UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SUMMARY OF REGIONAL GEOLOGY, PETROLEUM POTENTIAL, RESOURCE ASSESSMENT AND ENVIRONMENTAL CONSIDERATIONS FOR OIL AND GAS LEASE SALE AREA #56

Edited by

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

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INTRODUCTION

This report summarizes our general knowledge of the petroleum potential, as well as problems and hazards associated with development of petroleum resources in the area proposed for nominations for lease sale number 56. This area includes the U.S. eastern continental margin from the North Carolina-Virginia border south to approximately Cape Canaveral, Florida and from three miles from shore, seaward to include the upper Continental Slope and inner Blake Plateau. The area for possible sales is shown in figure 1; major physiographic features of the region are shown in figure 2.

No wells have been drilled for petroleum within this proposed lease area and no significant commercial production has been obtained onshore in the Southeast Georgia Embayment. The COST GE-1 stratigraphic test well, drilled on the Continental Shelf off Jacksonville, Fla. (fig. 1), reached basement at 3,300 m. The bottom third of the section consists of dominantly continental rocks that are typically poor sources of petroleum (Scholle, 1979) and the rocks that contain organic carbon adequate for generation of petroleum at the well are seen in seismic profiles always at shallow subbottom depths, so they probably have not reached thermal maturity. However, seismic profiles indicate that the sedimentary deposits thicken markedly in a seaward direction where more of the section was deposited under marine conditions; therefore, commercial accumulations of petroleum offshore are more likely.

Several potential sources of environmental hazard exist. Among the most important are hurricanes, the Gulf Stream, and earthquakes. The potential danger from high wind, waves, storm surges, and storm-driven currents associated with hurricanes is obvious. Evidence for

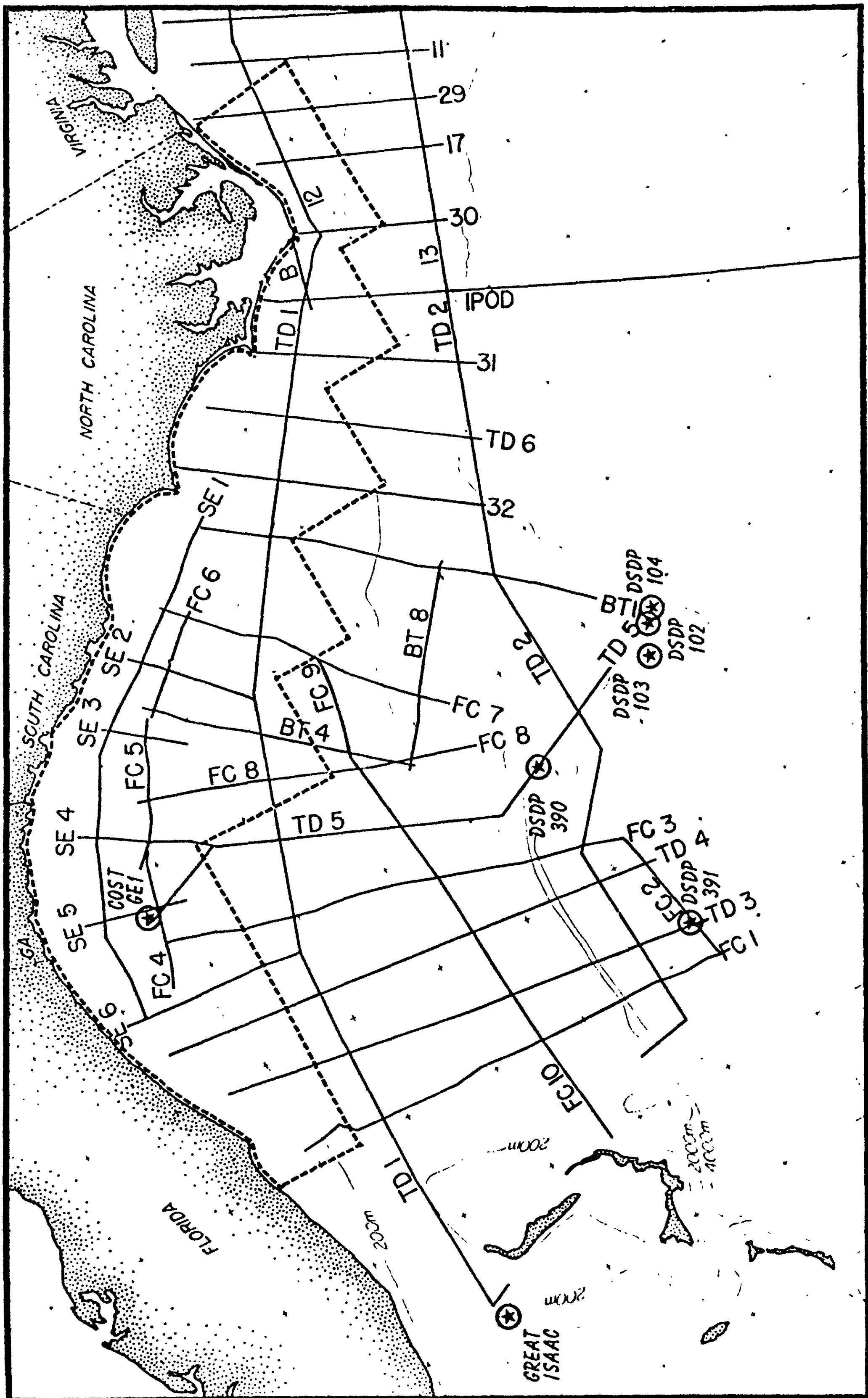

Fig. 1 Location of area of call for nominations for sale #56 outlined by dashed line. USGS multichannel seismic lines and selected stratigraphic drillsites in the region are also shown.

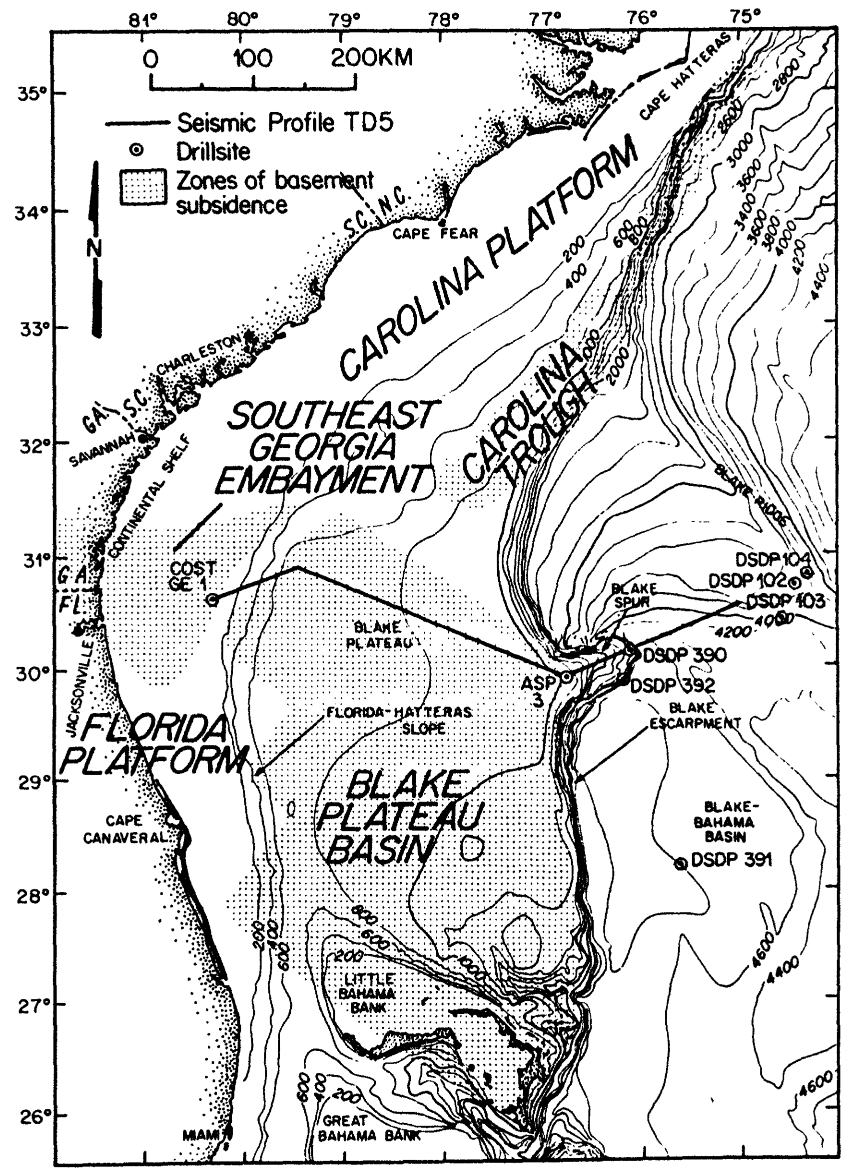

Fig. 2 Physiographic features and basins of the US southeastern continental margin.

significant bottom scour by the Gulf Stream is abundant; such scour is a threat to the stability of bottom-mounted structures. The fast-flowing water also will hamper floating drill rigs and control of drill strings. A major earthquake of about magnitude 6.8 struck Charleston in 1886; it may have been associated with a zone of active seismicity that crosses South Carolina. The likelihood of a repetition of the 1886 event is presently not predictable but a seismic hazard must be assumed to exist.

CHAPTER I

SUMMARY OF REGIONAL GEOLOGY

By

William P. Dillon, Kim D. Klitgord, Charles K. Paull, and John A. Grow

Basement structure

The continental margin area for which nominations are requested is associated with three zones of basement subsidence, shown by stippled patterns in figure 2. These are the Blake Plateau Basin, Carolina Trough, and the Southeast Georgia Embayment. A more detailed analysis of basement topography is shown by the map of depth to magnetic basement for the region (fig. 3). We find that seismic basement or, when that is not visible, the post-rift unconformity in our profiles corresponds very closely in depth to magnetic basement shown in figure 3, and undoubtedly represents economic basement. The Blake Plateau Basin, in the southern part of the area, displays basement depths of 8 to 14 km in an irregular pattern (figs. 2 and 3). North of the Blake Plateau Basin and paralleling the edge of the continent from about 31.5°N. to Cape Hatteras (35°N.) the elongate Carolina Trough reaches depths of 10-11 km to basement. The Southeast Georgia Embayment is a gently-subsided, eastward plunging depression recessed into the continent between two platform areas, the Carolina Platform on the north and the Florida Platform on the south (figs. 2 and 3). The area of possible sales covers parts of all of these features.

From our grid of seismic-reflection profiles (fig. 1), we selected four profiles that best exemplify the structure of the continental margin. The southernmost of these is profile TD5 (fig. 4, location

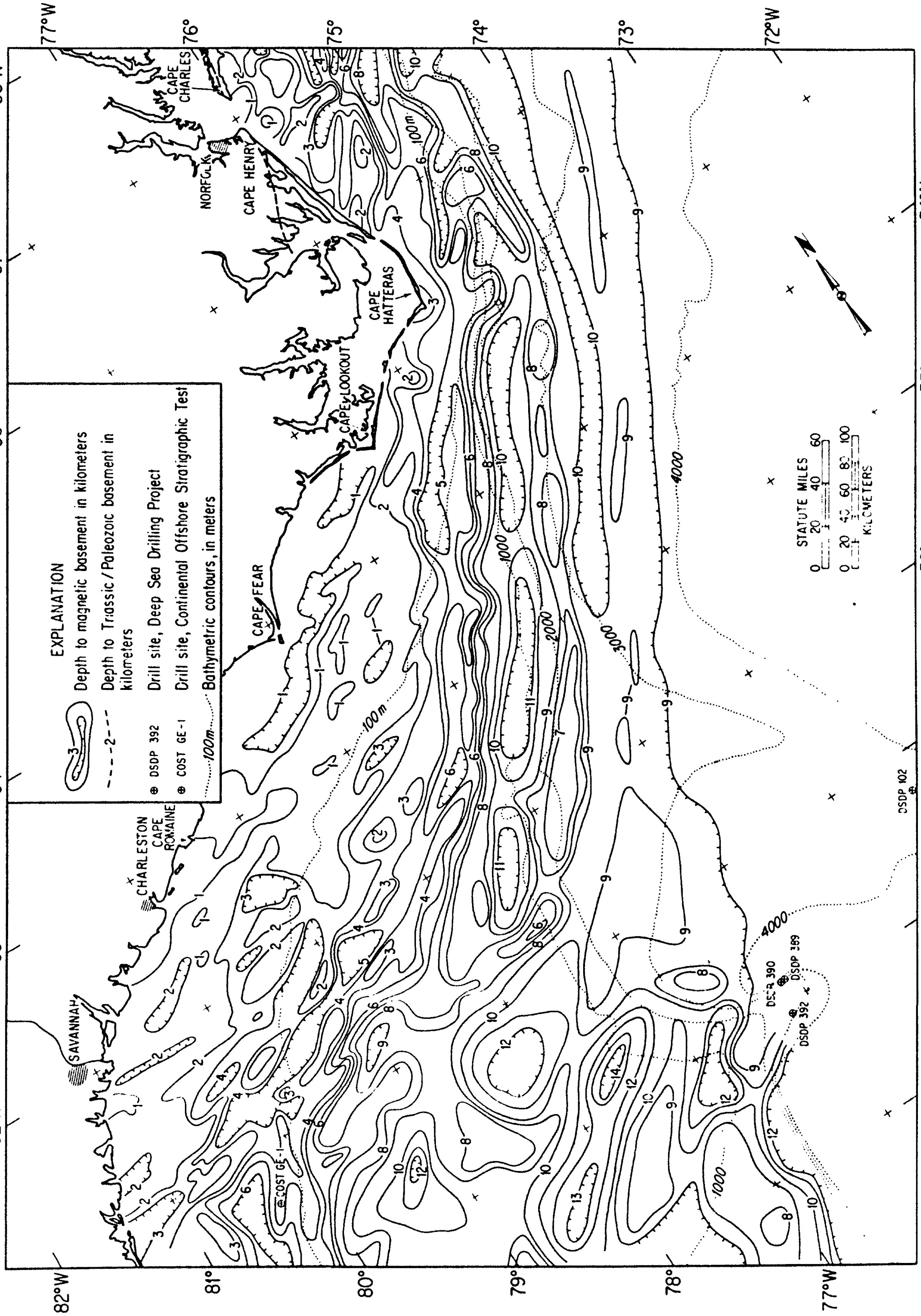

Fig. 3 Depth to magnetic basement.

