# Detailed Stratigraphic Description of the JOIDES Cores on the Continental Margin off Florida

GEOLOGICAL SURVEY PROFESSIONAL PAPER 581-D

*Prepared in cooperation with the Institute of Marine Sciences, University of Miami, and the Joint Oceanographic Institutions' Deep Earth Sampling Program*

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*By* W. B. CHARM, W. D. NESTEROFF, *and* SYLVIA VALDES

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*A description of 513 meters of core from six holes drilled into the continental shelf, the Florida-Hatteras Slope, and the Blake Plateau off the east coast of Florida*

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## DRILLING ON THE CONTINENTAL MARGIN OFF FLORIDA

Drilling on the continental margin off Jacksonville, Fla., in 1965 was the first project undertaken by the Joint Oceanographic Institutions' Deep Earth Sampling (JOIDES) Program, sponsored by the National Science Foundation through grant GP 4233 to Lamont Geological Observatory. The U.S. Geological Survey cooperated with the Oceanographic Institutions in this undertaking and is publishing the results of these investigations in a series of professional papers.

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# DETAILED STRATIGRAPHIC DESCRIPTION OF THE JOIDES CORES ON THE CONTINENTAL MARGIN OFF FLORIDA[1]

By W. B. CHARM,[2] W. D. NESTEROFF,[3] and SYLVIA VALDES [2]


## ABSTRACT

A total of 513 meters of core was recovered from six holes drilled into the continental shelf, the Florida-Hatteras Slope, and the Blake Plateau off the east coast of Florida. From every 76 centimeters of core, a sample was taken for petrologic examination and for determination of the calcium carbonate and the percent coarser than 62 microns.

Limestones, sands, silts, and clays, presumably of shallow-water origin, make up the Eocene and younger sediments that lie beneath the continental shelf east of Jacksonville, Fla. The upper Eocene and Oligocene sediments thicken slightly toward the edge of the shelf.

Alternating layers of clay and limestone were deposited on the Florida-Hatteras Slope during the Eocene and Oligocene Epochs. Since the Miocene (Miocene sediments are absent), they have been covered by a clay that grades upward into a sand.

Foraminiferal oozes and silts have prevailed since the Eocene on the Blake Plateau.


## INTRODUCTION

In May 1965, six holes were drilled on the continental shelf, the Florida-Hatteras Slope, and the Blake Plateau off Jacksonville, Fla. (John Schlee and Robert Gerard, unpub. data, 1965) (fig. 1). All six penetrated at least to the Oligocene, and two reached rocks of Paleocene age (fig. 2). Drilling depths in the six holes totaled about 2,052 meters, and 1,433 m of coring was attempted. Core was recovered from 513 m, and identifiable fragments were recovered from another 500 m or so of the cored interval. A reasonably complete picture of continental shelf and slope sedimentation throughout the Tertiary was thus obtained (table 1).

This paper presents a detailed stratigraphic log of the six cores, based on a sampling interval of 76 centimeters for the 513 m of core recovered. This will provide a general framework for further, more specialized and detailed studies of the cores by interested investigators. The cores are stored under refrigeration at the Institute of Marine Sciences, University of Miami, Miami, Fla.


## ACKNOWLEDGMENTS

The authors are greatly indebted to Cesare Emiliani, Enrico Bonatti, Wayne Bock, and Louis Lidz, all of the University of Miami, and John Schlee and R. H. Meade of the U.S. Geological Survey, who read the manuscript and contributed many valuable suggestions. We also thank Warren Kemp for the computer programing that produced the graphs. The work was supported by National Science Foundation grants GP5057, GP5012, and GA583.


## METHODS

Throughout the length of all six cores, a 10-gram sample was taken from half of each core at 76-cm intervals. In all, 650 samples were examined. The other half of the core was preserved as an archive section. Each sample was analyzed gasometrically for total calcium carbonate (Bien, 1952; Hülsemann, 1966) and sieved to determine the coarse fraction (fraction $>62\mu$). The components listed in columns 4–19 (pl. 1) were estimated rapidly from frequency estimation charts (Terry and Chilingar, 1955; Ingram, 1965).

Because of the many samples and the large number of parameters, the results are best illustrated on graphic logs (p. 1). Symbols indicate the percentage of organisms and minerals in the coarse fraction (Rusnak and Luft, 1963).

## CORE J–1

Eocene, Oligocene, Miocene, and post-Miocene sediments were recovered from core hole J–1 (pl. 1).

### EOCENE SANDS AND LIMESTONES

The Eocene sediments and sedimentary rock consist primarily of shallow-water clayey sands and limestone composed predominantly of bioclastic debris and shells.

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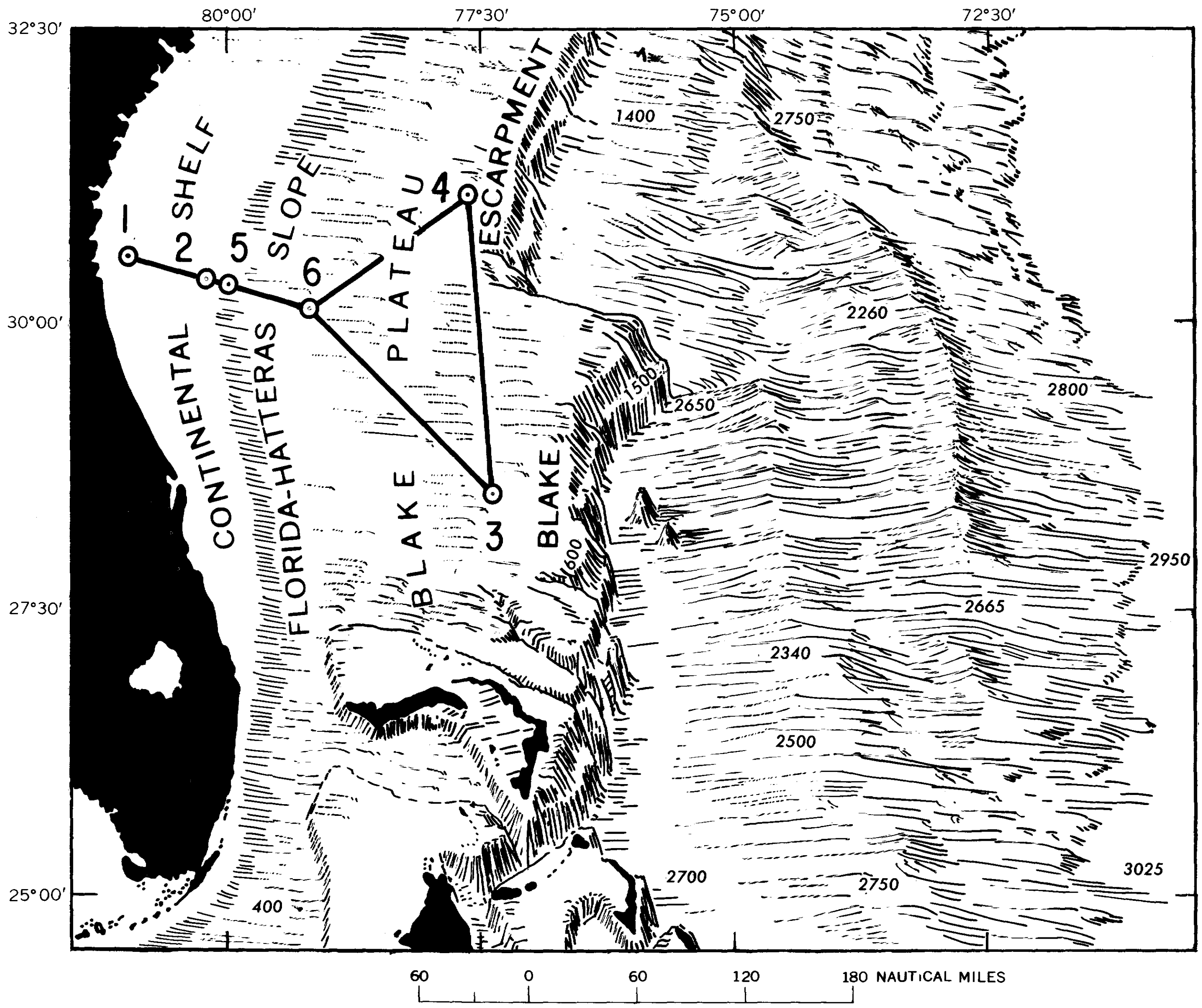



FIGURE 1.—JOIDES drill holes on the continental margin east of Florida. Vertical exaggeration × 30; depth in meters. Base from Heezen, Tharp, and Ewing (1959, sheet 1).

