4. SITE 328
The Shipboard Party
With Additional Reports From
Wayne K. Harris, Department of Mines, Adelaide, South Australia

SITE DATA

Date Occupied: 24-30 April, 1974
Time on Site: 137 hours, 15 minutes.
Position (satellite): 49°48.67’S, 36°39.53’W
Number of Holes: 3
Water Depth: 5095 corrected meters (echo sounding)
Bottom Felt at: 5103 meters (drill pipe)
Penetration:
- Hole 328: 397 meters
- Hole 328A: 17 meters
- Hole 328B: 471 meters.
Number of Cores:
- Hole 328: 12
- Hole 328A: 2
- Hole 328B 8th
Total Core Recovered:
- Hole 328: 62.1 meters (55%)
- Hole 328A: 7.4 meters (44%)
- Hole 328B: 62.5 meters (94%)
Age of Oldest Sediment: Upper Cretaceous
Acoustic Basement: Not penetrated, but estimated to lie at about 574 meters below sea bed.
Summary: Site 328 in 5103 meters of water in the Malvinas Outer Basin immediately to the east of the Falkland Plateau and to the south of the Falkland Fracture Zone, was chosen to examine correlatives of Argentine Basin acoustic reflectors, to obtain a deep-water southerly biostratigraphic section, and if possible, to date the underlying oceanic basement. Three holes were drilled at the site. The deepest penetrated 471 meters and bottomed in Upper Cretaceous gray zeolitic claystone. The top 13.5 meters consist of late Miocene-Quaternary diatomaceous ooze with abundant manganese nodules, sand, and large clasts. The lithology of these presumably ice-rafted clasts does not identify a specific source area. All are found around the Weddell Sea margin and the Antarctic Peninsula. The underlying 34 meters of silty, biogenic siliceous clay is of late Eocene-late Miocene age. Below this sediment Upper Cretaceous or Paleocene-upper Eocene siliceous clay and claystone extends to about 300 meters subbottom. The remainder of the section consists of Upper Cretaceous zeolitic claystone.

The reflector correlated with Horizon A of the Argentine Basin appears to represent a gradual diagenetic change from clay to claystone rather than a distinctive lithic layer. Extrapolation of sedimentation rates suggests that the uncored acoustic basement is of Albian age. The relatively high rate of sedimentation represented by the Upper Cretaceous-upper Eocene clay and claystone is believed to have been related to the mid-Cretaceous uplift of the Andean cordillera. A substantial reduction in sedimentation rate, decrease in clay content, and major breaks in the stratigraphic record indicate increase in bottom current velocity in the late Eocene continuing through the Miocene. Cold water microfossils become dominant in the middle Miocene, and certain ice-rafted material appears in the upper Miocene.

BACKGROUND AND OBJECTIVES

Site 328 is situated in the Malvinas Outer Basin (Ewing and Lonardi, 1971), which lies directly north of South Georgia and east of the Falkland Plateau. The northern boundary of the basin is the Falkland Fracture Zone, a narrow east-west basement ridge; Site 328 lies 90 km southwest of the single prominent gap in that ridge, through which the main northward flow of Antarctic Bottom Water is considered to take place (Figure 1). The site lies in 5095 meters of water and sediment thickness is estimated to be about 574 meters. Nearby reflection profiles (Robert Conrad 16-09; see Figure 2) indicate the presence of a thin (<0.1 sec) stratified layer above a seemingly homogeneous layer extending to a smooth acoustic basement at about 0.7 sec, and with only one very weak and diffuse intermediate reflector at about 0.5 sec. Further to the southwest, northwest of South Georgia, the upper stratified layer thickens to more than 1.5 sec, and was considered by Ewing and Lonardi (1971) to be a distal turbidite, although acoustic penetration was anomalously good. The underlying homogeneous layer, with its weak, diffuse intermediate reflector (Horizon A) and smooth, acoustically opaque base (Horizon B) has been seen through much of the Argentine Basin. There, Horizon A was tentatively correlated by Ewing et al. (1971) with an Eocene chert horizon found in the North Atlantic,

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2 Core 8 of Hole 328B was recovered when the bottom-hole assembly came on deck and probably comes from 471 meters, the greatest depth drilled.
Figure 1. Bathymetry of the Malvinas Outer Basin in the vicinity of Site 328 (after Lonardi and Ewing, 1971), with Robert D. Conrad 16-06 track.
and Horizon B, which obscures all but the highest oceanic basaltic basement peaks, with an earlier turbidite deposit.

The objectives at Site 328 were thus:
1) To determine the age of oceanic basement in the Malvinas Outer Basin.
2) To establish the nature and age of Horizons A and B and the upper stratified horizon.
3) To sample a high-latitude, deep-water stratigraphic column for comparison with the shallow-water Falkland Plateau sites (327, 329) and an Argentine Basin site further north (331).
4) To provide information on the glacial history of the region, Antarctic Bottom Water movement, initiation of the circum-polar current (Drake Passage opening), and possibly the separation of South America and Africa.

**SURVEY AND OPERATIONS**

The original locations of the three options for Site 328 had to be abandoned, being closer than 200 miles to South Georgia and hence in waters claimed by Argentina. A revised position was chosen on the basis of an RC 16-09 reflection profile (Figure 2) so as to permit the same basic objectives to be attained. The main sedimentary section showed 0.8 sec subbottom reflection time to Horizon B, a smooth reflector, overlying and usually masking the normal oceanic basaltic basement. At a point on the flank of the basin, however, this time was reduced to 0.65 sec, making Horizon B accessible. Further site survey was necessary to see if this flank province was more extensive off the preexisting tracks and could be considered representative of the basin as a whole.

_El Glomar Challenger_ approached along 334°T, slowing to 5.5 knots at 0132 on 24 April (Figure 3). A more extensive area with Horizon B at 0.65 sec was indeed visible on this profile (Figure 4), and a faint, diffuse Horizon A could be seen at 0.45 to 0.5 sec subbottom. Apart from this, and a trace of multiple reflections in the uppermost 0.05 sec, the sediments were transparent.

A check line was steamed at 110°T through the original position on track RC 16-09 and extended to guard against a southwest extension of the basement outcrop seen on that profile. The beacon was dropped at 0700 on 24 April, in 5095 meters of water in the middle of the newly surveyed flank province. Horizon B lay at 0.68 sec subbottom (see Figure 4).

The ship commenced lowering pipe at 0800 but because of positioning problems and the close approach (within 3 km) of an iceberg, the drill string was not spudded in until 0900Z (Table 1) on 25 April. The first core came on deck at 0900Z, and 11 others were cut in the next 28 hr, continuously to 26.5 meters and then intermittently to 397 meters subbottom. The wind speed then increased to the point at which, because of a 1 to 2 knot current, the ship could not keep station without withdrawing power from the Bowen unit. The pipe was pulled and the drill bit came on deck at 0300Z on 27 April. Meanwhile a sonobuoy line had been fired, between 1300 and 1500Z on 26 April, but without success because of rising seas. The bit was changed and the string lowered again, pausing at 1780 meters for successful tests of the Schlumberger unit. The pipe was spudded in at 0015Z on 28 April and the first (surface) core of Hole 328A came onboard at 0140Z, the plan being to core continuously the first seven intervals, so as to sample fully the interesting Neogene section found in Hole 328, and then to drill to below the last core of that hole before coring again. However, the second core gave very poor recovery and the bit was pulled out of the sea bed and respudded to repeat that interval,
thereby terminating Hole 328A and starting 328B. Recovery this time was good, and the remaining shallow intervals were quickly cored. A center bit then replaced the core tube for 13 hr before Core 7 was acquired at 435 to 444.5 meters subbottom. Before the next coring interval was reached, the nearness of an iceberg caused the pipe to be lifted to 5250 meters, so that about 150 meters of pipe remained in the hole. It appears that when the pipe was again lowered, after the iceberg had passed, the bit started to sidetrack rather than run easily back into the hole; the drillers noted some loss in string weight, which was regained after rotation but lost again upon lowering further. This time the pipe would not rotate, and it was feared that the bottom-hole assembly had been lost. The string weight increased again as pipe was pulled, however, and it seems fairly certain that some of the extra pipe lowered had been laid on the ocean floor. The string was recovered, coming on deck at 0015 on 30 April, and three joints of pipe were found to have been bent. A short core section found in the core tube was unlike anything found higher in the hole and is thought to have come from 471 meters, the depth reached before the approach of the iceberg.

Signals from the 13.5-kHz beacon were diminishing, so a 16-kHz beacon was dropped, some 0.25 km to the southwest. Because of high winds the pipe was not started down until 1400 on 30 April and was raised at 1700 on receipt of a forecast of further bad weather. The site was abandoned, and by 2115 the ship was passing over the new beacon position headed along 261° at 5-6 knots, bound for Site 329 on the Falkland Plateau.

**LITHOLOGICAL SUMMARY**

**General Statement**

Site 328 was spudded in the Malvinas Outer Basin east of the Falkland (Malvinas) Plateau in a water depth of 5103 meters. Three holes were drilled that, combined, amounted to continuous coring to 65 meters with overlap and intermittent coring thence to 471 meters subbottom. The lithology of a-l three holes is considered as a continuous section. The sedimentary column is described in terms of four lithologic units (Figure 5). However, the boundary between the third and fourth units is approximate as it occurs in an uncored interval.

