4. ANGOLA CONTINENTAL MARGIN—SITES 364 AND 365

The Shipboard Scientific Party

SITE DATA—364

Position: 11°34.32’S, 11°58.30’E (seaward edge of salt plateau on continental slope, southwest of Luanda, Angola)

Water Depth: 2448 corrected meters, echo sounding, 2439 meters, drill pipe measurement

Number of Holes: 1

Number of Cores: 46

Total Length of Cored Section: 427.5 meters

Total Core Recovered: 295.61 meters

Percentage Core Recovery: 69.1%

Oldest Sediment Cored:
- Depth sub-bottom: 1086 meters
- Nature: euxinic shale and dolomitic limestone
- Age: upper Aptian
- Measured velocity: 3.90 km/sec

Baseline:
- Depth sub-bottom: > 3 km (not reached)
- Nature: presumed basaltic, underlying evaporite sequence

Principal Results:
A sequence from the Pleistocene down into the basement:
- Age: upper Aptian
- Nature: presumed basaltic, underlying evaporite sequence

SITE DATA—365

Position: 11°39.10’S, 11°53.72’E (eastern side of a partly buried submarine canyon incised into the Cenozoic and Mesozoic cover above the salt and evaporite layer just to the southwest of Site 364 on the continental slope of Angola

Water Depth: 3018 corrected meters, echo-sounding, 3040 meters, drill pipe measurement.

Water Depth (rig floor): 3028 corrected meters, echo sounding

Bottom Felt at: 3050 meters, drill pipe

Penetration: 687 meters

Number of Holes: 1

Number of Cores: 7

Total Length of Cored Section: 63 meters

Total Core Recovered: 34.65 meters

Percentage Core Recovery: 55.0%

Oldest Sediment Cored:
- Depth sub-bottom: 687 meters
- Nature: radiolarian-bearing clay and mudstone
- Age: Oligocene-Miocene
- Measured velocity: 2.14 km/sec

Basement:
- Depth sub-bottom: > 3 km, not reached

Principal Results:
Site 365 was drilled rapidly with very intermittent coring in an unsuccessful desperate attempt to reach the Aptian evaporite and salt formation before time ran out at the end of the leg. Interstitial salinities in the last sediment core at 687 meters sub-bottom exceeded those at the base of Site 364, indicating that the salt was not far below.

The canyon fill consists primarily of Neogene-age terrigenous muds and mudstones containing primitive arenaceous benthic foraminifers, fish teeth, and palynomorphs, along with allochthonous blocks of Coniacian-Santonian nanofossil ooze and Cenomanian to upper Albian sapropelic mudstone reworked from the canyon wall. The Mesozoic strata indicated their displaced nature by extremely steep bedding inclinations ranging up to 70° from the horizontal and by mixed assemblages spanning a broad stratigraphic interval. The depositional
ANGOLA CONTINENTAL MARGIN - SITES 364 AND 365

SITE 365

11°39.10'S, 11°53.72'E
W. D. 3018 m

100
200
300
400
500
600
Rec.-Pleist.
Can.-Alb. (rew.)
prob. Mio.
Calc. nanno ooze

Miocene to Oligocene

Marly chalk with sapropel

T. D. 687 m

SITE 364

11°34.32'S, 11°58.30'E
W. D. 2448 m

Pleistocene
Pliocene-
CD

U-L
U-L
M-
Oligo.
Maestr.
Campanian
L. Conacian-
U. Turonian

Yellow brown and brown nanno chalk and marly chalk

Chalks, marly chalks, and mudstones with sapropels

Bluish gray to olive gray limestone and marly limestone

Bluish gray to olive gray dolomite and black sapropelic shales

Dark olive gray calcareous mud and clay

Olive gray marly nanno ooze and mud

Yellow brown pelagic clay and greenish gray rad mud

Yellow brown pelagic clay and greenish gray rad mud

Olive gray marly nanno ooze and mud

Calc. mud
Calc. mud
Calc. nanno ooze

Chalks, marly chalks, and mudstones with sapropels

Oliven gray marly nanno ooze and mud

Calc. mud
Calc. mud
Calc. nanno ooze

Marly chalk with sapropel

Chalks, marly chalks, and mudstones with sapropels

Bluish gray to olive gray limestone and marly limestone

Bluish gray to olive gray dolomite and black sapropelic shales

Olive gray marly nanno ooze and mud

Calc. mud
Calc. mud
Calc. nanno ooze

Marly chalk with sapropel

Chalks, marly chalks, and mudstones with sapropels

Bluish gray to olive gray limestone and marly limestone

Bluish gray to olive gray dolomite and black sapropelic shales

Olive gray marly nanno ooze and mud

Calc. mud
Calc. mud
Calc. nanno ooze

Marly chalk with sapropel

Chalks, marly chalks, and mudstones with sapropels

Bluish gray to olive gray limestone and marly limestone

Bluish gray to olive gray dolomite and black sapropelic shales

Olive gray marly nanno ooze and mud

Calc. mud
Calc. mud
Calc. nanno ooze

Marly chalk with sapropel

Chalks, marly chalks, and mudstones with sapropels

Bluish gray to olive gray limestone and marly limestone

Bluish gray to olive gray dolomite and black sapropelic shales
environment was continuously deep, well oxygenated, and, during the interval of the Miocene and Oligocene recorded in the cores, below the calcium compensation depth.

BACKGROUND AND OBJECTIVES

The Angola Basin is the deepest depression of the eastern South Atlantic (Figure 1). To the south, it is isolated almost entirely from the Cape Basin by the high-standing Walvis Ridge, and to the west, it is barred from the Brazil and Argentine basins by the broad cretal zone of the Mid-Atlantic Ridge.

Because of this high degree of isolation, its oceanic bottom water mass is significantly warmer and hence less corrosive to carbonate skeletal sedimentary components than that of all the other Atlantic Ocean basins. In fact, there are only four real routes for deep-water masses to enter into the Angola Basin.

The Antarctic Bottom-Water (AABW) arrives from the north by the deepest of these passages. Its course takes it from the Scotia Sea via the Argentine Basin through the Vema Channel to the Brazil Basin, then by means of a narrow route through the Romanche Fracture Zone to the Guinea Basin, and at last across a 4.8-km-deep sill southward along the western margin of Africa where it circulates as a weak, clockwise gyre within the central Angola Basin depression.

Deep and intermediate water masses can only flow into the Angola Basin from the Cape Basin through three portals in Walvis Ridge. The lowest standing sill to the south is approximately 3.8 km at a position east of Tristan da Cunha and lies across a late Paleocene basement isochrone. The next shallowest sill, at approximately 3.7 km, is over a Santonian to Campanian age isochrone at 30°S, 1°E. The shallowest sill is at 3.2 km through a heavily scoured passage between Frio Ridge and Valdivia Bank above a late Aptian to Albion isochrone.

The isolated setting of the Angola Basin was inherited from its very birth. Indeed, its first 20 million years were so restricted as to permit the formation of a huge layer of evaporites exceeding in places 3 km in thickness. This evaporite body is found today along the eastern rim of the ocean basin landward of a mid-Aptian isochrone identified at Sites 361 and 363 of Leg 40 as nearly coincident with magnetic lineation M-O of Larson and Ladd (1974).

The equatorial position of the Angola Basin and the deflection away from the Angola Basin of the cold, northerly directed Benguela current in the Cape Basin at the eastern intersection of the Walvis Ridge and the South West African continental margin, should result in highly calcareous pelagic deposition on topographic highs in the Angola Basin. These should be stratigraphically correlatable to worldwide sequences through well-studied lineages of tropical and semi-tropical faunas. The interplay of deep geostrophic currents headed southward along the continental rise, and surface- to intermediate-depth currents passing northward, both intersecting important volumes of clastic sediments arriving from the mouth of the Congo River, should also result in a highly cyclic and perhaps climatically controlled terrigenous sedimentation in topographic lows. The influence of deep-water masses on the degree of preservation of biogenic skeletal components should also have changed through time as the basin became progressively less isolated with the subsidence of and intermittent creation of gaps across the Walvis Ridge barrier, and as the Antarctic Bottom Water became volumetrically more important with the development of a polar icecap in the Cenozoic.

Scientific Objectives

A drill site location was selected along the eastern margin of the Angola Basin (Figure 1). Cored sequences of sediment to depths of 1000-1400 meters below the sea floor were expected to provide insight to the following investigations:

1) age of the upper limit of the marginal evaporite deposition;
2) depositional facies of the evaporites and associated salt deposits leading to an understanding of the processes by which they accumulated;
3) basin depth during and immediately after evaporite deposition;
4) quantitative information on subsidence rates of the continental margin during its earliest evolution;
5) age and nature of crust over which the seaward edge of the evaporite body is draped;

Figure 1. Bathymetric map of the continental margin of southern Africa off Angola (Emery et al., 1975).
6) age of the commencement of haleokinetic deformation resulting from flowage of the salt layer;
7) nature of the “transgressive” marine facies directly overlying the evaporite strata;
8) control on degree of carbonate preservation provided by inflowing bottom waters since the Lower Cretaceous (Aptian stage);
9) age and cause of a mid-Cenozoic major stratigraphic discontinuity seen in the vast majority of seismic reflection profiles across the West African continental margin;
10) correlation of high-latitude Austral-New Zealand faunal assemblages with their tropical to sub-tropical counterparts;
11) sediment contribution to the deep basin through time by the Congo River deltaic complex;
12) identification of age and nature of prominent seismic horizons including the Davy and Atlantis II reflectors of Emery et al. (1975).

Strategy

Because deep penetration was required to achieve the selected scientific objective of reaching into the marginal salt deposit, the first drill site (364) was targeted southward of the major fracture zone which intersects the coast between Luanda and Lobita, where the overburden above the roof of the evaporites is the thinnest of the entire West Africa margin and yet is still conformable.

A second requirement was to position the drilling location into the salt body in a synclinal setting with the seaward limb of the syncline cropping out on the marginal escarpment so as to minimize totally the possibility of hydrocarbon entrapment either within the evaporites or within the overlying horizons.

The Site 364 setting at 0340 hours, 12 July 1971, on Walda Profile 21 of the Jean Charcot met both of these requirements (Figure 2). Identified on the profile are five prominent reflecting interfaces:
1) the Mid-Cenozoic discontinuity (Reflector Davy);
2) an intermediate conformable horizon much more deeply buried in the basin than on the salt plateau (Reflector Atlantis II);
3) the roof of the evaporite body;
4) the base of the salt layer;
5) a non-coherent and topographically irregular acoustic basement thought to be Layer “2” of the oceanic crust.

When it became evident that drilling at Site 364 would not penetrate into the evaporite and salt layer due to destruction of the drill bit, an alternate location was picked (Site 365) to short-cut much of the stratigraphic sequence already successfully cored. This hole is within a canyon that had been excavated into the salt body and subsequently partially filled. Its position at 0145, 12 July 1971 on the same Walda Profile 21 offered the opportunity to enter the salt layer at a sub-crop below the level of the relatively thick Albian and Aptian limestones which had been responsible for the severe degradation of the core bit journal bearings at Site 364. At Site 365, though, it was necessary only to pass through considerably younger and hence less indurated canyon fill to reach the salt.

Operations

Approach to Site 364

We approached Site 364 from the southwest during the early morning of 30 January 1975 on a heading of 022° to try and intersect the Walda 21 profile at the desired target. At 0423 we slowed the Glomar Challenger to 5 knots and at 0442 jettisoned the acoustic positioning beacon and retrieved the towed seismic and magnetic gear. Satellite fixes while on station showed that we had slightly overshot the original target on the Charcot profile to the north, but the underway reflection profile indicated us to be in a synclinal setting optimum from the hydrocarbon safety point of view. Information on the Site 364 cores is given in Table 1.

Drilling at Site 364

The hole was spudded in at 1550, using a 4-cone journal bearing core bit with medium-length tungsten carbide inserts selected for efficiency in limestones, dolomites, and evaporites. We experienced some delays associated with the need to drop a second beacon, with difficulties in getting electrical power to the Bowen power sub, and with a malfunctioning valve in the hydraulic system for the sandline winch. Anomalously high torquing occurred in the cutting of Cores 1 through 6, accompanied by appreciable backflow of drilling fluid when the pipe joints were opened to retrieve the core barrel. This torquing and backflowing ended abruptly during the cutting of Core 7 at the level of a major erosional gap and mostly likely correlated with the very sticky nature of the Neogene terrigenous mud and pelagic clay which tore into chunks rather than washed into a slurry. Penetration rates slowed appreciably upon entering the Eocene section.

We experienced a second formation change at approximately 363 meters sub-bottom near the end of the cutting of Core 11, correlative with another significant decrease in the penetration rate. This break may coincide with a hiatus across the Cretaceous/Tertiary boundary.
Upon pulling the drill string during the morning of 6 February, after a week on site and more than 89 hours of rotation time, we found all four cones of the core-bit to have been sheared off; its throat was practically closed from grinding of the drill stem in the basal dolomitic limestones.

**Approach to Site 365**

Since we did not reach the objective of sampling the salt and evaporite formation at Site 364 by penetrating the Mesozoic and Cenozoic cover, we decided to spend the remaining two drilling days of the leg in a final effort to sample the salt, this time using a nearby canyon which had eroded out many of the indurated formations which had led to bit failure at Site 364. We did not stream seismic gear and the *Challenger* proceeded southwest at half speed using the dynamic positioning equipment to establish bearing from...
the position of Site 364. The new drill site (365) was reached by dead reckoning at midday on 6 February. It was some 10 km southwest of Site 364.

Drilling at Site 365

The coring summary for Site 365 is given in Table 2. Spudding in took place at 2345 and the first core was cut at 225 meters sub-bottom, revealing that we were penetrating the Neogene canyon fill as had been predicted. We worked the drill string down rapidly with both pumps. Other cores were cut at approximately 100 and 80 meter intervals to keep a check on lithology and the possible presence of gas. A small firm zone was detected at approximately 515 meters sub-bottom while within Core 5. Cores 6 and 7, however, continued to be cut rapidly. Unfortunately, time ran out before the canyon fill could be completely penetrated, and we decided to pull the string at 1100 on 8 February to make the scheduled arrival in Abidjan, Ivory Coast. We noticed a definite firming up of the formation at about 660 meters sub-bottom. It is difficult to estimate just how thick the canyon fill was, but it seems likely that another 300 meters might have been required to reach the salt and evaporites, entailing perhaps another day on site.

Interestingly enough, we encountered little torquing of the type experienced for the Neogene section of Site 364 at Site 365, perhaps as a consequence of a slightly coarse grain size at the latter site and a significantly higher rate of sediment accumulation.

LITHOLOGY

Site 364 Lithologic Descriptions

We expected Site 364 to provide insight into the age and depositional facies of the evaporite formation, leading to an understanding of the processes by which it accumulated. Unfortunately, we did not anticipate the thick sequence of indurated Cretaceous limestones encountered at the site. The bit was destroyed apparently only a few tens of meters from the objective, reaching lower Albian-Aptian dolomites. We expected Site 364 to provide insight into the age and depositional facies of the evaporite formation, leading to an understanding of the processes by which it accumulated. Unfortunately, we did not anticipate the thick sequence of indurated Cretaceous limestones encountered at the site. The bit was destroyed apparently only a few tens of meters from the objective, reaching lower Albian-Aptian dolomites.

We drilled Site 364 to a depth of 1086 meters sub-bottom in 2449 meters of water yielding sediments ranging from Pleistocene to lower Albian-Upper Aptian. Coring began at 7.5 meters sub-bottom and cores of 9.5 meters barrel length were taken throughout the site. Coring was not continuous except at the boundary between Tertiary and Cretaceous.

We took a total of 46 cores with a recovery of 69.1 per cent, representing 27.2 per cent of the total sediment column.

We subdivide the sediments into seven lithologic units on the basis of composition, color, texture, and sedimentary structures. They are summarized in Table 3 and Figure 3.

**Unit 1: Calcareous Mud**

Unit 1 is composed of dark olive-gray calcareous mud and soft clay. It was taken as a "punch" core. When split, it smelled of H₂S. The mud contains 60 per cent clay, 20 per cent nannofossils, 10 per cent plant debris, 5 per cent foraminifers, 4 per cent pyrite, and 1 per cent quartz. The black clay in Core 2 shows essentially the same composition. Abundance of clay flakes associated with plant debris indicates recent transportation of terrigenous materials to the site through many submarine canyons dissecting the continental margin; such canyons were observed on Glomar Challenger seismic profiles taken while approaching the site. The composition and H₂S odor, together with a lack of burrowing, suggest fairly stagnant bottom conditions.

The boundary between Unit 1 and Unit 2 is taken as the first appearance of distinct calcareous nannofossil ooze in Core 3.

**Unit 2: Marly Nannofossil Ooze and Mud**

The unit is represented by the first recovered calcareous nannofossil ooze of lower Pliocene age and by olive-gray zeolite-bearing mud of probable middle Miocene age. Composition of the ooze is 55 per cent nannofossils, 29 per cent clay, and 10 per cent foraminifers. Composition of the mud averages 60-90 per cent clay, 0-25 per cent nannofossils, 1-5 per cent quartz, 0-5 per cent zeolite, and 0-1 per cent foraminifers. Color, odor, and presence of pyrite are similar to Unit 1, indicating reducing conditions began to prevail about this time. Abundance of nannofossils may have contributed to high surface-water productivity.

The boundary between Unit 2 and Unit 3 is placed at the first pelagic clay recovered in Core 5 of middle Miocene age.

**Unit 3: Pelagic Clay and Radiolarian Ooze**

Core 5 starts with dark yellowish brown to olive marly nannofossil ooze at the top becoming to yellowish brown to gray pelagic clay toward the bottom. The composition of Core 5 averages 35-70 per cent clay, 5-50 per cent nannofossils, 5-10 per cent dolomite rhombs, 1-3 per cent quartz, and 0-5 per cent zeolite.

<table>
<thead>
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<td>Coring Summary, Site 365</td>
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<table>
<thead>
<tr>
<th>Core</th>
<th>Date</th>
<th>Time</th>
<th>Depth From Drill Floor (m)</th>
<th>Depth Below Sea Floor (m)</th>
<th>Length Cored (m)</th>
<th>Length Recovered (m)</th>
<th>Recovered (%)</th>
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<tr>
<td>1</td>
<td>7 Feb.</td>
<td>0700</td>
<td>3275-3284.5</td>
<td>225-234.5</td>
<td>9.5</td>
<td>9.5</td>
<td>100.0</td>
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<tr>
<td>2</td>
<td>7 Feb.</td>
<td>1330</td>
<td>3370-3379.5</td>
<td>320-329.5</td>
<td>9.5</td>
<td>3.45</td>
<td>36.3</td>
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<tr>
<td>3</td>
<td>7 Feb.</td>
<td>2020</td>
<td>3446-3455.5</td>
<td>396-405.5</td>
<td>9.5</td>
<td>9.5</td>
<td>47.4</td>
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<tr>
<td>4</td>
<td>7 Feb.</td>
<td>2345</td>
<td>3512.5-3522</td>
<td>452.5-472</td>
<td>9.5</td>
<td>9.5</td>
<td>33.2</td>
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<tr>
<td>5</td>
<td>8 Feb.</td>
<td>0230</td>
<td>3560-3569.5</td>
<td>510-519.5</td>
<td>9.5</td>
<td>4.65</td>
<td>48.9</td>
</tr>
<tr>
<td>6</td>
<td>8 Feb.</td>
<td>0730</td>
<td>3664.5-3674</td>
<td>614.5-624</td>
<td>9.5</td>
<td>5.75</td>
<td>60.5</td>
</tr>
<tr>
<td>7</td>
<td>8 Feb.</td>
<td>1520</td>
<td>3731-3737</td>
<td>681-687</td>
<td>6.0</td>
<td>3.65</td>
<td>38.4</td>
</tr>
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The bottom of the core, about 70 cm thick, consists of greenish gray radiolarian mud. The composition of the core averages 75-85 per cent clay, 15-20 per cent radiolarians, 5-10 per cent diatoms, 1-5 per cent sponge spicules, 0-5 per cent zeolite, and 1-2 per cent quartz. Core 7, excluding the core catcher, consists of brown to olive-gray pelagic clay similar to the lower half of the Core 5.

