Ocean Drilling on the Continental Margin

Most of the Tertiary section has been sampled in six core holes drilled in the continental shelf, in the Florida-Hatteras Slope, and in the Blake Plateau off the coast of northern Florida.

Joint Oceanographic Institutions' Deep Earth Sampling Program (JOIDES)

For many decades geologists have studied the continental margin and pondered how such areas connect continents and deep ocean basins. Knowledge of this transition is basic to our understanding of the history and development of ocean basins and continents. For example, do sedimentary formations on land continue beneath the continental shelf and slope to where they are faulted at the edge of the continental block? Do these formations thicken offshore in large troughlike accumulations of sediment similar to those deposited in the Appalachians during the Paleozoic Era? Do the land formations thin offshore and gradually change to deep-sea sediments? With these questions in mind, we here report the results of recent deep drilling on the continental margin off Florida.

During the past few decades dredge hauls and cores have provided much information about the geological history of the ocean floor. However, dredge hauls yield information only for outcrops, and cores reveal less than 20 meters of geologic section—usually post-Pliocene. Obviously, drilling to greater depths below the bottom is needed in order to penetrate a thicker stratigraphic section. Such drilling became practical in April 1961, when the Experimental Mohole was drilled off Mexico, in water depths of 3566 meters, to a sediment depth of 182 meters; the drill penetrated a section from Recent to middle Miocene (*1*).

The first project of JOIDES was to drill the continental margin off northern Florida. This area had been investigated by geophysical methods (*2–7*) and by coring (*8, 9*). The stratigraphy of the adjacent land had also been studied in wells (*10–13*). The data from these investigations suggested that Tertiary strata extend beneath the continental shelf. Strata of similar age also appeared to underlie the Blake Plateau, but at a much greater water depth, as though they had been displaced by a fault (*6*) between the shelf and the Plateau. Cores, refraction studies (*5, 6*), and the mapping of several prominent reflecting horizons (*4*) had shown that Tertiary sediments on the plateau thin eastward so that Upper Cretaceous strata on the outer part of the plateau might be within reach of a drill. The entire 450-kilometer width of the continental shelf and the Blake Plateau is generally less than 1000 meters deep (*14*), well within the drilling capability of available equipment. All these data suggested that a short-term drilling program might solve important structural and stratigraphic problems.

The drilling ship was M.V. *Caldrill I*, a converted 54-meter AKL-type navy vessel equipped for rotary drilling and operated by Caldrill Offshore Corporation of Ventura, California (Fig. 1). Holes were drilled from the ship between 18 April and 16 May 1965 at the positions indicated on Fig. 2. Water depths at these drill sites ranged from 25 to 1032 meters; penetrations into the bottom ranged from 120 to 320 meters (Table 1). Approximately 2052 meters of drilling was done; a total of 1433 meters of coring was attempted, with a total recovery of 513 meters. Core recovery averaged 36 percent overall: 28 percent on the continental shelf, 55 percent on the Florida-Hatteras Slope, and 38 percent on the Blake Plateau. Best recovery (46 percent) occurred in soft formations of silt and clay, whereas poorest recovery (22 percent) was in hard layers of chert and dolomite. Drilling speed ranged from 1 meter per minute in soft formations to 1 meter per hour in hard ones.

This report is based primarily on shipboard examination of cores. More detailed work is in progress to study the physical, chemical, and biological properties of the sediments. The cores are stored under refrigeration at the University of Miami for eventual distribution to interested investigators.

Results: Stratigraphy

The two holes on the continental shelf show that Tertiary units recognized on land continue beneath the shelf. The units are slightly shallower at hole 1 than they are on land (Fig. 3, Table 2). A similar shallowing of formations was reported off Georgia (*12*); hence a gentle fold along the coast of Georgia may continue southward to the shelf off Florida (*6*). Miocene sediments beneath the shelf are phosphatic grayish-green sandy silts and silty clays with phosphate pebbles. Beneath the outer shelf (at site 2) the upper and lower parts of the Miocene are preserved, but the middle Miocene is missing; its position is marked by a zone of dark-gray subangular phosphate pebbles. Rocks of middle and late Eocene age under the shelf are calcareous oozes, calcarenites, dolomitic calcarenites, and dolomites very similar to the Ocala limestone and older units of the Eocene on land. These limestones are porous, medium- to coarse-grained, well-sorted clastic carbonates composed of molluscan shell fragments, foraminiferal tests, algae, and coral debris cemented by calcite or dolomite. The good sorting and the broken nature of the calcareous skeletal debris indicate that these limestones originated in shallow water. Offshore, the limestones are fine grained, and their interstices are filled with silt- or clay-size carbonate; these beds probably formed in somewhat deeper water where currents were unable to sort the sediment.

Not only do recognizable stratigraphic units extend from land, but freshwater aquifers associated with them are also present beneath the shelf. Aquifers were encountered at hole 1 in limestone of late Eocene age and dolomitic limestone of middle Eocene

This report was prepared, on behalf of the participants in the JOIDES program, primarily by E. T. Bunce, K. O. Emery, R. D. Gerard, S. T. Knott, Louis Lidz, Tsunemasa Saito, and John Schlee.

The JOIDES Program

The JOIDES program was organized in May 1964. Participating institutions are the Woods Hole Oceanographic Institution, Lamont Geological Observatory, the Institute of Marine Science of the University of Miami, and Scripps Institution of Oceanography. Members of the advisory panel are J. S. Creager, C. L. Drake, K. O. Emery, D. A. Fahlquist, F. F. Koczy (chairman), J. I. Tracey, Jr., and Tj. H. Van Andel.