**Unit 1 (0-13.5 m, Cores 1-2 of Holes 328 and 328A, Core 1 of Hole 328B)**

The upper unit consists of 13.5 meters of predominantly diatom ooze and clayey diatom ooze that is distinguished by a subordinate component of silt- to pebble-size detritus. The ooze is soft and slightly sticky. Yellow, gray, green, and olive-gray colors
predominate, with the grays occurring in zones rich in clay and silt. Well-preserved diatoms are by far the dominant biogenic component of the ooze with from a few percent to about 15% radiolarians, sponge spicules, and other siliceous organisms. The coarser detrital component, which is predominantly ice rafted, occurs as disseminated throughout the ooze and also as discrete thin beds of sand, silty sand, or pebbly sand to 5 cm thick. It is composed of a wide variety of lithologic types of continental affinities. Typically, the clasts are angular to subangular and a few pebbles clearly show faceting and striations characteristic of abrasions by glacial transport. Table 2 summarizes the lithology and texture of the gravel-size fraction from core-catcher samples of Holes 328 and 328A. Pelletal glauconite is a minor constituent of the thin sand beds and large ferromanganese nodules, many of which are nucleated on pebbles, occur through the unit.

The lower contact of Unit 1 is picked at the lowest stratigraphic occurrence of granule-size detritus which is essentially at the same depth both in Holes 328 and 328B. This contact also coincides closely with a striking downward decrease in the abundance of detrital sand. Except for the disappearance of coarser detritus, the contact is gradational into Unit 2.

**Unit 2 (13.5-49 m, Cores 2-4 of Hole 328, Cores 1-5 of Hole 328B)**

Unit 2 consists of about 35.5 meters of slightly sticky to sticky siliceous ooze, clay, and silt in varying proportions. Colors are dominantly yellow-gray to yellow-brown in zones rich in biogenous material grading into grayish-orange, dark yellowish-orange, or grayish-yellow in clay-rich parts of the unit. As in Unit 1, the biogenic component is largely diatoms with sparse to common amounts of other siliceous organisms. Silt and sand occur mainly in the upper part of the unit and the clay content tends to increase progressively towards the base. Sand content is generally less than a few percent, although there is as much as 11% within the top meter of the unit.

Approximately 1 meter of diatom-bearing zeolite-rich clay occurs at the bottom of Core 3 in Hole 328, and at the base of the unit in Hole 328B there is a transitional zone 4.5 meters thick in which the clay contains abundant authigenic zeolites. The zeolite minerals are mainly clinoptilolite with minor phillipsite. In general, the content of siliceous organisms is highly variable in Unit 2 and there is a pronounced increase in the amount of dissolution of the tests towards the base of the unit.
Figure 5. Columnar section of Site 328 showing basic lithology recovered.
TABLE 2
Pebble-Size Clasts in Core-Catcher Samples. 328-1 and 328A-1

<table>
<thead>
<tr>
<th>Clast Lithology</th>
<th>328-1</th>
<th></th>
<th>Max. Size (cm)</th>
<th>328A-1</th>
<th></th>
<th>Max. Size (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manganese nodules and fragments</td>
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<td>–</td>
<td>–</td>
<td>Many</td>
<td>42</td>
<td>3.8</td>
</tr>
<tr>
<td>Rhyolite, dacite, pumice, felsic porphyry (1 faceted)</td>
<td>6</td>
<td>15</td>
<td>2.7</td>
<td>10</td>
<td>29</td>
<td>3.8</td>
</tr>
<tr>
<td>Shale, siltstone, argillite (faceted and striated in part)</td>
<td>14</td>
<td>20</td>
<td>3.6</td>
<td>13</td>
<td>17</td>
<td>4.0</td>
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<tr>
<td>Granite porphyry (possible faceted)</td>
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<td>25</td>
<td>5.3</td>
<td>–</td>
<td>–</td>
<td>–</td>
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<tr>
<td>Granodiorite, quartz monzonite, diorite</td>
<td>11</td>
<td>10</td>
<td>1.7</td>
<td>7</td>
<td>1.5</td>
<td>2.0</td>
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<tr>
<td>Basalt, andesite</td>
<td>3</td>
<td>10</td>
<td>2.7</td>
<td>1</td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td>Gabбро</td>
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<td>1.8</td>
<td>1</td>
<td>Tr</td>
<td>1.2</td>
</tr>
<tr>
<td>Quartz (1 possible faceted)</td>
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<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Sandstone, quartzite</td>
<td>14</td>
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<td>2</td>
<td>1.4</td>
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<td>Gneiss, schist, phyllite</td>
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<td>5</td>
<td>1.9</td>
<td>6</td>
<td>2</td>
<td>2.3</td>
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<tr>
<td>Sandy mudstone</td>
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<td>Tr</td>
<td>0.5</td>
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</table>

the unit. Deterioration of siliceous tests is especially apparent in the zeolite-rich zones, and the transition from diatomaceous clay to the nonfossiliferous zeolitic clay of Unit 3 occurs abruptly within a stratigraphic interval of 3 meters in Hole 328B.

Minor biogenic constituents noted in Unit 2 are fish debris, pyritized siliceous remains, and displaced Cretaceous radiolarians. Large ferromanganese nodules are common in all but the lower 9 meters of the unit with abundant micronodules throughout.

Chemical analyses of sediment samples bracketing the transition from biogenous ooze to zeolitic clay are presented in Table 3. They were made to test whether the essentially simultaneous appearance of zeolite and loss of siliceous organisms is isochemical, which would be expected if diagenetic alteration of biogenic silica were the source of silica in the zeolite. However, the drop in silica content from over 61% to about 52% across this interval as shown by the analytical data indicates that the system was not isochemical, and thus the zeolites are probably not directly related to the disappearance of the siliceous microorganisms.

Unit 3 (49-130 m, Cores 4-9 of Hole 328, Cores 5 and 6 of Hole 328B)

Unit 3 consists of 261 meters of rather monotonously homogeneous zeolitic clay and claystone. On the basis of color, the unit is subdivided into an upper part roughly 80 meters thick (3A), which is predominantly grayish-orange with yellow-brown mottling, and a lower part (3B) in which greenish-gray to olive-gray colors predominate. The upper half of the unit is a stiff, sticky clay grading through interbedded clay and moderately well indurated claystone in Core 7 of Hole 328 to claystone in the lower part of the unit. Clay minerals consisting of about equal amounts of illite, montmorillonite, and mixed-layer montmorillonite and illite typically comprise 80%-90% of the sediment. The remainder consists largely of authigenic zeolites (mainly clinoptilolite) and apatite with traces of glauconite,
### A. X-ray fluorescence analyses (weight percent)^a

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Unit 2. Biotic ooze</th>
<th>Unit 2. Interbedded ooze, clay ooze, and zeolithic clay</th>
<th>Unit 3. Zeolithic clay</th>
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<tbody>
<tr>
<td>36-328B-4-5</td>
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Table 3

Chemical and Semiquantitative Spectrographic Analyses of 14 Siliceous Ooze and Clay Samples from Cores 4 and 5, Hole 328B (Analyses by U.S. Geological Survey)

<table>
<thead>
<tr>
<th>Element</th>
<th>Unit 2. Biotic ooze</th>
<th>Unit 2. Interbedded ooze, clay ooze, and zeolithic clay</th>
<th>Unit 3. Zeolithic clay</th>
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<tr>
<td>SO₄²⁻</td>
<td>60.59</td>
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<tr>
<td>Al₂O₃</td>
<td>14.07</td>
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<td>Fe₂O₃</td>
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<tr>
<td>MgO</td>
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<tr>
<td>CaO</td>
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<td>Na₂O</td>
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<td>K₂O</td>
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<td>H₂O</td>
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<tr>
<td>TiO₂</td>
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</tr>
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<td>P₂O₅</td>
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<tr>
<td>CO₂</td>
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**TOTAL**

99.47

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### B. Semiquantitative spectrographic analyses (weight percent)^b

<table>
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<tr>
<th>Element</th>
<th>Unit 2. Biotic ooze</th>
<th>Unit 2. Interbedded ooze, clay ooze, and zeolithic clay</th>
<th>Unit 3. Zeolithic clay</th>
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<tbody>
<tr>
<td>Fe %</td>
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<td>Mg %</td>
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<tr>
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<tr>
<td>Si %</td>
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<td>G</td>
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<tr>
<td>Al %</td>
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<td>Na %</td>
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### C. Semiquantitative spectrographic analyses (parts per million)^b

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<th>Unit 2. Interbedded ooze, clay ooze, and zeolithic clay</th>
<th>Unit 3. Zeolithic clay</th>
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**TOTAL**

99.63

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^a Data from Cores 4 and 5, Hole 328B (Analyses by U.S. Geological Survey)

^b Data from Cores 4 and 5, Hole 328B (Analyses by U.S. Geological Survey)
fish debris, opaque minerals, radiolarian tests, goethite, and possibly some finely crystalline sphalerite. The opaque minerals are dominantly pyrite. Radiolarian tests commonly show the effects of dissolution and replacement by pyrite. Although the unit shows abundant color banding and mottling, these changes do not reflect detectable compositional or textural variations. A few local black color bands and patches are probably the trails of burrowing organisms. There are scattered small, soft patches of ferromanganese near the top of the unit and manganiferous micronodules are abundant throughout.

