Department of the Interior

U.S. Geological Survey

Summary report on the regional geology, environmental considerations for development, petroleum potential, and estimates of undiscovered recoverable oil and gas resources of the United States Southeastern Atlantic continental margin in the area of proposed Oil and Gas Lease Sale No. 78

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[References and illustrations are grouped at the end of each chapter]

INTRODUCTION

This report summarizes our general knowledge of the geology and petroleum potential, as well as potential problems and hazards associated with development of petroleum resources, of the area proposed for nominations for lease sale number 78. This area includes the U.S. eastern continental margin from the mouth of Chesapeake Bay to approximately Cape Canaveral, Florida, including the upper Continental Slope and inner Blake Plateau. The area for possible sales and the previous areas leased are shown in figure 1; physiographic features of the region are shown in figure 2.

Six exploration wells have been drilled within the proposed lease area (figs. 3 and 4) but no commercial discoveries have been made. All six wells were drilled on the Continental Shelf in the Southeast Georgia Embayment. No commercial production has been obtained onshore in the region. The areas already drilled have thin sedimentary sections, and the deeper rocks are dominantly continental facies. Petroleum formation may have been hindered by a lack of organic material and sufficient burial for thermal maturation. Analysis of drill and seismic profiling data presented here, however, indicates that a much thicker sedimentary rock section containing a much higher proportion of marine deposits exists seaward of the exploratory wells on the Continental Shelf. These geologic conditions imply that the offshore basins may be more favorable environments for generating petroleum.

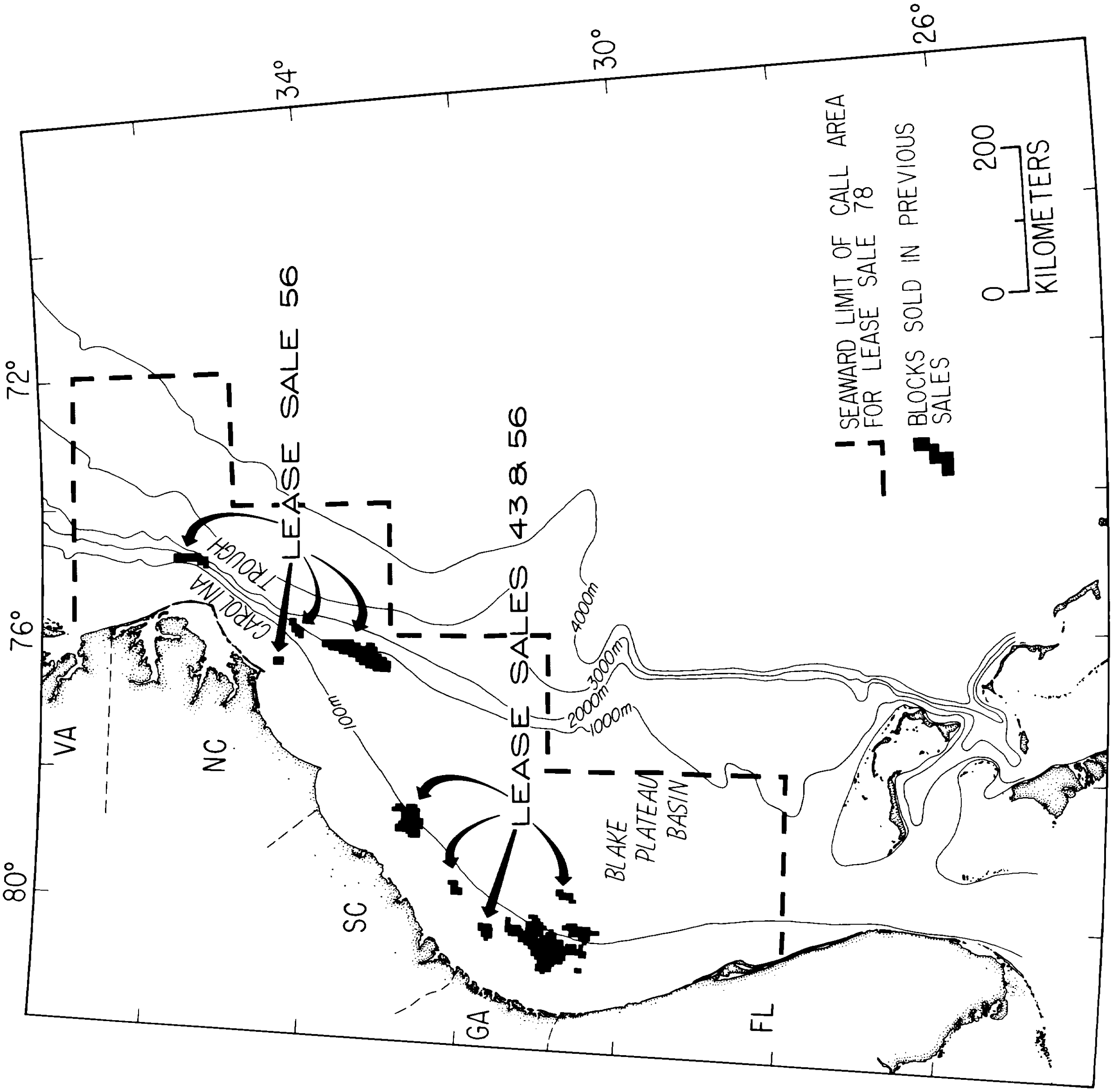

Figure 1.--Seaward limit of call area for sale 78 and location of blocks leased in previous sales.

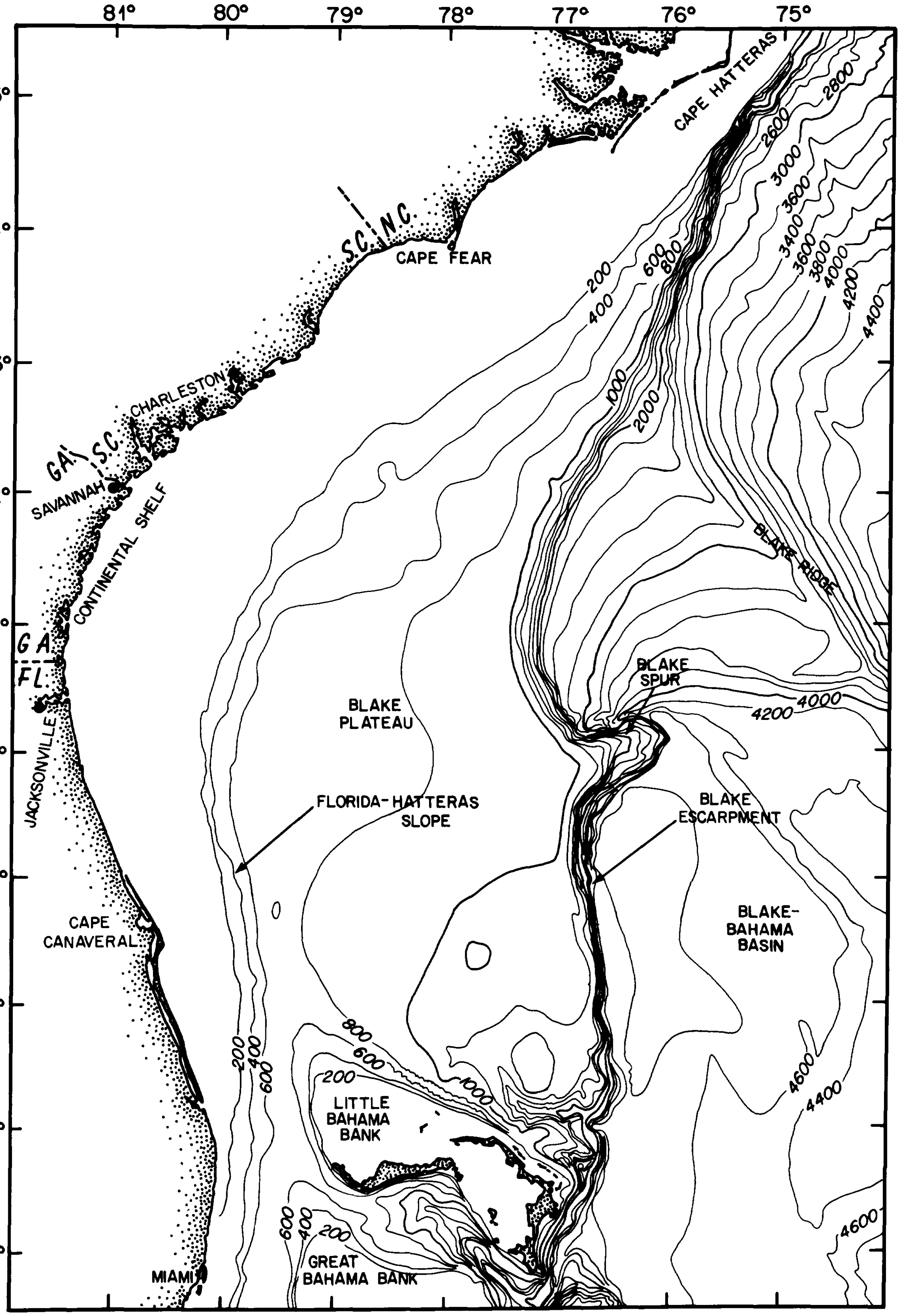

Figure 2.--Bathymetric map of the continental margin of the southeastern United States showing principal physiographic features. Depths shown in meters.

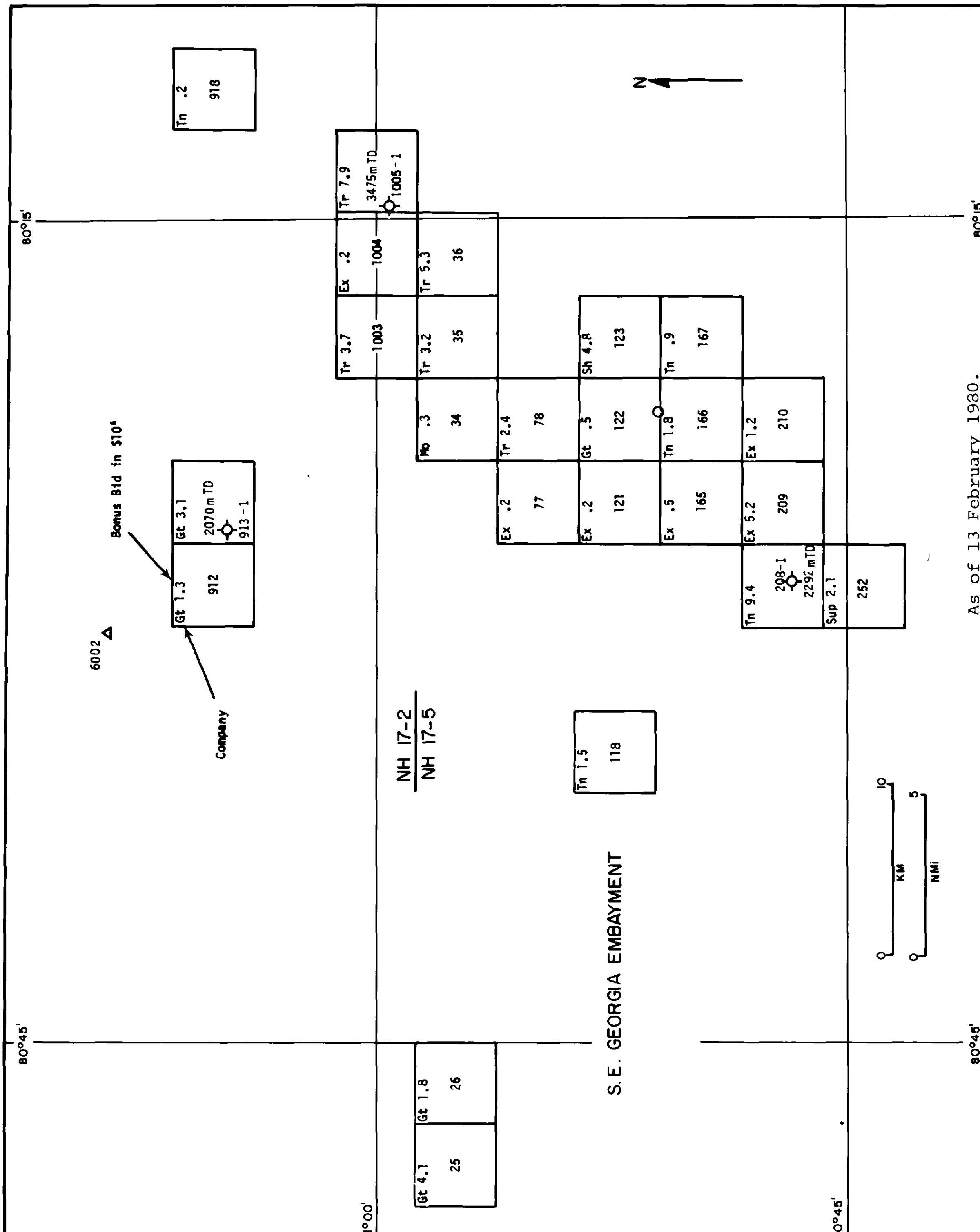

Figure 3.--Bids and location of wells drilled offshore in the Southeast Georgia Embayment, northern group. Total depth (TD) of well given in meters (m).

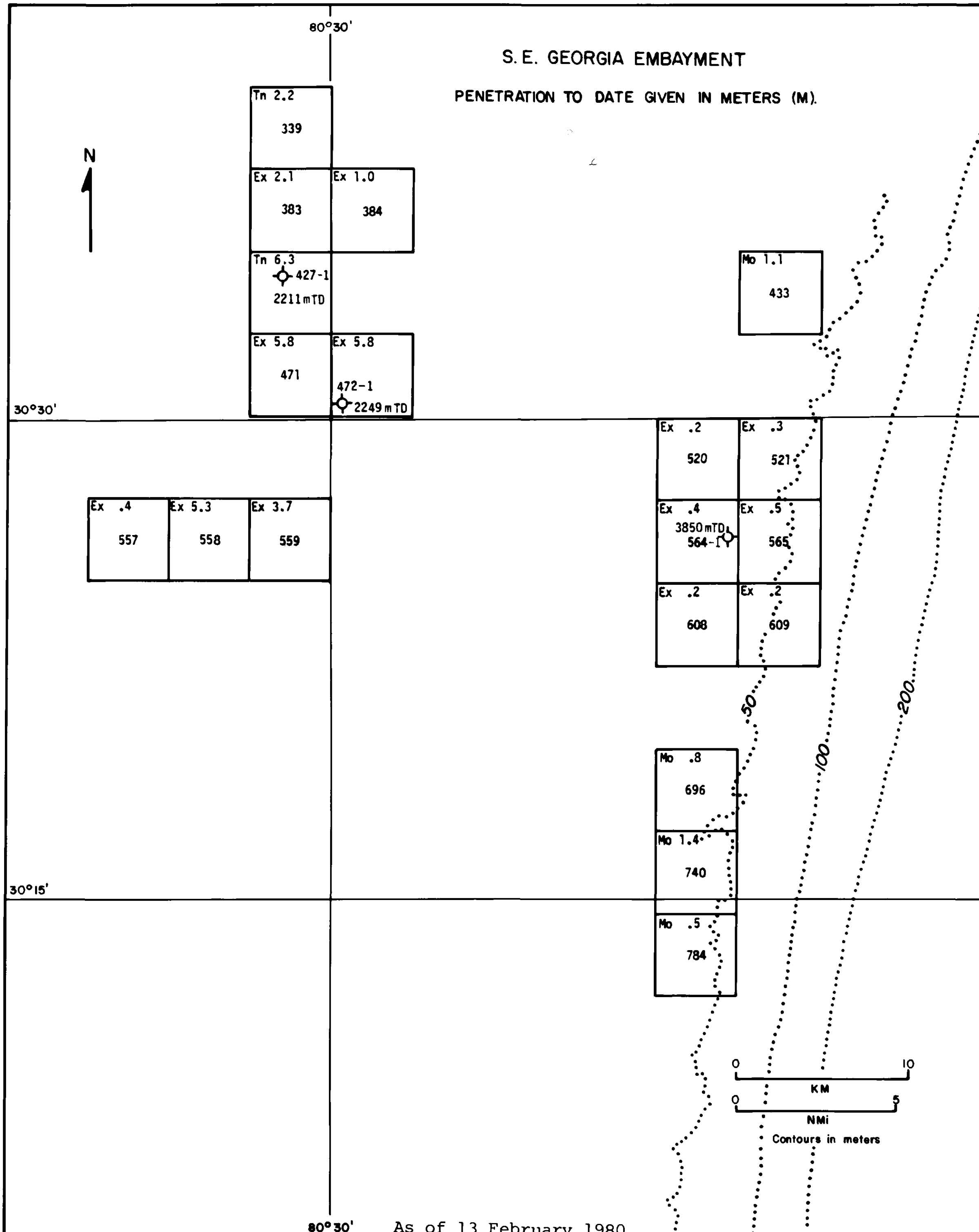

Figure 4.--Bids and locations of wells drilled offshore in the Southeast Georgia Embayment, southern group. Total depth (TD) of well given in meters (m).

CHAPTER I

REGIONAL GEOLOGY

By

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Two major zones of offshore continental margin subsidence, floored, presumably, by rift-stage crust, exist in the area proposed for nominations (fig. 5*). These are the Blake Plateau Basin, beneath the Blake Plateau east of Florida and Georgia, and the Carolina Trough beneath the Continental Slope east of South Carolina and North Carolina (Klitgord and Behrendt, 1979). The Southeast Georgia Embayment is a minor sag of continental basement that extends onshore beneath the Coastal Plain (fig. 5). This discussion will be based primarily on the U. S. Geological Survey's (USGS) grid of multichannel, common-depth-point seismic profiles shown in figure 6. Single-channel seismic profiling, gravity and magnetic surveys and stratigraphic drilling also have been carried out and aid in the interpretation.

Total thickness of sedimentary rock for the continental margin off the southeastern United States is shown in figure 7. The isopachs are based on data from the multichannel profiles (fig. 6). The two main basins are very clearly defined, and are separated by a northwest-trending ridge along the extension of a deep-sea fracture zone (the Blake Spur Fracture Zone). The basins' landward margins are quite linear and generally are aligned northeasterly, normal to the direction of ocean opening. In the following pages, a discussion of the southern part of the region (Southeast Georgia Embayment and Blake Plateau Basin,

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*Figures 5-45 are grouped at the end of this chapter, beginning on p. 18.

fig. 5) precedes a discussion of the northern part (Carolina Platform and Carolina Trough).

BLAKE PLATEAU BASIN AND SOUTHEAST GEORGIA EMBAYMENT

Structure and Stratigraphy

The general structure of the Blake Plateau is shown by seismic profile FC 3 (location, fig. 6; structural interpretation fig. 8; inferred stratigraphy, fig. 9). The plateau probably formed as a broad flat carbonate platform (Dillon and others, 1979a; Schlee and others, 1979). Thicknesses of sedimentary units do not vary greatly, but maximum thickness of Jurassic units occurs in the mid-basin, whereas younger depocenters are shifted landward. This landward shift implies that the center of subsidence shifted westward as time passed and it accounts for the general landward dip of strata across most of the basin.

Profile TD5 (location, fig. 6) allows a more precise stratigraphic and paleoenvironmental analysis (Dillon and others, 1979a, b), as it was collected across the drill sites of the COST No. GE-1 well (Poag and Hall, 1979, Valentine, 1979) and the Deep Sea Drilling Project No. 390 well (Benson, Sheridan, and others, 1978). An interpretation for the landward part of the profile, that part within the proposed sale area, is shown in figure 10, and a lithologic log for the COST No. GE-1 well is shown in figure 11. Detailed velocity logging of the well allowed precise correlation of reflection events to depths of biostratigraphic age picks and paleoenvironments (fig. 12). By extrapolating along reflections, we see that different major depositional environments that were recognized in samples from the well result in distinctive reflection characteristics, open-marine shelf deposits produce strong continuous reflections; continental deposits produce strong discontinuous reflections; slope-depth chalks and marls produce very weak reflections (Fig. 13). This seismic stratigraphic approach (Payton, 1977) allows analysis of facies distribution along profile TD5 as indicated in figure 10, and in more diagrammatic form in figure 14. The paleodepth pattern at the COST No. GE-1 well (Poag and Hall, 1979) and the transgression - regression pattern identified in the profile (fig. 14) show close correlation to the proposed worldwide coastal onlap-offlap pattern of Vail and others (1977). Therefore, that curve was used as a key to assign ages to episodes of transgression-regression identified in the profile but not penetrated at the well because of its updip position (fig 14). An indication that this approach produces reasonable (not necessarily accurate) results is provided by a comparison of the subsidence curve implied by these age assignments to a known curve for a well on the U.S. east coast, the COST No. B2 well in the Baltimore Canyon Trough (fig. 15).

Geologic History

The stratigraphic framework devised above, combined with the seismic profiling data, allows construction of a model of the history of the Blake Plateau Basin as shown in figure 16. In Triassic-Early Jurassic time, rifting, stretching, and intrusion began in a broad zone of continental crust that would become the basement of the Blake Plateau Basin. In Jurassic time (perhaps 170 million years (m.y.) ago, fig. 16), geometric center of the rifting jumped eastward (Vogt, 1973), subsequently, the new spreading center generated oceanic crust as Africa and North America drifted apart (fig. 17). Early subsidence of the Blake Plateau Basin was rapid (fig. 15), and reefs began to develop as interpreted in seismic profiles. Several profiles show that the reefs apparently died at the end of Neocomian time, but that new reefs developed to the west and seem to have flourished in Aptian and Albian time (fig. 16). Meanwhile, the shoreline migrated back and forth across the western Blake Plateau Basin (fig. 14). At the end of Early Cretaceous time, reef growth ceased and sedimentation rate decreased markedly although the continental margin continued to subside, resulting in water depth across the former shelf increasing by several hundred meters and in accumulation of chalks and marls extending westward into the Southeast Georgia Embayment. After the Paleocene, the Gulf Stream began to flow actively across the present Blake Plateau, eroding the inner plateau and preventing thick accumulation on the outer plateau. The seaward edge of the present Continental Shelf is restricted by the flank of the Gulf Stream (Paull and Dillon, 1980).

Relation of Regional Geology to Petroleum Potential

Six dry holes (figs. 3,4) have been drilled on the Continental Shelf in the southern part of the sale area (Southeast Georgia Embayment). Possible petroleum trapping are structures are not well developed beneath the shelf, as indicated by profiles FC4-FC5-FC6 (fig. 18), that form a strike line extending along the shelf from the Southeast Georgia Embayment northeastward onto the Carolina Platform (fig. 6). Minor reef structure seems to exist in the Southeast Georgia Embayment (km 10-20, fig. 18). Minor drape structure occurs to the northeast (km 220, fig. 18), where crystalline basement is inferred to project above a smooth layer of volcanic rock; the seismic record for the latter feature is shown in figure 19. In addition to an apparent dearth of traps, as observed on the broadly spaced, publicly available seismic profiles, source beds may be poorly developed beneath the Shelf. The deeper strata penetrated by the COST No. GE-1 well which show thermal maturity are continental and probably are poor hydrocarbon sources. The richest potential source rocks penetrated by the well are Upper Cretaceous chalks and marls (Miller and others, 1979). Unfortunately, these chalks and marls are buried to depths of less than 1,000 m beneath the shelf and are hardly covered across the Blake Plateau (fig. 14) so they probably are thermally immature.

Our profiles show that the sedimentary section underlying the inner Blake Plateau is much thicker than that underlying the present shelf, and that rocks under the Blake Plateau are dominantly marine (fig. 14), perhaps forming better source rocks than the rocks of continental facies beneath the present shelf. Stratigraphic traps might be associated with old shoreline features (such as barrier islands) that might be found at the contact between continental facies and open marine shelf facies. Pinchouts against basement might also form traps for locally generated petroleum. The regional landward dip across the Blake Plateau Basin (figs. 8, 10) would result in a general seaward migration of hydrocarbons, if long-distance migration took place. Such hydrocarbons could be trapped in reef and carbonate bank structures of the outer Blake Plateau, but these are outside the proposed sale area.

CAROLINA TROUGH AND CAROLINA PLATFORM

Structure and Stratigraphy

Only the western half of the Blake Plateau basin is included in the proposed sale area. However, because of the shape of the proposed area (fig. 1) and locations of the basins (fig. 7),almost the entire Carolina Trough is included in the call area, as is the saddle between the two basins.

The saddle between the major basins is covered by more than 7 km of sedimentary rock, so should not be discounted for petroleum. Structure along the saddle is shown by profile BT4 off Charleston (location fig. 6, structure and stratigraphy, fig. 20). The structure beneath the Continental Shelf is similar to that seen in the Southeast Georgia Embayment (fig. 10), but the sedimentary section is much thinner and strata probably onlap a volcanic layer that covers the postrift unconformity (Dillon and others, 1979c) (seismic section of shelf, Fig. 21, location shown in interpretation, fig. 20). Seaward of the volcanic layer, older strata onlap across an angular unconformity possibly cut on Triassic rocks (seismic section, fig. 22, location shown in interpretation, fig. 20). The outer end of the profile shows sedimentary buildups that may represent platform-edge carbonate banks (fig. 23).

Basement structure of the Carolina Trough and Carolina Platform is shown in figure 24. The trough is long, narrow, and linear, unlike the other east coast basins; it is about 450 km long and 40 km wide. A major system of normal faults extends for more than 300 km along the northwestern (landward) side of the basin, and a linear group of diapirs is on its southeastern side (fig. 24). Because of the distinct chlorinity gradient increasing downward in short sediment cores taken on top of them, the diapirs are assumed to be cored by salt (F. T. Manheim, unpublished data). Distribution of diapirs indicated in figure 24 is based on the multichannel seismic data collected along tracklines shown plus a much more dense grid of single-channel seismic lines and a long-range sidescan-sonar survey, discussed by Popenoe and others in Chapter II of this report. The structure of the Carolina Trough is shown by three adjacent multichannel seismic lines--BT1, 32, and TD6, locations for which are shown in figures 6 and 24. The parts of the profiles that cross the Carolina Trough and that are shown in figures 25, 26, 27, 28, 29, 32 and 33 are indicated by heavy lines on the profile tracks in figure 24.

The Carolina Trough part of profile BT1 is shown in figure 25 and its interpretation is shown in figure 26. An unconformity, marked by diffractions, dips to the southeast at the left side of the profile segment and extends beneath a set of very strong subhorizontal reflections at 6 to 7 seconds. The unconformity is considered to be the postrift unconformity and the strong subhorizontal reflections are thought to arise from evaporite deposits. Several faults are indicated in figure 26. The dominant fault on the left of the figure is observable in many profiles. Its near-surface location is mapped in figure 24 on the basis of both multichannel profiles and the single-channel profiling grid shown by Popoenoe and others (Chapter II, this report). In figure 24, hachures on the faults show downthrown side and also the locations of profile crossings. Several episodes of erosion of the Continental Slope are evident and a major progradational wedge appears (fig. 27, location shown on fig. 26).

Profile 32 (figs. 28, 29) also shows the major fault at the landward side of the Carolina Trough and the strong reflections inferred to come from salt. An upwarp at the seaward end of the section probably represents an incipient salt diapir. Details of the seismic record at the main fault on profile 32 are shown in figure 30. On this crossing, as on other profiles, the fault seems to continue steeply to the interpreted salt layer. The fault is well landward of the paleoshelf - slope break, it does not appear to curve and flatten into bedding, and it does not seem to have associated antithetic faults that would be expected with a curved fault plane (some associated faults do appear on profile TD6). Thus it is not characterized by features of ordinary slump-type faults of the continental margin. Certain distinctive packages of reflection events seem to be matchable across the main fault on all three CDP (common-depth-point) seismic profiles considered here. This ability to match reflectors allows us to calculate throws at various depths. A plot of these data (fig.31) shows that throw increases fairly smoothly as depth increases, indicating that this is a growth fault--one that is active during sediment deposition.

Stratigraphic estimates are not sufficiently controlled in this area for throw to be plotted versus age. However, if long-term sedimentation rate varied fairly smoothly, figure 31 suggests that movement on the growth fault at the three locations graphed was at an approximately constant rate. Throw is observed to increase downward at least as deep as a horizon inferred to be the top of Jurassic. Below that level, reflectors cannot be matched across the fault, although the fault clearly is traceable to the evaporite(?) layer. Thus the fault probably has been active at least since the end of Jurassic and probably earlier.

Seismic profile TD6 (figs. 32, 33) shows a general structure similar to that of the other profiles across the Carolina Trough. This profile crosses one of the salt diapirs, apparent at the right side of figures 32 and 33.

Geologic History

The Carolina Trough began to form as a result of the same Triassic-Early Jurassic rifting and stretching of continental crust that initiated development of the Blake Plateau Basin and affected all the Eastern United States (top diagram, fig. 34). As the stretching went on, a much narrower zone of continental crust was converted to rift-stage crust in the Carolina Trough than in the Blake Plateau Basin, but the thinning of this narrow strip was much more intensive. Models of crustal thicknesses along eastern North America based on gravity and refraction demonstrate this point (fig. 35), showing that basement thicknesses are much less in the Carolina Trough and Scotian Basin than elsewhere along the margin. These two margin basins are also the sites of most of the salt diapirism off eastern North America (fig. 36). The basins having thin, initially hot, rift-stage basements probably subsided isostatically much faster than the others and sank below sea level sooner, creating opportunity for salt deposition. Thus, they received thicker salt layers, resulting in generation of numerous diapirs.

Conversion from rifting to generation of new oceanic crust at a spreading center took place much sooner at the Carolina Trough than to the south. Therefore, by the time of the spreading-center jump, a considerable amount of new oceanic crust had been generated in the Carolina Trough, whereas little or none seems to have been produced before then off the Blake Plateau Basin (fig. 17). Open-marine circulation probably was instituted by the time oceanic crust began to form off the Carolina Trough. After the rifted blocks and graben deposits were beveled to form the postrift unconformity, basaltic flows spread across part of the Carolina Platform.

Rapid subsidence of the Carolina Trough during Jurassic accompanied by accumulation of a thick continental margin wedge resulted in loading of the salt, which began to flow seaward and rise into diapirs (140 m.y. ago, fig. 34). Continual removal of the salt from the main part of the basin, where it formed, caused the overlying block of sedimentary rock to subside, generating a growth fault. The disruption of the sea floor by diapirs and observation of fault offsets to within a few tens of meters of the sediment surface (Dillon and others, in press, Popenoe and others, Chapt. II, this report) demonstrate that salt diapirism and attendant subsidence of the trough block continue.

The Continental Shelf of the Carolina Trough continued to build during Cretaceous, and episodes of extensive progradation alternated with retreat by erosion. The Gulf Stream inhibited sedimentation during the Cenozoic in this region, as well as to the south. The most intense erosion, however, was the deep-sea erosion that created horizon A^u, approximately during Oligocene time (Tucholke, 1979). Finally, off the southern Carolina Trough, Neogene deposition resulted in a large sedimentary accumulation on the A^u unconformity (the Blake Ridge fig. 2).

Relation of Regional Geology to Petroleum Potential

No wells have been drilled in the Carolina Trough for petroleum. The Esso Hatteras Light well (dry hole) (fig. 37) was closest but should be considered a Carolina Platform, rather than a Carolina Trough, well. The trough seems to have subsided rapidly in Jurassic and thus may be likely to have a deeply buried marine section above deposits of the hypersaline episode.

Perhaps the most obvious sorts of traps in the Carolina Trough would be those associated with salt domes. Unfortunately, most of the domes are in water depths of more than 3,000 m (fig.24). The growth fault associated with salt withdrawal may provide traps. The structures associated with these probably would be different from ordinary roll-overs into listric, down-to-basin, faults, however. Because the faults probably are generated by removal of material from beneath the block, rather than by a seaward gliding of the block, the fault planes are steep and do not seem to flatten into bedding as shown in a depth converted section (fig. 38). Antithetic faults are rare.

Pinchouts against basement and shelf-edge carbonate banks may form traps (figs. 20, 22, 23). The episodes of progradation and erosion of the Jurassic-Early Cretaceous shelf edge (fig. 27) may have generated traps, but the possibility exists that any petroleum escaped during the deep erosion that created the A^u unconformity (during Oligocene time).

Subsidence of the axial region of the Carolina Trough, caused by lithospheric cooling, sediment loading, and salt withdrawal, has generated landward dips in the strata of the outer paleoshelf. Seaward dips beneath the paleoslope are depositional. The result is an anticline beneath the outer paleoshelf that is apparent in the depth-corrected section (fig. 38) and in structure contours on the Aptian and Jurassic surfaces (fig. 39 and 40). This anticline is very large in area and may, in some locations, form a petroleum trap.

Gas hydrate, a solid crystalline water-gas combination, is very extensive in the sediments of the Blake Ridge area (fig.41). Evidence for the extent of gas hydrate is from drilling and seismic profiles, in which a bottom-simulating reflector (BSR) is observed at sub-bottom depths of 200 to 800 m (figs. 25, 26, 28, and 29) (Tucholke and others, 1977; Shipley and others, 1979; Dillon and others, 1980; Paull and Dillon, 1981). The BSR is a reflection from the base of the sedimentary section that is cemented by gas hydrate. It parallels the sea floor because the phase boundary that limits its deeper formation tends to follow an isotherm, and as the geothermal gradient is fairly constant across an area, the isotherms are parallel to the sea floor. Such a near-surface layer of gas-hydrate-cemented sediment can act as a seal, and if configured properly can act as a gas trap. Because it parallels the sea floor, the base of a gas-hydrate layer will form a dome at any hill on the sea floor, as in the Blake Ridge. For example, a seismic line extending along the ridge axis is shown in figure 42 and an intersecting line crossing the ridge is shown in figure 43 (locations, fig. 41). Preliminary velocity analysis is shown in figure 44 for the point indicated by the arrow in figure 43. High velocities above the BSR are probably produced by gas-hydrate cementation. A layer of very low velocity (less than water velocity) below the BSR probably results from free gas in the sediments. This gas may not be producible, however, because of anticipated low permeability in the mudstones of the ridge sampled in the limited drilling that has been carried out (Hollister, Ewing, and others, 1972; K. Kvenvolden, oral communication, 1981). Another circumstance in which gas hydrates might seal gas is where permeable beds, interlayered with impermeable beds, dip back into the Continental Slope and are sealed at their updip ends by gas hydrate (fig. 45). Gas-hydrate-sealed shallow traps must also be considered to be hazards to drilling in this region.

