
  - Olive black (5Y 2.5/2) sandy vitric ash
  - Dark grayish brown (2.5Y 4/2), mud, silt
  - Olive black
    - Very dark grayish brown (2.5Y 3/2) with a black patch
    - Very dark gray (5Y 2.5/3)
    - Dark brown (7.5YR 3/2)
    - Very dark gray (5Y 3/1)
  - Dark grayish brown (2.5Y 4/2) ash layers
  - Very dark grayish brown (2.5Y 3/2)
  - Dark grayish brown (2.5Y 4/2) sandy vitric ash
- VITRIC SILEOUS CALCAREOUS MUD with SANDY VITRIC ASH and CALCARIEOUS SILTY MUD, olive gray (5Y 4/2) dark grayish brown (2.5Y 4/2), very dark gray (5Y 3/2), dark gray (5Y 4/2) and dark brown (2.5Y 3/2) mud interbedded with and grading into thin layers of very dark gray (2.5Y 3/2) or dark grayish brown (2.5Y 4/2) ash, which is mottled with olive gray (5Y 4/2) mud. Foraminifers visible in 1-90 to 100 cm.

**Section 3:**
- Three beds of olive black (5Y 2.5/2) sandy vitric ash between 30 and 50 cm, another between 115 and 135 cm, with some foraminifers.
- VITRIC SILEOUS CALCAREOUS MUD with SANDY VITRIC ASH and CALCARIEOUS SILTY MUD, olive gray (5Y 4/2) dark grayish brown (2.5Y 4/2), very dark gray (5Y 3/2), dark gray (5Y 4/2) and dark brown (2.5Y 3/2) mud interbedded with and grading into thin layers of very dark gray (2.5Y 3/2) or dark grayish brown (2.5Y 4/2) ash, which is mottled with olive gray (5Y 4/2) mud. Foraminifers visible in 1-90 to 100 cm.
LITHOLOGIC DESCRIPTION

SITE 459 HOLE B CORE 8 CORED INTERVAL: 64.5 to 74.0 m

- VITRIC ASH with a graded bed.
- 1 to 2 mm thick, sandy texture, disturbed variable lithology. 10 slabs of 3 X 10 cm.
- Dark gray, massive, vitric ash with bands of light gray silt and mudstone.
- A graded bed (1.4 to 4.3 cm) with fine sand, silt, and mudstone.

FOSSIL CHARACTER
- Fossil fragments: Small to medium-sized plant parts, shell fragments.

NANNOFOSSIL CHARACTER
- Nannofossil ooze with diverse assemblages.

LITHOLOGIC DESCRIPTION

- VITRIC MARLY CALCAREOUS Ooze, color darker than Core 8. Olive gray (5 Y 4/1).
- Very fine sand and silt, light gray.

SMEAR SLIDE SUMMARY

- VITRIC MARLY CALCAREOUS Ooze, color darker than Core 8. Olive gray (5 Y 4/1). Indurated patches shown.
- Nannofossil ooze with diverse assemblages.
- Plant and animal fragments.

TEXTURE:
- Sand 5
- Silt 60
- Clay 35
- Total detrital 98

COMPOSITION:
- Feldspar 5
- Clay 25
- Volcanic glass 65
- Carbonate unsp. 15
- Nannofossil ooze 15
- Palagonite 5

LITHOLOGIC DESCRIPTION

SITE 459 HOLE B CORE 9 CORED INTERVAL: 74.0 to 83.5 m

- VITRIC MARLY CALCAREOUS Ooze, color darker than Core 8. Olive gray (5 Y 4/1).
- Very fine sand and silt, light gray.

SMEAR SLIDE SUMMARY

- VITRIC MARLY CALCAREOUS Ooze, color darker than Core 8. Olive gray (5 Y 4/1). Indurated patches shown.
- Nannofossil ooze with diverse assemblages.
- Plant and animal fragments.

TEXTURE:
- Sand 5
- Silt 60
- Clay 35
- Total detrital 98

COMPOSITION:
- Feldspar 5
- Clay 25
- Volcanic glass 65
- Carbonate unsp. 15
- Nannofossil ooze 15
- Palagonite 5

LITHOLOGIC DESCRIPTION

SITE 459 HOLE B CORE 10 CORED INTERVAL: 83.5 to 93.0 m

- VITRIC MARLY NANNOFOSIL CHALK, Color olive gray (5 Y 4/1) to grayish green (5 Y 3/1). Laminated structure.
- 30-40 cm: Very deformed and soupy claystone.
- 40-45 cm: Disturbed, laminated claystone with sparse fossils.
- 55-65 cm: Very deformed and soupy claystone.

SMEAR SLIDE SUMMARY

- VITRIC MARLY NANNOFOSIL CHALK, Color olive gray (5 Y 4/1) to grayish green (5 Y 3/1). Laminated structure.
- Nannofossil ooze with diverse assemblages.
- Plant and animal fragments.

