U.S. Geological Survey
Open File Report 78-594

Summary Report of the Sediments, Structural Framework, Petroleum Potential, Environmental Conditions and Operational Considerations of the United States South Atlantic Continental Margin

Prepared for Bureau of Land Management
for Proposed Oil and Gas Lease Sale #54

by

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1978

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INTRODUCTION

This brief report has been compiled in response to a request from the Bureau of Land Management to the Geological Survey for information on the area of the Atlantic Continental Shelf off the southern United States where oil and gas lease sale #54 may be conducted, and it was submitted to that Bureau in July 1977. This area lies approximately between the North Carolina - Virginia border and Cape Canaveral and extends seaward beyond the 3-mile limit of state jurisdiction roughly to the 1000 m isobath, as shown in Figure 1. The area is known as the Southeast Georgia Embayment - Blake Plateau Trough. The two are not structurally separate features; the Trough is the seaward extension of the Embayment. Physiographic features are shown in Figure 2.

No wells have been drilled for petroleum within this potential lease area and no significant commercial production has been obtained onshore in the Southeast Georgia Embayment. However, the sediments thicken markedly in a seaward direction where more of the section was deposited under marine conditions; therefore, commercial accumulations of petroleum offshore are possible.

Several potential environmental hazards 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 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 drillstrings. 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.

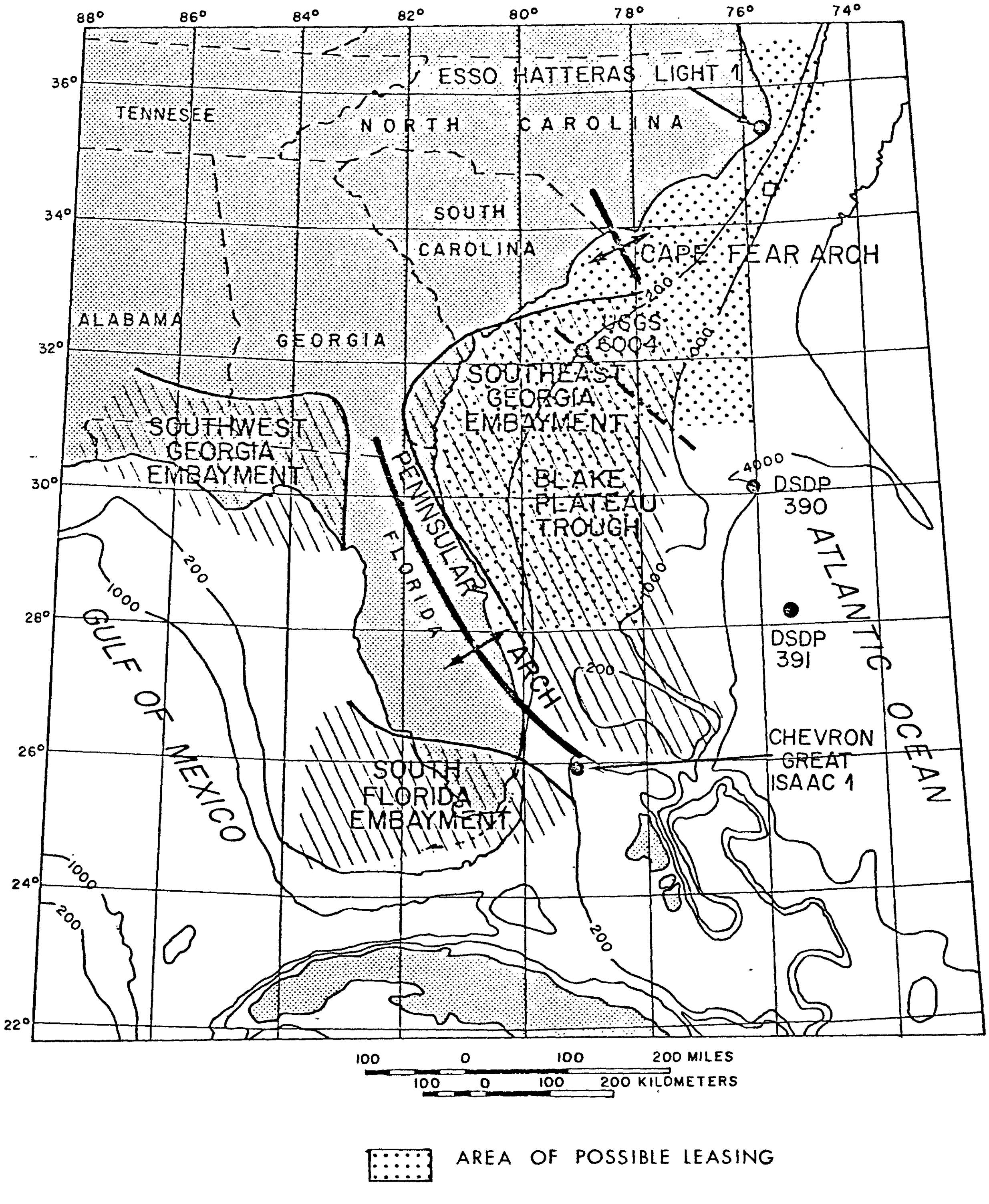


Fig. 1. The southeastern U.S.; structural features, possible lease sale area and selected drillsites.

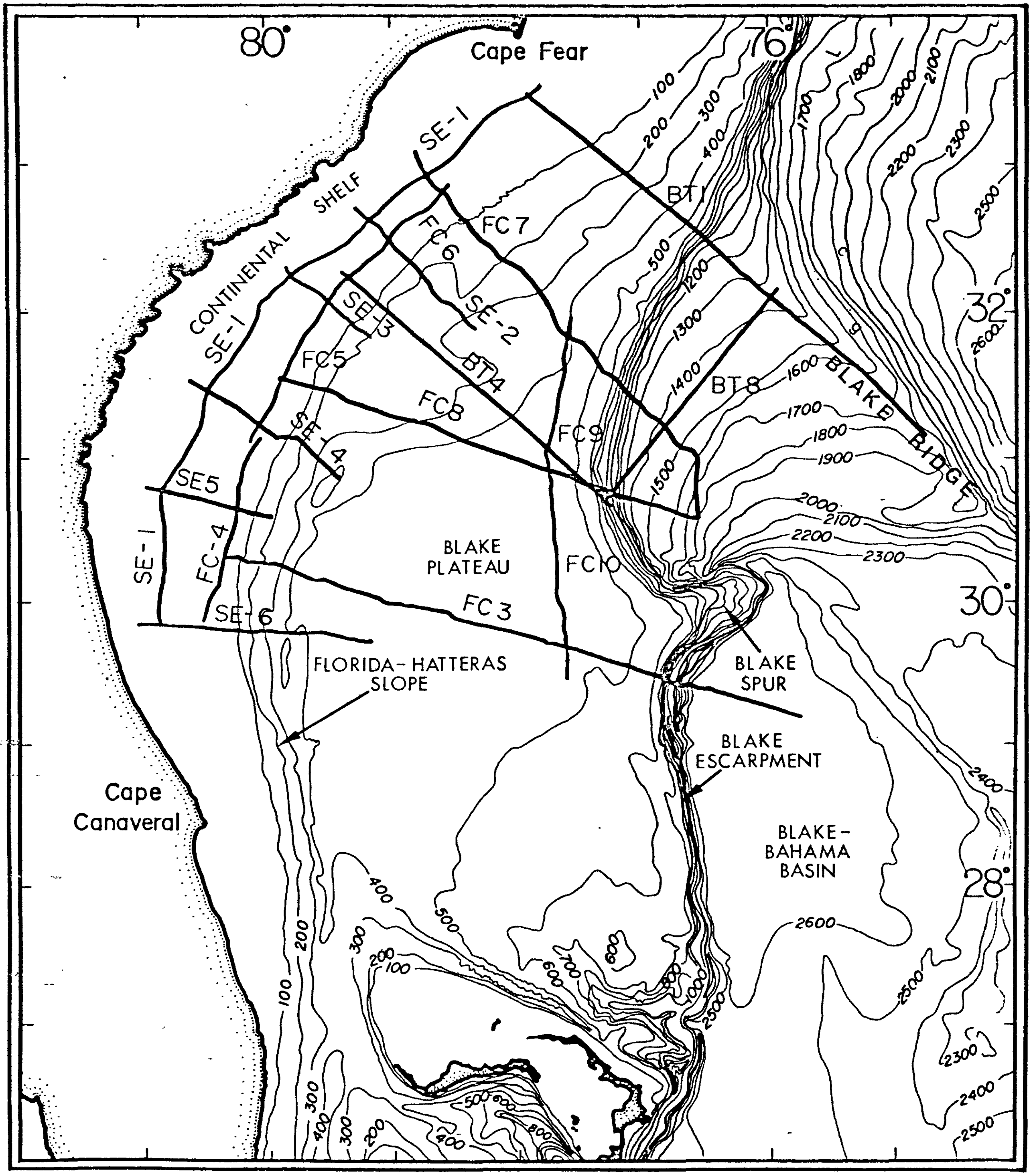


Fig. 2. Physiographic features and locations of some of the multichannel seismic profiles collected in the possible lease area. (Contours in fathoms).

