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SEDIMENTS, STRUCTURAL FRAMEWORK, PETROLEUM POTENTIAL, ENVIRONMENTAL CONDITIONS, AND OPERATIONAL CONSIDERATIONS OF THE UNITED STATES SOUTH ATLANTIC OUTER CONTINENTAL SHELF.

BY

U.S. Geological Survey

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Sediments, Structural Framework, Petroleum Potential, Environmental Conditions, and Operational Considerations of the United States South Atlantic Outer Continental Shelf

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By the U.S. Geological Survey

ABSTRACT

The area designated for possible oil and gas lease sale in Bureau of Land Management memorandum 3310 #43 (722) and referred to therein as part of the United States South Atlantic Outer Continental Shelf (OCS) contains about 98,000 square kilometres of the continental margin seaward of the 3 mile offshore limit and within the 600 metre isobath. The designated area, offshore of North Carolina, South Carolina, Georgia, and Florida, encompasses parts of three physiographic provinces: the Continental Shelf, the Florida-Hatteras Slope, and the Blake Plateau.

The structural framework of the U.S. South Atlantic region is dominated by the Southeast Georia Embayment --an east-plunging depression recessed into the Atlantic Coastal Plain and shelf between Cape Fear, North Carolina and Jacksonville, Florida. The embayment is bounded to the north by the Cape Fear Arch and to southeast by the Peninsular Arch.

Refraction data indicate a minor basement(?) ridge beneath the outer shelf between 30° and 32°N at 80°W. Drill hole data also suggest a gentle fold or accretionary structure (reef?) off the east

coast of Florida. Several other structural features have been identified by refraction and reflection techniques and drilling. These are the Yamacraw Uplift, Burton High, Stono Arch, and the Suwannee Channel.

Gravity and magnetic anomalies within the area probably result from emplacement of magma bodies along linear features representing fundamental crustal boundaries. Of these anomalies, the most prominent, is a segment of the East Coast Magnetic Anomaly which crosses the coast at Brunswick, Georgia. This anomaly has been interpreted as representing an ancient continental boundary where two formerly separate continental plates collided and were welded together.

There may be as much as 5,000 m of sedimentary rocks in the Southeast Georgia Embayment out to the 600 m isobath. Basement rocks beneath the Southeast Georgia Embayment are expected to be similar to those exposed in the Applachian Piedmont province. Triassic deposits are likely to exist beneath the inner Continental Shelf, and probably consist of nonmarine arkosic sandstones, shales, basalt flows, and diabase intrusions deposited in relatively narrow northeast-trending grabens. Jurassic marine carbonates in the Bahamas grade northward to carbonates, shales, sand, and arkose in North Carolina. Salt may be present in the basal Jurassic section in the Southeast Georgia Embayment. Up to 4,000 m of Jurassic-Lower Cretaceous rocks are expected out to the 600 m water depth. Lower Cretaceous rocks in southern Florida are shallow-water marine limestone and dolomites with beds of anyhydrite. In coastal North Carolina the Lower Cretaceous is a marine section made up of shales, sand, and sandy limestone. The Upper Cretaceous is composed almost entirely of marine carbonates in southern Florida grading northward to nonmarine to marginal marine, sandstones and shales with minor amounts of carbonates. In general, Upper Cretaceous rocks will probably maintain a fairly constant thickness (600 m) on the Continental Shelf and grade downdip from terrigeneous sands and shales to more marine chalks, limestones, and dolomites. The Cenozoic rocks are predominently shallow-water marine carbonates in Florida grading northward into a marginal marine to marine clastic facies composed of sands, marls, and limestones. The offshore Cenozoic section is expected to range in thickness from 600 to 1100 m.

A reconstruction of the geologic history suggests that the present continental margin is a result of a collision of the North American and African continental plates during late Paleozoic time and later modification during Late Triassic time when the continental plates separated, forming the present Atlantic Ocean.

No commercial production of hydrocarbons has been developed on the Atlantic Coastal Plain immediately adjacent to the studied area even though hydrocarbon shows have been encountered in onshore Coastal Plain wells of North Carolina, Georgia, and Florida. However, the offshore Southeast Georgia Embayment appears to have the necessary elements for hydrocarbon production -- traps, source rocks, and reservoir rocks. Potential hydrocarbon traps are expected to be chiefly stratigraphic, such as facies changes, updip pinchouts, reefs, and uncomformities, although drape structures and low relief anticlines may prove to be important. Potential source rocks in the Southeast Georgia Embayment may include organic-rich Lower Cretaceous shale (300 m thick) and carbonaceous Jurassic and Cretaceous carbonates. The Lower Cretaceous-Jurassic age rocks are considered to be the most perspective for hydrocarbon entrapment.

A geological analog to the Southeast Georgia Embayment might be the Senegal Basin on the west coast of Africa, and the Southwest Florida Embayment where the tectonic and stratigraphic frameworks appear to be similar.

Statistical mean estimates for the undiscovered recoverable petroleum resources are calculated to be 0.4 billion barrels of oil and 0.7 trillion cubic feet of gas. At the 5 percent probability level (1 in 20 chance) the undiscovered recoverable petroleum resources are calculated to be 1.5 billion barrels of oil and 2.8 trillion cubic feet of gas. These undiscovered recoverable petroleum resources are those quantities of oil and gas that may be reasonably expected to exist in favorable settings, but which have not yet been identified by drilling. Such estimates therefore carry a high degree of uncertainty.

The general paucity of "reserves" of hard minerals (other than oil and gas) of the U.S. Atlantic OCS area appears to result not from insufficient sampling but from an actual dearth of such minerals.

Potential hazards that could be associated with future petroleum development include: (1) weakening or possible damage to offshore construction due to collapse of solution cavities in carbonate rocks, poor support characteristics of shallow clay or peat layers, mobility of surficial sediments, or hurricane waves; (2) a shoreward concentration of surface drift toward the coast of northern Florida, especially in the vicinity of Cape Canaveral, which might concentrate offshore oil spills; (3) indications of continuing high level of seismic activity in the Charleston area and (4) exacerbation of salt water intrusion into the Floridan aquifer, a major source of potable water.

With respect to operational considerations, our highest estimates indicate that 20-25 platforms, 440 producing wells, 800 km of pipeline, and 4 onshore terminals may be needed. The time frame for production, using our high estimates (at the 5% probability level) for the undiscovered recoverable resources, could include 4-5 years for significant development, 6-7 years until production commences, and 12-16 years until peak production.

I. Introduction

This report was prepared in answer to the Bureau of Land Management (BLM) memorandum 3310 #43 (722) requesting, from the U.S. Geological Survey (USGS), a summary report describing the geology, potential mineral resources, estimated oil and gas resources, potential environmental hazards, and operational considerations of the United States South Atlantic Outer Continental Shelf (OCS) area. The report will be used in evaluating the possibility of an oil and gas lease sale. Researchers from academic institutions, government agencies, and industry have studied the United States South Atlantic OCS area and it is from their published knowledge and the ongoing USGS research and field projects that this synthesis is made.

The area under consideration for possible oil and gas lease sale in BLM memorandum 3310 #43 (722), and referred to therein as part of the South Atlantic (OCS), is shown in Figure 1. This area includes part of the United States East Coast Continental Shelf, part of the Florida-Hatteras slope, and the innermost part of the Blake Plateau. The area is bounded to the west and northwest by the 3 mile offshore limit, to the southeast by the 600 metre (m) isobath, to the northeast roughly by the Cape Fear Arch, and to the south by 28.5 degrees N latitude (Fig. 1). It encompasses approximately 98,000 square kilometres and is popularly referred to as the "Southeast Georgia Embayment".

The term Southeast Georgia Embayment was used by Toulmin (1955) to refer to an east-plunging depression recessed into the Atlantic Coastal Plain between Savannah, Georgia, and Jacksonville, Florida. This depression was originally named the "Okefenokee Embayment" by Pressler (1947) and

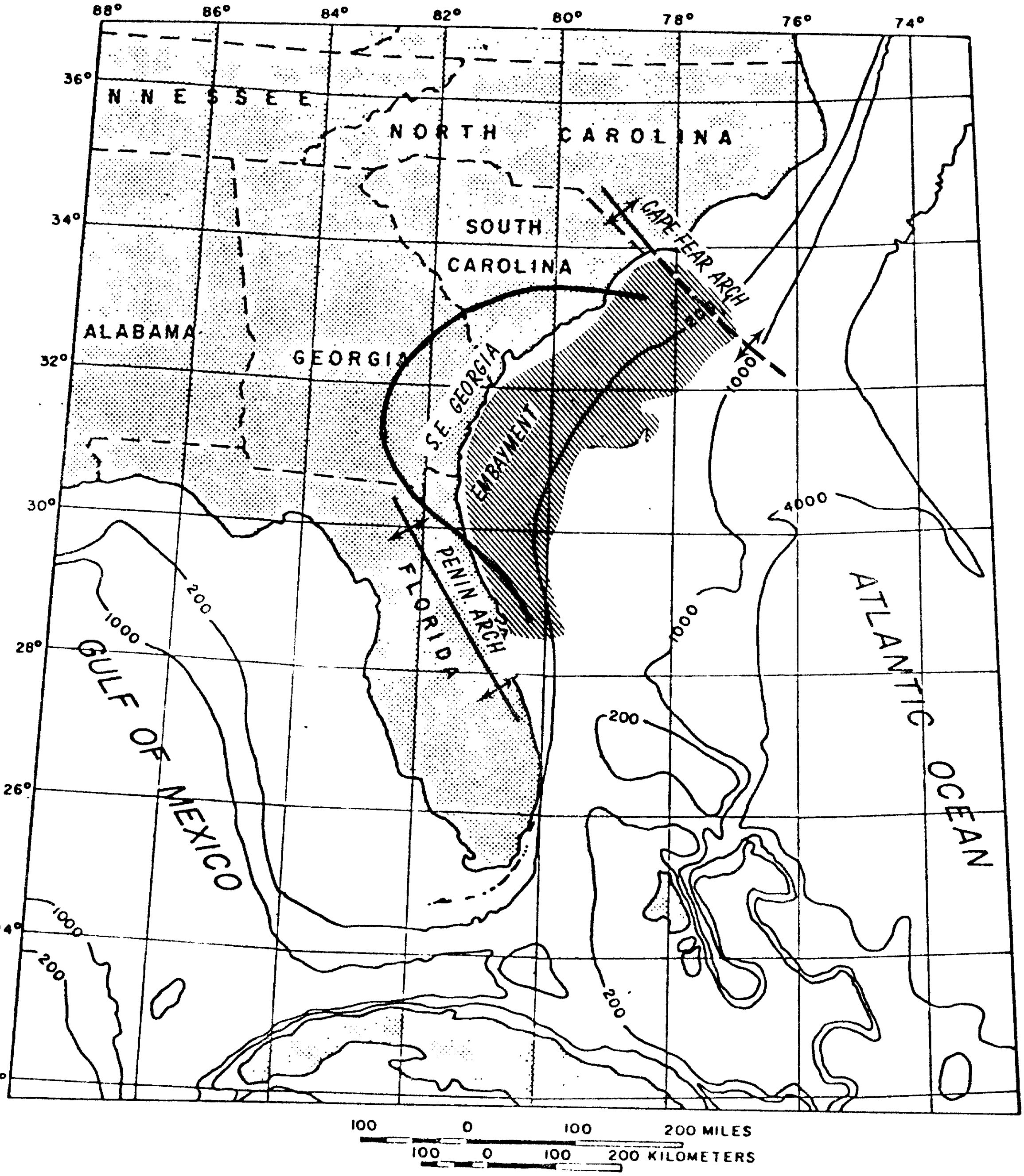


Figure 1. -- Location of study area (hachured) and major structural features of the southeastern United States. Contours in metres. Study area extends seaward to 600 m.

called the Atlantic Embayment of Georgia by Herrick and Vorhis (1963). Pressler (1947) did not give definite bounds to the Okefenokee Embayment, but did note that it was probably on the southern end of a larger embayment. Later, Murray (1961, Fig. 3.1) used the more inclusive term "Savannah Embayment" to refer to the structural depression which extends from the Cape Fear Arch to the Peninsular Arch and is open-ended in a seaward direction. Although the term "Savannah Embayment" may be the preferred usage for the area presently being studied, we will use the popular term "Southeast Georgia Embayment".

The Southeast Georgia Embayment has at least some and possibly all of the favorable geological characteristics of a prospective petroleum province. These are known to include a thick section of marine sedimentary rocks and hydrocarbon shows (onshore), and are believed to include potential hydrocarbon traps (both structural and stratigraphic), potential reservoir rocks, sealing beds to prevent vertical hydrocarbon migration, and potential source beds. Because no deep wells have been drilled in the immediate offshore area, the probability of finding petroleum can only be judged subjectively from the data of wells drilled along the coast and from limited geophysical surveys. Therefore, much of this report describes the surface and subsurface geology of the Coastal Plain in South Carolina, Georgia, Florida, and the Bahamas.

Based on the analysis of the petroleum geology of the Southeast Georgia Embayment, the Resource Appraisal Group (RAG) of the USGS appraised (in terms of probability) the "undiscovered recoverable petroleum resources" of the studied area. These undiscovered recoverable petroleum resources are those quantities of oil and gas that may be reasonably expected to exist in favorable settings, but which have not yet been identified by drilling. Such estimates, therefore carry a high degree of uncertainty. RAG's estimates, in turn, were used by the Conservation Division of the USGS to project the manpower, infrastructure, and time frame necessary for exploration and development of the South Atlantic Outer Continental Shelf oil and gas resources.

In addition to describing the geology, petroleum geology, and potential petroleum resources of the Southeast Georgia Embayment, this report was aimed at identifying potential environmental hazards. Studies of potential environmental hazards have been approached by examining the specifics of such considerations as: ocean circulation, weather conditions, movement and stability of shallow sediments, seismicity, aquifer conditions, potential drilling hazards, man-made hazards, etc.

BIBLIOGRAPHY

Herrick, S. M., and Vorhis, R. C., 1963, Subsurface geology of the Georgia Coastal Plain: Georgia Geol. Survey Inf. Circ. 25, 78 p.

Murray, G. E., 1961, Geology of the Atlantic and Gulf Coastal Province of North America: New York, Harper and Brothers, 692 p.

Pressler, E. D., 1947, Geology and occurrence of oil in Florida: Am. Assoc. Petroleum Geologists Bull., v. 31, no. 10, p. 1851-1862.

Toulmin, L. D., 1955, Cenozoic geology of southeastern Alabama, Florida, and Georgia: Am. Assoc. Petroleum Geologists Bull., v. 39, no. 2, p. 207-235.

II. Geology

A. Physiography of the Offshore Region

The continental margin between Cape Fear and Cape Canaveral may be divided into a continental shelf and a deep water plateau or continental borderland known as the Blake Plateau. The two are connected by a continental slope, the Florida-Hatteras slope (Fig. 2).

1. Continental Shelf

The continental shelf ranges greatly in width, from 33 km at Cape Hatteras to a maximum width of 135 km between Charleston, South Carolina and Jacksonville, Florida and then narrows to less than 1 km north of Miami, Florida (Fig. 3).

The shelf gradient is generally less than 0°10'. The depth of shelf break between Cape Romain and Cape Canaveral (temporarily called Cape Kennedy at the time when Fig. 3 was produced) is between 50 and 70 metres (Uchupi, 1967). The shelf surface is irregular, and cuspate projections occur off Capes Canaveral, Romain, and Fear (Emery and Uchupi, 1972) (Fig. 4) and sand ridges are aligned at right angles to the shoreline (Fig. 5). Shelf irregularities also include low algal banks along the Carolina coast (Pearse and Williams, 1951), terraces and reefs. As many as seven terraces or submerged shores have been recognized from echo-sounding data on the shelf between Miami and Cape Hatteras; one of these terraces is as deep as 120 m, thus well below the shelf break.

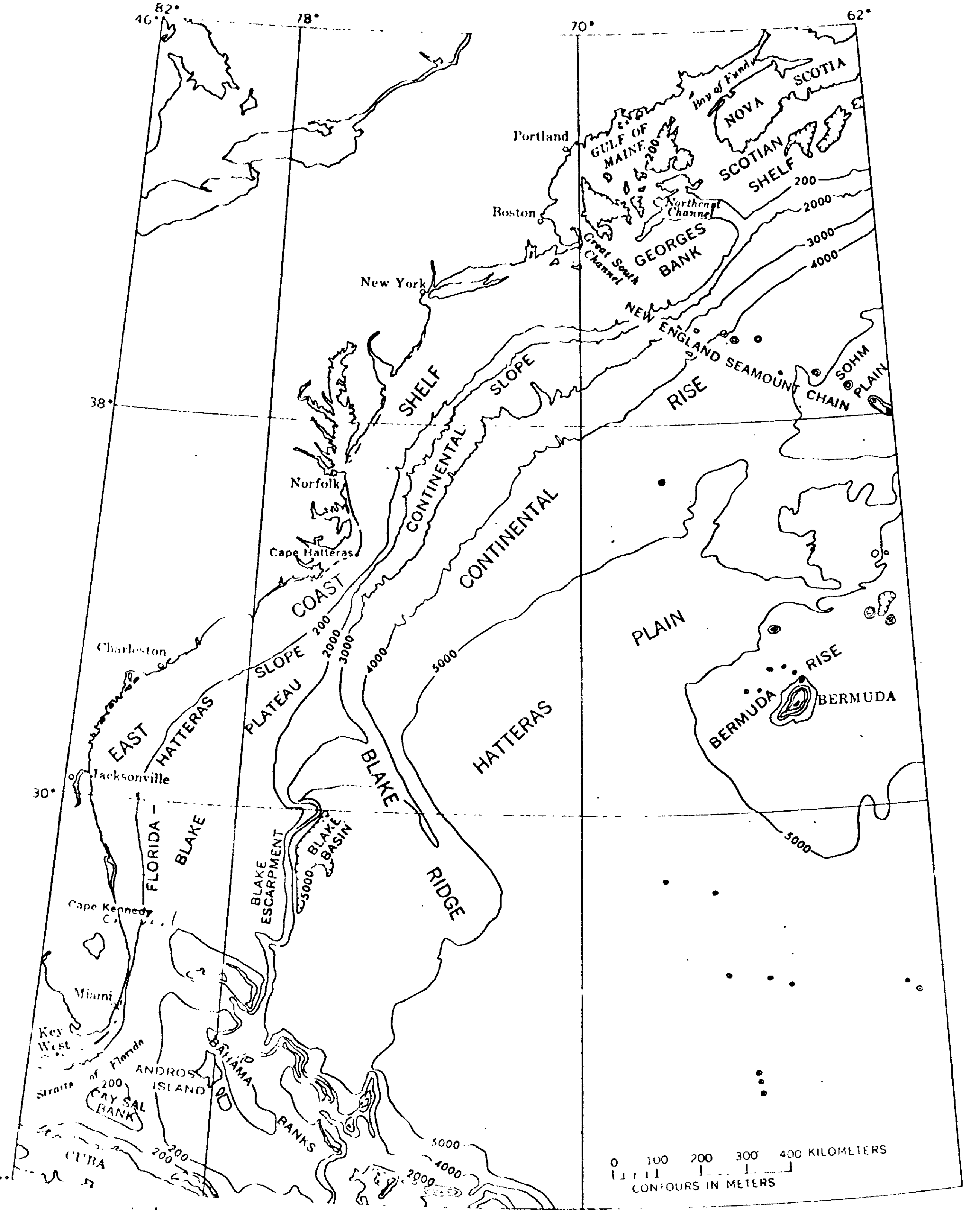
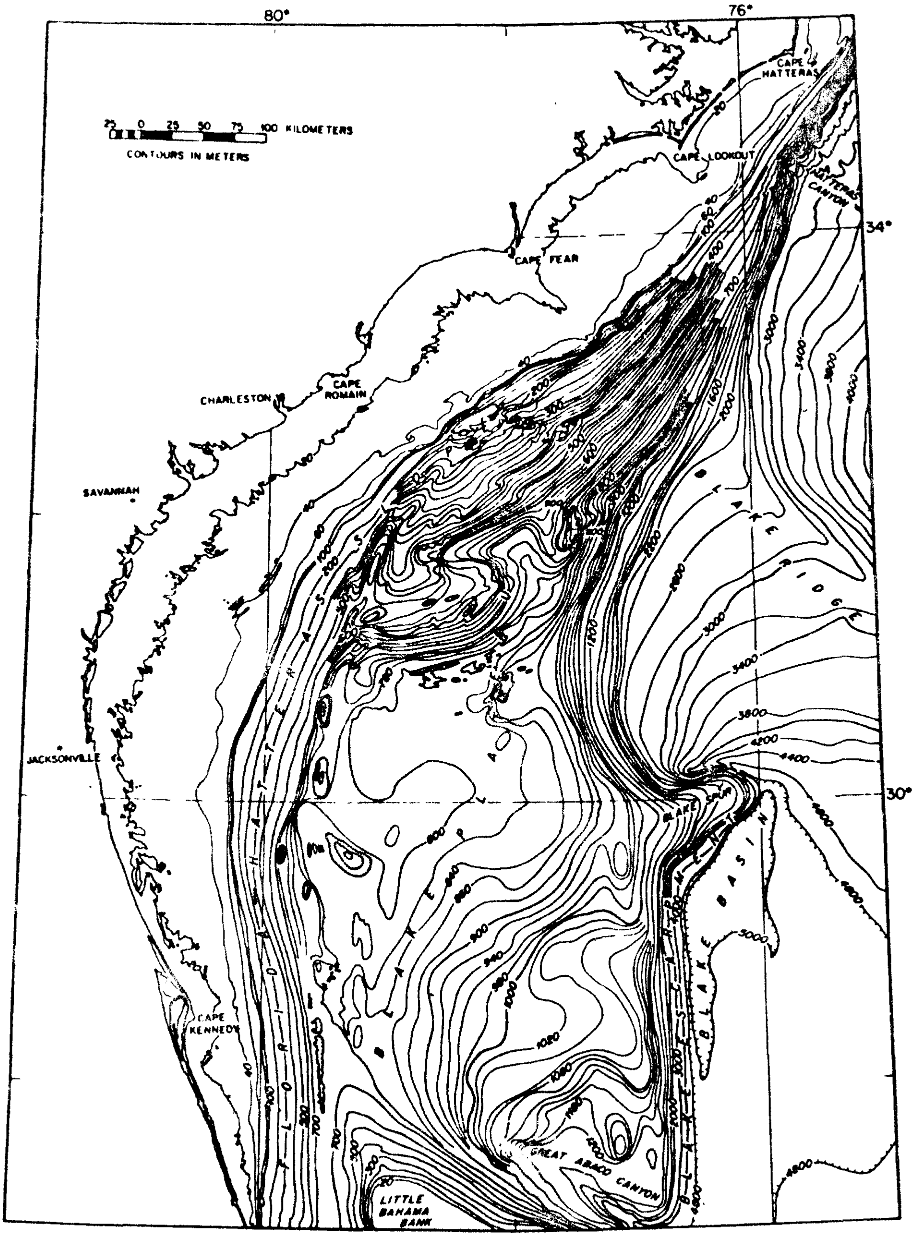
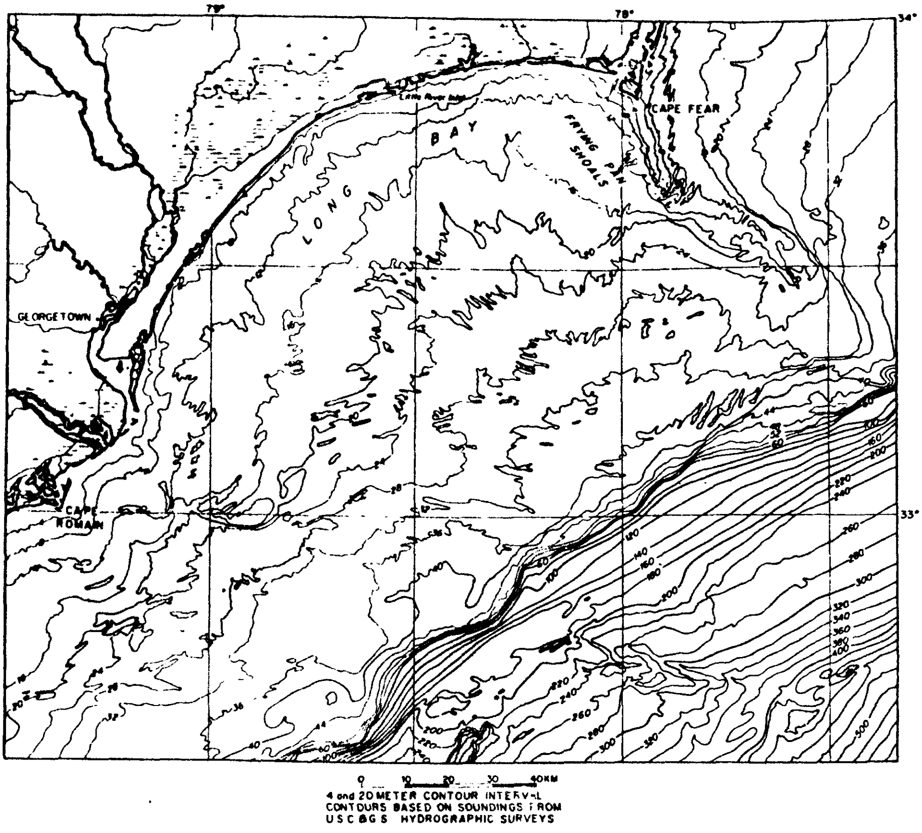


Fig. 2 - Physiographic provinces of the continental margin off the east coast of the United States (Uchupi, 1970).



Bathymetry of the continental margin between Cape Hatteras, North Carolina and Cape Kennedy, Florida. Based on sounding from the U. S. Coast and Geodetic Survey hydrographic surveys, and from a chart by Pratt and Heezen (1964, Fig. 1).

Fig. 3 - From Uchupi (1967, Fig. 1, p. 157).



Bathymetry of a segment of the continental margin between Cape Fear and Cape Romain. Based on soundings from the U. S. Coast and Geodetic Survey hydrographic surveys.

Fig. 4 - From Uchupi (1967, Fig. 2).

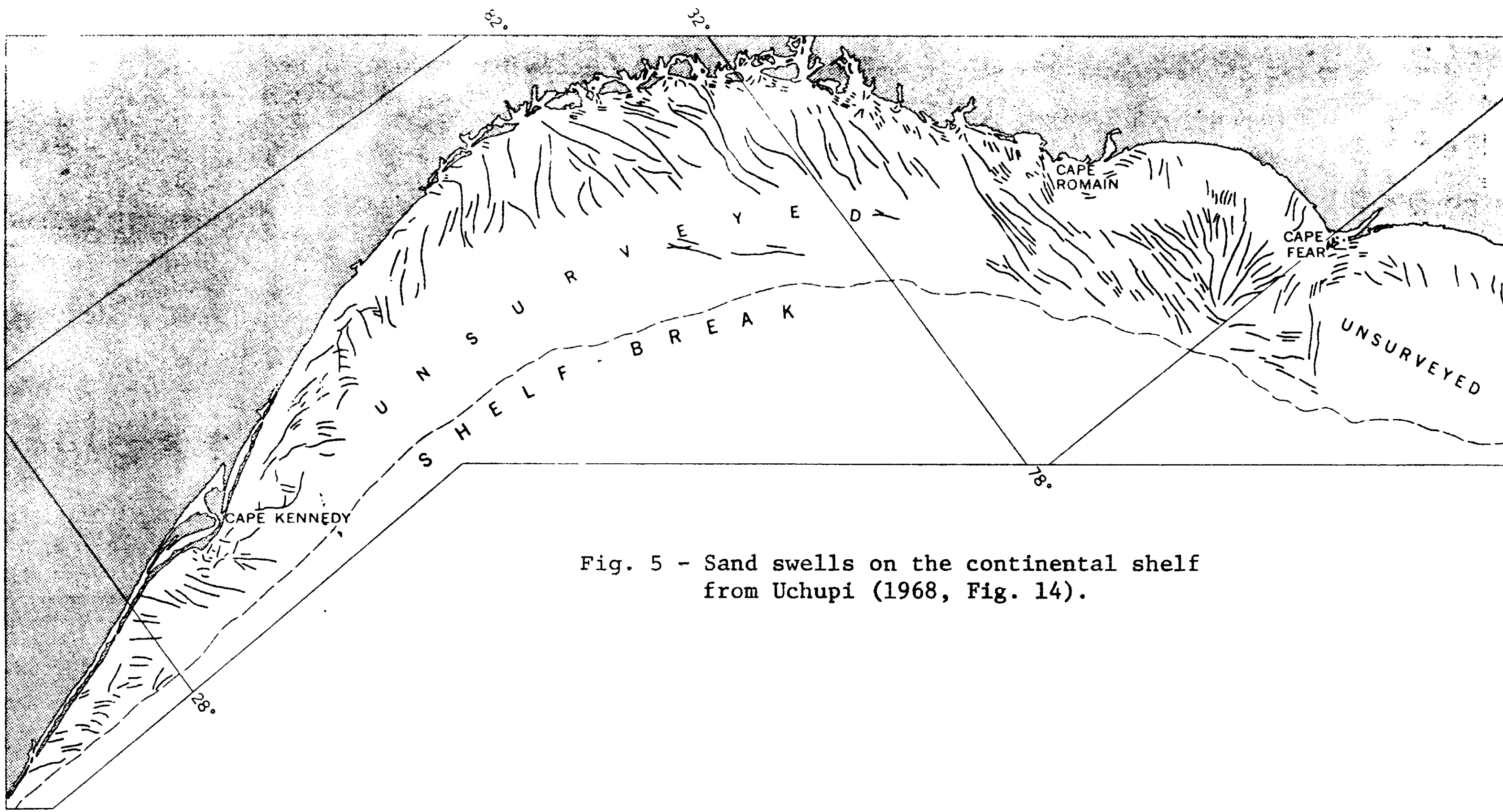


Fig. 5 - Sand swells on the continental shelf from Uchupi (1968, Fig. 14).

Numerous reefs also dot the shelf. Some are within a few kilometres of shore where they consist of lower Miocene marl overlain by a great variety of encrusting calcareous organisms. In addition to the actively growing inner shelf reefs, ancient algal reefs (dated at about 19,000 years old) border the shelf break. Sounding profiles indicate that these reefs extend more or less unbroken for the entire length of the slope from Miami to Cape Hatteras in water depths of 80-100 m.

Areas of smooth topography near the shore and along the shelf edge have fine-grained detrital and calcareous sediments, while areas of undulating topography covering most of the shelf have medium to coarse sands (see section on marine surficial sediments, below) (Uchupi and Tagg, 1966).

2. Florida-Hatteras Slope

The Florida-Hatteras Slope (Figs. 2 and 3) has been discussed by Uchupi (1967, p. 159) as follows:

> "Seaward of the shelf and separating it from the Blake Plateau is the Florida-Hatteras Slope, a relatively smooth slope with a gradient that rarely exceed 1° (7m/km). Its relief ranges from 700 meters east of Cape Kennedy to less than 10 meters off Cape Lookout. This slope extends only a few kilometers northeast of Cape Lookout before it blends with the Blake Plateau."

3. Blake Plateau

The Blake Plateau has an average depth of 850m and is described as follows by Uchupi (1967, p. 154):

> North of Latitude 32° the Blake Plateau is relatively smooth, dips seaward with a gradient greater than 0°30' (9m/km), and forms a transitional zone between the continental slope to the north and the broad and flat plateau proper to the south. The plateau is widest south of Latitude 30°. This segment of the plateau is relatively smooth, except for a rough zone near the base of the Florida-Hatteras Slope. This irregular zone extends from the Straits of Florida to Cape Romain. Between Latitudes 30° and 32° the jagged topography extends across the plateau. Within the area of rough topography are large, broad and generally flat-bottomed hollows with reliefs in excess of 40 meters. Around the margins of these lows and occasionally within them are innumerable conical hills that add to the relief of the depressions and accentuate the roughness of the topography. Bottom samples and bottom photographs indicate that the conical hills are coral mounds.

Seismic profiles (see section on shallow structure of the continental margin) clearly show that the depressions on the western Blake Plateau are erosional scour pits thought by Pratt and Heezen (1964) to be eroded by the Gulf Stream.

B. Marine Surficial Sediments

1. Texture

Sand veneers the shelf and slope (Fig. 6). Gravel is less than 10 percent of the surficial sediment and is limited to a few areas on the inner Blake Plateau below the Gulf Stream. Silt forms less than 20 percent of the sediment, although it can exceed 40 percent along the Florida-Hatteras Slope. Though clay is nearly absent in shelf sediments, it increases on the Florida-Hatteras slope.

Detailed studies of the Continental Shelf off Georgia show that fine sand is present near shore out to a water depth of 10 m (Howard, Frey, and Kingery, 1973; Howard, Frey, and Reineck, 1973) and coarse sand covers the mid-shelf area. This break in sediment size at the 10 m water depth has been postulated to be the relict-recent boundary (Pilkey and Frankenberg, 1964). Remnant marsh or estuarine deposits occur locally as patches of semi-consolidated mud.

2. Composition

Shelf sand becomes increasingly carbonate-rich both southward and seaward (Fig. 7) because of increasing fractions of fragments of mollusks, coralline algae, barnacles, and oolites (Milliman, 1972). Near shore, a relatively high feldspar-low carbonate sediment composition reflects the run-off from the Piedmont Province rivers (Field and Pilkey, 1969). Further seaward, shelf sediments show a

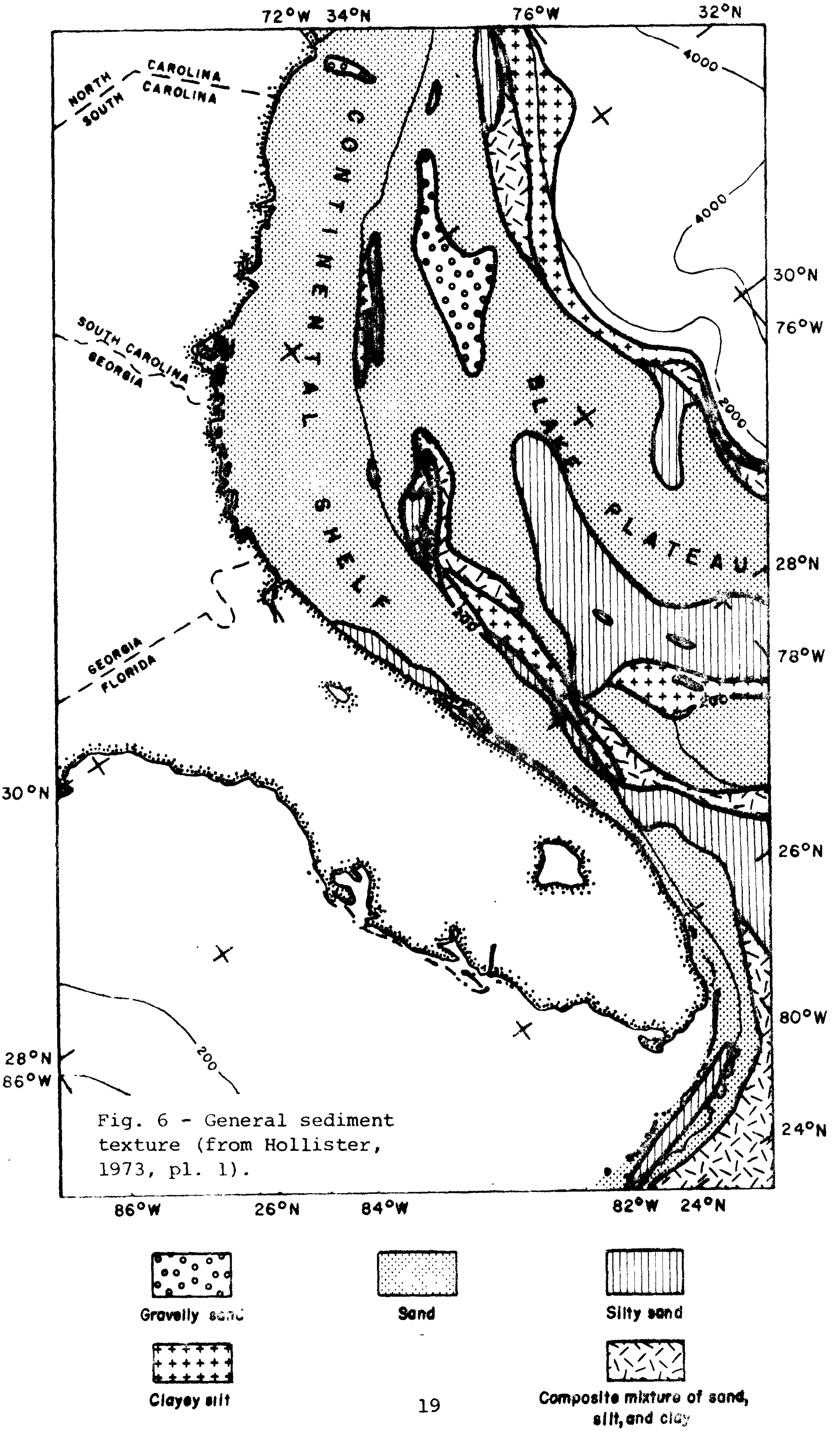


Fig. 6 - General sediment texture (from Hollister, 1973, pl. 1).

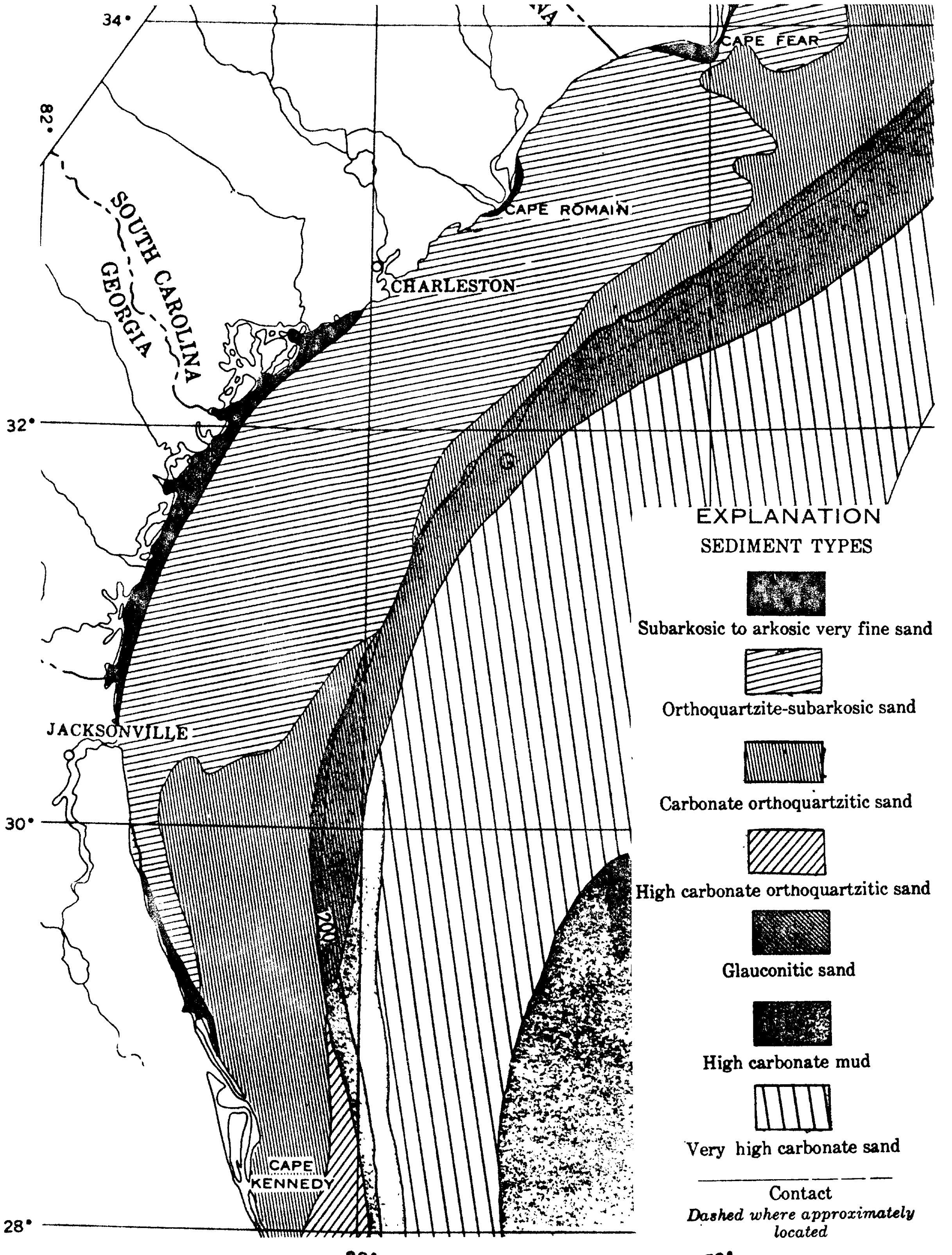


Fig. 7 - Sediment composition types between Cape Fear and Cape Kennedy (from Milliman, 1972, pl. 9).

low feldspar content and a high carbonate content. Non-carbonate grains include quartz and feldspar and glauconite with localized occurrences of phosphorite, rock fragments, mica, and siliceous biologic remains (Milliman, 1972).

On the inner shelf off Carolina the carbonate is concentrated in the fine fraction, whereas on the mid and outer shelf the carbonate becomes equal in all fractions and beyond the shelf break the carbonate becomes greatest in the coarser fraction (Molina and Pilkey, 1972). Carbonate sand is the dominant sediment type on the inner Blake Plateau.

On the Florida-Hatteras Slope relict dark glauconitic sands dominate (Milliman, 1972). The clay mineral facies of the shelf and slope is characterized by montmorillonite and kaolinite (Hathaway, 1971, 1972).

3. Sediment Sources

Surficial sediments of the continental margin are derived from rivers, carbonate precipitations and authigenic deposition. Fluvial sediments of the shelf and slope between Cape Fear and northern Florida are less feldspathic than sediments of the north and are probably derived from southern Piedmont rivers. (Milliman, 1972). Three heavy-mineral provinces have been identified off Georgia, originating from the Savannah, Ogeechee and Altamaha Rivers (Gadow, 1972).

Although Piedmont rivers furnished most shelf sediment and sediments have apparently had a complex history, and many were most recently derived from older continental margin deposits (Field and Pilkey, 1969; Pilkey and Field, 1972). The glauconite sands of the slope (Milliman, 1972) and phosphorites of the shelf (Pevear and Pilkey, 1966) apparently were produced in this manner.

Examination of cores taken from the inner shelf off central and northern Florida (Field and Meisburger, 1973) indicates that most of Holocene shelf sediments were derived from erosion and reworking of shelf substrata and that direct fluvial contribution has been negligible during the last rise of sea level. Easily eroded semi-lithified Tertiary and Pleistocene deposits crop out or lie a short distance below the bottom. Winnowing of sediments derived from these deposits probably accounts for the veneer of orthoquartzitic sand that mantles the inner shelf. Progressive upward depletion of fine constituents within the Holocene sand and presence of components (Foraminifera, phosphorite grains) apparently derived from below are regarded as evidence of continuity with underlying strata.

4. Depositional Environments

Some sediments on the shelf of the Southeast Georgia Embayment are clearly not in textural equilibrium with the present wave and current regime. The abundance of black shells, oolites, and shallow water fauna across the shelf indicate that some sediments were deposited in a reducing coastal environment during the last transgression of the sea (Pilkey and others, 1969). Lipp and others (1975, p. 510) have identified at least six depositional environments in shelf sediments off Ocracoke Inlet, North Carolina, including present day shelf sands, Holocene open estuary mud-sand-gravel sequences, early Holocene lagoon muds, early Holocene marsh peat, pre-Holocene sands, and pre-Holocene mud.

Milliman, Pilkey, and Ross (1972, p. 1315) summarize as follows:

> "Although most sediments are not in compositional equilibrium with the present-day shelf environment, there is considerable evidence to suggest that many may be in at least partial textural equilibrium. Holocene reworking has removed most of the fine-grained sediment, leaving only coarse to medium sand. Some fine-grained fluvial sediment escapes the estuaries and near-shore during floods and storms, but this influx is not sufficient to offset the effect of winnowing by currents and waves. A significant portion of the modern nearshore sediment, in fact, may be derived from landward transport of fine grained sediment from the central and outer shelf."

It is possible that much of the sediment transport that is taking place, occurs in a cross-shelf direction; and that lateral transport is not important, as sharp, cross-shelf boundaries are present in several sedimentary parameters (carbonate and phosphorite abundance, iron staining and feldspar anomalies) (Milliman, Pilkey and Ross, 1972).

C. Structure

1. Major Structural Features of the Region

The most prominent structural features on the United States South Atlantic Coastal Plain are the Cape Fear Arch, the Southeast Georgia Embayment, and the Peninsular Arch (Fig. 8).

Southeast Georgia Embayment. The Southeast Georgia Embayment is an east-plunging depression recessed into the Atlantic Coastal Plain between Cape Fear, North Carolina and Jacksonville, Florida. Basement dips seaward from the south flank of the Cape Fear Arch which bounds the embayment on the north, and the central Georgia Uplift and Peninsular Arch which bounds the western and southeastern limits of the embayment, respectively (Fig. 8). From the Fall Line, the basement surface dips seaward at 2 m/km to a depth of approximately 900 m then the dip steepens to about 23 m/km (Maher, 1971). Cross sections by Maher (1971) indicate the depth of basement rocks at the coast are in excess of 6,100 m in southern Florida, 1,500 m in southeast Georgia, and 420 m on the Cape Fear Arch.

Originally, Woollard and others (1957) identified offshore basement, which they considered Precambrian in age, as refractors with velocities in excess of 5.6 km/sec. Most recent studies also define basement in the area as rock with velocities in excess of 5.6 km/sec. Although basement is now considered simply as pre-Cretaceous in age, high-velocity (5.6 to 6.2 km/sec) Lower Cretaceous rocks certainly can exist.

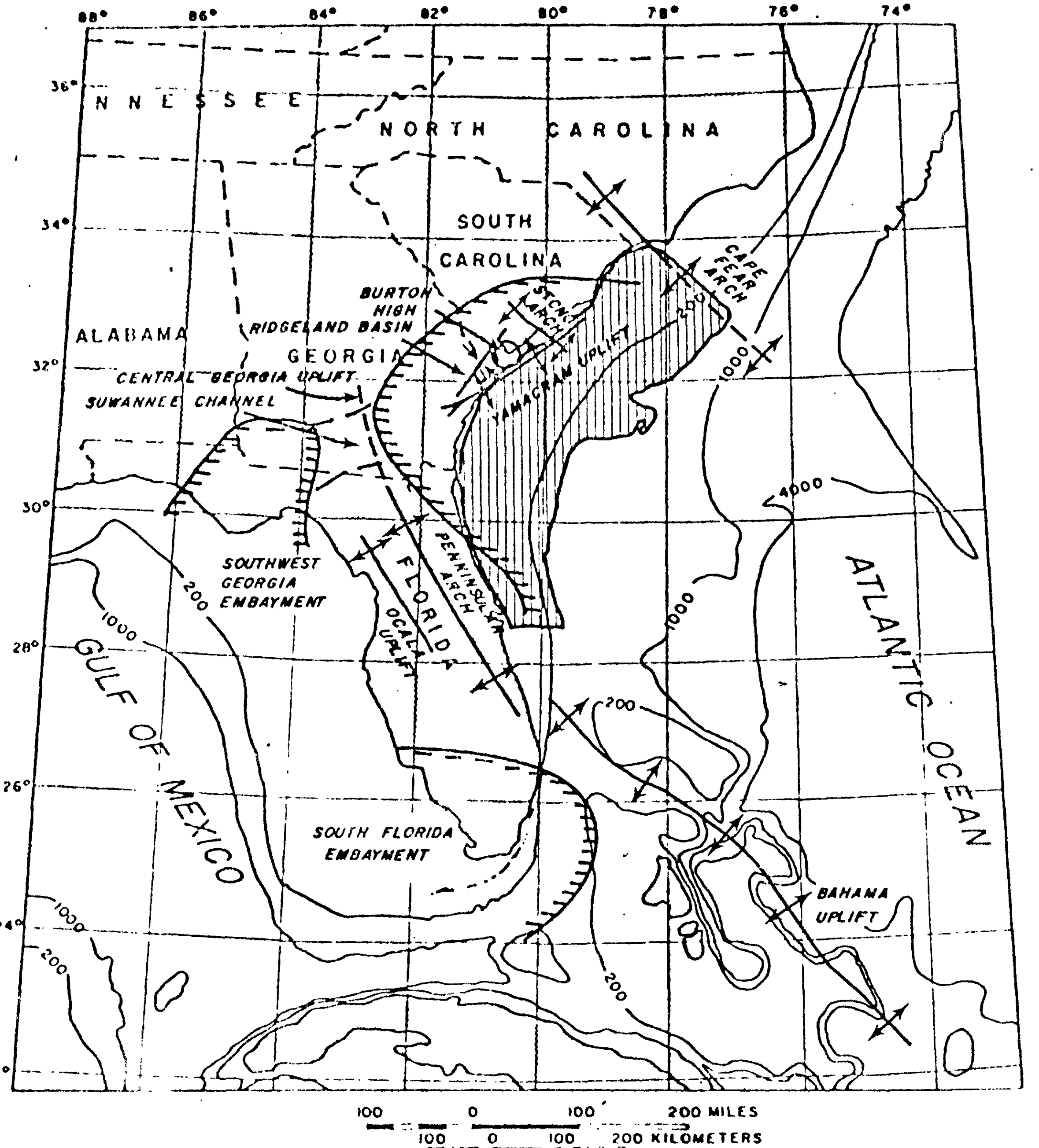


Fig. 8 - Structural features of southeastern United States (study area hachured).

In this report, the term basement will be used to mean rocks with velocities in excess of 5.6 km/sec, and it will be assumed that some high velocity Lower Cretaceous rocks may be included as shown in profiles (locations - Fig. 9, profiles - Fig. 10). Contours on this high velocity surface are shown in Figure 11.

Seismic refraction studies indicate that basement reaches depths in excess of 6 km on the mid-shelf just south of 30°N and that this is probably the deepest point in the pre-Cretaceous basement in the Southeast Georgia Embayment (Fig. 11).

In the Cape Fear area, Woollard attributed several high velocities (6+ km/sec) to refractors within the basement. If the lower velocity refractors (5.6-6.0 km/sec) were actually within the Cretaceous and the higher velocity refractors represent basement, then basement off Cape Fear may be at a greater depth than previously thought and may show some structural features to account for the sudden deepening. Data from coastal wells in Georgia indicate approximately 1,500 m of sediments over the pre-Cretaceous crystalline basement in the Southeast Georgia Embayment near the shoreline. Well data also indicate that the basement surface beneath the basin slopes uniformly seaward to about 80 km seaward of the coast, where its dip steepens greatly (Scott and Cole, 1975, Fig. 7).

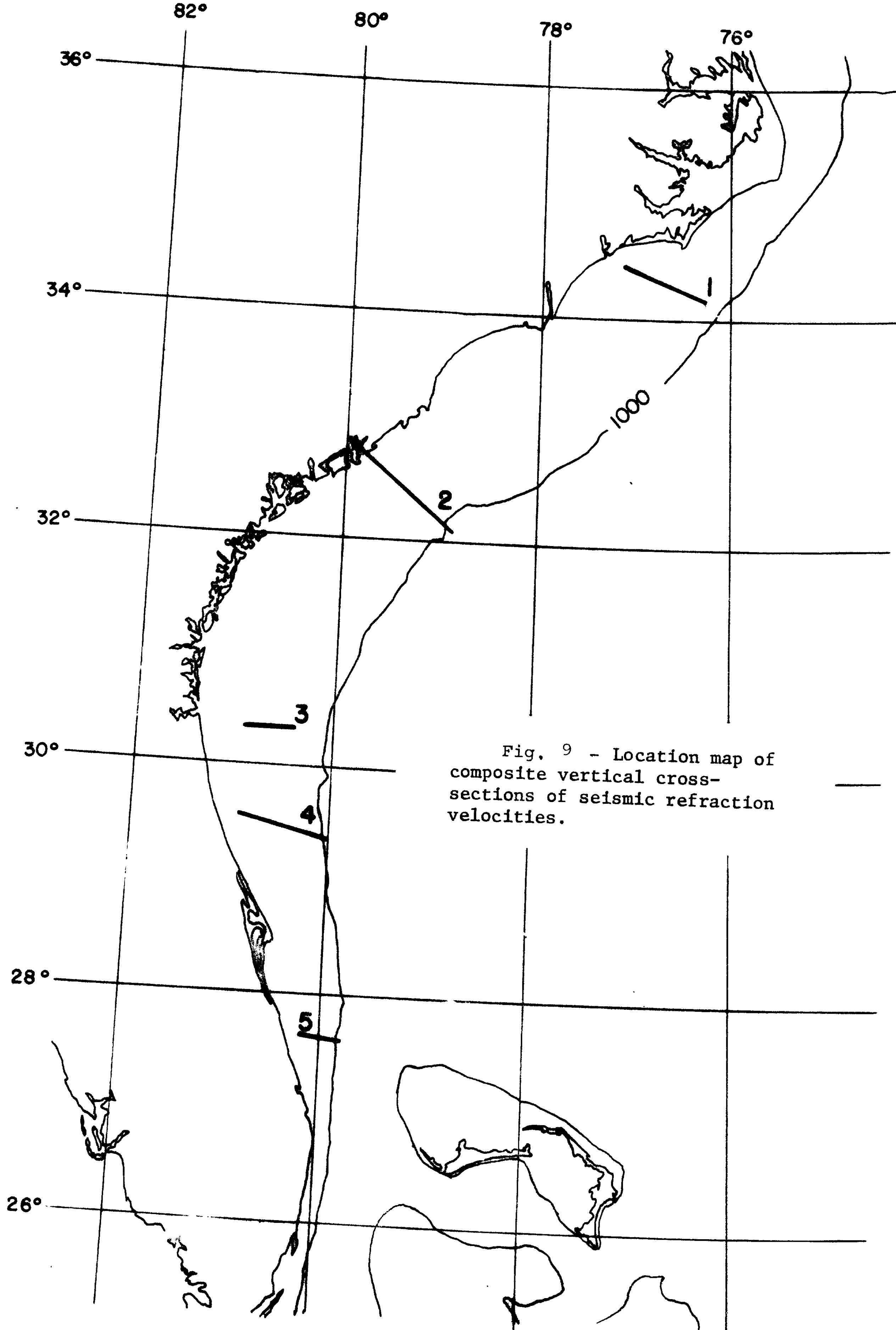


Fig. 9 - Location map of composite vertical cross-sections of seismic refraction velocities.

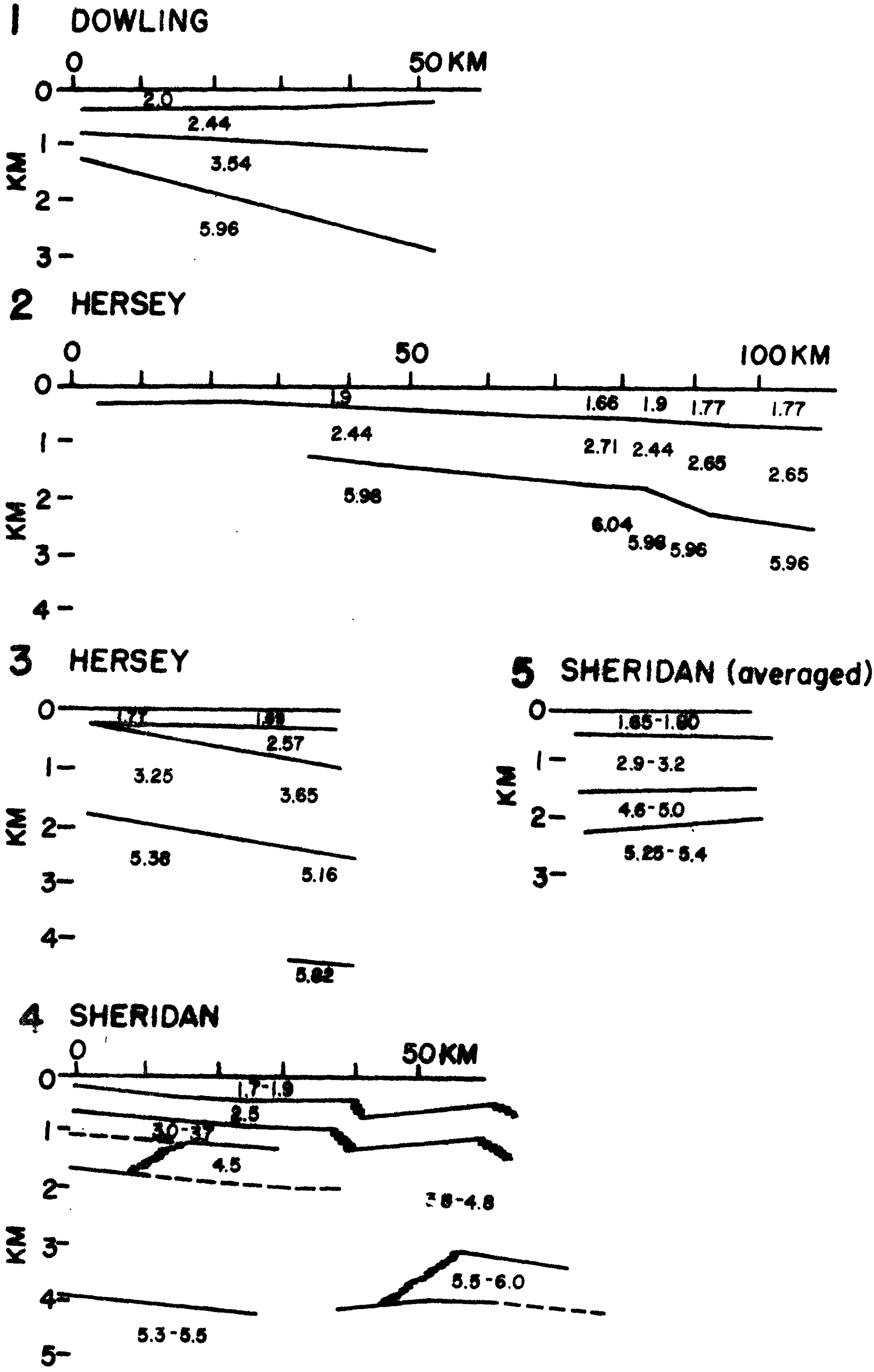


Fig. 10 - Vertical cross-sections across the shelf showing the depth and position of seismic refraction horizons with measured seismic velocities.