Benthic and planktonic Foraminifera, echinoderm spines and plates, holothurian spicules, bryozoans, and coral fragments are present (Joint Oceanographic Institutions' Deep Earth Sampling Program, 1965). Much of the bioclastic debris is not identifiable because it has been recrystallized. The terrigenous component of the coarse fraction is represented by a few angular quartz grains, approximately 120$\mu$ in diameter.

Most of the Eocene section is limestone that contains scattered dolomitic layers. Some of the section is still unconsolidated and contains numerous authigenic crystals of calcite and dolomite. In general, these authigenic crystals are less than 1 percent of the coarse fraction, but in some samples, the perfectly formed dolomite crystals constitute 60–70 percent of the coarse fraction. Other authigenic minerals, such as pyrite, appear to be associated with glauconite grains; pyrite is intergrown with glauconite in a few samples.

### OLIGOCENE OOZES

The Oligocene deposits are slightly shelly calcareous oozes. The coarse fraction ranges from 3 to 10 percent, and the total carbonate, from 70 to 95 percent. The coarse fraction is composed of biogenic debris and terrigenous angular quartz grains averaging 125$\mu$ in diameter and forming 2–25 percent of the coarse fraction. Many crystals of authigenic calcium carbonate or dolomite were observed in the unconsolidated sediments.

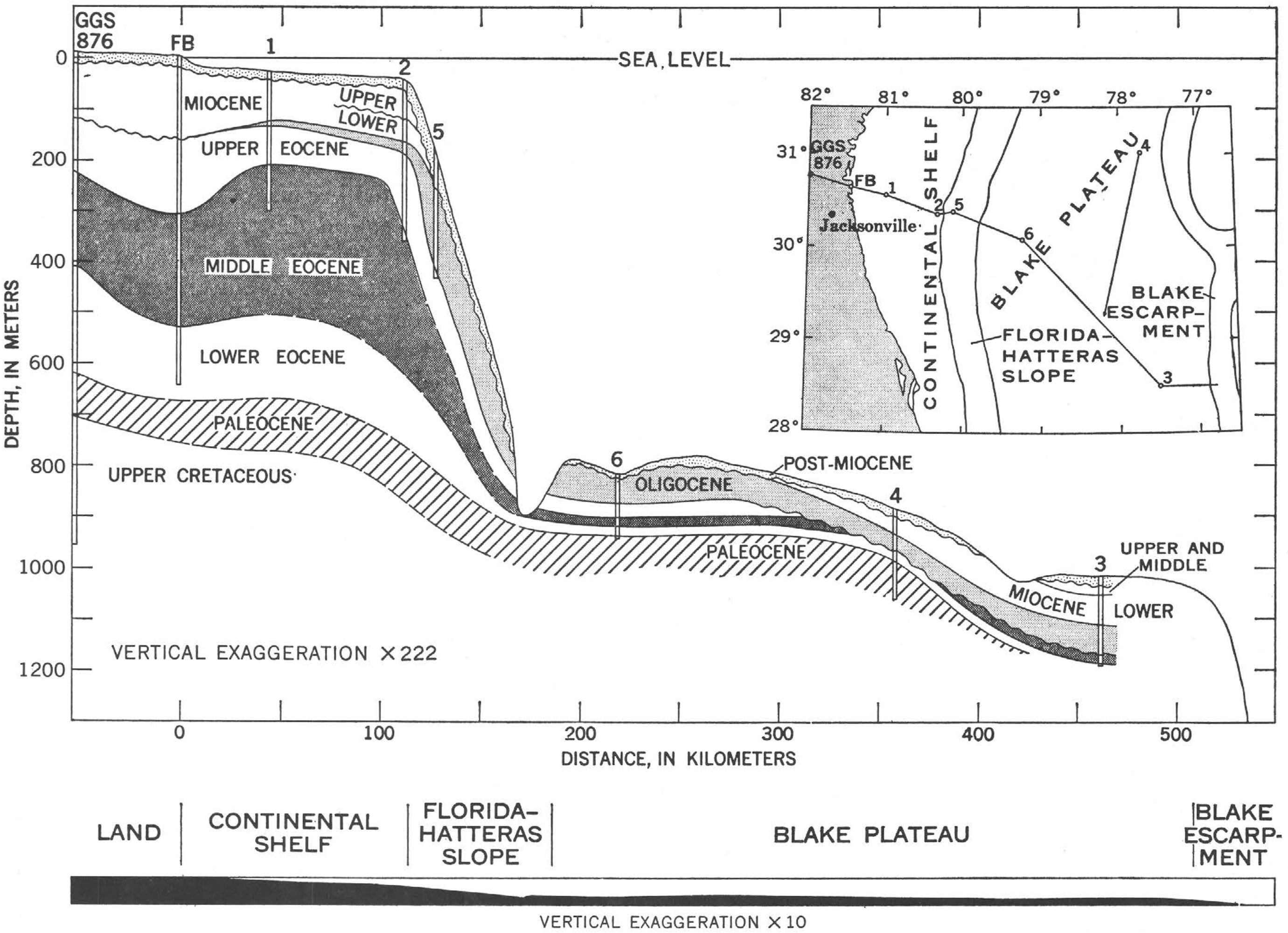



FIGURE 2.—Stratigraphic profile from JOIDES drill holes 1–6, 1965, and earlier drill holes in Florida (GGS 876 and FB). Actual inclination of Florida-Hatteras Slope is about 4°. (Modified from Joint Oceanographic Institutions' Deep Earth Sampling Program, 1965.)

Phosphate is represented by phosphatized shell debris and pellets; it ranges from rare to 3 percent of the coarse fraction. The pellets average 140$\mu$ in diameter, but some reach 500$\mu$. Pellets are always in greater abundance than are the phosphatized shells. A small amount of glauconite is associated with the phosphate, and pyrite (less than 1 percent) is present throughout the unit.

### MIOCENE SILTS

The Miocene deposits are distinctly different from the carbonate-rich Eocene and Oligocene sediments. They consist of terrigenous sandy and clayey silts.