For the initial program of JOIDES, Lamont Geological Observatory was chosen as the operating institution, with J. L. Worzel as principal investigator and C. L. Drake and H. A. Gibbon as program planners. The mutual interests of the several institutions and the U.S. Geological Survey led to the presence of a mixed group of scientists aboard the drilling ship: from Lamont Geological Observatory, R. D. Gerard (project supervisor and chief scientist), Tsunemasa Saito, and Mark Salkind; from the Woods Hole Oceanographic Institution or the U.S. Geological Survey based at Woods Hole, John Schlee (principal scientist), J. R. Frothingham, Jr., F. T. Manheim, and K. O. Emery; from the University of Miami, Louis Lidz, W. B. Charm, and Herman Hofmann; and from the U.S. Geological Survey, R. L. Wait, W. S. Keys, and E. M. Shuter. Valuable aid was provided by William Bogert (drilling advisor), from Pan American Petroleum Corporation, and by the drillers and crew of the M.V. *Caldrill I*.

age. Although the aquifers were not sealed off by packers, pressure was sufficient to displace the sea water in the drill string and create a head of approximately 9 meters above sea level (*15*).

Beneath the Florida-Hatteras Slope, sediments of Miocene age are absent (Fig. 3), but those of Oligocene age thicken markedly from the shelf. Eocene sediments are finer grained than those on the shelf. The substantial thickness of post-Miocene deposits on the slope may be due in part to sedimentation during the Pleistocene when sea level was lower. Some reworking of older sediments into the post-Miocene deposit is indicated by the abundance of gray phosphate grains similar to those present in beds of Miocene age of the continental shelf.

Most Tertiary units are thinner beneath the Blake Plateau than to the west, and the section is less complete because of two unconformities. Surface sediment consists almost entirely of the tests of foraminifers and pteropods. Sediments of Miocene age are a similar calcarenitic sand or ooze, although there is a large admixture of fine carbonate. The Miocene sediment differs from that cored on the continental shelf in that it is nonphosphatic and much more calcareous. The series is complete on the outer Blake Plateau (hole 3) but is less complete to the north and west (holes 4 and 6, Fig. 3).

As on the slope, Oligocene sediment of the Blake Plateau is a massive, poorly compacted, calcareous ooze composed of coccolithophorids and foraminiferal tests. Interlayered within the ooze are as many as five gray silty volcanic ash beds, each up to 10 centimeters thick and consisting of silt-size angular fragments of volcanic glass (*16*). Ash beds occur in the same stratigraphic position in holes 3 and 6; at hole 4 only one bed was noted, and this in a different stratigraphic position. In part, the absence of ash beds at the north may be due to thinning of the Oligocene. Eocene units

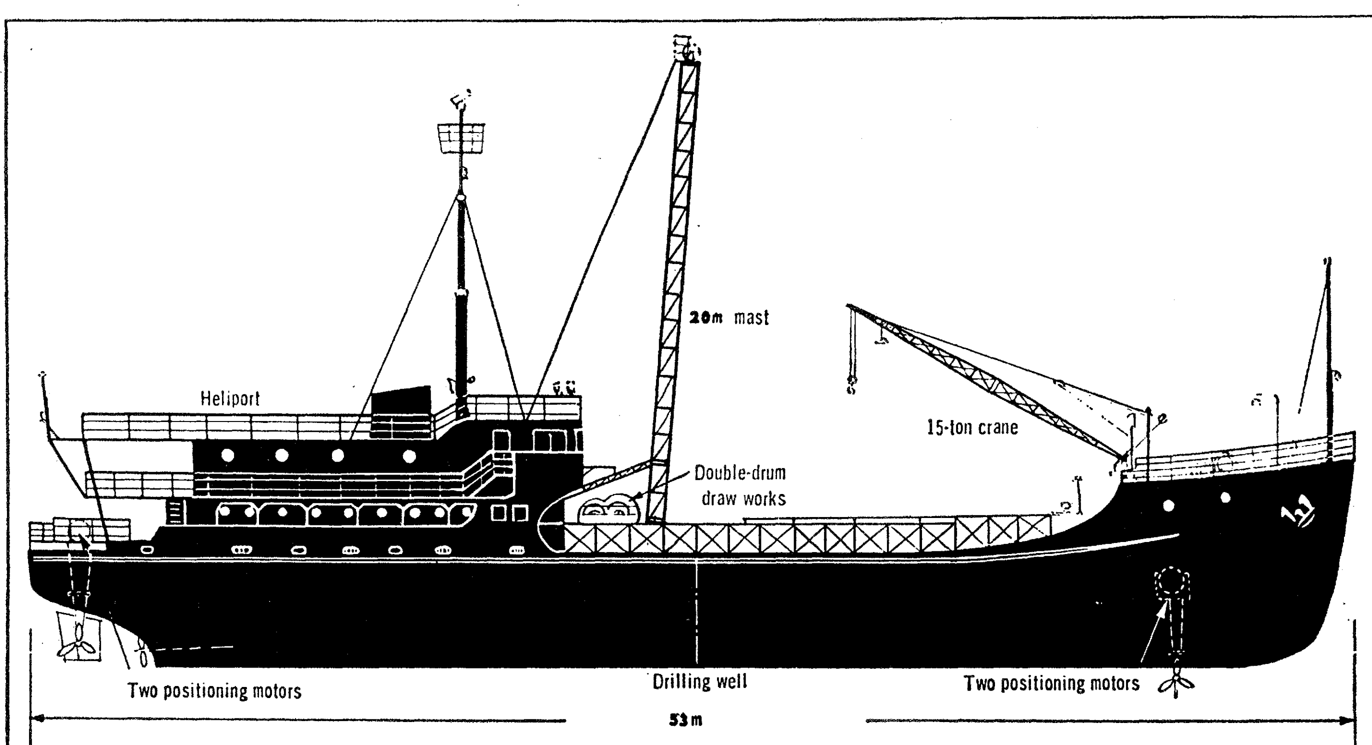

Fig. 1. Sketch of M.V. *Caldrill I.*

Table 1. Summary of drilling data.

