U. S. Geological Survey Open-File Report 80-147

FINAL EXECUTIVE SUMMARY REPORT - ENVIRONMENTAL STUDIES,

SOUTHEASTERN UNITED STATES ATLANTIC OUTER CONTINENTAL SHELF, 1977

GEOLOGY

By Peter Popenoe, 1933-

U. S. Geological Survey Open-File Report No. 80-147

This report is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards or nomenclature.

PREPARED FOR THE BUREAU OF LAND MANAGEMENT

UNDER MEMORANDUM OF UNDERSTANDING

NO. AA550-MU6-56

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FINAL EXECUTIVE SUMMARY REPORT--

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ATLANTIC OUTER CONTINENTAL SHELF, 1977, GEOLOGY

By Peter Popenoe

INTRODUCTION

Starting in mid 1976 and continuing into 1977 a variety of geological studies were carried out by the U. S. Geological Survey on the southeastern U. S. Atlantic Continental Margin to assess conditions and hazards that might cause or distribute oil spills or other pollutants, or constrain petroleum exploration or development of the area. These detailed investigations were requested and funded by the Bureau of Land Management to carry out its responsibility under the Outer Continental Shelf (OCS) Lands Act of 1969. Because of the energy crisis the decision had been made to lease on the southeastern continental shelf. A variety of studies had to be mounted quickly for input into decisions concerning the environment that would affect or constrain which lease tracks would be offered. The first lease sale, Lease Sale 43, took place in March 1978, and the environmental information on which this lease sale was based came in part from this initial effort and in part from a wide variety of pertinent data assembled from the literature by the Bureau of Land Management's Environmental Assessment Division. The compilation of relevant data for the Environmental Impact Statement for Lease Sale 43 also pointed up deficiencies in environmental knowledge in a number of areas. The Bureau of Land Management's environmental program for the Southeast Atlantic OCS was initiated to fill gaps in the environmental data base and to detect and assess impacts from oil and gas exploration and production.

SCOPE

Through a series of meetings with Federal, state, academic and knowledgeable individuals, a studies program was developed in chemical/biological oceanography, physical oceanography, and geological oceanography. The U.S. Geological Survey entered into an agreement with the Bureau of Land Management to conduct the Geological Oceanography phase of the research. This program was detailed in a Memorandum of Understanding, MOU AA550-MU6-56 dated September 30, 1976, in response to a Request for Proposal No. AA550-RP6-18. The general objectives of the geological oceanography program in 1976-1977 were to (1) measure the rate, direction, and forcing mechanisms of sediment mobility over the sea bed, and to monitor resultant changes in bottom morphology or texture; (2) determine the concentration, distribution, and flux of suspended particulate matter in the water column; (3) determine the vertical distribution of trace metals in the near-surface sediment at selected locations; (4) evaluate potential geological hazards to oil and gas development due to surficial and intermediate depth structure and mass sediment transport events; (5) identify and evaluate the distribution and significance of outcrop and reefal structures; and (6) support the activities of the chemical/biological contractor by obtaining information on sediment texture and composition, particularly as it relates to the physical, biological, and chemical processes of the shelf.

To fulfill these goals, the U. S. Geological Survey did the following: (1) constructed and deployed, for a one month trial period in the lease blocks, a bottom tripod equipped with sensors that measured current speed and directions, water temperatures and turbidity, wave spectra, and bottom-sediment motion and bedforms (via bottom photographs); (2) studied the natural particle (seston) composition, concentration, and distribution by means of suspended-matter samples and turbidity measurements in the water column; (3) studied the concentration and vertical distribution of trace metals in the near-surface sediments from undisturbed bottom cores; (4) studied the regional distribution of faults, slumps, areas of cut-and-fill or scour, sand waves, and other potential hazards, and determined the surface and near-surface sedimentary characteristics by detailed seismic surveys; (5) studied the distribution and characteristics of reefs and hardgrounds by high-resolution seismic and side-scan sonar reflection surveys; and (6) studied the surficial sediments and near-surface sediments by analyses of previously existing bottom samples and by collecting and analyzing a series of cores across the shelf. This report presents a summation of principal findings and conclusions from this initial effort; more detailed information on this U. S. Geological Survey work is presented in Popenoe (1980).

RELATION TO BENCHMARK CONTRACTOR

Texas Instruments, Inc. was chosen by the Bureau of Land Management to be responsible for both the chemical/biological and physical oceanography programs. Baseline stations in cross-shelf transects were selected jointly by Texas Instruments, the Bureau of Land Management, and the U. S. Geological Survey. Stations were reoccupied on seasonal cruises where chemical and biological data were taken. Transmissometer traces and suspended matter samples also were acquired on each cruise by a representative of the U. S. Geological Survey.

These data were sent to Woods Hole, Massachusetts and the University of South Florida at St. Petersburg.

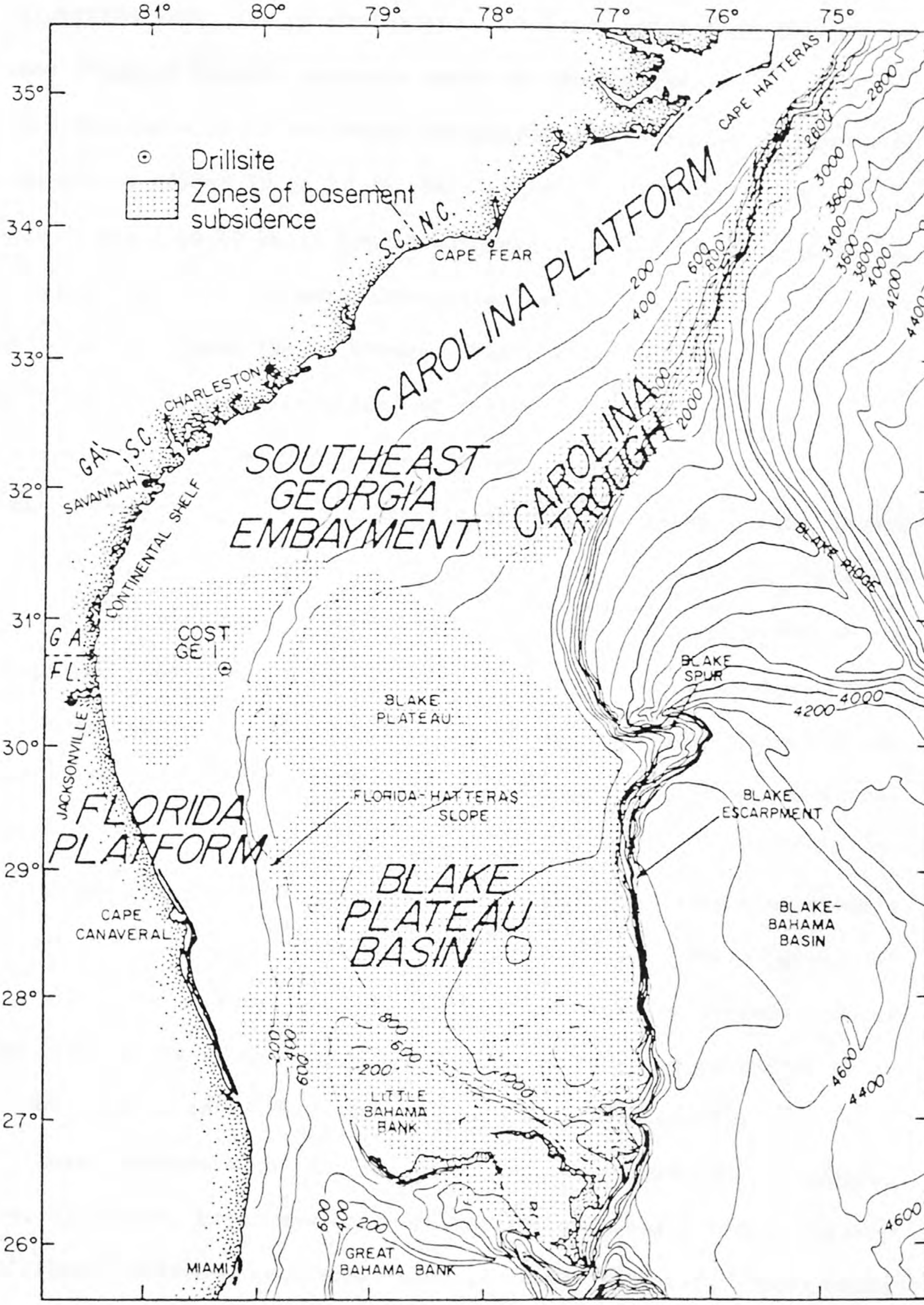
GEOLOGIC SETTING

The southeastern U. S. Outer Continental Shelf consists of two physiographic areas (Figure 1); a shallow flat bottomed inner shelf where water depths are under 100 metres (m), and an intermediate depth plateau, the Blake Plateau, where depths range from 350 to 1,000 m. A gently sloping transitional zone, the Florida-Hatteras Slope, connects the shelf to the plateau, and a steeply dipping slope, the Blake Escarpment, connects the Blake Plateau to the deep ocean. The lease areas of sale 43 lie in the Georgia Bight on the Florida-Hatteras Shelf. This area is the offshore extension of the Southeast Georgia Embayment, a seaward opening basin that extends into the coast between the Cape Fear Arch of North Carolina and the Peninsular Arch of Florida. The basin is underlain by an aggregate thickness of more than 3.4 km of Mesozoic, Tertiary, and Quaternary sediments (Scholle 1979) which have a potential for petroleum.

The Blake Plateau Basin and Carolina Trough, two deep basins which underlie the Blake Plateau (stippled on Figure 1), each contain from 10 to 14 km of Jurassic to recent sediments. No physiographic expression of the deeper basins is apparent on the shelf or plateau. Instead, the physical division at the mid-OCS, the Florida-Hatteras Slope, is formed by an irregular progradational wedge of Tertiary sediments unrelated to structure.

The flat surface of the shelf is almost entirely covered by a thin veneer of well-sorted and reworked sand (Hollister 1973) which, previous to the work of Ayers *et al* discussed in Popenoe (1980) was believed to

Figure 1. Physiographic features and basins of the U. S. southeastern continental margin (modified from Dillon et al 1979b).


81°
80°
79°
78°
77°
76°
75°
35°
34°
33°
32°
31°
30°
29°
28°
27°
26°
Drillsite
Zones of basement subsidence
CAPE HATTERAS
S.C. N.C.
CAPE FEAR
CAROLINA PLATFORM
CHARLESTON
GA S.C.
SAVANNAH
CONTINENTAL SHELF
SOUTHEAST GEORGIA EMBAYMENT
CAROLINA TROUGH
BLAKE RIDGE
GA
FL
COST GE 1
BLAKE PLATEAU
BLAKE SPUR
JACKSONVILLE
FLORIDA PLATFORM
FLORIDA-HATTERAS SLOPE
BLAKE ESCARPMENT
BLAKE PLATEAU BASIN
BLAKE-BAHAMA BASIN
CAPE CANAVERAL
LITTLE BAHAMA BANK
MIAMI
GREAT BAHAMA BANK

be totally residual from the last sea level transgression. South of Cape Hatteras this sand has a high carbonate content, as the area spans the transition from the predominantly carbonate province of Florida and the predominantly clastic province north of Cape Hatteras.