In the lower part of the Miocene (99–51 m below the sea floor), the sand-sized particles are detrital quartz grains and phosphatic pellets (pl. 2). The terrigenous component of the sand fraction is well-sorted angular quartz approximately 120$\mu$ in diameter, rare unidentified heavy minerals, feldspar, and mica. Some rare large (500$\mu$–1,000$\mu$) rounded and frosted quartz grains were noted. Abundant light- to blackish-brown phosphate pellets, 140$\mu$–200$\mu$ in diameter, are also associated with the terrigenous minerals. Phosphate granules, 1–4 mm in diameter, have also been found, as well as small amounts of phosphatized shell fragments. Phosphate is particularly abundant in the lower part of the Miocene, constituting 1–95 percent of the total sediment; the higher amounts are in discrete lenses. From 99 to 51 m, nearly all the bioclastic debris has been altered to phosphate; only occasionally does one find an unaltered foraminifer or shell fragment. Dolomitic aggregates are mixed with phosphate at some depths. They are generally rare and small (100$\mu$–300$\mu$), but are occasionally very large (2–3 cm) and may form 30 percent of the total sediment.

Between 51 and 46 m, the percentage of phosphate drops sharply, and very coarse quartz constitutes 60–65 percent of the whole sediment at 48 m. The

TABLE 1.—*Sediment types and index faunas of cores from offshore drill holes*

[Uncertainty in boundaries and thicknesses is at least ±1.5 m because faunas were identified in samples taken at 3-m intervals. From Joint Oceanographic Institutions' Deep Earth Sampling Program (1965), except for sediment types]

| Age | | J-1 (25m) [1] | | | | J-2 (42-46m) [1] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Depth (m) | Thickness | Sediment type | Index fauna | Depth (m) | Thickness | Sediment type | Index fauna |
| Post-Miocene | | 0-20.4 | 20.4 | Clayey quartzose sand to sandy clay | | 0-48.8 | 48.8 | Shelly quartzose sand and sandstone | |
| Miocene | Late | 20.4-99.0 | 78.6 | Silty and sandy clay to clayey phosphatic sand | *Globigerina apertura* | 48.8-79.2 | 30.6 | Quartzose sandy clay | *Globigerina apertura* |
| | Middle | | | | | | | | |
| | Early | | | | Diatom flora and radiolarian fauna | 79.2-124.3 | 42.1 | Quartzose sandy clay | *Globigerinoides altiapertura* |
| Oligocene | | 99.0-108.2 | 9.2 | Calcilutite | *Bulimina ovata primitiva*<br>*Pararotalia byramensis*<br>*Chiloguembelina cubensis*<br>*Globanomalina micra*<br>*Globorotalia postcretacea* | 124.3-149.4 | 28.1 | Calcilutite | *Chiloguembelina cubensis*<br>*Globanomalina micra*<br>*Globorotalia postcretacea* |
| Eocene | Late | 108.2-182.9 | 74.7 | Clayey calcarenite and limestones | *Cribrohantkenina marielina*<br>*Gyroidina crystalriverensis*<br>*Gyroidina nassauensis*<br>*Lepidocyclina ocalana*<br>*Operculinoides floridensis*<br>*Operculinoides ocalanus* | 149.4-298.8 | 149.4 | Calcarenite and calcilutite | *Eponides jacksonensis*<br>*Operculinoides ocalanus*<br>*Hantkenina primitiva* |
| | Middle | 182.9-277.4 | 94.5 | Clayey calcarenite limestones and dolomite | *Caskinolina floridana*<br>*Dictyiconus americanus*<br>*Discorbis inornatus*<br>*Valvulina martii*<br>*Lepidocyclina* sp. | 298.8-320.2 | 21.4 | Calcarenite and dolomite | *Dictyoconus americanus*<br>*Discorbis inornatus* |
| | Early | | | | | | | | |
| Paleocene | | | | | | | | | |

[1] Depth of ocean at drilling site.

grains are distinctly rounded and average 500μ–1,500μ. The phosphate grains, bioclastic phosphatized debris, and calcareous aggregates are also well rounded and glossy. Some mammalian teeth are present at 51 m.

Above 46 m, phosphate decreases sharply to less than 1 percent, and fine bioclastic carbonate sand increases to a maximum of 43 percent. For the first time in the Miocene, nonphosphatized shell fragments appear along with some glauconite and sponge spicules; all indicate a shallow marine environment. Between 38 and 33 m, the quartz fraction decreases from 35 to 5 percent, and the benthonic foraminifer *Uvigerina* forms as much as 5 percent of the coarse fraction. This fact suggests that the shelf area may have deepened. A rise in the percentage of mica accompanies these changes.

A new facies change towards a deeper water environment is recorded at 28 m. Planktonic Foraminifera that were rare or isolated now represent 50 percent of the coarse fraction and remain between 10 and 80 percent until the end of the Miocene. At the same place in the core, quartz decreases sharply to 8 percent or less.

## POST-MIOCENE SEDIMENTS

The post-Miocene deposits are similar to those of late Miocene age, but the amount of bioclastic debris, planktonic and benthonic Foraminifera, shell, and echinoderm fragments increases sharply to 32 percent of the coarse fraction. At 13.4 m below the sea floor, in the youngest strata sampled from hole J–1, phosphate is 30 percent of the coarse fraction, and the dolomitic aggregates are as much as 30 percent of the coarse fraction; the amount of the calcareous bioclastic debris decreases sharply. This association is similar to that in the clays at the base of the Miocene and may be interpreted as a reworking of ancient material particularly rich in phosphate. Interestingly, the volume

TABLE 1.—*Sediment types and index faunas of cores from offshore drill holes*—Continued

[Uncertainty in boundaries and thicknesses is at least ±1.5 m because faunas were identified in samples taken at 3-m intervals. From Joint Oceanographic Institutions' Deep Earth Sampling Program (1965), except for sediment types]

| Age | | J-5 (190m) [1] | | | | J-6 (805m) [1] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Depth (m) | Thick-ness | Sediment type | Index fauna | Depth (m) | Thick-ness | Sediment type | Index fauna |
| Post-Miocene | | 0-67.1 | 67.1 | Shelly quartzose sand (on top) foraminiferal calcilutite | | 0-6.1 | 6.1 | Foraminiferal-pteropod calcilutite | |
| Miocene | Late | | | | | | | | |
| | Middle | | | | | | | | |
| | Early | | | | | | | | |
| Oligocene | | 67.1-229.2 | 162.1 | Alternating clays and limestones | *Chiloguembelina cubensis*<br>*Globanomalina micra*<br>*Globorotalia postcretacea* | 6.1-47.2 | 41.1 | Calcilutite with ash beds | *Chiloguembelina cubensis*<br>*Globanomalina micra*<br>*Globorotalia postcretacea* |
| Eocene | Late | 229.2-245.0 | 15.8 | | *Chiloguembelina martini*<br>*Hantkenina primitiva* | 47.2-83.8 | 36.6 | Silty and sandy calcilutite and chert | *Globorotalia cerroazulensis*<br>*Hantkenina primitiva* |
| | Middle | | | | | 83.8-97.5 | 13.7 | Silty and sandy calcarenite | *Globigerinatheka barri*<br>*Globorotalia renzi*<br>*Globorotalia spinulosa*<br>*Hantkenina aragonensis*<br>*Truncorotaloides pseudodubia* |
| | Early | | | | | 97.5-116.7 | 19.2 | Silty and sandy calcilutite and chert | *Globanomalina wilcoxensis*<br>*Globorotalia aragonensis caucasica*<br>*Globorotalia wilcoxensis* |
| Paleocene | | | | | | 116.7-119.7 | 3.0 | Calcilutite and clay with chert bed | *Globorotalia velascoensis* |

[1] Depth of ocean at drilling site.

of the dolomitic aggregates is inversely proportional to that of the carbonate bioclastic debris, almost as though the aggregates were formed from the debris.