Compared with Unit 4, discussed below, Unit 3 shows a distinct increase in the level of calcium carbonate dissolution. This we attribute to Antarctic Bottom Water influx during the time of deposition of the middle and lower part of the unit. The base of the unit appears to be disconformably overlying Unit 4, with a possible missing interval of 16 million years.

**Unit 4: Nannofossil Chalk**

This unit is characterized by the dominance of carbonate. From Core 7, CC to Core 19, the sediment is composed of up to 95 per cent nannofossils. The unit is divided into two subunits; upper nannofossil chalk and lower nannofossil chalk, depending on the proportions of intercalations of terrigenous mudstones.

Subunit 4a (Cores 7-15) consists of yellow brown, light gray, brown and reddish yellow nannofossil chalk. The composition of the subunit averages 77 to 95 per cent nannofossils, 5 to 15 per cent clay, and 0 to 2 per cent quartz except for Core 12 which shows rather dark brown color and contains abundant terrigenous matter.

Subunit 4b (Cores 16-19) consists of brown, light brown, and pale brown nannofossil chalk. It differs from Subunit 4a in having abundant intercalations of calcareous mudstone. Core 16 has abundant terrigenous material and a thin carbonaceous layer.

**Unit 5: Marly Chalk with Sapropel**

This unit is characterized by the presence of finely laminated black sapropelic shales. It is divided into two subunits according to abundant appearance of the sapropelic shale.

Subunit 5a (Cores 20-22) consists of greenish gray to brown nannofossil chalk and marly nannofossil chalk interbedded with thin sapropels. In Core 22, marly nannofossil chalk is interlayered with dark greenish gray mudstone and very dark greenish brown claystone without sapropels.

Subunit 5b (Cores 23-25) consists of greenish gray and dark greenish gray marly chalk and calcareous mudstone interlayered with abundant black sapropelic shale. It contains barite, pyrite, and marcasite (Figure 4).

The unit indicates that euxinic conditions often prevailed in this part of the Atlantic Ocean during Coniacian/Santonian times.

**Unit 6: Limestone**

The unit is characterized by the abundance of calcium carbonate as limestone. It is divided into three subunits on the basis of composition, color, and induration.
Subunit 6a (Cores 26-28) consists of indurated marly nannofossil chalk with alternations of greenish gray and reddish brown material. Smear slides of Core 27 have 68 per cent unspecified carbonate, 15 per cent nannofossils, 15 per cent clay, 2 per cent foraminifers, and trace amounts of quartz.

Subunit 6b (Cores 29-31) consists of light bluish gray massive limestone, with stylolitic seams and "marble" structure (Figure 5). Core 29 has stylolitic 86 per cent unspecified carbonate, 10 per cent clay, a trace of nannofossils, and a trace of quartz. In massive limestones, there are segregation laminae of clay, which look like willow leaves.

Subunit 6c (Cores 32-38) consists of light bluish gray limestone and marly limestone. Cores 37 and 38 are olive-gray in color. Core 35 smear slides average 40 per cent clay, 33 per cent unspecified carbonate, 15 per cent nannofossils, 2 per cent pyrite, and 1 per cent quartz. Slump folds and microfaults are abundant (Figures 6 and 7).

**Unit 7: Marly Dolomitic Limestone With Sapropel**

The deepest unit is characterized by the occurrence of black sapropelic shale. It is divided into two subunits based on the proportion of sapropel.

Subunit 7a (Cores 39-41) consists of light gray to olive-gray marly limestone interbedded with thin black sapropelic shales. The composition of marly limestone in Core 41 is 48 per cent unspecified carbonate, 20 per cent dolomite rhombs, 20 per cent clay, and 2 per cent pyrite. Core 40 shows the steepest inclination of bedding planes, to about 60° from the horizontal, which might be caused by local slumping relating to salt deformation (Figure 8).
Subunit 7b (Cores 42-46) consists of light bluish gray dolomitic limestone and black shale. In Core 46, we recovered only 1 meter of dark olive-gray dolomite. The composition of the dolomite in Core 44 is 93 per cent dolomite, 5 per cent unspecified carbonate, and a trace of quartz. Figure 9 shows a nodular-type dolomite from this unit.

**Sedimentary History**

Unit 7 is characterized by a predominant sapropelic shale of lower Albian to upper Aptian age. Bottom water conditions were stagnant enough at this time to preclude the oxidation of carbonaceous matter and the formation of current-related sedimentary structures. Instead, finely laminated shales and carbonates predominate. The lowermost limestones have been extensively dolomitized, apparently in high Fe and Na solutions (Matsumoto et al., this volume). This probably reflects the formation of dolomite in the highly saline bottom water conditions that may have persisted into the euxinic stages of sedimentation in the Angola Basin. Dolomitization, however, may also have been diagenetic (Natland, this volume). From our drilling, it is clear that salt deposition ceased no later than upper Aptian in the site, but that euxinic conditions persisted into lower Albian, and recurred at the beginning of the Upper Cretaceous as seen in Unit 5. These facts lead to consideration that there was clearly a barrier ridge between the Cape and Angola basins during Cretaceous times. The older part of the barrier may correspond to formation of the Frio Ridge and the younger to the Valdivia Bank portion of the Walvis Ridge.

Units 6 and 4 indicate that the Cretaceous South Atlantic periodically achieved a state of interchange of shallow and deep waters through the Walvis Ridge barrier to the Angola Basin, allowing normal pelagic calcareous sediments to accumulate. The sediment accumulation rate of Unit 6 was a drastically fast, 55 m/m.y.; planktonic carbonate productivity was great enough to produce massive limestone. The sediment accumulation rate for Unit 4 is 12 m/m.y. (see below). Unit 3 indicates that a sharp drop in the sedimentation rate occurred in Eocene times. This may amount to an erosional hiatus. Such a hiatus appears on the profiler records and may be interpreted as a major mid-Tertiary disconformity, or it may be interpreted simply as the result of slow deposition caused by dissolution of planktonic carbonate. Major dissolution cycles detected at Sites 360 and 362 took place in the upper Miocene, the middle to lower Oligocene, and the upper Eocene. The latter cycle correlates well with Unit 3 at Site 364. Possibly Antarctic Bottom Water influx increased from this time, causing increased dissolution.

Units 1 and 2 are evidence for marked influx of terrigenous materials from the African continent to Site 364, probably by way of the Congo and other rivers. They also indicate fairly stagnant bottom conditions in the Angola Basin during their deposition persisting to the present day.

**Site 365 Lithologic Descriptions**

We drilled Site 365 to a sub-sea-floor depth of 687 meters, recovering sediments that range in age from Pleistocene to pre-upper Albian.
The primary drilling objective at this site was to reach an expected Aptian evaporite layer in the small amount of time remaining for Leg 40. Thus, only seven widely spaced cores were taken. The following sub-sea-floor intervals were cored: 225-243.5 meters, 320-329.5 meters, 396-405.5 meters, 462.5-372 meters, 510-519.5 meters, 614.5-624 meters, and 681-687 meters. A total of 33.2 meters of sediment was recovered.

The sediments are subdivided into five lithologic units on the basis of composition and texture (Table 4). Compositional percentages are based on visual estimates of smear-slide components. Coarse fractions (63-180 µm and > 180 µm) of each core catcher sample were also examined.

**Unit 1: Mud**

Unit 1 is composed entirely of olive-gray, olive-black, or dark gray-green soft mud. The unit has a maximum estimated thickness of 223.7 meters. The mud averages 70 per cent clay, 4 per cent quartz, 6 per cent plant fragments, 6 per cent pyrite, 3 per cent foraminifers, 3 per cent nannofossils, 2 per cent radiolarians, and 2 per cent mica, plus minor (<2 per cent) and trace amounts of a variety of components (see Core Summary Forms).

Unit 1 is represented solely by the sediment in Core 1, but these sediments are almost certainly not from the actual sub-sea-floor interval cored. Washing was started some time after seafloor penetration, and continued until the sediment was felt to "stiffen up." Washing was then stopped and coring began (at -225 m). Thus the sediments of Unit 1 may have entered the core barrel at any level, but probably before washing started. In all likelihood, they represent sediment from near the top of the stratigraphic column.

The boundary between Unit 1 and Unit 2 is taken as the first recovered stiff terrigenous mud, which is in Core 1, Section 6.

**Unit 2: Mud**

Unit 2 consists of a minimum thickness of 30 cm of moderate brown, stiff mud. The mud has no apparent bedding or burrowing; it is slightly mottled. Composition of the mud is 75 per cent clay, 15 per cent quartz, 5 per cent zeolites, 3 per cent pyrite, and 2 per cent iron oxides.

The boundary between Unit 2 and Unit 3 is at the nannofossil ooze contact in Core 1, Section 6.

**Unit 3: Nannofossil Ooze**

Unit 3 consists of an estimated thickness of 43 meters of light to moderate brown nannofossil ooze. There is no apparent bedding. The ooze is composed of 87 per cent nanofossils, 10 per cent clay, 2 per cent quartz, and 2 per cent plant fragments, plus minor and trace components. Examination of the coarse fraction of a red zone in core catcher sediment shows 65 per cent foraminifers, 35 per cent mica, and traces of fish teeth, glauconite, and pyrite; a gray zone in the same sediment showed 0 per cent foraminifers, 65 per cent pyrite, 4 per cent barite, and traces of quartz, mica, and fish teeth.
Figure 8. Reverse faults and steeply dipping beds in marly limestone of Unit 7, Site 364, Sample 40-4, 61-82 cm.

Figure 9. Nodular structure in dolomitic limestone, Site 364, Sample 43-1, 79-94 cm.

The boundary between Unit 3 and Unit 4 is arbitrarily placed halfway between the bottom of Core 1 and the top of Core 2.

Unit 4: Mudstone (Sapropel)

Unit 4 consists of an estimated thickness of 157 meters of predominantly black mudstone, with minor amounts of black claystone and bluish gray marly nannofossil chalk. The mudstones and claystones are thinly laminated, with bedding inclinations ranging from horizontal to 70°. Moderate burrowing is present.

The laminated mudstones and claystones average 69 per cent clay, 16 per cent pyrite and carbonaceous material, 8 per cent quartz, 6 per cent mica, and 3 per cent dolomite, plus minor and trace amounts of other components. Recognizable plant debris in the mudstones allows the term "sapropel" to be applied to them. The marly nannofossil chalk is composed of 55 per cent nannofossils, 30 per cent clay, 6
per cent quartz, and 5 per cent pyrite, plus minor and trace components. Examination of the coarse-fractions of the core catchers of Cores 2 and 3 gave the following averages: 70 per cent foraminifers, 22 per cent rock fragments, 6 per cent pyrite, 2 per cent quartz, and trace components.

The boundary between Unit 4 and Unit 5 is placed halfway between the bottom of Core 3 and the top of Core 4.

**Unit 5: Mudstone**

Unit 5 consists of an estimated 253 meters of predominantly bluish and greenish gray mudstones with minor, thin sandy layers, and one 10-cm bed of sandstone. Bedding of the mudstones is massive. Burrowing is moderate in both mudstones and sandy layers. Zoophycos is common.

The mudstones average 68 per cent clay, 18 per cent mica, 8 per cent quartz, and 2 per cent pyrite, plus minor and trace components. Trace amounts of iron oxides locally cause reddish colors in this predominantly gray unit. The coarse fraction averages 41 per cent quartz, 16 per cent unspecified carbonate, 15 per cent fish remains, 13 per cent rock fragments, 10 per cent mica, and 2 per cent pyrite. Angular mud clasts were found in Core 5. Numerous sand-sized white "specks" in the mudstones are agglutinated benthic foraminifers.

Sandstones average 47 per cent quartz, 19 per cent clay, 15 per cent dolomite, 8 per cent mica, 6 per cent zeolite, 3 per cent pyrite, and 2 per cent feldspar, plus minor and trace components. The dolomite occurs as cement. At least one sandy bed is graded, suggesting that these may be turbiditic sands.

**Sedimentary History**

The facies inferred to be immediately above salt at Site 364 is euxinic sapropelic shale alternating with dolomitic limestone. At Site 365, we attempted to bypass much of the overburden over the salt layer by coring into a deep cleft cut through virtually the entire sequence into the salt and filled with younger sediments. The origin of the canyon is uncertain. Erosion, faulting, or collapse into a gap created by dissolution of the halite beneath are all possibilities. Reflectors are directly traceable to the wall of the canyon from Site 364, a scant 10 km away. Unfortunately, coring did not penetrate the salt although drilling terminated over 300 meters below the inferred top of the salt horizon at Site 364. At this point, interstitial water salinities of 122 per mille were obtained (Sotelo and Gieskes, this volume), indicating that salt was very close at hand. We infer that the wall of the canyon where salt was expected was never penetrated, and that all that was cored is canyon fill.

The oldest in situ sediments cored are Miocene with some reworked Cretaceous. The Cretaceous sapropels of Unit 4 are clearly allochthonous, with high angled dips, and may represent a block caved from the canyon walls during Miocene time. The Miocene sediments were deposited primarily below the CCD and are laterally extensive to sediments in the deep Angola Basin west of the salt escarpment.

**GEOCHEMICAL MEASUREMENTS**

Neither the presence of gas nor evidence of liquid hydrocarbons was detected in the cores recovered at either Sites 364 or 365 (see Foresman, this volume).

**PHYSICAL PROPERTIES**

**Site 364**

The sediments at this site range in age from Pleistocene to upper Aptian. The lithology of this section is calcareous biogenic remains in various stages of alteration and lithification, with minor siliceous, authigenic, and terrigenous components. In Cores 29-40, much of the bedding shows steep dips and folding. This may be intraformational folding due to slumping or salt flowage. Because of the varying dips, the sonic velocity and GRAPE measurements were not always made parallel to the bedding.

**GRAPE**

The bulk density plotted in Figure 10 increases from 1.5 g/cm³ at 40 meters to maximum values of 2.5 g/cm³ at 1000 meters. The presence of sapropels causes deviations from normal patterns. The sapropels of Lithologic Units 5a, 5b, 7a, and 7b cause a major deviation in the plots of physical properties. These highly carbonaceous shales have low bulk density compared to other shales buried at comparable depths. One interesting feature in the GRAPE records is a very sharp bulk density peak, 2.79 g/cm³, at 50 cm in Core 38, Section 4. A comparison with the visual core descriptions shows this to be a thin layer of pyrite.

The porosity plotted in Figure 10 decreases with depth. The initial values of 75 per cent at 10-meters depth are reduced to a minimum of 9 per cent at 1045 meters. The low porosity values at depth are in cemented and dolomitic limestones. Both sapropel units have larger values of porosity than the adjoining chalks and limestones.

One interesting feature of both the bulk density and porosity plots is the interval between 100 and 250 meters where the values of each remain constant. In this interval, a pronounced lack of calcium carbonate is evident. The dominant lithology is a zeolite-bearing mud, rich in siliceous microfossils. The water content profile also displays uniformity over this same interval. These data add emphasis to the hypothesis that the lithology is the controlling factor for the major physical properties in this interval. There also appears to be a break in the plots of physical properties below this unit, suggesting a possible hiatus.

**Sonic Velocity**

Sonic velocity measurements ranged from 1.64 km/sec to 5.3 km/sec at Site 364 as shown in Figure 10. The acoustic units as shown in Table 5 correspond to major lithologic changes, but are not directly comparable to the lithologic units. Acoustic Unit I encompasses the first three lithologic units which range from calcareous mud, to marly nannofossil ooze, to a barren zeolite mud. Acoustic Unit II corresponds to the chalks of Lithologic Units 4a and 4b. At the base of these chalks, an euxinic facies represented by sapropels and hard chalks presents a good reflector which is Acoustic Unit III. Acoustic Unit IV signals the first appearance of limestones with some velocities greater than 3.0 km/sec. Interbedded with the limestones are low-velocity calcareous mudstones. Acoustic Unit V corresponds to high-velocity dolomites (greater than 4.0 km/sec) and low-velocity sapropels (velocities less than 2.8 km/sec). This
Figure 10. Bulk density, porosity, water content, sonic velocity, and shear strength versus depth at Site 364.
unit comprises the dolomites and sapropels on top of the salt and extends to the base of the salt at 2.4 seconds sub-bottom.

Shear Strength

The measured shear strength values plotted on Figure 10 increase from 33 g/cm² at a depth of 11 meters to a maximum of 1570 g/cm² at 198 meters. Below 200 meters, the shear strength decreases to 800 g/cm² as a chalk is entered at 275 meters. The high values of shear strength are in the middle of the non-carbonate mud where the values of water content, porosity, and bulk density remain constant. Water content in Figure 10 decreases from 126 per cent at a depth of 11 meters to a minimum of 4 per cent in the dolomites at 1045 meters. Abnormally high values of water content are associated with the sapropels between 580 meters and 710 meters.

Summary

Site 364 offered an opportunity to examine the changes of physical properties with depth in a mainly biogenic section. The only deviations from typical curves are in the non-calcareous muds of Lithologic Unit 3 and in the sapropels of Lithologic Units 4a, 5b, 7a, and 7b. The major reflectors shown in Figure 10 correspond with the major lithologic breaks. In the lower two acoustic units, extremely high velocities, between 3.0 and 5.3 km/sec, were measured for the recovered limestones and dolomites.

Site 365

Since Site 365 was a last-ditch effort to recover samples of the Angola Basin, salt cores were widely spaced both in depth and age. We recovered five different lithologies in seven cores. The lithologies varied from a Pleistocene mud to a Miocene nanofossil ooze with a large “slump” block of Cretaceous mudstones with interbedded sapropels resting on older Tertiary mudstones.

Although core control at this site is rather poor, certain generalizations can be made about the physical properties. As can be seen in Table 6, the bulk density, sonic velocity, and shear strength increase with depth. The slump unit of Cretaceous sediment does show values larger than expected for near-surface sediments. The exact nature of the slump cannot be determined from the limited amount of data available from this site.

### TABLE 5

<table>
<thead>
<tr>
<th>Acoustic Unit</th>
<th>Time to Base of Unit (sec)</th>
<th>Mean Measured Velocity (km/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0.29</td>
<td>1.68</td>
</tr>
<tr>
<td>II</td>
<td>0.62</td>
<td>1.91</td>
</tr>
<tr>
<td>III</td>
<td>0.73</td>
<td>2.27</td>
</tr>
<tr>
<td>IV</td>
<td>0.925</td>
<td>2.91</td>
</tr>
<tr>
<td>V</td>
<td>2.4</td>
<td>3.30</td>
</tr>
</tbody>
</table>

a Two-way reflection time

The only deviations from typical curves are in the non-carbonate muds of Lithologic Unit 3 and in the sapropels of Lithologic Units 5a, 5b, 7a, and 7b. The major reflectors shown in Figure 10 correspond with the major lithologic breaks. In the lower two acoustic units, extremely high velocities, between 3.0 and 5.3 km/sec, were measured for the recovered limestones and dolomites.

### BIOSTRATIGRAPHY AND PALEONTOLOGY

**General Remarks, Site 364**

At Site 364 in the Angola Basin, we penetrated 1086 meters of Pleistocene to upper Aptian sediments. Coring was not continuous except for Cores 10-12 across the Cretaceous/Tertiary boundary. Ten cores were taken in the Pleistocene to Paleocene (359 m). About 500 meters of Upper Cretaceous Maestrichtian to upper Turonian are represented by 13 fairly regularly spaced cores (11-23). The Lower Cretaceous (upper Albian to upper Aptian), some 420 meters thick, is represented by 23 cores, one core taken every 19 meters (50% coring).