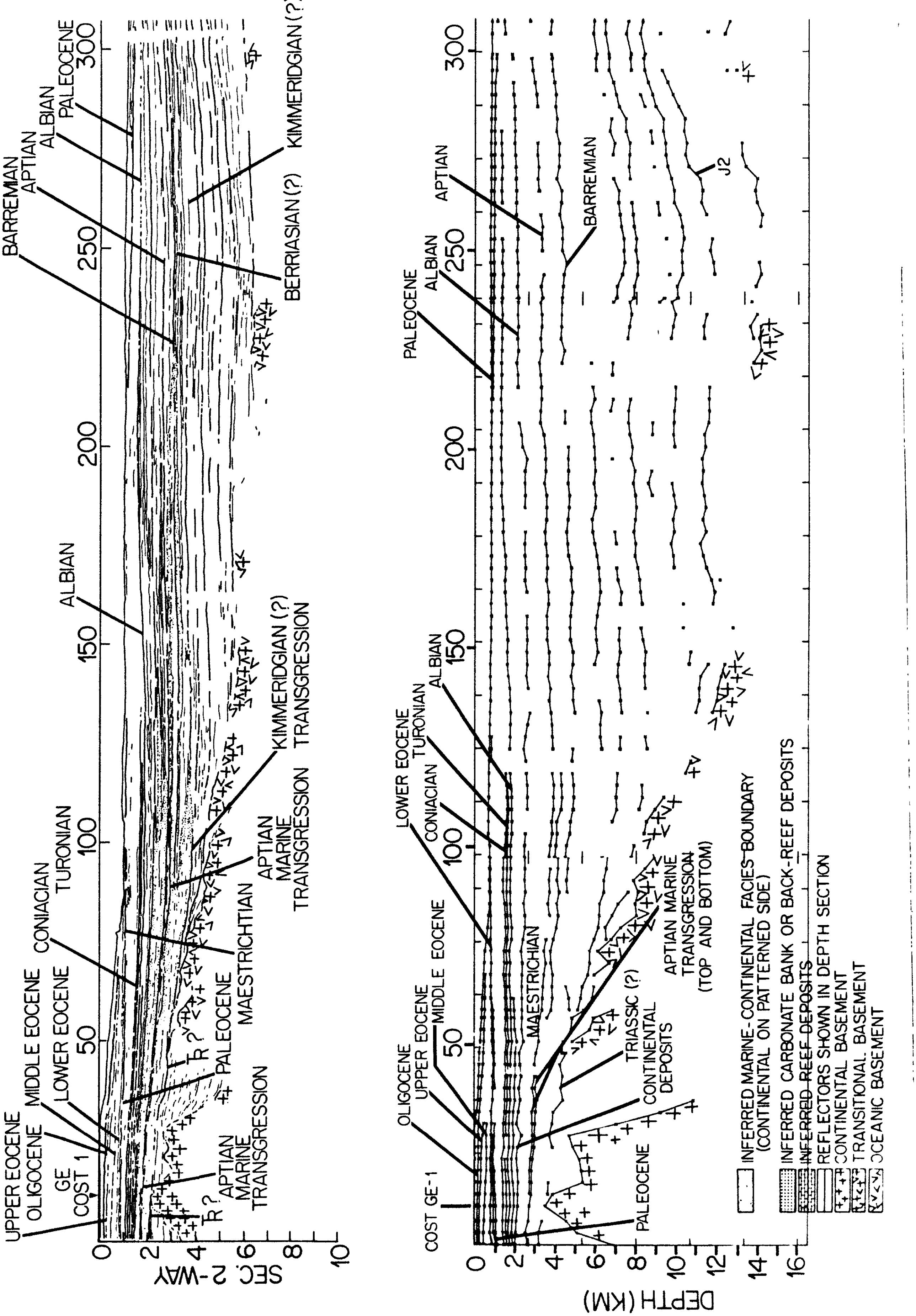

Fig. 4 A Profile TD 5 (western part) Interpreted time section above, calculated depth section below.

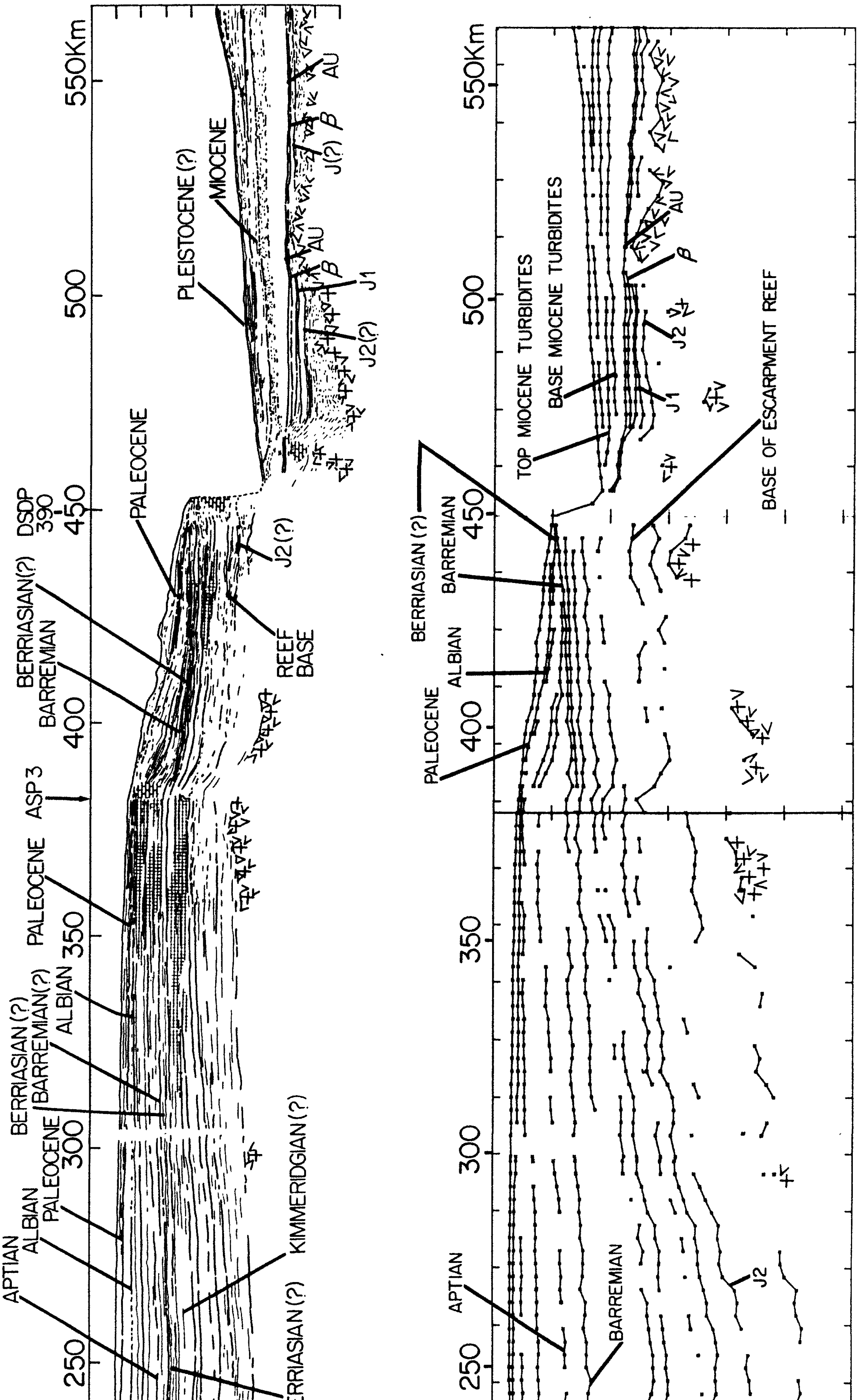

Fig. 4 B Profile TD-5 (eastern part) Interpreted time section above, calculated depth section below.

Plateau Basin at its northern end and passes across three stratigraphic drillsites (Figure 2) so that the stratigraphy along this line is best known of any profile across the eastern U.S. continental margin. Profile TD5 typifies the structure of the continental margin at the Blake Plateau Basin, where a deep broad basin underwent maximum subsidence near its landward side. The seaward side of this continental margin depositional basin was closed off by reefs that acted as sediment dams. Erosion of these reefs by deep sea processes has left a more than 3 km high cliff at the seaward side of the Blake Plateau that is known as the Blake Escarpment (Figure 2).

The basement beneath the Blake Plateau Basin is probably of a transitional nature as indicated in Figure 4. Transitional basement as defined here, indicates a basement probably formed of large amounts of continental basement fragments, mantle-derived intrusive and extrusive mafic rocks and considerable quantities of included sediments. Such basement is characterized by broad, low amplitude magnetic anomalies and a crustal thickness of generally 15-20 km, intermediate between continental and oceanic thicknesses.

The next profile to be considered, profile BT4, crosses the continental margin off Charleston, S.C. (location Figure 1). This profile is located on the axis of the zone of relatively shallow magnetic basement between the Blake Plateau Basin and the Carolina Trough. The top of magnetic basement along this line seems to occur 1 to 3 km above probable continental basement and at an angular unconformity (Figure 5, Triassic Top). This unconformity probably formed after rifting and before the continental margin subsided enough to begin to accumulate significant amounts of sediment; it is referred to as the post-rift unconformity. A relatively shallow part of the

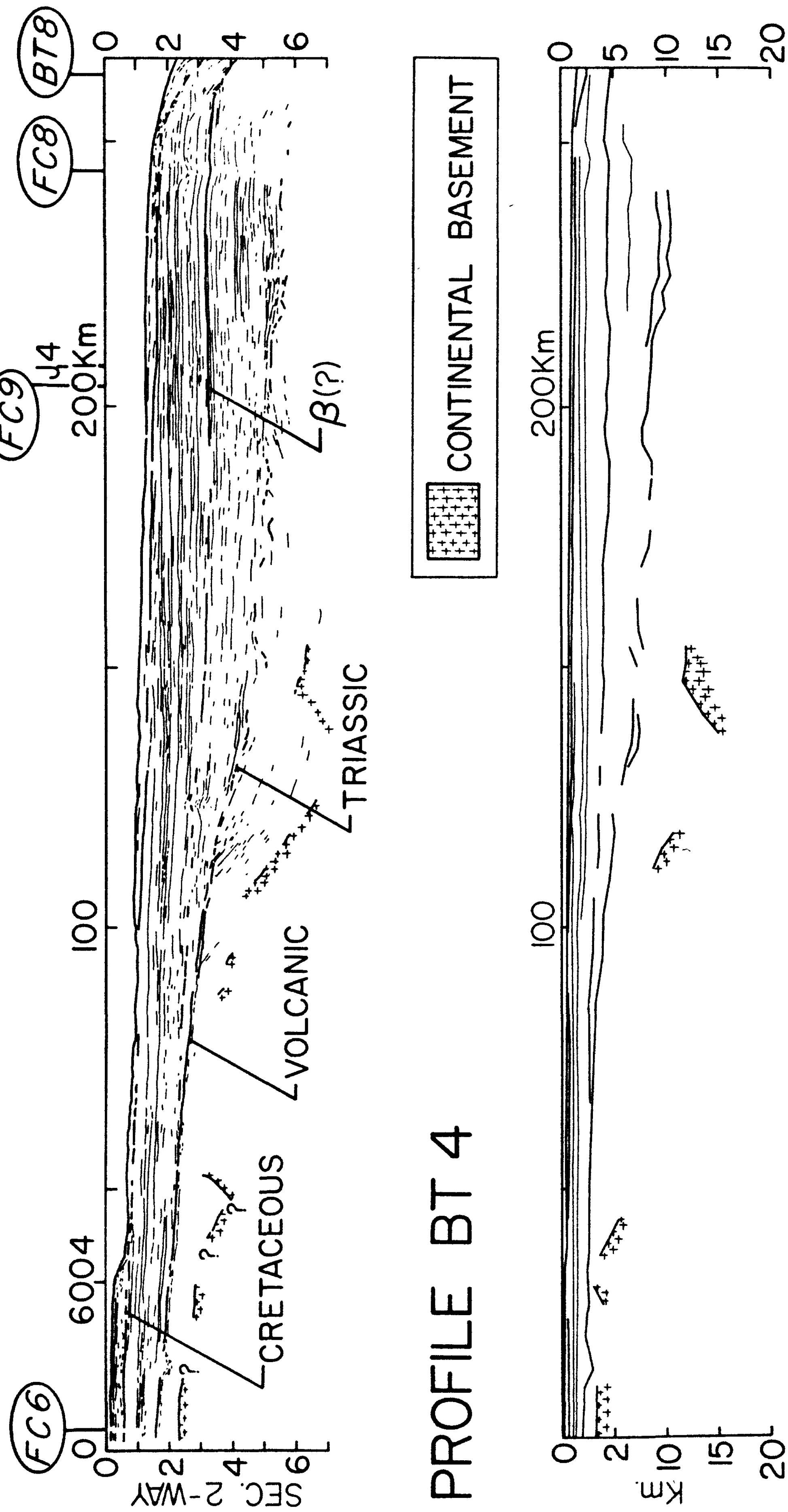

Fig. 5 Profile BT-4 Interpreted time section above, calculated depth section below.

figs. 1* and 2). This profile crosses the deepest part of the Blake Plateau Basin at its northern end and passes across three stratigraphic drill sites (fig. 2) so that the stratigraphy along this line is best known of any profile across the eastern U.S. continental margin. Profile TD5 typifies the structure of the continental margin at the Blake Plateau Basin, where a deep broad basin underwent maximum subsidence near its landward side. The seaward side of this continental margin depositional basin was closed off by reefs that acted as sediment dams. Erosion of these reefs by deep-sea processes has left a more than 3 km high cliff at the seaward side of the Blake Plateau that is known as the Blake Escarpment (fig. 2).

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Profile BT1 (fig. 6) crosses the continental margin off Cape Fear (location shown in figure 1 - the line is located seaward from the vicinity of the S.C.-N.C. border). The post-rift unconformity, probably formed on Triassic rocks here, extends seaward at shallow depth to about km 120, where it deepens rather abruptly into the Carolina Trough. Three faults break the sedimentary strata of the trough and continue downward to the deepest reflector that can be observed. The deepest part of the trough, from about km 130-170, probably is underlain by transitional basement.

The northern end of the Carolina Trough, just south of Cape Hatteras is crossed by line IPOD (fig. 1). Part of this line is shown in figure 7. The trough occurs approximately between shotpoints number 600 and number 800. Diapirs are present on this line between shotpoints 950 and 1150. These are part of a group of salt diapirs that occur along the continental margin just seaward of the Carolina Trough.

Sediment structure and continental margin development

Rifting between North America and Africa began in Triassic time. During the rift stage continental basement was fractured and extended, the process accompanied by intrusion and extrusion of mafic, mantle-derived material. Eventually, as the continents moved apart, the rift stage was followed by the drift stage, in which new oceanic crust was formed from similar mafic material. However, off the southeastern

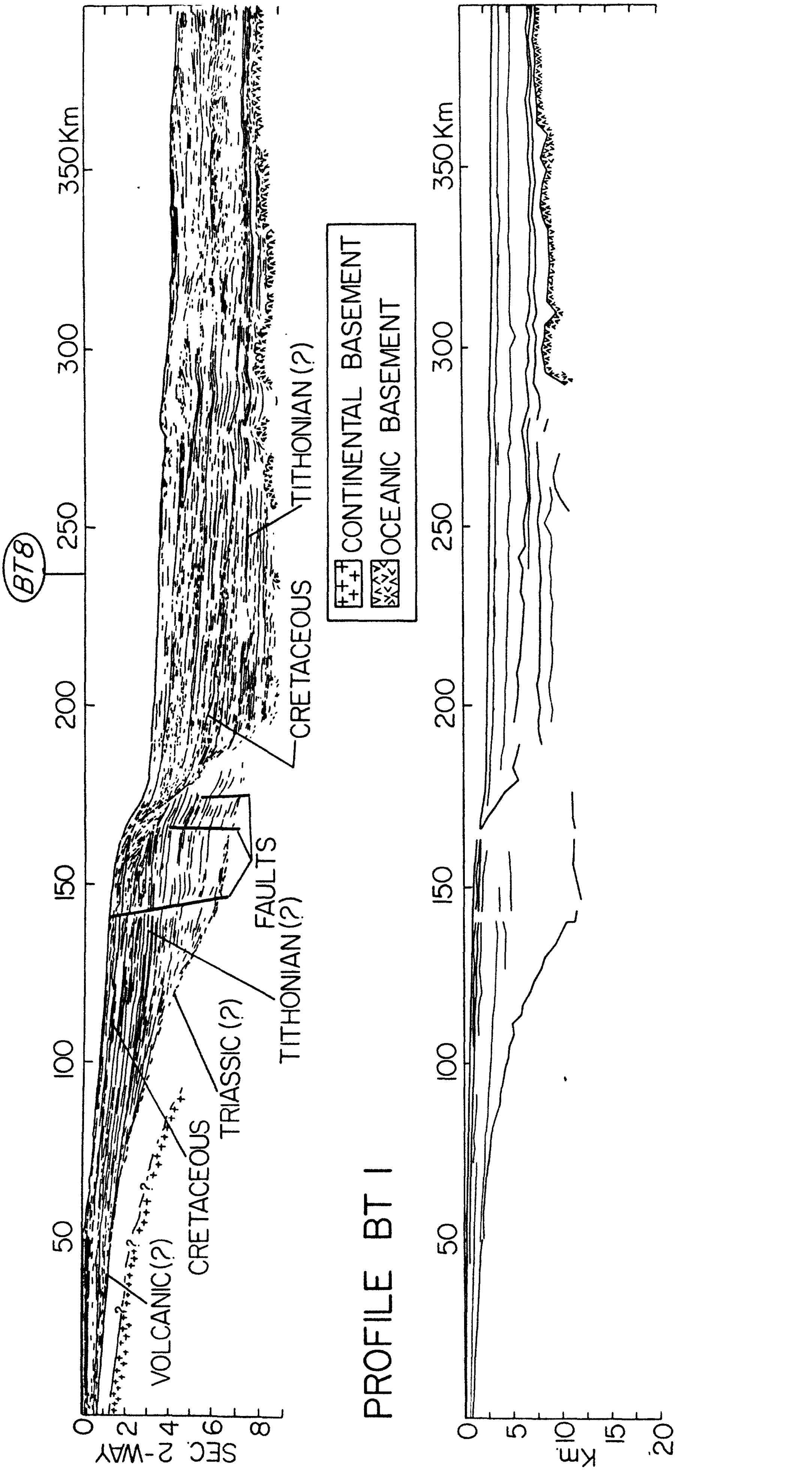


Fig. 6 Profile BT 1 Interpreted time section above, calculated depth section below.