The following discussion is based largely on analyses of 4700 km of multichannel, deep penetration seismic reflection profiles, as well as single channel seismic profiles and gravity and magnetics studies carried out by the U.S. Geological Survey's Office of Marine Geology. Selected references include Barnett (1975), Dowling (1968), Emery and others (1970), Ewing and others (1966), Hersey and others (1959), Herrick and Vorhis (1963), Maher (1971), Meyerhoff and Hatten (1974), Schlee (1977), Sheridan and others (1966), Tator and Hatfield (1975), and Uchupi (1967).

The basement surface in the area of South Atlantic lease sale #54 is characterized by broad subsidence off Georgia and South Carolina that is known as the Southeast Georgia Embayment - Blake Plateau Trough (Fig. 1). This zone of subsidence is bordered by two weak positive basement features, the Cape Fear Arch on the northeast, and the Peninsular Arch on the southwest (Fig. 1). Northeast of the Cape Fear Arch the basement dips gently seaward to the northern limit of the sale area. Basement, as defined here, includes Paleozoic igneous, metamorphic, sedimentary, and volcanic rocks, and Mesozoic (Triassic and Jurassic) continental sedimentary deposits and volcanic rocks.

The broadly warped basement is covered by marine sedimentary rocks of Jurassic to Cenozoic age. The region lies in a transitional zone between a predominantly terrigenous clastic depositional province north of Cape Hatteras and a carbonate province which includes Florida and the Bahamas. Many wells have been drilled onshore, but few have been drilled offshore. One shallow core (USGS 6004, Fig. 2) taken within the area being considered for leasing penetrated pre-Tertiary strata. At this site, Upper Cretaceous, silty, calcareous clay was sampled. Deeper wills drilled in the region allow us to estimate the ages of reflectors seen in seismic profiles. Some of these well locations are shown in Fig. 1.

A typical multichannel seismic profile, crossing the continental margin and passing through drillsite USGS 6004, is shown in Fig. 3 (location, Fig. 1).

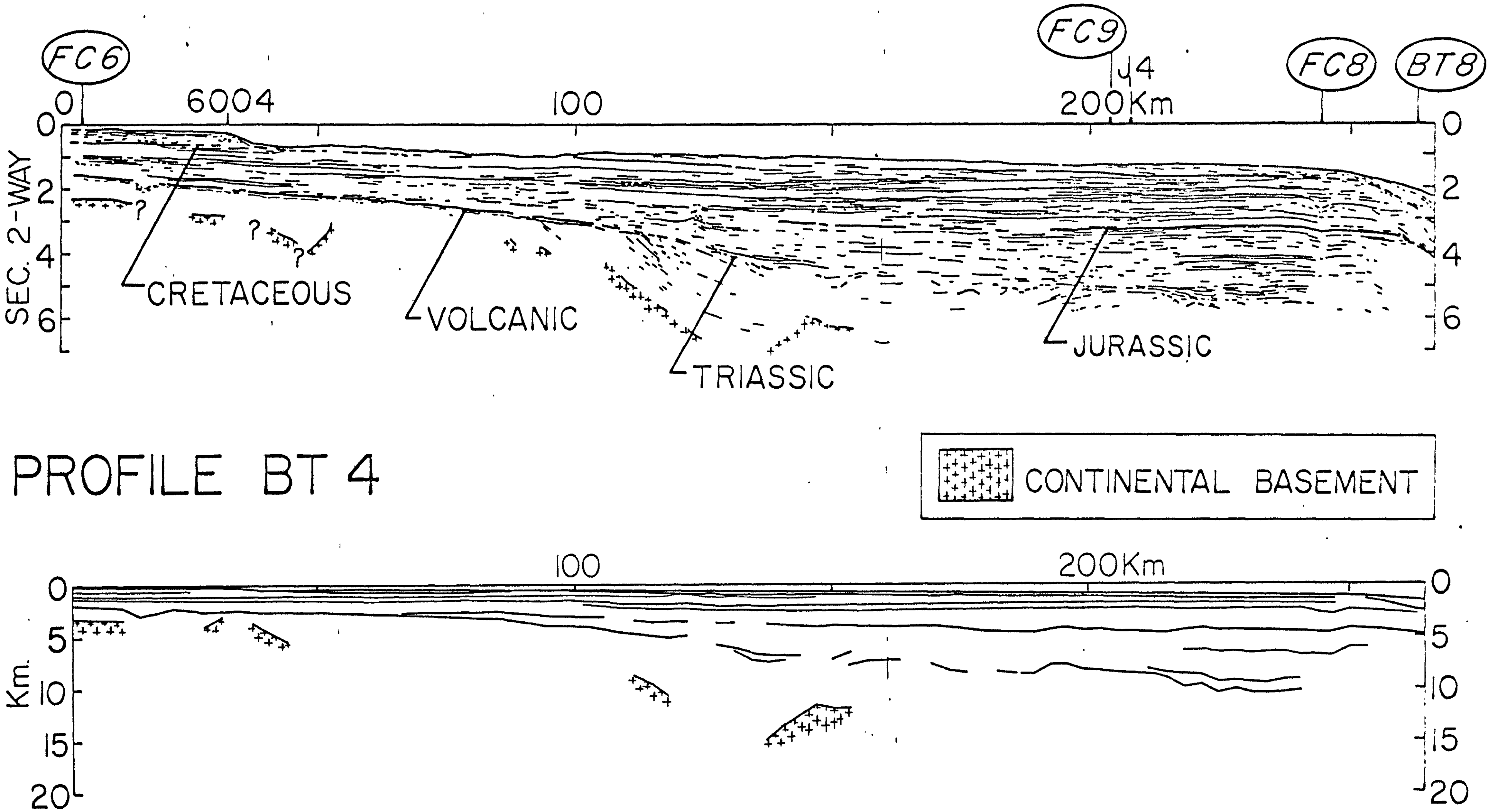


Fig. 3. A typical seismic profile across the possible lease sale area. Location of this profile is indicated in Fig. 1. The indicated ages of tops of sedimentary rock units generally represent conclusions based on geological reasoning, as only the Cretaceous top has been drilled.

The sedimentary structure of the Continental Margin (Fig. 3) may be represented as an undeformed wedge of sedimentary rock that thickens from its feather edge onshore at the western limit of the Southeast Georgia Embayment seaward to more than 12 km beneath the Blake Plateau. The strata are essentially horizontal and the seaward thickening results mainly from addition of units. The older strata pinch out against basement, which rises toward the northwest (Fig. 3).

Development of the region began in Triassic time, as North America and Africa began to split apart. Figure 4 depicts the probable sequence of events in the formation of the Southeast Georgia Embayment - Blake Plateau Trough along a section that crosses the possible lease sale area, off central South Carolina. As the continents separated in Triassic time (A, Fig.4) the continental crust was fractured into blocks that subsided. The irregular surface was eroded rapidly and coarse terrigenous sediment accumulated in the valleys. The fracturing and extension also allowed upwelling of molten rock from below and led to volcanic activity. Erosion and deposition smoothed the topography (B, Fig. 4) Meanwhile, the oceanic spreading center moved slowly away from the continental margin as new oceanic basement formed by intrusion and extrusion of mantle-derived magmas. About 175 million years ago (B, Fig.4) an abrupt change in position of the oceanic spreading center, associated with a rearrangement of plate drift, probably caused minor new fracturing of the continental basement and renewed outpouring of volcanic rock. This rock now occurs beneath much of the central Southeast Georgia Embayment in Georgia and South Carolina and the adjacent continental shelf.