TEXTURE:
- Sand 5
- Silt 60
- Clay 35
- Total detrital 98

COMPOSITION:
- Feldspar 5
- Clay 25
- Volcanic glass 65
- Carbonate unsp. 15
- Nannofossil ooze 15
- Palagonite 5

LITHOLOGIC DESCRIPTION

SITE 459 HOLE B CORE 11 CORED INTERVAL: 93.0 to 102.5 m

- VITRIC MARLY NANNOFOSIL CHALK, Color olive gray (5 Y 4/1) to grayish green (5 Y 3/1). Laminated structure.
- 30-40 cm: Very deformed and soupy claystone.
- 40-45 cm: Disturbed, laminated claystone with sparse fossils.
- 55-65 cm: Very deformed and soupy claystone.

SMEAR SLIDE SUMMARY

- VITRIC MARLY NANNOFOSIL CHALK, Color olive gray (5 Y 4/1) to grayish green (5 Y 3/1). Laminated structure.
- Nannofossil ooze with diverse assemblages.
- Plant and animal fragments.

TEXTURE:
- Sand 5
- Silt 60
- Clay 35
- Total detrital 98

COMPOSITION:
- Feldspar 5
- Clay 25
- Volcanic glass 65
- Carbonate unsp. 15
- Nannofossil ooze 15
- Palagonite 5

LITHOLOGIC DESCRIPTION

SITE 459 HOLE B CORE 12 CORED INTERVAL: 102.5 to 112.0 m

- VITRIC MARLY NANNOFOSIL CHALK, Color olive gray (5 Y 4/1) to grayish green (5 Y 3/1). Laminated structure.
- 30-40 cm: Very deformed and soupy claystone.
- 40-45 cm: Disturbed, laminated claystone with sparse fossils.
- 55-65 cm: Very deformed and soupy claystone.

SMEAR SLIDE SUMMARY

- VITRIC MARLY NANNOFOSIL CHALK, Color olive gray (5 Y 4/1) to grayish green (5 Y 3/1). Laminated structure.
- Nannofossil ooze with diverse assemblages.
- Plant and animal fragments.

TEXTURE:
- Sand 5
- Silt 60
- Clay 35
- Total detrital 98

COMPOSITION:
- Feldspar 5
- Clay 25
- Volcanic glass 65
- Carbonate unsp. 15
- Nannofossil ooze 15
- Palagonite 5

LITHOLOGIC DESCRIPTION

SITE 459 HOLE B CORE 13 CORED INTERVAL: 112.0 to 122.0 m

- VITRIC MARLY NANNOFOSIL CHALK, Color olive gray (5 Y 4/1) to grayish green (5 Y 3/1). Laminated structure.
- 30-40 cm: Very deformed and soupy claystone.
- 40-45 cm: Disturbed, laminated claystone with sparse fossils.
- 55-65 cm: Very deformed and soupy claystone.

SMEAR SLIDE SUMMARY

- VITRIC MARLY NANNOFOSIL CHALK, Color olive gray (5 Y 4/1) to grayish green (5 Y 3/1). Laminated structure.
- Nannofossil ooze with diverse assemblages.
- Plant and animal fragments.

TEXTURE:
- Sand 5
- Silt 60
- Clay 35
- Total detrital 98

COMPOSITION:
- Feldspar 5
- Clay 25
- Volcanic glass 65
- Carbonate unsp. 15
- Nannofossil ooze 15
- Palagonite 5

LITHOLOGIC DESCRIPTION

SITE 459 HOLE B CORE 14 CORED INTERVAL: 122.0 to 132.0 m

- VITRIC MARLY NANNOFOSIL CHALK, Color olive gray (5 Y 4/1) to grayish green (5 Y 3/1). Laminated structure.
- 30-40 cm: Very deformed and soupy claystone.
- 40-45 cm: Disturbed, laminated claystone with sparse fossils.
- 55-65 cm: Very deformed and soupy claystone.

SMEAR SLIDE SUMMARY

- VITRIC MARLY NANNOFOSIL CHALK, Color olive gray (5 Y 4/1) to grayish green (5 Y 3/1). Laminated structure.
- Nannofossil ooze with diverse assemblages.
- Plant and animal fragments.

TEXTURE:
- Sand 5
- Silt 60
- Clay 35
- Total detrital 98

COMPOSITION:
- Feldspar 5
- Clay 25
- Volcanic glass 65
- Carbonate unsp. 15
- Nannofossil ooze 15
- Palagonite 5
SITE 459 HOLE B CORE 24 CORED INTERVAL: 216.5 to 226.0 m

LITHOLOGIC DESCRIPTION

TURBIDITES, MARLY NANNOFossil CHALK and SILTY VITRIC TUFF

Section 1: Eleven graded sequences (fewer are shown schematically) with marly nannofossil chalk and silty vitric tuff. Color is white (top) grayish yellow green (5GY 7/2), darker olive black (5Y 2/1) at the bottom. Slump between 116 to 140 cm. Section 2: As above, but more olive black tuff layers; sixteen graded sequences. Burrowed Core-Catcher: Possible a part of a slump deposit.