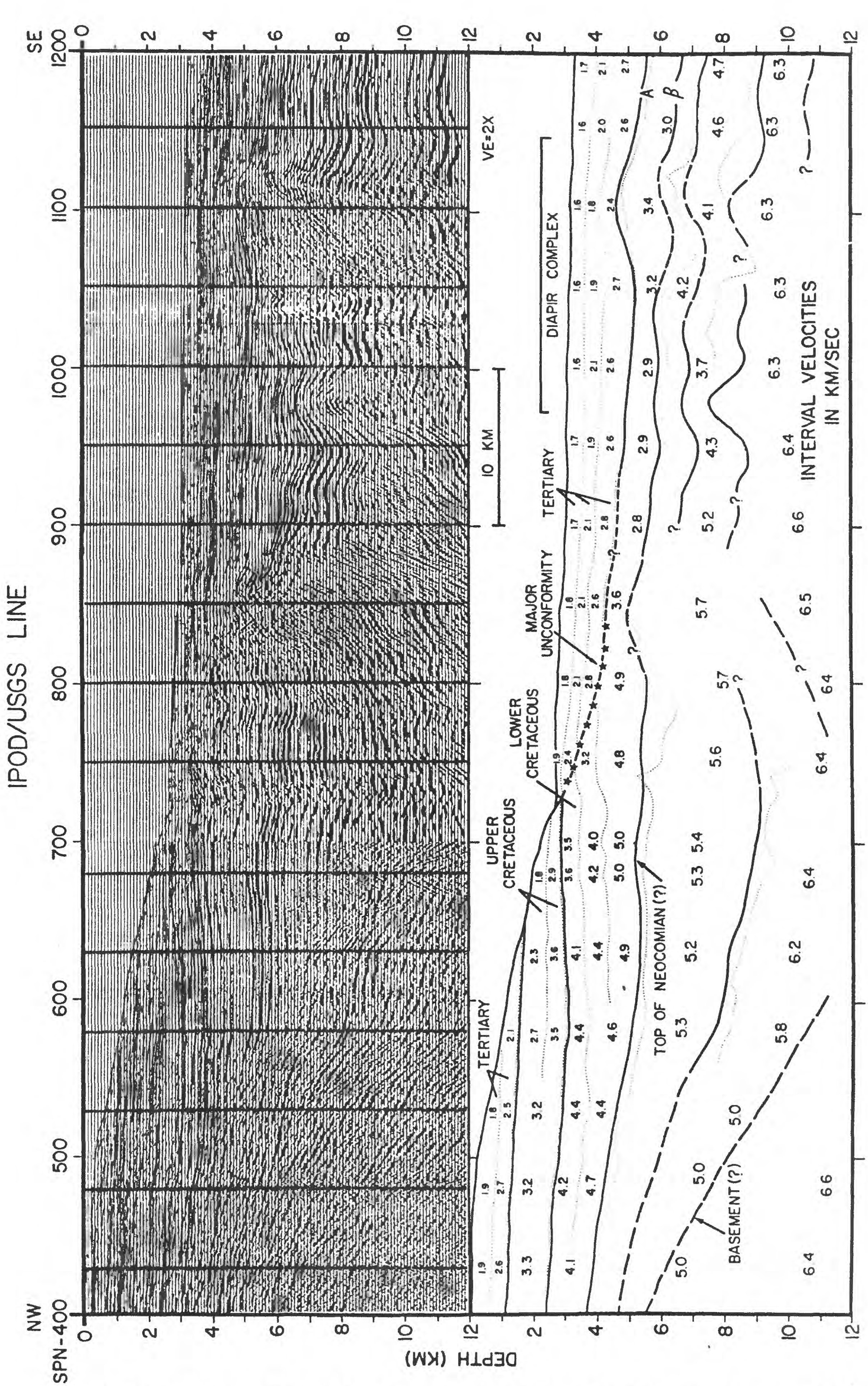


Fig. 7 Part of profile IPOD. Seismic depth section above, interpretation and interval velocities below.

U.S., these two stages were separated by an intermediate stage, in which a transitional basement was formed. The zones of deepest subsidence of continental margin basins seem to be underlain by this transitional basement. In the northern part of the potential lease sale area, where the Carolina Trough is present, the zone of transitional crust is rather narrow (fig. 8). However, south of the Blake Spur fracture zone, which separates the two basins, the zone of transitional crust is much broader (fig. 8). The spreading center that was active during earliest opening of the ocean, when the Blake Plateau Basin transitional crust was forming, ceased its activity at about 170 million years (m.y.) ago when a new spreading center developed to the east (fig. 8). This new spreading center has been active to the present.

Figure 9 is a diagrammatic presentation of the inferred stages of development of the Blake Plateau Basin at the location of line TD5 (fig. 4), a location that is considered typical for this basin. We will move through the steps of margin development there (off Jacksonville, Florida) and compare this to development to the north. The first diagrammatic section (fig. 9, 170 m.y.) shows the continental margin at the time of an eastward relocation of the spreading center (Early Jurassic). Figure 8 shows the relationships of continents and basins at the same time. In figure 9, the two centers of spreading are shown by the symbol of diverging arrows, the right hand set representing the newly developing spreading center. By this time (170 m.y.) the post-rift unconformity had formed and probably was being covered by sediments deposited in the newly formed rifted basin. Off South Carolina, northern Georgia and southern North Carolina a layer, probably of volcanic rock, covers the post-rift unconformity (figs. 5 and 6). The renewed volcanic activity may have occurred because of stresses

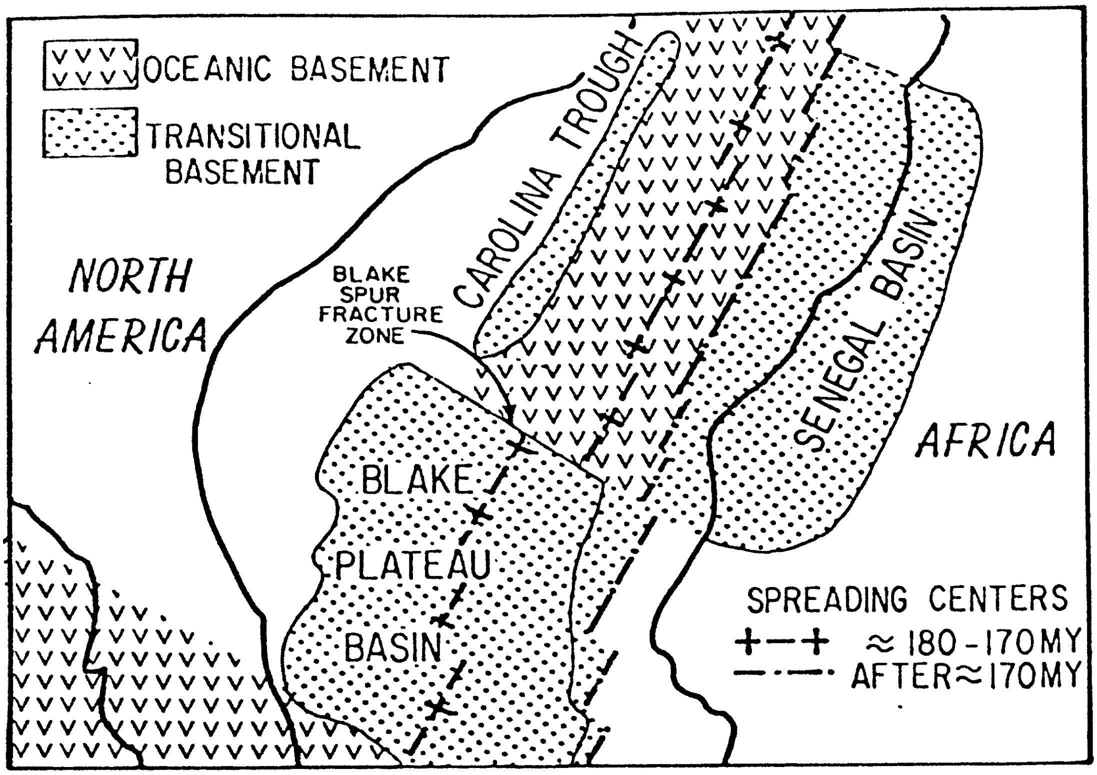


Fig. 8 Inferred reconstruction of North Atlantic basin at 170 million years ago, the approximate time of a spreading-center jump.

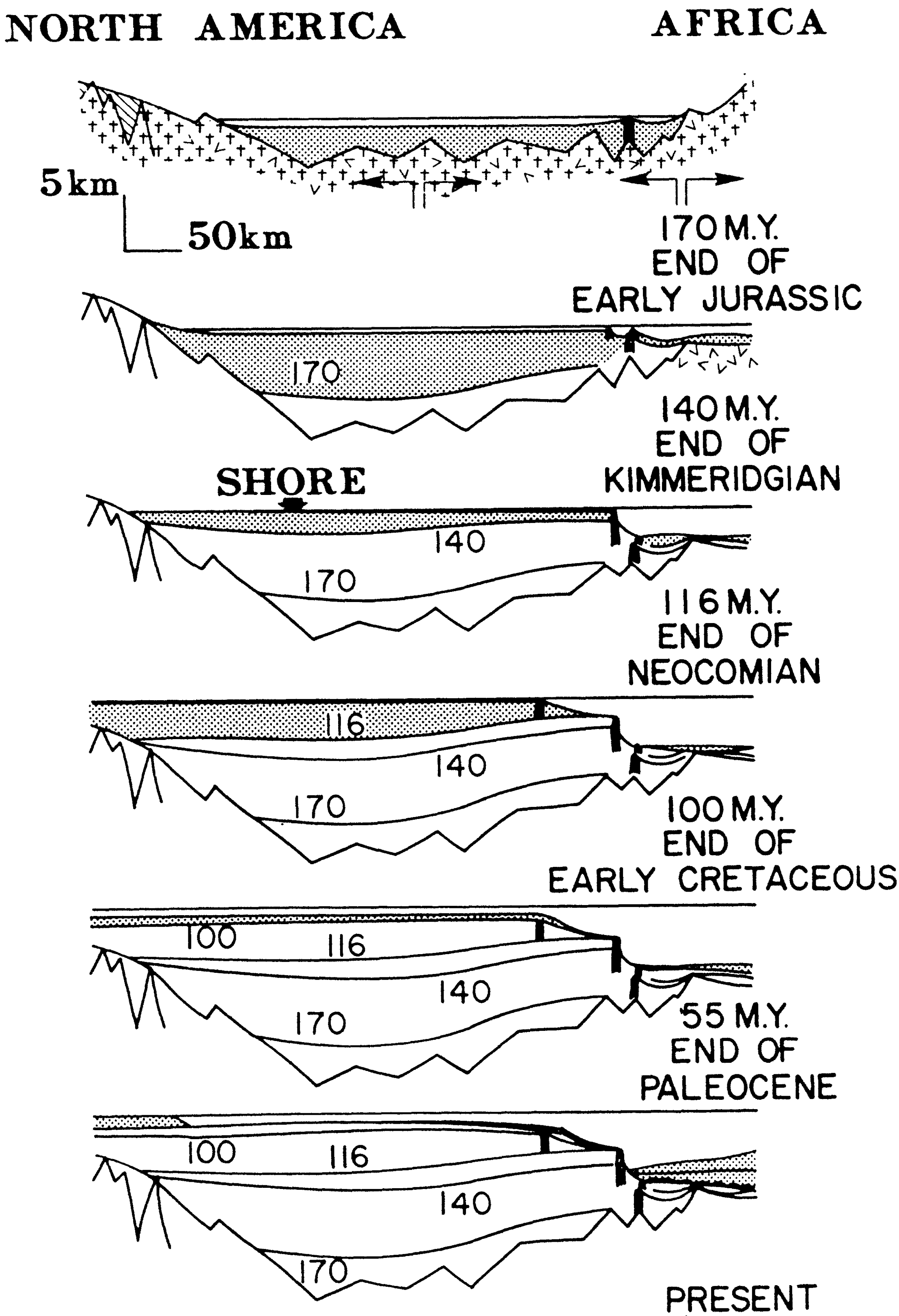


Fig. 9 Probable stages of development of the Blake Plateau Basin at the location of profile TD-5. A stippled pattern indicates deposits accumulated since the previous stage in diagram. Solid black indicates probable reefs. Hatched pattern in top section indicates Triassic deposits.

associated with the relocation of the spreading center. To the north of the Blake Plateau Basin was a zone of shallower basement at the Blake Spur fracture zone as noted in the discussion of profile BT4 (fig. 5). North of the Blake Spur fracture zone, a very much narrower zone of transitional crust had formed and then true oceanic crust began to develop, well before the spreading-center jump. Very early in the history of basin formation, ocean waters had invaded the opening rift, probably from the south. The Carolina Trough was closed off at its northern end and circulation apparently was very restricted across the fracture zone at its southern end. Such conditions allowed the precipitation of evaporites.

After the spreading-center jump, truly oceanic crust was accreted at the spreading center which became progressively farther eastward of the U.S. continental margin as the zone of new oceanic crust became wider. At 140 m.y. (fig. 9) the ocean was broader and reefs presently beneath the outer Blake Plateau but originally on the African side before the ridge jump, started to function as sediment dams. The greater part of continental margin basin subsidence occurred before 140 m.y. (approximately the end of the Jurassic Period). This early subsidence was much faster in the present basins and troughs than in adjacent areas, whereas later subsidence was more uniform across the entire continental margin region.

The major influx of sediment that was derived from the rough, block faulted terrain and trapped in the rapidly subsiding basins placed a load on the salt that was previously deposited in the Carolina Trough. This squeezed the salt seaward and formed a group of diapirs along the east side of the trough (fig. 7). Salt flow continued into Tertiary time and withdrawal of the salt into diapirs caused subsidence of sediments above the salt, probably resulting in continued growth faulting such as that shown in profile BT1 (fig. 6).

By 116 m.y. (fig. 9) one of the developing reefs became dominant and its growth and eventually erosion of its front formed the present Blake Escarpment. The Early Cretaceous (about 140 to 100 m.y. ago) was a period of extensive formation of back-reef and carbonate bank deposits on the outer Blake Plateau (fig. 4B). Meanwhile the shoreline oscillated across the inner Blake Plateau as shown by the marine-continental facies boundary (fig. 4A). At about the end of Neocomian time the main escarpment reef died and a new reef formed, growing during Aptian and Albian, before it, too, ceased to build. This step-back of the reef occurred along much of the outer Blake Plateau. The reef as a continuous feature does not extend north of the Blake Spur, although the seaward part of the Lower Cretaceous shelf is marked by probable patch reefs and carbonate banks. These are shown by structures that often appear as buried banks, such as that on profile BT1 at km 250 and about 3 sec. depth (fig. 5), and that commonly also have higher seismic velocities than adjacent rocks.