Early stages of ocean development commonly are associated with salt deposition. The only indications of salt in the northern Blake Plateau area are ten diapirs, probably salt, observed in our profiles. These are located on the East Coast magnetic anomaly between Cape Hatteras and the Blake Ridge (Grow

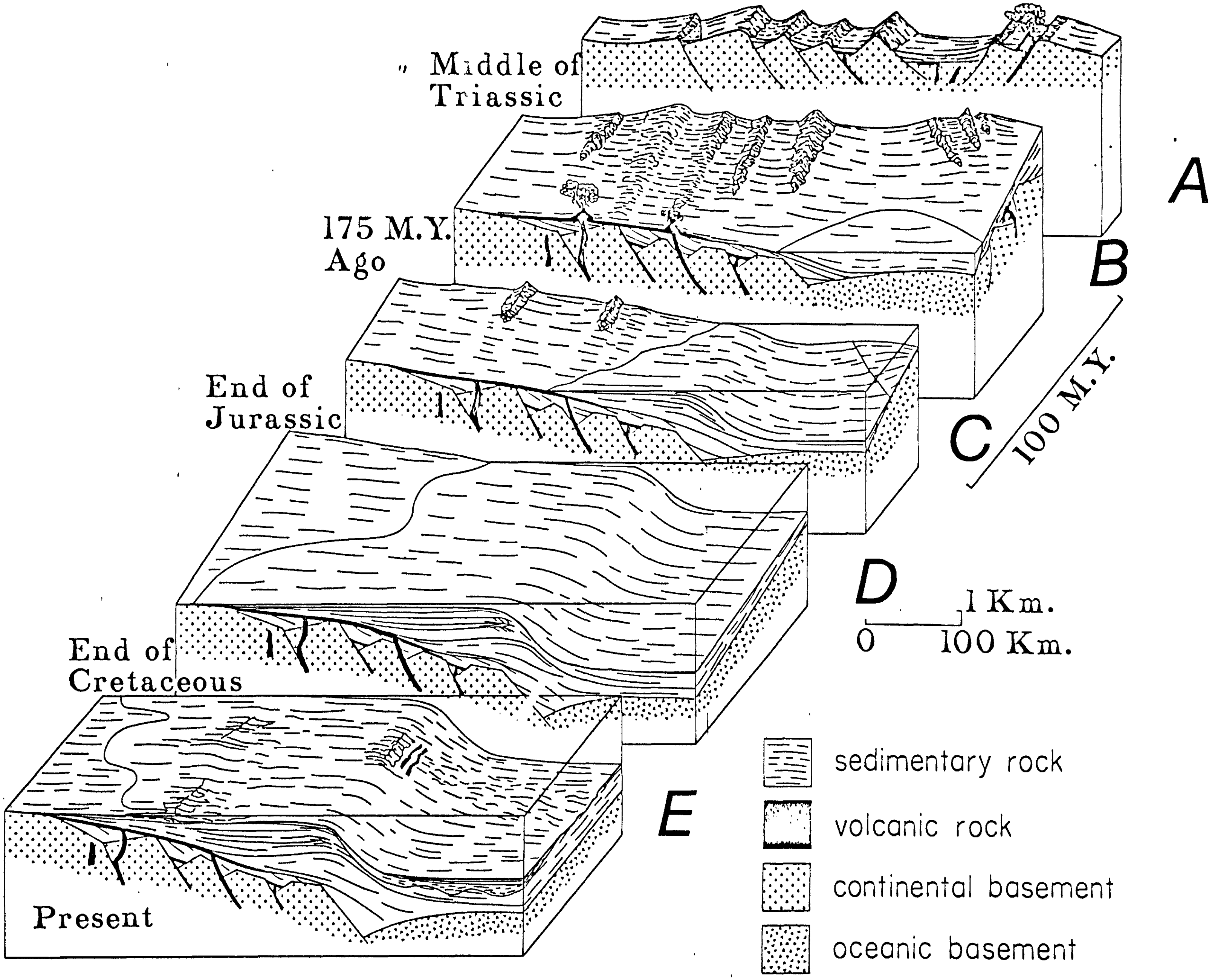


Fig. 4. Block diagram, with one axis drawn as time, to depict a concept of the development of the U.S. South Atlantic area.

Dillon and Sheridan, 1977), and probably indicate the location of a single narrow salt depocenter formed during the early rifting of the region. Evaporite minerals have been noted in the Hatteras Light well and bedded salt in the Great Isaac well (Fig. 1).

As the continental margin subsided, Jurassic marine sediments onlapped across an unconformity cut on Triassic deposits and then across the Early Jurassic volcanic layer which partially covered the unconformity (C, Fig. 4). Subsidence continued through Cretaceous time and a broad continental shelf was formed (D, Fig.4). Disconformities scattered throughout the section indicate that the shelf surface was maintained near sea level by accretion. In the northern Blake Plateau area, the structure and position of the shelf break resulted from a balance between subsidence, accretion, and erosion. Maximum subsidence took place well back from the platform edge, near the middle of the Blake Plateau.

The sedimentary-structural evolution of the shallow, narrow shelf and the broad, intermediate-depth plateau which is observed at present began when the prior balance of deposition and subsidence was disrupted by the establishment of Gulf Stream flow at the beginning of the Tertiary. This high-speed current inhibited deposition on the plateau during Cenozoic time; thus, sedimentation was not able to keep up with subsidence except near the coast where the small continental shelf was constructed (E, Fig. 4). North of about 32°N, where the Gulf Stream broadens and weakens, the shelf is bordered by a normal sloping continental rise. The area of possible leasing, in its most seaward part, also includes the northwestern portion of the Blake Ridge (Fig. 1). This ridge was formed during Cenozoic time as an accumulation of hemipelagic sediments that were apparently transported southward by deep water currents.

The southern Blake Plateau developed differently, in some aspects, from the northern part described above. South of latitude 30°N, the seaward edge of the plateau was dominated by Cretaceous reef development rather than by a depositional-erosional balance. Furthermore, south of 31°, the amount of subsidence especially in the Jurassic was apparently much greater. Over the southern Blake Plateau, the non-lineated, broad wavelength magnetic field is probably associated with a rift stage basement consisting of dense, mantle-derived rocks, highly contaminated by continental sediments, and containing fragments of continental basement.

PETROLEUM POTENTIAL

Commercial oil production usually occurs in areas where four requirements are met. First, there must be structure, that is, relief on a mappable surface. This relief 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 from source beds. Third, there must be a seal over the reservoir to trap hydrocarbons that are accumulating. Finally, there must be a sufficient quantity of recoverable hydrocarbons within the reservoir to justify the high cost of offshore development. The South Atlantic margin of the United States, including the continental shelf, slope and Blake Plateau, contains a number of geologic features where these requirements may be satisfied; this region thus, has petroleum production potential.

In several areas gravity and magnetic anomalies are coincident on the shelf and inshore part of the northern Blake Plateau (Dillon et al, 1975, Plate I). These anomalies have dimensions measured in miles and magnitudes (respectively) of tens of milligals and hundreds of gammas. They must represent intrabasement density and magnetic intensity contrasts. Our limited seismic reflection profiling coverage suggests that differential erosion may have resulted in basement topography with 100 to 200 meters of relief over these anomalies. Sediments draped over these buried basement hills may provide excellent traps for significant accumulations of oil and gas.

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 margin. Structural movement on the basement faults resulted in the formation of fault anticlines in the overlying sediments. These positive features may have provided environments for shallow water carbonate deposition and reef development. Such rocks may 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 an excellent target for petroleum exploration. Apparently, the subsidence and thickening of overlying sediments caused the flowage of underlying evaporites and resulted, in some areas, in the formation of diapiric or piercement structures. Our regional network of seismic profiles reveals a complex of possible diapirs at the base of the continental slope off Cape Hatteras and the previously-mentioned piercement off Cape Fear. Similar features are highly productive on the Gulf Coast.

The thick sections of low-angle eastward dipping strata seen in the Atlantic offshore of Florida, Georgia, and the Carolinas represent possible targets for production from updip pinchouts of porous, permeable strata encased in sealing clay shales, carbonates or evaporites. However, such stratigraphic traps are difficult to prospect for without more extensive well control and geophysical surveys.

Some additional data does exist from drilling on the South Atlantic coastal plain, the Bahamas, deep sea dredging on the Blake Scarp, and drilling on the adjacent slope and rise. Early Mesozoic rocks range southward from the predominantly terrigenous clastic section seen in the Hatteras Light well to carbonates and evaporites in Florida and the Bahamas. Changes in character of seismic reflectors eastward from the Hatteras well may indicate an increase in development of thin carbonate beds in the early Mesozoic section and possible carbonate bank buildups under the slope and rise. Rocks of good reservoir quality can be expected throughout the region in the Jurassic - Lower Cretaceous section. Seals of regional extent should be common in the north. 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 area.

In assessing the potential for commercial quantities of hydrocarbons, questions arise concerning source rock, maturation, and migration. As generalizations, the terrestrial origin of organic matter prevalent to the north and west favors the accumulation of natural gas while the marine origin of organic matter in the carbonate province to the south and east favors oil. Maturation, however, may be a critical problem. Geothermal gradients adjacent to the area are low. For much of the shelf, only the oldest and deepest sediments probably surpass the threshold temperature for maturation of hydrocarbons, assuming the highest reasonable thermal gradient. On the other hand, in the basin present on the southern Blake Plateau, where sediment thickness approaches 12 km, the lowest measured gradients adjacent to the area would still result in temperatures high enough to achieve maturation of a considerable part of the sedimentary column. Long range migration from this region of deep potential source rocks to traps in the shallower strata may be necessary for large petroleum addumulations to occur beneath the shelf.

ENVIRONMENTAL CONSIDERATIONS

A number of potential environmental problems have been identified for the U.S. South Atlantic province. Some that might cause or distribute oil spills are common to all areas of the U.S. east coast. Storms, high current speeds, mass sediment movement, and earthquakes all constitute hazards to rigs and similar structures. Of especial concern in this area are hurricanes, the Gulf Stream, seismicity, and limestone solution cavities beneath the shelf.

