5. SITE 278
The Shipboard Scientific Party

SITE DATA

Location: Southern Emerald Basin
Position: 56°33.42'S; 160°04.29'E

Water Depth:
- PDR, from sea level: 3675 meters
- From drill pipe measurement from derrick floor: 3708 meters (adopted)

Dates Occupied: 14-17 March 1973

Depth of Maximum Penetration:
- Hole 278: 438.5 meters
- Hole 278A: 44 meters

Number of Holes: 2
Number of Cores:
- Hole 278: 35
- Hole 278A: 2

Total Recovery:
- Length:
  - Hole 278: 277.8 meters
  - Hole 278A: 7.5 meters
- Percentage:
  - Hole 278: 85
  - Hole 278A: 39

Age of Oldest Sediment Cored: Middle Oligocene

Summary: Sediments at Site 278 are an almost complete Pleistocene to middle Oligocene sequence of 428 meters of alternating calcareous diatom and radiolarian oozes, and siliceous nannofossil oozes and chalks. Six sedimentary units belong to three general categories; 172 meters of radiolarian-diatom and diatom ooze of late Pliocene to Recent age; 214 meters of alternating siliceous nannofossil ooze and nannofossil-rich siliceous ooze of early Pliocene to earliest Miocene age; and 42 meters of early Oligocene nannofossil chalk with sponge spicules. These fluctuations probably indicate changes in the locations and strength of the Antarctic Convergence. Increased sedimentation rates occur towards the Recent with very low rates for the Oligocene (0.5 cm/1000 years), moderate rates for the Miocene-early Oligocene (1.3 cm/1000 years), and spectacularly high rates in late Pliocene and Pleistocene (7.5 cm/1000 years). Rates reflect increased productivity in this region throughout middle and late Cenozoic, probably related to intensification of the Antarctic Convergence. Upward increase in dissolution of calcium carbonate supports this theory. Much of the Pliocene is missing in disconformity. There is a tremendous increase in the amount of quartz grains of ice-rafted origin above this disconformity. The first evidence of glacial marine sediments at this site is of late Miocene (?) age. Excellent radiolarian and diatom biostratigraphy although calcareous microfossils are of varying abundance and preservation. Well-dated middle Oligocene (30 m.y. old) sediments lie directly on pillow basalts.

The Oligocene age of basement will have a profound effect on the inferred plate motions of the Macquarie triple junction.

BACKGROUND AND OBJECTIVES

Site 278 was drilled near the junction of the southeast extension of the Macquarie ridge and the Emerald basin in a water depth of 3700 meters (Figures 1 and 2). Due to lack of clearly lined magnetic anomalies (possibly due to intense fracturing) the age of the Emerald basin is not known. A short distance to the east of the drill site, the magnetic anomalies have been dated as Upper Cretaceous by Christoffel and Falconer (1972). A short distance to the west, Weissel and Hayes (1972) have dated the anomalies as lower Miocene. Hence the site is between two regions separated by 50-60 m.y. The sediments at the site are delicately layered and have the appearance of layered fine-grained material deposited from gentle bottom currents. A change in the
current regime seems to have occurred within the section; an unconformity can be seen in Figure 3.

The site was selected because of its present-day position at the Antarctic Convergence. The primary objectives of the site were:

1) To obtain a biostratigraphic sequence at the boundary between Antarctic and subantarctic waters. At a depth of 3600 meters at lat 56°30'S alternations possibly exist between calcareous and siliceous biogenic fractions related to latitudinal movement of the Antarctic Convergence (polar front). Calcareous nannoplankton in the present day do not extend into Antarctic waters (Hasle, 1960), and are also assumed not to have done so in the past. Fluctuations in nannofossils in the core obtained at this relatively shallow site should therefore largely reflect alternations in the Antarctic Convergence.

2) To examine changes in biogenic productivity associated with the Antarctic Convergence. The Antarctic Convergence separates highly siliceous biogenic sediments to the south from more calcareous-rich biogenic sediments to the north. Fluctuations in these components may thus reflect changes in the position of the Antarctic Convergence. Siliceous productivity in the northern Antarctic water-mass region is the highest in the world because of upwelling of nutrient-rich deep water. The history of this productivity will be examined as it relates the evolution of the Antarctic Convergence.

3) To obtain a paleoglacial history of Antarctica for that part of the Cenozoic sequence obtained at Site 278 by examination of ice-rafted debris; the site is within the range of icebergs. During Leg 28 no material older than late Eocene had been obtained. Glacial debris was found in cores as old as Oligocene supporting Oligocene Antarctic glaciation suggested by Margolis and Kennett (1970) and Kennett et al. (1972). Antarctic glaciation of early and middle Eocene age has been suggested by Margolis and Kennett (1970), although the extent of this glaciation is unknown.

4) To determine a history of bottom-water activity at Site 278. It is hoped that this will provide further information on major paleocirculation changes involving deep water in the area. The unconformity shown in Figure 3 at "A" may reflect a fundamental change in bottom water patterns in the region. This may relate to critical structural changes in the Australian-Antarctic oceanic region.

5) To determine age of basement.

OPERATIONS

Site 278 in the Emerald Basin was approached from the north along an Eltanin-34 track (Figure 4). The actual site was selected by correlation of sea-floor topography; the beacon was released on the first pass over the site.

With positioning in the manual mode, the hole was spudded in 3708 meters of water in very soft sediment and a mud line core was recovered. The hole was continuously cored from 3809 meters (101 meters penetration) to 4075 meters with very good recoveries on all but two cores which experienced a collapsed liner and a shattered liner. Alternate drilling and coring proceeded to 4103.5 meters where a continuous coring program was followed to a total depth of 4146.5 meters or 438.5 meters of penetration. Basalt was encountered at 4136 meters, cored for 10.5 meters with 4.6 meters recovered. Details of the coring are included in Table 1.

During the coring operations, the computer was repaired and positioning returned to automatic mode. The mud line was cleared and Hole 278A was spudded to core the 95 meter interval which had been washed down in Hole 278. The second coring attempt from 3723.5-3733 meters recovered 1.5 meters of sediment and 10 centimeters of basalt. It was evident that some of the basalt from Core 278-35 had fallen out of the core barrel, and lodged on top of the bit. In an attempt to
clear the bit, an extended core barrel was dropped and the hole cut from 3733-3742.5 meters. Recovery was 6 meters of sediment with several small pieces of basalt. A fourth attempt from 3742.5-3752 meters resulted in recovery of approximately 5 centimeters of basalt and no sediment.

LITHOLOGY

Approximately 428 meters of sediment and 5 meters of basalt were cored at Site 278. The sediment sequence consists of alternating calcareous diatom and radiolarian oozes, and siliceous nannofossil oozes and chalks (Figure 5). Hole 278A was drilled next to Hole 278 in order to recover cores from the upper 100 meters in this area. The lithological units are subdivided as shown in Table 2.

Unit 1

Unit 1 is characterized by a light brownish gray foraminiferal-bearing diatom ooze with alternating distinctly darker layers and gray mottles that contain as much as 20% terrigenous detrital minerals. The detrital material consists of angular quartz grains, rock fragments, and opaque minerals that are of possible icebergrafted origin. These sharply defined, alternating color changes perhaps suggest periods of increased iceberg ac-
TABLE 1
Coring Summary, Site 278

<table>
<thead>
<tr>
<th>Core</th>
<th>Cored Interval Below Bottom (m)</th>
<th>Cored (m)</th>
<th>Recovery (%)</th>
</tr>
</thead>
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<td>6.0</td>
<td>6.0</td>
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<td>405.0-414.5</td>
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<td>35</td>
<td>429.0-438.5</td>
<td>9.5</td>
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<tr>
<td>Total</td>
<td>324.5</td>
<td>277.7</td>
<td>85</td>
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</table>

Hole 278A

<table>
<thead>
<tr>
<th>Core</th>
<th>Cored Interval Below Bottom (m)</th>
<th>Cored (m)</th>
<th>Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15.5-25.0</td>
<td>9.5</td>
<td>1.5</td>
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<tr>
<td>2</td>
<td>25.0-34.5</td>
<td>9.5</td>
<td>6.0</td>
</tr>
<tr>
<td>Total</td>
<td>19.0</td>
<td>7.5</td>
<td>39</td>
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Figure 5. Stratigraphic sequence at Site 278.

TABLE 2
Lithologic Summary, Site 278

<table>
<thead>
<tr>
<th>Unit</th>
<th>Lithology</th>
<th>Subbottom Depth (m)</th>
<th>Unit Thickness (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Foraminifera and detrital silt-bearing radiolarian-diatom ooze</td>
<td>0-6</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>Nannofossil-rich spicule-bearing diatom ooze</td>
<td>100-172</td>
<td>72</td>
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<tr>
<td>3</td>
<td>Siliceous nannofossil ooze</td>
<td>172-236</td>
<td>64</td>
</tr>
<tr>
<td>4</td>
<td>Alternating nannofossil-rich siliceous ooze and diatom-rich nannofossil ooze</td>
<td>236-264</td>
<td>28</td>
</tr>
<tr>
<td>5</td>
<td>Detrital and nannofossil-bearing radiolarian-diatom ooze, alternating with siliceous ooze</td>
<td>264-386</td>
<td>122</td>
</tr>
<tr>
<td>6</td>
<td>Siliceous nannofossil chalk</td>
<td>386-428</td>
<td>42</td>
</tr>
<tr>
<td>7</td>
<td>Porphyritic pillow basalt with micritic limestone inclusions in interpillow areas</td>
<td>428-433</td>
<td>5</td>
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</tbody>
</table>
also found with the rock fragments. The color of the micronodules. It is generally non-stratified and contains (<10%), exhibits faint mottles, manganese streaks, and nannofossil chalk which is a semilithified equivalent of Unit 6 with angular outlines. Volcanic glass and sanidine are gray to light bluish gray, with the lighter colors associated with nannofossil-rich zones.