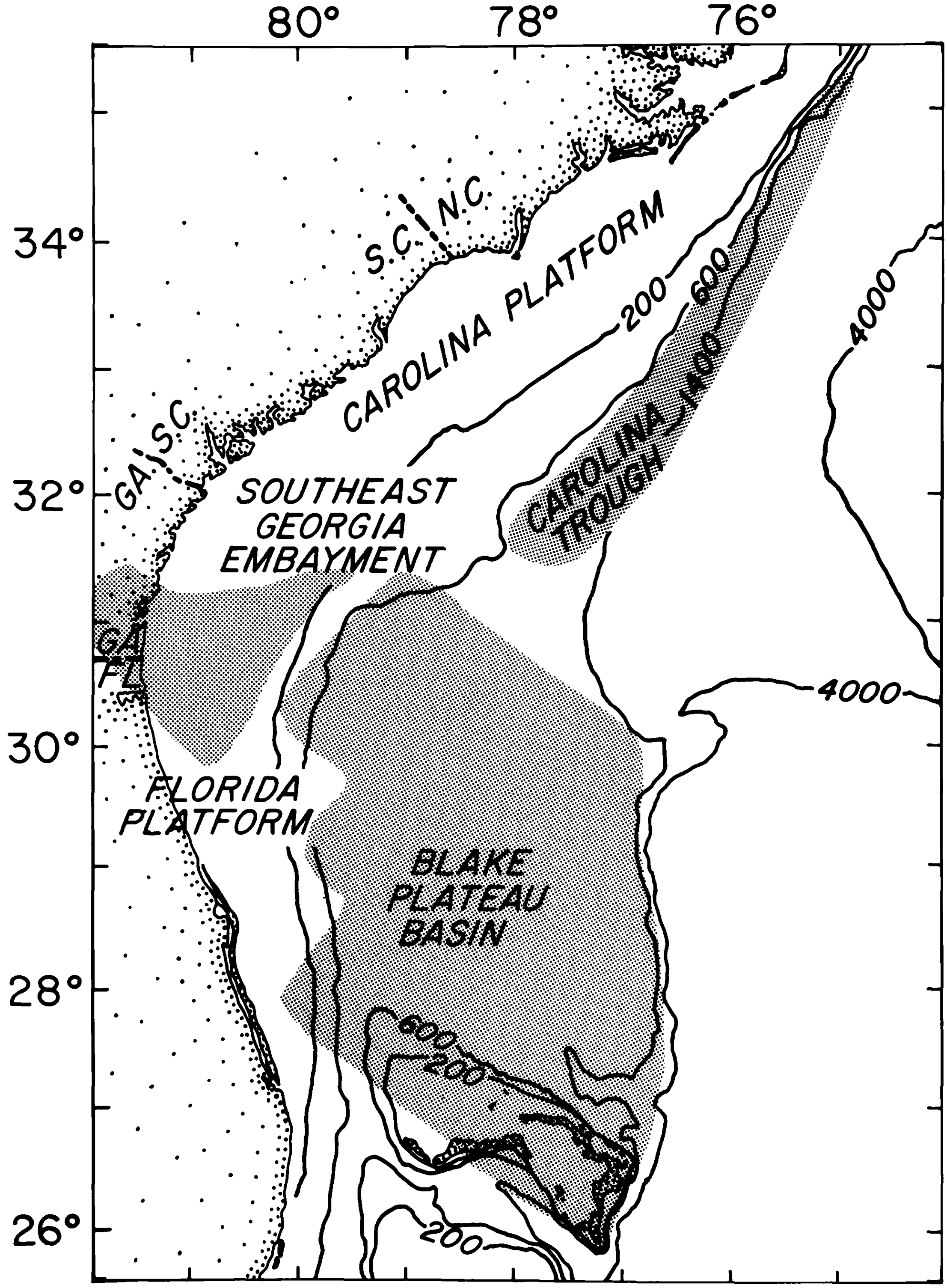


Figure 5 -Main basins of the continental margin off the southeastern United States. **Bathymetry in meters.**

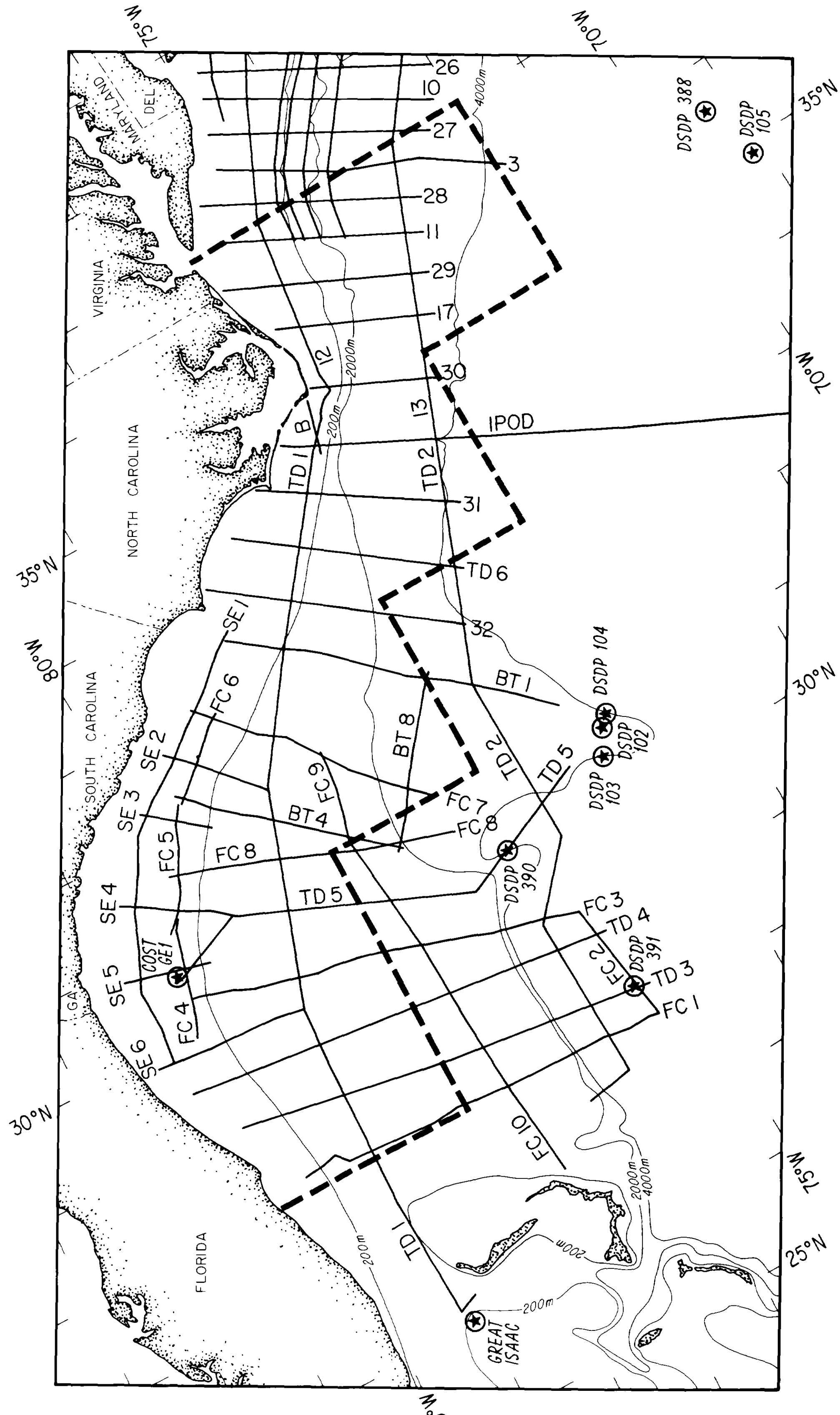


Figure 6.--Tracklines along which multichannel seismic profiles were collected by the U.S. Geological Survey. Heavy dashed line indicates seaward limit of call area of lease sale 78. Bathymetry in meters. Locations of selected drill-sites are shown. DSDP - Deep Sea Drilling Project, COST - Continental Offshore Stratigraphic Test, IPOD - International Phase of Ocean Drilling.

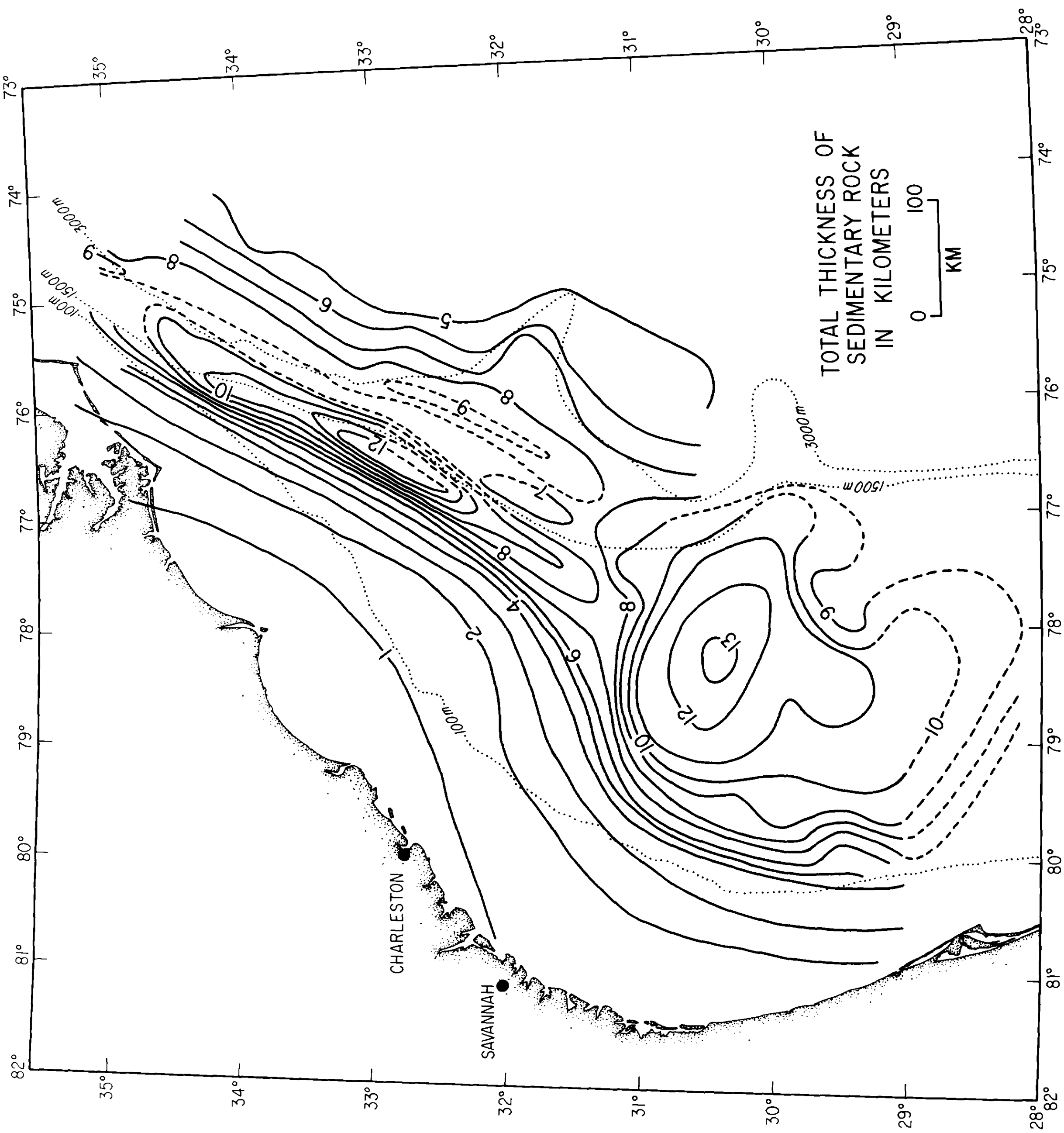


Figure 7.--Total thickness of sedimentary rock off the southeastern United States in kilometers. Map is based on multichannel seismic profiles collected along lines shown in figure 6. Bathymetry in meters.

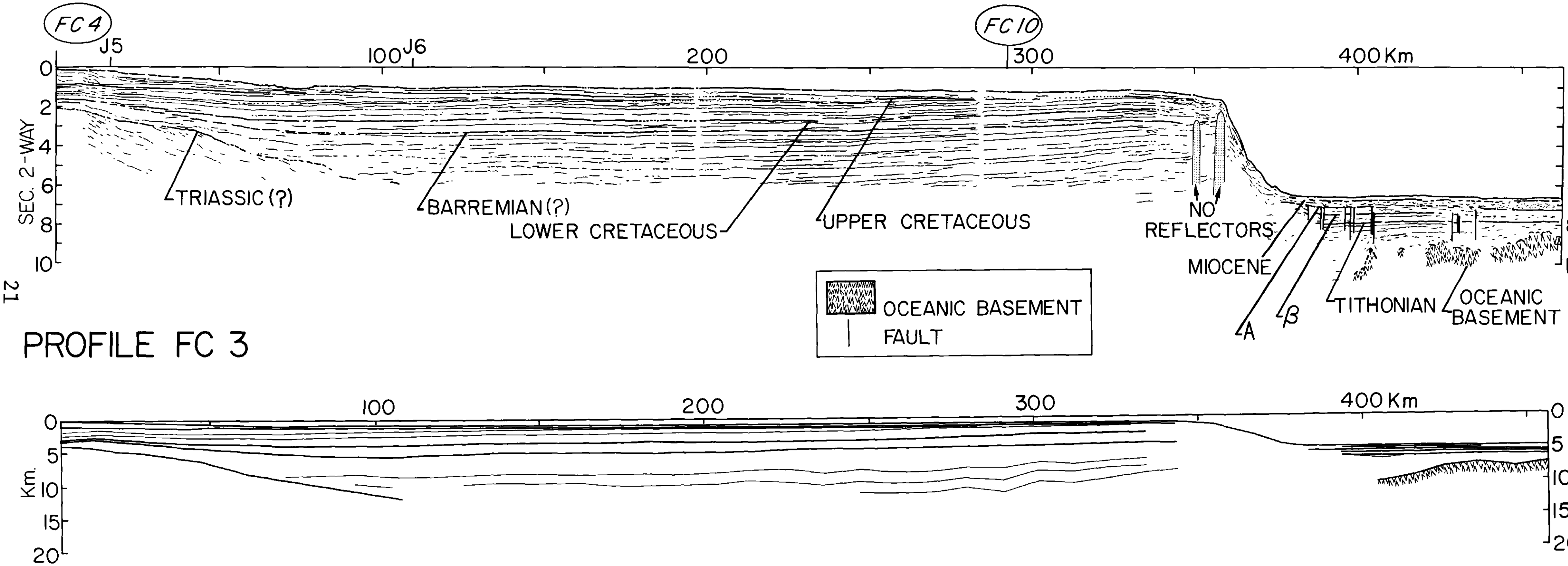


Figure 8 Interpretation (above) and calculated depth section (below) for profile FC3 off northern Florida. Location is shown in figure 6.

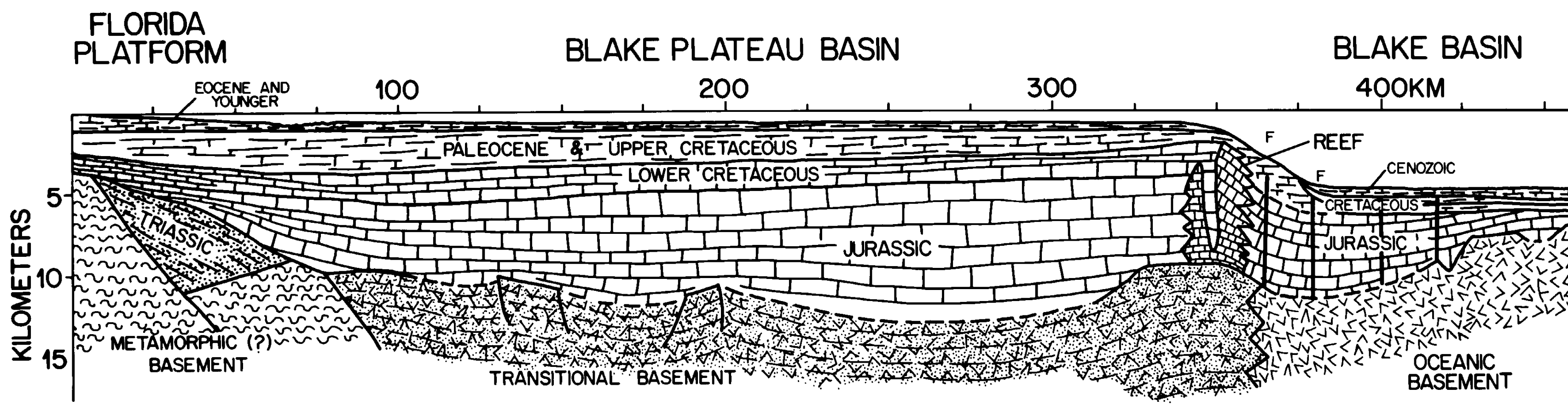


Figure 9 Inferred stratigraphy for seismic profile FC3, shown in figure 8.

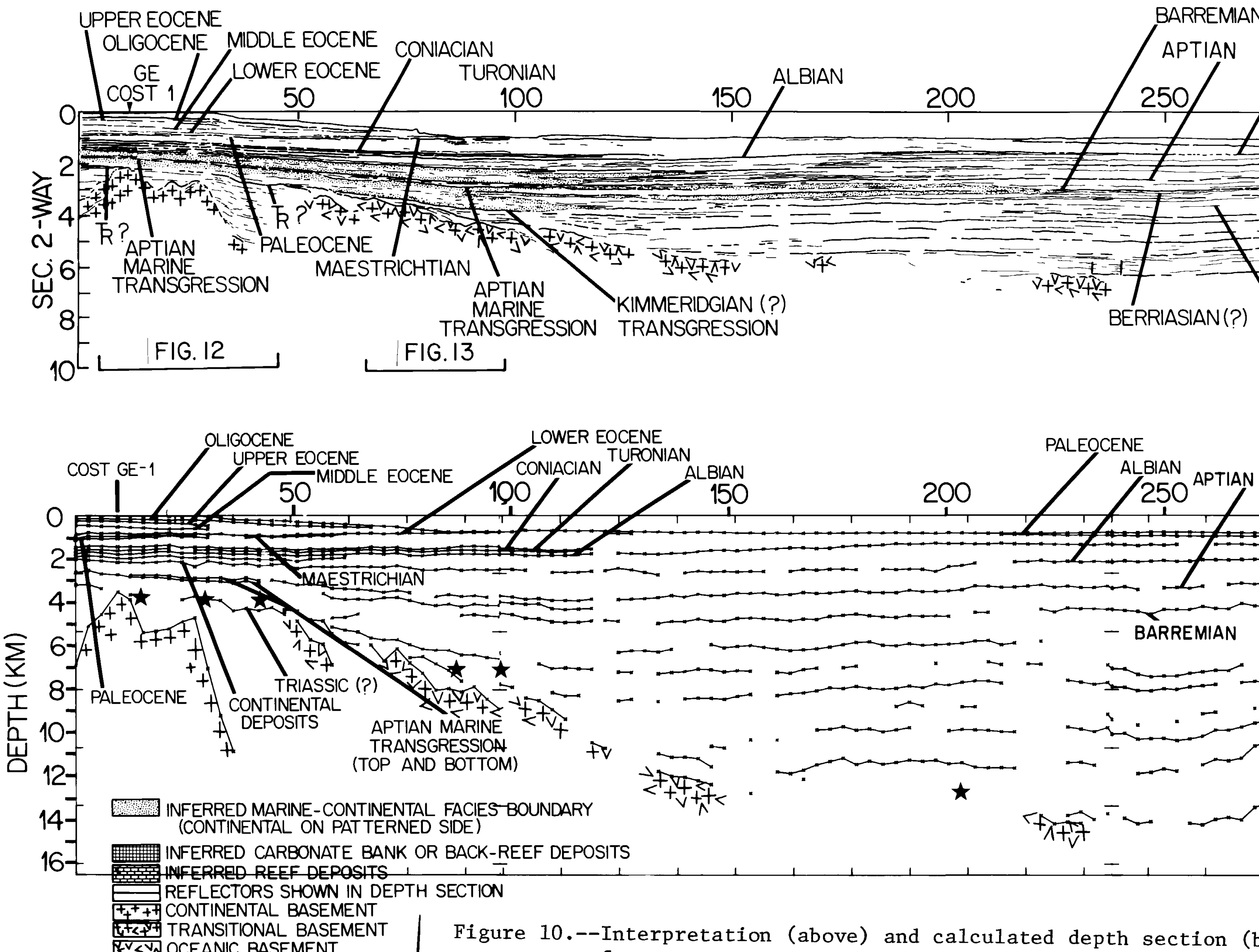


Figure 10.--Interpretation (above) and calculated depth section (below) for western part of seismic profile TD5 off northern Florida. Stars indicate magnetic-basement depth solutions. Profile location shown in figure 6. Profile crosses COST No. GE-1 drill site.

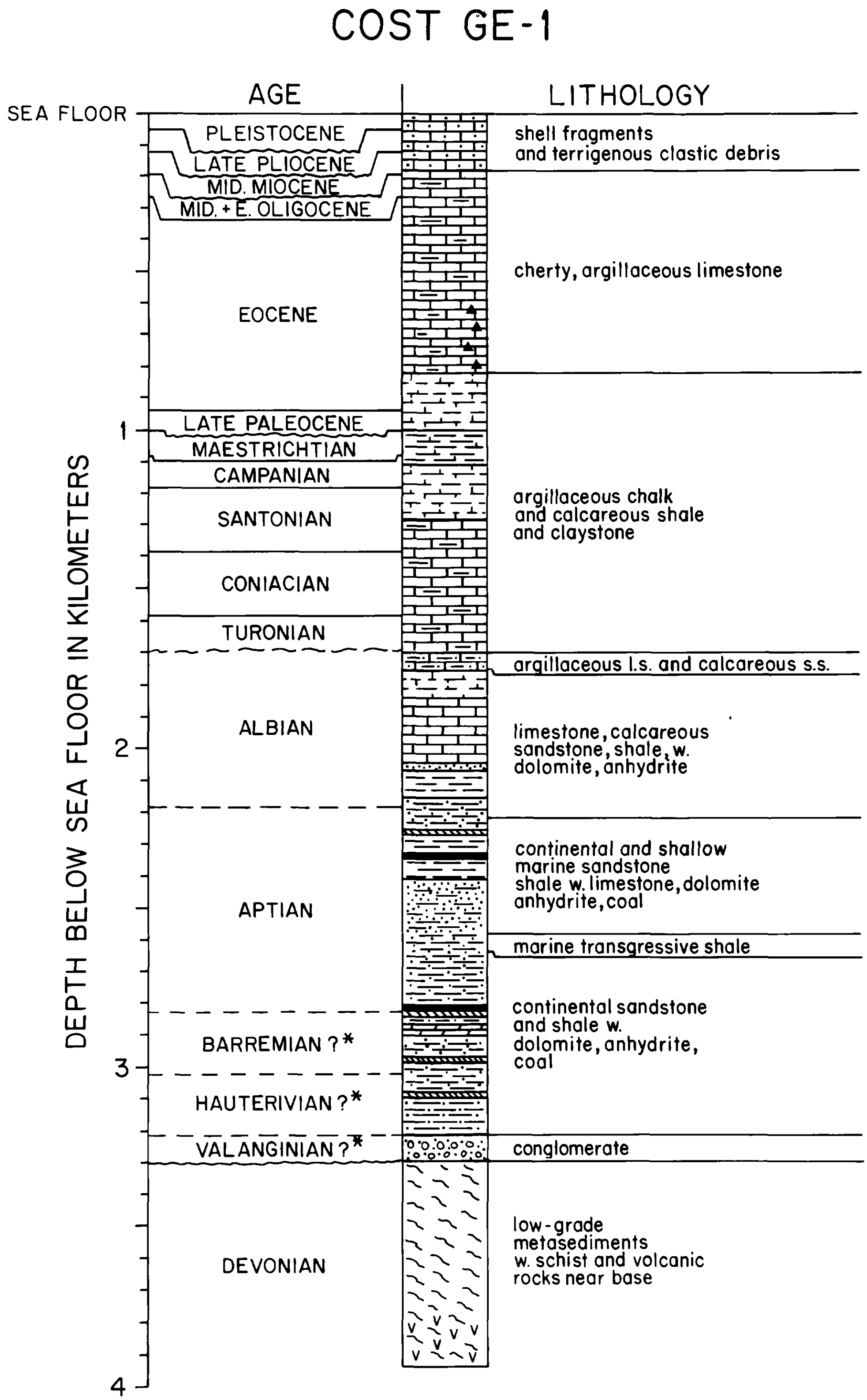


Figure 11 Lithologic log and biostratigraphic age estimates for rocks from COST No. GE-1 well. Ages marked with asterisks were not datable by the paleontological methods employed, and inferred ages are based on extrapolation of sedimentation rates.

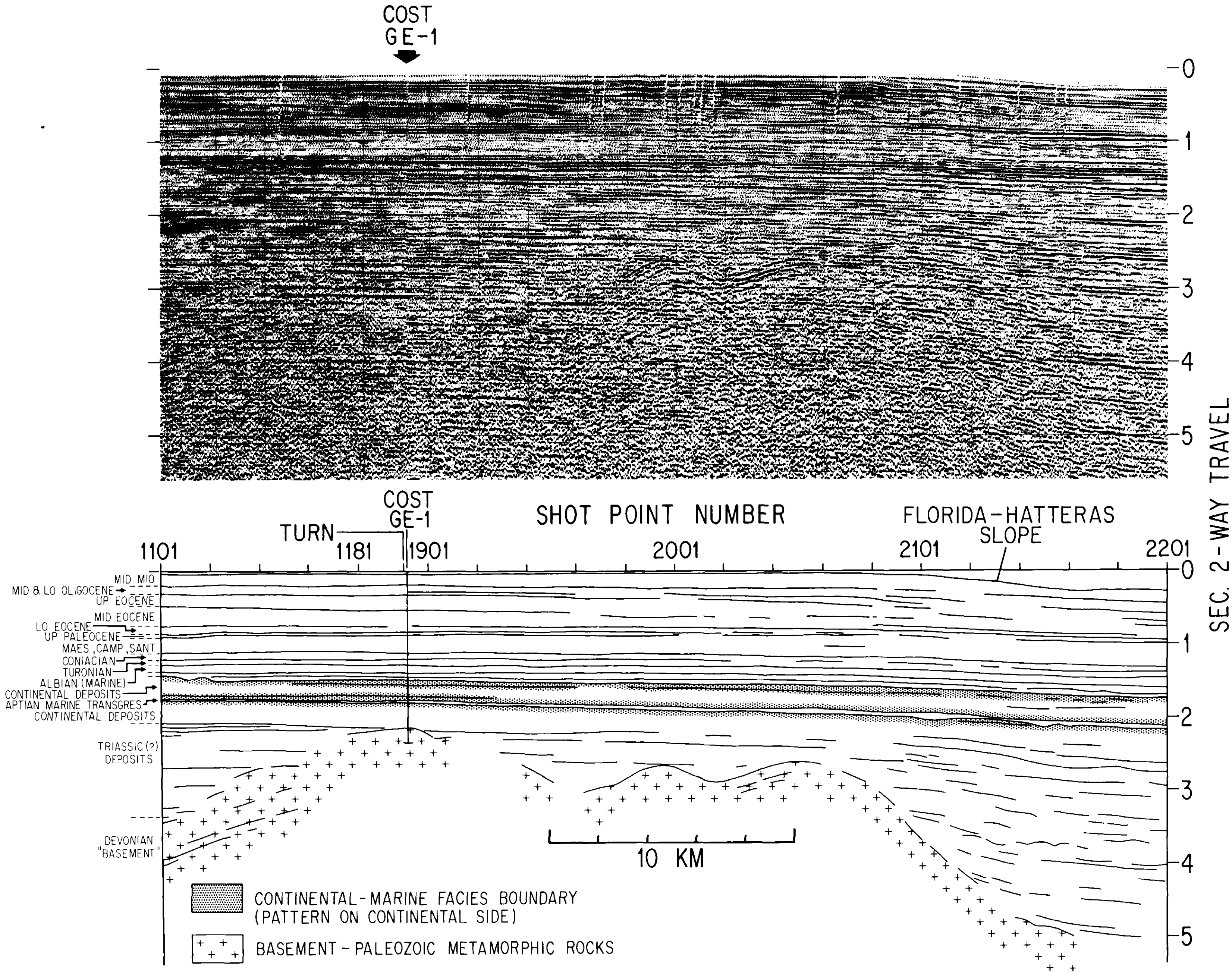


Figure 12.--Section of profile TD-5 through COST No. GE-1 drill site and interpretation showing correlations to biostratigraphy at the well. Location shown by brackets in figure 10.

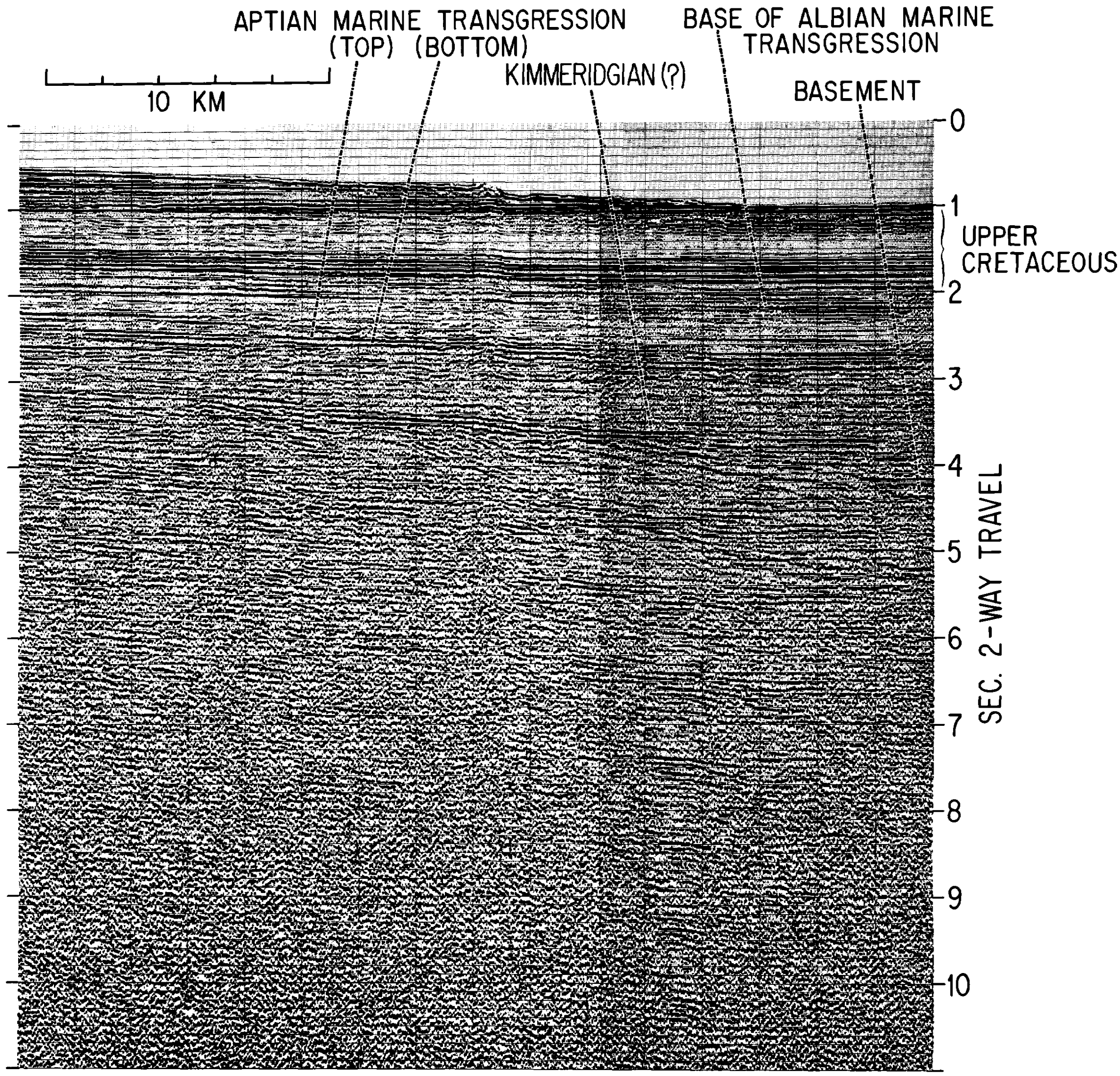


Figure 13 Part of profile TD-5 at lower Florida - Hatteras slope and inner Blake Plateau showing seismic stratigraphy inferred by comparison to strata sampled at the COST No. GE-1 well.

Location shown in figure 10.

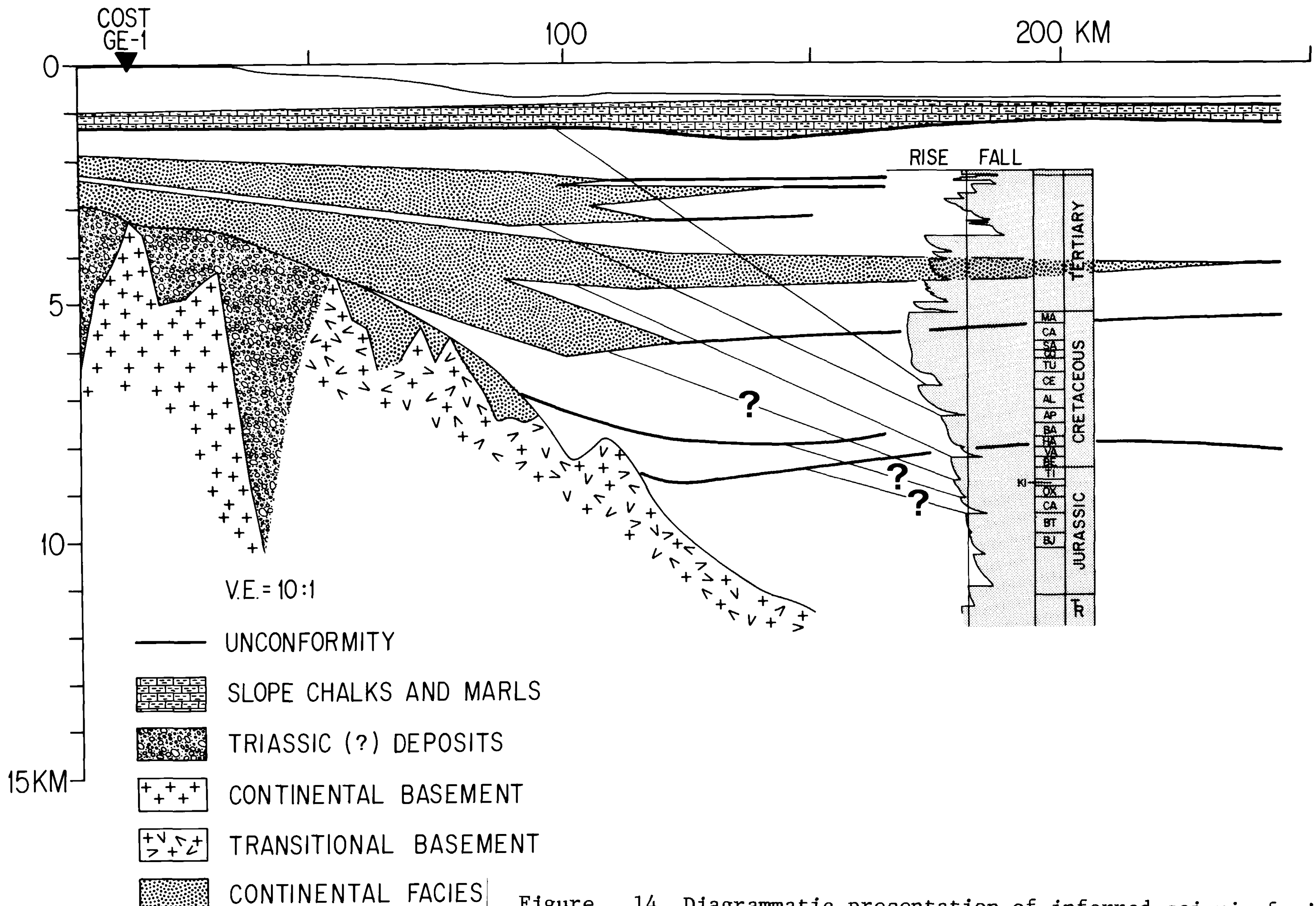


Figure 14 Diagrammatic presentation of inferred seismic facies distribution in the western part of profile TD-5.

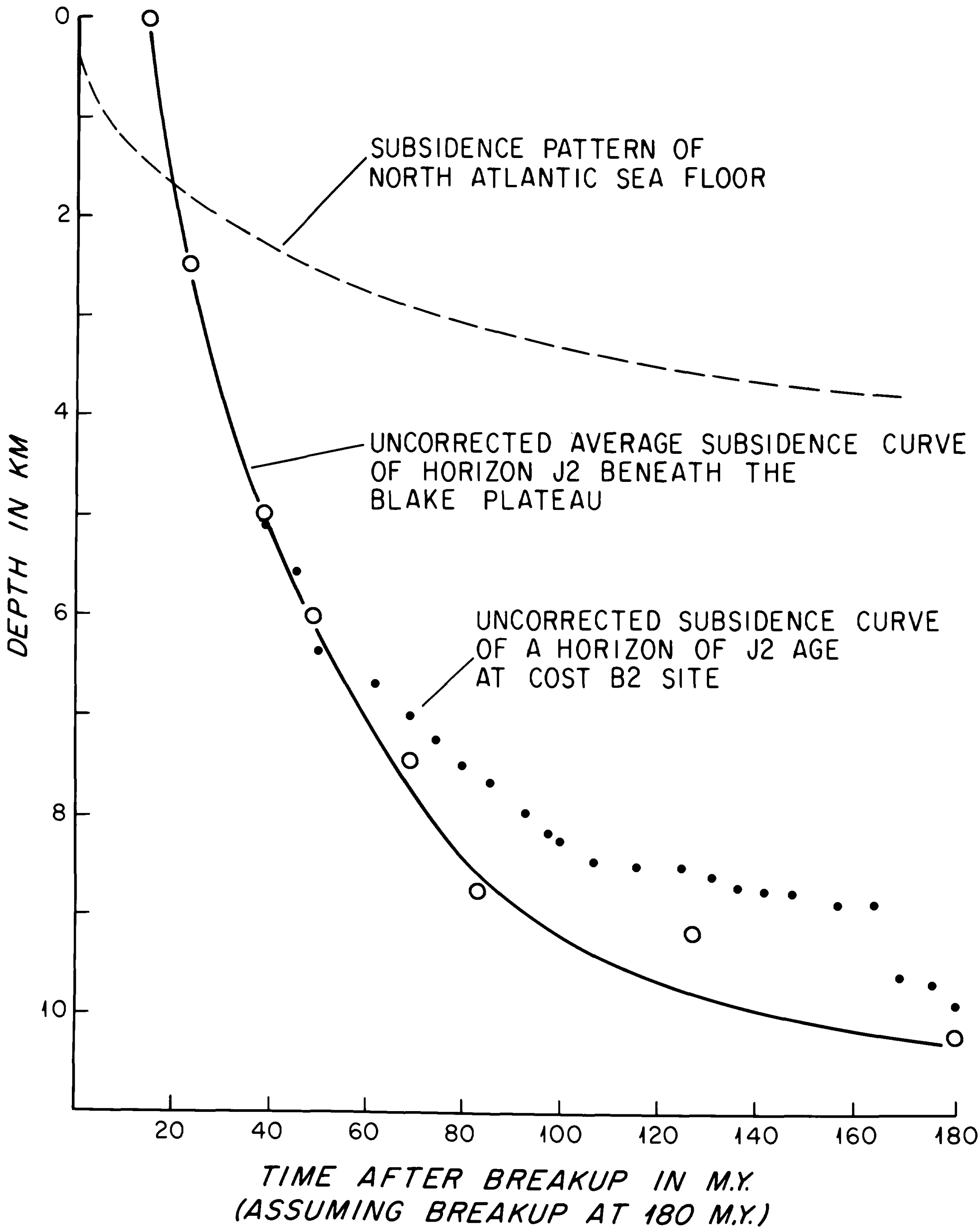


Figure 15.--Inferred subsidence curve for the Blake Plateau Basin compared to known curve for the COST No. B2 site in the Baltimore Canyon Trough (Steckler and Watts, 1978) and to the subsidence pattern of the North Atlantic oceanic crust (Parsons and Sclater, 1977).

