UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

SUMMARY REPORT OF THE SEDIMENTS, STRUCTURAL FRAMEWORK, PETROLEUM POTENTIAL AND ENVIRONMENTAL CONDITIONS OF THE UNITED STATES MIDDLE AND NORTHERN CONTINENTAL MARGIN IN AREA OF PROPOSED OIL AND GAS LEASE SALE NO. 82

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U.S. Geological Survey

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

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1. Introduction and Summary

by J.A. Grow, J.S. Schlee, J.M. Robb and D. O'Leary

This report has been compiled in response to a request by the Bureau of Land Management (Memorandum of 25 Sept 1981) to update and summarize the geology of the U.S. Atlantic continental margin between Cape Hatteras and the Georges Bank (Oil and Gas Lease Sale No. 82, fig. 1-1). This area extends beyond the tracts leased in sales 40, 42, and 49 and those proposed for Lease Sales 52, 59 and 76 (Grow, 1981). The seaward limit of the report area falls in water depths of more than 4,000 m.

Previous U.S. Geological Survey (USGS) summary reports for Lease Sales 49, 52, and 59 have emphasized primarily data relevant to leasing on the Continental Shelf and upper Slope (Mattick and others, 1981; Schlee and others, 1979a and b). The summary report for Lease Sale 76 (Grow, 1981) covers much the same area as this sale, except that the Georges Bank basin and the Gulf of Maine are included in Sale No. 82. Two Continental Offshore Stratigraphic Test (COST) wells B-2 and B-3 (fig. 1-2) have now been completed in the Baltimore Canyon Trough and provide valuable stratigraphic, lithologic, and geochemical information (Smith and others, 1976; Scholle, 1977a, and b; Amato and Simonis, 1979; Scholle, 1980). In addition, data from three nearby wells drilled were released when Shell and Gulf Oil companies relinquished the lease blocks on which they were drilled (Libby-French, 1981). Two more COST wells (G-1 and G-2) drilled in the Georges Bank Basin (Amato and Bebout, 1980; Amato and Simonis, 1980) encountered a thick sequence of Jurassic limestone, dolomite, and anhydrite. Additional scientific publications concerning the deep structure and evolution of the continental margin have identified Jurassic and Lower Cretaceous paleoshelf-edge systems beneath the present Continental Slope and thick sequences of sediments beneath the Continental Rise (Mattick and others, 1975; Schlee and others, 1976, 1977, 1979c; Grow and Markl, 1977; Grow and others, 1979a and b; Klitgord and Behrendt, 1979; Tucholke and Mountain, 1979; Grow, 1980; Poag, 1980; Schlee and Grow, 1980; Klitgord and Grow, 1980; Schlee, 1981; Mattick and others, 1981; Mountain, 1981; Schlee and Jansa, 1981).

Multichannel seismic-reflection profiles collected over the Continental Shelf, Slope, and Rise by the USGS and the German Geological Survey (BGR) between 1973 and 1979 (fig. 1-2) have delineated two main sedimentary troughs along the U.S. margin. The sedimentary fill is as much as 16 km thick in the Baltimore Canyon Trough and Georges Bank Basin; beneath the continental rise, sediments are up to 9 km thick (fig. 1-3). The sediment cover thins along the seaward edge of the Lease Sale 82 report area to an average of 3 to 4 km. Given adequate source rocks and a high enough geothermal gradient, sedimentary basins with 3 to 5 km of sediment might be expected to generate oil or gas. However, the absence of any deep penetration wells into the thick rise sequence to evaluate source rock or maturation conditions, makes quantitative resource estimates extremely difficult.

Lease Sale 59 includes lease tracts out to water depths of more than 2,000 m (fig. 1-1). The present record for exploration drilling in deep water is approximately 5,000 ft (approx. 1,500 m) and production capability has been developed for water depths of about 400-m. Existing drilling vessels can operate out to depths of approximately 6,000 ft (approx. 1,800 m), and these may be modified to operate at depths of up to 8,000 ft (approx. 2,500 m) by 1985.

During Lease Sale 59, Mid-Atlantic, Public Hearings, Dr. George Lock, Manager of the Offshore Systems Division at Exxon Production Research stated that subsea production concepts should be available to extend production capabilities to well beyond 2,000 feet (600m) in the early 1980's. N.D. Birrell, Chief Marine Engineer, Production Engineering, CONOCO, projected that industry's deepwater production capacity will extend beyond the 6,000 feet (1800m) by 1990. In view of these comments, it would appear unlikely that routine exploration drilling on lease tracts in water depths greater than 2,500 m (8000 ft) will be attempted before 1985 or that tracts deeper than 3,000 m (9900 ft) could be drilled before 1990. Therefore, the area under consideration for Lease Sale 82 deeper than 2,500 m (fig. 1-1) probably cannot be drilled for five to ten years.

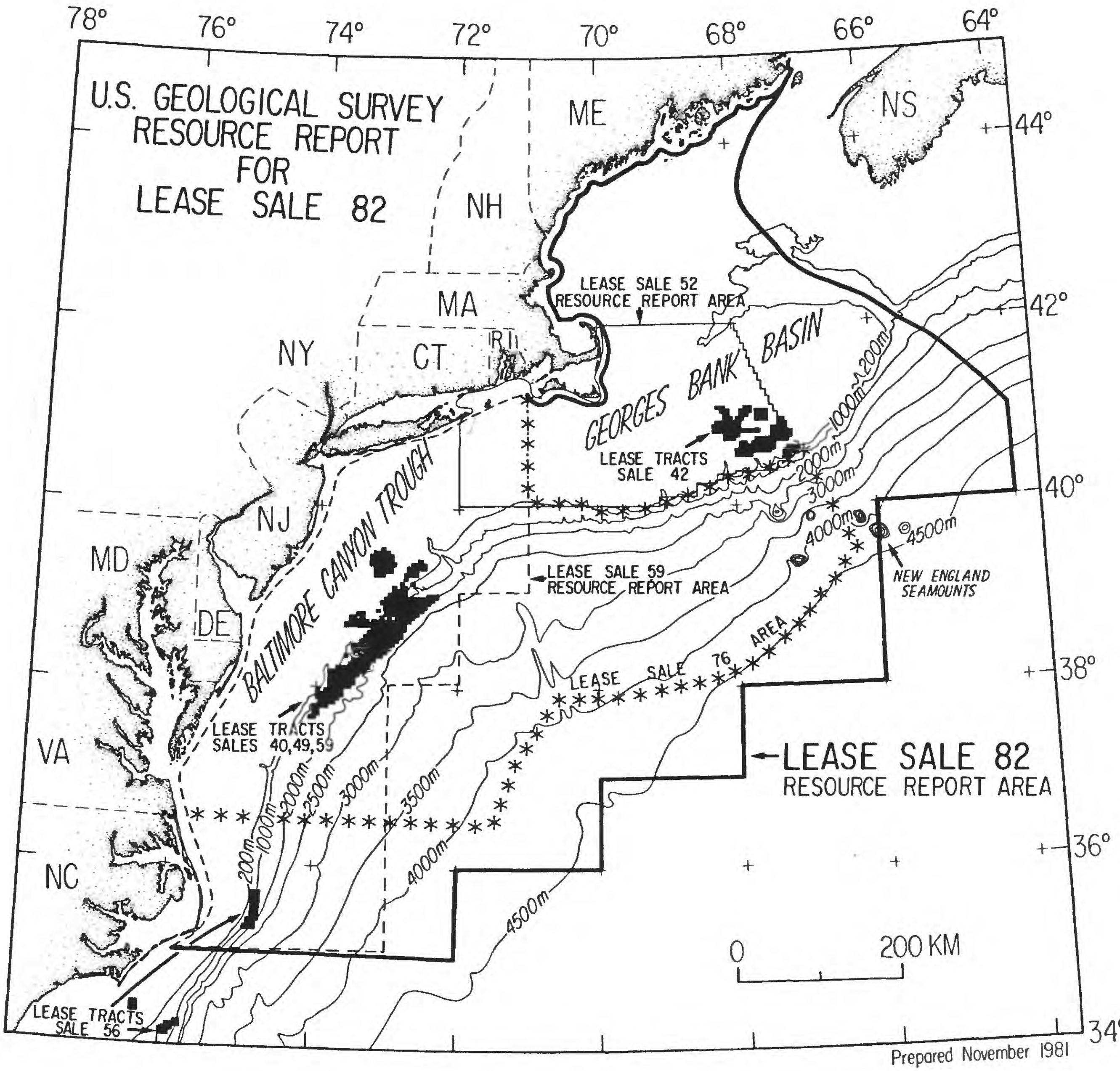


Figure 1-1 Call area for Lease Sale No. 82 with bathymetric contours in meters. Call areas for Lease Sales 52, 59, and 76, also shown along with previous lease tracts sold or pending from Lease Sale Nos. 40, 42, 49, 56, and 59.

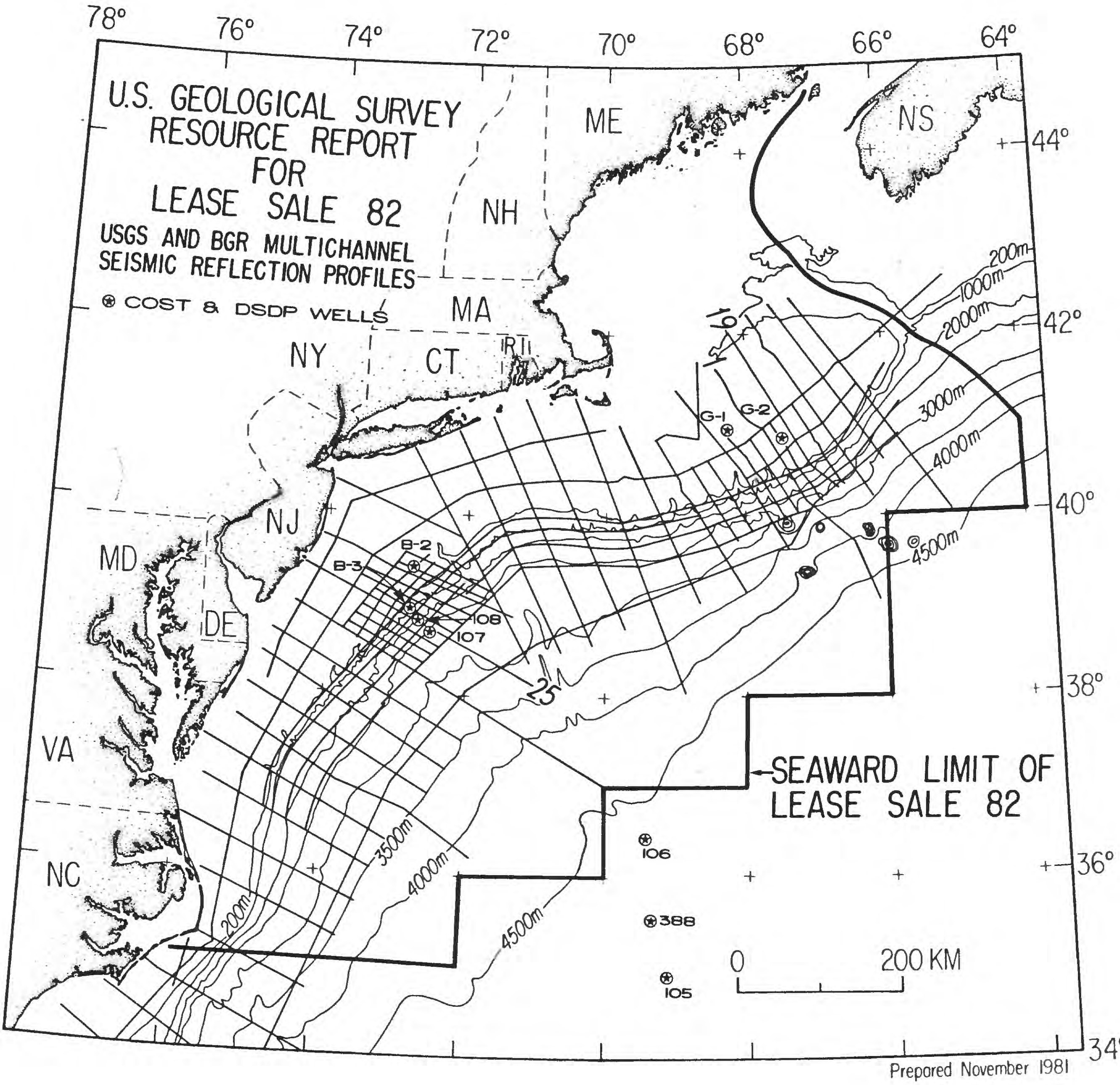


Figure 1-2 USGS and BGR multichannel seismic reflection profiles collected between 1973 and 1979. Interpretations of lines 1 and 25 are given in figures 3-2, 2-2, and 2-3, respectively.

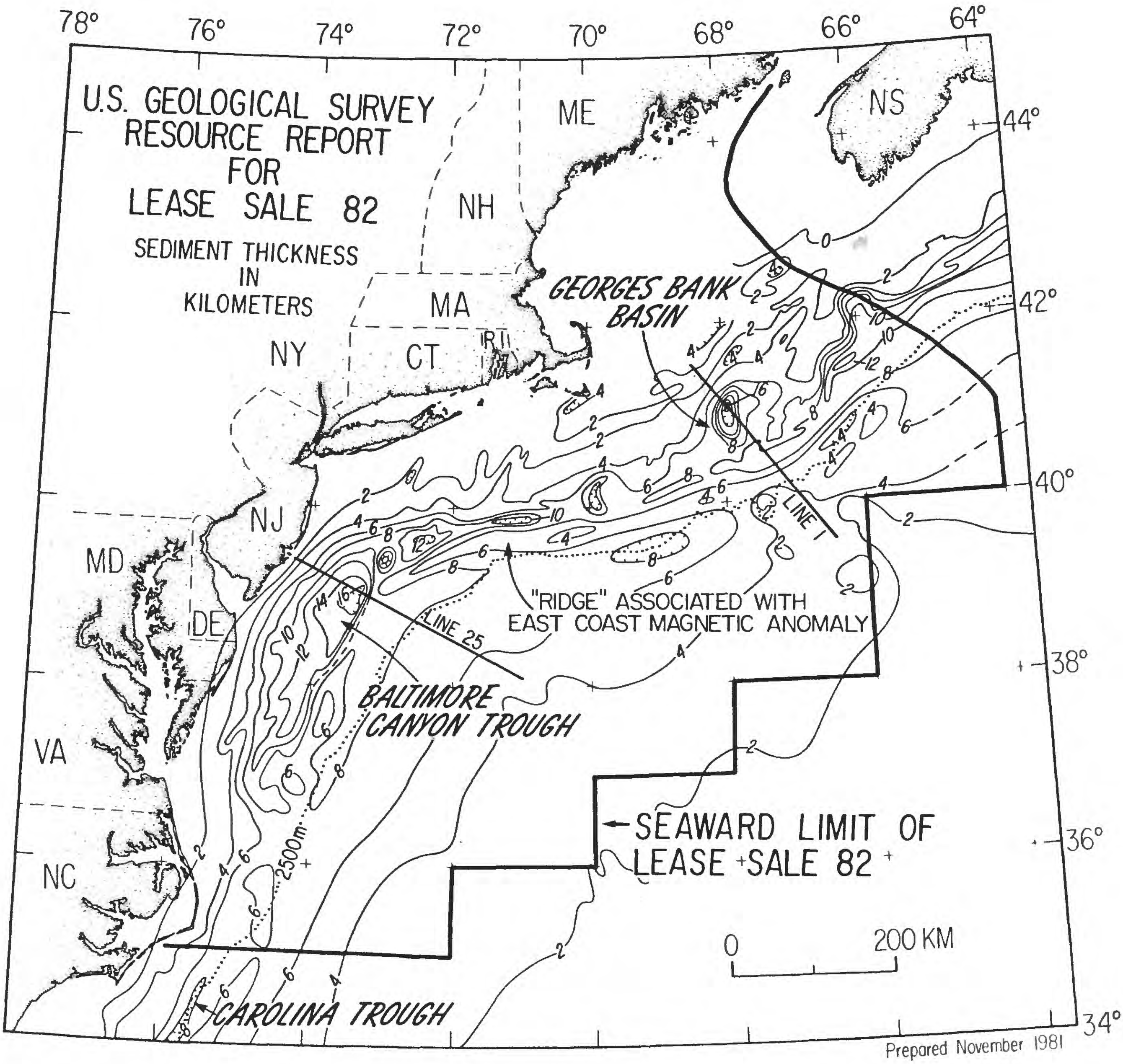


Figure 1-3 Isopach map showing total sediment thickness based on multichannel and single-channel seismic profiles. Modified from Tucholke and others (in press); Schlee (1981); Schlee (unpub. data); and Klitgord and Behrendt (1979). Major depocenters occur in Baltimore Canyon Trough and Georges Bank Basin. See figures 3-2, 2-2, and 2-3, for interpretations along seismic lines 1 and 25, respectively.

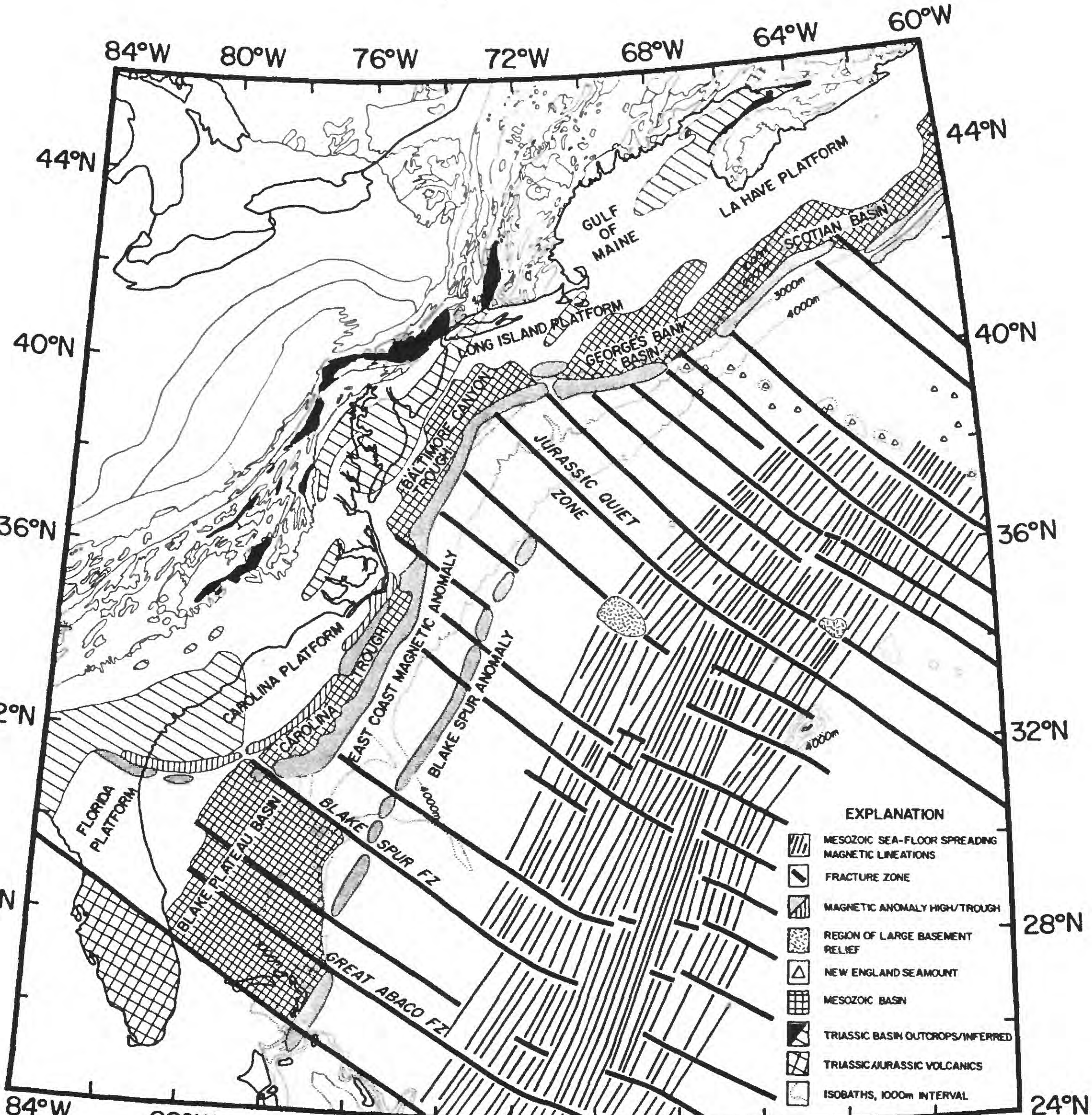


Figure 1-4 Tectonic map showing Baltimore Canyon Trough and Georges Bank Basin (from Klitgord and Behrendt, 1979). The East Coast Magnetic Anomaly (ECMA) marks the landward edge of oceanic crust formed by sea floor spreading which began in the Early Jurassic.

2. Regional geology and geophysics in the vicinity of Baltimore Canyon Trough

by John A. Grow, Kim D. Klitgord, and John S. Schlee

Extensional rifting between North America and Africa during the Triassic created numerous rift grabens within eastern North America and was followed by initiation of sea-floor spreading during the Early Jurassic, approximately 180 million years ago. Baltimore Canyon Trough is one of four major depocenters along the U.S. Atlantic margin (figs. 1-3 and 1-4) which formed during this rifting event and the subsequent phase of sedimentation and subsidence. The boundary between rifted continental crust and oceanic crust is marked by a very prominent magnetic anomaly known as the East Coast Magnetic Anomaly (ECMA; see figs. 1-4 and 2-1). Multichannel seismic profiles across the Baltimore Canyon Trough reveal that up to 13 km of generally undeformed sediments were deposited after sea-floor spreading began and overlie up to 5 km of sediments deposited during the rifting stage (figs. 2-2 and 2-3). Thick prisms of Continental Rise sediments were deposited on the new oceanic crust which formed seaward of the ECMA. Evaporitic conditions during the late stage of rifting and/or the earliest phase of sea-floor spreading resulted in the deposition of salt that formed subsequent diapir structures (figs. 2-4 and 2-5). A composite geologic cross section (fig. 2-5) through Baltimore Canyon Trough illustrates the major features of the Continental Margin off New Jersey with its extremely thick sequence of sedimentary rocks.

A buried carbonate platform and paleoshelf-edge systems of Jurassic and Early Cretaceous age occur beneath the Continental Slope (figs. 2-2, 2-3, and 2-4) and have been an area of strong exploration interest for Lease Sales 49 and 59. Paleoshelf-edge systems similar to those shown in figure 2-3 have also been found beneath the Continental Slope all the way from Cape Hatteras to Georges Bank (Grow and Markl, 1977; Mattick and others, 1978; Grow and others, 1979a; Schlee and others, 1979c). The COST B-3 well was drilled in 820 m of water on the landward side of this paleoshelf-edge system and encountered a show of gas before the well was plugged and abandoned (Amato and Simonis, 1979; Scholle, 1980). Present water depths over this paleoshelf-edge generally vary from 1,000 to 2,500 m. This paleoshelf-edge system has numerous complex structures and will probably continue to attract industry interest for Lease Sale 82. A broad slope "anticline" is located behind the paleoshelf-edge which was formed by differential subsidence and back-tilting of Upper Jurassic and Lower Cretaceous sedimentary units along growth faults (fig. 2-3; also see Grow and others, 1979a, and Grow, 1980). An eastward lensing out of these sedimentary units occurs toward the buried shelf edge (Amato and Simonis, 1979, p. 104) and the maximum structural relief of this slope anticline feature is as much as 300 m (fig. 2-3). Paleoslope complexes on the seaward side of the paleoshelf-edge could include stratigraphic traps with slope and fore-reef facies interfingering with fan deposits on the lower slope and upper rise. Water depths over these types of structures may exceed 2,500 m in places. Deeper water (water depths between 2,500 and 4,000 m) exploration opportunities may include differential compaction structures over buried seamounts and ridges in the oceanic crust (figs. 2-5 and 2-6).

Exploration for traps beneath the Continental Rise in water depths greater than 2,500 m will probably occur only if the exploration along the paleoshelf-edge and paleoslope complex in shallower water (i.e., between 200-2,500 m) is encouraging. Better source rocks are needed than have been found so far in the shallow water of the shelf and upper slope, or in Deep Sea Drilling Project (DSDP) holes much farther out in deep water (DSDP site 105, fig. 1-2). Therefore, although thick sediments occur beneath the Continental Rise in water depths greater than 2,500 m which may be capable of generating oil or gas, the primary interest for Lease Sale 82 will probably remain in water depths of less than 2,500 m.

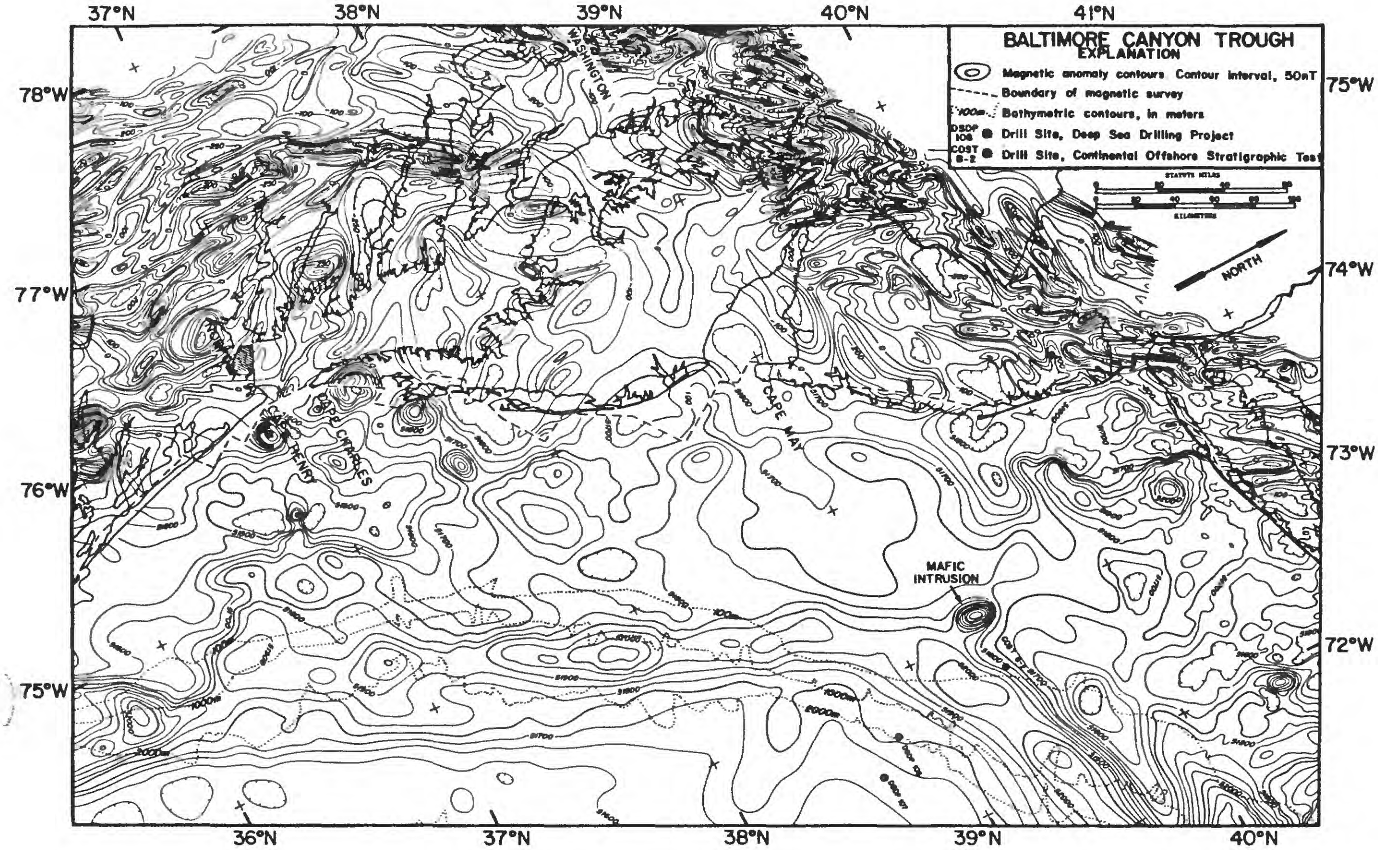


Figure 2-1 Magnetic anomaly contour map for the Baltimore Canyon trough region Contour interval is 50 nT (from Klitgord and Behrendt, 1979). "ECMA" stands for East Coast Magnetic Anomaly (see figs. 1-4, 2-2, 2-3, 2-4, and 2-5).

