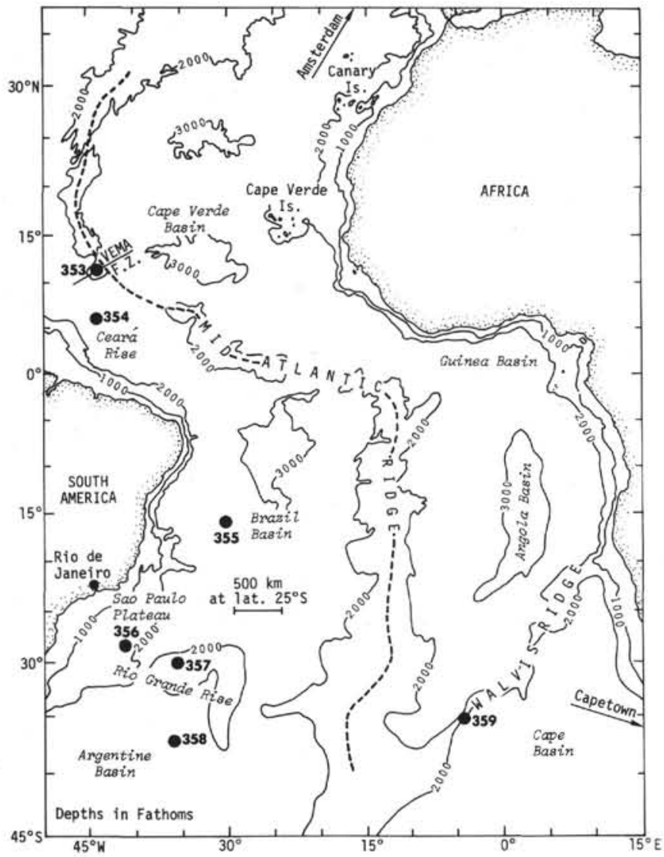
8. SITE 359: WALVIS RIDGE (SEAMOUNT)

The Shipboard Scientific Party[1]



SITE DATA

Date Occupied: 10 Dec 74 (1455Z)

Date Departed: 11 Dec 74 (2340Z)

Time on Site: 1 day, 8 hours, 45 minutes

Position: 34°59.10'S, 04°29.83'W

Water Depth: 1658 meters (drill pipe measurement)

Penetration: 107 meters

Number of Holes: 2

Total Length of Cored Section:
Hole 359: 50.0 meters
Hole 359A: 19.0 meters

Total Core Recovered:
Hole 359: 27.5 meters
Hole 359A: 14.9 meters

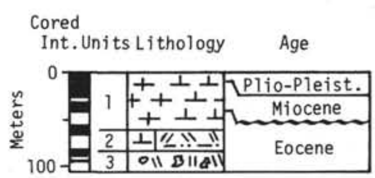
Principal Results: Site 359 was a contingency site selected near the crest of a positive feature (seamount) on the trend of the Walvis Ridge. Fifty-seven meters of upper Eocene and younger foraminifer-nannofossil ooze overlie 29 meters of upper Eocene calcareous volcanic mud. An important hiatus spans the upper Eocene to lower to middle Miocene. A middle to upper Miocene hiatus is also probably present. An upper Eocene sanidine-rich volcanic tuff was cored between a depth of 86 meters and the bottom of the hole at 107 meters.

BACKGROUND AND OBJECTIVES

After leaving Site 358 24 hr early because of bad weather, we held open the alternative of occupying a shallow-water site, to utilize remaining operational time on Leg 39. Because we had not sufficient time to deviate from the direct course to Cape Town, our options were to locate a site either on the shallow portion of the Walvis Ridge or on the shallow portion of the continental slope off South Africa (Figure 1).

In the late morning of 10 December, we reached the western flank of a positive feature which is part of the structural lineament of the Walvis Ridge. The reflection profile (Figure 2) showed what appeared to be igneous basement covered by 0.1-0.3 sec of semiconformable reflectors. We elected to drill on the Walvis Ridge if we could find a place with suitable sediment thickness in water shallow enough to allow meaningful work in the time left, about 30-36 hr. Just west of the crest of the feature we did find such a place; about 0.3 sec of sediment appeared to overlie basement and the section had intermediate reflectors at 0.11 and 0.20 sec.

The objectives at this site were to core the sedimentary section, paying particular attention to recovery of upper Paleogene (Oligocene, Eocene) sediments if these were present, and to sample igneous basement if time and drilling rates permitted. The site is in the region of anomaly 25 (Ladd, 1974), which probably represents a crustal age of about 53 m.y.B.P. (Tarling and Mitchell, 1976).



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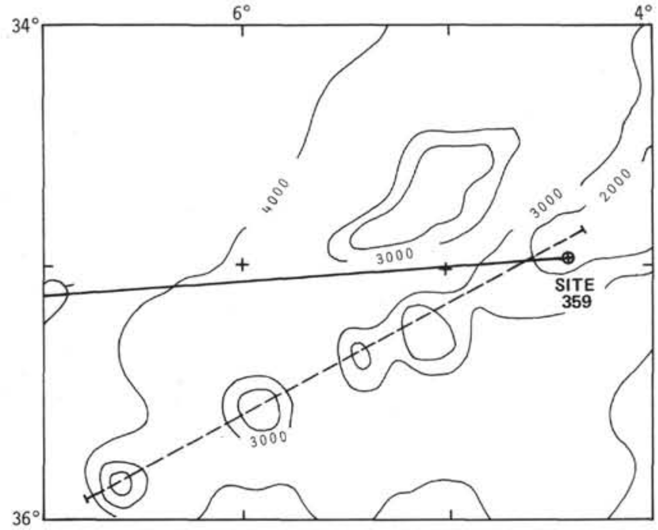

Figure 1. *Base map showing the location of Site 359 in the western (seamount) province of the Walvis Ridge. From bathymetric chart by Simpson (1974); heavy contour is 4500 meters, other contour lines at 500 meter intervals.*

Since Site 359 was a contingency site selected at sea, we were working without the advice of the JOIDES Atlantic Advisory Panel or the JOIDES Advisory Panel on Pollution Prevention and Safety. On the basis of the presumed pelagic nature of the sediments and the shallow water depth, we were fully confident that no potential hazard existed.

OPERATIONS

Glomar Challenger approached the vicinity of Site 359 on a course of 086°T at a speed of about 10 knots. The reflection profile obtained over the western flank of the Walvis Ridge province indicated (locally) at least two reflectors lying semiconformably over presumed basaltic basement 0.1 to 0.3 sec below (Figure 2). We crossed the crest of the topographic feature at 1325Z. After traversing the east flank until it lay at a depth that would have compromised operations in the short time available, we decided that the most favorable drill site was on a low sediment rise about 4-5 miles west of the ridge crest. We executed a Williamson turn onto 267°PGC at 1345Z, slowed the ship to 6.5 knots, and recrossed the crest at 1410Z (Figure 2). We dropped a

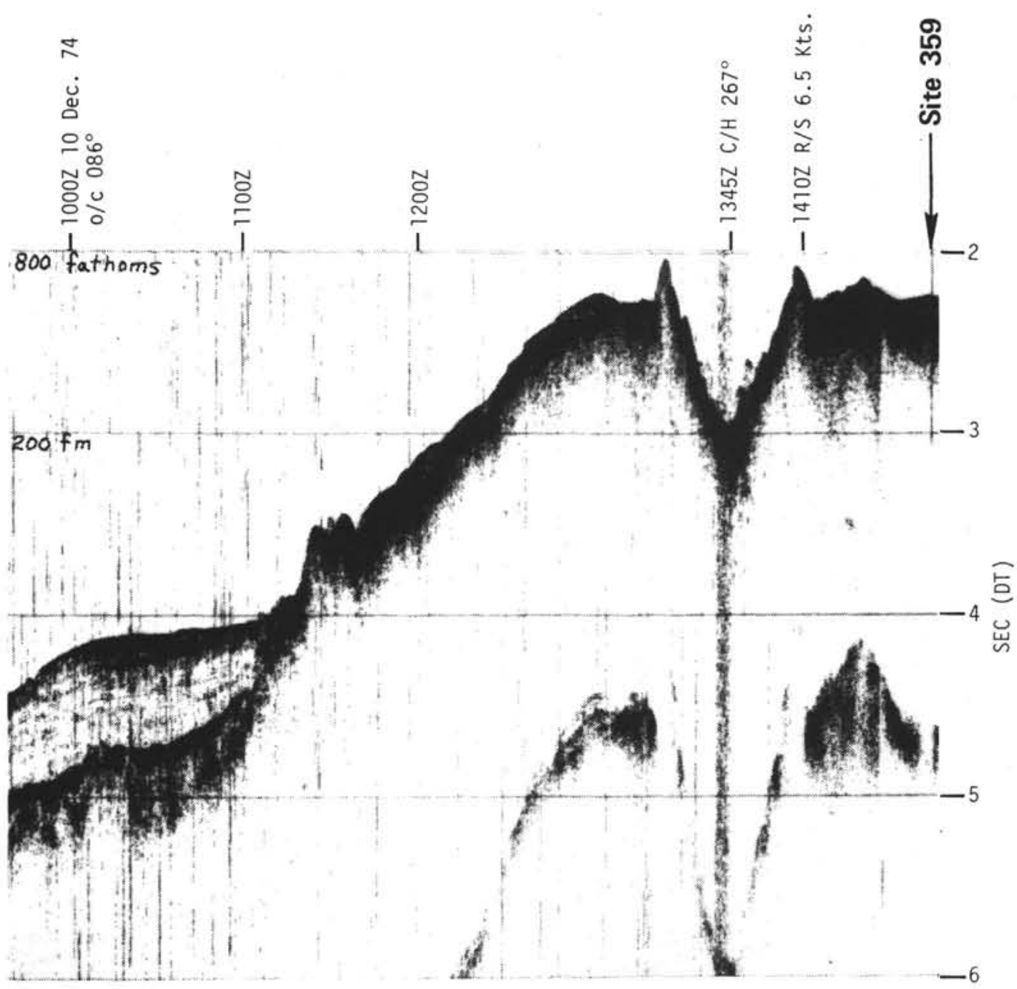

Figure 2. Glomar Challenger *seismic reflection profile obtained on approach to Site 359.*

13.5-kHz beacon while underway at 1455Z, retrieved geophysical gear, and returned to position the ship over the beacon.