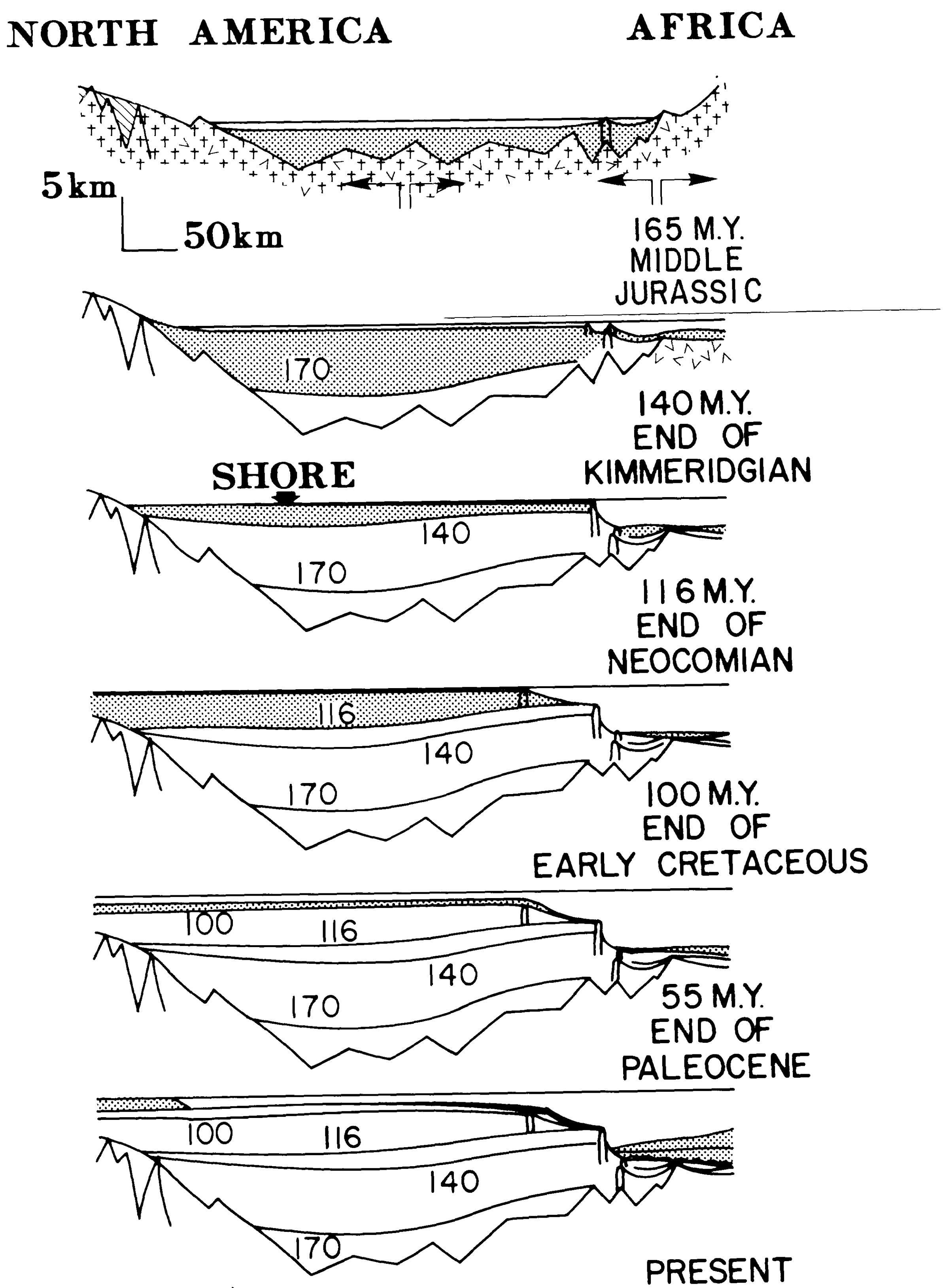


Figure 16.--Diagrams showing inferred stages in the history of the Blake Plateau Basin.

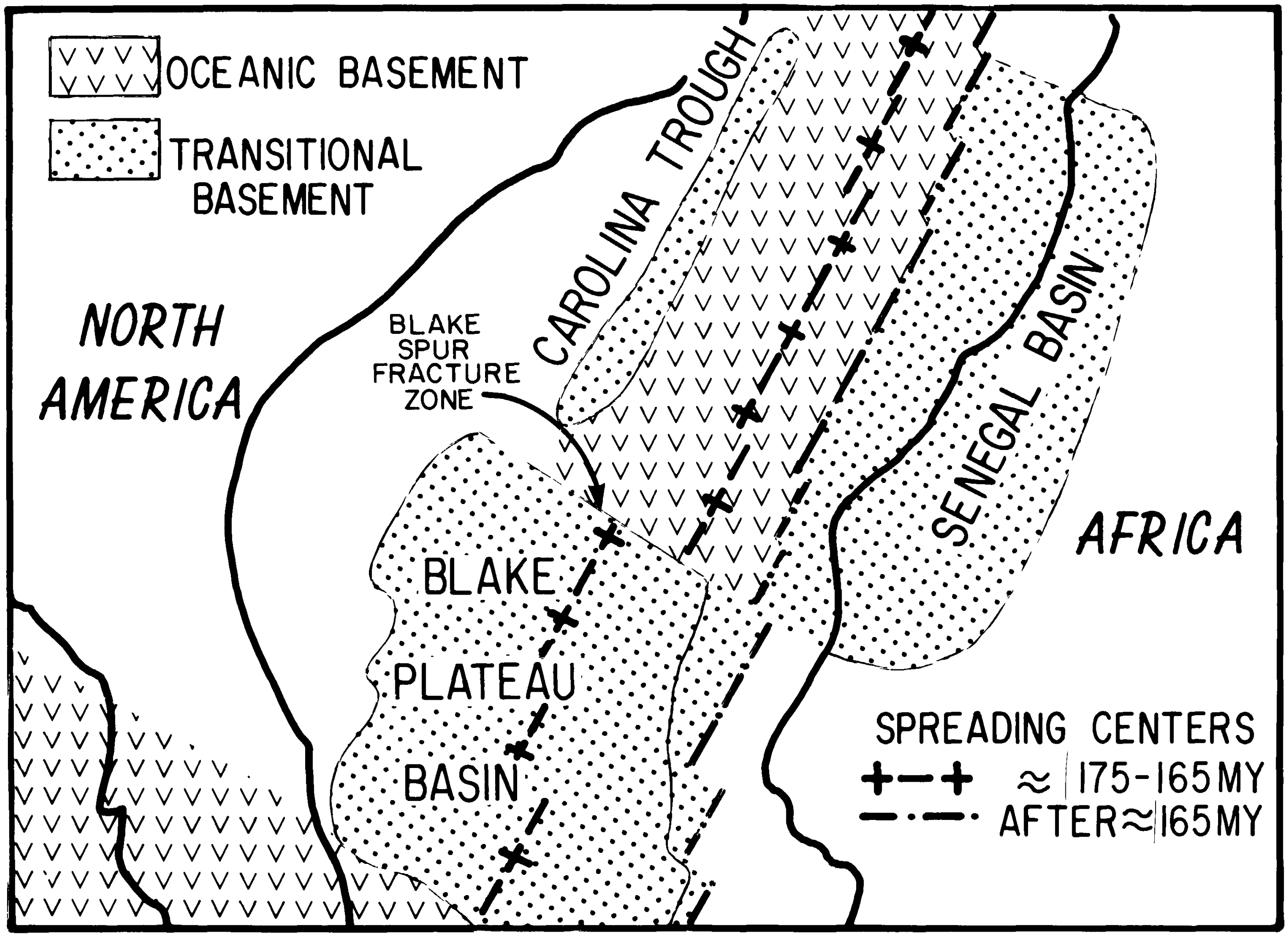


Figure 17 The North Atlantic Basin at the latitude of the proposed leasing area at the time of the spreading center jump (165 m.y.).

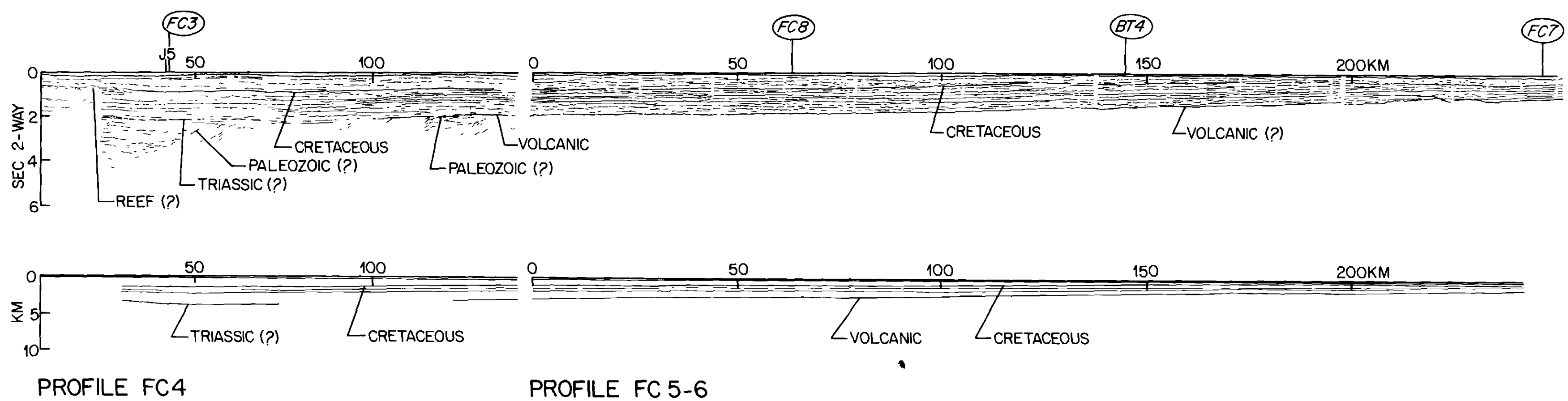


Figure 18.--Interpretation (above) and depth section (below) for profiles FC4, FC5, and FC6, extending from the Southeast Georgia Embayment to the Carolina Platform. Locations are shown in figure 6.

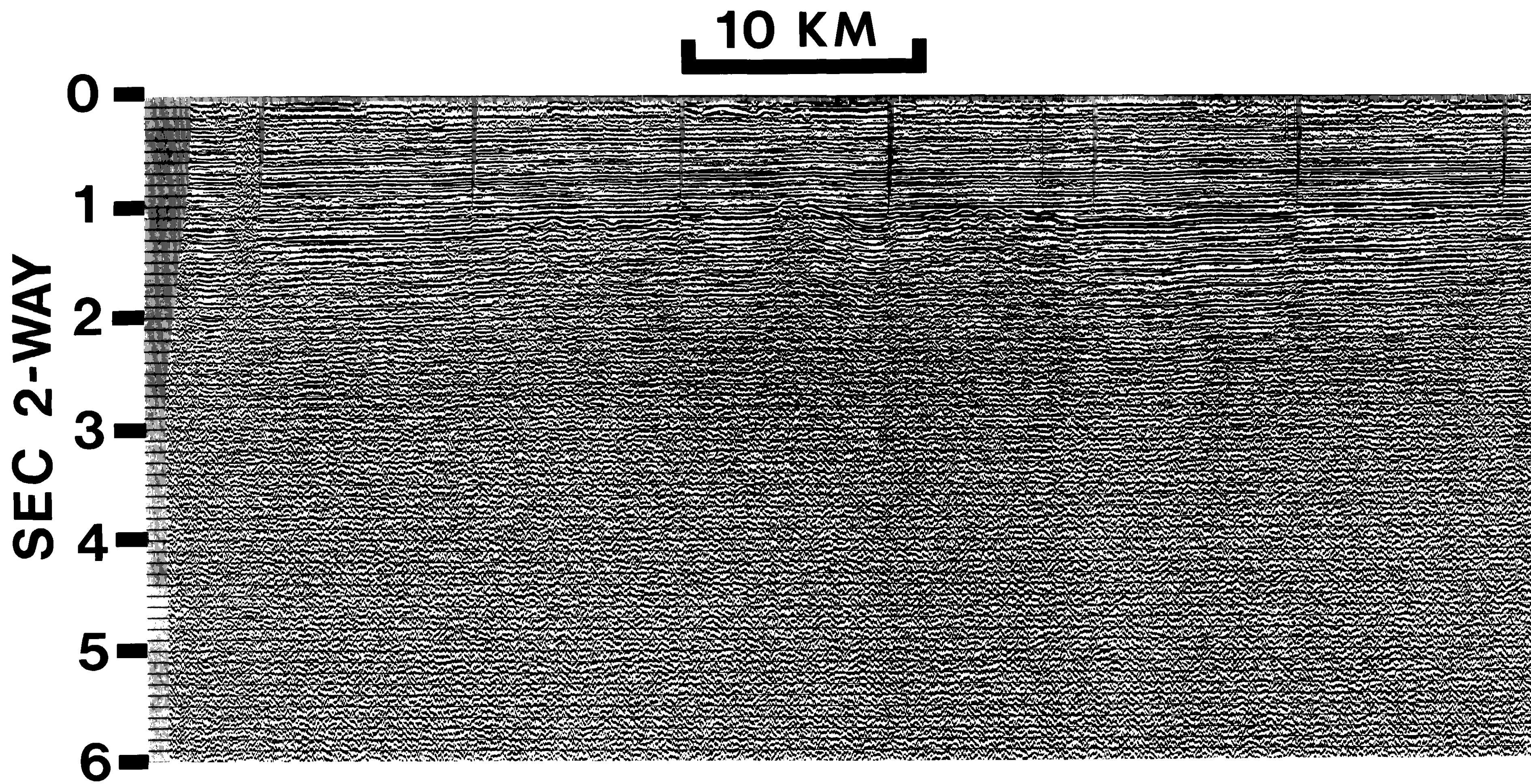


Figure 19 Part of seismic record of profile FC6, representing approximately kilometers 200 to 240 (fig. 18). Draping of strata over a basement peak is observed.

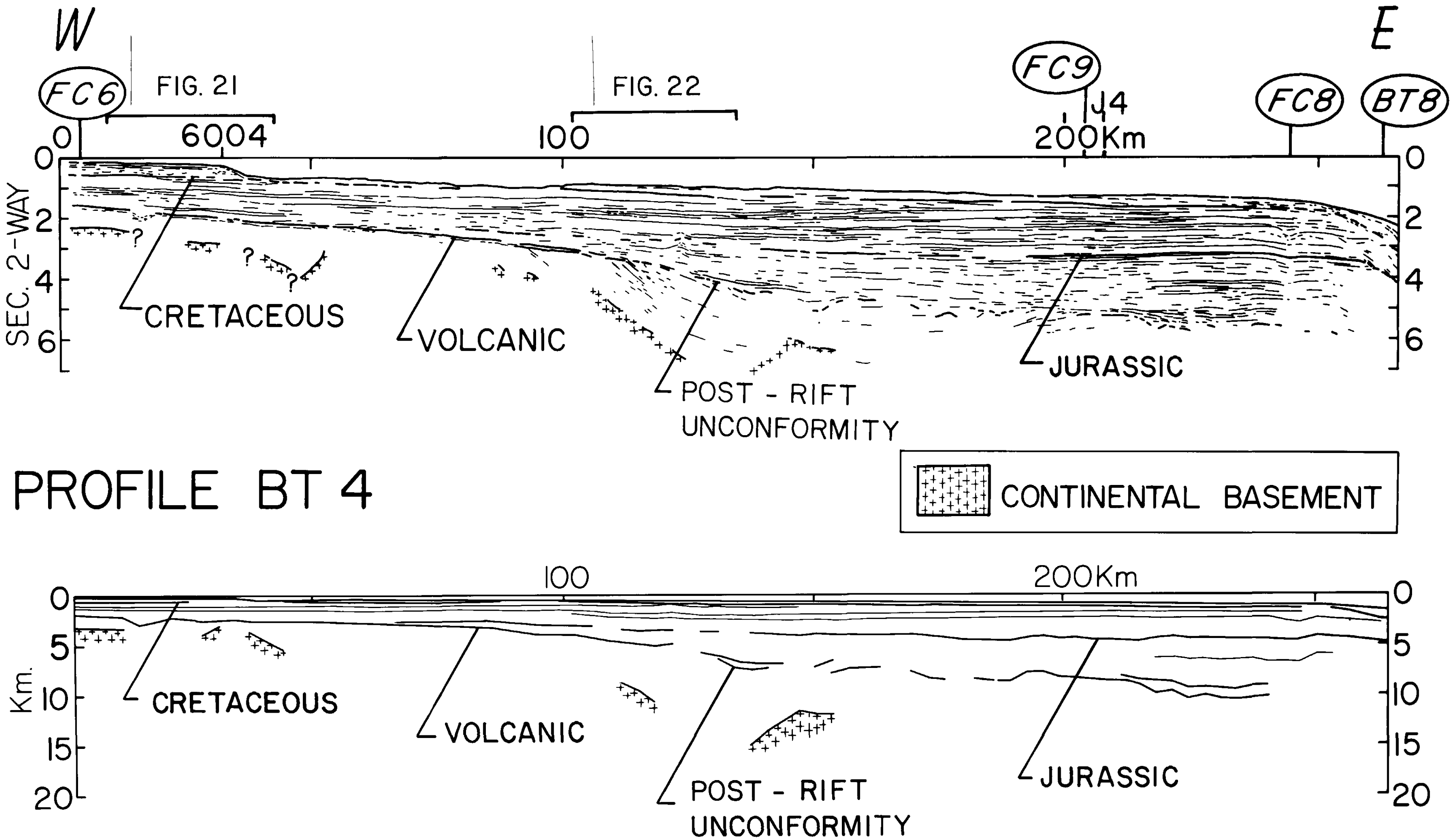


Figure 20.--Interpretation (above) and dpeth section (below) for seismic profile BT4 off Charleston. Location is shown in figure 6.

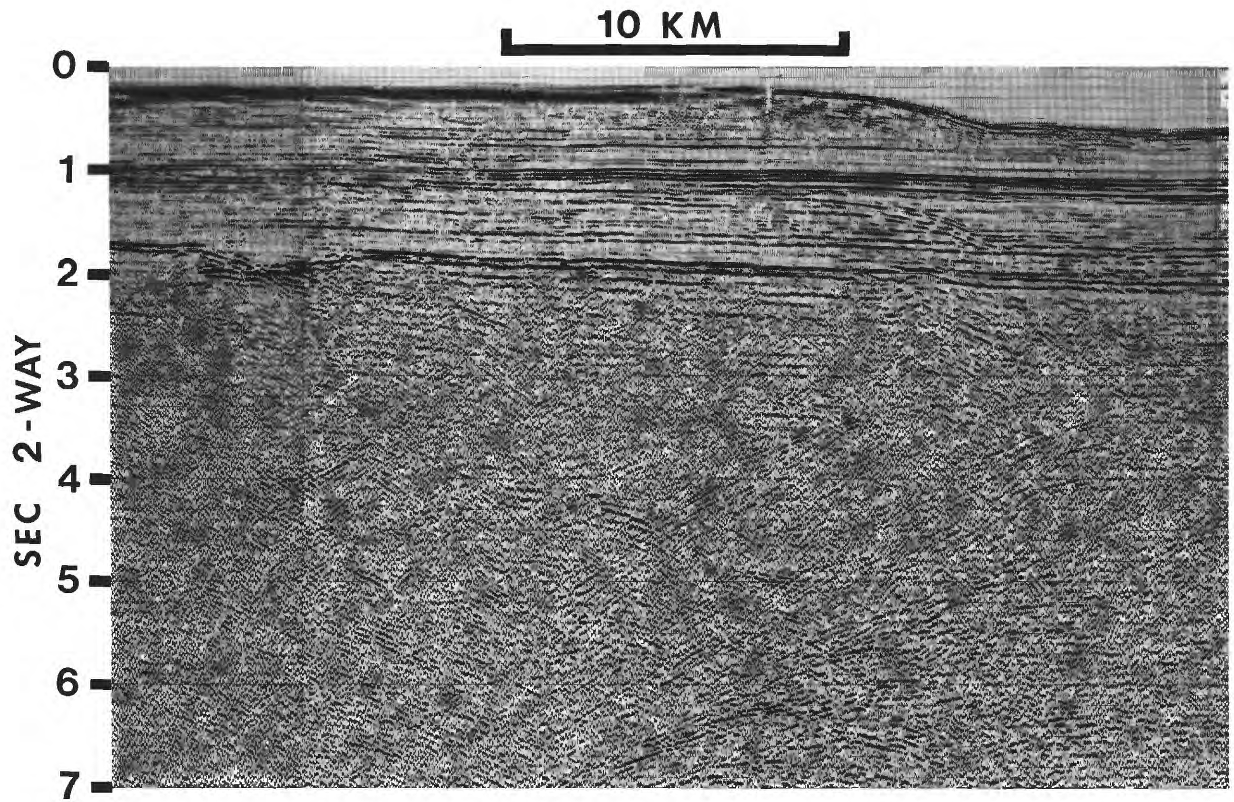


Figure 21.--Part of seismic record of profile BT4, showing Continental Shelf and strong reflection at about 1.7 to 2 seconds that is inferred to arise from a basalt layer. Location indicated on figure 20.

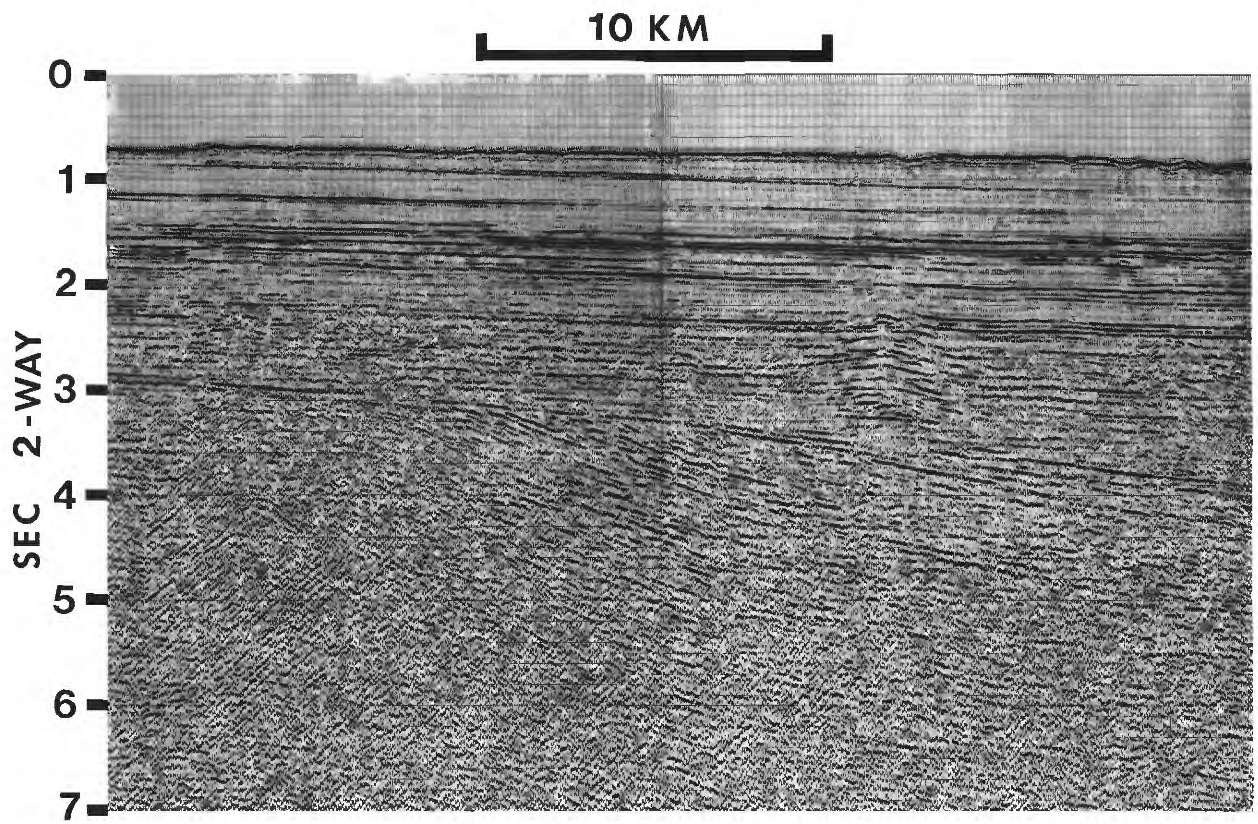


Figure 22.--Part of seismic record of profile BT4 on Blake Plateau. Post-rift unconformity over inferred Triassic strata is represented by an angular unconformity dipping seaward (right) from 2.9 to 4 seconds. Location indicated in figure 20.

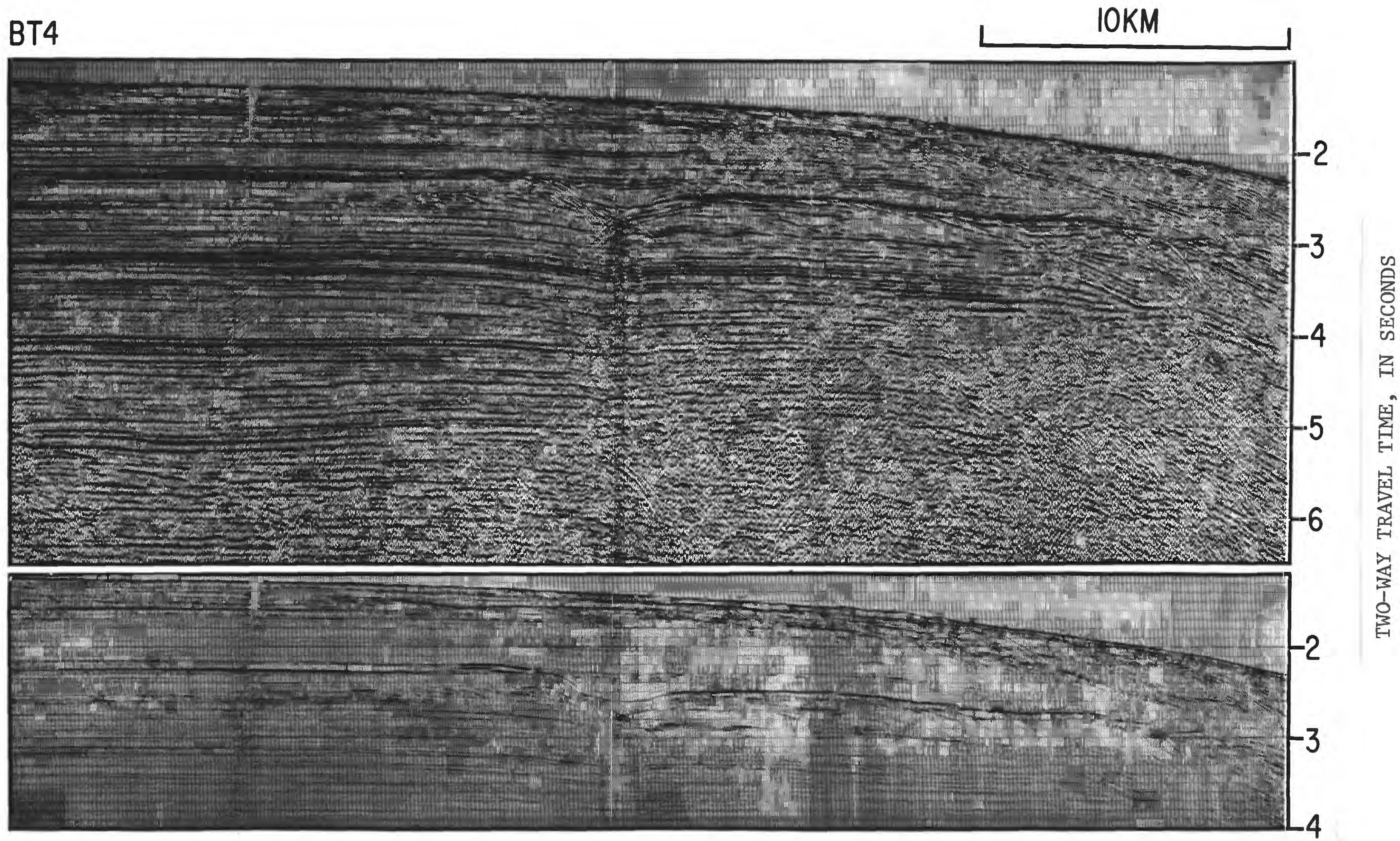


Figure 23.--Part of seismic record of profile BT4 at seaward (east) end of line. Upper section shows automatic-gain-control presentation, lower is true-amplitude record. Possible shelf-edge carbonate-bank structures are present.

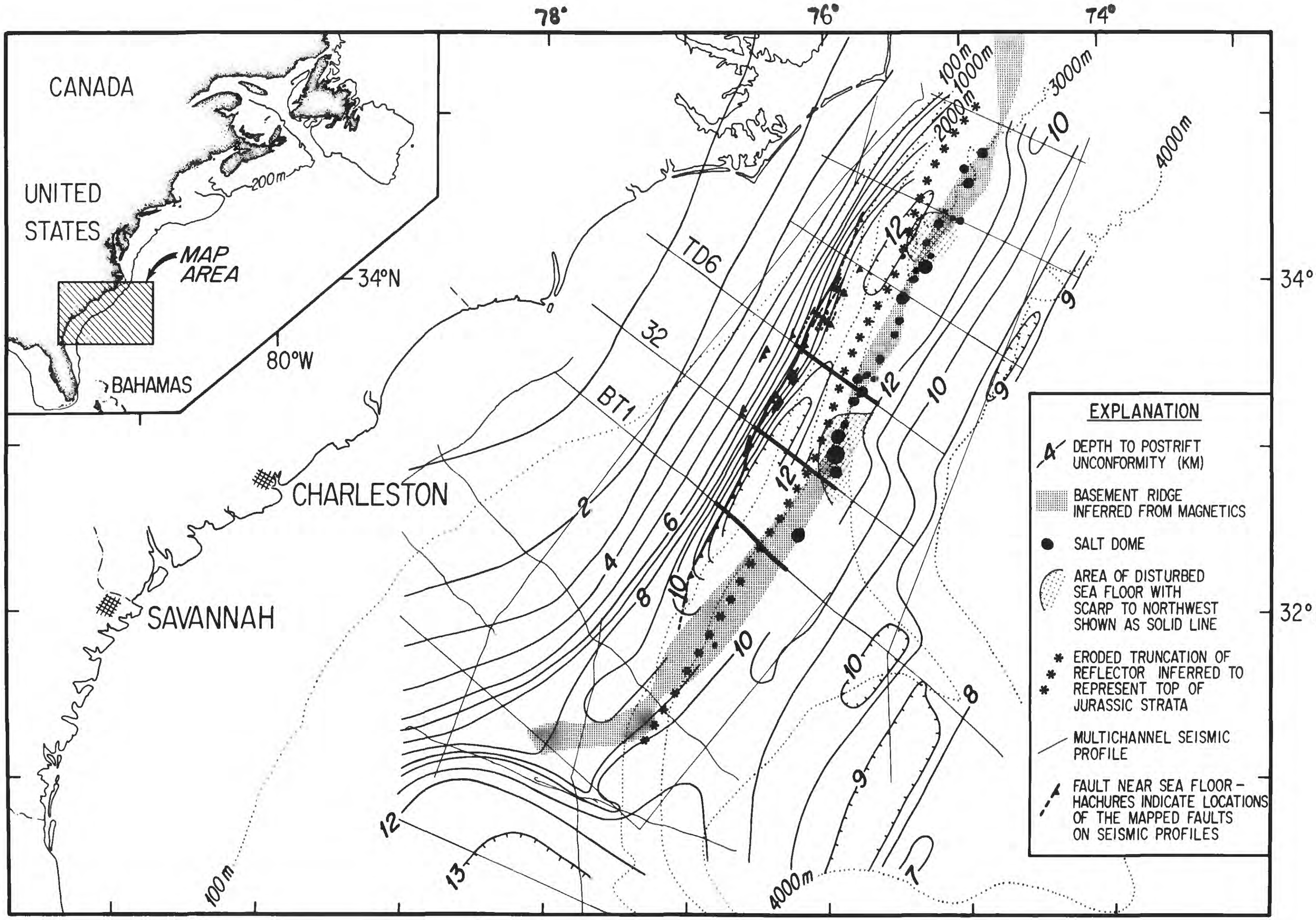


Figure 24.--Structural features of the Carolina Trough.

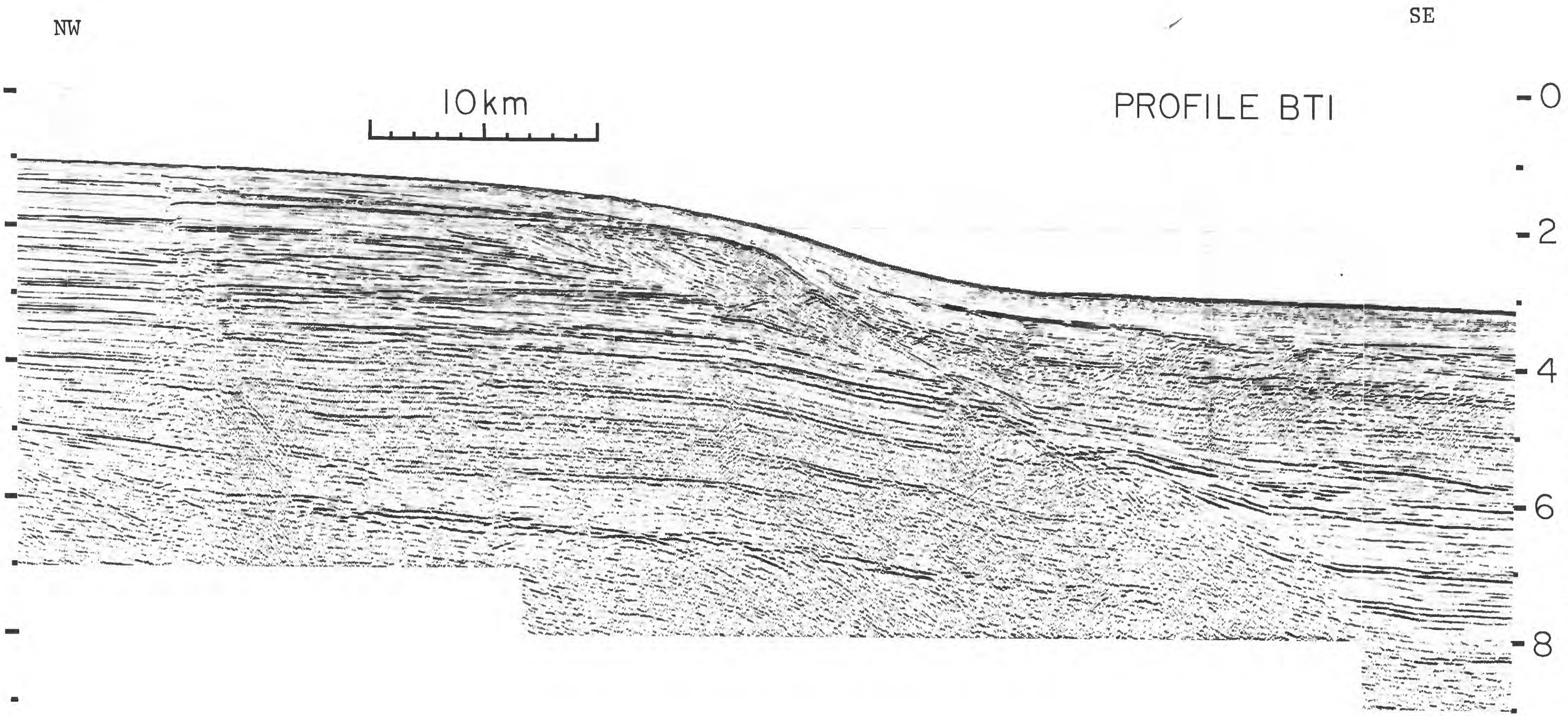


Figure 25.--Seismic profile BT1 across the Carolina Trough. The part of the profile shown is indicated by a heavy line on the profile track in figure 24.

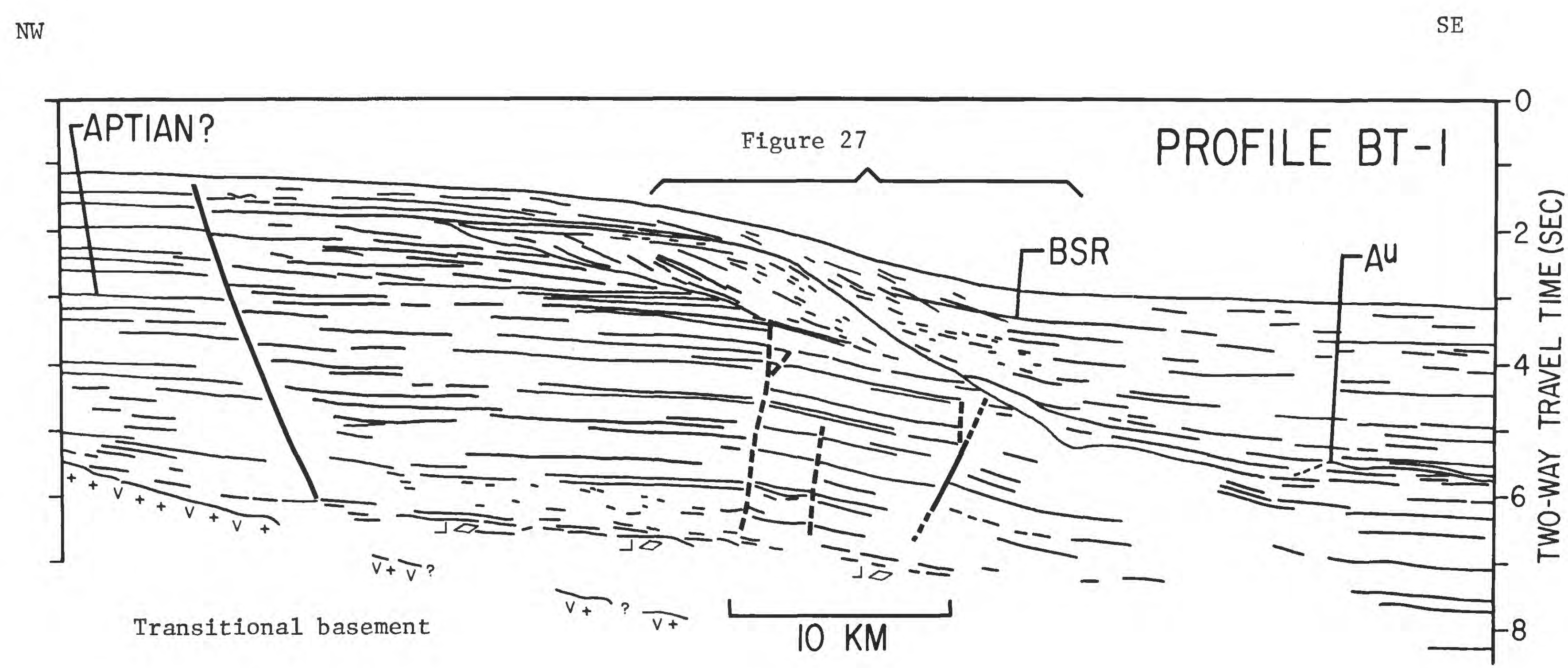


Figure 26.--Interpretation of seismic profile BT1 shown in figure 25.