In the Late Cretaceous and Paleocene (approximately 100-55 m.y. ago, fig. 9), rising ocean level left the former shelf as a broad submerged plateau that extended across the present Blake Plateau and outer Continental Shelf. Fine sediments, characteristic of outer shelf or slope depths, accumulated. Cenozoic history of the Continental Shelf south of Cape Hatteras is summarized in figure 10. At the end of the Paleocene there was a major erosional event that left an irregular surface along a belt 100 km wide beneath the present outer Continental Shelf and inner Blake Plateau, and that is believed to have been caused by the initiation of the Gulf Stream. This eroded zone was buried in

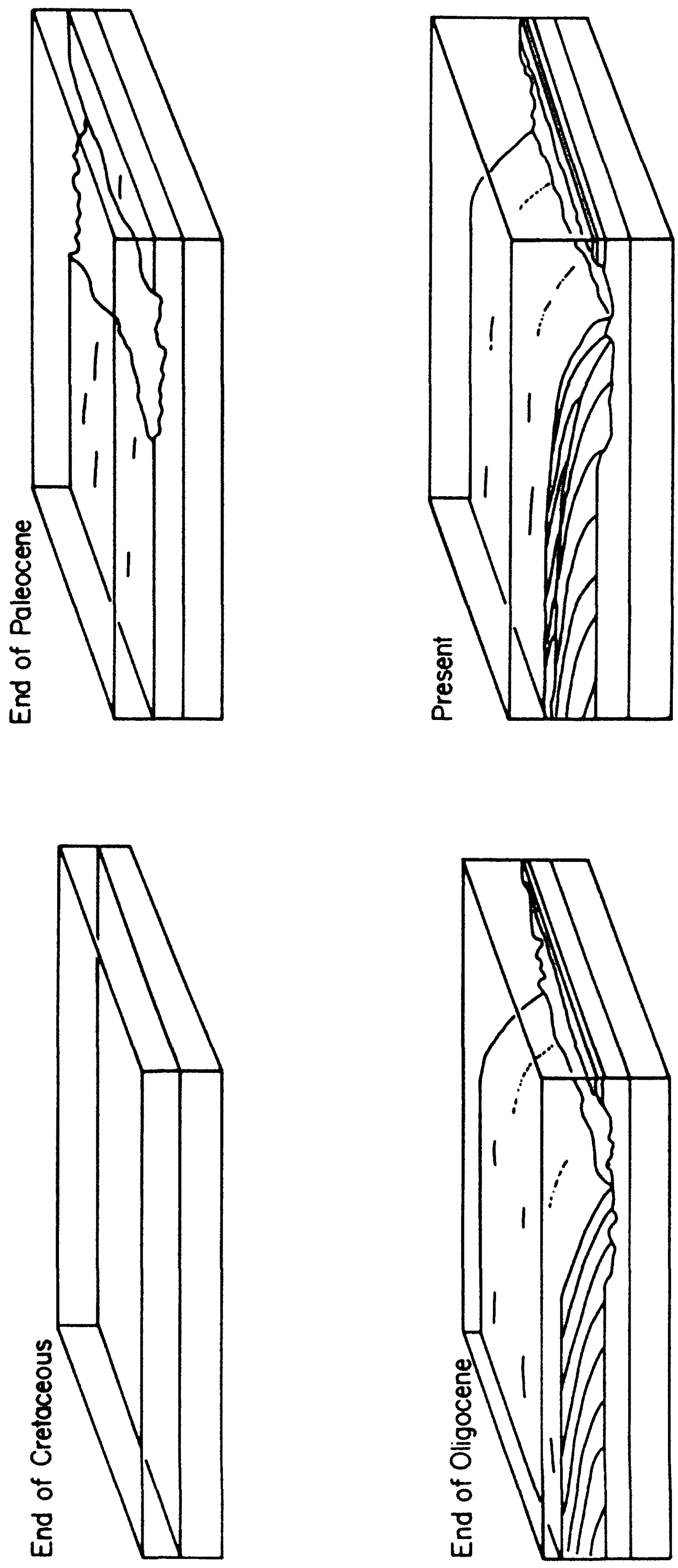


Fig. 10 Probable stages of development of the Florida-Hatteras shelf during Cenozoic time.

the Eocene by a seaward progradation of shelf sediments. This first Tertiary shelf progradation ended in the Oligocene with another regional erosive event, but one that was not as intense as the earlier Paleocene episode. This Oligocene erosion may have been related to a worldwide lowering of sea level. About at this time there also was an extensive episode of erosion in the deep sea that strongly affected the Continental Slope off the proposed lease sale area. That erosion formed a deep-sea unconformity (horizon AU) (fig. 4), caused major retreat of the Continental Slope north of the Blake Spur by erosion, as shown by truncated layers (fig. 7), and probably removed considerable amounts of material from the Blake Escarpment south of the Blake Spur.

The Oligocene unconformity beneath the present Continental Shelf is covered by a second Tertiary shelf progradation (fig. 10, Present). This progradational wedge is smaller than the Eocene wedge and apparently was delimited to seaward by the flank of the Gulf Stream. The Gulf Stream flow has been instrumental in forming the Tertiary depositional pattern; it has not allowed deposition on the inner Blake Plateau by preventing progradation of the shelf toward the east, and has maintained the upper Continental Slope north of Cape Fear free of sediments. A very thin layer of Tertiary deposits has accumulated on the outer Blake Plateau, seaward of the main flow of the Stream (fig. 9, Present).

CHAPTER II

PETROLEUM POTENTIAL

By

Mahlon M. Ball, Gordon L. Dolton, Richard B. Powers, and Abdul S. Khan

The South Atlantic margin of the United States, including the Continental Shelf, Slope, and Blake Plateau, appears to contain the geologic requirements necessary for the generation and accumulation of oil and gas.

Offshore commercial oil or gas production usually occurs in areas where four requirements are met. First, there must be a trap that may result from simple arching or doming of the sedimentary strata to a complicated interaction of tectonic, depositional, and erosional processes. Second, there must be rocks that serve as a reservoir in a suitable structural position to receive oil or gas from source beds. Third, there must be a seal over the reservoir rock to trap hydrocarbons that accumulate. Finally, there must be a sufficient quantity of recoverable hydrocarbons within the reservoir to justify the high cost of offshore development.

Source rocks

In general, the terrestrial origin of organic matter prevalent to the north and west of the area of proposed leasing favors the accumulation of natural gas as indicated by samples from the COST GE-1 well. The marine origin of organic matter in the carbonate province to the south and east favors oil.

Data concerning distribution of organic rich beds which are potential source rocks in the Carolina Trough are limited. However, recent information from the COST GE-1 well indicates that Upper Cretaceous shales contain the highest organic carbon content of the entire section drilled and contain substantial amorphous algal marine kerogens, which would be capable of yielding liquid hydrocarbons if thermally mature, however, they are probably immature due to lack of sufficient burial and low thermal history. Depositional patterns suggest that these organic rich beds may be present over considerable parts of the sale area. The Lower Cretaceous interval penetrated in COST GE-1 contained rocks generally low in organic content and the contained kerogen is dominantly herbaceous and woody. These rocks would be a very poor source for liquid hydrocarbons; however, they probably extend through much of northern and western parts of the sale area. Dominantly marine equivalents of these beds, possibly containing better source rocks, are believed to be present to the south and east (fig. 4). It should also be noted that the DSDP 391 well (fig. 1), seaward of the Blake Plateau, encountered organic-rich beds of Lower Cretaceous age. These are considered to offer source rock potential where sufficiently buried.

Maturation

Adequacy of maturation of potential source rocks is of concern in the sale area because of the low regional geothermal gradients. The COST GE-1 well documents a low geothermal gradient; geochemical data from the well indicate that the low gradient has persisted from Cretaceous time. For much of the shelf, only the oldest and deepest sediments probably surpass the threshold temperature for maturation of hydrocarbons in COST GE-1. However, in the Blake Plateau Basin and

Carolina Trough, where sediment thicknesses exceed 11 km (fig. 3), the gradients measured adjacent to the area, as at the Great Isaac well in the Bahamas (fig. 1), would result in temperatures high enough to achieve maturation of potential source beds within large parts of the Lower Cretaceous-Jurassic section. It is felt that long-range migration from this region of deep potential source rocks to traps in the shallower strata may be necessary for large petroleum accumulations to occur beneath the shelf. Increased heat flow may be associated with the complex of possible diapirs at the base of the Continental Slope off Cape Hatteras and the piercements off Cape Fear may have produced local thermal maturity in younger source rocks in these areas.

In summary, threshold maturity for generation of liquid hydrocarbons is probably not achieved for Upper Cretaceous and younger rocks over essentially the entire sale area, and only rocks of Lower Cretaceous age, and older, appear to have reached the thermal maturity required for liquid hydrocarbon generation over a broad area.

Seals

Seals of regional extent should be common in the north (fig. 1). From drilling experience in the Bahamas, however, absence of effective seals may be a major problem for petroleum accumulation in the southern part of the sale area.

Impermeable beds, which could act as seals for hydrocarbon entrapment, are indicated throughout the section in the COST GE-1 well. The common occurrence of shale and calcareous shale in the shallow, Upper Cretaceous, part of the section, and of thin beds of anhydrite in the deeper, Lower Cretaceous, part of the section provide the best potential for seals.

Reservoirs

Lower Mesozoic rocks range southward from the predominantly terrigenous clastic section seen in the Hatteras Light well at Cape Hatteras (fig. 1) to carbonates and evaporites in Florida and the Bahamas. Changes in character of seismic reflectors eastward from the Hatteras and COST GE-1 wells may indicate an increase in development of thin carbonate beds in the lower Mesozoic section and possible carbonate bank buildups under the slope and rise. Rocks of reservoir quality can be expected throughout the region in the Lower Cretaceous-Jurassic section, as shown in COST GE-1. For instance, GE-1 core data showed average porosity values in the Lower Cretaceous on the order of 15 to 25% and permeabilities from 1 to 200 md.; the samples include both sandstones and limestones. In addition, in the GE-1, very low permeability Eocene chalks are present at depths of from 300-900 meters, and where fractured or over-pressured, could act as reservoir units.

Reefal and carbonate bank deposits on basement highs of the Blake Plateau, especially at its seaward edge, may offer particularly attractive reservoirs, although these have not been penetrated to date. However, a large part of the region within which they occur is excluded from the sale area.

Traps

In several areas gravity and magnetic anomalies are coincident on the shelf and inshore part of the northern Blake Plateau (Dillon and others, 1975, plate I). Some of these anomalies have dimensions measured in kilometers and magnitudes, respectively, of tens of milligals and hundreds of gammas and may in part represent intrabasement density and magnetic intensity contrasts. However, our limited seismic-reflection profiling coverage suggests that basement faulting and erosion may have produced basement highs with relief of 100 to 200 meters that are associated with the geophysical anomalies. Sediments draped over these buried basement "hills" may provide excellent traps for significant accumulations of oil and gas. Approximately twenty structural closures were identified from more detailed seismic mapping of a limited part of the shelf area.

Block faulting which took place in early Mesozoic time formed geologic features that may be attractive exploration targets. Although these structures are smoothed by erosion and infilling, they are discernible in reflection seismic profiles and from basement depth estimates derived from magnetic data in the eastern downdip border of the South Atlantic margin.

Beneath the Blake Plateau, shallow water carbonate banks and reefs may form traps. Such structures may also serve as excellent reservoirs for petroleum. The reefal buildups on the basement highs at the seaward edge of the southern Blake Plateau may form the largest structural feature in the entire region and, hence, may be a particularly good target for petroleum exploration; however, prospects drilled in similar structural settings to the south in the Bahamas lack seals and are completely flushed by seawater.

Apparently, loading by overlying sediments caused flowage of underlying evaporites in the Carolina Trough and resulted locally in the formation of diapiric or piercement structures. Our regional network of seismic profiles reveals a complex of possible diapirs along the continental margin, just seaward of the trough, but most of the diapirs observed are slightly seaward of the proposed sale area. Features of a similar nature are highly productive on the Gulf Coast of Texas and

Louisiana.

The thick sections of low-angle eastward dipping strata seen offshore of Florida, Georgia, and the Carolinas represent possible targets for production if updip pinch-outs of porous, permeable strata encased in sealing clay shales, carbonates or evaporites are found.

CHAPTER III

ESTIMATE OF UNDISCOVERED RECOVERABLE OIL AND GAS RESOURCES

By

Richard B. Powers, Abdul S. Khan, and Gordon L. Dolton

The proposed lease sale area (fig. 1) comprises approximately 67,000 square miles (173,400 km^2), of which 43,300 square miles (112,100 km^2) lie between 0-200 meters water depth, and 23,600 square miles (61,200 km^2) lie in water depths greater than 200 meters (fig. 1). The bulk of the lease area lies within the South Atlantic shelf and Blake Plateau Provinces that were evaluated by the Resource Appraisal Group and described in USGS Circular 725 (Miller and others, 1975). As indicated in the USGS Circular 725 study, the South Atlantic shelf province extends seaward from shoreline to 200 meters water depth. The area of greater than 200 meters water depth to the international boundary or base of slope is considered to lie within the Blake Plateau province. The area in water more than 200 meters deep has been reduced by almost one half of that previously assessed for Lease Sale #54 (Dillon and others, 1978).

The south Atlantic margin of the United States, including the Continental Shelf, Slope, and Blake Plateau, contains a number of geologic settings where the possibility exists for petroleum accumulation. Magnitude of structures alone, as indicated by observed geophysical anomalies, assuming an average pay thickness on the order of 100 meters and effective porosities of around 10%, indicate that these features might contain hundreds of millions of barrels of oil and hundreds of billions of cubic feet of gas. However, maturation of source rocks is a critical problem based on regionally low geothermal gradients adjacent to the sale area. For much of the shelf, only the oldest and deepest sediments probably surpass the threshold temperatures necessary for maturation of hydrocarbons. Large reefal carbonate buildups sufficient for petroleum accumulations are prospective targets over much of the eastern margin of the Blake Plateau province, but are in part outside of the sale area. Rocks of good reservoir quality can be expected throughout the region in the Jurassic-Lower Cretaceous section. Effective seals of regional extent should be common in the north; however, absence of seals may prove to be a problem in the southeasternmost part of the carbonate province.

The estimates of undiscovered recoverable oil and gas resources in Sale Area No. 56 are based in part on volumetric and analog analytical methods that are fully explained in Geological Survey Circular 725. Analogs which may be considered for the sale area include the dominantly carbonate sediment-filled Salina Basin, the Florida Platform, the Permian, or Palo Duro Basins, and the less appropriate mixed clastic-carbonate provinces of the Alberta and Williston Basins. The Florida Platform and Permian Basin, with their extensive reef complexes, may offer appropriate stratigraphic analogues for portions of the Blake Plateau in particular. They provide an extreme range of hydrocarbon yield potential, within which rocks of the study area might fall. However, caution must be used in analogies of this sort because of the effect of significant differences in geology and history, as well as differences in economics.

Undiscovered recoverable resources are those resources which are estimated to exist in favorable geologic settings and to be economically recoverable at the present time. The estimates reported here are based on subjective probability procedures, which reflect judgements of quantities to be found, based on an analysis of all geologic information available. Because undiscovered recoverable resources are uncertain quantities, the degree of uncertainty is best expressed in the form of probabilities. These probabilities are expressed as a range of estimates, with a low estimate equating to a 95 percent probability that there is at least that amount and a high estimate equating to a 5 percent probability that there is at least that amount. A statistical mean is also generated.