Unit 4 (310-471 m, Cores 10-12 of Hole 328, Cores 7 and 8 of Hole 328B)

The lowest unit consists of 161 meters of variegated slightly zeolitic claystone that is only slightly more variable in lithology than Unit 3. Color banding occurs on a scale of centimeters to meters. Commonly, there is a cyclical gradation from reds and browns at the bottom through green or olive to gray and black at the top. The dark-colored bands tend to be relatively richer in finely divided plant-derived carbonaceous material. Bioturbation is evident at several horizons and Zoophycos and Chondrites, the feeding trails of burrowing organisms, are locally recognizable. The clay-size fraction is dominantly illite-montmorillonite mixed-layer clays with minor chlorite and kaolinite. Cristobalite in significant amounts occurs in X-ray analyses of two samples from Core 10 near the top of this unit, and 8% tridymite occurs in one of these samples. The presence of these minerals is probably related to diagenetic changes although there is no obvious megascopic lithologic change in this interval. Authigenic siderite, in aggregates having distinctive dumbell shapes, is a characteristic accessory constituent that is locally highly concentrated in thin zones a few meters thick. Other constituents present in minor amounts include pyrite, oxides and hydroxides of iron, fish debris, pyritized radiolarians, agglutinated benthonic foraminifera, and glauconite. The fish debris is in part altered to both apatite and collophane. The only coarse clastic unit is a 1-1/2-cm-thick microturbidite of very fine- to medium-grained size-graded sandstone in Core 7, Hole 328B. The sandstone, which is composed entirely of authigenic and biogenic material, includes a probable pre-Campanian displaced coccolith flora that represents the only calcareous microfossils recovered from Site 328.

PHYSICAL PROPERTIES

Wet bulk densities, porosities, and water content were determined underway using gravimetric and GRAPE methods. Sonic velocities were measured using the Hamilton frame system. These values are shown in the site summary graphic logs and core summaries.

With the exception of Core 8 (Hole 328) and Cores 1 and 2 (Hole 328A) which were highly disturbed, all the remaining 19 cores (Holes 328 and 328B) were sampled, and physical properties determined in all four lithological units.
A special effort was made to sample in detail the uppermost 60 meters (0.08 sec two-way travel time), a thinly stratified sequence which extends over a large area of this physiographic province and reaches a thickness corresponding to 2.0 sec to the southwest of the site. Sixty-four sonic velocity measurements were made in the top 65 meters of the hole, consisting of diatom ooze and silty siliceous zeolitic clay, and a similar number of wet bulk density, porosity, and water content determinations were performed.

Most of the undisturbed core sections down to 471 meters were also sampled for physical properties, across zeolitic clay and claystone (65-310 m) and zeolite-bearing claystone (310-471 m).

Down to about 100 meters sonic velocities decrease slightly from about 1.55 km/sec to 1.51 km/sec. Across this section (which includes the acoustically finely stratified upper sequence mentioned above) all other physical parameters are also relatively uniform. Porosities range typically from 50% to 65%, wet bulk densities from 1.25 g/cm³ to 1.50 g/cm³, and water content from 50% to 65%.

Between 100 and 310 meters there is a moderate increase in the degree of compaction of the clays, which become claystones at about 250 meters depth; this increase is mirrored in the velocity and density values.

Between 320 meters (top of the zeolite-bearing claystones of Lithological Unit 4) and 380 meters, sonic velocities gradually increase from about 1.58 km/sec to range between 1.75 km/sec and 1.94 km/sec in well-indurated claystones of similar composition. The average velocity between 380 meters and the base of the hole is close to 1.83 km/sec.

A similar rate of change is observed in average values of other mass physical properties. Porosities decrease from 72% (310 m) to 49% (400 m) to 52% (445 m).

Average wet bulk densities increase correspondingly from 1.52 g/cm³ (310 m) to 1.89 g/cm³ (400 m) and remain practically constant downhole (1.87 g/cm³ at 445 m).

Water content decreases on the average from 48% (310 m) to 28% (400 m) to 445 m).

Variations of acoustical impedance follow changes observed with depth in compressional velocities, and lie between an average 2.10 × 10⁵ g/cm²sec (±0.4) determined for the uppermost 65 meters to a maximum of 3.57 × 10⁵ g/cm²sec at 400 m, decreasing slightly to 3.35 × 10⁵ g/cm²sec near the bottom of the hole.

The plotted values are estimated to be accurate to ±7% syringe porosity, ±6% GRAPE porosity, ±0.1 g/cm³ syringe bulk density, and ±1% velocity.

PALEONTOLOGY

Biostatigraphic Summary

The 471-meter-thick sedimentary sequence drilled at this site reflects primarily a record of nearly continuous abyssal sedimentation from the early Late Cretaceous to the present. Changes in lithology represent only changes in the contributing sedimentary components at various points in time (see Lithologic Summary). The lack of calcareous microfossils throughout the section indicates deposition below the CCD during the entire documented depositional history. The major lithologic change from a zeolitic clay and claystone in the lower part of the column (55-471 m) to a siliceous ooze and silty siliceous clay above (0-55 m) reflects a major change in surface and near-bottom oceanographic conditions, possibly resulting from the separation of Australia and Antarctica in late Eocene time.

Only siliceous microfossils occur in the sediments of the upper 55 meters. Both diatoms and radiolarians show very similar trends in their respective abundances, degrees of preservation, and diversity throughout this section. From 55 to 295 meters (Cores 5-9) biostatigraphic control is very poor due to the scarcity of microfossils. Small amounts of agglutinated foraminifera are present in Cores 8, 9, 10, and 12. Rare terrestrial palynomorphs occur in Core 9 and marine dinoflagellate cysts are abundant in the deepest part of the hole (Cores 10, 11, 12 of 328 and Core 7 of 328B).

Paleontologic correlation based on diatoms and radiolarians and silicoflagellates is satisfactory for the upper part (26.5 m) of the sedimentary sequence which contains assemblages of Pleistocene, Pliocene, and middle to late Miocene age. Breaks in the stratigraphic record are indicated at the Miocene-Pliocene and Pliocene-Pleistocene boundaries.

There is very little doubt about the sudden change from the middle Miocene age of the sediments in Core 328B-2 (bottom) to those of earliest early Miocene (?) or late Oligocene age in Core 328B-2 (top). The top of Core 3 contains a few specimens of Cytrocapella tetrapera, whose first appearance occurs at the Oligocene-Miocene boundary, indicating that only the very earliest Miocene may be present at the top of Core 328B-3. At 328B-3-1, 5-7 cm, Rocella gemma is very common and indicates a late Oligocene age. A late Oligocene age for Cores 3 and 4 of 328B is supported by the silicoflagellates and radiolarians. Of the last group, common representatives are Lithomelissa challengeræ, L. robusta, Calocyclas semipolita, and Cyclampteterium longiventer.

Cores 328-4, 328B-5, and possibly the bottom of 328B-4 are of late Eocene age, evidence for which are the radiolarians Lychnocanoma bellum and L. amphitrite as well as the silicoflagellates.

Due to extensive dissolution of the assemblages, both radiolarians and diatoms become useless for dating sediments below 45 meters; the Radiolaria persist a few meters beyond the last occurrence of the diatoms due to their generally more robust skeletons.

No microfossils were found in the sediments from 55 to 200 meters. Below 200 meters palynomorphs are the most common microfossils and indicate ages from the late Paleocene to late Turonian.

The radiolarian, diatom, and silicoflagellate fauna and flora from the top 55 meters of the section indicate general cool surface water conditions throughout the Pleistocene through middle Miocene. The late Pliocene and Pleistocene record reflects the more frigid temperatures which are so characteristic of the circum-Antarctic environment today. Both the diatoms and the radiolarians indicate a possible slight warming trend in the middle Miocene. No estimate of surface oceanographic conditions can be made for the pre-late Oligocene time.
Since the late Turonian the sedimentary history of the site has been characterized by deposition of fine-grained clays and silts transported mainly by bottom currents. The presence of reworked older microfossils throughout the entire sedimentary sequence is mute evidence for this process. Besides the process of transport by bottom currents over some distance, downslope displacement of sediments from nearby topographic highs may have occurred as is suggested by the presence of small amounts of well preserved pre-Maestrichtian nanofossils in the lower part of the section (Lithologic Unit 4, below 300 m), as well as by moderately well preserved Cretaceous and Paleocene radiolarians in the sediments below 50 meters. The most likely source for this material is probably the eastern end of the Falkland (Malvinas) Plateau. The composition of the sedimentary components changed significantly in the late Paleogene and Neogene when siliceous organisms became an important factor of the sedimentary load. This change can be attributed to a rather abrupt increase in surface water productivity related to changing surface oceanographic conditions in late Eocene time. No record of a high Paleocene-early Eocene surface productivity, as observed at Site 327, was found in the sediments at this site suggesting that the period of Paleocene productivity may have been restricted to the waters of the relatively shallow Falkland Plateau, perhaps as a result of a rather unique local oceanographic regime.

**Foraminifera**

Rare arenaceous benthonic foraminifera were found in the lower part of the section, in Cores 8-10 and 12. At several levels, specimens have undergone fractionation, but relatively well preserved assemblages were recovered from Core 10. The following species could be identified: Ammodiscus cretaceous, Glomospira charoides, Rzehakina epigona, Haplophragmoides sp., H. excavata, Nodellum velasource, Bathysiphon spp., Saccammina complanata, Hormosina ovulum, Uvigerinammina sp., and Pararhizosolenia sp. This assemblage is characteristic for the Late Cretaceous-early Eocene interval from depths below the calcium carbonate compensation level.