FIGURE 2-1

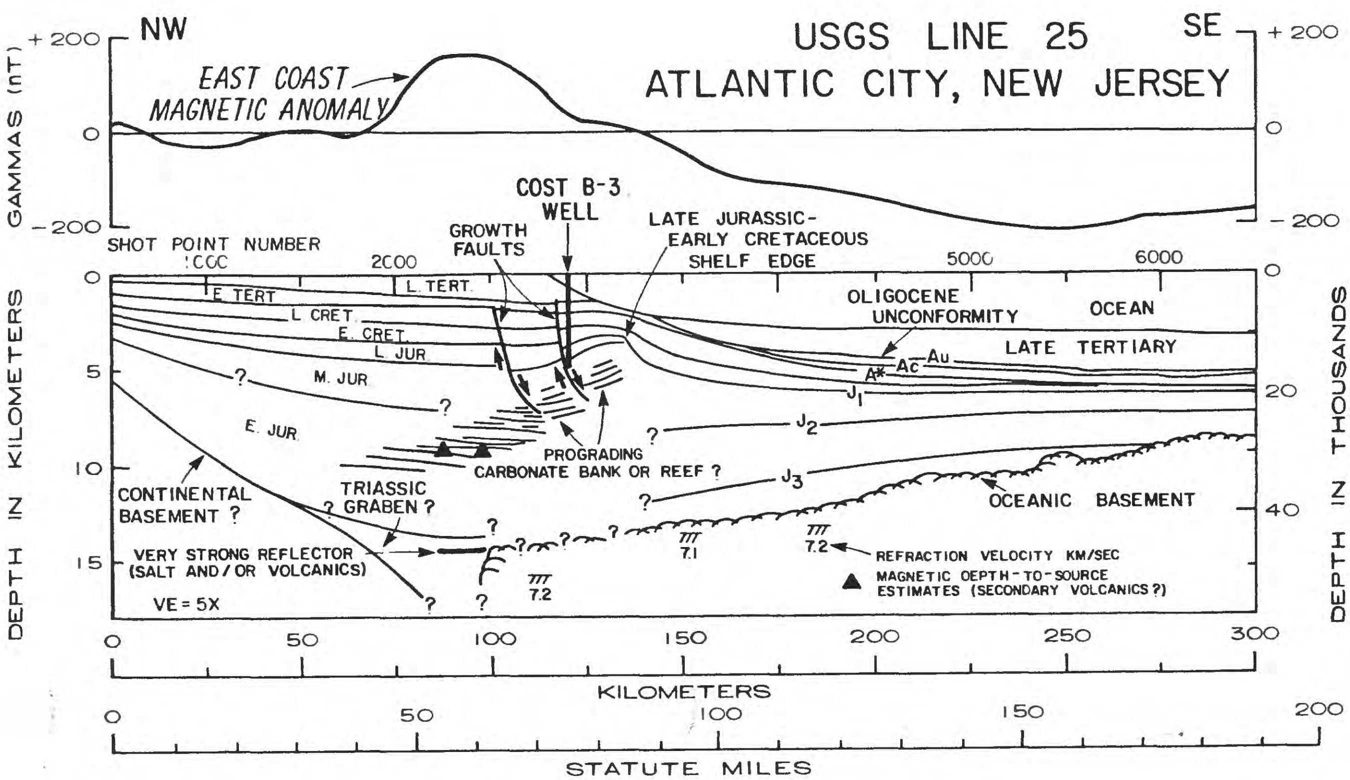


Figure 2-2 Structural cross section along USGS multi seismic line 25. The actual seismic record between shot points 1900 and 3600 is shown in figure 2-3 (from Grow, 1980).

FIGURE 2-2

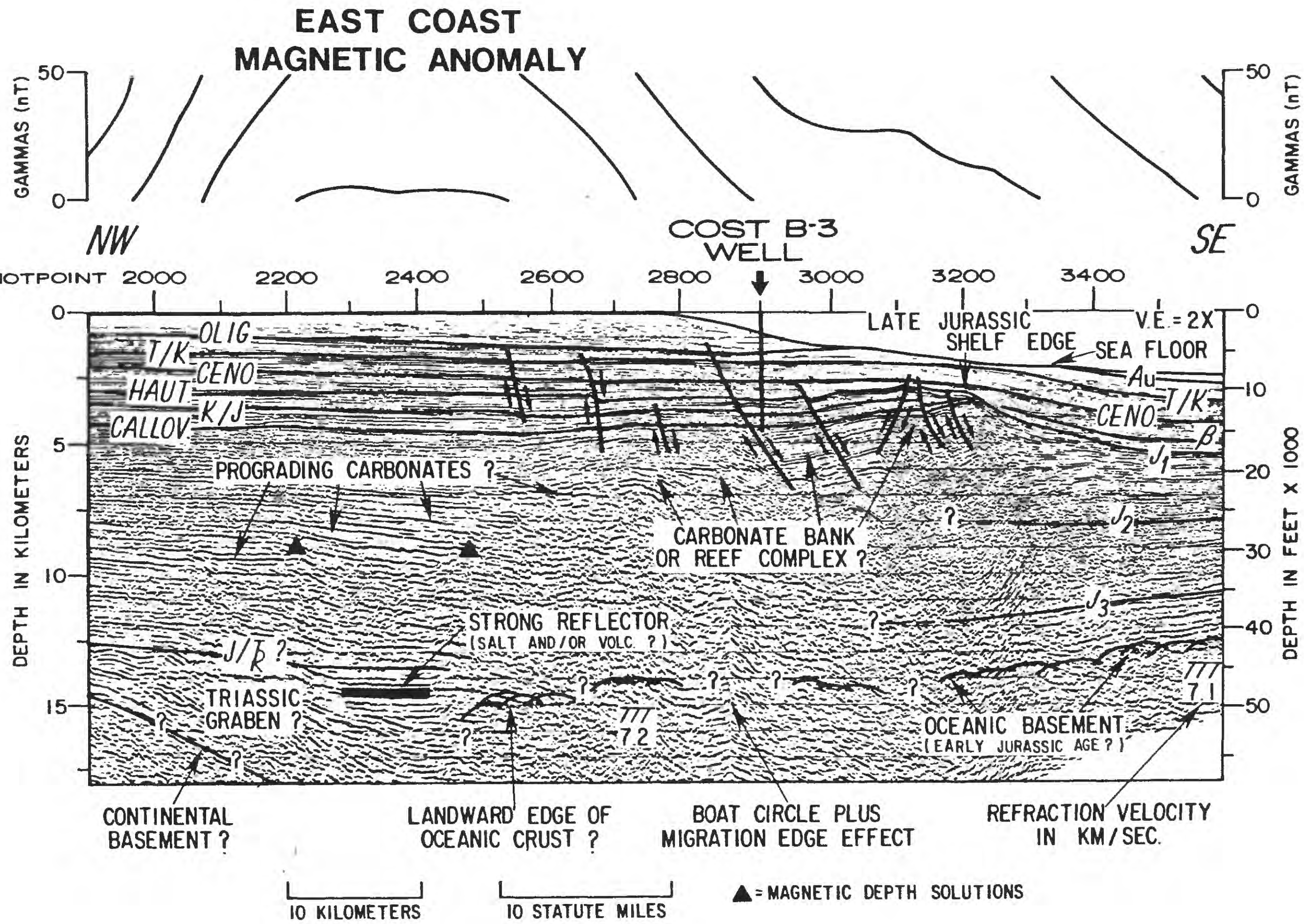


Figure 2-3 Annotated multichannel depth section (migrated) for USGS seismic line 25 with magnetic anomalies plotted at the top. Line 25 is the first seismic profile to achieve penetration deeper than about 4 mi (6 km) in the vicinity of the ECMA and the first profile to record reflected energy from deeper than 5-6 mi (9-10 km) in the region immediately seaward of the Late Jurassic-Early Cretaceous shelf edge. Age horizons on shelf from Amato and Simonis (1979), Poag (1980), and Valentine and others (1980). Deep-sea correlations from Klitgord and Grow (1980). Location shown in figure 2-4 (from Grow, 1980).

FIGURE 2-3

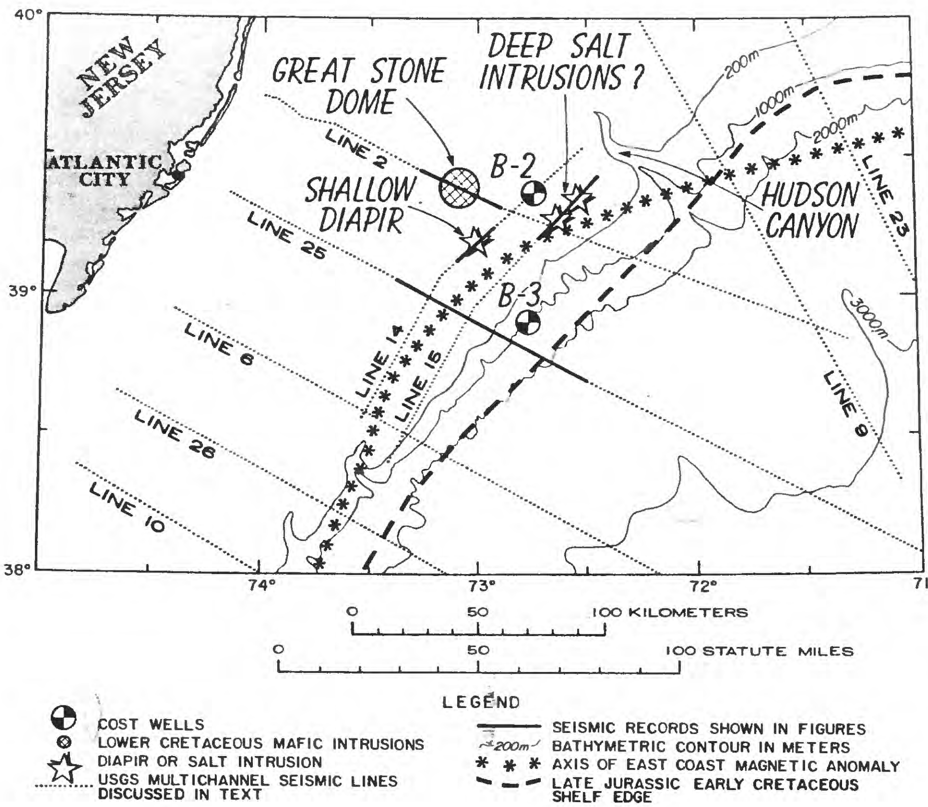


Figure 2-4 Continental Margin off New Jersey showing primary structural features and seismic profiles discussed in this report. The Late Jurassic-Early Cretaceous shelf edge has been mapped using eight seismic profiles and is approximately 12 mi (20 km) seaward of the present shelf edge as marked by the regional trend of the 650-ft (200-m) isobath. The boundary between continental and oceanic crust is inferred to be marked by the East Coast Magnetic Anomaly (ECMA). The COST No. B-3 well is about 3 mi (5 km) seaward of the present shelf edge and 9 mi (15 km) landward of the Late Jurassic-Lower Cretaceous shelf edge. Note that the shelf edge prograded 20 mi (30 km) in the region immediately to the northeast (from Grow, 1980).

FIGURE 2-4

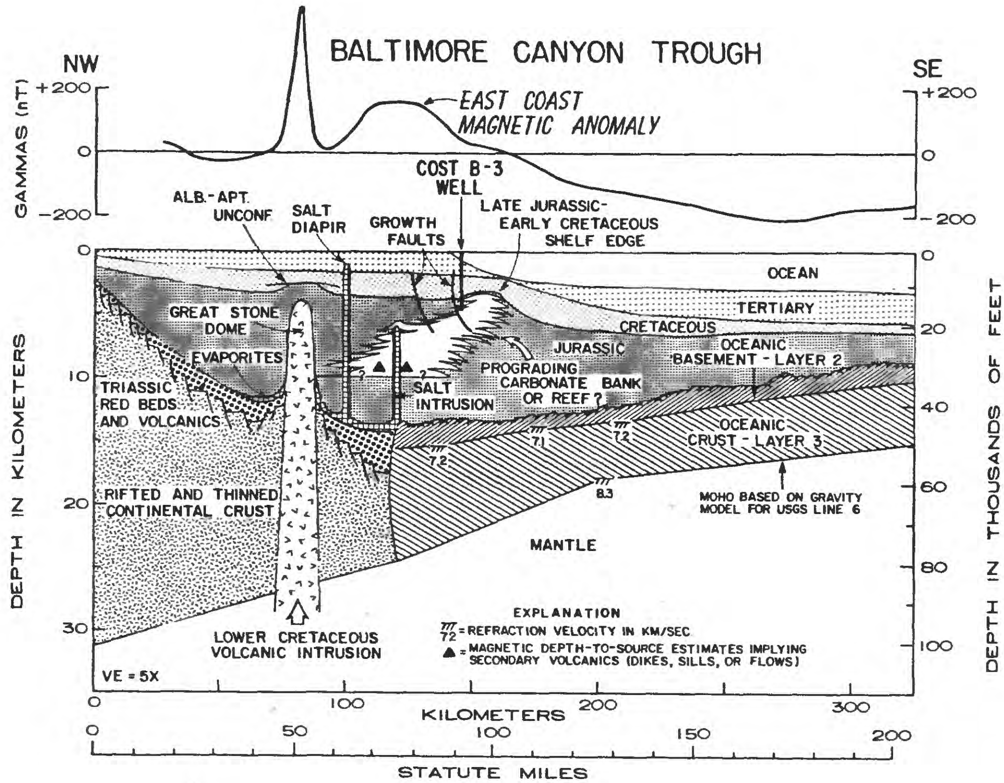


Figure 2-5 Schematic cross section through Baltimore Canyon trough approximately along seismic line 25 (figs. 2-2 and 2-3) with nearby COST No. B-3 well, geologic features, and geophysical parameters projected into the profile. Refraction data are from Ewing and Ewing (1959) and Sheridan and others (1979). The moho configuration is projected from a gravity model for line 6 (from Grow, 1980).

FIGURE 2-5

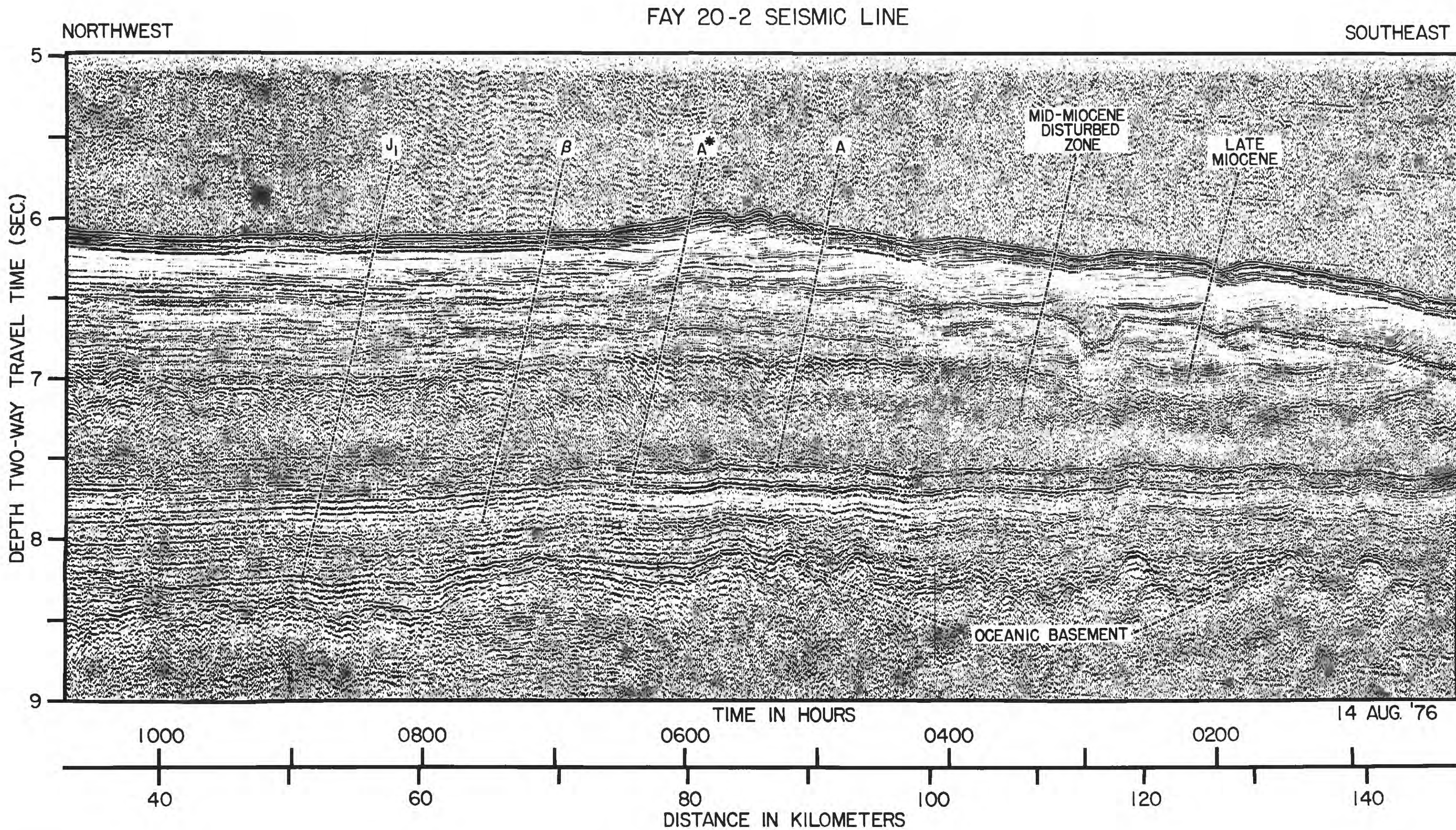


Figure 2-6 Single-channel seismic-reflection profile in 4,500 m of water (6 s) showing irregular basement highs on oceanic crust. Differential compaction around such basement highs beneath the Continental Rise sediments offers possible future exploration structures in deep water Profile from Klitgord and Grow (1980; fig. 10).

3. Regional geology and geophysics in the vicinity of Georges Bank Basin

by

John S. Schlee and Kim D. Klitgord

Georges Bank (67,500 km^2) is the eastward continuation of the Continental Shelf southeast of New England; it is flanked on the north by the Gulf of Maine, a roughly rectangular body of water between New England and Nova Scotia (Uchupi, 1966), and is flanked on the south by the Continental Slope and Rise. Intersecting the Continental Slope is the New England Seamount Chain, a linear zone of extinct submarine volcanoes 1,100 km long. The northern one-third of Georges Bank is covered by shallow, north-trending sand shoals and the remainder is a flat-floored shelf covered with rippled sand. Along the bank's southern side, several submarine canyons and numerous smaller gullies and ravines indent the slope and lead to a broad, gently inclined Continental Rise. Two shallow channels separate the bank from other parts of the shelf. To the west, Great South Channel (80 m deep) divides Georges Bank from Nantucket Shoals; and to the east, Northeast Channel (220 m deep) provides a deepwater entrance to the Gulf of Maine.

Information on the shape, thickness, lithology, and age of the sedimentary wedge that fills the Georges Bank Basin comes from a grid of geophysical profiles and three drill holes (fig. 1-2 and 3-1). The integration of magnetic data with multichannel seismic-reflection profiles collected over the past eight years by the USGS and the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) are most helpful in outlining the complex of subbasins that underlie Georges Bank. Examination of the well logs, coupled with interpretation of the seismic character of the multichannel reflection profiles allows us to infer the kinds of sedimentary rocks that underlie the area and to spot structures with hydrocarbon potential (Anderson and Taylor, 1981).

Within the broad tectonic framework of the continental margin off the northeastern United States (fig. 1-4), the Georges Bank Basin lies on the fragmented part of the North American continent. The East Coast Magnetic Anomaly (fig. 1-4 and 3-1) marks the boundary zone between oceanic crust and the main Georges Bank Basin. As can be seen from figures 1-4 and 3-1 to the south of Georges Bank the discontinuous ECMA trends approximately east as does a zone of basement structures west of the main basin (fig. 3-1). The modest angle these structures make to the oceanic fracture zones suggests that the North American continent was involved in oblique movement away from West Africa to form a shear zone. This slippage past a similar-trending bend in the African continent may have facilitated the complex pattern of rifting.

An isopach map of the area (fig. 1-3) shows that the Mesozoic-Cenozoic section is thickest under Georges Bank and thins in an irregular manner toward the Gulf of Maine and toward the Continental Rise, south of the Bank. The core of the bank is a wedge of Triassic(?) and younger sedimentary rock that overlies a rifted basement (fig. 3-2). Tectonically, Georges Bank is a collection of smaller subbasins, some of which are linear grabens that trend northeast (Ballard and Uchupi, 1975; Austin and others, 1980; Mattick and others, 1981; Klitgord and Schlee, in press). Collectively they are termed the Georges Bank Basin, and structurally, they are situated between the La Have Platform to the northwest, the Gulf of Maine Platform to the north, and the Long Island Platform to the west (fig. 3-1). A paleoshelf edge of Jurassic and Cretaceous age delineates the seaward edge of this complex of subbasins. Seaward of the main group of subbasins, a post-Triassic sedimentary sequence 4 to 5 km thick covers an irregular oceanic basement beneath the Continental Rise.

Under Georges Bank, the basement deepens from the adjacent platforms in a series of rifted blocks (figs. 3-1, 3-3). The most landward of these grabens is a shallow structure that lies along the northern edge of Georges Bank (Ballard and Uchupi, 1972; Oldale and others, 1974). An unconformity (fig. 3-2 and 3-3) that crosses the top of these grabens appears to correspond to the breakup unconformity of Falvey (1974). This unconformity increases in depth from less than 0.5 km below sea level adjacent to the Gulf of Maine to more than 8 km beneath the center of the bank. Acoustic basement rises at the seaward side of the main basin where the carbonate bank complex at the paleoshelf edge masks deeper sedimentary reflections.

In the deep water part of the call area, the New England Seamount chain intersects the Georges Bank region near lat. 40 N., long 69 W. where there is a major gap in the ECMA. Bear Seamount is located at this intersection and its large magnetic dipole signature in part may mask the continuity of the source of the ECMA across this gap. Within the Georges Bank Basin, three buried seamounts or intrusive bodies are inferred to be present from distinctive magnetic anomaly patterns. All three are just landward of the ECMA and have oval magnetic anomaly highs associated with them.

Stratigraphy

The COST G-1 and G-2 wells (fig. 1-2 and 3-4) provide the main body of deep stratigraphic information for the Georges Bank area. No deep test wells have been drilled seaward of the bank. The G-1 well (LaChance and others, 1980; Scholle and others, 1980a) encountered a sequence, mainly of sandstone, shale, and siltstone of Late Jurassic to Early Tertiary age, that overlies sandstone, anhydrite, and dolomite of Early(?) to Middle Jurassic(?) age. The

G-1 well penetrated into metamorphosed dolomite, quartzite, and phyllite of Paleozoic age at 15,630 ft (4,755 m) and reached a total depth of 16,071 ft (4898m) below K.B. (Kelly Bushing). At the COST G-2 well site, 67 km to the east, the section is both thicker and richer in carbonate and evaporite rocks. Again, the Upper Jurassic-Tertiary section contains abundant sandstone and mudstone, but thick beds of limestone are present, particularly toward the base of the Cretaceous. These limestones are probably equivalent to strata sampled in Heezen Canyon by Ryan and others (1978) in 1,250 to 1,300-m (4100-4265 ft) depth. They are Neocomian in age and were deposited in a reef-tract milieu. Oxfordian (Late Jurassic) and older rocks are dominantly limestone, dolomite, and anhydrite. The COST G-2 well bottomed in salt at 21,374 ft (7,612 m) total depth below K.B. (Simonis, 1980; Scholle and others, 1980b). The only other deep (524 m) hole (USGS 6001) was drilled on Nantucket (Folger and others, 1978b). It sampled poorly consolidated silts and clays of Late Cretaceous and Tertiary age of nonmarine to marine shelf origin and bottomed in weathered basalt approximately 183 m.y. old (Early Jurassic).

Several trends are shown by these three holes. The Cretaceous strata thicken and become finer grained and more calcareous toward the COST G-2 hole (eastward). The Jurassic rocks are present only in the two Georges Bank holes, where they thicken and become richer in carbonate and evaporitic rocks to the southeast over the main part of the basin. This trend been inferred from multichannel seismic-reflection profiles (Schlee and others, 1976; Schlee and others, 1979b; Mattick and others, 1981), not only here, but off the Mid-Atlantic states as well. The carbonate rocks are inferred to extend beneath the Continental Slope where they form a platform front and interfinger with deep-sea deposits of equivalent age in the North Atlantic oceanic basin (Grow and others, 1979a; Schlee and others, 1979c; Jansa and others, 1979; Klitgord and Grow, 1980) Our multichannel seismic profiles reveal that the seaward edge of the carbonate platform had two modes of expression: first as a pronounced break in the slope that formed a front approximately 2 km in relief (Schlee and others, 1979c, fig. 6) and second, as a ramp as shown by the shingled offlap of reflections that are presumably part of a seaward-prograding sequence that built into deep water (fig. 3-8; Schlee and others, 1979c, fig. 7). Most of the profiles show the first type of carbonate shelf edge; however, in the western part of the basin, a distinctly prograded arrangement of reflectors appears to indicate that the shelf built 20 km seaward over older slope and rise deposits (fig. 3-8). These two forms of platform development are similar to that described by Eliuk (1978) for the Scotian Shelf and Ahr (1973) for the Gulf of Mexico. On the Scotian margin, the Baccaro member of the Abenaki formation (Late Jurassic age) is a sequence of reef and back reef deposits that formed a pronounced shelf edge complex like that on Georges Bank. The platform built up vertically and had a steep seaward front (20-30^{o}) in areas away from the Sable Island delta; in the vicinity of the delta, the imbricate pattern of seismic reflections indicates that the shelf edge carbonate complex, migrated seaward to build a broad ramp into deepwater.

The Georges Bank seismic stratigraphy has been tied to drill hole information in adjacent basins (fig. 3-5). using multichannel seismic-reflection profiles (Wade, 1977; Austin and others, 1980). Judkins and others (1980) and Poag, (in press) tentatively have corrrelated the Georges Bank formations and key markers with the stratigraphic section set up for the Scotian margin by McIver (1972), Jansa and Wade (1975a), Gradstein and others (1975), Ascoli (1976), and Given (1977). The correlations show that the same major vertical and lateral stratigraphic trends seen on the Scotian margin are also present beneath Georges Bank. The trends represent a change from a section rich in red beds (sandstone and shale) for the inshore wells to a section rich in carbonates and evaporites at depth and towards the outer shelf holes.

The oldest sedimentary rock sequences encountered by the COST G-1 and G-2 wells are probably equivalent to the Iroquois Formation (dolomite and anhydrite), Argo Formation (salt at very bottom of the COST G-2 well), and the Mohican Formation (sequence of sandstone and shale of early Middle Jurassic to Early Jurassic age present in the COST G-1 well). The limestone of Middle Jurassic to earliest Cretaceous age beneath Georges Bank probably correlates with the Abenaki Formation, a sequence of platform limestone and shale on the Scotian shelf. Beneath the outer Scotian shelf and Georges Bank, the Abenaki Formation or its equivalent changes inshore to shelf sandstone, shale, and thin-bedded limestone termed the Mic Mac and Mohawk formations, off Canada.

The trend in rates of sediment accumulation with time for Georges Bank Basin seen in both COST holes is one of rapid sediment accumulation during the Jurassic and diminished rates thereafter. At least 4,875 m of the sedimentary rock accumulated during the first 50 m.y. of basin history as shown by the log of the COST G-2 well, whereas only 1,750 m of sediment accumulated in the last 141 m.y.; most (79%) of the latter sequence was deposited during the Cretaceous (141-65 m.y. B.P.). The overall trend is similar to that shown by Poag (1980, fig. 28) for the COST B-2 and B-3 wells (Baltimore Canyon Trough), although sediment accumulation rates, probably influenced by sea level fluctuations, vary widely over intervals of only a few million years.

The nature of formations beneath the slope and rise seaward of Georges Bank is extrapolated from distant Deep Sea Drilling Project (DSDP) holes (Poag, in press). DSDP holes are 600 km to the south (DSDP holes 105, 106, 388; fig. 1-2) and they reveal a sequence of Late Jurassic argillaceous limestone (Cat Gap Formation of Jansa and others, 1979) overlain by limestone, chalk, marl, and chert of Early Cretaceous age (Blake-Bahama Formation). Above this unit is a carbonaceous shale and claystone (Hatteras Formation) of Middle Cretaceous age, which is overlain by variegated clay of Late Cretaceous-Paleocene age (Plantagenet Formation). An Eocene sequence of olive-gray siliceous claystone and chert (Bermuda Rise Formation) is overlain by hemipelagic silty clay and mass-flow deposits of the Blake Ridge Formation (Eocene-Pliocene age). The formations are mainly fine grained, and defined well away from the margin, in the central North Atlantic basin. Poag (in press) has defined up-dip equivalents of these units on Line 19, (fig. 1-2) and discussed their origin.

Analysis of 1230 km of multichannel seismic profiles collected seaward of Georges Bank shows 4-5 km of post-Early Jurassic (?) sediment any rock lies above block faulted acoustic basement. The total section thins to less than 2 km beneath the lower continental rise to the south east (fig. 1-3). Six seismic sequences have been distinguished beneath the continental rise (Table 3-1). The oldest unit (A) is inferred to be debris that accumulated during the Jurassic in front of the ancestral carbonate platform (Unit A). The type of debris that was deposited there depended in part on the type of carbonate platform nearby and its relief. Adjacent to a steep boundstone platform with relief of a kilometer or two and a slope of 30-35 degrees, the seaward reef flank facies might be expected to be an olistostrome of reef blocks of varying sizes, slumped from the front and accumulating in fan shaped aprons to the southeast. The strong continuity and high amplitude of reflections within the sequence away from the platform front, may be indicative of turbidity flow deposits that carried finer carbonate detritus into abyssal depths. Adjacent to the carbonate ramp, where relief was more subdued, a deep water facies transition from oolitic sands (shallow water) to fine-grained pellet mud (deep water) might be expected (Ahr, 1973).