Estimates of undiscovered resources in the proposed lease sale area are made in two increments based on water depths: (1) between 0 and 200 meters; and (2) greater than 200 meters. The latter increment includes water depths down to 2,500 meters in places. An aggregate total for the entire sale is also calculated. In addition, these estimates incorporate a 40 percent marginal probability (risk) that any commercially recoverable oil and gas will be found between 0 and 200 meters of water, and a 30 percent marginal probability beyond 200 meters of water (see table on following page).

Unconditional (Risked)

Estimates of Undiscovered Recoverable Resources (as of January 1980)
in OCS Sale Area No. 56

0-200 Meters Water Depth
40% Marginal Probability

	95%	5%	Statistical Mean
Oil (billions of barrels)	0	1.2	0.3
Gas (trillions of cubic feet)	0	2.5	0.7

Greater than 200 Meters Water Depth
30% Marginal Probability

	95%	5%	Statistical Mean
Oil (billions of barrels)	0	1.3	0.3
Gas (trillions of cubic feet)	0	1.3	0.3

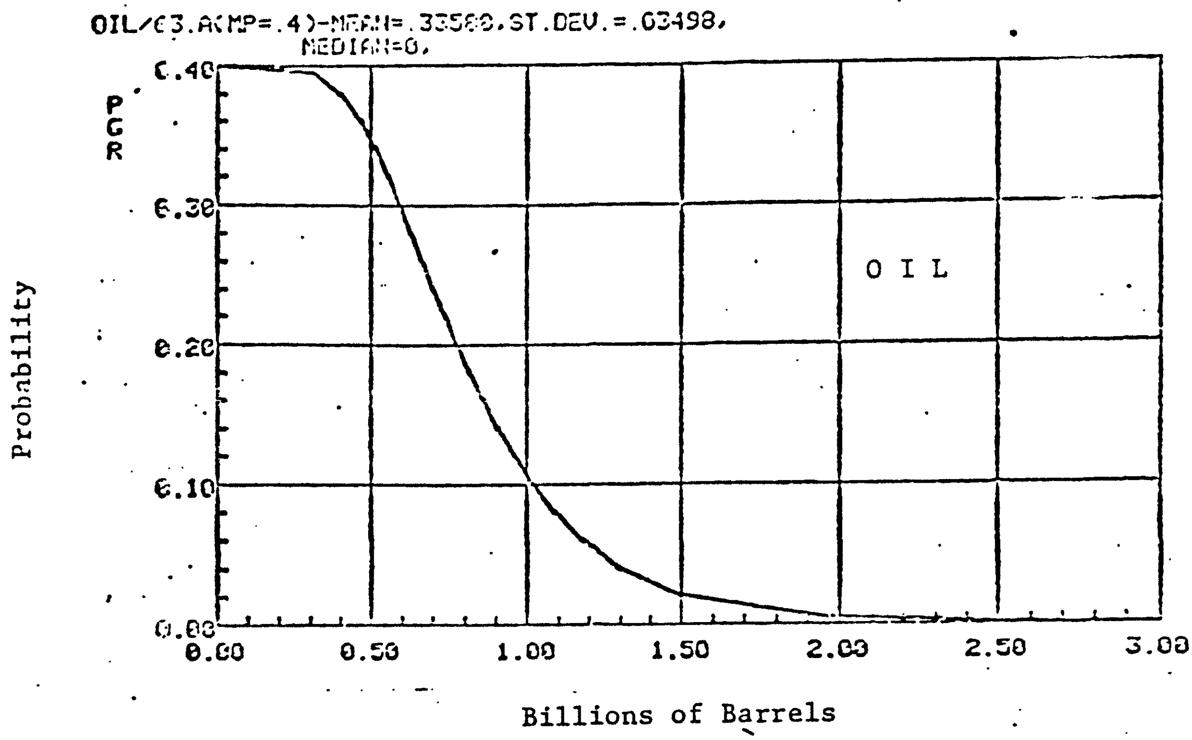
Aggregate for Total Sale Area

	95%	5%	Statistical Mean
Oil (billions of barrels)	0	1.9	0.6
Gas (trillions of cubic feet)	0	2.9	1.0

The proposed sale area includes within it tracts which have been nominated for lease at OCS Sale 54, and 43 tracts which were previously leased in OCS Sale 43 (approximately 990 km^2). These nominations and leases are largely based upon unavailable detailed proprietary geological-geophysical data, which have identified attractive areas. Thus, it is quite probable that some quantity of the total oil and gas resource potential of the proposed sale area may be related to these restricted tracts and will not be available for Sale 56. However, the total number of tracts which will be under lease at the time of Sale 56 remains indeterminate, and of those already leased, none has yet been drilled to allow confirmation of individual tract assessment.

The probability distribution curves (figs. 11, 12, 13) show estimates of undiscovered recoverable resources in proposed BLM Sale Area No. 56. Estimates of oil and gas resources at various probabilities can be read directly from the curves. These curves incorporate in their distributions the marginal probability (risk) of commercial oil or gas present in any quantity as described in Circular 725 (Miller and others, 1975).

Proposed Lease Sale #56
(0-200 meters)



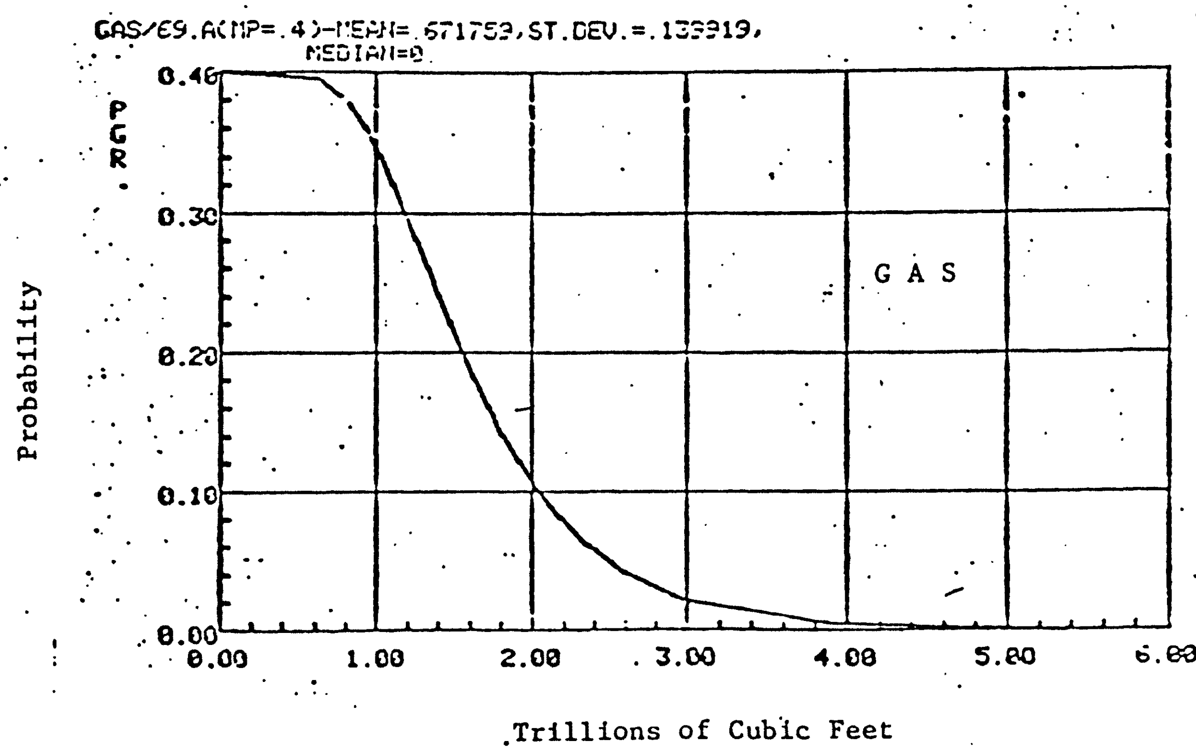
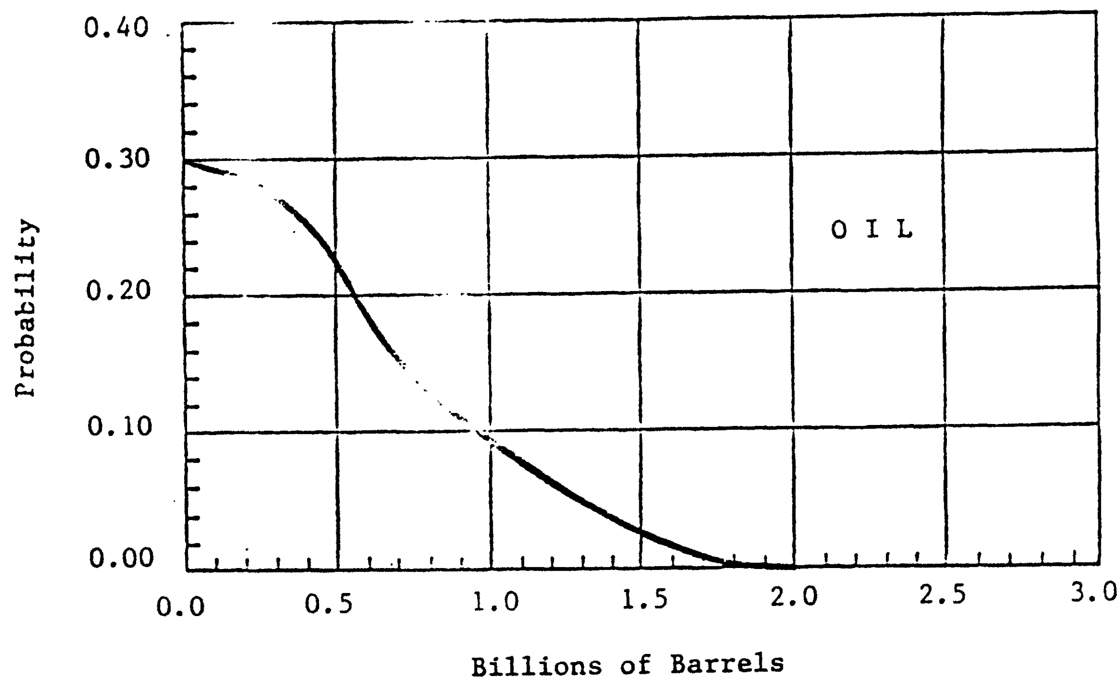


Figure 11 -- Lognormal probability distribution of undiscovered oil and gas for 0-200 meter water depth.

Proposed Lease Sale 56
(greater than 200 meters)



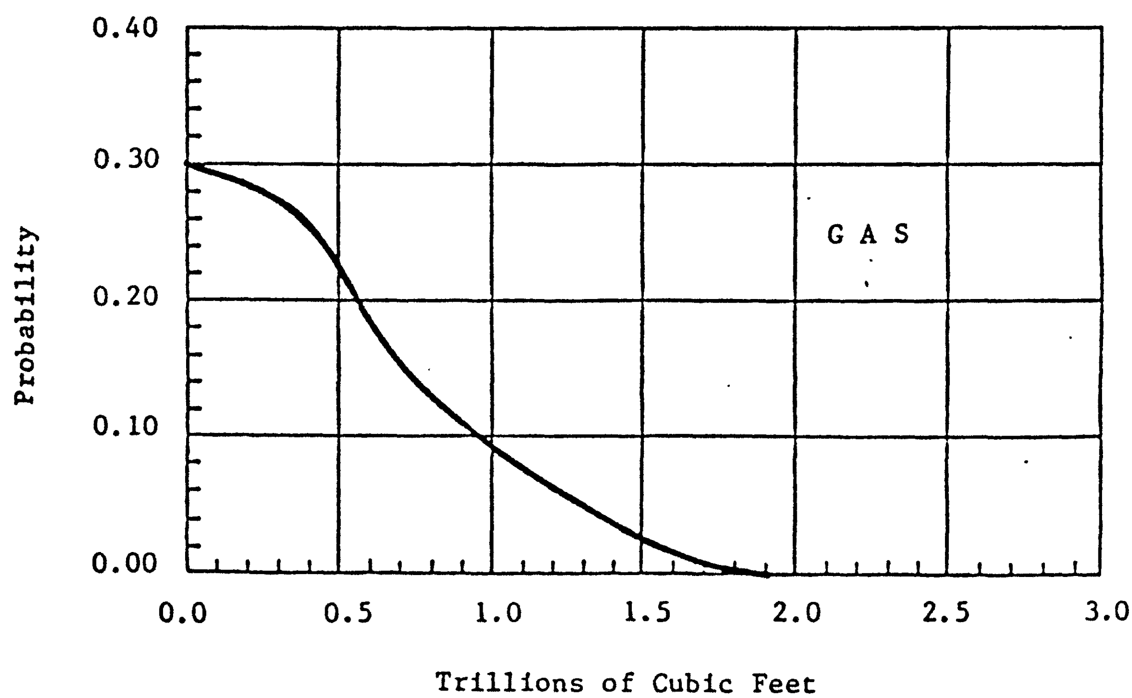
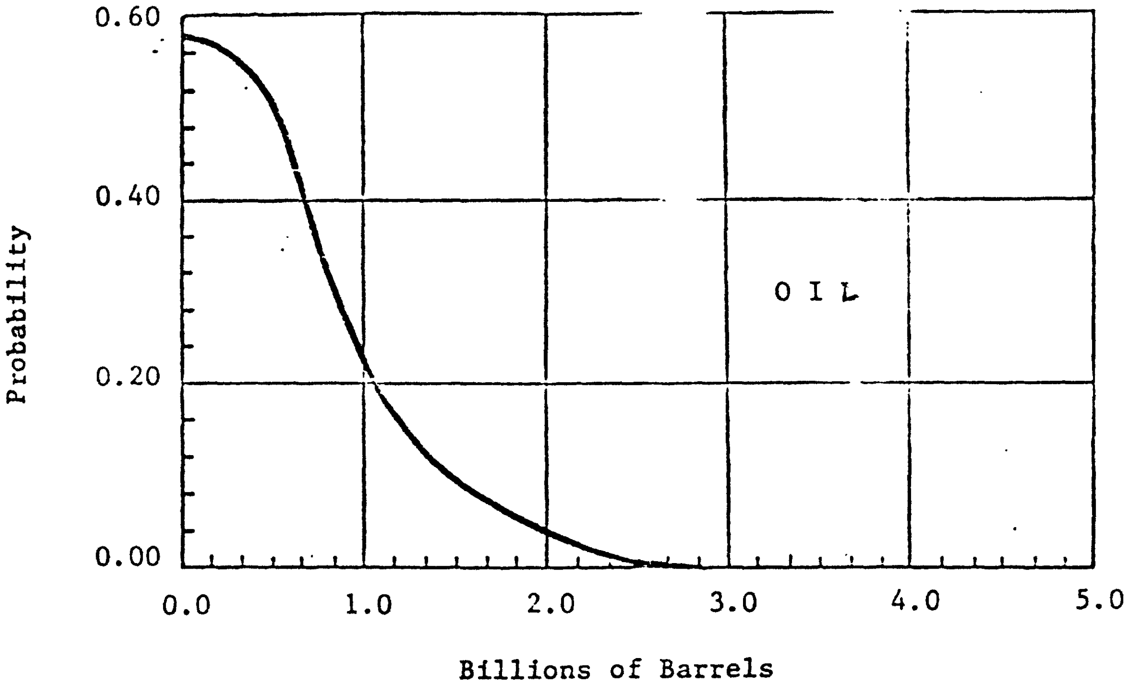


Figure 12 -- Lognormal probability distribution of undiscovered recoverable oil and gas for greater than 200 meter water depth.