Core 1 (7.5-17 m) is rich in tropical Pleistocene planktonic foraminifers and calcareous nanoplankton. Core 2 (36-45.5 m) is virtually devoid of calcareous microfossils; only in the core catcher are some planktonic foraminifers and coccoliths (which, in addition, also occur in Section 2) of upper Pliocene age present. Core 3 (64.5-74 m) is Pliocene on the basis of both planktonic foraminifers and calcareous nanoplankton. Core 4 (102.5-112) is upper Miocene. Cores 5 to 7, Section 1 (150-159.5, 197.5-207, and 245-254.5 m) are strongly affected by calcite carbonate dissolution and can only tentatively be dated as middle-lower Miocene. Dissolution is less marked in Cores 7, CC to 10 (254.5, 283-292.5, 321-330.5, and 341.5-359 m) in which a number of middle Eocene to lower Paleocene planktonic foraminiferal and calcareous nanoplankton zones are present.

Cores 11 and 12 (359-378 m) are void of planktonic foraminifers, but benthic foraminifers are present. They are dated as Maestrichtian on the basis of abundant calcareous nanoplankton. The Cretaceous/Tertiary boundary thus falls between Cores 10 and 11. Both the lower Tertiary and the uppermost Cretaceous are strongly affected by calcium carbonate dissolution. This is in contrast to the Walvis Ridge Site 363 where dissolution in the same stratigraphic interval is negligible. Cores 13-23 (397-653 m) are lower Maestrichtian-upper Turonian on the basis of planktonic microfossils. Core 24 (672.5-682 m) is already upper Albian; thus part of the Turonian and the whole of the Cenomanian appear to be missing as at Site 363 (but see discussion on calcareous nanoplankton below). Because of very poor faunas, Cores 24 and 25 are not datable using planktonic foraminifers. But below this, they are more frequent and are of a cooler water, boreal type, as at Site 363. Cores 24-34 (672.5-881.1 m) are placed in the Albian, and Cores 35-41 (891-1014.5 m) in the upper Aptian. Cores 42-46 (1024-1086 m) are devoid of planktonic foraminifers. On the basis of calcareous nanoplankton, Cores 24-33 are in the upper part of the Albian, Cores 34-41 in the upper part of the lower to middle Albian, and Core 41 (lower part) to Core 42 in the lower Albian.

Except for Core 6, CC and Section 7-1, which contain a rich Oligocene fauna, Cenozoic radiolarians are absent. Most of the Cretaceous is also barren in radiolarians, except for Cores 23 to 27.

Six different phylloceratid and desmoceratid ammonite species were recovered within the interval of the upper-middle Albian Cores 29-37. In spite of a somewhat different
depositional environment compared with the Walvis Ridge Site 363, the Angola Basin Site 364 ammonites are of the same preservation which indicates deposition on the outer shelf/upper continental slope in sediments of slightly reducing conditions.

Abundant spores and pollen, and rare dinoflagellates were studied from Cores 21 to 45 for their distribution and stratigraphic implication (Morgan, this volume).

Biostratigraphy, Site 364

The general planktonic foraminiferal and calcareous nanoplankton zonation of the section, and correlation of the zonal scheme applied is given in Tables 7 and 8.

Tertiary

Wide spacing between cores and strong calcium carbonate dissolution over much of the section prevents the recognition of continuous planktonic foraminiferal and calcareous nanoplankton zonal sequences through the 359 meters of Cenozoic sediments. But where present, the planktonic foraminiferal and calcareous nanoplankton associations allow good zonal assignments (see Table 8). The planktonic foraminiferal fauna is largely of tropical aspect. But the absence of Globorotalia tumida, which is one of the best warm-water indicators in the Pliocene-Pleistocene, is surprising. On the basis of planktonic foraminifers the Pleistocene Globorotalia truncatuloides truncatuloides Zone and the two Pliocene zones Globorotalia miocenica and Globorotalia margaritae were recognized in Core 1, and Cores 2 and 3, respectively. Core 4 is upper Miocene Neogloboquadrina dutertrei Zone. Because of dissolution virtually no planktonic foraminifers occur in Cores 5, 6, and the upper part of Core 7. Only the core-catcher sample of Core 5 could be dated as the middle Miocene Globorotalia fohsi peripherora Zona. The calcareous nanoplankton in Cores 1-7 confirm the planktonic foraminiferal ages. The core-catcher sample of Core 7 is already middle Eocene on the basis of both calcareous nanoplankton (Nannotetra fulgens Zone) and very poor planktonic foraminiferal evidence. The lower part of the Miocene, the Oligocene, and the upper Eocene are thus either absent or very strongly condensed in Core 6 and above the core catcher of Core 7.

The lower Eocene Globorotalia palmerae to Globorotalia aragonensis and the Globorotalia formosa formosa zones could be distinguished in Core 8, and the Globorotalia subbotinae and the Globorotalia edgari zones in Core 9. The core catcher of Core 9 is already upper Paleocene Globorotalia velascoensis Zone. The middle Paleocene Globorotalia angulata Zone and the lower Paleocene Globorotalia trinidadensis Zone occur in Core 10. On the basis of calcareous nanoplankton the lower Eocene Discoaster sublodoensis, Discoaster lodoensis, and Tribriachiatus orhostylius zones are condensed into Core 8. Core 9 is assigned to the lower Eocene Tribriachiatus contortus Zone. Core 10 contains the Heliolithus klitupelli and the Fasciiculithus tympaniformis zones in its upper and middle sections, and at its base the lower Paleocene Cruciplacolithus tenus Zone.

The Cretaceous/Tertiary Boundary

This boundary falls between Cores 10 and 11 of Site 364. Core 10 (with full recovery) is strongly affected by calcium carbonate dissolution which has only rudimentary planktonic foraminiferal and calcareous nanoplankton associations remaining. Core 10, CC is in the lower Paleocene Globorotalia trinidadensis Zone on the basis of planktonic foraminifers and in the Cruciplacolithus tenus Zone of calcareous nanoplankton. The lowermost Paleocene is thus absent in Core 10. Core 11 (also with full recovery) has no planktonic foraminifers, but benthic foraminifers are present as are calcareous nanoplankton. This is unlike Site 363 where rich and well preserved lower Paleocene calcareous mic-
#### TABLE 7
Correlation of Cretaceous Calcareous Nannoplankton and Planktonic Foraminiferal Zones, and Ages of Other Fossil Groups in Site 364

<table>
<thead>
<tr>
<th>CALENOUS NANNOPHANTON</th>
<th>DEPTH BELOW SEA FLOOR IN METERS</th>
<th>PLANKTOMIC FORAMINIFER</th>
<th>BENTHOMIC FORAMINIFER</th>
<th>RADIOLEA</th>
<th>AMMONITES</th>
<th>PALYNOMORPHS</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAESTRICHIAN</td>
<td>M/&lt;s/c&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arkhangelskiella cymbiformis</td>
<td>359 - 368.5</td>
<td>11</td>
<td>MAASTR.</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Tetralsithus trifidus</td>
<td>368.5 - 378</td>
<td>12</td>
<td></td>
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</tr>
<tr>
<td>Tetralsithus eximius</td>
<td>379 - 396.5</td>
<td>13</td>
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<tr>
<td>CAMPAAN</td>
<td>Eiffellithus eximius</td>
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<td>Santonian</td>
<td>Eiffellithus eximius</td>
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<tr>
<td>Upper Coniacian</td>
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<tr>
<td>L. CONIACIAN</td>
<td>Micula staurophora</td>
<td>17</td>
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<td>U. ALBIAN</td>
<td>Micula staurophora</td>
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<td>M. ALBIAN</td>
<td>Micula staurophora</td>
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<td>L. ALBIAN</td>
<td>Micula staurophora</td>
<td>20</td>
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</tr>
</tbody>
</table>

**Cretaceous**

Dating and zoning of the Cretaceous is based primarily on planktonic foraminifers and calcareous nannoplankton. Additional biostratigraphic information is supplied by ammonites, benthic foraminifers, and palynomorphs (see Table 8).

As pointed out above, the Maestrichtian of Cores 11-14 is incomplete in that its upper part is absent. Cores 15-20 are poor in planktonic foraminifers as a result of strong calcium carbonate dissolution. The residual fauna preserved is of Campanian to Santonian age. Planktonic foraminifers are again abundant in Cores 21 and 22 which are assigned to the upper Coniacian Globotruncana primitiva Zone. The more dissolved Core 23 planktonic foraminifers indicate a lower Coniacian-upper Turonian Globotruncana sigali Zone age. The calcareous nannoplankton zones follow a similar stratigraphic breakdown: Eiffellithus eximius Zone, Campanian (Cores 15-16); Marthasterites furcatus Zone, Santonian-upper Coniacian (Cores 17-23, upper part); Micula...
### Table 8

Correlation of Pleistocene to Paleocene Calcareous Nannoplankton and Planktonic Foraminiferal Zones in Site 364

<table>
<thead>
<tr>
<th>AGE</th>
<th>CALCAREOUS NANNOPLANKTON ZONES</th>
<th>DEPTH BELOW SEA FLOOR IN METERS</th>
<th>CORE</th>
<th>PLANKTONIC FORAMINIFERAL ZONES</th>
<th>AGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pleistocene</td>
<td></td>
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<tr>
<td></td>
<td>Emiliania huxleyi/ Gephyrocapsa oceanica</td>
<td>7.5-17</td>
<td>1</td>
<td>Globorotalia truncatulinoides truncatulinoides</td>
<td>Pleistocene</td>
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<td>Emiliania ovata</td>
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<tr>
<td>Pliocene</td>
<td>Discocystis brouweri</td>
<td>36-45,5</td>
<td>2</td>
<td>Globorotalia miocenica</td>
<td>Pliocene</td>
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<tr>
<td></td>
<td>Reticoletafonema pseudamplusblica</td>
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<td>3</td>
<td>Globorotalia margaritae</td>
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<td></td>
<td>Ceratolithus rugosus</td>
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<tr>
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<td>Ceratolithus acutus</td>
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<tr>
<td></td>
<td>Discocystis berggrenitti</td>
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<td>Neogloboquadrina dutertrei</td>
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<tr>
<td></td>
<td>Discocystis galaxis</td>
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<td>Discocystis hamatus</td>
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<tr>
<td></td>
<td>Helicosphaera ampliaperta</td>
<td>150-159,5</td>
<td>5</td>
<td>Globorotalia falsi peripheraranda</td>
<td>MIOCENE</td>
</tr>
<tr>
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<tr>
<td>Eocene</td>
<td>NaNotoaxina fulgens</td>
<td>197,5-207</td>
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<td>Discocystis sublobigeri</td>
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<td></td>
<td>Discocystis lodoensis</td>
<td>283-292,5</td>
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<td>G. palmerae - G. aragonensis</td>
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<tr>
<td></td>
<td>Tribrachitus arthystylos</td>
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<td>Globorotalia formosa formosa</td>
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<td>Tribrachitus contortus</td>
<td>321-330,5</td>
<td>9</td>
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<td></td>
<td>Globorotalia edgarri</td>
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<td>Globorotalia velascenosis</td>
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<tr>
<td>Paleocene</td>
<td>Helicosphaera kleinpellii</td>
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<td>Globorotalia angulata</td>
<td>PALEOCENE</td>
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</tr>
<tr>
<td></td>
<td>Cruciplacolithus tenuis</td>
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</tbody>
</table>

The two ammonite species *Puzosia quenstetti* and *Cainoceras* n.sp.ex. aff. *liberum* from Cores 29 and 32 are upper Albian, the four species *Cainoceras* aff. *angustidorsatum*, *Mortoniceratidae* gen. et sp. indet., *Neokentroceras* ? sp., and *Hamites tenus* are regarded as upper-middle Albian.

Specimens of *Inoceramus* sp. cf. *Inoceramus anglicus* occur in Core 39. The species has been described from the Albian of various regions.

On palynomorphs Cores 23-25 are regarded as Coniacian to upper Turonian, Core 27 Cenomanian or Vraconian, Cores 28-32 upper Albian, Cores 38-40 middle Albian, and Cores 42-46 lower Albian. Several zonal schemes have been considered for the Site 364 palynomorphs. Most useful seem those established in Senegal and Ivory Coast, to the north of Site 346. Others from coastal Brazil are thought applicable mainly for the Lower Cretaceous when South America and Africa were still close.

As at Site 363, Aptian-Albian age assignments at Site 364 differ from one fossil group to another (Table 8). Using planktonic foraminifers, the Albian-Aptian boundary lies between Cores 34 and 35. However, the oldest ammonites in Core 37 are still dated as upper to middle Albian. Using benthic foraminifers, the boundary lies between Cores 36 and 37, but using calcareous nannoplankton it is within Core 41. On the basis of palynomorphs, the Albian-Aptian boundary was not reached at Site 364.
Paleontology, Site 364

Because of wide spacing of cores, the 359 meters of Tertiary sediments at Site 364 were recovered in only a fragmentary way. Furthermore, the calcareous microfossils which constitute the overwhelming part of the faunas and floras were strongly affected or even completely destroyed in some cores by calcium carbonate dissolution. The presence and distribution of planktonic and benthic foraminifers, as well as calcareous nannoplankton, are therefore determined by these factors.

The effects of strong dissolution and diagenesis are also evident in much of the approximately 720 meters of Cretaceous sediments, especially in the Maestrichtian to Santonian and again in the upper part of the upper Albian, where they mainly affected the planktonic foraminifers. Benthic foraminifers and calcareous nannoplankton are much less affected and occur throughout the interval. Ammonites were recovered from Cores 29, 32, and 37. In contrast to Site 363 where Calcsphaerulidae occur from the lower Paleocene to upper Aptian, they are absent from the age-equivalent strata at Site 364. On the other hand, palynomorphs, in particular pollen and spores, but also dinoflagellates occur throughout the Cretaceous of Site 364.

The following faunal/floral groups of Site 364 are treated in special contributions to this volume (* in supplement volume):

Neogene-Paleogene planktonic foraminifers (Toumarkine)
Cretaceous planktonic foraminifers (Caron)
Paleogene benthic foraminifers (Proto Decima and Bolli)
Upper Cretaceous benthic foraminifers (Beckmann)
Lower Cretaceous benthic foraminifers (Scheibnerová)
Pleistocene to upper Aptian calcareous nannoplankton (Proto Decima, Medizza, and Todesco)
Cenozoic radiolarians (Pisias and Moore)
Cretaceous radiolarians (Foreman)
Ammonites (Wiedmann and Neugebauer)*
Inocerami (Matsumoto)*
Senonian to Alban palynomorphs (Morgan)

Planktonic Foraminifers

Neogene: Of the seven cores that recovered sediments within the 250 meters of Neogene sediments drilled, only Cores 1, 2, CC, 3, and 4 contain reasonably rich planktonic foraminiferal faunas. In the others the faunas were largely or completely destroyed by calcium carbonate dissolution. The Pleistocene planktonic foraminifers of Core 1 (7.5-17 m) are of a typical tropical-sub-tropical character. The typical tropical form, Globohuricula umida umida, is absent which suggests some cooling occurred during that period of the Pleistocene. The Pliocene fauna is characterized by the index fossils Globohuricula miocenica, Galeichammatula, G. martharicera, and Globigerinoides obliquus extremus, forms generally present in the tropical-sub-tropical Pliocene of the Atlantic and Caribbean areas.

Paleogene: Most samples examined from Cores 7, CC to 10, representing about 100 meters of Paleogene sediments, contain either no planktonic foraminifers, or forms that are strongly affected and reduced by calcium carbonate dissolution. It is mainly the thick-shelled species that resisted dis-
only few specimens representing a few species, but planktonic foraminifers in Cores 8 and 9 are more abundant. It is therefore possible that in this interval the faunal character was originally predominantly a planktonic one. In Core 10, on the other hand, quite a rich benthic fauna is present compared with impoverished planktonic foraminifers. Bandyella beckmanni is described as a new species from Sample 10-1, 58-60 cm (Proto Decima and Bolli, this volume).

**Upper Cretaceous:** Benthic foraminifers are present throughout the Upper Cretaceous Cores 11-23. Their frequency is variable and appears to be determined at least in part by calcium carbonate dissolution, which eliminated all the planktonic foraminifers in Cores 11 and 12, for example. Benthic foraminifers are comparatively rare in Core 18 where the planktonic forms are also nearly absent. The faunal composition through Cores 23 to 11 does not show a distinct trend or change. The appearance of Bathysiphon in the upper part of the section may be of ecological significance. Some faunal elements such as Bathysiphon, Gyroidina, Osangularia, and Nutallinella point to a deeper water middle- to possibly lower-slope environment. The scarcity of primitive agglutinated forms of Lithoidids, however, suggests a depth of not more than about 2000 meters. Without reliable data on paleoclimatology and bottom conditions, such depth estimates remain rather speculative.

The Upper Cretaceous benthic foraminifers of both Sites 363 and 364 show influences of tropical to subtropical, temperate and austral character. In particular, evidence for a warmer climate prevails in the Senonian and Maestrichtian of Site 364. This is also confirmed by the planktonic foraminifers.

**Lower Cretaceous:** Benthic foraminifers occur in the upper Albian to upper Aptian Cores 24-41 where they are fairly regularly distributed. Cores 42 to 46 contain only very poor benthic foraminifers or are barren. The fauna consists mainly of calcareous forms and is of the non-tropical austral type. Consequently, the Angola Basin at that time must have formed part of the Austral biogeoprovince. Ecological reasons may be responsible for some differences in the faunal composition of Sites 363 and 364. Though many species occur at both Sites 363 and 364, there are several taxa that are restricted to one or the other. For instance, Lingulogavelinella frankel africana only occurs at Site 364. A distinct faunal change takes place between Site 364 Cores 26 and 25 where such species as Orthohostella indica, Osangularia uiaturesis, and Spirobolivina australis disappear. A comparable change within the Albian has also been observed in the Great Australian Basin and in other areas of the Austral biogeoprovince.

**Calcareaous Nanoplankton**

Coccolith assemblages ranging in age from Holocene to Lower Cretaceous occur in this discontinuously cored section.

Good to moderately preserved Holocene-Pleistocene assemblages with abundant Helicosphaera carteri and Gephyrocapsa oceanica are present in Core 1. Core 1 (uppermost Section 1) contains many reworked Upper Cretaceous and Paleogene forms. In the core catcher of Core 1 a peculiar association composed almost exclusively of H. carteri was found. This species is characteristic of tropical or subtropical areas.

Samples from Core 2 (36-46.5 m) are barren except for Section 2, 9-10 cm and the core catcher that contains a poorly preserved upper Pliocene assemblage of the Discoaster brouweri Zone. Nanofloras are rare to common and contain reworked Upper Cretaceous and Cenozoic specimens.

Moderately well preserved lower Pliocene assemblages occur throughout Core 3 (64.5-74 m). The great abundance of discoasters, such as D. brouweri and D. pentaradiatus suggests warm-water conditions. Core 4 (102.5-112 m) contains upper Miocene coccolith assemblages. Preservation is moderate to good. Discoasters are abundant and sphenoliths are common.

Coccoliths are very rare in Core 5 (150-159.5 m) except for Sample 364-5-4, 9-10 cm (153 m) that contains an upper lower Miocene assemblage. The concurrence of abundant Sphenolithus heteromorphus, common Cyclococcolithina mcintyreii, and rare Helicosphaera ampliaperta suggests the assignment of this sample to the upper part of the Helicosphaera ampliaperta Zone.

Samples of Cores 6 (197.5-207 m) and 7 (245-254.5 m) are barren of calcareous nanofossils except for Sample 7, CC that contains a moderately preserved middle Eocene assemblage of the Nanotetritina fulgens Zone.

The lower Eocene Discoaster subdoenosis, Discoaster lodoensis, and Tribrachiatus orthostylus zones are condensed in Core 8 (283-295.5 m). Coccoliths are abundant, but are only moderately to poorly preserved.