The physiography of the shelf is dominated by a series of prominent sand swells or ridges 10 to 30 m in height above intervening swales. The ridges are 2 to 40 km in length with crests separated by 2 to 18 km. Originally these features were interpreted as remnant beaches and dunes (Sanders 1962; Shepard 1963); however, their alignment diagonal to the shore and parallel to directions of residual drift suggested to Uchupi (1968) that they may be produced by present hydraulic conditions of high-velocity bottom currents generated by winter gales. More recent work in the mid-Atlantic by Swift and Field (in press) and Field (in press) suggests that these ridges are formed at the shoreface and become stranded and modified as sea level transgression proceeds. Data presented by Ayers *et al* (*in* Popenoe 1980) suggest that these ridges, in part, reflect present-day processes rather than past nearshore events.

The thin sand cover of the shelf is in places absent exposing a harder, more indurated substrate of cemented sand. These areas of harder bottom are patchy and are discontinuously scattered. Where exposed they can be either smooth or roughly broken with relief of up to 15 m. The hard or rocky formations allow the attachment of a variety of sessile invertebrates such as sea fans, sea whips, hydroids, anemones, sponges, ascidians, bryozoans and hard corals, and shelter for a variety of reef-type fishes and crustacea, such as spiny lobster. These areas are commonly referred to as live or hard bottoms and constitute both recreational and commercial fishing areas. The most prominent reefal areas occur at the top of the slope where they are known as the shelf edge ridge or reef. Various areas have been reported or studied in detail, but the most important studies include those of Macintyre (1970), Macintyre and Milliman (1970), and Hunt (1974).

Textural studies by Hollister (1973) and Milliman (1972) have shown that the surface sediments of the shelf are primarily sands in the 2 to 0.250 mm range (-1 to 2 Ø). Generally finer (0.250 to 0.062 mm, 2 to 4 Ø) materials are present near the coast and on the slope. Along the base of the Continental Slope off Florida, just beneath the counter current of the Gulf Stream, a deposit of clayey silt occurs (0.062 to < 0.004 mm, +4 to > 8 Ø) with its northern termination about due east of Jacksonville, Florida (Hollister 1973). Shelf sands are generally well sorted and reworked by epifauna and currents so that very little fine-grained material is available for resuspension. Coarse-grained sand and gravel occur only in small scattered patches, primarily near the coast in southern Georgia and in Onslow Bay.

The shallow subbottom stratigraphy of the shelf, slope, and Blake Plateau has been studied principally by seismic refraction and reflection, and by shallow core samples. The principal early seismic reflection studies were made by Ewing et al (1966), Emery and Zarudski (1967), Uchupi (1967), Uchupi and Emery (1967), and Uchupi (1970) who inferred most of their units from the land stratigraphy. From 1964 to 1967 a number of offshore wells were drilled in the Southeast Georgia Embayment and Blake Plateau Basin (McCollum and Herrick 1964, Bunce et al 1965, JOIDES 1965, Hathaway et al 1976, and Schlee 1977). These, along with detailed networks of traverses obtained with modern high-resolution seismic equipment under BLM sponsorship, allow us to considerably refine these earlier interpretations (Popenoe 1980). In

1977 the Consortium Offshore Stratigraphic Test Georgia Embayment 1 (COST GE-1) was drilled in the center of the Georgia Bight (30°31′N latitude, 80°18′W longitude) to Paleozoic basement. This well was studied in detail, and its sediments were analyzed for petroleum potential by studying both source rocks and thermal maturity (Scholle 1979).

The regional structure of the shelf, slope, and Blake Plateau from the time of continental rifting to the present has been outlined by interpretation of Common Depth Point (CDP) seismic profiles by Buffler et al (1979), Dillon and Paull (1978), and Dillon et al (1979a and b), and most recently by Folger et al (in press). By far the most comprehensive and complete summary of the shallow stratigraphy of the shelf, Florida-Hatteras Slope, and inner Blake Plateau is presented by Paull and Dillon (of Popenoe 1980) and Edsall (Chapter 9, of Popenoe 1980) in reports that are a direct product of the U. S. Geological Survey - Bureau of Land Management environmental effort for FY77.

FIELD WORK

Seven cruises were conducted by the U. S. Geological Survey during 1975 to 1977 under total or partial BLM funding to carry out the objectives of the program. These cruises and observations or samples taken are listed in Table 1. The locations of geological cruise track lines are shown in Figure 2, and the locations of vibracore holes are shown in Figure 3.

ROLES OF KEY PARTICIPANTS

The following summary of significant results and findings is based on the conclusions reached in the written Final Reports of the Principal Investigators of each phase of the work. Those Principal Investigators

Table 1. Cruises conducted by the U. S. Geological Survey.

Cruise I.D.	Dates	Purpose	Number	Navigation
R/V FAY 005	31 October to	vibracore	22	Loran-C
	7 November	hydrostatically-damped		
	1975	gravity core	21	
		water samples	22	
		minisparker	568 km	
		3.5 kHz	568 km	
R/V FAY 017	20-29 June	Seismic Reflection		Integrated Navigation System
	1976	40 in.^{3} airgun	2,000 km	Loran-C (rho-rho)
		600 joule sparker	2,000 km	satellite receiver
		3.5 kHz profiler	2,000 km	Sperry MK29 Gyrocompass
		Magnetometer		speed log
		proton precession	2,600 km	Cesium vapor time standard
R/V FAY 018	2-15 July	Seismic Reflection		Integrated Navigation System
	1976	160, 80, 40, and 20 cu.		
		in. airguns	3,019 km	
		600 joule sparker	2,808 km	
		3.5 kHz profiler	2,515 km	
		Seismic Refraction		
		sonobuoy	12 profiles	
			(268 km)	
R/V FAY 025	21 September to	Seismic Reflection		Integrated Navigation System
	10 October	airgun	3,310 km	
	1976	minisparker	3,310 km	
		Magnetometer		
		proton precession	3,310 km	
		Gravity		
		vibrating string	5,560 km	
R/V FAY 026	16-25 October	vibracore	20	Loran-C
	1976	hydrostatically-damped		
		gravity core	15	
		side scan sonar	96 km	
R/V ADVANCE II	5- 7 August	deploy tripod		Loran-C
	1977			
	7-23 September	recover tripod		Loran-C
	1977			

Figure 2. Cruise tracklines for seismic reflection data obtained 1975-1977. Also shown are the locations of offshore wells used for stratigraphic control.

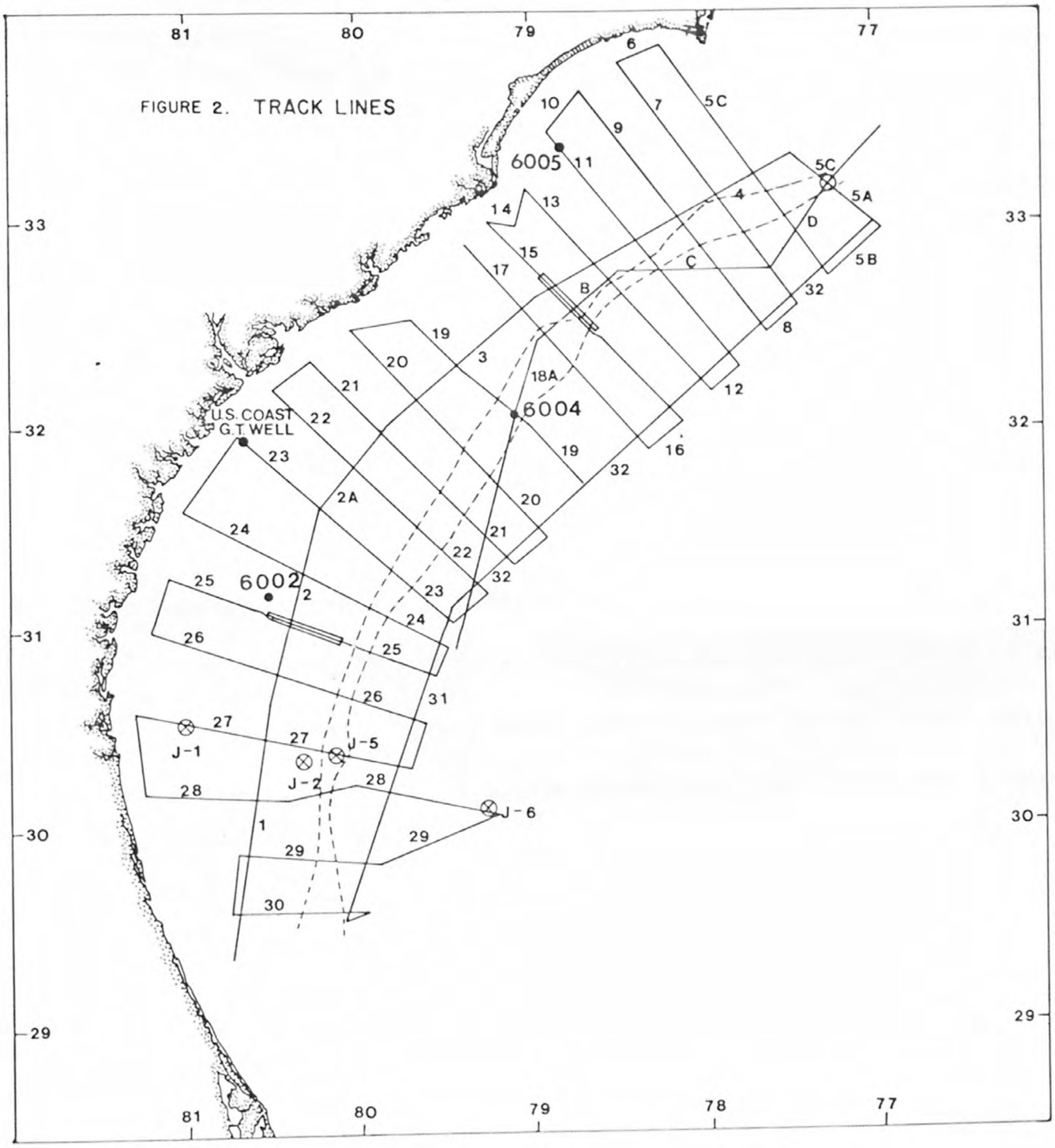
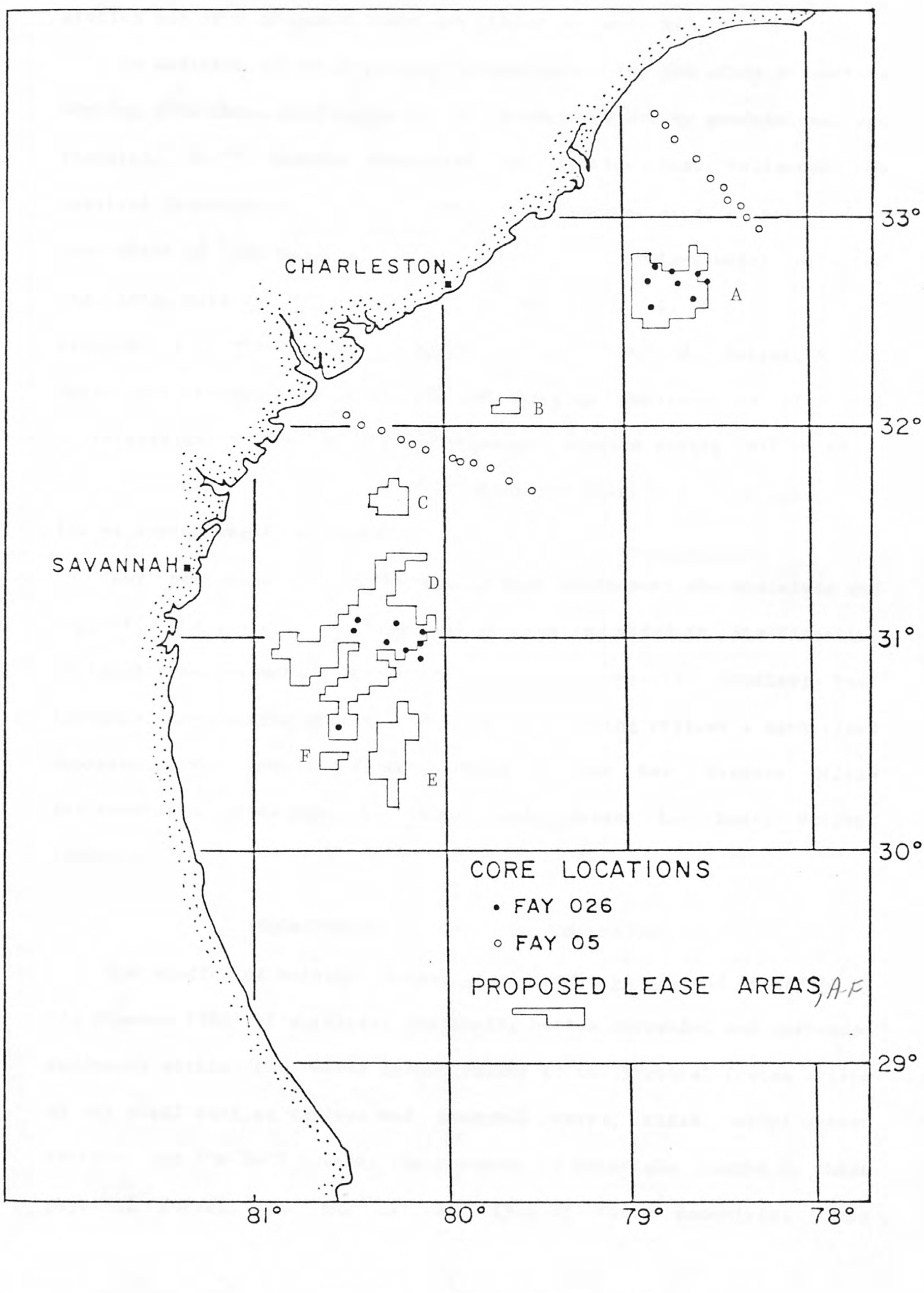