We had considerable difficulty in attempting to lock onto the beacon: the computer display showed the ship to be moving relative to the beacon at an unlikely rate. Various means of troubleshooting and computer repair were of no avail. During these repair attempts, the bottom-hole assembly units were magnafluxed. This was required preparatory to running in the hole at Site 359 anyway, so the time spent on trying to positon over the beacon was not totally lost.

The beacon signal began to fail after about 6 hr, and at 2130 hr (Z time zone same as LCT) we dropped a 16-kHz beacon at the same location. Problems continued with the new beacon. We started running pipe slowly at 2200 hr, in hope of finally having the computer accept the beacon. At about 0500 hr we satisfactorily locked onto the beacon. The site location (average of 10 satellite fixes) is 34°59.10'S, 04°29.83'W. Water depth by PDR is 1655 meters. Drill pipe measurement at bottom contact was 1668 meters to the rig floor; a water depth of 1658 meters is accepted.

Site 359 was spudded at 0630 hr 11 December. The top 107 meters of section was spot-cored; three cores were unconsolidated sediment, one was unconsolidated sediment and a hard black tuff, and one was tuff (Table 1). During the cutting of Core 5, the drill bit apparently became plugged, which accounts for the low recovery of tuff in Core 5 and the zero recovery in Core 6.

We had decided earlier that if the tuff appeared to be a thick deposit, our time would be better spent attempting to core the interval 9.5-28.5 meters, which would contain either missing section or evidence of a hiatus. Before we could attempt this, we had to free the bit. A chisel-faced center bit, pumped down the pipe at high pump pressure, succeeded in freeing the lodged material from the bit. Hole 359A was spudded at 1800 hr and the required two cores were taken. We began running out of the hole at 1915 hr.

Glomar Challenger got underway at 2340Z 11 December 74. We steamed north to stream gear, executed a slow turn to starboard, came up to 10 knots at 0005Z 12 December, and passed over the site with the beacon 70 meters to starboard at 0030Z (Figure 3). We held this course for 15 min (~2.5 nautical miles), then executed a starboard turn of one mile radius and came onto a course of 087° PGC for the steam to Cape Town.

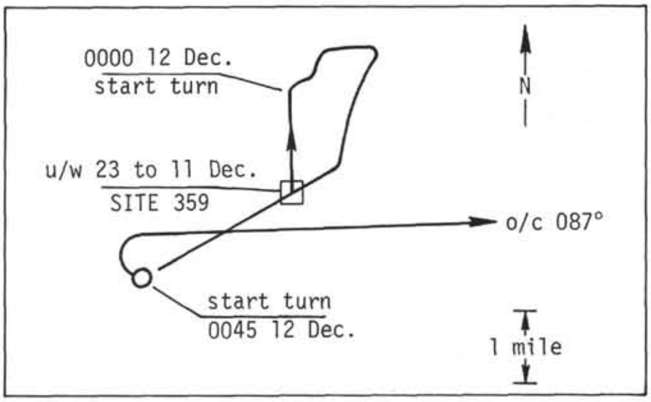

Figure 3. Glomar Challenger *track on departure from Site 359.*

LITHOLOGIC SUMMARY

The sediments and volcanic rocks of this site are divided into three distinct lithologic units (Figure 4, Table 2)

Unit 1

Unit 1 is Pleistocene to late Eocene in age, and divided into Subunits A and B on the basis of a slight change in composition and color. A thin pinkish light gray horizon marks the upper Eocene/middle Miocene hiatus and separates the two subunits.

Subunit A (Core 1 to Sample 2-6, 60 cm, 0.0-36.1 m) consists of a white soupy foraminifer-nannofossil ooze. The very homogeneous sediments contain occasional small pale yellowish specks. The dominant color grades downsection (Core 1 of Hole 359 to Core 2 of Hole 359A) into very pale orange; this color first occurs in several thin horizons in Core 1A. The major sediment

TABLE 1
Coring Summary, Site 359

Core	Depth From Drill Floor (m)	Depth Below Sea Floor (m)	Cored (m)	Recovered (m)	Recovery (%)
Hole 359					
1	1668.0-1677.0	0.0-9.0	9.0	6.1	68
2	1696.0-1705.5	28.0-37.5	9.5	9.5	100
3	1724.5-1734.0	56.5-66.0	9.5	9.5	80
4	1753.0-1762.5	85.0-94.5	9.5	3.5	37
5	1762.5-1772.0	94.5-104.0	9.5	0.8	8
6	1772.0-1775.0	104.0-107.0	3.0	0.0	0
		Total	50.0	27.5	55
Hole 359A					
1	1677.0-1686.5	9.0-18.5	9.5	8.4	88
2	1686.5-1696.0	18.5-28.0	9.5	6.5	68
		Total	19.0	14.9	78

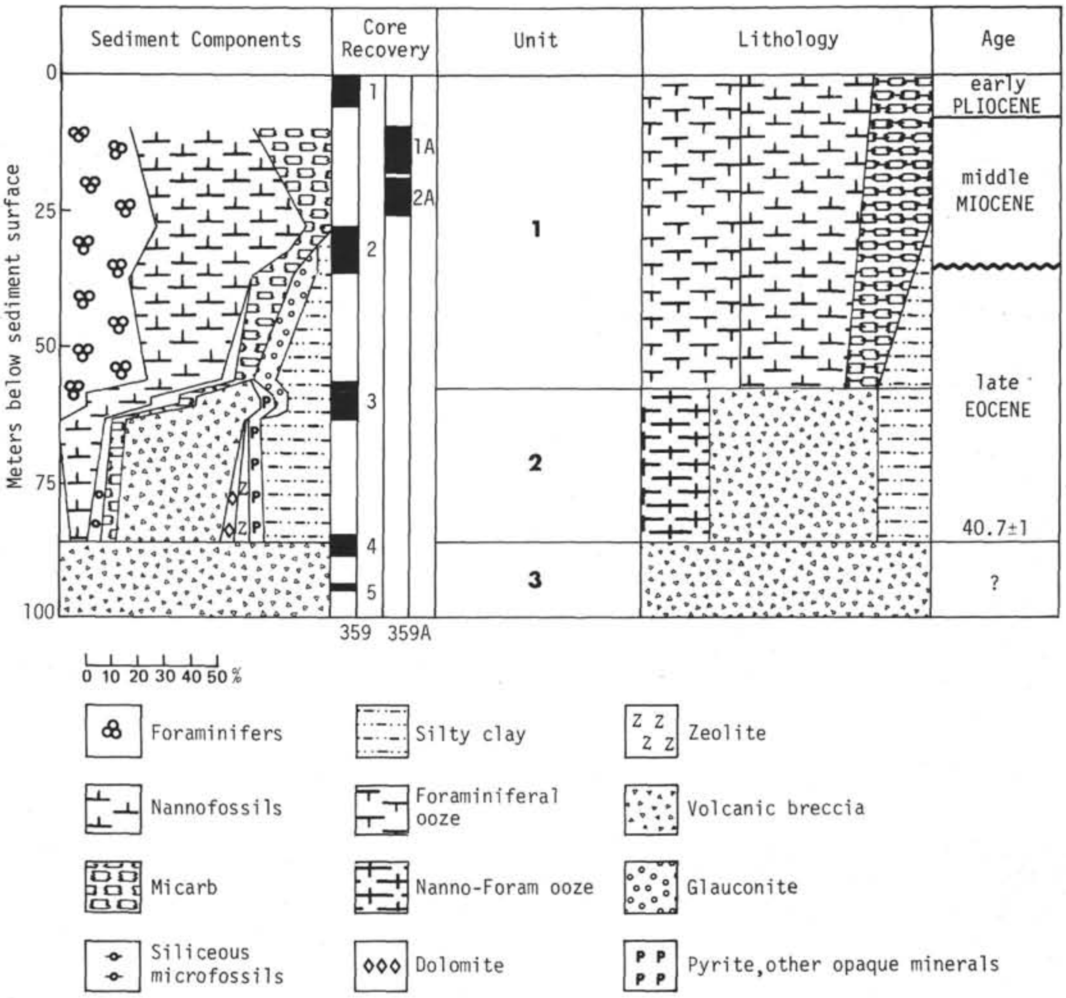

Figure 4. *Lithologic summary, Site 359. Sediment composition data based on shipboard smear-slide examination.*

components of Subunit 1A are calcareous nannofossils (50%-70%), planktonic foraminifers (10%-30%), and authigenic carbonate. Many calcareous fossils are heavily encrusted. Opaline skeletons are almost completely absent. Except for the faint color changes mentioned above, no sedimentary structures have been preserved in the soupy sediments.

The sediments in Subunit 1B below the upper Eocene/middle Miocene hiatus (from Sample 2-6, 60 cm to Sample 3-1, 45 cm, 36.1-56.9 m) consist of 20.8 meters of foraminifer-nannofossil oozes and occasional nannofossil-foraminifer oozes. The yellowish-gray color of these sediments begins below a sharp contact (the Eocene/Miocene hiatus), which is marked by a thin, slightly darker horizon. The sediments are similar to but slightly coarser than those of Subunit 1A. In addition to the above-mentioned main components, they contain glauconite, mainly as fillings within foraminifer tests and shallow (?) water fossils, such as small oyster-like bivalves, bryozoans, and barnacles. Small, dark brown sand-sized fragments of maganese crust occur frequently in the sediments of this unit.

Unit 2

The calcareous, mostly sandy volcanic muds which consistute this upper Eocene unit consist mainly of a mixture of biogenic and volcanogenic materials whose proportions change erratically. The term *volcanic mud*, therefore, includes sediments of quite different compositions. The dominant color is light olive-gray; irregular areas are slightly greener. Except for the pumice layers (see below) and a thin volcanic ash, no sediment structures are evident. Dominant components are foraminifers, calcareous nannofossils, sponge spicules, volcanic glass, clay minerals, and glauconite; authigenic carbonate, hornblende, pyroxene, feldspars, zeolites, diatom remains, radiolarians, dolomite rhombs, opaque minerals, and Fe oxides are of minor importance. Bivalves, brachiopods, and a solitary coral are macroscopic representatives of shallow water faunas.