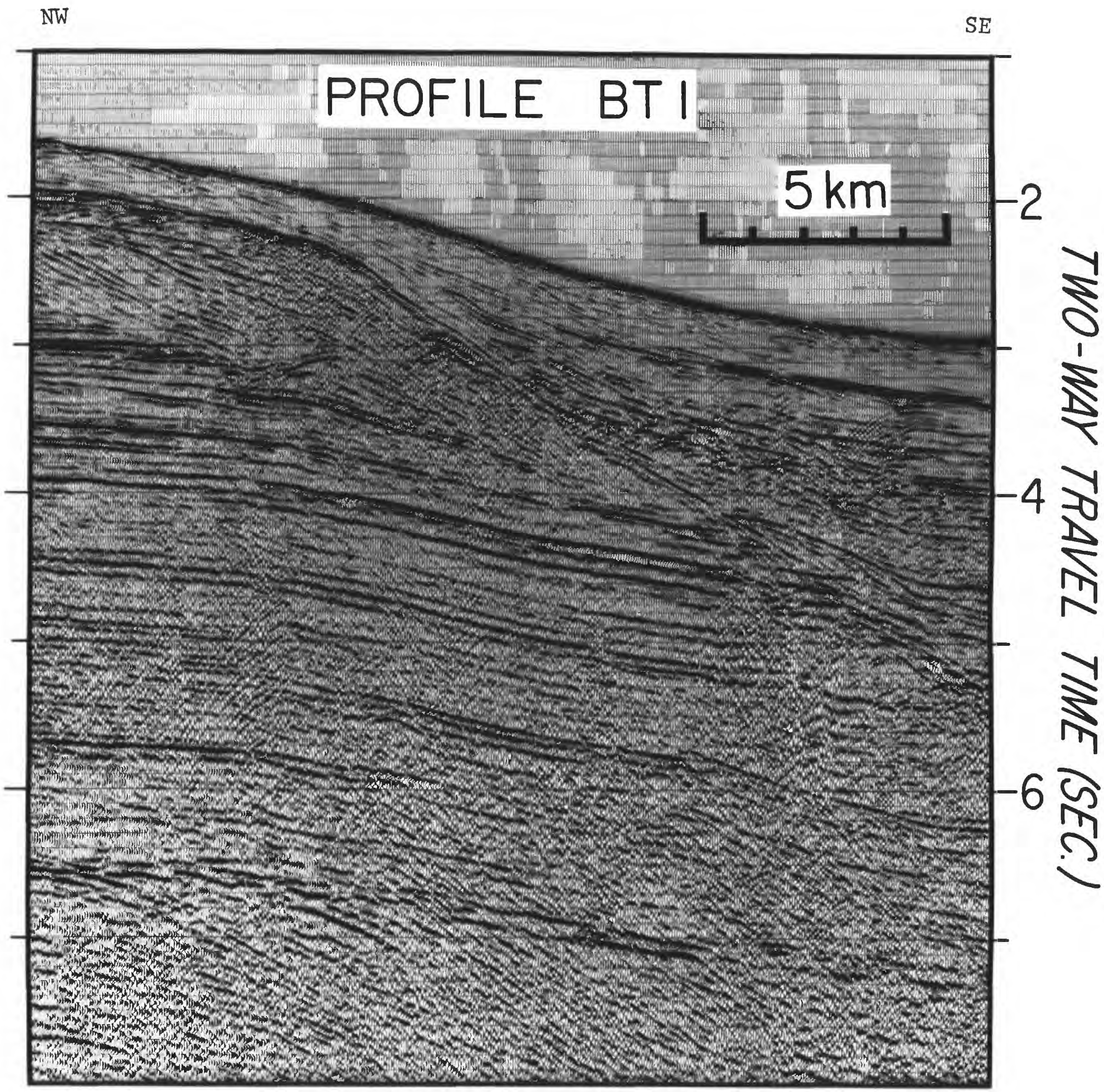


Figure 27.--Part of seismic record of profile BT1 showing eroded and reburied paleoslope. Location shown by bracket over interpretation in figure 26.

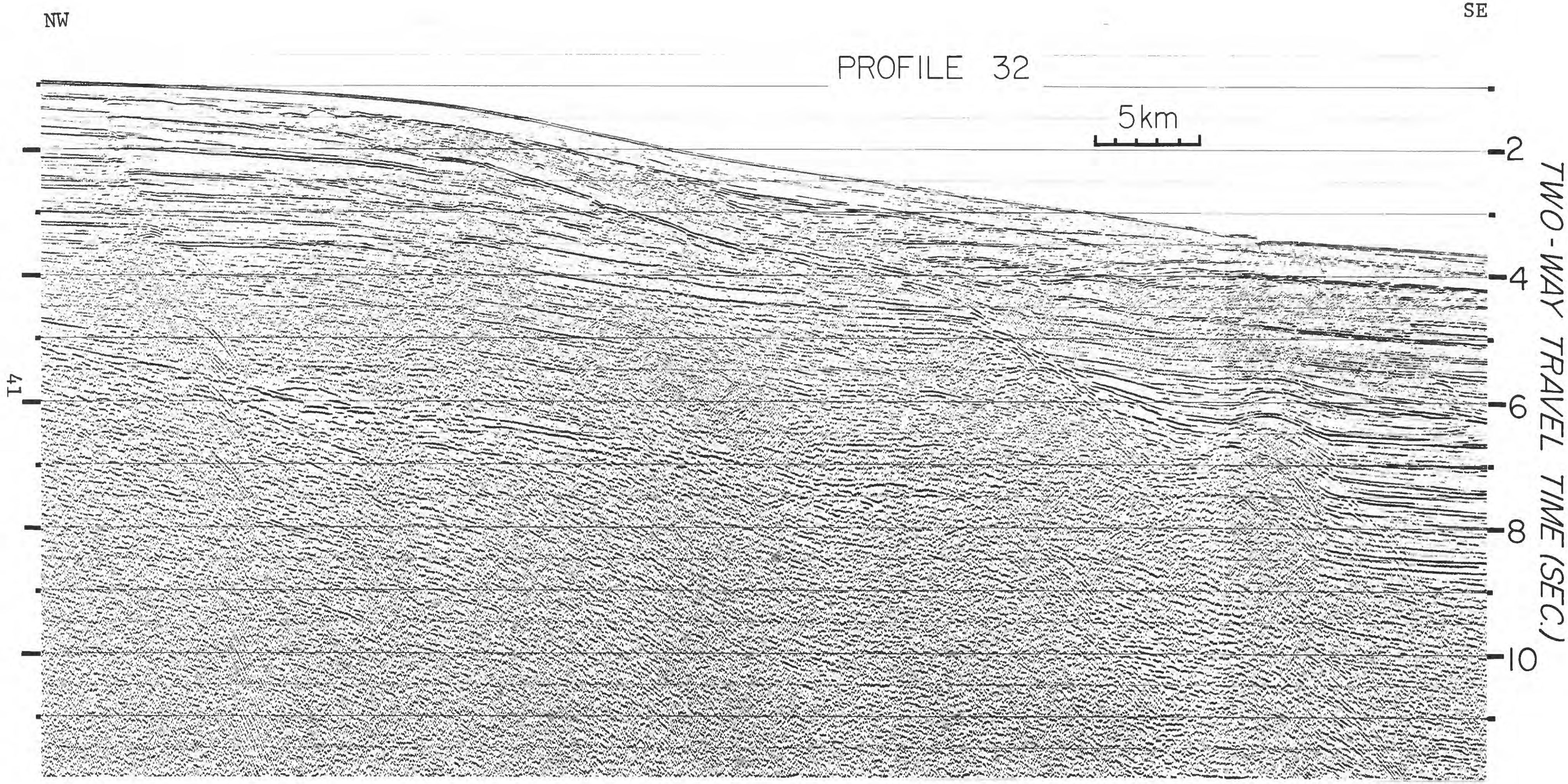


Figure 28.--Seismic profile 32 across the Carolina Trough. The part of the profile shown is indicated by a heavy line on the profile track in figure 24.

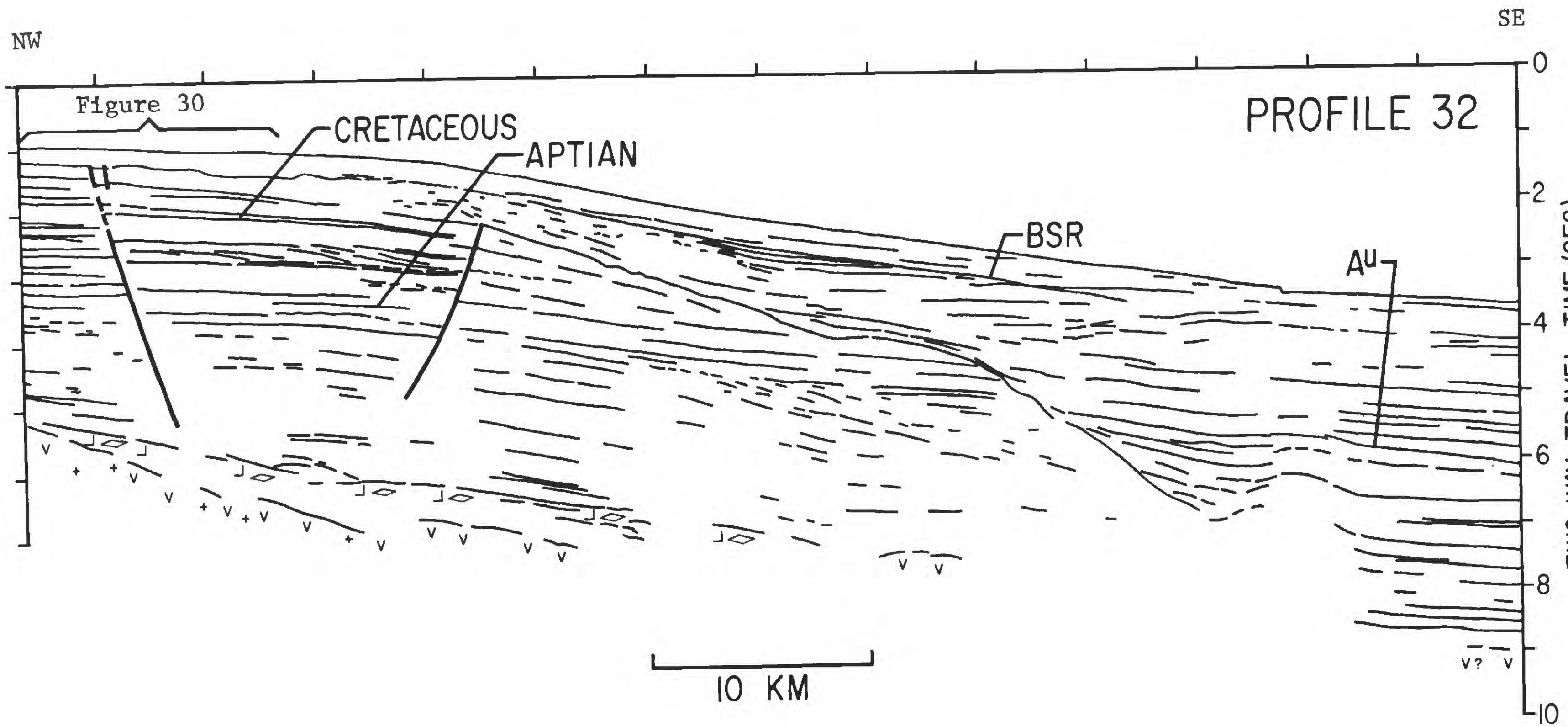


Figure 29.--Interpretation of seismic profile 32, shown in figure 28. BSR, bottom-simulating reflector, A^u, a widespread reflector.

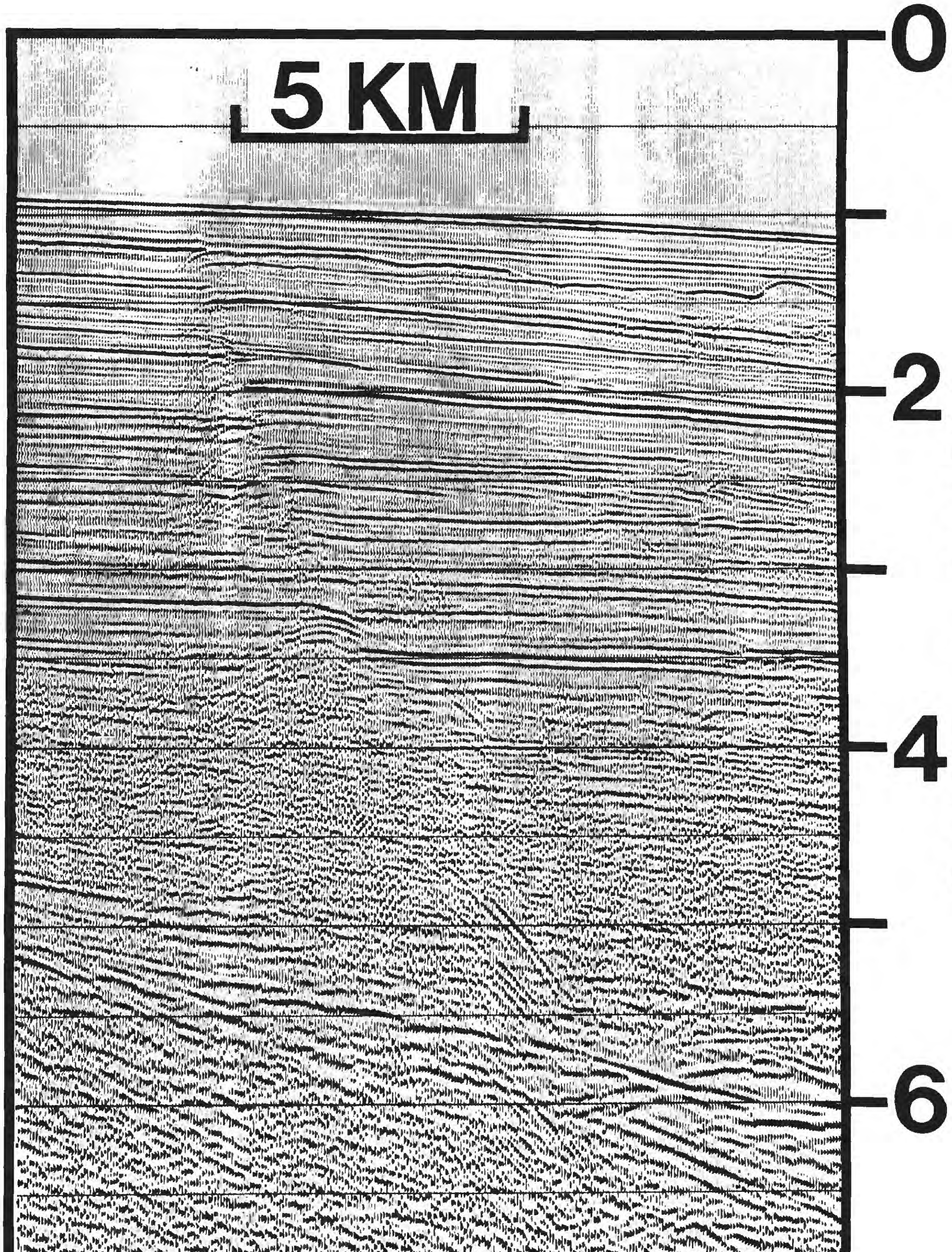


Figure 30.--Detail of seismic profile 32, showing growth fault. Location shown by bracket in figure 29.

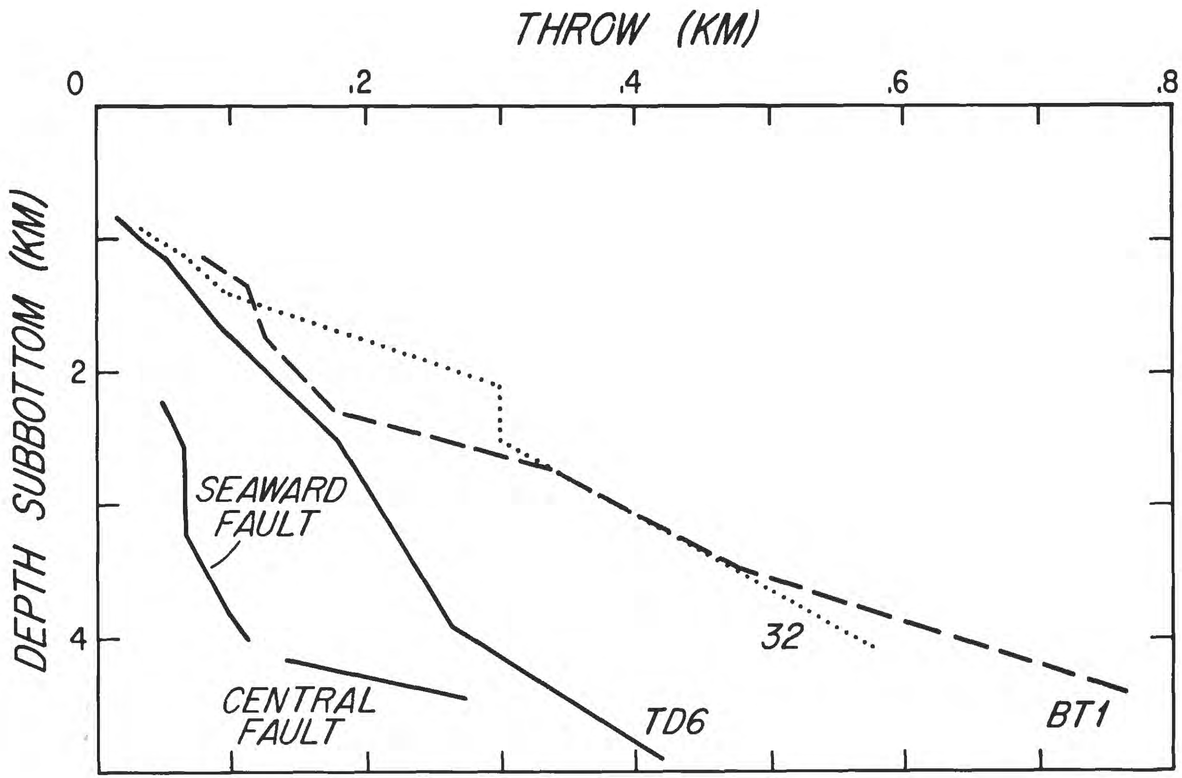


Figure 31.--Plot of throw of main growth fault versus depth to upthrown side for three profiles. Data from two associated faults on profile TD6 were also included.

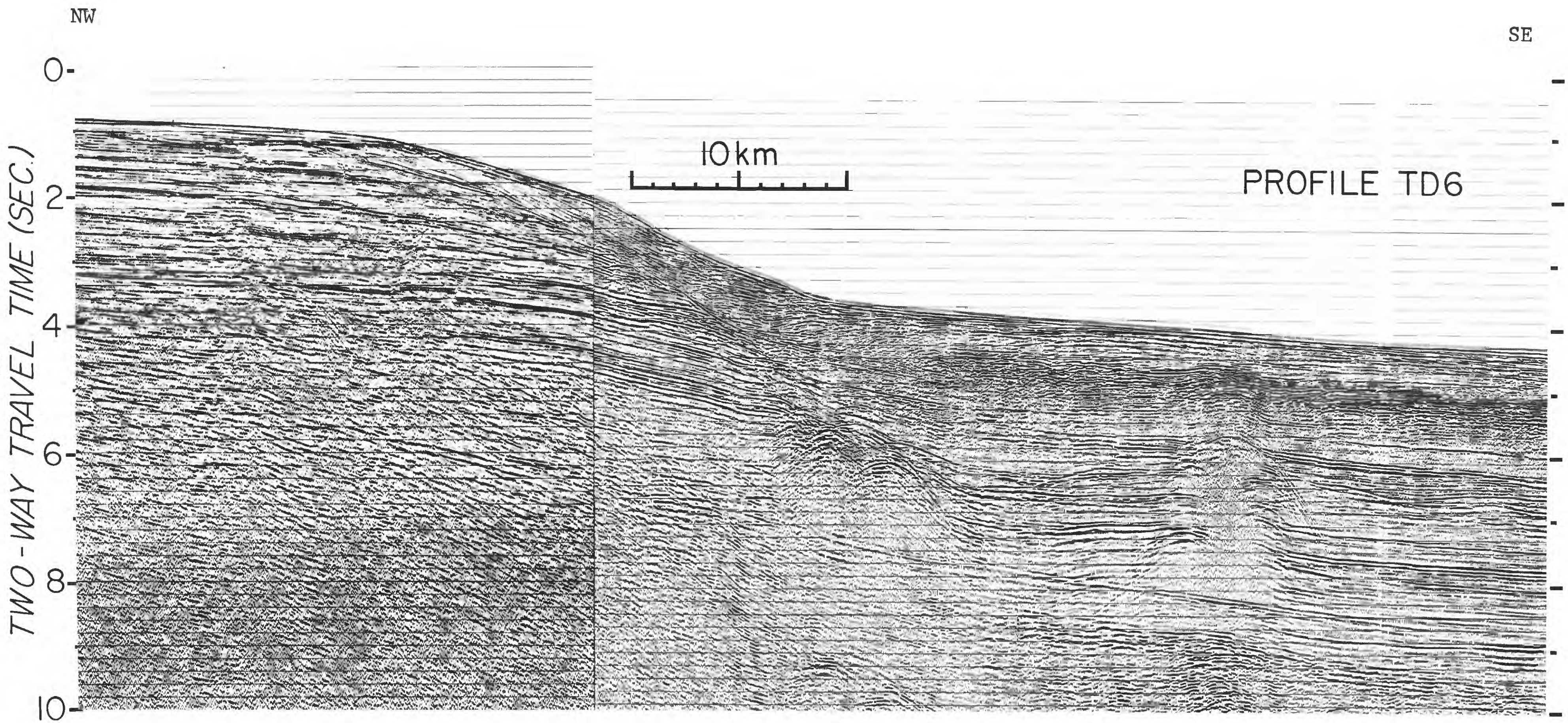


Figure 32.--Seismic profile TD6 across the Carolina Trough. The part of the profile shown is indicated by a heavy line on the profile track in figure 24.

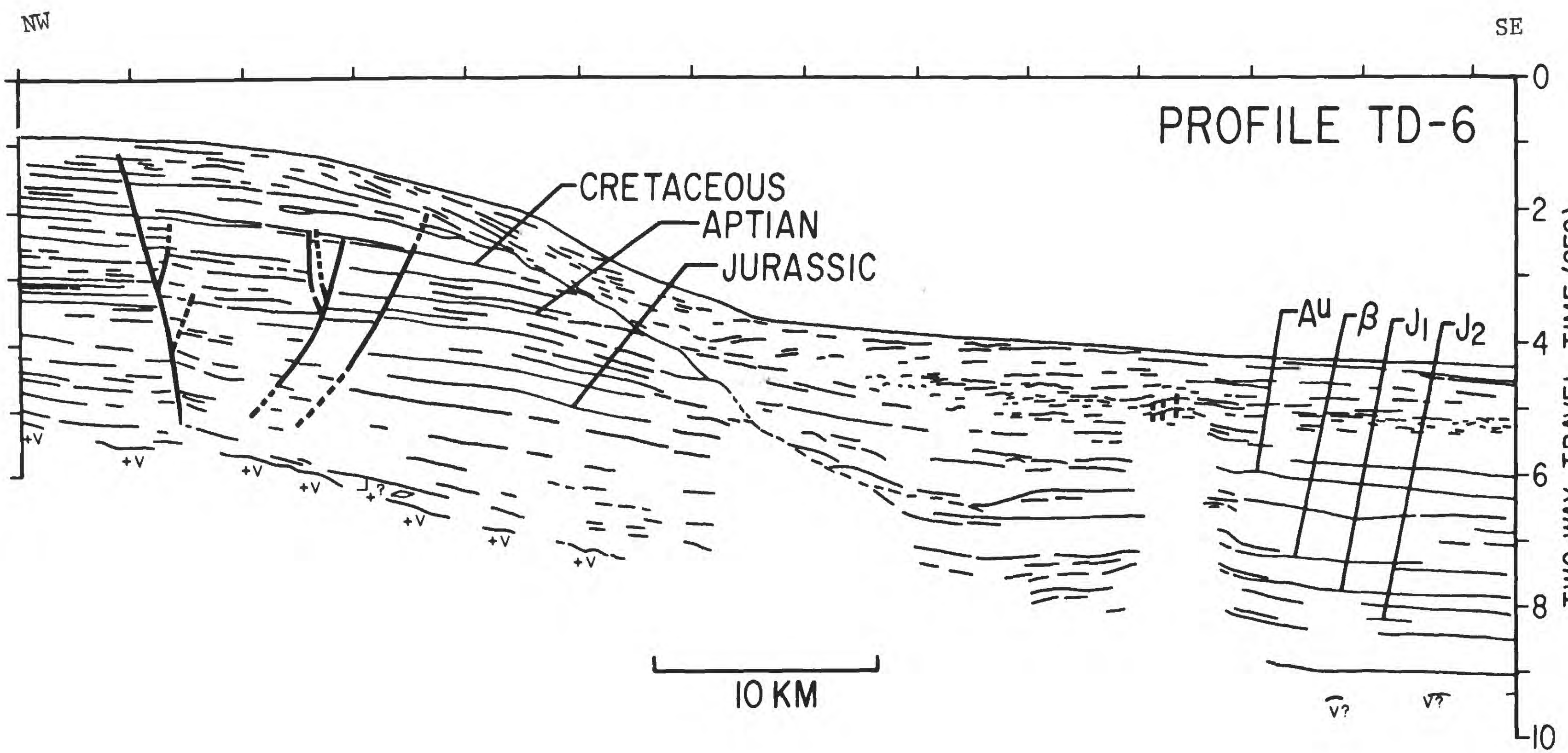


Figure 33. --Interpretation of seismic profile TD6 shown in figure 32.

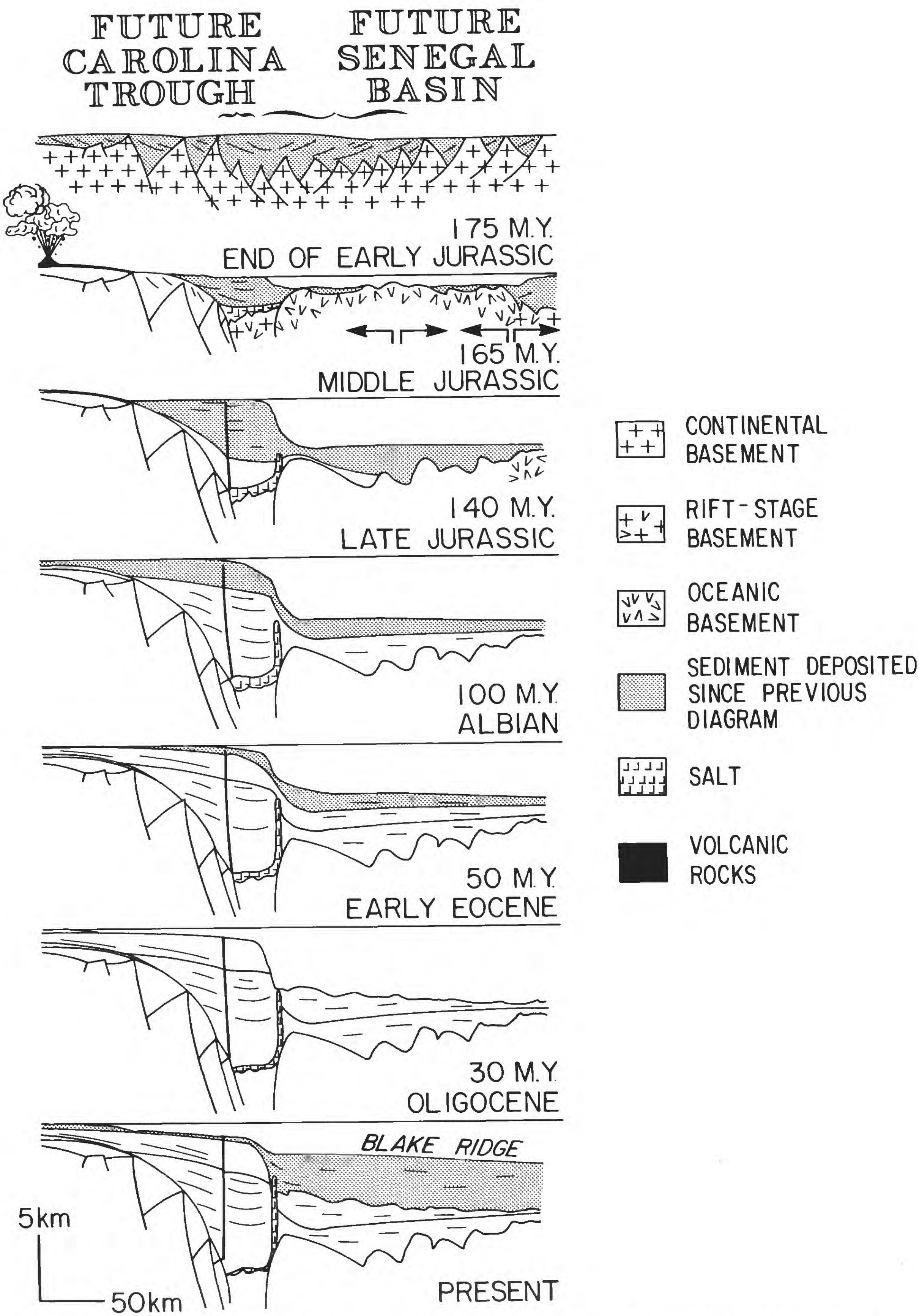


Figure 34.--Diagrams showing inferred stages in the geologic history of the Carolina Trough. Symbols are applied only to rocks formed after the previous stage except for salt, because the salt migrated throughout margin history.

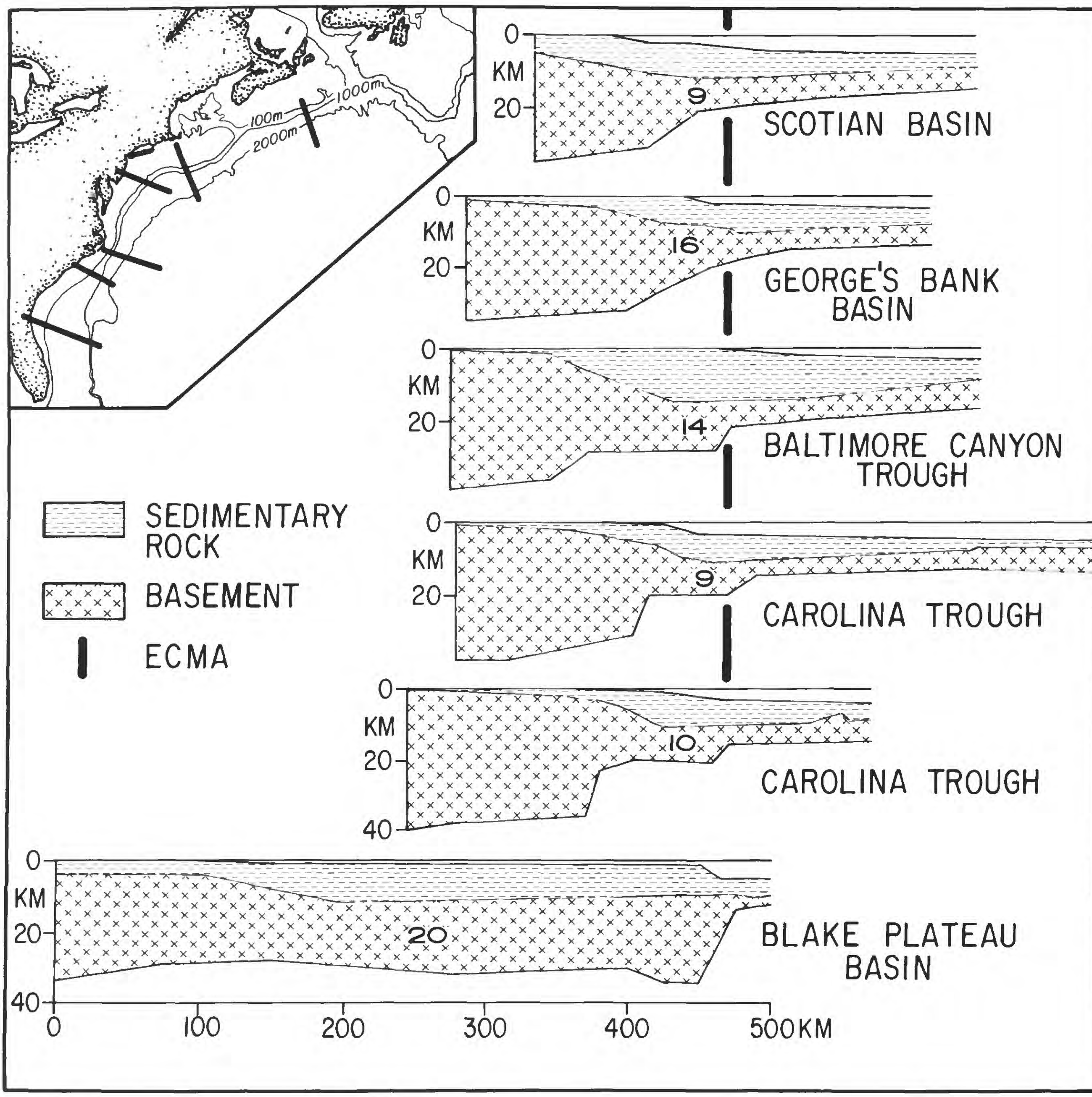


Figure :-35.--Crustal sections across basins of eastern North America based on gravity and refraction (Keen and others, 1975; Grow and others, 1979; Kent and others, 1979; Grow, 1980; Hutchinson and others, in press). The numbers represent basement thickness near the centers of the basins, at the locations where the numbers are written. Profiles are aligned by the East Coast Magnetic Anomaly (ECMA), except for the Blake Plateau Basin profile, where no ECMA exists.

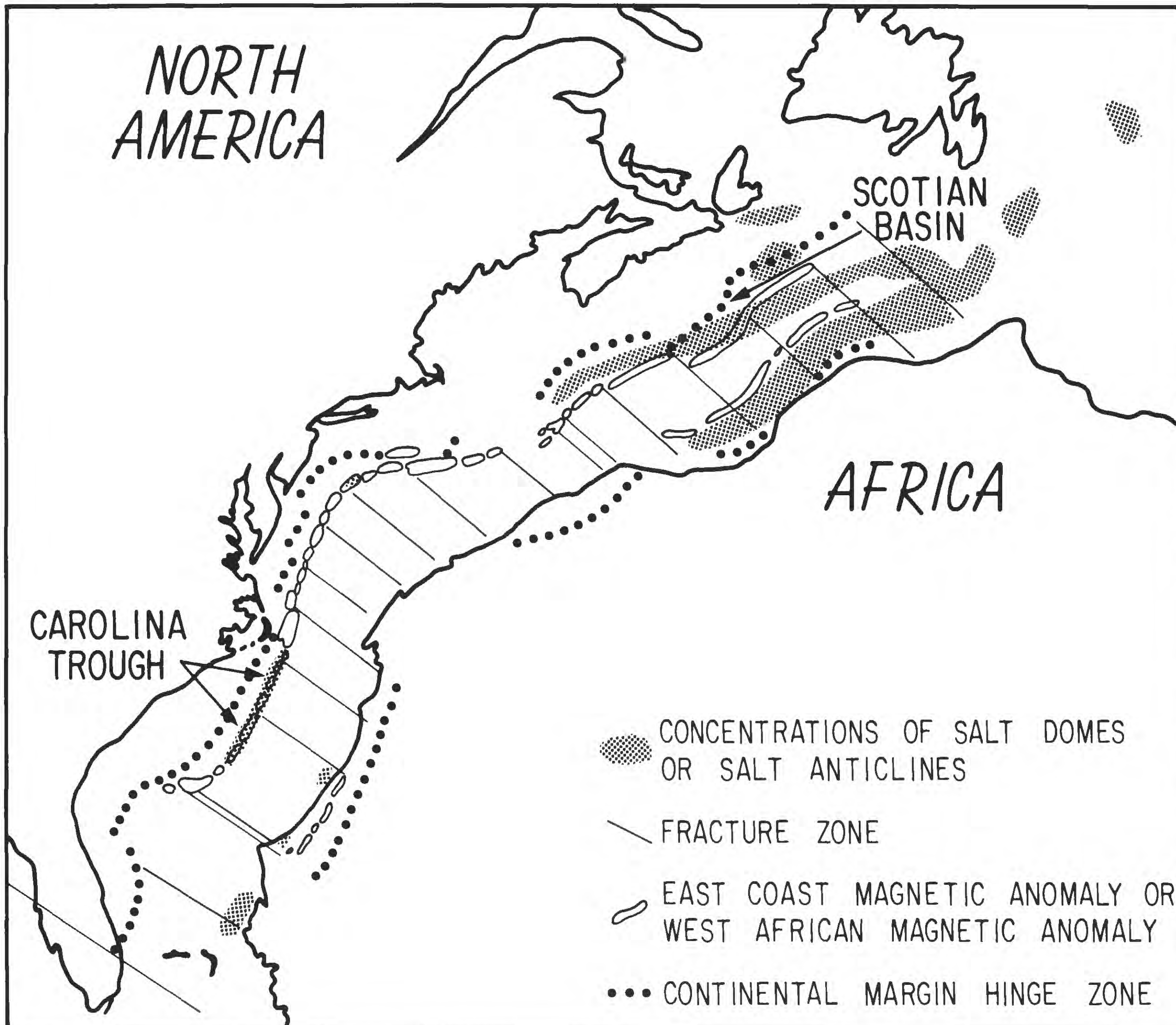
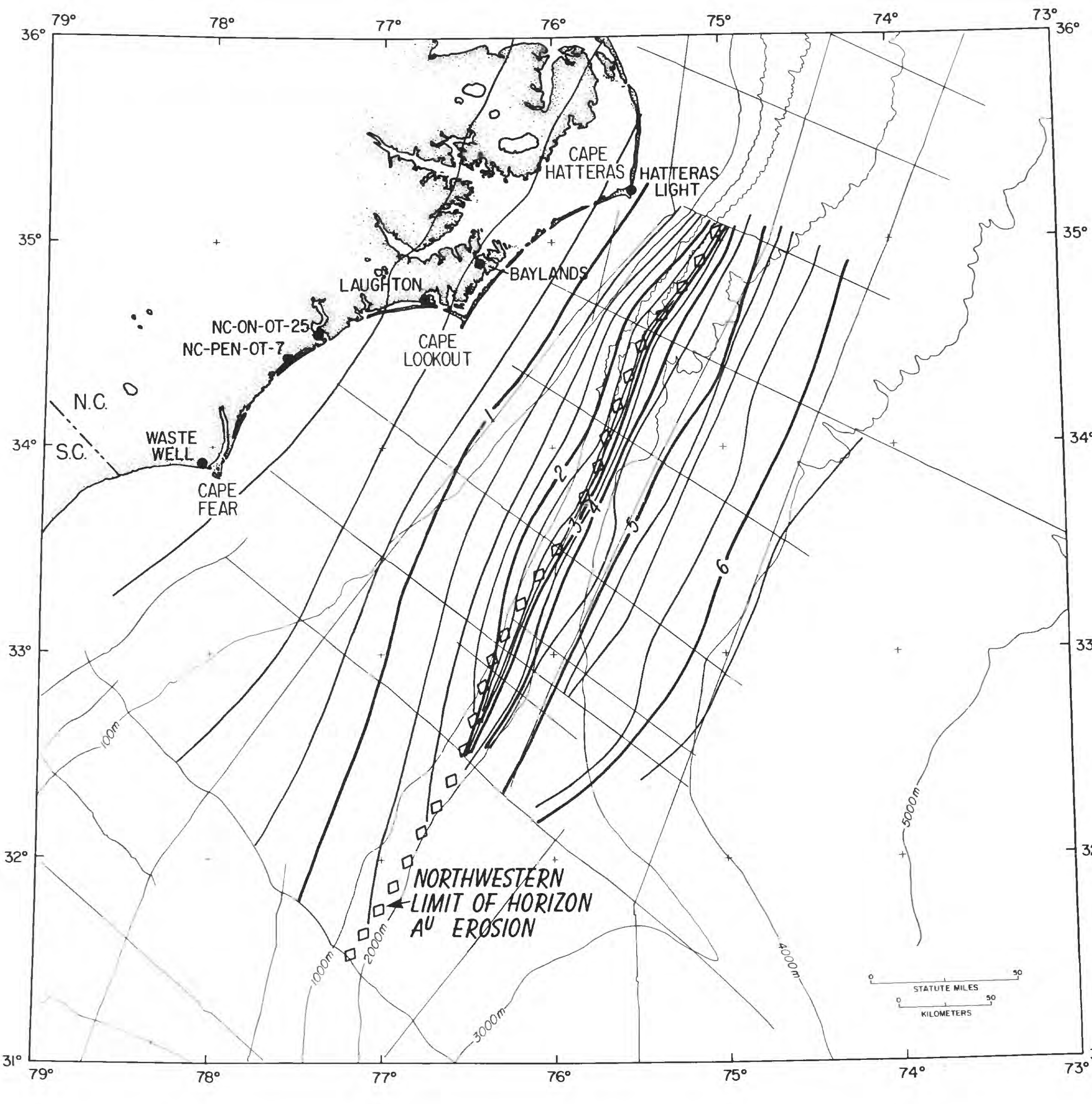


Figure 36.--Locations of salt diapirs plotted on a reconstruction of the North Atlantic basin at the time of spreading-center jump - approximately 165 million years ago (adapted from K. Klitgord, written communication, 1981).