FIGURE 2. TRACK LINES
81
80
79
77
78
33
32
31
30
29
6005
6004
6002
U.S. COAST G.T. WELL
5C
5A
5B
D
C
B
18A
2A
J-1
J-2
J-5
J-6

Figure 3. Location of vibracore transects across the shelf and within the lease block areas obtained 1975-1977. The illustration does not show the hydrostatically-damped gravity core sites, which were concentrated in the lease block areas near the vibracore sites.

Figure 3


CHARLESTON
SAVANNAH
A
B
C
D
E
F
33°
32°
31°
30°
29°
81°
80°
79°
78°
CORE LOCATIONS
• FAY 026
○ FAY 05
PROPOSED LEASE AREAS, A-F

and their contributions to the Compendium of Work Elements for geologic studies for FY77 (Popenoe 1980) are listed in Table 2.

In addition to the Principal Investigators and the other scientists working with them, many other U. S. Geological Survey professional and technical staff members supported the cruises that collected the physical oceanographic, sedimentary, and geological data, or assisted in some phase of the reports. Chief Scientists on cruises which collected the data were H. J. Knebel, W. P. Dillon, L. D. McGinnis, J. A. Grow, O. H. Pilkey, and Bradford Butman. D. W. Folger, M. M. Ball, and Peter Popenoe served as Program Managers to plan and coordinate all phases of the environmental program during 1975 to 1977. Special thanks are hereby given to Elizabeth Diamond for the monumental job of typing the Final Report.

Key personnel in the Bureau of Land Management who conceived and supported the geologic environmental program and aided in its direction included Frank Monastero, Chief, Branch of Environmental Studies; Paul Lubetkin, Contracting Officer; Ed Wood, Contracting Officer's Authorized Representative; Douglas Elvers, Chief of the New Orleans Office Environmental Assessment Division; and Jesse L. Hunt, Project Inspector.

SIGNIFICANT FINDINGS AND CONCLUSIONS

The studies of Bothner, Butman *et al*, Doyle *et al*, and Pilkey *et al* (*in* Popenoe 1980) of surficial sediments, bottom currents, and suspended sediments within the water column relate to the physical forces acting on the shelf such as surface and internal waves, tides, storm driven currents and the Gulf Stream, the movement of materials caused by these physical forces, and the ultimate fate of these materials. This

Table 2. Roles of key participants.

Chapter in Popenoe (1980)	Title	Principal Investigator	Affiliation
Chapter 1	Introduction	Peter Popenoe Editor	U. S. Geological Survey Woods Hole, MA 02543
Chapter 2	Seston of the Southeast Georgia Embayment	Larry J. Doyle	Univ. of South Florida St. Petersburg, FL 33701
Chapter 3	Turbidity in the Southeast Georgia Embayment	Michael H. Bothner	U. S. Geological Survey Woods Hole, MA 02543
Chapter 4	Bottom Currents and Bottom Sediment Mobility in the Offshore Southeast Georgia Embayment	Bradford Butman	U. S. Geological Survey Woods Hole, MA 02543
Chapter 5	Surficial Sediments of the U. S. Atlantic Southeastern United States Continental Shelf	Orrin H. Pilkey	U. S. Geological Survey Duke University Durham, N.C. 27708
Chapter 6	Vibracore Studies: Georgia Embayment Shelf	Orrin H. Pilkey	U. S. Geological Survey Duke University Durham, N.C. 27708
Chapter 7	Trace Metal Concentrations in Sediment Cores from the Continental Shelf off the South-eastern United States	Michael H. Bothner	U. S. Geological Survey Woods Hole, MA 02543
Chapter 8	Distribution and Occurrence of Reefs and Hardgrounds in the Georgia Bight	Vernon J. Henry	University of Georgia Skidaway Institute Savannah, GA 31406
Chapter 9	Southeast Georgia Embayment High-Resolution Seismic Reflection Survey	Douglas W. Edsall	U. S. Geological Survey U. S. Naval Academy Annapolis, MD 21402
Chapter 10	The Geology of the Florida-Hatteras Slope and Inner Blake Plateau	Charles K. Paull	U. S. Geological Survey Woods Hole, MA 02543
Chapter 11	South Atlantic Outer Continental Shelf Hazards Map	Mahlon M. Ball	U. S. Geological Survey Woods Hole, MA 02543

information is important in the engineering design of structures for use on the shelf and for predicting the dispersal of pollutants such as spilled oil, ocean dumped materials, or drilling muds. Fine-grained particulates and clays are scavengers of trace metals and knowledge of their movement across the shelf is needed to predict both pollutant dispersal pathways, and the ultimate areas of deposition. These types of materials are also extensively reworked by benthic or epibenthic organisms, thus the entire food chain is affected. Because this material is in suspension it is free to be transported by even the most gentle currents.

Suspended Sediments

Michael H. Bothner, Larry J. Doyle, Peter Betzer,

Martin Peacock, and Fredrick Wall

Sampling of suspended sediments involved a grid of 50 stations on seven transects across the OCS between Cape Canaveral, Florida and Cape Fear, North Carolina. In order to measure seasonal variations sampling was done in winter (February-March), spring (May), summer (August), and fall (November). Two depths were sampled at shallow stations and three at deeper stations in order to provide a three-dimensional perspective. In the June, August and November cruises an optical device was used to measure turbidity maxima. Stations occupied and vessels used were those of Texas Instruments, Inc. during their physical, biological and chemical sampling cruises.

Multi-depth sampling showed the total suspended load within the water column was highest in the winter season, slightly lower during the summer, and considerably lower during spring and fall. Total suspended load reflects both storm activity and biogenic productivity. During all seasons the total suspended load was highest in the nearshore environment associated with low salinity water. This is due to the higher wave-generated turbulence which resuspends bottom materials in the inshore area, the finer-grained bottom materials, and the input of silt and clay particles from river systems. The near-bottom suspended material decreased on the mid-shelf and increased again near the shelf edge.

In near-bottom materials, feldspar and quartz followed by kaolinite are the most abundant minerals in suspension. A study of the clays in suspension indicated a lack of smectite, a dominant clay mineral on both the Coastal Plain and Shelf sediments, and a predominance of kaolinite and illite, common clay minerals of the Piedmont province.

Since these clay minerals are not common in shelf sediments, the river derived materials apparently cross the shelf in the water column to be deposited on the slope or continental rise.

The highest plankton crop occurs during the spring and the lowest during the summer. At almost all stations sampled by the optical technique a 5- to 15-m near-surface layer of planktonic organisms was seen. Coccoliths, diatoms, and dinoflagellates followed by Foraminifera and coccospheres were the most abundant fauna and flora. Aggregates of fecal origin composed of fragments of coccoliths and other planktonic forms were common in the suspended matter.

Bottom Currents and Bottom Sediment Mobility

Bradford Butman, David W. Folger, and Stephanie Pfirman

In situ observations of bottom processes were made in a pilot study within Lease Block Area D on the mid-shelf in water of 86 m depth in August-September 1977. A bottom-mounted instrument system was deployed which measured bottom current speed and direction, temperature, light transmission, bottom pressure and waves, and at 2 hour intervals photographed the bottom.