A very similar assemblage of approximately the same age (Cretaceous-Paleocene) has been reported from Site 323 in the Bellingshausen Abyssal Plain (Rögl, in press).

**Calcaceous Nannofossils**

Sediments recovered in three holes at Site 328 were deposited in deep water well below the carbonate compensation depth and contain no nannoliths except for rare well preserved Mesozoic forms reworked into the zeolitic claystone in the lower part of the section (Lithologic Unit 4). These coccoliths are Watznaueria barnesia, a taxon common only in pre-Maestrichtian sediments of this region.

**Silicoflagellates**

The siliceous oozes in the top 51 meters at Site 328 contain abundant silicoflagellate assemblages which document the presence of Quaternary, Pliocene, late Miocene, late Oligocene, and Eocene strata. As expected at this high latitude site, the cool-water indicating genus Distephanus predominates, particularly in the Neogene section.

Assemblages recovered from the three holes drilled at this site can be zoned according to silicoflagellate biostratigraphic zonations developed from studies of materials recovered by DSDP Cruises 28 and 29 to the Pacific sector of the Southern Ocean and environs (Ciesielski, 1975; Bukry, 1975a, b). Quaternary assemblages may be assigned to the Dictyocha aculeata Zone of Bukry and Foster (1974) or to the Distephanus speculum A Zone of Ciesielski (1974), depending on which zonation is followed (see Busen and Wise, Bukry, both this volume). Similarly, both Ciesielski's Distephanus speculum B Zone or Bukry's Distephanus boliviensis boliviensis Zone may be distinguished in the somewhat sparse Pliocene floras (Hole 328, Cores 2 and 3 and Hole 328B, interval 1-3, 5 cm to 2-1, 144 cm). Sparse floras in Sections 328-3 and 328-4 are assigned to the Miocene Mesocena circulus/Mesocena-adodon Zones (of Busen and Wise, this volume) whereas Sections 328B-3-1 to 328B-4-5 belong to the late Oligocene Naviculopsis biapiculata Zone. Late Eocene assemblages assigned to the Dictyocha deflandrei Zone are present in Cores 328B-5 and 328-4 to 328-5.

**Diatoms**

Diatoms are common to abundant through the Neogene interval in Hole 328. Preservation of frustules is poor to moderate. Diatoms in the Paleogene interval in Core 4 are generally abundant and well preserved.

The following Neogene diatom zones of McCulloch (1975) are represented in Hole 328: Coscinodiscus leptogonus Partial-Range Zone (1-1, 1-3 cm to 1-3, 5 cm); Coscinodiscus elliptopora/Actinocyclus ingens Concurrent Range Zone (1-3, 81-83 cm to 1-3, 138-140 cm); Cosmodiscus insiginis Partial-Range Zone (2-1, 148-150 cm to 2-2, 5-7 cm); Nitzschia interfrigidaria Partial-Range Zone (2-2, 80-82 cm to 2-3, 5-7 cm); Denticula hustedtii/Denticula lauta Partial-Range Zone (2-3, 78-80 cm to 2-3, 5-7 cm); Denticula hustedtii/Denticula lauta/Paradenticula lauta Partial-Range Zone (2-5, 81-83 cm to 3-1, 5-7 cm); Denticula lauta/Denticula antarctica Partial-Range Zone (3-1, 81-83 cm to 3-2, 140-142 cm). The interval from Samples 3-3, 5-7 cm to 3-4, 81-83 cm was not zoned, but is included in the middle Miocene.

The Coscinodiscus leptogonus and Coscinodiscus elliptopora/Actinocyclus ingens zones are Quaternary in age. The Cosmodiscus insiginis and Nitzschia interfrigidaria zones are middle to early Pliocene in age. The Denticula hustedtii/Denticula lauta Zone is late Miocene. The Denticula lauta/Denticula antarctica Zone and the interval below it to Sample 3-4, 81-83 cm are middle Miocene.

The absence of the Rhizosolenia barboi/Nitzschia kerguelensis Partial-Range Zone and the Coscinodiscus kolbei/Rhizosolenia barboi Range Zone between the Coscinodiscus elliptopora/Actinocyclus ingens Concurrent Range Zone and the Cosmodiscus insiginis Partial Range Zone suggests the existence of a hiatus at this
level (i.e., between Samples 1-5, 138-140 cm and 2-1, 148-150 cm). Alternatively, the absence of these two zones may be explained fully or in part by a drilling gap of about 1 meter between Cores 1 and 2.

The *Nitzschia praerifrigidaria* Partial-Range Zone is missing from between the *Nitzschia interfrigidaria* Partial-Range Zone and the *Denticula hustedtii* Partial-Range Zone within Core 2 (i.e., between Samples 2-3, 5-7 cm and 2-3, 78-80 cm). This interval corresponds to the occurrence of deformed, centimeter scale laminae of sandstone at 3.7 meters in Core 2.

Samples 3-5, 10-12 cm to 3-6, 48-50 cm are barren of diatoms. Sample 3-6, 81-83 cm contains a trace of diatoms.

Core 4 is late Eocene in age. The *Pyrgopyxis eocena/Pterotheca aculeifera* Zone is represented in Samples 4-1, 147-149 cm through 4-3, 5-7 cm.

Diatoms are abundant and are moderately well to well preserved in the samples examined from Hole 328A. The *Coscinodiscus lentiginosus* Partial-Range Zone of McCollum (1975) is represented in Samples 1-1, 35-37 cm through 1-4, 70-72 cm. Samples 1-4, 146-148 cm through 2-1, 145-147 cm are assigned to the *Coscinodiscus elliptopora/Actinocyclus ingens* Concurrent Range Zone.

These zones are Pleistocene to Recent in age and have been correlated to the paleomagnetic time scale by McCollum. The Bruhnes-Matuyama boundary is nearly coincident with the boundary of the *Coscinodiscus lentiginosus* Zone with the *Coscinodiscus elliptopora/Actinocyclus ingens* Zone.

In Hole 328B, diatoms are of Neogene age from the top of Core 1 through Sample 2-4, 70-72 cm. In this interval the diatoms are common to abundant from the top of Core 1 through Core 2, Section 2. Preservation in this interval is moderate. Diatoms are rare and poorly preserved in the interval Core 2, Section 3 through Core 2, Section 4.

Samples 1-1, 89-91 cm through 1-2, 5-7 cm are placed within the *Nitzschia interfrigidaria* Zone based on the highest occurrence of *Nitzschia praerifrigidaria* in Sample 1-2, 70-72 cm. This indicates a Pliocene age for this interval. The remainder of the Neogene section is disturbed to the extent that it was not possible to assign zones. However, correlation with Hole 328 suggests a late Miocene age for Samples 1-2, 70-72 cm through 1-6, 70-72 cm, and a middle Miocene age for Samples 1-6, 140-142 cm through 2-4, 70-72 cm.

Samples 2-5, 5-7 cm and 2-5, 70-72 cm are barren of diatoms. Sample 2-6, 5-7 cm contains a trace of diatom fragments. Sample 2-6, 123-125 cm is barren of diatoms.

Diatoms are common to abundant and poorly to moderately well preserved in Cores 3 through 5. This interval is Paleogene and includes late Eocene through late Oligocene age sediments.

The late Eocene *Pyrgopyxis eocena/Pterotheca aculeifera* Zone is represented in Samples 5-1, 147-149 cm through 5-3, 84-86 cm. The late Eocene-late Oligocene *Hemialthus incicus* Zone is represented in Samples 4-4, 5-7 cm through 5-1, 9-11 cm. The late Oligocene *Cyclotella hannae* and *Pyrgopyxis prolongata* zones are represented in Samples 4-1, 45-47 cm through 4-3, 145-147 cm and 3-2, 70-72 cm through 3-6, 126-128 cm, respectively.

**Radiolaria**

Radiolaria occur in various abundances, degrees of preservation, and diversity throughout the Neogene and late Paleogene sections of all three holes drilled at this site, i.e., in Cores 1 through 4 of Hole 328, Cores 1 and 2 of Hole 328A, and in Cores 1 through 6 of Hole 328B.

Small amounts of reworked older fossils were observed in many of the samples examined and point to a nearly continuous record of eroding bottom currents in this area throughout the Tertiary.

Pleistocene assemblages are present in Core 328-1 and in both cores of Hole 328A. The co-occurrence of *Prunopyle antarctica* with *Stylatractus universus* in the first three sections of 328-1 indicate a late Pleistocene age. Specimens of *Antarctissa ewingi* occurring below Section 328-3-5 indicate an early Pleistocene age for the lower part of the core. Small numbers of upper Miocene and Pliocene radiolars indicate admixing of older sediments into those of Quaternary age, and compound the problem of detecting zone boundaries in the core. The top two sections of Core 328-1 are assigned to the upper Pleistocene *Antarctissa denticulata* Zone, and Section 3 seems to belong to the *Stylatractus universus* Zone. Scattered throughout the core are specimens of *Saturnalis circularis*. Considerable intraspecific variations in *Antarctissa denticulata* and *A. ewingi*, in addition to the admixing problems, make it difficult to recognize the boundary between the *S. universus* and *S. circularis* zones. It is rather arbitrarily placed between Sections 3 and 4.