Lowermost Eocene and Paleocene assemblages are present in Cores 9 to 10. The great abundance of discoasters and the poor preservation of placoliths suggest dissolution effects in this interval. Core 9 is assigned to the lower Eocene Tribrachiatus contortus Zone, Core 10 contains the middle Paleocene Heliolithus kleinpellii, Fasciculithus tympaniformis zones, and the lower Paleocene Cruciplacolithus tenuis Zone.

Cores 11 to 12 (359-378 m) contain abundant but poorly preserved coccolith assemblages which suggest an Upper Cretaceous Maestrichtian age. Because of the absence of diagnostic species a closer biostratigraphic assignment is difficult. However, the absence of Micula mura and Lithraphidites quadratus might suggest an Arkhangeloksiella cymbiformis Zone age.

Cores 13 to 14 (397-435 m) are assigned to the upper Campanian to lower Maestrichtian Tetralithus trifidus Zone except for Sample 364-13-1, 40-41 cm that is referred to the lower Maestrichtian Arkhangeloksiella cymbiformis Zone based on the absence of Tetralithus trifidus.

Cores 15 to 16 (463.5-511 m) yield assemblages including Bronsonia parca and Eiffellithus eximius typical of the Campanian Eiffellithus eximius Zone.

Cores 17 through 23, Section 1-3 (530-648 m) recovered assemblages of the Marthasterites furcatus Zone which is considered to be of Coniacian/Santonian age. Based on the absence of M. furcatus, Section 4, 7-8 cm of Core 23 is assigned to the lower Coniacian-upper Turonian Micula staurophora Zone.

In the interval represented by Cores 24 to 33 (672.5-853 m), assemblages occur typical of the upper Albian Eiffellithus turrisseifelli Zone. If the Cenomanian marker Lithraphidites alatus is absent for ecological reasons, Cenomanian could be present in the upper part of this interval.
Nannofossils are poor to moderately preserved; overgrowth and fragmentation have affected some assemblages.

Cores 34 to 41 (Section 2, 139-141 cm) (872-1007 m) contain coccoliths of the lower to middle Albian *Prediscosphera cretacea* Zone. The lower part of Core 41 (Sections 3-6 and core catcher) and Core 42 (1007-1033.5 m) yield only poorly preserved assemblages of the Aptian to Albian *Parhabdolithus angustus* Zone. The presence of *Hayesties albiensis* suggests a still lower Albian age.

Core 43 (1033.5-1043 m) is barren of calcareous nannofossils.

**Radiolarians**

The core catcher of Core 6, which contains no foraminifers or calcareous nannoplankton, has a radiolarian fauna that includes *Arthrophormis gracilis* and *Lithocystis crux*. It is assigned to the middle Oligocene *Theocyrtis tuberosa* Zone.

Cretaceous radiolarians that occur in Cores 23 to 27 and in 35 are mostly poor in number and preservation. Consequently, index forms are very scarce. *Dictyomitra rotundata* in Cores 25 and 26 is considered Cenomanian to upper Albian. *Acaemiotyle umbilicata* which occurs in the same cores but indicates lower Albian to upper Aptian we regard as reworked.

**Ammonites**

The following six ammonite taxa occur in the Albian of Site 364:

*Puzosia quenstedti* Samples 29-2, 26-29 cm, upper Albian, see Figure 11.

*Cainoceras* n.sp. ex aff. *liberum* Sample 32-3, 60-64 cm, upper Albian)

*Cainoceras* aff. *angustidorsatum* (Section 37-1, top, upper-middle Albian)

*Mortoniceratidaceae* gen. et sp. indet. (bottom of Section 37-2) upper to middle Albian)

*Neoentroceras* ? sp. (bottom of Section 37-2, upper to middle Albian)

*Hamites tenuis* (bottom of Section 37-2, upper to middle Albian)

Of the four levels within which these ammonites were recovered, two indicate upper Albian, and two upper to middle Albian ages. These levels include several trachyostraceous and one heteromorphi species, placing them in an inner shelf to epicontinental environment, rather than a bathyal one. This interpretation finds support in sedimentological observations and by the presence of *Placucopsis* (Plate 2, Figure 4 of Wiedmann and Neugebauer, supplementary volume). Based on ammonites, the lower Albian is regarded as the oldest marine sediment exposed in Angola. Ammonites of this age however, were not found in the deeper cores of Site 364. Their absence there may have resulted from ecological factors or they may be so rare that none were seen in the core material available.

**Inocerami**

Flattened molds of two specimens of *Inoceramus* sp. cf. *Inoceramus anglicus* occur in Sample 39-5, 86-89 cm (Figure 12) and are described and illustrated by Matsumoto (this volume).

**Palynomorphs**

Of the 19 Cretaceous samples processed between Cores 21 and 45, all yielded frequent spores and pollen and rare dinoflagellates. Most of them come from sapropels but some also are in marly shales. Ephedroid and gymnospermous (*Classopollis*) pollen dominate in Cores 27-44, while most of the flora in Cores 23-25 consists of poorly ornamented tricolepate pollen with secondary abundance of *Ephedrites*, *Cretaceiporites*, and *Hexapollonites*. Little attention has so far been paid to dinoflagellates in West Africa and eastern South America. Their occurrence at Site 364 together with pollen and spores offers a good opportunity to compare ages and ranges. Several dinoflagellate species which were previously recorded and dated elsewhere occur. They include *Hystrichosphaeridium arundinum* from the Albian of Europe and "*Dioxya" villosa* from the middle and upper Albian of Australia.

**General Remarks, Site 365**

Site 365, located on the marginal escarpment of the Angola Basin some 20 miles southwest of Site 364, was chosen to obtain a complementary section to Site 364; it was expected to bypass the upper part of the section at that site and reach the elusive halite layer. However, these objectives were not met and the hole terminated in upper Tertiary sediments. In all, 687 meters of Recent to upper Tertiary sediments were penetrated and seven cores taken from 225 meters down at widely spaced intervals.

Sections 1-5 of Core 1 (225-234.5 m) contain abundant Recent to Pleistocene planktonic foraminifers. Only the lower part of Section 6 and the core catcher carry older (Upper Cretaceous) microfossils. These include benthic foraminifers and calcareous nannoplankton, with *Marthasites furcatus* dating the sediments as Santonian to Coniacian in age. It is evident that the Recent to Pleistocene part of the core must come from the very top of the section. The Cretaceous fossils of the lower part of Core 1 either are part of a slump mass of that age or are reworked in the Tertiary. This is proven by the presence of upper Tertiary microfossils in Cores 4-7.

Core 2 (320-329.5 m) and Core 3 (396-405.5 m) are closely comparable with the lower part of Core 1 in that Cretaceous benthic foraminifers and calcareous nannoplankton of varying ages are abundant. Rare planktonic foraminifers are also present, but only in the core catcher of Core 3 are there numerous *Hedbergella* and *Pragelobotruncana* species. A single specimen of *Rotalipora apenninica* found with this fauna indicates the presence of Cenomanian in the Angola Basin (it was not recovered at Site 364).

The basal part of Core 1, and Cores 2 and 3 consist largely of dark brown to black partly sapropelic clay and mudstones. Cores 4-7 (462.5-472 m, 510-519.5 m, 614-624 m, and 681-687 m) consist of greenish gray mudstones with scattered fine sandy layers. These cores are quite different lithologically from those above and are also characterized by frequent small white specks which are primitive arenaceous foraminifers, mainly tubular *Bathyisiphon* specimens. This interval contains no Cretaceous calcareous foraminifers or calcareous nannoplankton. Of special interest here are the fairly abundant but pyrititized radiolarians in Sample 7-1,
The ammonite *Puzosia cuenstedti*, Site 364, Sample 29-2, 26-29 cm, upper Albian.

32-35 cm which are assigned to the middle Oligocene *Theocyrtil tuberosa* Zone, the same age as found for the radiolarians in the core catcher of Core 6, Site 364. Pollen, spores, and dinoflagellates which occur in Cores 4 to 7 give a still younger age, in the upper Tertiary, possibly upper Miocene. Ichthyoliths in Cores 4-7 suggest a lower Miocene to upper Oligocene age and diatoms in Core 7 an age not older than Tertiary.

The radiolarians, diatoms, palynomorphs, and ichthyoliths in Cores 4 to 7 are thus critical in defining the age of the sediments in the lower part of the section (462.5-487 m) as upper Tertiary. This proves that the Cretaceous microfossils encountered in Cores 1-3 are either reworked in the upper Tertiary, or are part of masses of Cretaceous sediments slumped into upper Tertiary sediments.

**Biostratigraphy, Site 365**

The general planktonic foraminiferal and calcareous *nannoplankton* zonation and correlation scheme for Site 365 is given in Table 9. Extremely widely spaced coring, downhole slumping, reworking or slumping within the section, and intervals devoid of diagnostic foraminifers and calcareous *nannoplankton*, render Site 365 difficult for an accurate biostratigraphic investigation. Despite this, three distinct faunal units can be distinguished:

1) Core 1, Sections 1-5 with a rich Recent to Pleistocene planktonic microfauna.

2) Core 1, Section 6, to Core 3, CC with foraminifers and calcareous *nannoplankton* of different Cretaceous ages.

3) Cores 4 to 7 with upper Tertiary arenaceous foraminifers, radiolarians, diatoms, palynomorphs, and ichthyoliths.

Faunal unit 2 contains foraminifers and calcareous *nannoplankton* of different Cretaceous ages. In Core 1, Section 6, and its core catcher, benthic foraminifers indicate a Santonian-? Campanian age, and *nannoplankton* a Coniacian to Santonian age. Core 2, Section 3, is Albian to Cenomanian on the basis of benthic foraminifers, and probably upper Albian on *nannoplankton*.

Core 2, CC is again Campanian on the basis of benthic foraminifers, and probably post-Santonian on *nannoplankton*. Finally, Core 3, CC is Albian to Cenomanian on the basis of benthic foraminifers, Cenomanian on planktonic foraminifers, and upper Albian on *nannoplankton*. Individual samples from Core 1, Section 6, to Core 3 contain quite homogeneous faunas and floras, an indication that we are probably dealing with sediment masses of different Cretaceous ages that slumped into younger Tertiary sediments.

The arenaceous foraminifers in Cores 4-7 are of little stratigraphic significance, except for *Cyclammina* sp. which points to a Tertiary age. The species association is that of a deep water fauna. Of significance is the total absence of any calcareous remains such as foraminifers or *nannoplankton*, and the presence of quite abundant fish debris including denticles. The absence of calcium carbonate and the amount of fish remains point to a condensation of the sediment...
Table 9
Correlation of Age Determinations in Site 365

<table>
<thead>
<tr>
<th>Depth Below Sea Floor in Meters</th>
<th>Core</th>
<th>Foraminifera</th>
<th>Nannoplankton</th>
<th>Palynomorphs</th>
<th>Radiolaria</th>
<th>Diatoms</th>
<th>Ichthyoliths</th>
</tr>
</thead>
<tbody>
<tr>
<td>225 -234,5</td>
<td>1</td>
<td>Recent to Pleistocene</td>
<td>Recent to Pleistocene</td>
<td>Camponian-Santonian</td>
<td>Santonian - Campanian</td>
<td>Recent to Pleistocene</td>
<td></td>
</tr>
<tr>
<td>320 -329,5</td>
<td>2</td>
<td>Camponian-Albian</td>
<td>probably Upper Albian</td>
<td>Campanian</td>
<td>probably post Santonian</td>
<td></td>
<td></td>
</tr>
<tr>
<td>396 -405,5</td>
<td>3</td>
<td>Camponian - U.Albian</td>
<td>Upper Albian</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>462,5-472</td>
<td>4</td>
<td>arenaceous facies fauna</td>
<td>Tertiary aspect</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>510 -519,5</td>
<td>5</td>
<td>arenaceous fauna</td>
<td>Upper Tertiary (probably Upper Miocene)</td>
<td></td>
<td></td>
<td></td>
<td>Miocene to Oligocene</td>
</tr>
<tr>
<td>614,5-624</td>
<td>6</td>
<td>Tertiary aspect</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tertiary</td>
</tr>
<tr>
<td>681 -687</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
through CaCO₃ dissolution. No sediments directly comparable with those of Cores 4 to 7 were cored at nearby Site 364. The most similar sediments at Site 364, and on the basis of radiolarians, most age-equivalent, are those of Core 6 which are also non-calcareous, and contain abundant radiolarians and some fish debris.

**Paleontology, Site 365**

Because of their erratic and restricted occurrence and the particular conditions of the section as pointed out above, foraminifers and calcareous nanoplankton were not treated in the same detailed way as in the other Leg 40 sites, and no distribution charts are presented. Occurrences and ages of the more important planktonic and benthic foraminifers are therefore listed here. The following faunal and floral groups of Site 365 are treated in special contributions in this volume (* = in supplement volume):

- Tertiary radiolarians (Pisias and Moore)
- Opal phytoplankton (Schrader)*
- Late Tertiary palynomorphs (Partridge)
- Ichthyoliths (Doyle, Dunsworth, and Riedel)*

**Planktonic Foraminifera**

The rich Recent to Pleistocene planktonic foraminiferal fauna of Core 1, Sections 1-5, consists of abundant Globorotalia menardii, G. menardii cultrata, Globigerinoides trilobus s.l., G. ruber (with many red colored specimens), and Orbulina universa. Also present are Globorotalia truncatuloides truncatuloides, G. tumida tumida, G. dutertrei, Pseudolinia obtuquiloculata, and others. The only other planktonic fauna of significance is that of Cenomanian age in the core catcher of Core 3. In addition to a single specimen of Rotalipora sp., the most abundant Globorotalia species from Core 1, Sections 1-5, consists of Hedbergella delrioensis, H. portsdowensis, H. costellata, Clavihedbergella simplicissima, Praeglobotruncanida delrioensis, P. stephani, P. stephani gibba, and Rotalipora praebalernaensis.

**Benthic foraminifers**

Rare benthic foraminifers occur with the abundant planktonic forms in Core 1, Sections 1-5. The following are the more important Cretaceous benthic species from Core 1, Section 6 to Core 3, core catcher (kindly determined by J. P. Beckmann):

- Sample 1-6, 82-84 cm: Bathysiphon sp., Recurvoides sp., Glomospira sp., Trochammina sp. The preservation of these specimens is similar to that found in the arenaceous forms of Cores 4-7, which are upper Tertiary.
- Sample 1-6, 127-129 cm: Bathysiphon sp., Spiroplectammina dentata (Alth), Gyroidina cf. rumoiensis Takayanagi, Gyroidina sp., Conorbina cf. marginata Brozten, Osangularia sp., Age: Santonian to Campanian, fauna possibly heterogeneous.
- Sample 1, CC (gray sediment): Clavulina gabonica Le Calvez, de Klasz, and Brun, Gyroidina cf. graminea (Martin), Conorbina cf. marginata Brozten, Gavelinella sp. (? costata Brozten), Osangularia sp. Age: About Santonian to Campanian.
- Sample 1, CC (red sediment): Clavulina gabonica, Tritaxia cf. insignis (Plummer), Dothalia cf. oxycon(Matt), Spiroplectammina dentata, Aragonia ozez-
catcher of this core. Cores 5 to 7 are totally barren of calcareous nannofossils.

Radiolarians

Of great importance for the dating of the lower part of the section (Cores 4-7) is a pyritized radiolarian fauna in Sample 7-1, 32-35 cm. The fauna includes *Artophormis gracilis*, *Lithocylia angustum*, *L. crux*, and *Dorcadospyris* spp. from which it is assigned to the middle Oligocene *Theocyrtis tuberosa* Zone. Though the zonal marker is absent, the zone is determined by the presence of *Lithocyclia angustum* and *L. crux*.

Opal Phytoplankton

A well-preserved Recent to Pleistocene tropical diatom assemblage with *Pseudoenuonita dolodius* and *Thalassiosira eestrupida* occurs in Core 1-1, 79-80 cm. The samples investigated from Cores 2 to 6 contain no opal phytoplankton. Samples 7-1, 24-25 cm and 7-2, 37-38 cm contain poorly preserved *Stephanopyxis* aff. *turris*, *Coscinodiscus marginatus* and *Coscinodiscus aff. marginatus*. Their age is tentatively assumed to be not older than Tertiary.

Palynomorphs

Samples from Cores 3-7 were investigated for dinoflagellates, acritarchs, spores, and pollen. Core 3 contains an Upper Cretaceous flora whose age agrees with that of the foraminifers and calcareous nannoplankton. The assemblage of Cores 4 to 7 is interpreted as having a general upper Tertiary age, probably upper Miocene. The lower age limit of this Neogene flora is determined by the common occurrence in all samples of the family Compositae. The most abundant species is *Tubulifloridites* sp., a form similar to the Recent genera *Mutisia* L. and *Echinops* L. Other Compositae present but not as abundant are *Tubulifloridites antipodica* and *Fenestrelleopsis spinosa*. *Acaciapollenites* sp., *Echiperiporites* sp., *Chenopodipollis* Marginipollis concinnus, and *Monoporites* sp. are other pollen that favor a young Tertiary age.

Ichthyoliths

Fish debris is quite abundant in Cores 4-7, where 26 subtypes of ichthyoliths have been distinguished (Doyle et al., supplement volume). From previous reports, most of these are known to occur in the Oligocene/Miocene, with several of the subtypes present in Cores 4 to 7 known only from this interval. The ichthyoliths thus confirm the Oligocene to Miocene age of these cores as determined by radiolarians and palynomorphs.

SEDIMENTATION AND ACCUMULATION RATES, SITES 364 AND 365

Procedures for deriving sedimentation and accumulation rates curves are described in Chapter 2 (this volume). Figure 13 presents plots of age versus depth; CaCO3 versus depth; the per cent of sand, silt, and clay versus depth; and derived sedimentation and accumulation rate curves versus depth for Site 364. No such curves are presented for Site 365 which was too sparsely cored for the exercise to be meaningful. Again, uniform sedimentation rates are assumed between zonal boundaries and are interpolated at 1-m.y. intervals. Again this results in artificially "stepped" accumulation rate curves for the Cretaceous, where zonal boundaries are far apart chronologically.

The mean sedimentation rate at Site 364 has been 9.49 m/m.y., lower only than Site 363 of all the Leg 40 sites. Notwithstanding a long Eocene to Miocene hiatus in the section, sedimentation rates have been nearly this low or lower since the late Albian. Only in the deposition of Unit 6 (18.8 m/m.y.) and Unit 7 (42.3 m/m.y.) have sedimentation rates been higher.

Because of the long Tertiary hiatus, possibly caused by single erosional events, and represented in profiler records by an angular unconformity, there is no way of knowing whether carbonate accumulation rate maxima occurred in the Miocene as they did at Sites 360, 362, and 363. There was a jump in carbonate accumulation in the early Eocene, however, which may represent part of the same broad Eocene maximum that occurred at Sites 360, 361, 362, and 363. Two generalized Cretaceous maxima occur, one just above the evaporites in the Unit 7 dolomites, the other straddling a sequence of black shales alternating with dolomitic limestones (Unit 5) and brown shales with limestones (Unit 4). A probable disconformity occurs in Unit 5 where the Cenomanian and Turonian are missing. Part of this interval could be present, however, if the Cenomanian marker fossil *Lithraphidites alatus* were absent for ecological reasons.

CORRELATION OF REFLECTION PROFIL WITH DRILLING RESULTS

Site 364

Six acoustic units are recognized on the *Charcot* reflection profile on which Site 364 has been projected (see Figure 14 and Table 10).

The base of Acoustic Unit I (Reflector *Davy* of Emery et al., 1975) occurs in Core 7 and marks a transition in the Eocene from low-carbonate muds of Lithologic Unit 3 to high-carbonate ooze and chalks of Lithologic Unit 4 (see Figure 15). At Site 361 in the Cape Basin, Reflector *Davy* is Paleocene in age and corresponds with a laterally extensive marly chalk horizon.