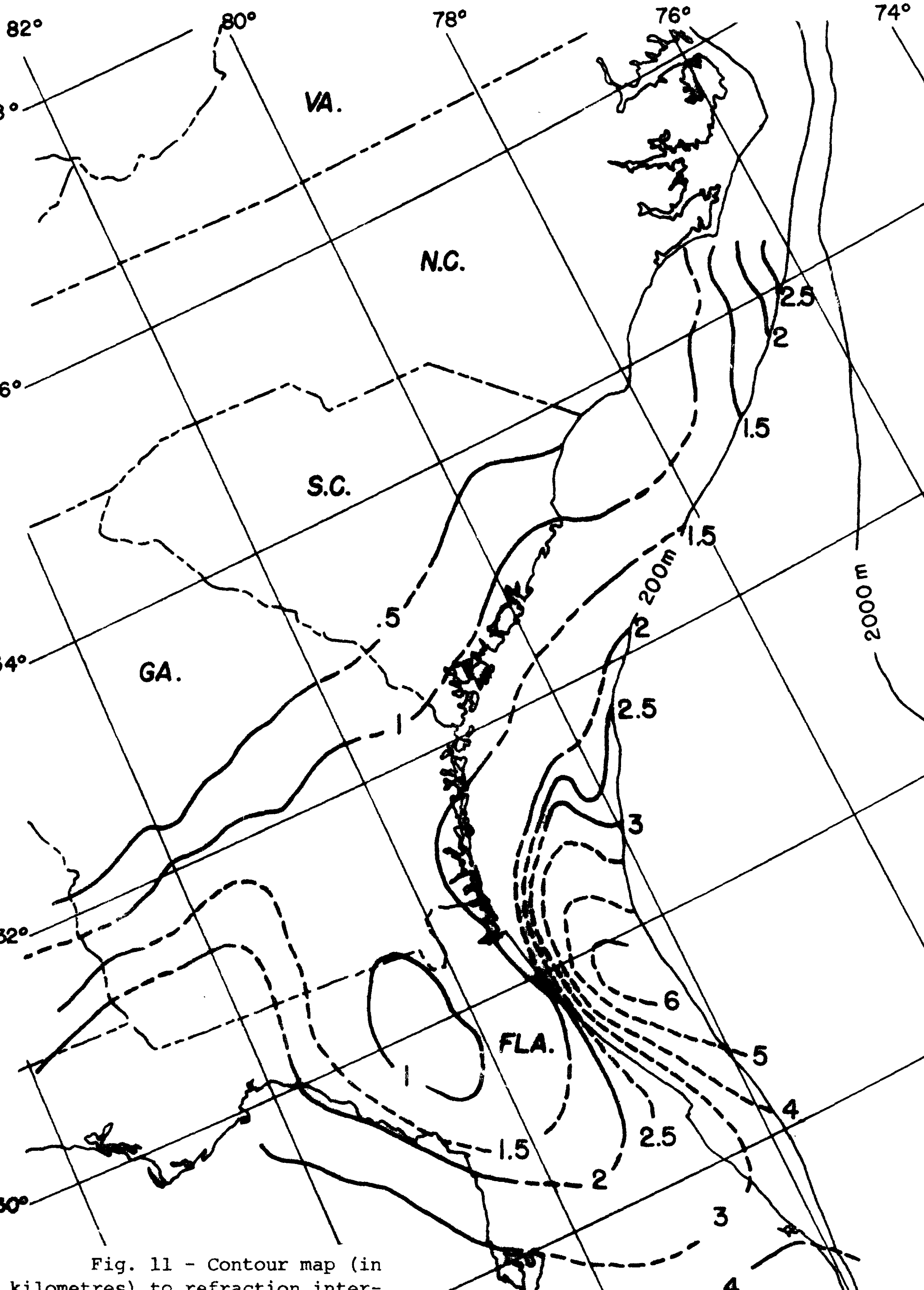


Fig. 11 - Contour map (in kilometres) to refraction interface with velocity greater than 5.6 km/sec. On land the basement contours are taken from the map of Maher (1971).

Cape Fear Arch - Flanking the Southeast Georgia Embayment to the northeast is a broad upwarp, the Cape Fear Arch (Stephenson, 1926, 1928). This upwarp is a southeast-plunging basement nose extending from near the Fall Line and to at least the North Carolina coastline. The time of origin of the Cape Fear Arch has been variously cited as from Early Cretaceous to early Miocene (Maher, 1971). Siple (1965) and Eardley (1951) have suggested that uplift probably occurred intermittently during various geologic periods. Cenozoic uplift of the arch resulted in widespread truncation of Cretaceous rocks, a relation that can be seen on the Geologic Map of U.S. Along the crest of the arch near the North Carolina coastline, the basement rocks are covered by about 470 m of sedimentary strata (Maher, 1971). The arch plunges southeastward at approximately 2.5 m/km onshore (Olson, 1973). Depth to basement along the flanks of the arch are about 1500 m near Cape Lookout, North Carolina and 760 m near Cape Romain, South Carolina.

Seismic refraction data (Meyer, 1956, Hersey and others, 1959) suggests a seaward extension of the arch across the continental shelf and the Blake Plateau. At the edge of the continental shelf, the basement rocks on the crest of the arch are 1200 m below sea level (Maher, 1971). Ewing, Ewing, and Leyden (1966, Fig. 26) suggest a more southerly direction for the seaward extension of the Cape Fear Arch. However, a U.S.G.S. seismic profile which is just landward and parallel to Ewing, Ewing, and Leyden's (1966) profile C-9, contains a reflector of probable Late Cretaceous age which is only slightly warped across the entire length of the profile (Dillon, 1974).

Peninsular Arch - The Peninsular Arch flanks the Southeast Georgia Embayment to the southwest and is the dominant positive subsurface structural feature in the southeastern United States. The Peninsular Arch formed the backbone of the broad Florida Platform throughout the entire geological time interval from Paleozoic to Holocene (Chen, 1965). Parts of the Peninsular Arch have been variously designated as "Central Georgia Uplift" and "Ocala Uplift" (Fig. 8), however the Peninsular Arch--Central Georgia Uplift represents the late Paleozoic and Mesozoic positive axis and the Ocala Uplift, located on the western flank of the arch, reflects lower Cenozoic upwarping (Murray, 1961). Isopach and lithofacies patterns suggest to Cramer (1974) that the Central Georgia Uplift may have also been positive during the early Cenozoic. The core of the Peninsular Arch -- Central Georgia Uplift is made up of Early Paleozoic rocks (Murray, 1961). Although the arch is a prominent northwest-southeast subsurface structural feature, gravity and magnetic data do not reveal its presence.

2. Structures Inferred from Gravity and Magnetic Anomalies

Many gravity and magnetic anomalies in the U. S. South Atlantic Province appear to result from compositional changes within the basement rather than major basement structural features. They may result from emplacement of magma bodies along linear features, probably representing fundamental crustal boundaries. Reactivation of these crustal boundaries by faulting throughout the epochs of

Mesozoic and Cenozoic sea floor spreading in the Atlantic might have influenced the overlapping sediments, as suggested by Brown and others (1972) and Sheridan (1974). Therefore, along these trends of major magnetic and gravity anomalies, slight horst or dome developments might be expected, as found in the Baltimore Canyon Trough.

The most prominent magnetic feature of the continental margin is the East Coast Magnetic Anomaly, a positive magnetic anomaly of about 150-250 gammas (Drake, Heirtzler, and Hirshman, 1963; Taylor, Zietz and Dennis, 1968). The Slope Anomaly is bounded on the seaward side by the magnetic "quiet zone" (King, Zietz, and Dempsey, 1961, Heirtzler and Hayes, 1967; Taylor, Zietz, and Dennis, 1968). Taylor, Zietz, and Dennis (1968) show bifurcation of the East Coast Magnetic Anomaly south of Cape Hatteras (Figs. 12 and 13). One positive trend continues under the central part of the Blake Plateau. Another prominent positive and negative magnetic anomaly swings westward and apparently crosses the coast at Brunswick, Georgia. There is also a prominent positive free-air gravity anomaly trending along the shelf slope boundary which bifurcates at 31°N lat. (Rabinowitz, 1973). One branch continues southward along the edge of the Continental Shelf off Florida and the other branch crosses the Georgia coast at about the same position as the magnetic anomaly.

A major lithologic boundary occurs in the pre-Cretaceous rocks where the anomalies go ashore in Georgia. Rhyolitic and basaltic volcanics are found south of granitic basement (Applin, 1951). Model

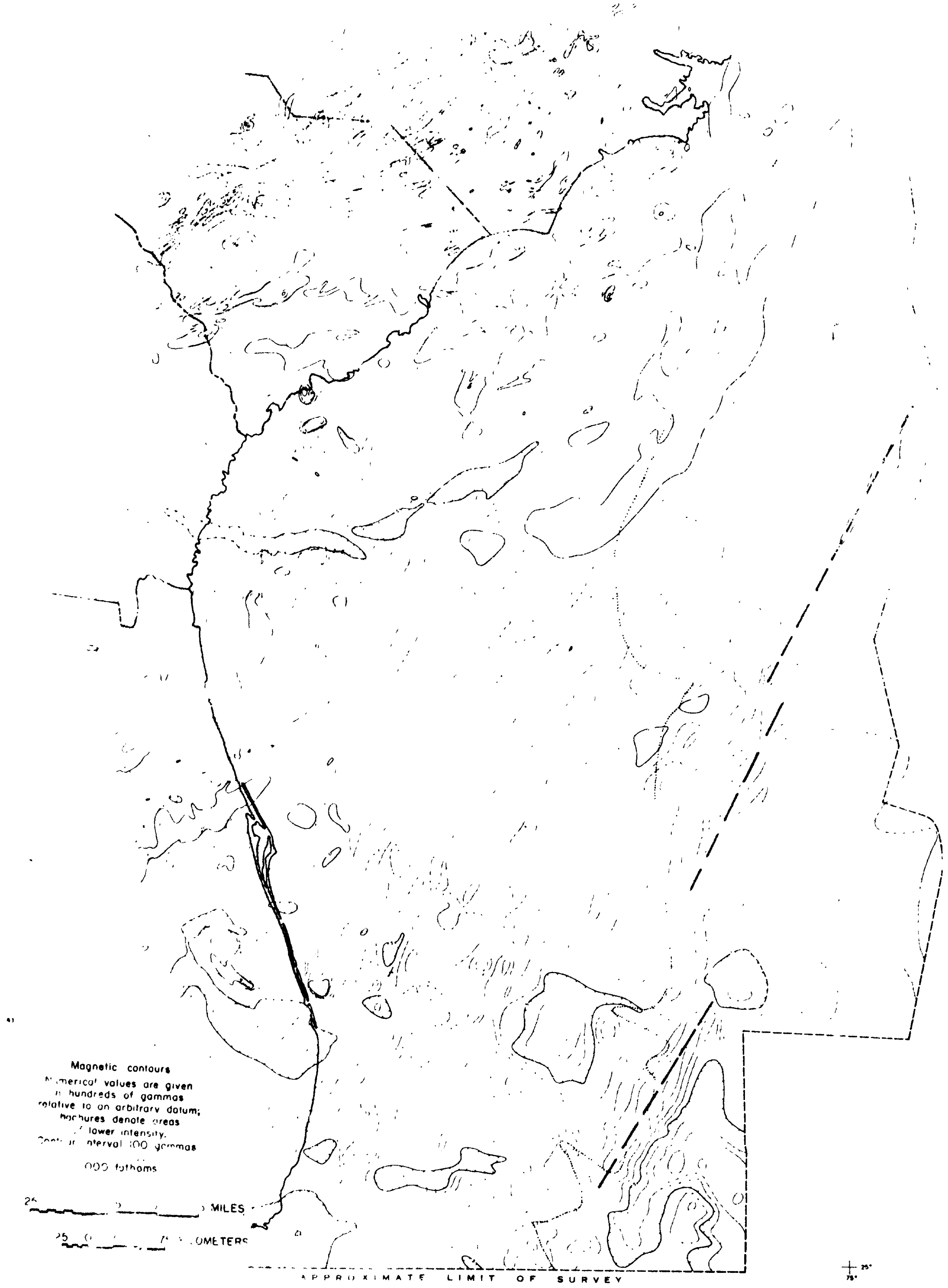


Fig. 12 - Total intensity magnetic anomaly map, relative to an arbitrary datum (after Taylor, Zietz, and Dennis, 1968). Contour interval equals 100 gammas.

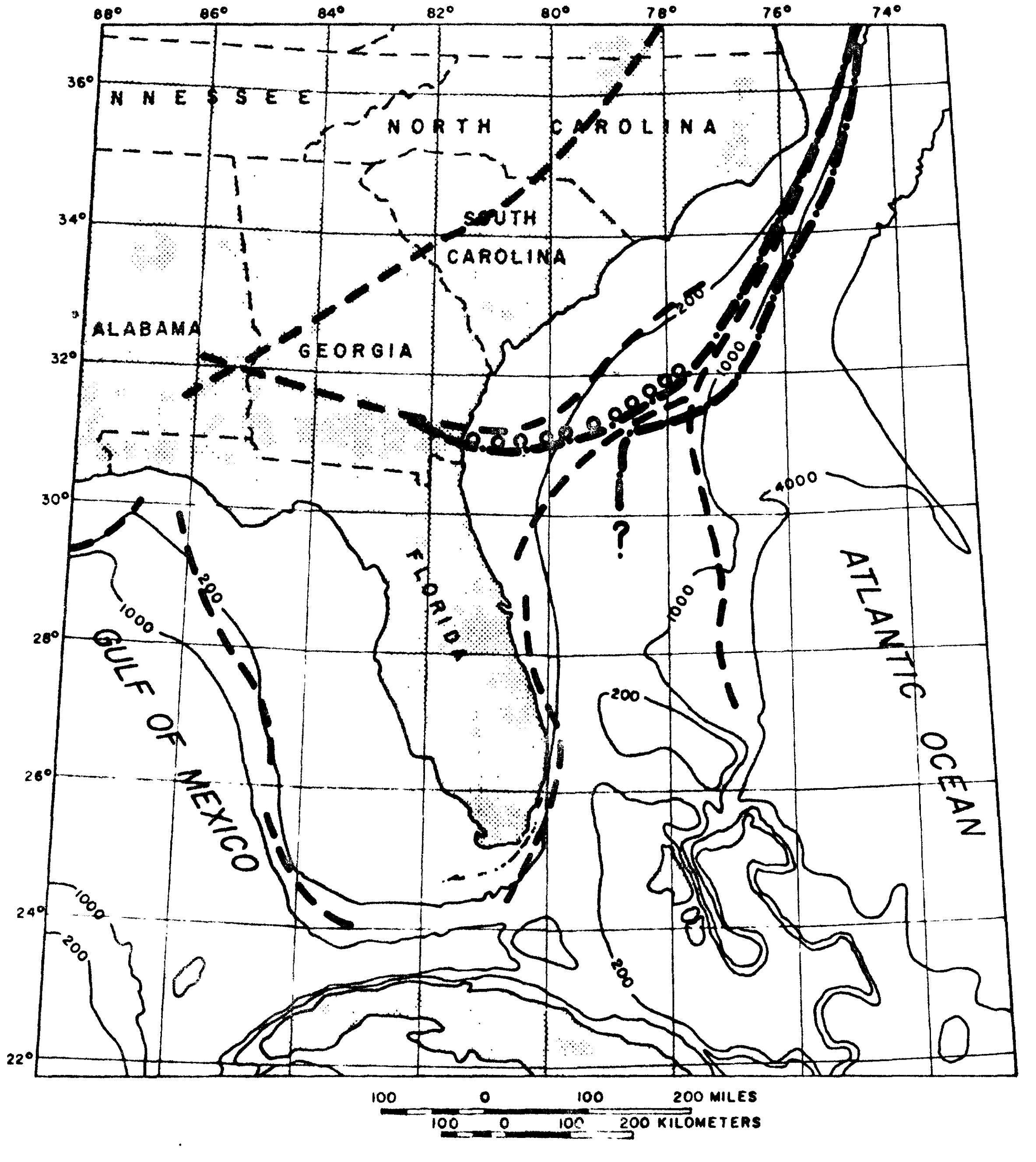


Fig. 13 - Major gravity and magnetic anomaly trends in the area. Dashed line is the positive free-air gravity greater than 20 mgal. Dot-dashed line is the positive total intensity magnetic anomaly, 150-250 gammas, running along the shelf edge and along the Appalachians. The line of circles maps the prominent negative magnetic anomaly swinging into Georgia.

studies suggest to Taylor, Zietz, and Dennis (1968) that the negative part of the east coast anomaly which crosses Georgia reflects a felsic intrusion. Rabinowitz (1973) and Long (1974) have also suggested a possible igneous intrusive body to account for the gravity high that swings through the Florida-Georgia area. In Tift County, Georgia there is a 50 mgal circular positive anomaly (the largest of three such anomalies) which may correlate with the westward extension of the East Coast magnetic anomaly (Long, 1974). The anomaly is the size and character of an anomaly that could be produced by a volcanic plug (Long, 1974).

These gravity and magnetic anomalies may be old plate boundaries. Long (1974) postulates that the anomaly over the southwestern Georgia Coastal Plain may reflect collision or separation between old plates. Taylor, Zietz, and Dennis (1968) also suggested that southern Georgia and Florida were added to the paleocontinent in pre-Paleozoic time.

There is substantial data to suggest this interpretation. Taylor, Zietz, and Dennis (1968) note that Applin (1951) and Murray (1961) have indicated that a change exists in the basement lithologies across the 31st parallel, using data from deep wells. Arden (1974) reports that deep drilling in the southeastern states has revealed a buried terrain of Lower Paleozoic and possibly older rocks that seem to have no counterpart in North America. Zietz (1975, personal communication) believes that continental crust is both north and south of the landward east-west anomaly, but that the crust is from two "different" continents. On the basis of faunal evidence, Wilson (1966) suggests that Florida was not connected to the North American land mass during the early Paleozoic. Cramer (1971) noted that Lower Paleozoic phytoplankton from northern Florida appear to have closer affinity with strata from western Africa than with the Appalachian area. Alternatively, Long and Lowell (1973) interpret the east-west magnetic anomaly as a narrow pre-Cretaceous, probably Triassic, rift zone.

In a different interpretation, Emery and Uchupi (1972) suggest that the westward trending magnetic feature is unrelated to the East Coast Anomaly. According to Emery and Uchupi (1972) "the causative body of the positive East Coast Magnetic anomaly" is a deep-seated ridge (about 10 km) of oceanic basaltic material normally polarized, which was emplaced during the initial stages of rifting. If this interpretation is correct, there could be a series of east-west oriented drape structures (see Potential Hydrocarbon Trap section) which could be potential hydrocarbon traps.

A group of magnetic and gravity anomalies which may result from structural effects are located between 32° and 33° N lat. at about 78°40'W long. south of Cape Romain. Three prominent circular Bouguer positives are aligned north-south, with values of +50 to +70 mgals (Plate 1). These Bouguer anomalies coincide with the magnetic anomalies, shown on the underlain Project Magnet Map (U.S. Navoceano Map Series No. 5953-5958, Total Magnetic Intensity, Survey attitude over the oceans - 500 ft., Contour Interval 50 gamma, Survey years 1964-1966). A model and an east-west profile over one of these magnetic anomalies is shown in Fig. 14. Susceptibility contrasts as between granite and gabbro and a remnant magnetization similar to the parameters determined paleomagnetically for the Jurassic White Mountains intrusives was used in the model. The coincidence of magnetic and gravity positives agrees well with the interpretation that the "Cape Romain Anomalies" are due to dense gabbroic intrusions in the crust.

Rabinowitz (1973) examined nineteen free-air gravity profiles across the United States Atlantic Margin, six of which were located south of Cape Hatteras. He found on all the profiles a free-air gravity high which corresponds almost exactly to the shelf-slope boundary. The topographic effect of the shelf edge and the isostatic compensation of the shallowing mantle for the increasing water depth and thick marginal sediments explains most of the free-air gravity high near the shelf edge (Rabinowitz, 1974). However, a small isostatic anomaly of approximately 40 mgal remains, perhaps due to dense reef rock within the sedimentary section.

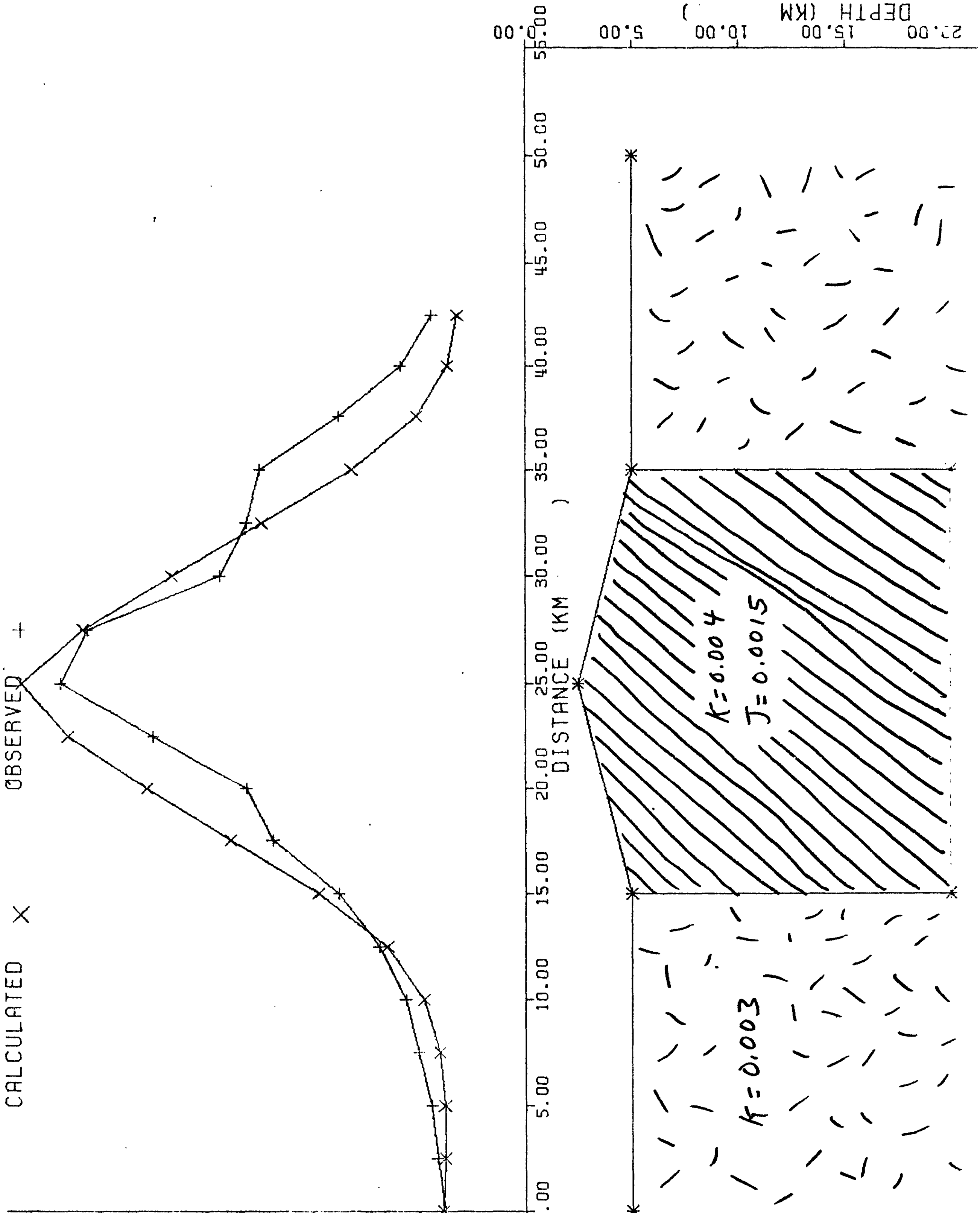
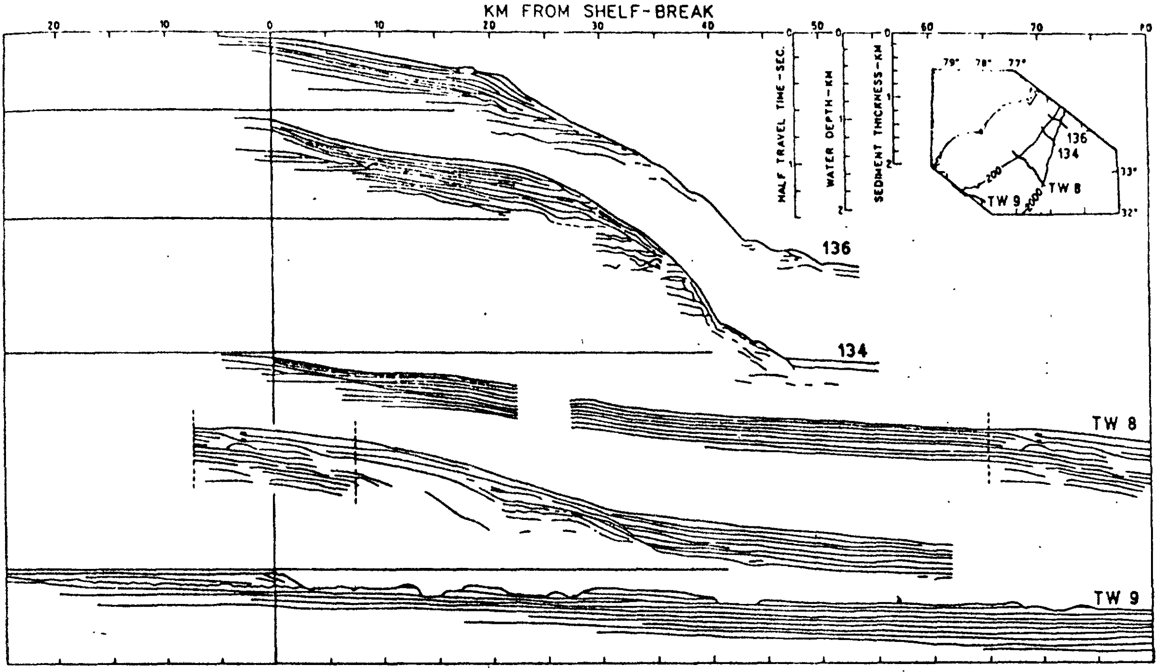


Fig. 14. Two dimensional magnetic model calculation along west to east profile across prominent north-south striking positive magnetic anomaly off Cape Romain. Susceptibility and magnetization values are in emu.

3. Shallow structure of the Continental Margin

The shallow structure of the shelf and inner Blake Plateau has resulted from a sedimentary (carbonate) upbuilding of the area during Tertiary--more rapid on the shelf than on the Blake Plateau. This is displayed best by the extensive set of single-channel seismic reflection profiles collected by a U.S. Geological Survey - Woods Hole Oceanographic Institution joint program and reported by Uchupi and Emery (1967), Emery and Zarudzki (1967) and Uchupi (1967, 1970). Figure 15 displays a series of these profiles at the north end of the area. Profiles 136 and 134 show deeper shelf reflectors truncated at the continental slope with progradation and mantling of the rise by younger sediments. These two profiles and profile TW 8 form a transition zone in slope structure between the typical shelf-slope-rise configuration found to the north and the shelf-Florida-Hatteras slope - Blake Plateau arrangment found to the south (Uchupi and Emery, 1967). In TW 8, the strata, as indicated by reflectors, have apparently prograded across the width of the Blake Plateau. The structure indicated in profile TW 9 is more typical of the area, with the shallow reflectors of the Blake Plateau dipping gently seaward, apparently having built up and out across this erosional surface. The same pattern is repeated in the proviles to the south (locations shown in Fig. 16, profiles in Fig. 17). The erosion of the Blake Plateau surface and the extension of this erosional surface westward



Profiles between Cape Lookout and Charleston. Profiles TW 8 and TW 9 were made by J. R. Curray aboard *R/V Thomas Washington;* note that profile TW 8 is in two sections with overlap of 15 kilometers.

Fig. 15 From Uchupi and Emery (1967, Fig. 6).

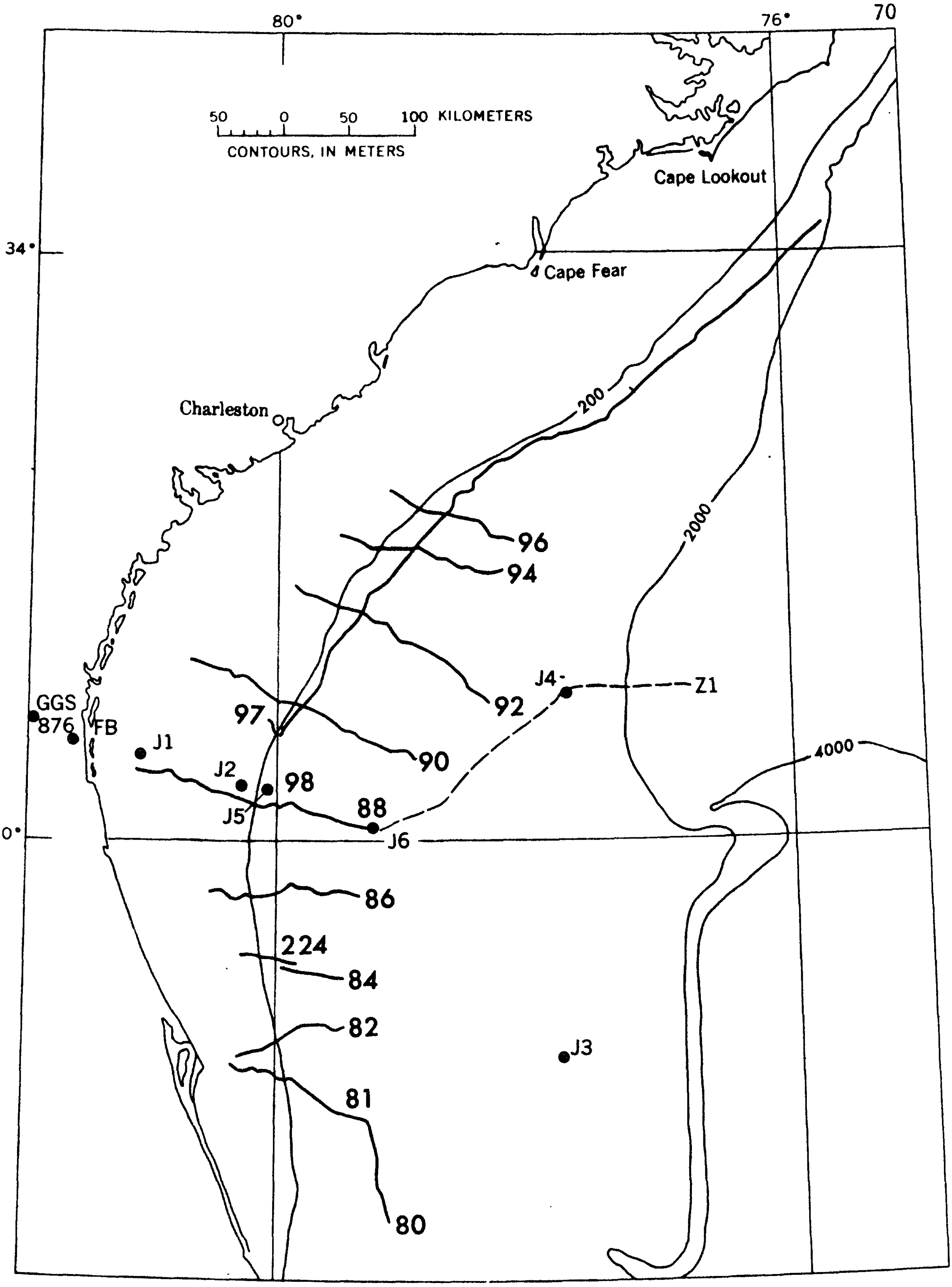
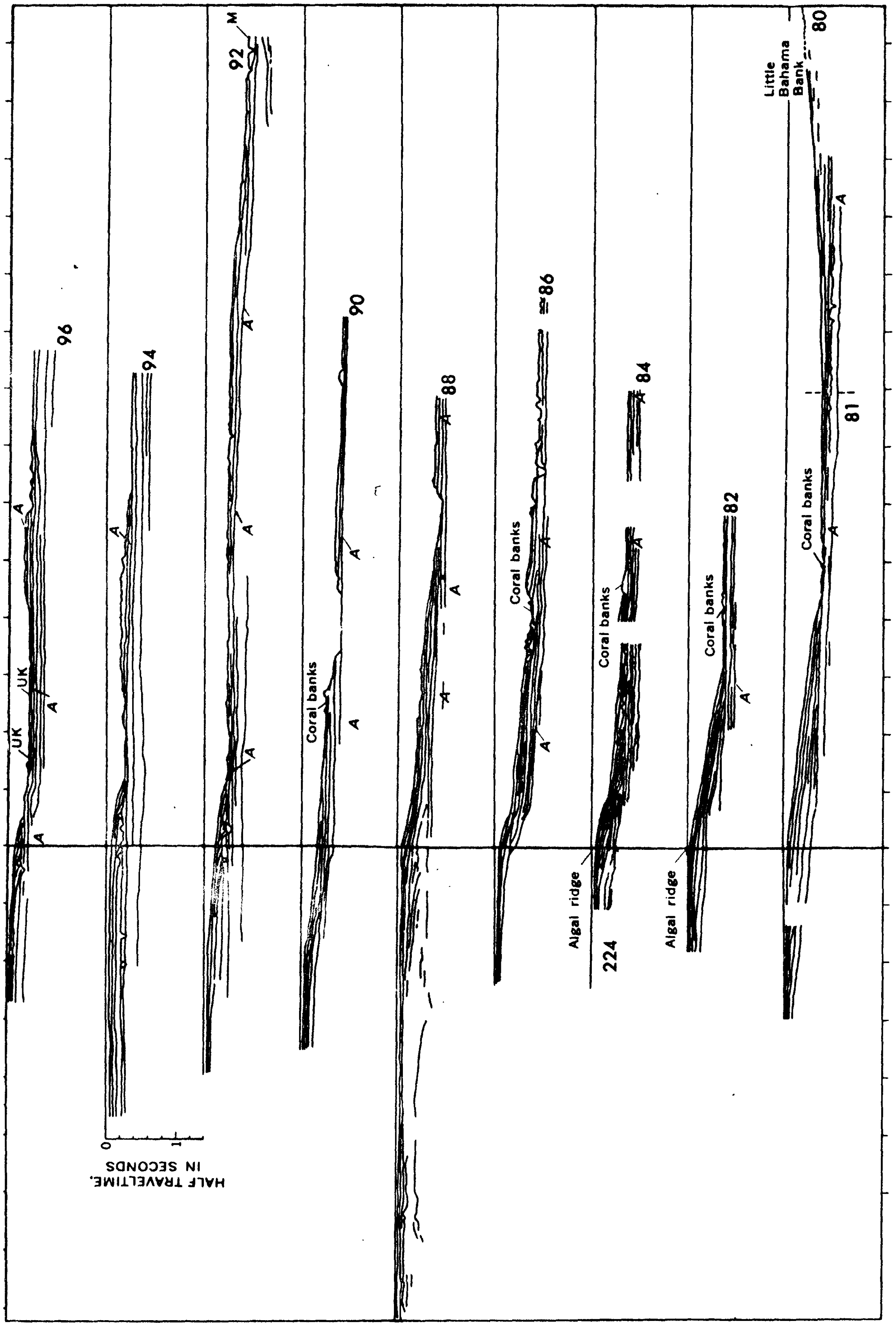


Fig. 16 . Locations of seismic profiles shown in figure I D 2c-3, J1 to J6 are the JOIDES drill sites, and FB and GGS876 are wells on land. Line Z1 (dashed line) extends from drill site J1 to J4 and from there eastward across the continental slope. From Uchupi (1970, Fig. 29).



Seismic profiles across the shelf, Florida-Hatteras Slope, and western margin of the Blake Plateau from Charleston to Cape Kennedy. Letters UK and M show positions of Upper Cretaceous and Miocene sediments dredged from the Blake Plateau (J. D. Milliman, F. T. Manheim, R. M. Pratt, and E. F. K. Zarudzki, written commun., 1968; R. M. Pratt, oral commun., 1968). Locations of profiles shown in figures 29. From Uchupi (1967b, fig. 6). Vertical exaggeration, × 8 (assuming a velocity of 1,500 m/sec). *A* indicates Tertiary and Cretaceous boundary.

Fig. 17 From Uchupi (1970, Fig. 28).

beneath the present shelf is thought to have been caused by scour of the Gulf Stream. The unconformity is apparently of Paleocene age based on drilling and, according to Uchupi (1970), may represent evidence for a time when the Gulf Stream invaded the Blake Plateau by way of the Straits of Florida. Uchupi (1970) further suggests that the erosion of the surface west of the present shelf break occurred before the Gulf Stream migrated to its present position. Subsequent outbuilding was within the Eocene and Miocene sections and post-Miocene (Bunce and others, 1965; Schlee, in prep.).

Contours on the inferred base of the Tertiary section and isopachs of supposed Tertiary deposits have been presented by Ewing, Ewing and Leyden (1966) and Uchupi (1967). These show considerable disagreement, the former authors indicate a landward dip to the top of the Cretaceous section and about 1500 m of Tertiary sediment at the shelf edge, whereas Uchupi (1967) shows a southward dip of the top of the Cretaceous beneath the Blake Plateau with about 600 m of Tertiary section at the shelf edge. The discrepancy probably results from different choices of a reflector to represent the top of the Cretaceous section. This interface has never been drilled, but Uchupi's choice was based on dredged Cretaceous fossils obtained from the surface of the Blake Plateau (Uchupi, 1975, oral communication). Uchupi (1970) suggests that reflector A (Fig. 17) represents the top of the Cretaceous and that the irregular reflector above it in profile 80-81 may mark the top of the Paleocene.

The outer shelf is characterized by a complicated pattern of erosion, deposition and slumping. Pilkey, MacIntyre and Uchupi (1971) recognized at least six such sedimentary sequences separated by disconformities off Cape Fear. These structures probably developed during the Pleistocene as a result of sea-level fluctuations and migrations of the Gulf Stream. Mounds, formed within this zone are considered probably to be produced by deep-water Pleistocene corals and ridges on the outer shelf are presumed to have been formed by late Pleistocene calcareous algae (Zarudzki and Uchupi, 1968). The pattern of development varies along the shelf edge, as north of profile 90 (Fig. 16) erosion and re-covering by sediments has occurred, whereas profiles 90, 88, and 86 were eroded with no subsequent mantling of sediment and profiles 81 and 82 show little evidence of erosion according to Uchupi (1967).

Profiles on the continental shelf and parallel to its edge have been presented by Uchupi (1970) and Dillon (1974). These profiles show a very gentle southwestward dip of strata away from the Cape Fear arch toward the Southeast Georgia Embayment.

Data collected recently in a cooperative program involving the U.S.G.S. and Institute Francais du Petrole has produced the first publicly available 24 channel CDP profiles for the U.S. South Atlantic Province. Preliminary processing of these profiles shows a flat, apparently undisturbed sequence of reflectors, above a relatively featureless basement beneath the outer shelf and inner Blake Plateau.

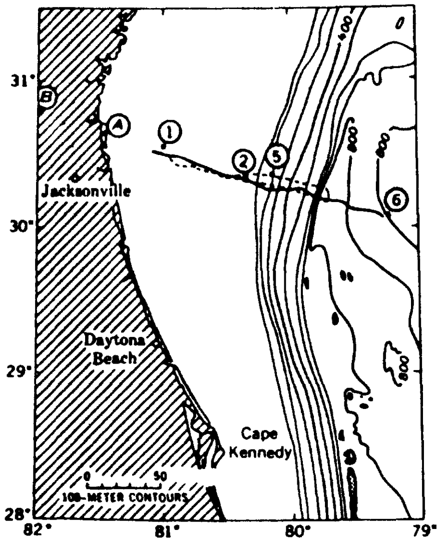
4. Other Structural Features

Despite the fact that the strata of the U.S. South Atlantic

Province generally appear undisturbed, some minor structures are present. Although the number of identified strucutres are few, they may be important to petroleum entrapment. Hence, they will be discussed individually.

Contours on the 5.6 km/sec refractor (Fig. 11)(defined as pre-Cretaceous basement although it may include some Cretaceous rocks - see discussion of Southeast Georgia Embayment) show a ridge beneath the outer shelf between 30° and 32°N at 80°W. A similar feature is shown by Drake and others (1968). This ridge may have formed an eastern boundary to the Southeast Georgia Embayment during part of Cretaceous time. Antoine and Henry (1965) have suggested that the part of the embayment which existed at the present location of the state of Georgia may have also been open to the south in Eocene time.

Between JOIDES hole 1 and JOIDES hole 2, off the east coast of Florida, Emery and Zarudzki (1967) showed a broad shallow upwarp probably of Cretaceous strata that may underlie the middle part of the continental shelf (Fig. 18). Bunce and others (1965) also recognized that the Tertiary units are slightly shallower at JOIDES hole 1 than they are on land, thus this may represent further evidence for a gentle fold or other structure off northern Florida. The feature appearing on Emery and Zarudzki's profile, occurs at a location where refraction data suggest a depression of "basement" (Fig. 11) so it might represent an accretionary structure (reef?) rather than a fold.



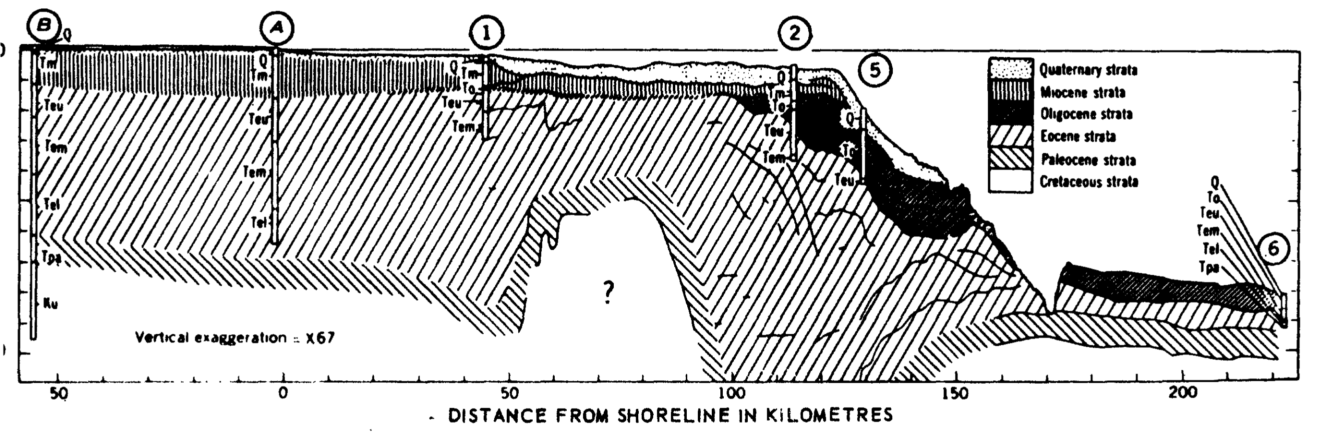


Fig. 18 · Geologic section from Florida, across Continental Shelf and Blake Plateau from JOIDES test holes. Note possible Upper Cretaceous ridge between hole 1 and 2. (from Emery and Zarudzki, 1967).

McCollum and Herrick (1964) noted a slight arching of Tertiary strata off Georgia based on drilling information as shown in Fig. 19

Several other structural features have been identified by refraction and reflection techniques and drilling, and named the Yamacraw Uplift, Burton High, Stono Arch and Suwannee Channel, shown on Fig. 8.

Yamacraw Uplift. -- Refraction seismic studies indicated to Meyer (1956) that in the South Carolina-Georgia area, the depths to pre-Cretaceous rocks (basement) were shallower than expected and that there was reverse dip on the pre-Cretaceous surface. He interpreted the above as being caused by an uplift parallel to the coast line of Georgia and South Carolina along the north flank of the Southeast Georgia Embayment and designated the feature the "Yamacraw Uplift" (Fig. 8). Meyer (1956) reports a north-south trending structure offshore from Charleston, South Carolina defined in the 5.8 km/sec refraction velocity interface. Both this structure and the Yamacraw Uplift seem to intersect at Charleston, a region of known earthquake activity, thus, he inferred a possible relationship between the two structures and the seismic disturbances. A later more detailed seismic survey by Pooley (1960, pl. 1) confirmed the existence of a basement ridge about 160 km long and 50 km wide with more than 300 m of relief that is not reflected in the overlying beds. He located its axis at the coastline between Parris Island, South Carolina, and Sea Island, Georgia. Data from wells drilled since 1960 at the southern extremity of the anomaly do not substantiate these dimensions (Maher, 1971).

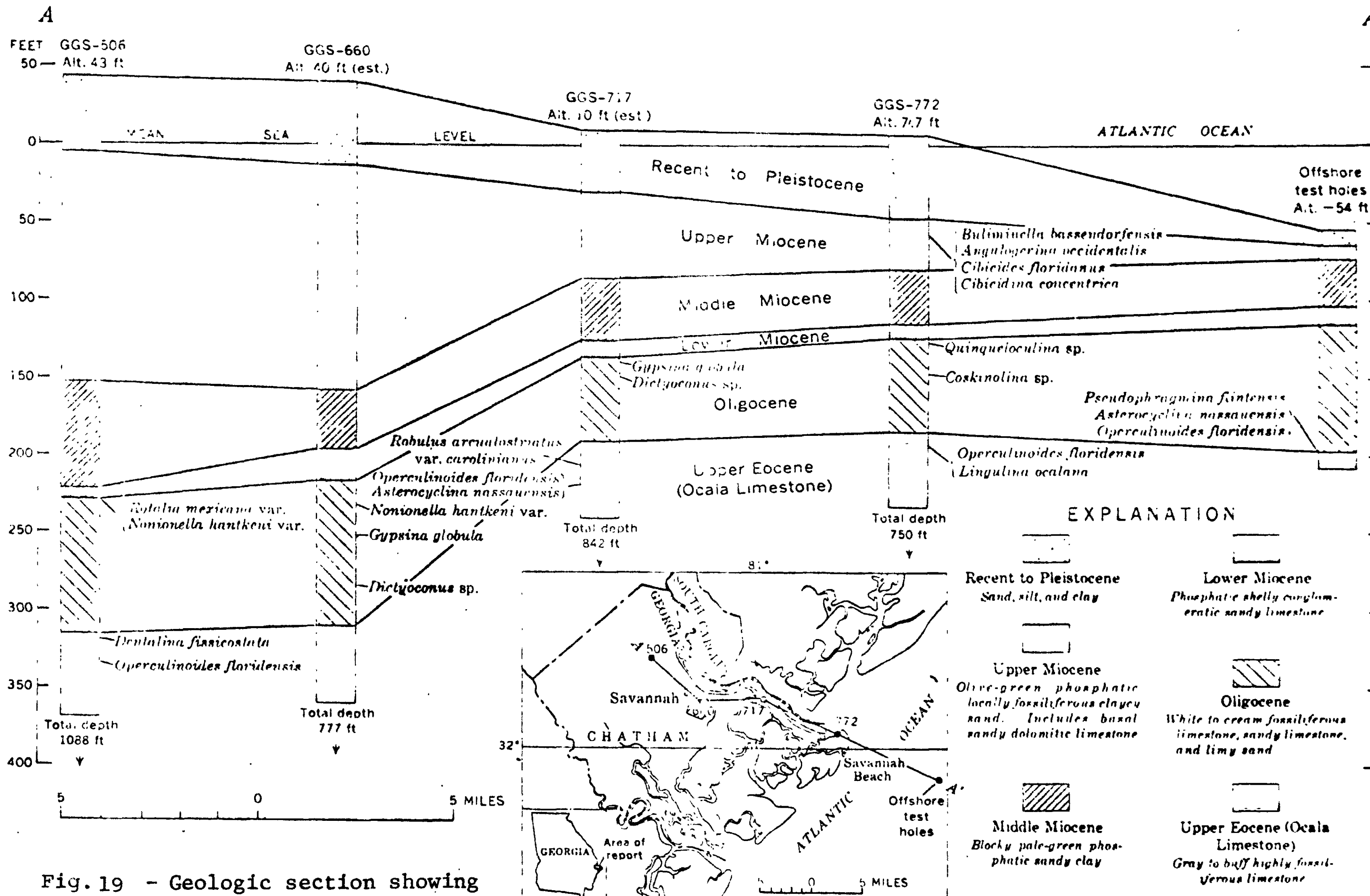


Fig. 19 - Geologic section showing upper Eocene to Recent stratigraphic sequence in Chatham County, Georgia, and 10 miles offshore. (from McCollum and Herrick, 1964).

Cramer (1974) believes that the Yamacraw Uplift involves the basement and may have been active during the Cretaceous. Cramer (1969) stated that it is impossible to tell whether the Yamacraw Uplift is a Pre-Cretaceous feature upon which coastal plain sediments were deposited or whether it formed during the Cretaceous, or both.

Burton High. -- Siple (1965, p. 443) has mapped a shallow (15 m to 30 m deep) small structural high on the Eocene-Miocene limestone sequences in the St. Helena Sound-Beaufort, South Carolina area which he designated the "Burton High" (Fig. 8). Heron and Johnson (1966 Fig. 3) also mapped a structural high on the Eocene Santee Limestone in the same vicinity although they show an arch rather than a closure trending north-east-southwest from 13 km Northeast of Savannah to St. Helena Sound. They named this the "Beaufort High". The Beaufort High dips westward to the "Ridgeland Basin" (Heron and Johnson, 1966) a small northeast-southwest trending Miocene low (Fig. 8). It is possible that the Burton High-Beaufort High is a shallow expression of the Yamacraw Uplift.

Stono Arch-- High resolution seismic reflection surveys reveal a small shallow (15 m to 60 m deep) anticline trending approximately east-west near Charleston, South Carolina which Colquhoun and Comer (1973) have named the "Stono Arch" (Fig. 8). The deformed reflectors that appear on the seismic record are within the Oligocene Cooper Marl and probably the underlying Santee Limestone of Eocene age (Colquhoun and Comer, 1973). These authors suggest that the Stono Arch is probably related to a more deeply seated basement fault.

Suwannee Channel.-- The Suwannee Channel (Fig. 8) (Chen, 1965; Jordan, 1954; Hull, 1962; Applin and Applin, 1967) is an elongated, structural feature in southern Georgia and northeastern Florida, where late Upper Cretaceous through upper Eocene rocks are abnormally thin and structurally low (Chen, 1965). It separates the Peninsular Arch from the outcropping Piedmont Precambrian (?) crystalline rocks and may coincide with a system of Triassic grabens which exhibited intermittent downward movement during Cretaceous and Tertiary time (Rainwater, 1971). In the area of the Suwannee Channel, a facies change takes place between clastic rocks to the north and carbonate rocks to the south (Chen, 1965; Applin and Applin, 1967). Cramer (1974) summarizes Applin and Applin's (1967) explanation for the origin of the Suwannee Channel:

> "The current explanation is that there was Upper Cretaceous arching, trending northeast-southwest, in what is now the saddle area, which resulted in thinner deposition over the arch, and a different sedimentary regimen established on either side. The arched area later became a relatively low area due to uplift to the north and to the south; the relatively low area than became the Suwannee Strait, or, to avoid the oceanographic inference, the Suwannee Saddle, to provide a structural connotation."

The theory of Chen (1965) has oceanographic inferences in that "the Suwannee Channel was a bathymetric depression and a natural barrier, both sedimentational and ecologic, during late Cretaceous and Early Tertiary time".

Chen (1965, Figs. 41-44) infers minor ocean currents and littoral drift passing through the Suwannee Channel from the Gulf of Mexico to the Atlantic Ocean during Paleocene and Eocene time. This may also have been the case during the late Cretaceous time, and may have had an effect on late Cretaceous-late Eocene sedimentation in the Southeast Georgia Embayment.

D. Stratigraphy

The Southeast Georgia Embayment lies in a transitional zone between a predominantly clastic depositional province north of Cape Hatteras and a carbonate province which includes Florida and the Bahamas. A summary geologic columnar section and a table of stratigraphic units and their Gulf Coast equivalents for the Southeast Georgia Embayment are shown in Figures 20 and 21. More than 400 wells have been drilled in Georgia and Florida, some of which reached basement rocks, and a few wells have been drilled in the Bahamas area, Geologic cross sections are shown in sections A-B and C-D (Fig. 22 and 23). In the offshore area, in addition to taking short cores, a few test holes have been drilled by the JOIDES program several hundred feet into the continental shelf off Georgia and Florida, but no well has been drilled offshore which penetrated pre-Tertiary strata. There are at least 2,800 m of sediments and possibly as much as 5,500 m of sedimentary rocks in the offshore basin beneath the Blake Plateau out to the 600 m water depth (Fig. 24). The basement ridge at the edge of the shelf, if it does exist, does not appear to have as great an influence on the distribution and thickness of the basin sediments as it does for the Baltimore Canyon Trough. It is likely that up to 4,000 m of Lower Cretaceous and Jurassic sedimentary rocks are present beneath the embayment.

1. Pre-Triassic

All available data indicate that the crystalline basement rocks beneath the Coastal Plain and adjacent continental shelf of southeastern United States are similar to those exposed in the Appalachian Piedmont

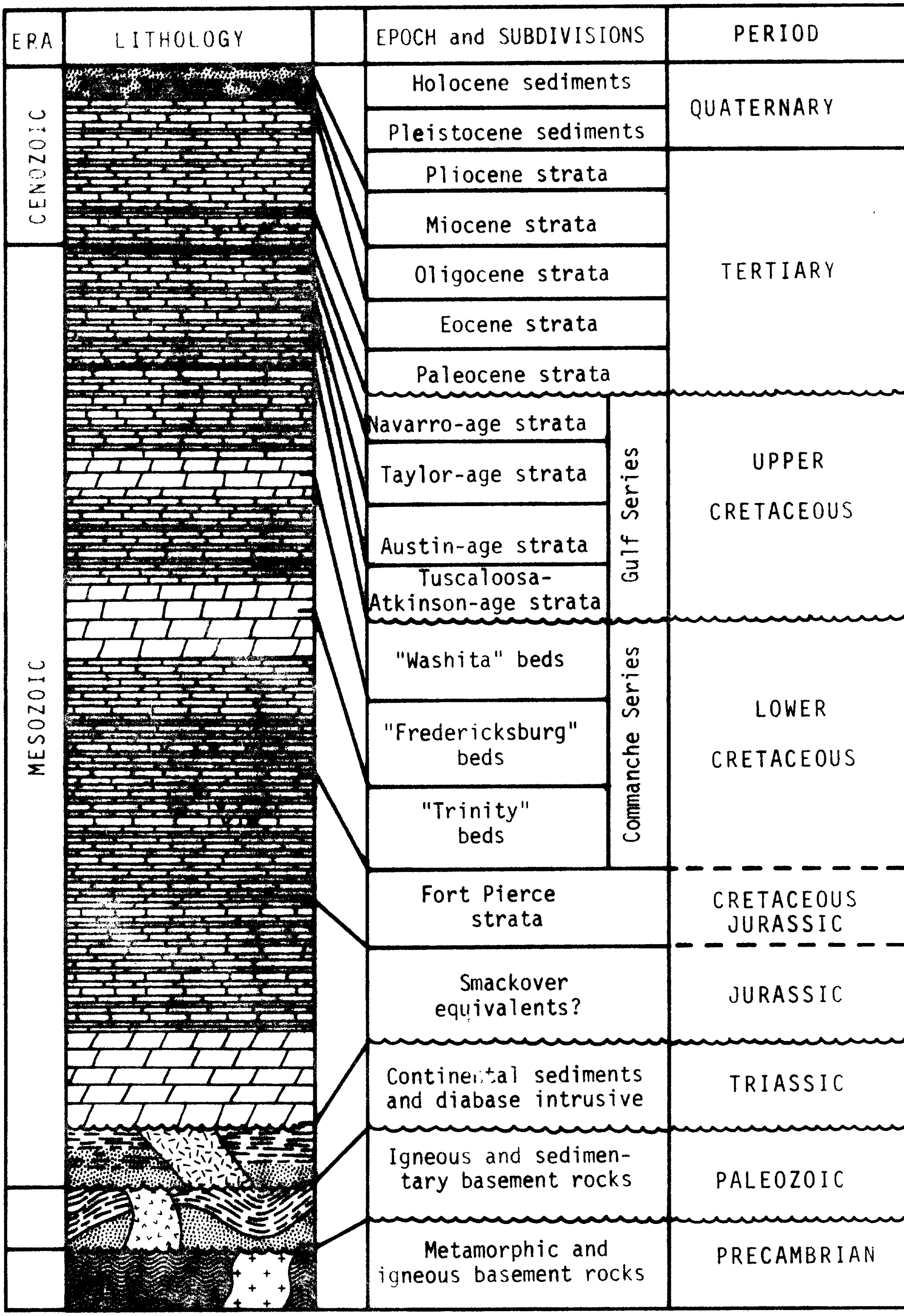


Fig. 20- Summary geologic columnar section.