SMEAR SLIDE SUMMARY

Marly Nannofossil Chalk Silty Vitric Tuff Marly Nannofossil Chalk

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SITE 459 HOLE B CORE 26 CORED INTERVAL: 226.0 to 235.5 m

LITHOLOGIC DESCRIPTION

TURBIDITES, VITRIC MUDSTONE and SILTY/SANDY VITRIC TUFF

Section 1: Overall color between dark yellowish brown (10YR 4/2) and moderate brown (5YR 3/4). Sequence of seventeen graded turbiditic cycles with three slump beds: 45 to 55 cm, 84 to 87 cm, and 105 cm. Bottom of graded beds usually have erosional contacts. Remarks: Volcanic glass strongly altered to tuff. SEDIMENTARY SUMMARIZATION.

TEXTURE: Sand 20 Clay 50 Heavy minerals 10

SMEAR SLIDE SUMMARY

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<th>Total Detrital Composition</th>
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SITE 459 HOLE B CORE 25 CORED INTERVAL: 226.0 to 235.5 m

LITHOLOGIC DESCRIPTION

TURBIDITES, VITRIC MUDSTONE, VITRIC MARLY NANNOFossil chalk AND SILTY/SANDY TUFF

Section 1: Overall color between dark yellowish brown (10YR 4/2) and moderate brown (5YR 3/4). Sequence of seventeen graded turbiditic cycles with three slump beds: 45 to 55 cm, 84 to 87 cm, and 105 cm. Bottom of graded beds usually have erosional contacts. Remarks: Volcanic glass strongly altered to tuff. SEDIMENTARY SUMMARIZATION.

TEXTURE: Sand 20 Clay 50 Heavy minerals 10

SMEAR SLIDE SUMMARY

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<th>Total Detrital Composition</th>
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</tbody>
</table>
LITHOLOGIC DESCRIPTION

TURBIDITES WITH INTENSE NORMAL FAULTING. MUDSTONE, VITRIC MUDSTONE, WITH SANDY/Silty VITRIC TUFF

Section 1: Similar to Core 31, but faults and fractures are abundant. Muddy matrix increases. Color is slightly darker than gray to olive black. Faults having nearly vertical 15° to 45° dip with walling component. Smaller, irregular fracture sets on both sides with planar component. Bounded by set of the faults. Nannofossil zone T13. Small, sooty mottlings in later smaller fault (110 cm), grayish black, fine to medium gravel. 98 to 148 cm.

Section 2: As above, but no significant faulted beds or planar faults observed.

Section 3: As above, but massive turbiditic cycles are common near the底部. Turbiditic cycles 0.5 to 1.5 m thick, with epiclastic components. 0.5 to 1.5 m.- 235 cm.; 235 cm.- 245 cm.; 245 cm.- 254 cm.

Section 4: As above, but 0.5 to 1.5 m thick, with planar faults.

Section 5: As above, but massive turbiditic cycles are common near the bottom. Turbiditic cycles 0.5 to 1.5 m thick, with epiclastic components. 0.5 to 1.5 m.- 235 cm.; 235 cm.- 245 cm.; 245 cm.- 254 cm.

Core-Catcher: Graded very fine sandstone to medium sandstone, between very dusky red (10R 2/2) and black, faintly mottled. 80 to 100 cm.