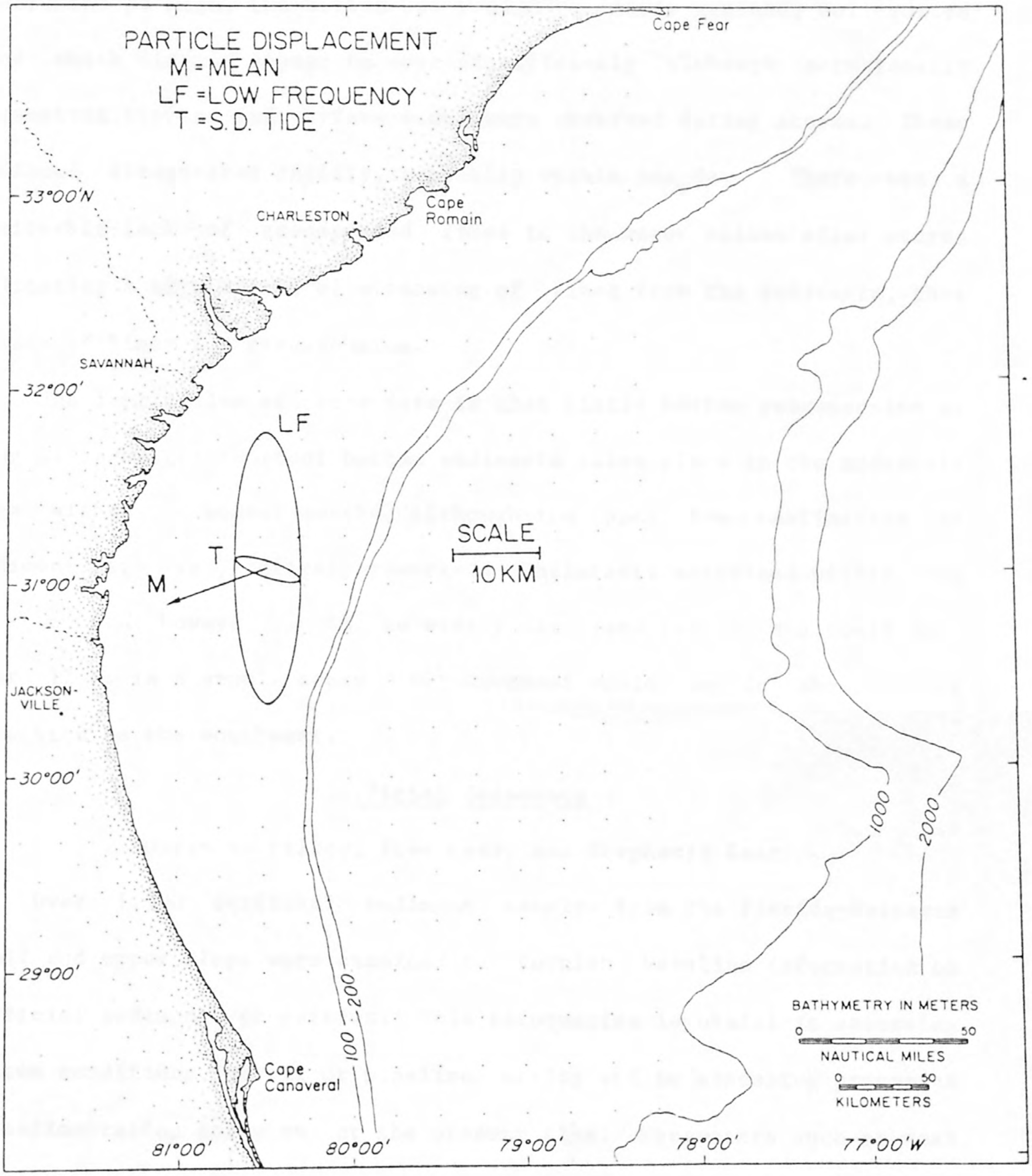
A summation of typical bottom particle displacements caused by the currents on the central part of the shelf is shown in Figure 4. This diagram illustrates forces acting to disperse particles in August. The currents are dominated by the semidiurnal tides which move in a clockwise cross-shelf elipse at speeds up to 25 cm/sec (1 km/hr). The average near-bottom speed from the tidal cycle is 19 cm/sec with speeds in excess of 30 cm/sec about 10% of the time. The tidal cycle would transport suspended particles 4 km cross-shelf and 1 km longshelf during each cycle. Superimposed on the tidal flow are high frequency current speed fluctuations of 10-15 cm/sec probably associated with internal waves.

Longer term low frequency displacements, probably due to meterological forcing and Gulf Stream incursions, are also evident. These currents are generally less than 10 cm/sec in the longshelf direction (north-south). Net particle displacement from these longer term currents would be about 12 km in 10 days either in a northerly or southerly direction depending on wind and resultant current direction.

The mean flow over the entire current record was about 1.3 cm/sec toward the southwest (251^{o}) or the inshore direction. These results for bottom suspended-particle dispersal are similar to the conclusions reached by modeling oil spill trajectories from wind and surface current data by Slack and Smith (1976) who show that the Jacksonville-Cape Canaveral, Florida area has the greatest beaching probabilities relative to the present lease block areas.

Observations of movement of bottom materials showed that the upper 5 to 10 cm of surficial sediments are continually reworked by both benthic organisms and by bottom currents. Within the area of the bottom

Figure 4. Typical water particle displacement associated with the mean current (M, computed for 10 days), the low frequency current (LF), and the semidiurnal tidal currents (T). The low frequency excursions were calculated as the displacement due to a sinusoidal current with an amplitude of the standard deviation of the low-passed current components and a typical time scale of 5 or 3 days for the longshore and cross-shore current, respectively. Note that the displacement scale is five times the map scale and thus the displacements are actually small compared to shelf dimensions.


PARTICLE DISPLACEMENT
M = MEAN
LF = LOW FREQUENCY
T = S.D. TIDE
Cape Fear
33°00'N
CHARLESTON
Cape Romain
SAVANNAH
32°00'
LF
SCALE
10 KM
T
M
31°00'
JACKSON-VILLE
30°00'
1000
2000
29°00'
100
200
BATHYMETRY IN METERS
0 50
NAUTICAL MILES
0 50
KILOMETERS
Cape Canaveral
81°00'
80°00'
79°00'
78°00'
77°00'W

instrument package, the bottom was medium to coarse grained, well-sorted sand which did not appear to move significantly although occasionally asymmetric ripples and surface scour were observed during storms. These bedforms disappeared rapidly, typically within one day. There was a noticeable lack of resuspended fines in the water column after storms indicating a high degree of winnowing of fines from the sediments, thus a lack of fines for resuspension.

The implication of these data is that little bottom resuspension or long distance transport of bottom sediments takes place in the mid-shelf area within the summer months, although the upper few centimeters of sediment are very actively reworked. Pollutants entrained within the water column, however, would be widely dispersed rapidly and could move over 12 km in a single storm. Net movement would be in the inshore direction to the southeast.

Surficial Sediments

Orrin H. Pilkey, Fred Keer, and Stephanie Keer

Over 1,500 surficial sediment samples from the Florida-Hatteras Shelf and upper slope were examined to furnish baseline information on surficial sediment properties. This information is useful in assessing bottom conditions for rig or pipeline siting and in assessing processes of sedimentation going on at the present time. Parameters such as mean grain size, total sediment color, carbonate color, non-carbonate color, and sediment lithofacies were recorded and surficial maps were made showing their distribution.

Grain size of shelf sediments is a highly variable parameter which changes rapidly over short distances. This was first documented by Gorsline (1963). However, in any given area, the samples are similar enough that certain generalizations can be made. Nearshore, and on the slope, grain size tends to be in the fine sand range, whereas on the central and outer shelf, grain size tends to be in the medium to coarse range. The transition from medium to coarse sand to fine sand and silt on the uppermost slope occurs rapidly, generally in the 100-300 m depth range. From Cape Romain south the shelf cover is generally medium sand. North of Cape Romain coarse sand becomes important. Color of sediments ranges from salt and pepper to gray, green, reddish-brown and orange yellow. Color is generally relatable to iron staining of quartz, feldspar, and carbonate, and reflects both the origin and oxidation state of the sediments. The general patchiness of color parameters indicates that regional mixing or long distance lateral transport of sediments does not take place.

Lithofacies groups based on a combination of grain size, color, and composition probably best characterize the sediments. Lithofacies maps are shown in Figures 5, 6, and 7 of the shelf area. These maps show that the dominant sediment type north of Cape Hatteras is fine terrigenous (high quartz-feldspar content) sand. South of Cape Hatteras and north of Cape Romain calcareous and terrigenous sand are present. The bottom in the Onslow Bay area and off Florida is predominantly calcareous sand. South of Cape Romain off Georgia and South Carolina terrigenous sands predominate.

Areas of silt or mud occur off Cape Hatteras, Cape Lookout, in the nearshore area between Cape Romain and St. Helena Sound and along both the shoreline and slope off Florida. These areas may mark locations where present deposition exceeds winnowing. The overall picture of surficial sedimentation indicates, however, that most of the sediments exclusive of the carbonate fraction, are relict and that little material is being added to the shelf at the present time.

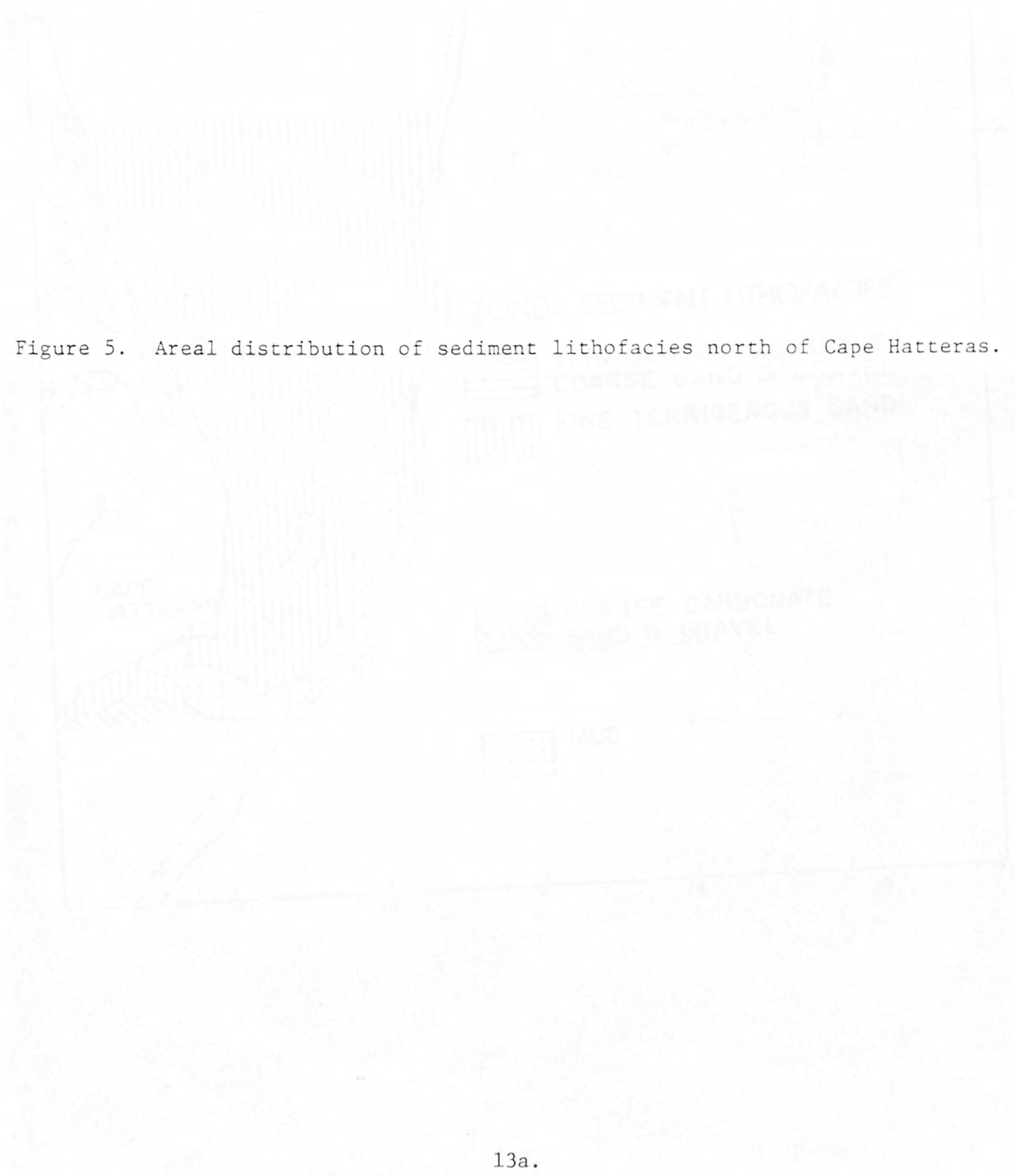


Figure 5. Areal distribution of sediment lithofacies north of Cape Hatteras.