Position	Date	Ocean bottom depth (m)	Surface current: Maximum velocity (cm/sec)	Surface current: Direction	Hole and bit type*	End of operation	Interval drilled (m)	Interval cored (m)	Time spent drilling and coring (hr)	Core recovery (%)
						Site 1				
30°33′N 81°00′W	4/28–5/1	25	13–36	Various (tidal)	1, R	Bad weather; pulled out	0– 7.6	7.6–135.6	37.5	32.8
					1a, R	Logged†	0–121.9	121.9–277.4		
						Site 2				
30°21′N 80°20′W	4/18–21	42	52 (est.)	Various (tidal)	2, D	Pulled out	0– 19.8		31.5	23.5
					2a, R	Logged†; backed off	0– 17.4	17.4–173.4		
30°20′N 80°20′W	5/10–11	46	26–41	Various (tidal)	2b, R	Logged †‡	0– 15.2 68.6– 76.2 88.4–146.3 152.4–158.5	15.2– 68.6 76.2– 88.4 146.3–152.4 158.5–320.2	21.0	
						Site 5				
30°23′N 80°08′W	4/22–26	190	72–144	N	5, R	Strong current; pulled out	0– 9.1	9.1– 30.5	56.5	55.0
					5a, R	Plugged; pulled out	0– 17.7	17.7– 57.3		
					5b, D	Plugged; pulled out	0– 50.6	50.6–100.6		
					5c, R	Logged†	0– 97.5	97.5–171.6 171.6–245.0 Intermittent		
						Site 6				
30°05′N 79°15′W	5/7	805	46	N	6, R	Drill tubing broke		0–119.7	17.5	43.5
						Site 4				
31°03′N 77°45′W	5/12	885	33–52	NNW	4, D	Poor recovery; pulled out		0– 91.4	57.0	24.5
					4a, R	Fouled taut-line.		Surface		
31°02′N 77°43′W	5/13–15	892			4b, R	Mud exhausted		0–178.3		
						Site 3				
28°30′N 77°31′W	5/3–5	1032	32–50	NNW–NNE	3, R	Logged†		0–178.3	40.5	67.6
					3a, D	Computer problem; pulled out	0–170.7	170.7–173.7		

* R, roller; D, diamond. † Gamma ray log. ‡ Velocity log.

are similar calcareous oozes, and they are interlayered with gray to green, cryptocrystalline, structureless to faintly laminated chert. An apparently complete section of the Eocene is present in hole 6 on the inner Blake Plateau. Toward the east and north, however, rocks of only lower and middle Eocene age were sampled. Siliceous calcilutites and clay of Paleocene age were the oldest units cored. Both holes 4 and 6 on the Blake Plateau (Fig. 3) ended in the Paleocene, but only in hole 4 was an appreciable thickness cored. The limestone is cherty, massive, dense, hard, and extremely fine-grained. Interbedded with it is a gray massive calcareous clay.

Fauna

Ages assigned the sediments (Table 2) in the cores are based mostly upon planktonic foraminifers because of their rapid evolution, their abundance, and their widespread use in stratigraphic correlations. In general, the established succession of the planktonic foraminifers in the Caribbean region (*17–19*) is used here, although this succession has yet to be fully integrated with the main divisions of the Tertiary as they were originally defined in Europe. In addition, nannoplankton from selected samples of these cores were studied by M. N. Bramlette, whose age assignments agree well with ours except for minor differences in placement of boundaries.

For sediments from the nearshore sites in which planktonic foraminifers are absent or scarce, geological ages are based upon benthonic forms and a comparison with the paleontology of formations on the adjacent land.

Paleocene. "Paleocene" is used in the sense of Bolli (*17, 19*) and Berggren (*20*), who defined its top by the first appearance of *Globanomalina wilcoxensis* (Cushman and Ponton) and the last occurrence of *Globorotalia velascoensis* (Cushman). The oldest sediments that were cored belong to the middle Paleocene *Globorotalia pusilla pusilla* zone of Bolli.

Eocene. Two distinct sedimentary facies are represented in the Eocene. The sediments of nearshore hole 1 consist predominantly of skeletons of benthonic organisms, whereas those of the offshore holes are composed largely of tests of planktonic foraminifers and coccolithophorids. The beds at site 2 contain transitional assemblages of microfossils.

Following Bolli (*19*), the genus *Hantkenina* is taken as the guide fossil to middle and upper Eocene strata. The top of the Eocene is defined by extinction of *Chiloguembelina martini* (Pijpers) and *Globorotalia cerroazulensis* (Cole). The same benthonic foraminifers recognized on land (*10, 21*) are present beneath the shelf in the Eocene strata. *Coskinolina floridana* Cole and *Dictyoconus americanus* (Cushman) were found in dolomitic limestones similar to the Lake City or Avon Park limestones of middle Eocene age in eastern Florida. *Operculinoides ocalanus* (Cushman) and *Eponides jacksonensis* (Cushman and Applin), typical of the Jackson stage,

Table 2. Paleontology and lithology of offshore drill holes. Sampling intervals for paleontologic age designations were generally 10 feet (3