## PHOSPHATE

Some horizons in core J–1 contain large amounts of shiny dark-brown particles which, when analyzed chemically with dilute nitric acid and ammonium molybdate solution, indicate the presence of calcium phosphate. X-ray examination shows the presence of well-crystallized apatite. Phosphate has been found in two forms: in small pellets and as biological debris that has been replaced by phosphate. The pellets are the more abundant form and are similar to the pellets described by Z. S. Altshuler (unpub. data, 1952) in Florida.

Most of the pellets are almost spherical or ovoid; a few are rod shaped (fig. 3*A*). The surface of the pellets, is somewhat irregular and marked by slight depressions and rises, and the texture is smooth, glossy, and varnish like. The pellets are well sorted; 80–90 percent range from 120$\mu$ to 200$\mu$. Large grains (200$\mu$–5,000$\mu$) are usually associated with the smaller pellets but make up only 5–20 percent of the phosphate fraction. Most large pellets are irregular in shape, but a few are spherical. The small pellets are translucent brown (10*YR* 4/2). Pellets larger than 200$\mu$ are more opaque and range from light to blackish brown (10*YR* 2/1); rarely, they are gray (*N*6). Color designations are based on the "Rock-color chart" of the National Research Council (Goddard and others, 1948).

Thin-section examination of the phosphates indicates two types of pellets. One type has a homogeneous matrix and often a quartz or shell nucleus. The other type is oolitic with a quartz or shell nucleus in a homogeneous matrix surrounded by concentric layers (fig. 3*B*). Each distinct phosphate horizon in the core seems to be characterized by one or the other of these two types.

TABLE 1.—*Sediment types and index faunas of cores from offshore drill holes*—Continued

[Uncertainty in boundaries and thicknesses is at least ±1.5 m because faunas were identified in samples taken at 3-m intervals. From Joint Oceanographic Institutions' Deep Earth Sampling Program (1965), except for sediment types]

| Age | | J-4 (885-892m) [1] | | | | J-3 (1,032m) [1] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Depth (m) | Thickness | Sediment type | Index fauna | Depth (m) | Thickness | Sediment type | Index fauna |
| Post-Miocene | | 0-18.3 | 18.3 | Foraminiferal calcarenite | | 0-12.2 | 12.2 | Foraminiferal calcarenite | |
| Miocene | Late | | | | | 12.2-22.9 | 10.7 | Foraminiferal calcilutite | *Sphaeroidinellopsis seminulina*<br>*Globoquadrina dehiscens* |
| Miocene | Middle | | | | | 22.9-39.0 | 16.1 | Foraminiferal calcarenite | *Globigerina nepenthes*<br>*Globorotalia mayeri* |
| Miocene | Early | 18.3-53.3 | 35.1 | Foraminiferal calcilutite | *Globigerina angulisuturalis*<br>*Globorotalia opima opima* | 39.0-88.4 | 49.4 | Foraminiferal calcilutite | *Globorotalia foshi robusta*<br>*Globigerinita dissimilis*<br>*Globigerinoides altiapertura* |
| Oligocene | | 53.3-82.0 | 28.7 | Foraminiferal calcilutite | *Chiloguembelina cubensis*<br>*Globanomalina micra*<br>*Globorotalia postcretacea* | 88.4-152.4 | 64.0 | Calcilutite with ash beds | *Chiloguembelina cubensis*<br>*Globanomalina micra*<br>*Globorotalia postcretacea* |
| Eocene | Late | | | | | | | | |
| Eocene | Middle | | | | | 152.4-161.5 | 9.1 | Calcilutite with chert beds | *Globigerapsis kugleri*<br>*Globorotalia spinulosa* |
| Eocene | Early | 82.0-88.4 | 6.4 | Calcilutite and clay | *Globanomalina wilcoxensis*<br>*Globorotalia rex*<br>*Globorotalia wilcoxensis* | 161.5-178.3 | 16.8 | | *Globigerina soldadoensis*<br>*Globorotalia aragonensis caucasica*<br>*Globorotalia formosa formosa* |
| Paleocene | | 88.4-178.3 | 89.9 | Calcilutite and clay | *Globorotalia pseudomenardii*<br>*Globorotalia pusilla pusilla*<br>*Globorotalia velascoensis* | | | | |

[1] Depth of ocean at drilling site.

Another type of phosphate is phosphatized biogenic debris, usually pelecypod shell fragments, fish teeth and vertebrae, diatoms, and echinoderm spines (fig. 3*C*). The size of the particles ranges from 80μ to several millimeters. The color is similar to that of the pellets, except for the shell fragments and diatoms, which are commonly transparent with an opalescent luster.

Large phosphate grains (2 mm) contain much foreign matter, including quartz and shell debris (fig. 3*D*). This material is bound within a homogeneous matrix which is usually enveloped by thin oolitic layers.

## DOLOMITE

Dolomitic aggregates occur not only throughout the Miocene but also through the post-Miocene section and are usually associated with the phosphate horizons. They are generally small (100μ–300μ), but, at certain depths (88, 70, and 14 m), thin layers of large dolomitic aggregates represent as much as 30 percent of the sediment. The structure of all the aggregates consists of quartz and phosphate pellets held together by a cement made up of two types of crystalline dolomite, one of which could be called a cryptocrystalline cement; the other is a cement whose crystals range in size from 10μ to 30μ. The association of these dolomitic aggregates with phosphatic horizons is indicative of a very particular biochemical environment that permitted a broad development of authigenic minerals.

Loose crystals of rhombohedral dolomite (fig. 4A) compose as much as 45 percent of the total sediment at the base of the Miocene at a depth of 98 m and in the middle Eocene.

## GLAUCONITE AND PYRITE

Glauconite is found throughout core J–1, but it is particularly abundant in Miocene and post-Miocene sediments. At the base of the Miocene, where the section is phosphatic, there is practically no glauconite. It is