System	Series	Gulf coast equivalent	Florida units	Georgia units	South Carolina units	North Carolina units
TERTIARY AND QUATERNARY	Holocene, Pleistocene, and Pliocene	Post-Miocene rocks	Post-Miocene rocks	Post-Miocene rocks	Post-Miocene rocks	Post-Miocene rocks
	Miocene	Miocene rocks	Miocene rocks	Miocene rocks	Absent on Cape Fear arch	Upper and middle Miocene rocks
						Lower Miocene rocks
TERTIARY	Oligocene	Oligocene rocks	Oligocene rocks	Oligocene rocks	Absent on Cape Fear arch	Rocks of uncertain age, possibly Oligocene in part
	Eocene	Rocks of Jackson age	Ocala Limestone	Rocks of Jackson age	Rocks of Jackson age	Upper and middle Eocene rocks
		Rocks of Claiborne age	Avon Park Limestone Lake City Limestone	Tallahhatta and Lisbon Formations undifferentiated	Middle and lower Eocene and Paleocene rocks undifferentiated	
		Rocks of Wilcox age	Oldsmar Limestone	Rocks of Wilcox age		Lower Eocene rocks
	Paleocene	Rocks of Midway age	Cedar Keys Limestone	Clayton Formation		Beaufort Formation
CRETACEOUS	Upper — Gulf	Rocks of Navarro age	Rocks of Navarro age	Rocks of Navarro age	Rocks of Navarro age	Pedee Formation
		Rocks of Taylor age	Rocks of Taylor age	Rocks of Taylor age	Rocks of Taylor age	Black Creek Formation
		Rocks of Austin age	Rocks of Austin age	Rocks of Austin age	Rocks of Austin age	
		Rocks of Woodbine and Eagle Ford age	Atkinson Formation	Rocks of Eagle Ford age	Rocks of Eagle Ford age	Rocks of Eagle Ford age
				Tuscaloosa Formation	Tuscaloosa Formation	Tuscaloosa Formation
	— ? — Lower — Comanche	Rocks of Washita age	Rocks of Washita age	Lower Cretaceous rocks	Lower Creataceous rocks	Rocks of Washita(?) age
		Rocks of Fredericksburg age	Rocks of Fredericksburg age			Rocks of Fredericksburg(?) age
		Rocks of Trinity age	Rocks of late Trinity age Sunniland Limestone Rocks of early Trinity age			Rocks of Fredericksburg or Trinity age
						Rocks of Trinity(?) age
— ? —	Lower Cretaceous (Neocomian) or Upper Jurassic	Lower Cretaceous (Neocomian) or Upper Jurassic	Lower Cretaceous (Neocomian) or Upper Jurassic	Lower Cretaceous (Neocomian) or Upper Jurassic absent	Lower Cretaceous (Neocomian) or Upper Jurassic absent	Mesozoic rocks of uncertain age, possibly Cretaceous (Neocomian)

Fig.21 - Stratigraphic units and their Gulf Coast Equivalents. (from Maher, 1971).

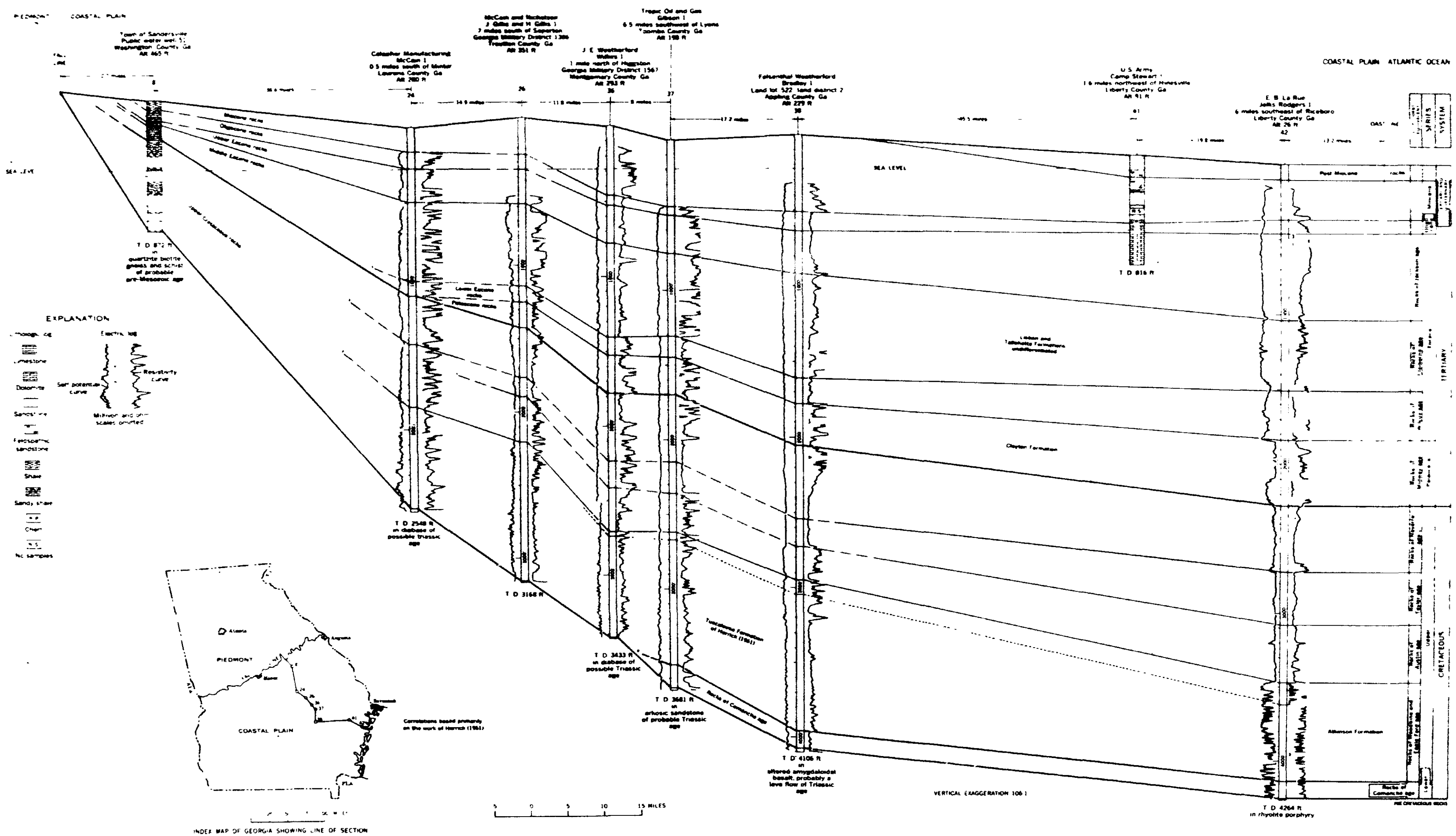


Fig. 22 - Stratigraphic section based on wells across the Coastal Plain of the Southeast Georgia Embayment. From Maher (1971).

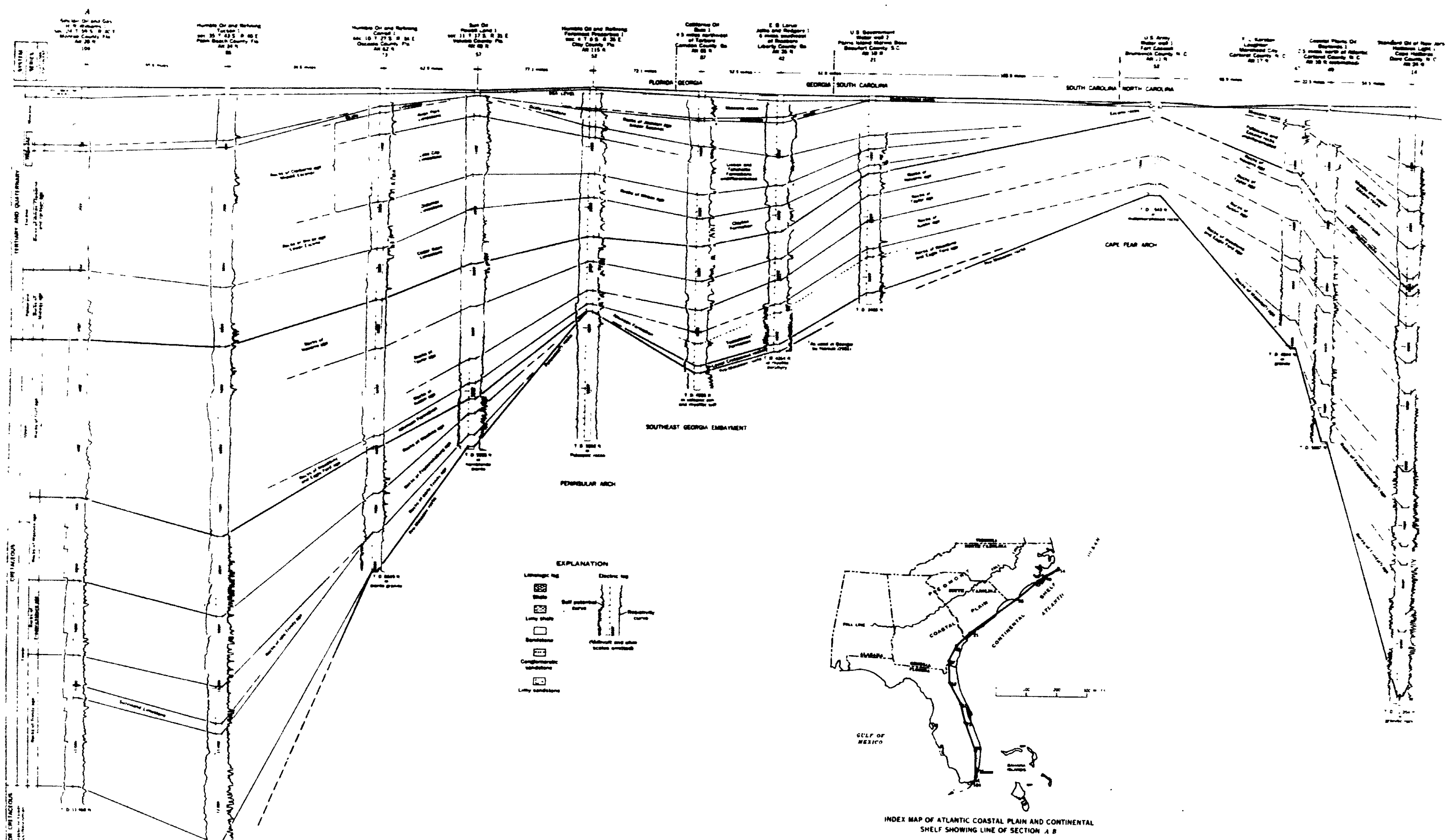


Fig.23 . - Stratigraphic section based on wells along the coast of the southeast U.S. From Maher (1971).

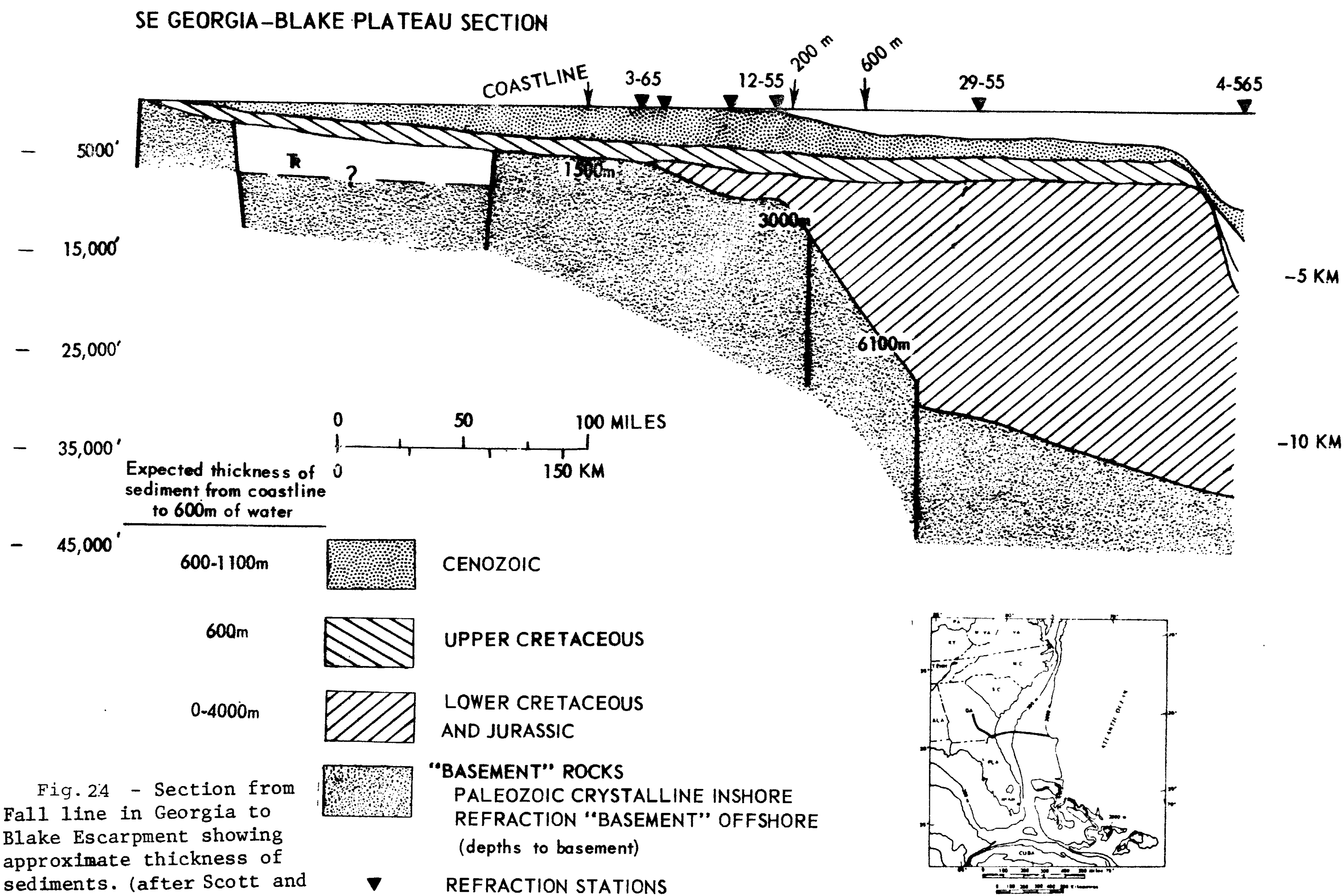


Fig. 24 - Section from Fall line in Georgia to Blake Escarpment showing approximate thickness of sediments. (after Scott and Cole, 1975).

province. The basement rocks of North Carolina, South Carolina, and northern Georgia are granites, gneisses, schists, and other igneous and metamorphic rocks. They are mostly early Paleozoic and late Precambrian in age (Spivak and Shelburne, 1971). Wells in southern Georgia and northern Florida encountered sandstone and shale of Ordovician to Devonian age (Applin, 1951, Rainwater, 1971). The generalized distribution of pre-Cretaceous rocks beneath the Georgia-Florida Coast Plain area is shown in Figure 25.

2. Triassic

The Triassic deposits of eastern North America consist of non-marine arkoses, sandstones, shales, basic flows and diabase intrusions, and are exposed from northern South Carolina to Nova Scotia in NE-SW trending narrow grabens downfaulted in the basement rocks of the Piedmont (Fig. 26). Marine and Siple (1974) have described a buried Triassic basin in the Savannah River area of South Carolina and Georgia. Similar Triassic filled grabens are thought to exist beneath the Coastal Plain (Bonini and Woolard, 1960), Marine and Siple, 1974, Scott and Cole, 1975, Fig. 1). Sedimentary rocks of probable Late Triassic age have been penetrated in several wells in northern Florida and southern Georgia (Rainwater, 1971, Marine and Siple, 1974, Fig. 1). The Stanolind Oil and Gas Co. No. 1 J. H. Pullen, Mitchell County, Georgia penetrated approximately 305 m of fine grained arkosic sandstone and red and green shale [basement (?)] from wells in Mitchell and Echols counties Georgia indicate an Upper Triassic age (Milton and Grasty, 1969).

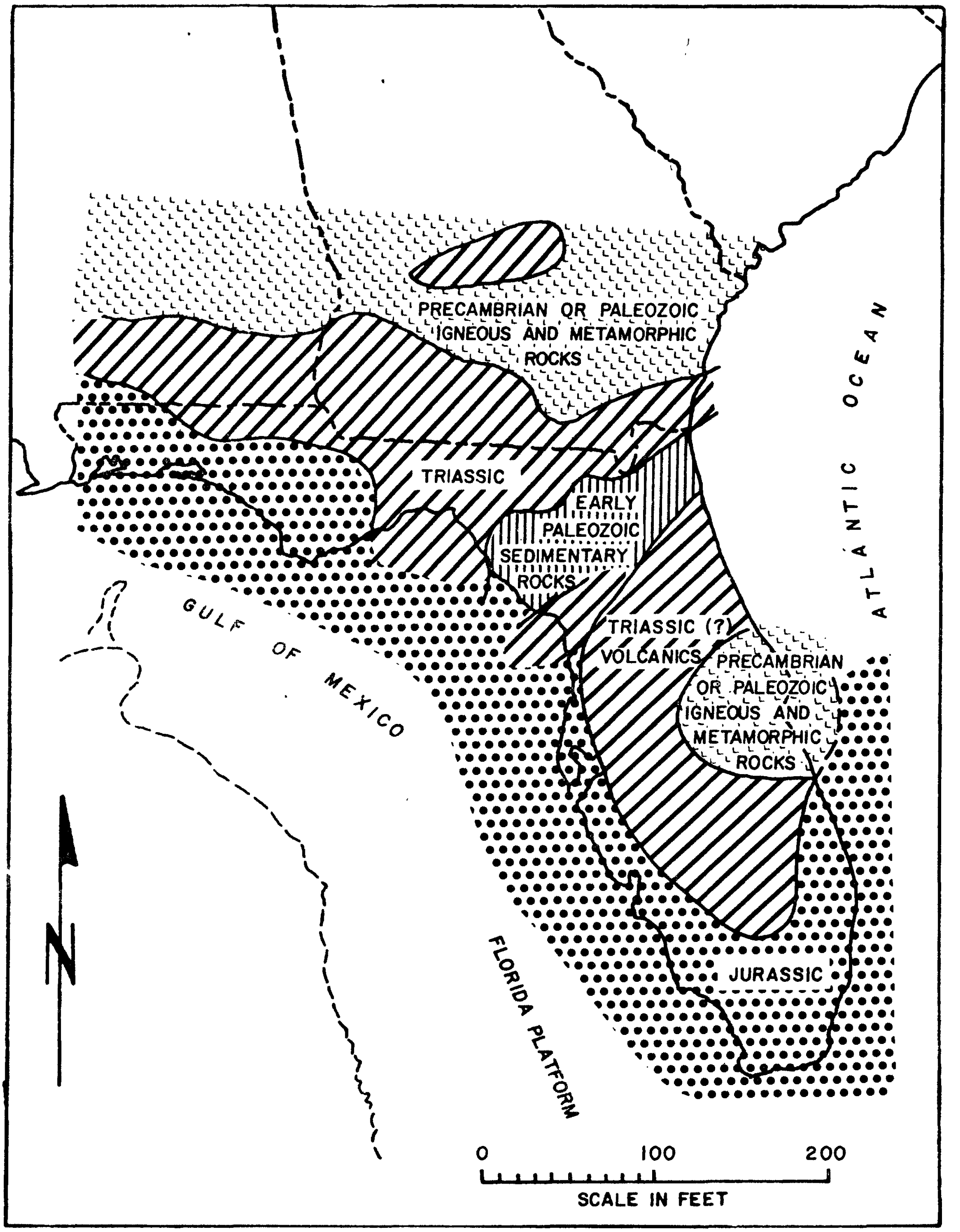


Fig. 25 - Possible pre-Cretaceous subcrop map. (modified from Rainwater, 1971, and Marine and Siple, 1974).

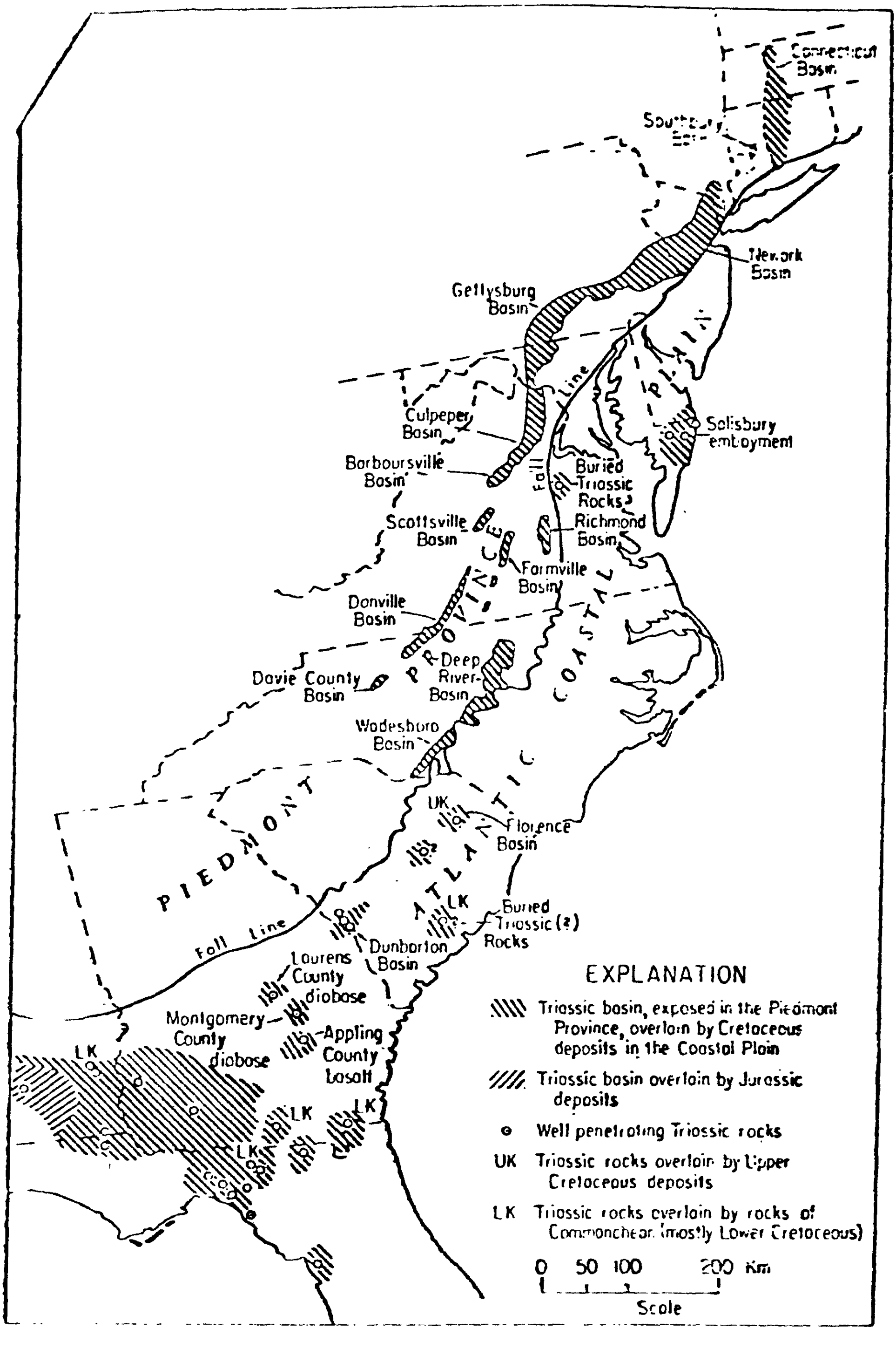


Fig. 26 - Exposed and buried Triassic rocks along the eastern seaboard showing age of overlying rocks. (from Marine and Siple, 1974).

It is likely that Triassic basins also exist beneath the inner continental shelf, because the same tectonic setting and the same type of basement would have existed in the present shelf area as in the area where known basins developed. Furthermore, sediment sources and depositional environments would be anticipated to have been similar in this probably upwarped region, where continental rifting was beginning to take place.

3. Jurassic

Rocks of late Jurassic age do not crop out in eastern North America. In North Carolina, the ESSO-Hatteras Light 1 well penetrated 280 m of possible Late Jurassic (or Early Cretaceous) rocks which Maher (1971) describes as finely crystalline, partly oolitic limestone and gray shale beds grading downward to red and green sandy conglomerate and arkose at the base. The lower part of this section is considered to be continental (Brown, Miller, and Swain, 1972) and rests on pre-Cretaceous "granite". The occurrence of Schluleridea cf. S. acuminata in the upper part of this section suggest to Brown, Miller, and Swain (1972) a correlation with the Cotton Valley Group of the Gulf coast. Successively younger Mesozoic rocks abut the basement updip from the Hatteras Light well. Applin and Applin (1965) designated a Late Jurassic (?)-Early Cretaceous (Neocomian) unit penetrated in the Amerada No. 2. Cowles well (St. Lucie Co., Fla) as the "Fort Pierce Formation". This type section includes 677 m of dolomite, oolitic limestone, anhydrite, and shale with a basal arkosic sand overlying metamorphic (Precambrian?)

basement. The formation has been penetrated by six deep wells in southern Florida, and it pinches out in a northward direction (updip) about 65 km south of Cape Canaveral (Maher, 1971). Meyerhoff and Hatten (1974) included the Fort Pierce Formation as the oldest unit in their "Marquesas Super-Group" which also includes other formations of either Early Cretaceous or Late Jurassic age or both in the Florida-Cuba-Bahamas area. Also included in this grouping are rocks of Trinity, Fredericksburg, and Washita age (Comanche Series - Lower Cretaceous), i.e., all strata to the Lower-Upper Cretaceous unconformity. The Chevron No. 1 Great Isaac well in the northwestern Bahamas reportedly penetrated this group in its entirety but thicknesses are not available. It has been reported that the well reached total depth in Jurassic carbonate overlain by 328 m of black, marine Jurassic(?) shale and that the Marquesas resembles that of wells in Southern Florida (Meyerhoff and Hatten, 1974).

Other formations assigned to this supergroup are the Glades Group, Punta Gorda Formation, Ocean Reef Group, Sunniland Limestone, Lake Trafford Formation, Dollar Bay Formation, Big Cypress Group, Naples Bay Group, "Andros Long Island" and "Cay Sal IV-1" facies and Cayo Coco, Perros, and Palenque formations of Cuba. These formations are all predominantly carbonate, with limestone more abundant than dolomite, along with lesser amounts of anhydrite and shale (Meyerhoff and Hatten, 1974).

4. Cretaceous

The Upper Cretaceous rocks of Georgia and Florida (Gulf Series) are separated from the Lower Cretaceous and older rocks by a major regional unconformity.

The Cretaceous system in the Gulf Coast region is divided into the Comanche and Gulf Series. For practical purposes, the Comanchean is considered by most geologists to be Lower Cretaceous, and Gulfian to be Upper Cretaceous (Murray, 1961).

Lower Cretaceous. The Comanche Series is subdivided into three groups: Trinity, Fredericksburg, and Washita. Comanchean rocks do not crop out along the coastal plain from Florida to North Carolina although they may be at or near the surface in North Carolina and western Georgia, but are indistinguishable from the overlying Upper Cretaceous rocks which are lithologically similar. Lower Cretaceous beds dip seaward from the Fall Line at rates from 3 m/km to 11 m/km (Maher, 1971). The Lower Cretaceous is approximately 1,500 m thick near Miami, Florida, and thins northward until it pinches out on the Peninsular Arch (Maher, 1971; Rainwater, 1971). In south Florida, shallow water marine limestones and dolomites with beds of anhydrite make up the principal lithologies. East of the Peninsular Arch in northern Florida and coastal Georgia, the Lower Cretaceous rocks are thin (30 m - 90 m) nonmarine clastics made up of arkosic unconsolidated sandstones and varicolored clays which were deposited on a broad, flat coastal plain (Rainwater, 1971; Brown, 1974; Herrick and Vorhis, 1963). The main depocenter for Lower Cretaceous strata in Georgia was the southwestern part of the state where as much as 1,100 m may have been deposited (Herrick and Vorhis, 1963). During this time, the northern part of the Peninsular Arch was a positive feature exposed to subaerial processes, and probably contributed clastics to the Florida-Georgia coastal plain. Preliminary work by Brown (1974) suggests that fossiliferous beds, now included in the lower member of the Atkinson Formation of Gulfian age, may, at least in part represent a brackish-water facies of Comanchean age.

Rocks of Lower Cretaceous age are absent, or very thin, in South Carolina. Siple (1965, Fig. 2; 1967, Fig. 1) identified rocks of Early Cretaceous (Comanchean) age from a deep water well in the Parris Island - Beaufort, South Carolina area. Brown (1973, oral comm.) in Olson (1973) reported that a well drilled on Seabrook Island (Charleston County) in 1972 to a depth of 822 m contained sediments of suspected Washita or Fredericksburg age equivalents in the bottom core samples. Lower Cretaceous rocks are missing from the higher parts of the Cape Fear arch except for the thin Cape Fear Formation below a regional unconformity, but thicken northward to 853 m at Cape Hatteras. In coastal North Carolina, Brown, Miller, and Swain (1972) describe the Lower Cretaceous as being a marine section made up of red and green shales, fine to medium grained sands, and sandy limestones containing oolitic lenses.

The four samples of Early Cretaceous rocks dredged from the Blake Escarpment at depths from 2,374 m to 4,747 m (Heezen and Sheridan, 1966) indicate the area was a shallow carbonate bank then. The lower two samples were algal calcarenite and algal dolomitic calcarenite, both were assigned an age range of Neocomian to Aptian. The upper two samples

-- oolitic, fragmental calcarenite suggest a shallower water environment of deposition than the upper calcilutite samples (Heezen and Sheridan, 1966).

On the continental shelf off southern Georgia and Florida, there may be a wedge of Lower Cretaceous clastic rocks (Scott and Cole, 1975, Fig. 7) similar to that under the North Carolina coastal plain as suggested by Rainwater (1971). Judging by the rate of thickening onshore and the scattered seismic profiles offshore, 4,000 m of Lower Cretaceous-Jurassic sediments are expected in the Blake Plateau trough (to the 600 m water depth) and 1,100 m of Lower Cretaceous-Jurassic sediments are expected out to the 200 m water depth.

Upper Cretaceous. The Upper Cretaceous Gulf Series is subdivided into five stages. They are, in ascending order: Woodbine, Eagle Ford, both of which are represented by the Atkinson Formation in Florida, Austin, Taylor, and Navarro (Lawson Limestone of Florida). The Gulf Series in the subsurface is divided into four stratigraphic units: The Atkinson Formation (oldest), Austin-age strata, Taylor-age strata, and rocks of Navarro age (Lawson Limestone). The Atkinson is a shallow-water marine deposit composed of dark, fossiliferous shale, sandstone, and interbedded limestone. The unit is the downdip equivalent of the littoral to nonmarine Tuscaloosa Formation. The Austin strata are mostly chalky limestones while two regional facies occur in rocks of Taylor age: a carbonate facies occupies the Florida Peninsula and a highly variable clastic facies occurs in northern Florida and southern Georgia. Two facies are also present in the strata of Navarro age: the Lawson

Limestone of southeast Georgia and the Florida Peninsula, and an updip clastic facies equivalent. The Gulf Series in south Florida and the Bahamas is represented by the Pine Key Formation--a chalky limestone. The Pine Key grades into the Atkinson-Lawson strata to the north and becomes the Card Sound Dolomite to the south in the Florida Keys and Bahamas (Applin and Applin, 1965).

Upper Cretaceous rocks crop out at the Fall Line in Alabama and extend to almost the shoreline near Cape Fear. The rocks dip seaward from 2 m/km near the Fall Line to more than 6 m/km at the coast (Maher, 1971). Upper Cretaceous rocks are approximately 853 m thick near Miami, Florida, and are composed almost entirely of marine carbonates (Maher, 1971). In northeast Florida and southeast Georgia, the dominant lithology is chalky fossiliferous shallow water marine limestone and dolomite approximately 600 m thick near the coast (Cramer, 1974; Maher, 1971). Northward, Upper Cretaceous rocks are non-marine to marginal marine Appalachian-derived sandstones and shales with minor amounts of carbonate and lignitic material (Brown, Miller, and Swain, 1972; Olson, 1973; Cramer, 1974). Rocks of Upper Cretaceous age thin (from a few metres to approximately 400 m) near the shore on the Cape Fear Arch, but reach a thickness of about 950 m at Cape Hatteras (Maher, 1971). Although the Upper Cretaceous thins over the Cape Fear Arch, the Navarro Stage thickens, suggesting that the arch was a structural depression during late Upper Cretaceous time (Swift and Heron, 1969).

In general, the Upper Cretaceous rocks thicken downdip from terrigenous sands and shales to more marine chalks, limestones, and dolomites. The offshore portion of the Southeast Georgia Embayment is probably almost entirely shallow water carbonates with the possible exception of late Upper Cretaceous fine clastics brought there by way of the Suwannee Channel (see section on Structure).

Submarine outcrops of Late Cretaceous age are known from the Blake escarpment and along the continental slope near Cape Hatteras (Maher, 1971). A bottom core sample of Cenomanian age (Woodbinean) lutite was recovered from the Blake Escarpment in 1,745 m of water off central Florida (Ericson and others, 1961).

The Upper Cretaceous rocks will probably maintain a fairly constant thickness of about 600 m for the OCS Southeast Georgia Embayment and the Blake Plateau.

5. Cenozoic

Cenozoic rocks range in thickness from 1,300 m under Miami, Florida, to 76 m on the Cape Fear Arch, to 900 m at Cape Hatteras (Maher, 1971). Offshore, Cenozoic rocks will range in thickness from 600 m to 1,100 m. In general, the Tertiary rocks are predominantly shallow water marine carbonates in Florida, grading northward into a marginal marine to marine clastic facies composed of sands, marls, and limestones. From Late Cretaceous to Late Eocene time, the clastic and non-clastic facies boundary was separated by the Suwannee Channel and has shifted northward through time (Chen, 1965).

Offshore, Tertiary rocks have been penetrated by five test holes within or in close proximity to the Southeast Georgia Embayment. Two were drilled at one site by the U. S. Coast Guard about ten miles offshore from Savannah Beach, Georgia (McCollum and Herrick, 1964) (Fig. 19). Three wells were drilled by the JOIDES program from 40-120 km offshore Jacksonville, Florida in water depth from 25-190 metres (Bunce and others, 1965) (Fig. 18). Most of the Tertiary units recognized on land continue beneath the shelf with similarity between Tertiary and recent depositional environments, suggesting that the continental margin has slowly subsided (Bunce and others, 1965).

Paleocene. The Paleocene rocks in peninsular Florida and most of southern Georgia are principally dolomites and anhydrites deposited on a slowly subsiding shelf with restricted ocean circulation (Rainwater, 1971). In Georgia, calcareous sandstone and claystones updip grade downdip to sandy carbonate rocks (Spivak and Shelburne, 1971). In the Carolinas, there is less carbonate and more shale and sands with a high percent (10-90) of glauconite (Brown, Miller, and Swain, 1972; Spivak and Shelburne, 1971).

Eocene. In peninsular Florida and most of coastal Georgia and South Carolina, fossiliferous limestone and dolomite, with a small amount of sands and silts, make up the Eocene rocks (Cramer, 1974; Rainwater, 1971; Chen, 1965; Spivak and Shelburne, 1971). In North Carolina, the lithologies are mostly glauconitic sands, siltstones, calcareous sands and limestones (Brown, Miller, and Swain, 1972). Most of the Eocene rocks were deposited in shallow open-sea to restricted marine environments (Rainwater, 1971). Offshore Georgia, the upper Eocene is a highly fossiliferous limestone (McCollum and Herrick, 1964). The middle and late Eocene off Jacksonville, Florida, is composed of calcareous oozes, calcarenites, dolomitic calcarenites, and dolomites very similar to the Ocala Limestone and older units of the Eocene on land (Bunce and others, 1965; Schlee, in prep.).

Oligocene. The Oligocene crops out in patches from Florida to South Carolina and is generally less than 60 m thick in the subsurface from coastal Florida to Cape Hatteras. The rocks are limestones in Florida and Georgia and grade northward to sandy limestone, shale, and sandstone (Spivak and Shelburne, 1971). Late Oligocene uplift of the Peninsular arch resulted in the removal of Oligocene rocks in the extreme southeast Georgia and northeast Florida (Cramer, 1974). Offshore Georgia, the Oligocene is composed of fossiliferous limestone, sandy limestone, and limey sand (McCollum and Herrick, 1964). Offshore Jacksonville, Florida, calcareous oozes make up the Oligocene (Charm, Nesteroff, and Valdes, 1970), though the main locus of deposition appears to be the upper slope (Schlee, in prep.).

Miocene. Marine to marginal marine sandy limestones and phosphatic sandstones in Florida (Rainwater, 1971) grade northward to sandy limestones and shales in North Carolina (Spivak and Shelburne, 1971). During middle Miocene time, parts of the Florida peninsula were emerged for the first time since early Late Cretaceous (Rainwater, 1971). The Miocene deposits offshore Georgia and Florida consist of sandy clays (McCollum and Herrick, 1964; Charm, Nesteroff, and Valdes, 1970).

Plio-Pleistocene. Marginal marine to non-marine clayey-sands, sands, and gravel make up the post-Miocene sediments from Florida to North Carolina (Brown, 1974; Brown, Miller, and Swain, 1972; Spivak and Shelburne, 1971). Sands, silt, and clay also make up the offshore sediments (McCollum and Herrick, 1964; Charm, Nesteroff, and Valdes, 1970).

E. Geologic History

The foregoing discussions on structure and stratigraphy provide the foundation for the following summary of the evolution of the United States South Atlantic continental margin.

Based on current interpretations of plate tectonics theory, the present overall structural-sedimentary framework of the United States continental margin is a result of a collision of the North American and African continental plates during Late Paleozoic time and later modification during Late Triassic time when the continental plates separated, forming the present Atlantic Ocean (Pitman and Talwani, 1972; Mattick and others, 1974).

An earlier Atlantic Ocean closed in the late Paleozoic when the North American plate collided with the African plate (Wilson, 1966). Basement rocks presently beneath the Atlantic Coastal Plain and Continental Shelf were part of the crystalline Appalachians (Olson, 1974). Most of the deformation of the crystalline basement rocks beneath the present day Coastal Plain and continental shelf probably resulted from lateral compressional forces and vertical upwarps caused by the closing of the old Atlantic. Brown, Miller, and Swain (1972) concluded that the geometry of the structural-sediment framework of the coastal plain is associated predominantly with the action of lateral compressional forces and that the vertical forces operative in the region are chiefly the resultants of "compressional stress".

During Late-Triassic time, a regional uplift simultaneously affected the whole area of the United States Atlantic continental margin (Mayhew, 1974; Olson, 1974). Block faulting associated with the uplift involved partial rejuvenation of Paleozoic fault patterns (Mayhew, 1974). Regional uplifting was initiated by subcrustal intrusions of hot mantle material which caused a series of rift valleys to develop with trends roughly parallel with the present Continental Rise (Olson, 1974). This was the site of a major rift system and the upwelling plume of a hypothetical convection cell which later formed the Mid-Atlantic Ridge (Talwani, LePichon, and Ewing, 1965). The environment was probably similar to that of the present Red Sea. Extensive evaporite deposition occurred in Late Triassic-Early Jurassic rift valleys in the Gulf Coast (Louann evaporite sequence), the Scotian Shelf, and the Grand Banks. The Baltimore Canyon trough may also contain salt deposits at the base of the sedimentary section as suggested by Mattick and others (1974). Rona (1970) has suggested that salt of Jurassic age should lie seaward of Cape Hatteras. The evaporite sequence may underlie the Bahamas as suggested by seismic evidence (Sheridan, 1974) and the presence of diapiric structures in Exuma Sound (Ball and others, 1971). According to Olson (1974), the Blake Plateau may also be underlain by bedded salt.

During Late Jurassic time, the Central Atlantic Ocean widened, allowing more normal seawater to circulate in a Mediterranean type sea between North America and northwestern Africa (Olson, 1974). This sea was longer and narrower than the Persian Gulf geosyncline of the same age (Olson, 1974), and was bounded on the south by northern South

America which did not separate from Africa until about 110 m.y. B.P. (Larsen and Pitman, 1972). Evaporite deposition gave way to carbonate sedimentation on the subsiding continental margin. Near the end of Jurassic time, a ridge beneath the outer Blake Plateau may have existed and served as a dam behind which terrigenous sediments accumulated (Emery and Uchupi, 1972). The ridge could have provided an excellent environment for the development of platform, fringing, and/or patch reefs, or possibly a huge barrier reef similar to that off eastern Australia (U.S.G.S., 1975). Carbonate sedimentation continued throughout the Cretaceous on the shallow relatively stable continental margin of the United States south of Cape Hatteras. Reefs continued to flourish until mid-Cretaceous time when reef accretion in the Bahamas slowed down (Emery and Uchupi, 1972).

During mid-Cretaceous time, the ridge along the Atlantic continental margin no longer was an effective sediment barrier as sediments began to flow over it, and the Continental Slope had developed to nearly its present morphology (Emery and Uchupi, 1972). The Blake Plateau gradually subsided, and by Late Cretaceous or early Cenozoic time, bathyal conditions prevailed over the Blake Plateau as the Gulf Stream extended its course northward (Emery and Uchupi, 1972). By the end of Late Cretaceous time, approximately 60 percent of the Atlantic continental drift between Africa and North America had taken place (Pitman and Talwani, 1972).

Throughout most of Tertiary time, the United States southern Continental Shelf continued to subside, although at much slower rates than the Gulf Coast. The basement has subsided in some places as much as 10-12 km (Sheridan, 1974). Deposition has generally kept pace with subsidence creating a shallow water environment of deposition throughout most of the Mesozoic and Cenozoic. A major regression in which the shoreline may have retreated to the present shelf edge occurred during the Oligocene and the Pliocene (Emery and Uchupi, 1972). During these lower stands of sea level, sediments were prograded across the Continental Shelf.

Since the Late Cretaceous, the remaining 40 percent of the continental drift between Africa and North America has taken place (Pitman and Talwani, 1972) moving the United States East Coast to its present position.

BIBLIOGRAPHY

Antoine, J. W., and Henry, V. J. Jr., 1965, Seismic Refraction Study of Shallow Part of Continental Shelf Off Georgia Coast: Am. Assoc. Petroleum Geolgists Bull., vol. 49, no. 5., p. 601-609.

Applin, P. L., 1951, Preliminary report on buried pre-Mesozoic rocks in Florida and adjacent states: U. S. Geol. Survey Circ. 91, 28 p.

Applin, P. L., and Applin, E. R., 1965, The Comanche Series and associated rocks in the subsurface of central and south Florida: U. S. Geol. Survey Prof. Paper 447, 84 p.

Applin, P. L., and Applin, E. R., 1967, The Gulf Series in the subsurface in northern Florida and southern Georgia: U. S. Geol. Survey Prof. Paper 524 G, 35 p.

Arden, D. D., Jr., 1974, A geophysical profile in the Suwannee basin, northwestern Florida, in Stafford, L. P., Symposium on the petroleum geology of the Georgia coastal plain, Bull. 87: Atlanta, 1974, p. 111-122.

Ball, B., Dash, P., Harrison, C. G. A., Ahmed, K. O., 1971, Refraction seismic measurements in the northeastern Bahamas (abs.): Eos (Am. Geophy. Union Trans.) v. 52, p. 252.

Bonini, W. E., and Woollard, G. P., 1960, Subsurface geology of North Carolina-South Carolina Coastal Plain from seismic data: Am. Assoc. Petroleum Geologists Bull., v. 44, no. 3, p. 298-315.

Brown, P. M., 1974, Subsurface correlation of Mesozoic rocks in Georgia, in Stafford, L. P., Symposium on the petroleum geology of the Georgia coastal plain, Bull. 87: Atlanta, 1974, p. 45-59.

Brown, P. M., Miller, J. A., and Swain, F. M., 1972, Structural and stratigraphic framework and spatial distribution of permeability of the Atlantic Coastal Plain, North Carolina to New York: U. S. Geol. Survey Prof. Paper 796, 79 p.

Bunce, E. T., Emery, K. O., Gerard, R. D., Knott, S. T., Lidz, Louis, Saito, Tsunemasa, and Schlee, John, 1965, Ocean drilling on the continental margin: Science, v. 150, no. 3697, p. 709-716.

Charm, W. B., Nesteroff, W. D ., and Valdes, S., 1970, Drilling on the continental margin off Florida: detailed stratigraphic description of the JOIDES cores on the continental margin off Florida: U. S. Geol. Survey Prof. Paper 581-D, 13 p.

Chen, C. S., 1965, The regional lithostratigraphic analysis of Paleocene and Eocene rocks of Florida: Florida Geol. Survey Bull. 45, 105 p.

Colquhoun, D. J., and Comer, C. D., 1973, The Stono arch, a newly discovered breached anticline near Charleston, South Carolina: South Carolina State Devel. Board, Div. Geology, Geologic Notes, p. 97-105.

Cramer, F. H., 1971, Position of north Florida Lower Paleozoic block in Silurian time--phytoplankton evidence: Jour. Geophys. Res., v. 76, p. 4754-4757.

Cramer, H. R., 1969, Structural features of the Coastal Plain of Georgia: Southeastern Geology, v. 10, p. 111-123; correction, v. 11, p. 202, 1970.

Cramer, H. R., 1974, Isopach and lithofacies analyses of the Cretaceous and Cenozoic rocks of the coastal plain of Georgia, in Stafford, L. P., Symposium on the petroleum geology of the Georgia coastal plain, Bull. 87: Atlanta, 1974, p. 21-43.

Dillon, W. P., 1974. Faults related to seismicity off the coast of South Carolina. U.S. Geological Survey, Reston, Va. open-file report.

Drake, C. L., Ewing, J. I., and Stockaid, H., 1968, The Continental Margin of the Eastern United States: Canadian Jour. Earth Sci., v. 5, p. 993-1010.

Drake, C. L., Heirtzler, J., and Hirshman, Julius, 1963, Magnetic anomalies off eastern North America: Jour. Geophys. Res., v. 68, no. 18, p. 5259-5275.

Eardley, A. J., 1951, Structural geology of North America: New York, Harper and Row, 624 p.

Emery, K. O., and Uchupi, Elazar, 1972, Western North Atlantic Ocean: Topography, rocks, structure, water, life, and sediments: Am. Assoc. Petroleum Geologists Mem. 17, 532 p.

Emery, K. O., and Zarudzki, E. F. K., 1967, Seismic reflection profiles along the drill holes on the continental margin off Florida: U. S. Geol. Survey Prof. Paper 581-A, 8 p.

Ericson, D. B., Ewing, M., Wollin, G., and Heezen, B. C., 1961, Atlantic deep-sea sediment cores: Geol. Soc. America Bull., v. 72, p. 193-286.

Ewing, J., Ewing, M., and Leyden, R., 1966, Seismic-profiler survey of Blake Plateau: Am. Assoc. Petroleum Geologists Bull., v. 50, no. 9, p. 1948-1971.

Field, M. E., and Meisburger, E. P., 1973, Erosional origin of inner shelf sediments -- evidence from north Florida (abs.): Am. Assoc Petroleum Geologists, Bull., v. 57, no. 4, p. 778.

Field, M.E., and Pilkey, O.H., 1969, Feldspar in Atlantic Continental Margin sands off the southeastern United States: Geol. Soc. America Bull., v. 80, p. 2097-2102, 4 figs.

Gadow, Sibylle, 1972, Georgia coastal region, Sapelo Island, U.S.A.: Sedimentology and biology. II. Provenance and distribution of heavy minerals: Senckenbergiana Marit., v. 4, p. 15-45.

Hathaway, J.C., comp. and ed., 1971, Data file, continental margin program, Atlantic Coast of the United States, v. 2, Sample collection and analytical data: Woods Hole Oceanog. Inst., Tech. rept. no. 71-15, 496 p.

Hathaway, J. C., 1972, Regional clay mineral facies in estuaries and continental margin of the United States East Coast: Geol. Soc. America, Mem. 133, p. 293-316.

Heezen, B. C., and Sheridan, R. E., 1966, Lower Cretaceous rocks (Neocomian-Albian) dredged from Blake escarpment: Science, v. 154, p. 1644-1647.

Heirtzler, J. R., and Hayes, D. E., 1967, Magnetic boundaries on the North Atlantic Ocean: Science, v. 157, p. 185-187.

Heron, S. D., Jr., and Johnson, H. S., Jr., 1966, Clay mineralogy, stratigraphy, and structural setting of the Hawthorn Formation, Coosawatchie District, South Carolina: Southeastern Geology, v. 7, p. 51-63.

Herrick, S. M., and Vorhis, R. C., 1963, Subsurface geology of the Georgia Coastal Plain: Georgia Geol. Survey Inf. Circ. 25, 78 p.

Hersey, J. B., Bunce, E. T., Wyrick, R. F., and Dietz, F. T., 1959, Geophysical investigation of the continental margin between Cape Henry, Virginia, and Jacksonville, Florida: Geol. Soc. America Bull., v. 70, no. 4, p. 437-466.

Hollister, C.D., 1973, Atlantic Continental Shelf and Slope of the United States - Texture of surface sediments from New Jersey to southern Florida: U.S. Geol. Survey Prof. Paper 529-M, 23 p.

Howard, J. D., Frey, R. W., and Kingery, F. A., 1973, Physical and biogenic characteristics of sediments from outer Georgia continental shelf (abs.): Am. Assoc. Petroleum Geologists, Bull., v. 57, no. 4, p. 784.

Howard, J. D., Frey, R. W., Reineck, H.-E., 1973, Holocene sediments of the Georgia coastal area: University of Georgia Marine Institute Contr. 268, 58 p.

Hull, J. P. D., Jr., 1962, Cretaceous Suwannee Strait, Georgia and Florida: Am. Assoc. Petroleum Geologists Bull., v. 46, no. 1, p. 118-121.

Jordan, L., 1954, Oil possibilities in Florida: Oil and Gas Jour., v. 54, no. 28, p. 370-375.

King, E. R., Zietz, Isidore, and Dempsey, W. J., 1961, The significance of a group of aeromagnetic profiles off the eastern coast of North America, in Short papers in the geologic and hydrologic sciences: U. S. Geol. Survey Prof. Paper 424-D, p. D299-D303.

Larson, R. L., and Pitman, W. C., III, 1972, Worldwide correlation of Mesozoic magnetic anomalies and its implications: Geol. Soc. America Bull., v. 83, p. 3645-3662.

Lipp, M. S., Sheridan, R. E., Newton, J. G., and Edgerton, H. E., 1975, Seismic reflection profiles and morphologic development of a ridge and swale topography on the Atlantic Continental Shelf off Ocracoke Inlet, North Carolina: Geol. Soc. America Abstracts with Programs, v. 7, no. 4, p. 510.

Long, L. T., 1974, Bouguer gravity anomalies of Georgia, in Stafford, L. P., Symposium on the petroleum geology of the Georgia coastal plain, Bull. 87: Atlanta, 1974, p. 141-166.

Long, L. T., and Lowell, R. P., 1973, Thermal model for some continental margin sedimentary basins and uplift zones: Geology, v. 1, p. 87-88.

Maher, J. C., 1971, Geologic framework and petroleum potential of the Atlantic Coastal Plain and Continental Shelf: U.S. Geol. Survey Prof. Paper 659, 98 p.

Marine, I. W., and Siple, G. E., 1974, Buried Triassic basin in the central Savannah River area, South Carolina and Georgia: Geol. Soc. America Bull., v. 85, p. 311-320.

Mattick, R. E., Foote, R. Q., Weaver, N. L., and Grim, M. S., 1974, Structural framework of United States Atlantic outer continental shelf north of Cape Hatteras: Am. Assoc. Petroleum Geologists Bull., v. 58, no. 6, part II of II (June, 1974), p. 1179-1190.

Mayhew, M. A., 1974, Geophysics of Atlantic North America, in Burk, C. A., and Drake, C. L., eds., The geology of continental margins: New York, Springer-Verlag, p. 409-427.

McCollum, M. J., and Herrick, S. M., 1964, Offshore extension of the upper Eocene to Recent stratigraphic sequence in southeastern Georgia, in Geological Research 1964: U. S. Geol. Survey Prof. Paper 501-C, p. C61-C63.

Meyer, R. P., 1956, The geologic structure of the Cape Fear axis as revealed by refraction seismic measurements: Madison, Wisconsin Univ. Ph.D. thesis, 176 p.; Ann Arbor, Mich., Univ. Microfilms, Inc. Pub. 21, 861.

Meyerhoff, A. A., and Hatten, C. W., 1974, Bahamas salient of North America: Tectonic framework, stratigraphy, and petroleum potential: Am. Assoc. Petroleum Geologists Bull., v. 58, no. 6, part II of II (June, 1974), p. 1201-1239.

Milliman, J.D., 1972, Atlantic Continental Shelf and Slope of the United States--Petrology of the sand fraction of sediments, northern New Jersey to southern Florida: U.S. Geol. Survey Prof. Paper 529-J, 40 p.

Milliman, J.D., Pilkey, O.H., and Ross, D.A., 1972, Sediments of the Continental Margin off the eastern United States: Geol. Soc. America Bull., v. 83, p. 1315-1334, 14 figs.

Milton, C., and Crasty, R., 1969, "Basement" rocks of Florida and Georgia: Am. Assoc. Petroleum Geologists Bull., v. 53, p. 2483-2493.

Molina, B. F., and Pilkey, O. H., 1972, Origin and distribution of calcareous fines on the Carolina continental shelf: Sedimentology, v. 18, p. 293-310.

Murray, G. E., 1961, Geology of the Atlantic and gulf coastal province of North America: New York, Harper and Row, 692 p.

Olson, N. K., 1973, Petroleum geology and related oil and gas potential of South Carolina: The Interstate Oil Compact Commission Committee Bull., v. XV, no. 2, Dec. 1973, 17 p.

Olson, W. S., 1974, Structural history and oil potential of offshore area from Cape Hatteras to Bahamas: Am. Assoc. Petroleum Geologists Bull., v. 58, no. 6, part II of II (June, 1974), p. 1191-1200.

Pearse, A. S., and Williams, L. G., 1951, The biota of the reefs off the Carolinas: Elisha Mitchell Sci. Soc. Jour., v. 67, p. 133-161.

Pevear, D. R., and Pilkey, O. H., 1966, Phosphorite in Georgia Continental Shelf sediments: Geol. Soc. of Amer. Bull., v. 77, p. 849-858.

Pilkey, O. H., Blackwelder, B. W., Doyle, L. J., Estes, Ernest, and Terlecky, P. M., 1969, Aspects of carbonate sedimentation on the Atlantic Continental Shelf off the southern United States: Jour. Sed. Petrology, v. 39, no. 2, p. 744-768.

Pilkey, O. H., and Field, M. E., 1972, Onshore transportation of Continental Shelf sediment: Atlantic southeastern United States in Swift, D. J. P., Duane, D. B., and Pilkey, O. H., eds., Shelf sediment transport: Dowden, Hutchinson, and Ross, Inc., Stroudsburg, Pa., p. 429-446.

Pilkey, O. H. and Frankenberg, D., 1964, The relict-recent sediment boundary on the Georgia continental shelf: Georgia Acad. Sci., Bull., v. 22, p. 37-40.

Pilkey, O. H., MacIntyre, I. G., and Uchupi, E., 1971. Shallow structures; shelf edge of continental margin between Cape Hatteras and Cape Fear, North Carolina. Am. Assoc. Petroleum Geologists Bull., v. 55, p. 110-115.