Age	J - 1 (25 m)*				J - 2 (42-46 m)*				J - 5 (190 m)*			
	Depth (m)	Thickness	Lithology	Index Fauna	Depth (m)	Thickness	Lithology	Index Fauna	Depth (m)	Thickness	Lithology	Index Fauna
POST-MIOCENE	0-20.4	20.4	Silty, fine to medium grained quartzose sand		0-48.8	48.8	Shelly quartzose sand and sandstone		0-67.1	67.1	Silty calcarenitic sand	
MIOCENE Upper	20.4-99.0	78.6	Calcareous sandy silt and silty phosphatic clay	Globigerina apertura	48.8-79.2	30.6	Calcareous sandy silt and silty phosphatic clay	Globigerina apertura				
MIOCENE Middle						0						
MIOCENE Lower				Diatom flora and Radiolarian fauna	79.2-121.3	42.1	Very coarse grained quartzose sand and sandy silt	Globigerinoides altiapertura				
OLIGOCENE	99.0-108.2	9.2	Silty calcareous plastic clay	Bulimina ovata primitiva Pararotalia byramensis Chiloguembelina cubensis Globanomalina micra Globorotalia postcretacea	121.3-149.4	28.1	Silty calcareous ooze	Chiloguembelina cubensis Globanomalina micra Globorotalia postcretacea	67.1-229.2	162.1	Calcareous siltstone, calcilutite and calcareous silt	Chiloguembelina cubensis Globanomalina micra Globorotalia postcretacea
EOCENE Upper	108.2-182.9	74.7	Calcarenitic sand and calcarenite	Cribrogloborotalia marielina Gyroidina crystalriverensis Gyroidina nassauensis Lepidocyclina ocalana Operculinoides floridensis Operculinoides ocalanus	149.4-298.8	149.4	Calcareous ooze, calcarenite and calcilutite	Eponides jacksonensis Operculinoides ocalanus Hantkenina primitiva	229.2-245.0	15.8	Calcareous, plastic silt and clay	Chiloguembelina martini Hantkenina primitiva
EOCENE Middle	182.9-277.4	94.5	Calcarenite and dolomite	Coskinolina floridana Dictyoconus americanus Discorbis inornatus Valvulina martii Lepidocyclina sp.	298.8-320.2	21.4	Fine grained calcarenite and dolomite	Dictyoconus americanus Discorbis inornatus				
EOCENE Lower												
PALEOCENE												

* Depth of ocean at drilling site.

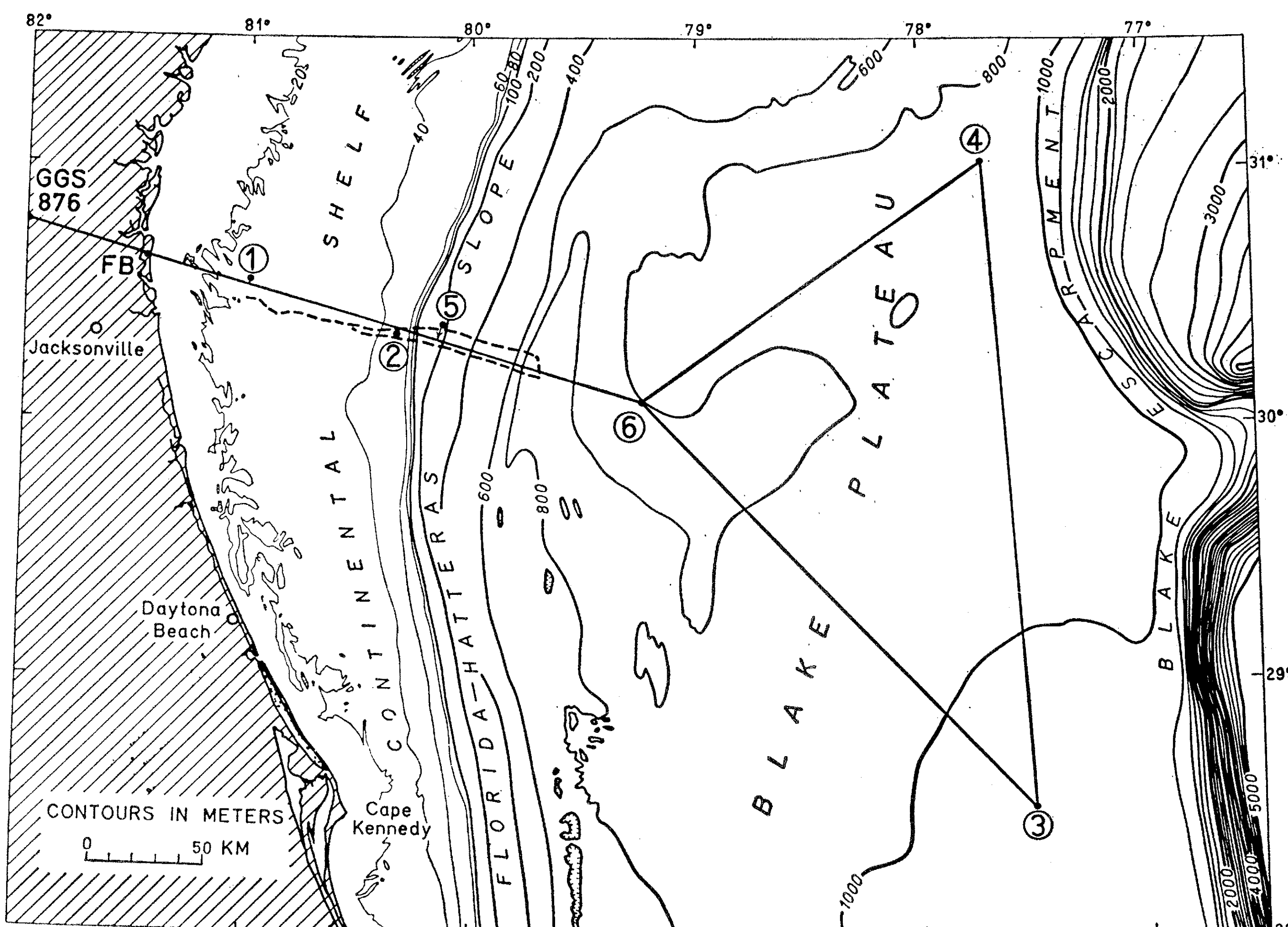

Fig. 2. Position of core holes and seismic profiles in the continental margin off northern Florida. The base map is a modified portion of a general chart by Uchupi (*32*). Solid lines show the position of the stratigraphic fence diagram (Fig. 3), and the broken line indicates the position of the continuous seismic reflection profiles (Fig. 4). The numbers 1 to 6 denote the offshore drill sites; *FB* is a well at Fernandina Beach (*13*); and *GGS 876* is a well whose log is in the files of the Georgia Geological Survey.

meters) resulting in a ± 1.5-meter uncertainty in the boundaries and thickness mentioned in table.