Unit 2

Unit 2 is basically a nannofossil/spore-spicule rich radiolarian and diatom ooze, differing from Unit 1 in having more nannofossils. Locally it contains micromanganese nodules, mica streaks and bands, and varies from light bluish gray to gray with greenish-gray streaks. It is generally soft and has faint mottles. Drilling created spectacular deformation structures.

Unit 3

Unit 3 is a very-pale-brown to white siliceous nannofossil ooze. Siliceous microfossils (diatoms, Radiolaria, and sponge spicules) comprise up to 40% of this unit, and it generally contains less than 10% detrital material. Micromanganese nodules and streaks are also locally abundant, although manganese makes up less than 30% of the sediment. It is soft to stiff in texture, and where undeformed, exhibits slight mottles and burrowing structures.

Unit 4

Unit 4 consists of thin alternating beds of nannofossil-rich siliceous ooze, and diatom-rich nannofossil ooze. The percentages of biogenic calcareous and siliceous materials varies extensively. The unit is generally soft to stiff, mottled, sparsely burrowed, with a low detrital mineral content. Colors range from greenish gray to light bluish gray, with the lighter colors associated with nannofossil-rich zones.

Unit 5

Unit 5 is generally similar to Unit 2, being a siliceous ooz. differing in having less than 10% detrital minerals, and in being more stiffly indurated. It is locally rich in nannofossils, radiolarians, and sponge spicules, as well as some manganese. Toward its base it is semilithified and contains traces of glauconite and silicoflagellates. Volcanic rock fragments (1-4 mm) are also rarely found with angular outlines. Volcanic glass and sandstone are also found with the rock fragments. The color of the sediment varies from bluish gray to greenish gray.

Unit 6

Unit 6 is a light-gray to very-pale-brown siliceous nannofossil chalk which is a semilithified equivalent of Unit 3. It contains appreciably less siliceous material (<10%), exhibits faint mottles, manganese streaks, and micronodules. It is generally non-stratified and contains only a trace of detrital minerals. Volcanic glass and rock fragments are abundant toward the base of the unit.

Unit 7

Unit 7 consists of a porphyritic plagioclase pillow basalt with carbonate and zeolite-filled veins, amygdules, and vesicles. The rims of the pillows are glassy; the glass is palagonitized and contains olivine crystals and feldspar laths. The pyroxenes are broken down. Between the glass rims are micritic limestone inclusions which are well lithified and contain rare casts of foraminifera. There is no evidence of baking or mineralization of the micritic limestone, although it was probably originally a nannofossil ooze. It was squeezed down between the pillow surfaces or was deposited between the pillows. The deepest basalt cored had a glass rim only on its top surface and may represent a massive flow basalt.

Conclusions

This site is of interest because of its location at the present-day Antarctic Convergence. The fluctuations in lithology from nannofossil ooze to siliceous diatom ooze may indicate changes in the location and strength of the convergence, with the siliceous oozes representing times when the convergence was nearby. The convergence brought nutrient and silica-rich waters to the surface, thereby increasing biological productivity and sedimentation rates. A detailed study in variations in the amount of ice-rafted materials in the sediments is presented in Chapter 30 (this volume). Significant fluctuations in the abundance of glacial marine sediments occur in the Pleistocene and late Pliocene sediments. Lesser amounts occur in the early Pliocene/late Miocene sediments, and no older ice-rafted grains were found at this site.

The siliceous nannofossil chalks which rest on top of the pillow basalt are middle-late Oligocene, establishing a minimum age for the basement in the area. The oldest (early Miocene) siliceous ooze occurs in Unit 5. These sediments contain more detrital sediments than the underlying chalk, although not as much as the younger sediments at this site. The transition zone of mixed siliceous and calcareous sediments (Unit 4) is mid Miocene and may represent a time during which the Antarctic Convergence repeatedly fluctuated from near its present position to south of it. The middle-late Miocene siliceous nannofossil oozes of Unit 3 may represent a time during which the convergence was south of its present position, possibly being affected by the development of the Macquarie Ridge, or represent a time of weaker upwelling.

Unit 2, a late-Pliocene-Pleistocene siliceous ooze, represents a time when the convergence was located near its present position and of similar intensity. Detrital mineral grains and rock fragments of ice-rafted origin are much more abundant than in underlying strata, and sedimentation rates are also considerably higher. Unit 1 is similar to Unit 2, except that it contains undissolved foraminifera and more ice-rafted material.

Additional notable features of the sequence at Site 278 are the small amounts of glauconite and the abundance of micro-manganese nodules (Chapter 34, this
volume) indicating well-oxygenated bottom waters. Also of interest is the absence of any chert in spite of the high silica content of the sediment.

GEOCHEMICAL MEASUREMENTS

Table 3 and Figure 6 summarize the analyses of interstitial waters at Site 278. The pH measurements by both punch-in and flow-through methods were all lower than that of the surface seawater reference, except the flow-through reading of 8.25 for Sample 278-22-4, 6-12 cm. The lowest pH (6.87) is a punch-in analysis from Sample 278-17-6, 0-6 cm.

Alkalinitities were all higher than that of surface seawater reference except in Sample 278-34-3, 75-85 cm which was identical (2.54 meq/kg). High alkalinity measurements of 4.69 meq/kg were found in Cores 2 and 4. Salinity values are all higher than surface seawater, the highest values (35.8 °/oo) occurring in Core 278-34, above the basalt, and in Core 278A-2. The basalt may be producing this high value.

BIOSTRATIGRAPHY

This late Pleistocene to mid Oligocene sequence, continuously cored below 101 meters, is of exceptionally high paleontological interest. Most of the sequence yielded very abundant, highly diverse, and well-preserved diatoms, Radiolaria, and silicoflagellates. The sequence is apparently continuous except that much of the Pliocene is missing in an unconformity in Core 278A-2.

Besides the siliceous microfossils, this sequence contains highly variable frequencies of poorly preserved and very low diversity calcareous nannofossil and planktonic foraminiferal assemblages. In the middle and, especially, lower parts of the sequence these microfossil groups are abundant, but in the upper part they only form a minor component of the sediment. This pattern results from variations in the degree of calcite dissolution.

The late Neogene ages obtained from the Radiolaria and calcareous nannofossils appear to strongly conflict with those indicated by the planktonic foraminifera. For the purposes of this report the radiolarian age assessments are adopted (Figure 7) because radiolarians are abundant and their succession conforms to the well-known Antarctic zonal scheme of Hays and Opdyke (1967) which has been matched against the paleomagnetic stratigraphy. If subsequent investigations sub-

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**TABLE 3**

<table>
<thead>
<tr>
<th>Core Section</th>
<th>Sample Interval</th>
<th>pH</th>
<th>Alkalinity (meq/kg)</th>
<th>Salinity (°/oo)</th>
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<td>7.92</td>
<td>2.54</td>
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<td>3</td>
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<td>Hole 278A</td>
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*a*Two analyses were run, the second on #50 Whatman filter paper. Values are: Flow-thru pH=7.23, Alk=4.35, and S=35.2°/oo.

*b*Cold squeeze (4°C) analyses also run. Values are: Flow-thru pH=8.25, Alk=2.98, and S=34.6°/oo.
Figure 6. Shipboard geochemical data versus depth, Site 278.
To substantiate the late Neogene ages adopted here, then it must follow that the planktonic foraminiferal zones are strongly diachronous compared to their occurrence at lower latitudes. One example of this diachrony, the base of *Globorotalia truncatulinoides*, has already been documented by Kennett (1972). The ages adopted for the Miocene and Oligocene intervals are based on the calcareous nannofossils, planktonic foraminifera, and diatoms (Figure 7). All of the microfossil evidence indicates normal oceanic deposition far from land.

**Foraminifera**

Eight of the 37 samples examined were barren of planktonic foraminifera. Apart from the specimens from Samples 278-31, CC, 278-32, CC, and 278-33, CC and Sample 1, CC from both holes, the samples showed indications of solution on the foraminiferal tests. Although the original diversity was low due to the high latitude position of the site, the diversity has been lowered further by selective solution of tests. The resultant abundance level in the samples is a false diversity,
and is not truly representative of the original living species. It also follows that the species that remain were subjected to solution, and consequently have relatively high solution-resistant tests.

Evidence exists to show that greater solution occurs within older sediments occurring within the surface layers. In Samples 278-1, CC and 278A-1, CC, there are five to seven species including the thin-walled taxa Globigerina (G.) bradyi, and G. (G.) quinqueloba. By comparison there are only two species in Samples 278-2, CC and 278A-2, CC, and it is assumed that these faunas have been subjected to longer solution attacks by active bottom water.

From the study of planktonic foraminifera, Site 278 appears to have been at or below the lysocline, apart from the middle Oligocene and earliest part of the early Miocene.

The following seven informal planktonic foraminifer zones are based on the occurrence of taxa from Holes 278 and 278A. Stratigraphic control for the Pliocene-Pleistocene is based on the work by Kennett (1972) on subantarctic faunas and on the published data of the New Zealand Oligocene-Miocene stratigraphic ranges of taxa by Jenkins (1971).