Pitman, W. C., III, and Talwani, M., 1972, Sea floor spreading in the North Atlantic: Geol. Soc. America Bull., v. 83, p. 619-646.

Pooley, R. N. 1960, Basement configuration and subsurface geology of eastern Georgia and southern South Carolina as determined by seismic refraction measurements: Madison, Wisconsin Univ. M.S. thesis, 47 p.

Pratt, R. M., and Heezen, B. C., 1964, Topography of the Blake Plateau: Deep-Sea Res., v. 11, p. 721-728.

Rabinowitz, P. D., 1973, The continental margin of the northwest Atlantic Ocean: A geophysical study [Ph.D. thesis]: Columbia Univ., New York.

Rabinowitz, P. D., 1974, The Boundary Between Oceanic and Continental Crust in the Western Atlantic: in The Geology of Continental Margins, C. A. Burke and C. L. Drake, eds., Springer-Verlags, p. 67-84.

Rainwater, E. H., 1971, Possible future petroleum potential of peninsular Florida and adjacent continental shelves, in Cram, I. H., Sr. ed., Future petroelum provinces of the United States -- their geology and potential; Am. Assoc. Petroleum Geologists Mem. 15, v. 2, p. 1311-1341.

Rona, P. A., 1970, Comparison of continental margins of eastern North America at Cape Hatteras and northwestern Africa at Cap Blanc: Am. Assoc. Petroleum Geologists Bull., v. 54,

Schlee, John, in prep., Stratigraphy and Tertiary development of the continental margin east of Florida: U. S. Geol. Survey Prof. Paper 581-F.

Scott, K. R., and Cole, J. M., 1975, U.S. Atlantic margin looks favorable: Oil and Gas Jour., v. 73, no. 1, p. 95-99.

Sheridan, R. E., 1974, Atlantic continental margins of North America, in Burk, C. A., and Drake, C. L., eds., The geology of continental margins: New York, Springer-Verlag, p. 391-407.

Siple, G. E., 1965, Salt-water encroachment of Tertiary limestones along coastal South Carolina, in Proc. Symposium on Hydrology of Fractured Rocks, Dubrovnik, Yugoslavia, 1965: International Assn. Scient. Hydrology, p. 439-453.

Spivak, J., and Shelburne, O. B., 1971, Future hydrocarbon potential of Atlantic coastal province, in Cram, I. H., Sr. ed., Future petroleum provinces of the United States--their geology and potential: Am. Assoc. Petroleum Geologists Mem. 15, v. 2, p. 1295-1310.

Stephenson, L. W., 1926, Major features in the Atlantic and Gulf Coastal Plain: Washington Acad. Sci. Jour., v. 16, no. 17, p. 460-480.

Stephenson, L. W., 1928, Structural features of the Atlantic and Gulf Coastal Plain: Geol. Soc. America Bull., v. 39, no. 4, p. 887-899.

Swift, D. J. P., and Heron, S. D., Jr., 1969, Stratigraphy of the Carolina Cretaceous: Southeastern Geology, v. 10, no. 4, p. 201-245.

Talwani, M., LePichon, X., and Ewing, M., 1965, Crustal structure of the mid-ocean ridges, 2. Computed model from gravity and seismic refraction data: Jour. Geophys., Research, v. 70, p. 341-352.

Taylor, P. T., Zietz, I, and Dennis, L. S., 1968, Geologic implications of aeromagnetic data for the eastern continental margin of the United States: Geophysics, v. 33, p. 755-780.

Toulmin, L. D., 1955, Cenozoic geology of southeastern Alabama, Florida, and Georgia: Am. Assoc. Petroleum Geologist Bull., v. 39, no. 2, p. 207-235.

Uchupi, Elazar, 1967, The continental margin south of Cape Hatteras, North Carolina: Shallow structure, Southeastern Geology, v. 8, p. 155-177.

Uchupi, Elazar, 1968, Atlantic Continental Shelf and Slope of the United States - Physiography: U.S. Geol. Survey Prof. Paper 529-C, 30 p.

Uchupi, Elazar, 1970, Atlantic Continental Shelf and Slope of the United States -- Shallow structure: U.S. Geol. Survey Prof. Paper 529-I, 44 p.

Uchupi, E. and Emery, K. O., 1967. Structure of continental margin off Atlantic coast of United States. Am. Assoc. Petroleum Geologists Bull., v. 51, p. 223-234.

Uchupi, E., and Tagg, A. R., 1966, Microrelief of the Continental Margin south of Cape Lookout, North Carolina: Geol. Soc. America Bull., v. 77, p. 427-430,

U. S. Geological Survey, 1975, Sediments, structural framework, petroleum potential, environmental conditions, and operational considerations of the mid-Atlantic area: U. S. Geol. Survey Open-File Report 75-61, 143 p.

Wilson, J. T., 1966, Did the Atlantic close and reopen?: Nature, v. 211, p. 676-681.

Woollard, G. P. , W. E. Bonini, and R. P. Meyer, (1957). A Seismic Refraction Study of the Subsurface Geology of the Atlantic Coastal Plain and Continental Shelf Between Virginia and Florida: Wisconsin Univ. Dept. Geology, Geophysics Sect. 128 p.

Zarudzki, E. F. K., and Uchupi, E., 1968. Organic reef alignments on the continental margin south of Cape Hatteras. Geol. Soc. Am. Bull. v. 79, p. 1867-1870.

III. Petroleum Geology

A discussion of the petroleum geology of the Southeast Georgia Embayment should be centered around the main factors which appear to control the occurrence of oil and gas. These factors are: (1) timely development of effective hydrocarbon <u>traps</u> and (2) the depositional environment that controls the formation of <u>source rocks</u> and <u>reservoir rocks</u>.

Because no deep wells have been drilled on the U.S. Atlantic Continental Shelf and because of the paucity of seismic information, these factors can only be judged subjectively from data on wells drilled along the coast and from analogies to similar provinces where the geology is better known.

A logical starting point for the discussion of petroleum geology then will be a brief discussion of the results of drilling along the Atlantic continental margin. This will be followed by a geological comparison of the Southeast Georgia Embayment to other provinces and then by a discussion of potential hydrocarbon traps. Finally, we will attempt to extrapolate well data seaward from coastal wells, southward from the Cape Hatteras area, and northward from the Bahamas in order to comment more specifically on depositional environments by geologic age and their influence on potential source rocks and reservoir rocks.

A. Drilling on the Atlantic Margin

Except for shallow core holes, there have been no wells drilled on the United States Atlantic Continental Shelf. If, however, we consider the Atlantic Continental margin of the United States and Canada, numerous deep wells have been drilled. These include about 100 wells off Canada mostly on the Scotian Shelf; four wells deeper than 4,420 m in the Bahamas; about 50 wells in North Carolina (Richards, 1967) including a 3,064 m deep well drilled on Cape Hatteras only 35 km west of the Continental Slope; 11 wells in South Carolina (Olson, 1973); 148 wells in Georgia (Pickering, 1974); and many wells on the Atlantic and Gulf coasts of Florida.

As to the results of this drilling: to date on the Scotian Shelf, six small discoveries have been made all within 50 km of Sable Island, and mostly from Cretaceous sands associated with salt-dome-related structures (Sherwin, 1975; Schlee and others, 1975). Hydrocarbon shows have been reported in wells in southern Georgia along with a few oil seeps in central Georgia. The J. R. Sealy No. 3 Spindle Top in Seminole County reported oil and gas shows and the Sealy No. 1 Fee in Decatur County tested a small amount of gas. A Carpenter Oil Company well in Coffee County and the Parsons and Hoke No. 1 Spurlin reported oil shows in the form of staining and fluorescence. Seeps and shows have been reported in the vicinity of Scotland in Telfair County where 30° API gravity oil and gas escape from surface sands and clays of probable Oligocene age (Maher, 1971). In northern Florida, the St. Mary's River Oil No. 1 Hilliard Turpentine in Nassau County was reported to have questionable asphaltic staining in the Cedar Keys Limestone (Paleocene), Taylor-age limestone and Atkinson Formation (Upper Cretaceous). On the Gulf coastal province of Florida, eight small fields have been discovered in the South Florida Embayment and large hydrocarbon discoveries have been made in the Jurassic at Jay Field in northwest Florida with reserves estimated in excess of 345 million bbls (McNabb, 1975).

In summary, we see that although discoveries have been made on the Scotian Shelf off Canada and on the Gulf coast of Florida, in the immediate vicinity of the Southeast Georgia Embayment, no commercial production of oil and gas has been established. The lack of production in the South Atlantic coastal province has been explained by many reasons. For coastal North Carolina and Georgia, the sedimentary section is probably too continental. For South Carolina, the basement is at a relatively shallow depth. The reasons for the poor production history for the Atlantic Coast of Florida could be lack of effective porosity and permeability, lack of source beds, lack of sufficient subsurface temperature needed to transform organic molecules into petroleum and even the difficulty of seismic exploration (Reel and Griffin, 1971). Whatever the reasons for the lack of oil and gas production onshore, there seems to be a general consensus that the southern U. S. Atlantic offshore will be better.

B. Geologic Analogies

As noted by Rouse (1971), "it is hard to find a seaboard or offshore producing area comparable to the Atlantic province". The Cape Hatteras-to-Bahamas offshore area has been compared by Olson (1974) to the Tampico Embayment of Mexico and the Saudi Arabian side of the Persian Gulf. Although this comparison is attractive, the justification is questionable. According to Dickinson (1974), "the tremendous accumulation of petroleum in the Persian Gulf province is attributed to its location near the platform edge of a rifted-margin prism in the correct position to catch fluids driven updip out of the prism by partial subduction along a late Cenozoic suture belt". In this respect, the tectonic history of the Southeast Georgia Embayment area is not comparable to the tectonic history of the Persian Gulf. In addition, Halbouty and others (1970), classify the Arabian platform and the Tampico embayment as type IV basins characterized by one or more troughs along the margins of continents that open into "small ocean basins". Whereas the Southeast Georgia Embayment is classified by these authors as a type V basin characterized by a stable coastal basin that represents the end phase of cratonic-rift basins, where sea-floor spreading probably separated or pulled apart the initial rift basins to oceanic proportions.

In terms of hydrocarbon potential, type IV and type V basins differ significantly. According to Halbouty and others (1970), type IV basins "are among the richest hydrocarbon-bearing basins of the world" with an average estimated recovery of oil of approximately 48,000 barrels per cubic kilometre of sediments; in contrast, the average estimated recovery of oil per cubic kilometre of sediment for a type V basin is 4,300 barrels. Halbouty and others (1970) list only one type V basin with giant fields - the Cabinda Embayment of Angola-Congo (Fig. 27). The two giant fields are Cabinda "B" with estimated reserves of 1.2 billion bbls and Emeraude Marin with estimated reserves of 500 million bbls. Both fields are anticlines on the continental shelf and produce from sandstones. Cabinda "B" produces from the Cretaceous and Miocene from an average depth of 3,000 m. Emeraude Marine produces from the Tertiary at depths of about 600 m. Although the Southeast Georgia and Cabinda Embayments are both type V basins, this may not be a valid comparison because the Southeast Georgia Embayment is predominantly a carbonate province with a thin, possible non-prospective Tertiary section.

The Southeast Georgia Embayment might be compared to the Senegal Basin on the northwest coast of Africa. The pre-continental drift reconstruction of Bullard and others (1965) places the Senegal Basin opposite the Southeast Georgia Embayment (Fig. 28). According to Rona (1970, Fig. 1), the opposing continental margins of Cape Hatteras and of Cape Blanc (just north of the Senegal Basin appear symmetrical with respect to late Precambrian, Paleozoic, and Mesozoic tectonic frameworks and early and middle Paleozoic, Mesozoic, and Cenozoic stratigraphic frameworks. Rona (1970) noted that:

> "Mesozoic and Cenozoic mean rates of subsidence and sequences of gross lithology generally correlate between the opposing continental margins and the adjacent ocean basin indicate that the continental margins have behaved as if vertically, as well as horizontally, coupled to the ocean basin."

Map Explanation

LAND GEOLOGY (MODIFIED FROM UMBGROVE (1942) BROWN ET AL (1968) CHURKIN (1969))

- PRECAMBRIAN AREAS FORMING CRATONIC SHIELD AREAS
- PALEOZOIC (HERCYNIAN OR CALEDONIAN) FOLDING
- POST PALEOZOIC FOLDING

OCEAN GEOLOGY (MODIFIED FROM BULLARD (1969) DEWEY AND HORSFIELD (1970) EMERY ET AL (1970))

- CREST OF WORLDWIDE SYSTEM OF RIDGES ALONG WHICH NEW OCEAN [illegible] BEING EXTRUDED (ACCRETING PLATE MARGIN)
- FRACTURE ZONE OF "TRANSFORM" MOVEMENT
- PRESENT POSITION OF EXTRUDED MATERIAL AS DETERMINED BY MAGNETIC STUDIES INCLUDING AGE DATING
- DIRECTION OF UNDERTHRUSTING "PLATE" MOVEMENT

BASIN GEOLOGY

- CRATONIC - SIMPLE SAUCER SHAPED BASINS
- CRATONIC COMPOSITE OR MULTICYCLE BASINS
- CRATONIC - RIFT BASINS
- INTERMEDIATE DOWNWARP TO OCEANIC AREA
- INTERMEDIATE COASTAL GRABEN BASIN
- INTERMEDIATE INTERMONTANE SECOND STAGE TRANSVERSE BASIN
- INTERMEDIATE INTERMONTANE STRIKE BASIN
- INTERMEDIATE UPPER TERTIARY DELTA

[1] *Editor's note:* This map, compiled by H. D. Klemme, is used as a basis for illustrating the basin classification presented herein. It should be noted that the ages shown in the ocean basins have been greatly generalized.

List of Basins

Map Number	Basin Location	Number of Giant Fields
I- 1.	Illinois basin, U S A	1
II- 2	Volga Ural basin U S S R	10
II- 3.	Pechora basin, U S S R.	3
II- 4.	West Siberian basin U S S R.	29
II- 5	North Sea basin, Western Europe	4
II- 6.	Netherlands West German basin	2
II- 7.	Aquitaine basin, France	2
II- 8.	Erg Oriental basin, Algeria	3
II- 9	Fort Polignac basin, Algeria	1
II-10.	Erg Occidental basin, Algeria	1
II-11.	Alberta basin, Canada	5
II-12	Appalachian basin, U S.A.	2
II-13	Powder River basin, U S A.	1
II-14	Uinta basin, U S A	1
II 15	San Juan basin, U S A	1
II-16	Anadarko Ardmore basin, U.S.A.	5
II-17	Oklahoma platform, U S.A.	3
II-18	Permian basin U S A	9
II-19	Szechwan basin, China	2
II-20	Pre Nan Shan basin, China	1
II-21	Tsaidam basin, China	1
II-22	Dzungaria basin, China	.1
II-23.	Great Artesian basin, Australia	2
III-24.	Sirte basin, Libya	13
III-25	Suez graben, Egypt	2
III-26	Red Sea graben, Egypt-Saudi Arabia	2
III-27.	Oman rift, Oman	2
III-28.	Dnepr-Donets basin, U S S R.	5
III-29.	Vilyuy basin, U.S S R.	2
III-30.	Tadzhik basin, U.S S R.	3
III-31.	Bukhara basin, U S S R	6
III-32.	Sungliao basin, China	1
IV-33.	Arabian platform and Iranian basin	56
IV-34.	Pre-Caucasus-Mangyshlak-Turkmen basin, U.S.S R	9
IV-35.	Indus basin, West Pakistan	2
IV-36.	Colville basin, Alaska	1
IV-37.	East Texas basin, U S.A.	2
IV-38	Gulf Coast basin, U.S A.	10
IV-39.	Tampico embayment, Mexico	4
IV-40.	Maturin basin, Venezuela-Trinidad	3
IV-41.	Pre-Carpathian depression, Rumania	1
IV-42	North Borneo basin, Brunei	2
V-43.	Cabinda embayment, Angola-Congo	2
VI-44.	Ventura basin, U.S.A.	1
VI-45.	Los Angeles basin, U.S.A.	4
VI-46.	Maracaibo basin, Venezuela	6
VI-47.	Piura basin, Perú	1
VI-48.	Gippsland basin, Australia	4
VI-49.	Baku basin, U.S.S.R.	7
VII-50.	Sacramento basin, U.S.A.	1
VII-51.	San Joaquin basin, U.S.A.	7
VII-52.	Cook Inlet basin, Alaska	1
VII-53.	Middle Magdalena basin, Colombia	1
VII-54.	Central Sumatra basin, Indonesia	1
VIII-55.	Mississippi Delta, U.S.A.	4
VIII-56.	Niger Delta, Nigeria	5

Fig. 27 Hydrocarbon basin classification with list of basins containing the worlds giant oil and gas fields. (from Halbouty & others, 1970

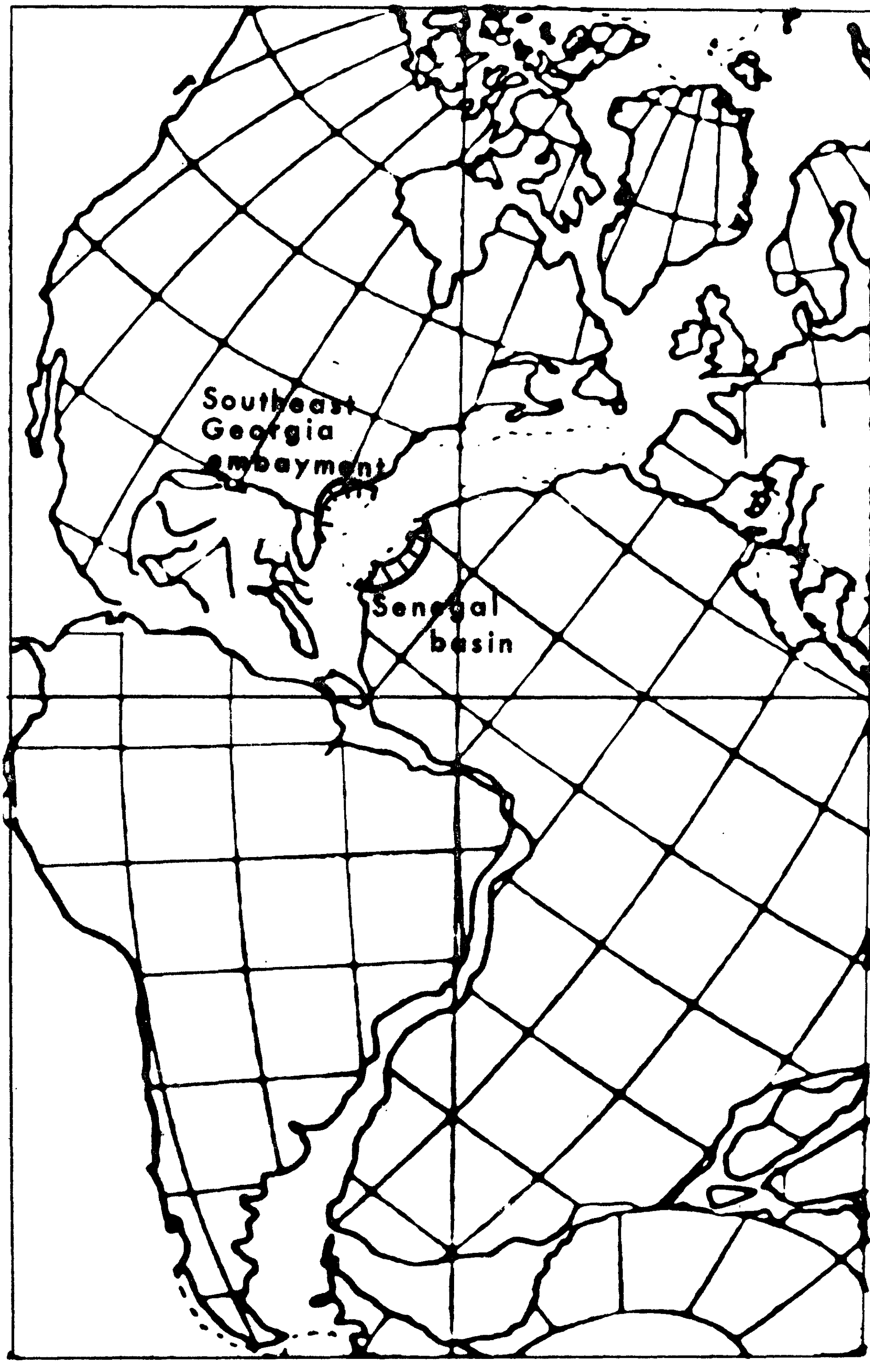
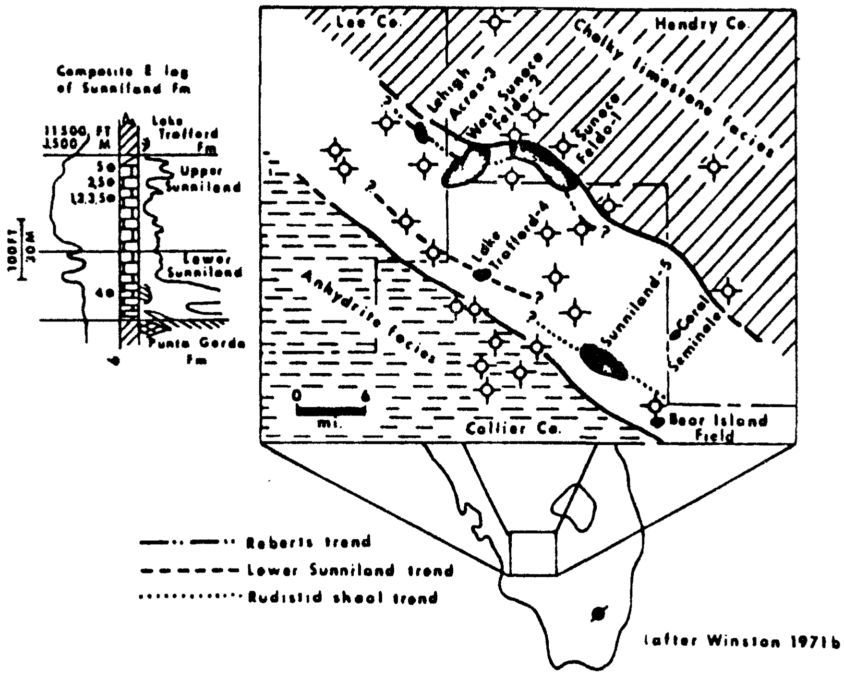


Fig. 28 - Position of continents during Jurassic time (170 m.y.B.P.). (after Briden, Drewry, and Smith, 1974).

Rona (1970) further states that "geologic characteristics relevant to the occurrence of petroleum" might be predicted between the opposing continental margins. If this is indeed true, then we might expect that disappointments in petroleum exploration similar to those experienced in the Senegal Basin (see Ayme, 1965) could occur in the Southeast Georgia Embayment.

On the basis of geographic proximity and similarity of depositional environments, the authors of this paper believe that, in terms of petroleum geology, the most realistic analogy to the Southeast Georgia Embayment is the South Florida Embayment located predominantly in the southern part of Florida between the Peninsular Arch, the Bahama Islands, and Cuba (Fig. 8). The following brief description of the stratigraphy and lithology of the South Florida Embayment is taken mainly from Winston (1971) (Fig. 29).

Approximately 4,500 m of Jurassic(?) through Pleistocene rocks have been penetrated in the South Florida Embayment. The 550 m of Jurassic(?)-Lower Cretaceous (Neocomian) rocks (Fort Pierce Formation) that have been drilled consist of a clastic transgressive facies near the updip wedge-out overlain by limestone and dolomite. Lower Cretaceous rocks (approximately 1,800 m thick) consist of numerous imcomplete cycles of limestone dolomite, and anhydrite (Fig. 30). Effective porosity is mainly in the dolomite and only occasionally in the limestone. Upper Cretaceous rocks (about 800 m thick) are chalk, except near the southeast coast of Florida and toward the Bahamas where dolomite (Card Sound Dolomite) becomes the principal lithology. Tertiary rocks (approximately 1,500 m thick) are chiefly limestones and dolomite with numerous anhydrite



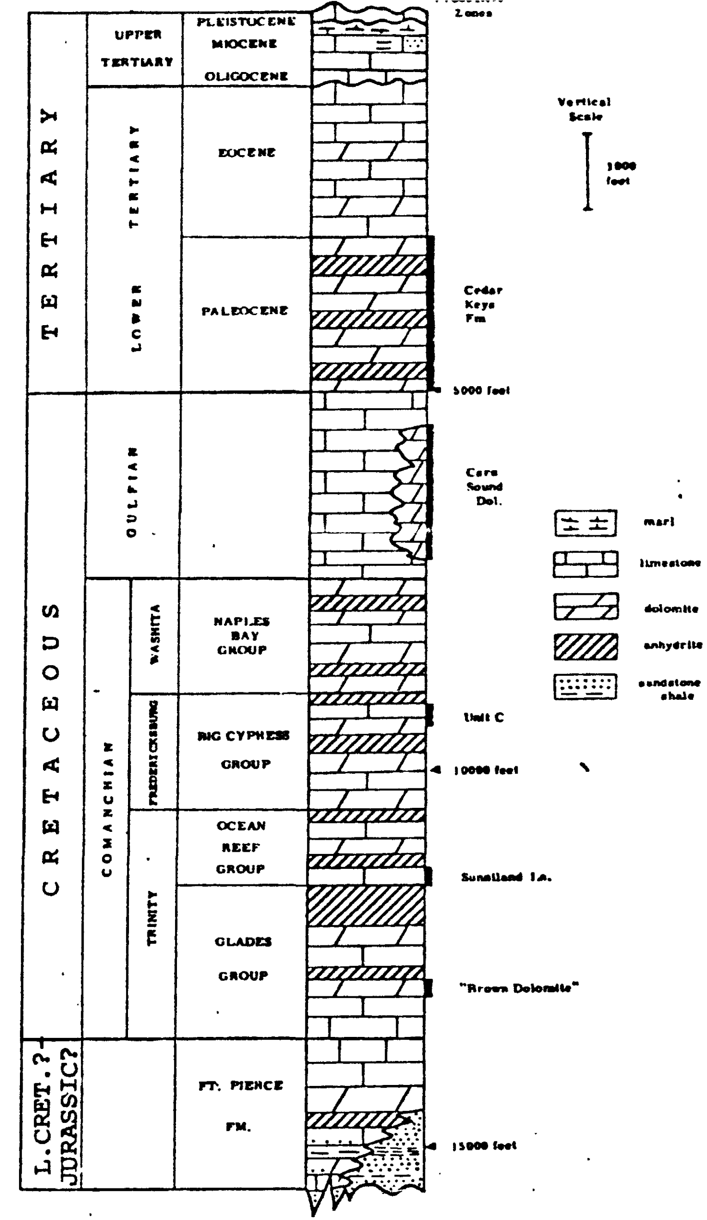
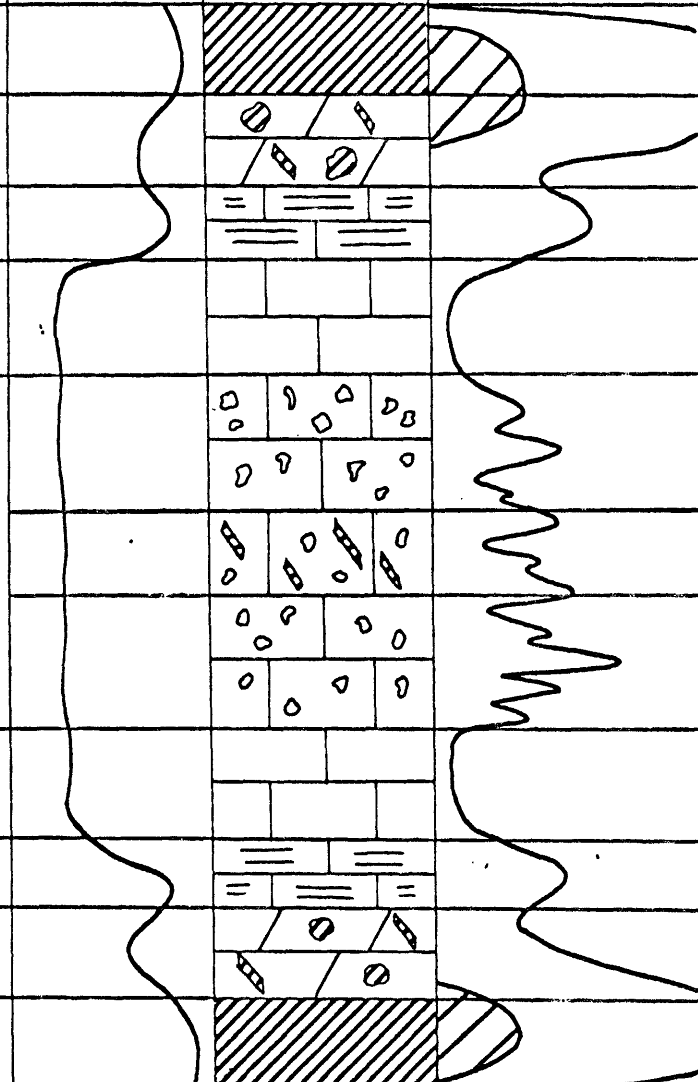


Fig. 29 - Oil fields in South Florida Embayment and generalized geologic column of South Florida Embayment. (left from Meyerhoff and Hatten, 1974, and right modified from Winston, 1971).



RESERVOIR CHARACTER	SP	LITHOLOGY	RESISITIVITY	BED NO.	COMPOSITION	DESCRIPTION	CAN BE:
seal				10	anhydrite	bedded; any color	micritic limestone
rarely porous				9	dolomite	microcrystalline with anhydrite crystals or nodules	limestone
seal				8	limestone	micrite, gray, argillaceous	dolomite
usually impermeable to oil				7	limestone	micrite or micrograined calcarenite, cream, Miliolidae; chalky porosity	dolomite
effective porosity				6	limestone	calcarenite, tan; skeletal, oolite, pellet or foraminiferal grains; intergranular or vug porosity	euhedral dolomite
				5	limestone	calcarenite with brown anhydrite crystals intergranular or vug porosity	euhedral dolomite
				4	limestone	calcarenite, tan; skeletal, oolite, pellet or foraminiferal grains; integranular or vug porosity	euhedral dolomite
usually impermeable to oil				3	limestone	micrite or micrograined calcarenite, cream, Miliolidae; chalky porosity	dolomite
seal				2	limestone	micrite, gray, argillaceous	dolomite
rarely porous				1	dolomite	microcrystalline with anhydrite crystals or nodules	limestone
seal				10	anhydrite	bedded; any color	micritic limestone

Fig. 30 - A schematic Comanchean (Lower Cretaceous) lithologic cycle (from Winston, 1971).

Eight small fields have been discovered in the South Florida Embayment (Fig. 29), none of which will recover more than 15-35 million bbls of oil (Meyerhoff and Hatten, 1974). The cumulative production was approximately 28 million bbls of oil by the end of 1972. Production is from several facies of porous Lower Cretaceous (Trinity) carbonate rocks at a depth of approximately 3,550 m (Winston, 1971). Producing traps in the South Florida Embayment are chiefly stratigraphic, however, two small closed local structures with low relief have been outlined by drilling (Winston, 1971).

A comparison of the above rock lithologies from the South Florida Embayment with those of the Southeast Georgia Embayment (see stratigraphic section of this report), indicates that both embayments have had similar depositional environments--shallow water carbonates with some anhydrites (Lower Cretaceous and Paleocene) which were deposited on a slowly subsiding shelf without major interruptions from Jurassic through Upper Cretaceous time. Both embayments even have the same relative thickness of stratigraphic units--a thick Lower Cretaceous section with a relatively thin Upper Cretaceous section. The differences in the stratigraphy of the two embayments are: (1) the Tertiary section of the South Florida Embayment is somewhat thicker, (2) whereas the Upper Cretaceous rocks are chiefly chalk in the South Florida Embayment, these age rocks are chiefly limestones with some clastics in the Southeast Georgia Embayment and (3) there is probably less anhydrite in the Paleocene section of the Southeast Georgia Embayment than in similar age rocks of the South Florida Embayment.

In summary, the depositional environment and tectonic history of both the Senegal Basin and especially the South Florida Embayment appear to be similar to the Southeast Georgia Embayment; the hydrocarbon potential of the Southeast Georgia Embayment and the South Florida Embayment may be similar. The following discussion on potential traps in the Southeast Georgia Embayment could equally be applicable to the South Florida Embayment.

C. Potential Hydrocarbon Traps

Hydrocarbon traps can be classified into three categories: (1) stratigraphic traps, (2) structural traps, and (3) combination traps--a combination of both structural and stratigraphic traps. Most producing traps are probably of the third type. Stratigraphic traps will probably be numerous in the Southeast Georgia Embayment, however, drape structures and low relief anticlines could provide substantial structural traps.

1. Stratigraphic Traps

Stratigraphic traps associated with facies changes. The facies change between downdip marine carbonates and updip marginal marine clastics may provide potential stratigraphic traps. This type of trap could occur along depositional strike as the predominantly carbonate section in the Bahamas grades northward into the predominantly clastic section of the Carolinas. Probably the best location to explore for these purely stratigraphic traps would be off the coast of southern Georgia.

Stratigraphic traps in carbonate sediments. Significant lateral variations in porosity and permeability may occur within the thick marine carbonates of Jurassic and Cretaceous age. Winston (1971) discusses this type of stratigraphic mechanism in the South Florida Embayment.

> "Another oil productive facies (Roberts Zone) [Sunniland Limestone] consists of very fine-grained skeletal limestone containing intergranular porosity. Within the favorable trend, this lithology becomes progressively finer-grained updip until low permeability prevents further oil migration. This change in pore size, and the related loss of permeability to oil forms the trap at Felda field and influences entrapment at West Felda field."

Updip pinchouts. Updip pinchouts of Jurassic and Cretaceous clastic units, especially in the near-shore area off the coast of South Carolina and North Carolina, offer possibilities for stratigraphic traps.

Reefs. Carbonate banks and reef traps may be developed on the Florida-Hatteras Slope and on basement highs, such as the Cape Romain anomaly (Plate 1).

Unconformities. Unconformities have been suggested as possible hydrocarbon traps in the Southeast Georgia Embayment (Maher, 1971; Spivak and Shelburne, 1971; Olson, 1973). According to Maher (1971):

> "Numerous unconformities subdivide the Coastal Plain deposits, but only a few extend far enough downdip and laterally to be important as avenues of migration or loci of hydrocarbon traps. However, these few may have provided excellent opportunities for the accumulation of petroleum in both secondary stratigraphic and combination traps."

There are possible unconformities separating sequences assigned to Late Jurassic or Early Cretaceous (Neocomian), Trinity(?), Fredericksburg (?), and Washita(?) age rocks which may provide traps (Maher, 1971). Maher (1971) has suggested the seaward nose of the Cape Fear Arch as a possible place for an Upper Cretaceous-Lower Cretaceous unconformity trap.

2. Structural Traps

Drape structures. Significant petroleum traps in the Southeast Georgia Embayment could be structural highs associated with draping and differential compaction over basement blocks. We have suggested earlier in this report that early Jurassic sediments in the Southeast Georgia Embayment were deposited on a highly block faulted basement surface. Such structures would have provided "timely" traps for hydrocarbons generated in Jurassic or Lower Cretaceous age rocks. Drape structures over basement blocks have provided substantial petroleum traps in other parts of the United States such as the giant Panhandle-Hugoton Field of Texas, Oklahoma, and Kansas (Pippin, 1970).

Anticlines not associated with basement rocks. Low relief anticlines should not be overlooked as potential traps in the Southeast Georgia Embayment. Although difficult to locate without detailed seismic coverage, this type of trap could be significant. In the Sunniland field of Florida, petroleum is presently being produced from low relief anticlines with as little as 11 m of closure (Meyerhoff and Hatten, 1974).

Fault traps. Continued movement of basement blocks during Jurassic and possibly during Lower Cretaceous time may have resulted in fault traps. If such fault traps exist, they are probably in the lower part of the sedimentary section.

D. Potential Source Rocks and Reservoir Rocks by Geologic Age

1. Paleozoic

Non-metamorphosed Paleozoic sandstones and shale have been penetrated in southern Georgia and northern Florida, and may be present immediately offshore in the vicinity of the Suwannee Channel. Meyerhoff and Hatten (1974) give three reasons why the Paleozoic section is a poor exploration target:

> "(1) The section consists of Early Ordovician-Middle Devonian marine strata which have been exposed for a great period of time--from Middle Devonian until Late Cretaceous time. Much erosion took place during the 250 m.y. time of exposure, and most hydrocarbons that might have been trapped probably would have escaped, (2) the section is well indurated, thin, and contains few porous sandstone beds, (3) the sandstone beds present are very fine-grained orthoquartzites, too tight to produce in commercial amounts (Bridge and Berdan, 1952; Braunstein, 1958; Carroll, 1963; Meyerhoff, 1967; Rainwater, 1971)."

However, Meyerhoff and Hatten (1974) and Rainwater (1971) think that Paleozoic prospects may be better in the Bahamas and beneath the continental shelf because in these areas the Paleozoic rocks were probably buried during most of their history.

2. Triassic

Most Triassic rocks in the eastern United States have little hydrocarbon generating potential. The continental shelf should prove no different. The main reason for this is that Triassic rocks were probably deposited in a continental to brackish water oxidizing environment in which most of the available organic material was oxidized before burial. However, some humic and lignitic material that escaped oxidation might have generated small quantities of gas.

According to Rainwater (1971), it is possible that Triassic grabens may contain porous sandstone beds which are structurally or stratigraphically sealed, even though Marine and Siple (1974) have described the Triassic rocks of the Dunbarton basin of the South Carolina-Georgia Coastal Plain as having "extremely low permeability".

3. Jurassic

Upper Jurassic-Lower Cretaceous sediments in excess of 4,000 m are expected on the continental shelf of the Southeast Georgia Embayment out to the 600 m water depth (Fig. 24). The Jurassic section is a prolific producer in the Gulf Coast and in the giant Jay Field in northwest Florida. Maher (1971) believes that porous dolomitic and oolitic limestone beds of Jurassic age may occur at depth offshore; if he is correct, these beds could be potential reservoir rocks. According to Maher (1971), the Esso-Hatteras Light No. 1 well penetrated 280 m of Late Jurassic rocks which Brown, Miller, and Swain (1972) has described as predominantly coarse sand and shale. Three deep wells in the Bahamas penetrated Late Jurassic (Portlandian or Early Cretaceous (Neocomian) rocks. These rocks were shallow-water carbonates and anhydrites in the Cay Sal IV-1 well, reef and backreef carbonates in the Long Island-1 well, and Jurassic carbonates overlain by 328 m of black, marine, Jurassic shale in the Great Isaac-1 well (Meyerhoff and Hatten, 1974).

The "black, marine, Jurassic shale" reported from the Great Isaac-1 well may be stratigraphically equivalent to the 293 m of Early Cretaceous black clay that was cored in DSDP Hole 101 (Cores 4-8), 450 km west of the Great Isaac-1 well (Figs: 31 and 32). Cores 4-8 have been dated as

Fig. 31 - Physiographic diagram of a portion of the western North Atlantic (Heezen and Hays, 1962) with locations of Leg II drilling sites (from Hollister and others, 1972).

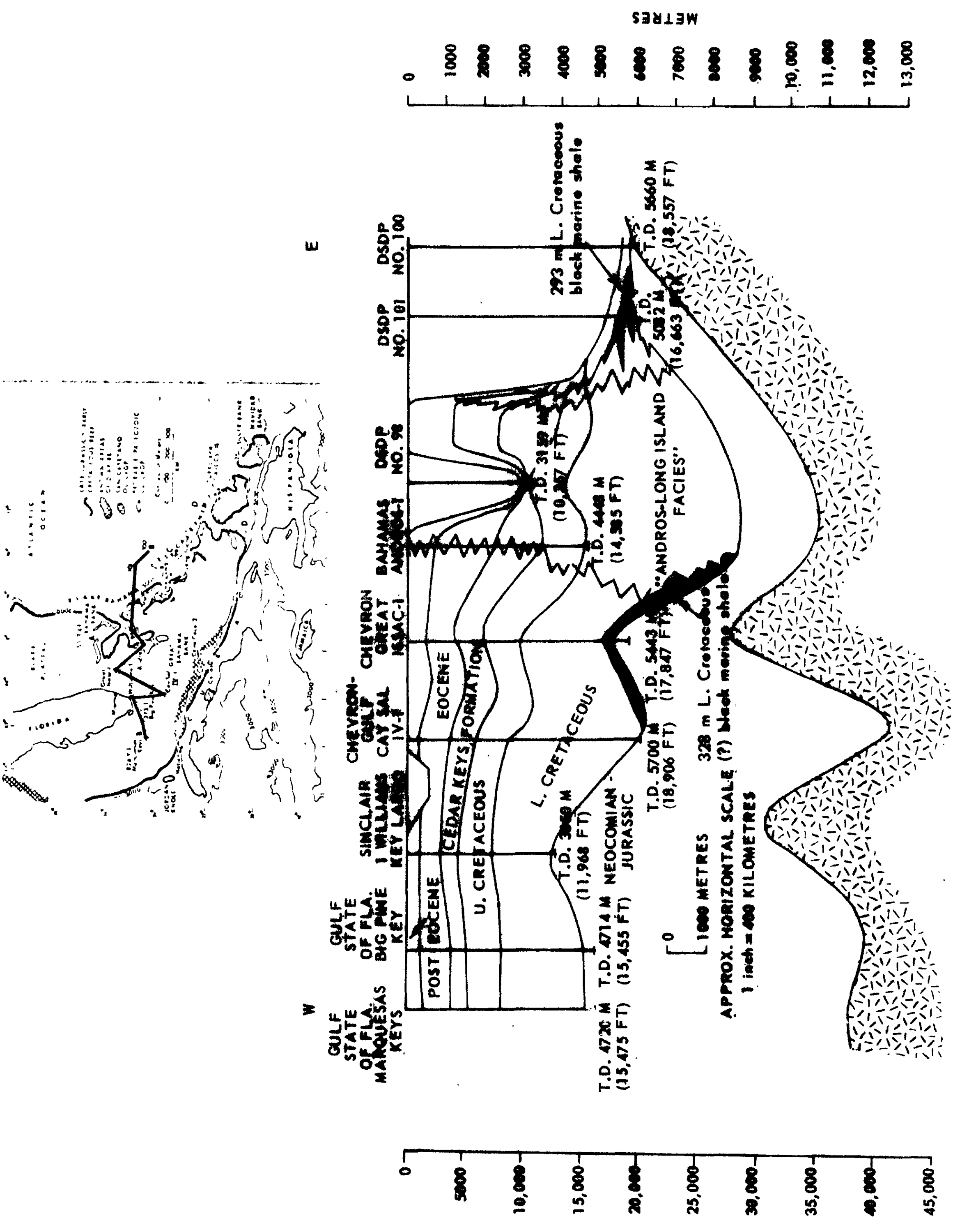


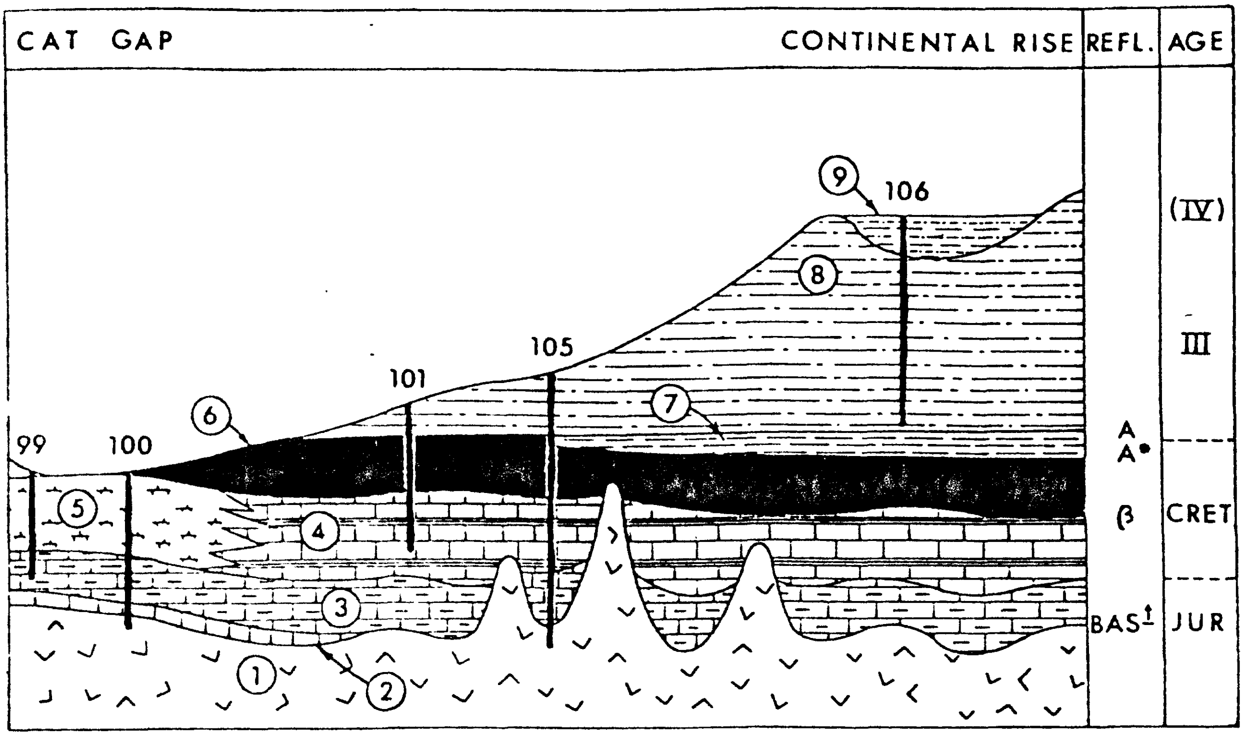
Fig. 32 - Diagrammatic east-west cross section from Florida Keys to Blake-Bahama escarpment showing Lower Cretaceous possible source rock. (modified from Meyerhoff and Hatten, 1974).

Albian through Neocomian by Hollister and others (1974), and according to these authors similar Lower Cretaceous black clays have been cored in DSDP Hole 105 (Fig. 33). The following conclusions concerning the depositional environment during late Neocomian time based on DSDP Hole 101 are from Hollister and others (1972):

> "The preservation of the extremely abundant organic matter in Cores 6 through 8 indicates that sea floor stagnation at Site 101 became even more prevalent during late Neocomian time. The black Neocomian clays in Core 8 contain bedded siderite with radiolarian molds which may indicate that the black, organic-rich and iron oxide-rich sediments were deposited beneath an open marine environment. The general absence of calcareous nannoplankton and the occurrence of abundant siderite may be due to the solution of calcium carbonate in low pH environment resulting from the accumulation of organic debris under anaerobic conditions."

Although at this time we are concerned primarily with the petroleum potential of the offshore portion of the Southeast Georgia Embayment, comments by Meyerhoff and Hatten (1974) on the hydrocarbon potential of the nearby Little Bahama Bank should be included:

> "The seismic data from this area are of such high quality, in contrast to the poor data from other areas of the southern Florida-Bahamas-northern Cuba area, that it is probable that (1) structures can be delineated here with some precision, and (2) a terrigenous clastic sequence of rocks, possibly an extension of the strata known to be present in the Southeast Georgia Embayment, underlies the Little Bahama Bank area. This favorable area may extend into the northermost part of Great Bahama Bank. Part of the reason for the better [seismic] reflection may be that the older part of the section (Jurassic, Paleozoic) rises closer to the surface from south to north. In any case, it is our opinion that the number of objectives is greatest in the Little Bahama Bank area; that the variety of reservoirs is likely to be greatest (sandstone, carbonate); that the possibilities for entrapment are greatest; and that depth of drilling to the shallowest and deepest objectives is least."



1. Basalt
2. Callovian -?- Oxfordian greenish-gray limestone
3. Late Jurassic red clayey limestone
4. Tithonian-Neocomian white and gray limestone
5. Tithonian-Neocomian calcareous ooze and chalk
6. Cretaceous black clay
7. Late Cretaceous -?- Early Tertiary multicolored clay
8. Tertiary hemipelagic mud
9. Quaternary terrigenous sand and clay

Fig. 33 - Synthetic sketch based on data from drilling and seismic profiler records in the North Atlantic basin during JOIDES Leg II. Note (6.) Cretaceous black clay, (from Lancelot, Hathaway, and Hollister, 1972).

4. Lower Cretaceous

With the exception of the recent Jurassic discoveries in northwest Florida-southwest Alabama, the Lower Cretaceous section contains the only producing strata in the immediate area and is expected to offer the best possibility for hydrocarbon entrapment in the offshore Southeast Georgia Embayment. There are three main reasons for this: (1) availability of seals to prevent the vertical migration and possible loss of hydrocarbon to the surface, (2) good reservoir rocks, and (3) possible hydrocarbon source rocks.

The warm shallow waters of the Early Cretaceous seas were conducive to anhydrite deposition on the stable southeast Atlantic continental shelf from Cape Hatteras to Cuba. Minor amounts of Lower Cretaceous anhydrite have been reported in the Esso No. 2 North Carolina well (Spangler, 1950) and the Hatteras Light-1 well (Brown, Miller and Swain, 1972), and alternate beds of Lower Cretaceous limestone, dolomite, and anhydrite have been reported in the Chevron Great Isaac-1 well (Meyerhoff and Hatten, 1974). Seaward from the Georgia coast and between these two wells, there is a good chance of encountering Lower Cretaceous anhydrite which would make an excellent hydrocarbon seal. Thin layers of shale would also make adequate seals. Although great thicknesses of Lower Cretaceous shale are not expected, not much is needed. It is worth noting that only 30 m of shale over the crest of Burgan field, Kuwait, seals 62 billion bbls of oil (Kamen-Kaye, 1970).

The downdip Lower Cretaceous carbonates are expected to have adequate porosity and permeability. Thirty-seven porosity and permeability measurements were made for Lower Cretaceous rocks from the Hatteras Light-1 well (Spangler, 1950; Maher, 1971). The average porosity and permeability based on these measurements are 26.1 percent and 487 millidarcys, respectively. Within Sunniland field, the porosity of the producing zone ranges from 15 to 24.5 percent and permeability averages 312 millidarcys parallel to the bedding and 84 millidarcys perpendicular to the bedding (Pressler, 1947). Within the Lower Cretaceous Sunniland Limestone near Miami, porosity ranges from 6.5 to 23.3 percent and permeability between 0 and 2.3 darcys (Meyerhoff and Hatten, 1974). Cavernous porosity has been reported in a well drilled on Andros Island, Bahamas (Meyerhoff and Hatten, 1974) and the Esso No. 1 Hatteras Light (Maher, 1971).

If it extends beneath the shelf in the Southeast Georgia Embayment area, the thick, black marine Jurassic(?)-Lower Cretaceous shale penetrated in the Great Isaac well and DSDP Holes 101 and 105 (Figs. 32 and 33) might provide an excellent source rock for overlying permeable Lower Cretaceous dolomites and limestones. Lancelot, Hathaway, and Hollister (1972) have discussed the organic matter of this shale from DSDP Holes 101 and 105:

> "The total organic carbon content, as determined on 34 samples from this part of the section, shows several values around 3 percent. One value from Core 9 of Site 105 reaches 14.8 percent. Concentration of carbon was high enough so that one sample could be burned aboard the ship. Detailed analyses of the organic matter from these carbonaceous clays indicate relatively low contribution from plant-derived organic debris."

The large geographic separation (over 1,000 km) between DSDP Hole 101 and 105 suggest broad areal distribution of these Albian through Cenomanian organic-rich clays in the western North Atlantic. Whether these beds exist beneath the shelf can only be answered by deep drilling. Even if these beds do not extend under the shelf of the Southeast Georgia Embayment, by appeal to long distance migration, they could still be a potential source of petroleum for shelf reservoirs. It should be added that the quantity of organic-carbon content of a rock by itself does not assure its source rock properties (Fuloria, 1967)--the convertibility of the organic matter to petroleum and the efficiency of oil expulsion are also important. The authors are not aware of evidence that indicates that these Lower Cretaceous deep-water clay deposits of the Western North Atlantic are associated with any commercial accumulations of hydrocarbons. Other potential Lower Cretaceous source rocks include organic rich carbonate muds which were not oxidized before burial. Winston (1971) has stated that the Lower Cretaceous Sunniland Limestone has good carbonate source rocks. According to Rona (1973), the sedimentation rate during the Lower Cretaceous was relatively fast on the southeastern continental margin of North America and northwestern Africa; hence hydrocarbon percursors may not have been exposed to oxidizing conditions for extended periods of time. Preliminary work by Fischer and Arthur (1975) suggests that on a world-wide basis, the Lower Cretaceous may not have been a period of extensive marine sediment oxidation. In their discussion at the 1975 AAPG-SEPM annual meeting, Fischer and Arthur presented data which indicate that the Albian, and to a lesser degree, the Aptian, was a time of deposition of extremely non-oxidized sediments. It may have been a time of reduced oceanic circulation, or a time when high rates of organic productivity overwhelmed the available oxygen. In connection with the latter, flourishing marine organisms could have created their own bottom-reducing conditions (see Hedberg, 1964, p. 1770). In general, the data of Fischer and Arthur suggest that this was a time of warmer temperatures, high faunal diversity, and heavy carbonate carbon isotopes.

Mattick and others (1974) have speculated on the possibility of Lower Cretaceous reef reservoirs occurring along the shelf edge in the Baltimore Canyon trough. Seismic evidence indicates that reefs could occur along the shelf edge in the Southeast Georgia Embayment area also. The importance of reefs in petroleum accumulation apparently is due to the fact that they furnished timely, high porosity reservoirs near favorable source areas (Hedberg, 1964). In this case, shelf edge reefs might be potential reservoirs, not only for petroleum generated on the shelf, but also, if we appeal to the concept of long distance migration, for petroleum generated on the slope. In this connection, the suggestion of Emery (1963), that sediment slides to the foot of the slope might create rich source material, should be considered. Conversely, however, Meyerhoff and Hatten (1974) are not impressed with the reservoir potential of shelf edge reefs off Florida. According to these authors, the Atlantic Ocean has been able to flush the exposed reefs of the Bahamas area since early in its history. Whether Lower Cretaceous reefs could or could not have generated petroleum, is open for debate. As to reef generation in general, Rainwater (1971) has stated:

> "Though enormous quantities of organic material are generated in reefs, most of it probably is oxidized. Only in the adjacent backreef protected area is there

> preservation of both indigenous and reef organic matter. If this material is converted to petroleum and is squeezed out of the fine-grained back-reef sediment into the porous reef rock, it will not be trapped unless the reef is covered by impervious beds such as anhydrite or clay. Inasmuch as conditions favorable for anhydrite deposition are not likely to develop quickly in a barrier-reef environment, the most likely seal is clay. Only during regressive periods of abundant supply of terrigenous sediments from bordering lands are the reefs likely to be smothered with clay and silt."

Lower Cretaceous shelf-edge reefs offshore from Georgia might be the most likely place in the U. S. South Atlantic for development of the conditions outlined by Rainwater. During Late Cretaceous time, silts and clays could have been transported to the continental slope by currents through the Suwannee Channel and could have sealed the Lower Cretaceous reefs. In addition, alternating marine regressions and transgressions during the lower Upper Cretaceous (Rona, 1970) could have provided a favorable environment to deposit clay and silt over the reefs.

Lower Cretaceous fore-reef deep-water shales and/or limestones of the U. S. Atlantic coast might have been capable of generating hydrocarbons, similar to conditions Meyerhoff and Hatten (1974) have suggested for the Golden Lane Fields of Mexico. Deep-water Early to Middle Cretaceous Tamabra Limestone and Tamaulipas Limestone of the Tampico Embayment of Mexico (Coogan and others, 1972) possibly contained the original organic materials that were transformed into petroleum for the giant reserves in the Golden Lane Fields which produce from the shallow water reef limestone of the El Abra Formation (Meyerhoff and Hatten, 1974).

5. Upper Cretaceous

Very stable shallow-water shelf conditions persisted throughout most of Upper Cretaceous time. Sedimentation rates were much slower than during Lower Cretaceous time. These two factors are not conducive to hydrocarbon generation. Organic matter that may have been deposited, either land derived or marine, was probably oxidized before it could be preserved. As noted by Ernst (1974):

> "...sediments (carbonates, orthoquartzites, etc.) on continental shelves of the Atlantic type accumulate in an environment that promotes oxidation and solution of unstable lithic, biogenic, and mineral grains and the formation of secondary quartz and carbonates".

Meyerhoff and Hatten (1974) take a negative view regarding the hydrocarbon potential of Late Cretaceous rocks, at least in the Bahamas sediment, because "there are no seals in evidence to protect a reservoir, once formed." They did indicate, however, that this may not be true in the Little Bahama Bank area where they believe terrigenous clastic rocks may extend upward into the Tertiary.

Rainwater (1971) summarized the petroleum potential of the Upper Cretaceous as follows:

> "It appears that the tectonic and sedimentational history of peninsular Florida and adjacent continental shelves during the Late Cretaceous time was not favorable for oil and gas generation. Though many porous carbonate rocks and sandstones are present, they are not likely to contain petroleum accumulations."