J - 6 (805 m)*				J - 4 (885-892 m)*				J - 3 (1,032 m)*			
Depth (m)	Thick-ness	Lithology	Index Fauna	Depth (m)	Thick-ness	Lithology	Index Fauna	Depth (m)	Thick-ness	Lithology	Index Fauna
0-6.1	6.1	Foraminiferal-Pteropod calcarenitic sand		0-18.3	18.3	Foraminiferal-Pteropod calcarenitic sand		0-12.2	12.2	Silty foraminiferal ooze	
								12.2-22.9	10.7	Silty calcareous ooze to silty calcarenitic sand	*Sphaeroidinellopsis seminulina* *Globoquadrina dehiscens*
								22.9-39.0	16.1	Silty, foraminiferal calcareous ooze	*Globigerina nepenthes* *Globorotalia mayeri*
				18.3-53.3	35.1	Foraminiferal calcarenitic sand	*Globigerina angulisuturalis* *Globorotalia opima opima*	39.0-88.4	49.4	Silty calcareous ooze	*Globorotalia fohsi robusta* *Globigerinita dissimilis* *Globigerinoides altiapertura*
6.1-47.2	41.1	Calcareous clayey oooze with ash beds	*Chiloguembelina cubensis* *Globanomalina micra* *Globorotalia postcretacea*	53.3-82.0	28.7	Silty foraminiferal calcarenitic sand	*Chiloguembelina cubensis* *Globanomalina micra* *Globorotalia postcretacea*	88.4-152.4	64.0	Calcareous clayey ooze with ash beds	*Chiloguembelina cubensis* *Globanomalina micra* *Globorotalia postcretacea*.
47.2-83.8	36.6	Calcareous ooze and chert	*Globorotalia cerroazulensis* *Hantkenina primitiva*								
83.8-97.5	13.7	Silty calcarenitic sand	*Globigerinatheka barri* *Globorotalia renzi* *Globorotalia spinulosa* *Hantkenina aragonensis* *Truncorotaloides pseudodubia*					152.4-161.5	9.1	Calcareous ooze interbedded with chert	*Globigerapsis kugleri* *Globorotalia spinulosa*
97.5-116.7	19.2	Chert and silty calcilutite	*Globanomalina wilcoxensis* *Globorotalia aragonensis caucasica* *Globorotalia wilcoxensis*	82.0-88.4	6.4	Calcareous silty clay and siliceous calcilutite	*Globanomalina wilcoxensis* *Globorotalia rex* *Globorotalia wilcoxensis*	161.5-178.3	16.8	Calcareous ooze interbedded with chert	*Globigerina soldadoensis* *Globorotalia aragonensis caucasica* *Globorotalia formosa formosa*
116.7-119.7	3.0	Chert and calcareous ooze	*Globorotalia velascoensis*	88.4-178.3	89.9	Calcareous clay and siliceous calcilutite	*Globorotalia pseudomenardii* *Globorotalia pusilla pusilla* *Globorotalia velascoensis*				