Three pumice layers, 5 to 10 cm thick, with generally lapilli-sized fragments and with distinct contacts, are intercalated with the sediments described above. The volcanic glasses differ from the surrounding volcanic mud by their olive-gray to grayish-olive color and by their distinct appearance as coarse (average grain diameter 0.5 ±2 mm) layers.

A few centimeters above the tuff of Unit 3, a marly limestone, 10-20 cm thick (Sample 4-2, 5 cm to 15 cm), occurs intercalated with volcanic mud. The sediments directly in contact with Unit 3 are laminated and show

TABLE 2
Lithologic Summary, Site 359 (Walvis Ridge)

Unit	Cores Hole 359	Cores Hole 359A	Depth Below Sea Floor (m)	Thickness (m)	Age	Description
1	1-3	1A and 2A	0-56.9	56.9	Pleistocene to Miocene and L. Eocene	Subunit 1A: Foram nanno ooze (white to pale yellow orange) Subunit 1B: Foram nanno to nanno foram ooze (yellowish-gray)
2	3-4		56.9-86.0	29.1	L. Eocene	Calcareous volcanic mud with pumice layers (light olive-gray)
3	4-5		86.0-95.5	9.5	L. Eocene	Volcanic ashflow tuff (black, medium to dark gray)

lensy bedding (sand in clayey sediments). They exhibit settling cracks with up to 1 cm displacement.

Unit 3

Below the Eocene volcanic muds, 3.3 meters of medium gray ash-flow tuff were recovered in Cores 4 and 5. At least 10 or 20 meters more probably escaped recovery because of a plugged drill bit. The ash-flow tuff contains abundant feldspar crystals (up to 5 mm long), minor amounts of green pyroxene crystals and biotite, and medium light gray pumice fragments up to 1 cm, in a fine-grained matrix. It is moderately indurated, although it crumbles slightly when rubbed. In hand specimens the tuff appears to be free of alteration and weathering.

Thin-section examination shows alkali feldspar as rectangular crystals averaging 0.5 to 1 mm in size, with distinct cleavage planes and Carlsbad twinning. Overall, the feldspar is unaltered. Infrequent clinopyroxene grains appear to be fresh, whereas the biotite is highly oxidized. Oxides are also present. The rock type is probably one of intermediate composition.

Pumice fragments are abundant; compaction ratios vary from 1:1 to about 10:1, and indicate moderate welding. Cellular and fibrous structures are no longer visible, probably because of devitrification and seawater alteration to clays. Similarly, the groundmass looks rather dusty and glass shards are not visible.

GEOCHEMISTRY

We analyzed three interstitial water samples for *p*H, alkalinity, salinity, Ca^{++} and Mg^{++} content. The results are presented in Table 3.

PHYSICAL PROPERTIES

No report for this site.

BIOSTRATIGRAPHIC SUMMARY

The eight cores taken at Site 359 range in age from Pliocene to late Eocene. The biozones represented are shown in Figure 5.

Pliocene/Pleistocene

Only a veneer of mixed Pliocene and Pleistocene sediment occurs at the top of the first core; below this level the sediment is early Pliocene in age. Thus, a hiatus exists between the Pleistocene and the lower Pliocene. Pliocene foraminifer faunas in the core contain subtropical species; nannofossil assemblages consist of high- and mid-lattitude elements. It appears that small nannofossil species have been winnowed out of the sediment. Benthic foraminifer faunas indicate bathyal water depths. No radiolarians are present.

Miocene

Miocene sediments occur in Core 2, Hole 359, and in both cores from Hole 359A. According to the foraminifer evidence, the section spans the upper Miocene into upper middle Miocene. The nannofossils, however, indicate a section down to the lower middle Miocene. The foraminifer assemblages contain subtropical open marine species, and benthic species indicate bathyal depths. The nannofossils are poorly preserved and no radiolarians occur.

Eocene

A hiatus between the middle Miocene and the upper Eocene occurs at the bottom of Section 359-2. The foraminifers from Cores 2 through 4 all belong to one zone, the lower upper Eocene Zone P15, and the nannofossils represent two lower upper Eocene zones (NP19 and 18).

The characteristics of the upper Eocene fauna and flora are entirely different from those of the Neogene.

TABLE 3
Summary of Shipboard Geochemical Data

Sample (Interval in cm)	Subdepth (m)	*p*H	Alkalinity (meq/l)	Salinity (°/₀₀)	CA++ (mmoles/l)	Mg++ (mmole/l)
3-3, 144-150	61	7.63	2.57	35.2	13.63	48.82
4-1, 75-80	85.5	7.64	2.54	35.3	13.60	48.27
1A-4, 144-150	15	7.57	2.97	35.2	11.58	51.48

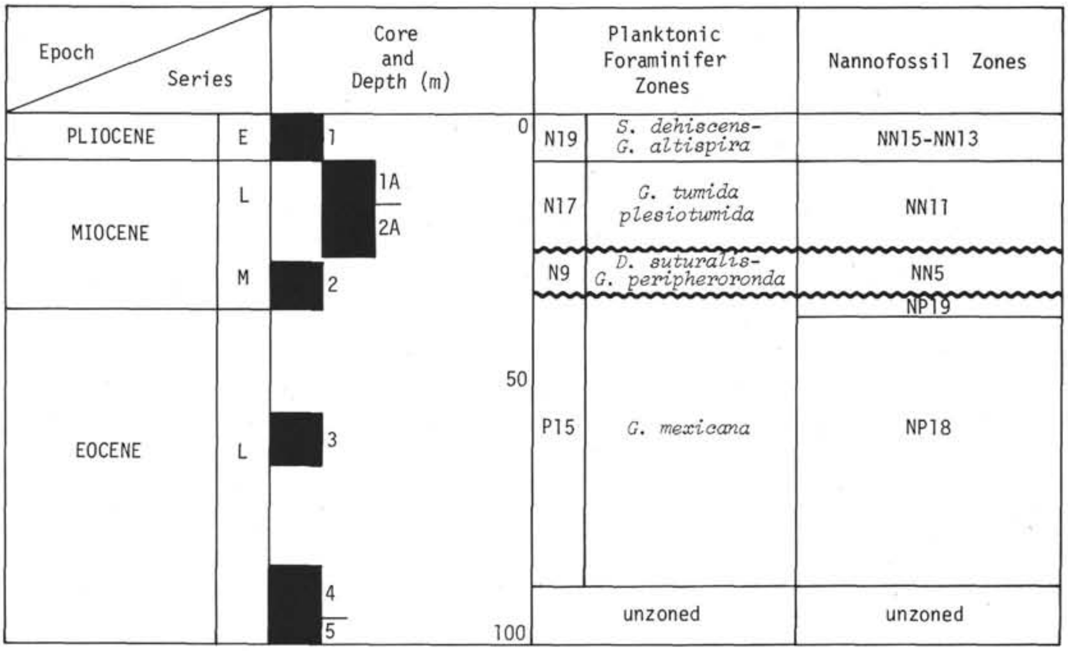

Figure 5. *Biostratigraphic summary, Site 359.*

For example, some poorly preserved radiolarians occur in Core 3. The presence of *Lychnocanium bellum*, commonly found in the southern Indian Ocean, indicates that cool-temperate waters flow into the eastern Atlantic up to at least the area of this site.

Many invertebrate fossils, some of shallow shelf origin, such as pelecypods and barnacles, occur mixed in with the foraminifer faunas in Cores 2 and 3. Only the more resistant planktonic species are present in most samples; the benthic foraminifers are diverse and suggest outer shelf depths. The nannofossil flora contains members of the Braarudosphaeraceae, which apparently prefer restricted conditions. In Core 4 the Braarudosphaerids decrease in abundance, as do the shallower invertebrate fossils. The shallower water indicators may have reached the depth of the deposition site from higher parts of this positive feature.

Foraminifers

Pliocene/Pleistocene

Core 1 contains both Pliocene and Pleistocene planktonic foraminifers. In Sample 1-1, 46-48 cm (the top), a thin tan layer contains a residue of Pleistocene (*Globorotalia truncatulinoides* Zone), mixed with Pliocene (*G. margaritae* Zone). Sediments below that layer are white, like the core-catcher sample, which contains foraminifers of the Pliocene *G. margaritae* Zone, such as the nominate taxon, *G. crassula, G. punticulata*, *G. conomiozea*, and *Sphaeroidinellopsis subdehiscens.*

If Pleistocene overlies the lower Pliocene, as suggested by the top layer of this core, then the upper Pliocene and the rest of the Pleistocene are missing at this site.

The planktonic forms in this core are subtropical and typical of open marine conditions. They are partially overgrown with calcite crusts, and many are corroded. Benthic species are fairly scarce, but are represented by bathyal species of the genera *Laticarinina*, *Angulogerina*, *Cassidulina*, and *Stilostomella*. Echinoid fragments and smooth ostracodes also occur.

Miocene

Miocene sediments occur in Core 359-2 and in two cores from Hole 359A. These Hole 359A cores appear to represent the section below Core 359-1 but above Section 359-2-6. Core 359A-1 contains a moderately well preserved fauna that includes the index species *Globoquadrina dehiscens*, *Globorotalia conomiozea*, *Globigerina nepenthes*, and *Globigerinoides sacculifer*. The specimens in Core 359A-2 are poorly preserved and the fauna is depleted, but the same index species, except *G. sacculifer*, are present.

Since *G. conomiozea* evolves in Zone N17 and *G. dehiscens* becomes extinct above Zone N17, we assign these cores to the upper Miocene (Zone N17).

Sample 359-2-6, 61 cm, is apparently older. *Globorotalia conomiozea* is no longer present, but *Globorotalia miozea* is. *Globigerina nepenthes, G. woodi*, *Globorotalia conoidea*, and *Globigerina bulloides* are abundant. This part of Section 2-6 apparently belongs in the middle to upper Miocene (Zones N14-N16).

Below Sample 359-2-6, 61 cm, a marked lithologic change occurs, from the Miocene creamy marl above to gray clayey marl below. Sample 359-2-6, 95 cm, from the marl sequence, contains a mixed fauna of Miocene and upper Eocene. The Miocene fauna, however, appears to be older than that in Sample 359-2-6, 61 cm. The co-occurrence of *Globorotalia praemenardii* and *G. miozea* in this sample suggests a middle Miocene age.