The deep water sequences of Cretaceous age (units B and C, table 3-1) are mainly onlapping basin fill characterized by fairly continuous reflections of moderate to low amplitude. We feel that this type of fill probably represents interbedded hemipelagic muds and fine-grained turbidity flow deposits. The Lower Cretaceous sequence north of the New England seamounts is characterized by broad lens-shaped packages of reflectors separated by unconformities with relief of as much as several hundred meters; internally these packages can show a sweeping imbricate arrangement of reflections - - an external and internal pattern of reflections that suggests the packages may have been deposited by geostrophic contour currents. Also present in the Lower Cretaceous sequence is a series of strong reflectors that extend out from Bear Seamount. Near the seamount they blank out returns from the older sequence; the reflections are interpreted to be volcanic flows and debris that cascaded away from volcanic center during its construction.

For the section inferred to be Cenozoic age, the multichannel seismic profiles show a major erosional event in the Oligocene (?) between Units D and E. Unit D (early Tertiary) showed a pattern of deep water rise construction similar to that evident in the Late Cretaceous, namely onlapping basin fill deposited by high and low energy gravity flows plus the rain of debris from the water column. The unconformity is inferred to have been formed in the late Oligocene when Vail and others (1977, fig. 6) postulate a major drop in sea level, on the order of 370 m. The unconformity can have a relief of several hundred meters over a distance of 10-20 km. Unit E above the unconformity appears to be gravity flow deposits (slumps, flows, channel fill) emplaced during and after the cutting of the unconformity. Broad channel-ways (as much as 15 km across) are a part of the unconformity; they trend normal to the present isobaths and narrow towards Georges Bank. Clearly the unconformity is an ancestral buried continental slope that is oriented similar to the present one. The most recent basin fill (unit F) is a sheet drape of hemipelagic silts and clays that extends across much of the continental rise seaward of Georges Bank; adjacent to the present slope, basin fill consists of channel deposits that have been laid down in the latest phase of submarine canyon cutting.

Magnetic studies

The magnetic anomaly data in the Georges Bank region (Taylor and others, 1968; Kane and others, 1972; Klitgord and Behrendt, 1977 and 1979) provide a means for estimating the general shape of the Georges Bank Basin. Since the sedimentary rocks which overlie the volcanic/metamorphic basement have very low susceptibilities, the shallowest major source of the magnetic anomaies is within this basement. The character of the magnetic field (fig. 3-6) can be used to divide the Georges Bank region into three provinces: 1) the shallow Long Island and Gulf of Maine platforms and the block-faulted zone along their seaward edge, typified by high amplitude, short-wavelength, magnetic anomalies; 2) the Georges Bank Basin with broad wavelength; non-linear anomalies; and 3) the region seaward of the ECMA with lower amplitude but fairly lineated magnetic anomalies. The integration of seismic-reflection data (Ballard and Uchupi, 1972; Schlee and others, 1976, 1979c; Schlee, 1981) with estimates of the depth-to-magnetic basement (fig. 3-7 and 3-8) (Kane and others, 1972; Klitgord and Behrendt, 1979) provides a basis for mapping basement structures (fig. 3-1) over the entire region (Klitgord and Schlee, in press). Crystalline basement for the Long Island Platform and Gulf of Maine Platform is generally at less than 4-km depth. A set of lineated, short-wavelength, high-amplitude anomalies oriented en echelon along 040° NE., between 40.5° N., 70.5° W., and 42.5° N., 66°W. marks the seaward limit of this region. A set of narrow grabens or basins is located along this boundary and forms a step-like pattern (fig. 3-6) as basement deepens into the Georges Bank Basin. Seaward of the ECMA, the magnetic anomaly data, seismic-reflection, and seismic-refraction data indicate that the basement is typical oceanic crust (Schlee and others, 1976; Grow and Schlee, 1976; Klitgord and Behrendt, 1979; Grow and others, 1979a; Sheridan and others, 1979; Klitgord and Grow, 1980). This change in basement character across the Georges Bank region can be seen in a cross section based on CDP line 19 (fig. 3-8).

The Georges Bank Basin, as defined by the magnetic data, lies landward of the ECMA and seaward of the previously mentioned set of lineated magnetic anomalies associated with the series of grabens oriented en echelon along a trend of 040° NE. The map of the depth-to-magnetic basement (fig. 3-7) indicates a rapid increase in basement depth on the landward side of the basin, as does the isopach map of total sediment thickness (fig. 1-3). A basement high beneath the ECMA marks the seaward edge of the basin. The buried carbonate and paleoshelf-edge complex reported near the shelf break of Georges Bank (Schlee and others, 1976, 1979c; Uchupi and others, 1977; Schlee, 1981) is located just above this outer high in the magnetic basement (Kligord and Behrendt, 1979). The seismic and magnetic data indicate that the deepest basement lies within the main basin and the Yarmouth Sag (fig. 3-7) between the block-faulted zone and the ECMA. There are isolated magnetic basement highs near lat 40.75° N., long 67.25° W; lat 40° N., long 69.5° W.; and lat 40° N., long 70.25° W., as well as a broad basement high near lat 40.5° N., long 68° W. which cuts the basin in half. These isolated magnetic basement highs may be intrusive bodies similar to the major intrusive body in the Baltimore Canyon Trough near lat 39.5° N., long 73° W., but they are about 2 km deeper and reach an estimated minimum depth of about 6 km.

The northeastern end of the basin is subdivided by the Yarmouth Arch (figs. 3-1 and 3-7). The Yarmouth Sag flanks the north side of the arch, and as it shallows to the northeast it merges into the LaHave Platform beneath the Scotian Shelf. The main basin continues along the southeastern side of the arch, eventually to connect with the Scotian basin.

Table 3-1 Depositional sequence inferred from seismic profiles beneath the slope and rise seaward of Georges Bank

Unit	Inferred Age	Seismic facies	Paleoenvironment
F	Middle Miocene (?) and younger	Mostly sheet drape and onlapping basin fill (parallel reflections)	Hemipelagic deposits particularly southwest of the Bear Seamount; slumping and complex channeling beneath slope.
E	Late Oligocene -Early Miocene	Chaotic fill and on-lapping fill(complex pattern of reflections)	Mass wastage deposits associated with a conspicous unconformity; complex channeling of slope-front fill
D	Paleocene - Early Oligocene	Onlapping fill (parallel reflections)	Hemipelagic deposits; possibly some low velocity turbidity flows.
C	Late Cretaceous	Onlapping basin fill (parallel reflections)	Mixture of hemipelagic deposits and low velocity turbidity flows; complex channeling and slump deposits beneath slope.
B	Early Cretaceous	Contourite; onlapping basin fill (parallel reflections)	Geostrophic current deposits as broad mounded lobes associated with anastomosing unconformities; volcanic debris around Bear Seamount; slump deposits and complex channel fill in vicinity of ancient continental slope.
A	Jurassic	Slope front fill; onlapping basin fill (parallel reflections)	Reef-front mass wastage deposits (blocks, debris) laterally giving way to more evenly bedded carbonate basin fill deposits. Possibly volcanic debris interlayered at base of sequence.

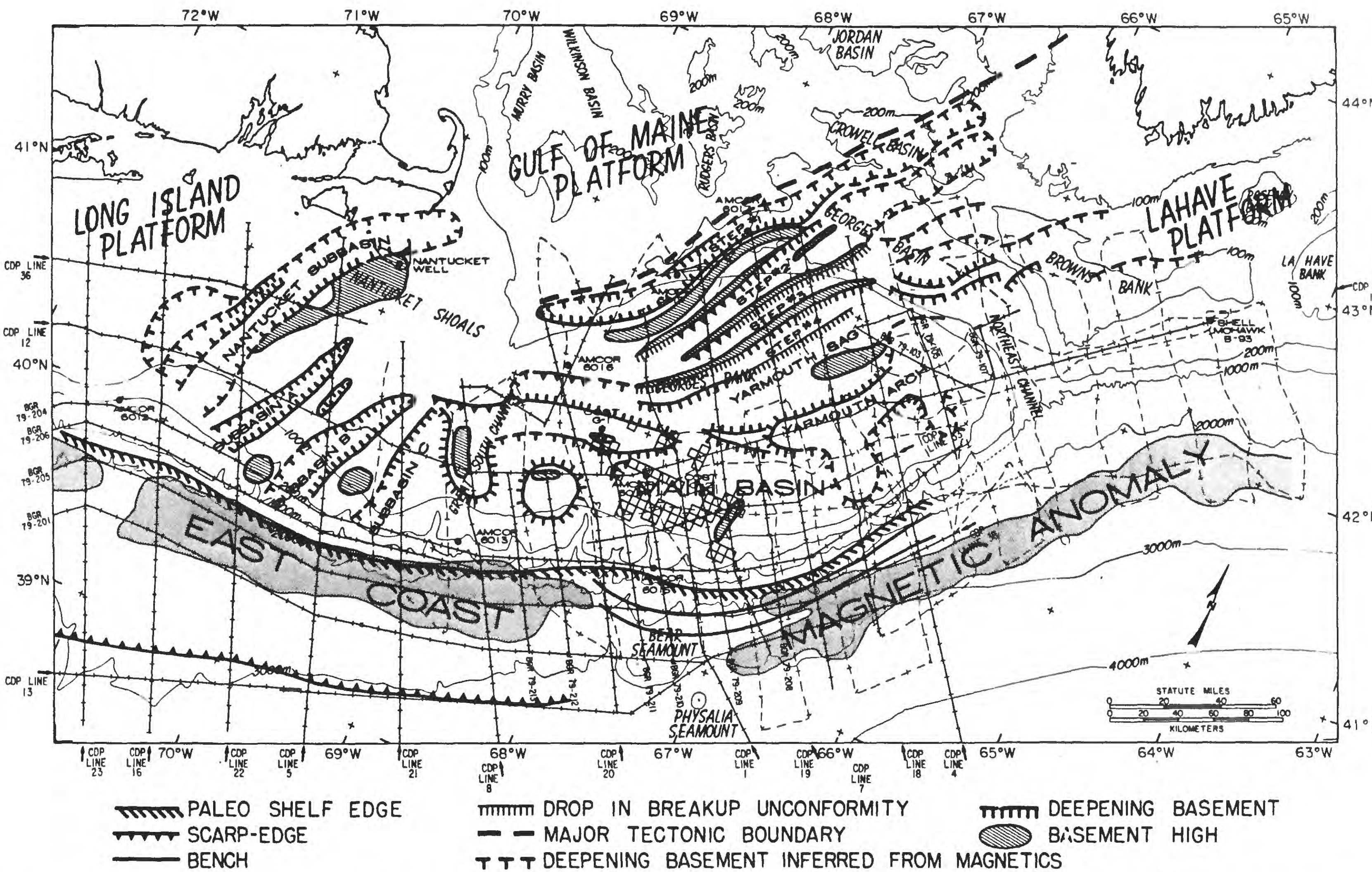


Figure 3-1 Tectonic-structural map of the Georges Bank region showing the stable, shallow platform of Paleozoic continental crust, areas of block-faulted crust and subbasins or grabens, steps (half grabens) and intervening basement highs, and Jurassic oceanic crust. The East Coast Magnetic Anomaly (ECMA) and ancient Jurassic shelf edge are indicated at the boundary between the block-faulted zone and the oceanic crust. The New England Seamounts and possible intrusive volvanic bodies are also shown. The lines indicate locations of multichannel seismic reflection profiles. Sale No. 42 lease blocks are indicated.

FIGURE 3-1

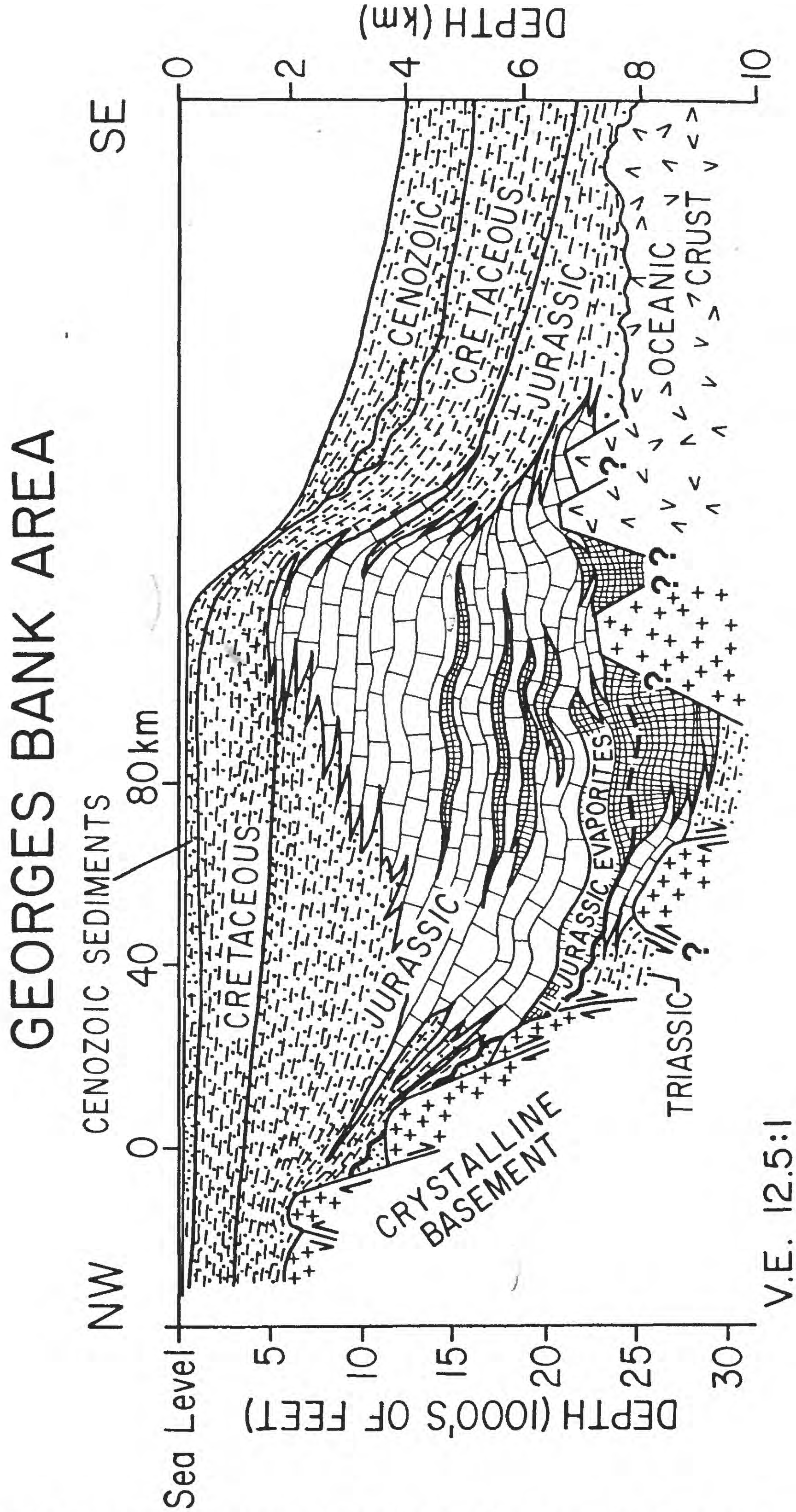


Figure 3-2 Schematic cross section through the Georges Bank area approximately along line 1 (fig. 1-2). The wavey line just above crystalline basement blocks represents the breakup unconformity. Note the broad buildup of carbonate rocks (brick pattern) beneath the middle and outer part of the shelf.

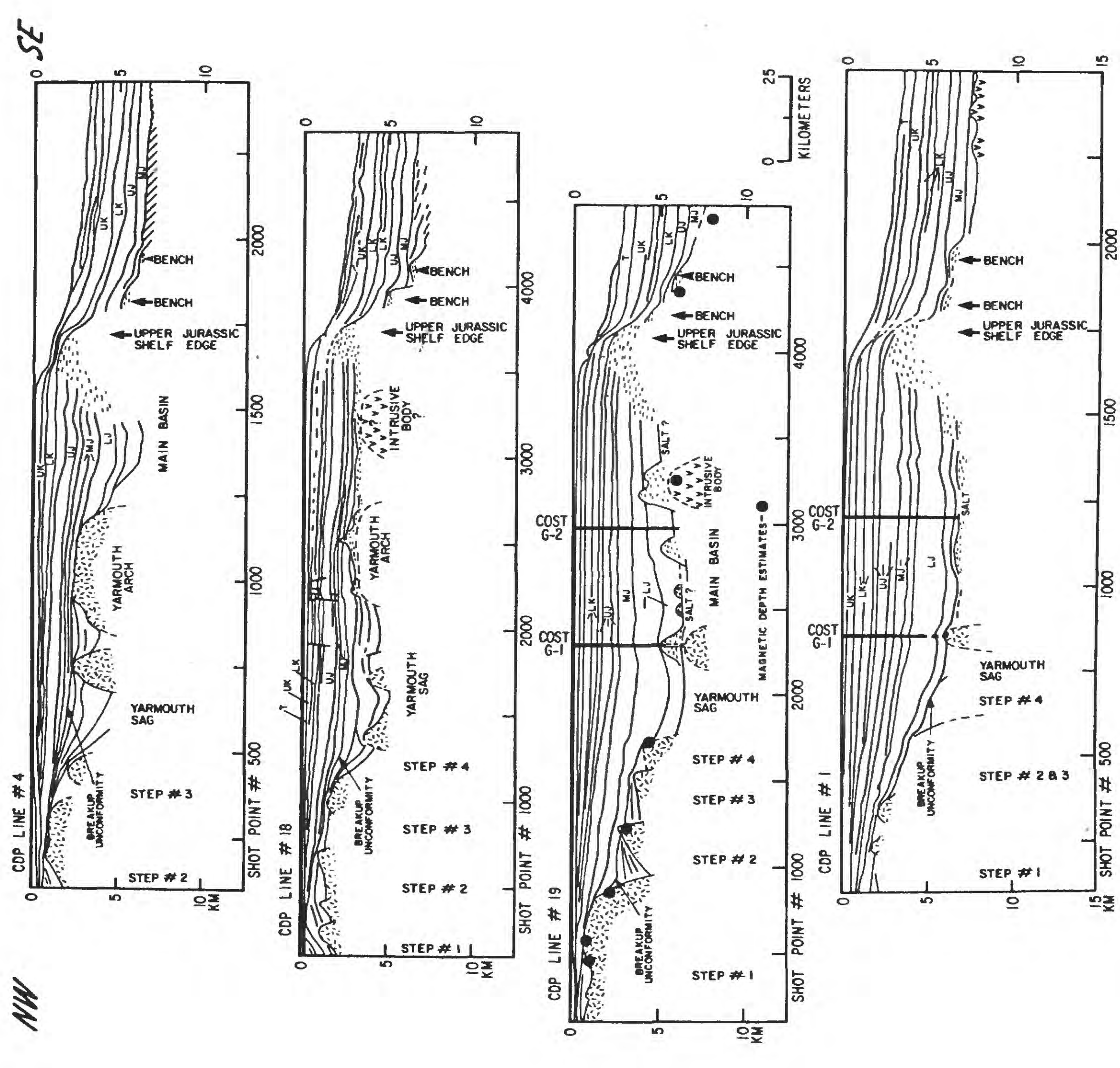


Figure 3-3 Cross sections of Georges Bank basin based on CDP lines 4,18,19, and 1. Line locations are shown on figure 3-1. The various sedimentary units are labelled according to age: Tertiary (T), Upper Cretaceous (UK), Lower Cretaceous (LK), Upper Jurassic (UJ), Middle Jurassic (MJ) and Lower Jurassic (LJ). The Carbonate Bank deposits near the paleoshelf edge are indicated with horizontal dashes. The locations of the COST G-1 and G-2 wells have been projected onto the profiles.

FIGURE 3-3

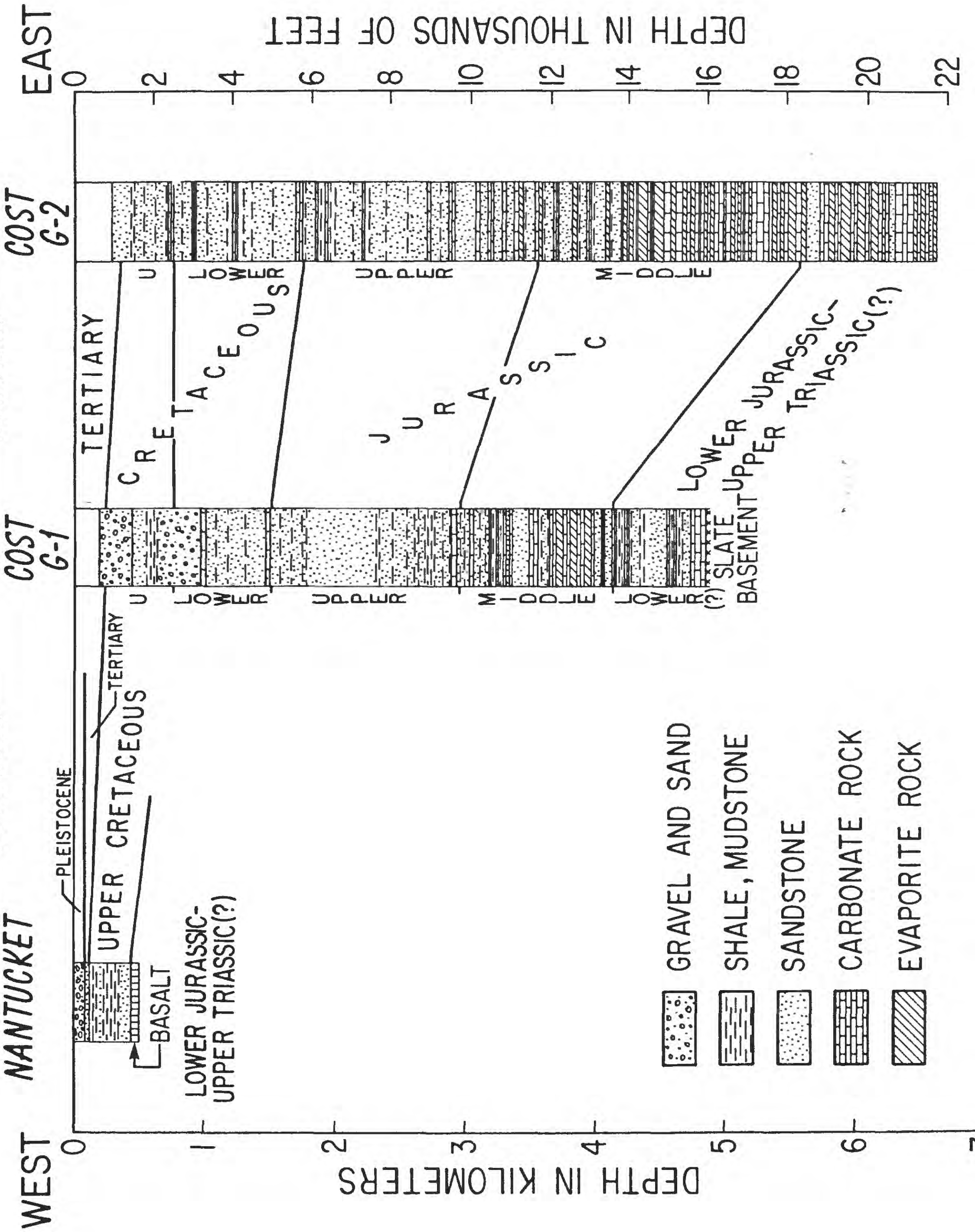


Figure 3-4 Lithologic logs of two COST holes and the Nantucket hole (USGS 6001). Modified from Scholle and others (1980a, b), Judkins and others (1980), and Folger and others (1978b).

FIGURE 3-4

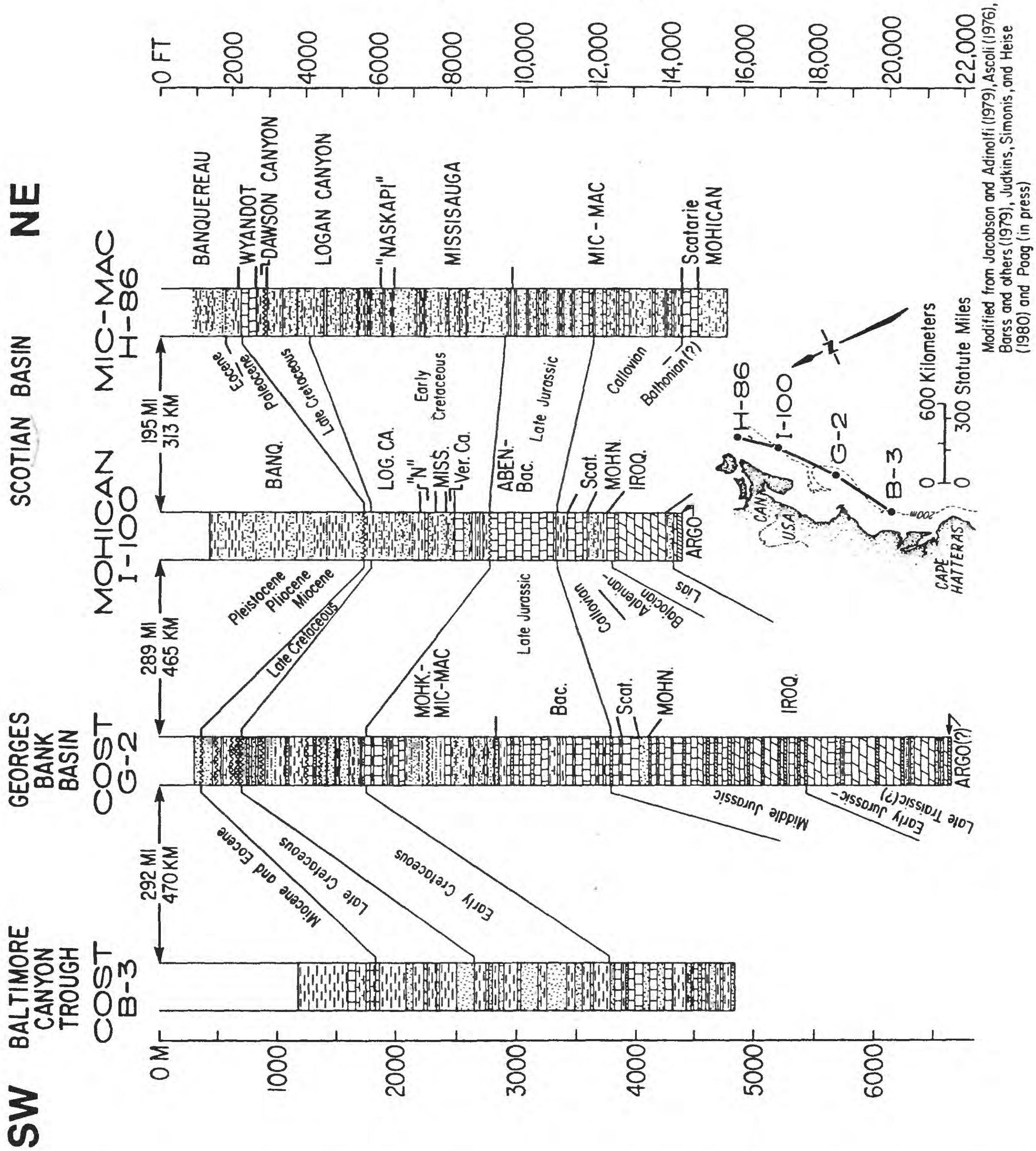


Figure 3-5 Lithologic logs of four wells drilled on the Atlantic margin. Datum is sea level. Abbreviations are Canadian formational units, most of which are spelled out to the right of the MIC-MAC H-86 well log. VER. CA. is Verrill Canyon Formation. ABEN. is Abenaki Formation and BAC. is the Baccaro member of the Abenaki Formation. MOHK. is the Mohawk Formation IROQ is the Iroquois Formation.