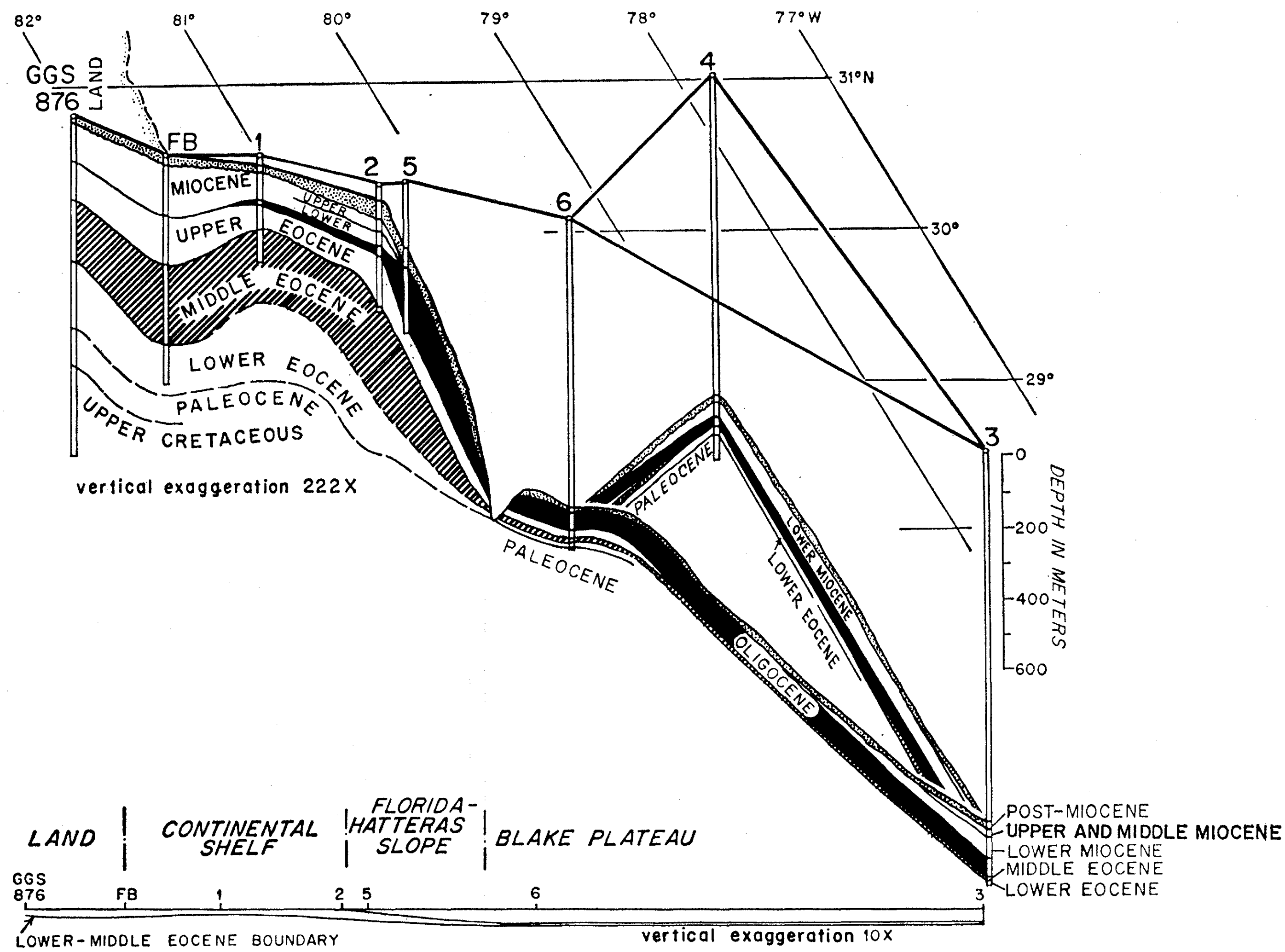

Fig. 3. Isometric fence diagram showing the stratigraphy of the continental margin off the east coast of Florida. Symbols are the same as for Fig. 2. Note the less exaggerated form of the diagram at the bottom.

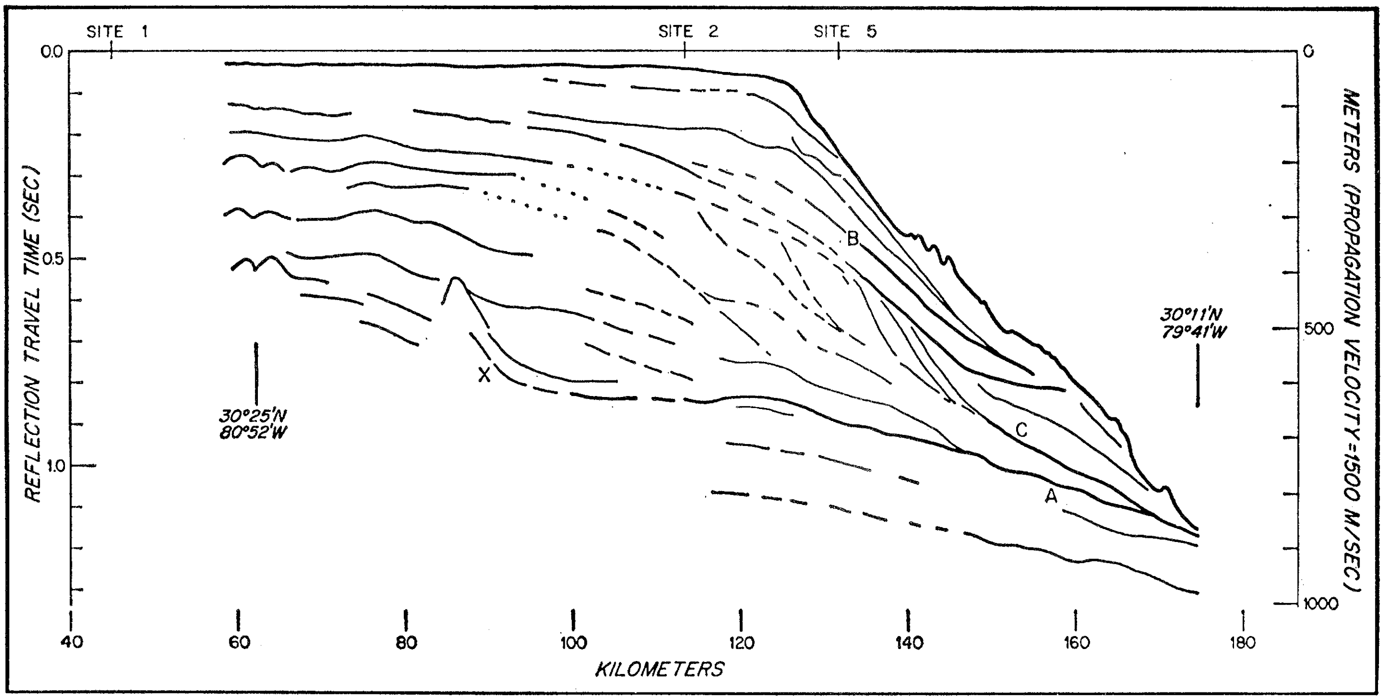

Fig. 4. Composite tracing of the continuous seismic profiles of Fig. 1. The line width indicates relative reflection strength. The horizontal scale represents the distance in kilometers from the Fernandian Beach (*FB*) site, at latitude 30°39'N, longitude 81°27'W (Fig. 1). Topographic exaggeration is × 67.

are associated with the diagnostic upper Eocene planktonic species *Hantkenina primitiva* Cushman (*22*).