**Globorotalia (G.) truncatuloides Zone**

*Site 278, Core 1, top of Section 1*

**Zone definition:** The total range of G. (G.) truncatuloides.

**Age:** Late Pleistocene-Recent.

**Remarks:** Globigerina (G.) bradyi, G. (G.) quinqueloba, Globorotalia (G.) truncatuloides, and G. (T.) pachyderma were found in the zone.

**Globorotalia (T.) inflata Zone**

*Site 278, Cores 278A-1, 2*

**Zone definition:** Top—initial appearance of Globorotalia (G.) inflata; base—initial appearance of G. (T.) inflata.

**Age:** Middle Miocene.

**Remarks:** Globigerina (G.) bradyi, G. (G.) bulloides, G. (G.) quinqueloba, Globigerinita glutinata, Globorotalia (T.) inflata, and G. (T.) pachyderma were found in the zone.

**Globorotalia (T.) punctulata Zone**

*Site 278, Cores 2-8*

**Zone definition:** Top—initial appearance of G. (T.) punculata; base—initial appearance of G. (T.) punculata.

**Age:** Pliocene-Pleistocene.

**Remarks:** Globigerina (G.) bradyi, G. (G.) bulloides, G. (G.) quinqueloba, Globorotalia (T.) pachyderma, G. (T.) punculata, and G. (T.) setulosa were found in the zone. The most common species in the zone is the thick-walled left-coiled G. (T.) pachyderma.

**Globigerina (G.) bulloides Zone**

*Site 278, Cores 9-16*

**Zone definition:** Top—initial appearance of G. (T.) punculata; base—extinction of Globorotalia (T.) conica.

**Age:** Middle-upper Miocene.

**Remarks:** Only G. (G.) bulloides is recorded.

Globorotalia (T.) conica Zone

*Site 278, Cores 17-20*

**Zone definition:** The total stratigraphic range of G. (T.) conica.

**Age:** Middle Miocene.

**Remarks:** Globigerina (G.) woodi woodi and Globorotalia (T.) conica were recorded in the zone.

Globigerina (G.) woodi Zone

*Site 278, Cores 21-33*

**Zone definition:** Top—initial appearance of G. (T.) conica; base—extinction of Globigerina (G.) angiporoides angiporoides.

**Age:** Middle Oligocene-Middle Miocene.

**Remarks:** Globigerina cf. bulloides, G. (G.) juvenilis, G. (G.) woodi woodi, Globigerinita dissimilis, G. unica, Globorotalia (T.) nana nana, and G. (T.) nana pseudocontinuosa were recorded in the zone. In Sample 278-33, CC, many of the tests of G. (G.) woodi woodi have been replaced by manganese.

Globigerina (G.) angiporoides angiporoides Zone

*Site 278, Core 34*

**Zone definition:** Top—extinction of G. (S.) angiporoides angiporoides; base—undefined but within the range of the zonal fossil.

**Age:** Middle Oligocene.

**Remarks:** G. (S.) angiporoides angiporoides, and G. (G.) ciperoensis angustiumbilicata were found in the zone. The fauna consists almost entirely of the zonal fossil.

**Calcereous Nannofossils**

Assemblages characteristic of the late Pleistocene to mid or late Oligocene interval were obtained from this biogenic sequence. Calcereous nannofossils are absent or rare to abundant and their preservation is very poor to moderate. Diversity is low in most samples, a predictable result of the high southern latitude of this site. Almost all of the species used by Martini (1971) for zon- ing the Oligocene to Pleistocene interval are missing. The age assignments given to the cores are based on the few species present (Table 4). This entire sequence appears to have been deposited below the lysocline and many of the nannofloras, notably those characteristic of most of the early Miocene, were undoubtedly deposited just above the calcite compensation depth.

The late Pleistocene Coccolithus pelagicus Zone occurs in Cores 278-1, 278A-1, and 278A-2. It is at least 31 meters thick, being underlain by a 70-meter-thick un- cored interval. Only Core 278-1 has been examined closely; those from Hole 278A were subjected to intense disturbance during drilling. The nannofloras are rare to common, and moderately well preserved, with very low diversities. Taxa more or less consistently present are Coccolithus pelagicus, Cyclococcolithina leptopora, questionable Emiliania huxleyi (only recognized in Sample 278-1), Gephyrocapsa spp. (small), G. cf. oceanica, and Helicotrichosphaera kamptneri. Of these C. leptopora and ?E. huxleyi are the most common. G. cf. oceanica and H. kamptneri mainly occur in Sections 2 and 3 of Core 278-1 where the overall nannofloral abundance is highest. This situation presumably results from...
a slight depression of the calcite compensation depth relative to this site. The highest and lowest samples examined, 278-1-1, 120 cm, and 278A-2, CC, respectively, appear to have been subjected to a greater degree of dissolution than the intermediate samples.

In 1958 (summer), the surface seawater temperatures above this site were about 2°C (Houtman, 1967, Fig. 2a). Comparison with the south Pacific study of Hasle (1960, 1969) indicates that the calcareous nannoflora living in the photic zone overlapping this site probably consists entirely of *E. huxleyi*. The consistent presence of other species in the sediments probably results from either mixing of different life assemblages during the settling process; or highly selective post-depositional dissolution.

The mid Pleistocene to late Pliocene *Pseudoemiliania lacunosa* Zone occurs from the top of Core 278-2 to the base of Core 278-8. It is at least 66 meters thick, overlain by a 70-meter-thick unsampled interval. The nannofloras are rare to common, rather poorly preserved, and of low diversity. Small unidentified Prinsiaceae dominate throughout. Common taxa are *C. pelagicus*, *C. leptopora*, and *P. lacunosa* (base at 278-6, CC; early Pleistocene by Radiolaria). Much more rare and sporadic in their occurrence are *G. spp.* (small; base about Sample 278-6-1, 110 cm), *G. cf. oceanica* (base in Sample 278-3-1, 110 cm), and *H. kamptneri*. The Prinsiaceae taxon *“Coccolithus” minutulus* s.l. occurs in most samples but has not been observed in Core 278-5. The base of this taxon is hard to determine but may be about Sample 278-7-5, 110 cm. *Cyclococcolithina macintyrei* occurs sporadically as high as Sample 278-2-6, 30 cm. Apart from very rare unidentifiable specimens in Sample 278-7-3, 110 cm, the genus *Discoaster* has not been observed in this interval. Consequently it is not possible to determine the position of the Pliocene-Pleistocene boundary by nannofossils in this sequence. The base of this zone coincides with the marked change in the radiolarian faunas, suggesting an unconformity.

The early Pliocene to late Miocene *Reticulofenestra pseudoumbilica* Zone occurs from Samples 278-8, CC to 278-15, CC. It is about 57 meters thick, and coincides roughly with an interval of siliceous nannofossil oozes. The nannofloras are usually very abundant but of poor preservation and low diversity. Small unidentified Prinsiaceae and *R. pseudoumbilica* overwhelmingly dominate the assemblages. The only other taxon fairly consistently present in this interval is *C. pelagicus* s.l., which is usually rare. Other taxa very sporadically present include *Coccolithus* eopelagicus* s.l.,* *Cyclococcolithina leptopora,* *C. macintyrei* (especially Core 278-9), *Discoaster pentaradiatus* (Samples 278-8, CC, and 278-9-1, 110 cm), *D.* sp. indeterminate, *Sphenolithus neobaeus* (highest specimen observed is in Sample 278-9-1, 110 cm), and *Thoracosphaera* sp.

The early mid Miocene *Cyclococcolithus neogammation* Zone occurs from Sample 278-16-1, 30 cm, to Sample 278-25-3, 110 cm. It is 90-meters thick and occurs within an interval consisting largely of radiolarian-diatom oozes. The nannofloras are generally more or less common and fairly diverse, but are poorly preserved. *C. pelagicus* s.l., *C. neogammation*, and small indeterminate Prinsiaceae are fairly common throughout. Other taxa relatively constantly present are *C. eopelagicus s.l.* (especially in Cores 24 and 25), *Discoaster* sp. indeterminate, and *D. variabilis* between Samples 278-17-6 and 278-20, CC. Much more sporadic in their occurrence are *Cyclococcolithina macintyrei*, *Discoaster adamanensis* (Sample 278-20, CC and below), *D. cf. bollii* (Samples 278-17, CC to 278-20, CC), *D. challenger* (Section 278-17-6 to Sample 278-20, CC), *D. deflandrei* group (Section 278-22-1 and below), *D. druggii* (Sample 278-20, CC and below), *D. elvis* (Section 278-16-6 to Sample 278-18, CC), *Reticulofenestra* sp., and *Sphenolithus* moriformis. The discoasters are usually poorly preserved (overgrown) and battered. They are always rare, and the identifications are based on single-specimen occurrences in several samples. They are considered to be visitors to this high-latitude site. The taxa have stratigraphic ranges elsewhere which are more or less consistent with the age adopted for this interval. A taxon reminiscent of the late Paleogene species *Reticulofenestra bisecta* occurs quite commonly in Core 278-21. A definite specimen was observed in Sample 278-23-3, 53 cm. Three single specimens of the Danian to earliest Miocene genus *Chiasmolithus* were observed in Samples 278-19-3, 13 cm, 278-21-2, 140 cm, and 278-24-4, 110 cm respectively. The uncertainty regarding the exact base of this zone results partly from the different taxonomic concepts of *D. deflandrei* employed by the two investigators, and partly from the rarity of this taxon in this sequence. It is possible that the base of this zone is as high as Sample 278-22-1, 110 cm, certainly it is not lower than the adopted position.