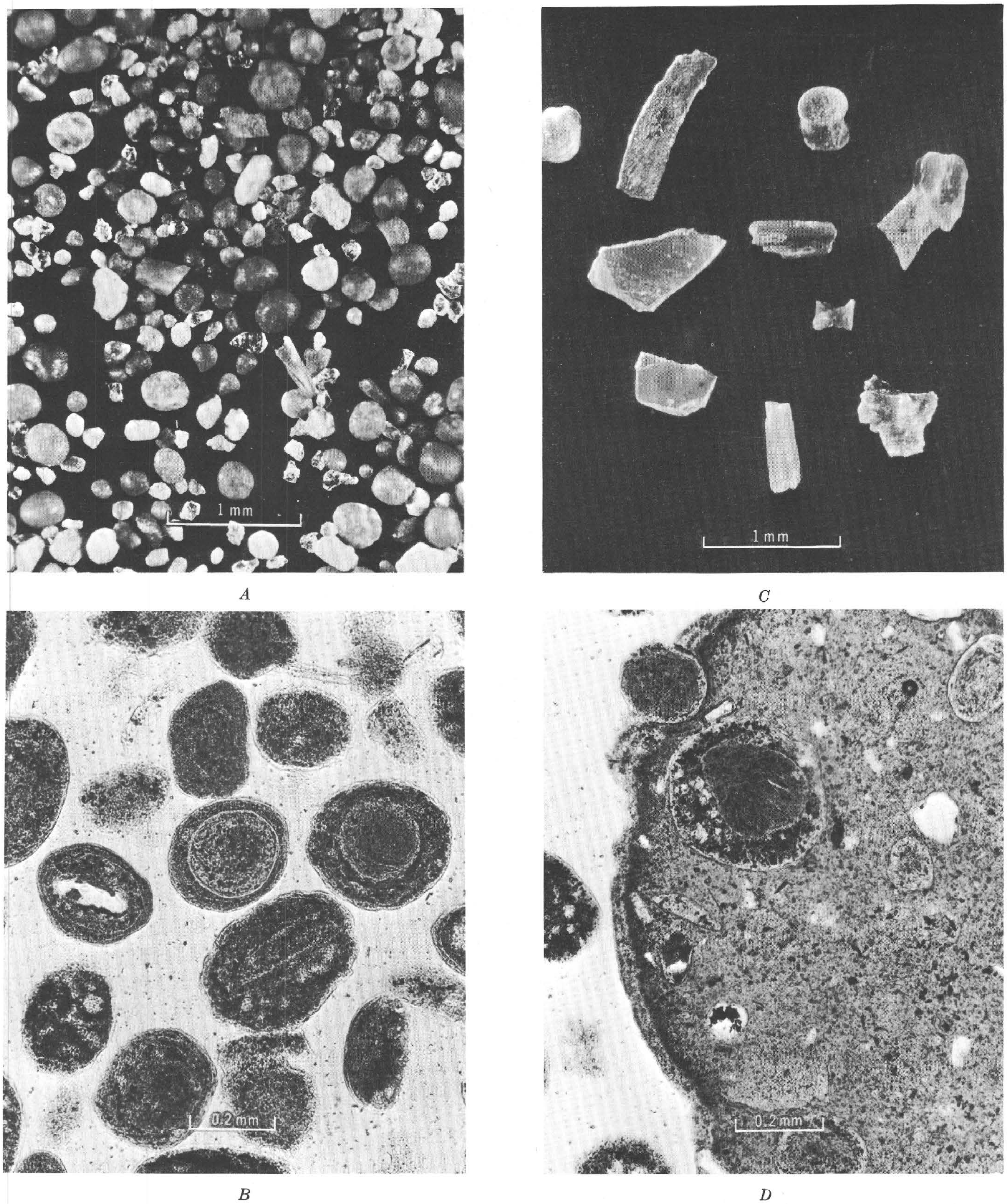
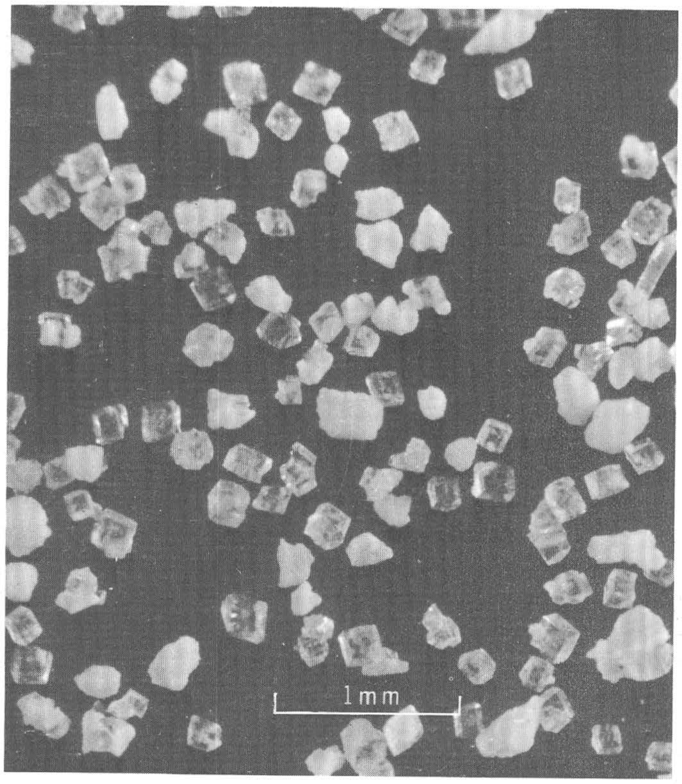
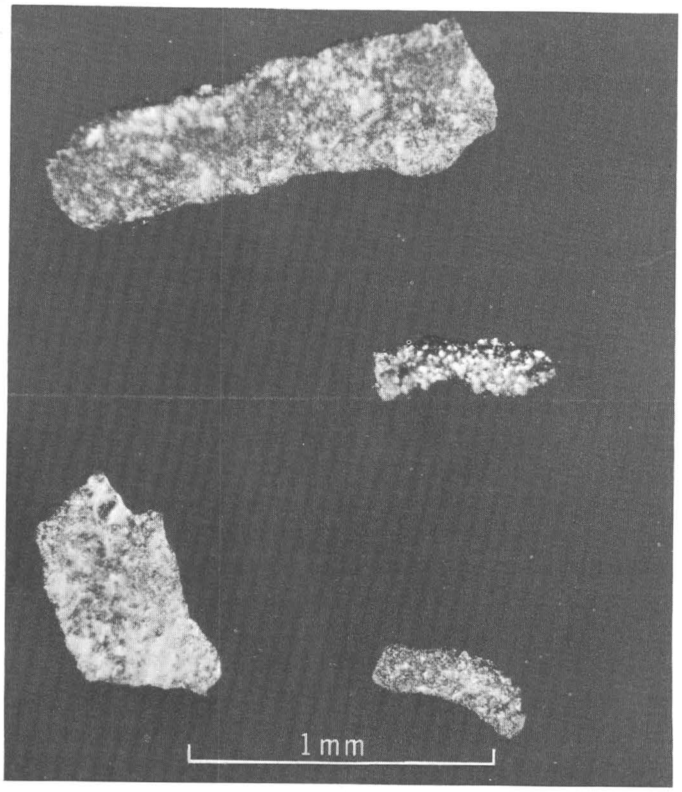



FIGURE 3.—Photomicrographs showing phosphate from core J–1. *A*, Phosphate pellets from 80 m below sea floor. *B*, Oolitic phosphate pellets from 77 m below sea floor. Note concentric rings and quartz nucleus. *C*, Phosphatized biogenic debris from several intervals. *D*, Large (2 mm) phosphate pellet containing smaller pellets, quartz, and shell debris from 77 m below sea floor.




A




B

FIGURE 4. Photomicrographs showing rhombohedral dolomite crystals (*A*) and pyrite fragments (*B*) from core J–1 at 98 and 119 m below the sea floor, respectively.

only where small quantities (1–2 percent) of glauconite and phosphate occur in the sediment that both minerals are usually observed together.

Pyrite crystals occur as solitary lumps or as infilling in Foraminifera shells (fig. 4*B*).

## CORE J–2

Core J–2 penetrated the farthest below the sea floor and entered rocks of middle and late Eocene, Oligocene, and Miocene age (pl. 1). When the upper Eocene and Oligocene units of cores J–1 and J–2 are compared, a slight thickening of the deposits in J–2 becomes evident. It suggests a small but continuous subsidence, which was perhaps interrupted by shoaling on the outer shelf during the middle Miocene. As the seismic investigations indicate, no major faulting exists in Tertiary rocks between sites 1 and 2 (Hersey and others, 1959; Ewing and others, 1966; Emery and Zarudski, 1967), and little topographic difference exists between corresponding horizons in J–1 and J–2 when compared with the dimensions of the deep structure of the shelf. A deepening and emergence affecting the Miocene of J–2 may have been produced by slight tectonic deformations at the edge of the shelf. (Joint Oceanographic Institutions' Deep Earth Sampling Program, 1965).

### EOCENE LIMESTONES, DOLOMITES, AND OOZES

The middle and upper Eocene strata are composed of consolidated limestones and dolomite as well as unconsolidated shelly calcareous ooze. The ooze contains pelecypod shell debris (as much as 1 cm in size), Foraminifera, Bryozoa, Algae, ostracodes, and echinoid fragments. At the base of the upper Eocene, shells and nonforaminiferal bioclastic debris are more abundant than the Foraminifera, whereas at the top of the Eocene, the Foraminifera are more abundant.