The base of Acoustic Unit II (Reflector *All* of Emery et al., 1975) occurs between Cores 19 and 20 and marks the top of a sapropel sequence corresponding to Lithologic Unit 5, which is Campanian-Santonian in age. At Site 361, Reflector *All* is APTian in age, and also corresponds with the top of a sapropelic unit. The two major reflecting horizons

<table>
<thead>
<tr>
<th>Acoustic Unit</th>
<th>Time to Base a</th>
<th>Depth to Base (m)</th>
<th>Velocity (km/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0.29</td>
<td>250</td>
<td>1.72</td>
</tr>
<tr>
<td>II</td>
<td>0.62</td>
<td>580</td>
<td>2.00</td>
</tr>
<tr>
<td>III</td>
<td>0.73</td>
<td>710</td>
<td>2.36</td>
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<tr>
<td>IV</td>
<td>0.925</td>
<td>1025</td>
<td>3.23</td>
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<tr>
<td>V</td>
<td>≈ 2.4</td>
<td>&gt;4100</td>
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*Times measured on *Glomar Challenger* seismic profile at the drill site.*
Figure 13. Biostratigraphic zonation, sedimentation rates, accumulation rates, and the proportion of sand to silt and clay at Site 364.

of Emery et al. (1975) thus have different ages in the Cape and Angola basins, although the cause of the reflectors is much the same in both basins.

The base of Acoustic Unit III occurs between Cores 25 and 26 and marks the base of the above-mentioned sapropel sequence.

The base of Acoustic Unit IV corresponds to the top of a dolomitic unit in Core 42 at which level a major drilling break was recorded. Apparently, the top of the salt layer is only tens of meters below this dolomitic facies in which the drilling was halted at 1085 meters.

The base of Acoustic Unit V corresponds to the base of the massive salt layer and the top of the acoustic basement.

Acoustic Unit VI is the acoustic basement which occurs at this site coincident with magnetic anomaly M-4 of Aptian age.

Site 365

No correlations are made to seismic reflectors at Site 365 because the cores were so widely spaced.

SUMMARY AND CONCLUSIONS

Site 364 is located in the Angola Basin atop a plateau some 10 km to the east of an abrupt escarpment that marks the presumed outer limit of a massive layer of salt and evaporites along the continental margin of southwest Af-
We recognize seven lithologic units at Site 364 which record the history of opening of the South Atlantic north of Walvis Ridge, the history of circulation of seawater, the development of microfossil assemblages in the Angola Basin, and the evolution of the Angola Basin marginal plateau since the late Aptian, shortly after cessation of evaporite deposition. The seven cores of Site 365 represent five lithologic units. These bear mainly on the development of a Tertiary erosional episode which cut canyons into the evaporite deposit and which is evidenced by a marked change in style and acoustic signature of sediments observed in profiler records across the flatter parts of the marginal plateau. This episode is seen at Site 364 as a break in sedimentation or an erosional gap in which up to 16 million years accumulation of sediments are missing.

The lower four units at Site 364 range in age from late Aptian(?) to Eocene. The bulk of the sediments at Site 364 (over 700 m) are Cretaceous in age, beginning at about the middle of Unit 4. Within this interval, two of the lithologic units (5 and 7) contain carbonates or marly carbonates interbedded with black, putrid, finely laminated sapropels with up to 15 per cent organic carbon and abundant pyrite. The lowest unit, Unit 7, presumably directly overlies the evaporite sequence, and is late Aptian-early Albian in age. The other sapropelic unit, Unit 5, is Coniacian-Santonian to late Albian in age. Unit 7, but not Unit 5, is characterized by dolomitic limestone and finely laminated, almost varved black shales and marly limestones. Unit 5 black shales are interbedded with burrowed limestones. Unit 6, which lacks sapropels, is mainly late Aptian-early Albian to mid-Albian massive limestone with stylolitic seams and "marble" structure. Units 6 and 7 accumulated at rapid rates of 18.8 and 42.3 m/m.y., respectively.

This Cretaceous sequence is of greatest importance for the history of circulation and continental margin development in the Angola Basin. At the time of our early summary of Leg 40 results (Bolli, Ryan, et al., 1975), we argued that the Angola Basin sapropels reflected a transition from very restricted evaporite conditions of sedimentation to one slightly less restricted, but by no means open, namely euxinic conditions of bottom stagnation and oxygen starvation. But since Site 364 was shallow in the Cretaceous, it is also possible that the carbonaceous sediments were the result of an oxygen minimum (Arthur, 1976; Thiede and van Andel, 1977). In this situation, high productivity would have exhausted the oxygen content of fairly shallow water masses; sediments deposited within these water masses would therefore have been carbonaceous. Oxygenated conditions would have prevailed above and below the oxygen depleted zone, allowing oxidation and eventual solution of most organic carbon before it was deposited in the sediments.

Our work since Leg 40 reaffirms our original contention that the Angola Basin was euxinic. The arguments for this rather than a prolonged oxygen minimum are geological, paleontological, and mineralogical.

1) The results of Site 363 establish that Walvis Ridge has been high standing since the Early Cretaceous. In Chapter 3, we presented arguments that the Sao Paulo and Frio ridges were once joined but were sundered and separated along an east-west-trending transform fault which left major scarps on opposing sides of the two ridges. When the two ridges were joined, the median trough of the Mid-Atlantic Ridge north of Walvis Ridge was to the north and east of Site 363. Between the site and the trough was the wide, shallow salt plateau now on the Brazilian side of the South Atlantic. Until a passage for water opened along the transform fault, the only way water could get from the Cape Basin into the Angola Basin was over both Walvis Ridge
**Figure 15. Correlation of anoxic events at various DSDP sites in the South Atlantic using nannofossil biostratigraphy.** Sites 327 and 330 were cored on the Falkland Plateau during Leg 36. Site 356 was cored on the São Paulo Plateau during Leg 39. All other sites were cored on Leg 40. Anoxic intervals indicated by columns in black, hiatuses (during which anoxic intervals were possible) are indicated by cross-hatches, and intervals of possible spillage of anoxic waters over Walvis Ridge into the Cape Basin (resulting in transport of pollen to Site 361) are indicated by dots.

2) The oldest sediments at Site 361 are Aptian sapropels deposited in the deepest parts of the Cape Basin at a time when evaporites were accumulating in the Angola Basin. Euxinic conditions developed in the Angola Basin before they broke up in the Cape Basin (see Figure 15), and persisted later, well into the Albian. This implies a gradual transition from evaporitic to oxygenated conditions in the Angola Basin, a logical consequence of gradual widening of the South Atlantic consistent with its degree of isolation from the world ocean.

3) Evidence for this isolation is largely paleontological, namely that only Austral-boreal planktonic and benthic foraminifers were deposited in Site 364 sediments until the Late Cretaceous (Caron, this volume; Scheibnerová, this volume). This confirms the results of Premoli-Silva and Boersma (1977) on Cretaceous sediments from Site 356 in the Brazil Basin. No warm-water assemblages worked their way into either the Angola or Brazil basins until the bulge of West Africa was fully separated from the north coast of Brazil, probably in Turonian times.

4) Oxygen minima are usually observed in areas of high productivity, yet Aptian-Albian planktonic foraminifers at Site 364 are dwarf forms, implying restricted conditions for growth in surface waters at that time.

5) Bottom-water conditions during both periods of sapropel deposition were inimical to much bottom life, since burrows and bioturbation are absent in the shales. But whereas burrows are absent even in interbedded dolomites in the first interval of sapropel sedimentation at Site 364, in the second interval they are abundant in the interbedded limestones. The first interval of sapropel sedimentation was therefore more intensely anoxic, more relentlessly poisonous to bottom life than the second. In the first interval, shaly layers alternate with thin carbonate laminae in a varve-like fashion. The second interval appears to have...
been more cyclic, with anoxic conditions alternating with better ventilated conditions. In neither period of anoxic conditions is there evidence for vigorous current activity. The first period of sapropel sedimentation we therefore consider to be one of gradual ventilation of the Angola Basin, the equivalent of the deposition of dolomites and carbonate shales above evaporites in the Red Sea at DSDP Sites 225, 227, and 228 (Stoffers and Ross, 1974; Supko et al., 1974). The second period of anoxic sedimentation at Site 364 is more problematical because of its cyclicity. Alternating conditions of density stratification are required. Pliocene and Quaternary sediments in the eastern Mediterranean have a somewhat similar alternation of sapropels and carbonate shales above evaporites in the Red Sea at DSDP Site 364. The first period of sapropel sedimentation we therefore consider to be one of gradual ventilation of the Angola Basin, but a Red Sea circulation model could still apply, though perhaps not in the most obvious way. Today, the Red Sea is oxygenated by the very vigor of its thermohaline circulation. Rates of evaporation are so high at its northern end that the dense, saline waters so created sink and locally flush the basin once every 20 years (Siedler, 1969). If we imagine that climatic conditions could fluctuate so that evaporation rates could slow, then either (a) residence times could be increased, allowing oxygen depletion to occur, or (b) surface waters would not be as dense, and would settle to shallower density levels, above stagnant anoxic bottom waters. A Red Sea-type circulation model is thus completely sufficient to explain the sedimentary facies of Site 364.

6) With access of water only from the south, warmer temperature prevailing over the Angola Basin than the Cape Basin (Morgan, this volume), and the presence of a barrier across the Mid-Atlantic Ridge including Walvis Ridge and the São Paulo Plateau, there seems little chance that a cold deep-water mass could have reached the Angola Basin to promote the circulation needed to cause nutrient-rich waters to well up. This would have limited productivity, and thus the potential for an oxygen minimum. Instead a circulation system analogous to paired linked basins separated by high sills (such as the Balearic and Ionian basins in the Mediterranean, or the Mediterranean-Black Sea basins) seems more likely (Natland, this volume; McCoy and Zimmerman, 1977).

7) Sapropelic sediments at Site 364 contain evidence for mineral precipitation or diagenesis in waters of high salinities. These are (a) the authigenic mineral assemblage in the sapropelic shales of kaolinite, illite, and phillipsite (Siesser and Bremner, this volume) requiring elevated Na+/K+ (Natland, this volume); and (b) high Na- and Fe-dolomite rhombs in associated dolomitie limestones analogous to Red Sea dolomite (Matsumoto et al., this volume). These dolomite rhombs replace calcite, much of which might have had a chemical rather than biogenic origin since the limestones are poor in calcareous microfossils. The original calcite may have formed in a manner similar to Friedman’s (1972) Red Sea deep-water evaporite facies, wherein gypsum reaching the sea floor is degraded by bacteria to calcite and hydrogen sulfide (Natland, this volume).

With these arguments for euxinic conditions in the Cretaceous Angola Basin now stated, we can summarize the interrelationships among the various DSDP sites in the South Atlantic which have reached Aptian and Albian sediments. Some of this has already been presented in the Summary and Conclusions sections of Chapters 2 and 3 of this volume, and other pertinent information and discussion is in Deep Sea Drilling Project Initial Reports Volumes 36 and 39. The pertinent data are presented on Figure 15. We would like to emphasize the following points.

1) Anoxic conditions ceased at Sites 327/330 on the Falkland Plateau and Site 361 in the Cape Basin in the same fossil zone. This implies that anoxic conditions at the two locations were linked (occurred in the same basin). The difference in depths between the two locations suggests that the anoxic water mass was at least 2200 meters deep. Today, Site 361 is anomalously shallow, perhaps because of Paleogene uplift (see Chapter 2, this volume). A more reasonable estimate of the depth of the anoxic water mass is therefore closer to 3000 meters.

2) Dolomitic limestones occur in the late Aptian and Albian of Sites 363, 356, and 364. This is the south-to-north geographic order for these sites in Albian times (Figure 36 of Chapter 3, this volume), and implies that unusually saline water prevailed at all three sites. This is supported by independent mineralogical arguments for Sites 363 (Chapter 3, this volume) and 364 (Matsumoto et al., this volume). Localized (i.e., lagoonal) dolomitization environments for Sites 356 and 363 are thus unlikely, and a more regional highly saline environment (water trapped behind the Walvis-São Paulo Ridge) is consequently favored.

3) Anoxic conditions at Site 364 were effectively continuous from the Aptian to the Coniacian-Santonian. A brief interval in the Albian has no sapropels, but this may merely mean that the site was briefly above the top of an anoxic water mass. The later interval of sapropelic sedimentation was, of course, cyclic, implying episodic stagnation and oxygenation.

4) A marked period of currents over Walvis-São Paulo Ridge and in the Cape Basin followed breakup of anoxic conditions at Sites 327/330 and 361. Much of this current activity could have been generated by spillage of dense, highly saline, periodically anoxic waters over Walvis-São Paulo Ridge from the Angola Basin (Natland, this volume). This may be tied to cyclic flushing of anoxic waters between intervals of sapropel deposition at Site 364. A facies change to a more basaltic provenance occurred at Site 361, apparently the result of currents sweeping fine clays and silts from the vicinity of the Orange River delta, the nearest source of sediments with a major Karroo basaltsource (Natland, this volume). In addition, a diverse (more tropical) pollen assemblage was also supplied to Site 361 in the Turonian (MacLachlan and Pieterse, this volume), and this, too, had to come from the north.

5) Both this diverse pollen assemblage and, respectively, possible and certain intervals of carbonaceous sedimentation at Sites 363 and 356 (Walvis-São Paulo Ridge) occurred during the interval of cyclic sapropel sedimentation at Site 364. The Cenomanian-Turonian portion of the section at all three sites may be unrecognizable because the marker nannofossil could be missing for ecological reasons (Proto-Decima et al., this volume). The hiatus at Site 363, though, seems too long to explain in this way. Additional erosion is required. All in all, though, the data allow us to
speculate that anoxic waters in the Angola Basin swept across Walvis-São Paulo Ridge, allowing carbonaceous sediments to be deposited on it, and periodically eroding it or dumping coarse clastic sediments on it (Site 356). Perhaps organic matter was carried all the way to Site 361. The termination of anoxic conditions at Sites 356 and 364 in the same nannofossil zone supports this, and is further evidence against an oxygen minimum explanation for the carbonaceous sediments. By this time in the Late Cretaceous, the two sites were on opposite sides of a South Atlantic ocean basin wider by about 500 km than in the Albian. The conditions that would have promoted an oxygen minimum are hardly likely to have operated for such a length of time and to have ceased simultaneously on both sides of the South Atlantic.

6) With cessation of anoxic conditions north of Walvis-São Paulo Ridge, currents at Sites 361 and 363 persisted through most of the remainder of the Cretaceous. Then tranquil conditions set in at all sites until the Tertiary climatic deterioration and development of Antarctic Bottom Waters began. Were it not for this, the normal condition of the South Atlantic would have been one of weak bottom currents and little erosion. This in itself is an argument that the current systems which were so strong in the much more restricted Cretaceous South Atlantic were generated within that basin, that the principal dynamic features of that circulation were thermohaline, driven by a high rate of evaporation over the Angola and Brazil basins. There is no other plausible mechanism for producing vigorous currents in the Cretaceous. The intervals of carbonaceous sedimentation at the various sites are linked to the sedimentary history of the other sites by the vicissitudes of this thermohaline circulation. Only a euxinic model successfully links all the aspects of Cretaceous sedimentation at all the sites represented on Figure 15.

Although the deep evaporite objective was not reached at either Sites 364 or 365, the high pore water salinities are evidence that we must indeed have been very close to salt at both sites. These salinities were not exceptionally high in the upper sapropel-dolomitic limestone sequence nor in the upper part of the deeper one (Sotelo and Gieskes, this volume), hence, it is doubtful that high interstitial water salinities were responsible for the diagenetic formation of the dolomite or the clay-zeolite minerals in the carbonaceous shales. At Site 365, the high interstitial water salinities appear to have resulted from lateral migration of saline pore fluids from the incised walls of the canyon cut through to the salt, into the Tertiary clays filling the canyon.

Thiede and van Andel (1977) propose that migration of the Angola Basin salts occurred between the times of deposition of the two sapropelic units, between about 80 and 90 million years ago during the time of deposition of Unit 6. This salt migration would have been seaward, uplifting carbonates and sapropels atop the evaporites, countering the effects of cooling and subsidence of the oceanic lithosphere, and keeping Site 364 within their proposed oxygen minimum zone of water. Paleontological evidence, however, summarized earlier in this chapter, indicates that Site 364 was at fairly shallow outer shelf or shelf break depths at the time of the first sapropel deposition, i.e., no more than 500 meters deep. Given that Site 364 and the underlying salt are on oceanic crust, which was extruded probably at about 2500 meters water depth, and that this crust may have subsided to 3000 meters by the end of evaporite deposition, then most of the 3 km of salt presently beneath Site 364 must have been there at that time. Some isostatic compensation would have carried the top of the salt a few hundred meters below sea level during the time of deposition of the first carbonaceous sediments.

There is no evidence for disturbance of sediments by the postulated salt migration between 80 and 90 million years ago. Our drilling results confirm interpretations of reflection profile records that sedimentation over the evaporites was essentially flat and conformable from the Aptian until the Paleogene.

We have no evidence bearing on the question whether evaporites beneath Site 364 were deposited either intraterritorially or in fairly deep water. Correlation of sediment physical properties with reflection records indicates that drilling at Site 364 terminated extremely close to if not actually below the pronounced reflector we presumed to be the top of the evaporites. This hole may have ended in a local depression in the salt not resolvable from the surface. The sediments we recovered in the deepest cores at Site 364 suggest outer-shelf or shelf-break depths, neither shallow enough nor deep enough to argue for or against desiccation of the Angola Basin as a cause of evaporite deposition.

Because of the isolation of the Angola Basin during most of the Cretaceous, and because Site 364 has been on a continental margin salt plate after that time, it is difficult to derive a meaningful history of the carbonate compensation depth pertinent to the entire Angola Basin. The Tertiary unconformity at Site 364 allows no comparison with possible dissolution cycles found at Sites 360 and 362 in the Miocene.

Understanding the behavior of the CCD in the Cretaceous is complicated by difficulties in evaluating the state of preservation of calcareous microfossils. Limestones associated with carbonaceous shales are extensively dolomitized and, as just discussed, may represent chemical precipitates rather than deposits of calcareous microfossil tests. Both primary and diagenetic features of the limestones might therefore be misinterpreted as representing poor calcareous microfossil preservation, hence, implying extensive carbonate dissolution. During deposition of Units 6 and 4, respectively, after the Aptian-Albian and Coniacian-Santonian sapropel sequences, preservation of calcareous microfossils was better and sediment accumulation rates high. Unit 6 is primarily massive limestone deposited at a rate of 18.8 m/m.y. Unit 7 sediment accumulation rates were higher than this partly because of greater terrigenous input, preservation of all organic carbon, and perhaps the formation of expansive chemical precipitates of calcium carbonate. Both CaCO$_3$ and non-CaCO$_3$ accumulation rates were higher for Unit 7 than Unit 6 (Figures 16 and 17).

Elevation of the CCD at Sites 364 and 365 seems most firmly established for the end of the Cretaceous, where part of the Maestrichtian is missing. CaCO$_3$ accumulation rates were low (Figure 16), and calcareous microfossils are poorly preserved. A less certain hiatus or erosional break may have occurred in the Cenomanian. However, the critical Cenomanian marker fossil Lithraphidites alatus may be missing for ecological reasons, and a Cenomanian
planktonic foraminifer assemblage is present in allochthonous material at Site 365 (Caron, this volume). Palynomorphs of Cenomanian age also occur at Site 364. These tend to suggest little or no break in sedimentation at this time, but are difficult to translate directly into the accumulation rate curves for Site 364 (Figures 16 and 17) because of uncertainties of correlation among fossil groups and between holes.