The early Miocene *Discoaster deflandrei* Zone occurs between Samples 278-25-4, 30 cm, and 278-30, CC. It is about 60 meters thick but neither the top nor the base (a 25-meter unsampled interval underlies) can be accurate-
ly fixed. Subsequent investigations may well result in this zone being combined with the overlying C. neogammation Zone at this site. This interval, which is almost entirely composed of radiolarian-diatom oozes, contains three distinct nannofossil assemblage groupings. The highest, which extends down to Section 278-27-3, contains common, but poorly preserved and low diversity nannofloras. C. pelagicus s.l., C. neogammation, and small Prinsiaceae are common and persistent. Consistently present but rare, are C. eopelagicus s.l. (Core 25 only), D. deflandrei, and Sphenolithus moriformis. Other taxa observed are very rare and sporadic Discoaster sp., indeteminate, D. druggii, and D. adamanteus. The middle nannofossil assemblage grouping occurs between Sections 278-27-4 and 278-29-6. Many of the samples taken from this interval lack calcareous nannofossils but others contain very small, poorly preserved nannofloras consisting mostly of small unidentified Prinsiaceae. Other taxa very sporadically present are C. pelagicus s.l., C. neogammation, and Reticulofenestra sp. This situation presumably results from the near total dissolution of the nannofloras due to a lowering of the calcite compensation depth at this site. The lower nannofossil assemblage grouping occurs from Samples 278-29, CC to 278-30, CC inclusive. The nannofloras are common but poorly preserved, and of low diversity. Abundant Reticulofenestra sp. indeteminate, common C. pelagicus s.l., and fairly common C. neogammation occur throughout. The typical high-latitude late-Eocene and Oligocene species Chiasmolithus altus occurs in and below Sample 278-30-2; 30 cm. Other very rare taxa sporadically present in this interval are D. adamanteus, D. deflandrei, and S. moriformis. A single specimen of the mid-Oligocene to early-Miocene taxon Triquetrorhabdulus carinatus was observed in Sample 278-30, CC. This interval is considered to be of earliest Miocene age because of the presence of Chiasmolithus altus and the absence of Reticulofenestra bisecta.

The late- to mid-Oligocene Reticulofenestra bisecta Zone occurs from the top of Core 31 to Sample 278-34-3, 110 cm. It is about 33 meters thick, and immediately overlies pillow basalt. The nannofloras are very abundant but poorly preserved and of relatively low diversity. Persistently present are abundant Reticulofenestra sp., common Chiasmolithus altus aff., Cyclicargolithus neogammation, and Ericsonia ovalis s.l., relatively common Reticulofenestra bisecta and R. lavis?, and rare Sphenolithus moriformis. Also present, in low sporadic numbers, are Coccolithus eopelagicus s.l., Discoaster deflandrei, and Thoracosphaera sp. Single specimens of Helicopontosphaera recta (Sample 278-34-1, 12 cm), Triquetrorhabdulus carinatus (Sample 278-31-1, 20 cm), and Zygophyllithus bitijugatus (Sample 278-31-2, 17 cm) were observed. The presence of the planktonic foraminifer Globigerina angiporoides at the base of this sequence indicates that most of this zone is of late Oligocene age (Hornbrook and Edwards, 1971).

**Diatoms**

The assemblages of Site 278 vary greatly in abundance, diversity, and preservation. This situation probably largely reflects the observed lithologic and compaction changes, since the poorest floras occur in the basal nannofossil chalk, and the richest assemblages occur in the upper part of the sequence with siliceous ooze. The highest frequencies of diatoms coincide with the greatest abundance of Radiolari, silicoflagellates, and sponge spicules. The following age groupings are suggested, and within these age grouping, a number of additional distinctive assemblages can be recognized. All of the taxa encountered in Hole 278 have a marine planktonic habit.

**Core 1 (late Pleistocene):** This contains abundant cold-water planktonic diatoms Characta actinochilus, Coscinodiscus excentricus var. jousen, C. oculus iridis, Fragilariopsis curta, F. lanceolata, F. ritcherii, F. kerguelensis, Shinperiella antarctica, Synedra jouseana, Synedra sp., Thalassiothrix longissima, plus many species still living; considered Pleistocene; preservation excellent.

**Cores 2-7 (Pliocene-Pleistocene):** Abundance of Actinocyclus including the extant A. ingens, A. octonarius, A. rothii, A. isugaurenis, Coscinodiscus tabularis, C. lenitgnosus, C. excentricus, C. marginatus, Thalassiosira gracilis, and relatively few Nitzschia and Denticula species. Since the Denticula and Nitzschia species are more abundant in the Miocene and the Pliocene sediments, these samples are considered to be of Pliocene to Pleistocene age. Cores 278-2 to 278-7 contain greater numbers of Centricae and silicoflagellates than the overlying sediments.

**Core 8 to Core 11, Section 6 (Pliocene):** Very high diversity, essentially similar to those of the overlying interval but also with the highest occurrences of Denticula species: D. punctata, D. dimorpha, D. hustedtii, D. irregularis, D. kamtschatica, and Rhizosolenia bergonii. Considered to be of slightly older Pliocene age.

**Sample 11, CC to Core 14 (late Miocene-early Pliocene):** Differ markedly from the overlying intervals, containing the highest known occurrences of Asteromphalus brookei, A. paroullus, Coscinodiscus marginatus, C. oculus iridis, Actinocyclus oculatus, A. isugaurenis, A. ingens, Denticula irregularis, and a distinctive new species. D. hustedtii and D. kamtschatica abundant with many other taxa; Denticula punctata, D. lauto, D. dimorpha still present; Nitzschia jouseana and N. miocenica absent. Fragilariopsis lanceolata, F. ritcherii, F. curta, F. separanda, and F. vanneurckii first occur in Core 14. This suggests that these assemblages are late Miocene. Centricae abundant with high diversity. Thalassiothrix spicules are abundant; fragments are common. The late Miocene radiolarian Lithomitra lineata also occurs within this interval.

**Cores 15-20 (late mid Miocene):** Centricae fewer and diversity decreases downward as with Denticula species; increase downward of Coscinodiscus marginatus, Raphoneis illatata, Actinocyclus, Raphoneis sacha-linensis, Rhiphidiscus microtortus; Cosmidsicus insignis are abundant in this zone; this suggests the late mid Miocene.

**Cores 21-25 (mid Miocene):** A decrease in the diversity and in the quality of preservation is evident within Cores 21-23; Cores 24 and 25 have a higher diversity. Coscinodiscus marginatus, Denticula lauto, Dimi-
Schiodes, T. hirosakiensis, and especially Thalassiolbrix. Stephanopyxis turris and longissima dium falcatum, and Endyctia robusta are abundant but all of the other forms are rare. Species not found higher include Pseudodosiris westii, Rhizosolenia aculeifera, R. curvirostris var. inermis, and Syedra jouseana is abundant. The assemblages are typical of the mid Miocene.

**Cores 26-30 (early Miocene):** A marked change occurs at this interval. Most of the Rhizosolenia species and all the Denticula species are absent. Stephanopyxis turris and Thalassionema hirokaiensis are abundant. Highest occurrences of Coscinodiscus palaeaceus, Asteromphalus brookei, A. heptactis, A. parvulus, and Bogorovia sp. Early Miocene seems most likely.

**Cores 31 and 32 (late Oligocene?):** Number and diversity of diatoms much smaller. The taxa consist of long-ranging species, but these assemblages can be easily separated from those which underlie by the lowest known occurrences of Syedra. Thalassionema nitzschiodes, T. hirokaiensis, and especially Thalassiosira longissima and Stephanopyxis turris are abundant. Late Oligocene is suggested.

**Cores 33 and 34 (mid Oligocene?):** Assemblages markedly different from the overlying, lacking certain typically Neogene diatoms (see above), and containing several forms which are completely new to science. These latter include new species of Coscinodiscus decrescensoides, Endyctia burketi, Macrora stella, Dicladia, and ?Pixilla. Mid Oligocene is tentatively suggested.

**Silicoflagellates**

Silicoflagellates are rare to common in the samples representing late Oligocene to Pleistocene sediments. The Pleistocene to late Pliocene assemblages are dominated by Distephanus speculum, while species of Dictyocha are very rare or absent. According to Mandra (1969), this is indicative of low temperatures during deposition, predictable at almost 60°S. However, a complete change of the assemblage occurs in an early Pliocene to late Miocene sample (278-10-1, 110 cm), where the Dictyocha/Distephanus ratio is surprisingly high, indicating higher temperatures. In early Pliocene and the Miocene, Distephanus and Mesocena dominate the assemblages, while Naviculopsis becomes common, from the early Miocene on downwards. Cannopilus is never common, but occurs in the Pleistocene and late Pliocene (Cores 278-2 to 278-7), and from the mid Miocene to late Oligocene (Cores 278-20 to 278-34). Cannopilus also prefers low temperatures (Bukry and Foster, 1973).

**Radiolaria**

Radiolaria have been examined in Cores 278-1 to 278-12 and Cores 278A-1 to 278A-3. Throughout this interval they are abundant and well preserved, allowing application of the zonation of Hays and Opdyke (1967).