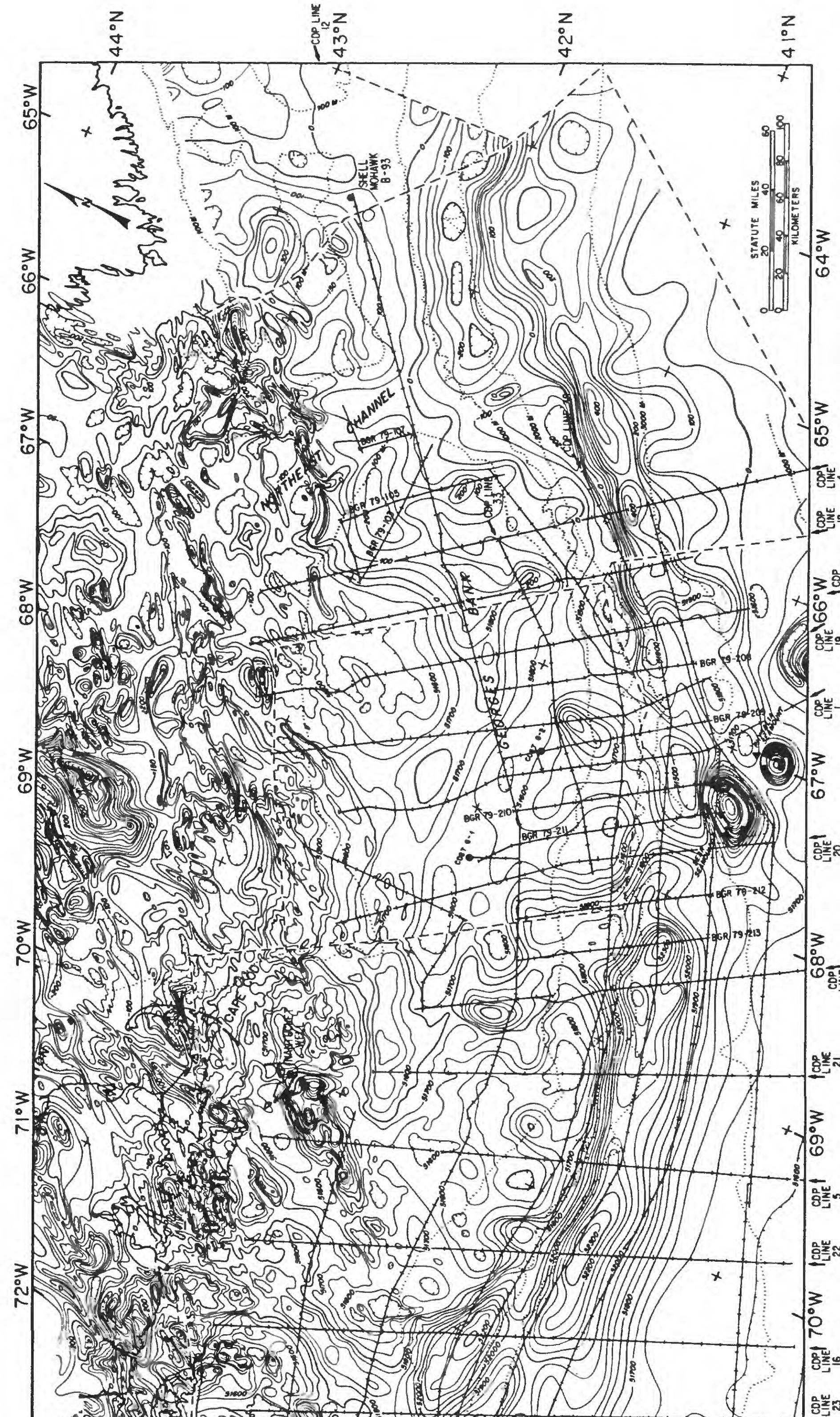


Figure 3-6 Magnetic anomaly maps on a Universal Transverse Mercator (UTM) projecton with 50-nT contour interval composited from the maps of Klitgord and Behrendt (1977) and Haworth and MacIntyre (1974).

Figure 3-6

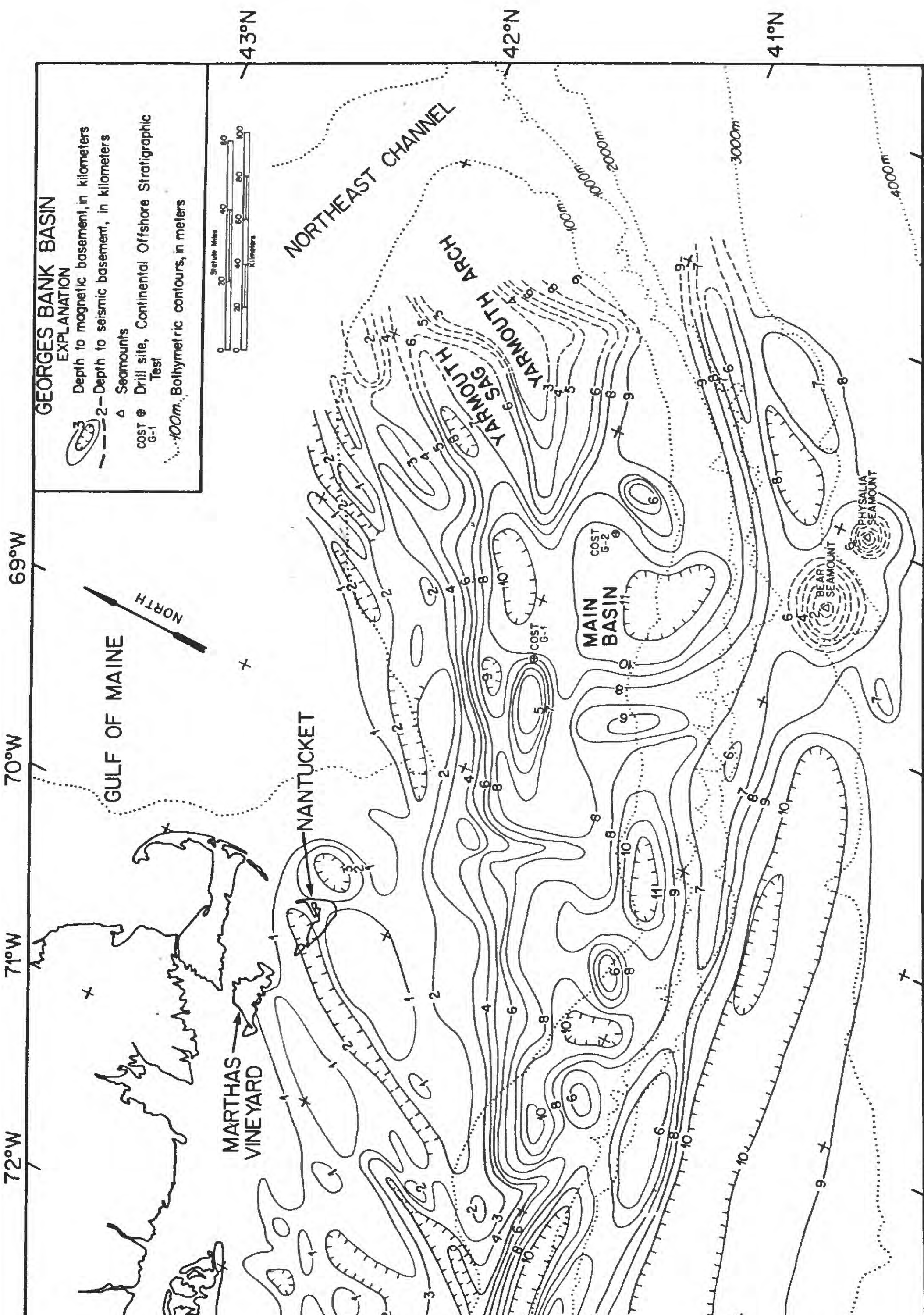


Figure 3-7 Depth-to-magnetic-basement map on a UTM projection with a 1-km contour interval (Klitgord and Behrendt, 1979, fig. 7c). The depths were determined using magnetic depth estimates to interpolate between CDP lines, 1, 4, 5, 7, 12, and 13.

FIGURE 3-7

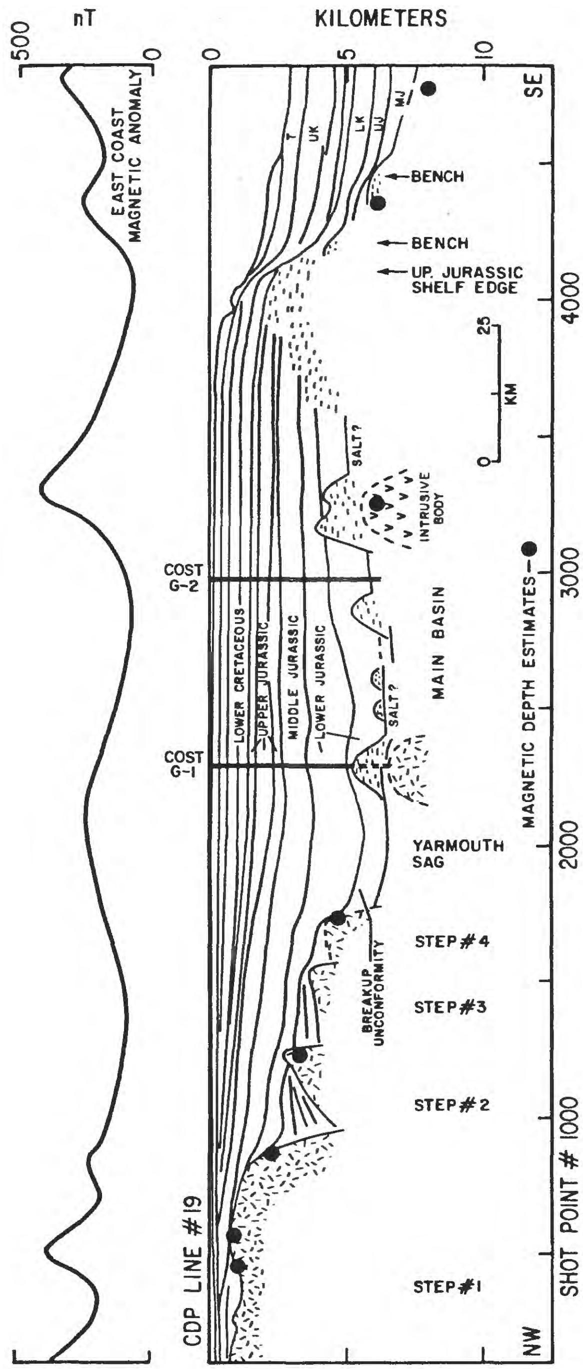


Figure 3-8 Typical cross section for the Georges Bank Basin based on CDP line 19. The dashed basement beneath the breakup unconformity is inferred from adjacent seismic profiles and magnetic data. The magnetic anomaly and free-air gravity anomaly profiles are shown. The locations of the COST G-1 and G-2 wells are projected onto the profile. Ages of seismic stratigraphic units are from Poag (in press) and Klitgord and Grow (1980). Locations of depth-to-magnetic-basement estimates from Klitgord and Behrendt (1979) are indicated.

4. Potential geologic hazards in the Baltimore Canyon trough area

by J. M. Robb and D. C. Twichell

Environmental geologic data

Since 1975 the U.S. Geological Survey (USGS), in cooperation with the U.S. Bureau of Land Management (BLM), has been investigating potential geologic hazards to development of the Mid-Atlantic Outer Continental Shelf area. Locations of high-resolution seismic-reflection data gathered by that effort (Robb and Kirby, 1980) are shown in the following figures. Figure 4-1 shows regional track-line coverage of high-resolution seismic-reflection profiles. Figure 4-2 shows the area of high-density seismic-reflection profiling and sidescan-sonar surveys performed prior to Lease Sales 40 and 49 (Carpenter and Roberts, 1979; Hall and Ensminger, 1979). Figure 4-3 shows the coverage of a long-range sidescan-sonar survey (GLORIA: Geologic LOng Range Inclined Asdic) of the Continental Slope area performed in October 1979 by the USGS in cooperation with the Institute of Oceangraphic Science (U.K.). Figure 4-4 shows the area of high-density seismic-reflection survey performed in preparation for Lease Sale 59 (Keer and Cardinell, 1981). Findings from these surveys, additional studies still in progress, and of other investigations reported in the literature are discussed below.

Continental Shelf

The near-bottom sediments of the Middle Atlantic shelf are characterized by a thin surficial sand layer underlain by a nearly ubiquitous clay layer of unknown thickness. Vibracores reveal that the sand layer is composed of a shelly, poorly sorted, medium-to-coarse sand of Holocene age. Seismic-reflection profiles indicate that the sand layer is 1 m to 20 m thick and forms a series of northeast-trending low-relief ridges and swales (Knebel and Spiker, 1977). The Pleistocene clay layer locally includes silt and sand (Knebel and Spiker, 1977; Folger and others, 1978a). Sangrey and Knebel (1978) found this clayey material in 15 of the 16 vibracores collected on the shelf south of the Hudson Shelf Valley to be very overconsolidated, with high shearing resistance and low compressibility. The material at the one station that was not very overconsolidated was still somewhat overconsolidated having an overconsolidation ratio of 5 as compared to 15+ for the other cores. Except locally, where the clay is more compressible, this layer does not present a hazard to facility siting.

The influence of known hydrographic conditions on the Mid-Atlantic Shelf surface appears to be slight. Ripples (Butman and others, 1979) and small-scale scours (McKinney and others, 1974; Knebel and others, 1976) are the result of modern storm-generated waves and currents. A large area of rough topography around Hudson Canyon has been mapped and is interpreted to be a relict erosional surface formed about 13,000 to 15,000 years ago (Knebel, 1979). Sand waves have been identified near the shelf edge around the heads of Wilmington Canyon (Knebel and Folger, 1976; Twichell, 1979) and Lindenkohl Canyon (Hall and Ensminger, 1979). However, based on their structure and the known hydrographic conditions, these sand waves are interpreted to be relict (Twichell, 1979) and, hence not to be a restriction to development. The ridge-and-swale topography, which covers most of the shelf, has been attributed both to modern storm-generated waves and currents (Uchupi, 1963; Moody, 1964; Swift and others, 1972), and to a relict barrier-beach origin (Veatch and Smith, 1939; Sanders, 1962; McClennen, 1973). The latter interpretation of these features is more plausible because on the southern New England shelf, the same bed forms are buried by as much as 14 m of Holocene silt and clay (Twichell and others, 1981).

Shallow faulting has been identified in a small area near the shelf edge south of Hudson Canyon where strata of Pleistocene age are displaced about 1.5 m (Sheridan and Knebel, 1976). A regional seismic-reflection survey of the Middle Atlantic shelf has revealed no other faults (Cousins and others, 1977). Geologic hazards and constraints within the lease blocks offered by OCS Sale 49 were evaluated by Hall and Ensminger (1979) based on high-resolution seismic profiles and sidescan sonar over a 800-m x 3,200-m grid. Hazards found within the sale area included shallow faulting in lease block NJ 18-6-837 on the shelf south of Baltimore Canyon and shallow gas deposits in lease blocks NJ 18-3-724, -770, and -773 on the shelf south of Hudson Canyon, but occurrences of such hazards were rare. Constraints to development included erosion and scour, filled channels, relict lagoon deposits, and gas-charged sediments, which could affect the stability of bottom-sited facilities and should be investigated on a site-specific basis.

Continental Slope

Topographically, the surface of the Continental Slope (100 to 2,200 m) is complex and rugged. Not only is it cut by a number of major canyons, but intercanyon areas are also generally characterized by a rugged terrain of valleys and gullies.

Bathymetric maps which include the Continental Slope from 37°31'N. to Georges Bank are published at a scale of 1:250,000 by the National Ocean Survey (N.O.S.). Several small areas of the Mid-Atlantic Continental Slope have been mapped at a finer scale and discussed by Bennett and others (1978), McGregor and others (1979), Bunn and McGregor (1980), Malahoff and others (1980), Merrill and Bennett (1981) and Robb and others (1981c and d) (fig. 4-6). All these studies show that the slope surface is complex and is not well described on available smaller scale maps.

A long-range sidescan-sonar (GLORIA) survey of the Continental Slope between Hudson and Baltimore Canyons shows many more submarine canyons than are shown on the most recent published bathymetric maps (National Ocean Survey, 1975, 1977; Twichell, in press). A large number of canyons incise the upper slope whereas only a small number indent the shelf edge, and the canyon walls are densely incised by small tributary gullies that are absent farther downslope (fig. 4-5). Many canyons merge on the middle and lower slope, and only a few channels cross the upper rise. The GLORIA images show that, in overview, the terrain of the slope is rough, and the areal extent of smooth intercanyon areas is greatly reduced from what is shown on the N.O.S. bathymetric maps (1975; 1977).

The Continental Slope is underlain in the Mid-Atlantic region by a paleoshelf-edge system with rocks of Jurassic through early Tertiary age (Poag, 1979; Grow, 1980; Schlee and others, 1979a), overlain by a wedge of Neogene sediment having slightly seaward dips (fig. 4-7). The present-day Continental Slope is covered by fine-grained Pleistocene deposits which are between 300 m and 500 m thick at the top of the slope, and become thinner downslope. These Pleistocene silty clays overlie Tertiary rocks on an unconformity that may be of Pliocene age.

A surficial geologic map of the area between Lindenkohl and South Toms Canyons (Robb and others, 1981c) (fig. 4-8) shows that the Pleistocene sediments extend downslope in lobate ridges. Eocene to Miocene rocks crop out on the lower slope and midslope of this area. In most other places along the Mid-Atlantic OCS substantial thicknesses of fine-grained Pleistocene deposits probably cover the entire Continental Slope surface, although older rocks are exposed in canyons.

The major potential geologic hazard of the Continental Slope in the Mid-Atlantic area is considered to be slope failure and the possibility of consequent, vigorous, downslope-moving turbidity currents. Twenty-seven lease blocks along the upper Continental Slope were withdrawn from Lease Sale 49 because there were thought to be hazards of slumping or sliding from failure of slope sediments in those areas (Hall and Ensminger, 1979). Subsequent analysis of additional data (Sale 59 geohazard survey, Keer and Cardinell, 1981) now indicates that many features formerly thought to be slumps or slides are cut-and-fill structures, or topographic features associated with underlying stratigraphic unconformities. However, the potential for slope failure has not been ruled out. Geotechnical analysis of samples from piston cores distributed along the Continental Slope shows that, although most sampled sediments are stable, some sites are marginally so (Booth and others, 1981a and b; Olsen and others, 1981; McGregor, in press). Considering the geomorphic complexity of the area, there are probably not enough analyses yet available for valid generalization. Also, most geotechnical analyses to date have been based on superficial samples from not greater than 8 m below the sea bottom. Consequently, evaluations of the stability of the Continental Slope must be based primarily on geological and geophysical inference.

A large subaqueous landslide deposit (approximately 11 km^3 in volume) on the Continental Slope northeast of Wilmington Canyon was described by McGregor and Bennett (1977) as resulting from a Pleistocene-aged event. However, there is some controversy as to whether the interpretation of their seismic data is correct, and whether the feature they describe is real. The deposit was not identified by Keer and Cardinell (1981).

Two probable large allochthonous blocks, 37 km x 10 km, and 60 km x 10 km in size, were identified from seismic profiles and GLORIA images of the lower slope and upper Continental Rise below Wilmington and Baltimore Canyons. GLORIA data over the upper Continental Rise show that although most canyons trend directly downslope, Baltimore and Wilmington Canyons are both directed eastward, diagonally across the lower slope and upper rise, their courses controlled by these two large, linear, sedimentary blocks. Upturned strata (i.e., probably disturbed, not in place) of clay, gravel conglomerate, and oxidized sandstone were observed from dives by DSRV ALVIN to investigate the nature of these blocks (Stubblefield and others, 1981). A tubular object, tentatively identified as a cast of a tree root, was recovered from the sandstone. The finding of conglomerate and oxidized sandstone outcrops and the tentative identification of tree-root casts certainly implies strongly that the material was initially deposited in some other, shallower location at the top of the slope. It is possible that these blocks may form part of a single slump deposit that was subsequently cut by canyons; however, the absence of an exposed scarp upslope from these blocks suggests that if they are in fact allochthonous material they must be old, having the upslope scarp buried by subsequent sedimentation. The age of the material in these blocks is not yet established. They may be as old as mid-Pliocene (B. A. McGregor, pers. commun., 1981). Except for these two large blocks, which are on the upper rise, large-scale slumping was not identified on the GLORIA records on this segment of the slope. Small-scale mass wasting probably occurs, however, and contributes to the formation of the gullies prevalent on the steep canyon walls of the upper slope.

Keer and Cardinell (1981) report a number of areas where slumping appears to have occurred in the proposed sale 59 area. Several notable occurrences are located in the area to the southwest of Hudson Canyon. Again, the age of these features is not determined.

The detailed mapping of the 40-km x 35-km segment of the Continental Slope and upper rise between Lindenkohl and South Toms Canyons off New Jersey (fig. 4-8) (Robb and others, 1981c) identified three slump or slide features in the heads and on the walls of canyons and valleys, and two slides in an intercanyon area. The slumps or slides, identified from seismic-reflection profiles, are located in Quaternary sediments and total about 1.3 percent of the Continental Slope area mapped. Other subaqueous slumps or slides on the Mid-Atlantic Continental Slope have been described by Rona and Clay (1967), Embley and Jacobi (1977), Knebel and Carson (1979), Bunn and McGregor (1980), and Malahoff and others (1980).

A large volume of Pleistocene sediments lies on the upper Continental Rise at the foot of the Continental Slope. These sediments may have accumulated as a result of mass wasting of the slope surface, or they may comprise sediments which bypassed the slope, transported by density flow from the shelf edge, or they may result from a combination of both processes. Samples from Deep Sea Drilling Project site 107 on the upper Continental Rise contained Pleistocene foraminifera from a sublittoral (shelf) environment. Mid-range sidescan-sonar data (Robb and others, 1981e) show that the uppermost Continental Rise surface is rougher than previously realized, having sharply defined, but poorly understood features of low relief. Some of these features may represent masses of sediment that slid from the slope, or they may be erosional features caused by bottom currents or turbidity currents. A field of blocky debris was observed on the Continental Rise at the mouth of South Toms Canyon, which suggests downcanyon transport of material (Robb and others, 1981c). Photographs taken from ALVIN dives to this area in 1976 (Woods Hole Oceanographic Institution, ALVIN archives) show blocks of rock similar in appearance to Eocene rocks that crop out nearby, upslope. Consequently, we feel that this debris accumulated as a result of rockfalls in the canyon area. We cannot identify the age of that activity or its intensity (how many occurrences over what period of time) from the available data.

Four dives by DSRV ALVIN during July 1981 to features observed on deep-towed mid-range sidescan-sonar images in the Carteret Canyon and South Toms Canyon areas (Robb and others, 1981a, e and USGS unpublished data) revealed unanticipated topographic roughness (very steep slopes, cliffs, and deeply incised channels, having relief to tens of meters) in areas of Eocene rock outcrop. The topographic relief and morphology of these features as observed directly from the submersible are generally either too small or too complex areally to be mapped using conventional profiling systems operated on the sea surface, but are nevertheless very significant to any engineering planning for bottom structures or pipelines in the area. While the features observed do not of themselves necessarily represent hazards, they bespeak the need to utilize proper engineering survey techniques to survey deepwater areas.

These accumulating observations from deep-towed mid-range sidescan-sonar images and carefully targeted, geologically oriented ALVIN dives imply that there has been "small-scale" bottom activity in the form of rockfalls and possibly, vigorous downslope currents. Talus blocks of Eocene rock were observed on the uppermost Continental Rise. However, most places observed had a general thin cover of very fine grained, bioturbated sediment, without ripples or evidence of substantial water movement. The time that any inferred event occurred cannot as yet be determined, and in many cases, the results of late Pleistocene or early Holocene activity cannot be distinguished at this time from an occurrence of the last hundred years, for example.

A zone of faulting is located along the lower Continental Slope. Where well surveyed, using both seismic and sidescan techniques, in the areas between Lindenkohl and South Toms Canyons (fig. 4-8), these faults do not appear to have disturbed Pleistocene sediments, and therefore may not constitute a seismic risk (Keer and Cardinell, 1981; Robb and others, 1981c). They may represent a constraint for drilling operations, however.

In summary, the Continental Slope has a rough topographic surface which is relatively poorly mapped. The major geologic hazard is thought to be slumping or sliding of its fine-grained sediments, or rockfalls in areas of Tertiary outcrop, and the downslope effect of such occurrences. The scales and rates of such processes that may occur intermittently in the present day remain unknown. Identified slump features of significant size are thought to be Pleistocene or late Tertiary in age. The greatest risk of slope failure appears to be associated with unconsolidated Quaternary sediments, which have variable, but not well mapped thicknesses. Canyon and valley axes may be an avenue for episodic turbidity currents. However, in places where detailed observations are available, a general cover of undisturbed fine-grained sediment implies that the Continental Slope is now quiescent.

Continental Rise

The major part of the Continental Rise is characterized by subdued topography, but has been only generally mapped. Though few data are available, hazards and constraints there may include filled channels, currents and scour, and shallow gas or clathrates. Filled channels, currents, and scour are more likely to be significant at shallower depths, from the top of the rise at about 2,000 m to depths of 2,500 m. Clathrate reflectors have been observed on seismic profiles in water depths from 2,500 to 3,800 m on the Continental Rise off the Mid-Atlantic OCS (Tucholke and others, 1977).

The uppermost Continental Rise, within several kilometers of the base of the Continental Slope, may receive intermittent mass-wasted material. Observed 10-m talus blocks were described above. Degree of present-day risk is unknown, but is probably slight, and restricted to areas downslope of Tertiary outcrop and canyon axes.

Recent long-term observations from the High Energy Bottom Boundary Layer Experiment (HEBBLE; Kerr, 1980) have revealed unanticipated, occasional very strong currents (up to 90 cm/s) near the bottom on the Continental Rise off Nova Scotia (Kerr, 1980; Richardson and others, 1981). Other, shorter term, observations of bottom currents on the Continental Rise off the North and Middle Atlantic areas had shown moderate southwesterly flows on the order of 10 to 20 cm/s (Zimmerman, 1971). The possibility of occasional high-velocity currents exists but there is no data on frequency or degree of risk.

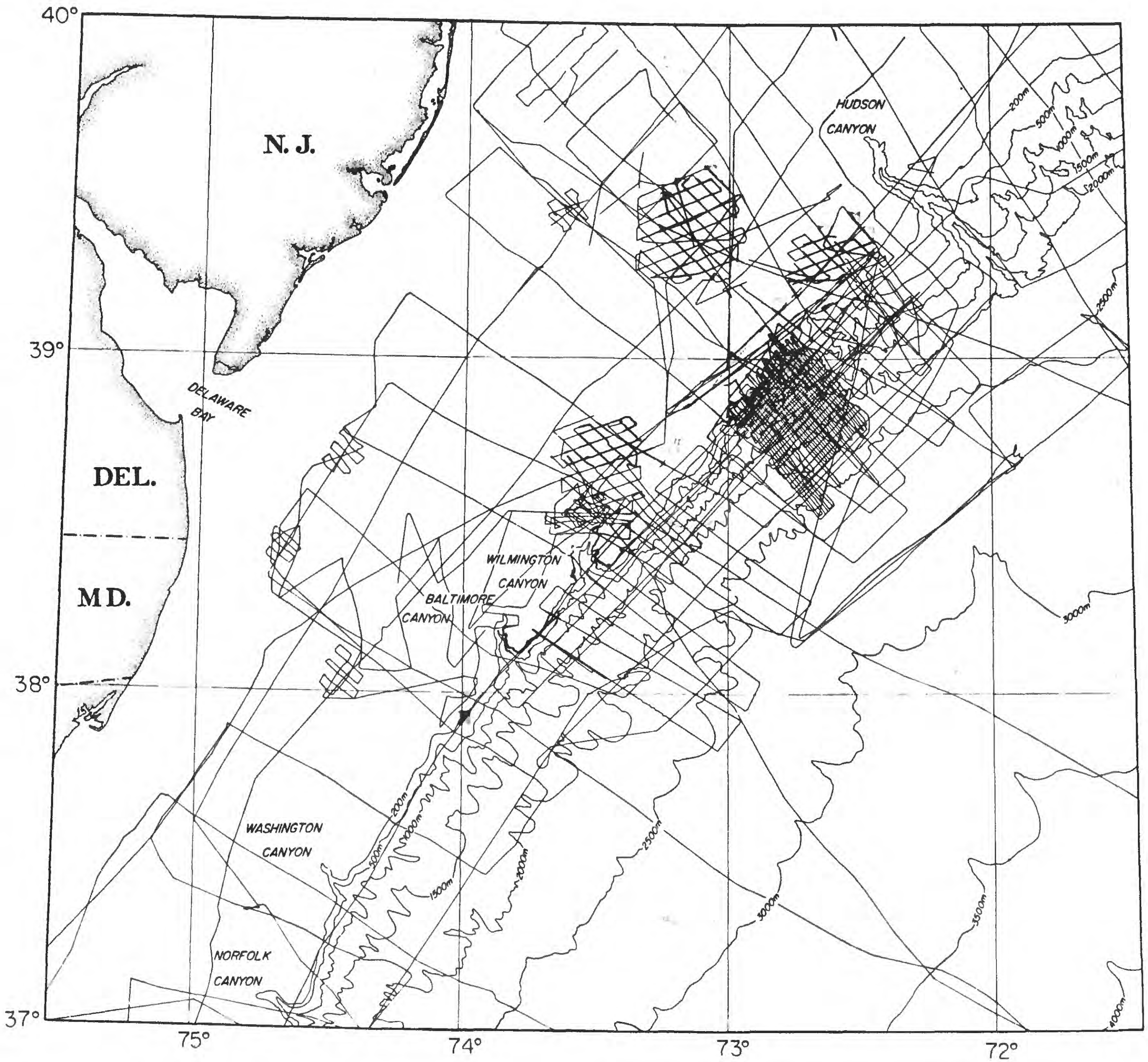


Figure 4-1 Regional track-line coverage of high-resolution seismic-reflection profiles in the Mid-Atlantic OCS acquired by the USGS from 1975 through 1979.