Evidence for an elevated CCD at the end of the Cretaceous was also present at Site 363 on Walvis Ridge, in the form of enhanced dissolution of calcareous microfossils (Chapter 3, this volume), and at Site 361 in the Cape Basin, which was much deeper than either Sites 363 or 364, where pelagic clays were deposited at this time. These patterns of sedimentation may be related to an apparent worldwide rise in the CCD (Worsley, 1974), and, because all three sites were affected, imply that the South Atlantic had achieved sufficient interchange of waters with the world ocean to be influenced by worldwide, rather than merely local, oceanographic conditions.

Whether the CCD rose in the middle Eocene at Site 364 is obscured somewhat by a number of factors. The Eocene-Miocene gap in sedimentation coincides in time with a change in the pattern of sedimentation on the Angola marginal plateau. Portions of the plateau were eroded, including the submarine canyon where Site 365 was placed. Erosional debris from Africa was more quickly added to the margin as prograded deltas and fan deposits. Dingle (1973) attributes
similar heightened sediment supply and incision of canyons into the continental margin west of Cape Town to a major late Eocene regression. This regression does not coincide with any known period of epeirogenic uplift of portions of continental Africa (Siesser, this volume). It may be related to development of the Antarctic ice cap.

On the other hand, Miocene elevation of the rift plateaus of East Africa (King, 1971) was instrumental in establishing the Congo River drainage. This was part of the "Post-African" erosional event of King (1967), which created the largest erosion surface in Africa. Terrigenous material from the Congo River may be included in the topmost cores of Site 364. The Eocene-Miocene gap at Site 364 could have resulted from a Miocene erosional event related to this uplift.

A factor which also may have reduced the influx of terrigenous material to Site 364 in the Paleogene and early Neogene could have been the formation of salt diapirs and...
microfossil tests on the sea floor before burial would have been high, allowing extensive dissolution at Site 364, and total dissolution at Site 365, which was about 800 meters deeper. The alternative is that much more cold water entered the Angola Basin in the Eocene to Miocene time period than now. This would require major gaps in the barriers around the Angola Basin, such as Walvis Ridge, to have opened, then to have served as a passage for cold water, and finally either to have closed, or to have stopped serving as a passage for cold water. We have no evidence for this one way or the other, but one of the deeper gaps in Walvis Ridge near Tristan da Cunha Island is now at a depth of 3800 meters on a basement isochrone which is Paleocene in age, and therefore could have served as a passage for cold water in the Eocene or Miocene.

**Comparison of Carbonate and Non-Carbonate Accumulation Rates at Sites 360-364**

It is useful to consider the various factors controlling continental margin evolution along the western coast of southern Africa in terms of CaCO3 and non-CaCO3 rates of accumulation. Where Figure 15 summarized evidence for oceanographic conditions at the Leg 40 drill sites, Figures 16 and 17 summarize the biogenous and terrigenous contributions to the sediments along the continental margin since the Cretaceous. Apart from a minor spurt of siliceous sedimentation at Site 362 in the Miocene, productivity has been chiefly calcareous at all sites. The non-carbonate component is almost overwhelmingly terrigenous.

In what follows, it is important to bear in mind the different settings of the various Leg 40 sites with respect to the edge of the continent. Site 361 and Site 364 are both above oceanic crust. Yet because of the thick sequences of evaporites at Site 364, the sediments we cored there have more of the characteristics of continental shelf or platform deposits than would otherwise be expected. Site 361 sediments, though, are massive to distal turbidites, and include deep marine pelagic clays. They are thus more typical of deep marine sediments shed primarily from a continental source. In terms of evaluating productivity or CCD fluctuations, though, all Leg 40 sites may be too close to the edge of the continent to interpret effects in the adjacent basins. Coastal upwelling may have been important, increasing productivity, and thus locally altering the carbonate preservation versus depth relationship. Site 363 may prove to be most instructive in this respect, since it is more distal than either Sites 360 or 362.

The accumulation rate curves (Figures 16 and 17) are highly generalized for the Cretaceous because of poor biostratigraphic control and correlation with absolute ages. Nevertheless, Sites 361, 363, and 364 had initially high non-carbonate accumulation rates in the Aptian and Albian. Site 360, closer to the African coast than any of these sites, had a high terrigenous sediment accumulation rate in the Eocene, which declined rather abruptly. In general, all these declines reflect a diminishing of sourceland relief with time. Increases in non-carbonate sediment accumulation rate at Site 362 since the Eocene reflect (1) progradation of deltas, such as that of the nearby Orange River, and (2) higher productivity, evidenced by the pulse of siliceous
sedimentation in the Miocene, a consequence of the entry of cold Antarctic waters into the South Atlantic. Miocene and post-Miocene uplift in central Africa may also have contributed to this trend, as well as the increase in non-carbonate accumulation rate at Site 364 since the Miocene.

Spikes in the non-carbonate accumulation rates at Sites 360, 362, and 363 in the Tertiary are coincident with spikes in the carbonate accumulation rate. Van Andel et al. (1975) noted a similar effect in equatorial sediments of the Pacific, but there it was not nearly so pronounced. It is perhaps surprising that increases in carbonate accumulation rate are not reflected in more purely calcareous sediments. It is possible that much of the silt and especially mud that reached the sea floor at the Leg 40 sites was carried there by descending biogenous particles such as fecal pellets that directly reflect the rate of carbonate supply. Alternatively, shelf and slope mixing processes might counterbalance heightened carbonate supply by accelerating bulk sediment transport rates, and therefore the mixing rates of terrigenous and carbonate sediments. A somewhat more ad hoc explanation could be that wind patterns and especially rainfall and consequent run-off were accelerated during periods of high productivity and possible coastal upwelling.

In the case of the Oligocene Braarudosphaera blooms, however, we apparently are seeing the effects of coring and sampling bias in the heightened terrigenous sediment accumulation rate. The Braarudosphaera oozes are much purer carbonate oozes than adjacent beds of more typical foraminifer-nannofossil ooze or chalk. Yet recovery of the Braarudosphaera oozes was much lower than their likely abundance at the sites. In addition, both Braarudosphaera ooze and foraminifer-nannofossil chalk samples were analyzed for CaCO3. The latter are certainly over-represented in terms of proportion of recovered lithologies because of the necessity to obtain data on contrasting lithologies. Proper weighting of the CaCO3 content through this interval to the proper proportion of Braarudosphaera oozes would almost certainly eliminate the spikes in the non-carbonate accumulation rates at Sites 362 and 363 in the Oligocene. This is shown on Figure 17 by indicating the peaks as asterisks, but leaving the non-CaCO3 accumulation rate curve essentially flat through the Oligocene.

Sharp peaks in CaCO3 accumulation rate occur at 6-7 m.y., 13-15 m.y., 22-24 m.y., and 41-43 m.y. at Sites 360 and 362/362A. Braarudosphaera blooms occurred 33-35 m.y. ago at Sites 362 and 363 only. A broad Eocene maximum from 44-50 m.y. also occurred at all three sites. The shape of the 362/362A curve is mimicked by the Site 363 curve from 22-50 m.y. ago, but the peaks are not as great. The first three maxima at Sites 360 and 362/362A correspond with maxima found in the equatorial Pacific by Van Andel et al. (1975). One maximum at 36 m.y. occurs at Site 360 but is not present at the other sites nor in the equatorial Pacific. A maximum at 30 m.y. is present in the equatorial Pacific but is not in the South Atlantic. Only a portion of the Eocene maximum occurs at Site 364 and perhaps at Site 361, although that site was in much deeper water than any of the other Leg 40 sites, and was close to the depth of the CCD.

Melguen (this volume) and Noël and Melguen (this volume) have proposed that the CCD was shallow in the middle Miocene and middle Eocene based partly on the poor state of preservation of planktonic foraminifers and nannofossils, respectively, at Sites 360, 362/362A, and 363. They also noted poor microfossil preservation associated with an apparent jump in the CCD at the Cretaceous-Tertiary boundary, considered by Worsley (1974) to be worldwide in extent. On the CaCO3 accumulation rate curves, there are spikes corresponding to the middle Miocene and middle Eocene, but none at the Cretaceous-Tertiary boundary. Rather than a “South Atlantic” jump in the CCD in the Eocene and Miocene, it is possible that the poor preservation of calcareous microfossils resulted from a local elevation of the CCD, near the continent of Africa, perhaps the consequence of high productivity due to upwelling. Increased organic matter in the sediments would produce carboxic acid, and dissolve carbonate microfossil tests (Adelseck, 1977). The high CaCO3 accumulation rate at Site 362 in the late Miocene, for example, resulted in rapid burial of organic carbon, present at levels of 2 to 4 per cent in the cores. It is therefore no surprise that calcareous microfossils in these sediments are poorly preserved. Anaerobic processes have since produced considerable H2S, which was evident at oxbow levels when the cores were split.

Two factors argue that the Tertiary CaCO3 accumulation rate spikes reflect productivity rather than a general rise in the CCD. First, the Tertiary “dissolution cycles” have been documented at continental margin sites with a history of Pleistocene upwelling (the Benguela current) which almost certainly occurred in some form during the Tertiary. The “dissolution cycles” cannot be separated from peaks in the CaCO3 accumulation rates, which probably resulted from such upwelling. The contrast with the Cretaceous-Tertiary boundary, where no peak occurs but preservation is still poor, is instructive in this regard. A more positive case for a shallower CCD at any time during the Tertiary would have existed had there been no peaks in CaCO3 accumulation rate during the intervals of poor preservation.

This argument cannot be made, though, without qualification. The most direct evidence for past episodes of upwelling in the geologic record would be pulses in primary productivity. In the Leg 40 sediments, opaline silica, which is not nearly so readily dissolved in the water column as CaCO3, is not sufficiently prevalent to serve as an indicator of productivity. We are left with CaCO3 accumulation rate data only, and are thus open to charges of possible circular reasoning. However, the peaks in CaCO3 accumulation rate coincide with periods of poor calcareous microfossil preservation. The CaCO3 accumulation rate would have been even higher if preservation had been normal. Therefore, the peaks can have been a consequence of high productivity resulting from upwelling.

The second factor favoring the upwelling-productivity argument is that the middle and late Miocene spikes at Sites 360 and 362/362A are not strictly coincident in time. The 36-m.y. pulse at Site 360 also must have a local explanation. These suggest a shifting, sometimes very local, zone of high productivity (perhaps of upwelling) along the conti-
tional margin, and are evidence that these pulses are not the result of an ocean-wide rise in the CCD. One could also argue that the reduced peaks at Site 363 compared with Site 362 are a consequence of Site 363 being separated from the brunt of upwelling by Walvis Ridge.

There remains the problem of the coincidence of the South Atlantic peaks in CaCO₃ accumulation rates with those of the equatorial Pacific. Upwelling of cold water along the southwestern African coast could have been coincident in time with pulses of cold water through the central Pacific basins. Where the result in the Pacific was to shoal the CCD, the effect in the South Atlantic may have been to promote productivity along continental margin zones of upwelling. A generalized South Atlantic rise in the CCD cannot be inferred from the fact that spikes in the CaCO₃ accumulation rates coincide in time with those in the Pacific. In fairness, though, South Atlantic-wide shoalings of the CCD in the Eocene and Miocene cannot be precluded on the available data. This possibility merely cannot be sorted out from theoretically similar effects resulting from heightened productivity. At least one argument favors a kind of peculiar blend of the two possibilities. If the CCD rises through most of the world ocean, and the supply of dissolved carbonate to the sea remains constant, then shallow sites (those still above the CCD) should receive an absolute glut of carbonate sediments, assuming mass balance. The possible link between a shallow Cretaceous CCD and the development of extensive force-reef facies at the same time was pointed out by Ryan and Cita (1977). Here we leave open the possibility that something similar occurred in the Tertiary. Assuming that productivity remains constant, however, preservation should get better at shallow depths in order to maintain a mass balance, and this has not occurred at the Leg 40 sites. Either productivity also had to increase, or there must have been peculiar local effects in the preservation versus depth relationships along the continental margin in the Cape Basin whose causes cannot as yet be evaluated.

REFERENCES


**Site 364**  
**Hole**  
**Core 1**  
**Cored Interval:** 7.0 - 17.0 m

### Lithologic Description

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<thead>
<tr>
<th>Meters</th>
<th>Lithology</th>
<th>Megascopic Core Description</th>
<th>Texture</th>
<th>Composition (SS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5Y 4/2</td>
<td>Dark olive gray calcareous mud bearing plant debris</td>
<td>Soft, plastic dark olive gray (5Y 3/2) mud with zones of olive gray (5Y 4/2) and black (5Y 2/2). Faint H2S odor throughout.</td>
<td>3-18 6-99</td>
<td>1-100 75% Clay 5Y 4/2 10% Plant debris 5% Zeolite 5% Carbonate unspecified 2% Quartz 2% Pyrite</td>
</tr>
<tr>
<td>5Y 3/2</td>
<td>Megasopic Core Description</td>
<td>Fine, plastic dark olive gray (5Y 3/2) mud with zones of olive gray (5Y 4/2) and black (5Y 2/2). Faint H2S odor throughout.</td>
<td>3-18 6-99</td>
<td>1-100 75% Clay 5Y 4/2 10% Plant debris 5% Zeolite 5% Carbonate unspecified 2% Quartz 2% Pyrite</td>
</tr>
</tbody>
</table>

### Graphical Data

- **Carbonate Bomb:** 1-27 to 28 cm = 11.1% CaCO3
- **Grain Size (DSDP):**
  - 5-96 (1.1, 1.9, 16.0)
  - 6-96 (5.7, 17.3, 86.0)

---

**Explanatory notes in Chapter 1**
### FOSSIL CHARACTER

#### Core Catcher

#### LITHOLOGIC DESCRIPTION

<table>
<thead>
<tr>
<th>Stratum</th>
<th>Color (Munsell)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5Y 5/2</td>
<td>Olive gray</td>
<td>Firm mud: most is olive gray (5Y 5/2) and gray (5Y 5/1) mud with some lighter greenish gray (5GY 6/1). Many black streaks and faint greenish streaks stretched vertically by drilling. Black patches appear to be finely disseminated pyrite.</td>
</tr>
<tr>
<td>5Y 5/2</td>
<td>Olive gray</td>
<td>Firm mud: highly disturbed with vertical color changes from dark greenish gray (5GY 6/1) and dark gray (5Y 4/1) to olive gray (5Y 5/2) and olive (5Y 4/3). Mottles observed through lower half.</td>
</tr>
</tbody>
</table>

#### COMPOSITION (SS)

- **Sand**: 2-60%
- **Silt**: 55%
- **Clay**: 29%
- **Nannos**: 10%
- **Forams**: 4-20%

#### Grain Size (DSDP)

- **4-20 mm** (2.5, 0.4, 22)
- **6-20 mm** (1.3, 0.2, 9)

#### Carbonate Bomb

- **1-29 cm = 7.9% CaCO₃**

#### Zeolite Bearing

Explanatory notes in Chapter 1
### Site 364 Hole Core 5 Cored Interval: 150.0-159.5 m

<table>
<thead>
<tr>
<th>ZONE</th>
<th>FOSSIL CHARACTER</th>
<th>LITHOLOGY</th>
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<tr>
<td>0</td>
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<td>10YR 4/4</td>
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<tr>
<td>0.5</td>
<td></td>
<td>5Y 5/3</td>
</tr>
<tr>
<td>1.0</td>
<td></td>
<td>10YR 5/4</td>
</tr>
</tbody>
</table>

**Megascopic Core Description**

Stiff mud: mostly yellowish brown (10YR 5/4) with minor gray (5Y 5/1), olive (5Y 5/3) and dark yellowish brown (10YR 6/4). Slightly mottled.

**Texture**

- 50% Sand
- 20% Silt
- 30% Clay

**Composition (SS)**

- 35-70% Clay
- 5-50% Nannofossils
- 5-10% Dolomite rhombs
- 1-3% Quartz
- 1-3% Zeolite

**Carbonate Bomb**

1-3 cm = 0.3% CaCO₃

**Central Section**

<table>
<thead>
<tr>
<th>ZONE</th>
<th>FOSSIL CHARACTER</th>
<th>LITHOLOGY</th>
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<tbody>
<tr>
<td>0</td>
<td></td>
<td>5Y 6/1</td>
</tr>
<tr>
<td>0.5</td>
<td></td>
<td>5Y 5/1</td>
</tr>
</tbody>
</table>

**Megascopic Core Description**

Stiff mud: greenish gray (5Y 5/1) with minor gray (5Y 6/1). Slight color changes too slight to give different names. Slightly mottled throughout.

**Texture**

- 60% Sand
- 30% Silt
- 10% Clay

**Composition (SS)**

- 75-85% Clay
- 15-20% Silt
- 5-10% Nannofossils
- 1-3% Quartz
- 1-3% Zeolite

**Carbonate Bomb**

1-3 cm = 8.7% CaCO₃

**Explanatory notes in Chapter 1**
**Fossil Character**

**Core**

**Site 364 Hole Site 364 Hole Core B Cored Interval: 201.0-202.0 m**

**Lithologic Description**

**Zones**

**Foresight**

**Character**

**Fossil**

**Color**

**Texture**

**Composition (SS)**

**Remarks**

**Carbonate Bomb:** 1-29 to 30 cm = 37.3% CaCO$_3$

**Grain Size (DSDP)**

**Grain Size (OG)**

**Explanatory notes in Chapter I**

**Globorotalia formosa formosa**
### FOSSIL CHARACTER

### LITHOLOGIC DESCRIPTION

- **7.5YR 6/4**
  - **CALCAREOUS NANNOFOSSIL CHALK**

**MEGASCOPIC CORE DESCRIPTION**

**Chalk. General cycles of color changes.**

- Mostly red (2.5YR 5/8) at base grading to light brown (7.5YR 6/4) to gray (5YR 6/4).
- Faint burrows almost unrecognizable because of strong mottling.
- Section 2 shows good laminated to thinly stratified nature in places.

### COMPOSITION

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Component</th>
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<tbody>
<tr>
<td>65-95%</td>
<td>Nannos</td>
</tr>
<tr>
<td>5-15%</td>
<td>Clay</td>
</tr>
<tr>
<td>2-4%</td>
<td>Forams</td>
</tr>
<tr>
<td>T-5%</td>
<td>Quartz</td>
</tr>
</tbody>
</table>

- **Carbonate Bomb: 1-20 to 21 cm = 72.2% CaCO₃**
- **Carbon-Carbonate (DSDP) 4-20 (7.8, 0.1, 64)**
- **Grain Size (DSDP) 4-88 (6.0, 38.1, 55.9)**

### EXPLANATORY NOTES

- **UPPER PALEOCENE (forams)**
- **LOWER EOCENE (nannos)**
### Site 364 Site 364

<table>
<thead>
<tr>
<th>Hole</th>
<th>Core 11 Core 12</th>
<th>Cored Interval: 365.0-368.5 m</th>
<th>Core Interval: 368.5-378.0 m</th>
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</thead>
</table>

#### FOSSIL CHARACTER

**Lithologic Description**

<table>
<thead>
<tr>
<th>Interval</th>
<th>Color/Composition</th>
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<tbody>
<tr>
<td>359.0-368.5 m</td>
<td>5Y 7/1&lt;br&gt;&lt;br&gt;Calciteous Nanofossil Chalk</td>
</tr>
<tr>
<td>368.5-378.0 m</td>
<td>7.5YR 5/4&lt;br&gt;&lt;br&gt;Calciteous Nanofossil Chalk</td>
</tr>
</tbody>
</table>

#### MEGASCOPIC CORE DESCRIPTION

**Chalk and marly chalk:** Alternate yellow brown (10YR 5/4) and light gray (5Y 7/1). Strong burrowing throughout. Drilling disturbed core by rotating slabs 1"-1 1/2" apart.