The Quaternary (late Matuyama and Brunhes; t = 1.79 m.y. to present) is 157 meters thick, extending from the surface to Section 278-7-6. By far the most dominant form is Antarcitissa denticulata. Other forms include A. strelkovii, Spongoplema antarcticum, Botryopyle antarctica, Lithelius nautiloides, and Spongopelthus glacialis.

The ψ-X boundary equivalent to the Brunhes-Matuyama paleomagnetic epoch boundary (Hays and Opdyke, 1967), is based on the last appearance of Pterocanium trilobum and Saturnaria circularis. In Site 278 this level occurs between Samples 278-2-4, 90 cm and 278-2-5, 40 cm.

From Samples 278-7-1, 90 cm to 278-7-6, 140 cm the presence of Clathroclycas bicornis and the absence of Eucrytium calvertense indicates an age equivalent to the Gilsa Event (t = 1.61-1.79 m.y.B.P.) which is of earliest Pleistocene age. The top of E. calvertense’s range in Sample 278-7, CC marks the ψ-X boundary. The lower portion of the Φ zone is apparently removed by an unconformity located between Samples 278-8, CC and 278-9-1 (40 cm). The existence of the unconformity is based on several changes: the abrupt appearance of A. strelkovii and A. denticulata at the unconformity; the absence of Pseudocubus vema; and the presence of Antarctissa sp. in sediment immediately below the unconformity.

The presence of Lychnocamnus grande rugosum and Triceraspis sp. in Samples 278-9-1, 40 cm to 278-12-6, 86 cm mark the Φ zone which is early-middle Gilbert (t = 3.97–5.0 m.y.B.P.)

No radiolarian zonal schemes are applicable to the sequence below Sample 278-12, CC. However, the continued presence of Desmospyris spongiosa and E. calvertense and absence of L. grande rugosum and Triceraspyris in Samples 278-12, CC to 278-15, CC does suggest a late Miocene age.

**SEISMIC DATA**

The material at this site represents an isolated pod of pelagic-type sediment, derived from bottom current transport and deposition. The area is well removed from the thick sequence of ponded turbidites in the Solander Trough. The minor mid-Pliocene hiatus of about 2 m.y. at a depth of about 170 meters, seems to correlate with the unconformity at a reflection depth of about 0.2 sec that appears in the profiler section (Figure 3).

**SEDIMENTATION RATES**

Sedimentation rates for Site 278 are shown in Figure 8. Three distinct episodes of sedimentation and one of non-sedimentation are shown from the middle Oligocene to the Recent. Sedimentation rates were very low (~0.5 cm/1000 yr) during the Oligocene to early Miocene episode of deposition. From the middle Miocene to early Pliocene sedimentation rates increased to an average of 1.3 cm/1000 yr during deposition of nannofossil-rich siliceous ooze and siliceous-rich nannofossil ooze. After a break in sedimentation during at least the middle Pliocene, a spectacular increase in sedimentation occurred from late Pliocene to Recent, of an average of 7.5 cm/1000 yr. This associated with deposition of diatom-radiolarian ooze.

The dramatic increase in productivity appears to herald the initiation of the high productivity associated with the Antarctic Convergence as it is known today. Alternatively, increased sedimentation rates at Site 278 may be partly related to increased deposition of sediment transported from extensive regions in the south Tasman Sea. This is not the major process as shown by excellent preservation of siliceous biogenic components, and reworking is not extensive. Although the cause of
Figure 8. Sedimentation rate curve at Site 278; ages based on adopted age, (Figure 7).
increased productivity is unknown it is probably related with more vigorous oceanic overturn, which is related to cooler Pleistocene climates.

Increased sedimentation in two main steps from the Oligocene to the present appears to be related to increased productivity of diatoms. This suggests increased upwelling of nutrient-silica-rich deep water in the Southern Ocean associated with the Antarctic Convergence.

SUMMARY AND CONCLUSIONS

Site 278 was drilled in the southwestern Emerald Basin well away from the flank of the Macquarie Ridge in 3708 meters of water (Figure 1), obtaining 37 cores with total penetration of 438 meters, the basal 5 meters of which consists of pillow basalt.

Six sedimentary units have been distinguished which can be grouped into three broader units as follows: The upper 172 meters consist of late Pleistocene (Recent?) to late Pliocene radiolarian-diatom ooze (Units 1 and 2). This is underlain by 214 meters of early Pliocene to early Miocene alternating siliceous nannofossil ooze and nannofossil-rich siliceous ooze (Units 3 to 5). This is underlain by 42 meters of early Oligocene nannofossil chalk rich in sponge spicules (Unit 6). Rates of sedimentation increase upward in step-like fashion. Sedimentation rates are very low for the Oligocene (0.5 cm/1000 yr), moderate for the Miocene-early Pliocene (1.3 cm/1000 yr), and very high for the late Pliocene and Pleistocene (7.5 cm/1000 yr). Well-dated middle Oligocene (30 m.y. old) nannofossil chalk lies directly on pillow basalt with zeolite-filled veins, amygdules, vesicles, and interpillow micritic limestone layers. The outer surfaces of the pillows are glassy, and the glass is palagonitized. Although the basalt/chalk contact was not recovered, there is no evidence of baking of the limestone or mineralization.

The almost continuous Quaternary to middle Oligocene sequence offers a particularly fine biostratigraphy of well-preserved and abundant diatoms and radiolarians throughout except in the Oligocene where siliceous microfossils other than sponge spicules are rare. The Oligocene contains abundant and moderately diverse assemblages of planktonic foraminifera and calcareous nannofossils. The Neogene calcareous assemblages show much evidence of dissolution. This has reduced the diversity of the calcareous assemblages.

Conclusions

The age difference between basement at Site 277 and basement south of the Campbell plateau, 300 km to the east, is about 50 m.y. This discrepancy calls for an important discontinuity in the sea floor, which is most likely related to the post-mid Eocene tectonic activity that has deformed the western edge of the Campbell plateau. A major fracture zone, and a 600-meter change in sea floor depth are present (see Chapter 42, this volume). The formation of the sea floor at Site 277 is probably contemporaneous with the onset of subsidence (Fleming, 1962) in the Waiau depression in Southland, New Zealand. The depression is located at the head of the Solander Trough-Emerald Basin (see Figure 1, Chapter 44, this volume).

The history of biogenic sedimentation at this site is of particular interest because of its location at the present-day Antarctic Convergence. The fluctuations in lithology from nannofossil ooze to radiolarian-diatom ooze appear to indicate changes in the location and strength of the Antarctic Convergence. The siliceous oozes represent times when the convergence was nearby, thereby increasing productivity and sedimentation rates.

The Oligocene nannofossil chalks reflect deposition initially above, and later slightly below the planktonic foraminiferal lysocline, under fully oceanic conditions. Very low sedimentation rates and the paucity of siliceous biogenic components other than sponge spicules suggest that upwelling was essentially nonexistent in the region. This implies the absence of an Antarctic Convergence at this time. Alternatively, the convergence would need to be squeezed between Site 278 and the Antarctic continent. It is possible that the Antarctic Convergence and the related upwelling did not develop before the beginning of the Neogene due to constricted circulation in the narrow Paleogene passage between Australia and Antarctica.

The Oligocene nannofossil chalks contain abundant sand-size feldspathic glass and sanidine grains, an indication of nearby volcanism. Significant fluctuations in the abundance of ice-rafted quartz sand grains occur in Pleistocene and late Pliocene sediments. Lesser amounts are found in early Pliocene/late Miocene sediments at this site. Ice-rafted grains are absent in all sediments older than late Miocene.

The first siliceous oozes to occur are early Miocene and at these latitudes they probably reflect siliceous productivity associated with the early development of the convergence. Moderately low sedimentation rates indicate, however, that siliceous biogenic productivity was relatively low and upwelling was generally sluggish. Alterations of siliceous-rich and calcium carbonate-rich biogenic sediments in the mid Miocene almost certainly record latitudinal fluctuations of the Antarctic Convergence. The consistent combination of siliceous and carbonate components in the ooze suggests, however, that the convergence did not change position greatly. The relatively fixed position of the convergence probably reflects the influence of the Macquarie Ridge throughout the Neogene. Today the Antarctic Convergence is diverted further south by the Macquarie Ridge.

The considerable increase in siliceous biogenic productivity that began about the middle-late Pliocene and has continued to the present indicates an intensification of upwelling associated with the Antarctic Convergence. The location of Site 278 on the southeastern side of the Macquarie Ridge in an area protected from erosion by the circumpolar current has enabled the deposition of an almost continuous sequence. It is possible that sedimentation rates may also have increased by sediment deposition by bottom currents at this location during the Plio-Pleistocene.

Large amounts of materials, most probably biogenic are known to have been eroded over extensive areas of the southern Tasman Sea during the Plio-Pleistocene. This material may have been transported by bottom currents associated with circumpolar currents to the
southwest Pacific basin via the area immediately south of the Macquarie Ridge, and through two deep east-west channels that cut through the Macquarie Ridge to the north. Some of this transported sediment may have been deposited on the leeward side of the Macquarie Ridge in the area of Site 278 and contributed to the very high sedimentation rate. Minor reworking of biogenic materials into the Plio-Pleistocene indicates some bottom current activity. However, the excellent preservation of the siliceous microfossil assemblages strongly suggests that high productivity is the primary cause of the high Plio-Pleistocene sedimentation rates. This is probably related to a critical development of world-wide glaciation at this time, as recorded by the initiation of ice-rafting in the North Atlantic and a marked increase in bottom-water erosion observed in the south Tasman Sea, the Ross Sea, and the central Pacific. At Site 278 increased dissolution of calcium carbonate from the Oligocene to the present day probably is related to higher bottom-water activity, itself related to the stimulated oceanic circulation.