The Pliocene record appears to be much shortened. The top of Cores 328-2 and 328B-1 contain rare *Desmospyris spongiosa*. This, plus admixed Oligocene and Miocene Radiolaria could indicate, albeit tentatively, the *Eucyrtidium calvertense* Zone, although it can also be interpreted that this zone is altogether absent. The *Helotholus vema* Zone is represented in Core 328-2, Sections 1, 2, and 3, 39-41 cm.

Assemblages of Miocene age are encountered in the remainder of Core 328-2 and in Core 3. The presence of *Actinomma tanyacantha*, *Antarctissa conradae*, *Eucyrtidium cienkowskii*, *Dendrospyris haysi*, *Prunopyle spiropyrinus*, *Cyttocapsella tetrapera*, *Ommatarrus antepenultimus*, *Ommatarrus* cf. *O. hughesi*, *Amphistylus angelinus*, *Theocalyptra bicornis spongotorax*, *Stichocorys peregina*, and *Stichocorys delmontenses* indicate the late Miocene *Theocalyptra bicornis spongotorax* Zone throughout most of this interval. Elements of Oligocene faunal assemblages, *Cyclampterierrium longiventer*, *Calocycles semipolita* ?, and *Lithocyclia* sp., point to reworking with older sediments. Core 328-3 does not appear to reach into any other Miocene radiolarian zones. The strongly disturbed nature of the sediments recovered in Cores 1 and 2 of Hole 328B makes it difficult to establish any kind of zonation for the Miocene.
Cyclampterium longiventer, Calocyclas semipolitata, Lithomelissa sphaerocephalitis, Lithomelissa challengereia, Lithomelissa robusta, Prunopyle spongopyrinus, Eucyrtidium sp., Artophormis sp. cf. A. gracilis, Lychnocanoma elongata, Dorcardospyris sp. cf. D. ateuchus, and Calocyclatra sp. occur at the top of Core 328B-3. Associated with these assemblages are a few specimens of Cyrtocapsella tetrapera, which indicates a thin veneer of lower Miocene sediment at the top of this core. The above-mentioned assemblage, minus C. tetrapera, is of Oligocene age.

No radiolarian zones exist yet for the fossil Oligocene assemblages from high latitudes, and thus it is not possible, from the radiolarian data, to establish if the sediment recovered is of a late or early Oligocene age. However, the silicoflagellates suggest late Oligocene. No change in the radiolarian assemblages was observed throughout Cores 328B-3 and 4. In both Cores 328-4 and 328B-5, late Eocene faunas are present, indicated by Lychnocanoma amphitrite, L. bellum, Lophocyrtis sp. cf. L. jactia, Theocampe urceolus, and Amphiphasphaera minor.

The number of radiolarians rapidly declines and preservation and diversity deteriorate sharply below Core 5, Section 5 in Hole 328 and below Section 4 in Core 5 in Hole 328B. This general decline of the fauna coincides with the sharp change in lithology from an essentially silty siliceous clay above to a zeolitic clay below. Core 6 of Hole 328B contains only a few poorly preserved radiolarians of Eocene age. Similar occurrences exist in Core 5 of Hole 328. In these intervals in Hole 328, a large part of the radiolarian fauna is composed of species typical for the Upper Cretaceous, Paleocene, and possibly lowermost Eocene. The presence of these older fossils again points to strong reworking processes operating at the site.

Cores 7, 8, and 9 of Hole 328, a zeolitic clay and claystone, are essentially barren of microfossils. Only a few nondiagnostic pyritized radiolarians were observed in the core-catcher sample of Core 9. The HCl-treated coarse fraction (>63 µm) from a sample taken from Core 10, Section 5, consisted nearly entirely of radiolarians. All specimens are poorly preserved, with most diagnostic characteristics obliterated, and many specimens are present only as zeolitic casts and inner molds. From the general shape of the forms, it is concluded that the fauna represents an assemblage of at most Maastrichtian to Paleocene age. No radiolarians were observed in the core-catcher samples of Cores 7 and 8 from Hole 328B.

The general appearance of the radiolarian assemblages is quite unlike those encountered at low latitudes and reflects their cool-water environment. Representatives of the warm-water Collosphaerids are generally absent. An exception is the middle Miocene interval. A few collosphaerids are consistently present in the samples examined as well as occurrences, admittedly rare, of such species as Calocyclatra costata, Cyrtocapsella cormata, Cannarius sp. cf. C. mammiferus, and Dorcardospyris sp., which are typical for tropical assemblages of the same age. Thus, although the evidence is far from conclusive, it seems possible to conclude that during that interval warmer water penetrated farther to the south than in subsequent times. This may have been the result of a regional change in current regimes, or it may represent an event of larger scale.

**PALynomorphs**

Palynomorphs are present in Cores 9 to 12 of Hole 328 and in Core 7, Hole 328B. There is in the core-catcher sample from Core 9 a small assemblage of spores and pollen and few dinoflagellate cysts. Abundant tracheid and cuticular material is also present. Haloragadites harrisii and Milfordia homeopunctata suggest a Tertiary age, probably no older than late Paleocene. There is some doubt, however, that the sample is in situ. In Cores 10 to 12, and 7 of Hole 328B marine dinoflagellates constitute 95% of the assemblage. Cores 10 and 11 contain Gillinita hymenophora, Zephyrion australis, and Nelsonia aceras and are of Campanian to early Maestrichtian age. Didopterygium cladoideum and Trichodinium castaneum appear in Core 12 suggesting an age older than Campanian. Core 7 of Hole 328B contains Aiora fenestra, Conosphaeridium striatoconus, and Cribroperidinium orthoceras and is late Turonian to early Senonian in age.

**CORRELATION OF REFLECTION PROFILES WITH LITHOLOGY**

Figure 6 shows the correlation of core lithology with the reflection profile obtained on leaving the site, and the quality of the fit between shipboard-measured acoustic velocities and the velocity-depth model used in the correlation.

The model is intended as an unbiased fit to the measured velocities, since there was no certain way to estimate and correct for differences between in situ and shipboard values. Sampling was good down to 65 meters but poor beneath. Acoustic impedance varies with velocity, so that reflections may be expected mainly at depths where velocity varies abruptly; a more precise correlation is precluded by relatively larger uncertainties in density measurements.

The uppermost 0.06 sec TW (two-way) of the reflection profile, containing many fine reflections, corresponds to the Eocene and younger biogenic siliceous ooze of Units 1 and 2. The fine structure of the measured velocities within this depth interval is probably real, but can be matched neither to particular reflectors nor to lithologic variations within the oozes. The amplitude of these fine variations decreases towards the base of Unit 2, but the poor sampling below 65 meters prevents our seeing whether they occur within Unit 3 where, between 0.06 and 0.42 sec, no reflections are seen. The faint and diffuse correlative of Horizon A of the Argentine Basin (Ewing and Lonardi, 1971) is seen at 0.42 sec TW (two-way), equivalent to a depth of 325 meters which is close to the boundary between Units 3 and 4. Thus, we may propose that, in the Malvinas Outer Basin, this diffuse reflector results from compaction with secondary diagenesis within a uniform sequence of siliceous clays and claystones. At
Site 328 the clays are of between Eocene and early Senonian to Turonian age and the reflector (Horizon A) lies directly below the Cretaceous-Tertiary boundary.

Acoustic basement near the site is rough and probably represents the oceanic basaltic layer. If the velocity-depth model can be extrapolated, the time of 0.68 sec TW to this reflector represents a depth of 574 meters, or about 100 meters below the base of the hole.

The upper, finely stratified layer identified with the biogenic ooze of Units 1 and 2 thickens westward from the site, as Figure 6 shows, and exceeds 1.5 sec TW in thickness farther to the southwest, directly east of the end of the Falkland Trough (Birmingham University, unpublished data). This variation in thickness argues against a model for sedimentation at Site 328 consisting of steady deposition of biogenic oozes through the Late Cretaceous and Cenozoic, with steady diagenetic dissolution of microfossils below a given depth to form the clays; a distinct change in either sediment sources or bottom currents or both in Eocene times is required.

**SUMMARY AND CONCLUSIONS**

Site 328 is located in the Malvinas Outer Basin immediately to the east of the Falkland Plateau and to the south of the Falkland Fracture Zone at 49°48.67'S, 36°39.53'W in 5103 meters of water. Of three holes drilled at the site the deepest one, Hole 328B, penetrated 471 meters and bottomed in Upper Cretaceous gray zeolitic claystone.

Hole 328 was cored continuously to 26.5 meters and intermittently below that level to 397 meters. Hole 328A was abandoned at 17 meters after recovery of two consecutive shallow cores. Hole 328B was cored continuously to 64.5 meters and then drilled to 435 meters where one additional core was cut. Finally 0.5 meters of core was recovered from the deepest interval before the hole had to be abandoned at 471 meters.

Objectives at Site 328 were to determine the age of basement in the South Atlantic Ocean south of the Falkland Fracture Zone, to obtain a deep-water biostratigraphic section for comparison with that of the proposed Site 331 to the north in the Argentine Basin and with the shallow-water sites on the Falkland Plateau (Sites 327, 329, and 330), and to determine the nature and age of an upper finely stratified unit and of other acoustic reflectors tentatively correlated with Horizon A and Horizon B of the Argentine Basin by Ewing and Lonardi (1971). All these primary objectives bear on problems associated with the separation of South America and Africa and the development of circulation patterns in the Southern Ocean, including the history of Antarctic Bottom Water and the circumpolar current. The site is located 90 km southwest of the opening in the Falkland Fracture Zone through which
Antarctic Bottom Water at present flows northwards into the Argentine Basin (Le Pichon et al., 1971).