SMOAR SLIDE SUMMARY

TURBIDITES, MARLY NANOFOSIL CHALK, LIMESTONE, MUDSTONE WITH SILTY AND SANDY VITRIC TUFF

**Fossil Character**
- Turbidites throughout
- Marly Nanofossil Chalk, Limestone, Mudstone with Silty and Sandy Vitric Tuff
- Section 1: 0 to 10 cm: Thin section frame with sandstone at the bottom; abundant pieces of euhedral white or pale green (0.5 to 2 cm in diameter, rounded)
- 10 to 20 cm: Laminated marly mudstone grayish yellow-green (Society 7/2)
- 20 to 30 cm: Barren
- 30 to 40 cm: Barren
- 40 to 50 cm: Barren
- 50 to 60 cm: Barren
- 60 to 70 cm: Barren
- 70 to 80 cm: Laminated
- 80 to 90 cm: Fine sandstone grading downward into marly limestone
- Section 2: Two turbidite cycles of Section 1 plus 0 to 6 cm, 10 to 12 cm, 15 to 20 cm, 30 to 40 cm, 50 to 60 cm, 70 to 80 cm, 80 to 90 cm, 90 to 100 cm, 100 cm
- Burrowed coarse sandstone
- Section 3: Sparse alternation of 6 to 15 cm, 21 to 40 cm, 56 to 91 cm, 87 to 102 cm, 114 to 144 cm, 146 cm, 150 cm, 152 cm, 155 cm, 158 cm, 161 cm, 163 cm, 165 cm, 168 cm, 170 cm, 172 cm, 174 cm, 177 cm, 180 cm, 182 cm, 185 cm, 188 cm, 190 cm, 192 cm, 195 cm, 198 cm, 200 cm, 203 cm, 206 cm, 209 cm, 212 cm, 215 cm, 218 cm, 221 cm, 224 cm, 227 cm, 230 cm, 233 cm, 236 cm, 239 cm, 242 cm, 245 cm, 248 cm, 251 cm, 254 cm, 257 cm, 260 cm, 263 cm, 266 cm, 269 cm, 272 cm, 275 cm, 278 cm, 281 cm, 284 cm, 287 cm, 290 cm, 293 cm, 296 cm, 299 cm, 302 cm
- Section 4: Ten turbidites, as above; 0 to 20 cm, 40 to 62 cm, 62 to 75 cm, 75 to 83 cm, 83 to 95 cm, 100 cm, 103 cm, 118 cm, 120 cm, 126 cm, 135 cm
- Core-Catcher: As above; dusky yellow-green and patches and beds
- Remarks: Foraminifera fragments (probably reworked) and minor fragments of detrital material, as above between 10 and 15 cm; between 0 and 10 cm, and 60 to 62 cm; fragments of reworked material in the upper part of the section, reworked material in the lower part of the section, and minor fragments of detrital material.

**SMEAR SLIDE SUMMARY**

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<th>TEXTURE</th>
<th>Fossil</th>
<th>Volcanic Tuff</th>
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**TEXTURE:**
- Sand
- Silt
- Clay
- Total
- Detrital Composition:

**LITHOLOGIC DESCRIPTION**
- TURBIDITES, MARLY NANOFOSIL CHALK, LIMESTONE, MUDSTONE WITH SILTY AND SANDY VITRIC TUFF
- Similar to Core 30, but with more carbonate content and less detrital material
- Lower part of the section: Barren and laminated sandstone
- Middle part of the section: Barren and laminated sandstone
- Upper part of the section: Barren and laminated sandstone
- Color:
  - Grayish yellow-green (Society 7/2)
  - Greenish gray (Society 6/2)
  - Yellow-green (Society 5/2)

**SMEAR SLIDE SUMMARY**

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<th>TEXTURE</th>
<th>Fossil</th>
<th>Volcanic Tuff</th>
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**TEXTURE:**
- Sand
- Silt
- Clay
- Total
- Detrital Composition:

**LITHOLOGIC DESCRIPTION**
- TURBIDITES, MARLY NANOFOSIL CHALK, LIMESTONE, MUDSTONE WITH SILTY AND SANDY VITRIC TUFF
- Similar to Core 30, but with more carbonate content and less detrital material
- Lower part of the section: Barren and laminated sandstone
- Middle part of the section: Barren and laminated sandstone
- Upper part of the section: Barren and laminated sandstone
- Color:
  - Grayish yellow-green (Society 7/2)
  - Greenish gray (Society 6/2)
  - Yellow-green (Society 5/2)
### SITE 459 HOLE B CORE 33 CORED INTERVAL: 302.0 to 311.5 m

#### LITHOLOGIC DESCRIPTION

**VITRIC MUDSTONE WITH SILTY LAYERS AND MUDDY/VITRIC TUFF**

**Section 1:** Color is mainly 5G 5/1 throughout. Coarser darker bands; burrowed 10 to 15 cm and 85 to 95 cm; vitric mudstone 0 to 95 cm; medium sandstone dark greenish gray (5GY 4/1) 95 to 100 cm. Muddy vitric tuff and siltstone, greenish gray (5G 5/1) 110 to 150 cm, faintly laminated. Core-Catcher: Several layers of siltstone above.

**SMEAR SLIDE SUMMARY**

**TEXTURE:**

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**TOTAL DETRITAL COMPOSITION:**

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### SITE 459 HOLE B CORE 34 CORED INTERVAL: 311.5 to 321.0 m

#### LITHOLOGIC DESCRIPTION

**NANNOFOSSIL VITRIC MUDSTONE WITH MUDDY/SILTY VITRIC TUFF LAYERS**

**Section 1:** 0 to 25 cm, brownish gray (5YR 4/1); parallel, greenish gray (5G 5/1) vitric mudstone with nannofossils.

**Section 2:** 0 to 10 cm, slightly mottled, laminated mudstone; greenish gray (5G 5/1). 0 to 40 cm, light olive gray (5Y 5/1), very fine sandstone, upper few cm burrowed. 40 to 80 cm, slightly laminated. Core-Catcher: Very fine sandstone, upper few cm burrowed. Remarks: Volcanic glass strongly altered; abundant siltstones.