**Texture:**
- 0% Sand
- 5-10% Silt
- 90-95% Clay

**Composition:**
- 50-70% Carbonate unspecified
- 15-30% Nannos
- 10-20% Clay
- 1-3% Quartz

**Carbonate Bomb:**
- 1-2 cm = 33.3% CaCO
- 4-20 cm = 33.3% CaCO
- 6-88 cm = 33.3% CaCO

**Grain Size:**
- 4-8 cm = 33.3% CaCO
- 6-88 cm = 33.3% CaCO

---

**Lithologic Description**

<table>
<thead>
<tr>
<th>Interval</th>
<th>Color/Composition</th>
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</thead>
<tbody>
<tr>
<td>359.0-368.5 m</td>
<td>10YR 4/4&lt;br&gt;&lt;br&gt;Calciteous Nanofossil Chalk</td>
</tr>
<tr>
<td>368.5-378.0 m</td>
<td>7.5YR 5/4&lt;br&gt;&lt;br&gt;Calciteous Nanofossil Chalk</td>
</tr>
</tbody>
</table>

#### MEGASCOPIC CORE DESCRIPTION

**Chalk - marly chalk:** Mostly brown (7.5YR 5/4) with minor light gray (5Y 7/2) mud. Brown part burrowed at top, gray part heavily burrowed. Drilling has broken core on 3 1/4"-1 1/2" slabs.

**Texture:**
- 0% Sand
- 3-5% Silt
- 95-97% Clay

**Composition:**
- 40-65% Carbonate unspecified
- 20-45% Nannos
- 10-30% Clay
- 1-3% Quartz

**Carbonate Bomb:**
- 1-2 cm = 33.3% CaCO
- 4-20 cm = 33.3% CaCO
- 6-88 cm = 33.3% CaCO

**Grain Size:**
- 4-8 cm = 33.3% CaCO
- 6-88 cm = 33.3% CaCO

---

**Explanatory notes in Chapter 1**
### Site 364 Hole Core 13 Cored Interval: 287.0–406.5 m

<table>
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<th>FOSSIL CHARACTER</th>
<th>LITHOLOGIC DESCRIPTION</th>
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<tr>
<td></td>
<td></td>
<td>CALCAREOUS NANNOSOSSIL CHALK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MEGASCOPIC CORE DESCRIPTION</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chalk. Very pale brown (10YR 7/4) and yellowish red (5YR 4/6) with minor light gray (5Y 7/2). Moderate to heavy burrowing throughout. Orientation of some parts is dubious due to drilling. First appearance of Inoceramus(?) fragment (calcite).</td>
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<tr>
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<td>LITHOLOGIC DESCRIPTION</td>
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<tr>
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<td>30YR 7/4</td>
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<td>COMPOSITION (SS)</td>
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<tr>
<td></td>
<td></td>
<td>40-70% Carbonate unspecified</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20-50% Nannos</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5-15% Clay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1-5% Quartz</td>
</tr>
<tr>
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<td></td>
<td>Carbonate Bomb: 1-36 to 37 cm = 60.65 CaCO3</td>
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<td>Carbon-Carbonate (DSDP)</td>
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<td></td>
<td></td>
<td>2-20 (0.1, 64.5, 35.4)</td>
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<tr>
<td></td>
<td></td>
<td>Grain Size (DSDP)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2-100 (0.1, 18.2, 81.7)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3-100 (0.1, 30.7, 69.4)</td>
</tr>
</tbody>
</table>

### Site 364 Hole Core 14 Cored Interval: 425.5–435.0 m

<table>
<thead>
<tr>
<th>ZONES</th>
<th>FOSSIL CHARACTER</th>
<th>LITHOLOGIC DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CALCAREOUS NANNOSOSSIL CHALK WITH MINOR NANNOSOSSIL CHALK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MEGASCOPIC CORE DESCRIPTION</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chalk. Reddish yellow (5YR 6/6) to brown (7.5R 5/6) with minor mottles and light gray (5Y 7/2). Heavily burrowed throughout. White prismatic carbonate (calcite) layers.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LITHOLOGIC DESCRIPTION</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5YR 6/6</td>
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<tr>
<td></td>
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<td>5YR 6/6</td>
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<td>5Y 7/2</td>
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<td>7.5R 5/6</td>
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<td>30YR 7/2</td>
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<td></td>
<td>COMPOSITION (SS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50-80% Carbonate unspecified</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15-40% Nannos</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10-40% Clay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1-5% Quartz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Carbonate Bomb: 1-98 to 100 cm = 75.08 CaCO3</td>
</tr>
<tr>
<td></td>
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<td>Carbon-Carbonate (DSDP)</td>
</tr>
<tr>
<td></td>
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<td>4-17 (8.5, 0.0, 71)</td>
</tr>
<tr>
<td></td>
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<td>5-150 (8.6, 0.0, 70)</td>
</tr>
<tr>
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<td>Grain Size (DSDP)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2-88 (0.1, 23.6, 76.2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5-130 (9.0, 0.0, 71)</td>
</tr>
</tbody>
</table>

Explanatory notes in Chapter 1
### LITHOLOGIC DESCRIPTION

**Site 364**

**Core 15**

**Cored Interval:** 463.0-473.0 m

<table>
<thead>
<tr>
<th>Age</th>
<th>Zones</th>
<th>FOSSIL CHARACTER</th>
<th>Lithology</th>
<th>Velocity</th>
<th>LITHOLOGIC DESCRIPTION</th>
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<td>0</td>
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<td>0.0</td>
<td>VOID</td>
<td>CALCAREOUS NONFOSIL CHALK AND MARLY NONFOSIL CHALK</td>
</tr>
</tbody>
</table>

**MEGASCOPIC CORE DESCRIPTION**

- Reddish yellow (5YR 6/6) and light brown (7.5YR 6/4) with 10-15% of light gray (5Y 7/2), to yellowish red (5YR 5/6). Heavily burrowed throughout.

**TEXTURE**

- Sand: 3-10%
- Silt: 30-35%
- Clay: 20-25%

**COMPOSITION (SS)**

- Carbonate unspecified: 35-50%
- Clay: 20-50%
- Nannos: 15-25%
- Quartz: 2%

**Carbonate Bomb:** 1-65 to 66 cm = 72.3% CaCO₃

**Carbon-Carbonate (DSDP)**

- Grain Size (DSDP): 4-88 (0.1, 30.0, 69.9)

---

**Site 364**

**Core 16**

**Cored Interval:** 501.5-511.0 m

<table>
<thead>
<tr>
<th>Age</th>
<th>Zones</th>
<th>FOSSIL CHARACTER</th>
<th>Lithology</th>
<th>Velocity</th>
<th>LITHOLOGIC DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<td>0.0</td>
<td>VOID</td>
<td>MARLY NONFOSIL CHALK TO CALCAREOUS NONFOSIL CHALK</td>
</tr>
</tbody>
</table>

**MEGASCOPIC CORE DESCRIPTION**

- Light brown (7.5Y 6/4) with 10-20% brown (5YR 5/4) and 15-30% light gray (5Y 7/2). First appearance of distinct layer of mudstone. Heavily burrowed throughout.

**TEXTURE**

- Sand: 5%
- Silt: 45%
- Clay: 50%

**COMPOSITION (SS)**

- Carbonate unspecified: 1-2%
- Clay: 20-80%
- Nannos: 10-80%

**Carbonate Bomb:** 1-65 to 66 cm = 59.4% CaCO₃

**Carbon-Carbonate (DSDP)**

- Grain Size (DSDP): 4-88 (0.1, 30.0, 69.9)

---

Explanatory notes in Chapter 1
### Site 364 Hole 17 Cored Interval: 530.0-539.5 m

**ZONE** | **FOSSIL CHARACTER** | **LITHOLOGIC DESCRIPTION**
---|---|---
| | | CALCAREOUS NANNOFOSSIL CHALK; MINOR CALCAREOUS MUDSTONE
| | | MEASURED CORE DESCRIPTION
| | | Neptie chalk; mixture of brown (7.5YR 5/4), light brown (7.5YR 6/4) and reddish brown (5YR 4/3). Intensely burrowed throughout.
| | | SY 5/2
| | | 5Y 6/4 Sand 3-10S Silt 90-95% Clay
| | | SY 5/2
| | | COMPOSITION (SS)
| | | 1-115
| | | 40% Carbonate unspecified
| | | 20% Nannos
| | | 20% Clay
| | | 15% Quartz
| | | 3-71
| | | 60% Clay
| | | 10% Nannos
| | | 15% Carbonate unspecified
| | | Textured: 1-22 cm = 73.5% CaCO3, Carbon-Carbonate (DSDP) 0.5-132 cm = 76.8% CaCO3
| | | COMPOSITION (CC)
| | | 1-132 (7.7, 0.1, 64)
| | | 1-150 (8.0, 0.1, 66)

### Site 364 Hole 18 Cored Interval: 549.0-558.5 m

**ZONE** | **FOSSIL CHARACTER** | **LITHOLOGIC DESCRIPTION**
---|---|---
| | | CALCAREOUS NANNOFOSSIL CHALK WITH MINOR MARLY NANNOFOSSIL CHALK
| | | MEASURED CORE DESCRIPTION
| | | Neptie chalk; mostly pale brown (10YR 6/4) with light gray (5Y 7/1) and light gray (10YR 7/2). Intensely burrowed.
| | | SY 5/2
| | | 5Y 7/1 Sand 35 Silt 97% Clay
| | | SY 5/2
| | | COMPOSITION (SS)
| | | 1-78
| | | 60% Clay
| | | 30% Carbonate unspecified
| | | 10% Nannos
| | | 5% Quartz
| | | 3-83
| | | 75% Carbonate unspecified
| | | 15% Nannos
| | | 10% Clay
| | | 10% Carbonate unspecified
| | | Textured: 3-132 cm = 76% CaCO3
| | | COMPOSITION (CC)
| | | 1-132 (7.3, 0.1, 64)
| | | 1-150 (8.0, 0.1, 66)

Explanatory notes in Chapter 1
### Site 364 Hole Core 19 Cored Interval: 568.0-577.5 m

<table>
<thead>
<tr>
<th>ZONES</th>
<th>FOSSIL CHARACTER</th>
<th>LITHOLOGIC DESCRIPTION</th>
</tr>
</thead>
<tbody>
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<td>AGE</td>
<td>FRAMES</td>
<td>SECTOR</td>
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</tbody>
</table>

**LITHOLOGIC DESCRIPTION**

- **CALCAREOUS NANNOFOSSIL CHALK**
  - MARINE NANNOFOSSIL CHALK; MINOR CARBONATE-FREE MARLY CLAYSTONE

**MEGASCOPIC CORE DESCRIPTION**

- NAPPE SLATE; MOST OF CORE IS PALE BROWN (10YR 6/4 and 10YR 6/3) AND BROWN (7.5YR 6/2) WITH LIGHT GRAY (5Y 6/1 and 5Y 7/1) AND MAJOR REDDISH BROWN (7YR 3/3) BEDS
- INTENSELY BURROWED

**TEXTURE**

- *DE Sand* 3%
- *DE Clay* 97%

**COMPOSITION (SS)**

- 2%-70% Carbonate unspecified
- 45% Nannos
- 30% Clay
- 2% Quartz
- 2% Zeolite
- 3-130 cm Carbonate Bomb: 1-20 to 30 cm = 63.65 CaCO₃

**CARBONATE CONTENT (DSDP)**

- 4-20 (8.6, 0.0, 71)

- Explanatory notes in Chapter 1

---

### Site 364 Hole Core 39 Cored Interval: 577.5-587.0 m

<table>
<thead>
<tr>
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<th>FOSSIL CHARACTER</th>
<th>LITHOLOGIC DESCRIPTION</th>
</tr>
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<td>SECTOR</td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**LITHOLOGIC DESCRIPTION**

- **CALCAREOUS NANNOFOSSIL CHALK WITH MINOR SAPropelic Beds and Carbonate-Free Brown Clay**

**MEGASCOPIC CORE DESCRIPTION**

- NARROWLY NAPPED; GREENISH GRAY (5G 6/1) WITH MINOR DARK GREENISH GRAY (5GY 4/1) AT THE TOP TURNING TO LIGHT BROWNSTONE (10YR 6/2) AT BASE WITH DARK BROWN (7.5YR 3/2)

**TEXTURE**

- *DE Sand* 10%
- *DE Clay* 90%
- *DE Zeolite* 3%

**COMPOSITION (SS)**

- 2%-84% Clay
- 10% Mica
- 3% Quartz
- 3% Zeolite
- 3-40 cm Carbonate unspecified
- 20% Nannos
- 35% Clay
- 3% Quartz
- 3-40 cm Carbonate Bomb: 1-100 to 101 cm = 70.8% CaCO₃

**GRAIN SIZE (DSDP)**

- 4-20 (8.6, 0.0, 71)

- Explanatory notes in Chapter 1

---

Explanatory notes in Chapter 1
**LITHOLOGIC DESCRIPTION**

Marly Nannofossil Chalk and Black Mudstone

**MEGASCOPIC CORE DESCRIPTION**

- Marly chalk, greenish gray (5G 6/1) slight laminated - burrows make most laminae discontinuous. Laminated mudstone, greenish gray (5G 6/1), slightly burrowed. Black (NI) shale laminated to thinly laminated.

- Rich in pyrite.

**TEXTURE**

- 2.81
- 6% Sand
- 95% Silt
- 995% Clay

**COMPOSITION (SS)**

- 3-143
- 50% Carbonate unspecified
- 30% Clay
- 20% Nannos
- 4.30
- 30% Carbonate unspecified
- 5% Quartz
- 15% Clay

**Carbonate Bomb (DSDP)**

- 1-58 to 59 cm = 55.3% CaCO3
- Carbon-Carbonate
- 4-85 (4.5, 31.5, 65.7)

**Carbonate Bomb (OG)**

- 1-27 to 28 cm = 53.5% CaCO3
- Carbon-Carbonate
- 1-58 (4.5, 31.5, 65.7)

**Grain Size (DSDP)**

- 2-88 (6.5, 26.5, 72.9)

**Grain Size (OG)**

- 2-88 (6.5, 26.5, 72.9)

**Explanatory notes in Chapter 1**
### Site 364, Hole 26, Cored Interval: 701.0-710.5 m

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Lithology Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>701.0-710.5</td>
<td>Muddy Nanofossil Chalk, Calcarenaceous Marine and Black Sphagnum Chalk</td>
</tr>
</tbody>
</table>

#### Megascopic Core Description
- Greenish gray (5G 6/1) to dark greenish gray (5G 4/1). Marly chalk intensely burrowed. Dark greenish gray (5G 4/1) mudstone shows laminations in several areas, heavily burrowed.

#### Texture
- Sand: 5% 3%
- Silt: 15% 17%
- Clay: 95% 97%

#### Composition (SS)
- Carbonate unspecified: 58% 22%
- Clay: 20% 15%
- Nannofossils: 10% 11%
- Foraminifera: 7% 8%

#### Carbonate Bomb: 1-122 to 123 cm
- CaCO₃: 2-135 to 136 cm

#### Grain Size (DSDP)
- 4-78 (3.0, 24.8, 72.2)
- 4-140 (5.6, 0.1, 46)

Explanatory notes in Chapter 1
### LITHOLOGIC DESCRIPTION

#### Site 364 Hole Core 31 Cored Interval: 805.5-815.0 m

- **LIMESTONE AND MARLY LIMESTONE**
  - **MEGASCOPIC CORE DESCRIPTION**
    - Limestone, light bluish gray (5B 7/1).
    - Burrows common throughout. Stylolitic seams develop in some parts. The irregular clay stringer and stylolitic seams give the rock a "marbled" appearance. Marly limestone.
    - Dark greenish gray (5GY 5/1), greenish gray (5G 6/1) with many laminations and sandy texture.

<table>
<thead>
<tr>
<th>Texture</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-30%</td>
<td>1-30%</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>20%</td>
<td>78%</td>
</tr>
</tbody>
</table>

#### COMPOSITION (SS)

<table>
<thead>
<tr>
<th>Carbonate unspecified</th>
<th>Clay</th>
<th>Forams</th>
<th>Nannos</th>
</tr>
</thead>
<tbody>
<tr>
<td>45%</td>
<td>2%</td>
<td>1%</td>
<td>4%</td>
</tr>
</tbody>
</table>

- **Carbonate Bomb:** 1-72 to 73 cm = 35.1% CaCO₃

#### Site 364 Hole Core 32 Cored Interval: 804.5-814.0 m

- **MIDDLE TO LOWER ALBIAN** (forams)
  - *Ticinella primula to Ticinella bejouensis*

### LITHOLOGIC DESCRIPTION

#### Site 364 Hole Core 31 Cored Interval: 805.5-815.0 m

- **LIMESTONE AND MARLY LIMESTONE**
  - **MEGASCOPIC CORE DESCRIPTION**
    - Limestone, light bluish gray (5B 9/1).
    - Looks like "marble" with irregular dark wispy bands are numerous. Burrowing throughout. Dark greenish gray (5GY 4/1), marly limestones show poorly defined laminations and some burrowing.

<table>
<thead>
<tr>
<th>Texture</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-5%</td>
<td>1-1%</td>
<td>92%</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>25%</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>20%</td>
<td>60%</td>
</tr>
</tbody>
</table>

#### COMPOSITION (SS)

<table>
<thead>
<tr>
<th>Carbonate unspecified</th>
<th>Clay</th>
<th>Nannos</th>
<th>Forams</th>
</tr>
</thead>
<tbody>
<tr>
<td>60%</td>
<td>25%</td>
<td>10%</td>
<td>2%</td>
</tr>
</tbody>
</table>

- **Carbonate Bomb:** 1-51 to 52 cm = 35.8% CaCO₃

#### Site 364 Hole Core 32 Cored Interval: 804.5-814.0 m

- **MIDDLE TO LOWER ALBIAN** (nannos)
  - *Ticinella primula to Ticinella bejouensis*

### LITHOLOGIC DESCRIPTION

#### Site 364 Hole Core 31 Cored Interval: 805.5-815.0 m

- **LIMESTONE AND MARLY LIMESTONE**
  - **MEGASCOPIC CORE DESCRIPTION**
    - Limestone, light bluish gray (5B 9/1).
    - Looks like "marble" with irregular dark wispy bands are numerous. Burrowing throughout. Dark greenish gray (5GY 4/1), marly limestones show poorly defined laminations and some burrowing.

<table>
<thead>
<tr>
<th>Texture</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-5%</td>
<td>1-1%</td>
<td>92%</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>25%</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>20%</td>
<td>60%</td>
</tr>
</tbody>
</table>

#### COMPOSITION (SS)

<table>
<thead>
<tr>
<th>Carbonate unspecified</th>
<th>Clay</th>
<th>Nannos</th>
<th>Forams</th>
</tr>
</thead>
<tbody>
<tr>
<td>60%</td>
<td>25%</td>
<td>10%</td>
<td>2%</td>
</tr>
</tbody>
</table>

- **Carbonate Bomb:** 1-51 to 52 cm = 35.8% CaCO₃

#### Site 364 Hole Core 32 Cored Interval: 804.5-814.0 m

- **MIDDLE TO LOWER ALBIAN** (nannos)
  - *Ticinella primula to Ticinella bejouensis*

### LITHOLOGIC DESCRIPTION

#### Site 364 Hole Core 31 Cored Interval: 805.5-815.0 m

- **LIMESTONE AND MARLY LIMESTONE**
  - **MEGASCOPIC CORE DESCRIPTION**
    - Limestone, light bluish gray (5B 9/1).
    - Looks like "marble" with irregular dark wispy bands are numerous. Burrowing throughout. Dark greenish gray (5GY 4/1), marly limestones show poorly defined laminations and some burrowing.