Despite differences in preservation of the faunas, these subtropical Miocene planktonic foraminifer faunas are markedly similar; few other fossils or components occur in the residues, and the benthic species characterize bathyal depths.

Eocene

Fossils of Eocene age occur in Samples 2-6, 95 cm, through 4-1, 120 cm. These fossils include not only planktonic foraminifers, but abundant shelf benthic foraminifers, echinoid remains, fish teeth, pelecypod remains, a few siliceous fossils, and structures resembling "grouped" barnacles. From the diversity of fossils it is difficult to assess how much of the material is in place and how much transported. Glauconite, also common in many samples, suggests microreducing conditions.

Samples 2-6, 95 cm and 2, CC contain upper Eocene faunas mixed with considerable numbers of Miocene planktonic forms. However, the Eocene foraminifer faunas in this and Sections 3-1 through 4-1 are very similar, and contain the species *Globigerinatheka mexicana*, *Globigerapsis index*, *Globigerapsis kugleri*, *Globorotalia (Turborotalia) cerroazulensis*, and in better preserved samples, *"Globigerinita" howei*, *Hantkenina alabamensis*, *Pseudohastigerina micra*, and *Chilogumbelina wilcoxensis*. Sample 4-1, 120 cm, contained in addition several species of round-edged acarininids.

All these samples indicate subtropical conditions and belong to the upper Eocene *G. mexicana* Zone (P15).

Each sample contains differing amounts and types of benthic fossils, and evidence for environmental type from these fossils often conflicts. For example, Sample 4-1, 120 cm, contains a slope fauna of benthic foraminifers, but also macroscopic pelecypods. Sample 3, CC contains typically slope-dwelling benthic species of *Stilostomella*, *Uvigerina*, *Gavelinella*, and *Anomalinoides*, along with structures that seem to be barnacles and pelecypod remains. If the deeper-dwelling fossils are in place, then Core 4 sediments may have come from a slightly deeper environment than sediments in Cores 2 or 3.

Calcareous Nannofossils

Calcareous nannofossils of early Pliocene to late Miocene-middle Miocene age and of late Eocene age occur in Cores 1 to 4 of Hole 359 and Cores 1 and 2 of Hole 359A. Figure 5 summarizes the distribution of coccolith zones. Tables in Perch-Nielsen (this volume) show the distribution of coccolith species.

Pliocene (Core 1)

Core 1 contains common but poorly preserved coccoliths, including only a few barely definable discoasters. The assemblage consists almost exclusively of large forms. This suggests extensive winnowing of this high- to mid-latitude assemblage. An early Pliocene age is suggested by *Cyclococcolithina macintyrei*, *Sphenolithus abies*, *Reticulofenestra pseudoumbilica*; *Pseudoemiliania lacunosa* is absent. Sample 359-1-1, 46 cm contains some species (*Syracosphaera histrica* and *Rhabdosphaera claviger*) which indicate a warmer climate (or less dissolution) than that inferred from Sample 359-1, CC.

Miocene (Cores 2, 1A, and 2A)

The Miocene assemblages also are poorly preserved and include none of the discoasters, sphenoliths, or ceratoliths used in the tropical and subtropical coccolith zonations. Thus the presence of *C. macintyrei* in all samples must be taken to indicate an age of middle to late Miocene. Its co-occurrence with *Cyclicargolithus floridanus* indicates an early middle Miocene age for Sections 1 through the top of 6 of Core 359-2 and Core 359A-2; Core 359A-1 may be of late middle to late Miocene age.

Late Eocene (Cores 2, 3 and 4)

Common and fairly well preserved coccolith assemblages of late Eocene age occur below Sample 359-2-6, 60 cm, and in Core 3 and the top of Core 4. Besides *Isthmolithus recurvus* and *Chiasmolithus oamaruensis*, which indicate an early late Eocene age, the assemblage includes common *Zygrhablithus bijugatus* and few *Braarudosphaera bigelowi* in Sample 2, CC. In Sample 3, CC, *I. recurvus* is missing, *Z. bijugatus*, *B. bigelowi*, and *Micrantholithus* sp. are few, and *C. oamaruensis* indicates the zone of this name. Both assemblages reflect a depth of deposition shallower than the present depth of this site (1658 m). Common *Z. bijugatus* suggests depths of less than 1000 meters, and members of the family Braarudosphaeraceae preferred very shallow and/or restricted seas (bays, fjords, etc.). The coccolith assemblage in the upper part of Core 359-4 is still of late Eocene age, but contains a more diverse flora, with fewer representatives of Braarudosphaeraceae. Small pieces of clay attached to the volcanic tuff of the core-catcher sample of 359-4 contain only rare coccoliths—probably contaminants.

SEDIMENT ACCUMULATION RATES

Figure 6 summarizes the sediment accumulation history at Site 359 in the southwestern part of the Walvis Ridge. Age was determined from planktonic foraminifers in the Neogene and from foraminifers and calcareous nannofossils in the Eocene.

No fossils occur in the hard volcanic tuff recovered in Core 5 and the bottom of Core 4; we obtained a K/Ar date of 40.7 $\pm$1 m.y. from the tuff. The oldest fossils (foraminifers and coccoliths) indicate at least a late Eocene age for the lowermost fossiliferous volcanic mud in Core 4. The bottom of Section 359-2-6 is of only slightly younger age than Core 4, so the accumulation rate was thus at least about 2 to 3 cm/1000 yr.

A hiatus spanning the uppermost Eocene, the entire Oligocene, and the lower to middle Miocene was cored in the foraminifer-nannofossil oozes in Section 359-2-6. Another hiatus may occur between Cores 2 and 2A and include middle to upper Miocene. This "hiatus" may, however, also be an artifact caused by the use of data from two holes. The accumulation rate during the late Miocene to early Pliocene was probably about 1 cm/1000 yr.

Sediments of late Pliocene and early Pleistocene age were not recovered at this site. Since only 68% of the sediment was recovered in Core 359-1, taken at the sediment surface, the Quaternary may have been present but missed in coring.

CORRELATION OF REFLECTION PROFILE WITH DRILLING RESULTS

Figure 7 contains a line drawing interpretaion of the Glomar Challenger seismic reflection profile obtained

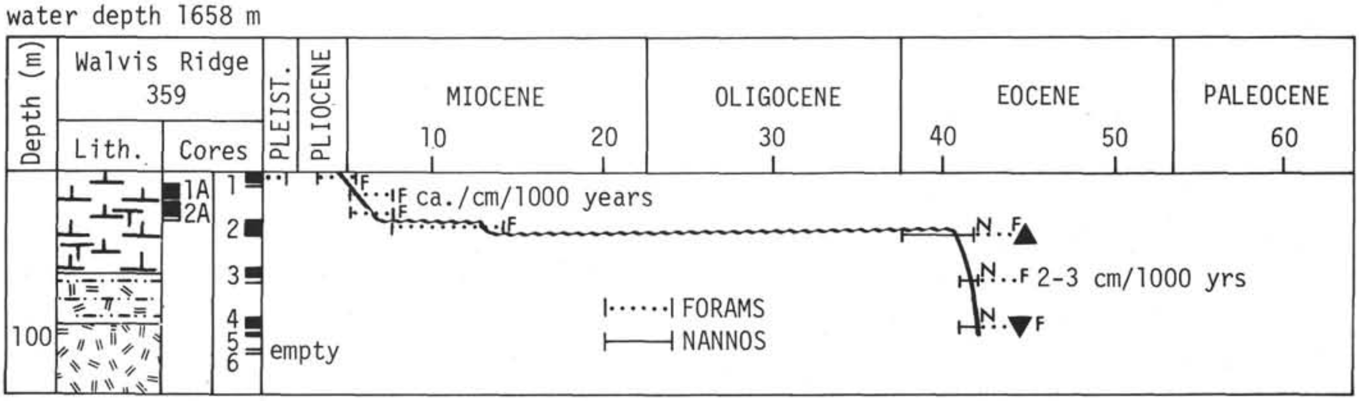

Figure 6. *Sedimentation history, Site 359.*

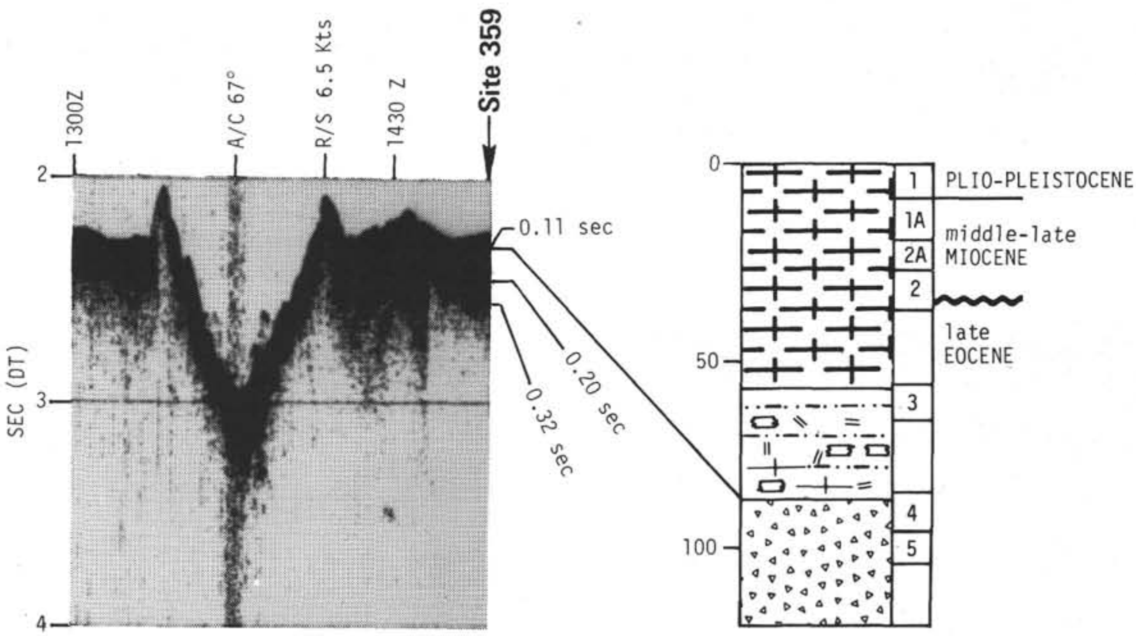

Figure 7. *Correlation of the seismic reflection profile with the stratigraphic sequence.*

on approach to Site 359 (Figure 2). Reflectors are present at 0.11 and 0.20 sec. A reflector appears at 0.32 sec on the original strip chart record, but its validity is doubtful.