**SMEAR SLIDE SUMMARY**

**TEXTURE:**

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**TOTAL DETRITAL COMPOSITION:**

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### SITE 459 HOLE B CORE 35 CORED INTERVAL: 321.0 to 330.5 m

#### LITHOLOGIC DESCRIPTION

**TURBIDITES: CLAYSTONE, VITRIC MUDSTONE, SILTSTONE, SANDSTONE (SILTY AND SANDY VITRIC TUFF; typical sequences of turbidite cycles, slumping.**

**Section 1:** 0 to 60 cm, 75 to 120 cm, 120 to 140 cm; 140 cm throughout Sections 2 and 3.

**Section 2:** 0 to 60 cm, sandy vitric tuff; 75 to 120 cm, claystone to mudstone; 120 to 140 cm, mudstone to fine sand.

**SMEAR SLIDE SUMMARY**

**TEXTURE:**

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<th>Clay</th>
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**TOTAL DETRITAL COMPOSITION:**

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### SITE 459 HOLE B CORE 36 CORED INTERVAL: 330.5 to 340.0 m

#### LITHOLOGIC DESCRIPTION

**TUFOIDES: CLAYSTONE, VITRIC MUDSTONE, SILTSTONE, SANDSTONE (SILTY AND SANDY VITRIC TUFF; typical sequences of turbidite cycles, slumping.**

**Section 1:** 0 to 60 cm, 75 to 120 cm, 125 to 140 cm, 145 cm throughout Sections 2 and 3.

**Section 2:** 0 to 60 cm, sandy vitric tuff; 75 to 120 cm, claystone to mudstone; 120 to 140 cm, mudstone to fine sand.

**SMEAR SLIDE SUMMARY**

**TEXTURE:**

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<th>Clay</th>
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**TOTAL DETRITAL COMPOSITION:**

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LITHOLOGIC DESCRIPTION

SITE 459 HOLE B CORE 37 CORED INTERVAL: 340.0 to 340.5 m

TURBIDITES, MUDSTONE, SILTSTONE, SANDSTONE, WITH VITRIC MUDSTONE TO SANDY VITRIC TUFF. One turbidite sequence very clear from top to bottom. Color grading associated with size grading (grayish brown, coarser).

Section 1: 0 to 3 cm, gray (5GY 1/1) to grayish green (5GY 1/2), top to bottom. Color grading associated with size grading. 115 to 140 cm, grading between dusky yellow green (5GY 5/2) to grayish olive green (5GY 3/2) to grayish brown (5YR 3/2), top to bottom. Color grading associated with size grading.

Section 2: 0 to 12 cm, pinkish orange (5YR 7/4) to pinkish orange (5YR 7/3) to pinkish orange (5YR 7/6) to pinkish orange (5YR 7/8), top to bottom. Color grading associated with size grading.

Section 3: 0 to 105 cm, grading between dusky yellow green (5GY 5/2) to grayish olive green (5GY 3/2). Color grading associated with size grading.

Section 4: 0 to 110 cm, grading between dusky yellow green (5GY 5/2) to grayish olive green (5GY 3/2). Color grading associated with size grading.

Core-Catcher: Pieces of very fine sandstone to siltstone, as above.

SMEAR SLIDE SUMMARY

TURBIDITE, MUDSTONE, SILTSTONE, SANDSTONE, WITH VITRIC MUDSTONE TO SANDY VITRIC TUFF. This turbidite sequence is very clear from top to bottom. Color grading associated with size grading (grayish brown, coarser).

Section 1: 0 to 3 cm, gray (5GY 1/1) to grayish green (5GY 1/2), top to bottom. Color grading associated with size grading. 115 to 140 cm, grading between dusky yellow green (5GY 5/2) to grayish olive green (5GY 3/2) to grayish brown (5YR 3/2), top to bottom. Color grading associated with size grading.

Section 2: 0 to 12 cm, pinkish orange (5YR 7/4) to pinkish orange (5YR 7/3) to pinkish orange (5YR 7/6) to pinkish orange (5YR 7/8), top to bottom. Color grading associated with size grading.

Section 3: 0 to 105 cm, grading between dusky yellow green (5GY 5/2) to grayish olive green (5GY 3/2). Color grading associated with size grading.

Section 4: 0 to 110 cm, grading between dusky yellow green (5GY 5/2) to grayish olive green (5GY 3/2). Color grading associated with size grading.

Core-Catcher: Pieces of very fine sandstone to siltstone, as above.