The frequency of terrigenous quartz ranges from rare to 15 percent of the coarse fraction; the greatest percentage is at the top of the Eocene section. Grains range in size from 120$\mu$ to 140$\mu$. Authigenic dolomite and calcium carbonate crystals occur frequently. The sequence is similar to the Eocene section of J–1, but because the sediment is finer, it is considered to be a deeper water facies (Joint Oceanographic Institutions' Deep Earth Sampling Program, 1965).

### OLIGOCENE OOZES

The Oligocene deposits are calcareous oozes having 70–80 percent total calcium carbonate and 1–3 percent coarse fraction. The coarse fraction is composed primarily of planktonic and benthonic Foraminifera, echinoderm plates and spines, shell debris, and ostracodes. Rare quartz grains, approximately 120$\mu$ in diameter, constitute as much as 5 percent of the terrigenous component of the coarse fraction. The Oligocene oozes are similar to those of the same age in J–1.

### MIOCENE CLAYS, SANDS, AND GRAVELS

The Miocene deposits are markedly different from the Oligocene oozes. Between 124.4 and 110.9 m is a clay that is low in total calcium carbonate (20–30 percent) and that contains less than 1 percent material coarser than 62$\mu$. The coarse fraction consists of rare angular quartz grains approximately 120$\mu$ in diameter, and larger isolated grains of rounded quartz as much as 2 mm in diameter. Above 121.3 m, phosphate pellets (1–5 percent) and phosphatized bioclastic debris are found along with dolomitic aggregates that may constitute as much as 30 percent of the coarse fraction. One layer at the base of the Miocene contains loose rhombohederal crystals of dolomite. This very fine clay is similar to the lower part of the Miocene section at J–1.

At 110.9 m, a change is indicated by an increase in the coarse fraction to 6 percent and the rare occurrence of large rounded and frosted grains of quartz in association with small angular grains. Glauconite and nonphosphatized Foraminifera also appear, along with a few phosphatized biogenic fragments. This change may indicate an encroaching source of beach and dune material (frosted quartz grains).

Within the interval of 107.9–101.5 m, the coarse fraction increases further (to as much as 44 percent), and its particles become very coarse (most quartz to as much as 1 mm in diameter). The phosphate pellets are glossy and well rounded. The dolomitic aggregates are rounded and their cement is phosphatized. Most of the calcium carbonate shell debris is phosphatized, but a small amount remains as calcium carbonate.

At 100 m another change takes place. The coarse fraction retains its importance, but the quartz grains become smaller and more angular and become less than 1 percent of the total sediment. The coarse fraction is mainly Foraminifera; the dolomitic aggregates and phosphates become rare. The fine fraction becomes more calcareous (40–50 percent).This foraminiferal clay is typical of a deeper water environment. A relative increase of the planktonic Foraminifera farther up the core suggests a more open-sea environment or a changing current pattern.

At 82.9 m, the clay is overlain by a clean sand with a coarse fraction of 98 percent (pl. 2). This sand is mainly rounded quartz grains as much as 2 mm in diameter. Associated with this quartz are small amounts of shell debris, dolomitic aggregates, and phosphate pellets. This sharp change from a clay to a coarse sand may be due to the winnowing of fine material by bottom currents or the formation of a beach. The formation of a beach, however, would have required a rather rapid change in relative sea level, if the foraminiferal clay does in fact represent a deep-water environment.

Above the clean sand, the upper Miocene sediments differ from the underlying lower Miocene clays by their greater percentage of quartz. The sandy clay at 75.9 m contains 35 percent fine angular quartz and 1 percent bioclastic debris. Glauconite and mica are also present. The sediments suggest gradual deepening conditions, and at 66.4 m, planktonic Foraminifera become dominant, thereby indicating an open-ocean environment. Although poor core recovery above 66.4 m prevented detailed sampling, the increase of planktonic forms and the occurrence of benthonic species suggest an open-ocean environment for most of the post-Miocene (Joint Oceanographic Institutions' Deep Earth Sampling Program, 1965).

## CORE J–5

Core J–5 contains Eocene, Oligocene, and post-Miocene sediments (pl. 1). Miocene sediments are absent.

### EOCENE AND OLIGOCENE SEDIMENTS

Only 15.6 m of Eocene sediments was penetrated. These sediments are very similar to the overlying basal 24.4 m of the Oligocene sediments, which consist of alternating limestone and ooze in layers about one-third of a meter thick, an occasional layer being as thick as 1 m.

The limestone is massive and recrystallized; its total calcium carbonate averages 90 percent. The limestone was composed originally of clayey bioclastic silt and sand. The sediment varies from layer to layer from silt to coarse broken shells.

The unconsolidated sediments are calcareous oozes whose total calcium carbonate averages 60–90 percent. The coarse fraction, which usually represents 1 percent but may be as much as 10 percent of the total sample, is composed mainly of Foraminifera (70–90 percent) and bioclastic debris (10–20 percent). Shell fragments, echinoderm plates and spines, ostracodes, and siliceous sponge spicules are also observed. Radiolarians are present throughout the Oligocene, and their frequency ranges from 4 to 60 percent of the coarse fraction. At certain depths, especially between 140.2 and 149.4 m, the radiolarians are covered with fine calcium carbonate crystals.

The terrigenous contribution, which is important in the Eocene strata (30 percent of the coarse fraction), decreases in the Oligocene to less than 1 percent. It is angular quartz, approximately 125$\mu$ in diameter, mica, and heavy minerals.

Phosphatized shell debris and phosphate pellets are found throughout the Oligocene. Though most of the other cores show a high proportion of pellets to phosphatized shells, only a trace of pellets is found with the phosphatized shells in the Oligocene section of J–5. Glauconite occurs sporadically in the lower Oligocene, and only traces are found throughout the rest of the section.

Calcareous and dolomitic aggregates constitute 5–80 percent of the total coarse fraction in certain horizons of the Oligocene section. These aggregates consist of small clear crystals bound together in a random arrangement to form irregular clumps.

### POST-MIOCENE SANDS AND OOZES

At the base of the post-Miocene section, the deposits consist of a calcareous foraminiferal clay having 60–70 percent total calcium carbonate and a coarse fraction of 10–30 percent. There is a gradual transition upwards to coarser and more terrigenous clay.

The coarse fraction is mainly composed of 80–90 percent Foraminifera and only 10–15 percent biological debris. The terrigenous coarse fraction contains 1–5 percent angular quartz grains (100$\mu$–125$\mu$ in size) associated with mica and heavy minerals. Throughout the post-Miocene section, phosphate is noted, but it is less than 1 percent of the coarse fraction; in contrast to conditions within the Oligocene phosphate, the pellets are more frequent than shell debris. They are very often black, but clear brown and transparent pellets similar to those of J–1 and J–2 have also been noted. They are small, 140$\mu$ in diameter, but some large black pellets range from 500$\mu$ to 2 mm in size.

Associated with the phosphate throughout this section are small (150$\mu$–200$\mu$) grains of glauconite, which usually constitute less than 1 percent of the coarse fraction. Intergrowths of glauconite and phosphate appear as mottled green-brown grains.

This mixture of foraminiferal calcareous ooze and terrigenous minerals probably originated in an outer-shelf environment. The fluctuations of the quartz and the large-shell-debris content show the evolution of the facies during the post-Miocene (pl. 2). At the base, shell debris makes up a small percentage of the sediment, but higher up, the percentage generally increases in a fluctuating pattern. The quartz is also variable (less than 1 percent of the total sediment at the base), and its percentage generally increases up the section in a fluctuating pattern.