Universal Transverse Mercator Projection, Central Meridian 75°W

Figure 37.--Depth (in kilometers) to reflector inferred to represent top of Cretaceous rocks. Locations of selected wells are shown by filled circles. Bathymetry in meters. Tracklines along which multichannel seismic data were collected are shown.

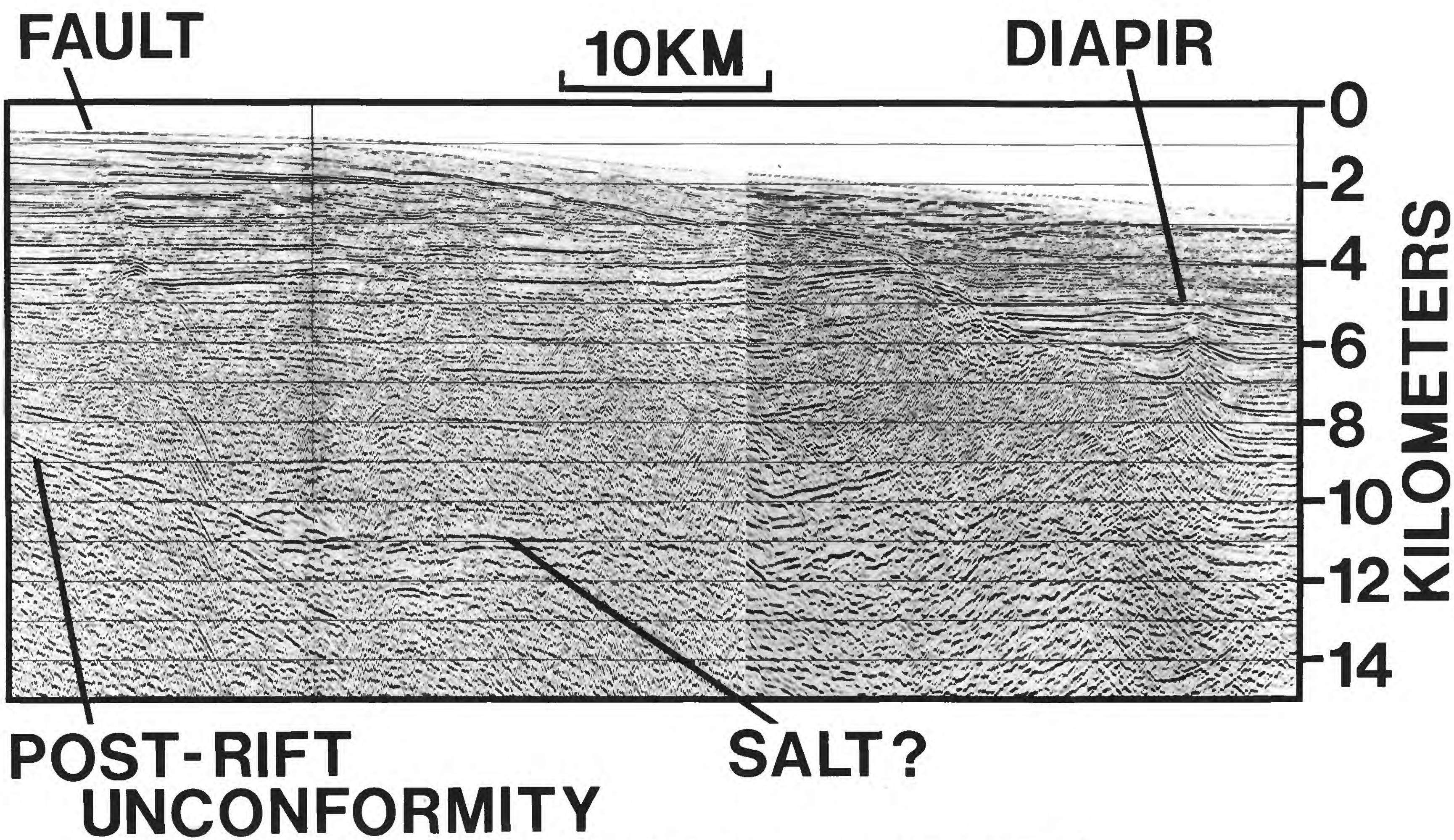
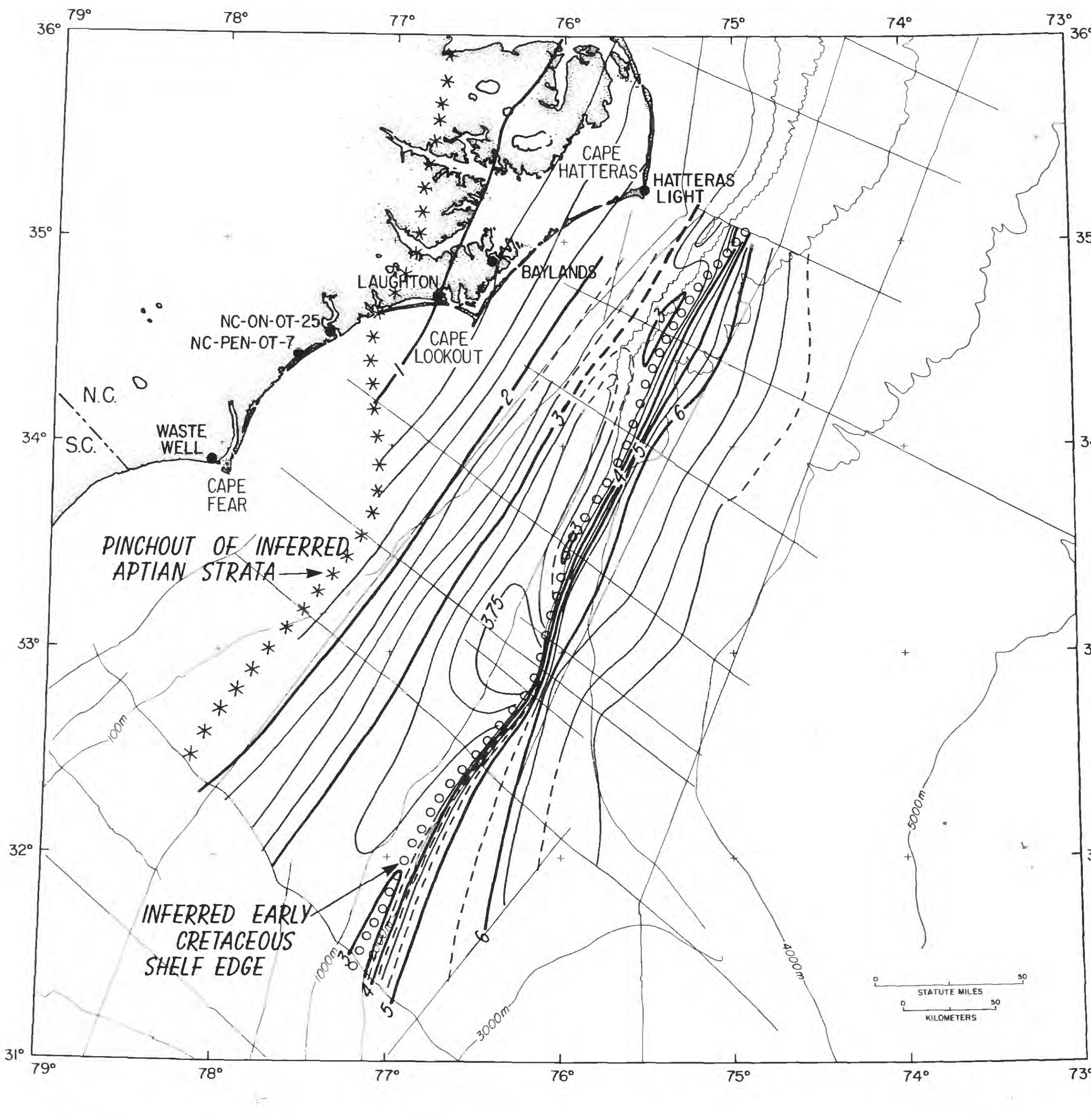


Figure 38.--Depth-converted seismic section across main part of Carolina Trough on profile 32. Compare to figures 28 and 29. Vertical exaggeration is 2:1



Universal Transverse Mercator Projection, Central Meridian 75°W

Figure 39.--Depth (in kilometers) to reflector inferred to represent top of Aptian rocks and deep-sea horizon beta (β) seaward of the paleo-shelf edge. Bathymetry in meters. Locations of selected wells are shown by filled circles. Tracklines along which multichannel seismic data were collected are shown.

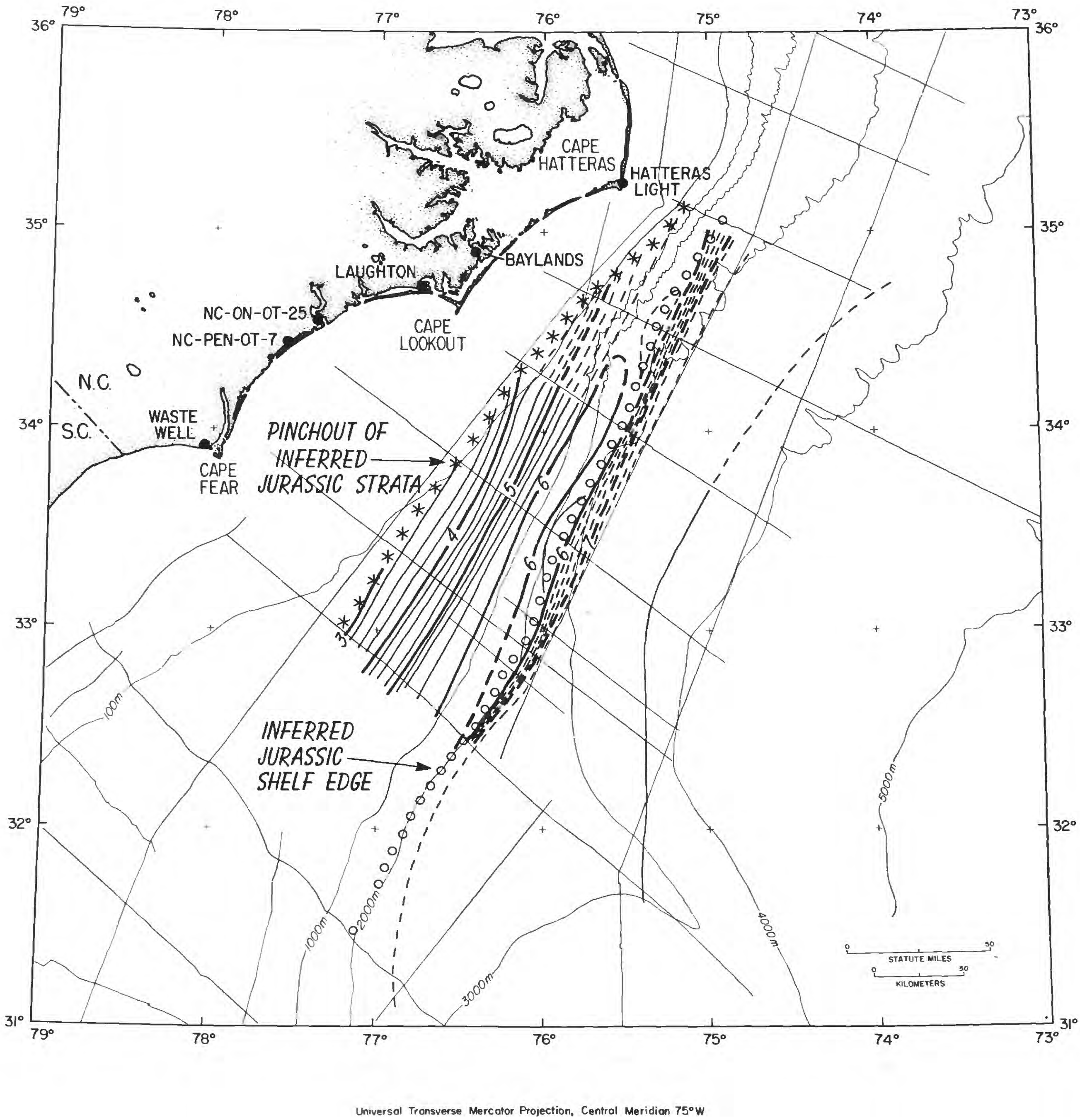


Figure 40.--Depth (in kilometers) to reflector inferred to represent top of Jurassic rocks. Bathymetry in meters. Locations of selected wells are shown by filled circles. Tracklines along which multichannel seismic data were collected are shown.

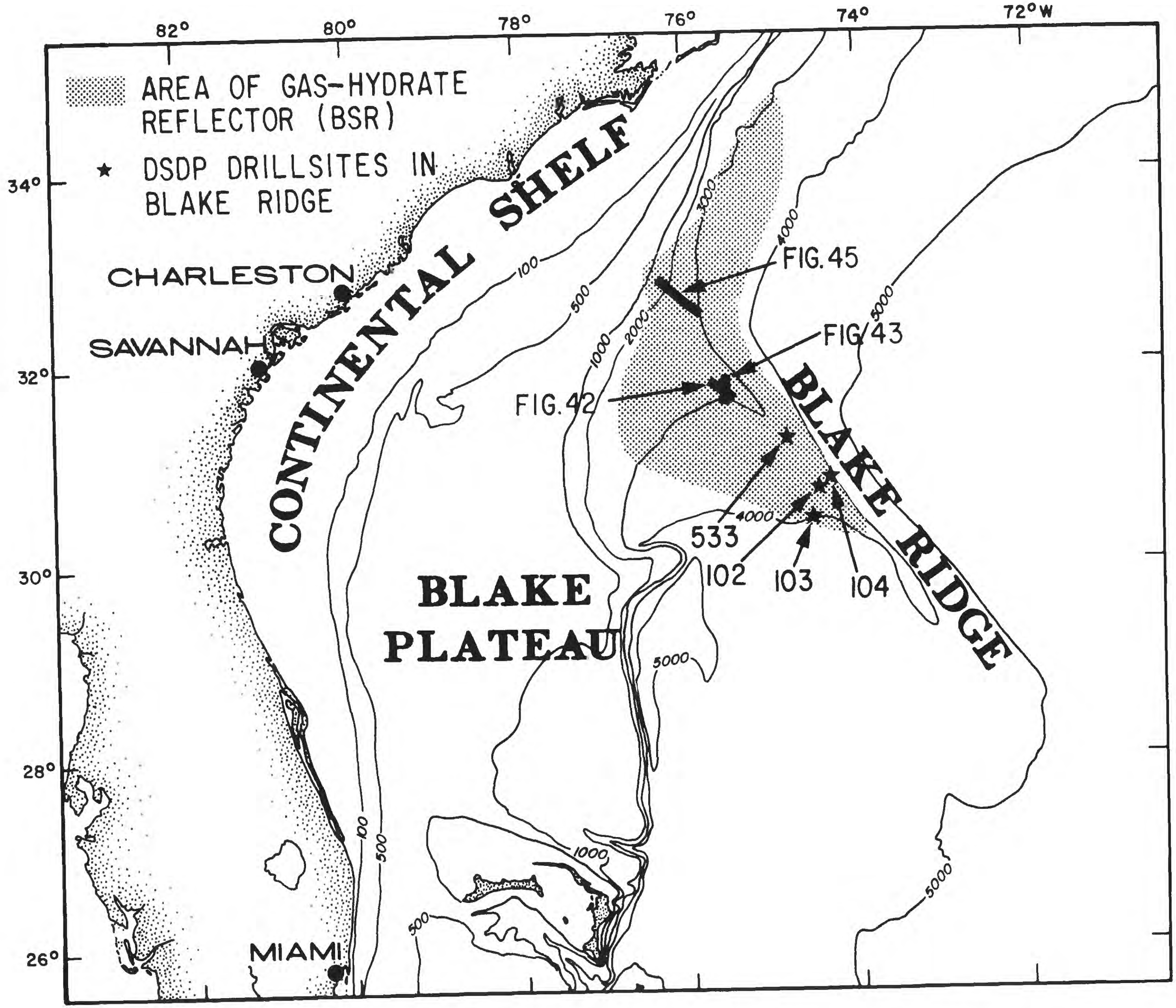


Figure 41.--Distribution of bottom-simulating reflector (BSR) considered to arise at the base of a gas-hydrate-cemented layer. DSDP, Deep Sea Drilling Project. Bathymetry in meters.

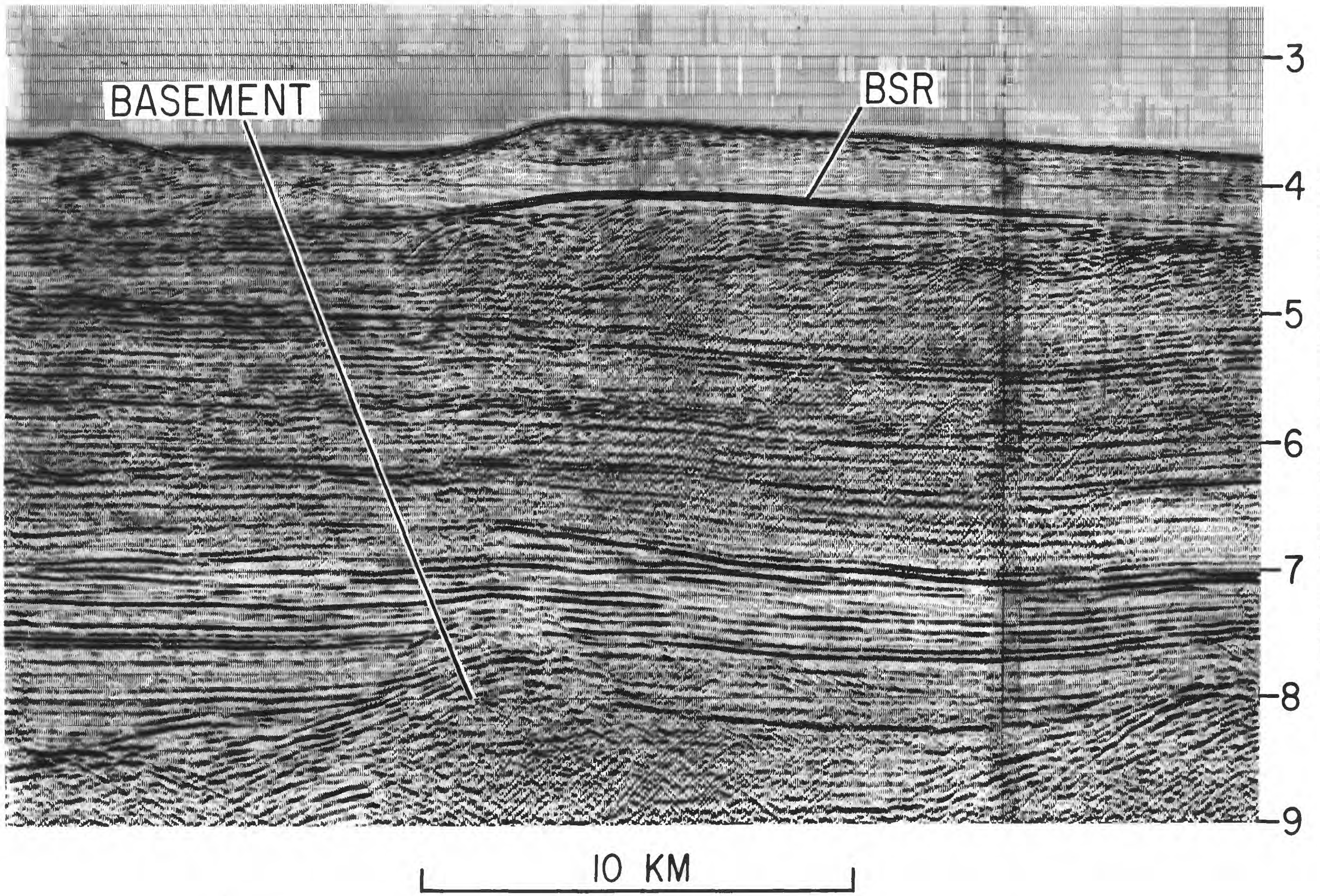


Figure 42.-- Seismic profile showing BSR in sediments of the Blake Ridge. Profile location shown in Figure 41.

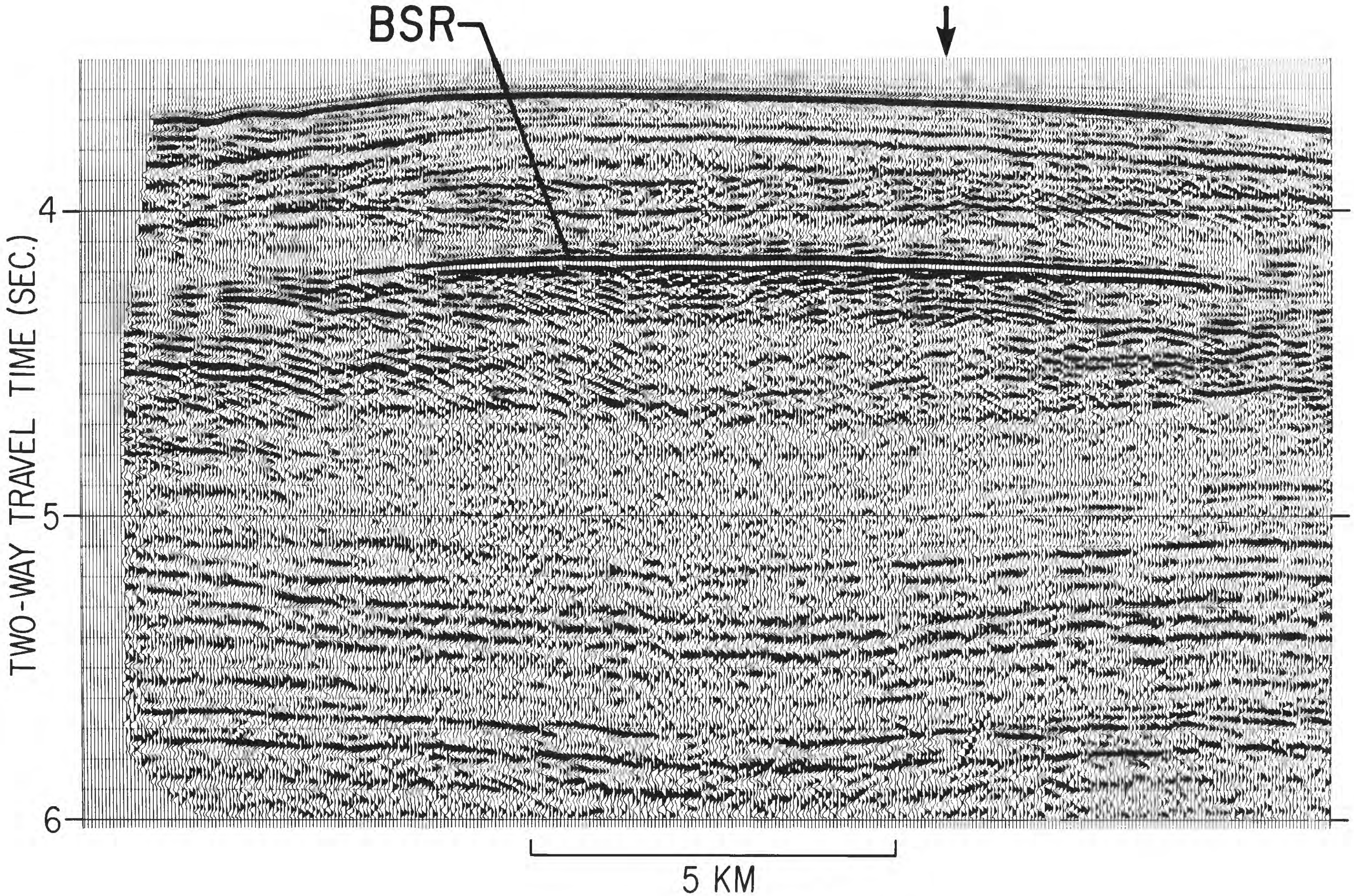


Figure 43.--Seismic profile showing strong BSR in profile that crosses Blake Ridge. Location is shown in figure 41. Arrow indicates location of velocity analysis shown in figure 44.

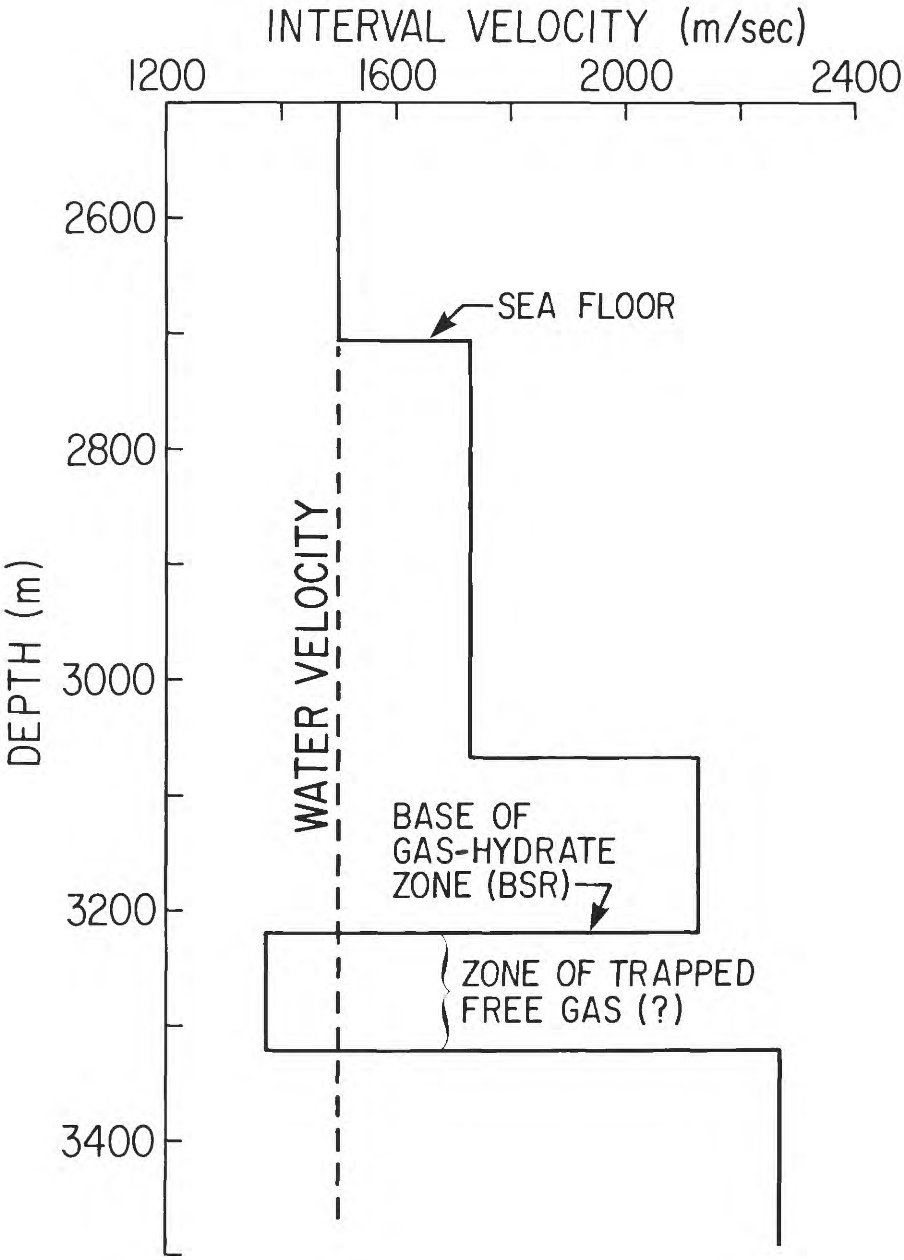


Figure 44.--Velocity analysis from seismic profile shown in figure 43 (at arrow in figure 43).

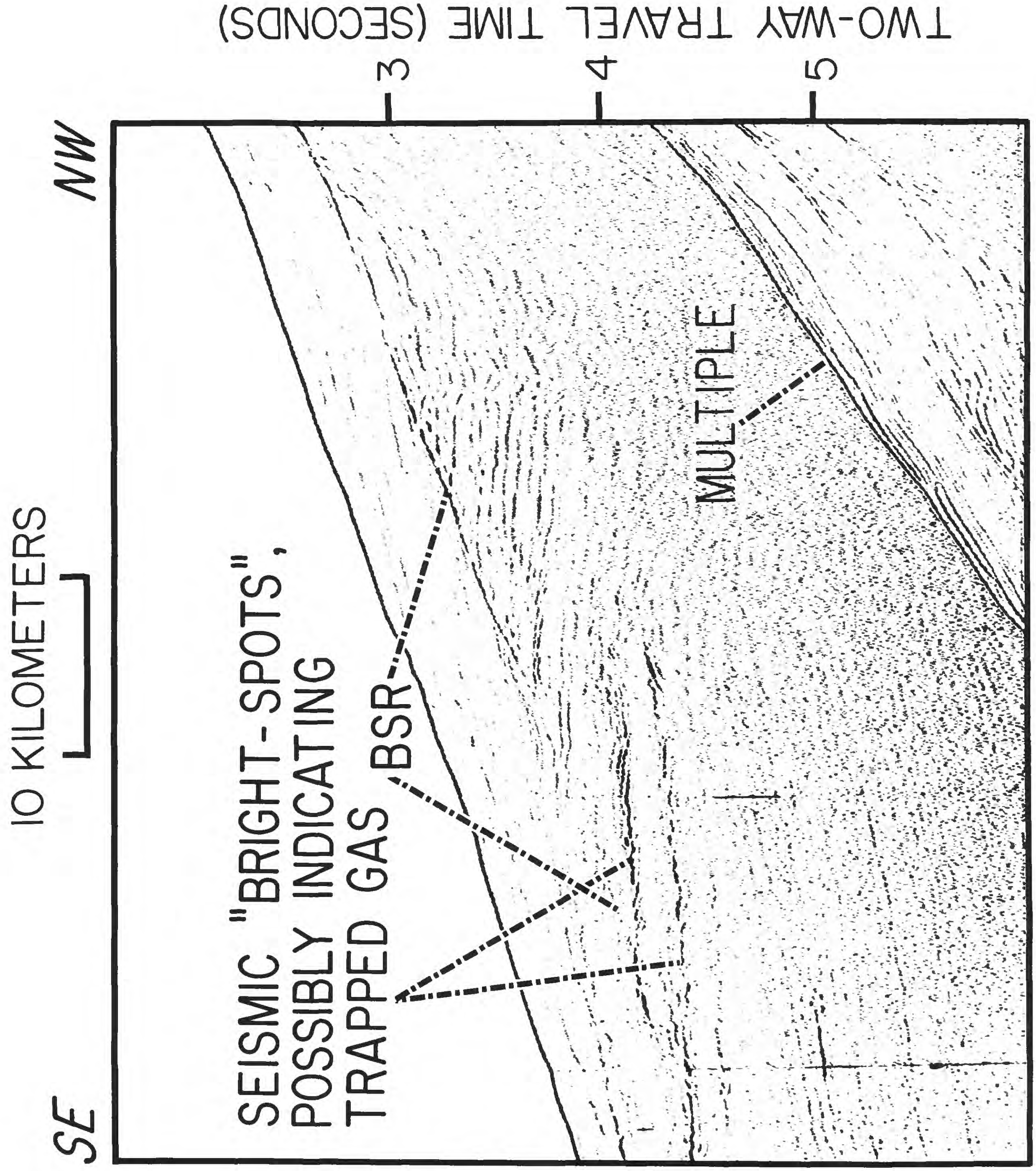


Figure 45.--Possible gas trap created by gas-hydrate cementation on Continental Slope. Location is shown in figure 41.

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CHAPTER II

ENVIRONMENTAL CONSIDERATIONS FOR OCS DEVELOPMENT, LEASE SALE 78 CALL AREA

By

Peter Popenoe, K. V. Cashman, and E. L. Coward

Since 1976, the U.S. Geological Survey (USGS), in cooperation with the U.S. Bureau of Land Management (BLM) has carried out a regional investigation of geologic hazards to and limitations on offshore petroleum exploration and development on the southeastern United States Atlantic Outer Continental Shelf (OCS). Figure 46* shows the track lines of high-resolution seismic-reflection profiling accomplished under this program. Results of the USGS-BLM studies through Fiscal Year-1978 have been released in two Open-File Reports (Popenoe, 1980, 1981). Regional hazards studies based on interpretation of the high-resolution seismic profiles of the Southeast Georgia Embayment and northern Blake Plateau were discussed by Ball and others (1980) and Pinet and others (1981) and were summarized by Popenoe and others (1981). Additional data and illustrations on regional hazards were submitted for the Draft Environmental Impact Statement, OCS Sale 56 (1980). Many networks of high-resolution seismic-reflection and sidescan-sonar surveys were performed within nominated tract areas for Lease Sales 43 and 56 (McCarthy and others, 1980; Carpenter, 1981). The USGS, in cooperation with the British Institute of Oceanographic Sciences, completed a long-range sidescan-sonar survey (GLORIA: Geologic LOng Range Inclined Asdic) of the lower Continental Slope and Rise off Cape Hatteras in October 1979. A mid-range sidescan-sonar

*Figures 46-64 are grouped at the end of this chapter, beginning on p. 73.

survey in cooperation with the USGS-BLM program and Lamont-Doherty Geological Observatory (LDGO) was completed in October 1980. The findings of these surveys, and of other investigations reported in the new literature, are summarized below.

CONTINENTAL SHELF AND BLAKE PLATEAU BOTTOM CONDITIONS

Middle and outer shelf sediments are sands (Pilkey and others, 1980). Regional transport does not appear to be an important process (Doyle and others, 1981). The presence of primary structures such as crossbedding, ripple marks, and graded bedding indicates 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, Cape Lookout, and Cape Romain, where large sand-wave fields are present which move during storms. The medium to coarse sands that 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 (McCarthy and others, 1980; Carpenter, 1981; Henry and others, 1981; Pilkey and others, 1981), which would result in scattered areas in which support capabilities could be poor, or could vary laterally in short distances. As channels and cut-and-fill structures on the shelf are patchy in their distribution, an engineering site-specific survey to determine their presence should be performed prior to rig placement.

The inner Blake Plateau is severely scoured by Gulf Stream currents (Pinet and others, 1981). Throughout most of the Tertiary and Quaternary periods, sediments were not deposited here because of these erosive conditions. As a result, the bottom in much of the area is an eroded terrace of Upper Cretaceous and Paleocene rocks (fig. 47). Slopes are steep in places and are covered by a pavement of manganese and phosphorite nodules (Ayers and Pilkey, 1981). 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.

Marine Habitats and Live Bottoms

The sand cover on the Florida-Hatteras shelf is absent in places, and a harder substrate of cemented sand is exposed. These areas of hard bottom are patchy and scattered. Their surfaces are smooth or roughly broken and have relief as great as 15 m (Continental Shelf Associates, 1979; Henry and Giles, 1980; Henry and others, 1981). 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, and soft and hard corals; these invertebrates offer shelter and forage for a variety of reef-type fish and crustaceans. These areas are commonly referred to as "live" or "hard" bottoms and constitute both recreational and commercial fishing areas. The more prominent of these areas occur near the top of the slope, where they are known as the shelf-edge ridges and reefs. Figure 48 shows the regional distribution of the shelf-edge reefs from regional high-resolution seismic-reflection surveys shown in figure 49 and prominent hard grounds reported from the literature (Continental Shelf Associates, 1979). Care should be taken in the placement of rigs to avoid such "live bottom" areas.