SMEAR SLIDE SUMMARY
**SITE 459 HOLE B CORE 41 CORED INTERVAL: 378.0 to 387.5 cm**

<table>
<thead>
<tr>
<th>TIME-LOCK</th>
<th>FOSSIL CHARACTER</th>
<th>GRAPHIC LITHOLOGY</th>
<th>LITHOLOGIC DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early Miocene</td>
<td></td>
<td></td>
<td>Core-Catcher: VITRIC MUDSTONE, finely laminated, grayish olive (10Y4/2).</td>
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**SPEAR SLIDE SUMMARY**

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<thead>
<tr>
<th>Unit</th>
<th>Texture</th>
<th>Volcanic glass</th>
<th>Radiolarians</th>
<th>Foraminifers</th>
<th>Feldspar</th>
<th>Clay</th>
<th>Total detrital composition:</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMS</td>
<td>Sand</td>
<td>5</td>
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**SITE 459 HOLE B CORE 42 CORED INTERVAL: 387.0 to 397.2 cm**

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<td>TURBIDITES, VITRIC MUDSTONE WITH SILTSTONE TO SANDSTONE (VITRIC TUFF) GRADED LAYERS</td>
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**SITE 459 HOLE B CORE 43 CORED INTERVAL: 392.0 to 408.5 cm**

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<td>TURBIDITES, MUDSTONE, VITRIC MUDSTONE WITH SILTSTONE TO SANDSTONE (VITRIC TUFF) GRADED LAYERS</td>
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**SITE 459 HOLE B CORE 44 CORED INTERVAL: 406.6 to 416.0 cm**

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SITE 459 HOLE B CORE 45 CORED INTERVAL: 416.0 to 425.5 m

LITHOLOGIC DESCRIPTION

TURBIDITIC DEPOSITS WITH PYROCLASTIC MUDSTONE AND SILETTE-SECTED SILETTE-TUFF (I)

Color is generally gray (5Y 6/1) with darker gray (5Y 3/1) in sandy layers, siltstone, and dewatered structures. Siltstone is generally graded, with thicknesses ranging from 5 to 30 cm. Layers of dewatered siltstone are typically gray to light grayish green (5GY 4/2). Micaceous layers are dark gray (5Y 3/1) to olive gray (5Y 4/1) and are typically 1 to 2 cm thick. Burrowed micaceous layers are typically 2 to 3 cm thick.

SWIM SLIDE SUMMARY

TEXTURE:
- Sand: 20%
- Silt: 30%
- Clay: 50%
- Total Clay: 80%

COMPONENTS:
- Feldspar: 5%
- Clay: 45%
- Volcanic glass: 5%
- Zeolite +: 10%
- Opaques +: 20%

SITE 459 HOLE B CORE 46 CORED INTERVAL: 425.5 to 435.0 m

LITHOLOGIC DESCRIPTION

MARLY NANNOFOSSIL CHALK AND VITRIC MARLY NANNOFOSSIL CHALK, WITH BIOTURBATION AND CHAOTIC DRAINAGE FEATURES IN SEDIMENTARY LIMESTONE (I)

Color is typically light gray (5Y 5/2) with darker areas of grayish green (5GY 6/2). Layers of light grayish green (5GY 6/2) are typically 1 to 2 cm thick. Burrowed layers are typically 2 to 3 cm thick. Laminated layers are typically 1 to 2 cm thick. Burrowed layers are typically 2 to 3 cm thick. Laminated layers are typically 1 to 2 cm thick.

SWIM SLIDE SUMMARY

TEXTURE:
- Sand: 20%
- Silt: 30%
- Clay: 50%
- Total Clay: 80%

COMPONENTS:
- Feldspar: 5%
- Clay: 45%
- Volcanic glass: 5%
- Zeolite +: 10%
- Opaques +: 20%
270 x 484
COLOR is grayish olive (5GY 3/2) or slightly
deformed by drilling between 15 to 35 cm. Coarser
mm) 20 to 30 cm.

SITE 459 HOLE B CORE 50 CORED INTERVAL: 463.5 to 473.0 m

LITHOLOGIC DESCRIPTION
MARLY NANNOFossil SILTSTONE AND CONGLOMER
Sandy beds up to 15 cm. Bioturbation and
normal faunal disturbance present throughout.
Section 1: yellowish green (5Y 7/2). Some
pebbles in Core-Catcher. As above
SMEAR SLIDE SUMMARY
Vitic Marly Nannofossil Chalk
194

TEXTURE:
Sandy: 30
Silt: 30
Clay: 40
Volcanic glass: 20
Nannofossils: 30
Radiolarians: –

TOTAL DETRITAL: 100

COMPOSITION:
Feldspar: 10
Clay: 40
Volcanic glass: 20
Nannofossils: 30
Radiolarians: –

VITRIC MARLY NANNOFossil CHALK, marly marly
nannofossil chalk with volcaniclastic conglomerate. Color is
generally pale olive (10Y 6/2). Mini-faults and microfractures
Section 1:
10 to 20 cm: Bioturbation and structure
10 to 30 cm: Bioturbated, brownish
Section 2:
0 to 5 cm: Bioturbated, brownish
5 to 10 cm: laminated, yellowish gray (5Y 7/2)
Laminates (normal)
Core-Catcher: As above
**SITE 459 HOLE B CORE 52 CORED INTERVAL:** 482.5 to 492.0 m