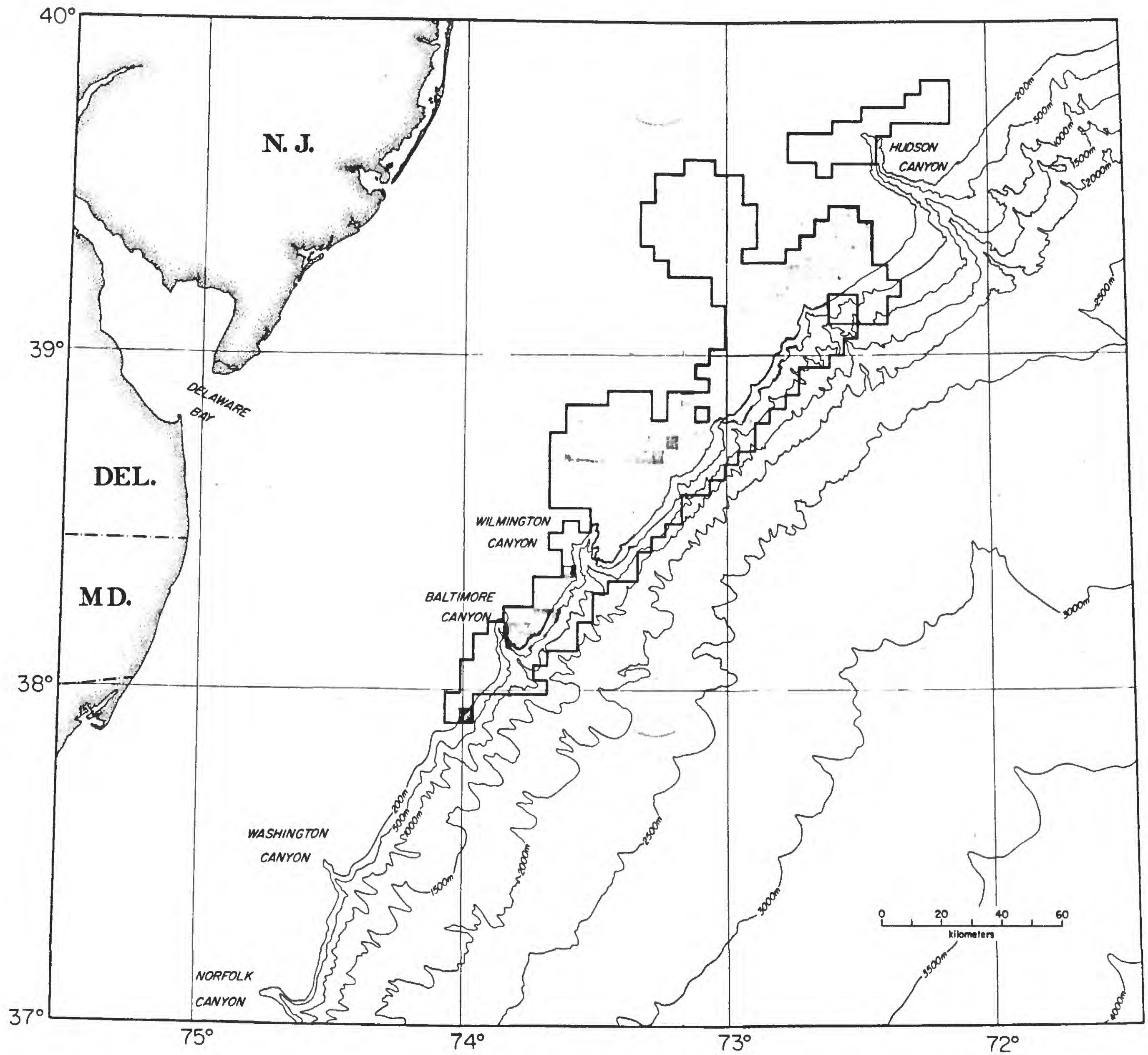


Figure 4-2 Dark outline encloses area of high-density geophysical profiling and sidescan-sonar imaging acquired prior to Lease Sales 40 and 49, to determine potential geologic hazards. Blocks leased in Sales 40 and 49 shown by gray tone.

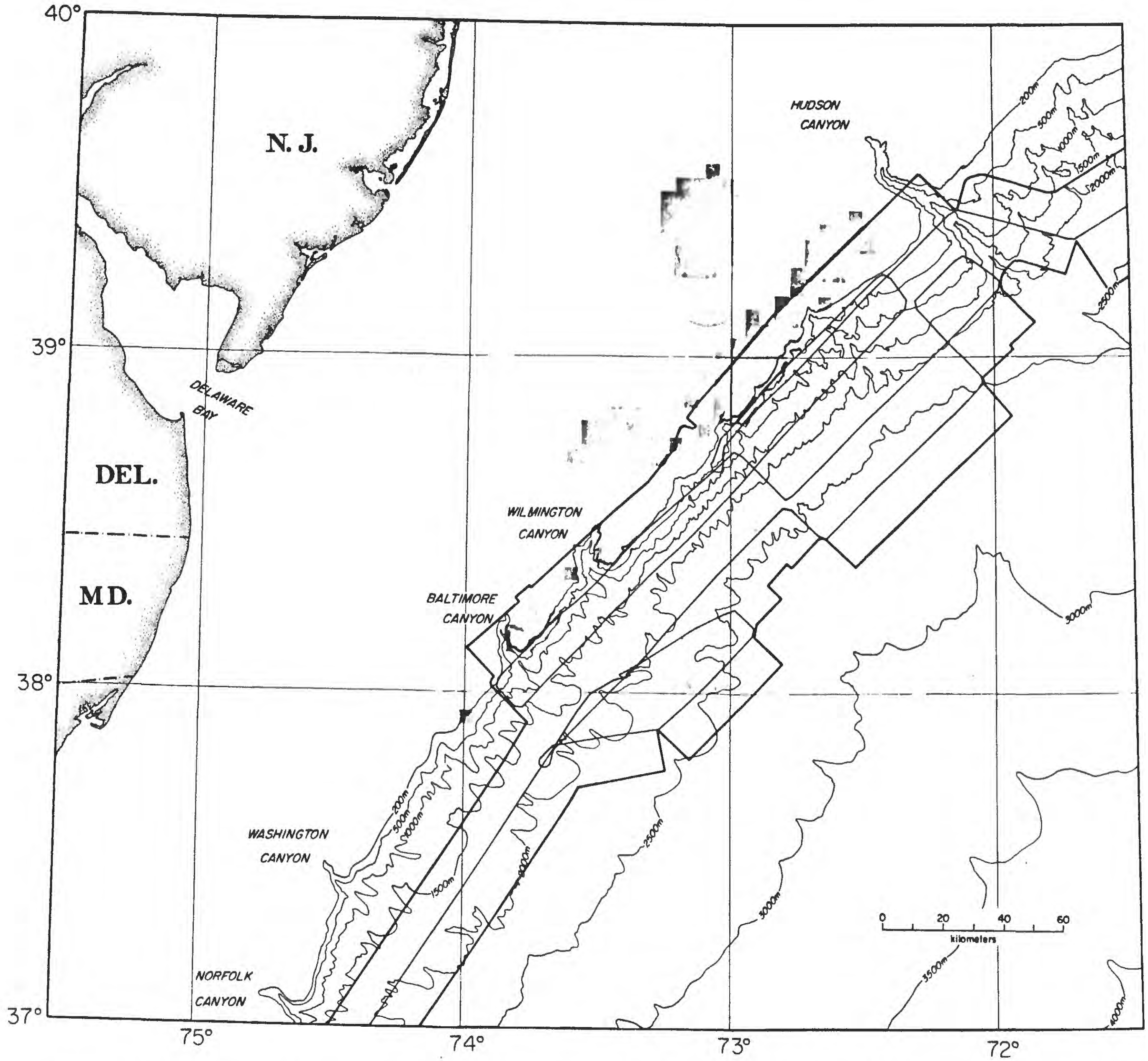


Figure 4-3 Area of GLORIA (Geologic LOng Range Inclined Asdic) sidescan-sonar imaging along Continental Slope.

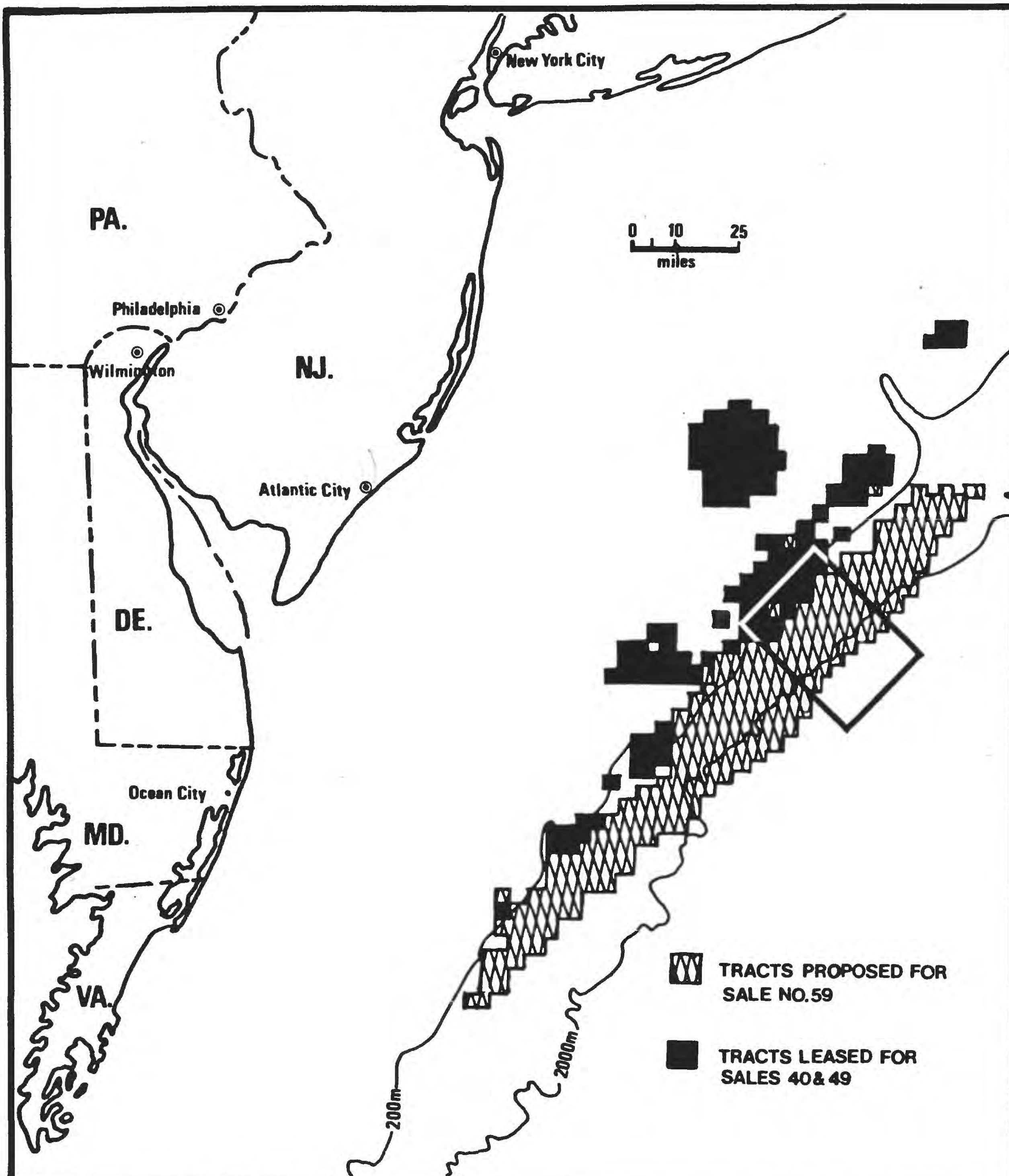


Figure 4-4 Area proposed to be leased under Lease Sale 59 along Continental Slope. Rectangle shows area of detailed geologic and bathymetric mapping on Continental Slope (see figs. 4-6, 4-8).

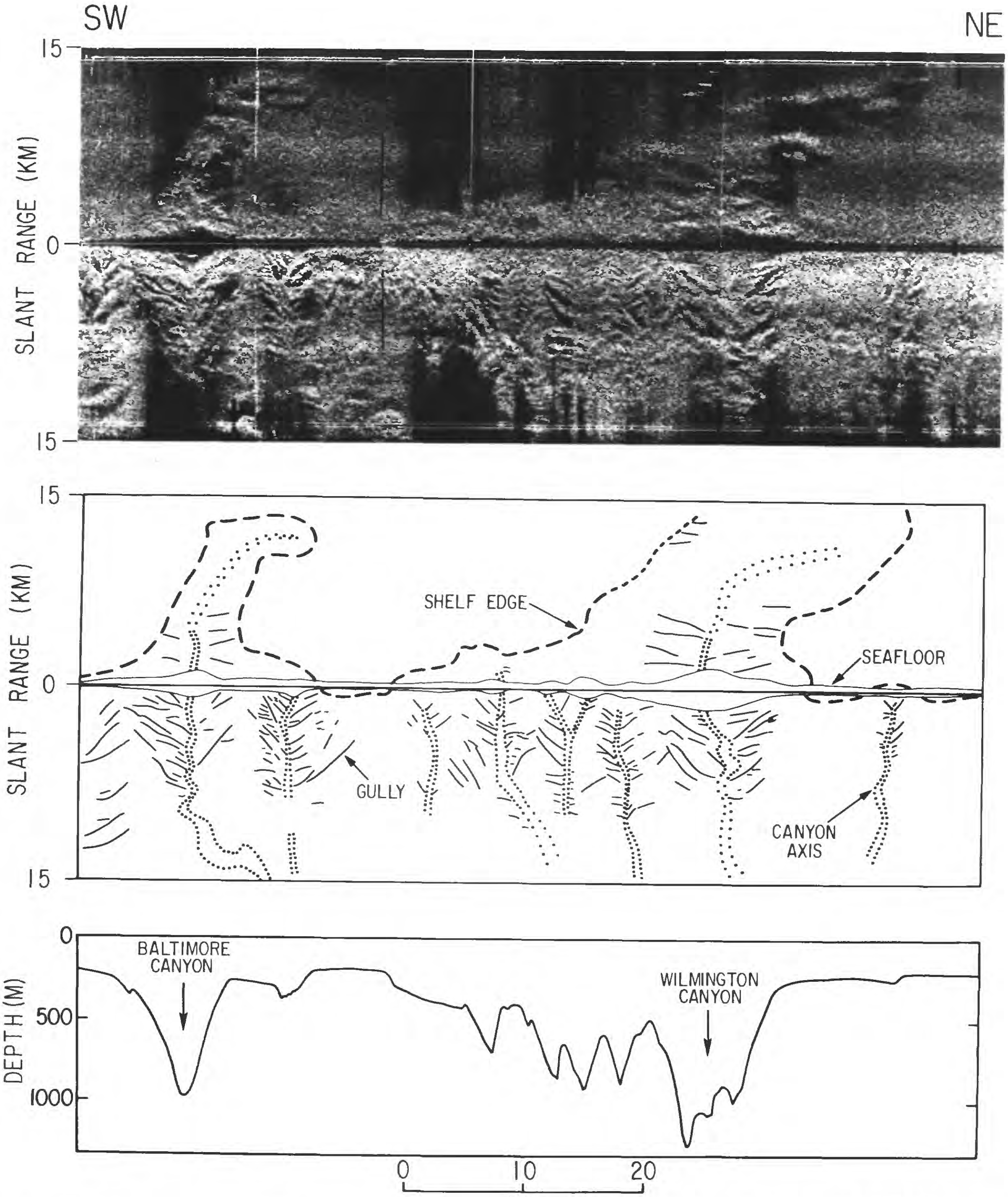


Figure 4-5 GLORIA image and interpretation in vicinity of Baltimore and Wilmington Canyon heads. Top: GLORIA image, center line from right to left is track of vehicle. Image extends 15 km to either side of center. Middle: Interpretation of GLORIA image. Dashed line shows location of shelf edge. Head of Baltimore Canyon to left; head of Wilmington Canyon to right. Canyon axes and gullies shown. Bottom: Bathymetric profile along vehicle track. Vertical exaggeration 13X.

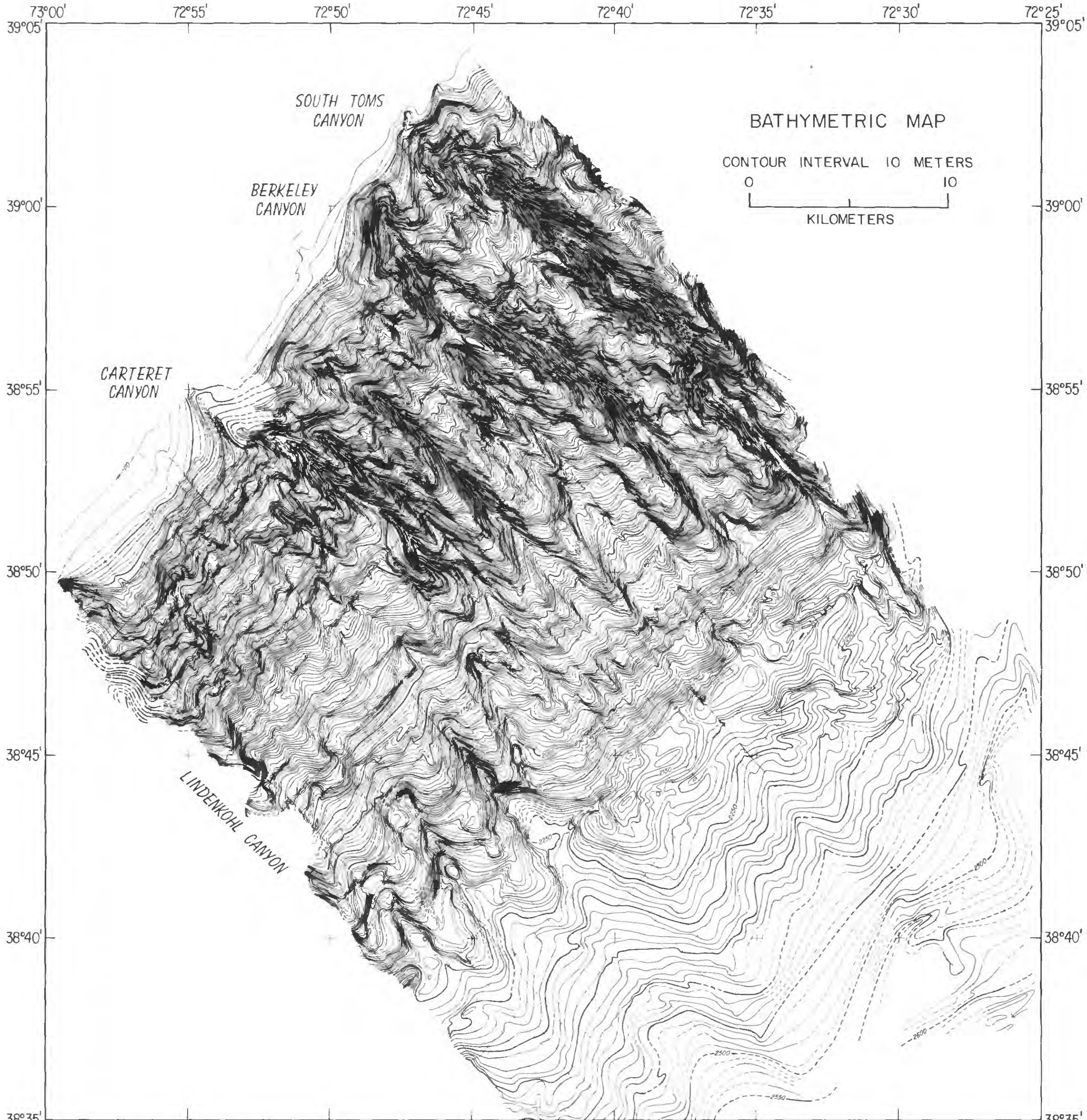


Figure 4-6 Bathymetric map of area between Lindenkohl and South Toms Canyons off New Jersey. Location shown on figure 4-4, contour interval 10 m. Shelf break at upper left, Continental Rise at lower right. Tracklines show data coverage (from Robb and others, 1981a).

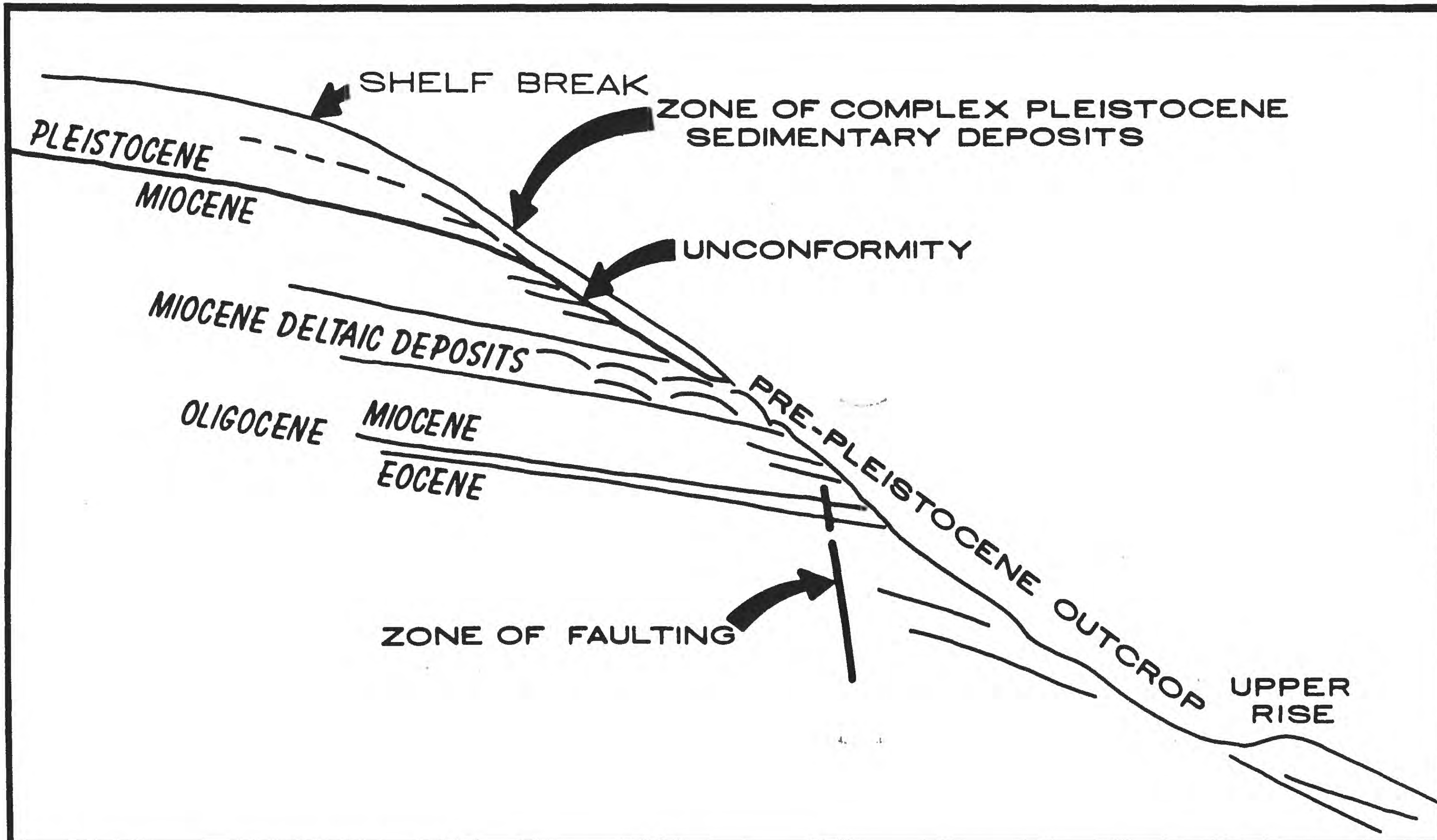


Figure 4-7 Generalized cross-sectional diagram of geology of Continental Slope between Lindenkohl and South Toms Canyons. Shelf break at 130 m depth, upper rise at 2,100 m depth. See geologic map, figure 4-8 to compare areal outcrop pattern of Pleistocene and Tertiary sediments (from Robb and others, 1981c).

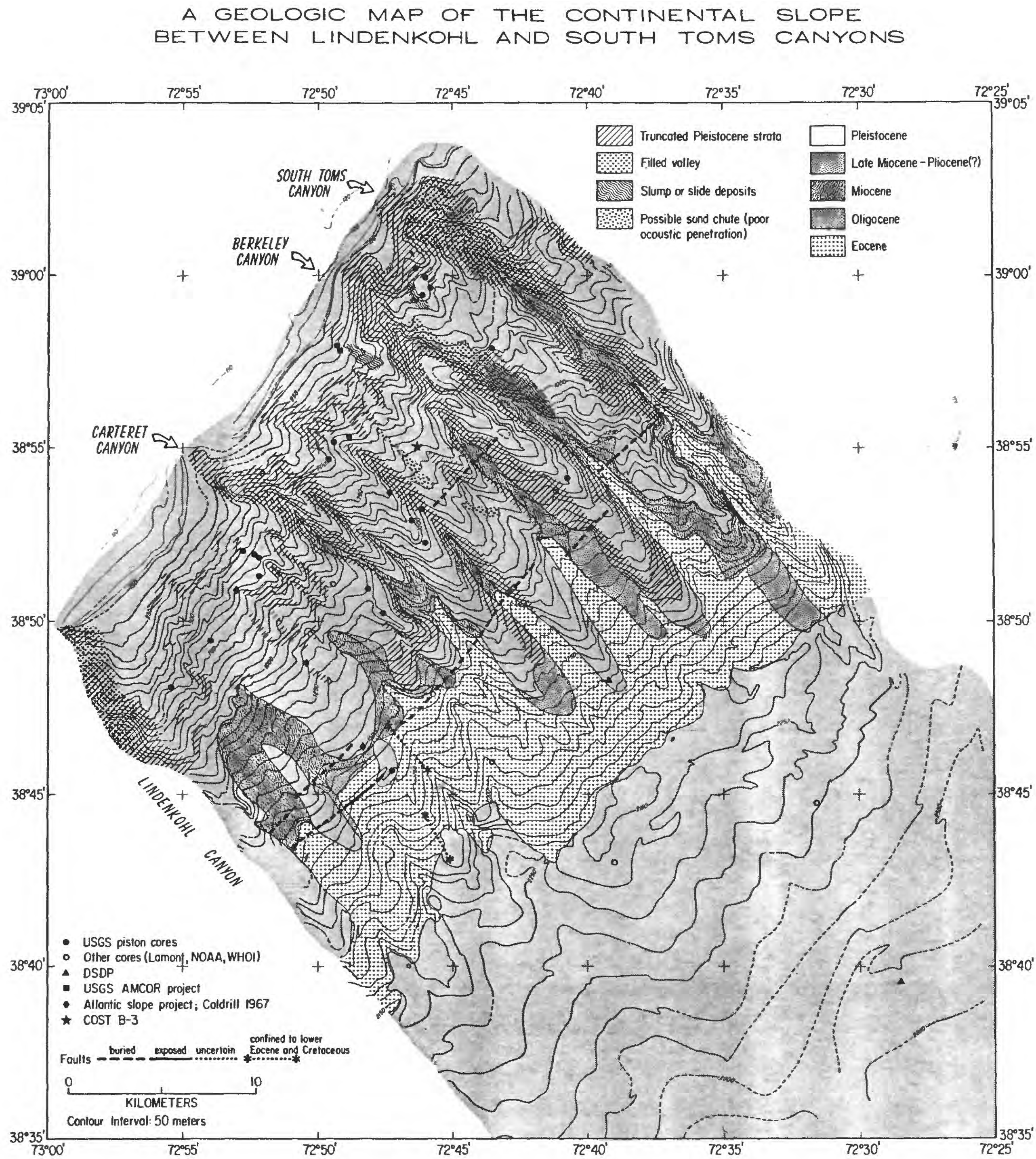


Figure 4-8 Geologic map of Continental Slope between Lindenkohl and South Toms Canyons, off New Jersey. Location shown on figure 4-4. Pleistocene sediments overlie Tertiary sediments on unconformity. Compare figure 4-7. Original mapping done at scale of 1:72,913 (Robb and others, 1981c).

5. Potential geologic hazards in the vicinity of Georges Bank basin

by D. W. O'Leary and D. C. Twichell

Continental Shelf

Georges Bank is a compound feature that resulted from erosion of Tertiary Coastal Plain strata followed by deposition of an extensive wedge of Pleistocene sediment on the eroded surface (Lewis and others, 1980). The Pleistocene sediments are heavily channelled; the channels probably formed when the area was subaerally exposed. Subsequent marine planation produced a smooth erosion surface, and this surface is unevenly covered by late Pleistocene drift which has been reworked first by waves when sea level was lower and presently by storms and strong tidal currents (Lewis and others, 1980). The regional seismic coverage did not provide sufficient data to map buried drainage patterns on Georges Bank; however, the profiles do cross some buried channels (fig. 5-1) which are believed to present a possible hazard because the variable nature of sediments within and outside the channels could lead to differential settling upon loading.