REFERENCES


## APPENDIX A

### Summary of X-Ray, Grain Size, and Carbon-Carbonate Results, Hole 278

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<thead>
<tr>
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<td>Foraminifera and detrital silt-bearing radiolarian-diatom ooze</td>
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<td>278-7-2</td>
<td>228.1</td>
<td>Nannofossil-rich siliceous ooze, diatom-rich nannofossil ooze</td>
<td>2-20µ</td>
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<td>Clayey silt</td>
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<td>Unit 5</td>
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<td>Mica</td>
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<td>Plag.</td>
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<td>Rad-diatom ooze and siliceous ooze</td>
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<td>Calc.</td>
<td>Plag.</td>
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<td>Clayey silt</td>
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<td>Plag.</td>
<td>Clayey silt</td>
<td>7.7</td>
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<td>278-8-1</td>
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<td></td>
<td>Calc.</td>
<td>Plag.</td>
<td>Plag.</td>
<td>Clayey silt</td>
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<td>278-8-2</td>
<td>427.1</td>
<td>Unit 6</td>
<td>Middle</td>
<td>Mica</td>
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<td>Clayey silt</td>
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<td>278-8-3</td>
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<td>Siliceous nannofossil chalk</td>
<td>2-20µ</td>
<td>Calc.</td>
<td>Plag.</td>
<td>Plag.</td>
<td>Clayey silt</td>
<td>7.0</td>
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</tbody>
</table>

Note: * = see comment column.

*Complete results of X-ray, Site 278 will be found in Appendix I, Table 4.

*Legend in Appendix A, Chapter 2.

*Peaks at 5.76Å, 3.63Å, & 8.12Å among others in bulk fraction for Samples 278-1-1, 1-4, 2-4, 3-5, and 6-3 in amounts of 5.25% for all samples except 6-3, which reports Trace (5%) amounts.
Site 278 - Hole 1 - Core 1
Cored Interval: 0.0-6.0 m

LITHOLOGIC DESCRIPTION

Light brownish gray (2.5Y 6/2) FORAM-BEARING RAD DIATOM OOZE with dark gray mottles due to an increase in detritals and mica. Glacial-type quartz grains: this grades into a FORAM AND DETRITAL Silt-Bearing RAD DIATOM OOZE at base of Sec. 1. Other lithologies and color changes noted were: Secs. 2 and 3 darker bands containing detritals are firm and less deformed, while lighter bands are moderately deformed to soupy, grayish brown (2.5Y 6/2) layer rich in SAND DETRITALS (Sec. 2 60-110 cm); light yellowish brown (2.5Y 6/4) layer, PELAGIC (Sec. 2 110-120 cm) and a grayish brown layer (2.5Y 6/2) at 120-130 cm, Sec. 2. Sec. 3 contains a light yellowish brown (2.5Y 6/4) DETRITAL Silt-Rich FORAM-BEARING RAD DIATOM OOZE (0-170 cm) and a grayish brown (2.5Y 6/2) layer at 170-180 cm, Sec. 3. Other lithologies and color changes noted were: Secs. 2 and 3 darker bands containing detritals are firm and less deformed, while lighter bands are moderately deformed to soupy, grayish brown (2.5Y 6/2) layer rich in SAND DETRITALS (Sec. 2 85-100 cm); light yellowish brown (2.5Y 6/4) layer, PELAGIC (Sec. 2 100-120 cm) and a grayish brown layer (2.5Y 6/2) at 120-130 cm, Sec. 2. Sec. 3 contains a light yellowish brown (2.5Y 6/4) DETRITAL Silt-Rich FORAM-BEARING RAD DIATOM OOZE, with a couple of layers of light gray (2.5Y 7/2) and gray (2.5Y 6/2).
### Lithologic Description

- **Light bluish gray (5B 7/1) with micaceous dark streaks:**
  - MICARB-RICH DIATOM OOZE in Section 1 to 130 cm in Section 3;
  - NANNO-RICH DIATOM OOZE in Section 3 (130 cm) to Section 6 (20 cm)
  - SPONGE SPICULE-RICH DIATOM OOZE in CC; deformation is usually intense causing color streaking.
  - Colors are light gray (7.5GY 7/0), light bluish gray (5B 7/1), light greenish gray (5G 8/1) and greenish gray (5G 6/1).

### Sedimentology

- **SS 1-127**
- **M -15%**
- **F -10%**
- **N -10%**
- **D -30%**
- **SS CC -2%**
- **-3?**
- **75X**

### X-ray 5-120 (Bulk)

- **Calc - M**
- **Quar - TR**
- **Plag - TR**
- **Mica - TR**

### Grain Size 5-124 (3.4, 44.0, 52.6)

### Carbon Carbonate 5-127 (4.1, 0.1, 33)

### Fossil Character

**Core Catcher**

**Lithologic Description**

- Light bluish gray (5B 7/1) MICARB-RICH DIATOM OOZE; the core catcher is SPICULE-RICH (SS CC).
- The core is highly deformed with a decreasing micarb content down core.

### Explanatory notes in Chapter 1
Site 278 Hole 5 Cored Interval: 129.5-139.0 m

**LITHOLOGIC DESCRIPTION**

Light bluish gray (5B 7/1) with streaks of light greenish gray and greenish gray (5G 8/1), SPICULE-BEARING MICARB-RICH RAD DIATOM OOZE grading into a MICARB-BEARING RAD/DIATOM OOZE in Sec. 5; and to a SPONGE SPICULE AND MICARB-BEARING DIATOM OOZE in the core catcher: core shows swirling and streaking and is intensely deformed grading into moderate deformation in Secs. 3 through 6.

---

Site 278 Hole 6 Cored Interval: 139.0-148.5 m

**LITHOLOGIC DESCRIPTION**

Light bluish gray (5B 7/1), medium bluish gray (5B 5/1) to greenish gray streaked MICARB-RICH DIATOM OOZE; intensely deformed varying with moderate deformation throughout the core. Sec. 2 shows excellent color mottling of grayish green and greenish gray colors and is a RAD DIATOM OOZE, with clay blebs and mild bioturbation: it grades into a MICARB/SPONGE SPICULE-BEARING DIATOM OOZE in Sec. 3; a dusky yellow green (5GY 5/2) coloration with greenish gray streaks and intense deformation occurs in Sec. 5.

---

Explanatory notes in Chapter 1
**Fossil Character**

**Core Catcher**

**Lithological Description**

Light bluish gray (5B 7/1 to greenish gray (5G 6/1), DIATOMOOZE, which is generally moderately deformed, although slight and intense deformation does occur: swirled and streaked colorations noted and bioturbated areas occur. The core shows both soft to stiff characteristics: In Secs. 2 and 3 a greenish gray (5G 7/1), dusky yellow green (5G 6/2), gray (5B 6/1) colors are noted and the core has a stiff to firm induration. Sec. 6 is well indurated faintly mottled and laminated, with bluish gray to light greenish gray colors with the colors getting lighter toward the bottom. In Sec. 5 at 130 cm is a contact to a yellowish gray (5G 7/1), 10YR olive gray (5G 7/1), R5AD AND DETRITAL SILTY SAND-RICH DIATOM Ooze.

**Explanatory notes in Chapter 1**

**Site 278**

<table>
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<tr>
<th>Age</th>
<th>Zone</th>
<th>Lithology</th>
<th>Description</th>
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</thead>
</table>
| 0.1 | 1    | Light bluish gray (5B 7/1) to greenish gray (5G 6/1), DIATOM
|     |      |           | Ooze, which is generally moderately deformed, although slight and intense deformation does occur: swirled and streaked colorations noted and bioturbated areas occur. The core shows both soft to stiff characteristics: In Secs. 2 and 3 a greenish gray (5G 7/1), dusky yellow green (5G 6/2), gray (5B 6/1) colors are noted and the core has a stiff to firm induration. Sec. 6 is well indurated faintly mottled and laminated, with bluish gray to light greenish gray colors with the colors getting lighter toward the bottom. In Sec. 5 at 130 cm is a contact to a yellowish gray (5G 7/1), 10YR olive gray (5G 7/1), R5AD AND DETRITAL SILTY SAND-RICH DIATOM Ooze. | |
| 0.5 | 1    | Pale yellow brown (10YR 6/2), greenish gray to light bluish gray (5B 7/1) DIATOM Ooze, becoming SPECULITE-RICH (5G 6/10) in Sec. 2. The core shows intense deformation at the top (Sec. 1) becoming firmer (moderate-slight deformation) at the bottom, (Secs. 4-6). Other colors occurring are: light bluish gray (5B 7/1), pale yellow brown with light mottles, and a very pale orange (10YR 8/2) to pale yellow brown (10YR 6/2) and in faint mottles with greenish gray (5G 6/1) as well as a mixture of 5G 6/1 and 10YR 6/2 in Sec. 2, very pale brown (10YR 7/3) dark streaks and brown (10YR 6/2) to very pale brown with greenish gray streaks in Sec. 4 (100 cm) through Sec. 5; Sec. 1 (30 cm) is a RAD DIATOM Ooze with an incorporated ice-rafted pebble of granite grading into a Silt AND Silt DETRITAL-RICH SILICEOUS Ooze in Sec. 6 and a SPECULITE AND SANDY DETRITAL-RICH DIATOM Ooze in the core catcher. |
LITHOLOGIC DESCRIPTION

The core consists of a very light brown (10YR 5/3) DIATOM Ooze with white (10YR 8/1) and light gray (10YR 7/2) colors which are swirled and streaked, vertically banded. A SAND AND SILT-RICH SILICEOUS Ooze in Sec. 2 (0-65 cm) grades into a SILICEOUS-RICH NANNO Ooze white (10YR 8/1) at 65 cm in Sec. 2 going to 15 cm in Sec. 3. Sec. 3 (15 cm) is MIXED NANNO + DIATOM Ooze and a very pale brown (10YR 7/3) SILICEOUS NANNO Ooze in Sec. 4 (0-70 cm). Swirled and mixed colors with mild mottling is common. The core is stiff but tends to be deformed intensely. MN micronodule streaks increase in Sec. 5. The core catcher consists of a very pale brown (10YR 7/3) RAD/DIATOM-RICH NANNO Ooze (SS CC).