The reflector at 0.11 sec is correlated with the top of the black tuff encountered in Core 4 at a depth of 87 meters. This would result in an average sonic velocity of 1.58 km/sec for the upper ooze sequence.

The tuff layer, of which we penetrated 20 meters, probably does not extend from 0.11 to 0.20, since a tuff over 100 meters thick would absorb all the non-reflected energy within itself and its top at 0.11 sec would appear as acoustic basement on the profile record. The reflector at 0.20 sec indicates that there is probably nontuffaceous sediment in the interval between 0.11 and 0.20 sec. It is unclear whether acoustic basement is the 0.20 sec reflector or whether a reflector actually occurs at 0.32 sec.

The tuff horizon seems to crop out slightly upslope from the drill site (Figure 7). The outcropping tuff imparts a very dark reflective appearance to the seismic profile record. No subbottom reflectors are evident in the region where tuff is exposed.

SUMMARY AND CONCLUSIONS

The mode(s) of origin and structural history of the Walvis Ridge are critical to understanding the development of the South Atlantic ocean basin, particularly with regard to the ridge's role as a barrier to surface water exchange and deep flow in the meridional direction at various stages of development of the South Atlantic. The most comprehensive compilations of data are those of Connary (1972), Barnaby (1974), Goslin et al. (1974), and Goslin and Sibuet (1975); Dingle and Simpson (manuscript) review these and other references.

Wilson (1965), Dietz and Holden (1970), and Morgan (1971, 1972) have proposed that the Walvis Ridge was generated by the southeast Atlantic crustal plate having moved away from a "hot spot" on the accreting plate boundary of the Mid-Atlantic Ridge. Le Pichon and Hayes (1971) and Francheteau and Le Pichon (1972) favor a transform-fault origin. Goslin and Sibuet (1975) explain the different strikes of the three recognized subprovinces (Connary, 1972) of the Walvis Ridge as resulting from extrusion of mantle-derived volcanics along structurally controlled lines of weakness.

Site 359 lies within the western Walvis Ridge province where between it and the Mid-Atlantic Ridge the Walvis Ridge consists of individual seamounts, guyots, and the islands of Tristan da Cunha and Gough. Between Site 359 and about 3°E, the western, or seamount, province consists of discontinuous and narrow elongate elements with steep sides, presumbaly chains of closely spaced seamounts (Dingle and Simpson, in preparation). Although other factors may be of controlling importance for the central and eastern Walvis Ridge, we assume that the seamounts of the western province were generated at a point on the accreting plate boundary and carried to the east by the sea-floor spreading process. We do not know whether the source of igneous material was a mantle plume or merely a locus of increased igneous activity nor do we know whether such a feature has migrated over time.

The ash flow tuff which comprises the basal rocks recovered at Site 359 has a trachytic bulk composition, similar to the trachytes on the nearby islands of Tristan da Cunha and Gough. Fodor et al. (this volume) describe the mineralogy and chemical composition of the tuff, and note that ash flow tuffs are reported from several Atlantic oceanic islands. They suggest, on the bases of lack of graded bedding, lack of evidence or reworking, and lack of entrained shell material and clasts of marine sediment, that the Site 359 ash flow may have been subaerially emplaced. This, if so, would imply either that any sediments underlying the tuff (see Correlation section, above) are nonmarine or that the seamount was tectonically raised above sea level between deposition of such sediments and deposition of the tuff.

Site 359 is at the approximate location of anomaly 23-25 (Ladd, 1974), which has an age range of 47-53 m.y.B.P., according to Tarling and Mitchell (1976).[2] The average South Atlantic spreading rate of 2 cm/year for this period (Larson and Pitman, 1972) would account for its present position about 1000 km from the crest of the Mid-Atlantic Ridge. The tuff is 40.7 ±1 m.y. old according to a K/Ar date obtained on feldspar (Fodor et al., this volume) and is overlain by calcareous volcanic mud of roughly the same age (late Eocene, Zone P15). Overlying upper Eocene biogenic oozes contain no volcaniclastic components; this indicates that volcanic activity ceased before the end of the Eocene. The seamount thus probably came into being as a basaltic outpouring on the Mid-Atlantic Ridge about 50-55 m.y.B.P., and drifted east as the sea-floor spread and underwent geochemical differentiation until the late Eocene, when volcanic activity ceased. At a spreading rate of 2 cm/year, the seamount would have moved laterally away from the spreading center a distance of 200-300 km before volcanic activity ceased; this implies that an active magma chamber was entrained beneath the seamount for at least 10 m.y.

An attempt to reconcile the supposedly subaerial nature of the tuff with the environmental indicators (fossils) in the overlying calcareous volcanic mud of roughly the same age must confront some enigmas. The sediments contain abundant open marine planktonic nannofossils and foraminifers; but they also contain benthic foraminifers of continental slope depth ranges and shallow-water indicators such as large mollusc fragments and brachiopods. Boersma (this volume) states that environmental data are difficult to determine from fossils at this site, but that if the more obvious shallow-water indicators were introduced from upslope, the site could have had a depth of about 900 meters in the late Eocene. Working with this as a constraint, Fodor et al. (this volume) have suggested that the subaerial tuff subsided catastrophically about 1000 meters by summit collapse of a shield volcano.

A problem with the hypothesis that the depositional site was at a depth close to 1000 meters is that if its subsidence rate is presumed to be along the curve defined by Sclater and Detrick (1973), subsidence between 40 m.y.B.P. and the present should have resulted in a present site depth of about 2400 meters rather than 1650 meters. An alternative explanation, whereby the benthic slope fauna represents a somewhat shallower depth (say, 300 m), increases the chances of introduction of very shallow water components, is more easily reconcilable with the tuff being subaerial, and allows submergence along the model favored for normal oceanic crust. The abundance of open marine pelagic organisms is explained by the proximity of deep water all around.

The major upper Eocene-middle Eocene hiatus within the pelagic ooze sequences may be a consequence of nondeposition, erosion by currents, or slumping. It is of local importance only, since sediments representing these ages were recovered at Sites 17 and 18, on the eastern flank of the Mid-Atlantic Ridge close to the Walvis Ridge (Maxwell, Von Herzen et al., 1970). A Plio-Pleistocene hiatus, if present, could also be a result of any one of the causes mentioned above.

The uppermost nannofossil and foraminifer oozes have been intensively winnowed, resulting in a relatively coarse grain size and a large portion of foraminifers. Heavy overgrowth on both foraminifers and nannofossils are qualitative indicators of a high $CaCO_3$ mobility in the interstitial waters of these sediments.

[2]Although more recent work indicates an age range of 54-59 m.y.B.P. for anomalies 23 to 25 (La Brecque et al., in press).

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APPENDIX A
Smear-slide Summary

	Sand	Silt	Clay	Quartz	Feldspar	Mica	Heavy Minerals	Clay	Volcanic Glass	Iron Oxides	Glauconite	Opaques	Dolomite	Zeolite	Authigenic Carbonate	Foraminifers	Calcareous Nannofossils	Diatoms	Radiolarians	Sponge Spicules	Fish Remains
Hole 359																					
2-1, 20	10	20	70	1				5							5	15	75				
2-2, 100	35	30	35												10	35	55	1		1	
2-4, 75	30	30	40					5		1	1				10	30	55		1		
2-6, 62	25	25	50	5	1			5		5	5				10	25	45	1			
3-1, 40	35	55	10	5	5			10	1		10			1	5	35	30	1	1	1	1
3-1, 128	5	45	50	5	1			10	25	1	5	5			5	10	25	1	1	10	
3-3, 100	5	45	50	5	1	1	1	10	25		5	5			5	10	25	1	1	10	
3-4, 73	20	70	10	10	5	1	10		55			5			5		10	1		1	
4-1, 115	10	35	55	5		1		15	30	1	1	5	5	5	1	15	20	1		1	
4-1, 140		35	65	5	1			25	30		1		5	10	5	5	10	5		1	1
4-2, 3	5	70	25					15	30				5	5	45						
4-2, 10		30	70	1				30	20	1		5	5		40						
4-2, 37		20	80					40	50					10							
Hole 359A																					
1-3, 100	20	60	20												30	25	45	1			

APPENDIX B
Carbonate and Quartz Determinations

Section	Sediment Depth (cm)	$CaCO_3$ (%)	Org (%)	Total Carb (%)	Qtz (%)
Hole 359					
1-1	119	94.45	0.02	11.36	
1-2	251	86.15	0.03	10.37	
1-3	372	89.31	0.15	–	
2-2	3050	88.28	0.03	10.63	
2-6	3672	72.28	0.04	8.72	
2-6	3675	63.96	0.78	8.45	4.30
2-6	3682	71.80	0.18	–	
3-1	5679	51.40	0.79	6.96	3.35
3-2	5900	29.54	1.00	4.54	1.49
3-4	6166	3.25	0.24	–	
3-5	6299	56.29	0.24	–	
3-5	6371	32.54	0.96	4.86	2.44
4-2	8667	7.50	0.39	–	
4-2	8672	7.36	0.26	1.14	
4-2	8676	11.55	0.04	1.43	
Hole 359A					
1-4	1425	84.11	1.14	11.24	
1-4	1460	87.81	0.45	–	
1-6	1770	88.35	0.03	10.63	
2-2	2080	90.06	0.66	–	
2-4	2402	85.12	0.43	10.64	
2-4	2410	92.92	0.03	11.19	
2-5	2506	88.35	0.14	10.75	4.53

Site 359 Hole Core 1 Cored Interval: 0.0-9.0 m

AGE | ZONE | FOSSIL CHARACTER (FORAMS, COCCO-LITHS, RADS) | SECTION | METERS | LITHOLOGY | DEFORMATION | LITHO.SAMPLE | SED. STRUCT. | LITHOLOGIC DESCRIPTION

AGE: EARLY PLIOCENE

ZONE: NN15?; (N19) S. dehiscens/G. altispira

Fossil character: AG CP (Section 1); AG CP — (Core Catcher)

Sections: 0, 1 (0.5, 1.0), 2, 3, 4, Core Catcher

Lithology: VOID (top of Section 1)

Litho. sample: * (Section 2); CC

10YR 8/6
N9

FORAM NANNO OOZE, pale yellowish orange to white, soupy, homogeneous FORAM NANNO OOZE. The dominant white portion with rare small pale yellowish specks.