Maher (1971) is more optimistic in his assessment of Upper Cretaceous rocks. He believes that thick marine source rocks may be expected beneath the shelf and writes:

> "Upper Cretaceous rocks have good possibilities for oil and gas production beneath the continental shelf...".

6. Tertiary

The Tertiary strata of the Southeast Georgia Embayment offer little hope for commercial quantities of petroleum. There is a lack of sealing beds within the Tertiary (Meyerhoff and Hatten, 1974; Cramer, 1974). The section is less than 1,100 m thick (Scott and Cole, 1975), contains fresh-to-brackish water, and crops out in part along the continental shelf and Blake Plateau. Any indigenous oil that may have formed has probably been flushed out by fresh waters.

Reported shows of oil or gas in the Tertiary of Florida are rare (Winston, 1971). In three JOIDES holes drilled offshore Jacksonville, "oil odors and asphalt specks" have been reported (Schlee and Gerard, 1965, Emery and Zarudski, 1967). Hollister and others (1972) reported "a substantial amount of gas, consisting primarily of methane with a trace of ethane" for DSDP Hole 103 drilled on the southwest flank of the Blake-Bahama Outer Ridge (Fig. 31).

E. Estimate of Undiscovered Recoverable Oil and Gas Resources

The proposed lease sale area is included essentially within two principal provinces of the Atlantic Coast Region evaluated recently in a U.S. Geological Survey study of the Nation's resources by the Resource Appraisal Group (Miller, and others, 1975). In that recent study boundaries at water depths less than 200 m may be considered to approximate those of the South Atlantic Shelf Province and portions at greater water depths (200 - 600 metres) to fall within the Blake Plateau Province.

The proposed lease sale area comprises approximately 98,000 square kilometres.

1. Appraisal Procedures

The appraisal procedure consists of three principal phases: 1) data acquisition and summation; 2) individual and collective appraisals of the concerned provinces, using as references volumetric-yield procedures, basin analysis, Hendricks potential area categories, and other published appraisals; 3) computer fitting of lognormal curves to the high, low and modal values of the Resource Appraisal Group's assessment to compute the probability distribution for each province, and related statistical treatment.

Data assembly. These estimates of undiscovered oil and gas resources are based upon data obtained through geologists of the U.S.G.S., published references, and unpublished U.S.G.S. materials. A full treatment of the geologic aspects is given in previous sections of this report.

Geologic data from the South Atlantic and Blake Plateau Provinces were summarized on data formats (see Appendix I) which contained not only an inventory of the information base but a quantification of the summarized information needed to characterize the basic geology. Approximately 85 basic categories of information were tabulated.

The province data formats and supporting data were reviewed by the Resource Appraisal Group and other U.S.G.S. personnel. Special emphasis was placed upon accuracy of areal determination of provinces by planimetry, determination of thickness and volumes of sediments in each of the provinces, and selection of yield values by analog basins or provinces. One page province summary sheets were compiled for the South Atlantic and Blake Plateau provinces to facilitate data handling (Form 3, Appendix I).

Initial Appraisal. All of the geological data summary reports and total production and reserve information for these provinces were subjected to a series of resource appraisal methods.

A series of geological and volumetric-yield analog procedures was applied to each province to determine a range of hydrocarbon yield values. Geologic analogs, which were limited to the United States and Canada, can be considered only approximate, especially those analogs where volumetric yield data was not available.

Those analogs selected for use in the South Atlantic Shelf Province consisted of the dominantly carbonate sediment filled Salina Basin, the mixed clastic carbonate provinces of Alberta and Denver basins, and the

Table 1. Resource appraisal - province estimate - U.S. South Atlantic Continental Shelf (0-200m)

FORM # 4-A

RESOURCE APPRAISAL --PROVINCE ESTIMATE

Region Atlantic Coast Offshore - [illegible] RAG No. ____
Province So. Atlantic Continental Shelf (0-200m)
Province Area 39,347 (mi^2) Province Volume: 56,[illegible] (mi^3)

PRODUCTION AND RESERVES	OIL (Bill. BBLS)	NGL (Bill. BBLS)	GAS (TCF)
Cumulative Production:	0	0	0
Identified Reserves:			
Measured Reserves			
Indicated Reserves			
Inferred Reserves			
Total (Cumulative & Identified):	↓	↓	↓

UNDISCOVERED RESOURCES Resource Appraisal Methods (1 Denver, 2 Alberta, 3 Texas-La Gulf Coast, 4 Texas Coast, 5 Salina, Ks)	OIL (Billion Barrels) In-Place	OIL Total Rec. Resource	OIL Undiscovered Rec. Resource	NGL (Billion Barrels) In-Place	NGL Total Rec. Resource	NGL Undiscovered Rec. Resource	GAS (Trillion Cubic Feet) In-Place	GAS Total Rec. Resource	GAS Undiscovered Rec. Resource
METHOD I--VOLUMETRIC-ANALOG ~~Analog 1: Analog 2:~~	1	—	1.345	—	—	—	—	—	0.347
Yield Factors: 1: —; 2; 3; 4; 5	2	—	3.710	—	—	—	—	—	[illegible]7.766
Oil: 24,000; 66,200; 42,711; 26,400; 19,200 X.	3		2.3[illegible]4			0.650			[illegible].797
Gas: 6.2; 317.00; 371.056 [illegible]; 274.60 [illegible]; 500	4		1.4[illegible]			0.545			5.330
~~Rec. Factors~~ [illegible]: ; 11,606; 9,730; 2.	5		1.07[illegible]						[illegible].230
METHOD IV: HENDRICKS' CATEGORIES Dis.-Rec. Factors: Category #: 2	34.847		6.96[illegible]	2.789		1.115	94.541		[illegible]8.816
25/50/50 3	8.717		1.747	0.697		0.229	17.424		[illegible].369
Category #: 4	3.485		0.[illegible]97	0.349		0.139	8.712		2.[illegible]25
5	—		—	—		—	0.871		[illegible]
METHOD: (~~Peninsular Florida~~ - Volumetric) Yield Factors: Oil: [illegible] Gas: 294 NGL: 57			0.191			0.103			0.15[illegible]
Prod.Area/Unexpl.Area: [illegible]			0.159			0.035			[illegible]8
DOCUMENTED RESOURCE APPRAISAL ESTIMATES:									
AAPG, Memoir 15, 1971									
CRAMER (1974) entire Georgia Coastal Plain			0.250						[illegible].7
National Petroleum Council Estimates, 1973 (Atlantic Coast [illegible] 33°, 0-600')	0.250	(NPC 0.333 OE 0.083)							
ANOGRE Estimates									
OTHER									

Posted by KC-GLD Date ____ Approved [illegible] Date ____

Table 1. Resource appraisal - province estimate - U.S. South Atlantic Continental Shelf (0-200m) (continued)

Region: [illegible]
Province: [illegible] Continental Shelf (0-200m)
Province Area: 33,2[illegible] (mi²)
Province Volume: [illegible] (mi³)

RESOURCE APPRAISAL --PROVINCE ESTIMATE

PRODUCTION AND RESERVES	OIL (Bill. BBLS)	NGL (Bill. BBLS)	GAS (TCF)
Total (Cumulative & Identified)	0	0	0

REGIONAL REPRESENTATIVE Resource Appraisal	OIL (Billion Barrels) In-Place	OIL Total Rec. Resource	OIL Undiscovered Rec. Resource	NGL (Billion Barrels) In-Place	NGL Total Rec. Resource	NGL Undiscovered Rec. Resource	GAS (Trillion Cubic Feet) In-Place	GAS Total Rec. Resource	GAS Undiscovered Rec. Resource
a. Reasonable Min. (95% "at least")			0.10						0.05
b. Reasonable Max. (5% "at least")			1.00						0.50
c. Most Likely			0.40						0.32
d. Expectation: (a + b + c)/3			0.50						0.42
Method:									
Rec.--Yield Factors:									
Classify: Hypothetical ___ Speculative ___			30%						

Posted by GLD Date ______

RESOURCE APPRAISAL GROUP Recommended Appraisal:	OIL In-Place	OIL Total Rec. Resource	OIL Undiscovered Rec. Resource	NGL In-Place	NGL Total Rec. Resource	NGL Undiscovered Rec. Resource	GAS In-Place	GAS Total Rec. Resource	GAS Undiscovered Rec. Resource
a. Reasonable Min. (95% "at least")			0.4						0.3
b. Reasonable Max. (5% "at least")			1.5						2.0
c. Most Likely			1.0						0
d. Expectation: (a + b + c)/3			(0.97) 0.39						(1.9) 0.76
Method:									
Rec.--Yield Factors: 0.40 for Oil and Gas									
Marginal Probability:									

Posted by GLD Date ______ Approved ______ Date ______

Table 2. Resource appraisal - province estimate - Blake Plateau (combined 200-2500m)

FORM # 4-A

RESOURCE APPRAISAL --PROVINCE ESTIMATE

Region *Atlantic Coast Offshore* RAC No. ______
Province *Blake Plateau (combined 200-2500 m)*
Province Area *50,519* (mi²) Province Volume *201,313* (mi³)

PRODUCTION AND RESERVES	OIL (Bill. BBLS)	NGL (Bill. BBLS)	GAS (TCF)
Cumulative Production:	0	0	0
Identified Reserves:			
Measured Reserves			
Indicated Reserves			
Inferred Reserves			
Total (Cumulative & Identified):			

Resource Appraisal Methods: *1. Total Fla. 2. Palo Duro 3. Salina, Ks. 4. Williston*

METHOD I--VOLUMETRIC-ANALOG (~~Analog 1:~~ ~~Analog 2:~~)

Yield Factors:	1.	2.	3.	4.
Oil:	8190	2,000	19,200	14,000 $
Gas:	3.39	2.50	5.00	15.00
Rec. Factors:				$

UNDISCOVERED RESOURCES	OIL (Billion Barrels) In-Place	OIL Total Rec. Resource	OIL Undiscovered Rec. Resource	NGL (Billion Barrels) In-Place	NGL Total Rec. Resource	NGL Undiscovered Rec. Resource	GAS (Trillion Cubic Feet) In-Place	GAS Total Rec. Resource	GAS Undiscovered Rec. Resource
METHOD I--VOLUMETRIC-ANALOG	1.		1.649			(.014) 200-1000 m. only			.783
	2.		.523						.533
	3.		3.865						1.007
	4.		2.819						3.019
METHOD IV: HENDRICKS' CATEGORIES Dis.-Rec. Factors: Category #: 3	12.539		2.503				25.07		10.03
Category #: 4	5.015		1.003				12.53		5.002
METHOD: ( ) Yield Factors: Oil: Gas:									
Prod.Area/Unexpl.Area:									
DOCUMENTED RESOURCE APPRAISAL ESTIMATES:									
AAPG, Memoir 15, 1971									
National Petroleum Council Estimates, 1973 *Atlantic Coast So. of 33° Excl. Fla., 2600*	1,500	NPC 0.33 ... =	0.495						
ANOGRE Estimates									
OTHER									

Posted by *KV* Date *3-24-75* Approved ______ Date ______

Table 2. Resource appraisal - province estimate - Blake Plateau (combined 200-2500m) (continued)

FORM # 4-B

Region ______ Province ______
Province Area 52,519 [illegible]
Province Volume 201,318 [illegible]

RESOURCE APPRAISAL --PROVINCE ESTIMATE

PRODUCTION AND RESERVES	OIL (Bill. BBLS)	NGL (Bill. BBLS)	GAS (TCF)
Total (Cumulative & Identified)	0		0

REGIONAL REPRESENTATIVE Resource Appraisal	OIL (Billion Barrels) In-Place	OIL Total Rec. Resource	OIL Undiscovered Rec. Resource	NGL (Billion Barrels) In-Place	NGL Total Rec. Resource	NGL Undiscovered Rec. Resource	GAS (Trillion Cubic Feet) In-Place	GAS Total Rec. Resource	GAS Undiscovered Rec. Resource
a. Reasonable Min. (95% "at least")			.28						.22
b. Reasonable Max. (5% "at least")			3.38						5.06
c. Most Likely			.54						1.13
d. Expectation: (a + b + c)/3			1.50						2.14
Method:									
Rec.--Yield Factors:									
Classify: Hypothetical __ Speculative ✓			30%						30%

Posted by ______ Date ______

RESOURCE APPRAISAL GROUP Recommended Appraisal:	OIL In-Place	OIL Total Rec. Resource	OIL Undiscovered Rec. Resource	NGL In-Place	NGL Total Rec. Resource	NGL Undiscovered Rec. Resource	GAS In-Place	GAS Total Rec. Resource	GAS Undiscovered Rec. Resource
a. Reasonable Min. (95% "at least")			0.4						0.4
b. Reasonable Max. (5% "at least")			2.5						2.9
c. Most Likely			1.0						2
d. Expectation: (a + b + c)/3			(1.3) 0.39						(1.3) 0.39
Method:									
Rec.--Yield Factors.									
Marginal Probability: 0.30 for Oil & Gas									

Posted by ______ Date ______ Approved ______ Date ______ predominantly clastic province of the Gulf of Mexico (which, however, contains in its Jurassic and Cretaceous portions rocks similar in age and possibly similar in lithology to the Atlantic Coast sequence). Additional, possibly closer, geologic analogs may be made, particularly for given elements or parts of this province, as indicated in the accompanying chapters devoted to the geologic setting.

Those analogs with yield data selected for use in the Blake Plateau Province consisted of the carbonate provinces of the onshore Florida Platform, Palo Duro Basin, Salina Basin and the mixed clastic-carbonate Williston Basin. Yield values from these analogs were applied to sediment volumes in the South Atlantic Shelf and Blake Plateau Provinces and calculated for total recoverable oil and gas.

In addition, a series of Hendricks' productive-area categories was calculated on the basis of province area to evaluate a range of potential for each of the commodities. Finally, all published and documented resource appraisal estimates were compiled on a special summary form (Form 4) with all the above estimates that were calculated for each of the methods (Tables 1 and 2).

The Resource Appraisal Group geologists made a comprehensive comparison of all of the above information and appraisals and then, assuming the existence of oil and gas in commercial quantities in the province, made an initial resource appraisal by a subjective probability technique as follows:

1. A low resource estimate corresponding to a 95 percent probability (19 in 20 chance) that there is at least that amount present.
2. A high resource estimate with a 5 percent probability (1 in 20 chance) that there is at least that amount present.
3. A modal estimate of the resource which the estimator associates with the highest probability of occurrence that there will be that amount.
4. A statistical mean which is calculated by adding the low value, the high value, and the modal value and dividing the sum by 3.

These estimates were recorded on the resource appraisal summary sheets for use in the final evaluation by the Resource Appraisal Group Committee (Tables 1 and 2).

Final Resource appraisal procedures. The Resource Appraisal Group Committee and regional geologic representatives met to complete the final resource appraisal estimates for each province. The representative presented a summary of the geology and pertinent information related to an evaluation of the province's petroleum potential. A collective review was made by the committee of all the summary sheets and data formats, significant supportive data, all the other estimators' figures, and the Resource Appraisal Group representative's evaluation.

Following the detailed reviews, each member of the committee and the appropriate representatives and area experts individually made their resource appraisal estimates for the province by the subjective probability procedures described in the previous section. Individual estimates were posted for review and after discussion, a group consensus was arrived at for a range of estimates, as defined.

The final figures as arrived at by the Resource Appraisal Group for the low (95 percent), high (5 percent), and modal estimates and the calculated statistical mean are the raw estimates that were then statistically analyzed, as discussed below.

Methodology for processing probabilistic assessments. The procedures described for estimating the undiscovered oil and gas for the Atlantic petroleum provinces involve subjective probabilities (Raiffa, 1968). Judgments were expressed by the Resource Appraisal Group Committee for each province as percentile assessments limited to judgment of quantities associated with the 5 and 95 percent range. These moderate intervals were selected to realistically account for at least 90 percent of the range of the probable undiscovered oil and gas resources. Also included were the assessment of a modal value and a calculated statistical mean.

A lognormal distribution was fitted by computer program (Kaufman 1962) to the high, low, and modal value of the Resource Appraisal Group assessment to compute the probability distribution for each province.

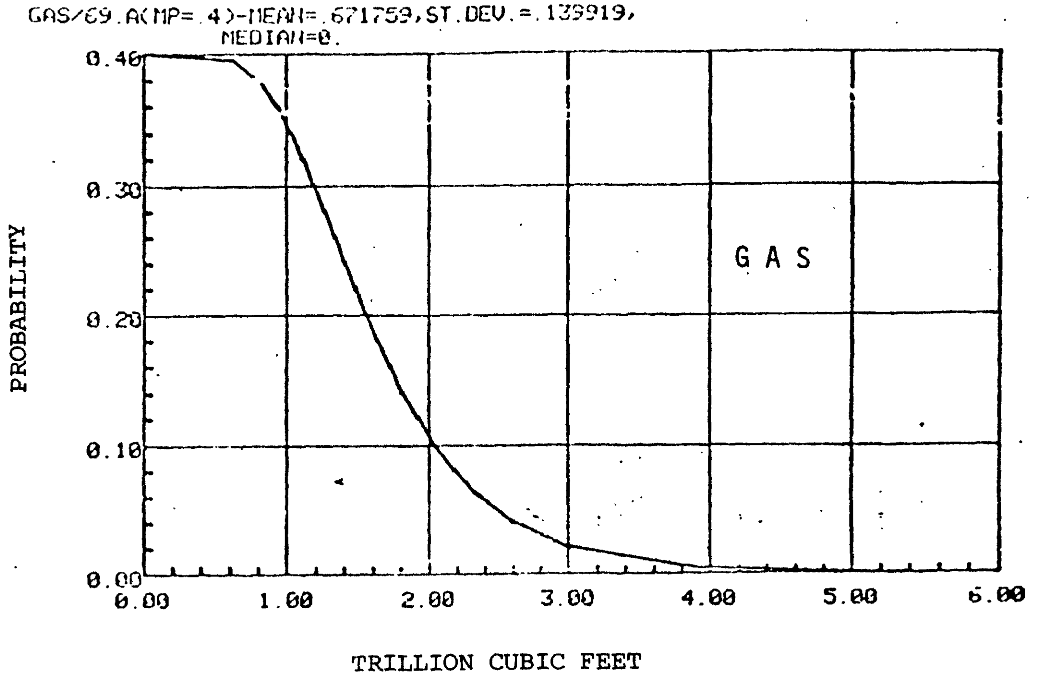
Marginal probability. In the initial resource appraisal for each province, an assumption was made that oil and gas existed in commercial quantities. This assumption cannot be made with certainty in frontier OCS areas in which no petroleum has been discovered to date, as in the South

Atlantic Shelf. It was necessary, therefore, to assign a marginal probability to the event "commercial oil found" and to the event "commercial gas found". These marginal probabilities were determined by consensus of the Resource Appraisal Group Committee. They were then applied to the estimated subjective probability judgments of the undiscovered recoverable resources to determine a final probability distribution of those resources.

At the present time there has been no oil or gas found in the offshore provinces of the South Atlantic. The probability of finding oil and/or gas in commercial quantities was calculated as approximately 40 and 30 percent for the South Atlantic and Blake Plateau Provinces respectively (corresponding to a 60 and 70 percent probability of finding no oil or gas in commercial quantities). Consequently the probability curves (Figs. 34 and 35) reflect marginal probabilities for the South Atlantic Shelf and Blake Plateau Provinces.

These curves may be used to provide estimates of undiscovered recoverable resources at any chosen probability. For example, for the South Atlantic Shelf province, the estimated undiscovered recoverable oil at a 1 percent probability (1 in 100 chance) of at least that amount is 1.8 billion barrels. At the other end of the curve, an estimate of 0 at the 40% probability means that there is less than 4 in 10 chance of commercial quantities of oil being present.

South Atlantic Coastal Shelf Province
(0-200m)



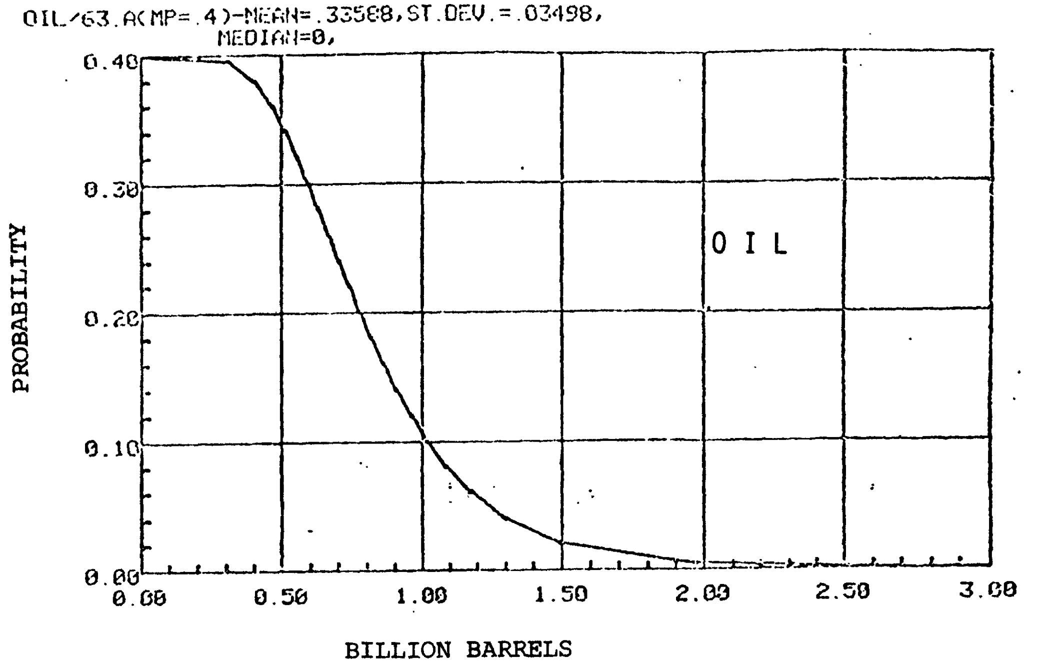
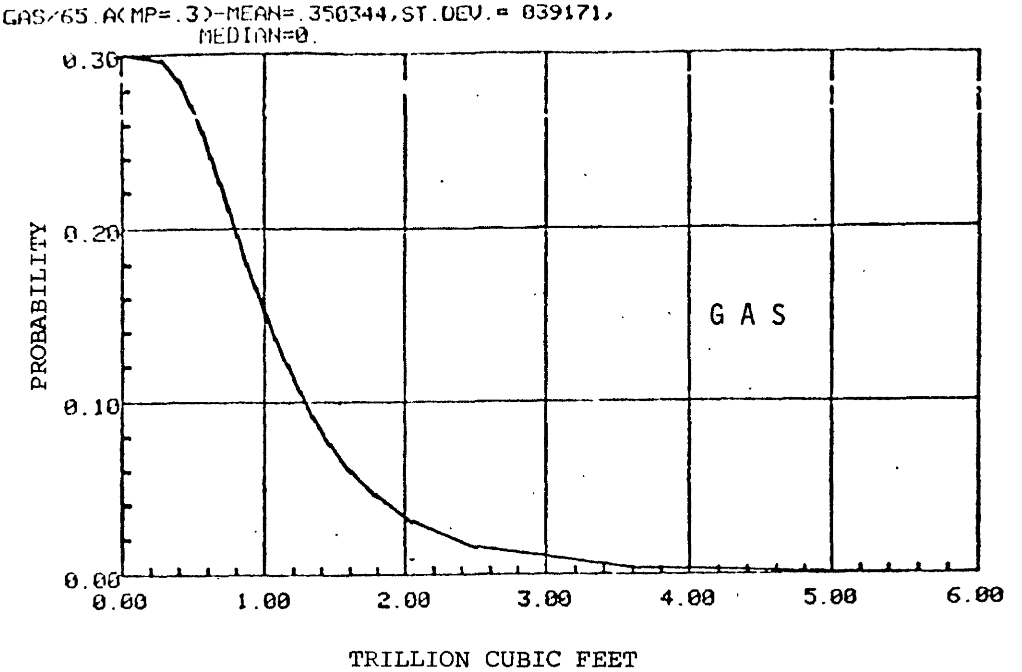


Fig. 34 - Lognormal probability distribution of the undiscovered oil and gas for South Atlantic Shelf Province.

Blake Plateau Province
(200-2500 m)



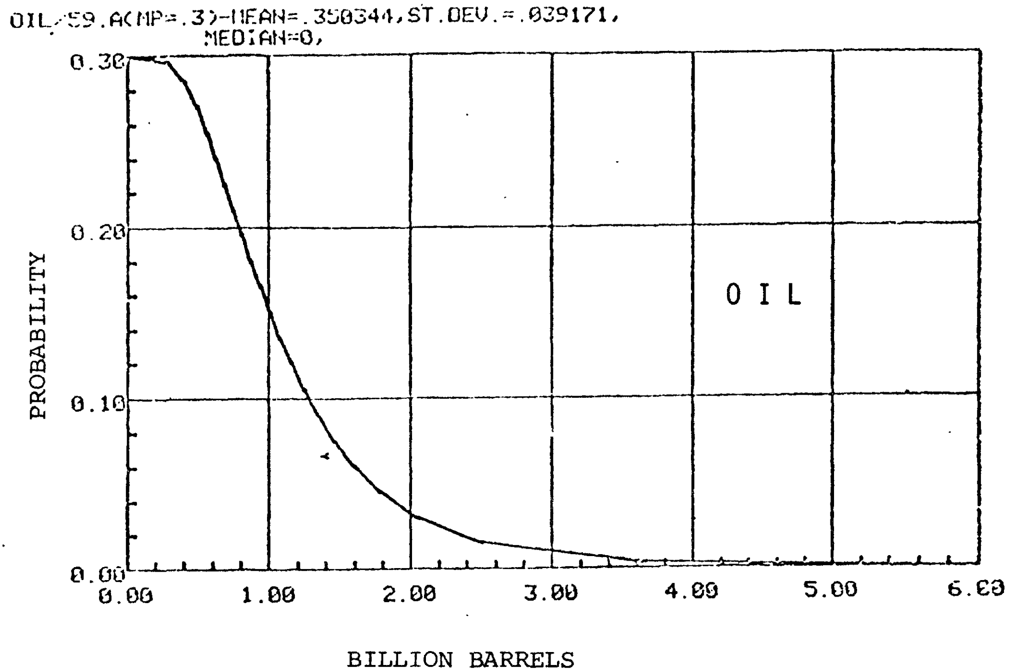


Fig. 35 - Lognormal probability distribution of the undiscovered oil and gas for Blake Plateau Province.

2. South Atlantic Proposed Lease Sale Area Appraisal

The proposed lease sale area, comprising approximately 98,000 square kilometers and containing 350,000 cubic kilometers of sediment, falls within the previously appraised provinces of the South Atlantic Shelf and Blake Plateau. Geologic analogs, for which volumetric yield data were available were employed (as indicated on Forms 4-A) to provide guidance for independent estimates of resources in these provinces.

The estimates of undiscovered recoverable oil and gas determined for the South Atlantic Shelf Province (Fig. 34) are considered to approximate that part of the lease area generally at less than 200 m water depth, and can be viewed in that context. This assessment provides the following estimate of at least these amounts of oil and gas at the indicated probabilities:

UNDISCOVERED RECOVERABLE RESOURCES

	25% probability	5% probability	Statistical mean
Oil (billions of bbls)	0.7	1.2	0.3
Gas (trillion cubic feet)	1.4	2.5	0.7

Portions of the proposed lease sale area extend into waters up to 600 metres and fall within the previously cited Blake Plateau Province. Resource estimates of the total Blake Plateau Province are indicated in Figure 35. Based on area and sedimentary volumes and possible distribution of resources, it is estimated that approximately 15% of the estimated resource of the Blake Plateau Province should be allotted to those parts of the lease area between 200 and 600 m water depth. This assessment provides the following estimate of at least these amounts of oil and gas at the indicated probabilities:

UNDISCOVERED RECOVERABLE RESOURCES

	25% probability	5% probability	Statistical mean
Oil (billions of bbls)	0.1	0.3	0.1
Gas (trillion cubic feet)	0.1	0.3	0.1

Ideally, these separate estimates of resources for the South Atlantic Province and the fractional part of the Blake Plateau Province should only be combined through statistical probability procedures (Monte Carlo) to provide an aggregate resource estimate for the total area. Although this aggregation is not available nor provided here, a crude approximation may be achieved in this instance by a summation of the respective probabilities, which will provide at those respective probabilities, limits within which the actual values must fall. In other words, the limiting maximum resource volume which should be determined at the 5 percent probability level would be somewhat less than this sum, while total resource estimates falling below the statistical mean at higher probabilties should be somewhat larger than their particular sums, the sum of the statistical means remaining unchanged. The limiting values for the proposed lease sale area at the indicated probabilities are as follows:

UNDISCOVERED RECOVERABLE RESOURCES

	25% probability	5% probability	Statistical mean
Oil (billions of bbls)	0.8	1.5	0.4
Gas (trillion cubic feet)	1.5	2.8	0.7

Additional hydrocarbons, occuring as natural gas liquids, might be anticipated if quantities of natural gas were to be discovered. Data do not permit direct estimation of these liquids here. However, on a national basis, the NGL/gas production ratio is approximately 33 barrels of NGL for each million cubic feet of gas produced.

Aymé, J. M., 1965, The Senegal salt basin, in Salt basins around Africa: London, Inst. Petroleum, p. 83-90.

Briden, J. C., Dewey, G. E., and Smith A. G., 1974, Phanerozoic equal-area world maps: Jour. Geology, v. 82, p. 555-574.

Brown, P.M., Miller, J.A., and Swain, F.M., 1972, Structural and stratigraphic framework, and spacial distribution of permeability of the Atlantic Coastal Plain, North Carolina to New York: U.S. Geol. Survey Prof. Paper 796, 79 p., 59 pls.

Coogan, A. H., Bebout, D. G., and Maggio, C., 1972, Depositional environments and geologic history of Golden Lane and Poza Rica trend, Mexico, an alternative view: Am. Assoc. Petroleum Geologists Bull., v. 56, p. 1419-1447.

Cramer, H. R., 1974, Isopach and lithofacies analyses of the Cretaceous and Cenozoic rocks of the coastal plain of Georgia, in Stafford, L. P., Symposium on the petroleum geology of the Georgia coastal plain, Bull. 87: Atlanta, 1974, p. 21-43.

Dickinson, W. R., 1974, Plate tectonics and migration of petroleum, in Geologic interpretations from global tectonics with applications for California geology and petroleum exploration: San Joaquin Geological Society, February 1974, p. 15-1 - 15-4.

Emery, K. O., 1963, Oceanographic factors in accumulation of petroleum: 6th World Petroleum Conference, Frankfurt/Main, Germany, sec. 1, paper 42, p. 483-491.

Emery, K. O., and Zarudzki, E. F. K., 1967, Seismic reflection profiles along the drill holes on the continental margin off Florida: U. S. Geol. Survey Prof. Paper 581-A, 8 p.

Ernst, W. G., 1974, Diagenetic environments along continental margins, <u>in</u> Geologic interpretations from global tectonics with applications for California geology and petroleum exploration: San Joaquin Geological Society, Feb., 1974, p. 14-1 - 14-5.

Fischer, A. G., and Arthur, M. A., 1975, Secular variations in oceanic circulation [abstract]: Am. Assoc. Petroleum Geologists and Soc. Econ. Paleontologists and Mineralogists, Ann. Mtgs. Abstracts, 1975, Dallas, Texas, vol. 2, April 1975, p. 23.

Fuloria, R. C., 1967, Source rocks and criteria for their recognition: Am. Assoc. Petroleum Geologists Bull., v. 51, no. 6, p. 842-848.

Halbouty, M. T., King, R. E., Klemme, H. D., Dott, R. H., Sr., and Meyerhoff, A. A., 1970, Factors affecting formation of giant oil and gas fields, and basin classification, in Halbouty, M. T., ed., Geology of giant petroleum fields: Am. Assoc. Petroleum Geologists Mem. 14, p. 528-555.

Hedberg, H. D., 1964, Geologic aspects of origin of petroleum: Am. Assoc. Petroleum Geologist Bull., v. 48, no. 11, p. 1755-1803.

Hollister, C. D., Ewing, J. I., Habib, D., Hathaway, J. C., Lancelot, Y., Luterbacher, H., Paulus, F. J., Poag, C. W., Wilcoxon, J. A., and Worstell, P., 1972, 4. Site 101--Blake-Bahama Outer Ridge (southern end), _in_ Kaneps, A. G., sci. ed., Initial reports of the Deep Sea Drilling Project, Volume XI: Washington, D. C., U. S. Govt. Printing Office, p. 105-134.

Hollister, C. D., Ewing, J. I., Habib, D., Hathaway, J. C., Lancelot, Y., Luterbacher, H., Paulus, F. J., Poag, C. W., Wilcoxon, J. A., and Worstell, P., 1972, 6. Site 105--lower continental rise hills, _in_ Kaneps, A. G., sci. ed., Initial reports of the Deep Sea Drilling Project, Volume XI: Washington, D. C., U. S. Govt. Printing Office, p. 219-312.

Kamen-Kaye, M., 1970, Geology and productivity of Persian Gulf synclinorium: Am. Assoc. Petroleum Geologists Bull., v. 54, p. 2371-2394.

Kaufman, G. M., 1962, Statistical decision and related techniques in oil and gas exploration: Harvard Univ., PhD dissertation.

Lancelot, Y., Hathaway, J. C., and Hollister, C. D., 1972, 31. Lithology of sediments from the western North Atlantic Leg II Deep Sea Drilling Project, in Kaneps, A. G., sci. ed., Initial reports of the Deep Sea Drilling Project, Volume XI: Washington, D. C., U. S. Govt. Printing Office, p. 901-949.

Maher, J. C., 1971, Geologic framework and petroleum potential of the Atlantic Coastal Plain and Continental Shelf: U.S. Geol. Survey Prof. Paper 659, 98 p.

Marine, I. W., and Siple, G. E., 1974, Buried Triassic basin in the central Savannah River area, South Carolina and Georgia: Geol. Soc. America Bull., v. 85, p. 311-320.

McNabb, D., 1975, Major finds spur score of southeast U.S. deep tests: Oil and Gas Journal, v. 73, no. 17, p. 27-30.

Meyerhoff, A. A., and Hatten, C. W., 1974, Bahamas salient of North America: Tectonic framework, stratigraphy, and petroleum potential: Am. Assoc. Petroleum Geologists Bull., v. 58, no. 6, part II of II (June, 1974), p. 1201-1239.

Miller, B. M., Thomsen, H. L., Dolton, G. L., Coury, A B., Hendricks, T. A., Lennartz, F. E., Powers, R. B., Sable, E. G., and Varnes, K. L., 1975 Geological estimates of undiscovered recoverable oil and gas resources in the United States: U. S. Geol. Survey Circ. 725, 78 p.

Olson, N. K., 1973, Petroleum geology and related oil and gas potential of South Carolina: The Interstate Oil Compact Commission Committee Bull., v. XV, no. 2, Dec. 1973, 17 p.

Olson, W. S., 1974, Structural history and oil potential of offshore area from Cape Hatteras to Bahamas: Am. Assoc. Petroleum Geologists Bull., v. 58, no. 6, part II of II (June, 1974), p. 1191-1200.

Pickering, S. M., Jr., 1974, Petroleum potential of Georgia, in Stafford, L. P., Symposium on the petroleum geology of the Georgia coastal plain, Bull. 87: Atlanta, 1974, p. 11-14.

Pippin, Lloyd, 1970, Panhandle-Hugoton Field, Texas-Oklahoma-Kansas--the first fifty years, in Geology of Giant Petroleum Fields: Am. Assoc. Petroleum Geologists Mem. 14, p. 204-222.

Pressler, E. D., 1947, Geology and occurrence of oil in Florida: Am. Assoc. Petroleum Geologists Bull., v. 31, no. 10, p. 1851-1862.

Rainwater, E. H., 1971, Possible future petroleum potential of peninsular Florida and adjacent continental shelves, in Cram, I. H., Sr. ed., Future petroelum provinces of the United States -- their geology and potential; Am. Assoc. Petroleum Geologists Mem. 15, v. 2, p. 1311-1341.

Reel, D. A., and Griffin, G. M., 1971, Why most of the Florida Peninsular remains dry is not fully explained: Oil and Gas Jour., v. 69, no. 45, p. 90-91.

Raiffa, Howard, 1968, Decision analysis - introductory lectures on choices under uncertainty: Reading, Mass., Addison-Wesley, 300 p.

Richards, H. G., 1967, Stratigraphy of Atlantic Coastal Plain between Long Island and Georgia: review: Am. Assoc. Petroleum Geologists Bull., v. 51, p. 2400-2429.

Rona, P. A., 1970, Comparison of continental margins of eastern North America at Cape Hatteras and northwestern Africa at Cap Blanc: Am. Assoc. Petroleum Geologists Bull., v. 54,

Rouse, J. T., 1971, Possible future petroleum potential of Atlantic Coastal Plain, Peninsular Florida, and adjacent Continental Shelves-Region 11, in Cram, I. H., Sr. ed., Future petroleum provinces of the United States-their geology and potential: Am. Assoc. Petroleum Geologists Mem. 15, v. 2 p. 1291-1294.

Schlee, John, and Gerard, Robert, 1965, Cruise report and preliminary core log M/V Caldrill I, 17 April to 17 May, 1965: JOIDES Blake Panel Rept., 64 p.

Scott, K. R., and Cole, J. M., 1975, U.S. Atlantic margin looks favorable: Oil and Gas Jour., v. 73, no. 1, p. 95-99.

Sherwin, D. F., 1975, Canada's East Coast petroleum potential only been scratched: Oil and Gas Journal, v. 73, no. 17, p. 100-104.

Spangler, W. B., 1950, Subsurface geology of Atlantic Coastal Plain of North Carolina: Am. Assoc. Petroleum Geologist Bull., v. 35, no. 1, p. 100-132.

Spivak, J., and Shelburne, O. B., 1971, Future hydrocarbon potential of Atlantic coastal province, in Cram, I. H., Sr. ed., Future petroleum provinces of the United States--their geology and potential: Am. Assoc. Petroleum Geologists Mem. 15, v. 2, p. 1295-1310.

Sheldon, R. P., 1967, Long-distance migration of oil in Wyoming: Mountain Geologist, v. 4, p. 53-65.

U. S. Geological Survey, 1975, Sediments, structural framework, petroleum potential, environmental conditions, and operational considerations of the mid-Atlantic area: U. S. Geol. Survey Open-File Report 75-61, 143 p.

Winston, G. O., 1971, Regional Structure, stratigraphy, and oil possibilities of the south Florida basin: Gulf Coast Assoc. Geol. Socs. Trans., v. 21, p. 15-29.

IV. Resources Other Than Petroleum

The "total resources", as defined by U.S. Geological Survey (GS) and U.S. Bur. Mines (BuM) Committee (1973), of the U.S. Atlantic OCS are judged to be very large. GS and BuM include as reserves all the naturally occurring materials -- those known and those yet unidentified but expected to exist based on geologic evidence. Thus "total resources" would include materials such as oil and gas (these are discussed in a separate section of this report), hard minerals (placer-type deposits), sand and gravel, and minerals either dissolved in or precipated from seawater. An over-whelmingly large amount of the total resources of the United States Atlantic OCS are "undiscovered resources" and correspondingly few resources lie within the definitions of "identified" and "demonstrated" resources (GS and BuM, 1973). Even a smaller part of the identified resources can be classified as a "reserve" (GS and BuM, 1973).

Because the surface of the Atlantic OCS area has been sampled about as intensely as any part of the Continental Shelf off the United States, the general paucity of "reserves" of hard minerals appears to result not from insufficient sampling, but from an actual dearth of such minerals in the area. Nevertheless, lack of detailed sampling of various areas known to contain hard subeconomic mineral deposits, places most of the minerals present in the "Identified subeconomic resources classification" (GS and BuM, 1973).

The materials listed in table 3 with their corresponding data have been encountered on or within the seabed of the United States Atlantic OCS. All these materials except sand, gravel, and mud are placed in the "Identified-subeconomic resources" category (GS and BuM, 1973).

Sand and gravel, and perhaps the ceramic muds (Manheim, 1972) represent, among the materials listed in table 3 those resources most intensively, but not yet fully, investigated. Nevertheless, resource estimates show economic deposits exist and sand and gravel resources at present can be established as "economic reserves" (GS and BuM, 1973). Sand and gravel deposits most likely available now for economic extraction are large, so that, even though only partly evaluated, the indicated reserves on the United States Atlantic OCS (including the Southeast Georgia Embayment area) are at least 450 billion tons of dry sand and at least 1.4 billion tons of gravel. The total gravel amount may exceed 50 billion tons and the inferred sand resources are probably 10 or more times greater than now estimated.

Table 3

Data sources for resources other than oil and gas for the Atlantic OCS

Material	Selected Data Sources
Phosphorite	Stanley and others, (1967); McKelvey and Wang, (1969), p. 10, pls. 1 and 4; Manheim, (1972, p. 11-13); Milliman (1972); McKelvey and others (1969, p. 5A53-5A57)
Anhydrite	McKelvey and Wang (1969, pl. 4)
Manganese nodules - including trace elements: Ni, Cu,,Co, Sn, Fe, Zn, Ag, Ba, Al, B, Ti, V, Ar, and many others	McKelvey and Wang (1969, p. 11, pl. 1); Horn, Horn and Delach (1973); Mero (1965, p. 180); Horn (1972, p. 10); Manheim (1972, p. 11)
Ilmenite, monazite, zircon, rutile staurolite, kyanite, sillimanite, and garnet	Trumbull and others (1958, p. 52-53); McKelvey and Wang (1969); Emery and Noakes (1968); Hathaway (1971); Manheim (1972, p. 7-11); Ross (1970); McKelvey and others (1969, p. 5A1-5A117); Manheim (1972, p. 2, 11)
Copper and zinc (chalcopyrite and sphalerite minerals)	Manheim (1972, p. 2, 11)
Sand, gravel and mud	Manheim (1972, p. 13-18; 22) Schlee (1964; 1968); Schlee and Pratt (1970); Emery (1965); Duane (1968); Davenport (1971); Taney (1971); Economic Associates Inc. (1968); Milliman (1972); Ross (1970); McKelvey and Wang (1969, p. 10); McKelvey and others (1969, p. 5A64); Nossaman and others (1969); Doumani (1973); Rexworthy (1968)
Glauconite	McKelvey and others (1969, p. 5A91
Carbonate	Hülsemann (1967); Milliman (1972, p. J7)

BIBLIOGRAPHY

Davenport, J. M., 1971, Incentives for ocean mining: a case study of sand and gravel: Marine Technology Soc. Jour., v. 5, no. 4, p. 35-40.

Doumani, G. A., 1973, Ocean wealth -- policy and potential: Spartan Books, 285 p.

Duane, D. B., 1968, Sand deposits on the Continental Shelf - a presently exploitable resource: Natl. Symposium Ocean Sci. and Engineering Atlantic Shelf, Philadelphia, Pa., March, 1968, Trans., p. 289-297.

Economic Associates, Inc., 1968, The economic potential of the mineral and botanical resources of the U.S. continental shelf and slope: Wash., D.C., Clearinghouse for Federal Sci. and Tech. Info., Springfield, Va., 520 p.

Emery, K. O., and Noakes, L. C., 1968, Economic placer deposits of the Continental Shelf: U. N. Econ. Comm. Asia Far East Comm. Coord. Joint Prosp. Mineral Resources Asian Offshore Areas Tech. Bull., v. 1, p. 95-111.

Hathaway, J.C., comp. and ed., 1971, Data file, continental margin program, Atlantic Coast of the United States, v. 2, Sample collection and analytical data: Woods Hole Oceanog. Inst., Tech. rept. no. 71-15, 496 p.

Horn, D. R., ed., 1972, Ferromanganese deposits on the ocean floor: Lamont-Doherty Geol. Observatory, Columbia Univ. Palisades, N.Y., Jan. 20-22, 1972, 292 p.

Horn, D. R., Horn, B. M., and Delach, M. N., 1973, Ocean manganese nodules, Metal values and mining sites: Tech. Rept. 4, NSF - GX 33616, Office Interrat. Decade Ocean Exploration , U.S. Nat. Sci. Fdn., Wash., D.C., 57 p.

Hülsemann, Jobst, 1967, The continental margin off the Atlantic coast of the United States; carbonate in sediments, Nova Scotia to Hudson Canyon: Sedimentology, v. 8, p. 121-145.

Manheim, F.T., 1972, Mineral resources off the northeastern coast of the United States: U.S. Geol. Survey Circ. 669, 28 p.

McKelvey, V.E., and Wang, F.F.H., 1969, World subsea mineral resources: U.S. Geol. Survey Misc. Geol. Inv. Map I-632, 4 sheets, 17 p. [Reprinted and revised, 1970.]

McKelvey, V. E., Wang, F. H., Schweinfurth, S. P., and Overstreet, W. C., 1969, Potential mineral resources of the United States outer continental shelf, Appendix S-A, in Public Land Law Review Commission, vol. 4 (Appendices): U.S. Dept. Commerce, PB 188 717, p. 5A1-5A117.

Mero, J. L., 1965, The mineral resources of the sea: New York, N. Y. Elsevier Pub. Co., 312 p.

Milliman, J.D., 1972, Atlantic Continental Shelf and Slope of the United States--Petrology of the sand fraction of sediments, northern New Jersey to southern Florida: U.S. Geol. Survey Prof. Paper 529-J, 40 p.

Nossaman, Waters, Scott, Krueger, and Riordan, Consultants, 1969, Study of Outer Continental Shelf lands of the United States, vol. IV (Appendices): Public Land Law Review Commission, U.S. Dept. Int.- Bur. Land Management Pub., p. 5-A-1-5-117.

Rexworthy, S. R., 1968, The sand and gravel industry of the United States of America with special reference to exploiting the deposits offshore the eastern seaboard: Unpub. rept. for Ocean Mining Aktiengesell., 48 p.

Ross, D.A., 1970, Atlantic Continental Shelf and Slope of the United States--Heavy minerals of the continental margin from southern Nova Scotia to northern New Jersey: U.S. Geol. Survey Prof. Paper 529-G, 40 p.

Schlee, John, 1964, New Jersey offshore gravel deposit: Pit and Quarry, v. 57, no. 6, p. 80, 81, 95.

Schlee, John, 1968, Sand and gravel on the Continental Shelf off the northeastern United States: U.S. Geol. Survey Circ. 602, 9 p.

Schlee, John, and Pratt, R.M., 1970, Atlantic Continental Shelf and Slope of the United States--Gravels of the northeastern part: U.S. Geol. Survey Prof. Paper 529-H, 39 p.

Stanley, D. J., Swift, D. J. P., and Richards, H. G., 1967, Fossiliferous concretions on Georges Bank: Jour. Sed. Petrology, v. 34, no. 4, p. 1070-1083, 7 figs.

Taney, N. E., 1971, Comments on "Incentives for Ocean Mining"- A case study of sand and gravel: Marine Technology Soc. Jour. v. 5, p. 41-43.

Trumbull, J. V. A., Lyman, John; Pepper, J. F., and Thomasson, E. M., 1958, An introduction to the geology and mineral resources of the continental shelves of the Americas: U.S. Geol. Survey Bull. 1067, 92 p.

U. S. Geological Survey and U. S. Bureau Mines, 1973, Resource classification and operational procedures: Joint U. S. Geol. Survey - U. S. Bur. Mines Memorandum Nov. 1973, 4 p.

V. Environmental Considerations

A number of separate and distinct potential environmental problems have been identified for the U.S. South Atlantic Province. Some of these are common to all areas of the U.S. east coast, such as those associated with oil spills which might impinge on the coast, and hazards to rigs from storms or sediment movement by scour or by mass movement. Certain potential hazards do not arise here, such as ice problems, but others are of especial concern in this area. In the latter category are hazards associated with the possible trend of seismicity through Charleston, the possibility of accelerated contamination of the principal artesian aquifer, a major water source to the region, and drilling in an area of known solution cavities in the limestone of the shelf.

A. Potential Hazards Associated with Ocean Circulation and Weather Conditions

Currents and weather are factors associated with several potential environmental hazards. These include transport of oil spills to shore by current and wind effects, potential damage to rigs by storm waves, and drilling in the strong ocean currents of the area.

1. Weather Conditions

Gale winds are much less frequent south of Cape Hatteras than to the north, occurring generally on less than 15 days per year (see meteorological records in table 4). However, such winds have been recorded at all stations along the coast at almost any time of the year. Gale winds usually accompany sharply defined frontal systems, severe cyclonic storms, hurricanes, or occasionally severe local thunderstorms.

Tropical cyclones (hurricanes) are the most severe weather hazard in this area. Such storms develop over the southern portions of the North Atlantic, including the Gulf of Mexico and Caribbean Sea mostly from June through October, ocassionally in May and November, but rarely at other times of year. The hurricane season reaches its peak in September.

The tracks of selected hurricanes are shown in Fig 36. Note that, as opposed to the Winter-Spring pattern of storm movement, (from southwest to northeast), the storm tracks from July through October show the much more erratic pattern of hurricane movements. Movement is generally from south to north. Although such storms are relatively infrequent

METEOROLOGICAL TABLE FOR COASTAL AREA FROM SAVANNAH, GA., TO CAPE FEAR, N.C.

Boundaries: Between 32°N. and 34°N., and from 75°W. westward to coast

	Weather Elements	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
% frequency	Wind ≧ 34 knots	5.6	5.9	4.5	1.0	1.6	1.0	0.5	0.2	1.8	6.7	3.4	3.1
	Wave height ≧ 10 feet	13.2	16.9	12.6	5.8	5.5	4.5	1.8	1.9	11.0	12.6	8.6	7.8
	Visibility < 2 naut. mi.	0.7	1.0	0.6	0.4	0.4	0.6	0.5	0.5	0.4	0.8	0.4	0.6
	Precipitation	6.4	6.1	5.8	3.1	4.6	5.4	5.3	4.9	4.7	5.3	4.3	5.2
	Sky overcast or obscured	31.9	32.4	29.6	19.1	18.8	20.3	17.4	17.7	20.5	22.1	20.5	27.9
	Thunder and lightning	0.6	0.8	1.4	1.6	2.5	3.0	3.2	4.0	2.2	1.6	1.1	0.5
	Temperature ≧ 85°F	*	0.0	0.1	0.1	1.3	5.7	14.8	15.2	6.1	0.7	0.2	0.0
	Temperature ≦ 32°F	*	0.3	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	*
	Mean temperature (°F)	60.9	61.2	63.3	68.7	74.4	78.3	81.4	81.7	79.3	73.9	68.2	62.9
	Mean relative humidity (%)	73	73	73	73	76	80	80	79	77	74	72	72
	Mean cloud cover (eighths)	5.1	5.1	4.9	4.1	4.2	4.6	4.6	4.6	4.7	4.6	4.5	5.0
millibars	Mean sea-level pressure	1019	1018	1017	1018	1017	1017	1018	1017	1017	1017	1018	1020
	Extreme max. sea-level pressure	1041	1039	1038	1035	1033	1033	1032	1028	1032	1034	1037	1037
	Extreme min. sea-level pressure	983	985	989	990	990	985	992	986	999	989	993	995

METEOROLOGICAL TABLE FOR COASTAL AREA FROM PONCE DE LEON INLET, FLA., TO SAVANNAH, GA.

Boundaries: Between 29°N. and 32°N., and from 78°W. westward to coast

	Weather Elements	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
% frequency	Wind ≧ 34 knots	2.4	4.5	1.7	0.6	0.7	1.4	0.4	0.1	2.7	2.9	1.9	2.0
	Wave height ≧ 10 feet	8.5	14.1	6.5	3.6	3.1	4.2	1.1	1.1	12.9	10.1	7.4	4.9
	Visibility < 2 naut. mi.	0.3	0.4	0.3	0.3	0.2	0.5	0.2	0.2	0.6	0.5	0.2	0.5
	Precipitation	4.6	5.0	3.8	2.6	2.8	4.1	3.6	3.3	5.1	4.2	3.0	3.2
	Sky overcast or obscured	26.7	24.6	21.2	15.2	12.6	15.5	11.7	12.6	18.5	17.9	15.5	21.8
	Thunder and lightning	0.8	0.9	1.5	1.6	2.4	2.8	4.0	4.4	2.7	1.9	1.2	0.6
	Temperature ≧ 85°F	0.1	0.1	0.2	0.5	3.1	10.3	23.0	23.3	11.4	2.6	0.3	0.3
	Temperature ≦ 32°F	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Mean Temperature (°F)	65.3	66.1	68.2	72.2	76.8	80.2	82.7	82.8	81.0	76.7	71.8	67.3
	Mean relative humidity (%)	72	73	72	72	75	79	79	78	77	73	71	71
	Mean cloud cover (eighths)	5.0	4.8	4.6	4.0	3.8	4.4	4.2	4.4	4.7	4.5	4.4	4.7
millibars	Mean sea-level pressure	1020	1018	1018	1018	1017	1017	1018	1017	1016	1016	1018	1020
	Extreme max. sea-level pressure	1039	1038	1035	1032	1032	1031	1031	1030	1032	1033	1035	1038
	Extreme min. sea-level pressure	996	990	978	979	989	991	1000	987	982	990	998	1000

* 0.00-0.05%

These data are based upon observations made by ships in passage. Such ships tend to avoid bad weather when possible, thus biasing the data toward good weather samples.

Table 4. Meteorological records in the southeast Georgia Embayment area (data from United States Department of Commerce. 1974, p. 78)

Winds, currents and storms in the Southeast Georgia embayment area.

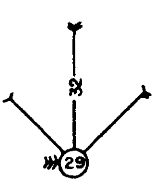
The arrows on the chart are approximations of the prevailing direction and the figures are approximations of the average speed expressed in knots. The arrows with the solid shaft represent the approximate set of currents as obtained from ship log data. The arrows with the broken shaft represent the approximate set of generally known currents for which few data are available. The number over the arrow is the mean drift in knots.

The dotted lines indicate the paths followed by the centers of the more severe storms that have occurred during the month in past years.

(From Pilot Charts of the North Atlantic Ocean, 1974, U.S. Naval Oceanographic Office pub. N.O. 16)

EXPLANATION OF WIND ROSES

Prevailing winds and calms - The wind rose, in each 5-degree square shows the character of the winds that have prevailed within that square. The wind percentages are concentrated upon eight points. The arrows fly with the wind. The length of the arrow, measured from the outside of the circle on the attached scale, gives the percent of the total number of observations in which the wind has blown from or near the given point. The number of feathers shows the average force of the wind on the Beaufort scale. When arrow is too short, feathers are shown beyond its end. The figures in the center of the circle gives the percentage of calms, light airs, and variable winds. When the arrow is too long to be shown conveniently, the shaft is broken and the percentage is indicated by numerals.



For example: The attached wind rose should be read thus: In the recorded observations the wind has averaged as follows:
From N. 32 percent, force 4; from NE. 20 percent; force 3;from W. 1 percent, force 6; from NW. 18 percent, force 2; calms, light airs, and variables, 29 percent.