The surface of the Blake Plateau is covered in many areas by hummocks and mounds that represent carbonate buildups produced by thriving deep-water coral reefs (figs. 48-50) (Stetson and others, 1962; Ayers and Pilkey, 1981; Pinet and others, 1981). Bottom photographs and dredge samples reveal that chiefly two species of branching coral produce reef banks on the Blake Plateau: Lophelia prolifera and Dendrophyllia profunda, although as many as 20 species may be present (Ayers and Pilkey, 1981). Other species appear to dominate in the Straits of Florida (Reed, 1980). Reef buildups are common in three areas on the plateau. The main area occurs over the central plateau at about lat 32°N. Smaller areas occur on the western plateau between lat 30°N and 31°N. and along its eastern margin at the same latitude (figs. 48, 49) (Pinet and others, 1981). These reefal areas should be considered in rig placement.

SUB-BOTTOM CONDITIONS

Compactional Faults

Many shallow faults with very small displacement (1-3 m) have been observed on the Florida-Hatteras shelf offsetting Miocene and Oligocene rocks within the Southeast Georgia Embayment (Ball and others, 1980; McCarthy and others, 1980; Popenoe and others, 1981; Carpenter, 1981). These faults appear to die out at depth and do not reach the sea floor with one possible exception (McCarthy and others, 1980). On the inner Blake Plateau and beneath the outer shelf, many faults having larger displacement (10-30 m) have been observed offsetting rocks of Upper Cretaceous age (figs. 47, 48, 51). These faults also appear to die out at depth and terminate upwards against Paleocene rocks (fig. 47, 51). Both types of faults are believed due to sediment compaction or to subsidence rather than tectonism (Ball and others, 1980; Paull and Dillon, 1980).

Tectonically Related Faults

Two faults that have been traced seismically may result from basement tectonism. Behrendt and others (1981) have traced an east-north-east trending fault, the Helena Banks Fault (fig. 48), offshore of Charleston, S.C., and Cape Romain, S.C., for a distance of about 30 km and possibly 70 km. This fault displaces basement about 80 m, is down to the southeast, and appears to be a high-angle reverse fault. Behrendt and others (1981) described near-surface "warping" or monoclinal flexure indicating post-Pliocene movement.

A similar fault or structural lineament (fig. 48) has been traced in seismic-reflection profiles in near-surface middle Miocene sediments in Onslow Bay, N. C., southwest of Cape Lookout (Snyder and others, 1981). This feature, named the White Oak Lineament, strikes almost N.-S. along the 77°W. meridian and is expressed by a monoclinal structure in Bogue Sound, an abrupt thickening of the Pungo River Formation offshore, and a subsurface scarp having more than 25 m of relief further offshore. Seismic-reflection profiles (fig. 46) in the area described by Snyder and others (1981) show a flexure of Miocene rocks (fig. 52) which can be traced discontinuously from the coast to near the Florida-Hatteras shelf edge. Analyses of deeper penetrating CDP (common-depth-point) data (Dillon and others, 1981) indicate that Aptian age rocks terminate against basement along the lineament (fig. 39), possibly supporting a structural origin for the feature.

Faults Related to Subsidence in the Carolina Trough

A major growth fault occurs off the North and South Carolina coast near the eastern edge of the Blake Plateau and beneath the Continental Slope (Sylwester and others, 1979; Dillon and others, 1981). This fault, which has been traced for more than 350 km (figs. 48, 49, 53) shows increasing throw with depth from about 1 m at 10 m depth to 450 m at 5 km depth (Dillon and others, 1981). The movement of salt at depth from the western Carolina Trough into salt diapirs on the Continental Rise, thereby removing support for the overlying block of sedimentary rock at the shelf edge, has been proposed as the mechanism of faulting (Sylwester and others, 1979; Dillon and others, 1981; Dillon, chap. I, this report). A large number of small-displacement splay faults extending many kilometers west (fig. 48) and east are associated with the main growth fault (Carpenter, 1981).

There is no known seismicity associated with any of the above-described faults. A lack of recorded seismicity offshore is notable both historically (Bollinger, 1977) and in recent studies (J. W. Dewey, unpublished data, 1981). Seismicity associated with the two possible tectonic faults cannot be discounted entirely; however, the lack of historical seismicity suggests that if events do take place on the shelf, they are infrequent. On this basis, ground accelerations associated with seismicity would appear to constitute a low risk to offshore operations.

All of these faults are considered of environmental concern as they could cause loss of drilling fluids or serve as avenues for the escape of high pressure gas from depth, if penetrated during drilling. If the locations of the faults are known during drilling operations, the risk they pose can be mitigated through design and drilling procedures.

Collapse Structures and Cavernous Porosity

In Florida, extensive networks of caves and solution-riddled limestone are known to be present extending from the land surface to depths at oil horizons at about 3,500 m in southern Florida. These caves are part of both the Florida aquifer system and the deeper "Boulder Zone" (Kohout, 1965). Cavernous limestones have caused problems in drilling exploratory wells onshore; however, the extent of cavernous porosity offshore is less known. The two best known areas of cavernous porosity on the Florida Shelf are the sink holes known as the Crescent Beach Spring (Brooks, 1961) and Red Snapper Sink (Wilcove, 1975; Kohout and others, 1977). Karstic caves or "blue holes" are common in the Bahamas, and during the drilling of the Bahamas Oil Andros Island well, circulation was lost in about 15 zones (Meyerhoff and Hatten, 1974).

Regional high-resolution seismic-reflection surveys taken offshore southern Georgia and Florida indicate that the Red Snapper Sink and Crescent Beach Spring occur on a regional high on the subsurface Eocene limestones, which has placed these karstic units in a relatively elevated position and allowed these sinkholes to breach the surface of the sea floor. Seismic data show evidence for numerous sink holes and karst topography in the subsurface of the shelf as far north as Savannah, Georgia, and south at least to the Florida Keys, which is the southern limit of our survey area. The shallowest horizon associated with karst development in northern Florida is the Oligocene unconformity, which dips to the north into the Southeast Georgia Embayment from the Crescent Beach-Red Snapper Sink high, and to the south into the South Florida Embayment. Figure 54 shows the nature of this surface 45 km south of Red Snapper Sink on the central shelf off

Daytona Beach, Florida. Just south of Daytona Beach, Florida, high-resolution seismic-reflection surveys have shown one other sink hole into which overlying sediments have collapsed to within 15 m of the sea floor, thus constituting a rig-support hazard. Offshore development in this area should include a site-specific survey to determine if such features underlie lease tracts.

On the northern Blake Plateau between lat 33°N and 34°N, a number of large collapse structures as wide as 2 km have been noted in regional high-resolution seismic-reflection survey records (figs. 48, 55). The structures occur over deep erosional pits in the mid-Oligocene or Eocene unconformity, and affect overlying strata of early Miocene age but do not appear to affect strata above the middle Miocene unconformity or below the Eocene. Multiple track crossings of the structures show that they are elongate in a north-northeast direction, trending essentially parallel to the major growth fault on the outer Blake Plateau. This parallelism suggests that the trend and location of the collapse structures are controlled by splay faults of the growth-fault system described above (fig. 48) along which strong erosion or solution has taken place. The seismic character of the Eocene-Oligocene strata and deep erosional pits in the top of this unit suggest limestone or karst solution (sink holes). Cavernous porosity associated with lower Createaceous carbonates caused lost circulation between depths of 2550 and 2575 m during the drilling of the ESSO1 Hatteras Light well (Maher, 1971). New data indicate that cavernous porosity may be a problem in younger rocks offshore, particularly the Eocene.

On the inner Blake Plateau near lat 31°15'N., long 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 rocks (Paull and Dillon, 1979). Subsurface karst topography and solution features of Paleocene limestones have been inferred on the southern Blake Plateau from high-resolution seismic-reflection analyses (figs. 49, 56) (Pinet and others, 1981). A large sink hole off Miami Beach in the area of the Straits of Florida was documented by a high-resolution seismic survey during the cruise of the R.V. GYRE, September 18-October 14, 1980 (Popenoe, unpublished data, 1980).

Thus, caverns may exist throughout the Sale 78 area and may constitute a threat to bottom-mounted platforms and structures or cause drilling problems.

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 throughout its entire geographic range (Counts and Donsky, 1963). The aquifer probably remains in these same units offshore (Paull and Dillon, 1980b). Off northern Florida, the JOIDES drilling (holes J-1, J-2) found fresh water within these units almost out to the shelf break. However, AMCOR 6002, which was drilled at mid-shelf off central Georgia, encountered water having salinities above that of normal seawater within the units (Manheim and Paull, in press). A line that separates the Tertiary strata containing water of less than 10 ‰ from those with greater than 10 ‰ has been drawn by F. A. Kohout (unpub. data, 1978) and is shown in figure 57. 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.

CONTINENTAL SLOPE AND UPPER RISE

Slope Instability and Mass Wasting

The Florida-Hatteras Slope, which divides the shelf from the Blake Plateau, locally shows some evidence of instability features, but such features appear to be rare. This rareness is probably due to a low declivity, a winnowing of fine-grained materials from slope sediments by the currents of the Gulf Stream, and a low rate of deposition on the slope. Probable slope instability features were noted on only two of thirty-two regional high-resolution seismic-reflection lines that cross the Florida-Hatteras slope at 20-km intervals (fig. 46). These two features are normal faulting of the slope south of Jacksonville and a slump mass and scar at the base of the slope due east of Savannah, Georgia (fig. 48) (Ball and others, 1980; Ayers and Pilkey, 1981). Radiocarbon dates of mud taken from the slump mass off Savannah, Georgia, ranged from 31,290 to 20,225 years BP, suggesting a late Quaternary age for the slumping (Ayers and Pilkey, 1981). The presence of only a subdued possible slump scar upslope suggests that the feature is relatively old.

Slope instability features appear to be common along the Continental Slope between the Blake Escarpment and Virginia. One area of particularly pronounced slumping is due east of Cape Romain, South Carolina (fig. 48) on the Continental Slope in and below nominated lease blocks, OCS sale 56, in the Cape Fear and contiguous OCS

Topographic-bathymetric Series quadrangles. Here, steep scarps having as much as 80 m of relief terminate bedding on the slope (fig. 58), and rotational slump faults are evident upslope of the scarps. Interpreted long-range sidescan sonographs (GLORIA) in the area of slumping (fig. 59) show that an arcuate area of the slope more than 40 km in width has been removed. Mid-range sidescan sonographs (fig. 60) indicate that large blocks 3-10 km wide probably moved downslope as relatively coherent masses, cutting deep furrows in the bottom. Crossing slump tracks downslope of the scar indicate repeated downslope movement of major blocks. The lack of marine sedimentation over furrows suggests that slumping was relatively recent. This occurrence of slumping and its association with active salt diapirism downslope suggest that this slumping is due to oversteepening of the slope by subsidence and leaching associated with salt removal in a large breached diapir complex near the Continental Slope-Rise boundary (figs. 59, 48).

A large scar on the outer Blake Plateau believed to be related to slumped sediments within the lease sale 56 nominated blocks has been described by Carpenter (1981).

A third area of sharply terminated bedding suggesting massive slumping occurs on the slope at about lat 36°15'N offshore of the Virginia-North Carolina border (fig. 48) (Popenoe, unpub. data, 1980; McGregor, 1981). Here, a large block of Pleistocene sediments (USGS, unpublished data) has apparently been removed. Although the USGS does not have detailed data on this feature, an inspection of the recent Currituck Sound Topographic-Bathymetric Series Map (NJ 18-11) suggests that canyon drainage exists in the slump scar, suggesting a late Pleistocene or early Holocene age for the feature.

At the top of the Continental Slope between lat 31°N. and 32°N, the bottom is offset as much as 75 m along the upper slope for a distance of more than 60 km by a normal fault (fig. 61)(Pinet and others, 1981). CDP seismic-reflection profiles across this fault show it to be a listric fault, which flattens with depth and shows at least four antithetic faults seaward of the normal fault (Dillon and Paull, 1978). Chaotic reflectors downslope and at depth suggest a long history of instability movement resulting in slumping. No cores have been taken in this area, however, offset bottom and lack of sedimentation in the offset area suggest relatively recent movement on the gravity fault.

The Continental Slope south of lat 31°N. and on the Blake Spur and Escarpment appear to be dominated chiefly by processes associated with shelf-edge spillover, erosion, and biogenic degradation. Minor slumping is shown in seismic records collected north of the Blake Spur (Pinet and others, 1981); however, the steep declivity of the slope and the lack of detailed surveys prevent the delineation of unequivocal slump related features. Submersible dives with the ALVIN (W. P. Dillon and others, unpub. data) on the Blake Spur and Escarpment have shown vertical cliffs having as much as 1000 m of relief on the escarpment; the cliffs are apparently maintained by both current and biologic erosion. Piles of rubble at the base of the escarpment indicate that large blocks of material have broken off periodically and tumbled downslope.

Submarine Canyons

Between Cape Hatteras and Virginia, mass wasting and slumping associated with submarine canyons appear to be the dominant downslope processes of sediment movement on the slope and upper rise. The slope is highly dissected along the edge of the northern Blake Plateau and north of Cape Hatteras by submarine canyons, and relief between thalwegs and ridges is as much as 500-700 m. Sonograms from the mid-range sidescan-sonar system show both sharp divides and undissected slope between canyons (figs. 62, 63). Geomorphic patterns of canyons are best described as pinnate, reflecting the steep slopes on which the canyons are developed (12°). The probable mechanism of downslope movement is undercutting at the thalweg and slumping down chutes, thus causing headwall erosion. The canyons are cut into both Pleistocene and underlying Miocene and older rocks, indicating that they are late Pleistocene and perhaps Holocene features.

CLATHRATES AND ACCOMPANYING TRAPPED GAS

A bottom simulating seismic reflector believed to arise from the impedence contrast between the lower boundary of a frozen gas-hydrate layer (clathrate) in the shallow subsurface and unfrozen sediment has been described as occurring beneath the slope and upper rise on the eastern edge of the Blake Plateau (Shipley and others, 1979; Dillon and others, 1980; Paull and Dillon, 1980). Gas hydrates can form and be stable in the marine environment at temperatures as high as 27°C if pressures are sufficiently high (Tucholke and others, 1977). The gas hydrate or clathrate is an icelike crystalline lattice of water molecules in which gas molecules become trapped. On the Blake Outer Ridge and on the upper rise, the lower phase boundary of the clathrate generally occurs about .4 to .6 seconds (two-way travel) subbottom, where the gas hydrate becomes unstable owing to the geothermal gradient. At this phase boundary, gas hydrate-gas or gas hydrate-water contacts within the sedimentary section cause "bright spots" or amplitude anomalies on seismic profiles (fig. 58, 61). The areal distribution of the gas-hydrate reflector has been mapped by Paull and Dillon (1980) (fig. 41). Recently collected seismic-reflection data off North Carolina have extended the area of probable clathrate and associated "bright spot" anomalies northward to offshore Virginia on the upper Continental Rise (fig. 48).

Drilling into clathrates should not pose a threat to operations unless shallow gas (such as methane, ethane, carbon dioxide, hydrogen sulfide) is trapped beneath the frozen layer. The penetration of shallow gas pockets beneath permafrost off Mackenzie Delta, Alaska has led to the loss of several drill rigs (Peter Day, Phillips Petroleum Company, personal communication, 1980), and this danger probably also is associated with gas trapped beneath clathrates. Very little is known of the hazards associated with clathrates because these frozen layers occur in water depths that are at the frontier of exploration or production technology at the present time. As exploration proceeds into greater water depths, shallow gas trapped beneath clathrates may prove to be a primary hazard. Only one area on the Blake Plateau (near lat 33°45'N., long 76#13'W.) shows possible gas trapped at a very shallow depth (fig. 64). The association of the "bright spots" anomalies shown with shallow splay faults of the growth-fault system suggests that gas has migrated up fault zones and has become trapped in a shallow structure that is perhaps associated with a barrier sequence. No gas seeps were noted in this area.

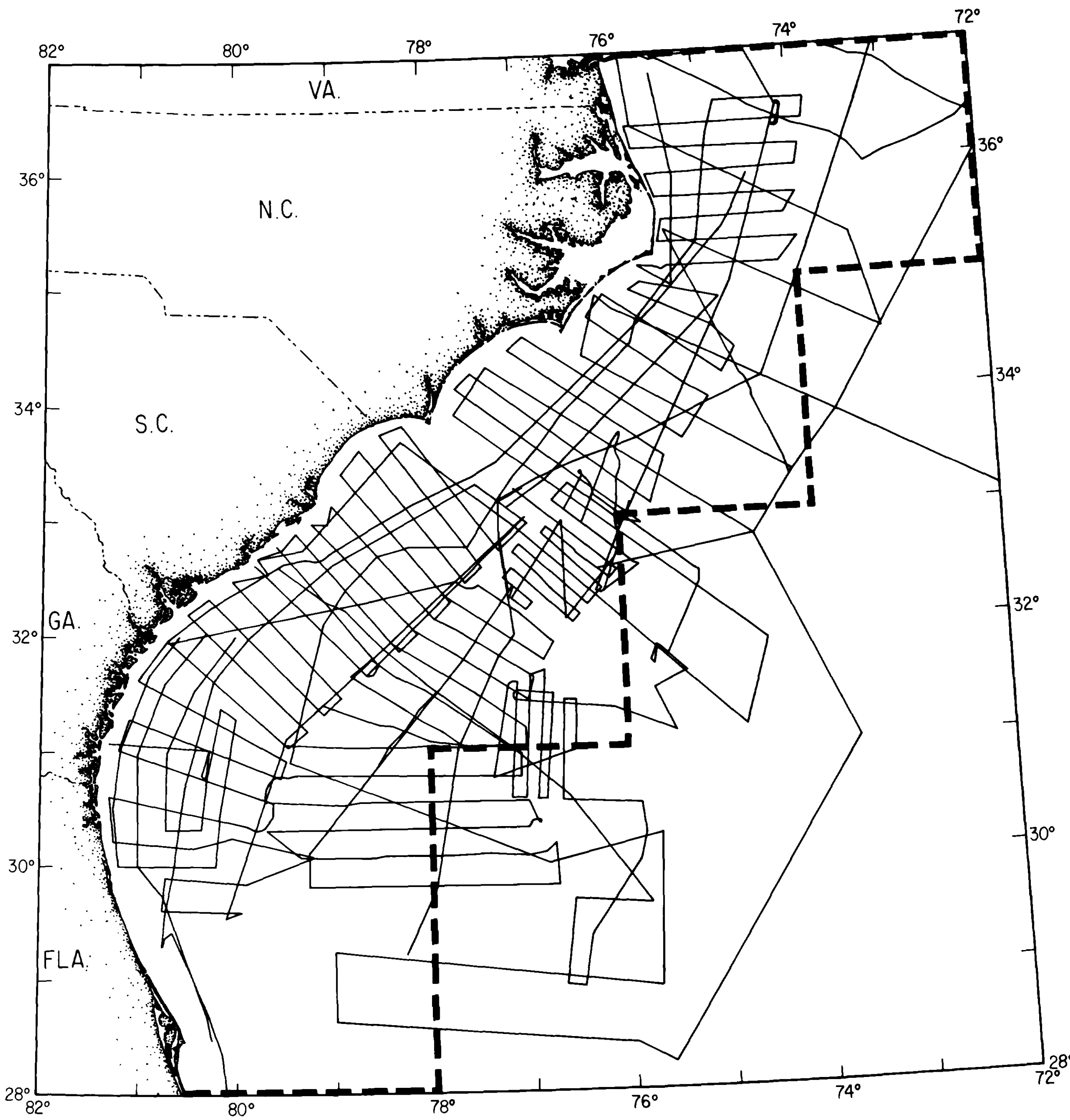


Figure 46.--Track chart showing the distribution of U.S. Geological Survey high-resolution seismic-reflection survey data in the call area, OCS Lease Sale 78. Light lines are track lines, heavy dashed lines indicates boundary of call area.

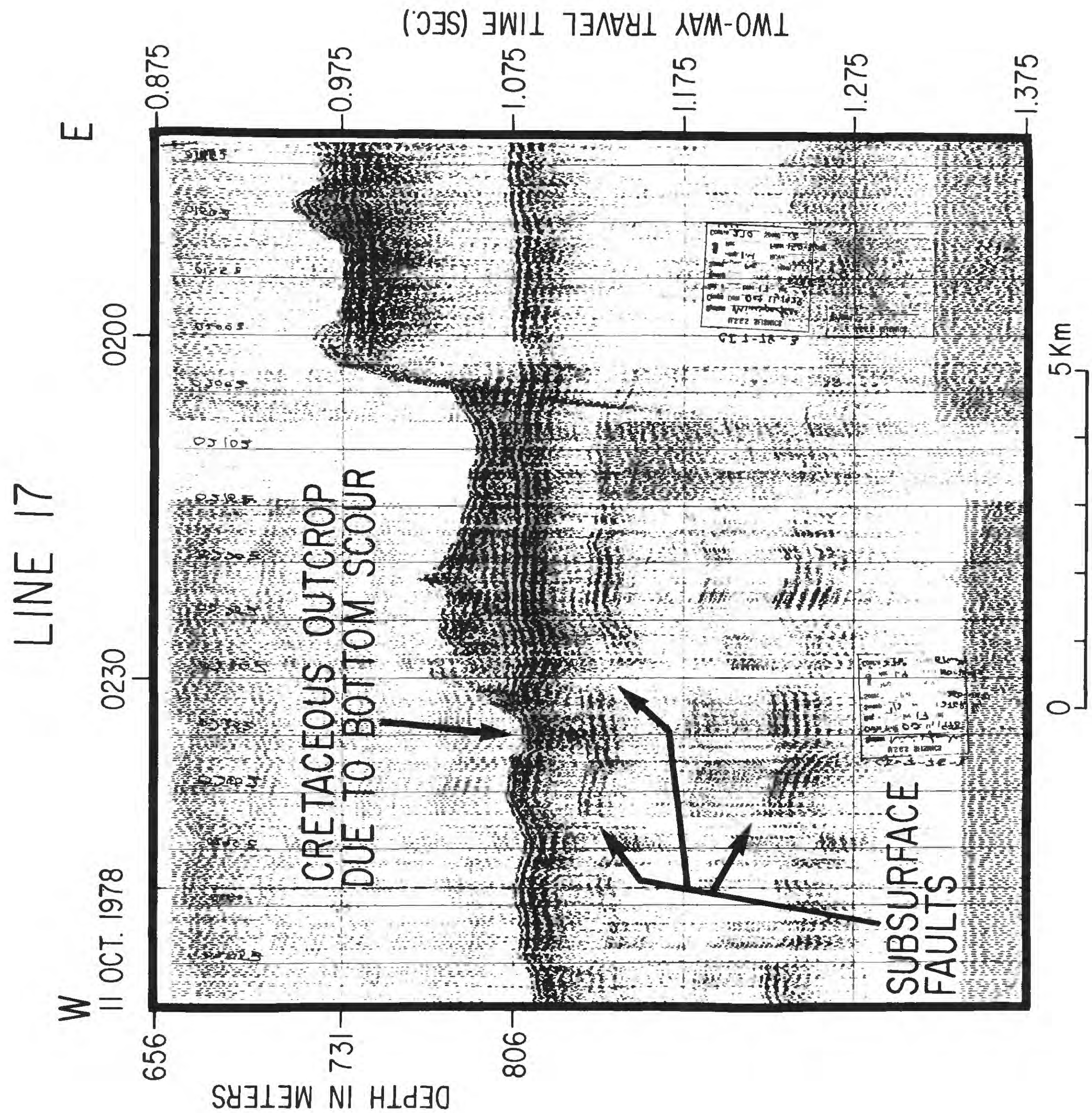


Figure 47.--Picture of high-resolution seismic-reflection record showing typical scour topography on the inner Blake Plateau near lat 30°45'N, long 79°15'W. Note steep slopes and deep-water reef mounds. Subsurface faults in Upper Cretaceous age marls are probably of compactional origin. Location of line 17 is shown in figure 49.

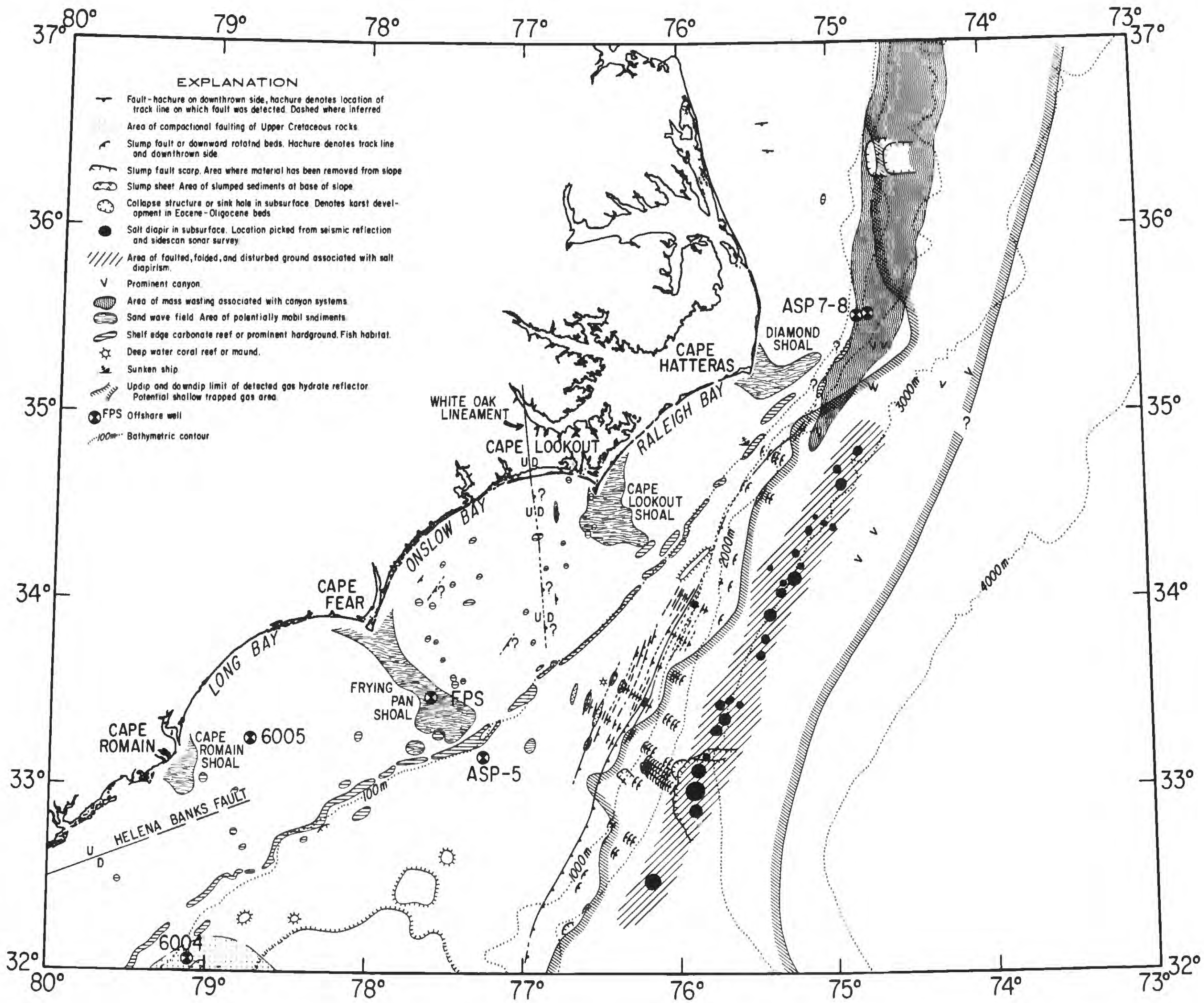


Figure 48.--Environmental geology map covering the northern part of Federal OCS Call Area, Sale 78 based on interpretation of high-resolution seismic-reflection data collected along tracklines shown in figure 49, sidescan-sonar surveys discussed in text, and published literature.

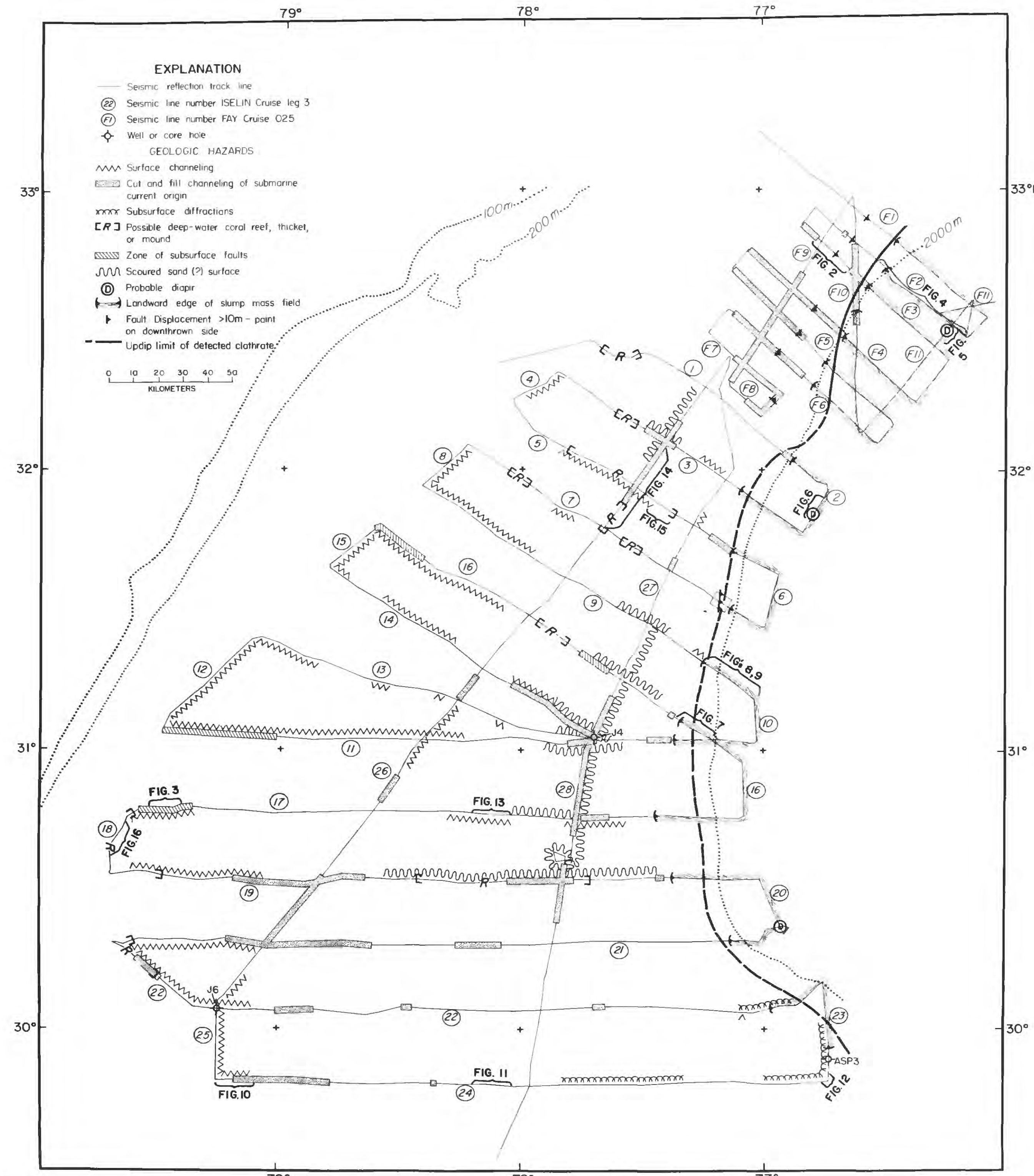


Figure 49.--Environmental geology map of part of the northern Blake Plateau based on interpretation of high-resolution seismic-reflection data (Pinet and others, 1981). Figure numbers refer to illustrations in Pinet and others, (1981). Identification of slump mass field on the Continental Slope is liberal by intent on the basis of slope instability known to be associated with steep bottom gradients.

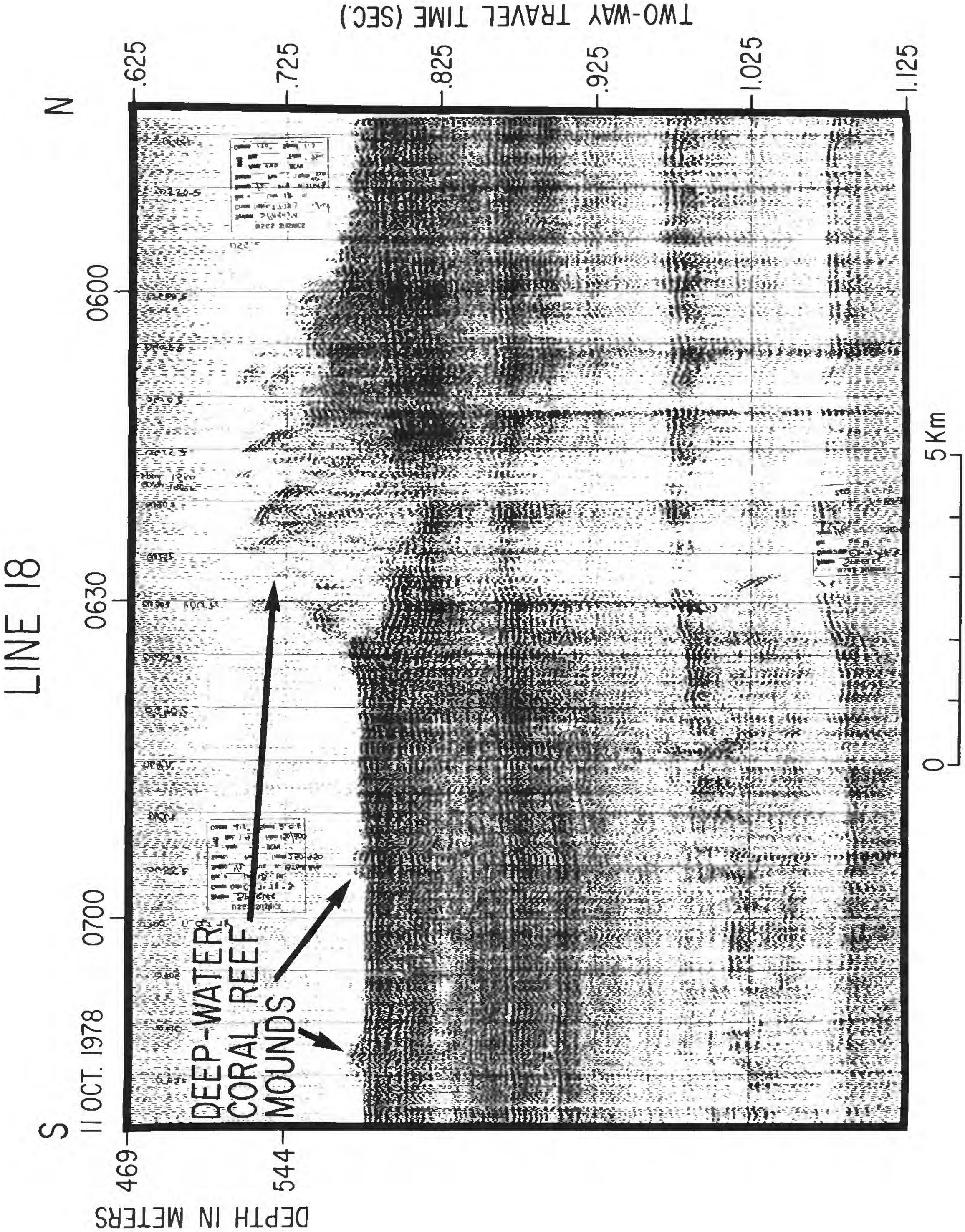


Figure 50.--Picture of high-resolution seismic-reflection record showing deep-water coral thickets and mounds which are characteristic of large areas on the Blake Plateau (figs. 48,49). These reefs occur in the aphotic zone, generally in areas of scour topography. Location of line 18 is shown in figure 49.