Proposed Lease Sale 56
(Aggregate, 0 to greater than 200 meters)



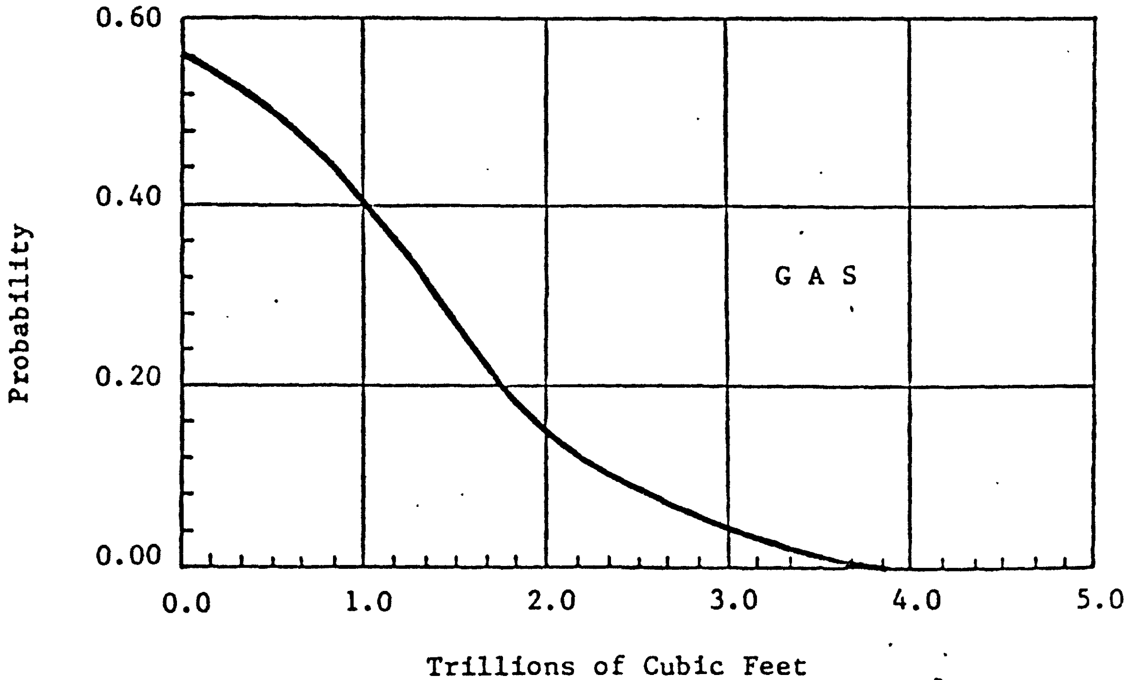


Figure 13 -- Aggregate probability distribution of undiscovered recoverable oil and gas for total sale area, 0 to greater than 200 meter water depth.

CHAPTER IV

ENVIRONMENTAL CONSIDERATIONS

By

Peter Popenoe, William P. Dillon, Charles K. Paull, and James M. Robb

A number of potential environmental problems within the Lease Sale 56 area are common to all areas of the U.S. east coast. These include hazards related to storms, hurricanes, variations in bottom conditions and support characteristics, high energy zones near the capes where strong currents and scour should be expected, buried stream channels and shallow faulting. Additional factors peculiar to this area that must be considered in respect to environmental damage include very strong currents and severe bottom scour associated with the Gulf Stream, a freshwater aquifer which extends offshore, areas of active growth of benthic organisms, cavernous porosity, possible seismicity, and frozen gas hydrates of the Blake Ridge. Although slope instability does not appear to be a problem on the Florida-Hatteras Slope, slump features do occur on the steeper Continental Slope north of Cape Hatteras.

Potential hazards associated with ocean circulation and weather conditions

Currents and severe weather conditions constitute potential environmental hazards, as associated water movements may cause transport of oil spills to shore and storm waves may damage drill rigs and platforms or undermine bottom-mounted platforms and structures due to scour of sediments.

Weather conditions - Gale winds south of Cape Hatteras usually occur less than 15 days per year. However, they have been recorded at all stations along the coast and can occur at almost any time of the year associated with sharply defined frontal systems, severe cyclonic storms, hurricanes, or severe local thunderstorms.

Tropical cyclones (hurricanes), the most severe weather hazard in this area, occur mostly from June through October, occasionally in May and November, and reach their highest frequency during September.

Large waves associated with hurricanes will act as shallow-water waves anywhere on the shelf and can cause platform failure from cyclic loading. Refraction of waves by capes and offshore shoals may result in concentrations of wave energy, and thus areas of much larger breaking waves than would normally be anticipated. In the shoal waters east of Cape Hatteras these effects are particularly severe.

Shelf circulation and movement of oil slicks - Information on water flow in this area of the shelf is scanty. The most useful available data on net water circulation on the shelf are provided by drift bottles and bottom drifters. No comparable information is available farther offshore.

According to Bumpus (1973, p. 129): "It would appear that two conflicting systems are at play here, a 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." Water on the Continental Shelf of the Southeast Georgia Embayment is apparently renewed both from the Gulf Stream and from noncontinuous flow south past Cape Hatteras, as well as from river input. Geopotential topography of the sea surface south of

Cape Hatteras (Stefansson and others, 1971) suggests the presence of counterclockwise gyres in this vicinity.

The movement of bottom drifters suggests that the thermohaline circulation is modified by wind (Bumpus, 1973). Off North Carolina, the shoreward component of bottom drift extends farther from shore than off Georgia. Bottom drift toward Cape Canaveral is well documented by high rates of recovery of bottom drifters in that region. Intrusion of slope water onto the shelf apparently occurs in summer (Stefansson and others, 1971), when bottom onshore velocity of 12 cm/s 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 and others, 1971).

Experiments have indicated that oil spills are driven by the wind at about 2-3% of wind velocity (Schwartzberg, 1971; Harrison, 1974). An oil spill may cause a contiguous slick for up to 20 days before it disintegrates (Offshore Oil Group, M.I.T., 1973). During the fall, winds blow in a generally onshore direction (east, southeast, northeast) almost half of the time at an average velocity of force 4 (5-7 m/s) (U.S. Dept. of Commerce, 1974). Such wind speeds might be expected to produce about 0.1-0.2 m/s onshore movement of slicks. In addition to this surface wind effect, Bumpus's (1973) data and the pilot charts both suggest a southeasterly moving surface current during this period with a minimum drift of about 9 mi/d (20 cm/s) (pilot charts indicate a rate of about 35 cm/s which is probably closer to true speed). The high recovery rate of drifters noted by Bumpus for September probably indicates a significant onshore component of water movement. 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 4 days or 500 miles in 20 days, and easily impinge on the shore. Thus, fall may be the time of the most extreme danger from oil spills because this is also the season for hurricanes which could inflict damage to rigs.

The results of both drift-bottle studies and bottom drifters show a strong drift toward Cape Canaveral. Spills near that cape, thus, have a much greater chance of drifting ashore than spills elsewhere; therefore, lease sites near Cape Canaveral should be examined with this consideration in mind.

Oil spill trajectory modeling studies (Slack and Smith, 1976) based on the available wind and current data have resulted in the estimated beaching probabilities shown in figure 14.

The Gulf Stream and associated flows - Offshore circulation in this region is dominated by the Gulf Stream-Florida Current flow which reaches speeds up to at least 180 cm/s. This strong current which skirts the edge of the Continental Shelf could transport oil spills out of the Southeast Georgia Embayment-Blake Plateau area. However, the high speed of the current could also pose a potential threat to drilling or development operations.

The Gulf Stream is about 100 km wide off Florida, and broadens northward (Richardson and others, 1969; Richardson and Knauss, 1971). It generally forms a single, essentially unidirectional flow to Cape Hatteras, but minor meandering has been reported as far south as Cape Canaveral (Chew and Berberian, 1970) and irregularities have been observed on its western border which may be due to tidal effects (von Arx and others, 1955). The most intense flow, of about 180 cm/s, occurs

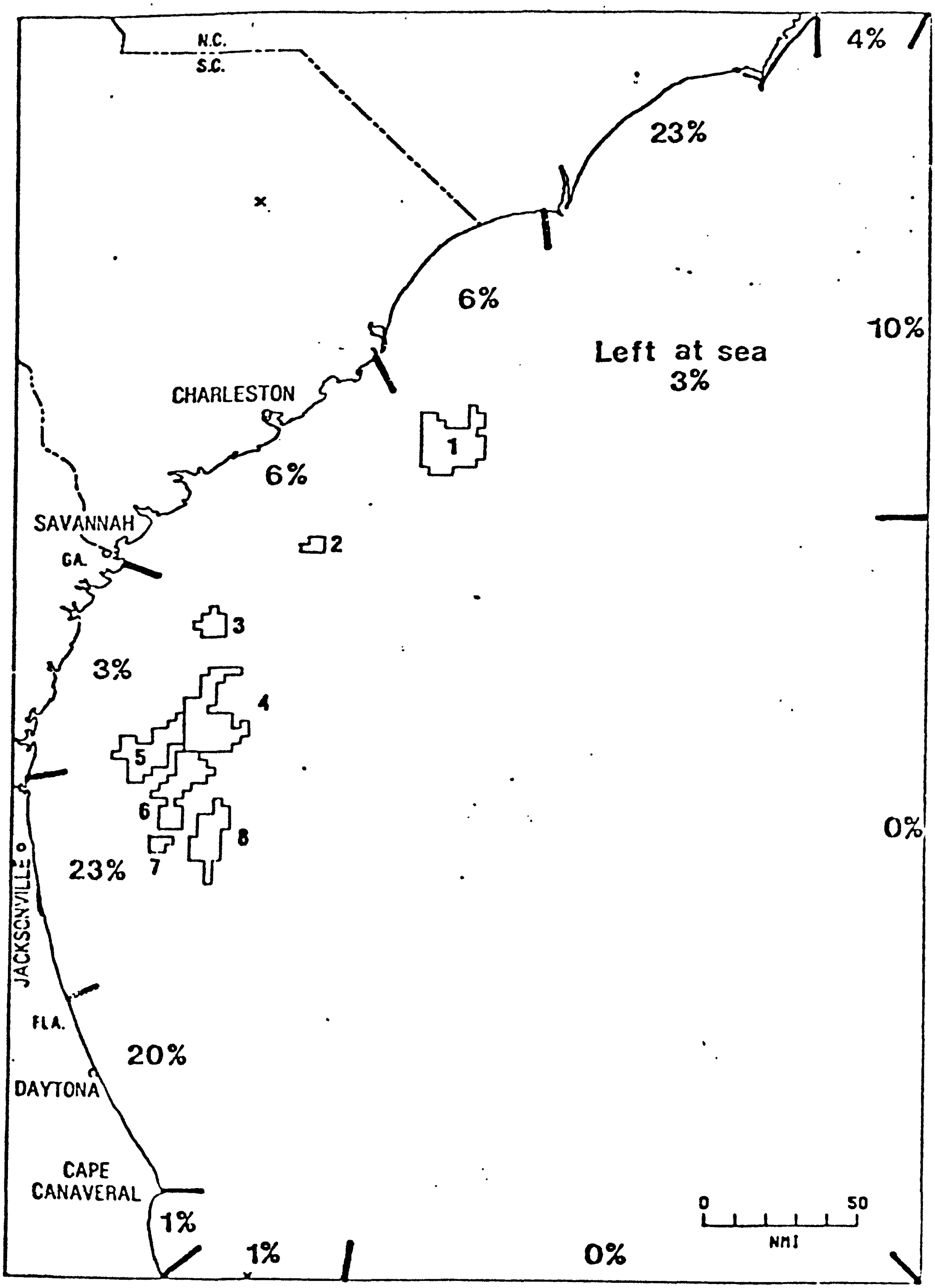


Figure 14. Beaching probability for oil spills generated within U.S. South Atlantic lease area (Slack and Smith, 1976) for sale #43.

about 20 to 30 km seaward of the shelf edge and northward flow reaches about 40 cm/s at the seafloor in water depths of about 400 to 800 m (Schmitz and Richardson, 1968; Richardson and others, 1969). The flow commonly almost fills the Strait of Florida (Richardson and others, 1969) but its area of contact with the bottom decreases toward the north and was calculated to be only 3 km wide near Cape Hatteras at a time when the surface width of the main stream was 135 km (Richardson and Knauss, 1971).

Reverse flows to the Gulf Stream may occur both near surface (counter currents) and on bottom (undercurrents). 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 and others, 1971). This undercurrent is noticeable in its effects on the sediments, particularly at depths of 1,200 to 3,600 m (Heezen and others, 1966; Rowe and Menzies, 1968) and velocities of up to 26 cm/s in the southward direction have been measured (Amos and others, 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 (Duing and Johnson, 1971; Weatherly, 1972).

In the Gulf Stream, considerable difficulty was experienced in holding position during the drilling of the JOIDES holes on the Florida Shelf and Blake Plateau; in addition, bending of the drill string during retrieval has also been a problem (Schlee, J. and Gerard, R., 1965; JOIDES Blake Panel Report, unpublished manuscript, 64 p.). More recently, the drill ship GLOMAR CONCEPTION encountered similar difficulty at drilling sites located in the Gulf Stream (Hathaway and others, 1977).

Bottom conditions

The mid and outer shelf sediments are sands which appear to be in textural equilibrium on the shallow shelf. Regional transport does not appear to be an important process. The presence of primary structures such as crossbedding, ripple marks, and graded bedding indicate that active deposition or redeposition is going on, however, shallow seismic-reflection data (Edsall, 1978) show that in most areas only the top few meters of sediment are actively reworked by current scour. Exceptions to this occur in the high energy zones near the capes, particularly Cape Hatteras and Cape Romain, where large sand-wave fields are present which move during storms. The medium to coarse sands which predominate on the shelf are well-compacted as a result of reworking by both currents and benthic infauna and thus should offer good support (McClelland, 1974). However, dense sands typically provide great resistance to pile penetration. Patches of lagoonal muds and peats, stream channel fillings and areas of submarine cut-and-fill occur on the shelf which would result in scattered areas in which support capabilities could be very poor, or could vary laterally over short distances.

The inner Blake Plateau is severely scoured by Gulf Stream currents. Throughout most of Tertiary and Quaternary time sediments were not deposited here because of these erosive conditions and the bottom in much of the area is an eroded terrace of Upper Cretaceous and Paleocene age rocks. Slopes are in places steep, and covered by a pavement of manganese and phosphorite nodules. Scour around structural supports and problems in the setting of risers and other structures in strong currents should be expected on the inner Blake Plateau.

On the slope, sediments are generally finer than on the shelf, consisting of fine-grained sands, muddy sands, silts, and muds (Hollister, 1973). In general, fine calcareous sands and silts predominate between Cape Hatteras and Jacksonville, Florida.

Slope instability - The Continental Slope between Cape Hatteras and Jacksonville, Florida appears to be relatively stable. Areas of slumping and normal faulting are present locally but their occurrence appears to be rare. Drilling in this area (Hathaway and others, 1976) indicates that thin clay layers of Pleistocene age are present at shallow depths beneath Holocene fine sands. These clay layers could affect static bearing capacity and stability with additional loading from development structures. On the slope north of Cape Hatteras slump features occur in depths as shallow as 350 meters and extend to the bottom of the Continental Slope.

Marine habitats and live bottoms - The sand cover on the shelf is in places absent exposing a harder substrate of cemented sand. These areas of hard bottom are patchy and scattered. Their surfaces are smooth or roughly broken with relief of up to 15 meters. The hard or rocky bottoms provide a place of attachment for a variety of sessile invertebrates such as sea fans, sea whips, hydroids, anemones, sponges, bryozoans, soft and hard corals, and shelter for a variety of reef-type fishes and crustaceans. These areas are commonly referred to as live or hard bottoms and constitute both recreational and commercial fishing areas. The most prominent of these areas occur near the top of the slope where they are known as the shelf-edge ridge and reef. Care should be taken in the placement of rigs to avoid disturbing these marine habitats.