Slump features have not been observed on the Continental Shelf. Although silt and clay layers may be susceptible to failure during undrained cyclic loading, there is no evidence that direct loading by waves has caused collapse to occur in the Georges Bank region. The possibility of failure due to transient loading by earthquakes is remote. Oldale and others (1974) cited "large submarine slumps or landslides" along the north flank of Georges Bank. Slumps along this boundary are undoubtedly of Pleistocene age, originating from collapse of melting stagnant ice buried under sediment. Slumps may be found seaward of the mouth of Northeast Channel where depositional oversteepening would have been at a maximum during periods of maximum glacial advance and early retreat.

Other hazardous conditions are related to the present hydraulic regime and the reworking and transport of the sediments on Georges Bank by these currents. The hydraulic regime of Georges Bank is characterized by strong clockwise rotary tidal currents augmented by wave and storm induced currents (fig. 5-2; Aaron and others, 1980). Near-surface tidal currents measured at 15 m water depth near the crest of the bank at times exceed 75 cm/s, and on the north and south flanks of the bank attain about 35 cm/s (Moody and Butman, 1980). West of Nantucket Shoals, on the southern New England shelf, tidal currents drop sharply to 8 to 10 cm/s. During storms surface waves increase bottom stress and cause increased sediment resuspension. Some scour and resuspension by internal waves were observed in summer on the southern flank of the bank in a water depth of 85 m (Aaron and others, 1980).

In addition to the tidal and storm-related currents, a clockwise mean drift around Georges Bank and the westward drift onto the southern New England shelf, first proposed by Bigelow (1927), have been confirmed by long-term current measurement (Butman, unpub. data, 1980). The mean flow is strongest along the northern edge of the bank where it reaches speeds as much as 20 cm/s, while along the southern side of the bank the mean current is only 8 to 10 cm/s (fig. 5-2). Flow appears to diverge at Great South Channel; some water flows north and some continues westward across the southern New England shelf. Although the mean drift is not strong enough to erode sediment, it can transport material put into suspension by the tidal currents, storm-related currents and waves, or internal waves.

Potential hazards resulting from the strong currents are scour and mobile bed forms. Sediment removed by scour from the base of support structures (platform legs, footings, and pipelines) may generate stresses due to uneven support or cause differential settlement of the structures. The structure itself is an obstruction that tends to increase local current velocities at the bottom, resulting in increased erosion.

Mobile sand waves and megaripples are wavelike masses of sand formed and moved by fluid flow over an erodible granular bed (fig. 5-1). Sand waves are migratory features; their size, geometry, and speed and direction of movement are related to the availability of sediments, grain size of sediments in the bottom, and to flow conditions such as water depth and current velocity. On the eastern United States Continental Shelf, the largest area of sand waves is located on Georges Bank and Nantucket Shoals, mainly in water depths of 60 m or less (fig. 5-2). Sand waves range in height from 1 m to 20 m and in wavelength from 150 m to 750 m (Jordan, 1962; Twichell, 1981). On Georges Bank, sand waves do not cover the entire sea floor; they are concentrated on a series of northwest-trending ridges and are absent in the troughs between the ridges. This sand-wave distribution pattern reflects the availability of sand on the ridges; in trough areas sand has been swept away. The presence of smaller ripples on top of the sand waves indicates that they are active. Two groups of echo-sounding surveys 25 to 28 years apart (Stewart and Jordan, 1964) showed that sand waves on Georges Shoal migrated 300 m for an annual migration rate of 12 m/y. Preliminary results from a study being conducted by the U.S. Geological Survey in a 1.5 by 2 km area on Little Georges Bank show that from June through September 1980 parts of some sand waves moved as much as 30 m but from September to April they moved less than 10 m.

Sand waves are potential threats to the stability of support structures because they can weaken the structure by changing the resonant frequency for which they are designed (Garrison and Bea, 1977). This may have been the cause of the collapse of the Texas Tower radar installation erected on Georges Bank during the late 1950's (Emery and Uchupi, 1972).

Sand wave distribution and asymmetry and surface sediment texture can be used to infer net sediment transport paths on the New England shelf. On Georges Bank in water depths less than 60 m, the large sand waves indicate that the strong tidal currents are actively reworking surface sediments. Sand-wave asymmetry suggests transport away from the crest of the bank (Twichell, 1981) and on the north and south flanks of the bank where tidal currents are weaker, surface sediment texture becomes increasingly fine with distance from the bank crest, further supporting this interpretation. The fining of the sediment away from the crest of the bank has resulted in silt and clay deposits both in the Gulf of Maine and on the southern New England shelf (fig. 5-2). The fine sediment on the southern New England shelf previously was thought to be relict (Garrison and McMaster, 1966; Schlee, 1973), however, recent seismic-reflection profiles show that it rests on three Holocene terraces and therefore the fine sediment has accumulated since the last rise in sea level (Twichell and others, 1981). Carbon-14 ages and lead-210 profiles further suggest that this sediment has accumulated in the last 10,000 years and may be actively accumulating at present (Bothner and others, in press).

The location of the fine sediment on the southern New England shelf is controlled by the current regime. The strong tidal currents erode material from the crests of Georges Bank and Nantucket Shoals; it is then transported by the weaker tidal currents and the mean drift westward to the southern New England shelf where the sharp drop in tidal-current strength (fig. 5-2) permits the fine suspended sediment to be deposited. If the deposit still is actively accumulating, this area may be a sink for any fine material and sediment-related pollutants that might be introduced to the Georges Bank area during exploration, development, production, or transportation of hydrocarbon resources.

Continental Slope and Rise

A systematic study of the North Atlantic Continental Slope, from longitude 71°W. to Northeast Channel, was begun in 1978; 8,340 km of seismic profiles were obtained along the slope and outer shelf edge by the ISELIN 2 cruise (1978) and the GILLISS 3 cruise (1979) (fig. 5-3). Dip lines were spaced at about 10 km, strikelines at about 5 km. In 1979, over the same survey area, overlapping sidescan-sonar image data were acquired by the GLORIA (Geologic LOng Range Inclined Asdic) system (fig. 5-3). In 1980 GYRE cruise 80-7 completed a seismic survey of a 2,800-km area on the slope adjacent to lease sale area 52, between and including Oceanographer and Lydonia Canyons (fig. 5-3). Profiles were spaced 1 km along the slope and 5 km down the slope. GYRE cruise 80-8 acquired mid-range sidescan-sonar images of the same area with a spatial resolution of about 3 m. In 1981 GYRE cruise 81-G-12 acquired mid-range sidescan-sonar image coverage over 1,875 km^2 of the slope west of 70°W. (fig. 5-3). These data were used to guide coring operations for geotechnical studies of Continental Slope sediments. Results of the data analyses have not yet been published; the following text is an outline of the major environmental findings and implications of the study. Despite its low angle of declivity (3° to 8°) the Continental Slope is extensively and relatively deeply eroded with local slopes that commonly exceed 20°.

Sidescan-sonar images indicate that the Continental Slope in the lease sale 82 area is an expression of two distinct kinds of terrain: an older, unincised terrain and a younger incised terrain. The unincised terrain is a regionally smooth, gently undulatory landscape with minor, low-relief surficial features that reflect the most recent deposition and current erosion and, locally, biological activity. This surface is the top of the Holocene to latest Pleistocene sediment blanket that covers the slope. The unincised terrain is graded directly to the Continental Rise and all material eroded from it moves directly downslope toward the rise. The unincised terrain is marked by a variety of mass movement features that include slides, block rubble fields, slump scars, transverse and longitudinal scarps. The more extensive incised terrain is a rough, relatively deeply eroded landscape formed at the expense of the unincised terrain. Approximately seventy percent of the Continental Slope surface in the Lydonia and Oceanographer Canyons is eroded. Most slope erosion is associated with the numerous submarine canyons. Sidescan-sonar images show that the type of erosion varies with depth on the Continental Slope. Near the top, between about 250 m and 1,000 m, submarine canyons are fringed with wide areas of ridge and gully terrain in which networks of gullies are tributary to the central channels of the canyons. The canyons themselves are relatively wide, flat-floored features; their smooth generally featureless bottoms indicate that they are sites of deposition as well as erosion. Below about 1,500 m, eroded forms of the Continental Slope are complex and not all of them are related to canyons that extend farther up the slope. Sparse observations from submersibles, and bottom core samples indicate that much erosion has occurred within the last 200,00 years. Most of this erosion is believed to have been caused by bottom currents during Late Tertiary glacial lowstands of sea level (John Grow, pers. commun., 1981). Erosion of the canyons has generaly been ascribed to the action of turbidity currents, but the diversity of erosional forms on the slope indicates complex mechanisms, including various kinds of slumping.

Three potential hazards are associated with the Continental Slope and rise: mass wasting on unstable slopes, structurally unstable sediments, and potentially mobile surfaces.

Unstable slopes and mass wasting

In the North Atlantic region potentially unstable slopes (greater than 20°) are found in the eroded terrain related to the numerous submarine canyons incised in the Continental Slope. Submersible observations give evidence that slopes greater than 45° in the vicinity of the canyons are mechanically unstable. Away from such steep slopes erosion is apparently progressive. Along Veatch Canyon, at depths between 150 and 160 m, Slater (unpub. data) noted slopes of 45° that are actually series of rubble-covered terraces, 2 to 5 m wide, separated by steep (75°) cliffs 1 to 3 m high. These terraces are interpreted to be slumps or wall segments that have slid out of place (fig. 5-4). Near Veatch Canyon Slater (unpub. data) observed that rills near the 180-m contour are shallow straight features, 1 m across and 25 cm deep; at 200 m depth they are as wide as 3 m with hummocky, burrowed sides sloping 20°, but there is no evidence that these slopes are unstable; they are apparently graded to a gully network in which shelly debris, lag gravels, and winnowed sand and silt are presently being concentrated. Between canyons the eroded slopes flatten smoothly onto the unincised, broadly featureless surface of the Continental Slope.

Between depths of 1,000 and 2,000 m on the Continental Slope sidescan-sonar images show that steep slopes bound the eroded terrain related to the canyons; in general, a relatively steep headwall locally marked by slump features forms a boundary with the unincised, featureless Continental Slope surface. Discontinuous headwall scarps and intermediate terraces (figs. 5-5, A; 5-6, A), reentrants and promontories (fig. 5-5, B), ravinelike incisions (figs. 5-7, A; 5-8, A), and rubble-strewn lower slope surfaces (figs. 5-7, B; 5-8, B) are found on the incised terrain and indicate that the relatively steep, etched slopes facing the canyon systems were formed, at least in part, by mass movement. Various morphological features indicate that in many places this process is incomplete or has been arrested. Locally the lower slopes and bottoms of the depressions show slight scarps that suggest that even relatively flattened slopes may be unstable within the incised terrain (figs. 5-5, C; 5-7, C). Discontinuous terraces at different levels suggest toreva blocks (figs. 5-6, A; 5-8, D).

Significant examples of fresh, recent movement have not been found and it may be that mass wasting occurs locally or regionally at widely spaced intervals of time. If slumping events occur at intervals of centuries their hazard potential is low. Some morphological features suggest that scarped slopes may be metastable, awaiting only an appropriate stress to trigger the collapse. Until stress thresholds and trigger mechanisms can be analyzed for such suspect features it would be prudent to site large structures well away from the collapsed slope breaks.

In places along steep slopes, large blocks of sediment have slid down or have become detached from the scarp and adjacent upper surface. Block collapse is apparently caused by the sliding away of subjacent sediment or by the slumping and steepening of the cliff base. Collapse blocks range in size from block field rubble fragments a few meters across to large scarp segments tens of meters across. Blocks and blocky rubble are found along the mouths of amphitheaters which open out into canyons or large downslope troughs (fig. 5-8, C). Many of the cirquelike forms are the result of slumping. The rubble of collapsed blocks is evidence of mass movement, but fine mixed debris which should be present, is nowhere clearly recognizable. Apparently slumping leads to suspension of most of the dislodged fine sediment which is carried down to the canyon axes.

Sliding is probably a less violent mass-movement phenomenon and perhaps is more akin to creep than to slumping, because debris is ordinarily not moved far from its source. Slides are prevalent in the unincised terrain west of 70° (fig. 5-3). They include isolated tongue-shaped bodies formed on an apparently otherwise undisturbed surface, slides formed at the base of downslope-facing scarps, slides that also include characteristics typical of slumping or block collapse. All these slides have one thing in common: they are formed on conformable, undisturbed, well-layered sediment which has not been incised by other kinds of erosion.

Isolated slides originate along arcuate fractures (fig. 5-9). Material below the fracture slides out and down the slope in a long, tongue-shaped mass of debris which comes to rest at an angle of repose just sufficient to prevent further motion. The distal ends of the slides are acoustically "bright" (fig. 5-9) which indicates texturally rough material and implies that coarse debris is concentrated at the slide front. Echo-sounding profiles (e.g., fig. 5-10) indicate that as much as a 20 to 25 m thickness of slope sediment can be detached along a bedding plane, leaving behind a sharply cut-out depression with little or no residue. Sliding tends to flatten a gravitationally unstable slope. Seismic profiles indicate that in slide-prone areas the Continental Slope steepens with depth. Therefore, the areas at the toes of slides are probably prone to further sliding because they are steep.

Large fan-shaped fields of blocky rubble with upslope apices, sharply bordered by scarps (fig. 5-10) represent areas in which a noncompetent bed has failed, possibly by incremental sliding, under a more indurated layer. The downslope sliding has caused overlying material to break up. In places rubble fields converge to arcuate slump-slide heads (fig. 5-11) which may represent the loci of initial failure. More common west of 70° are large polygonal areas bounded by smooth scarps (fig. 5-12). No rubble or other debris is evident in these areas, yet detachment and removal of slabs is distinctly indicated. Slab removal at successively lower stratigraphic levels downslope is indicated by stepped surfaces.

Small slides are locally present above the 500 m isobath. A well-defined trough is present within the sediment-filled channel of Oceanographer Canyon at 1,000 m (within the projection of the 500 m slope isobath). This feature has cut headward into the most recent sediment laid down in the canyon thalweg. Because it is a pronounced incision with a distinct upslope terminus in otherwise undisturbed surroundings, it probably originated by mass movement.

The upper Continental Rise shows evidence of widespread debris deposition from both the undissected slope surface and from the canyons. The canyons are the chief conduits for debris flows which fan out onto the rise in overlapping sheets. Large slumps and slides may produce such debris sheets: moving layers of slurry which are thick enough to entrain blocky rubble on the surface show overlapping borders and digitate forward margins, yet are fluid enough to form stream lines and flow over a one degree slope. A core obtained below 2,000 m near the mouth of Powell Canyon (Booth, oral commun., 1981) showed thinly layered sediments of varied texture, color, and mechanical properties. The layered debris sheets on the upper Continental Rise and their heterogeneous mechanical properties suggest that this region, between 2,000 and 2,500 m, is potentially unstable and should be thoroughly tested for mechanical strength.

Unstable sediments

The incised terrain of the upper Continental Slope is underlain by a cohesive gray clay which is widely veneered by fine sand or silt as much as

10 cm thick. The clay seems to have been deposited from suspension on steeply gullied slopes formed during an earlier episode of erosion. Seismic profiles show that many of the earlier gullies are completely filled and some are reincised. The gully and rill network has been reestablished following deposition of the clay (within the last 200,000 years). The thickness of the clay unit is not known. However, Valentine and others (1980) estimate the total thickness of Quaternary sediments along the outer shelf and slope on either side of Oceanographer Canyon to be about 300 m.

The sand and silty sand layer capping the outer shelf and upper slope is glacial outwash sediment deposited during the main phase of glacial retreat from the top and northern margin of Georges Bank. The underlying clay layer seems to be a widespread stratum that thickens with and follows the dip of the underlying slope. This clay layer apparently crops out below about the 250-m isobath and dips downslope, as observed by Slater (1981). The overlying outwash sediments pinch out at this depth. The association of scattered boulders and cobbles with the exposed clay suggests that the clay was deposited from melting pack ice and shelf ice in quiet water during the period of maximum ice stability on the shelf, just prior to the rapid retreat of the ice and consequent outwash deposition. Clay deposition abruptly ceased and the clay was rapidly buried by a blanket of relatively coarse, sandy sediment. This geological condition points to a potential hazard; the uppermost clay layer, dipping down the slope, may be overpressurized because of rapid burial. Structural footings that fail to penetrate the clay layer may induce local loading phenomena that could result in plastic or even thixotropic failure of the silty clay. There is some evidence in seismic profiles that creep has occurred in subsurface layers along the edge of the Continental Shelf off Georges Bank.

The Pleistocene clay exposed near Alvin Canyon was cored (Booth and others, 1981c) to determine its geotechnical properties. The cored sediment has a relatively high shear strength for surface sediment (average 9.5 kPa) and is very stress sensitive. Bulk density is higher (1.71 g/cc, average) and water content is lower (53%, average) than normal. Sediments failed by "plastic" shear at about 8 percent to 10 percent strain. Tests for shear strength and index properties suggest that the core sites near Alvin Canyon were once buried under 10 to 35 m of overburden. However, slope-stability analysis indicates that the cored sediment is stable (normal to slightly overconsolidated). The sediments have angles of internal friction between 21 and 28--typical values for fine-grained marine sediments.

Pleistocene sediments draped on previously eroded but stable slopes may have been locally oversteepened due to rapid sedimentation rates, and subsequently they have sloughed off. If this condition were widespread, many slopes may be metastable on the upper part of the Continental Slope today. Detailed site-specific coring studies are strongly suggested in this region. An example of a potential hazard associated with this condition occurs above the 500 m contour at 70°28'W.; a shallow trough shows longitudinal streamlines caused by laminar shearflow in an area of otherwise rough terrain. The roughness may be caused by differential creep in interbedded Pleistocene sand and clay. The streamlines cut across the terrain pattern parallel to the slope and suggest that the trough is a site of downslope sliding with material contributed from the sides. This is a post-Pleistocene feature because the forms are developed on Pleistocene, perhaps Holocene, sediment. However, the trough itself may have been formed much earlier.

The north slope of Georges Bank and the adjacent Gulf of Maine are subject to the same geologic conditions as the seaward edge of the Continental

Shelf. In fact, collapse phenomena, channel filling, and local clay lenses are likely to be more important there because the area between the bank and the retreating ice front would have been an area of ponded ice meltwater and sediment deposited on and around detached blocks of melting stagnant ice. The wide variability of adjacent rocks and sediments precludes any general statements about the potential hazards of the sea floor in this region; site-specific assessments for hazards are required throughout this region.

Mobile surface sediment layer

Fine sediment winnowed from the glacial outwash of the shelf surface is distributed as a rippled surficial layer on the upper Continental Slope. Observers agree that this winnowed sediment is being transported to the floors of the canyons where it apparently concentrates (Valentine and others, 1980; Slater, 1981). Stanley and Freeland (1978) concluded that the transport ceases to be effective below about 175 m water depth. Valentine and others (1980) noted that the "mud line" (the approximate boundary between erosion or transport, and deposition or stability) has not been recognized along the east slopes of the submarine canyons, where coarser, rippled surfaces extend to greater depths. The different surface textures on the east and west walls suggest that currents are much more effective at transporting sand along and down the east walls than over the west walls. Valentine and others (1980) also noted that sediment on the canyon walls appears to move along the walls rather than directly downslope into the axes.

Below the "mud line" in the Alvin Canyon area the fine-grained sediment surface shows surprising resistance to erosion. Experiments conducted by MacIlvaine and Ross (1979) on surface samples obtained at 1,800 m depth showed that current velocities of 150 cm/s were required to slightly modify the surfaces. The MacIlvaine and Ross experiments suggest that deflationlike irregularities may be the dominant result of bottom current erosion on the lower Continental Slope. However, they noted that the surface may be smoothed of perturbing irregularities by epibenthic fauna and infauna. Further, small annelids appear to establish an intricate network or mat of fibrous binding material associated with their burrows near the surface. Clearly, any activities which destroy the biogeological relationships of apparently stabilized surfaces should be monitored for increased erosion effects and consequent bottom weakening, especially in areas where metastable slopes are indicated. The influence of epibenthic fauna in maintaining submarine surface stability may prove to be as important as the influence of binder vegetation or turf in maintaining subaerial surface stability.

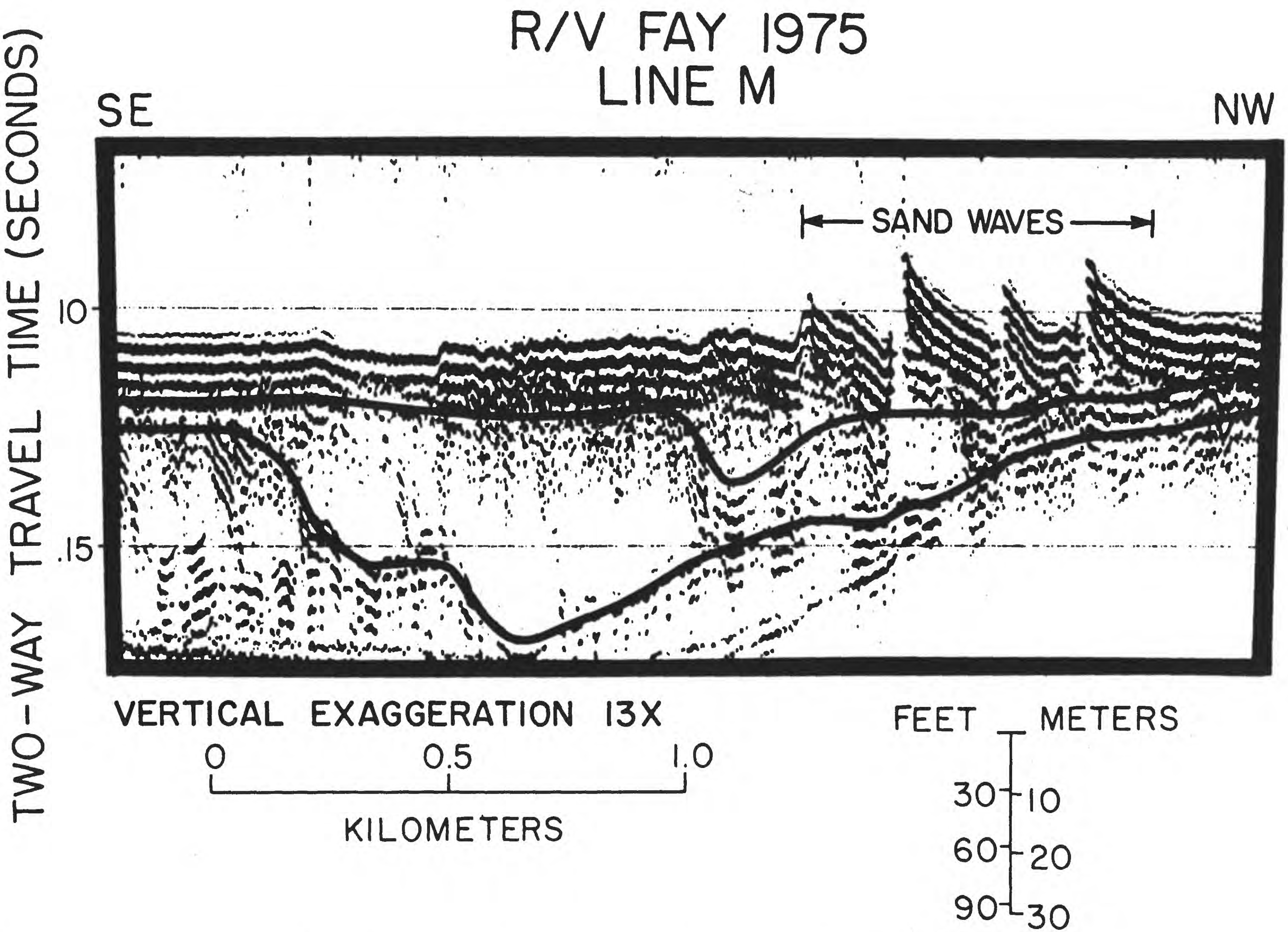


Figure 5-1 High-resolution (minisparker) seismic profile across part of Georges Bank showing asymmetric sand waves on bottom and buried channels. Heavy lines depict two episodes of channel cutting.

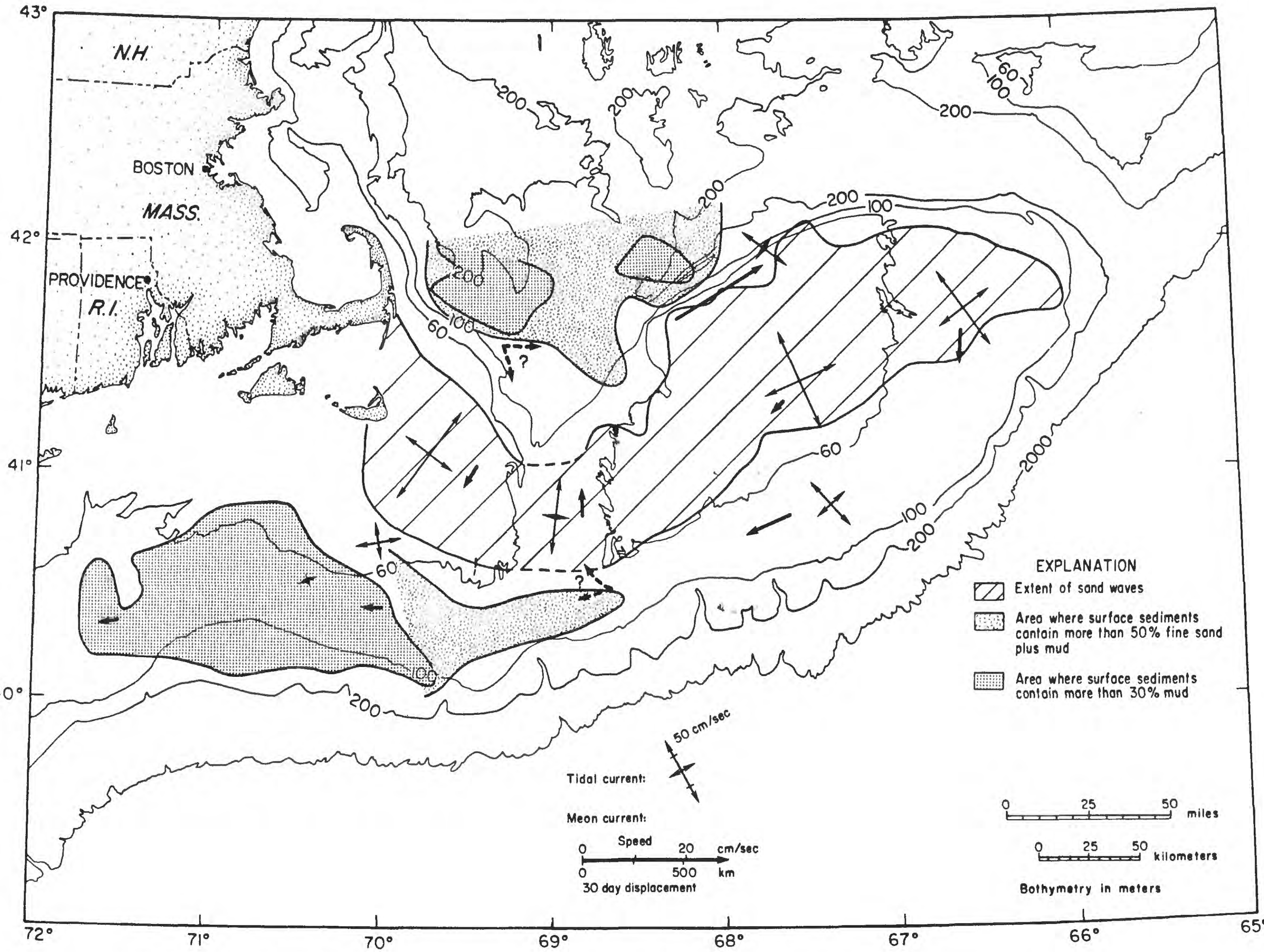


Figure 5-2 Distribution of sand waves, fine sediment deposits, tidal currents, and mean currents on Georges Bank and the adjoining shelf areas.