Potential Hazards Associated with Ocean Circulation and Weather Conditions

Currents and weather constitute potential environmental hazards as these forces may cause transport of oil spills to shore, damage drill rigs and platforms by storm waves, and cause structural instability to bottom-mounted platforms or structures due to scour of sediments resulting from strong ocean currents.

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. Their refraction 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.

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 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". Water on the continental shelf of the Southeast Georgia Embayment is apparently renewed both from the Gulf Stream and from non-continuous flow 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) 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 where it is closer to the coast. 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, Atkinson, and Bumpus, 1971), when bottom 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).

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/day (20 cm/sec) (pilot charts indicate a rate of about 35 cm/sec 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 5A.

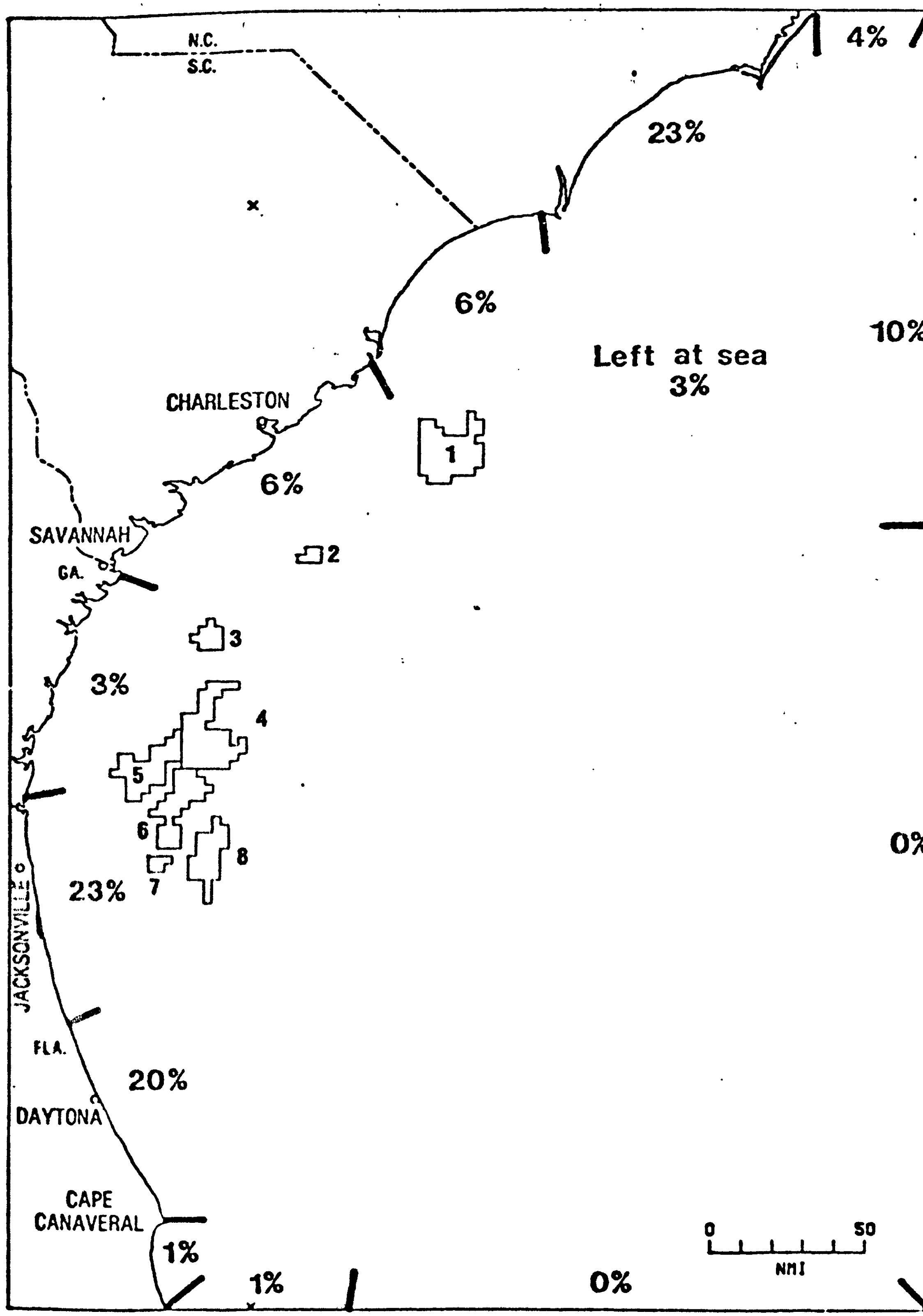


Figure 5a.- Probability that if an oilspill occurs in the South Atlantic lease area, it will reach a particular geographic location.

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/sec. 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, Schmitz and Miller, 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, 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 flow reaches about 40 cm/sec at the sea floor in water depths of about 400 to 800 m. (Schmitz and Richardson, 1968; Richardson, Schmitz and Niiler, 1969). The flow commonly almost fills the Strait of Florida (Richardson, Schmitz and Niiler, 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 main stream was 135 km (Richardson and Knauss, 1971).

Reverse flows to the Gulf Stream may occur both near-surface (counter currents) and on the 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, 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).

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 while it was being retrieved 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).

Potential Hazards Associated with Bottom Conditions

Platforms constructed in the outer continental shelf could be damaged due to the substrate failure associated with scour, mass movement, or by collapse of solution cavities.

Sediment transport and scour - The mid and outer shelf sediments are sands which appear to be in textural equilibrium on the 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, sediment migrates shoreward from the central and outer shelf.

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

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 (McClelland, 1974). However, dense sands typically provide great resistance to pile penetration. Patches of lagoonal muds and peats and stream channel fillings 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 thin layers of clay.

Slumping, though apparently rare, may occur on the slope where fine sediments are being deposited, and in areas of truncated foreset beds near the shelf break. Clays being deposited on the slope are semi-consolidated at best, have had no subaerial exposure and, lacking desiccation, may retain their plasticity.

Faulting - A large fault was discovered by analyses of USGS seismic profiles on the eastern edge of the Blake Plateau near the northwest end of the Blake Ridge 175 km southeast of Cape Fear, North Carolina (Fig. 5b). The fault strikes NNE for approximately 50 km, dips steeply to the SE, and probably has at least 400 m of normal-type offset. It is the largest fault known to offset the Tertiary sediments on the Atlantic coast. Although no offset can be resolved at the sea floor, a 3 m offset appears 40 m beneath the sea floor, probably indicating activity in Cenozoic time. The fault certainly was active in Late Cretaceous and quite probably during all of Cretaceous time.

One other small fault has been identified in our high resolution profiles beneath the Florida-Hatteras slope at about 30°N.

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 may 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. 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 was also encountered in Lower Cretaceous carbonates in the ESSO No. 1 Hatteras Light between depths of 2,550-2,575 m (Maher, 1971). Thus, such caverns may exist throughout the Southeast Georgia Embayment area and constitutes a significant threat to bottom mounted platforms and structures.