SS
N
D
R
S
4-21
-60%
-20%
-12%
-8%

LITHOLOGIC DESCRIPTION

White (10YR 8/2) stiff induration with a uniform texture DIATOM/RAD-RICH NANNO Ooze, speckled with MN micronodules. Some mixing with a pale yellow brown (10YR 7/2) color occurs as well as some dark streaks of clay and MN in Sec. 3. Sec. 6 consists of a soft to stiff light gray (10YR 7/2) DIATOM-RICH NANNO Ooze and the core catcher is a SPONGE SPICULE-RICH DIATOM NANNO Ooze (SS CC).

Explanatory notes in Chapter 1
### Site 278 Hole Core 11 Cored Interval: 186.5-196.0 m

**LITHOLOGIC DESCRIPTION**

Light gray (10YR 7/1) DIATOM-RICH NANNO Ooze. The core is stiff, in upper sections becoming soft in Sec. 3 and firm again in Secs. 4-6. A mottling of colors occurs with light brownish gray (10YR 7/2) and light gray (10YR 7/1). The core catcher consists of a DIATOM-RICH NANNO Ooze (SS CC).

### Site 278 Hole Core 12 Cored Interval: 196.0-205.5 m

**LITHOLOGIC DESCRIPTION**

White (5Y 8/1) to very light gray (5Y 7/1). The core is soft to soupy (Sec. 6) and shows a light mottled, swirled texture with colors of light greenish gray (5G 8/1) very light gray (N8) and light bluish gray (5B 7/1). The basic lithology is DIATOM-RICH NANNO Ooze grading into a RAD AND DIATOM-RICH NANNO Ooze in Sec. 4. The core catcher is a DIATOM-BEARING RAD-RICH NANNO Ooze.
Light bluish gray (5B 7/1) DIATOM-BEARING RAD-RICH NANNO OOZE in Secs. 5 and 6 and a DIATOM-RICH NANNO OOZE in core catcher (SS CC). The core is intensely deformed in Secs. 1 and 2, becoming soft to stiff lower in the core. A slight mottling is noted as well as specs of Mn occurring in Sec. 3.

SS CC

**X-ray 4-44 (Bulk)**

Calc - M
Quar - TR
K-Fc - TR
Plag - TR
Mica - TR
Mont - TR

**Grain Size 4-41 (0.1, 23.2, 76.6)**

Carbonate 4-40 (7.7, 0.1, 64)

**LITHOLOGIC DESCRIPTION**

Light bluish gray (5B 7/1) SILICEOUS NANNO OOZE. A microdiorite(?) pebble occurs at 85 cm Sec. 1. The core is soft with intense deformation (soupy) with a stiffening in Sec. 4. The core lithology in Secs. 1, 2 and 3 grades into a light bluish gray (5B 7/1) DIATOM-RICH NANNO OOZE in core catcher. Other colors noted with some mottling are greenish gray (5B 6/1) and bluish white (5B 9/1).
The core is greenish gray (5GY 6/1) RAD/DIATOM NANNO OOZE (Sec. 1) grading into a light olive gray (5Y 6/1) NANNO-BEARING SILICEOUS OOZE (SS 2-20) in Sec. 2 (10-60 cm), and to a pale brown (10YR 6/3), very firm, DIATOM-BEARING NANNO OOZE in Sec. 2 (60 cm) to Sec. 6 (80 cm). Sawfish brown (10YR 6/7) colorations and MN specks occur in Sec. 3 and 4. The core is firm in Sec. 6 (80-150 cm) consists of light gray (10YR 7/1) NANNO-BEARING SILICEOUS OOZE and the core catcher is a DIATOM-BEARING NANNO OOZE (SS CC).

Core consists of a yellowish gray (5Y 8/1) very stiff, SILICEOUS NANNO OOZE, SILICEOUS OOZE to a NANNO-BEARING SILICEOUS OOZE. Deformation is intense to slight, with intense areas showing color mottling. Color occurrences throughout core include greenish gray (5GY 6/1), light gray (5Y 7/1), yellow gray (5Y 8/1). The core catcher consists of a light bluish gray (5B 7/1) NANNO-RICH SILICEOUS OOZE.

Explanation notes in Chapter 1.
LITHOLOGIC DESCRIPTION

Light bluish gray (5B 7/1) NANNO-RICH SILICEOUS Ooze to a soft SILICEOUS-RICH NANNO OOZE starting in Sec. 2 of a light olive gray (5Y 6/1) color. The core catcher is a stiff DIATOM-RICH NANNO OOZE. Other colors noted were: grayish green (5GY 6/1) in Sec. 3, light gray (10YR 7/2) and greenish gray (5GY 6/1) in Secs. 5 and 6. Intense mottling noted especially in Secs. 5 and 6. Core is soft to stiff in lower portions.

SS 2-3
D - π
N - 80%
D - 10%
R - 3%
S - 6%

SS CC
DE - 1%
N - 40%
D - 40%
R - 15%

X-ray 6-70 (Bulk)
Calc - A
Quar - P
K-F - P
Plag - P
Kaol - TR
Chlo - TR
Mica - P
Glim - TR
Hematite - TR

Grain Size 6-67 (1.7, 29.1, 69.2)
Carbon Carbonate 6-65 (3.7, 0.1, 30)

Explanatory notes in Chapter 1
Cored Interval: 281.5-291.0 m

LITHOLOGIC DESCRIPTION
Light bluish gray (5B 7/1) NANNO-BEARING SILICEOUS OOZE with the core catcher consisting of a NANNO-RICH DIATOM OOZE (SS CC). Deformation is intense with drilling breccia (Sec. 4) to an absence of deformation. Soft to stiff with a hard layer in Sec. 2 (60-80 cm). A faint mottling is noted in Sec. 6 as well as an olive gray (5Y 6/2) coloration.

X-ray 6-54 (Bulk)
Calc, Quar, K-Fe, Plag, Mica, Chlo, Mont

Core Catcher

Fossil Character

AGE
ZONE

DEFORMATION
LITHOLOGIC DESCRIPTION

SILICEOUS OOZE (SS CC)
NANNO-BEARING SILICEOUS OOZE
NANNO-RICH DIATOM OOZE
SILICEOUS OOZE (SS CC)

Explanatory notes in Chapter 1
### Site 278 Hole Core 23 Cored Interval: 300.5-310.0 m

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<th>Fossil Character</th>
<th>Section</th>
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<th>Lithologic Description</th>
</tr>
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<td>300.5</td>
<td>NC P</td>
<td>1</td>
<td>Light bluish gray (5B 7/1) Nanno-bearing Siliceous Ooze, being Nanno-rich in core catcher. Core is generally firm, with slight mottling. Greenish gray (5G 6/1) colors in Sec. 3 and MN Flecks noted in Sec. 4.</td>
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<tr>
<td>310.0</td>
<td>NC P</td>
<td>3</td>
<td>Light blue gray (5B 7/1) Siliceous Ooze (SS CC). Some dark mottles and streaks noted including MN streaks in Sec. 3. Greenish gray (5G 6/1) colors noted in Sec. 5. Core is soft to stiff, and semilithified.</td>
<td></td>
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**Explanatory notes in Chapter 1**
Cored Interval: 319.5-329.0 m

FOSSIL CHARACTER

LITHOLOGIC DESCRIPTION
Greenish gray (5G 6/1) SILICEOUS OOZE, with a MKR-RICH DIATOM Ooze in core catcher (SS CC). Intense Mn flecks noted in Sec. 2 and some in Sec. 3. Core is very stiff to semi-lithified, with faint mottling, streaking and slight or no deformation. Sec. 4 shows a light bluish gray (5B 7/4) coloration.

SS CC
CM
N
D
R
S
Si
- TR
-63%
-10%
-2%

Cored Interval: 329.0-338.5 m

FOSSIL CHARACTER

LITHOLOGIC DESCRIPTION
Light bluish gray (5B 7/1) SILICEOUS OOZE to a NANNO AND RAD-BEARING DIATOM Ooze Sec. 5 (70 cm) and Sec. 6 and a RAD NANO-RICH DIATOM Ooze in core catcher. Greenish gray (5G 6/1) coloration noted in Sec. 3. Core deformation is drilling breccia to moderate (Sec. 4) or no deformation Sec. 5 (70 cm) and Sec. 6.