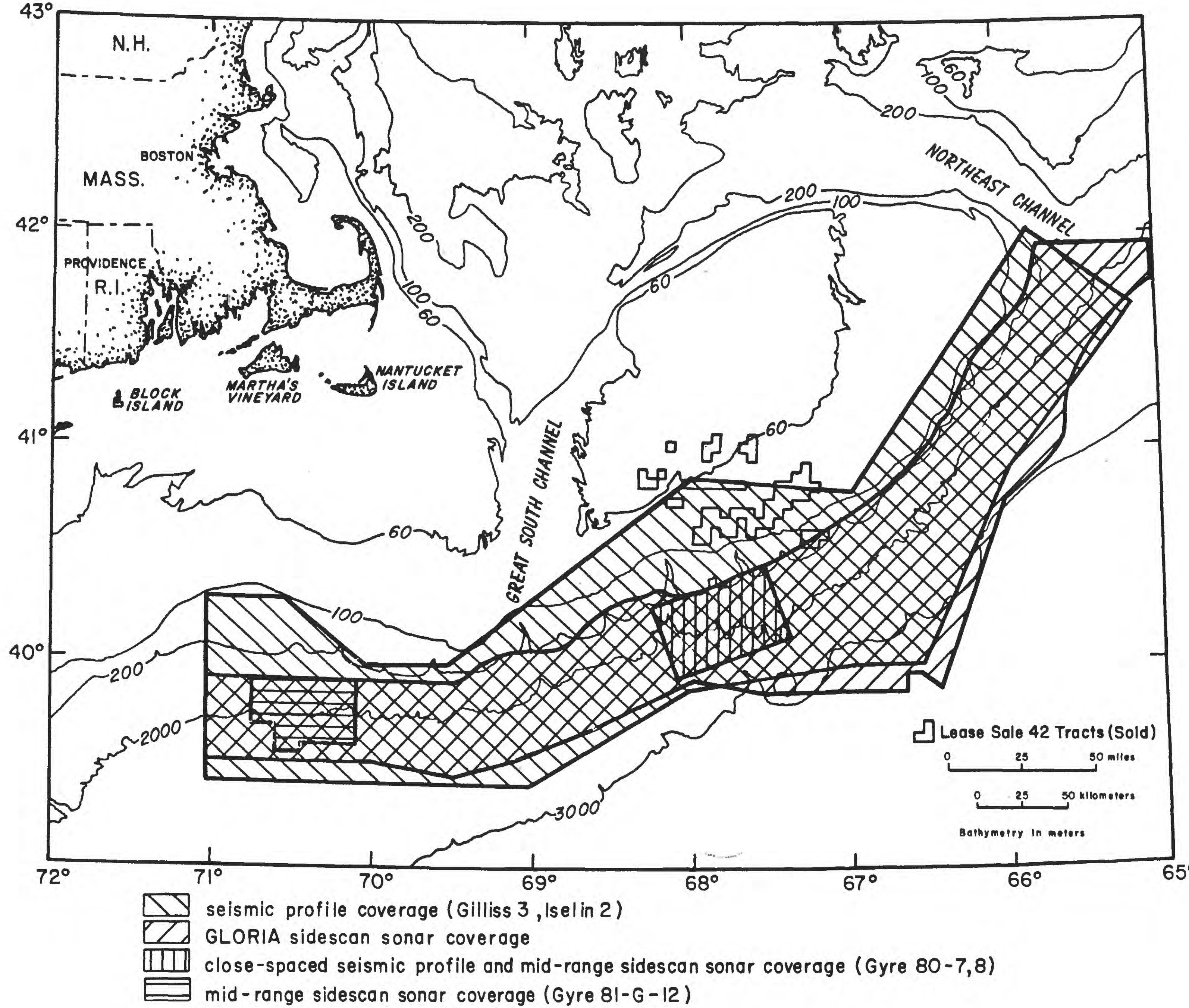


Figure 5-3 USGS-BLM data coverage, North Atlantic Continental Slope and rise.

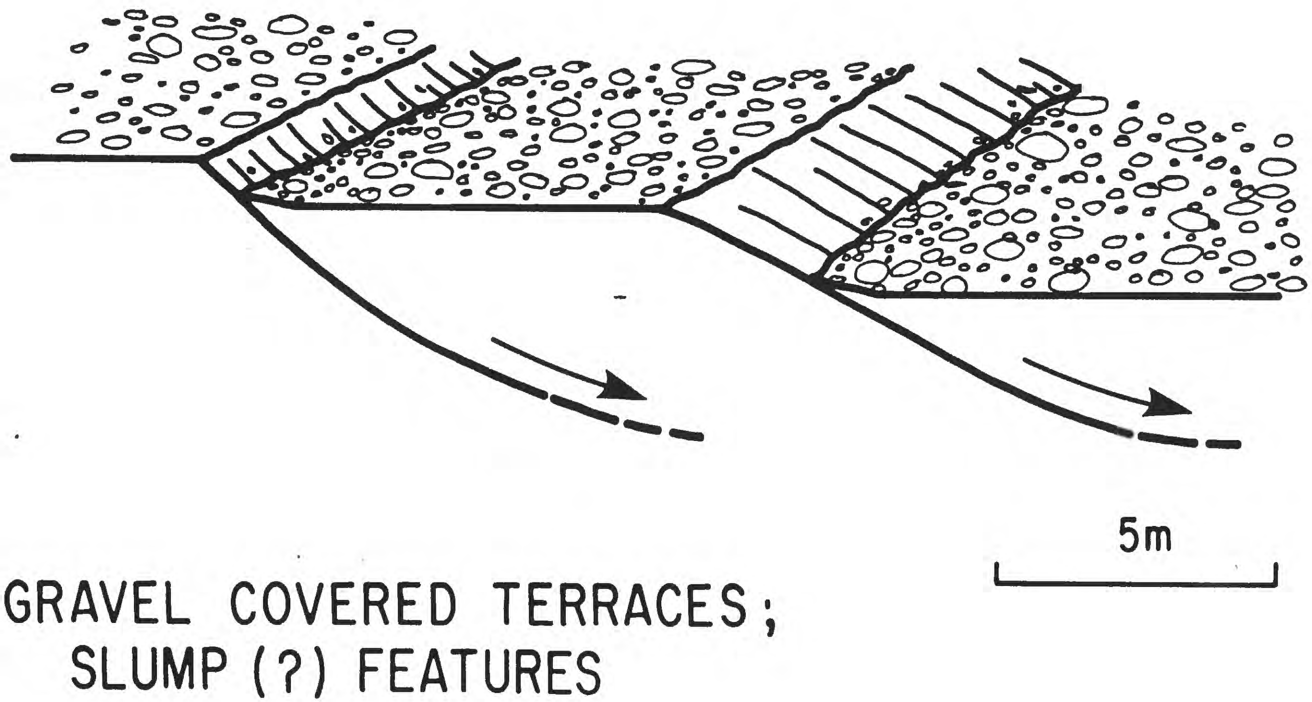


Figure 5-4 Schematic interpretation of slump morphology near Veatch Canyon.

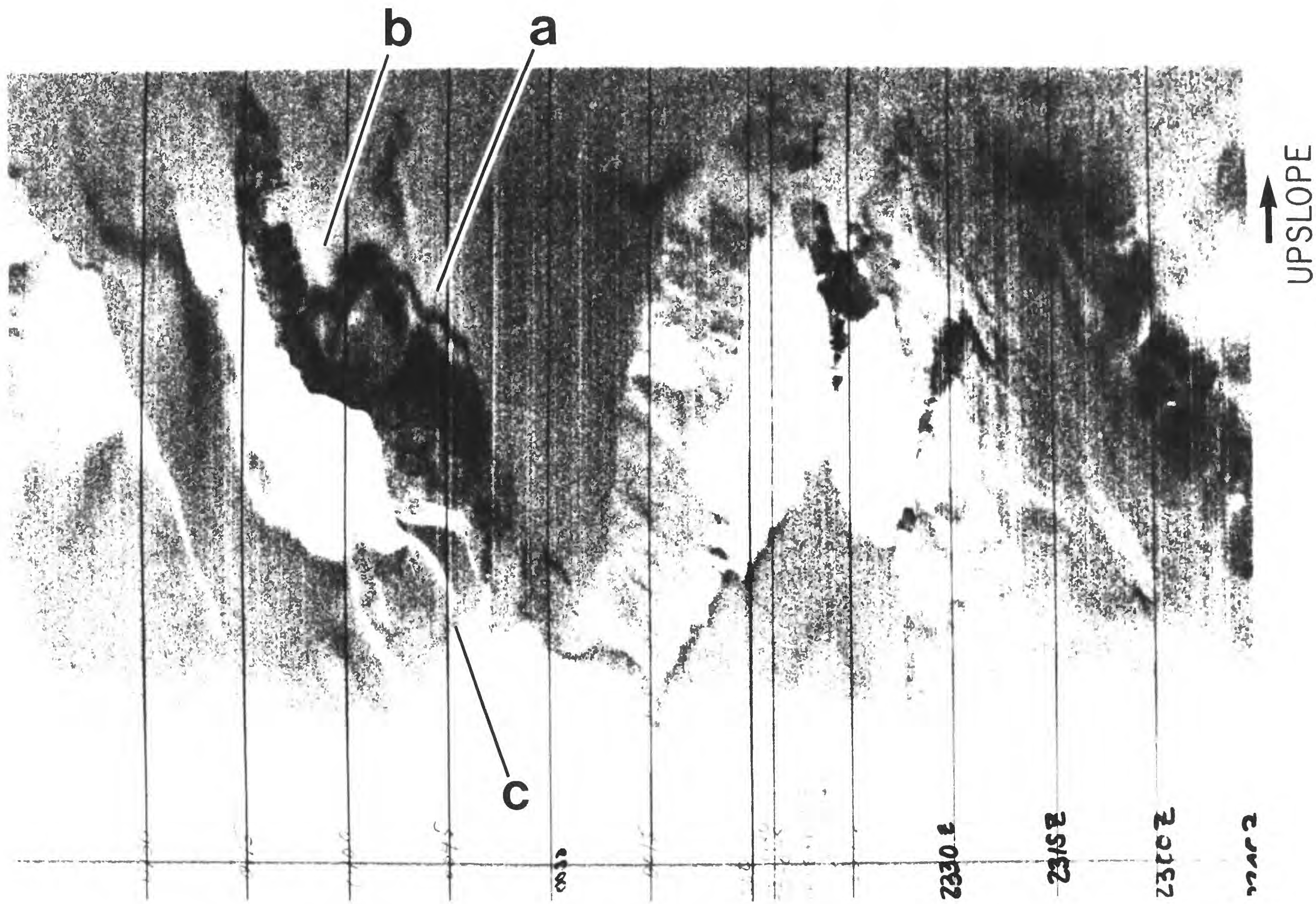


Figure 5-5 Slant-range corrected sidescan-sonar image of slope between Chebaco and Filebottom Canyons, vicinity of 67°55'W., approximately 2-5 km; vertical grid spacing about 0.8 km.

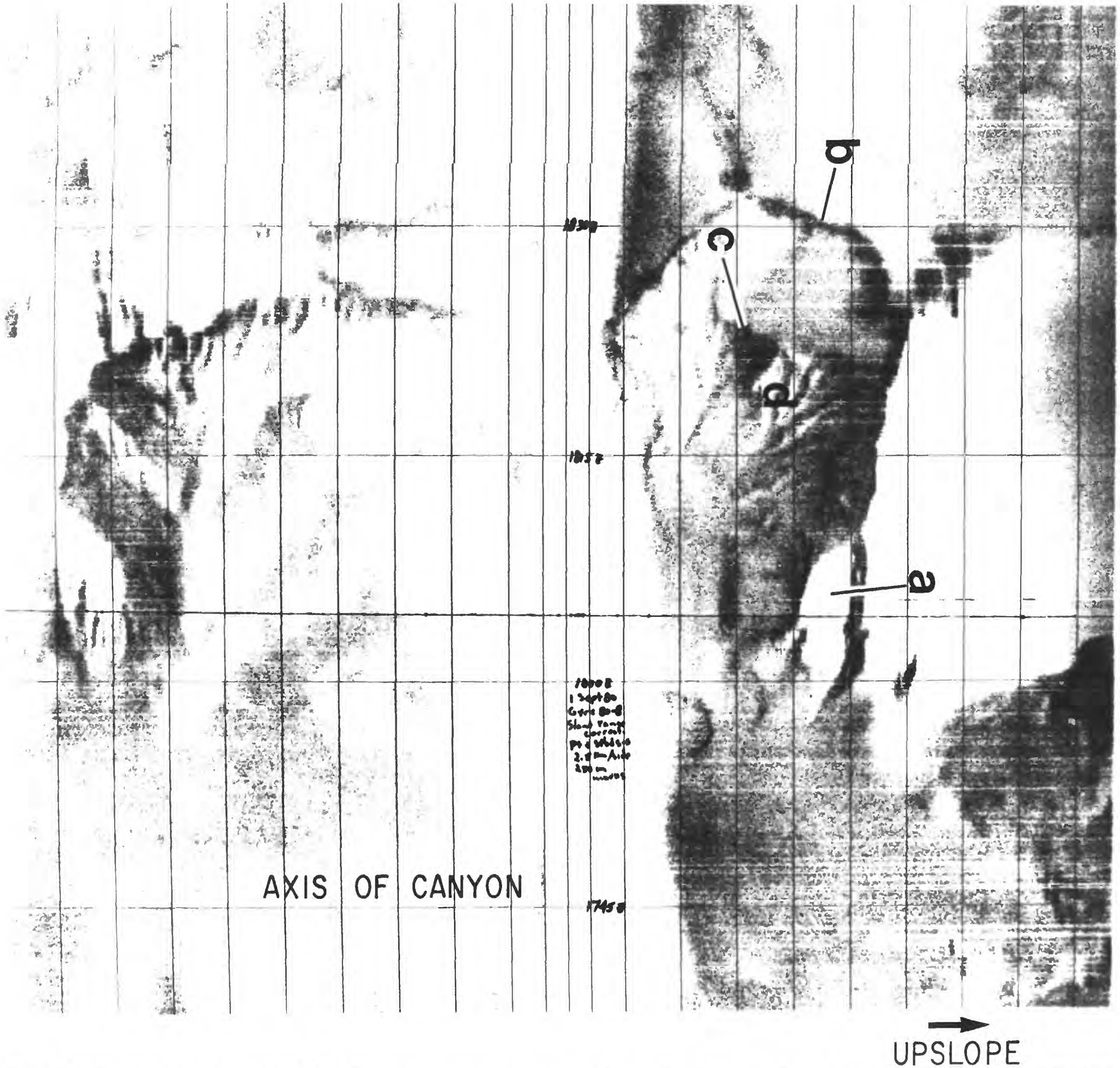


Figure 5-6 Slant-range corrected sidescan-sonar image of etched terrain along west side of Lydonia Canyon, vicinity of 67°43'W., approximately 2,100 m depth. Horizontal grid spacing 250 m; vertical grid spacing about 1 km.

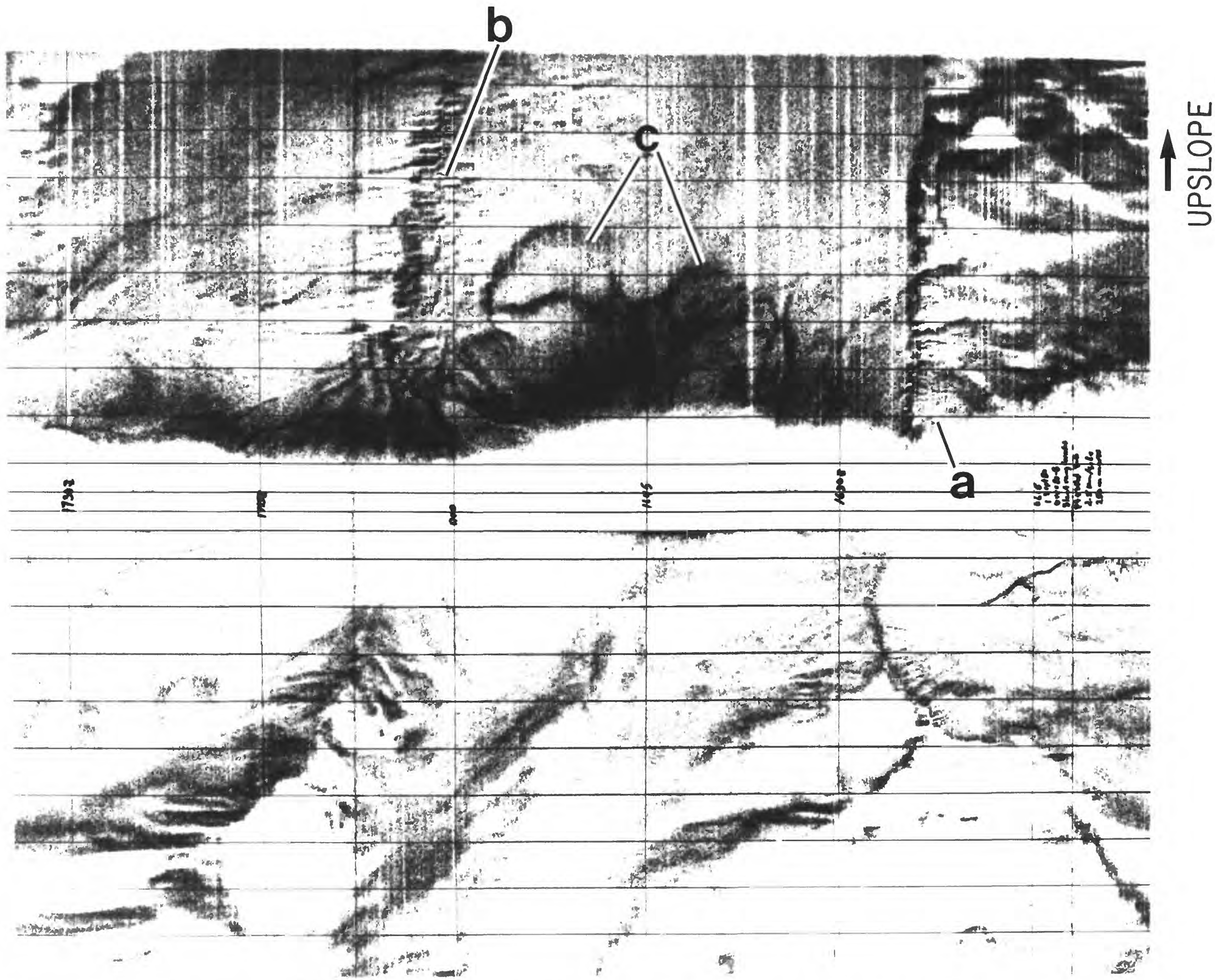


Figure 5-7 Slant-range corrected sidescan-sonar image of slope east of Lydonia Canyon, vicinity of 67°40'W., approximately 1,800 m depth. Horizontal grid spacing 250 m; vertical grid spacing about 0.8 km.

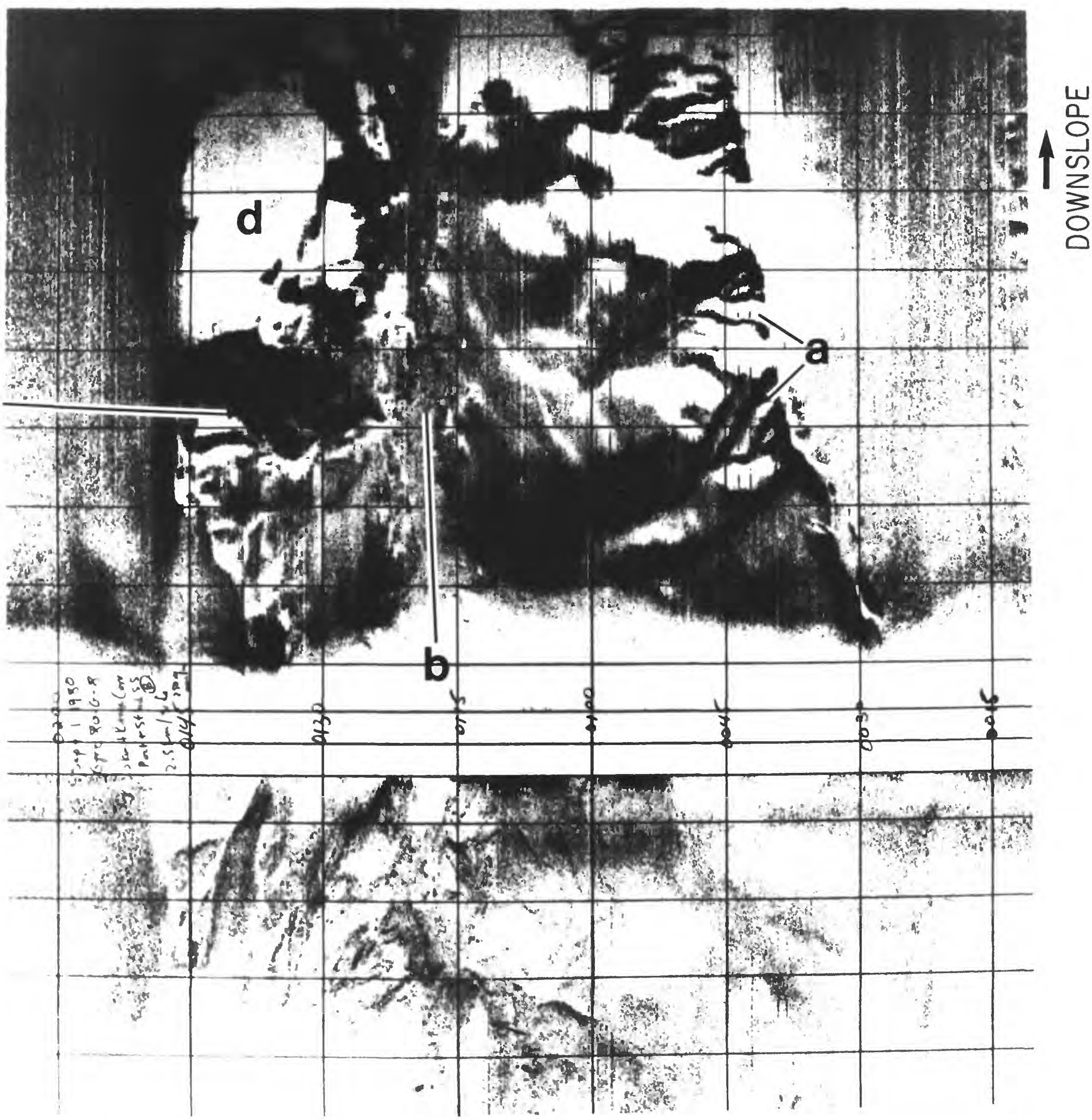


Figure 5-8 Slant-range corrected sidescan-sonar image of slope east of Lydonia Canyon; vicinity of 67°35'W., 1,300 to 1,500 m depth. Horizontal grid spacing 250 m.

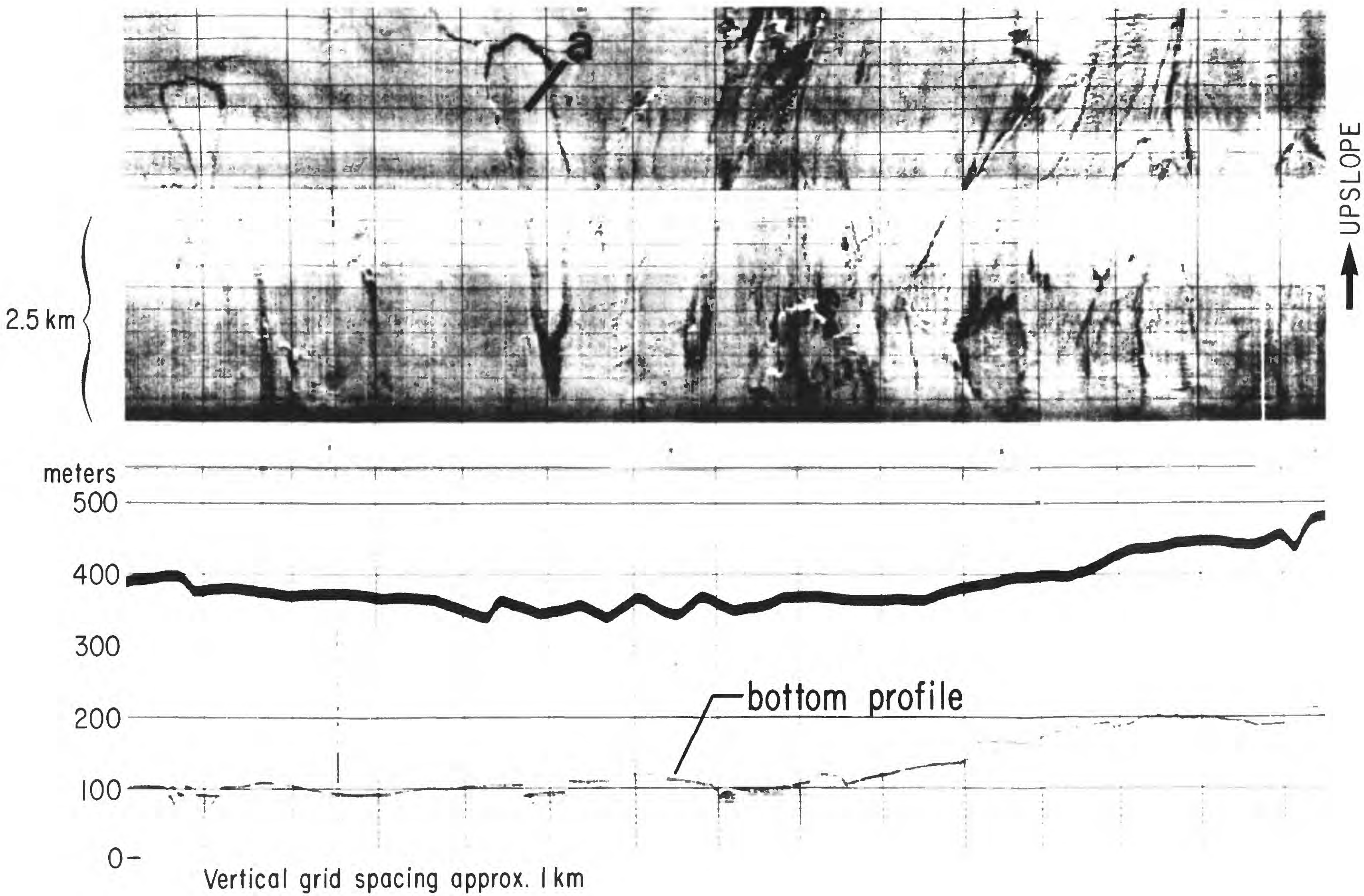


Figure 5-9 Sidescan-sonar image with correlative bottom profile shows slides on Continental Slope at about 2,000 m water depth between 70°38'W. and 70°46'W. The slide a is approximately 750 m wide at its head, 4 km long. The correlative bottom profile shows that the slide surface is marked by a flat-floored depression 15-20 m deep.

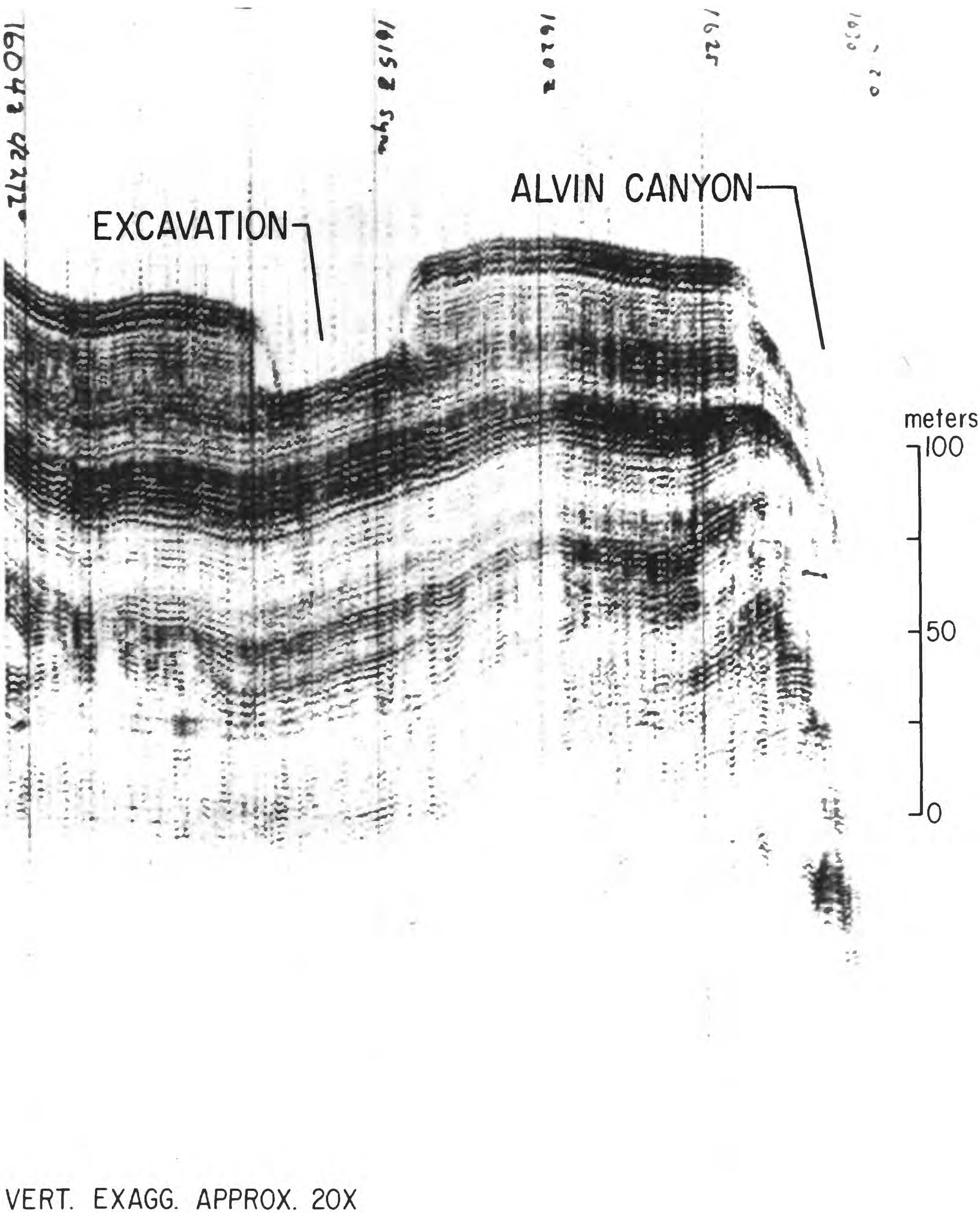


Figure 5-10 Seismic profile (sparker, 450-1000 Hz) from 39°50'N., 70°26'W. to 39°50'N., 70°28'W. (slope surface on east side of Alvin Canyon). The flat-floored excavation represents a cross section of a slide detected by sidescan sonar.