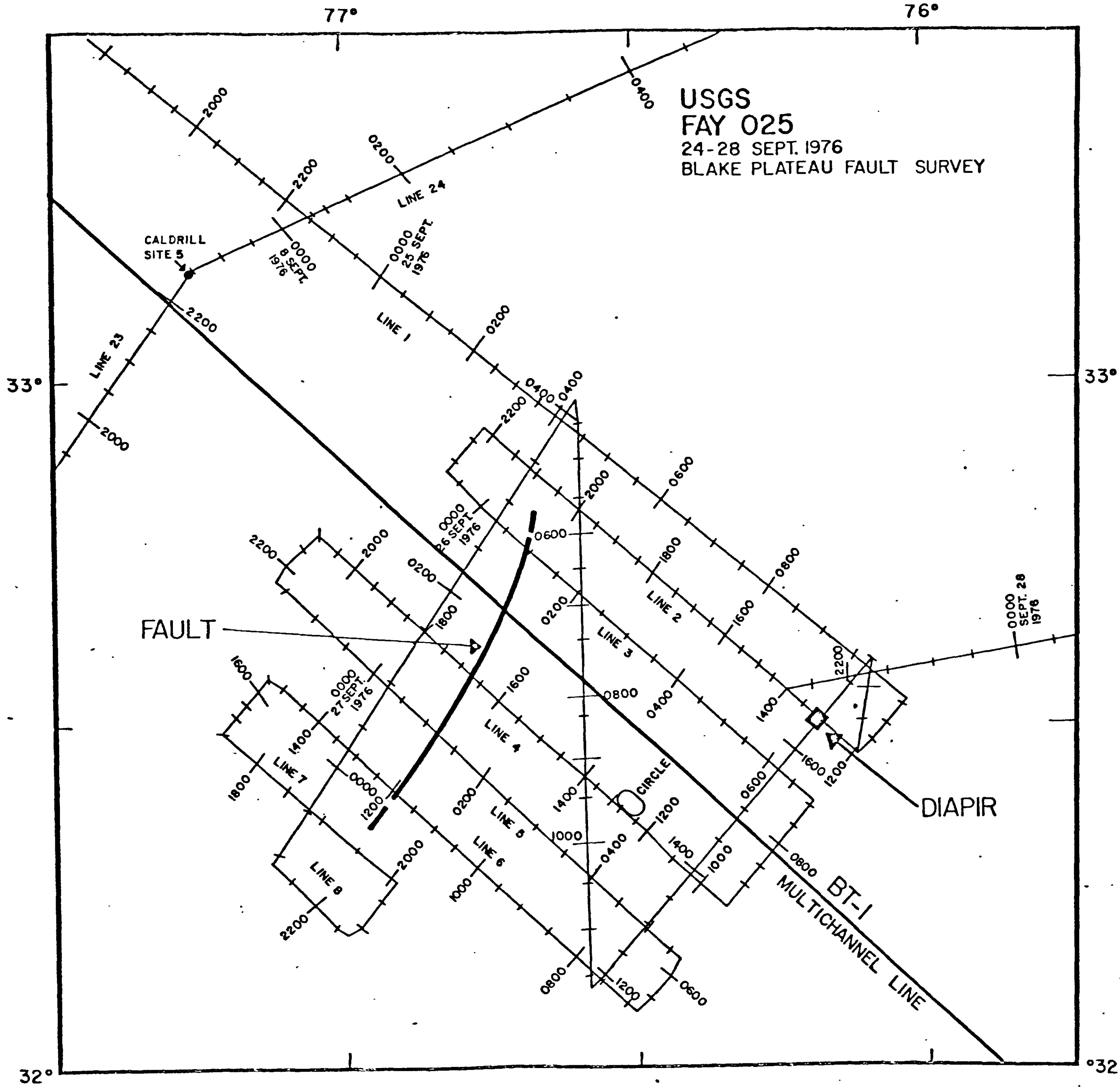


Fig. 5b. Survey of fault off Cape Fear.

Although the eastern U.S. is an area of generally low earthquake activity, a narrow zone of higher seismicity extends across the Coastal Plain in the central part of the area of possible leasing. This zone is thought to extend northwestward through Charleston, S.C. (Bollinger, 1972; A. Tarr, personal communication, 1977). Charleston was also the site of one of the largest earthquakes ever to occur in the eastern U.S. This event, in 1886, was felt as far away as Boston, Mass., Green Bay, Wisconsin, Cuba and Bermuda (Dutton, 1889). It probably had a maximum MM intensity of X for the epicentral region and magnitude of about 6.8, and caused structural damage at distances of several hundred kilometers (Bollinger, personal communication, 1977).

The Charleston trend of seismicity appears to lie along a small circle about the early opening pole of the North Atlantic (Sbar and Sykes, 1973). It may reflect a landward extension of the Blake Spur Fracture Zone, a location of major offset in the spreading center during early Atlantic basin development (Fig. 6) (Emery and Uchupi, 1972; K. Klitgord, personal communication, 1977). USGS multichannel seismic profiles show 3 to 4 km of vertical offset of an unconformity inferred to be of Early Jurassic or Late Triassic age along the extension of this Blake Spur Fracture Zone, and indicate that it was associated with major tectonic effects, early in continental margin development (Fig. 6).

In summary, a major, old fracture of the lithosphere may be associated with a zone of continuing earthquake activity, which crosses the central part of the possible lease area. The zone has experienced one major earthquake in the last century, which resulted in extensive damage. Although some earthquakes have been located on this zone offshore, it is only poorly defined near shore and undefined further seaward, perhaps because installation of ocean bottom seismographs necessary to obtain this data on small earthquakes has not been carried out. The likelihood of recurrence of an earthquake similar to the 1886 one is being studied by the USGS and associated researchers. Presently, such a recurrence must be considered a possibility and seismic activity sould be expected along the trend formed by an extension of the seismic zone on land and the Blake Spur Fracture Zone at sea.

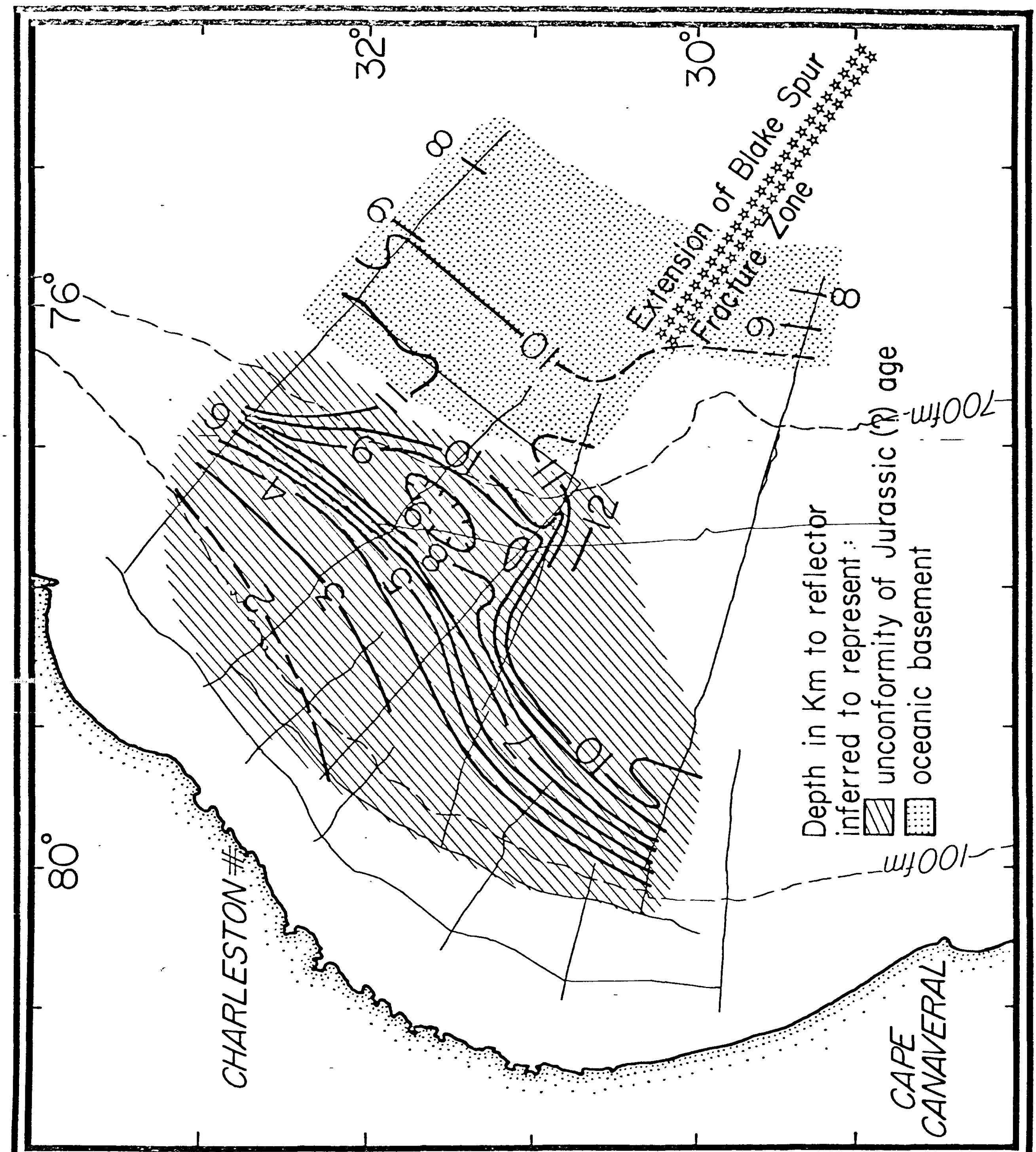


Fig. 6. Surface of the unconformity at the top of inferred Triassic rocks. The extension of the Blake Spur Fracture Zone and the offset in the unconformity seem to continue the trend of earthquake activity observed on shore.

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. South Atlantic is subject to hurricanes, and therefore, drilling platforms in this region 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. Reflection measurements also reveal some possible shallow faulting and channel fills. These conditions can result in shallow, gas-charged reservoirs, because faults can connect deeper charged reservoir to shallow depths, and channel fills, if sealed, can trap gas generated within them.

Clathrates, frozen gas-hydrates, are believed to be present in the sediments of the Blake Ridge within the area of possible leasing. Because temperature within the sediments increases with depth, the solid, frozen, clathrates would exist only above an isotherm which tends to follow the shape of the sea floor. Evidence for the clathrates in this area includes: (1) presence of a sub-bottom reflector which parallels the sea floor and intersects reflectors which we believe to represent sedimentary layers; (2) a strong velocity inversion associated with the reflector from about 2.5 km/sec above to about 1.8 km/sec below (this would be predicted from laboratory measurements of affects 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 1000-1500 meters at sub-bottom depths of several hundred to 1000 meters (JOIDES Panel, 1976).