$CaCO_3$ 2-80: 93%

SS 2-100	
35% Sand	55% Nannos
30% Silt	35% Forams
35% Clay	10% Micrite
	1% Rads
	1% Diatoms

Site 359 Hole Core 2 Cored Interval: 28.0-37.5 m

AGE | ZONE | FOSSIL CHARACTER (FORAMS, COCCO-LITHS, RADS) | SECTION | METERS | LITHOLOGY | DEFORMATION | LITHO.SAMPLE | SED. STRUCT. | LITHOLOGIC DESCRIPTION

AGE: MIOCENE; LATE EOCENE

ZONE: (N14-N15) G. nepenthes-G. continuosa NN5?; (P16) Isthmolithus recurvus NP 19; Hiatus

Fossil character: AM (Section 1); CM (Section 2); CM (Section 3); CM (Section 4); CM (Section 5); CM, CP, CM, CM CM (Section 6); CM CM — (Core Catcher)

Sections: 0, 1 (0.5, 1.0), 2, 3, 4, 5, 6, Core Catcher

Litho. sample: * (Sections 1, 4, 6)

10YR 8/2

Very pale orange, coarse grained, very homogeneous, soupy NANNO FORAM OOZE to FORAM NANNO OOZE with smeared whitish lump at Sec. 1-15-25.

SS 1-20	
10% Sand	75% Nannos
20% Silt	15% Forams
70% Clay	5% Micrite
	5% Clay
	1% Quartz

SS 4-75	
30% Sand	55% Nannos
30% Silt	30% Forams
40% Clay	10% Micrite
	1% Clay
	1% Fe-oxide
	1% Glauconite
	1% Rads

SS 6-62	
25% Sand	45% Nannos
25% Silt	25% Forams
50% Clay	10% Micrite
	5% Quartz
	1% Clay
	5% Fe-oxide
	5% Glauconite

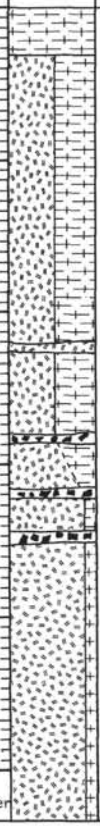
5YR 8/1 Pinkish whiteish gray with thin slightly darker layers.

5YR 7/2 Yellowish gray NANNO FORAM OOZE with black specks: pieces of manganese crust at Sec. 6-64, bivalve shell ($\phi\sim$1 cm), oyster-like.

Explanatory Notes in Chapter 1

Site 359 Hole Core 3 Cored Interval: 56.5-66.0 m

AGE	ZONE	FORAMS	NANNOS	RADS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	SED. STRUCT.
LATE EOCENE	P15; (P16); C. inflata; Chiasmolithus oamaruensis NP18	CG, RP, AM, AM, AM, AM, AM, CG	CM	RP	0, 1, 2, 3, 4, 5, Core Catcher	0.5, 1.0				



LITHOLOGIC DESCRIPTION

10YR 7/4 — Grayish orange FORAM NANNO OOZE.

5Y 5/2 — Light olive gray, sandy, calcareous VOLCANIC MUD with areas of slightly more greenish hues.

SS 1-40

35% Sand	5% Quartz?
55% Silt	5% Feldspar
10% Clay	5% Micrite
	1% Volcanic glass
35% Forams	1% Zeolite
30% Nannos	1% Diatoms
10% Glauconite	1% Rads
10% Clay	1% Sponge spicules

SS 1-128

5% Sand	5% Quartz
45% Silt	5% Opaques
50% Clay	5% Glauconite
	5% Micrite
25% Nannos	1% Feldspar
25% Volcanic glass	1% Fe-oxide
10% Clay	1% Diatoms
10% Forams	1% Rads
10% Sponge spicules	

10Y 4/2, 5Y 3/2, 10Y 4/2, 5Y 5/2, 5Y 3/2, 5Y 5/2, 5G 3/2, N3, 5Y 5/2

OYSTER-LIKE BIVALVE (~1.5 cm) at Sec. 3-20. VOLCANIC ASH at Sec. 3-30-32. Coarse, sand-sized (ϕ~1-2 mm) olive gray, lower and upper boundary grayish olive VOLCANIC PUMICE at Sec. 3-119-124.

SS 3-100

5% Sand	5% Quartz
45% Silt	5% Opaques
50% Clay	5% Glauconite
	5% Micrite
25% Nannos	1% Feldspar
25% Volcanic glass	1% Mica
10% Clay	1% Heavy minerals
10% Forams	1% Diatoms
10% Sponge spicules	1% Rads

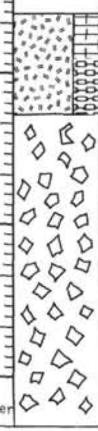
VOLCANIC PUMICE (ϕ average 0.5-1.0 mm) at Sec. 4-25-30 and Sec. 4-64-73 (dusky green to dark gray).

SS 4-73

20% Sand	10% Nannos
70% Silt	5% Feldspar
10% Clay	5% Opaques
	5% Micrite
55% Volcanic glass	1% Mica
10% Quartz?	1% Diatoms
10% Heavy minerals	1% Sponge spicules

Site 359 Hole Core 4 Cored Interval: 85.0-94.5 m

AGE	ZONE	FORAMS	COCCO-LITHS	RADS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE
LATE EOCENE	(P16); C. inflata; Chiasmolithus oamaruensis NP18	CM, AM	CM, RM?		0, 1, 2, 3, Core Catcher	0.5, 1.0	VOID		* * * * *



LITHOLOGIC DESCRIPTION

Medium to coarse grained VOLCANIC MUDSTONE with pumice layers. Little brachiopod at Sec. 1-100, coral at Sec. 1-146.

5GY 6/1 to 5G 6/1; 5B 5/1; 5G 4/1; 5B 3/1

SS 1-115

10% Sand	5% Opaques
35% Silt	5% Dolomite rhombs
55% Clay	5% Zeolite
	1% Mica
30% Volcanic glass	1% Glauconite
15% Clay	1% Micrite
20% Nannos	1% Fe-oxide
15% Forams	1% Diatoms
5% Quartz	1% Sponge spicules

SS 1-140

0% Sand	5% Diatoms
35% Silt	5% Forams
65% Clay	5% Micrite
	5% Dolomite rhombs
30% Volcanic glass	6% Feldspar
25% Clay	1% Glauconite
10% Zeolite	1% Sponge spicules
10% Nannos	1% Fish remains

In Sec. 2: medium bluish gray to dark greenish gray, banded to laminated, lensy bedding. Settling cracks up to 1 cm across. Lowermost 10 cm of sediment dark bluish gray, extremely fine grained (soupy).

Sec. 2, 3, and CC:
ASH-FLOW TUFF (Trachyte)
A coherent, porphyritic rock, medium gray (N5) in color, composed of abundant feldspar (anorthoclase to sanidine, avg. $An_4Ab_{56}Or_{40}$) crystals, rare high-Ca pyroxene ($Fs_{18.5}En_{36.6}Wo_{44.9}$), biotite, magnetite (FeO 75-82 wt.%; TiO_2 5-12 wt.%), and ilmenite, and pumice fragments in a fine-grained, dusty, ash(?) matrix; glass shards are indistinct. Feldspar is up to 4 mm and pumice fragments are up to 1 cm in length. Compaction ratios of pumice vary from 1:1 to 10:1. Mineral compositions determined by electron microproble.

Bulk composition:

SiO_2	62.21	CaO	0.93
TiO_2	0.80	Na_2O	5.70
Al_2O_3	19.55	K_2O	6.50
Fe_2O_3	1.67	H_2O^-	0.46
FeO	0.75	H_2O^+	0.96
MnO	0.04	P_2O_5	0.15
MgO	0.42	Total	100.14

Analyst: J. W. Husler, Univ. New Mexico

SS 2-37

0% Sand
20% Silt
80% Clay
50% Volcanic glass
40% Clay
10% Zeolite

SS 2-3

5% Sand	45% Micrite	15% Clay
70% Silt	30% Volcanic glass	5% Dolomite rhombs
25% Clay		5% Zeolite

SS 2-10

0% Sand	40% Micrite	5% Dolomite rhombs
30% Silt	30% Clay	5% Opaques
70% Clay	20% Volcanic glass	1% Feldspar
		1% Fe-oxide

Explanatory Notes in Chapter 1

Site 359 Hole Core 5 Cored Interval: 94.5-104.0 m

AGE	ZONE	FOSSIL CHARACTER: FORAMS	COCCO-LITHS	RADS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
					Core Catcher					Black VOLCANIC TUFF, see petrologists review.