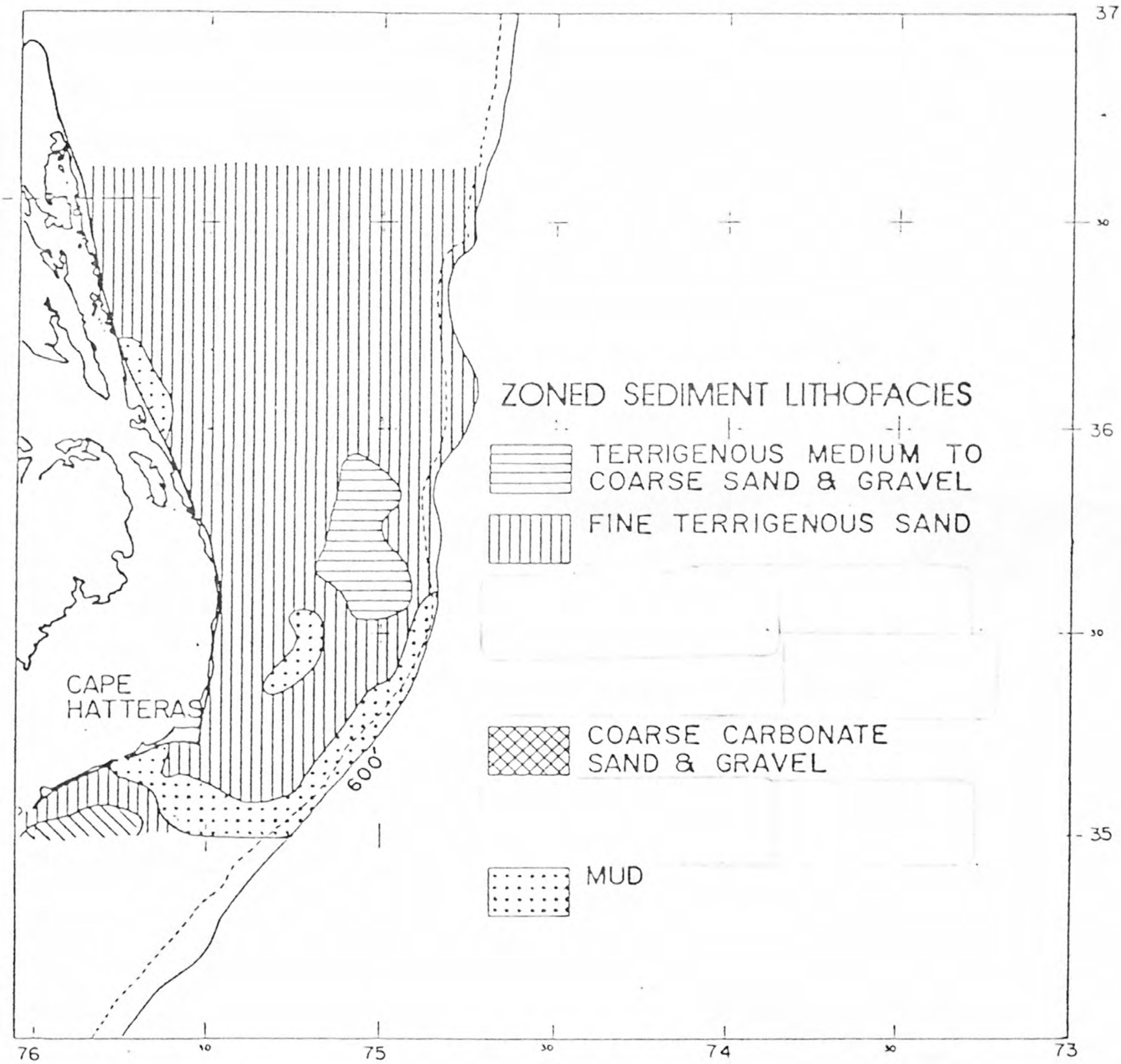
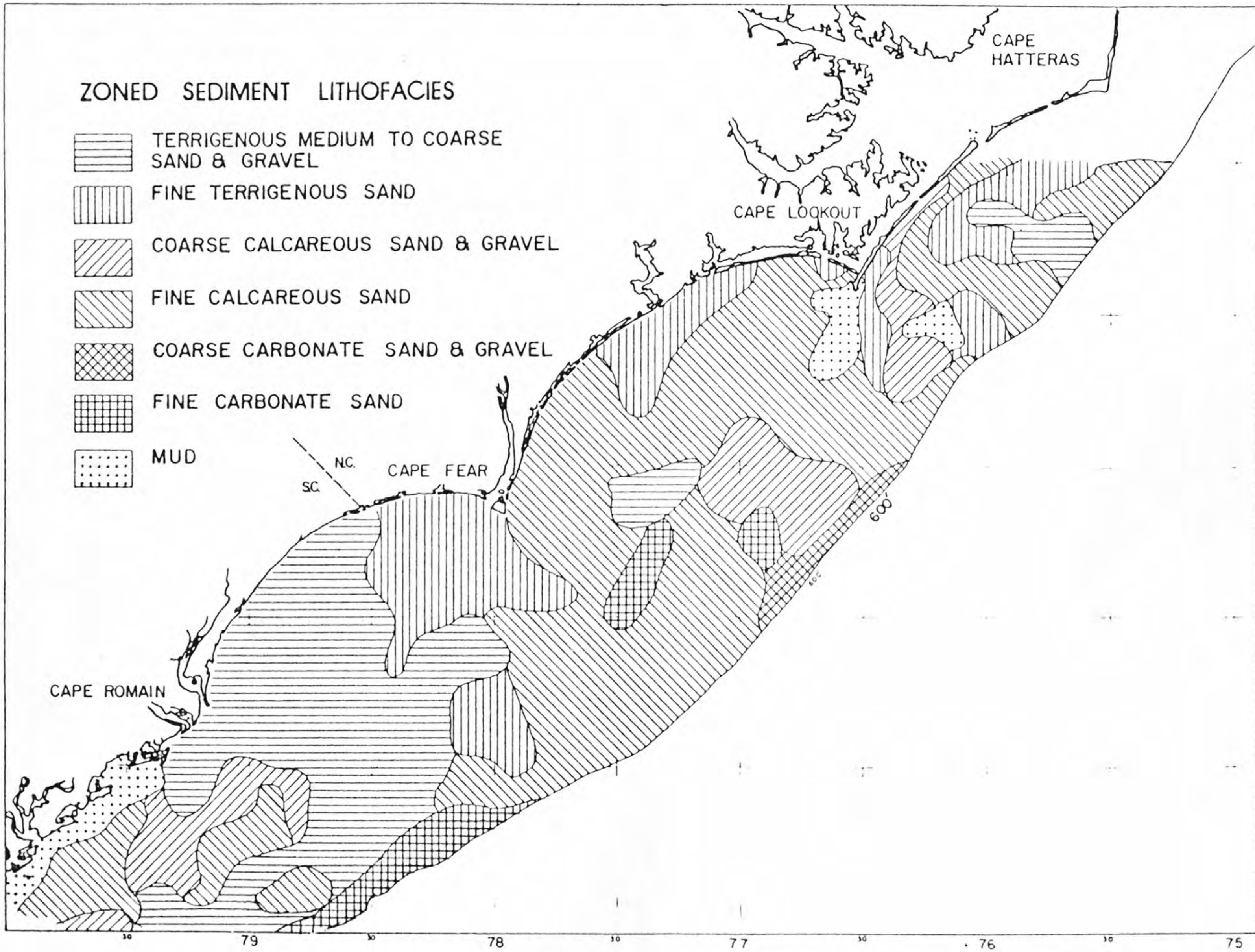

ZONED SEDIMENT LITHOFACIES
TERRIGENOUS MEDIUM TO COARSE SAND & GRAVEL
FINE TERRIGENOUS SAND
COARSE CARBONATE SAND & GRAVEL
MUD
CAPE HATTERAS
600
37
36
35
76
75
74
73

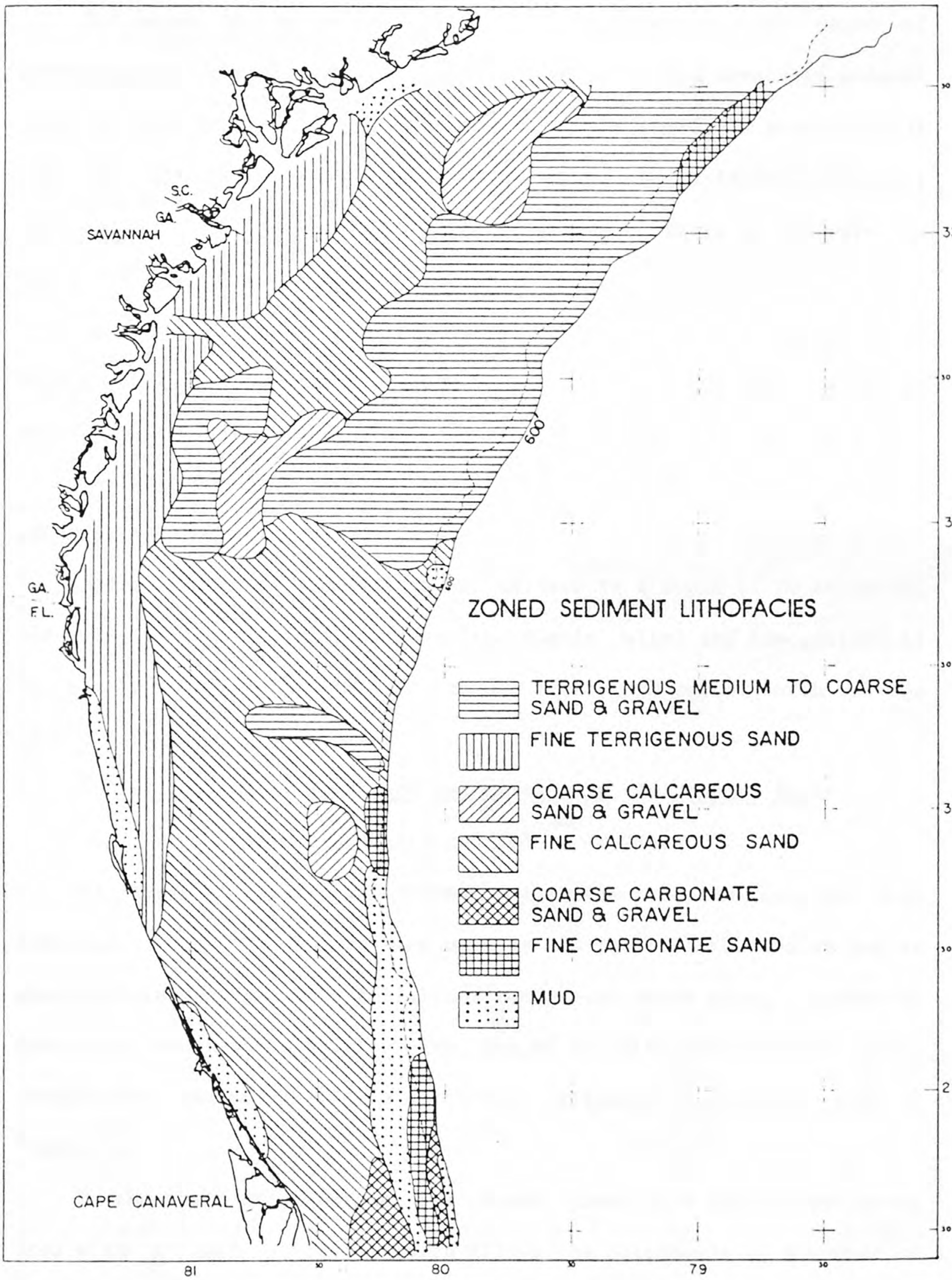
Figure 6. Areal distribution of sediment lithofacies; Cape Hatteras to Cape Romain.