Support characteristics of bottom sediments may be inadequate in some locations, to prevent collapse of structures. Minor slumping and faulting occurs on the Florida-Hatteras slope. Major slumping and faulting is present at the edge and on the slope of the Blake Escarpment. A few inshore peat and mud outcrops may have poor support characteristics. 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 gyres off the Gulf Stream have been reported and have caused abandonment of drill sites in both the JOIDES and USGS drilling programs on the Blake Plateau.

ESTIMATE OF UNDISCOVERED RECOVERABLE OIL AND GAS RESOURCES

The proposed lease sale area is included within parts of four offshore provinces of the Atlantic Coast region that were evaluated recently by the Resource Appraisal Group (USGS Circular 725, Miller and others, 1975). The four provinces are: South Atlantic Shelf, Blake Plateau, Southeast Florida Shelf and Straits, and Middle Atlantic Shelf (and Slope), with the bulk of the sale area lying within the South Atlantic Shelf and Blake Plateau provinces. In the Circular 725 study, the area of the South Atlantic Shelf province coincides with the area where water depths are less than 200 meters and the area of greater water depths (220 to 2,500 m, or 200 miles international boundary) are considered to lie within the Blake Plateau province. The proposed lease sale area comprises approximately 82,869 square miles of which 33,451 square miles lie between 0-200 meters water depth, and 49,418 square miles lie in water depths greater than 200 meters (Figure 1).

Undiscovered recoverable resources are those resources which are estimated to exist in favorable geologic settings and to be economically recoverable at the present time. 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 estimated.

Estimates of undiscovered recoverable resources in the proposed lease sale area are estimated for the two areas defined by water depths: (1) between 0 and 200 meters; and (2) greater than 200 meters. The latter estimate includes areas of water depths down to 2,500 meters in places. An aggregate total for the entire sale area is also calculated. In addition, it is also estimated that there is a 40 percent marginal probability that no oil or gas in commercially recoverable quantities will be found between 0 and 200 meters of water, and a 30 percent marginal probability that no oil will occur beyond 200 meters of water. In a frontier area such as this sale area, the occurence of no commercial oil or gas is very rare. Consequently, a marginal probability has been applied to this area. In this instance, marginal probabilities of 40 percent and 30 percent are estimated; therefore, estimates of the quantity of resources to be found at the 95 percent levels is zero in both cases.

The estimates of undiscovered recoverable resources in Sale Area No. 54, by water depth, are as follows:

0-200 meters

Range

	95%	5%	Statistical Mean
Oil (billions of barrels)	0	1.25	0.34
Gas (trillions of cubic feet)	0	2.5	0.67

Greater than 200 Meters

Range

	95%	5%	Statistical Mean
Oil (billions of barrels)	0	1.7	0.35
Gas (trillions of cubic feet)	0	1.7	0.35

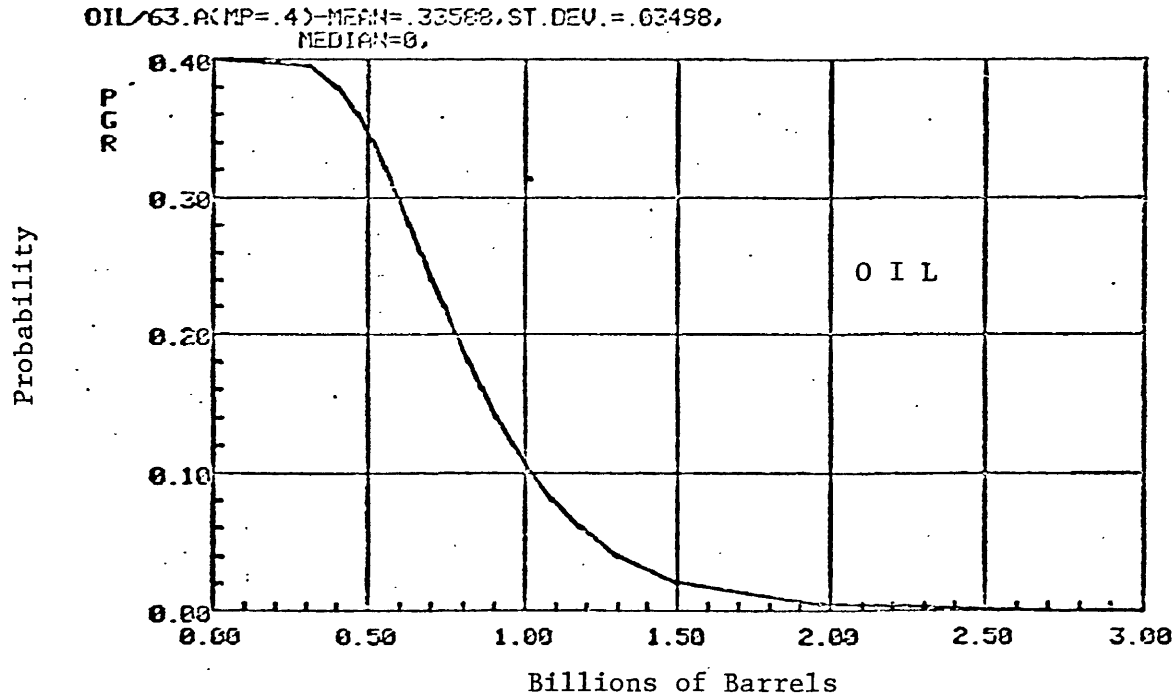
Aggregate for Total Sale Area

Range

	95%	5%	Statistical Mean
Oil (billions of barrels)	0	2.2	0.7
Gas (trillions of cubic feet)	0	3.1	1.1

The marginal probabilities, the 95 percent and 5 percent probabilities, and the statistical means were processed as probability distributions, and are graphically illustrated as lognormal curves as shown in Figures 7, 8, and 9.

Proposed Lease Sale #54
(0-200 meters)



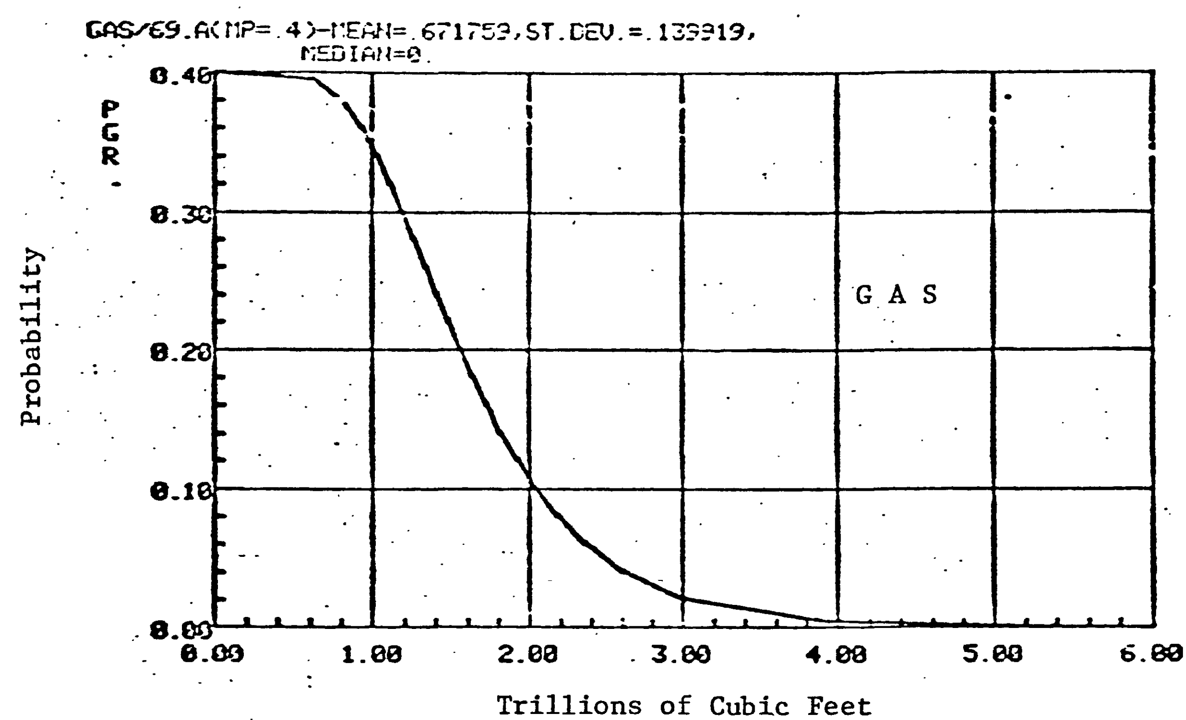
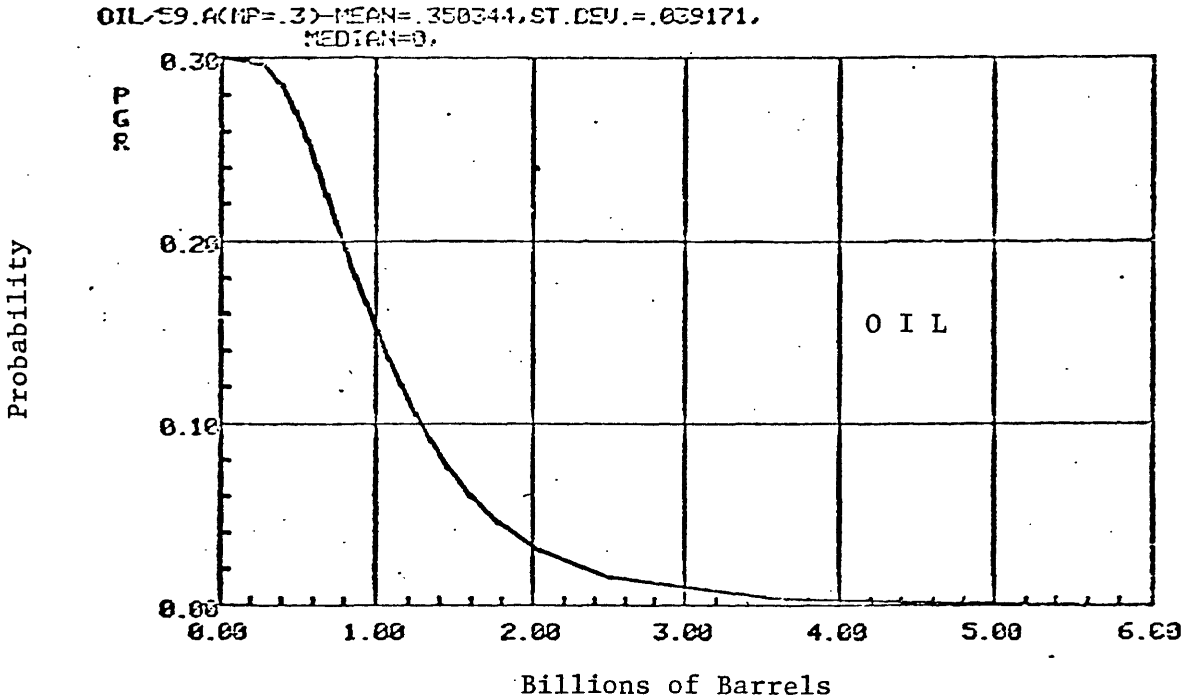