<table>
<thead>
<tr>
<th>Texture</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-5%</td>
<td>1-1%</td>
<td>92%</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>25%</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>20%</td>
<td>60%</td>
</tr>
</tbody>
</table>

#### COMPOSITION (SS)

<table>
<thead>
<tr>
<th>Carbonate unspecified</th>
<th>Clay</th>
<th>Nannos</th>
<th>Forams</th>
</tr>
</thead>
<tbody>
<tr>
<td>60%</td>
<td>25%</td>
<td>10%</td>
<td>2%</td>
</tr>
</tbody>
</table>

- **Carbonate Bomb:** 1-51 to 52 cm = 35.8% CaCO₃

#### Site 364 Hole Core 32 Cored Interval: 804.5-814.0 m

- **MIDDLE TO LOWER ALBIAN** (nannos)
  - *Ticinella primula to Ticinella bejouensis*

### LITHOLOGIC DESCRIPTION

#### Site 364 Hole Core 31 Cored Interval: 805.5-815.0 m

- **LIMESTONE AND MARLY LIMESTONE**
  - **MEGASCOPIC CORE DESCRIPTION**
    - Limestone, light bluish gray (5B 9/1).
    - Looks like "marble" with irregular dark wispy bands are numerous. Burrowing throughout. Dark greenish gray (5GY 4/1), marly limestones show poorly defined laminations and some burrowing.

<table>
<thead>
<tr>
<th>Texture</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-5%</td>
<td>1-1%</td>
<td>92%</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>25%</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>20%</td>
<td>60%</td>
</tr>
</tbody>
</table>

#### COMPOSITION (SS)

<table>
<thead>
<tr>
<th>Carbonate unspecified</th>
<th>Clay</th>
<th>Nannos</th>
<th>Forams</th>
</tr>
</thead>
<tbody>
<tr>
<td>60%</td>
<td>25%</td>
<td>10%</td>
<td>2%</td>
</tr>
</tbody>
</table>

- **Carbonate Bomb:** 1-51 to 52 cm = 35.8% CaCO₃

#### Site 364 Hole Core 32 Cored Interval: 804.5-814.0 m

- **MIDDLE TO LOWER ALBIAN** (nannos)
  - *Ticinella primula to Ticinella bejouensis*
### Lithologic Description

**Limestone**
- Colors alternate from olive gray (5Y 4/1), light bluish gray (5B 7/1) to light brownish gray (5YR 6/1). Zones of well-developed lamination cut by alternate with nonlaminated laminae are wavy and irregular.

**Texture**
- Sand 95%, Clay 5%

**Composition (SS)**
- 53% Carbonate unspecified
- 40% Clay
- 7% Foraminifera
- 2% Nannos

**Carbonate Bomb:** 1-105 to 106 cm = 86.3% CaCO₃

**Grain Size (DSDP)**
- 4-53 (7.5, 0.3, 60)

**Grain Size (OG)**
- 3-130 (6.7, 0.6, 51)
- 3-150 (6.4, 0.1, 51)

### Megascopic Core Description

- Limestone. Light bluish gray (5B 7/1) with minor grayish green (5GY 5/1).
- Stylolitic seams, burrows, irregular laminae, and nodular structure are common. Marly limestone. Dark green gray (5GY 4/1), greenish gray (5GY 6/1) to olive gray (5Y 5/1).

**Texture**
- Sand 95%, Clay 5%

**Composition (SS)**
- 53% Carbonate unspecified
- 40% Clay
- 7% Foraminifera
- 2% Nannos

**Carbonate Bomb:** 1-105 to 106 cm = 86.3% CaCO₃

**Grain Size (DSDP)**
- 4-53 (7.5, 0.3, 60)

**Grain Size (OG)**
- 3-130 (6.7, 0.6, 51)
- 3-150 (6.4, 0.1, 51)

---

**Middle to Lower Albian (Torridon, Upper Albian (Ham))**

- Tectonic prisms to Twin Valley depletions
- Effective porosity? Folds
- Core Catcher
- Wear Track (NG)
### Site 364 Hole Core 35
Cored Interval: 991.0-900.5 m

<table>
<thead>
<tr>
<th>Section</th>
<th>Meters</th>
<th>Lithology</th>
<th>Lithologic Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>Void</td>
<td>Contorted bedding with zone of greenish gray (5G 5/1), ( \text{CaCO}_3 ) 74.2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Contorted layers deformed locally. Burrowing present only in light layers especially near top.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Limestone. Light bluish gray (5B 7/1) to light bluish gray (5B 7/1) with minor greenish gray (5G 5/1) stringers and laminae. The lower half core is strongly folded and appear to be &quot;slump&quot; structure.</td>
</tr>
<tr>
<td>1</td>
<td>0-1</td>
<td>Clay</td>
<td>Sand</td>
</tr>
<tr>
<td>2</td>
<td>1-2</td>
<td>Clay</td>
<td>Silt</td>
</tr>
<tr>
<td>3</td>
<td>2-3</td>
<td>Clay</td>
<td>Silt</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Contorted bed</td>
</tr>
</tbody>
</table>

### Site 364 Hole Core 36
Cored Interval: 910.0-919.5 m

<table>
<thead>
<tr>
<th>Section</th>
<th>Meters</th>
<th>Lithology</th>
<th>Lithologic Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>Void</td>
<td>Contorted bedding with zone of greenish gray (5G 5/1), ( \text{CaCO}_3 ) 74.2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Contorted layers deformed locally. Burrowing present only in light layers especially near top.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Limestone. Gray (5Y 6/1) to light bluish gray (5B 7/1) with minor greenish gray (5G 5/1) stringers and laminae. The lower half core is strongly folded and appear to be &quot;slump&quot; structure.</td>
</tr>
<tr>
<td>1</td>
<td>0-1</td>
<td>Clay</td>
<td>Sand</td>
</tr>
<tr>
<td>2</td>
<td>1-2</td>
<td>Clay</td>
<td>Silt</td>
</tr>
<tr>
<td>3</td>
<td>2-3</td>
<td>Clay</td>
<td>Silt</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Contorted bed</td>
</tr>
</tbody>
</table>

Explanatory notes in Chapter 1
**LITHOLOGIC DESCRIPTION**

**SITE 364**

**MEGASCOPIC CORE DESCRIPTION**

**LIMESTONE AND MARLY LIMESTONE**

*Marly limestone* olive gray (5Y 4/1) laminated heavily. Burrowing limited. Limestone, light bluish gray (5B 7/1) massive limestone, heavily burrowed. Blush black haloes around some structure may be organic remains.

**TEXTURE**

<table>
<thead>
<tr>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>5%</td>
<td>30%</td>
<td>65%</td>
</tr>
</tbody>
</table>

**COMPOSITION (SS)**

<table>
<thead>
<tr>
<th>Carbonate unspecified</th>
<th>Organic matter</th>
<th>Nannos</th>
<th>Clay</th>
<th>Dolomite rhombs</th>
<th>Forams</th>
<th>Pyrite</th>
<th>Quartz</th>
</tr>
</thead>
<tbody>
<tr>
<td>38%</td>
<td>25%</td>
<td>15%</td>
<td>10%</td>
<td>15%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
</tr>
</tbody>
</table>

**Carbonate Bomb**: 1-21 to 22 cm - 86.6% CaCO

**Carbon-Carbonate (DSDP)**

<table>
<thead>
<tr>
<th>SY 4/1</th>
<th>SY 4/1</th>
<th>SY 4/1</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-146 (7.8, 1.2, 55)</td>
<td>6-116 (10.0, 1.3, 73)</td>
<td>109</td>
</tr>
</tbody>
</table>
**Site 364**

**Hole** Core 99 Cored Interval: 967.0-976.5 m

### Lithologic Description

<table>
<thead>
<tr>
<th>ZONE</th>
<th>FOSSIL CHARACTER</th>
<th>METERS</th>
<th>LITHOLOGY</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>0-0.5</td>
<td>VOID</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>0.5-1</td>
<td>5Y 4/1</td>
<td>Marly limestone and black shale with minor sapropelic shale.</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>1-2</td>
<td>5Y 3/1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>2-3</td>
<td>5Y 6/1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>3-4</td>
<td>5Y 5/2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>4-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>5-6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Megascopic Core Description**

- Marly limestone, dark gray (5Y 7/1) and light olive gray (5Y 6/1) to olive gray (5Y 4/1). Black shale, petroliferous odor. Olive gray (5Y 4/1) to olive black (5Y 2/1). Laminated.

**Texture**

- Sand 2-118
- Silt 2-118
- Clay 2-118

**Composition (SS)**

- Carbonate unspecified 2-118
- Organic matter 2-118
- Dolomite rhombs 2-118
- Nannos 2-118
- Quartz 2-118
- Pyrite 2-118

Carbonate Bomb: 2-132 to 133 cm 85.

**Laminae**

- 1-140 to 141 cm = 16.1 X

**Explanatory notes in Chapter 1**

**SITE 364**

**Hole** Core 40 Cored Interval: 885.0-995.5 m

### Lithologic Description

<table>
<thead>
<tr>
<th>ZONE</th>
<th>FOSSIL CHARACTER</th>
<th>METERS</th>
<th>LITHOLOGY</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>0-0.5</td>
<td>VOID</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>0.5-1</td>
<td>5Y 4/1</td>
<td>Marly limestone and black shale with minor sapropelic shale.</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>1-2</td>
<td>5Y 3/1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>2-3</td>
<td>5Y 6/1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>3-4</td>
<td>5Y 5/2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>4-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>5-6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Megascopic Core Description**

- Marly limestone, dark gray (5Y 7/1) to olive gray (5Y 4/1). Black shale, petroliferous odor. Olive gray (5Y 4/1) to olive black (5Y 2/1). Laminated.

**Texture**

- Sand 1-132
- Silt 15%
- Clay 85%

**Composition (SS)**

- Carbonate unspecified 1-132
- Organic matter 35%
- Dolomite rhombs 8%
- Nannos 3%
- Quartz 3%
- Pyrite 2%
- Barite vein 1-132

**Carbonate Bomb: 2-132 to 133 cm 85.85 CaCO₃**

**Reverse Faults**

- Inclination 60° maximum

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

**MARLY LIMESTONE, BLACK SAPROPECIL SHALE AND DOLOMITIC LIMESTONE**

**MEGASCOPIC CORE DESCRIPTION**
- Thinly laminated marly limestone with petroliferous odor and appearance of sandy texture. Mostly olive gray (5Y 4/1).
- In the lower half of the core, some layers of massive limestone with burrowing with greenish black (5G 2/1).

**TEXTURE**
- 5% Sand
- 40% Silt
- 55% Clay

**COMPOSITION (SS)**
- 48% Carbonate unspecified
- 20% Dolomite rhombs
- 20% Clay
- 2% Pyrite

**Carbonate Bomb: 2-140 to 141 cm = 16.5% CaCO₃**

**Carbon-Carbonate (DSDP)**
- 4-32 (12.7, 7.3, 45)
- 4-75 (12.7, 7.3, 45)
- 6-32 (25.5, 22.5, 25)

**Explanatory notes in Chapter 1**
**Site 364**

**Core 43**

Cored Interval: 1032.5-1043.0 m

### LITHOLOGIC DESCRIPTION

<table>
<thead>
<tr>
<th>ZONES</th>
<th>HOUSING</th>
<th>HOUSING</th>
<th>HOUSING</th>
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<th>LITHOLOGIC DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LIMESTONE AND BLACK SHALE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(Part of limestone is dolomitic)</td>
</tr>
</tbody>
</table>

**MEGASCOPIC CORE DESCRIPTION**

Limestone, greenish gray (5G 6/1) to light bluish gray (5B 7/1). Very heavily burrowed, somewhat brecciated, dolomitic. Lower part has numerous fractures and faults. Black shale, olive black (5Y 2/1). Some evidence of minor burrowing at top.

**TEXTURE**

- 30% Sand
- 28% Silt
- 42% Clay

**COMPOSITION (SS)**

- 9% Clay
- 28% Dolomite rhombs
- 10% Carbonate unspecified
- 1% Pyrite

**Carbonate Bomb:** 2-109 to 110 cm = 53.5% CaCO₃

**Carbon-Carbonate (OG)**

1-150 (9.5, 0.3, 77)

---

**Site 364**

**Core 44**

Cored Interval: 1043.0-1052.5 m

### LITHOLOGIC DESCRIPTION

<table>
<thead>
<tr>
<th>ZONES</th>
<th>HOUSING</th>
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<th>LITHOLOGIC DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ALTERNATING DOLOMITIC LIMESTONE AND BLACK SHALE</td>
</tr>
</tbody>
</table>

**MEGASCOPIC CORE DESCRIPTION**

Black (5Y) shale interbedded with olive gray (5Y 4/1), dark greenish gray (5GY 4/1) and olive gray (5Y 4/1) limestone. Limestone moderately heavily burrowed. Shale thinly laminated. Fine-grained, uniformly black shale is calcareous.

**TEXTURE**

- 49% Clay
- 0% Sand
- 46% Silt
- 5% Clay

**COMPOSITION (SS)**

- 96% Dolomite
- 5% Carbonate unspecified
- 3% Quartz

**Carbonate Bomb:** 2-17 to 18 cm = 52.15% CaCO₃

**Carbon-Carbonate (DSDP)**

4-10 (11.1, 1.2, 84)

---
Site 364 Hole Core 45 Cored Interval: 1062.0-1071.5 m

<table>
<thead>
<tr>
<th>ZONE</th>
<th>FOSSIL CHARACTER</th>
<th>LITHOLOGY</th>
<th>LITHOLOGIC DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>Void</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>

**DOLOMITIC LIMESTONE AND BLACK SHALE**

**MEGASCOPIC CORE DESCRIPTION**
- Olive gray (5Y 4/1) to olive black (5Y 2/1) dolomite, heavily burrowed.
- Faulting and contorted laminae are observed at the lower half of the core.

**TEXTURE**
- 2-5

**COMPOSITION (SS)**
- 58% Dolomite
- 30% Clay
- 5% Carbonate unspecified
- 2% Pyrite

**Carbonate Bomb: 1.440 to 1.45 cm = 0.026 CaCO3**

---

Site 364 Hole Core 46 Cored Interval: 1081.0-1086.0 m

<table>
<thead>
<tr>
<th>ZONE</th>
<th>FOSSIL CHARACTER</th>
<th>LITHOLOGY</th>
<th>LITHOLOGIC DESCRIPTION</th>
</tr>
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<tbody>
<tr>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>

**DOLOMITE**

**MEGASCOPIC CORE DESCRIPTION**
- Olive gray (5Y 4/1) to dark olive-gray (5Y 3/1) dolomite, heavily burrowed.

**TEXTURE**
- 2-5

**COMPOSITION (SS)**
- 75% Dolomite
- 13% Clay
- 2% Carbonate unspecified
- 2% Pyrite

**Explanatory notes in Chapter 1**
### Site 365 Hole Core 1 Cored Interval: 225.0-234.5 m

#### FOSSIL CHARACTER

<table>
<thead>
<tr>
<th>Core</th>
<th>Catcher</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### LITHOLOGIC DESCRIPTION

<table>
<thead>
<tr>
<th>Meter</th>
<th>5Y 4/1</th>
<th>5Y 2/1</th>
<th>5G 2/1</th>
<th>5G 6/1</th>
</tr>
</thead>
</table>
| 75    | 7.1 meters of olive gray (5Y 4/1), olive black (5Y 2/1), and dark gray green (5Y 4/1) mud containing calcareous nannofossil material and pyrite. Underlying the mud is 30 cm of moderate brown (5YR 6/3) tuffaceous mud and 50 cm of moderate brown (5YR 6/3) tuffaceous mudstone.
<table>
<thead>
<tr>
<th>Meter</th>
<th>76</th>
<th>75</th>
<th>74</th>
<th>73</th>
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#### LAMINATED MUDSTONE (Sections 1 and 2)

<table>
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<tr>
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<th>5Y 4/1</th>
<th>5Y 2/1</th>
<th>5G 2/1</th>
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#### MARLY NANNOFOSSIL CHALK (Section 3)

<table>
<thead>
<tr>
<th>Meter</th>
<th>5Y 4/1</th>
<th>5Y 2/1</th>
<th>5G 2/1</th>
</tr>
</thead>
</table>
| 75    | 7.1 meters of olive gray (5Y 4/1), olive black (5Y 2/1), and dark gray green (5Y 4/1) mud containing calcareous nannofossil material and pyrite. Underlying the mud is 30 cm of moderate brown (5YR 6/3) tuffaceous mud and 50 cm of moderate brown (5YR 6/3) tuffaceous mudstone. Thin interbeds of black lithified nannofossil present in Section 3. Laminae dipping 30° in top 10 cm of Section 2.
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**CAMPANIAN** (in reworked forams and nannos)

**EXPLANATORY NOTES IN CHAPTER 1**
**Site 365 Hole Core 3**

**Cored Interval:** 394.0-405.5 m

<table>
<thead>
<tr>
<th>Layer</th>
<th>Lithologic Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Laminated claystone and mudstone with 1 thin bluish white (5B 9/1) limestone bed. Black (NI) is predominant color. Dark greenish gray (5GY 4/1), greenish black (5G 2/1), and brownish black (5YR 2/1) layers are present. Soft mud occurs near base of Section 2. Moderate burrowing.</td>
</tr>
<tr>
<td>2</td>
<td>Laminated claystone and mudstone with minor amounts of dark reddish brown (10YR 3/4) mudstone. Red and brown colors identical to grays except for percent of iron oxide. Section 2 has 10 cm of greenish gray (5GY 6/1) dolomite cemented sandstone.</td>
</tr>
<tr>
<td>3</td>
<td>Brownish gray (5YR 4/1) and medium bluish gray (5B 5/1) mudstone with minor amounts of dark reddish brown (10YR 3/4) mudstone. Red and brown colors identical to grays except for percent of iron oxide. Section 2 has 10 cm of greenish gray (5GY 6/1) dolomite cemented sandstone.</td>
</tr>
</tbody>
</table>

**SITES**
Greenish gray (5G 6/1) mudstone with scattered fine sandy layers that probably represent turbidites. One bed is graded. Burrowing is moderate but most sandy layers are burrowed. Good Zoophycos occur in Sections 1 and 2. Angular mud clasts occur in Section 3 between 75 and 150 cm.

MUDSTONE

- 65-70% Quartz
- 5% Feldspar
- 3-5% Mica
- 15-20% Clay
- 2-3% Pyrite
- 3-5% Pyrite
- Sand: 1%, Silt: 25%, Clay: 74%

Coarse fractions: 6 cc
- Quartz 65%, Fish debris 33%, Mica 25%, Unspecified carbonate 10%, and Pyrite 2%

Carbon-Carbonate (DSDP)
- 4-16 (2.5, 16.7, 38.9)

Explanatory notes in Chapter 1
Site 365  Hole  Core 7  Cored Interval: 681.0-687.0 m

FOSSIL LITHOLOGIC DESCRIPTION

Zoophycos

Core Catcher

Medium bluish gray (5B 5/1) mudstone with abundant white benthonic foraminifera. Slightly burrowed. At top is 12 cm of greenish gray (5B 6/1) sand with numerous black grains. This same sand fills between the core and the liner in both sections and probably represents a sandy unit between Cores 6 and 7 that was washed instead of cored.

MUDSTONE

SS 1-75, 2-90, 2-125, CC
80% Clay
5-15% Mica
3% Quartz
2% Pyrite
T-2% Chlorite
1-% Zeolites
0-3% Organics

Sand: 1%, Silt: 10-15%, Clay: 84-89%

SAND

SS-5
49% Quartz
10% Mica
20% Clay
6% Pyrite
15% Zeolites

The numerous euhedral silt-sized zeolites in this sand suggest it is a washed residue from the drilling operation.

Coarse fractions 7 cc
Quartz  and Feldspar 60%, Lita, fragments 50%, Fish teeth 9%, Mica 5%, unspecified carbonate 2%, Pyrite 2%, Foramin 2%. Pyritized rad 2%. Some quartz well-rounded.

Carbon-Carbonate (DSDP)
1-63 (0.1, 0.1, 0)
Grain Size (DSDP)
1-38 (0.4, 40.5, 59.1)

Explanatory notes in Chapter 1