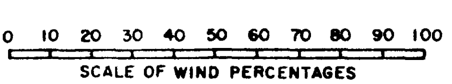


Fig. 36a - Explanation

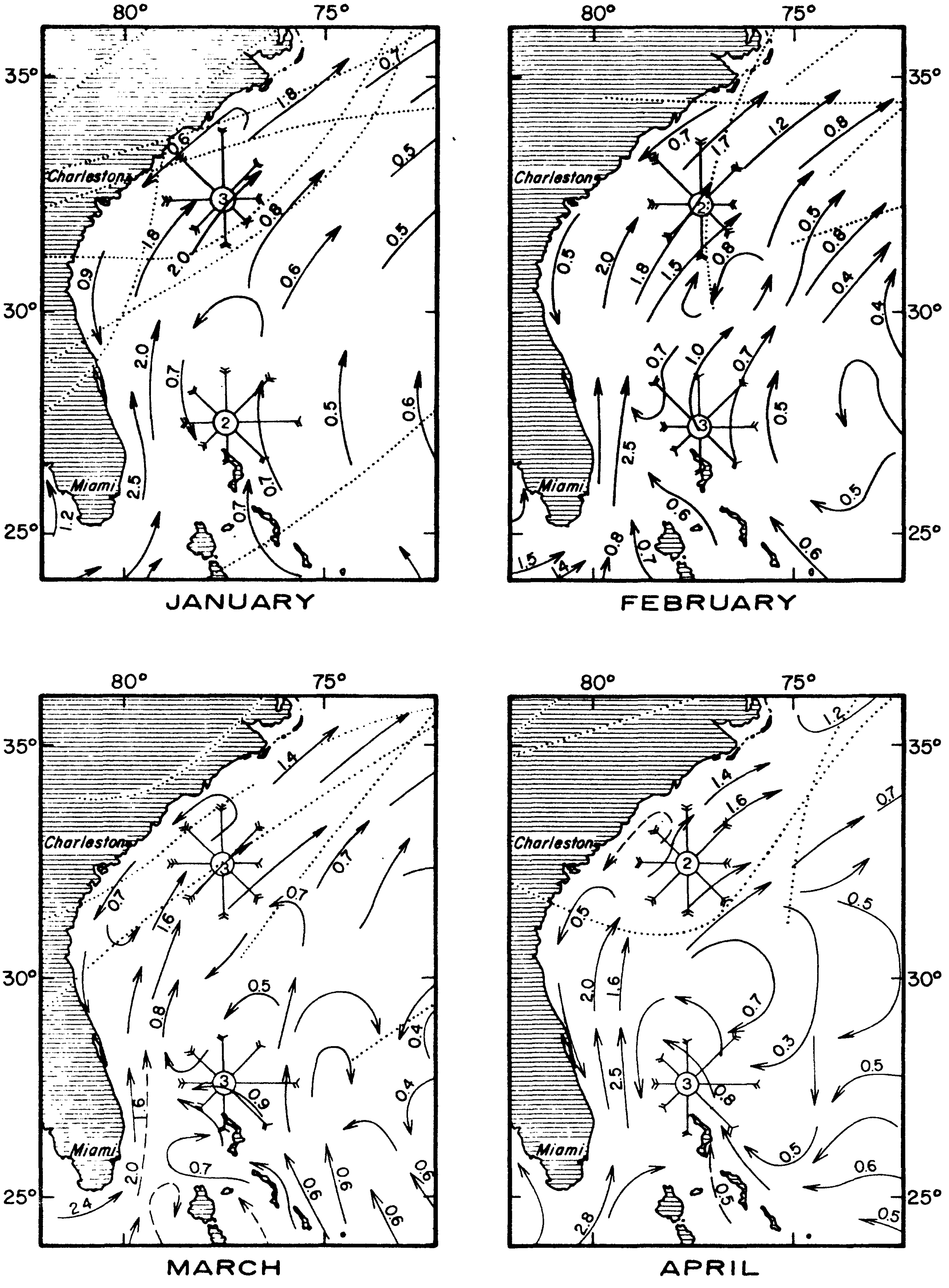


Fig. 36b- January - April

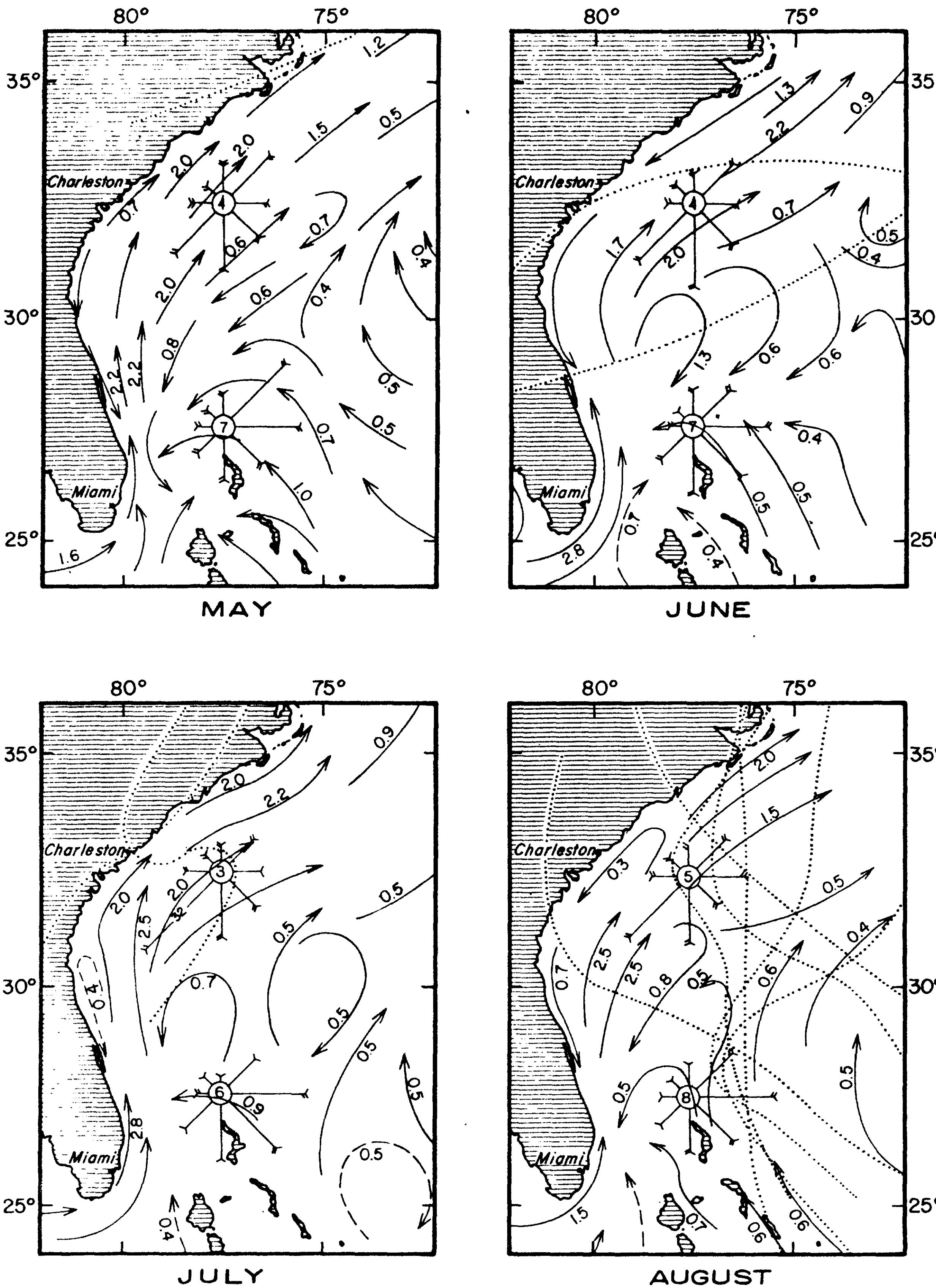


Fig. 36c- May - August

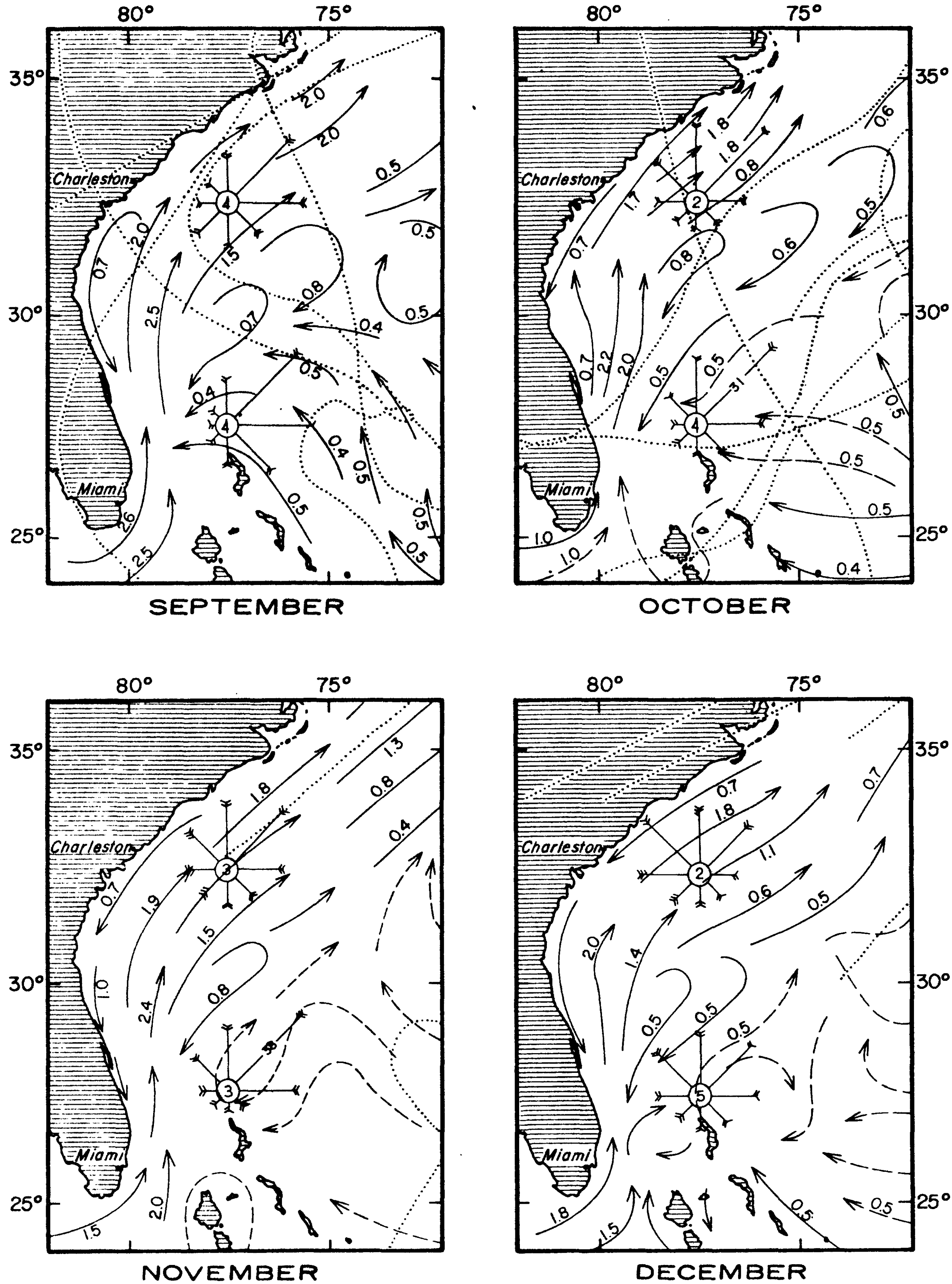


Fig. 36d - September - December

compared to winter gales, having affected Savannah on the average of about once every 10 years (United States Department of Commerce, 1974, p. 126), they are extremely dangerous. Winds speeds of 122 knots have been estimated at Palm Beach (United States Department of Commerce, 1974, p. 167).

Hurricane winds will, of course, produce much larger waves than those cited in record (table 4). Such large waves will act as shallow-water waves anywhere on the shelf, and the effect of refraction of these waves toward headlands and shoals must be examined. It is possible that refraction by the capes and their offshore shoals may result in concentration of wave energy and, thus, much larger breaking waves on these shoals than would be anticipated along most coasts.

2. Shelf Circulation and Movement of Oil Slicks

We will consider the relatively scanty information on water flow on this shelf, briefly examine the probable driving forces and look at possibilities of drift of oil spills which would result. Oil spills on the shelf would have most likelihood of reaching the shore.

Perhaps the most useful data on long term water flows on the shelf are afforded by use of drift bottles and bottom drifters, as reported by Bumpus (1973). The bottles are ballasted to float with a minimum of freeboard and thus are affected mainly by water movement at a depth of a few centimeters, so that they may not respond precisely as an oil slick would, but they are certainly our best indication of water currents which effect slick movement. The surface circulation data for the eastern U. S. continental shelf represents results from release of 165,566 ballasted drift bottles, 10% of which were recovered.

Results of drift bottle studies are shown in Appendix II. They show a poorly defined northerly drift at about 5 nautical miles per day during January and February for most of the shelf with a well defined drift toward Cape Canaveral in the southern part of the U. S. South Atlantic area. A southerly drift near shore off northern Florida is apparent, as is an intrusion of water to the south past Cape Hatteras. This intrusion of water is strongest in March. The weak northerly drifts of the early part of the year give way in May to stronger southerly drift (as much as 7 nautical miles per day) with onshore components. In June and July, the weak northerly drifts resume but with stronger onshore components and considerable variability. A very strong and well defined southwesterly drift involves the entire shelf in August and September and recovery rates of drifters are very high, indicating strong onshore movement. During October through December, recovery rates are poor and general shelf circulation poorly defined, but recoveries from nearshore release points are high. According to Bumpus (1973, p. 129):

> "It would appear that two conflicting systems are at play here, a geostrophic current interrupted by invasions of the Florida Current. The geostrophic current tends to flow southerly and does so successfully in May, during late summer, and early autumn from Frying Pan Shoals southward It is interrupted frequently by invasions of the Florida Current riding up over the shelf carrying the surface

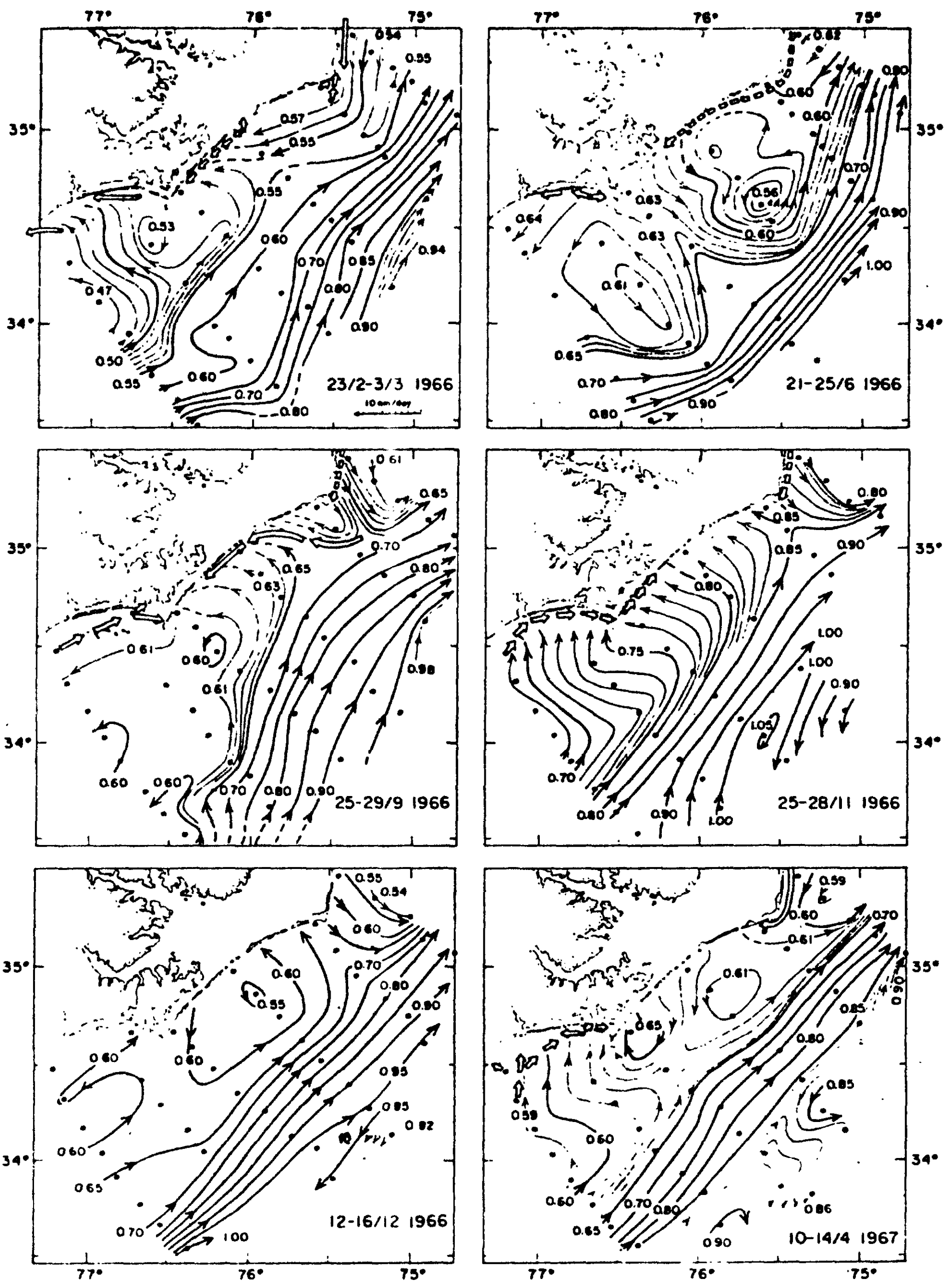
water northward. On those occasions when the recovery rate is poor in the South Atlantic Bight, one can generally assume the surface water has been forced out by a meander of the Florida Current, and the drift bottles have been carried north past Cape Hatteras and out of the immediate system."

From 1961 to 1970, 75,485 sea-bed drifters were released on the continental shelf of the eastern U.S. As of September 1971, 12,008 (15.9%) had been recovered from the shores of North America and 2106 (2.8%) had been recovered from the bottom by fishermen. Bumpus (1973, p. 138). Results from bottom drifter returns are shown in Appendix 2. Bumpus points out that the pattern of sea-bed drifter returns is not seasonal, that is, such drifters are recovered continuously during the year, whereas drift bottles are found chiefly during the warm half of the year. He regards this as evidence that the drifts reflect the thermohaline circulation, modified by wind. Where the salt wedge is well developed, as off North Carolina, the shoreward component of bottom drift extends farthest from shore and rates of return are highest. Where salt wedge development is poorer, as off Georgia, shoreward bottom drift is restricted closer to the coast. Bottom drifts toward Cape Canaveral are especially notable with high rates of recovery there.

Water on the continental shelf of the southeast Georgia Embayment is apparently renewed both from the Gulf Stream and from non-continuous flows south past Cape Hatteras as well as from river input. Geopotential topography of the sea surface south of Cape Hatteras (Stefansson, Atkinson and Bumpus, 1971) (Fig. 37) suggests the presence of counterclockwise gyres in this vicinity.

Intrusion of water along the bottom onto the shelf apparently occurs in summer when shelf water becomes warmed and less dense than offshore water. This movement has been inferred from nutrient distributions and oxygen anomalies (Stefansson, Atkinson, and Bumpus, 1971) and an onshore velocity of 12 cm/sec was calculated by Blanton (1971). This onshore bottom flow apparently mixes upward with shelf waters on the inner shelf and may be compensated by an offshore surface flow. A reverse of this situation probably occurs in the winter, when nearshore water may acquire sufficiently high density by cooling to flow offshore along the bottom and cascade down the continental slope (Rowe and Menzies, 1968; Blanton, 1971; Stefansson, Atkinson and Bumpus, 1971). Bottom transport of water landward, with upwelling along the coast of central eastern Florida is indicated by decreases in water temperatures in July and August in 14 out of 18 years (Taylor and Stewart, 1959). This may be caused by Ekman transport related to summer change in wind pattern. Onshore and offshore flows may also be caused by oscillations of the Gulf Stream which have an amplitude of 10-30 miles (Stefansson, Atkinson, and Bumpus, 1971).

Southward transport of water on the shelf past Cape Hatteras into the southeast Georgia Embayment area by northeastly winds may



Geopotential topography of the sea surface in dynamic meters referred to the 400 dbar surface during six cruises 1966–1967. Surface drift bottle data shown by non-solid arrows, length of which indicates speed. Broken arrows indicate direction of drift only. No drift bottle data available for December 1966.

Fig. 37 - from Stefansson, Atkinson and Bumpus (1971, Fig. 11).

be a fairly common feature of shelf circulation (Gray and Cerame-Vivas, 1963; Stefansson, Atkinson, and Bumpus, 1971, Bumpus, 1973). Such a current would probably develop most strongly during winter months when northerly winds are strongest and most common and when runoff is greatest to the north. Under such conditions, flushing time for the shelf south of Cape Hatteras might be as little as 7 to 14 days, whereas when this current is negligible, a flushing time of 200 days has been calculated (Stefansson, Atkinson and Bumpus, 1971).

Experiments have indicated that oil spills move with the wind at about 2-3% of wind velocity (Schwartzberg, 1971, Harrison 1974). Most toxic fractions are believed to disappear from a slick in 3-8 hours (Harrison 1974) ("disappear" in this context includes solution into water as well as evaporation). However, a test at sea has indicated that thicker patches of oil, which are indentifiable from the air, will persist for at least 4 days (Jeffrey, 1973) and the assumption has been made that a spill can be considered a contiguous slick for up to 20 days (Offshore Oil Task Group, MIT, 1973).

In considering the meterologic and physical oceanographic data presented above, it would appear that the worst case might occur during the Fall period. At that time of year winds blow in a generally onshore direction (east, southeast, and northeast) almost half the time and average force 4 (11-16 mph) (Fig. 36). Such winds speeds might be expected to produce about 0.2 to 0.4 mph movement of slicks.

In addition to this surface wind effect, Bumpus' (1973) data (Appendix II) and the pilot charts (Fig. 36) both suggest a S.E. surface current, which Bumpus refers to as geostrophic. Bumpus (1973) determined a mimimum drift of about 9 mi/day (0.4 knots) and the pilot charts indicate a rate of about 0.7 knots which is probably closer to true velocity. The high recovery rate noted by Bumpus for September probably indicate a significant onshore component to water movement then. Thus it is quite likely that a slick could move in an approximately SW direction at a rate of a knot, covering perhaps 100 miles in the 4 days in which we know that slicks can maintain themselves, or 500 miles in 20 days, thus easily impinging on the shore. This time of year is also a worst case situation because it is the hurricane season in the region and such storms can inflict damage on rigs.

The above is indeed a worst case consideration, however. Winds through much of the year are relatively light and during the winter stormy period dominant winds blow from the NW quadrant, thus tending to blow slicks out to sea. The Gulf Stream, sweeping the shelf edge, will tend to carry away spills and keep them away from coastlines until they are dispersed.

The results both of drift bottle studies (Appendix II. A) and of bottom drifters (Appendix II. B) show a decided drift toward Cape Canaveral and very high rates of retrieval of drifters there. It is apparent that a spill near that Cape has a much greater chance of drifting ashore than spills elsewhere. Therefore, lease sites near Cape Canaveral should be examined with this consideration in mind.

3. The Gulf Stream and Associate Flows

Circulation in this region is dominated by the Gulf Stream-Florida Current flow which commonly reaches speeds of over 2 knots (see Fig. 36). This strong current skirts the edge of the continental shelf, and would have the effect of sweeping oil spills out of the area and maintaining them at sea until dispersed. However, the flow could create difficulties during drilling. The Gulf Stream is about 100 km wide off Florida, broadening northward to the offings of Cape Fear (Richardson, Schmitz and Niiler, 1969; Richardson and Knauss, 1971). It generally forms a single, essentially unidirectional stream to Cape Hatteras, then breaks up into meanders to the north (Stommel, 1958; Fuglister, 1963; Robinson, 1971), although minor meandering has been reported as far south as Cape Canaveral (Chew and Berberian, 1970) and irregularities have been observed in the western border of the stream which may be due to tidal effects (von Arx, Bumpus, and Richardson, 1955). The most intense flow, of about 180 cm/sec, occurs about 20 to 30 km seaward of the shelf edge and northward velocities reach about 40 cm/sec at the sea floor at depths of about 400 to 800 m. (Schmitz and Richardson, 1968; Richardson, Schmitz and Niiler, 1969). Transport of water by the Gulf Stream increases northward at a rate of increase in volume of 7% per 100 km (Knauss, 1969), by entraining water from the margins. The flow commonly almost fills the Straits of Florida (Richardson, Schmitz and Niiler, 1969) but area of contact with the bottom decreased toward the north and was calculated to be only 3 km wide near Cape Hatteras at a time when the surface width of main stream was 135 km (Richardson and Knauss, 1971). The Gulf Stream is essentially a constant phenomenon, although Niiler and Richardson (1973) have measured a transport variation off Miami between Winter and Summer of $25.4 \cdot 10^6$ m^3/sec (Winter) to $33.6 \cdot 10^6$ m^3/sec (Summer).

Reverse flows to the Gulf Stream may occur both near-surface (counter currents) and on the bottom (undercurrents) such a southward flowing surface current may exist on the east side of the stream (Stommel, 1958). Southward flowing undercurrents may exist on both sides of the stream (Richardson and Knauss, 1971) but this seems best documented for the western side where it is known as the Western Boundary Undercurrent (Barrett, 1965; Amos, Gordon and Schneider, 1971). This undercurrent is noticeable in its effects on the sediments, particularly at depths of 1200 to 3600 m (Heezen, Hollister, and Ruddiman, 1966; Rowe and Menzies, 1968) and velocities of up to 26 cm/sec in the southward direction have been measured (Amos, Gordon and Schneider, 1971). The main flow of the Western Boundary Undercurrent probably occurs north of the Blake-Bahama Ridge, but reversals of flow have been reported to the south, which may be tidal (Düing and Johnson, 1971; Weatherly, 1972).

Considerable difficulty was experienced with position-keeping in the Gulf Stream during the drilling of the JOIDES holes on the Florida Shelf and Blake Plateau. For example, at site 5 on the Florida-Hatteras slope, the cruise narrative (p.34) reports that "after about 33 meters of penetration it was necessary to pull out of the hole quickly due to strong currents which were hitting the ship broadside." (Schlee, J. and Gerard, R., 1965. Cruise report and preliminary core log, M/V CALDRILL I - 17 April to 17 May, 1965. JOIDES Blake Panel Report, unpublished manuscript, 64 p.). On occasion, variations in current speed with depth apparently created difficulties as indicated on p. 40 of the cruise narrative:

> "The conditions at a location between position 3 and 6 were tested on the run back toward Jacksonville. At one position (29°24.5'N, 78°36'W) currents were too strong to permit position-keeping. A chip-log current measurement revealed a surface velocity of 75 cm/sec (1.5 knots) toward the south at this location, where the depth was about 800 meters. Although not as strong as surface currents at some sites already worked, this appeared to be a deep-reaching current, which created severe bending in the drill string after about 100 meters of tubing had been put in the water. This site was abandoned..."

Bending of the drill string while being retrieved also occurred at site 5. Although modern drill rigs have greater capabilities than the one used in these operations, the problem still should be considered.

B. Potential Hazards Associated with Bottom Conditions

Platforms constructed in the outer continental shelf could be damaged by movement of their supporting material. This movement can occur by sediment transport either by scour or by mass movement and by collapse of sea floor rocks related to solution cavities.

1. Sediment Transport by Scour

As noted in the section on marine surficial sediments, the mid and outer shelf sediments are sands which appear to be in textural equilibrium on this shallow shelf. The presence of primary structures such as cross bedding, ripple marks, and graded bedding indicate active deposition or redeposition. In the high energy zones near the capes, mud and sand are carried seaward by current and wave action across the shelf and deposited on the slope. Between the capes, a shoreward migration of grains from the central and outer shelf occurs.

The dynamic sedimentary environment of this shallow shelf indicates the possibility that bottom structures would be affected by scour around their supports. This would also be a problem on the inner Blake Plateau where erosional features are common, produced by the Gulf Stream flow.

2. Mass Movement of Sediments

The medium to coarse sand which predominates on the shelf would be relatively dense as a result of reworking by ocean currents and thus should offer good support characteristics (McClelland, 1974), However, dense sands typically provide great resistance to pile penetration. Patches of lagoonal muds and peats which occur on the shelf would result in scattered areas in which support capabilities could be very poor, since static bearing capacity and stability against sliding can be drastically reduced by the presence of even a very thin layer of clay.

Slumping occurs on the slope where fine sediments are being deposited. Clays being deposited here are semi-consolidated at best. Slope sediments have had no subaerial exposure and, lacking desiccation, retain their mobile plasticity.

3. Collapse of Cavernous Limestones

Many of the limestone formations of the Florida Peninsula and Bahamian Banks area are known to contain extensive networks of caves which present serious problems in drilling and completing wells. Cavernous limestones are especially prevalent in the shallower Tertiary sections where subsurface erosion may have taken place during Pleistocene time when the sea stood at lower levels.

The Ocala Limestone (Eocene) is one of the principal aquifers of southeastern Georgia and Florida and is known to be cavernous throughout most of this area.

The cavernous porosity encountered during the drilling of the Bahamas Oil No. 1 Andros Island has been well documented (Maher, 1971; Meyerhoff and Hatten, 1974). Important caverns were penetrated at depths of 21 m, 165 m, 820 m, 2,929 m, 3,056 m, 3,252 m, 3,260 m, 3,954 m, 4,027 m, 4,028 m, 4,030 m, 4,034 m, 4,060 m, 4,082 m, and a total depth 4,448 m; the largest cavern of all was that reached at total depth. A length of drill pipe 2,430 m was lost in the hole and vanished. The most careful surveys could not locate the lost pipe and the well was abandoned. (Meyerhoff and Hatten, 1974). Circulation of drilling mud was lost at nearly all of cavernous zones listed above, indicating that they extended laterally for considerable distances. Cavernous porosity was also encountered in Lower Cretaceous carbonates in the Esso No. 1 Hatteras Light between depths of 2,550-2,575 m (Maher, 1971). Such porosity may exist throughout the Southeast Georgia Embayment area.

In areas where karst features are present, loading of the shelf surface above a cavern by a bottom mounted platform could cause collapse with damage to structures and possible leakage of water or oil.

C. Seismic Hazards

Earthquakes can cause damage to platforms, pipelines, etc. Although the eastern U. S. occurs entirely within a lithospheric plate and only a low level of earthquake activity generally is present, some trends or concentrations of seismicity exist (Sbar and Sykes, 1973). Such trends or concentrations are indicated on the map of seismicity in the southeast Georgia Embayment area (Fig. 38) (from Hadley and Devine, 1974). As noted by these authors, (p. 1):

> "Because of the relatively low frequency of occurrence of eastern earthquakes (about 6.2 earthquakes of MM IV-V or greater per year during 1900-1970), it was considered desirable to include data from the earlier period of less complete records in order to obtain as long a record of seismic activity as possible. This means that probably 85 percent of the epicenter locations used are based on macroseismic rather than instrumental observations and are limited correspondingly in accuracy."

Figure 38 displays a low density of seismologic activity in North Carolina, Georgia, and Florida with a higher level in South Carolina and an exceptional concentration near Charleston. As noted by Hadley and Devine (1974, p. 6):

> "A highly anomalous exception to the characteristic seismic inactivity of most of the Coastal Plain is the well known record of earthquakes in the vicinity of Charleston, South Carolina. This record includes several unusual features that distinguish it from seismic activity elsewhere in the eastern United States. The intensity IX-X earthquake of 1886 seems to have occurred after a century or more of little seismic activity in the region, and the many subsequent shocks that occurred within a 20 to 30 year period all took place in the area of the original earthquake, thus, they have been referred to as a long sequence of aftershocks of the 1886 event. No other part of the Coastal Plain or other locality in the eastern United States shows a similar record.
>
> The wide extent of high-intensity effects of the 1886 earthquake, as well as the large region in which it was felt, indicate that it originated at considerable depth in the crustal rocks below the Coastal Plain sedimentary cover."

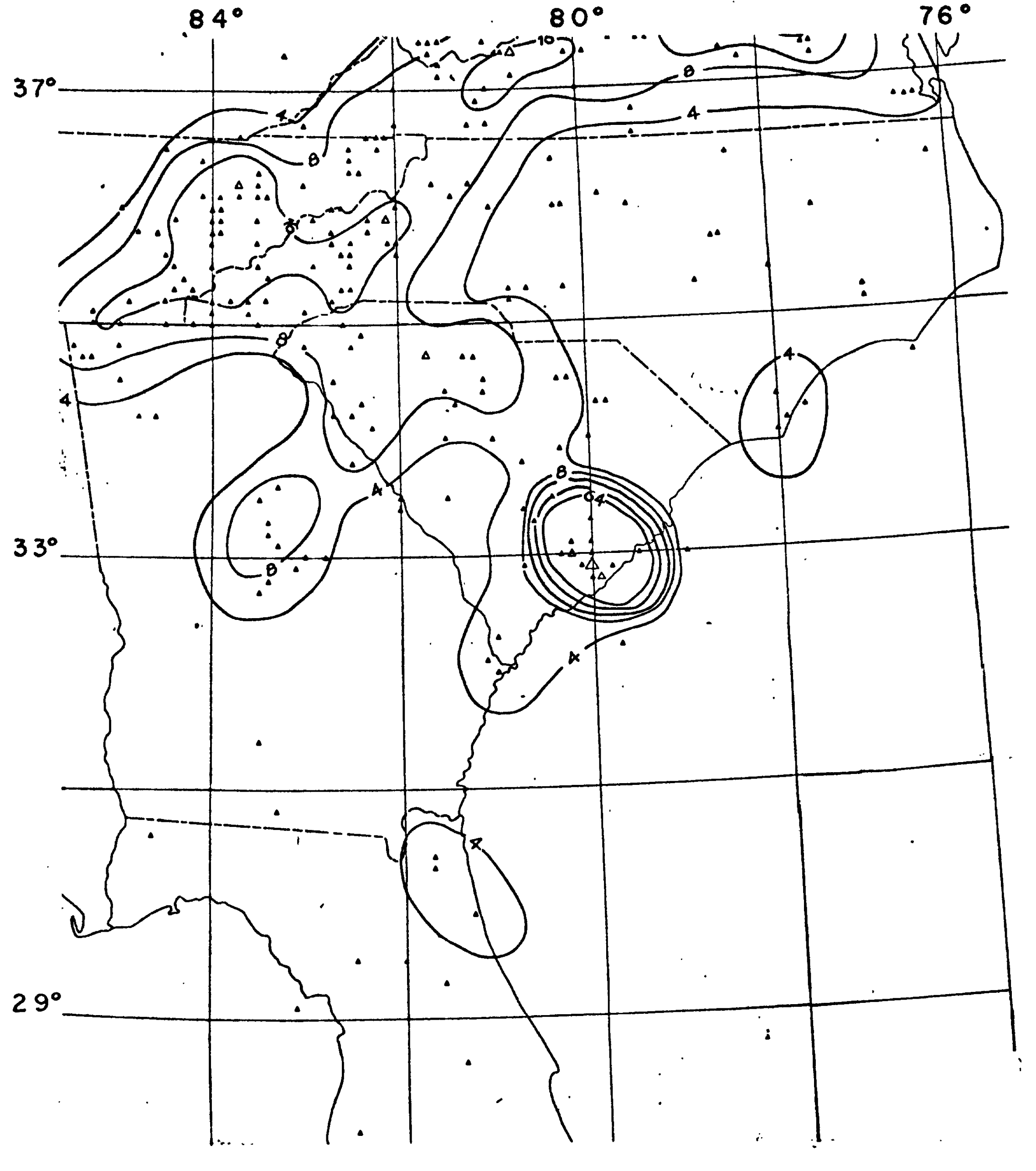


Fig. 38. Map of seismicity in the southeast Georgia Embayment area.

EXPLANATION

Modified Mercalli Intensity

△ III to VI

△ VII

△ VIII

△ IX-X

△ XII

The center of each triangular symbol indicates the epicentral location of one or more seismic events, plotted to the nearest 0.1 degree of latitude and longitude. The intensity shown is maximum Modified Mercalli (MM) intensity in the epicentral area of the largest event at the plotted location. Most locations are based on observations of intensity rather than on instrumental records

—8—

Seismic frequency contour representa the areal distribution of earthquake epicenters with epicentral intensity of MM III and greater, as indicated by the total number per $10^4 km^2$ during the period 1800-1972. Contour intervals are 0-4, more than 4 but less than 8, more than 8 but less than 16, more than 16 but less than 32, more than 32 but lesa than 64, and more than 64. The contours are considerably generalized and are shown only aa a guide for estimating regional seismicity. They have no value for precise location of seismic boundaries

NOTE: This map was compiled in 1973 from earthquake data of the Environmental Data Service of the National Oceanic and Atmospheric Administration and from data of the Dominion Observatory, Ottawa, Canada

SCALE 1:5,000,000

1 inch equals approximately 80 miles

25 0 25 50 75 100 125 150 175 200 MILES

25 0 25 50 75 100 125 150 175 200 KILOMETERS

Fig. 38. Map of seismicity in the southeast Georgia Embayment area (explanation

The Charleston earthquake of 1886 was an exceptionally severe one which was felt as far away as Boston, Green Bay, Cuba, and Bermuda (Dutton, 1889). Isoseismals for this event are shown in Fig. 39.

The possibility of a northwest trend of epicenters across South Carolina is noted by Hadley and Devine (1974, p. 6) (see Fig. 38) but they state that it may or may not indicate real structural effects and a similar view has been expressed by Tarr and King (1973). Conversely, Woollard (1969), Bollinger (1972), and Sbar and Sykes (1973) have all argued that a northwest trend to seismicity exists, extending approximately through Charleston, A plot of epicenters recorded between January 1961 and June 1974 is shown in Fig. 40. Epicenter location data obtained since 1961 are considered more dependable than older data and this plot may show an indication of the northwest trend. Epicenters at the northwest end of the trend might be associated with an Appalachian group of earthquakes. However, although there may be an Appalachian group, the Appalachians could simply be acting as a stress concentrator and fractures on which movement occurs need not necessarily parallel the Appalachian trend.

The hypothesized Charleston seismic trend lies along a small circle about the early opening pole for the North Atlantic (Sbar and Sykes, 1973, p. 1876) and has been considered an extension of the "Blake Spur" Fracture Zone (Emery and Uchupi, 1972, p. 145). Sbar and Sykes (1973) point out that several of the largest earthquakes in eastern North America have occurred near inferred extensions of oceanic fracture zones and suggest that fractures may be anticipated within a block at such locations. Thus, it is possible that an active fault exists that developed during the Mesozoic, perhaps simultaneous with formation of the

Fig. 39. Isoseismals of the 1886 Charleston earthquake (Dutton, 1889).

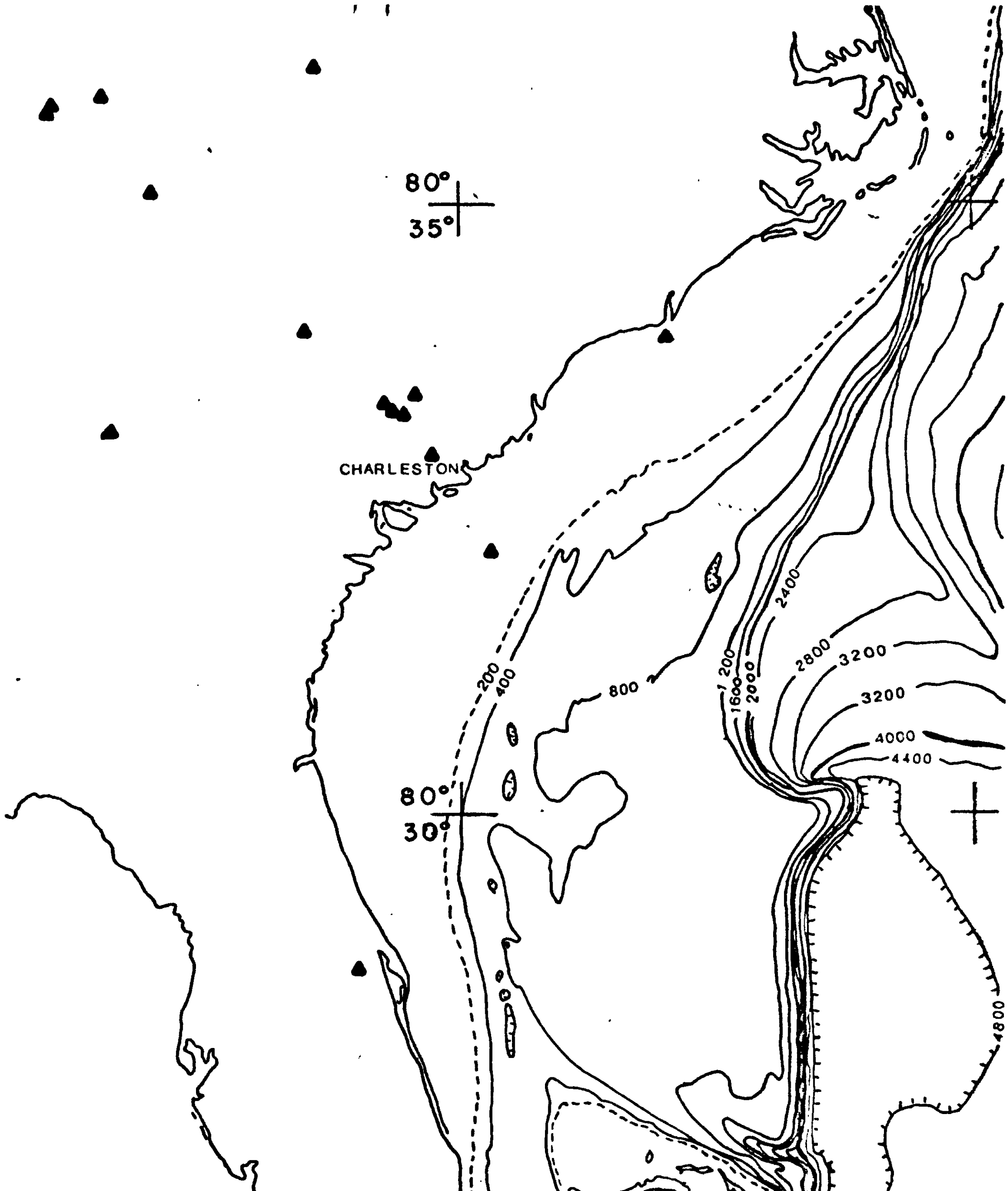


Fig. 40. Epicenters of all earthquakes recorded from January 1961 to June 1974. Date from Hypocenter Data File, National Geophysical and Solar-Terrestrial Data Center NOAA, Boulder, Colorado.

parallel diabase dikes of the Piedmont.

Long (1975) has suggested that some of the seismicity in the Charleston trend results from stress concentration due to inhomogeneities in crustal structure which are suggested by gravity anomalies. Popenoe (1975, person comm.) has suggested the same relationship, also based on gravity data for the epicenter(s) of the 1886 Charleston earthquake and indicates that the density contrast producing the gravity anomaly is likely to be due to a mafic intrusion. Thus, the hypothesis of a similarity of the feature localizing faulting and the northwest trending Mesozoic mafic dikes of the Piedmont is reinforced.

Several lineations in magnetic anomalies (terminations and offsets) also seem to parallel this northwest direction as shown in the map of east coast magnetic anomalies published by Taylor, Zietz, and Dennis (1968). Some possible evidence for faults in the strata of the continental shelf on the Charleston trend has also been reported (Dillon, 1974).

In summary, the possible trend of seismicity and the size of the 1886 Charleston earthquake are two factors of concern in evaluating the Southeast Georgia Embayment for seismic risk. We are not sure whether the earthquake result from faults which break the surface. As pointed out by Tarr and King (1973), there are some unanswered fundamental questions concerning earthquake mechanisms, such as the susceptibility of the Charleston area to another large earthquake and the expectable maximum intensity.

In general, the areas away from the Charleston zone of earthquakes show extremely low seismicity and therefore should have relatively low seismic risk. In contrast, Stewart (1975) has examined leveling data which indicate upwarping of the land surface near Southport, North Carolina, on the Cape Fear Arch and has concluded that "a major earthquake is a likely event within the next few decades or less". Conditions causing concern in this area include: (1) rise of land surface at 5 to 6 mm per year, (2) artesian pressures in the sediments immediately above bedrock, reaching heads greater than 30 m above land surface, and (3) salty ground water at unusually shallow depths along the Cape Fear River (R. C. Heath, 1975, written comm.). Therefore, care probably should be taken with regard to location and strength of structures in this area also.

D. Potential Drilling Hazards

In addition to drilling hazards noted above related to weather conditions, currents, support of structures, earthquakes, etc., shallow hazards and geopressures are potential problems.

1. Shallow Hazards

Shallow or near bottom features that could present natural hazards include gas at shallow depths, hydrogen sulphide (sour gas), ground water outflows, and surface or near-surface faulting. Of these hazards, only outflows have been documented in the Southeast Georgia Embayment area, although some or all of the other hazards may also be present. Effects of groundwater flows are discussed in section V.E, below.

2. Geopressures

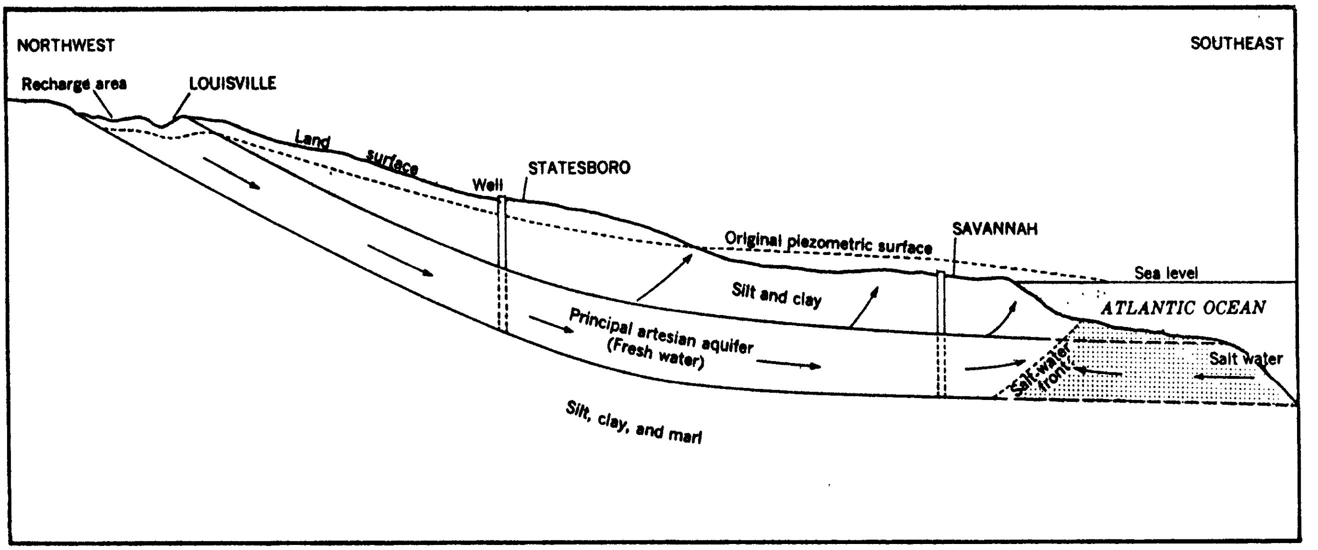
Geopressures (abnormal subsurface fluid pressures) are caused by rapid sedimentation, compaction and diagenesis of sediment associated often with shale and salt diapirs and faulting. Such pressures may lead to blowouts if proper precautions are not taken during drilling. Geopressures are commonly reported in the Tertiary and Mesozoic sequences of the Gulf Coast. However, in that area, geopressures are handled successfully on a routine basis. A mud weight of 15.5 pounds was required for one Sable Island test, and another east coast Canadian well encountered gradients of 0.73 psi/ft. A gradient of 0.465 psi/ft and 9 lbs/gal. mud weight are considered normal.

E. Possible Effects on Aquifers

Improper well completion or trenching practices could cause contamination of artesian aquifers in the Southeast Georgia Embayment, where the so-called principal artesian aquifer (known as the Floridan aquifer in Florida) is very extensively employed. Many municipalities along the coast depend entirely, or in part, on this aquifer for their freshwater supplies, including Savannah and Brunswick, Georgia and Jacksonville, Daytona Beach, Cape Kennedy, and Orlando, Florida (Counts and Donsky, 1963; Klein, 1971; W. Leve, 1975, written comm.).

1. Nature of the Aquifer

The principal artesian or Floridan aquifer is artesian (as the name implies) due to the geometry of the dipping strata of the coastal plain and their varying permeability, as diagrammed in Fig. 41. This aquifer consists of Eocene, Oligocene and Miocene limestone containing beds of dolomite, sand, silt, clay, and marl (Callahan, 1964). Limestones of the Ocala Group (late Eocene age) occur as part of the aquifer in Florida, Georgia, and South Carolina; the Eocene Castle Hayne limestone is apparently equivalent in North Carolina. Most of the water is produced from Eocene and Oligocene limestones in the Savannah area (Counts and Donsky, 1963). In Florida, the lower part of the aquifer consists of highly cavernous dolomitic limestone, ranging in age from early Eocene to Paleocene. The unit has been named the "Boulder Zone", because of its drilling characteristics, although no boulders exist. The Boulder Zone probably contains nonpotable water throughout the state (Klein, 1971). Potable water is generally produced from permeable zones in the limestone and from solution cavities in the upper part of the aquifer in Florida.

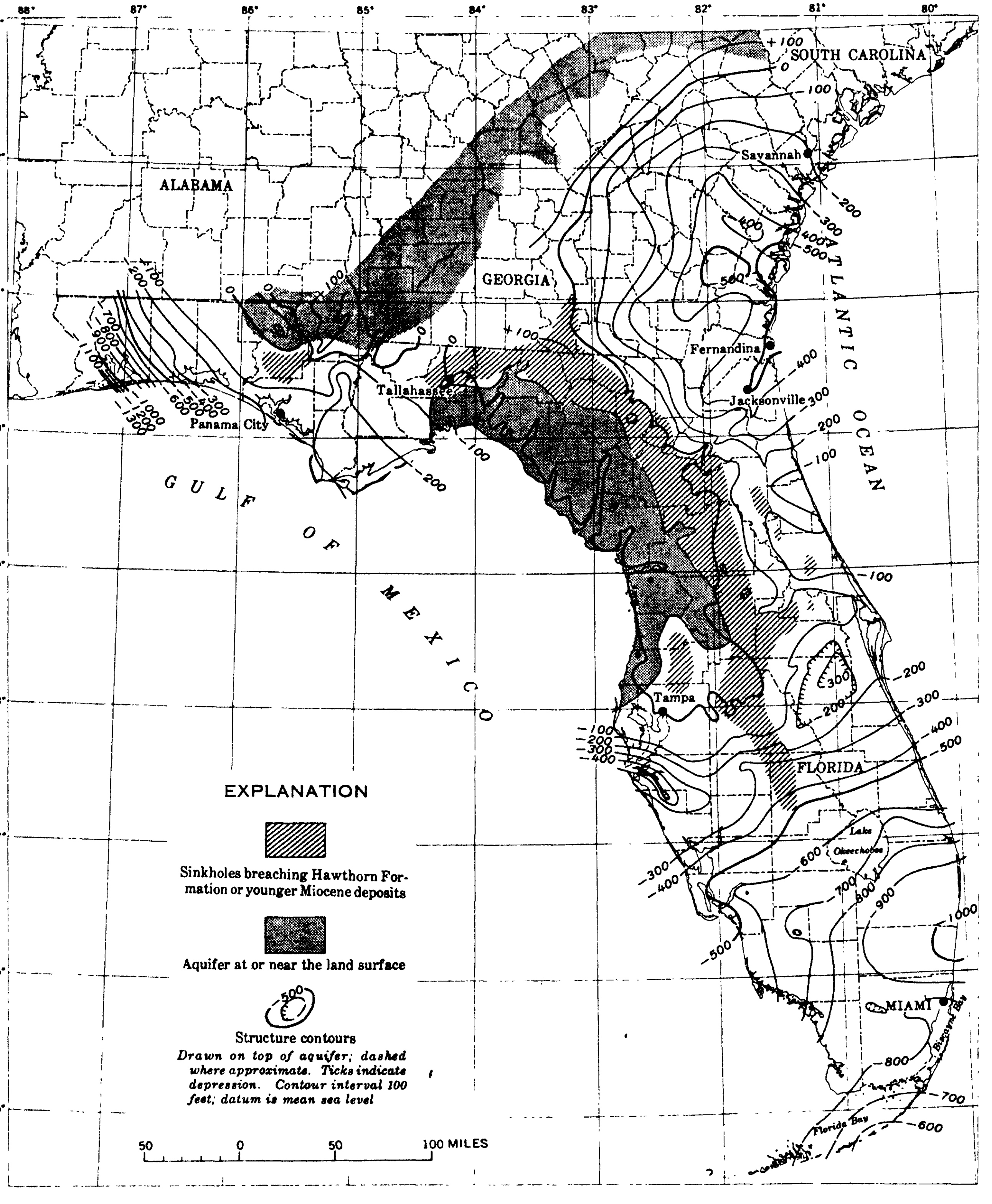


Diagrammatic section of principal artesian aquifer, showing theoretical fresh water-salt water interface.

Fig. 41 - From Counts and Donsky (1963, Fig. 9)

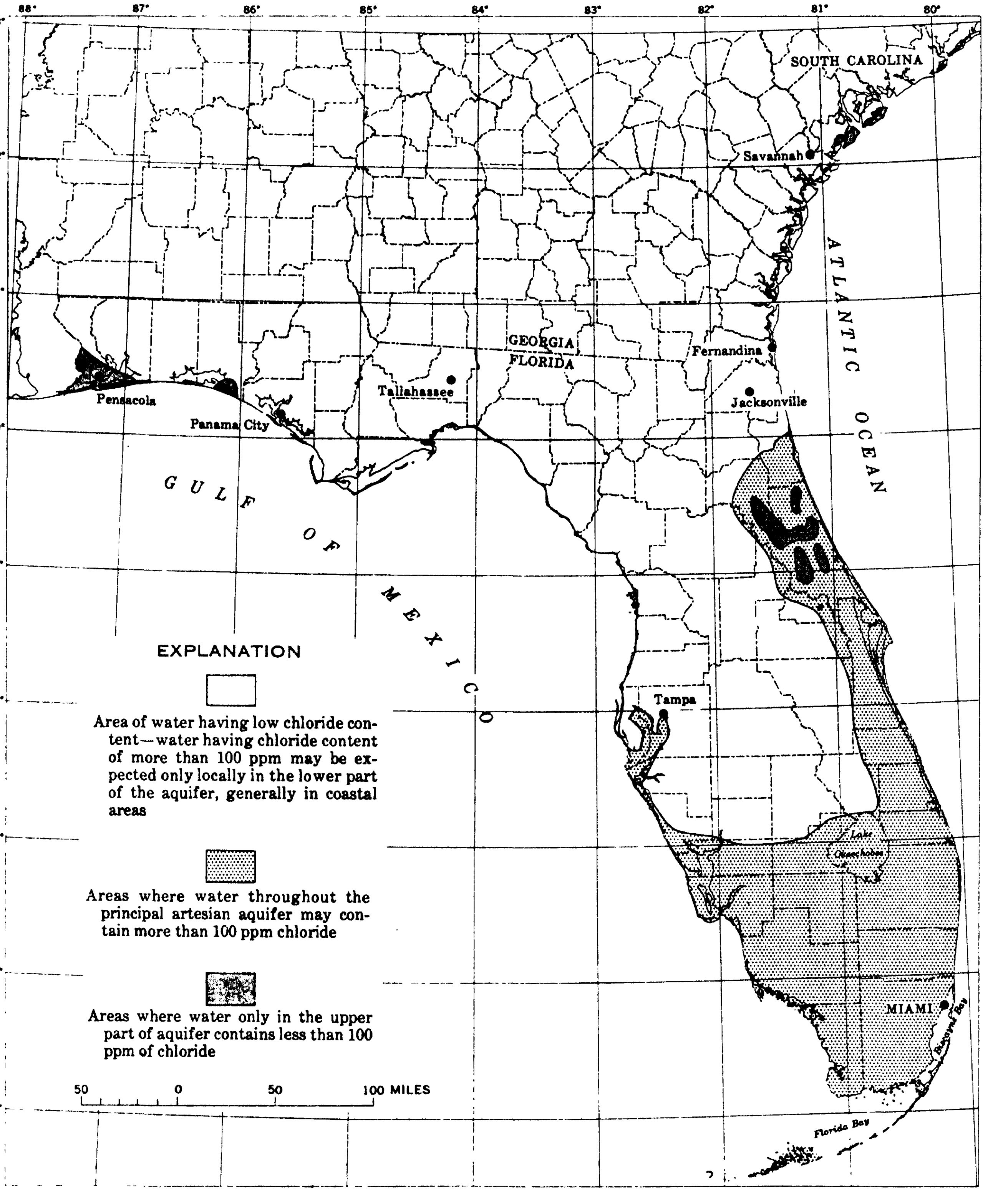
The principal artesian aquifer (called Floridan aquifer in Florida) underlays all of Florida and the coastal plains of Georgia, South Carolina, and North Carolina (Callahan, 1964; Stringfield, 1966; Vernon, 1973). Contours on the top of the aquifer are shown in Fig. 42 . The depth to the top of the aquifer in the Southeast Georgia Embayment is greatest in the Brunswick, Georgia-Fernandina, Florida area and approaches a sea floor outcrop near Parris Island, South Carolina, and Daytona Beach, Florida. The depth of the base of potable water is approximately 600m in the Jacksonville, Florida-Brunswick, Georgia area and freshwater is being obtained at depths of 760 m near the South Carolina coast (H. Counts, 1975, oral comm.). The principal artesian (Floridan) aquifer contains salt water at Parris Island, South Carolina, and Daytona Beach, Florida (H. E. Gill, 1975, written comm.). Chloride content in waters in the aquifer is shown in Fig. 43.