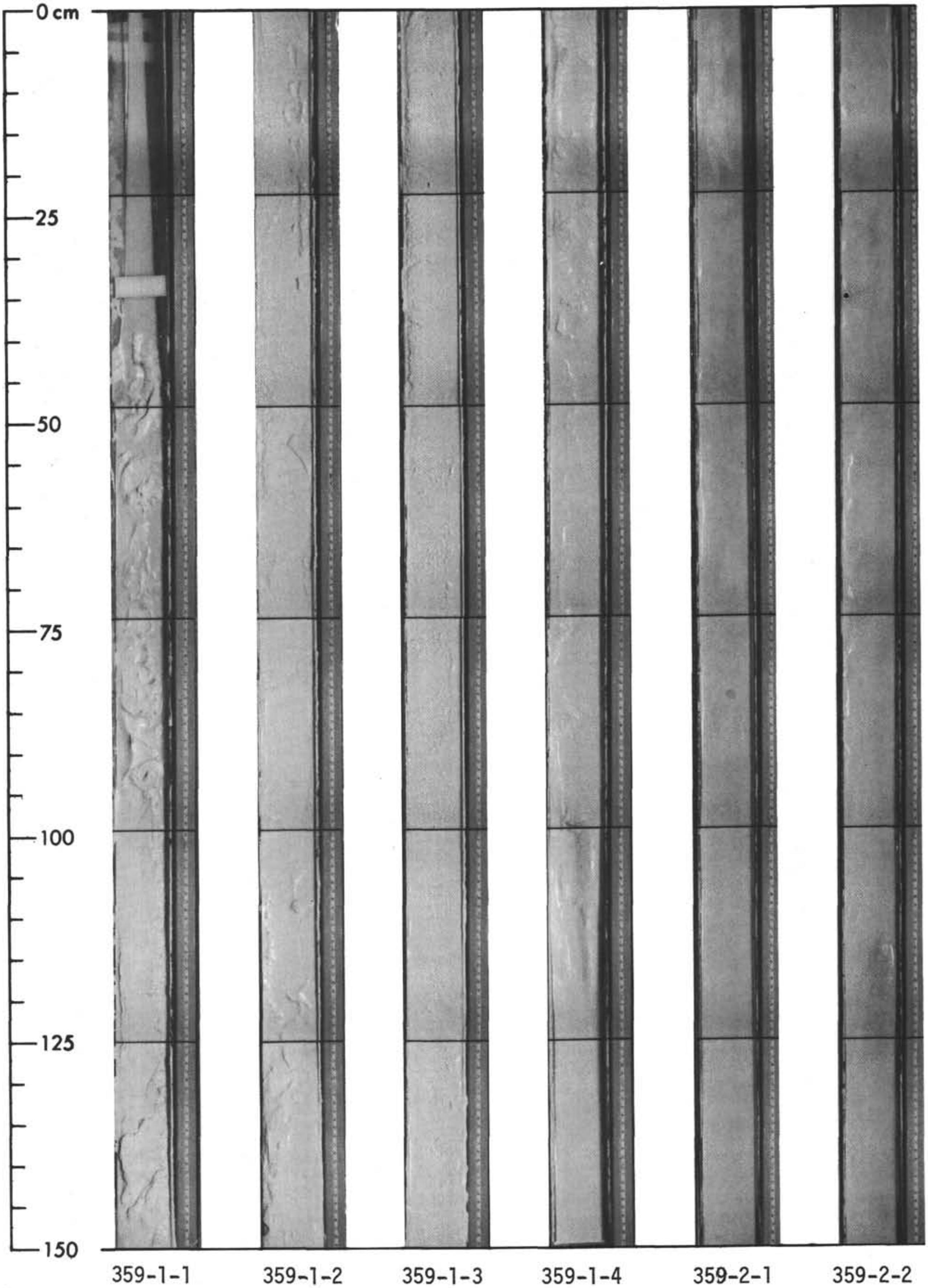
Site 359 Hole A Core 1 Cored Interval: 9.0-18.5 m

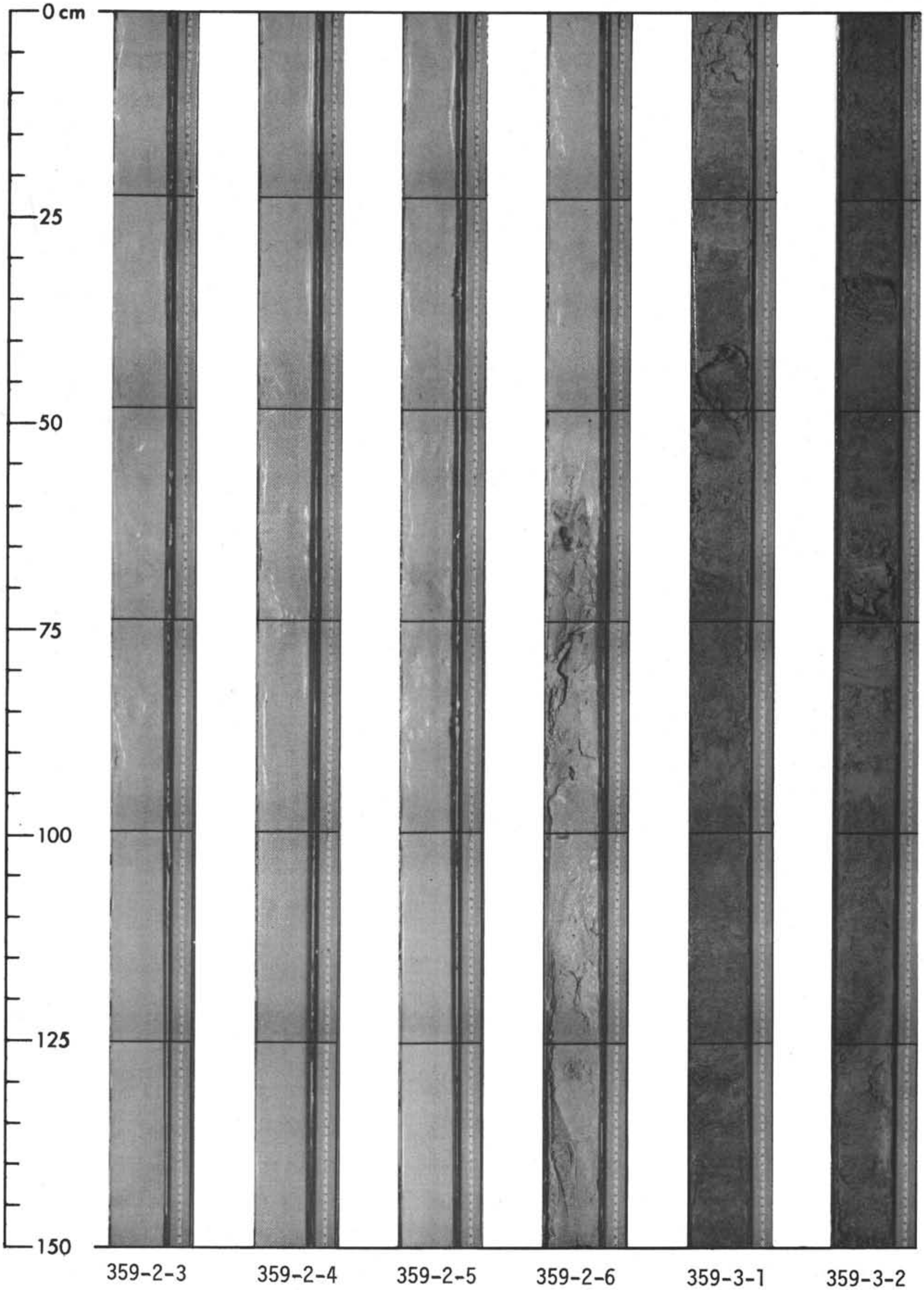
AGE	ZONE	FOSSIL CHARACTER: FORAMS	COCCO-LITHS	RADS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	SED. STRUCT.	LITHOLOGIC DESCRIPTION
LATE MIOCENE	(N17) G. tumida plesiotumida				0						
		AG			1	0.5, 1.0	VOID				N9 Soupy, white, homogeneous FORAM NANNO OOZE, with sand-sized dark and greenish grains.
		AG			2						10YR 8/2 Very pale orange. N9 $CaCO_3$ 2-80: 93% 10YR 8/2
		AG			3				*		10YR 8/2 N9 SS 3-100: 20% Sand, 60% Silt, 20% Clay; 45% Nannos, 30% Micrite, 20-25% Forams, 1% Diatoms
					4						10YR 8/2 N9
		AG			5						
		AM			6						10YR 8/2
		CG	CM	—	Core Catcher						N9

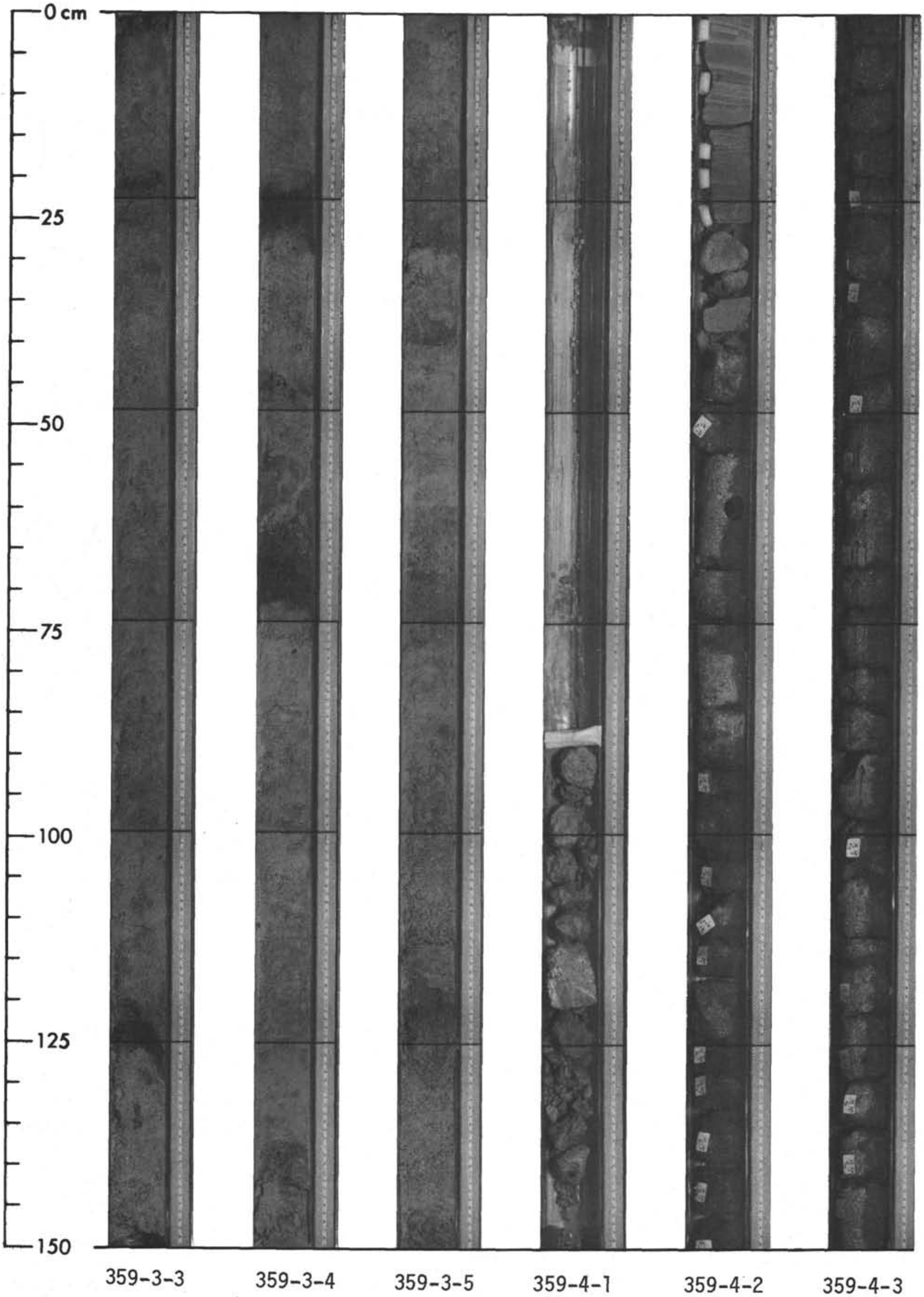
Site 359 Hole A Core 2 Cored Interval: 18.5-27.0 m