Figure 7.--Lognormal probability distribution of undiscovered oil and gas for 0-200 meter water depth.

Proposed Lease Sale #54

(>200 meters)



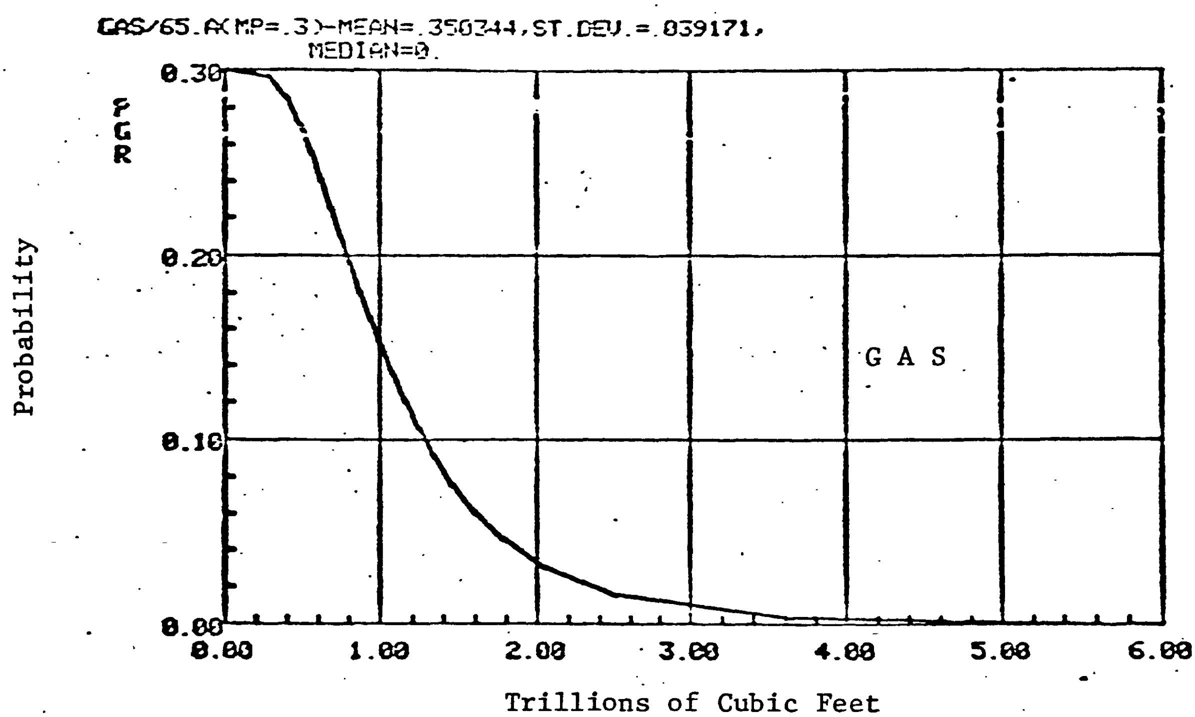
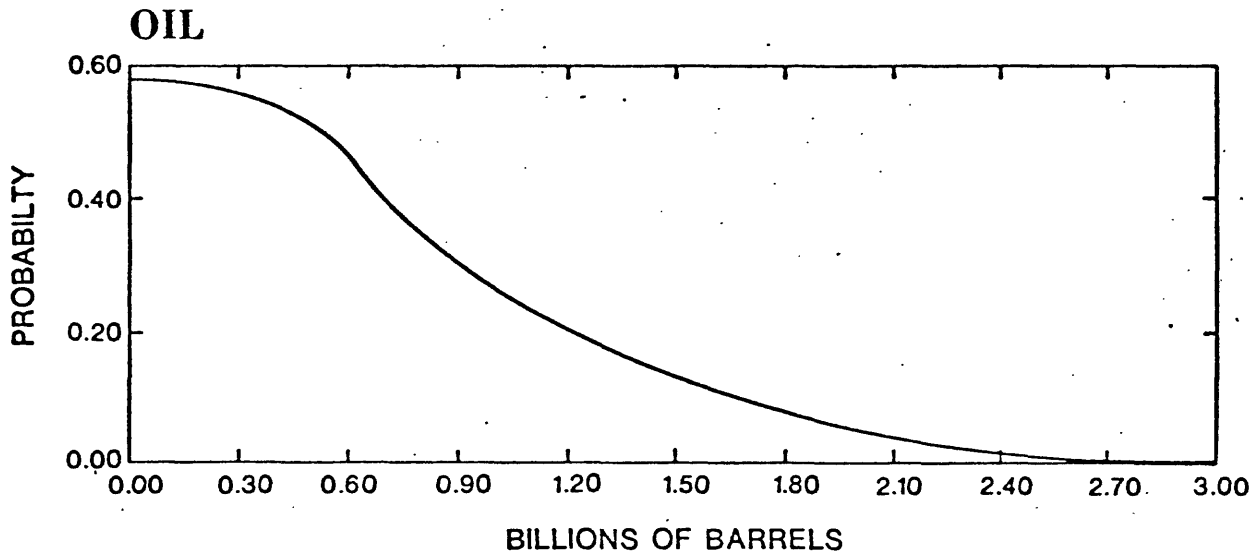


Figure 8.--Lognormal probability distribution of undiscovered oil and gas for greater than 200 meter water depth.

Proposed Lease Sale 54

(Aggregate, 0-greater than 200 meters)



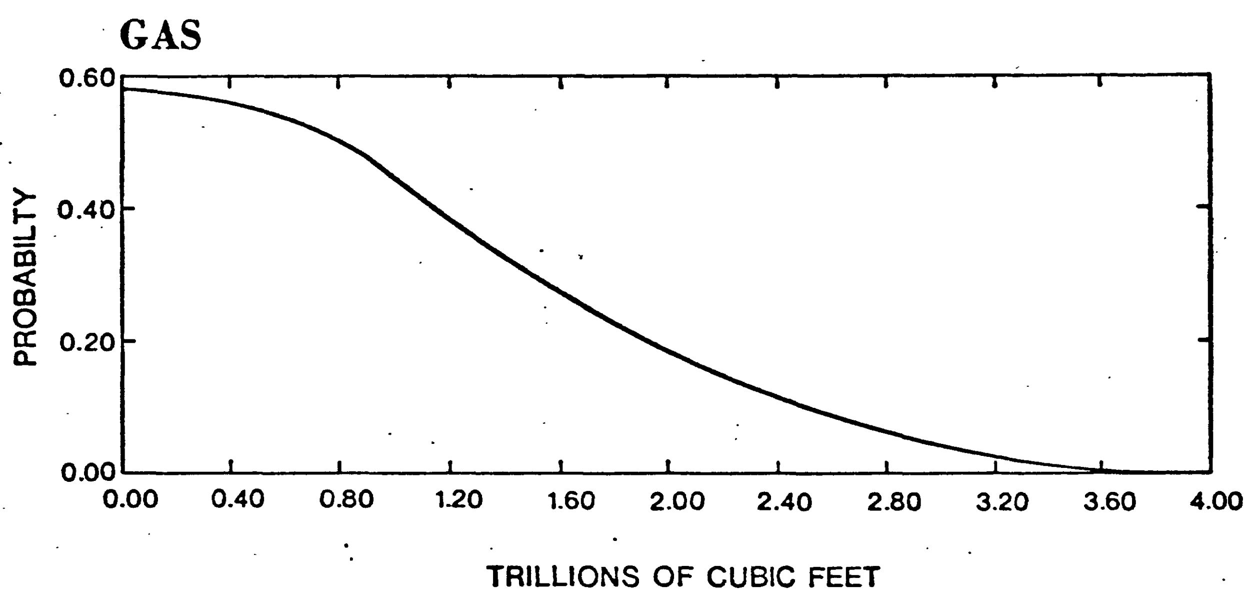


Fig. 9. Aggregated lognormal probability distribution of undiscovered recoverable oil and gas for total sale area, 0-greater than 200 meters water depth.