It is clear that the principal artesian aquifer extends offshore beneath the continental shelf. Freshwater from this aquifer flowed from the drill pipe at JOIDES hole J-1 on the inner shelf 40 km off Jacksonville, and slightly saline water was obtained at hole J-2 on the outer shelf 120 km from the coast (Fig. 44) (Manheim, 1967). Brackish water was obtained from the deepest sample of hole J-5 on the Florida-Hatteras slope from upper Eocene deposits. The most permeable and probably freshest zones are likely to be under-represented in Fig. 44 , because measurements were made on water extracted from cores and core recovery was believed to be poor in highly permeable strata. In the Savannah area, the present fresh water-salt water contact in the aquifer is thought to be farther seaward than would be predicted from a static balance based on position of sea-level and the head of water in



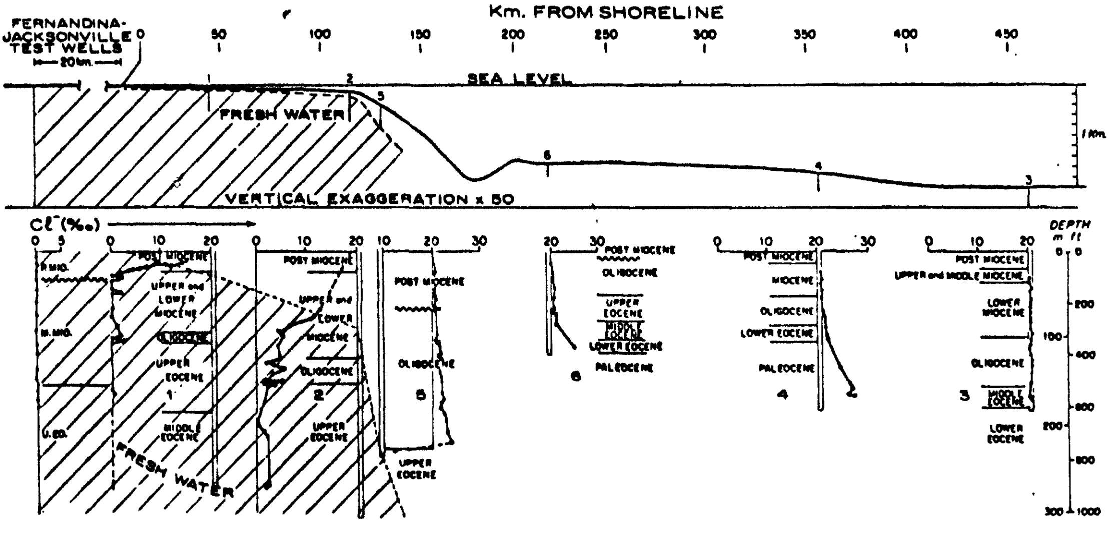
Contour map of top of principal artesian aquifer. (Florida, from Vernon, 1955; Georgia, from Warren, 1944.)

Fig. 42 - From Stringfield (1966, Fig. 23)



Map showing areas where water of the principal artesian aquifer has more than 100 ppm of chloride.

Fig. 43 - From Stringfield (1966, Fig. 36)



Distribution of chlorinity in interstitial waters squeezed from JOIDES cores. Data on chlorinity in water wells at Jacksonville and Fernandina, Florida, were provided by G.W. Leve, U.S.G.S., Jacksonville. Double vertical lines designate position of offshore holes.

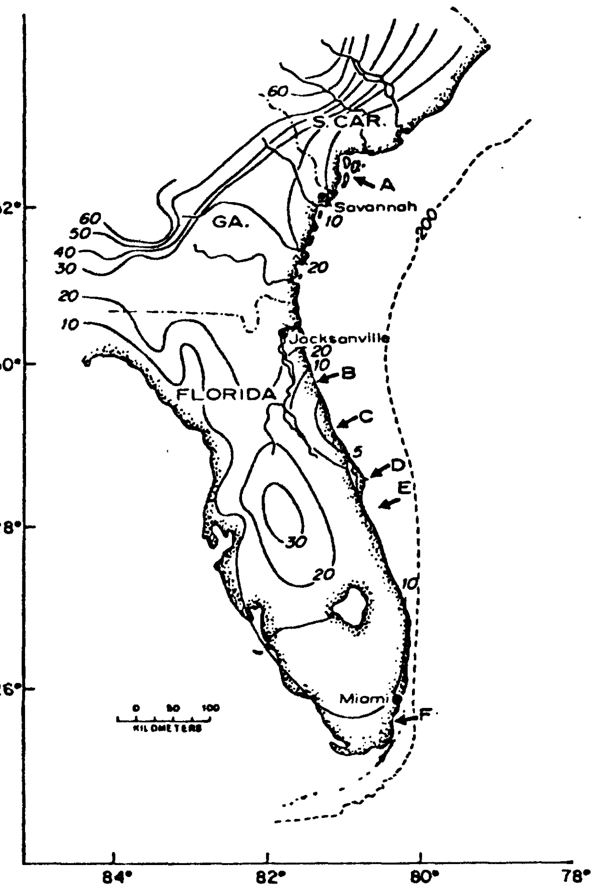
Fig. 44 - From Manheim (1967, Fig. 5)

the aquifer (Counts and Donsky, 1963). This is considered to be due to flushing of salt water from the aquifer during Pleistocene sea-level lowering and a lag in landward movement of the salt-fresh interface after sea-level rise. Freshwater apparently persists in the offshore part of the aquifer as far as Cape Lookout, North Carolina, where it is believed to extend a few miles offshore, whereas north of Cape Lookout all offshore beds contain salty water (R. C. Heath, written comm.). Offshore spring also provide evidence for offshore extension of the aquifer (Callahan, 1965; Stringfield, 1966; Manheim, 1967) and locations of some of these are shown in Fig. 45. Submarine springs are formed by breaches in the confining bed of the aquifer, of course, and represent locations where ocean water can enter the aquifer if head is not maintained. Such saltwater intrusion apparently is happening in the Savannah area (Counts and Donsky, 1963). The deeper parts of the principal artesian (Floridan) aquifer beneath much of the Florida platform are considered to be open to slow circulation of ocean water driven by geothermal heating (Kohcut, 1965; 1965; Henry and Kohout, 1972). This probably has caused accelerated solution of rocks to form caves and sinkholes.

An estimate of the appearance of the piezometric surface before extensive use of ground water is presented in Fig. 45. In contrast, Fig. 46 shows the 1961 surface which is marked by several cones of depression caused by pumping in areas of dense population, notably at Savannah, Brunswick, Georgia, and Fernandina Beach, Florida.

2. Saltwater Intrusion

Along the coast of the Southeast Georgia Embayment, the principal artesian aquifer has been affected by saltwater intrusion. This has

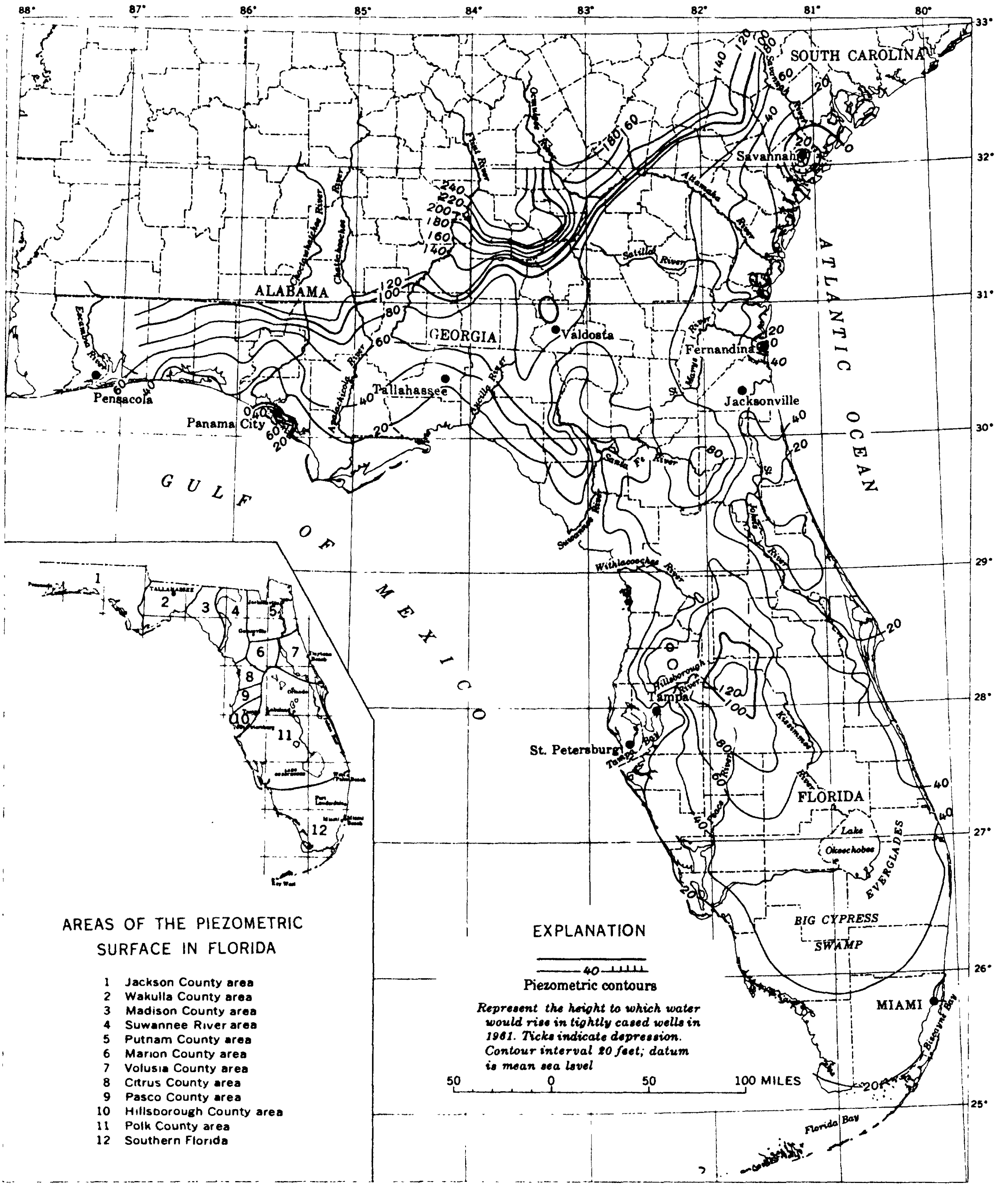


Estimated piezometric map of the principal aquifer of the southeastern Atlantic coast of the United States. The contours are based on data from Warren (1944), Siple (1952, 1955), Stringfield (1964) and Stringfield and Le Grand (1966). The contours estimate the height in meters above sea level to which waters would have risen in drill holes penetrating the aquifer before extensive use of ground water by man (about 1880). Present day maps show piezometric depressions in urban and highly populated areas, but Stringfield (1967) indicates that levels in recharge areas and less populated zones around them can be taken to roughly approximate "original" aquifer conditions. The 200 m contour offshore indicates depth of the sea bottom below sea level.

The points of the arrows show the approximate position of reported submarine discharge near the coast. Land reference points and recent references are given where available:

A. Off Beaufort, South Carolina (Callahan, 1964).
B. Off Crescent Beach, Florida (Brooks, 1961).
C. South of Daytona Beach, Florida (Sanford & Matson, 1913; Stringfield, 1966).
D. Northeast of Cape Kennedy, Florida (Brown *et al.*, 1962).
E. 30 km seaward of Eau Gallie, Florida (Brown *et al.*, 1962).
F. Biscayne Bay, Miami, Florida (Kohout, 1965).

Fig. 45 - From Manheim (1967, Fig. 1). References are to be found in that article.



Piezometric surface of water in the principal artesian aquifer, 1961. (From Healy, 1962; Stewart and Croft, 1960; and Warren, 1944.)

Fig. 46 - From Stringfield (1966, Fig. 29)

occurred in two ways, first by movement of seawater into the aquifer and its migration horizontally to areas of heavy pumpage, and second by migration of salty water upward from deep parts of the aquifer or through underlying confining beds.

An example of seawater migration into an aquifer apparently is provided at Savannah, Georgia. There, seawater enters the aquifer in the sounds of coastal South Carolina and offshore where the aquifer is exposed on the sea floor (Callahan, 1964; Krause and Gregg, 1972). This seawater then moves down the hydraulic gradient toward the cone of depression caused by pumpage at Savannah. Rates of water movement in the aquifer are relatively slow, perhaps less than 10 m/yr. (Manheim, 1967) and at double the present rate of pumping, it has been estimated that it will take perhaps as long as a century for the saltwater-freshwater interface to migrate the 24 km necessary to reach Savannah (Counts and Donsky, 1963).

Counts and Donsky (1963) suggest that such lateral migration of seawater is the most likely source of contamination for Savannah's ground-water supply, but to the south of Savannah the aquifer is exposed on the ocean floor only further to the east, and thus migration of ocean water into areas where pumping occurs is of less concern. However, migration of salty water which already exists in the aquifer can also cause contamination. Salty water occurs in the lower part of the aquifer at Savannah (Counts and Donsky, 1963) and also at Brunswick, Georgia, where salty and fresh water interfinger. At Fernandina, Florida, chloride content has increased in the lower part of the aquifer (Callahan, 1964). Upward migration of salty water has caused contamination of wells at

Brunswick, Georgia. Apparently, trapped brackish water moves upward due to heavy pumpage (over one hundred million gallons per day) which has reduced the head in the principal artesian aquifer (Wait, 1965).

The examples given above of contamination of the principle artesian aquifer by salty water indicate that care must be exercised in any activity which penetrates it or its confining beds. Obviously, open holes penetrating the aquifer can allow an artesian flow which will lower the head, thus increasing the likelihood of saltwater contamination. Breaching of the upper confining beds beneath the ocean also can create the possibility of seawater intrusion into the aquifer closer to pumping locations that is the case with the present natural openings in the confining beds. Thus, the conditions which result in seawater encroachment near Savannah, could be duplicated further south where they do not presently exist. In this regard, the breaking of the upper confining beds by trenching to bury pipelines is probably a more serious potential problem than opening by drill holes because the area opened during a trenching operation would be much larger.

Openings between layers within the aquifer can also lead to saltwater contamination as is indicated by the example of Brunswick, Georgia. Counts and Donsky (1963) note that, although saltwater is present in materials underlying the principal artesian aquifer throughout the Savannah area, vertical movement is largely sealed by a layer of clay, silt, and marl about 30 m thick. Clearly, if such aquicludes, which separate freshwater and saltwater zones, are opened by drilling, contamination can be initiated or accelerated. Such contamination has taken place in the Indian River citrus belt in St. Lucie, Indian River, and Brevard counties, Florida, where heavy pumping from irrigation wells has permitted upward movement of water from more saline parts of the aquifer through open-bore wells which were inadequately cased (Klein, 1971). In order to prevent deleterious effects, surface casing should be set below the depth of potable water, abandoned holes should be properly sealed and plugged, and burial of pipes probably should not be carried out in locations where thin aquicludes occur above the aquifer. An alternative to the latter suggestion would be to backfill with impermeable materials after trenching, if that is possible.

3. Summary and Conclusions

Perhaps the most valuable natural resource in the region of the Southeast Georgia Embayment is its water supply, with much of that coming from the principle artesian (Floridan) aquifer. Callahan (1964, p. 40) states that "the potential yield of this aquifer is very large and...with good management this yield can be sustained almost indefinitely". However, water quality problems have arisen, in Brunswick and Savannah, Georgia, and efforts should be made to avoid creating such problems in other locations. Vertical migration of contaminating water can be initiated or encouraged by poor well completion practices. Artesian flow of water into the ocean can result in loss of head and subsequent saltwater intrusion. It is necessary to set surface casing below the depth of potable water in the aquifer, and abandoned holes must be plugged. Trenching which permanently would remove confining beds above the aquifer near shore should be avoided.

As pointed out by Leve (G. W. Leve, 1975, written comm.):

> "Much beneficial information could be obtained on water resources by petroleum exploration programs. For example, many of our investigations (model studies) in coastal regions require knowledge of the extent and thickness of the aquifers offshore and the quality and quantity of water in these aquifers. Any information that could be obtained by seismic profiles, test drilling, logging, drill stem tests, etc. would aid in appraising the total water resources in coastal areas."

An effort should be made to provide as much as possible of the information developed in the petroleum search to those involved in water resources development.

F. Man-made Hazards

Man-made hazards in this area may include such objects or activities as: unexplored arsenal dumps and depth charges, sunken ships, dump sites for solid and chemical waste, shipping lanes to port cities (Savannah and Charleston) and cables on the sea bottom. Most of these hazards are well documented in navigation reports and charts.

BIBLIOGRAPHY

Amos, A. F., Gordon, A. L. and Schneider, E. D., 1971. Water masses and circulation patterns in the region of the Blake-Bahama Outer Ridge. Deep-Sea Research, v. 18, p. 145-165.

Barrett, J. R., Jr., 1965. Subsurface currents off Cape Hatteras, Deep-Sea Research, v. 12, p. 173-184.

Blanton, J., 1971. Exchange of Gulf Stream water with North Carolina Shelf water in Onslow Bay during stratified conditions. Deep-Sea Research, v.18, p. 167-178.

Bollinger, G. A., 1972. Historical and recent seismic activity in South Carolina. Seismol. Soc. Am. Bull. v. 62, p. 851-864.

Bumpus, D. F., 1973. A description of the circulation on the continental shelf of the east coast of the United States. Progress in Oceanography, v. 6, p. 111-157.

Callahan, J. T., 1964. The yield of sedimentary aquifers of the coastal plain southeast river basins. U.S. Geol. Surv., Water-Supply Paper 1669-W, 56 p.

Chew, F. and Berberian, G. A., 1970. Some measurements of current by shallow drogues in the Florida current. Limnology and Oceanography, v. 15, p. 88-99.

Counts, H. B. and Donsky, E., 1963. Salt-water encroachment, geology and ground-water resources of Savannah area, Georgia and South Carolina. U.S. Geol. Surv., Water-Supply Paper, 1611, 100 p.

Dillon, W. P., 1974. Faults related to seismicity off the coast of South Carolina. U.S. Geological Survey, open-file report, Reston, Va.

Düing, W. and Johnson, D., 1971. Southward flow under the Florida current. Science, v. 173, no. 3995, p. 428-430.

Dutton, C.E., 1889, The Charleston earthquake of August 31, 1886: Ninth Ann. Report of U.S. Geological Survey, p. 203-528.

Emery, K. O. and Uchupi, E., 1972. Western North Atlantic Ocean: Am. Assoc. Petroleum Geologists Mem. 17, 532 p.

Fuglister, F. C., 1963. Gulf Stream '60. Progress in Oceanography, v. 1, p. 265-383.

Gray, I. E. and Cerame-Vivas, M. J., 1963. The circulation of surface water in Raleigh Bay, North Carolina. Limnology and Oceanography, v. 8, p. 330-337.

Hadley, J. B. and Devine, J. F., 1974. Seismotectonic map of the Eastern United States. U.S. Geological Survey MF 620.

Harrison, W., 1974, The fate of crude oil spills and the siting of four supertanker ports. The Canadian Geographer, v. 18, no. 3, p. 211-231.

Heezen, B. C., Hollister, C. D. and Ruddiman, W. F., 1966. Shaping of the continental rise by deep geostrophic contour currents. Science, v. 152, p. 502-508.

Henry, H. R., and Kohout, F. A., 1972. Circulation patterns of saline groundwater affected by geothermal heating - as related to waste management and environmental implications, Mem. 18, Am. Assoc. Petroleum Geologists, p. 202-221.

Jeffery, P. G., 1973. Large-scale experiments on the spreading of oil at sea and its disappearance by natural factors. (in) Proceedings of joint conference on prevention and control of oil spills. American Petroleum Institute, Washington, D. C., p. 469-474.

Klein, H., 1971. Depth to base of potable water in the Floridan aquifer. U.S. Geol. Surv. - Fla. Dept. Nat. Res., Map Series No. 42.

Knauss, J. A., 1969. A note on the transport of the Gulf Stream. Deep-Sea Research, Supplement to v. 16, p. 117-124.

Kohout, F. A., 1965. A hypothesis concerning cyclic flow of salt water related to geothermal heating in the Floridan aquifer. Trans. N.Y. Acad. Sci., Ser. II, v. 28, p. 249-271.

Kohout, F. A., 1967. Ground-water flow and the geothermal regime of the Floridan plateau. Trans. Gulf Coast Assoc. Geological Socs., v. 17, p. 339-354.

Krause, R. E., and Gregg, D. O., 1972. Water from the Principal artesian aquifer in coastal Georgia. U.S. Geol. Surv. and Georgia Dept. Nat. Resources, Hydrologic Atlas I.

Long, L. T., 1975. A model for the earthquake tectonics of the Bowman and Summerville, South Carolina epicentral zones. Geol. Soc. Am., Abs. w. Programs, v. 7, no. 4, p. 511.

Maher, J. C., 1971, Geologic framework and petroleum potential of the Atlantic Coastal Plain and Continental Shelf: U.S. Geol. Survey Prof. Paper 659, 98 p.

Manheim, F. T., 1967. Evidence for submarine discharge of water on the Atlantic continental slope of the southern United States and suggestions for further search. Trans. N.Y. Acad. Sci., Ser. II, v. 29, p. 839-852.

McClellend, Bramlette, 1974, Geologic engineering properties related to construction of offshore facilites on the Mid-Atlantic Continental Shelf, in: Marine environmental implications of offshore oil and gas development in the Baltimore canyon region of the mid-Atlantic coast: Estuarine Research Federation Outer Continetal Shelf Conference and Workshop, College Park, Md., Dec. 2-4, 1974, Proc., p. 217-242.

Meyerhoff, A. A., and Hatten, C. W., 1974, Bahamas salient of North America: Tectonic framework, stratigraphy, and petroleum potential: Am. Assoc. Petroleum Geologists Bull., v. 58, no. 6, part II of II (June, 1974), p. 1201-1239.

Niiler, P. P., and Richardson, W. S., 1973. Seasonal variability of the Florida Current. J. Marine Research, v. 31, p. 144-167.

Offshore oil group, MIT, 1973. The Georges Bank Petroleum Study, v. 2, Mass. Institute of Technology. Rpt. no. MITSG 73-5.

Richardson, P. L. and Knauss, J. A., 1971. Gulf Stream and Western Boundary Undercurrent observations at Cape Hatteras. Deep-Sea Research, v. 18, p. 1089-1109.

Richardson, W. S., Schmitz, W. J., Jr., and Niiler, P. P., 1969. The velocity structure of the Florida Current from the Straits of Florida to Cape Fear. Deep-Sea Research, Supplement to v. 16, p. 225-231.

Robinson, A. R., 1971. The Gulf Stream. Phil. Trans. R. Soc. (A), v. 270, p. 351-370.

Rowe, G. T., and Menzies, R. J., 1968. Deep bottom currents off the coast of North Carolina. Deep-Sea Research, v. 15, p. 711-719.

Sbar, M. L., and L. R. Sykes, 1973. Contemporary compressive stress and seismicity in North America: an example of intra-plate tectonics. Geol. Soc. Am. Bull. v. 84, p. 1861-1882.

Schmitz, W. J. and Richardson, W. S., 1968. On the transport of the Florida Current. Deep-Sea Research, v. 15, p. 679-693.

Schwartzberg, H. G., 1971. The movement of oil spills. (in) Proceedings of joint conference on prevention and control of oil spills. American Petroleum Institute, Washington, D. C., p. 489-494.

Stefansson, V., Atkinson, L. P. and Bumpus, D. F., 1971. Hydrographic properties and circulation of the North Carolina Shelf and Slope Waters. Deep-Sea Research, v. 18, p. 383-420.

Stewart, D. M., 1975. Is a major earthquake imminent in North Carolina centered near Southport? Geol. Soc. Am., Abs. w. Programs v. 7, no. 4, p. 540.

Stommel, H., 1958. The Gulf Stream - a physical and dynamical description. U. Calif. Press, Berkley, 202 p.

Stringfield, V. T., 1966. Artesian water in Tertiary limestone in the southeastern United States. U.S. Geol. Surv. pp. 517, 226 p.

Tarr, A. C., and King, K. W., 1973. South Carolina seismic program. U.S. Geological Survey open-file report.

Taylor, C. B. and Stewart, H. B., Jr., 1959. Summer upwelling along the east coast of Florida. J. Geophysical Res., v. 64, p. 33-40.

Taylor, P. T., Zietz, I., and Dennis, L. S., 1968. Geologic implications of aeromagnetic data for the eastern continental margin of the United States. Geophysics, v. 33, p. 755-780.

United States Department of Commerce, 1974. United States Coast Pilot 4, Atlantic Coast, Cape Henry to Key West, twelfth edition. National Ocean Survey, Washington, D. C., 229 pp.

Vernon, R. O., 1973. Top of the Floridan artesian aquifer. U.S. Geol.Surv. - Fla. Dept. Nat. Res., Map series No. 56.

von Arx, W. S., Bumpus, D. F., and Richardson, W. S., 1955. On the fine structure of the Gulf Stream front. Deep-Sea Research, v. 3, p. 46-65.

Wait, R. L., 1965. Geology and occurrence of fresh and brackish ground water in Glynn county, Georgia. U.S. Geol. Surv., Water -Supply Pap. 1613-E 94 p.

Weatherly, G. L., 1972. A study of the bottom boundary layer of the Florida current. J. Physical Oceanography, v. 2, p. 54-72.

Woolard, G. P., 1969. Tectonic activity in North America as indicated by earthquakes. (in), P.J. Hart, ed. The Earth's Crust and Upper Mantle Am. Geophys. Union, Geophysical Mon. 13, p. 125-133.

VI. Operational Considerations

A. Technology

The technology required for exploration of areas in the South Atlantic OCS on the Continental Shelf, in water depth of less than 200 m is available, most of it being continuously demonstrated in the Gulf of Mexico OCS. Technology is not presently considered available, however, for all the operational phases of any potential development in areas from 200 m up to 600 m water depth (see Fig. 47).

Most drilling units for exploratory drilling are in great demand and must be obtained from the Gulf of Mexico or other offshore areas. A recent offshore mobile rig count 275 total units in operation, 13 idle and 5 in transit, with an additional 163 units under construction or planned comprising 41 drill ships or drill barges, 63 jack-ups and 59 semi-submersibles. (Offshore, 1975). It is estimated that 133 offshore rigs will be completed in 1975, and 126 in 1976 (Ocean Oil Weekly Report, 1975, and see Table 5).

Table 5.-- Size of drilling rigs under construction and projected (from Ocean Oil Weekly Report, 1975)

	1974		1975 (estimate)		1976 (estimate)	
Size	Land	Offshore	Land	Offshore	Land	Offshore
5,000-10,000 ft	25	8	44	6	45	13
10,001-18,000 ft	42	22	40	37	45	17
18,001-and over	10	50	17	90	29	96
TOTALS	77	80	101	133	119	126

Offshore areas in the South Atlantic OCS which appear favorable for oil and gas exploration, based on presently available seismic data, occur from 48 km to about 137 km from shore in water depth from less than 20 m to 200 m. Most of those areas are in water depths of less than 100 m.

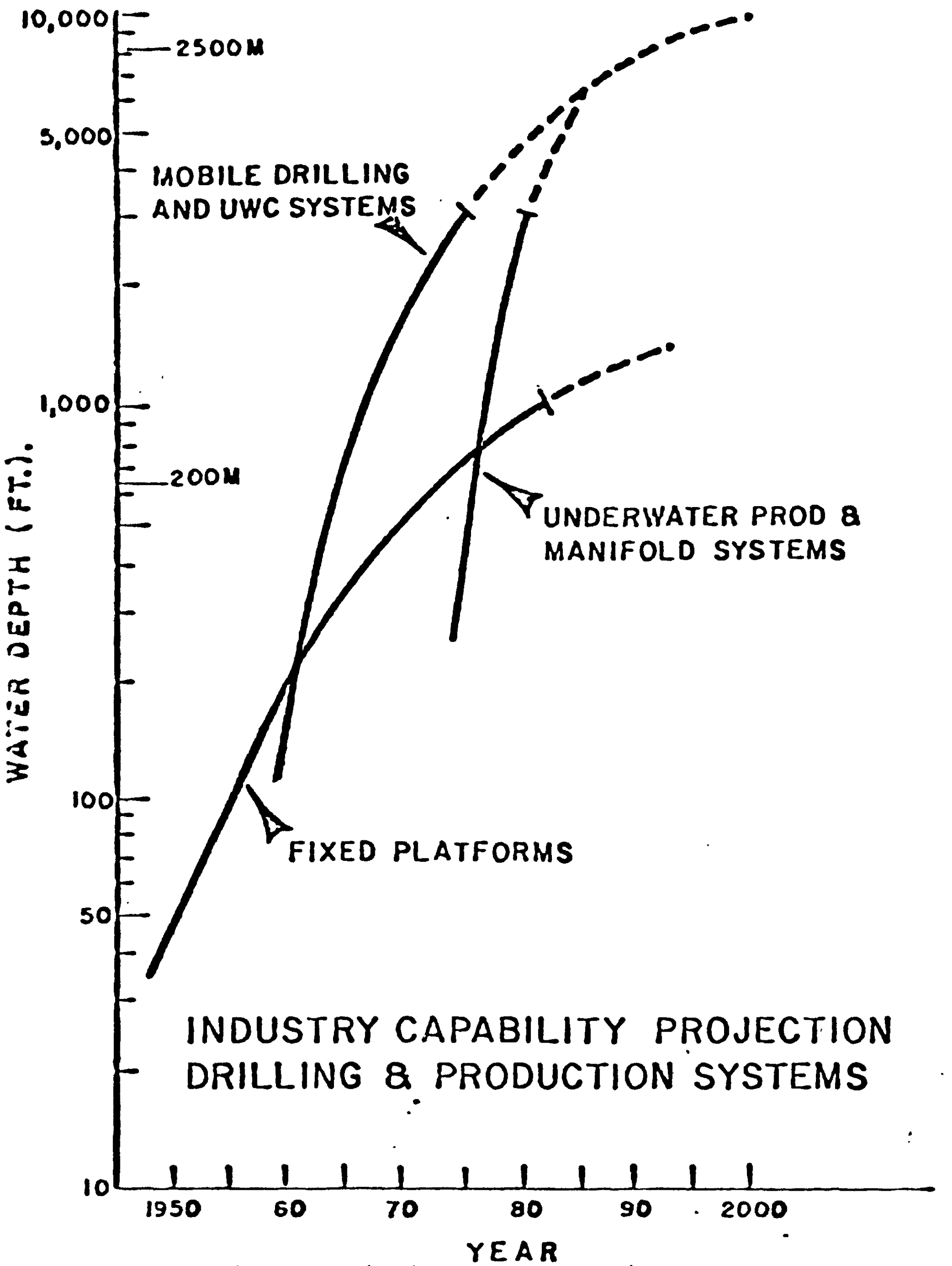


Fig. 47 - Projection of drilling and production capability. (from Greer, 1973).

The paucity of seismic data beyond 200 m has only identifed a few structures.

Technology is presently available to accomplish exploratory drilling as well as the construction of platforms to accomodate development drilling, production facilities and all other operations at the expected distances from shore and at water depth up to 200 m (see Fig. 47 and 48). Technology for drilling and completing (underwater completions) wells at water depth up to 600 m and greater is considered to be available, however, production facilities and pipeline or storage systems are now considered to be in the research and development stage. Only prototype production systems have been tested for these depths with no complete system yet in a fully operational state anywhere in the world.

B. Manpower

Most of the skilled manpower for exploratory drilling will have to come from other areas such as the Gulf of Mexico. The reservoir of skilled manpower for other operations, such as development drilling, production, and installation of platforms, pipelines and onshore facilities, is also relatively small throughout adjacent onshore areas due to the lack of previous petroleum development in the coastal portions of the South Atlantic seaboard states. Although the skilled manpower for most of these operations is expected to come from the Gulf of Mexico where there is a similar climatic environment, there should be adequate manpower in the South Atlantic seaboard states available for training. Also, it is possible that some personnel will be available from other Atlantic OCS areas by the time the first leases are issued in the South Atlantic OCS.

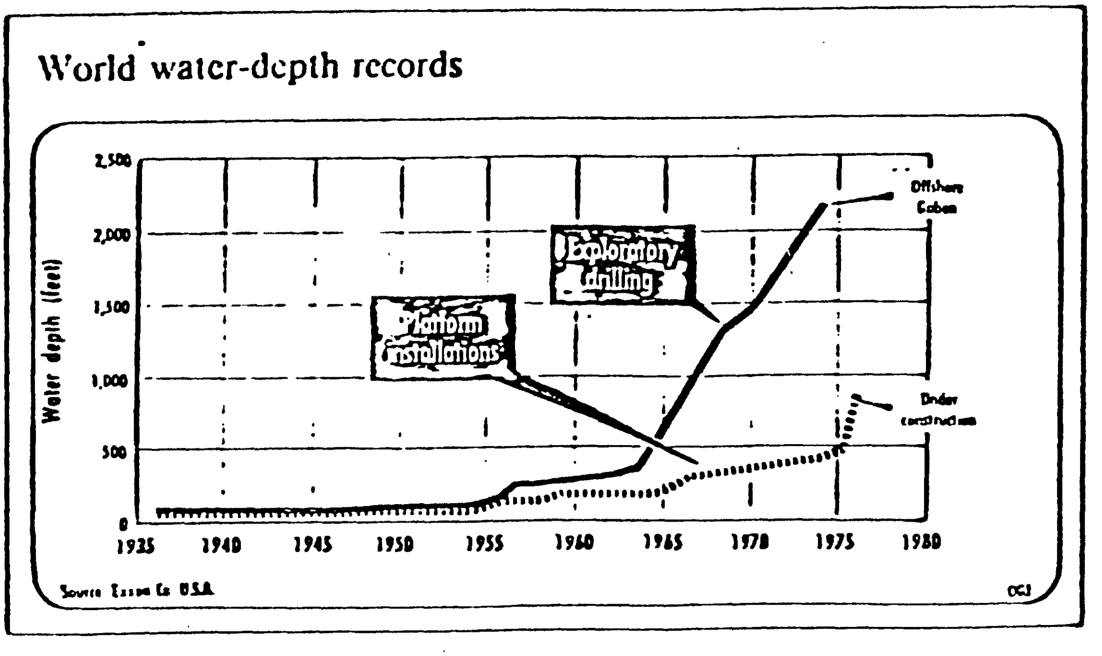


Fig. 48 - World water-depth drilling records.
(from Oil and Gas Journal, 1975)

C. Time Frame

Although initial exploratory drilling may be commenced within months following a lease sale, the time frame for significant development may be 4-5 years subsequent to a sale. It is estimated that it will be 6-7 years after a sale until actual production is commenced and 12-16 years until peak production for the area is attained.

D. Infrastructure

Preliminary estimates of peak production and facilities requirements are highly speculative in the absence of demonstrated reserves of oil and gas.

Based on the assumptions that the areas leased will contain 400 million barrels of oil and 700 billion cubic feet of gas (being the mean of the estimated undiscovered recoverable resources), about 140 oil wells, some of which will produce appreciable amounts of gas, and 15 gas wells, contributing a significant amount of condensate and NGL, or 155 producible wells, will be needed, along with an additional 18 or more exploratory wells which will be dry holes. Also, there will need to be 10 drilling and production platforms, about 322 km of large diameter pipelines, and 2 onshore terminals. Peak daily production may reach 70,000 barrels of oil and 125 million cubic feet of gas.

Based on a 5 percent Resource Probability under which there is a 1 in 20 chance that the areas leased will contain more than 1.5 billion barrels of oil and 2.8 trillion cubic feet of gas, about 400 oil wells, some of which will produce appreciable amounts of gas, and 40 gas wells, contributing a significant amount of condensate and NGL, or 440 producible wells, will be needed, along with an additional 45 or more exploratory wells. Also, there will need to be 20-25 drilling and production platforms, about 800 km of large diameter pipelines and 4 onshore terminals. Peak daily production may reach 200,000 barrels of oil and 400 million cubic feet of gas.

The above estimates are based on the assumption that the estimated undiscovered resources will be produced during a 25-30 year period following the date of initial production from development wells drilled at an average distance of 97 km from shore.

BIBLIOGRAPHY

Greer, R. L., 1973, "Offshore drilling and production technology - Where do we stand and where are we headed?: Amer. Petroleum Institute Meeting, April 9-11, 1973, Denver, Paper 362-C.

Ocean Oil Weekly Report, 1975, Vol. 9, No. 30, Apr. 21, 1975.

Offshore Magazine, 1975, World wide rig location: v. 35, no. 5, p. 397.

VII Summary and Conclusions

The area designated for possible oil and gas lease sale in Bureau of Land Management memorandum 3310 #43 (722) and referred to therein as part of the United States South Atlantic Outer Continental Shelf (OCS) contains about 98,000 square kilometres of the continental margin seaward of the 3 mile offshore limit and within the 600 metre isobath. The area, offshore of North Carolina, South Carolina, Georgia, and Florida, encompasses parts of three physiographic provinces: the Continental Shelf, the Florida-Hatteras Slope, and the Blake Plateau. The Continental Shelf has a gradient generally less than 50 m/km. Topographically, the shelf's surface is quite irregular and marked by extensive shoals off the major capes. Seaward of the shelf and separating it from the Blake Plateau is the Florida-Hatteras Slope with a gradient of around 7 m/km. Relief on the Florida-Hatteras Slope ranges from 700 m in the southern part of the area and decreases northward. The Blake Plateau is part of a relatively flat continental borderland that has been extensively eroded by the Gulf Stream.

Within the studied area, surficial sediments are predominently sand that becomes increasingly carbonate-rich both southward and seaward. Most of the sediments are derived from rivers, carbonate precipitation, and from authigenic processes. Much of the sediment transport on the shelf takes place in a cross-shelf direction.

The major structural features in the U.S. South Atlantic region are the Southeast Georgia Embayment, the Cape Fear Arch, and the Peninsular Arch. The Southeast Georgia Embayment is an east-plunging depression recessed into the Atlantic Coastal Plain between Cape Fear, North Carolina and Jacksonville, Florida. Basement rocks (rocks of pre-Cretaceous age with velocities in excess of 5.6 km/sec) dip seaward from the south flank of the Cape Fear Arch, which bounds the embayment on the north, and the Peninsular Arch which bounds the southeastern limit of the embayment. The basement surface beneath the basin slopes seaward at about 23 m/km to about 80 km offshore where the dip steepens greatly. The Cape Fear Arch is a southeast plunging basement nose extending from the Fall Line to at least the North Carolina coastline. The Peninsular Arch is the dominant positive subsurface feature in the southeastern United States and formed the backbone of the broad Florida Platform throughout most of Paleozoic to Holocene time.

Gravity and magnetic anomalies within the area probably result from emplacement of magma bodies along linear features representing fundamental crustal boundaries. The most prominent magnetic feature of the continental margin is the East Coast Magnetic Anomaly which trends along the shelf-slope break north of the study area and bifurcates south of Cape Hatteras. One branch continues under the Blake Plateau and the other branch swings westward and apparently crosses the coast at Brunswick, Georgia. There is also a prominent positive free-air gravity anomaly trending along the shelf-slope boundary also bifurcating south of Cape Hatteras with one branch crossing the Georgia coast at about the same position as the magnetic anomaly. The segments of the gravity and magnetic anomalies that cross the Georgia coast have been interpreted as representing an ancient continental boundary where two formerly separate continental plates collided and were welded together. A group of magnetic and gravity anomalies south of Cape Romain herein called the "Cape Romain Anomalies" are interpreted as due to dense gabbroic intrusions in the crust.

Seismic reflection profiles indicate that the present shelf was formed by upbuilding and outbuilding, and that the difference in elevation of the continental shelf and Blake Plateau is due solely to a more rapid Tertiary sedimentary buildup on the shelf than on the plateau. The dating of this accumulation is based on data from the early JOIDES cores. Refraction data indicate a minor basement (?) ridge beneath the outer shelf between 30° and 32° N at 80° W. JOIDES data also suggest a gentle fold or an accretionary structure (reef?) off the east coast of Florida. Several other minor structural features have been identified by refraction and reflection techniques and drilling. These are named the Yamacraw Uplift, Burton High, Stono Arch, and Suwannee Channel. Late Cretaceous through late Eocene sedimentation probably was influenced by the Suwannee Channel.

There may be as much as 5,500 m of sedimentary rocks in the Southeast Georgia Embayment (out to the 600 m water depth) which were deposited on crystalline basement rocks. Basement rocks beneath the Southeast Georgia Embayment are similar to those exposed in the Appalachian Piedmont province--pre-Cretaceous granites, schists and other igneous and metamorphic rocks. Triassic deposits are likely to exist beneath the inner Continental Shelf and are believed to consist of nonmarine arkosic sandstones, shales, basalt flows, and diabase intrusions deposited in northeast-trending, relatively narrow grabens downfaulted in the basement rocks.

Rocks of possible Jurassic age have been described from the Esso Hatteras Light well and also from wells in the Bahamas. Jurassic marine carbonates in the Bahamas grade northward to carbonates, shales, sand, and arkose in North Carolina. Salt of Jurassic age may be present in the Southeast Georgia Embayment. Up to 4,000 m of Jurassic to Lower Cretacous rocks are expected out to the 600 m water depth. A thick wedge of Lower Cretaceous rocks probably underlies the Continental Shelf off Florida and Georgia. In southern Florida, shallow-water marine limestones and dolomites with beds of anhydrite make up the principal subsurface rock types. In coastal North Carolina, the Lower Cretaceous is a marine section made up of shales, sand and sandy limestone. Lower Cretaceous rocks have been dredged from the Blake Escarpment at depths from 2374 m to 4747 m. The Upper Cretaceous is composed almost entirely of marine carbonates in southern Florida. Northward, the rocks are nonmarine to marginal marine, sandstones and shales, and minor amounts of carbonates. In general, Upper Cretaceous rocks will probably maintain a fairly constant thickness (600 m) for the OCS and grade downdip from terrigenous sands to more marine chalks, limestones, and dolomites.

The Cenozoic rocks are predominantly shallow-water marine carboanates in Florida grading northward into a marginal marine to marine clastic facies composed of sands marls, and limestones. From Late

Cretaceous to late Eocene time, the clastic and non-clastic facies boundary was separated by the Suwannee Channel and has shifted northward through time. The offshore Cenozoic section has been penetrated by JOIDES and U.S. Coast Guard test holes and is expected to range in thickness from 600 m to 1100 m.

A reconstruction of the geologic history suggests that the present continental margin began to form as a result of continental rifting during Triassic time. During the remainder of the Mesozoic and Tertiary, while the North American and African plates drifted apart, more than 6 km of sediment may have been deposited. Deposition generally kept pace with subsidence creating a shallow water environment. Because of erosion by the Gulf Stream, Tertiary sediments are extremely thin on the Blake Plateau and somewhat thicker shoreward where they have formed the sedimentary accumulation which is the present Continental Shelf.

No commercial production of hydrocarbons has been developed on the Atlantic Coastal Plain immediately adjacent to the studied area even though hydrocarbon shows have been encountered in onshore Coastal Plain wells of North Carolina, and Florida. However, the Southeast Georgia Embayment has in the past been compared on certain parameters to producing areas such as the Tampico Embayment of Mexico and the Saudi Arabian side of the Persian Gulf. However, based on other parameters and differences in basin types and geology, these comparisons may not be justified. The area might be compared to the Senegal

Basin on the west coast of Africa where the opposing continental margins appear symmetrical with respect to the tectonic and stratigraphic framework. The Southeast Georgia Embayment might best be compared to the South Florida Embayment on the basis of geographic proximity and similarity in depositional environments. Both basins contain shallow-water carbonates deposited on a slowly subsiding shelf without major interruptions from Jurassic through Upper Cretaceous time. Both basins even have the same relative thickness of stratigraphic units--a thick Lower Cretaceous section with a relative thin Upper Cretaceous section.

The offshore Southeast Georgia Embayment appears to have the necessary elements for hydrocarbon production--traps, source rocks, and reservoir rocks. Potential hydrocarbon traps are expected to be chiefly stratigraphic such as facies changes, updip pinchouts, reefs, and unconformities, although large drape structures and low relief anticlines will also be important. Based on all available well data, comments can be made on potential source rocks and reservoir rocks by geologic age. Nonmetamorphosed Paleozoic rocks will probably make poor exploration targets because of the general lack of reservoir rocks and the lengthy exposure to sub-aerial processes Most Triassic rocks in the Southeast Georgia Embayment have little hydrocarbon generating potential because of the continental to brackish water oxidizing environments in which the rocks were deposited.

However, the sands of these units might make good reservoirs. The Jurassic section is a prolific hydrocarbon producer in the Gulf Coast and in the giant Jay Field in northwest Florida and should offer promising prospects for hydrocarbon production in the Southeast Georgia Embayment. A thick section of porous dolomite and limestone which would make excellent reservoir rocks is expected offshore. The Lower Cretaceous section produces in the South Florida Embayment and is believed to offer the best possibility for hydrocarbon entrapment in the Southeast Georgia Embayment because of the presence of seals, good reservoir rocks, and possible hydrocarbon source rocks. Lower Cretaceous anhydrite and shales are expected offshore and should make excellent hydrocarbon seals. Adequate porosity and permeability as well as cavernous porosity is expected from Lower Cretaceous rocks. The early Cretaceous may not have been a time of extensive oxidation of marine sediments, and organic rich carbonate muds in contact with potential reservoir rocks could provide significant source rocks. Approximately 300 m of black marine Lower Cretaceous shale has been penetrated by two DSDP holes and is probably equivalent to the 328 m of black marine shale that has been reported from a well drilled in the Bahamas. This could be an excellent source rock for Upper Jurassic and Lower Cretaceous reservoir rocks. Very stable shallow-water shelf conditions and slow rates of sedimentation during the Upper Cretaceous lessens the hydrocarbon potential of Upper Cretaceous rocks. The thin, shallow, and flushed Tertiary strata of the

Southeast Georgia Embayment offer little possibility for commercial quantities of hydrocarbons.

Estimates of undiscovered recoverable oil and gas resources for the area under study have been prepared. The appraisal procedure consists of 1) carefully reviewing the available geological and geophysical data gathered by area specialists, 2) individual and collective appraisals of the areas using as references volumetric-yield procedures, basin analysis, Hendricks potential area categories, and other published appraisals, and 3) computer fitting of lognormal curves to the high, low, and modal values of the Resource Appraisal Group's assessment to compute the probability distribution for each province, and related statistical treatment. Statistical mean estimates for the undiscovered recoverable petroleum resources are calculated to be 0.4 billion barrels of oil and 0.7 trillion cubic feet of gas. At the 5 percent probability level (1 in 20 chances), the undiscovered recoverable petroleum resources are calculated to be 1.5 billion barrels of oil and 2.8 trillion cubic feet of gas. These undiscovered recoverable petroleum resources are those quantities of oil and gas that may be reasonably expected to exist in favorable settings, but which have not yet been identified by drilling. Such estimates therefore carry a high degree of uncertainty.

The general paucity of "reserves" of hard minerals (other than oil and gas) of the U.S. Atlantic OCS area appears to result not from insufficient sampling, but from an actual dearth of such minerals. Sand and gravel deposits most likely available now for economic extraction are large--even though only partly evaluated. Reserves on the U.S. Atlantic OCS (including the Southeast Georgia Embayment area) are at least 450 billion tons of dry sand and at least 1.4 billion tons of gravel. The total amount of gravel may exceed 50 billion tons and the inferred sand resources are probably 10 or more times greater than now estimated.

With respect to potential hazards, studies based on surface current drifters indicate probable oil spill trajectories, and show strong shoreward components of drift at some times of the year. The most notable shoreward drifts, resulting in very high recovery rates of drifters, are those toward the coast of northern Florida, with a rather strong concentration at Cape Canaveral. Weather conditions are generally not as severe as in areas to the north, but hurricanes and occasional severe storms occur. The irregular, shallow shelf may cause wave refractions which could prove dangerous.

Mud or possible peat layers, formed behind barrier beaches during a lower sea level, might occur on the shelf. Such layers probably would not provide good support characteristics. Ripple marks and crossbedding found in sediments of the outer shelf indicate the surficial sediment may be mobile.

The eastern United States, situated entirely within a single tectonic plate, experiences a low overall level of seismic activity with one or two local exceptions. A severe earthquake occurred at Charleston in 1886 and the Charleston area has had a distinctly higher seismicity than the rest of the southeastern United States east of the Appalachians. It has also been suggested that precursors for an earthquake have been recognized in the Cape Fear area.

The most utilized aquifer in the Southeast Georgia Embayment area is the "principal artesian" or "Floridan" aquifer in Tertiary limestone. It is locally affected by salt water intrusion from both salty zones within the aquifer and the ocean. Precautions are required during well completion and trenching to avoid exacerbating these problems. Solution caverns, expected in the limestones of the southern part of the area, could cause difficulty in drilling or perhaps collapse, resulting in damage to bottom-mounted platforms and possible leakage of water or oil.

With respect to operational considerations, the technology for petroleum exploration on the Continental Shelf in water depths of less than 200 m is available. Technology is not at present considered readily available, however, for all the operational phases of any potential development in water depths from 200 m up to 600 m water depth. Mobile drilling units are in great demand around the world and will have to be brought in from other areas, along with skilled manpower. Our highest estimates indicate that 20-25 platforms, 440 producing wells, 800 km of pipeline, and 4 onshore terminals may be needed. The time frame for production, using our high estimates (at the 5% probability level) for the undiscovered recoverable resources, could include 4-5 years for significant development, 6-7 years until production commences, and 12-16 years until peak production.

Appendix I. Resource Appraisal by Geologic Province

A. Province Summary Sheets

1. South Atlantic
2. Blake Plateau

B. Data Formats

1. South Atlantic
2. Blake Plateau

FORM #3

Region *Atlantic Coast Offshore*
RAC No. ____

PROVINCE SUMMARY SHEET

PROVINCE *SOUTH ATLANTIC CONTINENTAL SHELF (0-200 meter isobath)*

*Stage of Exploration: Early ____ Intermediate ____ Late ____

*Area (Mi^2)-----Total Sed. Province: *34847* % Productive ____

see attached page { Areas by Depth Units: 5000' ____ 5000-10,000' ____
10,000'-15,000' ____ 15,000-20,000' ____
20,000'-30,000' ____ 30,000' ____

*Thickness of sediments (Ft.): Avg. *8,492* Max. *16,400*

*Volume of sediments ($Mi.^3$) ____
Total Province: *56,044*
% Drilled *<0.1*
% Explored *Essentially none*

Stratigraphic Age Range: From *(U. J ?) Lower Cretaceous* Through *Holocene*

*Producing and/or Prospective Horizons ____
Age: *Jurassic(?)* a. *Lower K.* b. *Upper K.* c. *Lower T.* d. *[illegible] T. & Q.*
Gross Thickness: *100'+* *2000'+* *2000'+* *500'+* Total: *4,600+*

*Dominant Lithology (Total Province) ____
Type *ls + [illegible]* , *clastics (mainly sands)*
% of Volume *~80%* *~20%*
Ratio, Marine/non-marine *9:1 (est.)*

Types of Traps ____
Stratigraphic *Ss & carbonate pinchouts*
Structural *Unknown*

*Structural Aspects ____
Type Basin *Stable [illegible] Margin*
Geometry *Asymmetrical*

Indications of Hydrocarbons ____
Producing Trends *NA*
Seeps, Tar Sands, etc. *[illegible] & shows reported from [illegible] & from North Carolina onshore.*

Probable Source Beds (Age and Lithology) ____

Major Seals (Age and Lithology) ____

Field Size Distribution:	Avg.	R.Min.	R.Max.
Oil (mill.bbls):	*NA*		
Gas (bcf):	*NA*		

Nature of Hydrocarbons:	Avg.	R.Min.	R. Max.
API Gravity	*NA*		
Sulfur Content	*NA*		
*Recovery Factor	*NA*		

*Production, Reserves, & Resources:	Crude Oil	NGL	Nat. Gas
Cum. Production (bill.bbls.;tcf)			
Measured Reserves "			
Indicated Reserves "			
Inferred Reserves "			

*Wells Drilled to Date: *([illegible] 1 & 2)* Date: ___/___/___
Exploratory Wells *--*
Development Wells *--*

*Resource Estimates (Undiscovered--In Billion BBLS or Trillion Cu.Ft.)
([illegible]) Recoverable In Place
Outside Sources *([illegible]) 250 mill bbls oil & 1.7 tcf gas for entire [illegible] Coastal Plain*
U.S.G.S. Evaluator ____
Analogs *[illegible]*
RAG Estimate ____
NPC *(Atlantic Coast [illegible] 0-600' wtr [illegible] .250 [illegible], .083 [illegible])*
*Province Qualitative Rating: Oil ____ Gas ____

Posted by: *[illegible]* Date *[illegible]* Approved *GLD* Date *3-12-7[illegible]*

* Data most pertinent to resource appraisals. 2/4/75

FORM #3

Region ATLANTIC COAST OFFSHORE
RAG No. ______

PROVINCE SUMMARY SHEET

PROVINCE BLAKE PLATEAU, Adjacent Slopes and Continental Rise (200-2500 m. isobath) Including Blake Plateau Trough

*Stage of Exploration: Early (very little) Intermediate ______ Late ______

*Area (Mi^2)-----Total Sed. Province: 50,519 % Productive ______

See attached form

Areas by Depth Units: 5000' ______ 5000-10,000' ______
10,000'-15,000' ______ 15,000-20,000' ______
20,000'-30,000' ______ 30,000' ______

*Thickness of sediments (Ft.): Avg. 21,041 Max. >9 km. (29,700)

*Volume of sediments ($Mi.^3$) 201,318
Total Province: ______
% Drilled <0.1
% Explored Essentially none

Stratigraphic Age Range: From Upper Jurassic Through Holocene

*Producing and/or Prospective Horizons ______
Age: a. ______ b. ______ c. ______ d. ______
Gross Thickness: ______ Total: ______

*Dominant Lithology (Total Province)
Type Limestone & dolomite ; clastics (mainly muds)
% of Volume ~90% ~10%
Ratio, Marine/non-marine ______

Types of Traps
Stratigraphic Reefs, Pinchouts
Structural ______

*Structural Aspects
Type Basin Extracontinental (Atlantic type margin)
Geometry Asymmetrical to Symmetrical (steep slopes)

Indications of Hydrocarbons ______
Producing Trends ______
Seeps, Tar Sands, etc. ______

Probable Source Beds (Age and Lithology) J. & K. (Black muds)

Major Seals (Age and Lithology) Unknown

Field Size Distribution:	Avg.	R.Min.	R.Max.
Oil (mill.bbls):	NA		
Gas (bcf):	NA		

Nature of Hydrocarbons:	Avg.	R.Min.	R. Max.
API Gravity	NA		
Sulfur Content	↓		
*Recovery Factor	↓		

*Production, Reserves, & Resources:	Crude Oil	NGL	Nat. Gas
Cum. Production (bill.bbls.;tcf)	NA		
Measured Reserves "	↓		
Indicated Reserves "	↓		
Inferred Reserves "	↓		

*Wells Drilled to Date: JOIDES DSDP 4,5,6 Date: ___/___/65
Exploratory Wells 0
Development Wells 0

*Resource Estimates (Undiscovered--In billion BBLS or Trillion Cu.Ft.)

	Recoverable	In Place
Outside Sources	NPC 1973 (Atlantic Coast ... excluding Fla. offshore OIP	...
U.S.G.S. Evaluator		NPC 0.33 Rec. 1500 ...
Analogs		
RAG Estimate		

*Province Qualitative Rating: Oil ______ Gas ______

Posted by: Kori Carlson Date 2-2-75 Approved GLD Date 2-11-75

* Data most pertinent to resource appraisals. 2/4/75

RAG Province Number ____

Completion Date ____

Author(s) W. J. PERRY & C. GIRARD

DATA FORMAT RESOURCE APPRAISAL AND EVALUATION BY GEOLOGIC PROVINCE

*I. IDENTITY AND LOCATION OF GEOLOGIC PROVINCE

*A. Name of Province or Basin(s): South Atlantic Continental Shelf (0-200 meter isobath)

B. Geographic Location:

1. Country: UNITED STATES, OFFSHORE FROM NORTH FLORIDA, GEORGIA, & SOUTH CAROLINA.

2. Location:

Latitude between parallels	N or S	29°	N	
	and N or S	35°	N	
Longitude between meridians	E or W	81°	30'	W
	and E or W	75°	15'	W

	Yes	No
Onshore:		✓
Offshore:	✓	

C. Name of the author(s) of the form: PERRY AND GIRARD

D. Date of completion of the form: FEBRUARY / 4 / 1975

* Items preceded by an asterisk are explained in instruction sheets

November 18, 19

*II. AVAILABILITY OF BASIC INFORMATION FOR PROVINCE

*A. Indicate available maps of area and mapped intervals of horizons:

Maps	Intervals or horizons
1. None	
2. Structural maps	DEPTH IN KILOMETERS BELOW SEA LEVEL TO LAYER 3, (top of ocean crust) [EMERY AND UCHUPI, FIG. 109
3. Isopach maps	1:5,000,000 TOTAL SEDIMENT THICKNESS (IN KM) PERRY & GIRARD (UNPUB — do — ATLANTIC OCS PROJECT (FIG. 8 OF MAPS PROVIDED MARCH 1974)
4. Facies maps	
5. Basement configuration maps	GENERALIZED BASEMENT DEPTH CONTOUR MAP (SHERIDAN, 1974, FIG. 12
6. Oil and gas field maps	
7. Geophysical maps (Seismic, gravity, etc.)	BOUGUER GRAVITY (MAHER, 1971, U.S.G.S. PROF. PAPER 659, PLATE 7) AEROMAGNETIC MAP (TAYLOR, ZIETZ, DENNIS, 1968, GEOPHYSICS, V. 33, F

* Items preceded by an asterisk are explained in instruction sheets.