SS CC
N -20%
D -53°/
R -15%
S -10%
G - IX

Explanatory notes in Chapter 1
Site 278  Hole  Core 27  Cored Interval: 338.5-348.0 m

LITHOLOGIC DESCRIPTION

Light greenish gray (5G 6/1) to medium bluish gray (5B 5/1) and non-lithified diatom ooze to a diatom ooze in core catcher. Drilling breccia and vesicles. Core is stiff in Secs. 1, 5, and 6. Mottling and a light bluish gray (5B 7/1) color noted in Sec. 5.

LITHOLOGIC DESCRIPTION

Greenish gray (5G 6/1) rad-bearing diatom ooze (SS CC). The core is stiff in Secs. 1, 2, and 5 to semilithified in Secs. 3, 5, and 6. Slight mottle is noticed: layers and streaks of Mn occur in Secs. 3 and 6. Deformation is slight, with no noticeable deformations in Secs. 3 and 4.
### Core 30 Cored Interval: 395.5-405.0 m

**Lithologic Description**

- **Age**: 1
- **Zone**: NA
- **Pos.**: NA
- **Section**: NA
- **Meters**: 0.5
- **Lithology**: Void
- **X-ray 3-55 (Bulk)**
  - Carbonate 3-54: 7.6, 0.1, 63

**Fossil Character**

- **Core Catcher**: NA

**Notes**: Grain Size 1-51 (0.4, 36.9, 62.5)

Carbonate 3-34 (7.4, 0.1, 63)

---

### Core 31 Cored Interval: 395.5-405.0 m

**Lithologic Description**

- **Age**: 1
- **Zone**: NA
- **Pos.**: NA
- **Section**: NA
- **Meters**: 0.5
- **Lithology**: Void
- **X-ray 3-55 (Bulk)**
  - Carbonate 3-54: 7.6, 0.1, 63

**Fossil Character**

- **Core Catcher**: NA

**Notes**: Grain Size 1-51 (0.4, 36.9, 62.5)

Carbonate 3-34 (7.4, 0.1, 63)

---

### Core 30 Cored Interval: 386.5-396.0 m

**Lithologic Description**

- **Age**: 1
- **Zone**: NA
- **Pos.**: NA
- **Section**: NA
- **Meters**: 0.5
- **Lithology**: Void
- **X-ray 3-55 (Bulk)**
  - Carbonate 3-54: 7.6, 0.1, 63

**Fossil Character**

- **Core Catcher**: NA

**Notes**: Grain Size 1-51 (0.4, 36.9, 62.5)

Carbonate 3-34 (7.4, 0.1, 63)

---

### Core 31 Cored Interval: 386.5-396.0 m

**Lithologic Description**

- **Age**: 1
- **Zone**: NA
- **Pos.**: NA
- **Section**: NA
- **Meters**: 0.5
- **Lithology**: Void
- **X-ray 3-55 (Bulk)**
  - Carbonate 3-54: 7.6, 0.1, 63

**Fossil Character**

- **Core Catcher**: NA

**Notes**: Grain Size 1-51 (0.4, 36.9, 62.5)

Carbonate 3-34 (7.4, 0.1, 63)

---

### Core 30 Cored Interval: 376.5-386.0 m

**Lithologic Description**

- **Age**: 1
- **Zone**: NA
- **Pos.**: NA
- **Section**: NA
- **Meters**: 0.5
- **Lithology**: Void
- **X-ray 3-55 (Bulk)**
  - Carbonate 3-54: 7.6, 0.1, 63

**Fossil Character**

- **Core Catcher**: NA

**Notes**: Grain Size 1-51 (0.4, 36.9, 62.5)

Carbonate 3-34 (7.4, 0.1, 63)

---

### Core 31 Cored Interval: 376.5-386.0 m

**Lithologic Description**

- **Age**: 1
- **Zone**: NA
- **Pos.**: NA
- **Section**: NA
- **Meters**: 0.5
- **Lithology**: Void
- **X-ray 3-55 (Bulk)**
  - Carbonate 3-54: 7.6, 0.1, 63

**Fossil Character**

- **Core Catcher**: NA

**Notes**: Grain Size 1-51 (0.4, 36.9, 62.5)

Carbonate 3-34 (7.4, 0.1, 63)

---

### Core 30 Cored Interval: 367.5-377.0 m

**Lithologic Description**

- **Age**: 1
- **Zone**: NA
- **Pos.**: NA
- **Section**: NA
- **Meters**: 0.5
- **Lithology**: Void
- **X-ray 3-55 (Bulk)**
  - Carbonate 3-54: 7.6, 0.1, 63

**Fossil Character**

- **Core Catcher**: NA

**Notes**: Grain Size 1-51 (0.4, 36.9, 62.5)

Carbonate 3-34 (7.4, 0.1, 63)

---

### Core 31 Cored Interval: 367.5-377.0 m

**Lithologic Description**

- **Age**: 1
- **Zone**: NA
- **Pos.**: NA
- **Section**: NA
- **Meters**: 0.5
- **Lithology**: Void
- **X-ray 3-55 (Bulk)**
  - Carbonate 3-54: 7.6, 0.1, 63

**Fossil Character**

- **Core Catcher**: NA

**Notes**: Grain Size 1-51 (0.4, 36.9, 62.5)

Carbonate 3-34 (7.4, 0.1, 63)
**LITHOLOGIC DESCRIPTION**

**Site 278 Hole Core 32**

- **Cored Interval:** 405.0-414.5 m

| AGE | ZONE | FOSSIL CHARACTER | PRESS. | WET SHEET | LITHOLOGY | ECONOMIC \n|-----|------|-----------------|--------|-----------|-----------|----------
| NAP | 1    | Light gray (10YR 7/2 to 7/3) SILICEOUS NANNO CHALK stiff-flow to semi-lithified (lithified) and no noticeable deformation; small streaks of MN occur and a faint mottling is noticed with the gray colors and very pale brown (10YR 7/3); MN nodules, micronodules and some burrowing was noticed. The burrows include zoophycus type burrows. The core appears to have a massive bedding (non-stratified). The core catcher contains a RAD-BEARING NANNO CHALK. |
| NAP | 2    | Light gray (10YR 7/2) SILICEOUS NANNO CHALK with MN streaks. The core is very stiff to semi-lithified, with drilling breccia in Sec. 4. Color in Sec. 6 is a very pale brown (10YR 7/3). |

**Site 278 Hole Core 33**

- **Cored Interval:** 414.5-424.0 m

| AGE | ZONE | FOSSIL CHARACTER | PRESS. | WET SHEET | LITHOLOGY | ECONOMIC |
|-----|------|-----------------|--------|-----------|-----------|----------
| NAP | 1    | Light gray (10YR 7/2) SILICEOUS NANNO CHALK with MN streaks. The core is very stiff to semi-lithified, with drilling breccia in Sec. 4. Color in Sec. 6 is a very pale brown (10YR 7/3). |

Explanatory notes in Chapter 1.

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**Notes:**

- The sediment is described as light gray, with streaks of MN. The core is stiff to semi-lithified, with some drilling breccia and a very pale brown color in certain sections.

---

**Core Catcher:**

- The core catcher contains a RAD-BEARING NANNO CHALK.
**Site 278 Hole**

**Core Interval:** 424.0-429.0 m

**Lithologic Description:**
- Very pale brown (10YR 7/3) Nanno Chalk and light gray (10YR 7/1) Siliceous Nanno Chalk: deformation is intense to a drilling breccia in Sec. 3. The contact to a Plagioclase Porphyritic Basalt olive black (5Y 2/1) occurs in Sec. 3 (115 cm). The basalt has black glass rinds (4% SiO₂ of palagonite). Micritic limestone inclusions are light gray (10YR 7/2), with white rare calcite filled amygdules 0.5 mm.
- Calcite, Dolomite, Quartz, K-Fe, Plagioclase, Kaolinite, Mica, Chlorite
- Grain Size: 3-11 (5.9, 43.4, 50.7)
- Carbonate: 3-10 (6.8, 0.0, 57)

**Site 278 Hole A**

**Core Interval:** 15.5-25.0 m

**Lithologic Description:**
- Plagioclase Porphyritic Basalt olive black (5Y 2/1) with black palagonite rinds, inclusions of micritic limestone, calcite, and vesicles. Rock is altered olivine pillow basalt. Feldspar is labradorite. Some material has been lost between segments so there is no lithologic continuity in core. Basalt has 15% Plagioclase euhedra (x 2-3 mm), feldspar laths, and acicular pyroxene with iddingsite after olivine. The micrite contains foraminifera, 1 cm thick and bounded by glass. The micrite believed to be preserved in inter-pillow area. There is no evidence of alteration or baking. Glass in colorless, contains fresh labradorite phenocrysts and talc and olivine euhedra. Micrite may have been a Nanno Ooze. Segment occurs in Sec. 4, 2 segments in Sec. 5, and 1 segment in core catcher. 9 pieces of basalt were found. 0.5-5 mm fragments, without glass as described above.

**Site 278 Hole**

**Core Interval:** 25.0-34.5 m

**Lithologic Description:**
- Light gray (N7) Detrital Bearing Calcareous? Diatom Ooze. Most of core loss was due to basalt chips caught in core catcher dogs.

**Site 278 Hole A**

**Core Interval:** 25.0-34.5 m

**Lithologic Description:**
- Medium gray (N5), light gray (N7), Detrital Bearing Calcareous Diatom Ooze. Intense deformation shown by vertical color banding; some soft zones in Sec. 4 and dark greenish gray (5G 4/1) colors.

Explanatory notes in Chapter 1
SITE 278

WET-BULK DENSITY, gm/cc

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POROSITY, %

Grain Density

SECTION

278-11

CM
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