Four lithologic units are distinguished in the cores recovered at Site 328. Unit 1 was penetrated by all three holes, and Units 2, 3, and 4 by Holes 328 and 328B. While general lithologic correlation between the holes is satisfactory, individual layers of manganese nodules, ice-rafted clasts, and glauconitic sand cannot be identified in more than one hole.

Unit 1, which extends to about 13.5 meters subbottom in Holes 328 and 328B and includes both the cores recovered from Hole 328A, consists of diatomaceous ooze with abundant manganese nodules, sand, and large clasts. Many of the nodules have formed around large terrigenous clasts. The lower limit of pebbles and abundant sand is taken as the base of the unit which contains late Miocene to Quaternary siliceous microfossils. The composition of the coarse clasts does not identify a specific source area for most of this presumably ice-rafted detritus, although the Beacon Supergroup of Antarctica is the likely source for some distinctive quartz sandstone and red bed components. Clasts include granodiorite, granite, rhyolite, andesite, basalt, pegmatite, schist, gneiss, graywacke, arkose, quartzite, sandstone, and siltstone. All are found either around the Weddell Sea margin, the present source of icebergs in the southern Atlantic Ocean, or else on the Pacific margin of the Antarctic Peninsula.

Unit 2 consists of upper Eocene-upper Miocene silty, biogenic siliceous clay, extending from 13.5 meters subbottom to 46 meters in Hole 328B and to 48 meters in Hole 328. Sand in amounts generally less than a few percent occurs throughout the upper part of the unit. The diatoms present show extensive dissolution in the lower part. The underlying Unit 3 extends to about 300 meters in Hole 328 (only the topmost part was cored in Hole 328B). This unit consists of Upper Cretaceous or Paleocene to upper Eocene siliceous clay and (towards the base) claystone containing abundant phillipsite and clinoptilolite. Unit 4 is wholly made up of Upper Cretaceous zeolitic claystone except for a thin (1-1.5 cm) graded silty sandstone containing reworked Cretaceous (pre-Maastrichtian) nanofossils. The claystone, unlike the clay of Unit 3 is variegated.

The reflector correlated with Horizon A of the Argentine Basin occurs within the upper part of this unit and at this site appears to represent a gradual diagenetic change to claystone rather than a particularly distinctive lithologic layer. The smooth acoustic basement at 0.68 sec TW reflection time subbottom, tentatively correlated with Horizon B of the Argentine Basin by Ewing and Lonardi (1971), is estimated to lie at 574 meters subbottom. If Unit 4 sedimentation rates are assumed to apply down to this interface, its age will be about 12 m.y. older than the base of Core 7 of Hole 328B or about Alban. The South American source postulated below for the thick pelagic clay deposits in the Upper Cretaceous section at Site 328 existed since the Alban or Cenomanian (see below), hence extrapolation of the sedimentation rate appears to be justifiable.

The upper Turonian or Senonian to upper Eocene clays and claystones of Units 3 and 4 were deposited below the carbonate compensation depth (CCD) in an environment essentially isolated from coarse-grained terrigenous sediments and sufficiently quiescent to allow the settling of fine clays. A notable scarcity of siliceous microorganisms suggests low productivity during this interval. The sedimentation rate averages about 10 m/m.y. with some indication from subtle lithologic changes and the sparse microfauna of a hiatus of about 5-10 m.y. near the Cretaceous-Tertiary boundary. This abnormally high rate of clay accumulation at Site 328, roughly an order of magnitude higher than rates reported for clays elsewhere in deep ocean basins, must be a consequence of an unusual supply of argillaceous material and efficient trapping of sediment in the partially enclosed Malvinas Outer Basin.

By the time the Upper Cretaceous claystone cored at the base of Holes 328 and 328B was being deposited, the Falkland Plateau had entirely separated from Africa, opening a deep seaway into the Atlantic Ocean basin from the south. An African source for the sediment is unlikely in view of the efficient sedimentary barriers along the Falkland-Aguilas Fracture Zone (Le Pichon et al., 1971) and because the sedimentation continued at essentially the same rate for over 40 m.y. without any major change while Africa was moving away from the Falkland Plateau. A more likely source for the argillaceous material deposited in the Malvinas Outer Basin during the Late Cretaceous is the Andean cordillera and possibly the West Antarctic cordillera with which it was joined (Dalziel and Elliot, 1973).

The initial tectonic uplift of the Andean cordillera occurred in the late Alban-Cenomanian (Dalziel, 1974). At that time detritus eroded from the rising cordillera along the Pacific margin of southern South America was deposited as relatively fine grained flysch in the deepening Magallanes Basin on the continental side of the cordillera. Excellent and consistent paleocurrent data indicate that sedimentary transport in this basin was southward and parallel to the cordillera (Scott, 1966). As the Magallanes Basin merges with the deeper submarine Falkland Trough between the Falkland Plateau and the submerged continuation of the cordillera (the North Scotia Ridge), transport of material by turbidity currents eastwards down the Falkland Trough is likely to have occurred. The thick Upper Cretaceous clay and claystone sequence in the Malvinas Outer Basin indicates that the fine-grained component of the turbidity currents was transported into the basin and redistributed there by bottom currents, presumably as a nepheloid layer.

Material being eroded from the rising cordillera included siliceous, intermediate, and mafic igneous rocks and volcanoclastic sedimentary rocks; hence, the cordillera would have been a suitable source for the clays and claystones of the Malvinas Outer Basin which are rich in montmorillonite, have a high amorphous content, and commonly contain zeolite.

At the present time bottom currents are flowing northwards over Site 328 and through the gap in the Falkland Fracture Zone into the Argentine Basin. They are believed to be carrying clay-sized material into that basin (Ewing and Lonardi, 1971; Le Pichon et al., 1971). However, the currents consist of cold Antarctic
Bottom Water and there is no reason to believe that significant cooling of surface waters around the Antarctic continent took place before the Oligocene (Hayes, Frakes, et al., 1975; Shackleton and Kennett, 1975). Hence there are no compelling arguments for the presence of Antarctic Bottom Water during the Late Cretaceous and early Paleogene. Moreover, earlier suggestions that the present current regime in the Malvinas Outer Basin and in the Argentine Basin date back at least as far as the late Mesozoic (Ewing and Lonardi, 1971) were based on assumptions concerning the age of reflecting Horizon A in the Argentine Basin that are now known to be incorrect. Hence the bottom current regime in the Malvinas Outer Basin during the Late Cretaceous and early Paleogene is not known. However, the fast deposition of fine clays in the basin at that time clearly indicates relatively slow bottom current activity.

The variegated color of the claystone in Unit 4 is likely to be related to alternations of oxidizing and reducing conditions that may reflect climatic deterioration near the Cretaceous-Tertiary boundary as seen on the Falkland Plateau at Site 327. An upward increase in oxidation of the sediments is evidenced in the Paleogene part of the sequence (Unit 3) by a color change, the loss of palynomorphs, and the occurrence at the top of the unit of manganese micronodules. Influx of a limited amount of silty terrigenous material towards the top of Unit 3 may reflect an increase in bottom current velocity possibly related to the onset of Antarctic glaciation.

A major change in the conditions at Site 328 occurred at the close of the Eocene. The sedimentation rate dropped substantially to about 1.8 m/m.y. during the Oligocene (Figure 7), and there was a significant increase in the quantity of siliceous organisms in the sediments accompanied by a spectacular decrease in clay content (lower part of Unit 2). Major breaks occur in the stratigraphic record at the site from the late Eocene to the late early Oligocene (approximately 5 m.y.) and from the latest Oligocene to the middle Miocene (approximately 10 m.y.). There is a slight decrease in the sedimentation rate to 1.6 m/m.y. during the middle and

![Figure 7. Sedimentation rates at Site 328.](image-url)
late Miocene (upper part of Unit 2) with evidence of winnowing and increase in the quantity of manganese nodules and coarse clastic detritus during this time interval. Hence an increase in the bottom current velocity is indicated beginning probably in the late Eocene and continuing through the Miocene. Cold-water microfossils become dominant in the middle Miocene, and although there is no certain ice-rafterd material below the uppermost Miocene (5-7 m.y.), the sand-sized fraction could represent glacially derived material at least in part.

At present the exact cause of increased bottom current activity in the Malvinas Outer Basin in post-late Eocene time must remain speculative. Establishment of continental glaciation in Antarctica and hence the likely generation of Antarctic Bottom Water, continued opening of a seaway between Antarctica and Australia, and initial opening of the Drake Passage to allow a complete circumpolar current are all thought to have occurred at or about this time (Barker, 1970, in press; Hayes, Frakes, et al., 1975). All three events contributed to vastly improved circulation in the Southern Ocean.