From 45.7 to 30.5 m, shell debris increases and averages 10 percent of the total sediment, and the quartz ranges from 1 to 14 percent. Above 30.5 m, the shell debris increases further, and the quartz averages 17 percent of the total sediment. During this interval of sedimentation, apparently, the continental influence was increasing. At approximately 27.4–26.8 m, a facies change occurs; the sediment is a muddy sand, the coarse fraction consisting of equal amounts of Foraminifera, quartz, and shell debris. A shallow-water environment is suggested, perhaps close to a beach.

Higher up in the section, the sediment is again a muddy skeletal sand (possibly a shelf environment with less quartz), and then, at approximately 10.2–7.0 m, it becomes a half-terrigenous and half-skeletal sand. This latter sand is very coarse and represents 96 percent of the coarse fraction. It is composed of poorly sorted, rounded quartz (200$\mu$–400$\mu$ in diameter), mica, heavy minerals, and feldspar. The skeletal sand is composed of large broken shell fragments, 5–6 mm in diameter, and some well-rounded calcareous debris. Some of the shell fragments are burrowed by *Cliona*. This sediment is very similar to the material on the shelf today.

### CORES J–3, J–4, AND J–6

Core holes J–3, J–4, and J–6 were all drilled into the Blake Plateau, in depths of water that exceeded 800 m. Cores J–3 and J–6 are rather similar in that their post-Paleocene sediments consist mainly of foraminiferal oozes and silts. Only one core hole, J–4, penetrated any substantial thickness of Paleocene sediments, which at this coring site are terrigenous clays and limestones. Logs of the three cores are shown on plate 1, and the average proportions of calcium carbonate and material coarser than 62$\mu$ are summarized in table 2. Because of the similarity of the Eocene and younger sediments in the three cores, the age-by-age description given for the three more landward cores is not given here, but some of the components of the coarse fraction are described in the following sections.

TABLE 2.—*Percentage of coarse fraction (material>62$\mu$) and of calcium carbonate in cores from Blake Plateau*

| | | J-6 | | J-3 | | J-4 | |
|---|---|---|---|---|---|---|---|
| | | Coarse fraction | $CaCO_3$ | Coarse fraction | $CaCO_3$ | Coarse fraction | $CaCO_3$ |
| Post-Miocene | | | | 50 | 80–90 | 70 | 85–90 |
| Miocene | | | | 20–40 | 80–90 | 40–50 | 85–90 |
| Oligocene | | 1–10 | 80–90 | 1 | 80–90 | 20–30 | 85–90 |
| Eocene | upper | 1–20 | 80–90 | | | | |
| | middle | | | 1 | 80–90 | 1–10 | 40–60 |
| | lower | 20 | 90 | | | | |
| Paleocene | | 5–20 | 40–60 | | | 1–10 | 40–60 |

### BIOGENIC COMPONENTS

Most of the coarse fraction (80–90 percent) is made up of Globigerinidae; the remaining 5–10 percent consists of a variety of other biogenic debris that includes foraminiferal shell fragments. Except for the Foraminifera, each individual component making up the biological debris is always less than 1 percent of the coarse fraction. Echinoderm spines and plates are the most common of these individual components and are found throughout the cores. Ostracodes are less frequent and are missing from certain horizons.

Radiolaria and siliceous sponge spicules are found closely associated with volcanic ash layers; they constitute as much as 30 percent of the coarse fraction (table 3). The Radiolaria disappear above and below the ash layers. A small percentage of sponge spicules appears at 72.2 and 85.3 m in core J–3 (fig. 5). The association of Radiolaria and sponge spicules with volcanic ash layers may have been due to the increased amount of dissolved silica in the water. In addition, the occurrence of glass shards saturating the water may prevent or lower the dissolution rates of the fossil remains on the bottom.


FIGURE 5. Photomicrograph showing volcanic glass shards, Foraminifera, and radiolarians from core J–3 at a depth of 120 m below the sea floor.

### TERRIGENOUS COMPONENTS

Quartz grains are generally small ($100\mu$–$140\mu$) and angular, but larger ($500\mu$–$800\mu$) grains are also found. The latter are round, glossy, and somewhat frosted. Associated with this quartz is a smaller quantity of mica ranging in size from $100\mu$–$500\mu$.

### VOLCANIC ASH

Gray volcanic ash layers are found in all three cores (table 3). They are composed of angular glass shards ranging in size from $30\mu$ to $400\mu$. In some layers, the shards form as much as 99 percent of the sediment. Other layers are composed of small quantities of glass shards mixed with a high percentage of calcareous fine-grained sediment. Disseminated glass shards are also found just above and below the ash layers. This vertical mixing may be caused by boring organisms, a feature shown by Bramlette and Bradley (1942) in sediments from the North Atlantic. Preliminary attempts to correlate the ash layers of cores J–3 and J–6 on the basis of mineralogy and stratigraphic position have given good results (J. R. Dymond, Louis Lidz, and Enrico Bonatti, oral commun., 1967). The association of some chert with ash layers (core J–6, 80.6 m) suggests that chert may have formed from silica liberated from the ash.

### PHOSPHATE

Phosphate is present in small amounts throughout the three cores. It consists mainly of phosphatized shell fragments and phosphatic pellets. The shell fragments are transparent and light brown and are commonly about $100\mu$ in diameter. The phosphate pellets are almost transparent light brown to black and either spherical or ovoid. They range in diameter from $100\mu$–$250\mu$. Large shell fragments or large irregular plates (5 mm in diameter) are scattered throughout the section. The phosphate percentage in cores J–3, J–4, and J–6 is very small and represents less than 1 percent of the coarse fraction.

The vertical distribution of phosphate within the three cores is irregular. In J–4, phosphate is first observed at 17.3 m (post-Miocene) and continues to the bottom of the core. Conversely, in J–6, the phosphate appears with some regularity only below 34.7 m. In J–3, phosphate is rare, but small partially phosphatized shell debris is found throughout the core. Much of the phosphate found farther down these holes, however, may be due to slumping from above (Louis Lidz, oral commun., 1967).

### GLAUCONITE AND PYRITE

Pale-green glauconite grains, $100\mu$–$150\mu$ across, are found from 17.3 m to the base of the Eocene section in

TABLE 3.—*Distribution of volcanic ash and siliceous organisms in cores from Blake Plateau*

[Abundances expressed as percentage of coarse fraction (numerals), rare (r), or trace (Tr.). ×, chert was present. Depth in meters]