Oligocene. Our interpretation of the Oligocene is based upon planktonic foraminifers in the Vicksburg group of the Gulf Coast (*23*). The cores provide an excellent composite stratigraphic section from the Eocene through the Oligocene into the Miocene. The lower limit of the Oligocene is placed at the horizon where typical Eocene species such as *Hantkenina primitiva* and *Globorotalia cerroazulensis* disappear and are replaced by a smaller planktonic foraminiferal population, among which *Globorotalia postcretacea* (Myatiluk), *Globanomalina micra* (Cole), and *Chiloguembelina cubensis* (Palmer) are diagnostic. The delineation of the Oligocene-Miocene boundary accords well with Lagaaij (*24*) and Berggren (*25*), who placed the boundary within the *Globorotalia opima opima* zone of Bolli. The Oligocene interval at the nearshore hole 1 is marked by the joint occurrence of planktonic foraminifers and *Pararotalia byramensis* (Cushman), a benthonic species diagnostic of the Vicksburg group.

Miocene. The top of the lower Miocene (Table 2) is placed between the *Globorotalia fohsi robusta* and the *Globorotalia mayeri* zones; and the top of the middle Miocene is put at the top of the *Globorotalia menardii*/*Globigerina nepenthes* zone of Blow (*26*). *Globigerina apertura* Cushman, a species described from the Yorktown Formation, is taken as the top of the upper Miocene. At site 1 thick beds of nonforaminiferal phosphatic clay occur between the Oligocene and the upper Miocene. The clay contains several layers rich in diatoms and radiolarians.

Post-Miocene. In part because of poor core recovery in the upper portion of the core holes, sediments younger than Miocene are defined only as post-Miocene.

Ecology. The entire section beneath the shelf at sites 1 and 2 is characterized by benthonic foraminifers typical of shelf depths. The Eocene strata were deposited in especially shallow depths, perhaps even in a coastal lagoon, as indicated by the abundance of arenaceous benthonic foraminifers, the scarcity of planktonic forms, and the presence of bryozoans and calcareous algae (for amplification of these criteria see *27*). Further, the occurrence of carbonaceous debris in the middle Eocene rocks of the shelf suggests a coastal environment. The proportion of planktonic foraminifers increases toward the upper part of the section; this increase indicates that later Tertiary sediments were deposited in deeper water.

The section beneath the Blake Plateau contains only deep-water benthonic species, and these species are far less numerous than planktonic forms. Thus the sediments were deposited in water approximately as deep as that in which they are now found.

Geophysics

Extensive seismic refraction and reflection work had been done in the area by Lamont Geological Observatory (*3–5, 7*) and Woods Hole Oceanographic Institution (*6*). To supplement data from these studies, two seismic reflection profiles were recorded aboard R.V. *Chain* between sites 1 and 6 just prior to drilling (Fig. 2). The spark source and receiver of the continuous seismic profiler (*28*) were towed at the same depth and close together (25 meters maximum separation) to obtain near-vertical reflections from shallow structures.

On both profiles a prominent reflector (A in Fig. 4) continues beneath the shelf and slope, becomes part of the sea floor in an eroded swale at the foot of the slope (Fig. 3), and extends across a broad area of the Blake Plateau (*29*). At the foot of the slope the reflector was tentatively identified as the top of the Paleocene by correlation with the stratigraphy of hole 6. Beneath the Florida-Hatteras Slope the reflector has a gentle eastward dip on which is superimposed one rather abrupt rise (*X* in Fig. 4). The relatively thick sections of sediment beneath the shelf and above the prominent reflector, A, thin and pinch out downslope. Two other reflectors (*B* and *C* in Fig. 4) may correspond to the top of the upper Eocene and the top of the middle Eocene, respectively. A high-resolution sparker record made aboard R.V. *Conrad* in 1963 shows that the highly stratified post-Miocene section continues to the base of the slope, where a nonreflective zone, presumably Oligocene, is exposed. Major faults between the continental shelf and the Blake Plateau are not evident on Fig. 4.

Lithologic support for a major seismic reflector is provided by a change from crumbly limestone (upper Eocene) to dense dolomitic limestone (middle Eocene) under the continental shelf. On the Blake Plateau the boundary between the calcareous ooze (middle Eocene) and the calcareous ooze interbedded with chert or siliceous limestone (early Eocene and Paleocene) may also serve as a reflector. The reflectors need not correspond precisely with biostratigraphic boundaries.

Sound velocity was measured successfully in hole 2b with a pressure-compensated hydrophone on a well-logging cable. Small explosive charges were set off near the surface of the ocean, and sounds were received at various depths in the hole. The results show a sound velocity of 1.60 kilometers per second in the upper 100 meters of sediments, and 1.96 kilometers per second below this depth to at least 275 meters. These measurements make it possible to check velocities obtained by shipboard surveys of seismic refraction.

Gamma-ray logging (Table 1) was carried out at four sites by E. M. Shuter and R. L. Wait. Strong signals in phosphate-rich horizons provided good correlations between stratigraphic units at sites 1, 2, and 5.

Drilling

Ship position was determined in this project by loran A. For maintenance at a fixed position in the ocean during extended periods of drilling, the ship is equipped with an automatic positioning system, which utilizes four 300-horsepower Harbormaster outboard motors, two at the bow and two at the stern. The speed and direction of the propellers are automatically controlled by signals from an analog computer. This computer receives signals from a gyro compass and an angle-sensing transducer mounted above a constant-tension taut wire from the ship to a 250-kilogram anchor resting on the ocean bottom. If the ship drifts away from a place directly above the anchor, the transducer senses the departure of the wire from the vertical and generates signals through the computer to the outboard motors, which then move the ship back into position. The position-keeping equipment allowed the ship to drill in surface currents up to 140 centimeters per second (2.7 knots) and winds up to 20 meters per second (40 knots) while maintaining position over the hole to within 3 percent of the water depth.