NOTE: – Include copies of all available maps with this completed form. If it isn't feasible at this time for all the maps available, please indicate the location and source of this information for inventory and reference purposes.

Maps	Significant Reports	Location	Source (or author)
GENERALIZED STRUCTURE OF PRE-CRETACEOUS SURFACE	AAPG MEMOIR 15	ATTACHED	RAINWATER (1971, p. 1317, fig. 4)
AGE OF BASEMENT RX. GENERALIZED SEDIMENT THICKNESS	} AAPG MEMOIR 17	—— do ——	EMERY & UCHUPI (1972, FIG. 89 & 188

*B. Indicate available cross-sections of area and include copies with form, or indicate source:

Type	Known	Number	Source
1. None			AAPG MEM. 1
2. Geological	✓	{ 1 1	SPIVAK & SHELBURNE (1971, p. 1300, fig U.S.G.S. PROF. PAPER 581-E, p. 7. 1
3. Geophysical (seismic, etc.)	✓	1 1	SHERIDAN (1974, fig. 9, p. 399) SPIVAK & SHELBURNE (1971, p. 1300, AAPG)
4. Stratigraphic column	✓	1	EMERY & UCHUPI (1972, fig. 81, p. 9

*C. Indicate available logs in area:

Type	Known	Number
1. None		
2. Electric (SP) logs		
3. Induction logging		
4. Sonic logs		
5. Neutron logs		
6. Others	JOIDES 1, JOIDES 2	2

*D. Comments upon the source, availability and location of any of the above information:

U.S.G.S. PROF. PAPER 581 A-E

*E. Indicate the level or degree of knowledge concerning this province as a whole:

	Yes	No	
1. Surface geologic studies	✓		
2. Drilling stages:			
a. No drilling (no seismic)		✓	EXCEPT JOIDES 1 + 2
b. No drilling (w/seismic)	✓		
c. Early stage (immaturely explored)		✓	
d. Intermediate stage (fairly well explored)		✓	
e. Late stage (maturely explored)		✓	
3. Province well-explored to basement depths:			
a. Drilling only		✓	
b. Drilling and seismic		✓	
c. Seismic only		✓	

*III. BASIC GEOLOGY BY PROVINCE

*A. Province geometry:

*1. Configuration of province: ARCUATE, MARKEDLY ELONGATE (>2:1)

*2. Area of province:

		Area(square mile)	Percent explored	Percent productive	VOLUME
Total sedimentary rock Province		34,847	NONE	UNKNOWN	
Area with maximum depths to basement of:	TO CALC. VOLUMES:				
a. less than ~~5,000 feet~~ 2 KILOMETERS	(0.6213636 x)	12,285	—do—	—do—	7,633.5 mi
b. ~~5,000 to 10,000 feet~~ 2-4 KM	(1.8640907 x)	17,450	—do—	—do—	32,528.4 mi
c. ~~10,000 to 15,000 feet~~ 4-6 KM	(3.106818 x)	5,112	—do—	—do—	15,882.1 mi
d. 15,000 to 20,000 feet					
e. 20,000 to 30,000 feet					
f. greater than 30,000 feet					

TOTAL VOLUME 56,04[illegible]

NOTE: a through f should not exceed total area of province

*3. Thickness of sedimentary rock to basement:

	Minimum thickness	Average thickness	Maximum thickness
Total province:	1400 ft	8500 ft	16,400 ft.

*4. Sedimentary rock thicknesses to basement of productive parts of the province. If more than one area within the province is productive, list each area separately below: NOT APPLICABLE

Productive Areas (Identify)	Minimum Thickness	Average Thickness	Maximum Thickness	Depth to significant production	
				Minimum	Maximum
a.					
b.					
c.					
d.					
e.					

*5. Estimated volume of sedimentary rock in total province: 56,044 cubic miles.

a. Indicate method used for above estimation; or source of information:

Σ (SUBAREAS × AVG. THICKNESSES)

b. Estimate percent of rock volume in province that is:

(1) Drilled: <0.1 %

(2) Explored: ESSENTIALLY NONE %

(use of seismic, etc.)

*B. Geologic Age:

1. Give the range in age (by geologic periods) of the perserved sedimentary rock section:

a. From (U. JURASSIC?) LOWER CRETACEOUS to HOLOCENE.

b. Missing sections:- PRE-LOWER CRETACEOUS OVER MOST OF AREA. OLIGOCENE IN PART. PLIO-PLEISTOCENE IN PART.

2. Age of major tectonic episodes or orogenies:

a. NONE, EXCEPT FOR INITIAL RIFTING DURING JURASSIC

b. MINOR ARCHING DURING TERTIARY.

c.

d.

e. Is there evidence of recurrent structural growth? ✓ Yes ____ No ARCHING - CAPE FEAR ARCH.

3. Age of major faulting:

	Age	Type of faulting
a.	UNKNOWN; TERTIARY?	NORMAL FAULTS OFF SOUTH CAROLINA - N.P.D. (UNPUB. D.
b.		
c.		
d.		
e.		

*4. Age and maximum gross thickness of sedimentary rock of major producing horizons and/or prospective horizons.

	Age	Maximum Gross Thickness	Indicate: Producing	Prospective
a.	JURASSIC?	THIN, PROBABLY ONLY PRESENT NEAR SHELF EDGE	NO	YES
b.	LOWER CRETACEOUS	100+ft*	NO	YES
c.	UPPER CRETACEOUS	2000+ft*	NO	?
d.	LOWER TERTIARY	2000+ft*	NO	NO
e.	UPPER TERTIARY & QUATERNARY	500+ft*	NO	NO
f.				
g.				

* THICKNESSES ARE MAXIMA FOR COASTAL WELLS

*C. Stratigraphy and Lithology:

*1. Principal sedimentary environments of deposition related to B-4 above of major producing and/or prospective horizons.

	Age	Environment of deposition
a.	JURASSIC	TERRESTRIAL (ALLUVIAL) TO SHALLOW-WATER MARINE
b.	CRETACEOUS	SHALLOW-WATER MARINE TO NON-MARINE
c.	TERTIARY	——— do ———
d.		

*2. Most abundant lithologies in the province and estimated percentage by volume of the total province.

	Lithology	Percent Volume
a.	LIMESTONE & DOLOSTONE	~ 80%
b.	CLASTICS, MAINLY SANDS	~ 20%
c.		
d.		
e.		

3. Ratio of marine to non-marine sedimentary rocks in the basin (by volume): MAINLY MARINE - ESTIMATED 9:1

*4. Major regional unconformities: Number 3

	Age	Magnitude
a.	PRE-CRETACEOUS AND BASAL CRETACEOUS	> 100 MILLION YEARS
b.	MIOCENE/EOCENE	< 10 MILLION YEARS
c.	POST-MIOCENE	< 3 MILLION YEARS
d.		

5. Presence of exceptional geologic features; depositional or structural (such as reefs, deltas, salt domes or diapirs, strat pinchouts, etc.); If maps are available on the location of such features please indicate.

Types	Geologic Age	Associated Lithologies	Mapped
a. CAPE FEAR ARCH	TERTIARY	CRYSTALLINE BASEMENT	HIGH — " ONSHORE
b. STRAT PINCHOUTS	JURASSIC?-LOWER CRETACEOUS	SANDS AND CLAYS (SAPROLITE) AT BASEMENT CONTACT	} NO
c.			
d.			
e.			

*6. The presence of known or potential stratigraphic traps:

Trap Type	Geologic Age	Productive	Non-productive	Prospective	Mapped
a. STRAT PINCHOUTS	AS ABOVE	UNKNOWN	UNKNOWN	YES	NO
b.					
c.					
d.					
e.					

7. Evaporites and their relationships to major reservoirs:

	Present (Check one)	Act as seals to major reservoirs Yes	No
a. No evaporites in section			
b. Evaporites above potential reservoirs			
c. Evaporites below potential reservoirs			
d. Evaporites above, below and within potential sections	INFERRED	UNKNOWN	

8. Geothermal history:

a. The presence of igneous rock occurrence in the sedimentary rock section:

	(Check one)
(1) None	
(2) Rare	
(3) Occassional	✓
(4) Frequent	
(5) Information Unavailable	

POSSIBLE NORTH-SOUTH CHAIN OF VOLCANOES OR IGNEOUS INTRUSIVES AT 79°W LONGITUDE.

b. Have any studies been made on the maturation of organics within the sedimentary section?

Yes	No	Uncertain
	✓	

c. If "yes" to 8b, please comment on results and indicate source of information: ______

*D. Structural aspects:

*1. Type of basin (or basins) included within province (see Basin Classification in instructions): STABLE COASTAL MARGIN

2. Structural basin geometry:

	(Check one)
a. Asymmetrical	✓
b. Symmetrical--gentle slopes	
c. Symmetrical--steep slopes	
d. Information unavailable	

3. Presence of regional structural or erosional highs:

	Yes	No	Estimated Number	Mapped	
a. Known highs	✓		1	ONSHORE	CAPE FEAR ARCH
b. Suspected highs	✓		1	BASED ON GRAVITY	SEE 8a.(3)

c. Regional highs:

CAPE FEAR ARCH

Probable Nature or Origin		General Geometry	Magnitude (in feet)(closure, relief)
BASEMENT ARCH		S.E. PLUNGING ARCH	≳ 0.5 KM (>1500 ft)

F. Presence of current non-producible hydrocarbons in the province:

1. Presence of natural oil and gas seeps: VERY FEW - ONLY ONSHORE IN WESTERN GEORGIA.

	Extent			
	None	Minor	Significant	Abundant
a. Oil	UNKNOWN			
b. Gas	—do—			
c. NGL	—do—			
d. Combinations of above	—do—			

2. Indicate whether the following are known to occur within the province:

	Yes	No	Unknown
a. Heavy oils (API gravity less than 12)		✓	
b. Tar sands		✓	
c. Oil shales		✓	
d. Tight gas sands		✓	
e. Other bitumen or solid hydrocarbons		✓	
f. Significant oil and gas shows		✓	

*G. Offshore province information:

1. In offshore provinces indicate the depths of water:

a. Average water depth < 300 feet.

b. Most reasonable maximum water depth 660 feet. (200 m)

c. Most reasonable minimum water depth 0 feet.

*2. For the following categories of water depths indicate the area of the province represented, and the sediment thicknesses underlying each depth category:

Depth categories	Area of province % or square miles	Average sediment thickness	Remarks
0-200 meters	100%	8500 feet	TOTAL VOLUME/TOTAL AREA
200-1000 meters	NONE		
1000-2500 meters	NONE		
Greater than 2500 meters	NONE		

*IV. FIELD AND RESERVOIR INFORMATION BY PROVINCE

*A. Producing reservoirs in order of importance of gross OIL potentials and/or prospective reservoirs:

Order	Geologic Age	Principal horizon or pay zone	Lithology	Maximum thickness of reservoir	Areal extent within province % or square miles	Indicate Productive or Prospective	Cumulative Production	Measured and/or Indicated Reserves
1								
2								
3								
4								
5								
6								
7								
8								

*B. Producing reservoirs in order of importance of gross GAS and NATURAL GAS LIQUID potentials and/or prospective reservoirs:

Order	Geologic Age	Principal horizon or pay zone	Lithology	Maximum thickness of reservoir	Areal extent within province % or square miles	Indicate Productive or Prospective	Cumulative Production GAS	Measured and/or Indicated Reserves	Cumulative Production NGL	Measured or Indic Reserves
1										
2										
3										
4										
5										
6										
7										
8										

*C. Characteristics of major reservoir beds and/or prospective reservoir beds: TERTIARY SECTION IN [illegible] 1 & 2 CONTAINS BRACKISH TO FRESH WATER - SECTION APPARE[illegible] FLUS[illegible]

Order	Geologic Age	Type of traps	Average Porosity	Lithology	Reservoir Geometry	Type of Seals	Environment of deposition	Oil, Gas, Oil & Gas	Indicate: Productive or Prospective
1	CRETACEOUS	← UNKNOWN	→	CARBONATES	← UNK	NOWN →	MARINE	UNKNOWN	PROSPECTIVE
2									
3									
4									
5									
6									
7									
8									

*B. Cumulative oil and gas production, reserves and resources:

	Crude Oil	Natural Gas Liquids	Natural Gas: Associated	Natural Gas: Non-Associated
1. Total production				
2. Measured reserves				
3. Indicated reserves				
4. Inferred reserves				
5. Undiscovered recoverable resources				
6. Estimated original oil-in-place				

C. Exploration and development information:

1. Date of first producing well:
   a. Oil ________
   b. Gas ________
2. Date of first producing major field discovery:
   a. Oil ________
   b. Gas ________
3. Date of first well drilled within the province: JOIDES LAND 2
4. Number of exploratory wells within the province at time of first discovery (either oil or gas): ________.
5. Number of exploratory wells within the province at time of first major discovery (either oil or gas): ________.
6. Total number of exploratory wells drilled to date: ________ (date): ____/____/____.
7. Total number of development wells drilled to date: ________ (date): ____/____/____.

8. Well density per square mile in province by depth: NOT APPLICABLE.

	Number of wells penetrating to depths of:	Well density per square mile
a. Less than 5000 feet		
b. 5000 to 10,000 feet		
c. 10,000 to 15,000 feet		
d. 15,000 to 20,000 feet		
e. 20,000 to 30,000 feet		
f. Greater than 30,000 feet		

9. Oldest beds penetrated in basin to date: ONSHORE:

a. LOWER CRETACEOUS (geologic age)

b. ~ 4900 (depth in feet)

10. Deepest beds penetrated in basin to date:

a. LOWER CRETACEOUS (geologic age)

b. ~ 4900 (depth in feet)

11. Drilling history; show by table or graph, on an annual basis:

	(Available) Yes	No
a. Number of exploratory wells drilled per year		
b. Number of development wells drilled per year		
c. Total number of all wells drilled per year		
d. Number of successful exploratory wells, or success ratio per year		

VI. RESOURCE ESTIMATES BY PROVINCE

A. Resource estimates that have been cited in the literature and other sources, relating to hydrocarbons in the province:

	Sources of reference or data	Estimated amounts (bbls or cuft)	Indicate the units reported
1.	*CRAMER (1974) {BASED AAPG MEM. 15 SPIVAK & SHELBURNE}	250 MILLION BBLS / 1.7 TRILLION CU. FT. / 50 MILL. BBLS.	CRUDE OIL / GAS / N.G.L. } FOR ENTIRE GEORGIA COASTAL PLAIN
2.			
3.			
4.			

* A SEMIFACETIOUS ESTIMATE, CERTAINLY UNREALISTICALLY HIGH BASED ON CURRENT DRILLING ONSHORE.

B. The evaluator's estimate of the resources within the province:

Amounts (bbls or cuft.)	Indicate method or source of information used

Comments:

C. The evaluator's opinion as to the most similar producing (or non-producing) analog basin(s):

	Name of Province or basin	Location	Indicate whether it is presently-- Producing	Non-producing	Prospective
1.	NORTHERN PENINSULAR	FLORIDA.		✓	
2.	ATLANTIC COASTAL PLAIN	EASTERN U.S.		✓	
3.					

D. Additional comments and/or special problems to be noted by the author(s):

OLSON (1973, AAPG, V. 58, NO. 6, PART 2, P. 1191-1200) EQUATES THE HATTERAS TO BAHAMAS OFFSHORE TO "THE TAMPICO EMBAYMENT AND THE SAUDI ARABIAN SIDE OF THE PERSIAN GULF" - AN OUTRAGEOUS COMPARISON!

RAG Province Number ______
Completion Date 1-31-75
Author(s) PERRY AND GIRARD

DATA FORMAT RESOURCE APPRAISAL AND EVALUATION BY GEOLOGIC PROVINCE

*I. IDENTITY AND LOCATION OF GEOLOGIC PROVINCE

*A. Name of Province or Basin(s): Blake Plateau, adjacent slopes and continental rise (200 - 5000 METER ISOBATH) INCLUDING BLAKE PLATEAU TROUGH

B. Geographic Location:

1. Country: UNITED STATES, ATLANTIC OFFSHORE

2. Location:

Latitude between parallels N ~~or S~~ 35° N
and N or S 27° N

Longitude between meridians E or W 70° W
and E or W 80° 10' W

	Yes	No
Onshore:		✓
Offshore:	✓	

C. Name of the author(s) of the form: PERRY AND GIRARD

D. Date of completion of the form: JANUARY / 31 / [illegible]

*II. AVAILABILITY OF BASIC INFORMATION FOR PROVINCE

*A. Indicate available maps of area and mapped intervals of horizons:

Maps	Intervals or horizons
1. None	
2. Structural maps	DEPTH IN KILOMETERS BELOW SEA LEVEL TO LAYER 3 (top of oceanic crust) [EMERY AND UCHUPI, FIG. 109
3. Isopach maps	1:5,000,000 TOTAL SEDIMENT THICKNESS (IN KM) PERRY & GIRARD (UNPUB)
	1:5,000,000 — ATLANTIC OCS PROJECT (FIG. 8 OF MAPS PROVIDED MARCH, 1974)
4. Facies maps	
5. Basement configuration maps	GENERALIZED BASEMENT DEPTH CONTOUR MAP (SHERIDAN, 1974, FIG. 12)
6. Oil and gas field maps	
7. Geophysical maps (Seismic, gravity, etc.)	BOUGUER GRAVITY (MAHER, 1971, U.S.G.S. PROF. PAPER 659, PLATE 7)
	AEROMAGNETIC MAP (TAYLOR, ZEITZ, DENNIS, 1968 GEOPHYSICS, V. 33, FIG

* Items preceded by an asterisk are explained in instruction sheets.

NOTE: Include copies of all available maps with this completed form. If it isn't feasible at this time for all the maps available, please indicate the location and source of this information for inventory and reference purposes.

Maps	Significant Reports	Location	Source (or author)
AGE OF BASEMENT RX.	EMERY AND UCHUPI (1972, FIG 89)		AAPG MEM. 17
DEPTH IN KM TO TOP CRETACEOUS	—do— FIG. 189		
TOTAL SEDIMENT THICKNESS	—do— FIG. 190		

*B. Indicate available cross-sections of area and include copies with form, or indicate source:

Type	Known	Number	Source
1. None		1	U.S.G.S. PROF PAPER 581-E, PLATE 2
2. Geological	✓	1 1	SPIVAK & SHELBURNE (AAPG, MEM. 1[illegible] SHERIDAN (1974, FIG. 13)
3. Geophysical (seismic, etc.)	✓	2 3	SPIVAK & SHELBURNE (AAPG, MEM. [illegible] SHERIDAN (1974, ATLANTIC CONTINENTAL MARGIN)
4. Stratigraphic column	INFERRED	2	SPIVAK & SHELBURNE (AAPG, MEM. 15) EMERY & UCHUPI (1972, AAPG, MEM. 17, FIG. 81, 82 AND 8[illegible]

*C. Indicate available logs in area: LOGS OF BAHAMA WELLS GIVEN BY EMERY AND UCHUPI (1972, AAPG, MEM. 17)

Type	Known	Number
1. None		
2. Electric (SP) logs		
3. Induction logging		
4. Sonic logs		
5. Neutron logs		
6. Others	JOIDES 3,4,5 (1965) DSDP 102, 103, 104, 105	3

*D. Comments upon the source, availability and location of any of the above information:

MEYERHOFF & HATTON (1974, AAPG, V. 58, p. 1217, FIG. 8) CAY SAL & ANDROS I

*E. Indicate the level or degree of knowledge concerning this province as a whole:

	Yes	No	
1. Surface geologic studies	✓		
2. Drilling stages:			
a. No drilling (no seismic)		✓	EXCEPT JOIDES & DSDP
b. No drilling (w/seismic)	✓		VERY LITTLE
c. Early stage (immaturely explored)		✓	
d. Intermediate stage (fairly well explored)		✓	
e. Late stage (maturely explored)		✓	
3. Province well-explored to basement depths:			
a. Drilling only		✓	
b. Drilling and seismic		✓	
c. Seismic only		✓	

*III. BASIC GEOLOGY BY PROVINCE

*A. Province geometry:

*1. Configuration of province: (2.5:1) MARKEDLY ELONGATE

WATER DEPTH CLASS 200-2500 METE
PROVINCE BLAKE PLATEAU

Total sedimentary rock Province

Area with maximum depths to basement of:

a. less than ~~5,000 feet~~ 2 KM
b. ~~5,000 to 10,000 feet~~ 2-4 KM
c. ~~10,000 to 15,000 feet~~ 4-6 KM
d. ~~15,000 to 20,000 feet~~ 6-8 KM
e. ~~20,000 to 30,000 feet~~ >8 KM
f. greater than 30,000 feet

NOTE: a through f should not exceed total a

SEDIMENT:

SEDIMENT THICKNESS TO BASEMENT	AREA (MI²)	VOLUME (MI³)
~~0 – 5000'~~ 0-2 KM	384	240
~~5 – 10,000'~~ 2-4	2,386	4,474
~~10 – 15,000'~~ 4-6	14,699	45,935
~~15 – 20,000'~~ 6-8	25,449	111,339
~~20 – 30,000'~~ >8	7,601	39,330
>30,000	0	0
TOTAL	50,519	201,318

THICKNESS: AVE. ______; MAX. ______.

*3. Thickness of sedimentary rock to basement:

	Minimum thickness	Average thickness	Maximum thickness
Total province:	< 2 KM (~1500M)	3.8 MI. OR 20,167 ft ~6.1K	> 9 KM (~9500M)

*4. Sedimentary rock thicknesses to basement of productive parts of the province. If more than one area within the province is productive, list each area separately below: NOT APPLICABLE

Productive Areas (Identify)	Minimum Thickness	Average Thickness	Maximum Thickness	Depth to significant production	
				Minimum	Maximum
a.					
b.					
c.					
d.					
e.					

*5. Estimated volume of sedimentary rock in total province: 466,[illegible] cubic miles.

a. Indicate method used for above estimation; or source of information:

Σ (SUBAREAS X AVG. THICKNESSES)

b. Estimate percent of rock volume in province that is:

(1) Drilled: < 0.1 %

(2) Explored: ESSENTIALLY NONE %

(use of seismic, etc.)

*B. Geologic Age:

1. Give the range in age (by geologic periods) of the perserved sedimentary rock section:

   a. From UPPER JURASSIC to HOLOCENE.

   b. Missing sections: AT TERTIARY / CRETACEOUS BOUNDARY INCLUDING MUCH OF UPPER CRETACEOUS IN DSDP 105. OLIGOCENE [illegible] ON PALEOCENE IN JOIDES'

2. Age of major tectonic episodes or orogenies:

   a. NONE EXCEPT FOR INITIAL RIFTING DURING JURASSIC.

   b.

   c.

   d.

   e. Is there evidence of recurrent structural growth? ✓ Yes ____ No

3. Age of major faulting:

	Age	Type of faulting
a.	JURASSIC	INFERRED HIGH-ANGLE NORMAL FAULTS (SHERIDAN, 1974, FIG.
b.		
c.		
d.		
e.		

*4. Age and maximum gross thickness of sedimentary rock of major ~~producing horizons and/or~~ prospective horizons.
UNDER BLAKE PLATEAU TROUGH

Age	Maximum Gross Thickness	Indicate: ~~Producing~~	Prospective
a. JURASSIC	~4 KM (SHERIDAN, 74)	N.A.	YES, CARBONATES & INFERRED EVAPORITES
b. LOWER CRETACEOUS	~2.5 KM — do —		YES
c. UPPER CRETACEOUS	~2 KM — do —		YES, MARGINALLY
d. TERTIARY	~1 KM — do —		NO
e. QUATERNARY	< 0.5 KM — do —		NO
f.			
g.			

*C. Stratigraphy and Lithology:

*1. Principal sedimentary environments of deposition related to B-4 above of major producing and/or prospective horizons.

Age	Environment of deposition
a. JURASSIC	SHALLOW MARINE TO TERRESTRIAL
b. CRETACEOUS	SHALLOW-WATER SHELF TO DEEP WATER
c. TERTIARY	DEEP WATER
d. QUATERNARY	—— do ----

*2. Most abundant lithologies in the province and estimated percentage by volume of the total province.

	Lithology	Percent Volume
a.	LIMESTONE AND DOLOMITE	~[illegible]
b.	CLASTICS, MAINLY MUDS	~10%
c.		
d.		
e.		

3. Ratio of marine to non-marine sedimentary rocks in the basin (by volume): 10 : 1 – marine : non-marine

*4. Major regional unconformities: Number 2

	Age	Magnitude
a.	UPPER CRETACEOUS AND BASAL TERTIARY	≤ 70 MILLION YEARS
b.	OLIGOCENE/EOCENE	≲ 5 MILLION YEARS
c.		
d.		

5. Presence of exceptional geologic features; depositional or structural (such as reefs, deltas, salt domes or diapirs, strat pinchouts, etc.); If maps are available on the location of such features please indicate.

Types	Geologic Age	Associated Lithologies	Mapped
a. REEFS	JURASSIC ?- CRETACEOUS	CARBONATES	NO, INFERRED
b. STRAT PINCHOUTS	— do —	MARINE CARBONATES SAND CLASTICS AT BASEMENT CONTACT	NO, "
c. ANTICLINES	— do —	CARBONATES	1 SEISMIC PROFILE
d.			
e.			

*6. The presence of known or potential stratigraphic traps:

Trap Type	Geologic Age	Productive	Non-productive	Prospective	Mapped
a. REEFS	AS ABOVE	NO	NO	YES	NO
b. STRAT PINCHOUTS	AS ABOVE	NO	NO	YES	NO
c.					
d.					
e.					

7. Evaporites and their relationships to major reservoirs:

	Present (Check one)	Act as seals to major reservoirs Yes	No
a. No evaporites in section			
b. Evaporites above potential reservoirs			
c. Evaporites below potential reservoirs			
d. Evaporites above, below and within potential sections	INFERRED	UNKNOWN	

8. Geothermal history:

a. The presence of igneous rock occurrence in the sedimentary rock section:

	(Check one)
(1) None	UNKNOWN
(2) Rare	
(3) Occassional	
(4) Frequent	
(5) Information Unavailable	

b. Have any studies been made on the maturation of organics within the sedimentary section?

Yes	No	Uncertain
		✓

c. If "yes" to 8b, please comment on results and indicate source of information:

PRELIMINARY ORGANIC ANALYSES OF THE DEEP-SEA DRILLING PROJECT (DSDP) CORES, LEG 11 (REF. GIVEN IN BOOKLET ON NORTH ATLANTIC F.IS

*D. Structural aspects:

*1. Type of basin (or basins) included within province (see Basin Classification in instructions): EXTRACONTINENTAL - ATLANTIC TYPE MARGIN,

2. Structural basin geometry:

	(Check one)
a. Asymmetrical	✓ (to)
b. Symmetrical--gentle slopes	
c. Symmetrical--steep slopes	✓
d. Information unavailable	

3. Presence of regional structural or erosional highs:

	Yes	No	Estimated Number	Mapped
a. Known highs				
b. Suspected highs	✓		UNKNOWN	No

c. Regional highs: INSUFFICIENT DATA

Probable Nature or Origin		General Geometry	Magnitude (in feet)(closure, relief)

F. Presence of current non-producible hydrocarbons in the province:

1. Presence of natural oil and gas seeps:

	Extent: None	Minor	Significant	Abundant
a. Oil	UNKNOWN			
b. Gas	— do —			
c. NGL	— do —			
d. Combinations of above				

2. Indicate whether the following are known to occur within the province:

	Yes	No	Unknown
a. Heavy oils (API gravity less than 12)		✓	
b. Tar sands		✓	
c. Oil shales		✓	
d. Tight gas sands		✓	
e. Other bitumen or solid hydrocarbons		✓	
f. Significant oil and gas shows		✓	

*G. Offshore province information:

1. In offshore provinces indicate the depths of water:

a. Average water depth ~~feet.~~ 500-1000 METERS

b. Most reasonable maximum water depth ~~feet.~~ (5000 M)

c. Most reasonable minimum water depth 660 feet. (200 M)

*2. For the following categories of water depths indicate the area of the province represented, and the sediment thicknesses underlying each depth category:

Depth categories	Area of province % or square miles	Average sediment thickness	Remarks
0-200 meters	NONE		
200-1000 meters	~55%	~7 KM	ESTIMATED
1000-2500 meters	~10%	~6 KM	—do—
Greater than 2500 meters	~35%	~4 KM	—do—

*IV. FIELD AND RESERVOIR INFORMATION BY PROVINCE

*A. Producing reservoirs in order of importance of gross OIL potentials and/or prospective reservoirs: NOT APPLICABLE

Order	Geologic Age	Principal horizon or pay zone	Lithology	Maximum thickness of reservoir	Areal extent within province % or square miles	Indicate Productive or Prospective	Cumulative Production	Measured and/or Indicated Reserves
1								
2								
3								
4								
5								
6								
7								
8								

*B. Producing reservoirs in order of importance of gross GAS and NATURAL GAS LIQUID potentials and/or prospective reservoirs:

Order	Geologic Age	Principal horizon or pay zone	Lithology	Maximum thickness of reservoir	Areal extent within province % or square miles	Indicate Productive or Prospective	Cumulative Production GAS	Measured and/or Indicated Reserves	Cumulative Production NGL	Measured or Indice Reserves
1										
2										
3										
4										
5										
6										
7										
8										

*C. Characteristics of major reservoir beds and/or prospective reservoir beds:

Order	Geologic Age	Type of traps	Average Porosity	Lithology	Reservoir Geometry	Type of Seals	Environment of deposition	Oil, Gas, Oil & Gas	Indicate: Productive or Prospective.
1	JURASSIC	- UNKNOWN	→	CARBONATES	- UNKNOWN	→	MARINE	UNKNOWN	PROSPECTIVE
2	CRETACEOUS	-do-	-do-	do	do	do	do	do	do
3									
4									
5									
6									
7									
8									

*D. Characterization of probable source beds:

Order	Geologic Age	Gross Maximum Thickness	Gross Maximum Volume	Lithology	Estimated Number of beds	Marine	Non-marine	Reasonable Proximity of Reservoir Beds Yes	No
1	JURASSIC	←UNKNOWN	———→	BLACK MUDS*	UNKNOWN	YES	NO	UNKNOWN	
2	CRETACEOUS	- do -	- do -	- do -	- do -	- do -	NO	- do -	
3									
4									
5									
6									
7									
8									

* SEE DSDP 105 REPO

*E. Characterization of major seals in the stratigraphic section: UNKNOWN

Order	Geologic Age	Lithology	Significant Hydrodynamic conditions Yes	No	Seals Continuous	Discontinuous
1						
2						
3						
4						
5						
6						
7						
8						

	Crude Oil	Natural Gas Liquids	Natural Gas Associated	Natural Gas Non-Associated
1. Total production				
2. Measured reserves				
3. Indicated reserves				
4. Inferred reserves				
5. Undiscovered recoverable resources				
6. Estimated original oil-in-place				

C. Exploration and development information:

1. Date of first producing well:

   a. Oil ____________

   b. Gas ____________

2. Date of first producing major field discovery:

   a. Oil ____________

   b. Gas ____________

3. Date of first well drilled within the province: [illegible] 4,5,6, 1965

4. Number of exploratory wells within the province at time of first discovery (either oil or gas): ____________.

5. Number of exploratory wells within the province at time of first major discovery (either oil or gas): ____________.

6. Total number of exploratory wells drilled to date: ____________ (date): ____/____/____.

7. Total number of development wells drilled to date: ____________ (date): ____/____/____.

8. Well density per square mile in province by depth: NOT APPLICABLE

	Number of wells penetrating to depths of:	Well density per square mile
a. Less than 5000 feet		
b. 5000 to 10,000 feet		
c. 10,000 to 15,000 feet		
d. 15,000 to 20,000 feet		
e. 20,000 to 30,000 feet		
f. Greater than 30,000 feet		

9. Oldest beds penetrated in basin to date:

a. JURASSIC * (geologic age)

b. 19,236 ft (2,057 ft. SED. PENETRATION) (depth in feet)

10. Deepest beds penetrated in basin to date:

a. JURASSIC * (geologic age)

b. 19,236 ft, AS ABOVE (depth in feet)

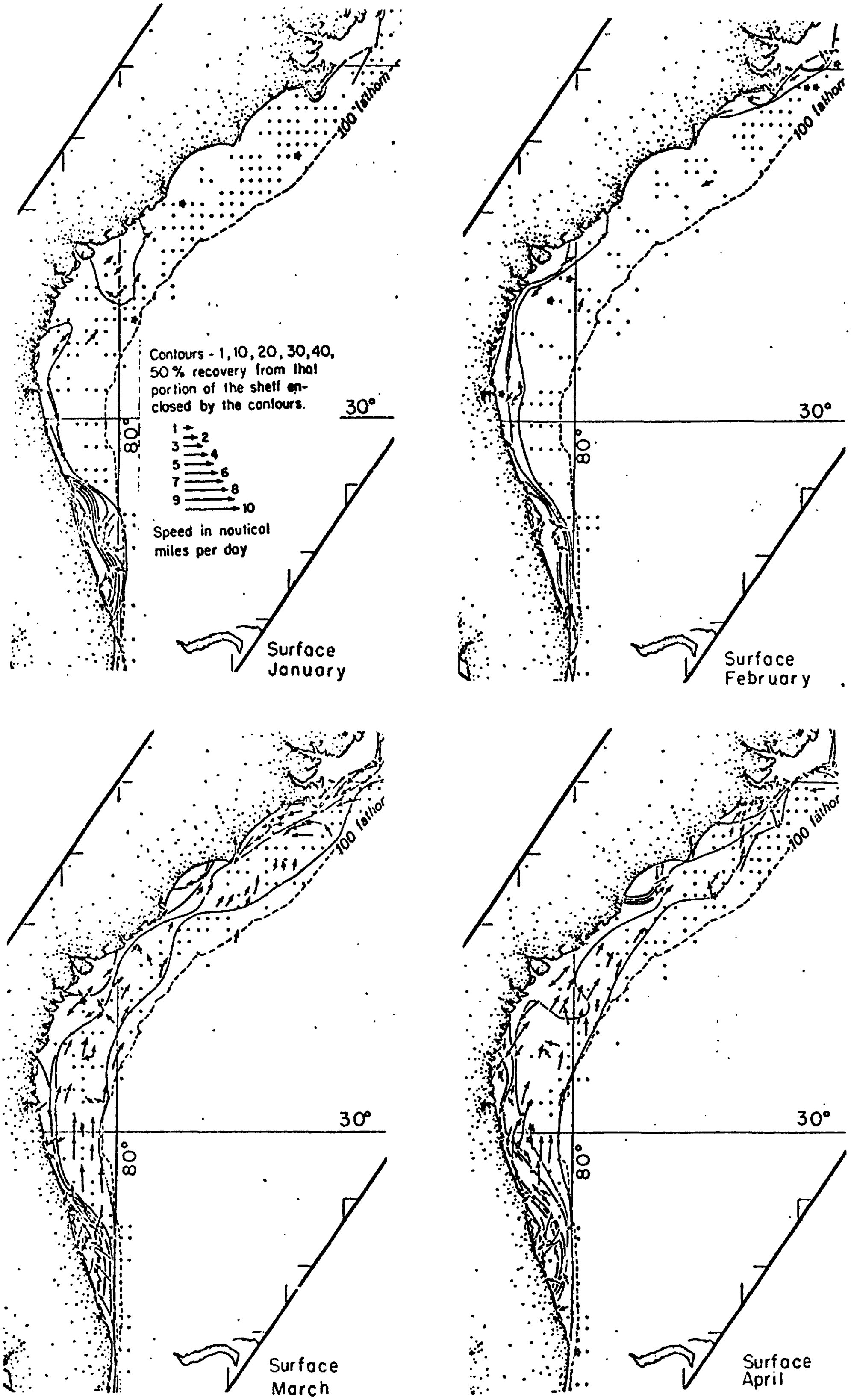
11. Drilling history; show by table or graph, on an annual basis:

	(Available) Yes	No
a. Number of exploratory wells drilled per year		
b. Number of development wells drilled per year		
c. Total number of all wells drilled per year		
d. Number of successful exploratory wells, or success ratio per year		

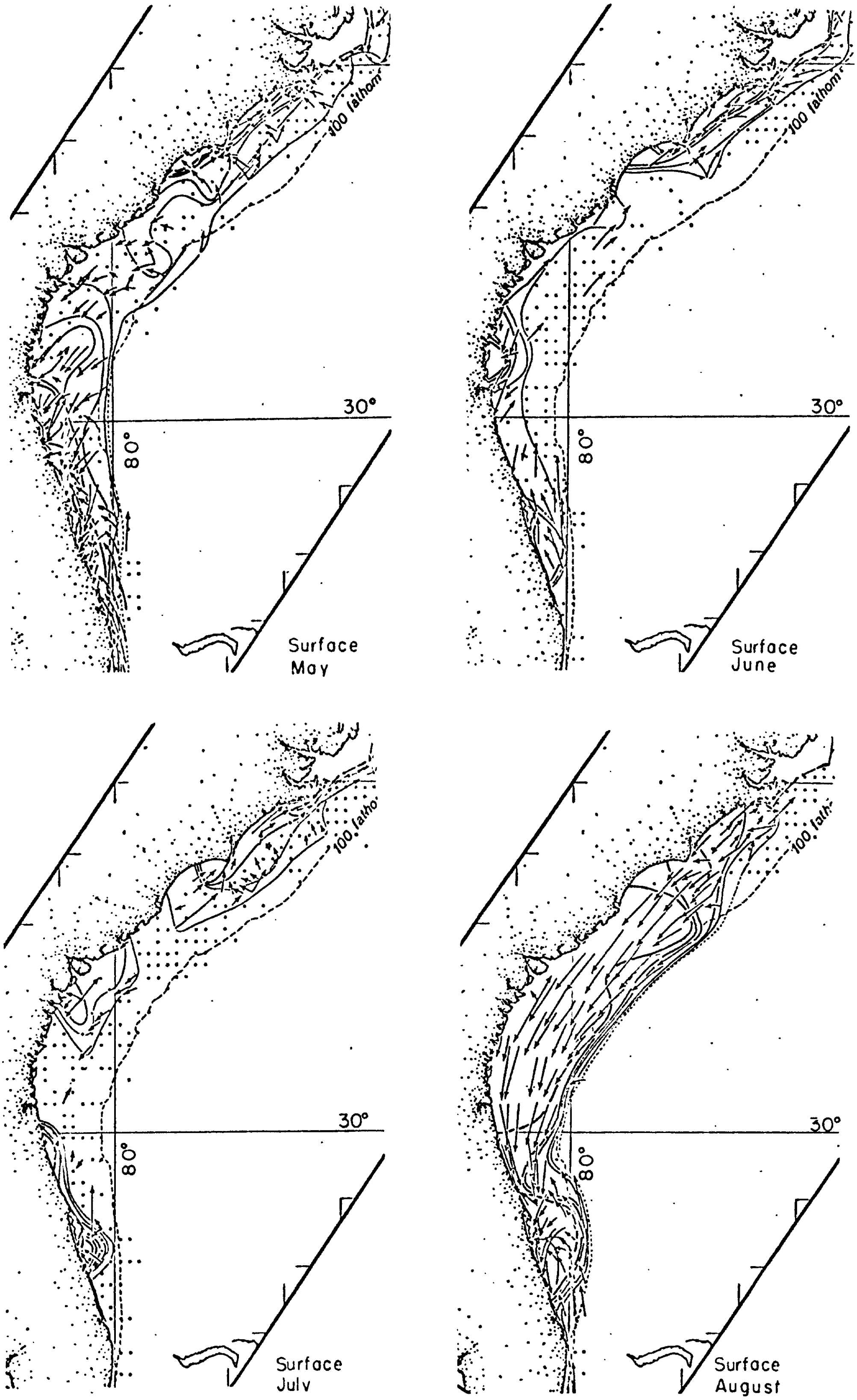
Appendix II. Ocean Circulation

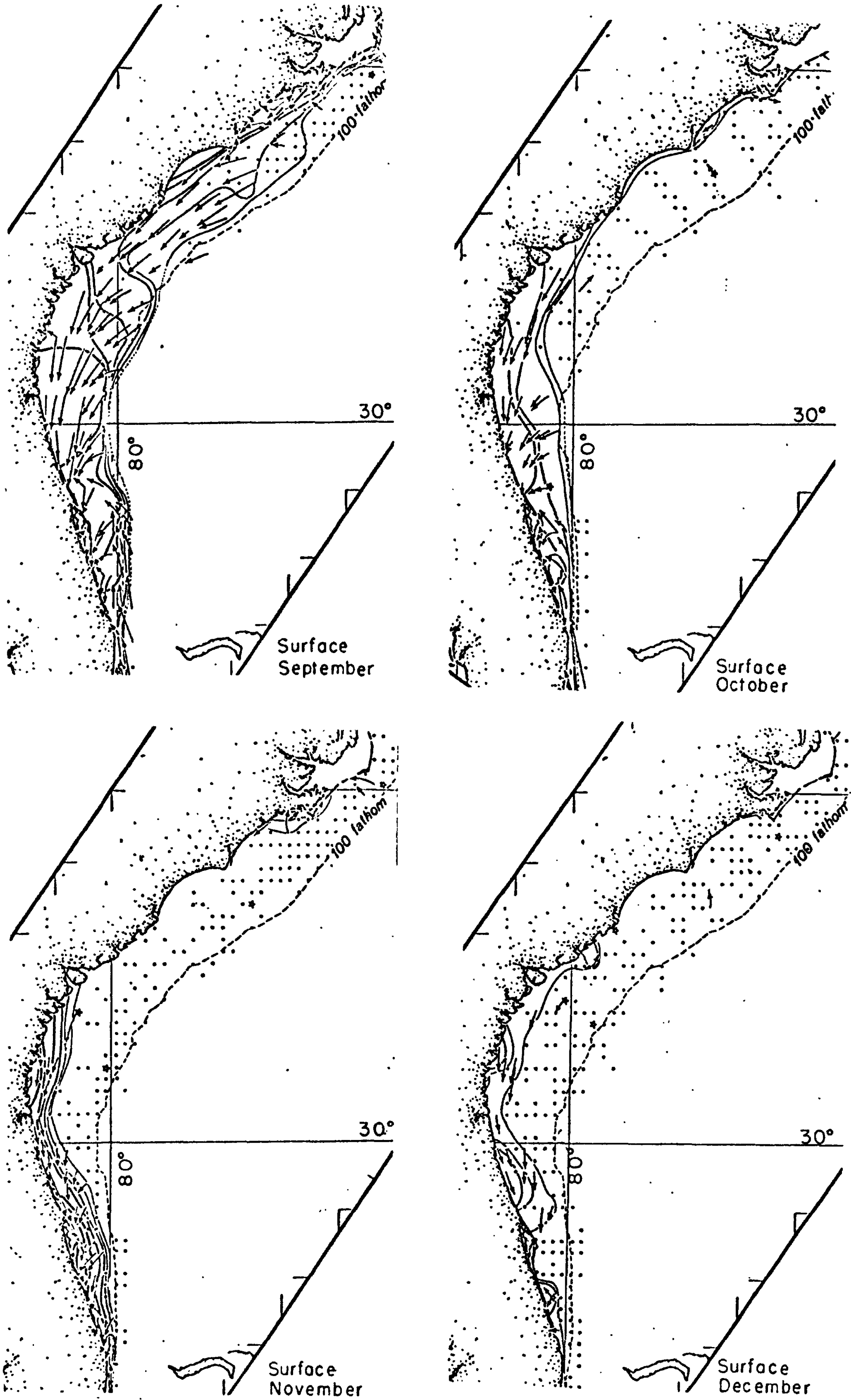
A. Results of surface drift bottle studies in the South Atlantic Bight

B. Results of bottom drifter studies for the South Atlantic Bight

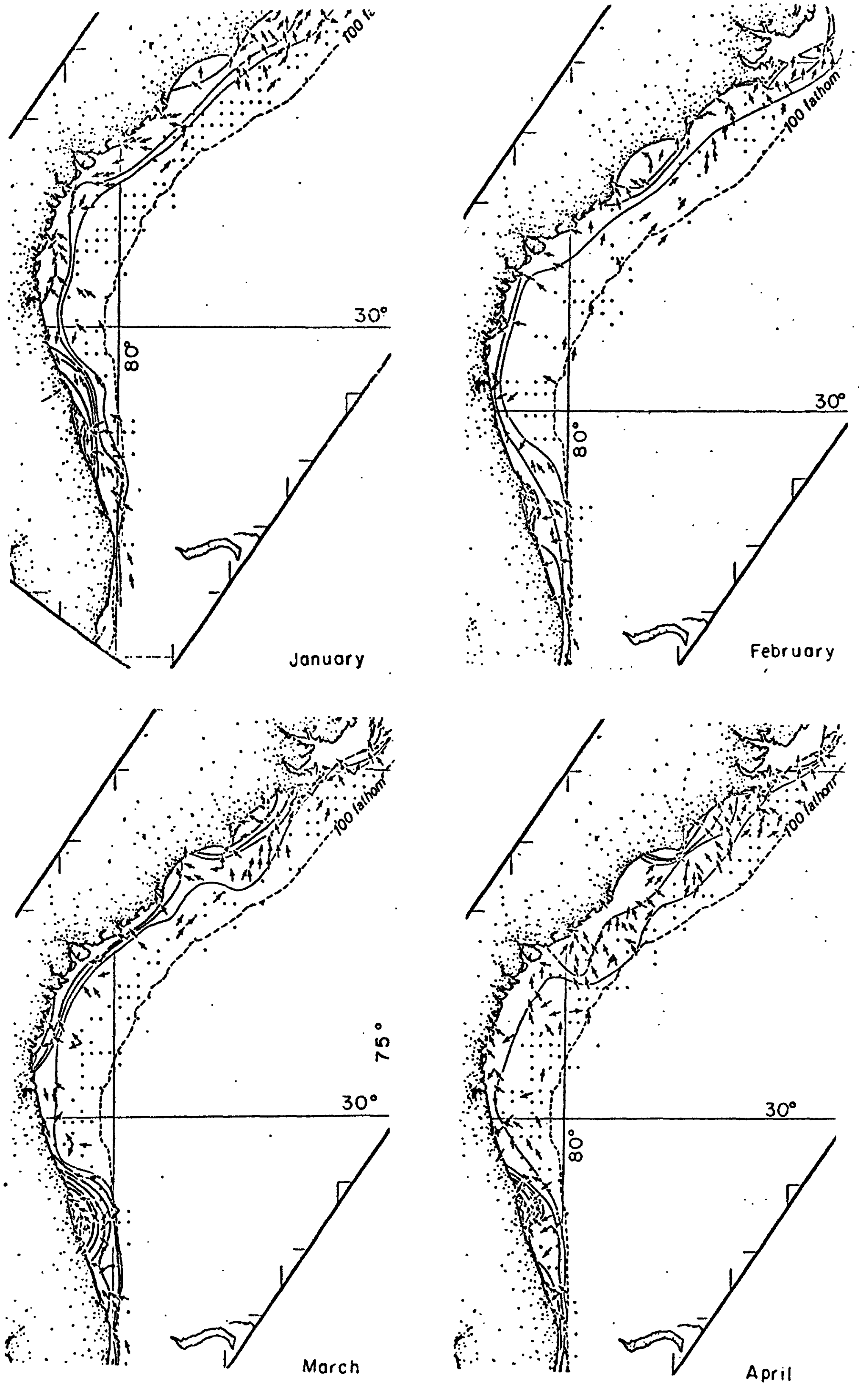


A. Results of surface drift bottle studies in the South Atlantic Bight (Bumpus, 1973). A dot is placed at the center of each 10 minute rectangle from which no bottles were recovered and a star if bottles drifted overseas. Arrows indicate direction of drift, with length proportional to fastest drift recovered.

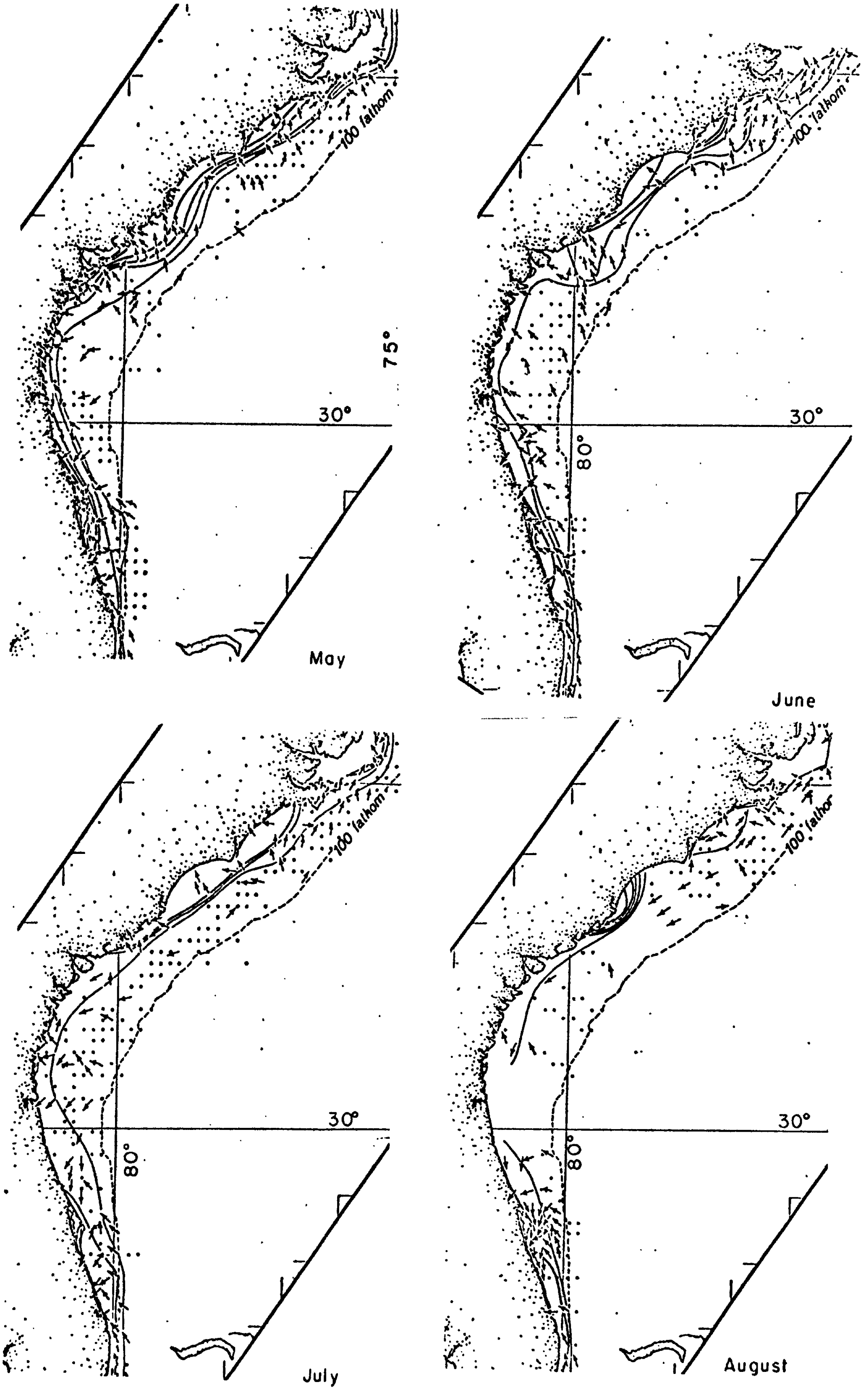

100 fathom
30°
80°
Surface
May
30°
80°
Surface
June
30°
80°
Surface
July
30°
80°
Surface
August

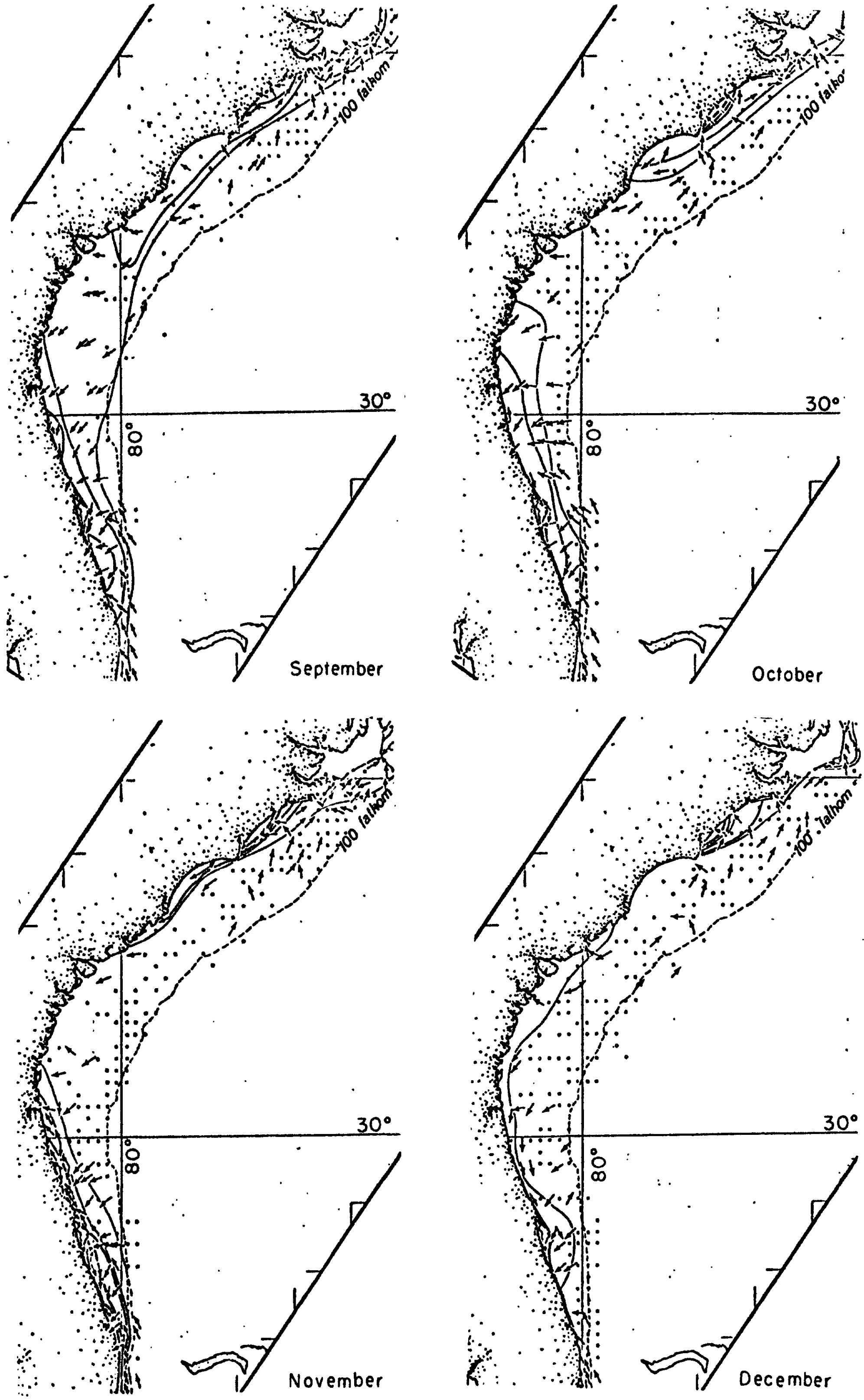

100 fathom
30°
80°
Surface
September
Surface
October
Surface
November
Surface
December

B. Results of bottom drifter studies for the South Atlantic Bight (Bumpus, 1973). A dot is placed at the center of each 10 minute rectangle from which no drifters were recovered. An arrow indicates the inferred mean direction of drift from each 10-min. rectangle from which drifters were recovered; in these charts speed is not indicated, and the arrows are all the same length. Recovery rates of 10, 20, 30, 40, 50, and 60% are contoured; recoveries greater than 60% have not been contoured.



100 fa
30°
80°
January
100 fathom
30°
80°
February
100 fathom
75°
30°
March
100 fathom
30°
80°
April


100 fathom
75°
30°
May
100 fathom
30°
80°
June
100 fathom
30°
80°
July
100 fathom
30°
80°
August


100 fathom
30°
80°
September
October
November
December

EXPLANATION OF LARGE MAP

Explanation:

Bouguer gravity anomaly map of the U.S. South Atlantic Province. This map was prepared using data collected and compiled by the Defense Mapping Agency. Most of the data used were collected on the USNS Keathley using a LaCoste and Romberg and Bell Aerospace meters. Track spacing was generally less the 10 km and solid contours are shown where the data is good.

Accuracies are considered good with errors of less than $\pm$ 5 mgals. Simple Bouguer corrections were applied by interpolating from the bathymetric map of the area published by AAPG for the conversion of the DMA supplied free air values. A density of 2.67 g/cc was used for the assumed replacement of rock for the water column. The offshore Bouguer contour maps were merged with updated Bouguer maps on land in the various states of Florida, Georgia, and South Carolina.

NOTE: The Explanation typed on the map of Open-File Report 75-411 is not readable. Therefore, it is retyped here.