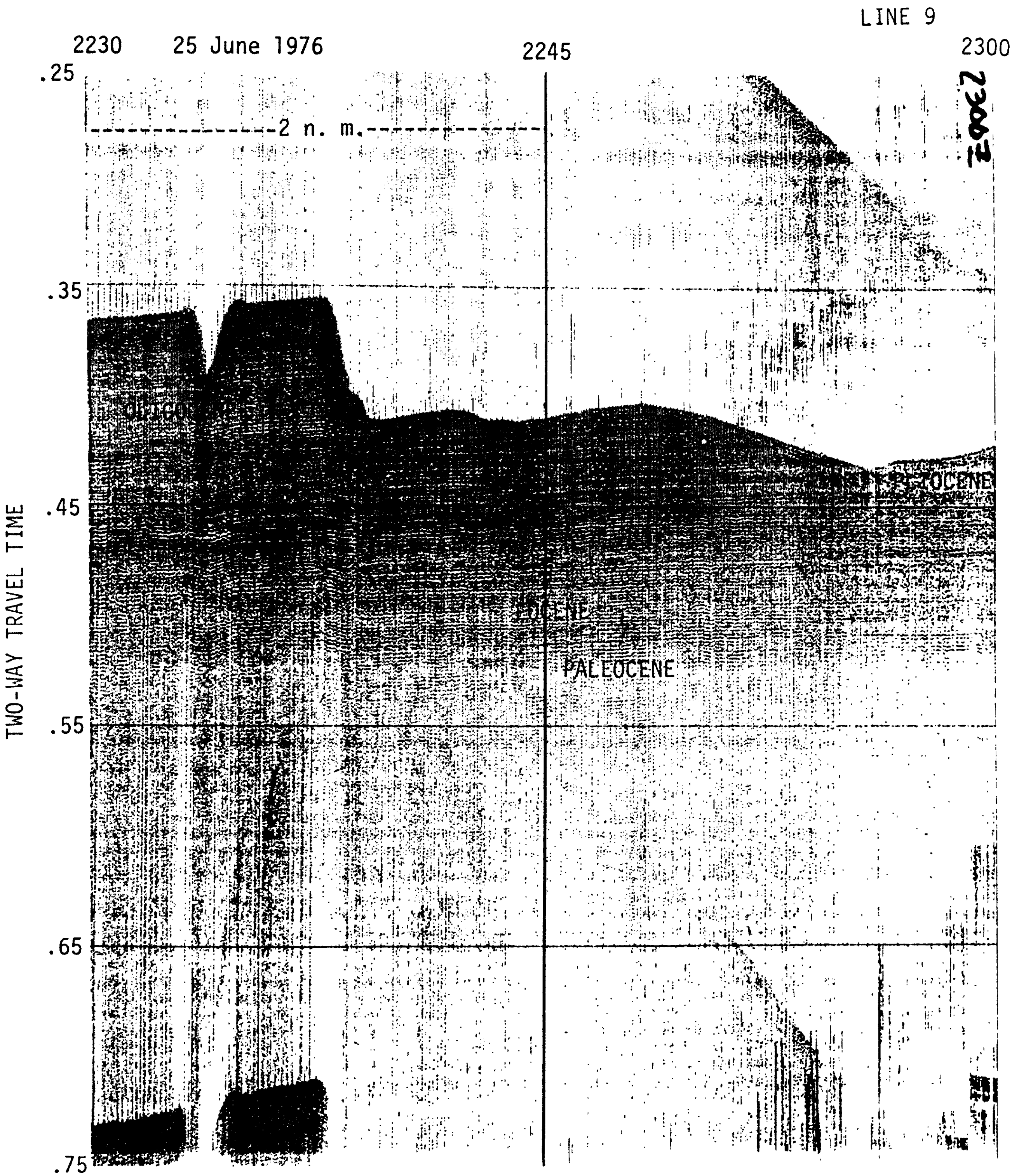


Figure 15 - Typical erosional appearance of the bottom on the inner Blake Plateau. Vertical exaggeraiton about about 13 to 1.

Shallow subbottom conditions

Faulting - Regional seismic-reflection surveys have shown that small displacement (1-3 m) faults occur on the shelf within the Southeast Georgia Embayment, and that larger displacement faults (10-30 m) occur on the inner Blake Plateau (Ball and others, 1979; Paull and Dillon, 1979). The shelf faults are developed chiefly south of Charleston, S.C. and are particularly abundant east of Savannah, Georgia. These faults mainly displace Miocene and Oligocene rocks, do not displace the surface, and appear to die out with depth. The faults on the inner Blake Plateau are confined to Upper Cretaceous rocks. These faults terminate at the overlying Paleocene-age rocks (fig. 16) and die out with depth. Both the shelf and Blake Plateau faults are believed to be due to compaction of the Upper Cretaceous calcareous sediments.

Faults are considered an environmental hazard as shallow faults could cause both a loss of drilling fluids when penetrated and could serve as conduits to allow the escape of high pressure gas from depth. This second possibility could result in fire and blowout danger to rigs or structures. If the locations of faults are known, the zones can be cased and the hazards minimized.

Two large-displacement growth faults were discovered by analyses of USGS seismic-reflection profiles on the eastern edge of the Blake Plateau near the northwest end of the Blake Ridge, 150 km southeast of Cape Fear, North Carolina. The southern fault (figs. 17 and 18) which has been studied in detail (Sylwester and others, in press) strikes north-northeast for approximately 50 km and has at least 200 m and possibly 400 m of normal offset. The second fault has been crossed by only one profile at 33°07'N., 76°28'W. This fault has at least 400 m of

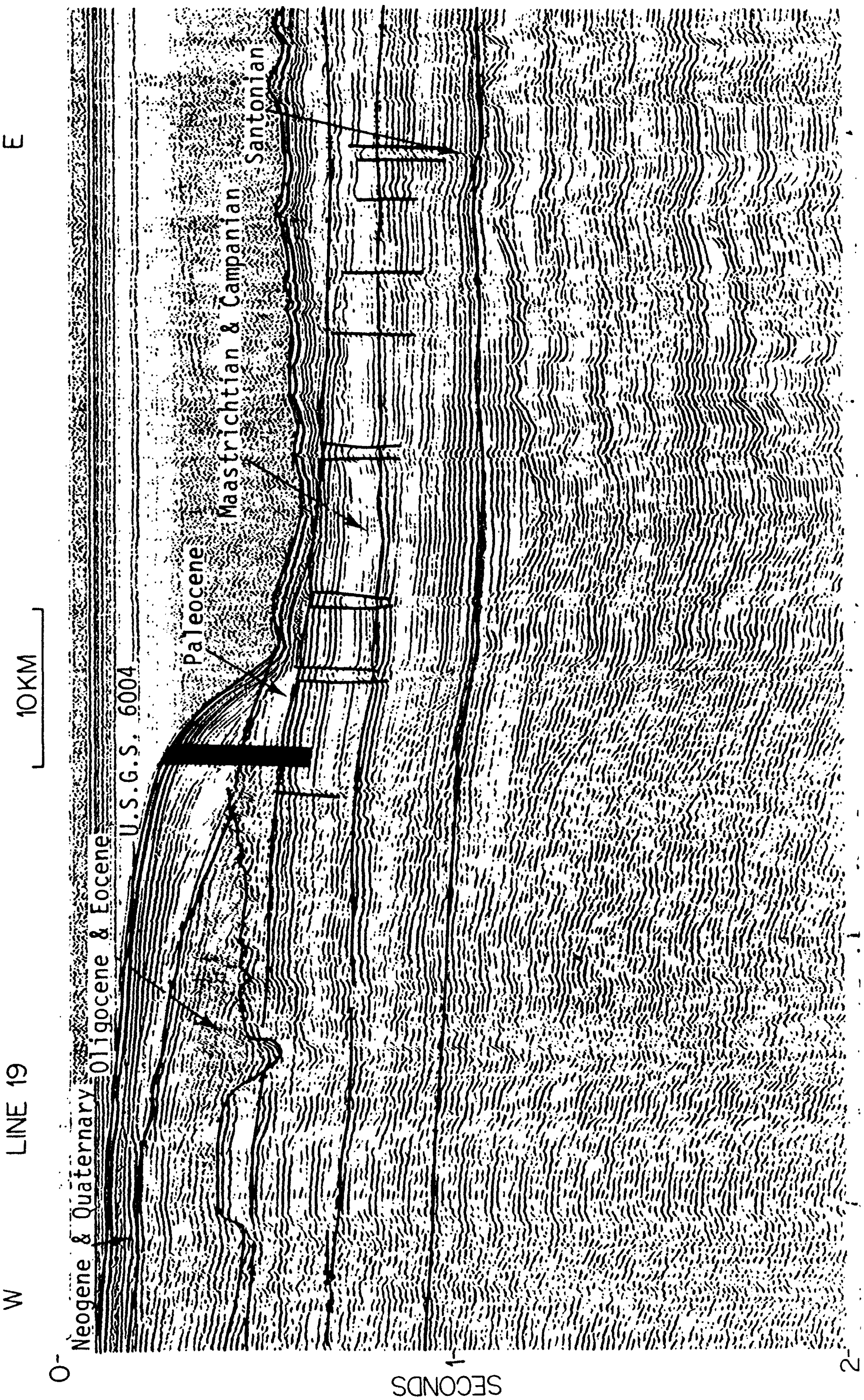


Figure 16. Interpreted seismic reflection record showing faulting of Upper Cretaceous strata on the inner Blake Plateau. Displacements are about 10 to 30 m.

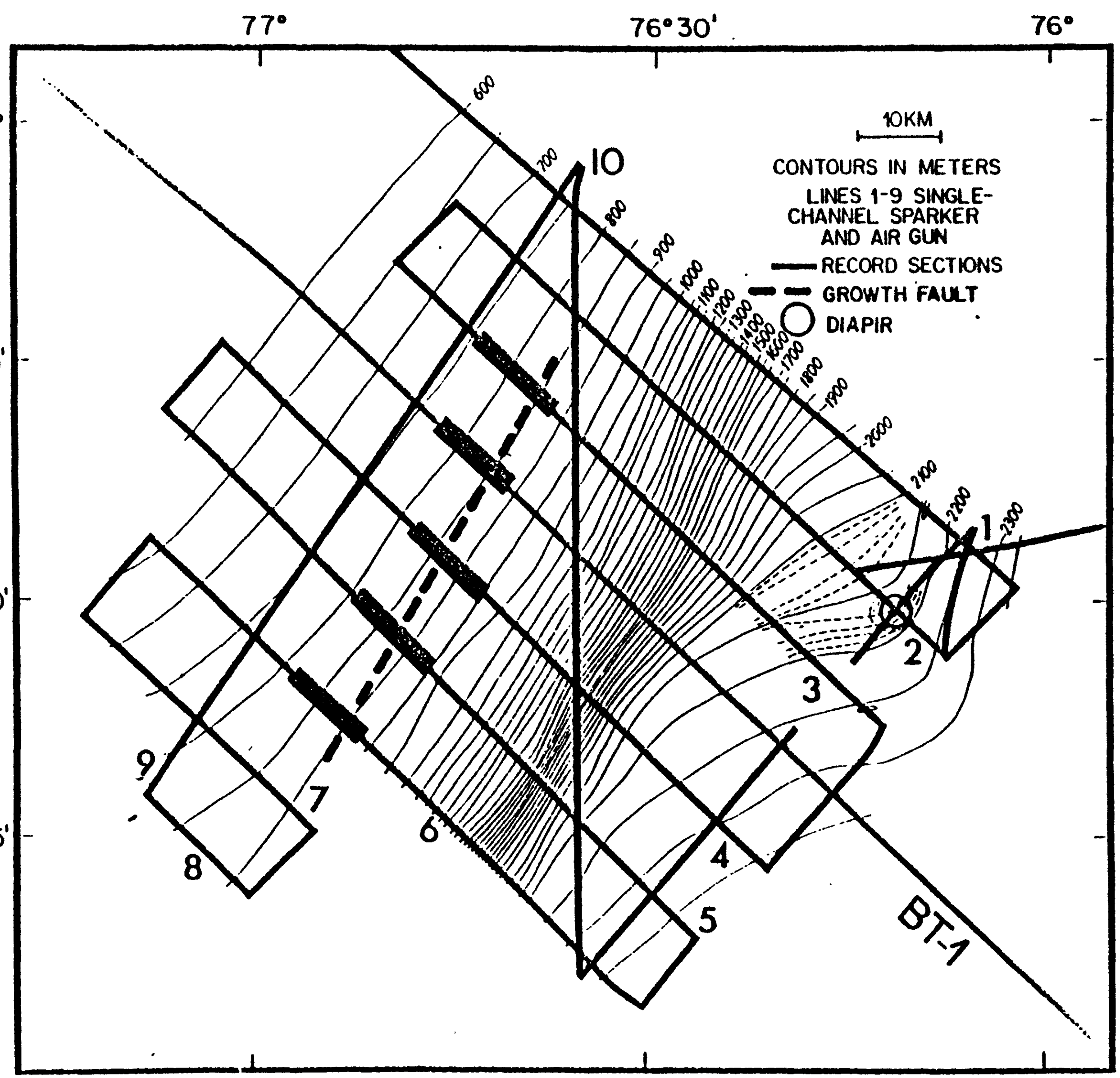


Fig. 17 - Survey of fault off Cape Fear

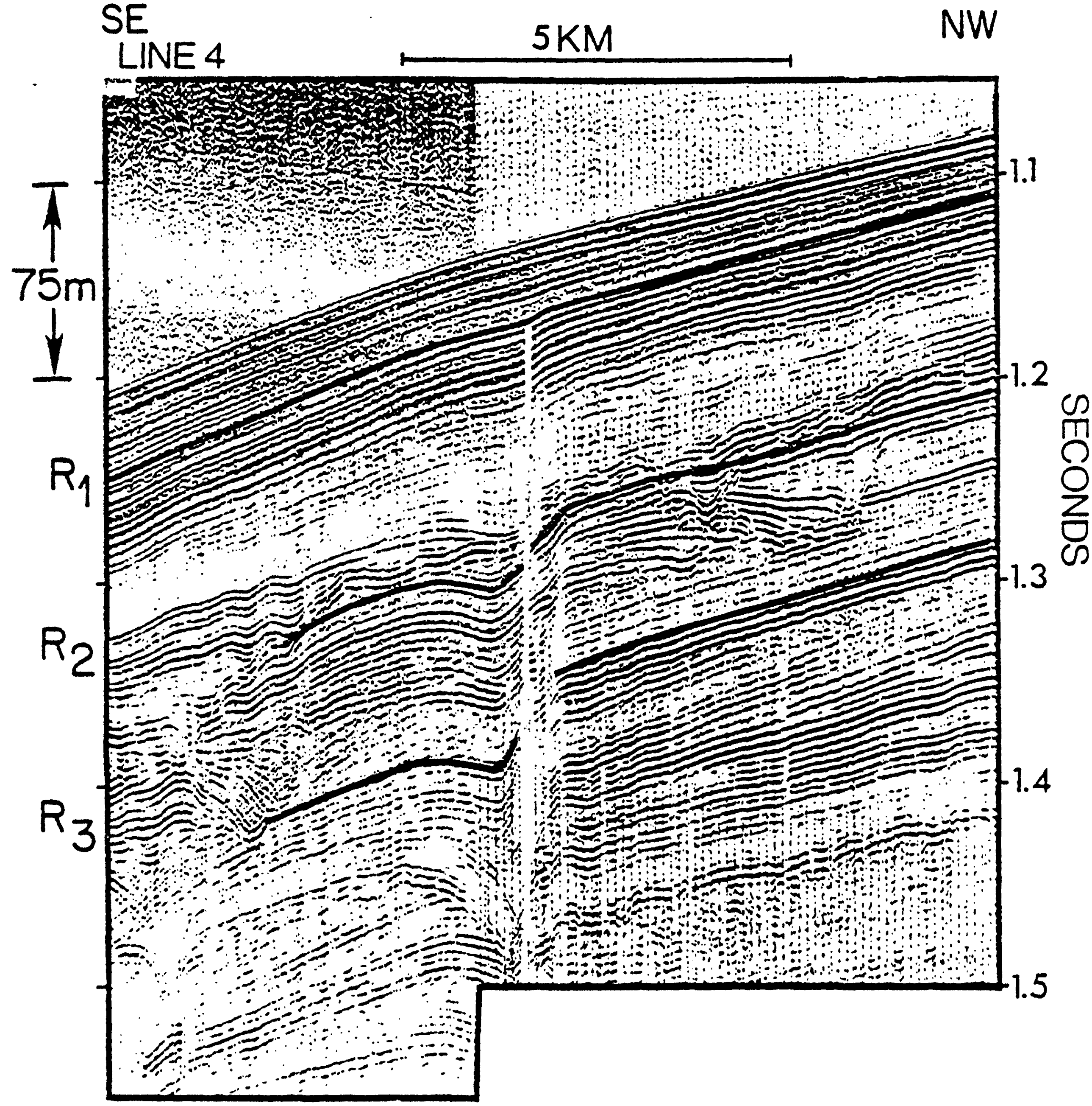


Fig. 18 Interpreted high-resolution seismic profile across fault shown in fig. 17. Although the fault does not appear to extend to the surface, the displacement on horizon R_1 is approximately 3m.