ZONED SEDIMENT LITHOFACIES
TERRIGENOUS MEDIUM TO COARSE SAND & GRAVEL
FINE TERRIGENOUS SAND
COARSE CALCAREOUS SAND & GRAVEL
FINE CALCAREOUS SAND
COARSE CARBONATE SAND & GRAVEL
FINE CARBONATE SAND
MUD
CAPE HATTERAS
CAPE LOOKOUT
CAPE FEAR
N.C.
S.C.
CAPE ROMAIN
600
35
34
33
79
78
77
76
75

Figure 6

Figure 7. Areal distribution of sediment lithofacies; Cape Romain to Cape Canaveral.


S.C.
GA.
SAVANNAH
GA.
F.L.
CAPE CANAVERAL
600
ZONED SEDIMENT LITHOFACIES
TERRIGENOUS MEDIUM TO COARSE SAND & GRAVEL
FINE TERRIGENOUS SAND
COARSE CALCAREOUS SAND & GRAVEL
FINE CALCAREOUS SAND
COARSE CARBONATE SAND & GRAVEL
FINE CARBONATE SAND
MUD
32
31
30
29
81
80
79

Trace Metal Concentrations in Sediment Cores from the Continental Shelf

Michael H. Bothner, Phil Aruscavage, Wayne Ferrebee, and Joan Lathrop

In order to determine the level and changes with depth of anthropogenic contamination and to measure background levels of natural trace metals in the surficial sediments of the shelf, 10 gravity cores and 10 cores taken with a device to preserve the surficial sediments were collected and analyzed for 12 trace metals. These metals were Al, Ba, Cd, Cr, Cu, Fe, Mn, Mo, Ni, Pb, V and Zn.

Analyses show that the trace metal concentrations within all cores were generally uniform with sediment depth and were low with respect to average crustal abundance. Values were characteristic of an area having uncontaminated coarse-grained sediments, and show no evidence of anthropogenic contamination, even in the water-sediment interface zone.

Sediment texture appeared to be uniform to a depth of 70 cm in all cores indicating that sediments are thoroughly mixed and homogenized by benthic organisms and currents to at least this depth, which was the limit of the coring instrument.

Distribution of Reefs and Hardgrounds in the Georgia Bight

Vernon J. Henry and Robert T. Giles

Minisparker and 3.5 kHz seismic reflection profiles coupled with side scan sonar techniques were used to map the distribution of and to characterize geophysically reefal and hardground areas along a number of transects crossing the shelf within two of the BLM Lease Sale 43 areas. Ground truth was obtained from vibracores collected at stations shown in Figure 3.

On the shelf off Georgia and South Carolina a reefal area is an area with a hard substrate which allows the attachment of a number of sessile benthic organisms such as sponges, sea fans, hard and soft corals, sea whips and algae, and which supports a community of reefal and predatory fish. Mapping the distribution of these areas is important to assure their protection during development activities since they are both recreational and commercial fishing areas. These areas are locally known by a number of names including patch reefs, live bottoms, hard bottoms, coral patches, fishing banks, snapper banks, black rocks, and limestone reefs.

The occurrence of hardgrounds appears to be related to outcroppings of one or more shallow, near-surface acoustically hard layers which are exposed in low areas that have resulted from either erosion or non-deposition, or to submerged ancient shore lines (beachrock?). The distribution of hardground areas is patchy and more common in the mid- to outer shelf areas where the sand cover appears to be thinner and less dissected by Pleistocene river channels. Hardground areas appear to be more common off North Carolina, South Carolina, and Florida than off the Georgia coast.

The study identified three general morphotypes of reefs and hardgrounds. The most common are low-relief hardgrounds that occur as relatively smooth, flat lying rock outcrops cyclically covered and uncovered by a veneer of sand several centimeters or more in thickness. The areas are identified by the presence of a sparse growth of attaching organisms--principally sponges, alcyonarions, and ascidians--that extend through the flat, sandy bottom. Geophysically, these areas are difficult to identify, but they are best identified by indications of an acoustically hard bottom on 3.5 kHz seismic records and by fish signatures on fathometer records.

Moderate-relief hardgrounds are less common on the shelf. These areas which may exhibit relief of 2 m or more support a moderately abundant to abundant benthic and demersal community. Like low-relief hardgrounds, their occurrence appears to be related to outcrops of one or more near-surface acoustically hard layers. The age of the layers or the cementation mechanism has not been determined except at Gray's Reef (Hunt 1974) off the Georgia coast where the substrate is described as dolomitic sandy biomicrite of Pliocene age. Hardgrounds may be developed on several ages of substrate, because as Ayers et al (Chapter 6, of Popenoe 1980) show, lower Pleistocene age (Waccamaw) rock fragments make up the hard substrate in Lease Block Area A and Paleocene age rocks make up a near-surface hard layer in Onslow Bay. Although often difficult to identify on fathometer records by bottom roughness alone, moderate-relief hardgrounds are more easily discerned by sonograms used in conjunction with 3.5 kHz seismic profiles.

The third type of reefal area occurs as a discontinuous, but well-defined, generally high-relief ridge or series of ridges near the initial break in slope at the edge of the Continental Shelf. This type occurs in water depths ranging from 20 to 110 m from Cape Hatteras to Fort Lauderdale, Florida (Macintyre and Milliman 1970). Shelf-edge reefs support a moderately abundant to abundant benthic and demersal community. The origin of these ridges is probably related, in part, to ancient shorelines, as reef substrate dredged from a location due east of Sapelo Island consisted of a well-lithified oolitic (beachrock?) conglomerate. The formation of oolite requires a shallow, high energy, turbulent marine environment. In addition, surfaces interpreted to be erosional wave-cut terraces are seen seaward of some of the ridges (Edsall 1978, Figure A-20).

Vibracore Studies: Georgia Embayment Shelf

Mark Ayers, Blake W. Blackwelder, James D. Howard, Fred Keer,

Harley J. Knebel, and Orrin H. Pilkey

Forty vibracores were taken across the Continental Shelf of the Southeast Georgia Embayment and studied in detail. Aspects studied included faunal assemblages, sediment textures, compositions and structures. Twenty-two of the vibracores were taken in two detailed, linear cross-shelf transects and 18 vibracores were taken in the proposed BLM Lease Areas A and D. Location of cores is shown in Figure 3. These are the first vibracore transects across any continental shelf and they offer a unique basis for examining shelf sedimentation history and shelf sedimentation processes. The cores from this study were used both for this purpose and for trace metal and reef and hardgrounds studies as previously discussed.

Core penetration rates and Tertiary consolidated rocks recovered from the base of the cores demonstrate that the unconsolidated Holocene-Pleistocene sand cover of the shelf is everywhere quite thin, usually under 4 m and rarely over 6 m in thickness. A number of the cores penetrating through the sand cover recovered Lower Pleistocene (Waccamaw) age rocks along the southern transect and in Lease Block Area A; in Onslow Bay Paleocene age rocks were recovered. In spite of repeated transgressions during the Pleistocene very little sediment has been contributed to the shelf. Most sediment is tied up in the present shoreface wedge or in old stranded shorefaces on the present Coastal Plain. The presence of lagoonal deposits on the mid-shelf clearly indicates barrier islands were at one time present on the mid- to outer shelf, but these sediments have now migrated to the present shoreface, or been removed.

The shelf cover has undergone extensive mixing during the Holocene, probably largely the result of alternate scouring and filling during storms. This mixing occurred in small surges. Cores were highly bioturbated indicating that sufficient time elapsed between depositional events such as storms for complete sediment turnover and that storm events do not affect a very thick section of the sedimentary column.

Only late Pleistocene to Holocene fossils were present within the shelf cover. These fossils represent four different assemblages: offshore, shallow shelf, inlet-backbarrier and mixed backbarrier shelf. Figure 8 shows the distribution of those units along the two transects crossing the shelf. The full cycle of deposition was not present in many cores, thus lagoonal beds were directly reworked into open shelf deposits without the progression to shallow shelf beds.

The lack of either early Pleistocene mollusks or Tertiary fossils eroded from the underlying sediments suggests: (1) that rising sea level affects only the upper few meters of sediments on the shelf; and (2) that the carbonate fraction of the shelf cover has been destroyed during each regression of sea level by weathering processes. The implication here is that the carbonate fraction is not relict as is the quartz fraction, but it is renewed with each transgression.

There are a number of environmental implications in the data. The dating of shallow water oysters in growth position across the shelf indicates that existing sea level curves for this area are in error (Figure 9). Thus, archeological sites, if present on the shelf, would be confined to a smaller area than previously believed. The thickness of the zone of in-place sediment suggests that minor topographic features are not relict or inherited from pre-existing shoreface environments (Swift 1976) but they may in part reflect present day

Figure 8. Vibracore stratigraphy of the shelf sediment cover. Stratigraphic units plus the depositional environment of the overlying Pleistocene-Holocene unconsolidated sediment cover are shown. Note the extreme vertical exaggeration.