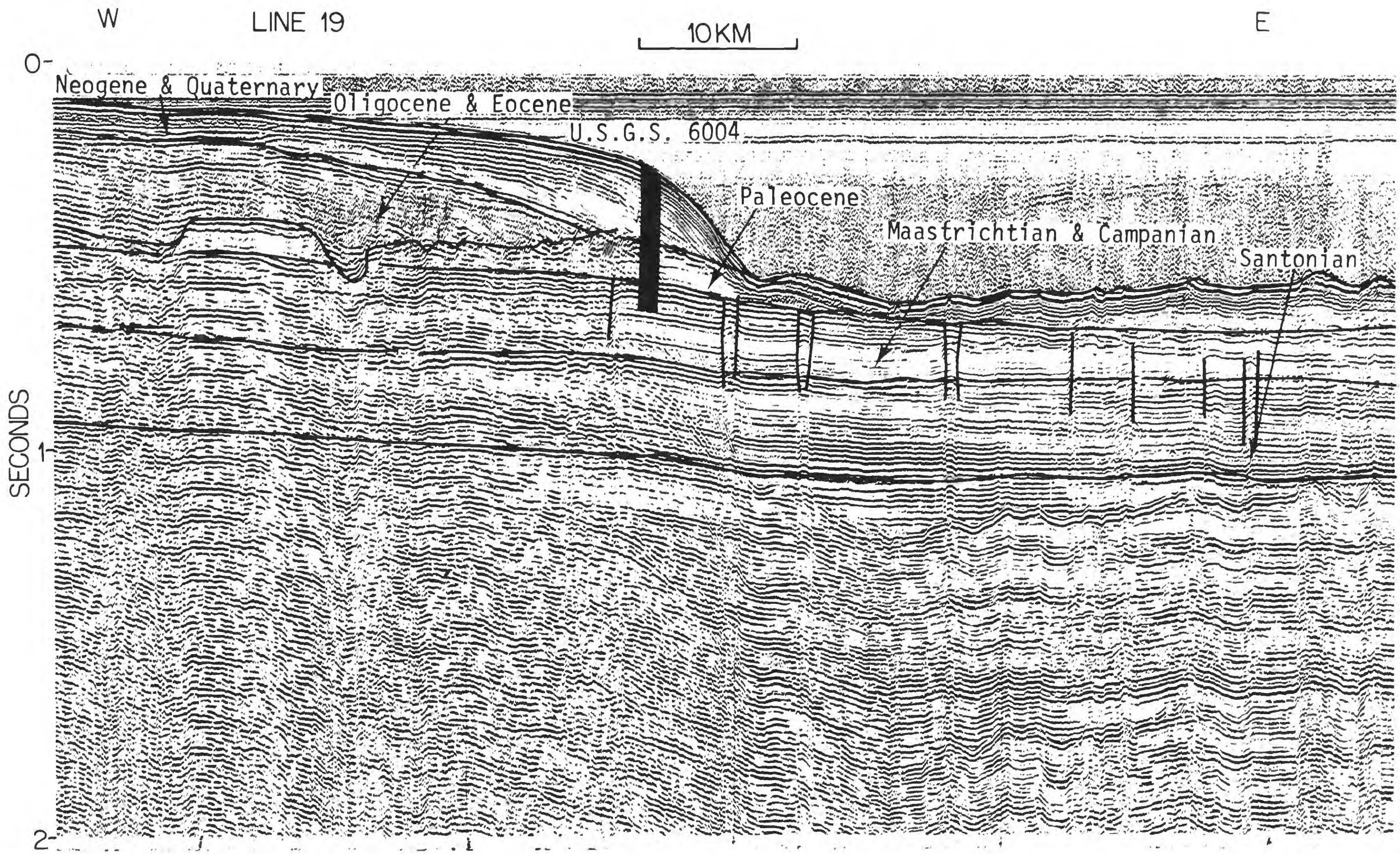


Figure 51.--Picture of interpreted high-resolution seismic-reflection profile near lat 32°N., long 79°W. showing faults in Upper Cretaceous rocks believed to be caused by compaction. Note that the faults appear to die out at depth and do not affect overlying Paleocene rocks.

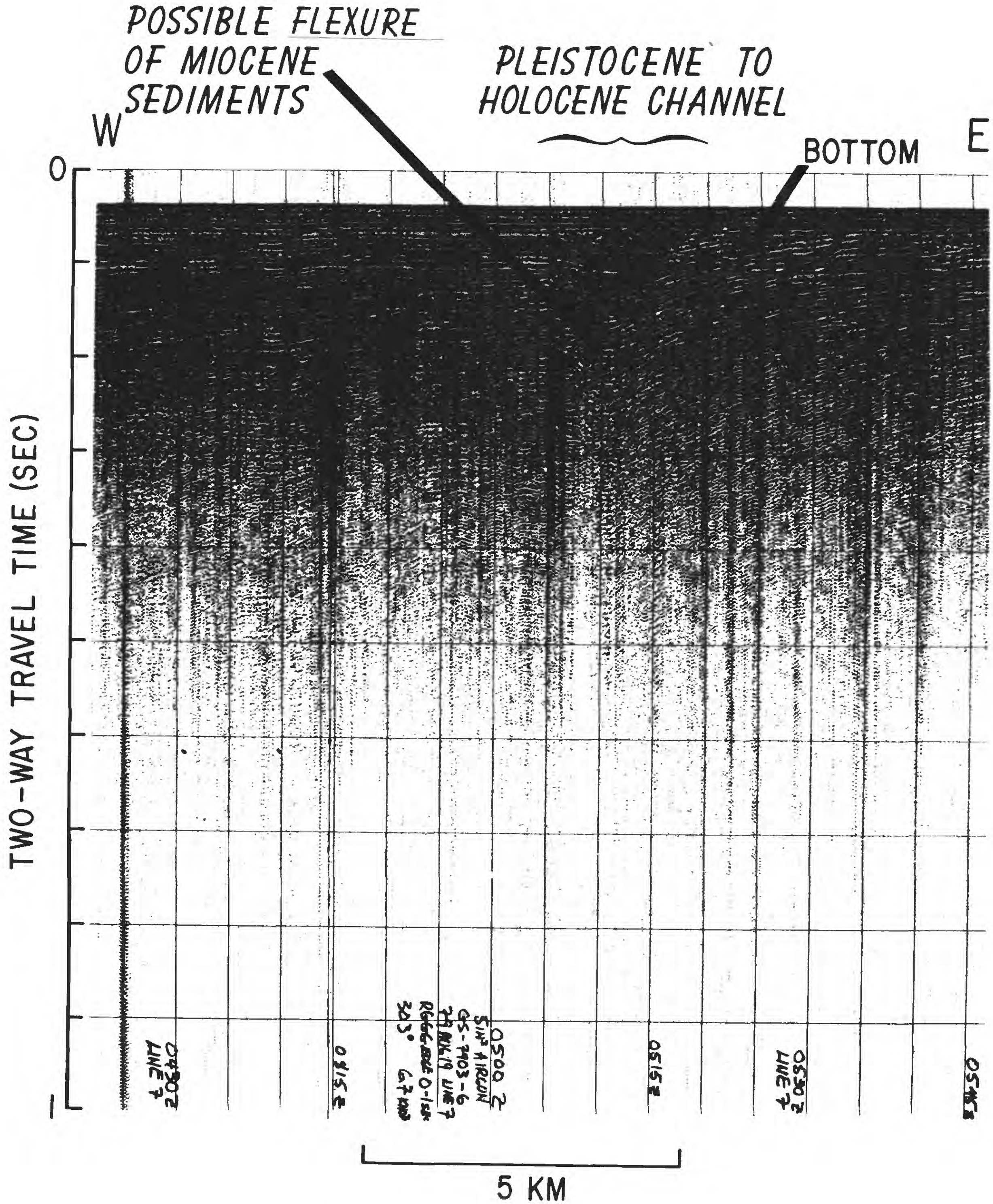


Figure 52.--Picture of high-resolution seismic-reflection record near lat 34°20'N., long 76°55'W. showing flexure associated with the White Oak Lineament of Snyder and others (1981).

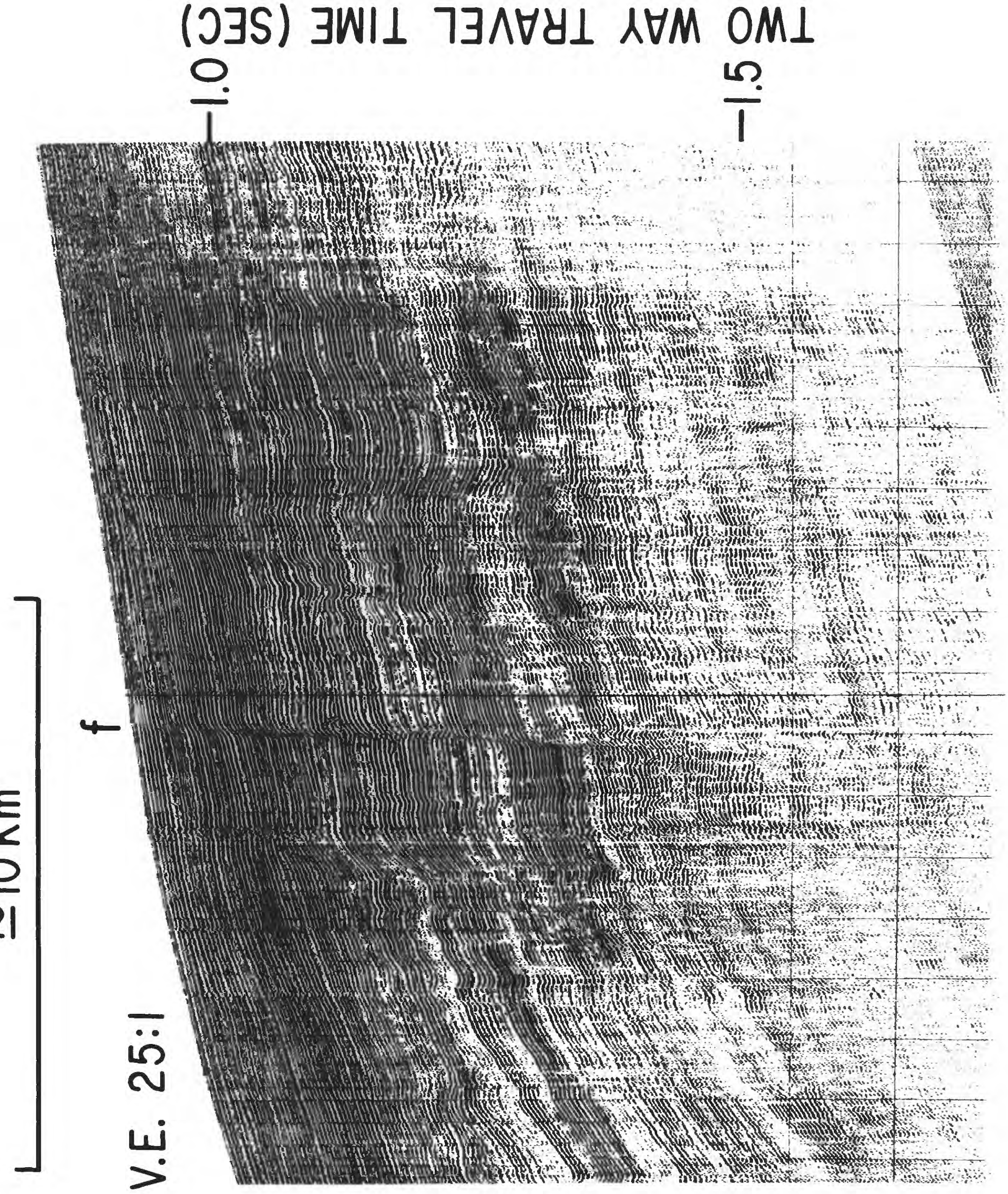


Figure 53.--Picture of high-resolution seismic-reflection profile near lat 33°18'N., long 76°20'W. showing the shallow expression of the major growth fault (f) that marks the landward edge of the Carolina Trough (fig. 48). A slight offset of beds can be seen at about 10 m depth over the main fault; the beds at about 1.3 seconds depth are offset by about 35 m. Note the many small-displacement splay faults both upslope and downslope of the main fault.

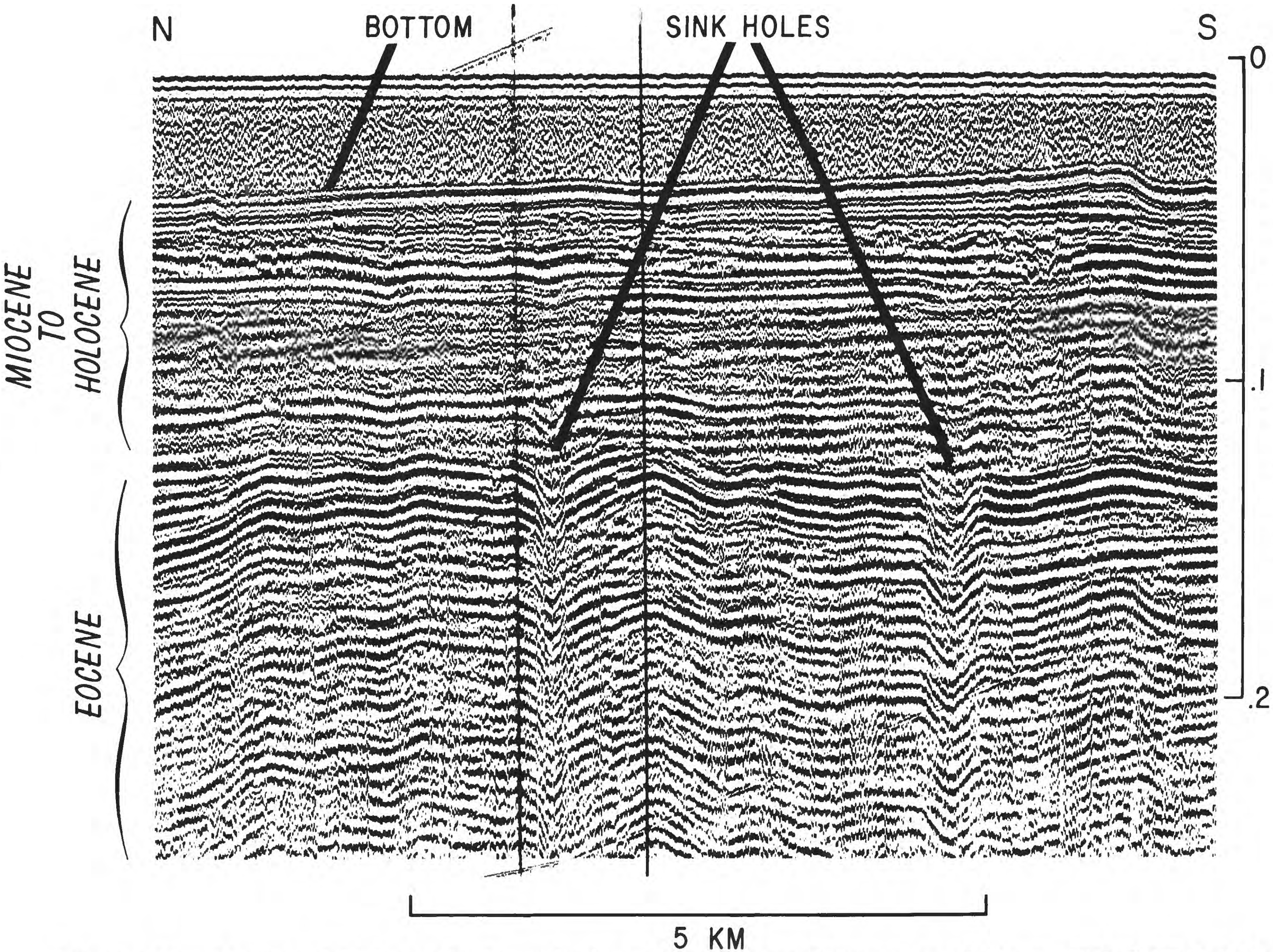


Figure 54.--Picture of high-resolution seismic-reflection record from area of the central Florida-Hatteras shelf off Daytona Beach, Florida, showing buried sink holes and karst topography in subsurface rocks. The wavey unconformity is of Oligocene age and is cut on Eocene-age limestones. Note that beds overlying the unconformity have collapsed into underlying sink holes.

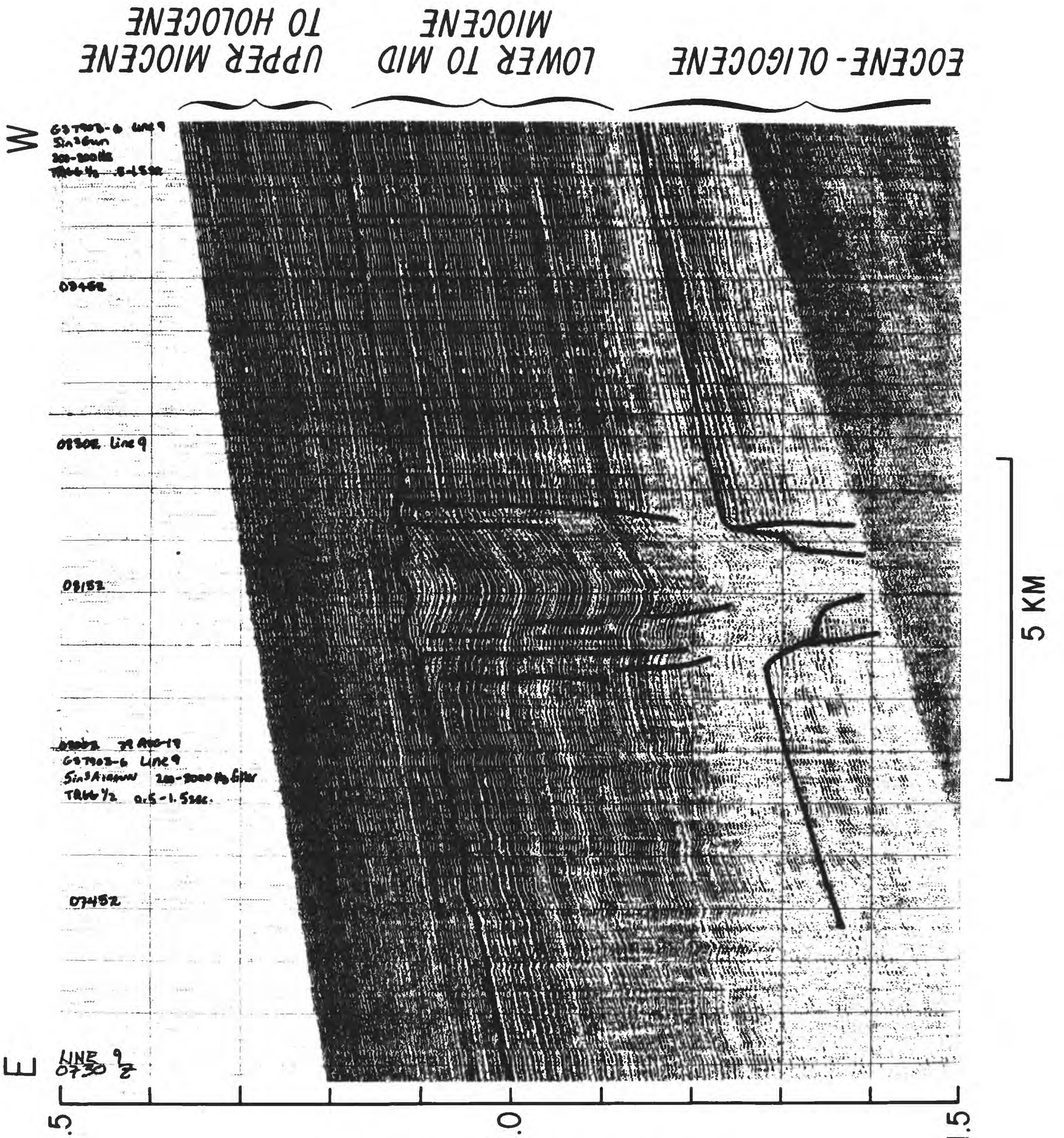


Figure 55.--Picture of high-resolution seismic-reflection record from the northern Blake Plateau near lat 33°25'N., long 76°30'W. showing large subsurface collapse structure (sink hole) (fig. 48). A large cavity is developed on Oligocene-Eocene age rocks into which Lower Miocene age rocks have collapsed. Rocks of Late Miocene age or younger are not affected. This presence of such collapse structures in this area is a strong indication of cavernous porosity in the Eocene-Oligocene section. Older underlying rocks do not appear to be affected.

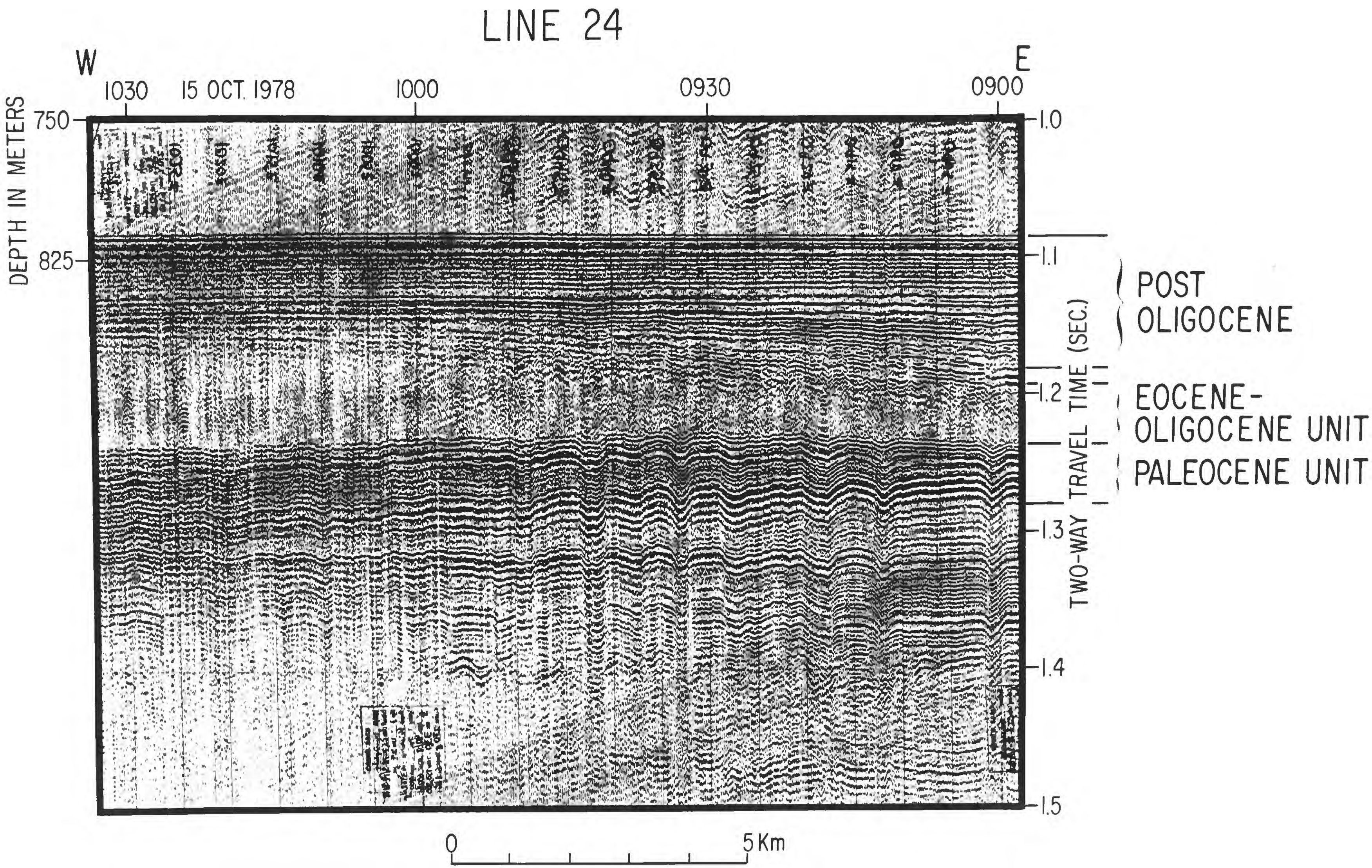


Figure 56.--Picture of high-resolution seismic-reflection profile near lat 29°50'N., long 78°00'W. showing wavey reflectors in the subsurface interpreted to be due to solution cavities in Paleocene limestones.

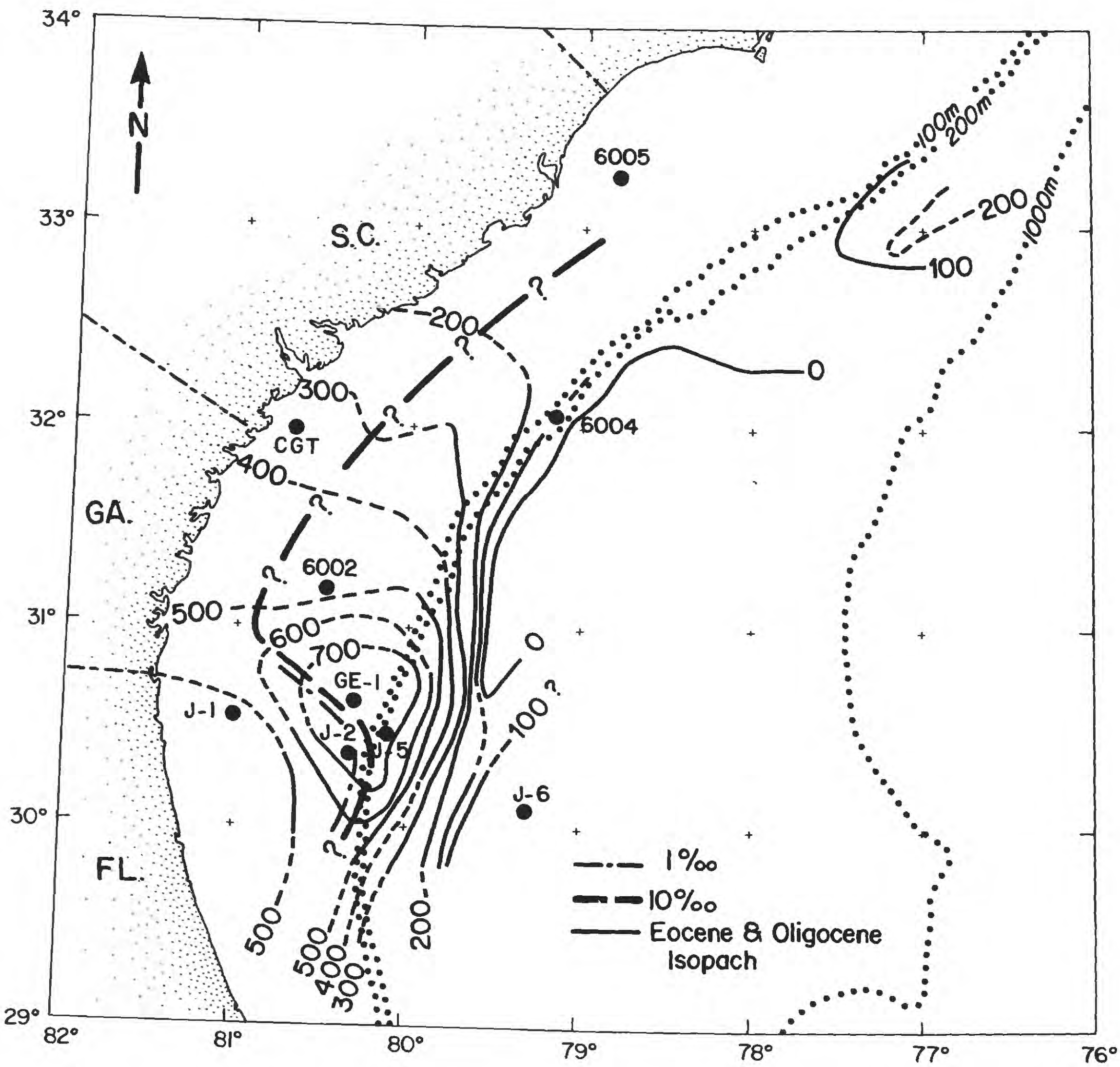


Figure 57.--Isopach map of Eocene and Oligocene sediments that probably make up the aquifer beneath the Florida-Hatteras shelf, offshore Georgia, Florida, and South Carolina. The heavy queried line has been adopted from F. A. Kohout (unpub. data, 1978) and divides waters as fresh as 10 ‰ from more saline waters. Isopachs in meters.

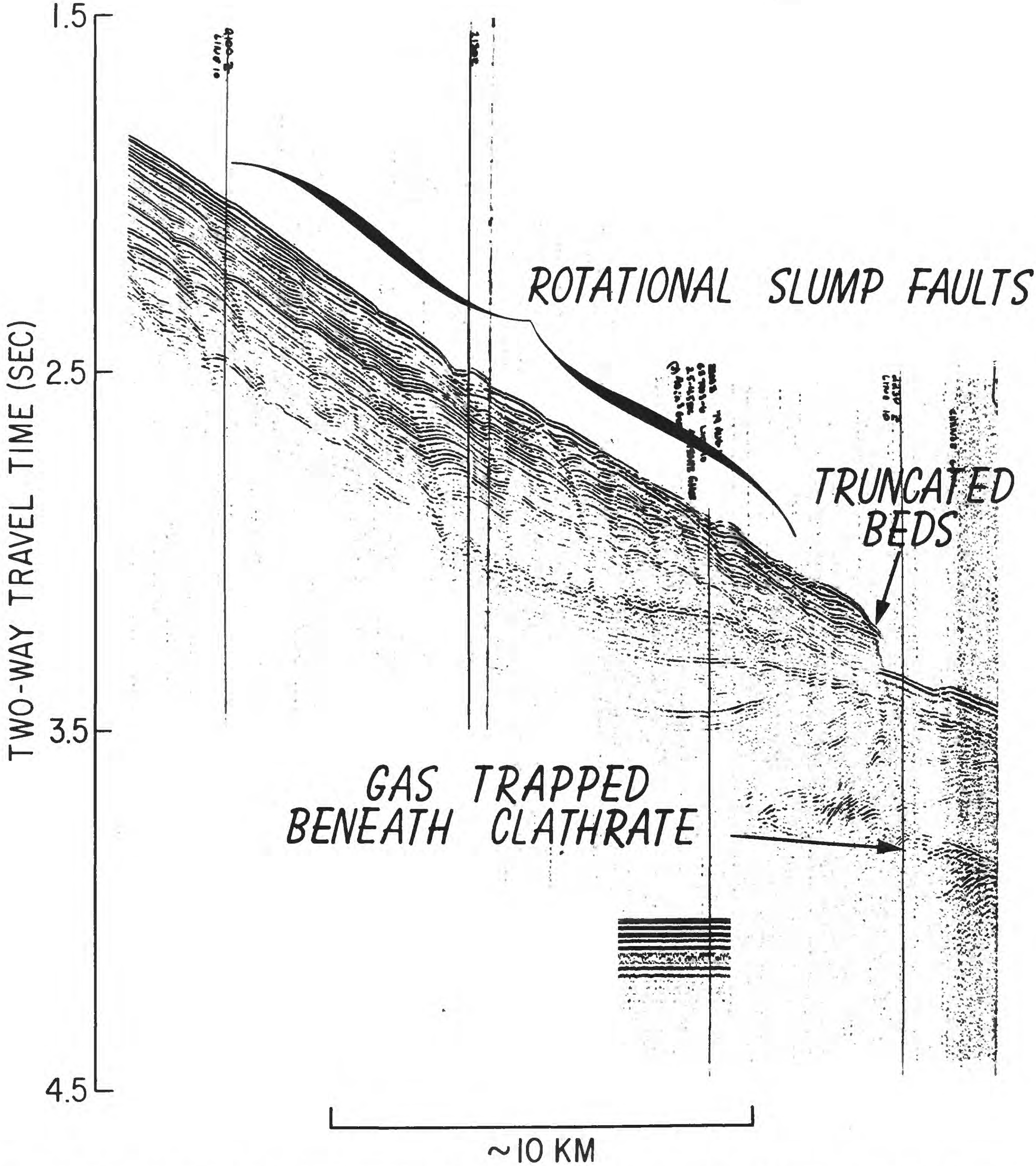


Figure 58.--Picture of high-resolution seismic-reflection profile near lat 33°N., long 76°W. showing truncated beds associated with a large slump scarp (figs. 48, 59, 60) and rotational slump faults on the lower Continental Slope. Note the bottom-simulating reflector believed to be due to a frozen clathrate layer and "bright spots" believed to be caused by gas trapped beneath this layer.

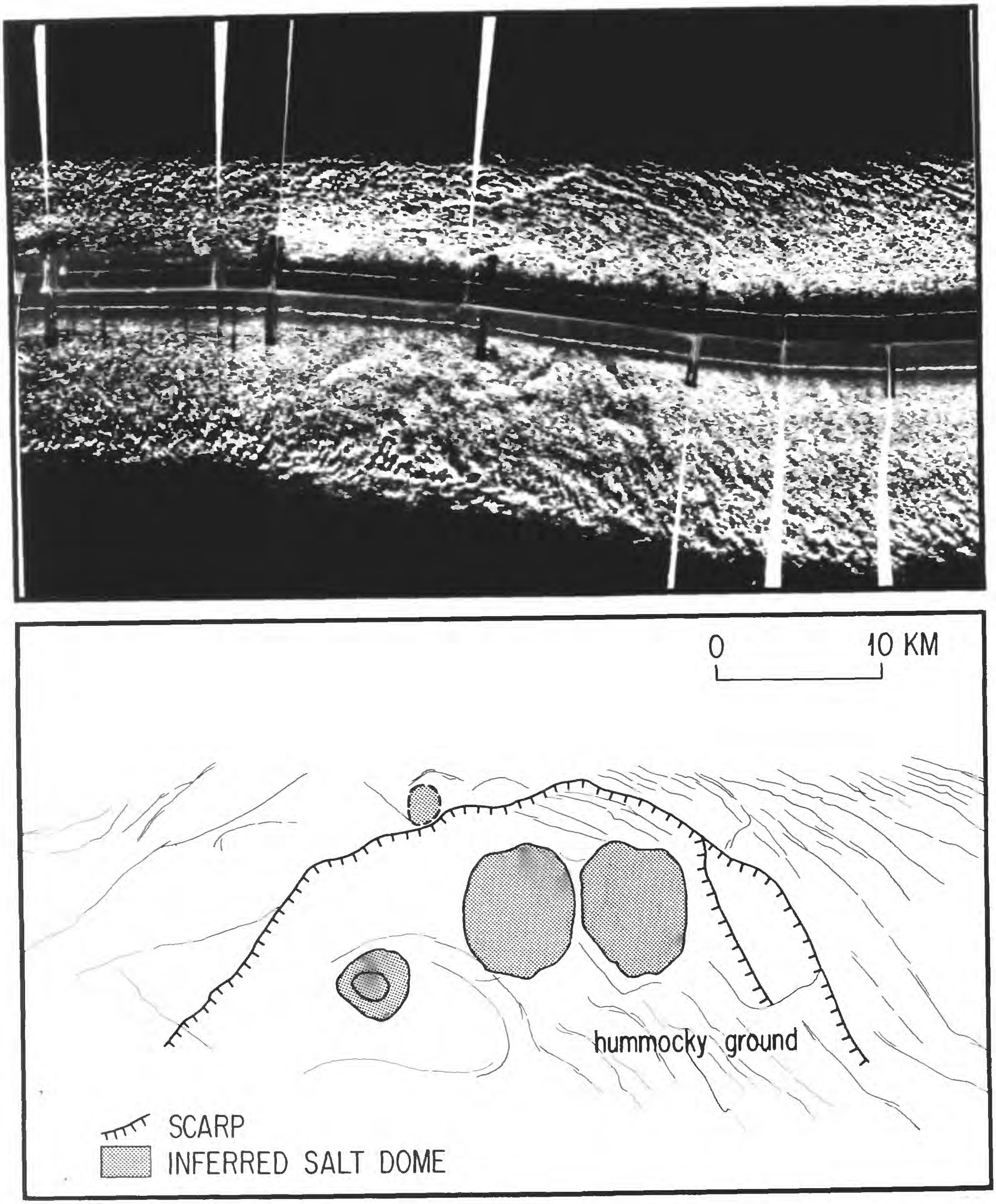


Figure 59.--Long-range sidescan-sonar image (GLORIA) and its interpretation showing slump scarp near the base of the Continental Slope near lat 33°N., long 76°W. (fig. 48). This expression of massive slumping is unique to this area and is believed to be caused by subsidence related to removal of salt through the large two diapirs shown, which are breached.

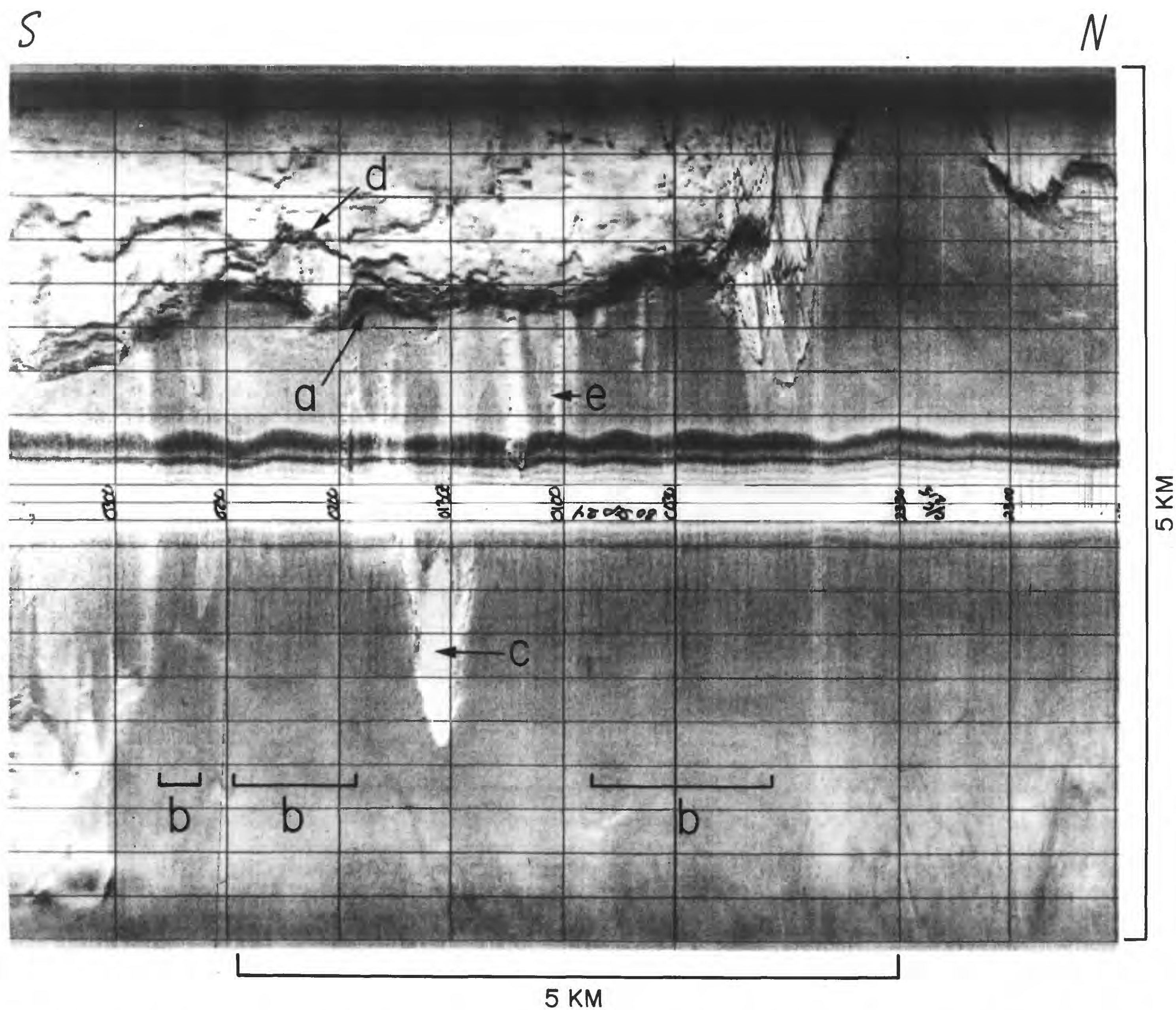


Figure 60.--Mid-range sidescan-sonar image of a section of the slump scarp (a) shown on figs. 48, 58, and 59. Below the scarp, the bottom is furrowed by deep tracks (10m)(b) caused by large blocks breaking off the face and sliding downslope. Crossing tracks show that this breaking off of blocks is a continuing process. On this image strong returns are dark and shadows are light.