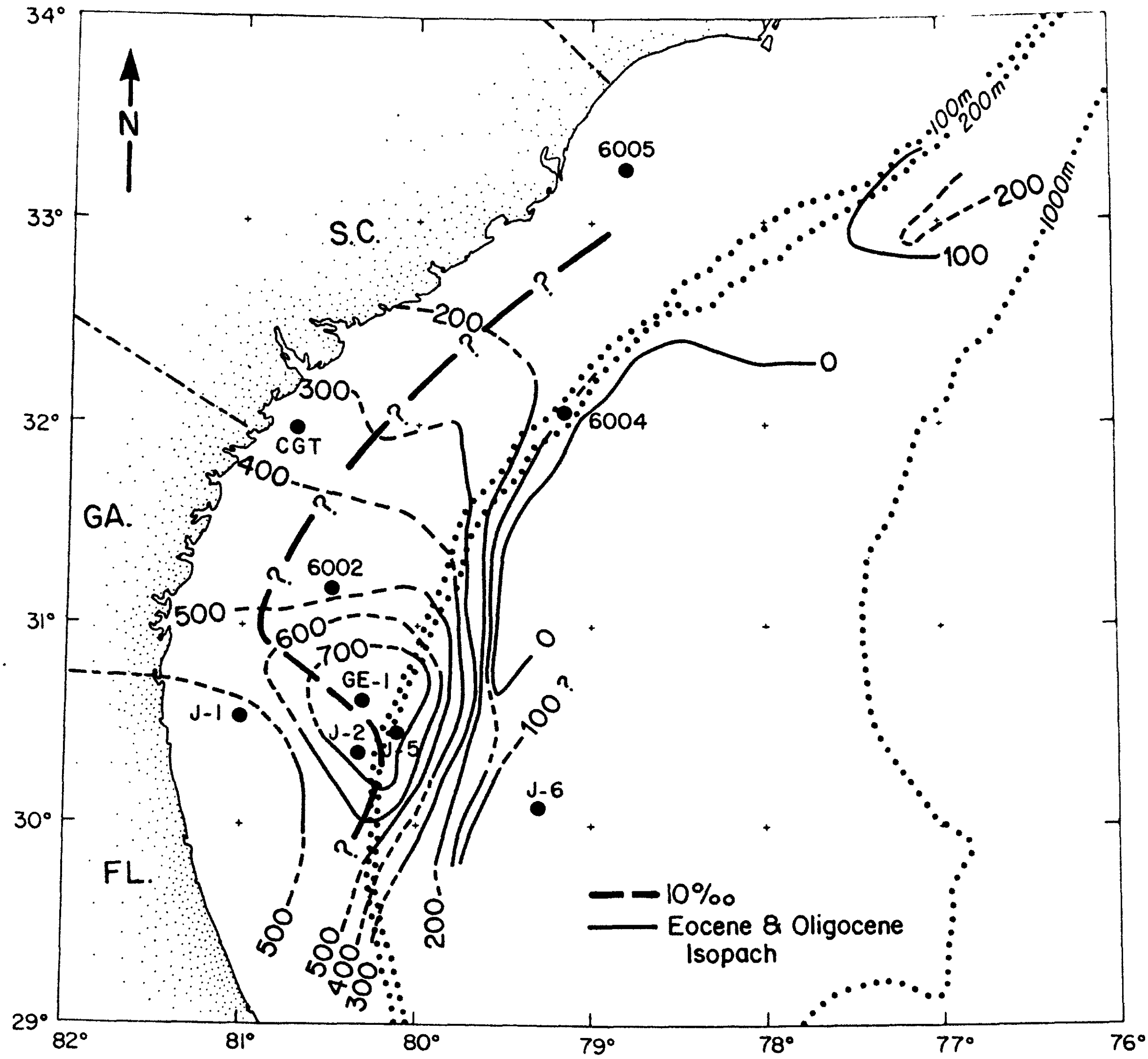


Figure 19: Isopach map of Eocene and Oligocene sediments indicating a basin under the Shelf that has an axis which extends onshore in Southern Georgia. The boundary of Tertiary units which contain waters as fresh as 10°/oo has been adopted from Kohout, 1979. The asis of the Tertiary depocenter and the seaward jog of the fresh water appear to correspond.

normal offset. These are the largest faults known to offset Tertiary sediments on the Atlantic coast. The northern fault may offset the seafloor, although the evidence for this is inconclusive as no high-resolution seismic-reflection data are yet available. A three meter offset of beds can be demonstrated 40 meters beneath the seafloor for the southern fault (fig. 18). Both faults are believed to be the result of subsidence related to salt diapirism in the Carolina Trough.

The offshore aquifer - The offshore extent of the Tertiary freshwater aquifer is poorly known, but this aquifer is one of the major resources of the Coastal Plain in the Southeastern United States. Onshore the aquifer is primarily developed in Eocene age rocks, but its boundaries overlap into Oligocene and Paleocene rocks over its entire geographic range (Counts and Donsky, 1963). The aquifer may remain in these same units offshore. Off northern Florida, the JOIDES wells (J-1, J-2, fig. 19) encountered freshwater within these units almost out to the shelf break. However, AMCOR 6002 which was drilled at mid-shelf off Central Georgia encountered waters with salinities above normal seawater within the units. A line which separates the Tertiary strata containing water of less than $10^{o}/oo$ S from those with greater than $10^{o}/oo$ S has been drawn by Kohout (1978) and is shown in figure 19. This contour, although it is based on somewhat sparse data, is probably the best estimate of the offshore extent of the aquifer. Tertiary sections of wells on the shelf should probably be cased in order to prevent contaminating the aquifer.

Cavernous limestone - Many of the limestone formations of the Florida Peninsula and Bahamian Banks area are known to contain extensive networks of caves which may present serious problems in drilling and completing wells. Cavernous limestones are especially prevalent in the shallower Tertiary sections where erosion and solution may have taken place during Pleistocene time when the sea stood at lower levels. Cavernous porosity encountered during the drilling of the Bahamas Oil No. 1 Andros Island has been well documented (Maher, 1971; Meyerhoff and Hatten, 1974); circulation of drilling mud was lost in about 15 zones. Cavernous porosity also was encountered in Lower Cretaceous carbonates in the ESSO No. 1 Hatteras Light between depths of 2,550-2,575 m (Maher, 1971).

Several areas of cavernous porosity are known within or near the Sale 56 area. On the Florida-Hatteras Shelf a submarine spring has been mapped two and one-half miles off Crescent Beach, Florida (Brooks, 1961) and a large sinkhole known as Red Snapper Sink was discovered further offshore of Crescent Beach at 29°44'N. and 80°45'W. (Kohout and others, 1977). The extent of cavernous limestone on the shelf is not known but cavernous porosity is probably more prevalent in the southern part of the shelf off Florida. On the inner Blake Plateau near 31°15'N., 79°15'W., the presence of cavernous porosity and freshwater outflow was inferred from a loss of buoyancy of a submersible and a change in water temperature near a 50 m deep depression (Manheim, 1967). This cavernous porosity occurs in Upper Cretaceous-age rocks (Paull and Dillon, 1979). Thus, caverns may exist throughout the Sale 56 area which may constitute a threat to bottom mounted platforms and structures or cause drilling problems.

Clathrates - Clathrates - frozen gas-hydrates - are believed to be present in the sediments of the Blake Ridge within the area of possible leasing. Because temperatures within the sediments increase with depth, the solid, frozen clathrates would exist only above an isotherm which tends to follow the shape of the seafloor. Evidence for the clathrates in this area includes: (1) presence of a subbottom reflector which parallels the seafloor and intersects reflectors which we believe represents sedimentary layers; (2) a strong velocity inversion associated with the reflector from about 2.5 km/s above to about 1.8 km/s below it as is predicted from laboratory measurements of effects of clathrates on sediment velocity by Stoll and others (1971); (3) presence of large amounts of gas within the sediments, observed to be released from cores (Lancelot and Ewing, 1972); (4) physical conditions conducive to gas-hydrate formation (Lancelot and Ewing, 1972). Clathrates may seal high-pressured gas accumulations where water depths exceed 1,000-1,500 meters at subbottom depths of several hundred to 1,000 meters (JOIDES Panel, 1976).

Seismicity

Although the eastern U.S. is an area of generally low earthquake activity, the largest earthquake recorded in the eastern U.S. occurred near Charleston, S.C. in 1886 (Dutton, 1889). This earthquake of about 6.8 Richter magnitude (Bollinger, 1977) was felt as far away as Boston, Massachusetts, Green Bay, Wisconsin, Cuba, and Bermuda and caused structural damage for several hundred kilometers from the epicenter.

Only one small earthquake is known historically to have occurred on the shelf or Blake Plateau (Tarr, 1977), but seismicity on the Coastal Plain of South Carolina appears to occupy a narrow zone which strikes northwest through Charleston, S.C. The linearity of the zone and an offset of an unconformity inferred to be of Early Jurassic or Late Triassic age on the shelf along trend (fig. 20) suggests that the South Carolina seismicity may be related to stresses along the landward extension of the Blake Spur fracture zone (Dillon and others, 1979; Sbar

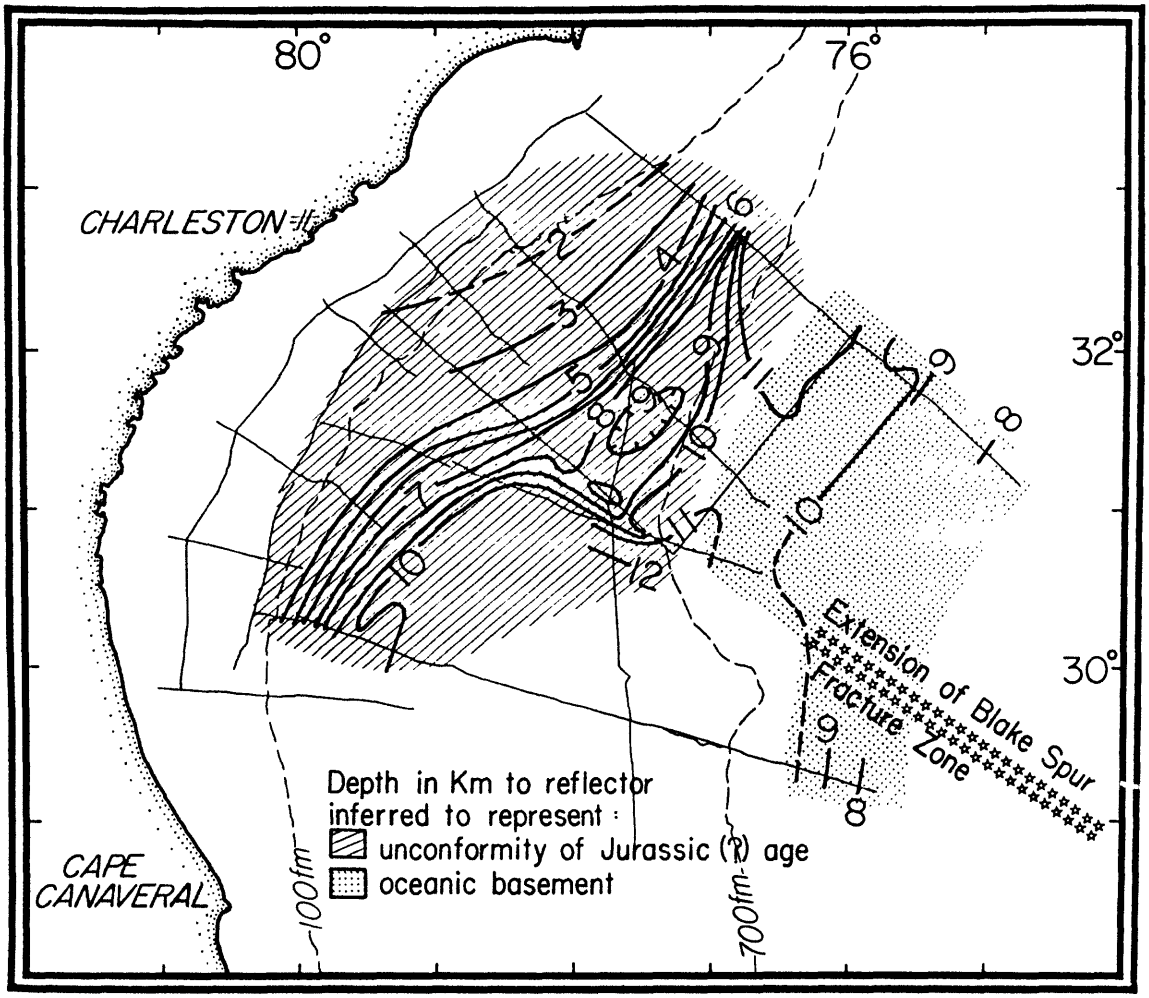


Fig. 20 Depth to the post-rift unconformity. The extension of the Blake Spur Fracture Zone and the offset in the unconformity seem to continue the trend of earthquake activity observed on shore.

and Sykes, 1973), a location of major shear during early Atlantic basin development. The likelihood of a large magnitude earthquake recurrence along the zone is presently being studied by USGS and associated researchers. Presently, such a recurrence must be considered a possibility.

Drilling hazards

Gas and oil leaks during drilling are the principal hazards to personnel safety and the marine environment. They may cause blowouts, collapse of structures, etc. The entire U.S. Atlantic margin is subject to hurricanes, and therefore, drilling platforms should be designed to withstand severe storm wave and current action. Platforms and pipelines off Charleston should be constructed to withstand earth motions similar to those experienced during the 1886 seismic event. High-resolution reflection surveys contracted by USGS Conservation Division have revealed water-column anomalies that may reflect natural gas leaks. Regional seismic-reflection measurements have also revealed channel fills and possible shallow faulting. These conditions can result in shallow, gas-charged reservoirs. Faults can connect deeper charged reservoirs to shallow depths. Channel fills, if sealed, can trap gas generated within them.

Slope stability may be inadequate in some locations to support bottom-mounted structures. Although minor slumping and faulting occurs on the Florida-Hatteras Slope major slumping and faulting is present on the Continental Slope off Cape Hatteras and on the slope of the Blake Escarpment. Peat and channel-fill material on the shelf may result in poor support characteristics for rigs or structures. Solution of karst features may weaken foundations of platforms or cause loss of circulation of drilling fluids. In the southeastern carbonate province, maintenance of circulation will be hampered by major deep unconformities with extensive solution caverns, such as the so-called "boulder zone." Strong and unpredictable currents resulting from the Gulf Stream and its gyres on the outer shelf, slope, and inner Blake Plateau have caused abandonment of drill sites in both the JOIDES and USGS drilling programs. These strong currents are expected to be a major problem in drilling operations.

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