**LITHOLOGIC DESCRIPTION**

- MARLY NANNOFOSIL LIMESTONE, VITRIC MARLY NANNOFOSIL CHALK, CLAYSTONE WITH CROSS-LAMINATED AND GRADED SILTY TO SANDY VITRIC TUFF LAYERS (SUBSIDED DEPOSAL)

- Sections:
  - 1: Grayish to light gray (5Y 6/2) micritic and sublithid nanofossil chalk, bioturbated. Cross-laminated and graded silty to sandy vitric tuff layers (turbidites) ideal.
  - 3: Light brownish yellow (5YR 5/4) micritic and sublithid nanofossil chalk. Clays, silt, and sandstone.
  - 4: Gray (5Y 7/2) micritic and sublithid nanofossil chalk. Cross-laminated, bioturbated.

**SMEAR SLIDE SUMMARY**

- TEXTURE:
  - 110
  - 1

**SITE 459 HOLE B CORE 53 CORED INTERVAL:** 492.0 to 502.5 m

**LITHOLOGIC DESCRIPTION**

- MARLY NANNOFOSIL CHALK, NANNOFOSIL LIMESTONE, VITRIC NANNOFOSIL CHALK, CLAYSTONE WITH CROSS-LAMINATED AND GRADED SILTY TO SANDY VITRIC TUFF LAYERS (SUBSIDED DEPOSAL)

- Sections:
  - 1: Grayish to light gray (5Y 6/2) micritic and sublithid nanofossil chalk, bioturbated. Cross-laminated and graded silty to sandy vitric tuff layers (turbidites) ideal.
  - 3: Light brownish yellow (5YR 5/4) micritic and sublithid nanofossil chalk. Clays, silt, and sandstone.

**SMEAR SLIDE SUMMARY**

- TEXTURE:
  - 110
  - 1

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**SITE 459 HOLE B CORE 55 CORED INTERVAL:** 502.5 to 512.0 m

**LITHOLOGIC DESCRIPTION**

- MARLY NANNOFOSIL CHALK, NANNOFOSIL LIMESTONE, VITRIC NANNOFOSIL CHALK, CLAYSTONE WITH CROSS-LAMINATED AND GRADED SILTY TO SANDY VITRIC TUFF LAYERS (SUBSIDED DEPOSAL)

- Sections:
  - 1: Grayish to light gray (5Y 6/2) micritic and sublithid nanofossil chalk, bioturbated. Cross-laminated and graded silty to sandy vitric tuff layers (turbidites) ideal.
  - 3: Light brownish yellow (5YR 5/4) micritic and sublithid nanofossil chalk. Clays, silt, and sandstone.
LITHOLOGIC DESCRIPTION

FOSSIL CHARACTER

GRAPHIC LITHOLOGY

FORAMINIFER-NANNOFossil LIMESTONE and Dusky Brown CALCAREOUS TURBIDITES (REWORKED FORAMINIFEREL.

LITHOLOGIC DESCRIPTION

SITE 459 HOLE B CORE 56 CORED INTERVAL 520.5 to 530.0 m

SITE 459 HOLE B CORE 57 CORED INTERVAL 530.0 to 539.5 m

TEXTURE:

Gel 10
Cement 10
Fossil 10
Ammonite 10
Nannofossils 10

COARSE SANDSTONE

TEXTURE:

Gel 10
Cement 10
Fossil 10
Ammonite 10
Nannofossils 10

COARSE SANDSTONE
OJ

Claystone and aphric basalt

Section 60-1, 40-190 cm and Section 6, 40-90 cm. Fine- to medium-grained, highly vesicular (20-30%), nearly holocrystalline, partially altered aphric basalt. Color is greenish-gray (5Y 6/1) with mesostasis altered to brown clay (bioédinite). Carbonate is present on exterior fracture surfaces and as vesicle fillings. Some clay on interior fracture surfaces is pink in color. Apparently, the core is part of a massive flow unit, possibly nearly 30 meters thick.

Thin Section Descriptions

60-1, 40-42 cm. Altered microcline to orthoclase aphric basalt. Presents top of large flow or sill. The rock contains about 15% skeletal elongate microlites of plagioclase, about 5% clinopyroxene scherlites (fibrous) and about 2% quartz. There are about 10% regular vesicles (0.1-0.5 mm). The rest is micocrystalline to spotty, generally altered to clays. Texture is quite variable in this thin section (batholithic on one side, microlitic on the other).

60-1, 150-115 cm. Subophitic to interbedded aphric basalt. The rock contains about 40% plagioclase, 30% clinopyroxene, 25% augite, and about 25% altered and devitrified glass. Vesicles are filled with carbonate and microphenocrysts of brown chlorite. The rock is highly vesicular (0.1-3 mm) and nearly holocrystalline pervasivey altered to brown clay (bioédinite) material. There are minor veins of yellow-green clay. There are about 3% fragments of altered and devitrified glass as well as material between plagioclase and cpx.