The presence of icebergs in the region is apparent from dropstones throughout the upper Miocene, Pliocene, and Quaternary when the sedimentation rate varied between 1.6 and 5.0 m/m.y. Small breaks in the late Neogene record occur at the Miocene-Pliocene and Plio-Pleistocene boundaries; the latter could, however, result from a coring gap. Increased productivity in the Neogene would result from the upwelling of cold nutrient-rich water around the Antarctic and its transportation into the Malvinas Outer Basin by the circumpolar current. Unpublished seismic reflection profiles (University of Birmingham, England) show that the Eocene and younger siliceous ooze above the clays of Units 3 and 4 thickens to at least 1.5 km in the southwestern part of the basin. (See Figure 8.) This suggests that the condensed section at Site 328 is a local effect due to its location at the extreme distal end of the deep sea fan built eastward from the eastern end of the Falkland Trough. Terrigenous sediment supply from the Andean cordillera probably slowed after the mid-Cretaceous Andean orogeny. Nevertheless, the fact that the sedimentation rate did not exceed 5 m/m.y. in the Neogene suggests that much of the fine-grained

---

1 Falkland Trough (Malvinas Basin)
2 Magallanes Basin
3 San Jorge Basin

Figure 8. Relation between the Falkland Trough and the Magallanes Basin. Isopachs represent kilometers of late Mesozoic and Cenozoic sedimentary cover on top of Middle-Upper Jurassic volcanic or Paleozoic-early Mesozoic metamorphic- plutonic basement (after Urien and Zambrano, 1973). Axis of gravity minimum from unpublished data of the University of Birmingham.
was transported away as a nepheloid layer into the Argentine Basin as is happening at the present time (Le Pichon et al., 1971). The location of Site 328 directly southwest of the gap in the Falkland Fracture Zone (Figure 1) through which the bottom current flows into the Argentine Basin is probably significant. Elsewhere in the Malvinas Outer Basin deposition of argillaceous material may take place in current eddies and backwaters.

REFERENCES


SITE 328

**LITHOLOGIC DESCRIPTION**

- **SITE 328**

<table>
<thead>
<tr>
<th>DEPTH (m)</th>
<th>CORE NUMBER</th>
<th>LITHOLOGY</th>
<th>LITHOLOGIC DESCRIPTION</th>
<th>AGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Diatom ooze with ice-rafted detritus</td>
<td>Quaternary</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pliocene</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Siliceous ooze, clayey ooze and zeolitic clay</td>
<td>Miocene</td>
</tr>
<tr>
<td>100</td>
<td>2</td>
<td></td>
<td></td>
<td>Oligocene</td>
</tr>
<tr>
<td>100</td>
<td>3</td>
<td></td>
<td>Zeolitic clay and claystone</td>
<td></td>
</tr>
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</table>

**WATER CONTENT**

- Gravimetric Porosity
- Compressibility
- Wet-Bulk Density (gm/cc)
- Sonic Velocity

**SITE 328**

- Siderite
- Mn nodules
- Organic

- + VERTICAL
- HORIZONTAL
- UNDIFFERENTIATED

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SITE 328A

**LITHOLOGIC DESCRIPTION**
- **Unit 1**: Diatom ooze with ice-rafted detritus
- **Unit 2**: Siliceous ooze, clayey ooze and zeolitic clay

**AGE**
- Quaternary
- Miocene

**WATER CONTENT**
- **GRAVIMETRIC POROSITY**
- **WET-BULK DENSITY (gm/cc)**
- **SONIC VELOCITY**

**DEPTH (m) CORED INTERVAL**
- **1A**
- **2A**

**USIDERITE**
- Mn nodules
- Organic

* + VERTICAL  HORIZONTAL  UNDIFFERENTIATED*
SITE 328

SITE 328B

DEPTH (m)

LITHOLOGY

LITHOLOGIC DESCRIPTION

AGE

QUATER-
NARY

PLIOCENE

MIOCENE

OLIGOCENE

LATE
CRET.

TO
LATE
EOCENE

UNIT 3

Zeolitic clay and claystone

UNIT 2

Siliceous ooze, clayey ooze and zeolitic clay

UNIT 1

Diatom ooze with ice-rafted detritus

\[ \begin{array}{cccc}
1 & 2 & 3 & 4 \\
Diatom ooze & Siliceous ooze, & Zeolitic clay and claystone & \\
with ice-rafted detritus & clayey ooze and zeolitic clay & \\
& & & \\
5 & 6 & & \\
& & & \\
\end{array} \]

\[ \begin{array}{cccc}
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<th>GRAVIMETRIC POROSITY</th>
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</tr>
<tr>
<td>50</td>
<td>50</td>
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</tbody>
</table>
\]

GRAPE DENSITY

WET-BULK DENSITY (gm/cc)

SONIC VELOCITY

1.0 2.0 3.0 1.5 2.0 2.5

Siderite

Mn nodules

Organic

* + VERTICAL  HORIZONTAL  △ UNDIFFERENTIATED

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<table>
<thead>
<tr>
<th>DEPTH (m)</th>
<th>CORE NUMBER</th>
<th>CORE INTERVAL</th>
<th>LITHOLOGY</th>
<th>LITHOLOGIC DESCRIPTION</th>
<th>AGE</th>
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<tbody>
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<td>250</td>
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<td>Variegated claystone</td>
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</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
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<td>450</td>
<td></td>
<td></td>
<td></td>
<td>Variegated claystone</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**SITE 328**

- **LITHOLOGY**: Variegated claystone
- **AGE**: Late Turonian to Senonian
- **WATER CONTENT**: GRAVIMETRIC POROSITY
- **GRAPE DENSITY**: WET-BULK DENSITY (gm/cc)
- **SONIC VELOCITY**: 1.0, 2.0, 3.0, 1.5, 2.0, 2.5
LITHOLOGIC DESCRIPTION

CLAYEY BIOSILICEOUS Ooze
Homogeneous, slightly sticky, yellow gray to medium yellow brown. Contains dispersed silt and sand throughout with pebbles, in part coated with manganese, down to 0.5 cm. Deformed cm scale waves of SANDSTONE at 3.7 and 5.9 m. Very fine-grained, pebbly and SANDY SILT at 3.5 and 3.0 m. Minor microfossils throughout.

Grain size:
- 3-110 6-124 5-110
- 67.3 33.1 46.8 64.0 56.0
- Sand
- Silt
- Clay

Characteristic smear slide:
- 1.16 2.103 1.64
- 5-111 4-110 5-55 5-110
- 97.8 99.5 31.2 21.4 28.6

Explanatory notes in Chapter 1
### Site 328 Hole 3 Core 3 Cored Interval: 17.0-26.5 m

**Core 3 Cored Interval: 17.0-26.5 m**

- **Site:** 328
- **Hole:** 3
- **Core 3**

**Lithologic Description**

- **Mottled with:**
  - 10YR 7/4
  - 10YR 8/2
  - 10YR 5/4
  - 10YR 7/4
  - Zeol. micronods.
  - CaCO₃ o. carb.
  - Carbon-carbonate diatoms, rads

- **Fish debris:**
  - Representative smear slide
  - Slightly sticky, grayish orange with dark streaks and patches manganese, silty.

- **Characteristics:**
  - Shells, ooids, ooids and rads throughout.
  - Zeolite nodules to 8 cm diameter, silt.
  - Manganese nodules to 8 cm diameter, silt.
  - Moderate yellow brown to grayish orange.

- **Montmorillonite:**
  - Mica
  - Amphibole
  - Chlorite
  - K-feldspar
  - Quartz

- **Grain Size:**
  - Sand: 0.01-0.012
  - Silt: 0.002-0.001

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Lithology</th>
<th>Description</th>
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<tr>
<td>17.0-26.5</td>
<td>Mottled</td>
<td>10YR 7/4, 10YR 8/2, 10YR 5/4, 10YR 7/4, Zeol. micronods, CaCO₃ o. carb., Carbon-carbonate diatoms, rads</td>
</tr>
</tbody>
</table>

**Explanation:**

- **Zone:** 3
- **Fossil Character:**
  - Fish debris: Representative smear slide
  - Slightly sticky, grayish orange with dark streaks and patches manganese, silty.

- **Material:**
  - Shells, ooids, ooids and rads throughout.
  - Zeolite nodules to 8 cm diameter, silt.
  - Manganese nodules to 8 cm diameter, silt.
  - Moderate yellow brown to grayish orange.

- **Minerals:**
  - Montmorillonite:
    - Mica
    - Amphibole
    - Chlorite
    - K-feldspar
    - Quartz

- **Grain Size:**
  - Sand: 0.01-0.012
  - Silt: 0.002-0.001

Explanatory notes in Chapter 1
### LITHOLOGIC DESCRIPTION

<table>
<thead>
<tr>
<th>ZONE</th>
<th>FOSSIL CHARACTER</th>
<th>LITHOLOGY</th>
<th>LITHOLOGY SAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>5G 6/1</td>
<td>ZEOLITIC CLAY</td>
<td>Slightly sticky to sticky, dark greenish gray mottled with dark gray and with mm-scale dark gray laminae. Rare radiolarians. Fish debris in core catcher sample.</td>
<td>Representative smear slide</td>
</tr>
</tbody>
</table>

**Carbon-carbonate**
- t. carb 0.4
- o. carb 0.4
- CaCO3 0.0

**Representative smear slide**
- clay 88 93 98 90 CC
- zeol. 10 7 - 7 10
- opaques 2 - - 3 -
- sphalerite(1) - - 2 - TR

**Bulk X-ray**
- amor. 46.3 50.6
- calc. - 3.5
- quar. 15.8 16.4
- KFe2 4.0 4.4
- plagi. 5.0 6.0
- kaol. 1.0 1.5
- mica 14.0 13.8
- chlo. 1.0 1.3
- mont. 46.6 82.1
- poly. 7.2
- clin. 0.7 0.7
- amphi. - 1.4

**Grain size**
- sand 86.8
- silt 19.8
- clay 80.1
Site 328 Hole Core 7 Cored Interval: 188.0-197.5 m

Table 1: Lithologic Description

<table>
<thead>
<tr>
<th>Sample</th>
<th>Color</th>
<th>Texture</th>
<th>Claystone Lump</th>
<th>Fossils</th>
<th>Smear Slides</th>
<th>X-Ray</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dark Greenish Gray to Olive Gray</td>
<td>Sticky, Homogeneous</td>
<td>3 cm thick</td>
<td>Rare Pyritized Radiolarians</td>
<td>Representative</td>
<td></td>
<td>Early Eocene</td>
</tr>
</tbody>
</table>

Lithology:
Zeolitic Clay and Claystone Breccia of sticky clay containing lumps of harder claystone. Dark greenish gray to olive gray.