The estimates of undiscovered recoverable oil and gas resources in Sale Area No. 54 are based in part on volumetric and analog analytical methods that are fully explained in Geological Survey Circular 725 (Miller and others, 1975). Analogs selected for use in the sale area include the dominantly carbonate sediment-filled Salina Basin, onshore Florida Platform, Palo Duro Basin and the mixed clastic-carbonate provinces of the Alberta and Denver Basins and Williston Basin. Yield values from these analogs were applied to sediment volumes in the four offshore provinces included in the sale area and calculated for recoverable oil and gas.

The lognormal probability distribution curves (Figures 7, 8 and 9) show estimates of undiscovered recoverable resources in proposed BLM Sale Area No. 54. Estimates of oil and gas resources at various probabilities can be read directly from the curves.

OPERATIONAL CONSIDERATIONS

The technology required for development of a major portion of the sale area containing the shelf and upper part of the slope in the Blake Plateau area of the South-Atlantic is not well developed at this time.

Water depths up to approximately 1,100 meters are found in the extreme southeastern portion of the sale area and more than 2,250 meters in the northeast portion. Minimum water depths near land at the three mile limit are approximately 10 meters with an average over the entire sale area of about 750 meters.

Technology for exploratory drilling has been developed for depths up to approximately 1,200 meters. Platforms can be set in depths up to 350 meters for development drilling. In the deeper water semi-submersibles or drill ships will eventually be used for making subsea well completions. Risers present a problem in depths greater than 350 meters. Prototype sub-sea well head production systems are being tested on dry land and 30 meters (100 ft) of water for design water depths up to 600 meters. (Tests in water at design depths may present additional problems, however).

Another major difficulty will be the laying of pipelines and making pipe line hook-ups in the deeper water. Present technology can operate in 350 meters of water and within a year is expected to be operational on a limited basis in 500 meters of water.

Drilling and development in water depths up to 200 meters is now routine in the petroleum industry. From 200 to 350 meters water depth is a grey area of technological development in progress. Approximately 60% of the sale area is in water depths greater than 200 meters. In this portion undiscovered recoverable resources are estimated at .35 billion barrels of oil and .35 trillion cubic feet of gas (statistical mean) and 5% probablilty of 1.7 billion barrels of oil and 1.7 trillion cubic feet of gas.

Based on the assumption that the leased area within 0 to 200 meters of water will contain .34 billion barrels of oil and . 67 trillion cubic feet of gas (statistical mean of the undiscovered recoverable resources) about 156 oil wells (some producing substantial amounts of associated gas), about 15 gas wells (producing condensate, also) and about 70 or more non-producing wells (exploratory, delineation and dry holes) will be drilled in this portion of the sale area. There would also be 8 to 12 drilling and production platforms, about 325 kilometers of large diameter pipelines and one onshore terminal. Peak daily production, from this portion of the sale area may reach 86,000 barrels of oil and 185 million cubic feet of gas.

Based on the assumption that the leased area within the 0 to 200 meters will contain 1.25 billion barrels of oil and 2.5 trillion cubic feet of gas (5% probability of the undiscovered recoverable resources) about 574 oil wells (some producing substantial amounts of associated gas), about 55 gas wells (producing condensate, also) and about 250 non-producing wells (exploratory, delineation and dry holes) will be drilled. There would also be 27 to 40 drilling and production platforms, about 650 kilometers of large diameter pipeline and two onshore terminals. Peak daily production from this area may reach 320,000 barrels of oil and 690 million cubic feet of gas.

Although initial exploratory drilling may start within a few months following a lease sale, it will probably be 6 to 7 years after the sale when actual production from the 0-200 meter water depth begins. It would probably be 12 to 16 years after the sale when peak production is attained in this portion of the sale area. Development of the deep-water portion of the sale area will take longer.

These estimates are based on the assumption that the resources will be produced in a 25 to 30 year period following initial production from wells located an average distance of 120 kilometers from shore.

The supply of drilling units for exploratory drilling presently exceeds demand. A recent worldwide-offshore mobil rig count indicates 400 units in operation, 50 idle, and 27 planned or under construction. The units to be constructed consists of 6 drill ships, 9 semi-submersibles, and 12 jack-ups.

Much of the skilled manpower for exploratory drilling will initially have to come from other operationally mature areas such as the Gulf of Mexico. However, since Sale 54 will follow Sale 43 in the South Atlantic as well as previous sales in Mid and North Atlantic, some skilled personnel probably will be available within the Atlantic seaboard states.

SUMMARY AND CONCLUSIONS

The area of possible lease sales during sale #54 covers the continental margin from the North Carolina-Virginia border to Cape Canaveral, and extends seaward to water depths exceeding 1000 m. This region is bounded on the south by the Peninsular Arch of Florida and includes the Cape Fear Arch of North Carolina. Both arches are broad, weak, upwarps of basement. The sediments above economic basement form a seaward-thickening wedge terminated by a reef off the southern Blake Plateau and exceed 14 km in thickness beneath the southern Blake Plateau Trough.

Structural traps, which appear to be somewhat scarce, include drape features over irregularities on the basement, possible reefs, and a few diapirs in deep water. The onlapping wedge of sediment may also contain updip pinchouts which might trap oil. Information on possible reservoirs and seals is generally lacking, but we might anticipate good reservoir rocks throughout the area and seals of regional extent at least in the northern part. The lack of petroleum discoveries on land, the thin sedimentary section, and low thermal gradients beneath the Continental Shelf probably are negative factors with regard to likelihood of shallow water (shelf depth) discoveries. However, seaward of the shelf, the thicker section and therefore the higher temperatures at greater depth may be encouraging.

Environmental hazards include hurricanes, which tend to occur in the Fall, when other factors may result in the highest probability of a spill reaching shore. The Gulf Stream, a very high speed flow, has caused extensive scour and erosion, particularly on the inner Blake Plateau; this could be a significant problem for bottom-mounted structures.

Presence of cavernous limestones has resulted in loss of circulation and damage to drill strings in this region, and collapse of caverns can cause damage to structures. A northwest-trending structural lineament, which crosses the continental margin near Charleston, seems to be associated with a zone of earthquake activity which includes the major Charleston earthquake of 1886. Future seismicity on this lineament should be anticipated. Other hazards to drilling include possible presence of shallow, gas-charged reservoirs in old filled channels and presence of relict peat and mud deposits on the shelf which would offer poor structural support. Clathrates, frozen gas hydrates, are probably present within the Blake-Bahama Outer Ridge and may form a gas-trapping seal. The problems of casing, use of heat-producing cements, etc. must be considered before drilling through this clathrate horizon.

Estimates of undiscovered recoverable resources for the sale area in the 0-200 meter water depth range are: for oil, a mean estimate of 0.34 billion barrels with 95% and 5% probabilities of 0 and 1.25 billion respectively; and for gas, a mean of 0.67 trillion cubic feet with 95% and 5% probabilities of 0 and 2.5 trillion. In the part of the area seaward of the 200 m isobath, the mean estimate for oil is 0.35 billion barrels, with 95% and 5% probabilities of 0 and 1.7 billion; and for gas, a mean estimate of 0.35 trillion cubic feet with 95% and 5% probabilities of 0 and 1.7 trillion.

The principle concern with regard to operational considerations is the very great depth of water (>2500 m) in part of the proposed possible lease area. Once the need is established, it may be 10 to 15 years before technology is available for petroleum development in 1000 m of water and a further 10 years before the 2500 m depth might be practicable. Beyond water depths of 350 m, which includes approximately half the area being considered, subsea completions will probably be necessary. Initially, oil probably would be delivered to anchored tankers, but this solution might be impractical if gas fields were discovered. Production facilities in deep water will be very costly, and, therefore, large reserves and well production of perhaps 5,000 to 6,000 barrels per day will probably be required.

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