The drilling tower is a 20-meter mast mounted amidship, having a lifting capacity of 120 tons. A double-drum draw-works supplies the lifting power for handling the drill string through a 3-meter center well. Instead of the usual kelly and rotary table, a hydraulic power swivel rotates the drill string, at a maximum of 60 revolutions per minute. Drilling fluid is sea water, except for occasional use of mud. Drill tubing (8.8 cm outside diameter) in 10-meter lengths is stored horizontally on pipe racks having a total capacity of 1800 meters. Other features of the ship have been described by Rogers (*30*).

Most of the drilling was done with a hard-formation roller bit; a diamond bit was ineffective in coring soft sediments. A constant bit weight was provided by one to three drill collars (1 ton each), fixed below one or two 1.5-meter stroke bumper subs (telescoping joints) which compensated for vertical motion of the ship.

Samples were obtained with a 3-meter wire-line core barrel that was dropped through the drill string to a clamped position at the bottom. Rotation and penetration of the drill string produced a core whose diameter ranged from 3.5 to 5.0 centimeters. The core barrel and its contents were retrieved, usually at 3-meter intervals of drilling, by a weighted wire line dropped through the tubing. Cores were extruded into plastic-lined steel trays from the barrel by hydraulic pressure behind a rubber piston or by a wooden ram and piston. After inspection and sampling, they were heat-sealed in "lay-flat" polyethylene tubing, packaged, and stored at 5°C; lengths ranged from a few centimeters to 3 meters.

Conclusions

Strata from Paleocene to Miocene age were identified from fossils in cores obtained by the JOIDES offshore drilling program. The sections provide an excellent opportunity for establishing a succession of pelagic flora and fauna during the Tertiary and will be valuable for worldwide correlations of marine sediments.

Study of the cores shows that land formations and possible economic deposits extend beneath the continental shelf. Eocene and Miocene strata on the shelf are nearly identical with those on land. Several artesian fresh-water aquifers in upper and middle Eocene calcarenites of Florida and Georgia were encountered on the inner shelf. Several zones of phosphate pebbles were found in Miocene clays at the same stratigraphic position that they occupy on land.

Borings and seismic profiles indicate that sedimentation has been dominant on the shelf and on the Blake Plateau during the Tertiary. Accumulation of 100 to 200 meters of sediment on the shelf and upper slope has prograded the area eastward approximately 15 kilometers since the Eocene. Seismic reflection profiles (Fig. 4) show that seaward construction of the shelf and slope occurred probably throughout the entire Tertiary. Shelf conditions existed at nearshore sites during the Tertiary, and very shallow water prevailed during deposition of well-sorted calcarenites of Eocene age. Finer sediment accumulated offshore in deep water, giving rise to the calcareous oozes of the slope and Blake Plateau. The thickness of the upper Eocene section (Table 2) corresponds to rates of deposition during this 9-million-year interval of 1.6 centimeters per 1000 years on the shelf to 0.3 centimeter per 1000 years on the Blake Plateau. The rates for the Blake Plateau are well within the range of deep-sea sediments having little contribution of land detritus, but they are lower than the rate (4.5 centimeters per 1000 years) for uncompacted post-Pleistocene sediments of the continental rise north of the Blake Plateau (*9*).

Major unconformities occur in the deep-sea sedimentary record and result in a thinner cover of sediment on the Blake Plateau. The unconformities are post-Oligocene on the landward part of the Blake Plateau and middle-to-late Eocene on the seaward part. Fauna and lithology of sediment adjacent to the unconformities give no indication of shoaling depths. These relations suggest that sedimentation was absent over a long period of geologic time or that pre-existing pelagic deposits were eroded by bottom currents. The area of missing post-Oligocene strata underlies the present Gulf Stream. Soundings and seismic reflection profiles reveal maximum erosion of Tertiary units along the base of the slope parallel to the Gulf Stream axis. Furthermore, underwater photographs show that bottom currents are actively moving sediment on the inner part of the Blake Plateau (*31*).

The picture which emerges shows the continental margin as a wedge-shaped constructional feature, thinning seaward. What has been the role of contemporaneous deformation in modifying this wedge? Drill holes and seismic evidence (*6, 12*) show a gentle warping of Tertiary strata (Fig. 3) on the inner part of the continental shelf. The strata also appear to be warped downward beneath the Florida-Hatteras Slope, but in fact they were deposited at about their present depth when the shelf and slope were prograded during the Tertiary. No evidence was found for a major rift under the Florida-Hatteras Slope, as had been postulated (*7*). The continuity of seismic reflectors beneath the slope, as shown on the seismic profile, precludes major faulting between the continental shelf and the Blake Plateau during the Tertiary; hence, if a fault is present, it is Cretaceous or earlier. Some minor offsets may have occurred in connection with warping of Tertiary strata on the shelf, but the close similarity between Tertiary and modern depositional environments suggests that the continental margin has slowly subsided.

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Mature Research Institutions and the Older Scientist

The dominance of youth in professional research is disappearing in favor of experience and maturity.

Leslie G. Cook and George W. Hazzard

Scientific research as a full-time profession, instead of as merely part of an academic career, is a phenomenon largely of the last few decades. Since World War II the number of large industrial laboratories in this country has increased by 50 percent, and the total number of scientists in these laboratories has doubled (*1*).

The number of males who graduate from college with degrees in science and engineering has been increasing at the rate of 12 percent per year, as compared with 5 percent for college graduates generally and only 2 percent for people of age 22 in the total U.S. population (*2*). All in all, there has been a remarkable and disproportionate increase in the flow of young people into the science professions, matching the equally remarkable flow of money into research and development activities.

As a consequence, most scientists in professional research laboratories have thought of themselves as young people, in young organizations and with unlimited growth opportunities. Yet now, looking around, they are intuitively aware that, on the whole, they are working with older people. What exactly has been happening in these laboratories?

Data were available to us on seven

Dr. Cook is manager of project analysis at the General Electric Research Laboratory, Schenectady, N.Y. Dr. Hazzard is associate provost of Washington University, St. Louis, Mo.