60-2, 30-31 cm. Spherulitic to subophitic interbedded basalt. The rock contains about 30% plagioclase, 20% clinopyroxene, 10% augite, and about 20% altered and devitrified glass. There are 3% vesicles up to 0.5 mm and irregularly shaped, and 40% mesostasis. The latter is cryptocrystalline but with skeletal plagioclase, skeletal clinopyroxene, and altered clinopyroxene. There may also be minor veins of yellow-green clay.

60-1.1, 126-129 cm. Diabase. This rock is very similar to the one just described, but has less glass (less than 10%), more quartz or calcite feldspar, and contains carbonate among secondary minerals.

60-2, 30-31 cm. Diabase. This rock is similar to the one just described, but has less than 3% clinopyroxene (aphric basalt with some resedimented material).
Thin Section Description

64-1 24-27 cm
Hyalopilitic aphyric basalt. The rock consists of about 70% plagioclase, 15% clinopyroxene, 5% skeletal titanomagnetite, and 10% altered glass. The rock is aphyric, with 3% vesicles (0.2-7 mm), and contains 57% plagioclase (An 0-50%), 15% augite, and 3% skeletal and altered glass mesostasis. Clays make up between 60 and 70% of the rock, filling vesicles and replacing mesostasis. There is about 25% altered, devitrified, sometimes rock. Spherulitic glass, and 10% irregular vesicles up to 7 mm in size. Clays make up about 50% of the rock, and fill vesicles and replace glassy interstitial material. 

64-1 24-27 cm
Hyalopilitic aphyric basalt. About 3% plagioclase microlites and 5% clinopyroxene crystals are set in a partly devitrified and badly altered glassy groundmass. Vesicles comprise 10-15% of the rock (0.2-7 mm) and are round to irregular in shape. Clays and Fe-hydroxides make up 50% of the rock.

64-1 24-27 cm
Hyalopilitic to intersertal aphyric basalt. The rock consists of about 15% plagioclase, and 10% clinopyroxene micro-lites, with 3% skeletal titanomagnetite. Vesicles make up about 15% of the rock, and the remainder is a partly devitrified and badly altered mesostasis. Clays make up about 50% of the rock, filling vesicles and replacing mesostasis.

64-1 24-27 cm
Hyalopilitic aphyric basalt. The rock consists of about 3% plagioclase, 10% clinopyroxene, and 65% altered glass. The rock is aphyric, with 3% vesicles (0.2-7 mm), and contains 57% plagioclase (An 0-50%), 15% augite, and 3% skeletal and altered glass mesostasis. Clays make up between 60 and 70% of the rock, filling vesicles and replacing mesostasis. There is about 25% altered, devitrified, sometimes rock. Spherulitic glass, and 10% irregular vesicles up to 7 mm in size. Clays make up about 50% of the rock, and fill vesicles and replace glassy interstitial material.
The basalts are fine-grained, and moderately vesicular (5-10%). Microphenocrysts of plagioclase (1%) and clinopyroxene (1%) dominate. Piece 16 of Section 1 has an altered glassy rind. In Section 2 have larger vesicles (5-8 mm). These are round. Thin carbonate veins occur in the groundmass of smaller plagioclase (25%), augite (15%), titanomagnetite (2%), and altered devitrified glass (50%). Ilmenite needles may also be present. Vesicles (50%) and clinopyroxene microphenocrysts up to 8 mm, set in a groundmass of plagioclase (20%), clinopyroxene (15%), and olivine (10%). The latter color is concentrated about fractures in the rock. The rock is aphyric, and consists of 30% ptagioclase (An68-1, 24-26 cm. Intersertal basalt. The rock is aphyric, and consists of 30% ptagioclase (An68-1, 24-26 cm. Intersertal basalt. The rock is aphyric, and consists of 30% ptagioclase (An68-1, 24-26 cm. Intersertal basalt. The rock is aphyric, and consists of 30% ptagioclase (An68-1, 24-26 cm. 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Aphyric basalt:

Dark greenish-gray to grayish-black, vesicular, fine-grained, and flow-banded. The rock contains about 50% of the rock and up to 0.8 mm across. The lower 10 cm of the core is true basaltic breccia with greenish-gray olivine phenocrysts. Vesicles are about 2% of the rock and are lined with green or brown secondary minerals. They are filled with clay, which also replaces vesicles. Vesicles are 5-7% of the rock and up to 0.8 mm across. The lower 10 cm of the core is true basaltic breccia with greenish-gray olivine phenocrysts. Vesicles are about 2% of the rock and are lined with green or brown secondary minerals. They are filled with clay, which also replaces vesicles. Vesicles are 5-7% of the rock and up to 0.8 mm across.