| Age | J-4 | | | | J-6 | | | | | | J-3 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Observed and sampled depth | Ash | Sponge spicules | Radiolaria | Observed ash-layer depth | Sampled depth | Ash | Sponge spicules | Radiolaria | Chert occurrence | Observed ash-layer depth | Sampled depth | Ash | Sponge spicules | Radiolaria |
| Miocene | | | | | | | | | | | | 62.2 | Tr. | | |
| | | | | | | | | | | | | 63.4 | r | | |
| | | | | | | | | | | | | 71.4 | Tr. | | |
| | | | | | | | | | | | | 88.3 | Tr. | | |
| | | | | | | | | | | | | 88.7 | Tr. | | |
| Oligocene | | | | | 10 | 10 | 5 | r | r | | | | | | |
| | | | | | | | | | | | 109.2 | 109.2 | 94 | 1 | r |
| | | | | | 15.8 | 15.8 | 60 | r | r | | | 109.3 | 3 | 1 | r |
| | | | | | 15.9 | 15.9 | 90 | r | r | | | | | | |
| | | | | | | | | | | | | 113.5 | Tr. | | |
| | | | | | | 19.5 | 10 | r | r | | | | | | |
| | | | | | | 22.3 | 10 | r | r | | | 114.7 | 5 | 1 | r |
| | | | | | | | | | | | 115.2 | 115.2 | 97 | r | r |
| | | | | | 32.7 | 32.6 | 10 | r | | | | 115.3 | 1 | Tr. | Tr. |
| | | | | | 32.8 | 32.8 | 94 | | | | | | | | |
| | | | | | | | | | | | | 117.4 | 50 | r | 3 |
| | | | | | 33.5 | 33.5 | r | r | | | 117.6 | 117.6 | 95 | r | r |
| | | | | | 33.7 | 33.7 | 85 | | r | | | | | | |
| | | | | | | | | | | | 134.2 | 134.2 | Tr. | | |
| | | | | | | 34.7 | r | r | r | | 134.3 | 134.3 | 85 | r | 3 |
| | | | | | Streaks | 38.2 | Tr. | Tr. | | | 138.5 | 138.4 | 13 | 1 | 1 |
| | | | | | | | | | | | 138.7 | 138.6 | 100 | | |
| | | | | | 39.3 | 39.4 | 10 | | | | | 139.1 | r | | |
| | | | | | 39.6 | 39.6 | 44 | 1 | r | | | | | | |
| | | | | | | 43.3 | 2 | r | | | 151.5 | 151.6 | 98 | | |
| | | | | | | | | | | | 151.6 | | | | |
| Eocene, middle | | | | | | | | | | | 157.2 | 157.3 | 60 | r | 30 |
| | | | | | | | | | | | 157.4 | 157.4 | | r | |
| | | | | | | 80.7 | r | r | Tr. | × | | | | | |
| Eocene, early | | | | | | | | | | | 171.0 | 171.1 | 20 | | 10 |
| | | | | | | | | | | | | 171.1 | 20 | | 10 |
| | | | | | | | | | | | 171.2 | 171.2 | r | | |
| Paleocene | | | | | | 119.7 | | r | Tr. | × | | | | | |
| | 104.2 | r | 1 | | | | | | | | | | | | |
| | 168.2 | r | r | 5 | | | | | | | | | | | |

core J–4. Only slight traces are found in the Paleocene rocks. Glauconite is absent from cores J–3 and J–6.

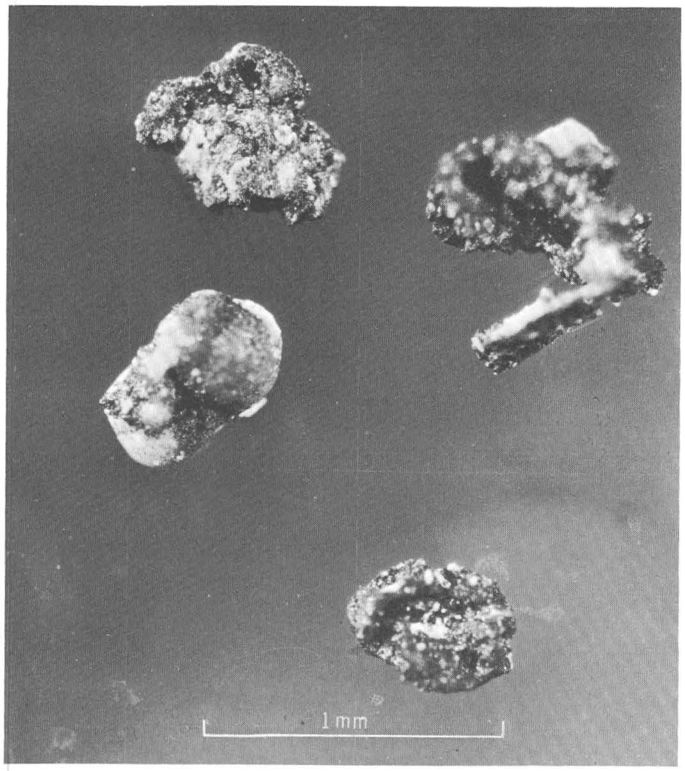
Pyrite is found through much of J–4 but is more abundant in the Paleocene section; only one occurrence was found in the Miocene sediment. One pyrite horizon is in the Paleocene sediments of J–6, and another is at the base of the Oligocene in J–3. The pyrite occurs as small isolated lumps, as a filling in foraminiferal shells, and, in one exceptional place, as a replacement of siliceous ash, radiolarians, and sponge spicules (J–4, 101.4 m). The percentage of pyrite with respect to the total sediment is less than 1 percent.

## CALCITE AND DOLOMITE

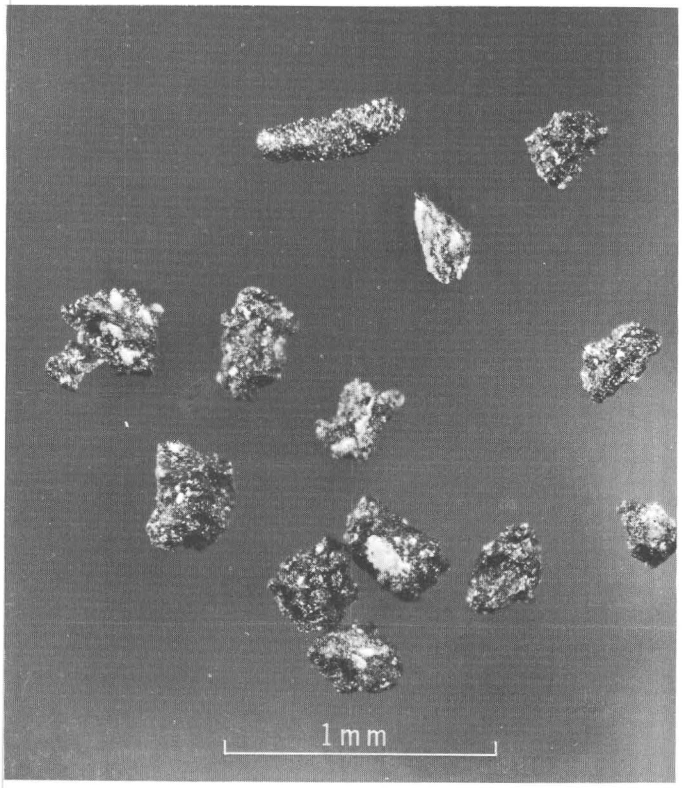
Small crystals of calcium carbonate were found throughout cores J–3, J–4, and J–6. The angular crystals are without any particular form, and range in size from 100$\mu$ to 200$\mu$. Some dolomite crystals are associated with the calcium carbonate. These minerals are rare and represent less than 1 percent of the total sediment.

## BLACK FRAGMENTS

Two types of black fragments occur sporadically throughout cores J–3, J–4, and J–6. One type is usually hard, but at times friable; it varies from 100$\mu$ to 1 mm and is dark brown to black. This material occurs as a cementing agent and as a filling in foraminiferal tests (fig. 6*A*). A spectrographic analysis indicated a high manganese content. The other type is soft; it ranges from 200$\mu$–300$\mu$ in diameter, and it melts when heated, leaving an asphaltic substance apparently organic in origin (fig. 6*B*). Black fragments have also been observed in the shallow calcareous sediments




*A*




*B*

FIGURE 6. Photomicrographs showing black fragments from core J–4. Friable black fragments (*A*) and soft asphaltic fragments (*B*) from 130 and 428 m below the sea floor, respectively.

(Eocene and Oligocene) of J–1, J–2, and J–5. Contamination from the drill string is a possible source.

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