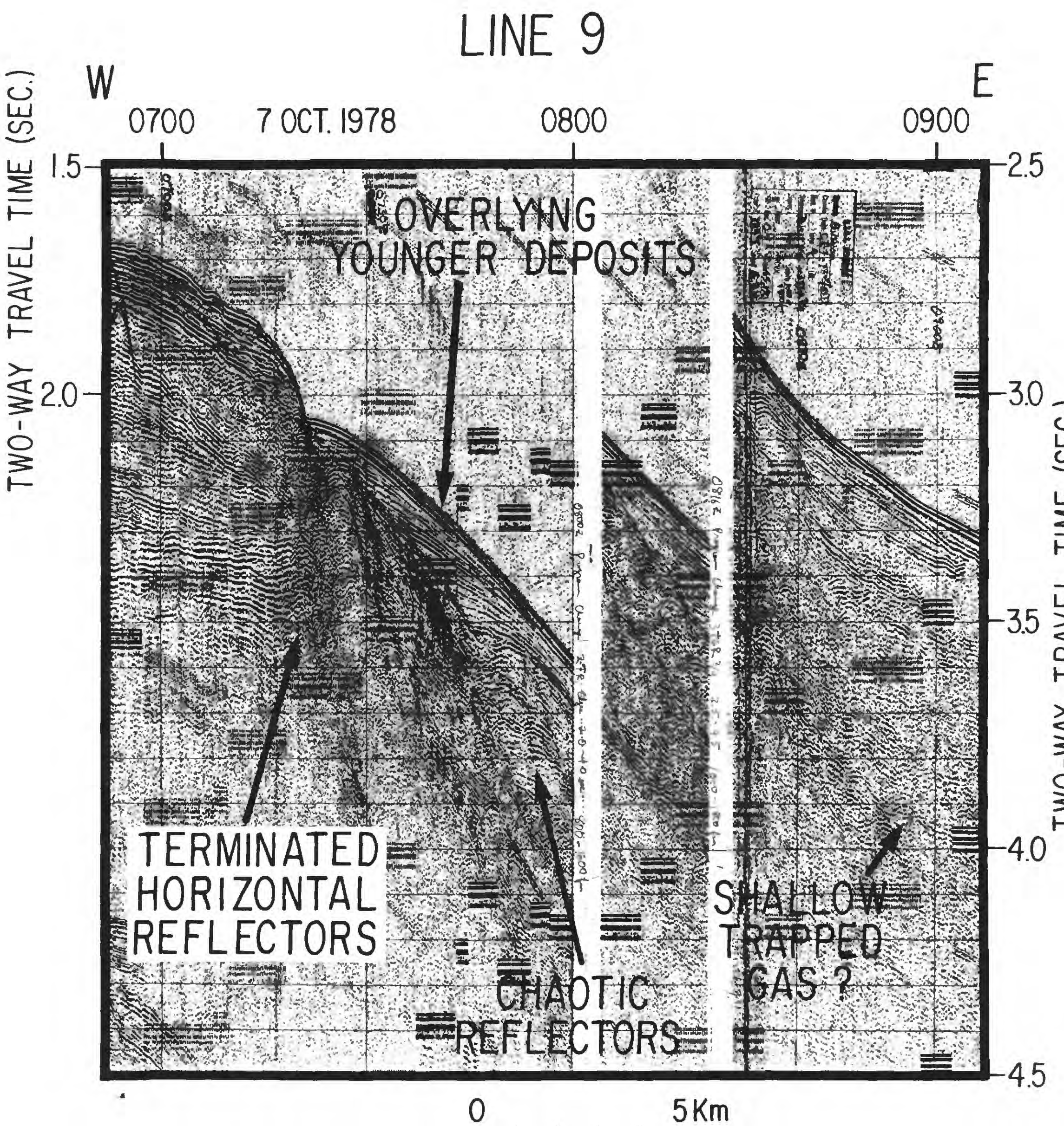
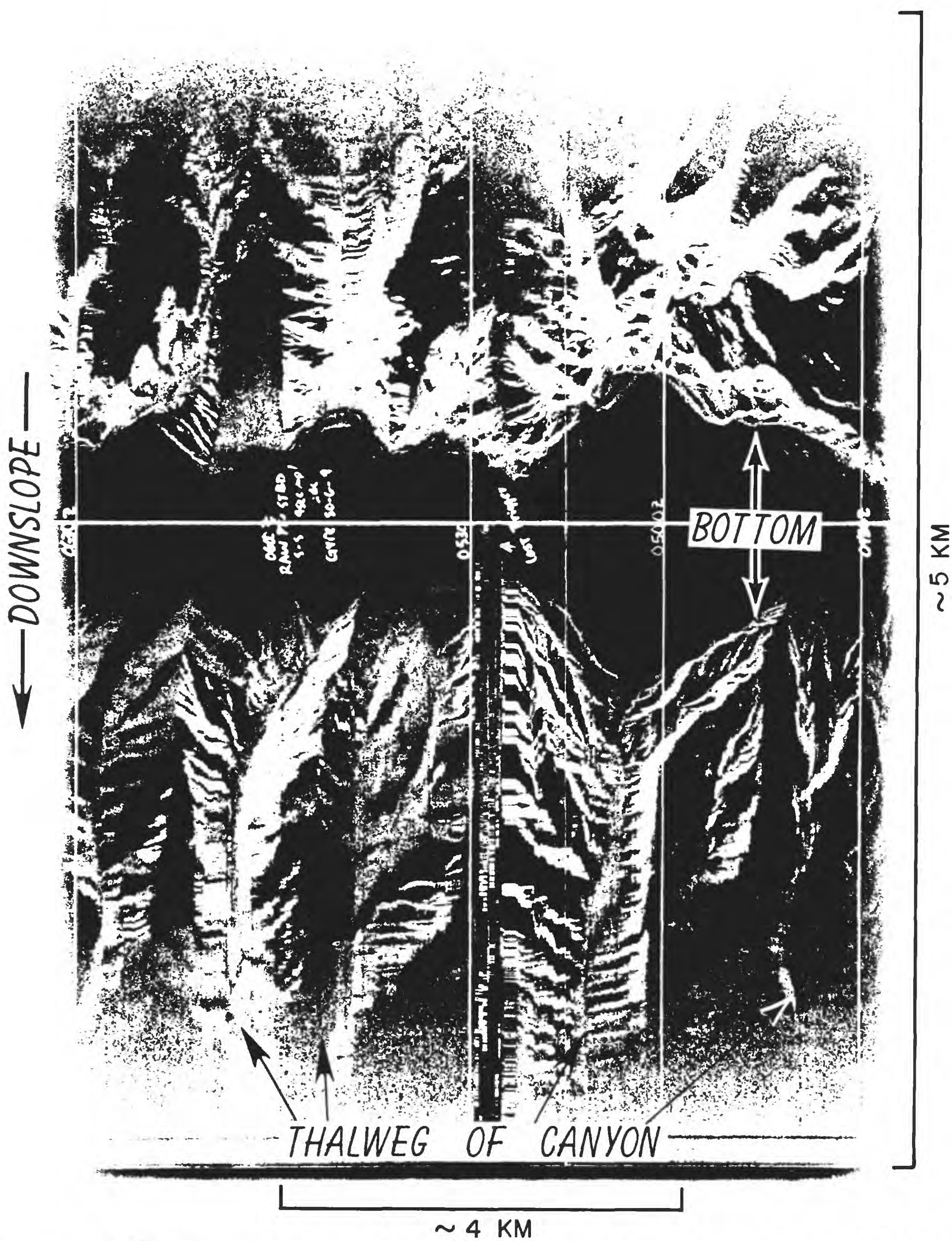


Figure 61.--Picture of high resolution seismic-reflection profile near lat 31°15'N., long 77°15'W. showing the shallow expression of a large listric fault which offsets the bottom near the top of the Continental Slope. The fault can be traced for about 80 km along slope between lats. 31° and 32°N. The chaotic reflectors downslope of the offset bottom are believed to be evidence for the past slope instability. Also shown in the picture are "bright spots" believed to be due to shallow trapped gas beneath the clathrate layer (fig. 48).



re 62.--Mid-range sidescan sonar image of the upper slope in nominated lease blocks, Manteo OCS quadrangle, Lease Sale 56, showing canyon systems. Photo is reverse printed so that strong returns are light and shadows are dark. The image is not slant-range corrected, therefore the relief on both sides of the center line of the record is a profile of the bottom along the slope. The top of the record shows the canyons in an upslope direction from the towed fish, the bottom of the record is downslope. The canyon whose thalweg is near 0500z is approximately 700 m deep between adjacent ridges.

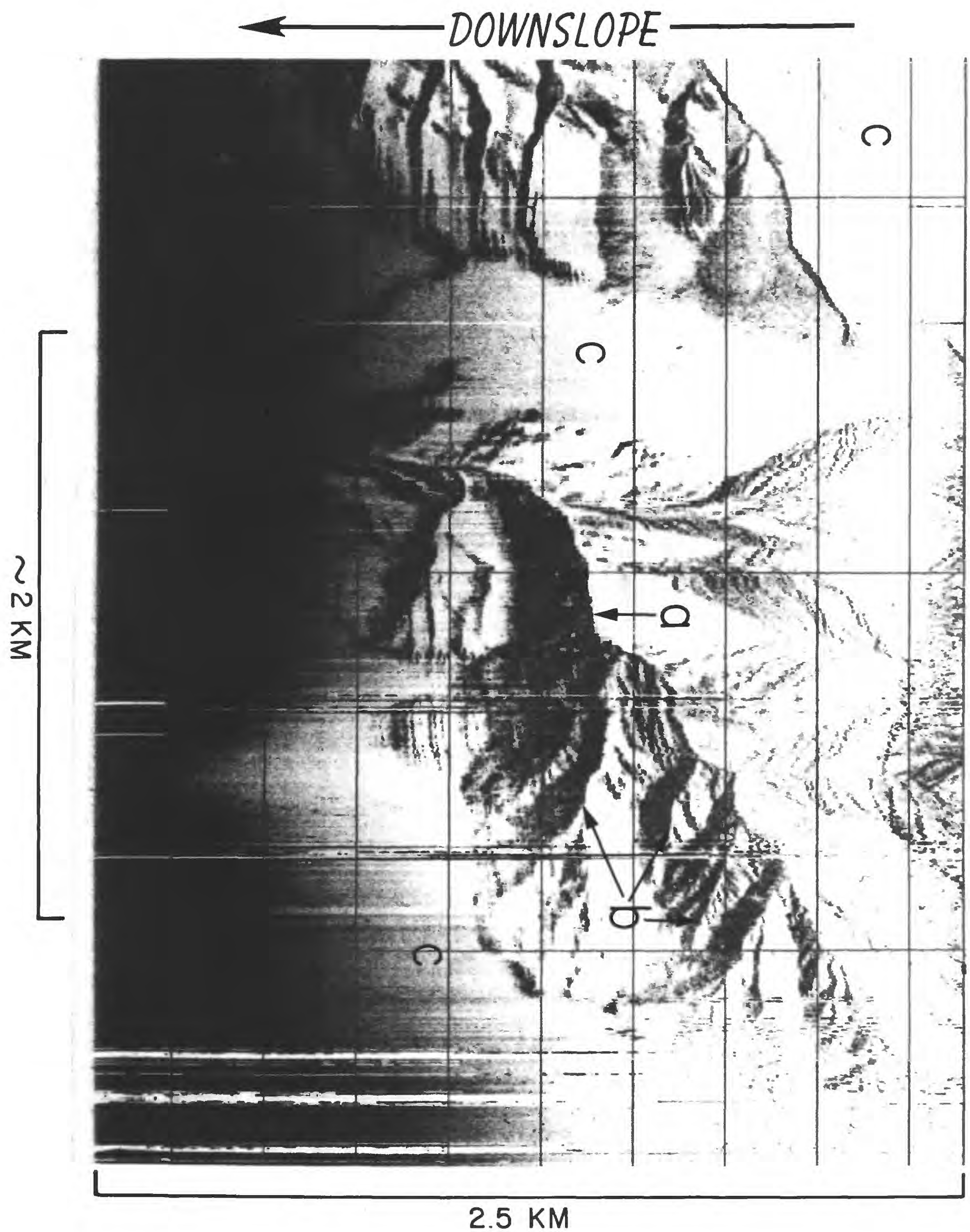


Figure 63--Downslope side of mid-range sidescan-sonar image showing details of a submarine canyon. Dark areas are strong return, light areas are shadows or smooth slope. Axis of canyon (a) is marked by meanders along tributary chutes (b). Note undissected slope (c).

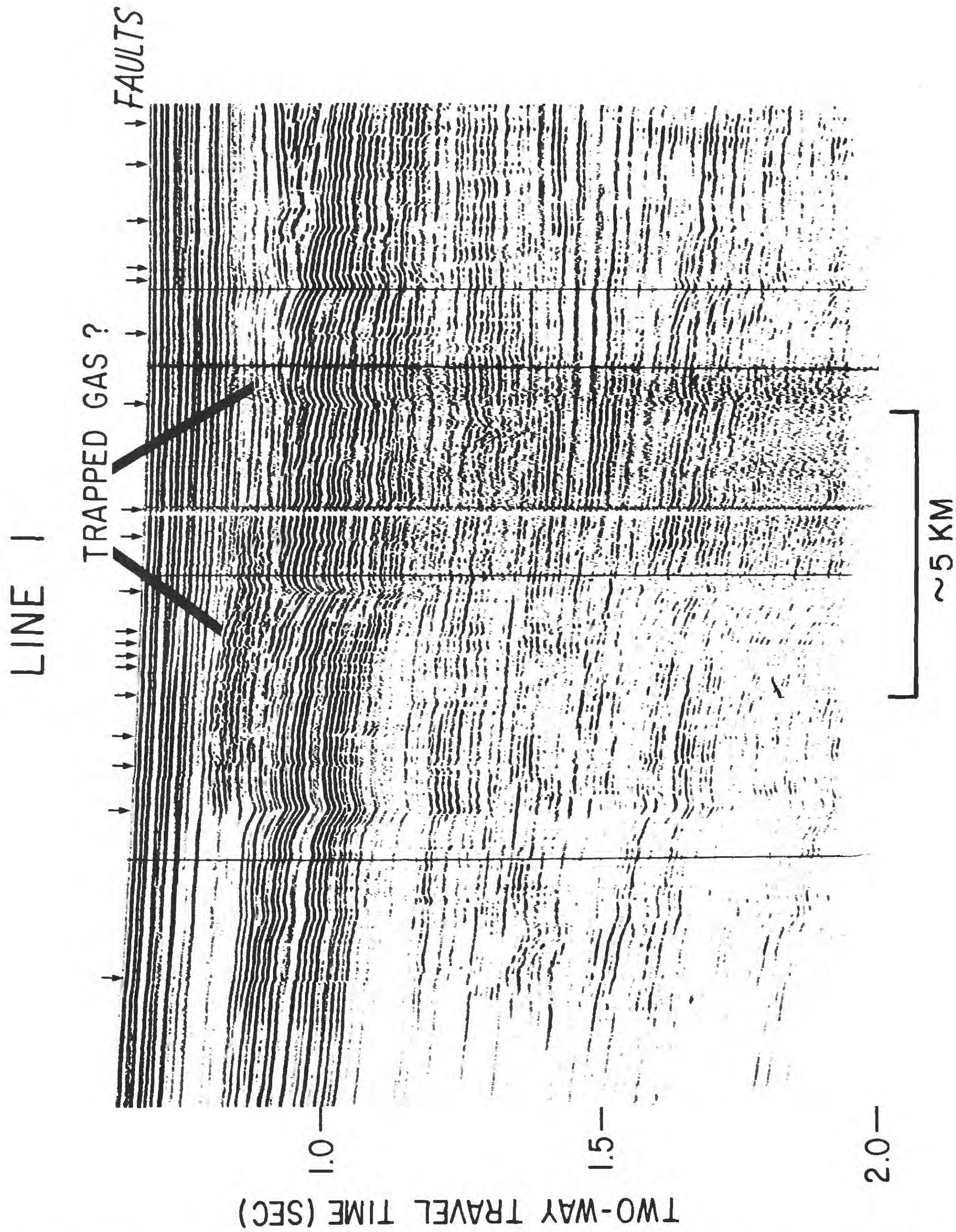


Figure 64.--Picture of high-resolution seismic-reflection profile from the northern Blake Plateau at lat 33°45'N., long 76°13'W., showing a strong signal return in the shallow subbottom which may be due to a shallow gas. The association of this feature with the numerous shallow splay faults of the major growth-fault system (marked by arrows) suggests gas migration from depth along the faults and trapping within closure perhaps associated with a barrier sequence in the shallow subsurface.

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CHAPTER III

PETROLEUM POTENTIAL AND ESTIMATES OF UNDISCOVERED RECOVERABLE OIL AND GAS RESOURCES, LEASE SALE 78 CALL AREA

By
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The call area for proposed lease sale 78 includes three provinces (the South Atlantic Continental Shelf, the Blake Plateau, and the Carolina Trough) that were assessed in the recent report, "Estimates of undiscovered recoverable resources of conventionally producible oil and gas in the United States - a summary" (Dolton and others, 1981). For this discussion, the undiscovered recoverable oil and gas resources were assessed by province (shelf, Blake Plateau, and Carolina Trough) and the estimates were aggregated by Monte Carlo technique for 0-200-m and 200-2,500-m water depth areas. The petroleum potential of the areas beyond 2,500-m water depth included in the call area for the proposed lease sale was not assessed because geological information is insufficient.

The undiscovered recoverable resources are those quantities of crude oil and natural gas that are estimated to exist in favorable geologic settings. The estimates of these quantities are based on a careful geological analysis, province exploration history, analog calculations, and volumetric-yield procedures (Miller and others, 1975).

The initial estimates were made by using a direct subjective assessment procedure, a Delphi approach (Dolton and others, 1981). Because of uncertainties involved in assessing undiscovered resources, estimates of their quantities are expressed as a range of values corresponding to different probability levels. In frontier areas such as the South Atlantic, where no commercial discoveries have been made and where very little drilling has been done, there is an uncertainty (risk) that no recoverable hydrocarbon exists. This risk of commercially recoverable resources being present is expressed in terms of a marginal probability.

The estimates of undiscovered recoverable oil and gas resources were assessed in two separate events. First, the province was assessed for the likelihood of any recoverable hydrocarbons being present, i.e., a marginal probability or a risk that the recoverable hydrocarbons exist. Second, the quantities of these recoverable oil and gas commodities were assessed as probability estimates of a low (F95) value and a high (F5) value corresponding to 95 percent and 5 percent probabilities of occurrence of more than that amount. Also, a modal value, that is, an estimate of the quantity of resource associated with the greatest likelihood of occurrence was estimated. From these initial estimates, a probability distribution curve was generated.

SHELF

In 1978, the Federal leasing of the South Atlantic Continental Shelf was offered for the first time and 43 OCS tracts were sold. Subsequently, six exploratory wells were drilled in the southeast Georgia Embayment. The results of this drilling were disappointing. All wells were plugged and abandoned at drilled depths less than 2,666 m (8,000 ft) without any commercial discoveries or indication of significant shows of hydrocabons.

The sedimentary section beneath the Continental Shelf is relatively thin (less than 3 km) and, for the most part, lacks the thermal maturity for hydrocarbon generation. The COST GE-1 well, described in Chapter

I (fig. 11) of this report and by Amato and Bobout (1978) and Scholle (1979), indicated that only Lower Cretaceous or Jurassic sedimentary rocks below 2,600 m (8,000 ft) would attain sufficient maturation for hydrocarbons to be generated. The younger rocks particularly those between 933 m (2,800 ft) and 1,866 m (5,600 ft) have high organic carbon content but are too thermally immature to be considered as source beds. Long-range migration of hydrocarbons from the adjacent basins of the slope, where the sedimentary rocks are thicker than 12 km, would be necessary to create any significant accumulation beneath the shelf. Good-quality reservoirs, effective seals, and potential structural and stratigraphic traps are available for petroleum entrapment. However, a general lack of thermally mature source rocks coupled with recent disappointing results from the exploratory drilling reflects a somewhat low hydrocarbon potential beneath the shelf.

In view of the above geological evaluation, the marginal probability (MP) or chance that commercial volumes of hydrocarbons are present beneath the shelf is estimated to be .15 for oil and .27 for gas. These MP's mean that there is only a 15 percent probability of finding any commercial quantities of undiscovered recoverable oil and a 27 percent probability of finding any commercial quantities of undiscovered recoverable gas. The F95 and F5 values are the unconditional estimates of undiscovered recoverable oil and gas resources, corresponding to 95 percent and 5 percent probabilities of occurrence of more than that amount; also, a statistical mean value was calculated.

Shelf: 0 m to 200 m

	F95	F5	Mean
Oil (billion barrels)	0	.33	.05
Gas (trillion cubic feet)	0	.95	.16

Figure 65 shows the probability curves for these estimates. No significant resources are expected to be present nearshore within the 3-mile limit of State waters.

SLOPE

In this assessment, the slope from 200-m to 2,500-m water depth includes two geologic provinces, the Blake Plateau and the Carolina Trough. With the exception of a few shallow (less than 1,000 m) core holes, no exploratory well has been drilled either in the Blake Plateau or Carolina Trough area. The subsurface information comes mostly from seismic interpretations made by Dillon (chap. I, this volume).

The Blake Plateau is a broad, relatively flat, physiographic feature which extends seaward approximately 200-300 km from the shelf break at around 200-m water depth to the Blake Escarpment. The subsurface basinal structure is one of a rift-type geosyncline overlying a block-faulted basement of partly transitional and partly oceanic crust. The Carolina Trough, to the north of Blake Plateau, is a long (450 km), narrow (40 km), and linear basin, characterized by a major growth-fault system on its landward side and a salt-diapir system along its seaward edge at around 3,000-m water depth (Dillon and others, in press). Apparently, the two basins are separated by the Blake Spur Fracture Zone.

Beneath the Blake Plateau, the basin is filled by carbonates, evaporites, and some terrigenous clastics of Jurassic and younger age; the total sedimentary rock thickness is estimated to be 13 km. The total sediment thickness in the Carolina Trough is estimated to be a little more than 12 km, and seismic correlations indicate that Lower Jurassic strata overlie the postrift unconformity. Sections ranging through Cretaceous and younger age are present in both the Blake Plateau and Carolina Trough. The rocks of the outer Blake Plateau are characterized by Cretaceous and older reef banks and marginal reef-complex facies that extend regionally through the Bahama carbonate platform to Cuba and into offshore western Florida. Organic-matter-rich beds of Early Cretaceous age were reported from DSDP 391, a shallow core hole at the eastern edge of the Blake Plateau. These beds, if present and buried deep enough in other parts of the basin, could achieve maturation and offer potential source beds. Further, some reefal and carbonate buildup on the basement highs, particularly toward the eastern margin of the Blake Plateau, provides favorable geologic conditions for hydrocarbon accumulation. Seismic evidence indicates that the potential structures on the Blake Plateau are larger than those on the adjacent shelf, there is every reason to believe that Blake Plateau province offers a better geologic setting for oil and gas accumulations than the adjacent Continental Shelf. However, the water depth would be an important limiting factor in exploration of prospective targets.

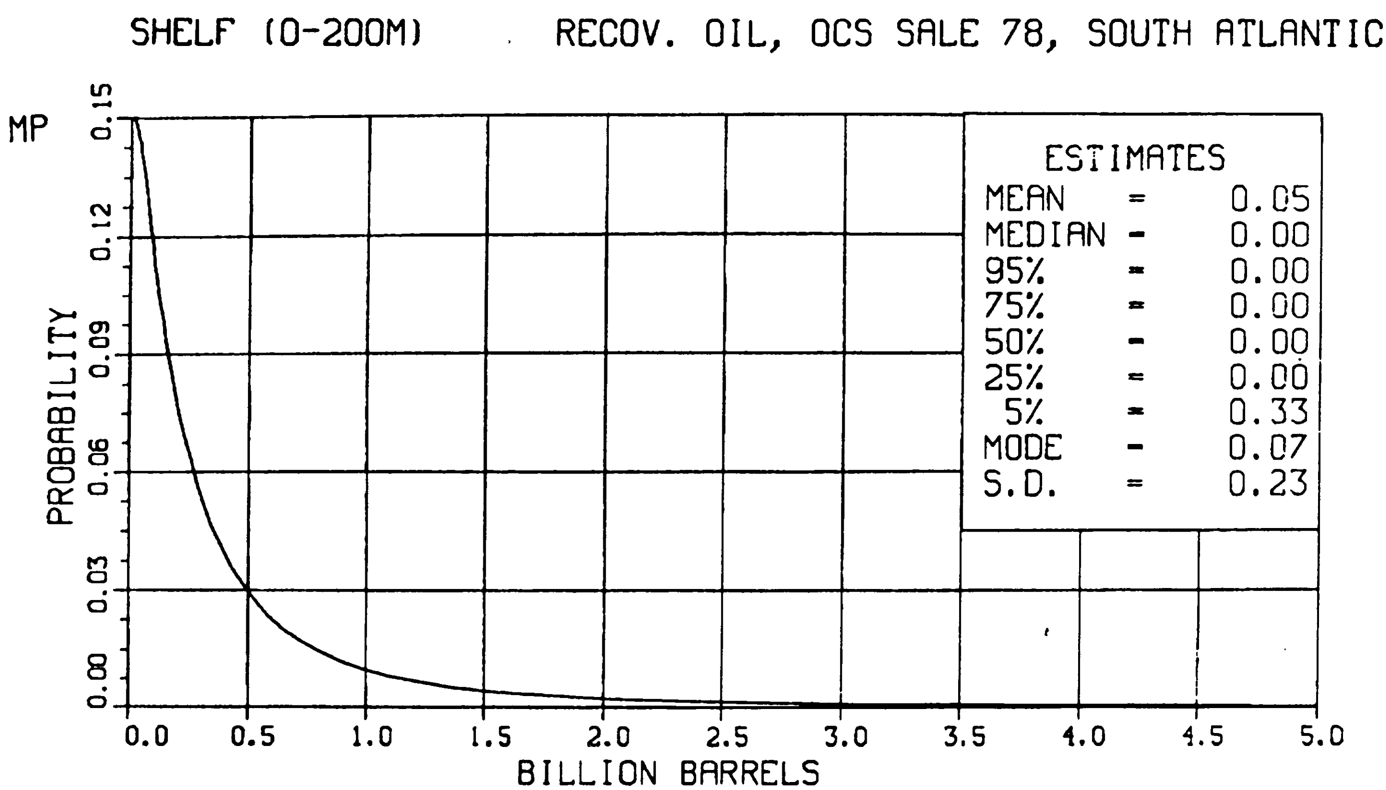
North of the Blake Plateau, the Carolina Trough is believed to be a zone of transitional facies from a predominantly carbonate facies of the Blake Plateau to a mixed carbonate-clastic deltaic facies in the Middle and North Atlantic. The strata beneath the Carolina Trough are, therefore, expected to include both carbonate and noncarbonate rocks, providing ideal conditions for stratigraphic traps. A regional unconformity at the base of the Cretaceous section overlies Jurassic sedimentary rocks that would have reached thermal maturity, and possible hydrocarbon accumulations could occur beneath the unconformity. Other possible traps would be structural traps associated with the salt diapirs and growth faults. The oil and gas resource potential of the Carolina Trough is considered to be greater than that of the other geologic provinces in the South Atlantic.

The aggregated marginal probability (Powers, 1979) for the slope area of OCS Sale 78 (Blake Plateau and Carolina Trough) is .53 for the oil and .78 for the gas. Following are the unconditional estimates of undiscovered oil and gas resources for this area, corresponding to 95 percent and 5 percent probabilities of occurrence of more than that amount, together with a statistical mean.

Slope: 200 m to 2,500 m

	F95	F5	Mean
Oil (billion barrels)	0	3.71	.93
Gas (trillion cubic feet)	0	12.11	3.57

Figure 66 shows the probability curves for the oil and gas resource estimates for the slope.



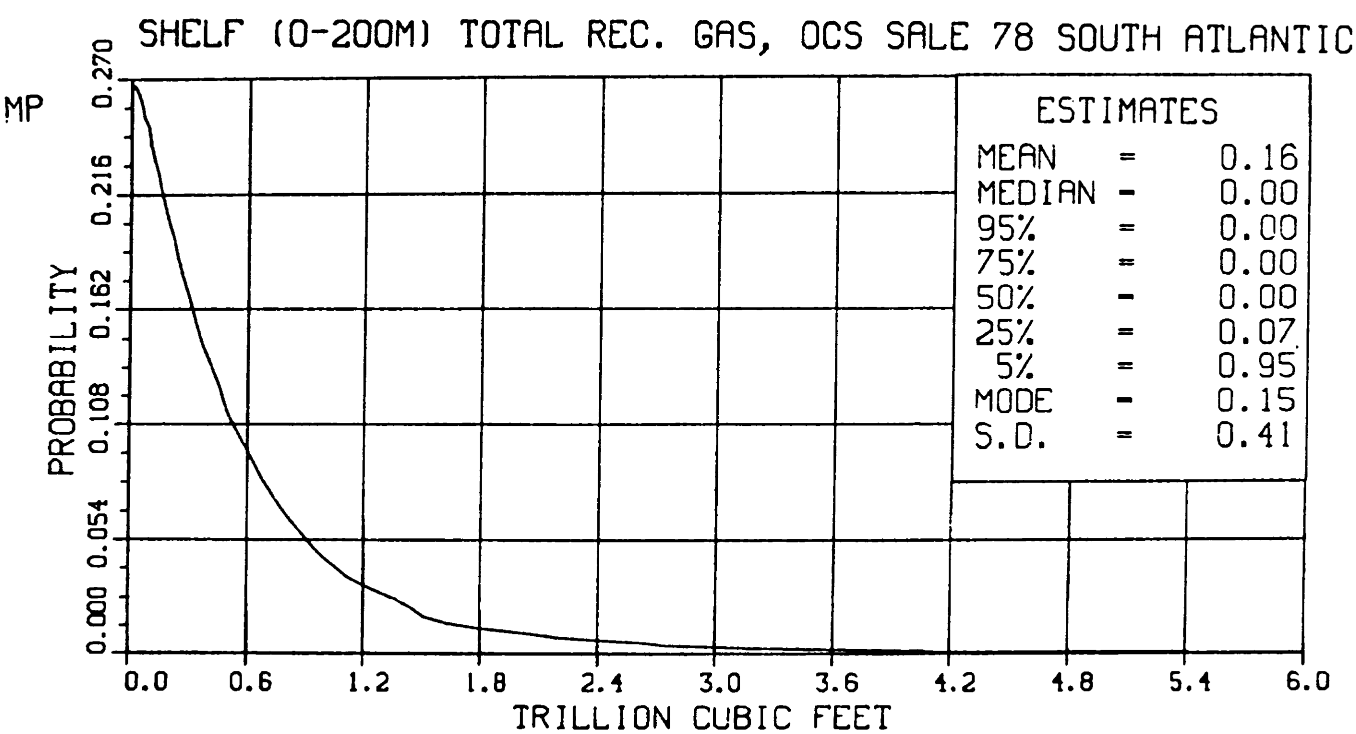
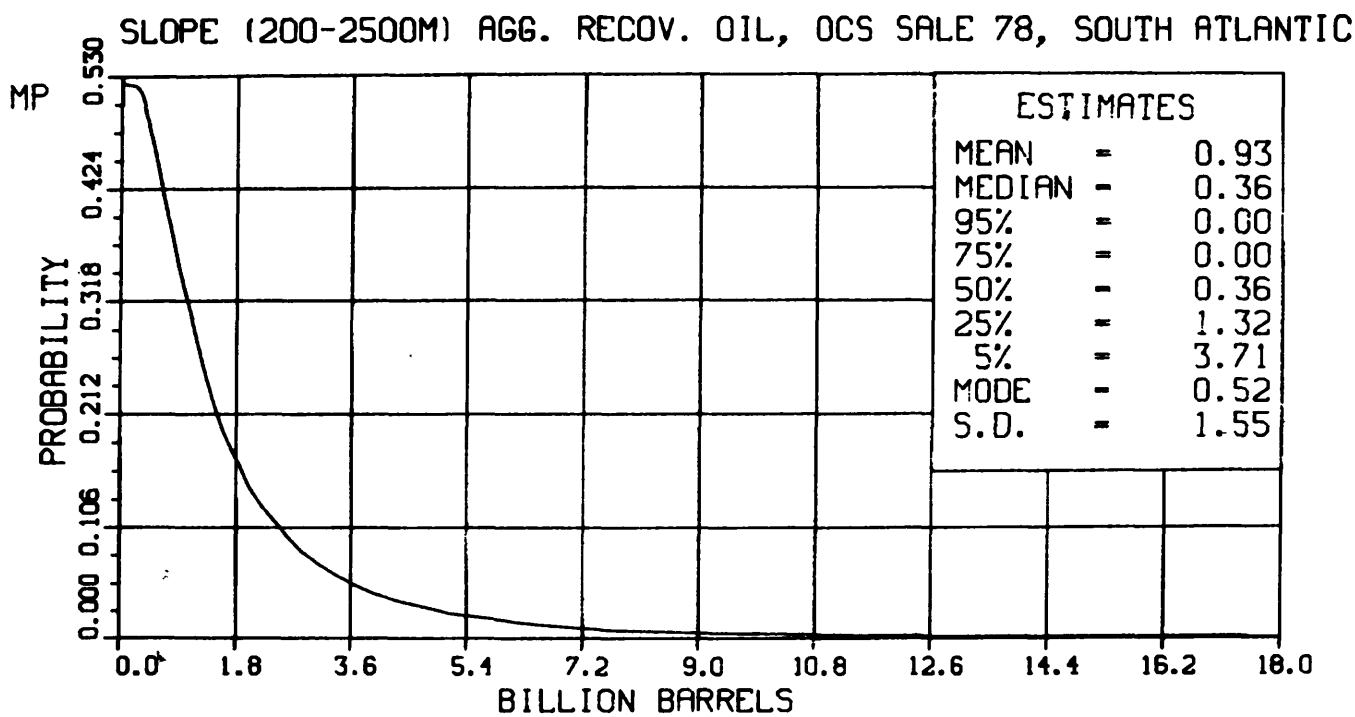


Figure 65.--Probability distribution curves showing marginal probability (MP), standard deviation (SD), and probability estimates for undiscovered recoverable oil and gas; OCS Sale 78 (0-200 meter water depth, shelf).



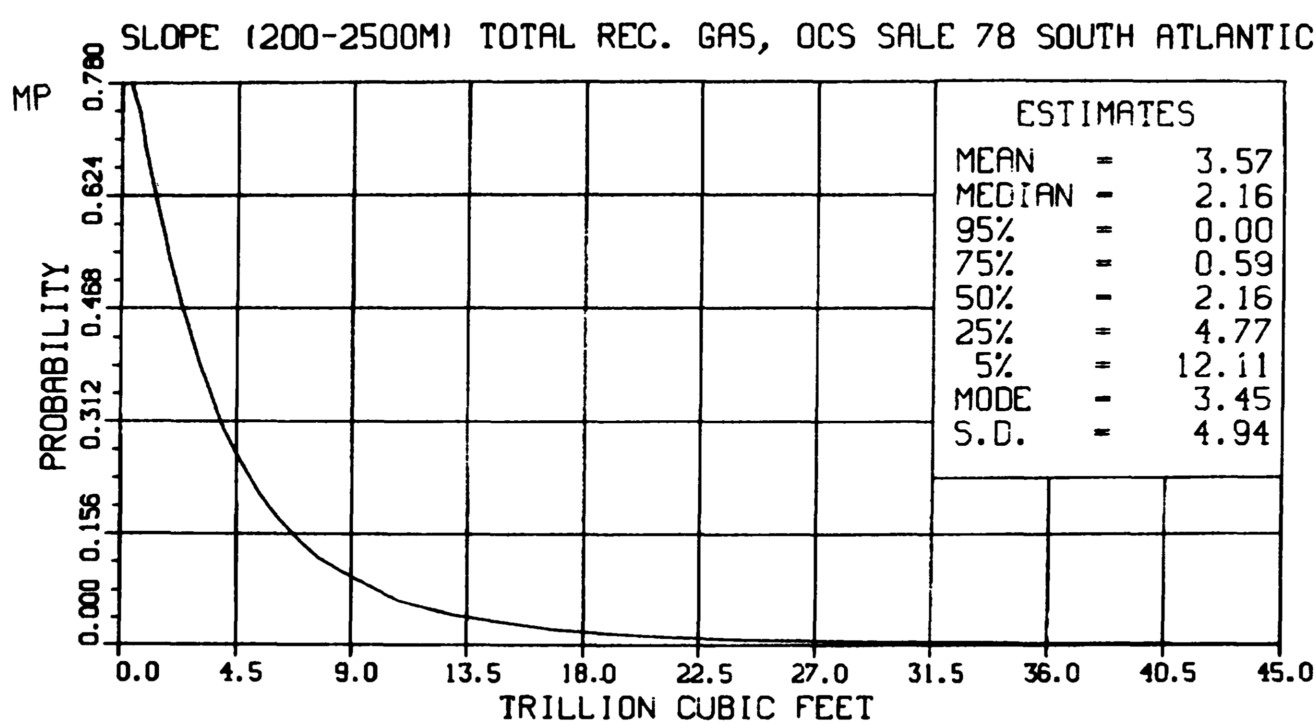


Figure 66.--Probability distribution curves showing marginal probability (MP), standard deviation (SD), and probability estimates for undiscovered recoverable oil and gas; OCS Sale 78 (200-2500 meter water depth, slope).

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