Representative smear slides:

- cpv an
- cla
- goethite

X-Ray:

- amor 41.8
- quar 14.5
- K-Fe 3.1
- plag 3.7
- kaol 1.4
- mica 13.9
- chlo 0.6
- mont 53.2
- paly 5.3
- phil 4.3

Grain size:
- sand 0.3
- silt 19.9
- clay 80.0

CaCO₃:
- 0.3
- 0.3

Explanatory notes in Chapter 1
ZEOLITIC CLAYSTONE
Brecia of hard claystone lumps in matrix of ground up sticky clay. Olive-gray to desl greenish gray, faintly color-banded. Fossil debris in core catcher sample.

Representative smear slide:
- Zeolite
- Clay
- Zeolite
- Opal
- Goethite
- Sphalerite
- Cellophane
- Bulk X-ray
- Ammonite
- Foraminifer
- Plagioclase
- Kaolinite
- Mica
- Chlorite
- Montmorillonite
- Palygorskite
- Carbonate
- Grain size

Lumps of hard claystone in sheared matrix of sticky clay. Cyclical cm- to decimeter-scale color banding in brown, gray, olive, green, and black. Rare casts and tests of microfossils visible megascopically.

Representative smear slide:
- Clay
- Zeolite
- Opal
- Goethite
- Sphalerite
- Cellophane
- Bulk X-ray
- Ammonite
- Foraminifer
- Plagioclase
- Kaolinite
- Mica
- Chlorite
- Montmorillonite
- Palygorskite
- Carbonate
- Grain size

Explanatory notes in Chapter 1
### FOSSIL CHARACTER

- Core Catcher

### EXPLANATORY NOTES IN CHAPTER 1

#### LITHOLOGIC DESCRIPTION

**CLAYSTONE**
- Well indurated, finely color-laminated, gray, grayish black, greenish black, reddish brown, and grayish red purple.
- Mn-scale black carbonaceous wisps, patches, and laminations throughout.
- Abundant authigenic siderite in coarse dumbell-shaped crystals from 84-87 cm and disseminated throughout core.
- Fish debris in core catcher. Minor zeolite.

**Representative smear slide**
- Clay, zeolite, opaques, collophane(?), siderite.
**Lithologic Description**

- **5Y 7/2**
- **10Y 6/2**
- **mottled with**
- **5Y 7/2**
- **10Y 6/2**
- **5Y 7/2**

**Biosiliceous ooze, biosiliceous clay**

Slightly sticky to sticky, yellow gray to pale olive. Abundant disseminated silt, sand, and pebbles to 2.2 cm maximum dimension. Coarse clasts are angular to subangular, polymictic, in part faceted. Disseminated manganese nodules and manganese rinds on pebbles.

Representative smear slide

1-75 1-140 4-7

Diatoms

Rads

Clay

Qtz., feld., etc.

Silico.

**Grain size**

- **Sand**
- **Silt**
- **Clay**

**Explanatory notes in Chapter 1**
### LITHOLOGIC DESCRIPTION

**Site 328 HoleB**

**Cored Interval:** 7.5-17.0 m

**LITHOLOGIC DESCRIPTION**

<table>
<thead>
<tr>
<th>Grain Size</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
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<tbody>
<tr>
<td>1-100</td>
<td>5 96</td>
<td>1 2</td>
<td></td>
</tr>
<tr>
<td>2-100</td>
<td>2 25</td>
<td>2 1</td>
<td></td>
</tr>
<tr>
<td>3-100</td>
<td>4 1</td>
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</tr>
<tr>
<td>4-200</td>
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</tr>
<tr>
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</tr>
<tr>
<td>7-100</td>
<td>1 0</td>
<td>2 1</td>
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</table>

**Color**

- 10YR 7/4
- 5BG 7/2
- 10YR 7/4

**Silty and Clayey Biosiliceous Ooze**

Slightly sticky, yellow gray to grayish orange. Disseminated polymictic pebbles to 3.3 cm maximum dimension, some of which are faceted. Interbeds of very fine-grained, incoherent, subangular to rounded, moderately well sorted sand to 5 cm thick. Scattered manganese nodules to 6.7 cm diameter and manganese rinds on pebbles.

Representative smear slide

10YR 5/4

5Y 7/2

5YR 3/4

5YR 7/2

10YR 6/2

**Lower Limit**

- Granules

**Grain Size**

- qtz., feld., etc.
- clay
- diatoms
- rads
- heavies
- rock frags.

**Deformation**

Lithologic Description

**Explanatory notes in Chapter 1**
**LITHOLOGIC DESCRIPTION**

10YR 5/4
- Slightly sticky with scattered lumps moderately hard clay. Graphite orange to moderate yellow brown or light brown. Abundantly dissolved diatoms.
- Representative smear slide: 1-46 6-22 6-70
  - qtz., feld. 3 3 3
  - clay 75 87 78 55 40
  - diatoms 5 7 5 20 40
  - radiolarians 15 3 15 20 15
  - sponge spic. 2 - - - -
  - silic. - - - 2 -
  - collophane (?) - - 1 - -
- Grain size: sand 1-20, silt 20-200, clay >200
- Carbonate: t. carb: 0.1, o. carb: 0.1, CaCO3: 0

10YR 7/4 with laminae
- Slightly sticky, grayish orange to pale yellow brown mottled with yellow gray. Rare soft manganese nodules to 2 cm diameter and abundant micrite crystals. Rare nannofossils.
- Representative smear slide: 1-20 6-22 6-70
  - qtz., feld. 3 3 3
  - clay 75 87 78 55 40
  - diatoms 5 7 5 20 40
  - radiolarians 15 3 15 20 15
  - sponge spic. 2 - - - -
  - silic. - - - 2 -
- Grain size: sand 1-20, silt 20-200, clay >200
- Carbonate: t. carb: 0.1, o. carb: 0.1, CaCO3: 0

Explanatory notes in Chapter 1
LITHOLOGIC DESCRIPTION

1. ZEOLITE CLAY AND BISODILLOUS ZEOLITE CLAY
Sticky, grayish orange to grayish yellow. Dissolution of diatoms common. Abundant manganiferous streaks and patches throughout. Zeolite is euhedral clinoptilolite.

Representative smear slide:
- Clay
- Zeolite
- Opaque
- Diatoms
- Collophanite
- Qtz.
- Micronodules
- Grain size: sand, silt, clay
- Carbonate: CaCO₃

2. ZEOLITE CLAY
Slightly sticky color banded and mottled in grayish orange and moderate yellow brown. Abundant anhedral to euhedral clinoptilolite. Rare soft manganese nodules.

Representative smear slide:
- Clay
- Zeolite
- Sphalerite
- Apatite
- Grain size: sand, silt, clay
- Carbonate: CaCO₃

Explanatory notes in Chapter 1
### LITHOLOGIC DESCRIPTION

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<th>ZONE</th>
<th>FOSSIL CHARACTER</th>
<th>LITHOLOGY</th>
<th>DEFORMATION</th>
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<td>N-D</td>
<td>CLAYSTONE</td>
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</table>

#### CLAYSTONE
- Well indurated, varicolored in shades of red, brown, green, gray, and black. Locally finely-humic and carbonaceous. Thin to medium-scale black feeding trails of Zoophycos. On-scale concentrations of medium-grained siderite aggregates with distinctive dumbbell form. Claystone desiccates and cracks markedly on exposure to air. Thin bed 0-1 cm thick.

- SILTY SANDSTONE at 70 cm. Graded, channelled base, mainly angular crystals of K-feldspar to 0.4 mm diameter.

- Representative smear slide

- T. cere 0.4 0.4 0.4 0.4
- e. dark 0.2 0.3 0.4 0.1
- GOB 0.0 0.0 0.0 0.0

- Thin X-ray

- Explanatory notes in Chapter 1
SITE 328

POROSITY, %

100 0

Grain Density

SONIC VELOCITY (km/sec)

WET-BULK DENSITY (gm/cc)

SECTION

cm

1 2 3 4 5

λ-\n
-\n
1-λ

PERP. □ HORIZ. △ UNDIFF.

★ 2-MINUTE GRAPE —— CONTINUOUS GRAPE

126
POROSITY, %

Grain Density

SONIC VELOCITY (km/sec)

WET-BULK DENSITY (g/cc)

*  PERP.  □  HORIZ.  △  UNDIFF.

**  2-MINUTE GRAPE  --- CONTINUOUS GRAPE

SECTION

| 1 | 4 |

CM

0 25 50 75 100 125 150