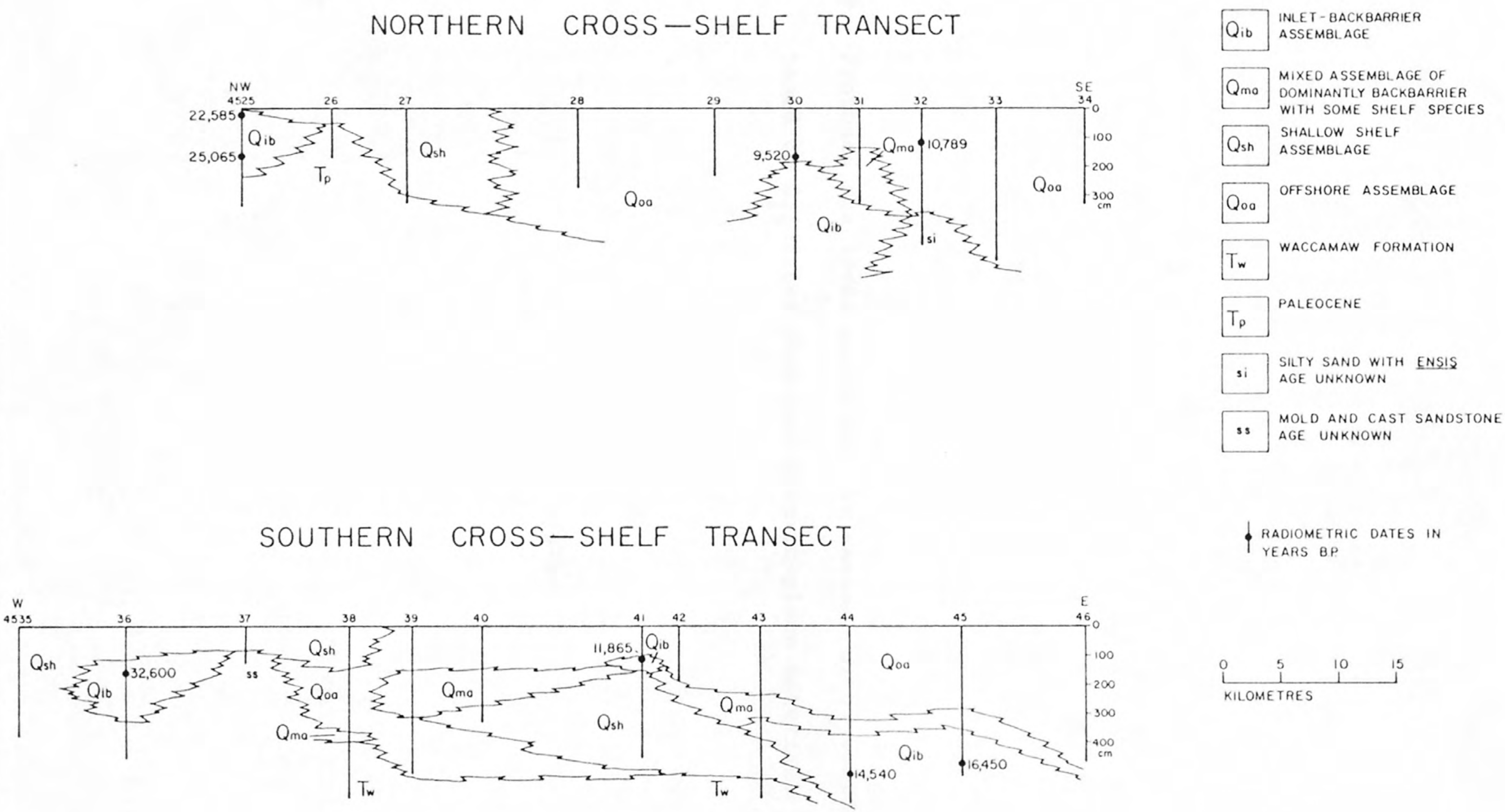

NORTHERN CROSS—SHELF TRANSECT
NW
SE
4525
26
27
28
29
30
31
32
33
34
22,585
25,065
9,520
10,789
Qib
Qsh
Tp
Qoa
Qma
si
0
100
200
300 cm
SOUTHERN CROSS—SHELF TRANSECT
W
E
4535
36
37
38
39
40
41
42
43
44
45
46
32,600
11,865
14,540
16,450
Qsh
Qib
ss
Qoa
Qma
Tw
0
100
200
300
400 cm
Qib INLET-BACKBARRIER ASSEMBLAGE
Qma MIXED ASSEMBLAGE OF DOMINANTLY BACKBARRIER WITH SOME SHELF SPECIES
Qsh SHALLOW SHELF ASSEMBLAGE
Qoa OFFSHORE ASSEMBLAGE
Tw WACCAMAW FORMATION
Tp PALEOCENE
si SILTY SAND WITH ENSIS AGE UNKNOWN
ss MOLD AND CAST SANDSTONE AGE UNKNOWN
RADIOMETRIC DATES IN YEARS B.P.
0 5 10 15
KILOMETRES

Figure 8

Figure 9. Proposed sea level curve for the eastern U. S. Continental Shelf based on C_{14} dates obtained from in-place material.

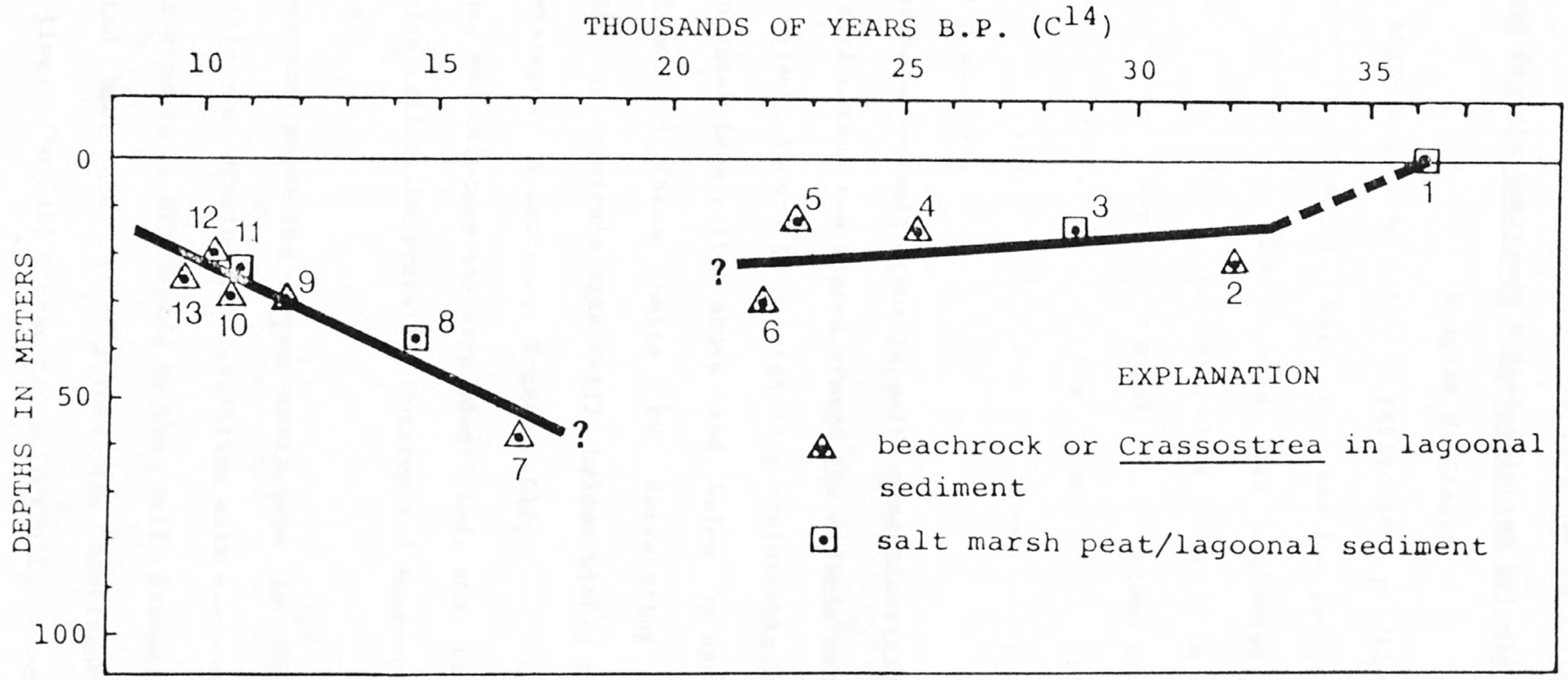

THOUSANDS OF YEARS B.P. (C^{14})
10
15
20
25
30
35
DEPTHS IN METERS
0
50
100
1
2
3
4
5
6
7
8
9
10
11
12
13
?
?
EXPLANATION
beachrock or Crassostrea in lagoonal sediment
salt marsh peat/lagoonal sediment

Figure 9

processes. The complete mixing of indigenous middle to outer shelf faunas into the shelf sediment cover indicates that significant sand movement does occur, most likely in response to major storm conditions.

Southeast Georgia Embayment High-Resolution Seismic Reflection Survey

Douglas W. Edsall

The high-resolution seismic reflection profiles collected along lines shown in Figure 2 were analyzed for Cenozoic stratigraphy and geologic hazards. The records were collected with a 600-joule minisparker along 21 dip lines spaced at about 30 km and three NE-SW tie lines. Penetration was on the order of 1/2 second on the outer shelf, slope, and Blake Plateau. On the inner shelf bottom reverberation problems (multiples) caused a deterioration of data quality, and the penetration was less.

Eight major seismic acoustic units were identified on the shelf and their distribution was traced around the seismic network. An acoustic unit on a seismic record is a relatively conformable sequence of related strata separated from units above and below by unconformities. Ages were assigned to these units by correlating reflectors with stratigraphic units within nine drill holes within the area. Units of Upper Cretaceous, Paleocene, Eocene, Oligocene, Miocene, Pliocene, Pleistocene, and Holocene age were identified, and line drawings were made of each reflection profile. Outcrop and subcrop maps then were constructed.

The sequence above the upper Cretaceous is thin and exhibits a complex history of erosion and deposition with numerous unconformities. Most of the erosion is attributed to the Gulf Stream as the currents have shifted back and forth across the continental margin since Paleocene time. The Gulf Stream has effectively blocked the seaward accumulation of the various Cenozoic sequences, and in places on the northern Blake Plateau has deeply eroded older Upper Cretaceous, Paleocene, and Oligocene rocks.

Although the study was mainly stratigraphic, a number of potential environmental hazards were identified and illustrated in photographs of the seismic records. These included features due to currents such as sand waves on the shelf, erosion and steep topography on the inner Blake Plateau, erosional unconformities beneath the shelf and slope, structural features such as a slump at the base of the slope in the central part of the area, and normal faulting on the slope. Also discussed or illustrated were the shelf edge reefs (discussed previously) and ubiquitous seismic hyperbolas on the Blake Plateau which reflect deep-water reefs.

The Geology of the Florida-Hatteras Slope and Inner Blake Plateau

Charles K. Paull and William Dillon

The structure and stratigraphy of the outer Florida-Hatteras Shelf and slope and inner Blake Plateau were studied by the analyses of airgun seismic reflection profiles along tracks shown in Figure 2. Major reflectors were traced on the records and the reflecting units were correlated with paleontologically-dated stratigraphic units in offshore wells and with dredge haul samples. Depths to significant surfaces were converted from time records to depth (structure) and unit thickness (isopach) maps based on interval velocities determined from root-mean-square (RMS) velocity analyses of common depth point (CDP) multi-channel seismic records.