AGE	ZONE	FOSSIL CHARACTER: FORAMS	COCCO-LITHS	RADS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
LATE MIOCENE	(N17) G. tumida plesiotumida				0					
		AM			1	0.5, 1.0	VOID			10YR 8/2 Very pale orange FORAM NANNO OOZE, soupy, homogeneous. Sand-sized dark grain throughout.
		AM			2					
		AM			3					
					4					
		AG			5					
		AG	AM	—	Core Catcher				CC	

Explanatory Notes in Chapter 1


0 cm
25
50
75
100
125
150
359-1-1
359-1-2
359-1-3
359-1-4
359-2-1
359-2-2


0 cm
25
50
75
100
125
150
359-2-3
359-2-4
359-2-5
359-2-6
359-3-1
359-3-2


0 cm
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359-3-3
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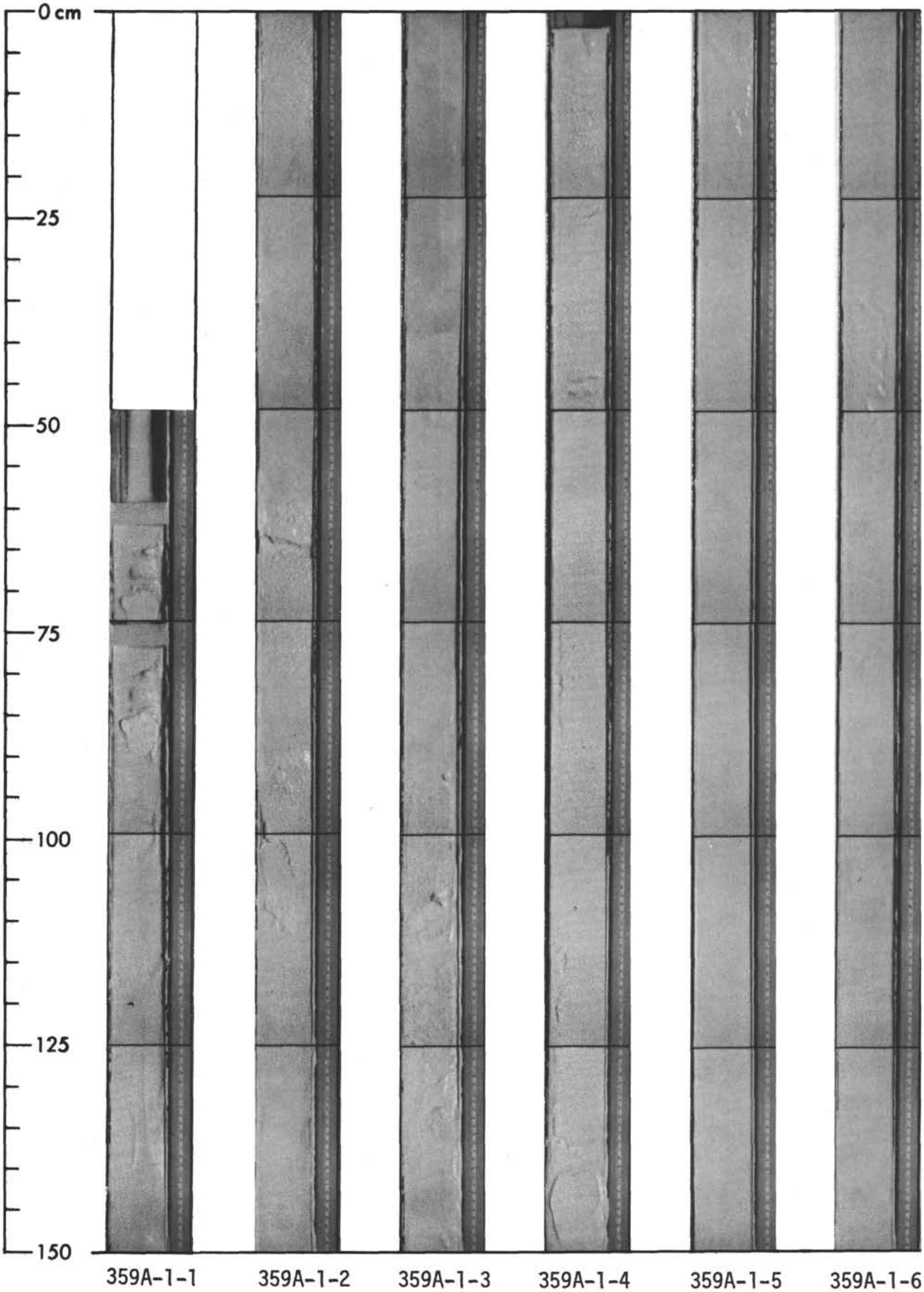
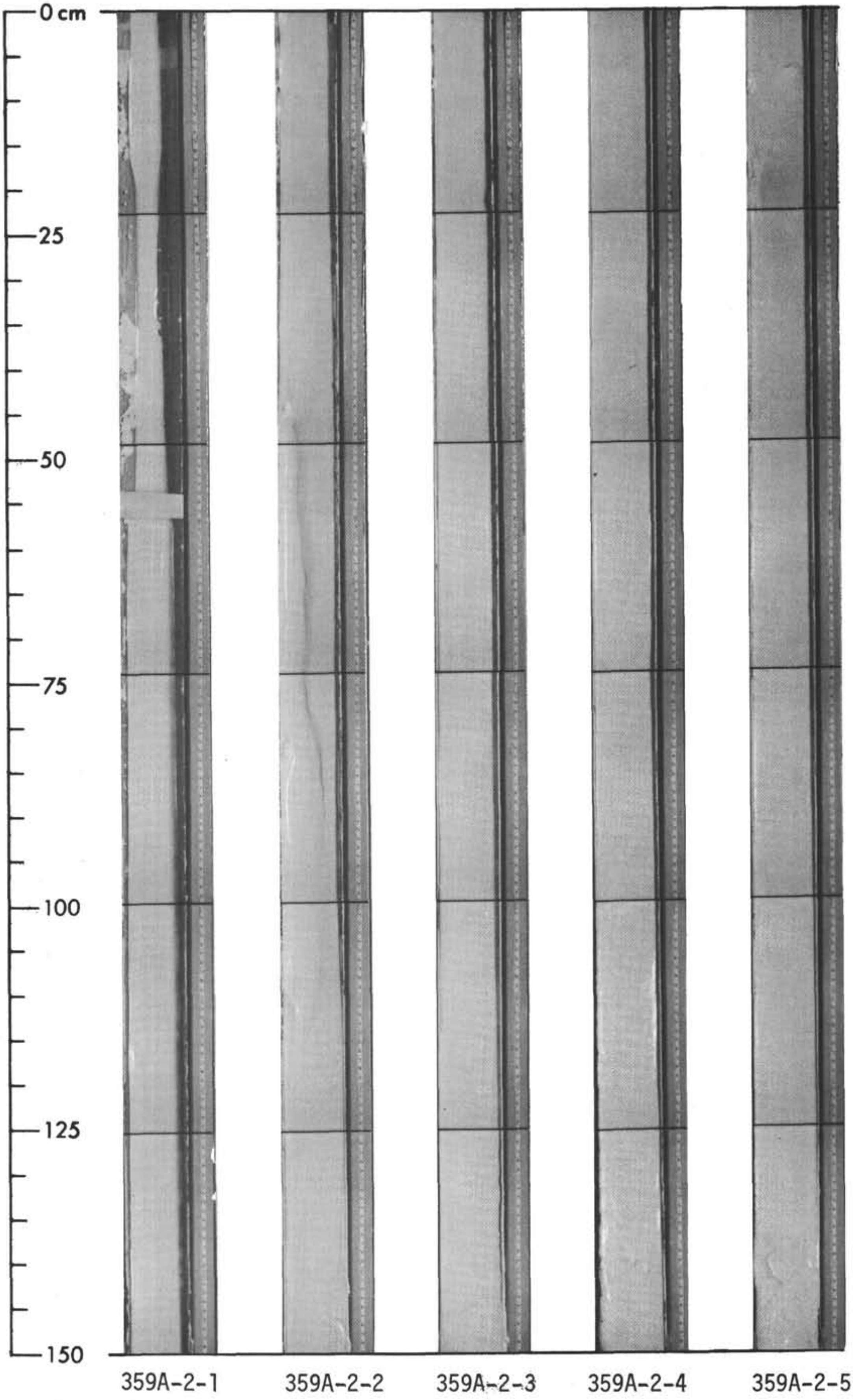
359-3-5
359-4-1
359-4-2
359-4-3


0 cm
25
50
75
100
125
150
359A-1-1
359A-1-2
359A-1-3
359A-1-4
359A-1-5
359A-1-6


0 cm
25
50
75
100
125
150
359A-2-1
359A-2-2
359A-2-3
359A-2-4
359A-2-5