Within the survey area the Upper Cretaceous and Paleocene age rocks were deposited on a broad, flat shelf and show no evidence that a feature similar to the Florida-Hatteras Shelf existed at the beginning of the Tertiary. Three units can be seismically distinguished in the Upper Cretaceous: the Turonian to Coniacian; the Santonian; and the Campanian and Maastrichtian. These units are overlain conformably by flat-lying Paleocene age strata.

At the end of the Paleocene a major erosional event occurred which carved a 100-km wide channel into the top of the Paleocene strata just west of the axis of the present Gulf Stream. This event marks the initiation of the Gulf Stream which has controlled sedimentation on the shelf and Blake Plateau throughout the Tertiary.

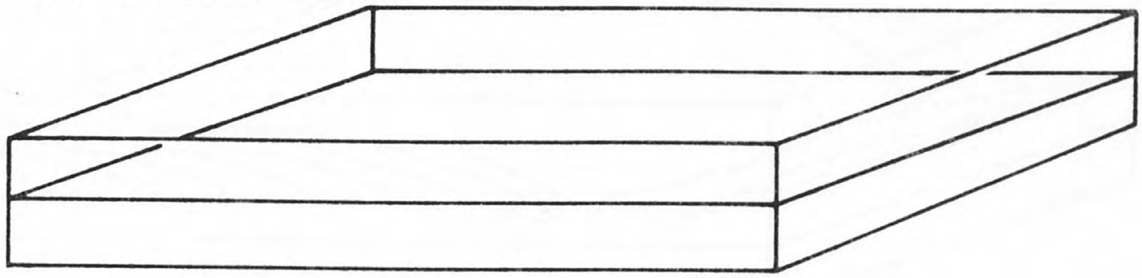
Eocene, Oligocene, and Miocene age beds, which have built the shelf up and out, form a thick progradational sequence overlying the Paleocene west of the present Gulf Stream. Under and seaward of the present Gulf Stream, these units are either quite thin or absent. Thus sediments have not been able to cross this barrier, and the difference in accumulation rate accounts for the shelf and slope.

During Eocene and Oligocene time the axis of the Gulf Stream shifted seaward about 50 km and sediments covered the Paleocene unconformity. This progradation was terminated by a major erosional event which again incised the toe of the Oligocene rocks. A thin section of Miocene, Pliocene and Quaternary has been deposited over the Oligocene. This sequence of events is illustrated in Figure 10 (from Chapter 10, of Popenoe 1980)

Of particular environmental interest in the seismic interpretation is a discussion of the offshore aquifer. The onshore aquifer in the Carolinas, Georgia and Florida is primarily developed in Eocene age rocks, although its boundaries may overlap into Paleocene and Oligocene age rocks. Isopach and structure contour maps were made of these units in the offshore area as was a map of the thickness of the Neogene, the

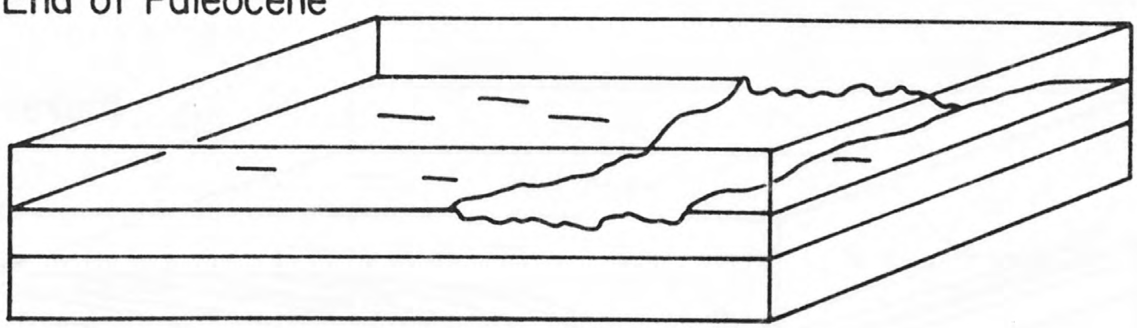
Figure 10. a. and b. Idealized block diagrams showing inferred Tertiary development of the Florida-Hatteras Slope.

End of Cretaceous

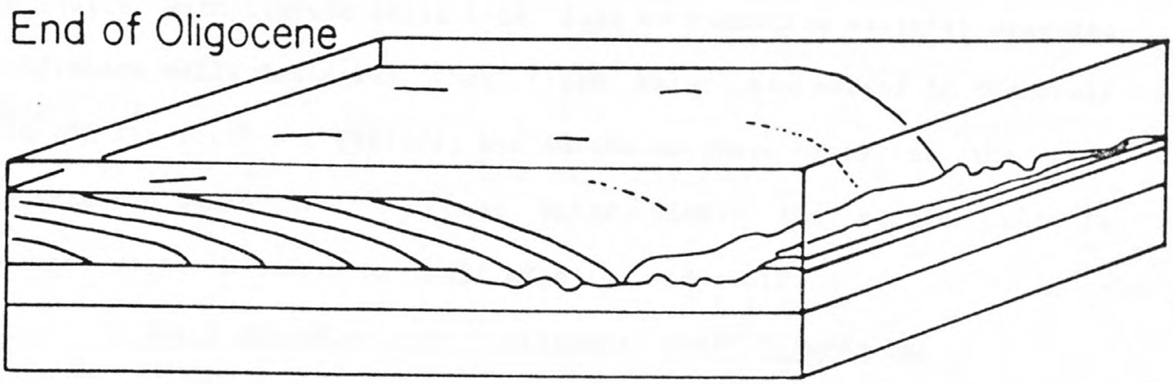


At the end of the Cretaceous this area was a broad, level, submerged platform. There was no appreciable distinction between the eastern and western portions of the surveyed area. The Cenozoic-Mesozoic boundary is marked by a small but not particularly distinct unconformity.

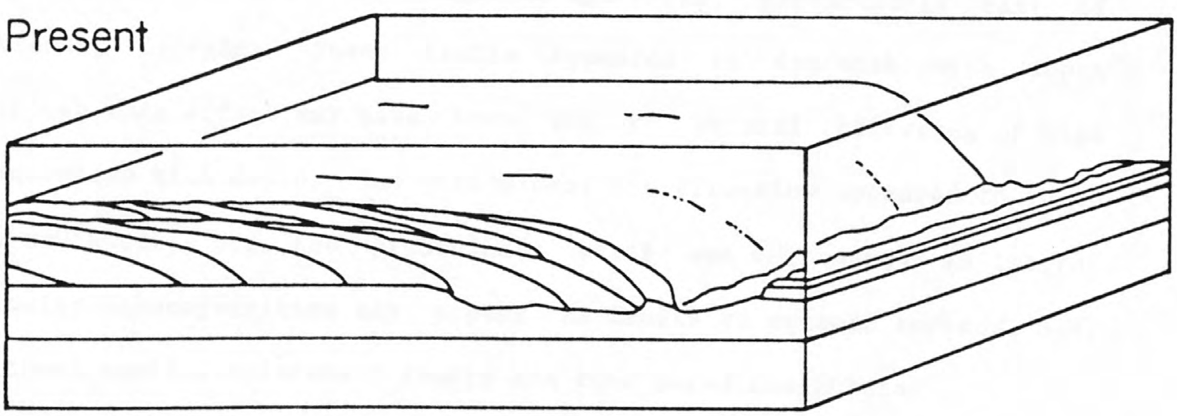
End of Paleocene



A sequence of Paleocene strata about 100 meters thick overlays the Cretaceous units. The top of the Paleocene section is irregularly eroded. Reliefs on this surface are up to 100 meters. This erosion is related to the initiation of the Gulf Stream in this area.



The late Paleocene unconformity is buried by a large seaward progradational wedge of Eocene to Oligocene age. This progradation was terminated by an erosional event at the end of the Oligocene.



The late Oligocene erosion surface was buried by an additional progradation of the shelf and slope from Miocene to recent times. The Tertiary accumulations under the shelf are much greater than on the Blake Plateau.

unit which caps the aquifer. A correlation of the extent or exposure of the aquifer with limited drill hole data on formation salinity measured in offshore wells indicates that fresh water may extend to the shelf edge in the south off Florida, but in the northern part of the area (Georgia and South Carolina) most water within the aquifer unit is probably saline between the shelf edge and mid-shelf.

South Atlantic Outer Continental Shelf Hazards Map

Mahlon Ball, Peter Popenoe, Michael Vazzana, Elizabeth Coward, William Dillon, Thomas Durden, Jack Hampson, and Charles Paull

A geologic hazards analysis was made based on the seismic reflection profiles collected along lines shown in Figure 2. Features such as sand waves, submarine cut-and-fill, scour or steep topography, faults, slump masses, water column anomalies, the shelf edge reef, and deep-water reefs were determined and plotted on a geologic hazards map.

Four types of faults were identified. On the shelf a number of very small displacements of 1 to 2 meters were noted displacing near-surface Miocene and Oligocene age rocks, particularly east of Savannah, Georgia. These faults appeared to diminish with depth although this effect may have been due to natural filtering of high frequencies with depth. The predominant dip direction appeared to be to the southwest, and the predominant strike was northward. As lateral velocity inhomogeneities may appear as faults on seismic records, many of these small displacement faults are considered conjectural.

Beneath the outer shelf and inner Blake Plateau larger faults of 10-20 m were noted displacing Upper Cretaceous rocks. These faults terminate against the overlying Paleocene and also appear to diminish with depth. Paull and Dillon (1979) attributed these faults to compaction in the Upper Cretaceous chalky sediments.

Only two normal faults were revealed in the high-resolution data in 21 crossings of the slope. These faults, which occurred on line 29, were down to the east with 10 m displacements and buried by about 10 m of undisturbed sediments.

One large slump mass approximately 5 km long and 50 m thick occurs at the base of the slope on line 19. Two other small possible slump masses occur on lines 5A and 11. Attempts to core the large slump on line 19 resulted in bent core barrels suggesting that the slump had been in place long enough to have been armored by phosphorite gravel.

The fact that there are so few slump faults probably reflects slow deposition and winnowing of the fines by the Gulf Stream before deposition on the slope and a low angle of declivity of the slope.

Hazards reflecting strong currents included cut-and-fill structures, steep topography, and scour. Cut-and-fill channeling of both river and submarine current origin were identified. River or back-barrier channeling is concentrated mainly on the inner and mid shelf. Cut-and-fill of submarine current origin is concentrated mainly on the outer shelf, slope, and inner Blake Plateau.

The inner Blake Plateau is characterized by severe submarine scour. As a result, the bottom is eroded into a series of mesas and valleys separated by steep escarpments held up by lag phosphorite and manganese nodules. This erosion is particularly severe in the northern part of the area where Cretaceous and Paleocene age rocks are exposed.

Constraints to rig or structure placement such as the shelf edge reef at the top of the slope and deep-water bioherms on the Blake Plateau were also mapped.

The conclusion of the study is that with proper precautions, only the strong currents of the Gulf Stream will present a major hazard to exploration or development of the margin. All other problems can be overcome by proper engineering or rig placement.

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