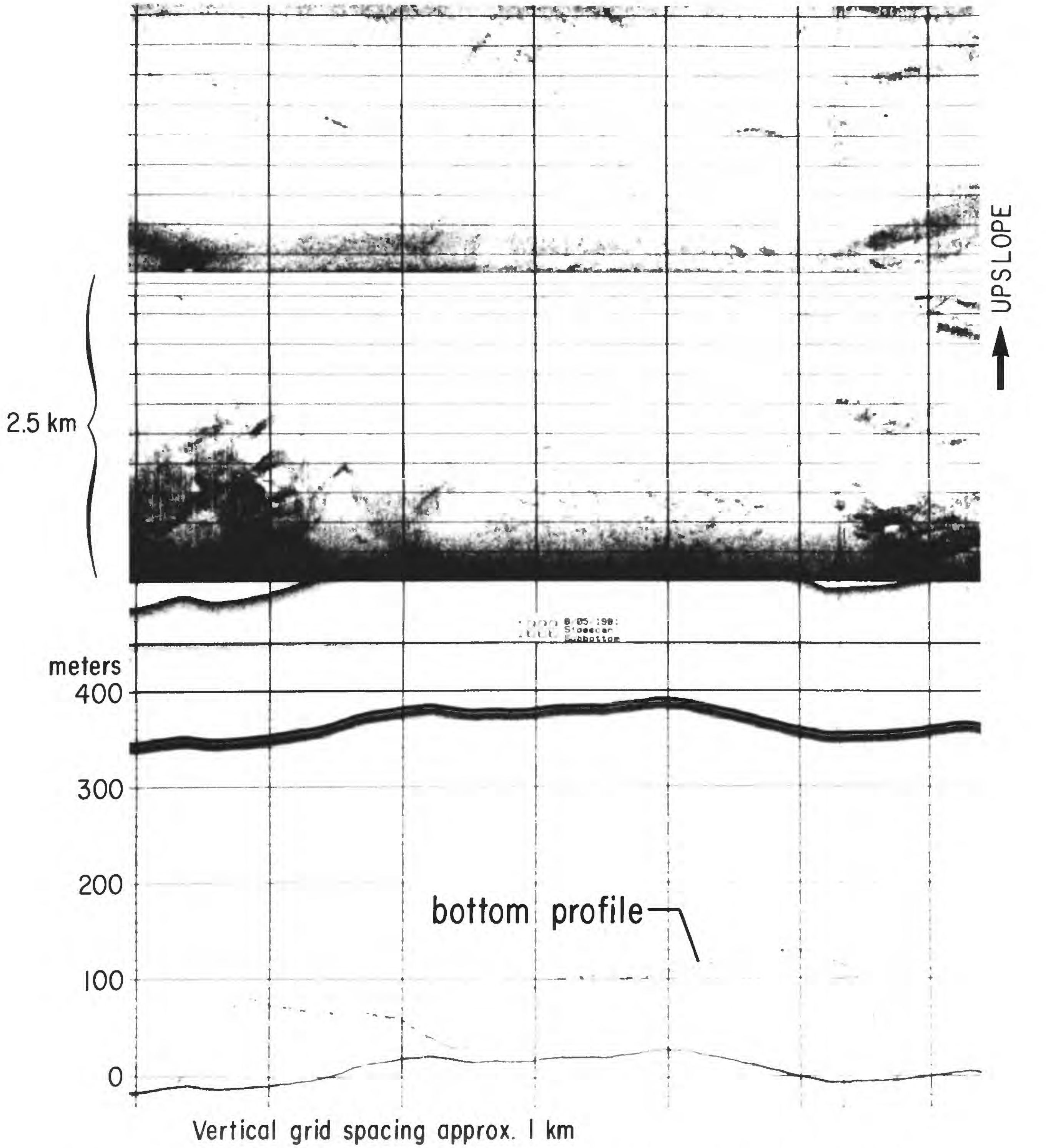


Figure 5-11 Sidescan-sonar image shows rubble field bounded upslope by polygonal scarp. Note convergence of scarp to arcuate slump scars (enclosing coarser rubble) at about the 1000 Z time line. The correlative bottom profile also depicts the blocky character of the surface. Image recorded between 70°16'W. and 70°20'W. (slope south of Martha's Vineyard) in 750 m water depth.

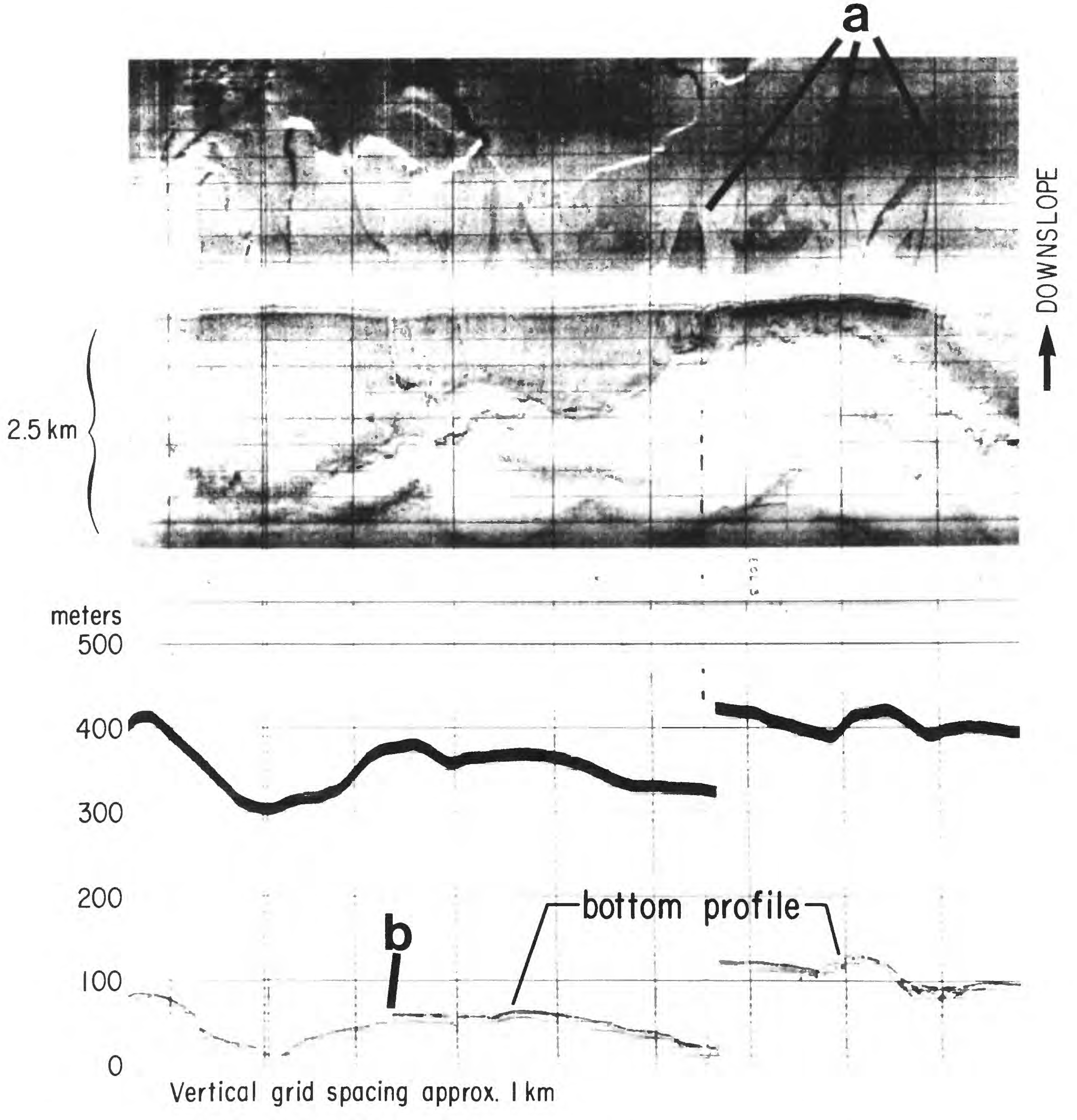


Figure 5-12 Sidescan-sonar image shows slides (a) extending from base of steep local slope at about 1,500 m water depth between 70°45'W. and 70°49'W. Note crisp, polygonal scarps shown in upper left corner of figure. Correlative bottom profile indicates that one of these has a relief of 10 meters (b).

SALE 82. Petroleum geology

by

Robert E. Mattick and Mahlon M. Ball

Much of the information included in this report is based on studies of COST well data (figs. 6-1 and 6-2) together with Deep Sea Drilling Project results (fig. 1-2) and data from a grid of common-depth-point (CDP) seismic-reflection profiles (fig. 1-2). These data have established the existence of structures, reservoirs, and seals adequate to provide trapping configurations for commercial quantities of hydrocarbons. What remains to be determined is whether there are mature source rocks of sufficient quality and quantity to provide commercial accumulations of hydrocarbons in the traps. The following discussion of the petroleum geology of the call area briefly sets forth types of structures, reservoirs, and seals noted from seismic-stratigraphic studies integrated with drilling results. The status of wildcat drilling in the Baltimore Canyon Trough is reviewed. Finally, an assessment of potential for source rocks is presented.

Structures, Reservoirs, and Seals

As explained by Grow and others (this report) and Schlee and Klitgord (this report), the geologic history of the sale 82 call area includes early Mesozoic rifting when horsts and grabens developed in pre-Mesozoic basement rocks. Salt accumulated in structural lows, followed by Jurassic and Early Cretaceous carbonates that built upward in step with subsidence of the early Atlantic Basin. Behind the carbonate platform edge, accumulations of terrigenous sandstones, siltstones and shales thicken in the seaward direction and change in character from dominantly nonmarine to marine. Seaward of the platform edge, deep-water argillaceous carbonates and hemipelagic mudstones are inferred to interfinger with fore-reef facies. The deep-water deposits overlie rough oceanic basement and attain thicknesses in excess of 4 km in structural lows.

These conditions have given rise to development of compactional closures over basement highs, salt swells and diapirs, and growth faults with attendant fault anticlines. The faults are formed by salt flowage or compaction of sediments. In addition, magnetic data reveal a number of igneous intrusions that may have bowed up overlying sediments or created topography upon which younger sediments are draped. This family of structures provides ample opportunity for development of structural and stratigraphic traps adequate to hold commercial quantities of hydrocarbons.

A variety of lithologic units are present, grading from subaerially deposited sandstones and siltstones beneath the inner shelf to marine sandstones, shales, and limestones beneath the outer shelf. Reeflike carbonates with presumed evaporites occur at the paleoshelf edge, beneath the slope. These deposits appear to grade basinward into marls and mudstones. These units constitute a full gamut of potential reservoirs and seals. Possible reservoirs include quartz sands and porous carbonates, while potential seals are represented by shales, tight carbonates, and evaporites.

The COST B-2 well (fig. 6-1) penetrated many thick sandstone units throughout the section in the Baltimore Canyon Trough. However, the reservoir quality of these rocks deteriorates as depth increases because of a progressive breakdown of feldspar accompanied by the growth of authigenic clay and silica cement (Scholle, 1977b, p. 8). As a result, only a few of the sandstone units penetrated below 3,500 m in the

COST B-2 well have permeabilities of more than one millidarcy. Farther seaward, at the COST B-3 site, time-equivalent sandstone beds have higher permeabilities (tens of millidarcies). The difference in permeabilities at the two well sites, probably results from a lower content of clay minerals at the latter site due to depostion in a higher energy environment.

In a seaward direction from the COST B-2 well, some sandstone beds apparently pinch out or grade laterally into shale and carbonate rich facies. In the Jurassic section penetrated by the B-3 well, thin sandstone beds, about 3 to 10 m thick, total about 47 m. Porosity values measured on sidewall cores ranged from 17 to 25 percent. Logs indicated that porosities were more than 8 percent and permeabilities mostly less than 10 millidarcies (Simonis, 1979, p. 102). These data suggest that conditions could be favorable for the entrapment of natural gas in Jurassic sandstone reservoirs.

Prior to drilling of the COST G-1 and G-2 wells, the deep stratigraphy of the Georges Bank basin, based on seismic-reflection data, was assumed to be similar to that of the Nova Scotia margin which has been extensively drilled (McIver, 1972; Jansa and Wade, 1975a, b; Given, 1977; Eliuk, 1978). Results from the COST G-1 and G-2 wells (Amato and Bebout, 1980; Amato and Simonis, 1980) have confirmed the stratigraphic similarity between the Scotian Shelf and the Georges Bank areas.

A cross section from the COST No. G-1 well to the COST No. G-2 well is shown in figure 6-2. The COST No. G-1 well penetrated 4,898.4 m of Cambrian(?) through Tertiary rocks and the COST No. G-2 well penetrated 6,667.2 m of Triassic(?) through Tertiary rocks. In general, the rocks penetrated in the G-2 well are more indicative of marine conditions in comparison to those penetrated in COST No. G-1 well. In the COST No. G-2, Bielak and Simonis (1980) described a section composed chiefly of sandstone and mudstone with interbeds of chalky limestone to a 700 m depth. Coal and lignitic shale were penetrated to a depth of about 1,750 m below the drill platform. Environments of deposition for this interval ranged from nonmarine to shelf edge or upper slope. Between depths of 1,750 and 2,100 m the section is predominantly micritic to chalky limestone deposited in a middle to outer shelf environment. The interval from 2,100 to 2,926 m, deposited in a nonmarine to shallow marine environment, consists of interbedded sandstones, grey and red shales, and oolitic limestone with streaks of coal. The section from 2,926 to 4,072 m consists chiefly of limestone, in part oolitic, deposited in a shallow marine environment. The thin interval between depths of 4,072 and 4,160.5 m consists of brown-red sandstone, mudstone, and shale and reflects a nonmarine environment. The section from 4,160.5 to 6,654.7 m consists of dolomite, limestone, anhydrite, and anhydritic carbonate rocks. The carbonate rocks range from mudstone to oolitic limestone and grainstone. Depositional environments for this section range from shallow restricted marine for the mudstone facies, to high energy shallow marine for the oolitic limestone, and to sabkha for anhydrite and anhydritic carbonate rocks. From 6,654.7 m to the bottom, the section consists of salt which probably reflects deposition in a restricted rift valley setting.

Structures, reservoirs, and seals are confirmed beneath the shelf and strongly indicated beneath the slope. Lack of sufficient reservoir quality in the presumed muddy deep basin facies beneath the lower slope and rise may limit hydrocarbon potential in the deeper water regions of the Sale 82 call area.

Wildcat Wells

Wildcat drilling in the Baltimore Canyon Trough began in March 1976 and was concentrated in the vicinity of the Great Stone Dome and along the shelf edge (fig. 6-3). The Great Stone Dome is inferred to be an Early Cretaceous mafic intrusion (Mattick and others, 1976; Schlee and others, 1976) and appears to be the largest and most promising single structure on the shelf. The six wells drilled on the structure reported no oil or gas shows.

As of January 1981, seventeen additional wells had been put down along the edge of the Continental Shelf. Significant hydrocarbon shows were reported from five of these, all probably drilled on the same structure. The first show was reported by Texaco on block 598 (fig. 6-3). The Texaco 598-1 well flowed natural gas at the rate of 210,000 m^3 (7.4 mmcf) per day from 12-m interval below 4,270 m. A second 12-m interval, below 3,960 m, flowed gas at 270,000 m^3 (9.5 mmcf) per day. Two confirmation wells, Texaco's 598-2, about 1.5 km to the west, and 598-3, about 1 km to the north, were reported dry. A fourth well on block 598 had not been completed at this writing.

In May 1979, Tenneco, in their 642-2 well located just south of block 598, announced that natural gas flowed from a interval of Jurassic sandstone at a depth of 4,020 m. The initial flow rate was 340,000 m^3 (12 mmcf) of natural gas and 16 m^3 (100 bbl) of condensate per day. Another test at 2,535 m flowed oil at a rate of 100 m^3 (640 bbl) per day from a thin Lower Cretaceous sandstone bed.

Texaco announced that their 642-1 well flowed natural gas at a rate of 160,000 m^3 (5.7 mmcf) and condensate at a rate of 3 m^3 (20 bbl) per day from an interval below 4,720 m. Two additional zones, at 3,879 m and 3,962 m were tested in November 1979. The respective daily flow rates were 535,000 m^3 (19 mmcf) and 402,000 m^3 (14 mmcf) of natural gas. During testing, the Texaco 642-3 well flowed natural gas from two 6 m thick intervals at the rate of 103,000 m^3 (3.6 mmcf) and 170,000 m^3 (6.0 mmcf) per day at depths of 4,305 m and 4,357 m, respectively.

Exxon reported that its 599-1 well just west of block 598 flowed natural gas at a rate of 227,000 m^3 (8 mmcf) per day from a 15-m interval at a depth of 3,779 m. A deeper interval flowed natural gas at a daily rate of 28,000 m^3 (1 mmcf).

Although the combined daily flow rates of these five wells total about 2.5 million m^3 (90 mmcf), a commercial field has yet to be established. It has been estimated that it would require a daily flow of about 5.7 million m^3 (200 mmcf) and reserves of about 34 billion m^3 (120 bcf) of natural gas to warrant establishment of an offshore production platform and a pipeline to transport gas to shore (Crawford, 1978). Gulf reported a noncommercial gas discovery below 5,378 m on block 857 and Murphy Oil reported that logs from their well on block 106 detected noncommercial shows of gas from thin zones between 4,573 m and 5,611 m. Only one hydrocarbon show was reported from the COST wells which were purposely drilled off-structure. The COST B-3 well penetrated a natural gas deposit in the interval from 4,798.8 m to 4,801.2 m. The dry methane gas probably was trapped stratigraphically in a thin Jurassic sandstone bed (Simonis, 1979).

Source Rock Analyses

In the COST B-2 and B-3 wells, data from color alteration of visible organic matter, pyrolytic-decomposition temperatures, carbon preference index (CPI), and vitrinite-reflectance indicate that the

Tertiary section and the Cretaceous section, is thermally immature to a depth of about 2,500 m and is unlikely to have yielded hydrocarbons other than biogenically generated methane (Scholle, 1977b, p. 8; Simonis, 1979, p. 100).

There is a disagreement as to the maturity of the sedimentary rocks below 2,500 m in the COST B-2 well with respect to liquid-hydrocarbon generation (Scholle, 1977b, p. 8). Observations of visible organic matter indicate moderate to full maturity in the 2,500- to 4,900-m depth range, but geochemical analyses of disseminated organic matter indicate that none of the penetrated rocks are mature with respect to liquid-hydrocarbon generation. In the B-3 well, maturity is reached at a depth of about 3,500 m; below 4,600m, the maturation of kerogen is certainly within the main phase of oil and gas generation (Simonis, 1979, p. 103). However, below about 3,000 m, the dominance of terrestrial over marine-derived organic matter in samples from both wells reduces the probability that economic amounts of oil were generated. This does not preclude the generation of gas. At the COST G-1 site, values of the Thermal Alteration Index (TAI) of 2+ to 3 suggest that liquid generation from adequate source rock is possible below depths of 4,200 m. On the basis of primary vitrinite reflectance (Ro) values, Smith and Shaw (1980) placed the oil generation window between depths of 2,000 and 4,000 m. At the COST G-2 site, TAI values measured by GeoChem Laboratories, Inc., reach 2-, and were interpreted as indicative of possible immature oil generation, at a depth of 2,400 m. TAI values which reflect peak oil generation were not measured on any of the well samples (Smith, 1980). On the basis of vitrinite reflectance values, Smith (1980) placed the depth of peak oil generation at a depth of about 2,500 m.

Miller and others (in press) conclude that the onset of thermal maturation occurs at a depth of about 4,700 m in the COST G-1 well and at about 5,500 m in the COST G-2 well. Their conclusions were based on CPI values, temperatures of maximum pyrolysis, and molecular distributions and concentrations of the C_{15+} hydrocarbons. Miller and others (in press) believe that the slope of the reflectance (Ro) profile below about 2,000 m may have been influenced by oxidized vitrinite or recycled organic matter, thereby resulting in anomalously high time-temperature history for the sedimentary rocks down to about 4,600 m.

Regardless of the varying interpretations of the thermal maturity of the rocks in the Georges Bank Basin, studies of the organic carbon content of these rocks are discouraging. These studies are usually of two types: measurement of the total organic carbon content and analysis of the composition of the kerogen. To be considered a potential source rock, shales must have a minimum organic content of 0.5 percent by weight; the minimum for carbonate rocks is 0.3 percent by weight. The type of kerogen determines whether the source rock will tend to produce oil or gas at thermal maturity.

The only zone at the COST G-1 site with an organic content sufficiency high to be considered potential source rock was penetrated between depths of 1,400 and 1,900 m. According to Smith and Shaw (1980), this zone contains both oil- and gas-prone kerogen types, but is thermally immature and would have to be more deeply buried or be subjected to higher temperatures to generate large quantities of oil or gas.

In the G-2 well, a dominantly clastic section at about 3,000 m has an average organic content of about 0.6 percent by weight; the predominantly carbonate rock section below 3,000 m has an average organic carbon content of about 0.25 percent by weight (Smith 1980). Smith (1980) concludes that, with few exceptions, the entire sedimentary section penetrated by the COST G-2 well contains sufficient organic carbon to be considered potential source rock. Smith's conclusion, however, is based on the supposition that carbonate rocks need contain only 0.2 percent by weight of organic carbon to be considered potential source rocks. If the minimum organic carbon content for carbonate rocks is 0.3 percent, as stated by Tissot and Welte (1978), then the source potential of the section below 3,000 m must be considered marginal. The possibility for gas generation exists in the Jurassic section below 5,500 m (Miller and others, in press). If we consider the source rock potential of the carbonate section together with the permeability data which show only a few tenths of millidarcies below 3,000 m, the chances of finding significant hydrocarbon deposits on the Continental Shelf are low.

Deepwater Potential

The increase in amount of carbonate rocks from the COST B-2 site to the B-3 site and the thick carbonate section penetrated in the COST G-2 well appear to confirm the interpretation made from seismic data that the Jurassic shelf margin consists of a carbonate platform edge, or reef, that will include forereef, reef, and backreef facies. If basinal shales beneath the lower slope prove to have had the capacity for generating large amounts of petroleum and if migration paths exist to the reef facies, the key to finding hydrocarbons will be locating strata in the reef facies with high porosity and permeability.

Seaward of the platform-edge complex, DSDP results and seismic data are the main basis for assessment of hydrocarbon potential. The seismic lines confirm presence of compactional structures in the sediments over basement highs (fig. 2-6). Jansa and others (1979) reported that most of the section known from DSDP drilling sampling to be Late Jurassic and Cretaceous sediments consists of hemipelagic mud, deep water limestones, chalks, clays, and oozes. Chalks and other deep water limestones are the most likely reservoir facies. With the exception of the middle Cretaceous Hatteras Formation, all the basinal sediments appear to have been deposited in well oxygenated waters and to have low organic content. The Hatteras Formation could constitute a source rock if buried deeply enough with a high enough geothermal gradient to achieve maturation. As emphasized by Dow (1978), migration and accumulation are most efficient where reservoir sequences prograde over mature source beds. It follows that areas where the Jurassic-Cretaceous platform edge builds out over the adjacent slope shale facies should be prospective.

Conclusions

Compactional structures over buried basement blocks and carbonate buildups, salt swells and diapirs, growth faults with attendant fault anticlines, and reefs and anticlines over igneous intrusions provide a wide range of possible trapping configurations adequate to contain commercial quantities of hydrocarbons within the Sale 82 well area. The flanks of these structures are potential settings for stratigraphic traps. Drilling confirms existence of reservoir and seal facies on the shelf. Breakdown of feldspar in arkosic sands may inhibit reservoir quality below 3.5 km. Porous Jurassic carbonates at the platform edge, which prograded over adjacent basinal shale facies, may prove to be attractive exploration targets. Reservoir quality in basin facies seaward of the platform margin may be impaired by the muddy nature of these deposits. Lack of identification of rich, mature source materials remains a problem in U.S. Atlantic margin exploration. Significant shows on Texaco's 598 structure are major encouragements.

In general, the most prospective areas contained in Lease Sale 82 are located near the edge of the Continental Shelf and on the Continental Slope in water depths of less than 2,500 m (fig. 6-4). Although potential targets for petroleum exploration drilling and especially field development in these water depths will not be availab until the late 1980's or early 1990's (Grow, this report). The probability is low that significant oil or natural gas deposits will be found in nearshore areas of the Continental Shelf and the Gulf of Maine — sedimentary rocks in these areas are relatively thin and, hence, source rocks are not expected to be mature with respect to hydroarbon generation. Further seaward on the Continental Shelf, the prospects are good for finding natural gas deposits (fig. 6-4). Some of the most prospective areas for finding oil and natural gas are those areas where shelf facies have prograded over basin or slope facies resulting in close contact between potential reservoir rock and source rock. These areas are shown by a dot pattern in Figure 6-4. Reef and forereef facies are expected hydrocarbon targets on the upper part of the Continental Slope in the northern part of the sale area and on the mid to lower slope in the southern part of the sale area (Fig. 6-4).

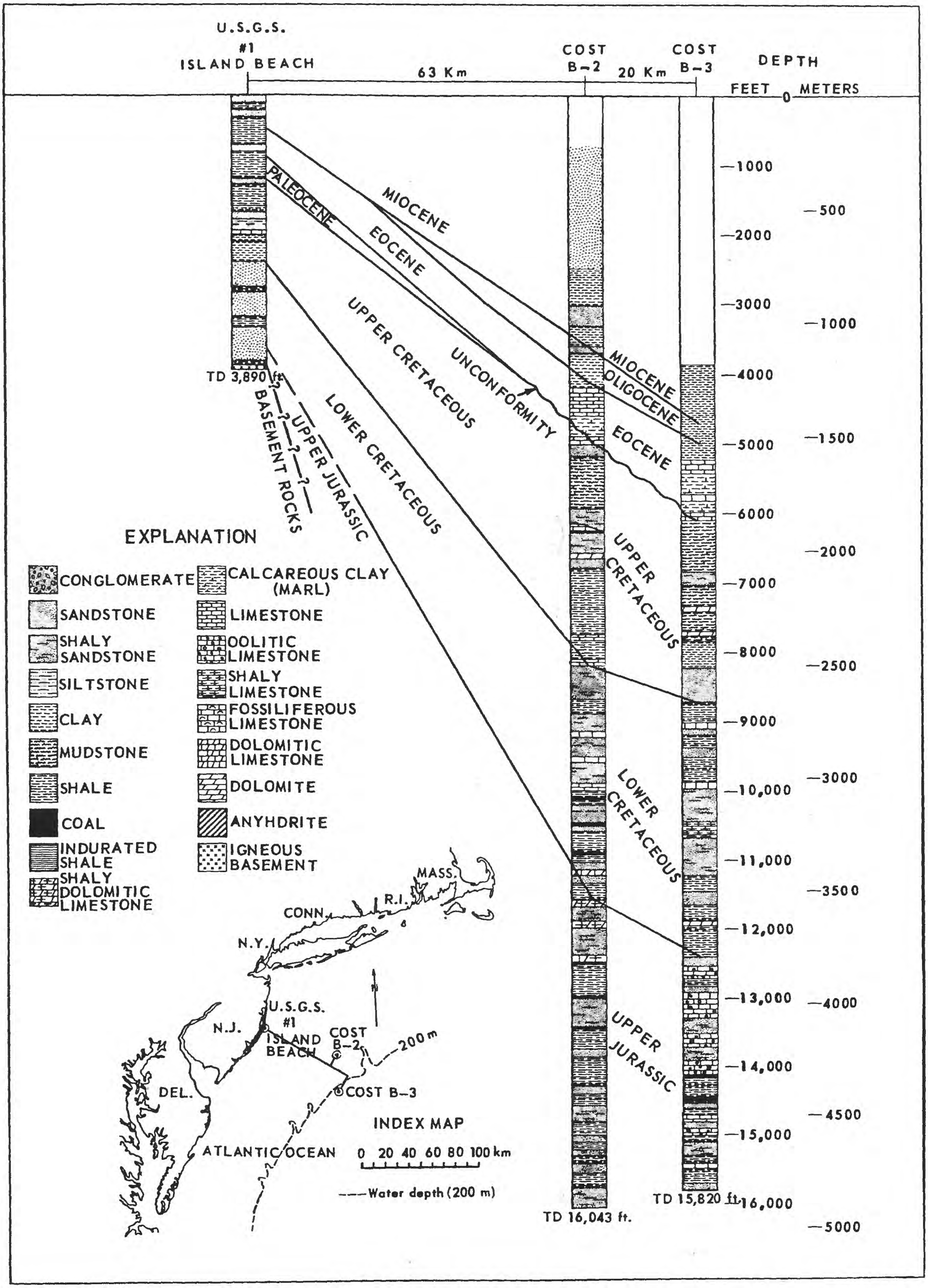


Figure 6-1 Geological cross section of the Baltimore Canyon trough. Modified from Adinolfi and Jacobsen (1979, pl.4).

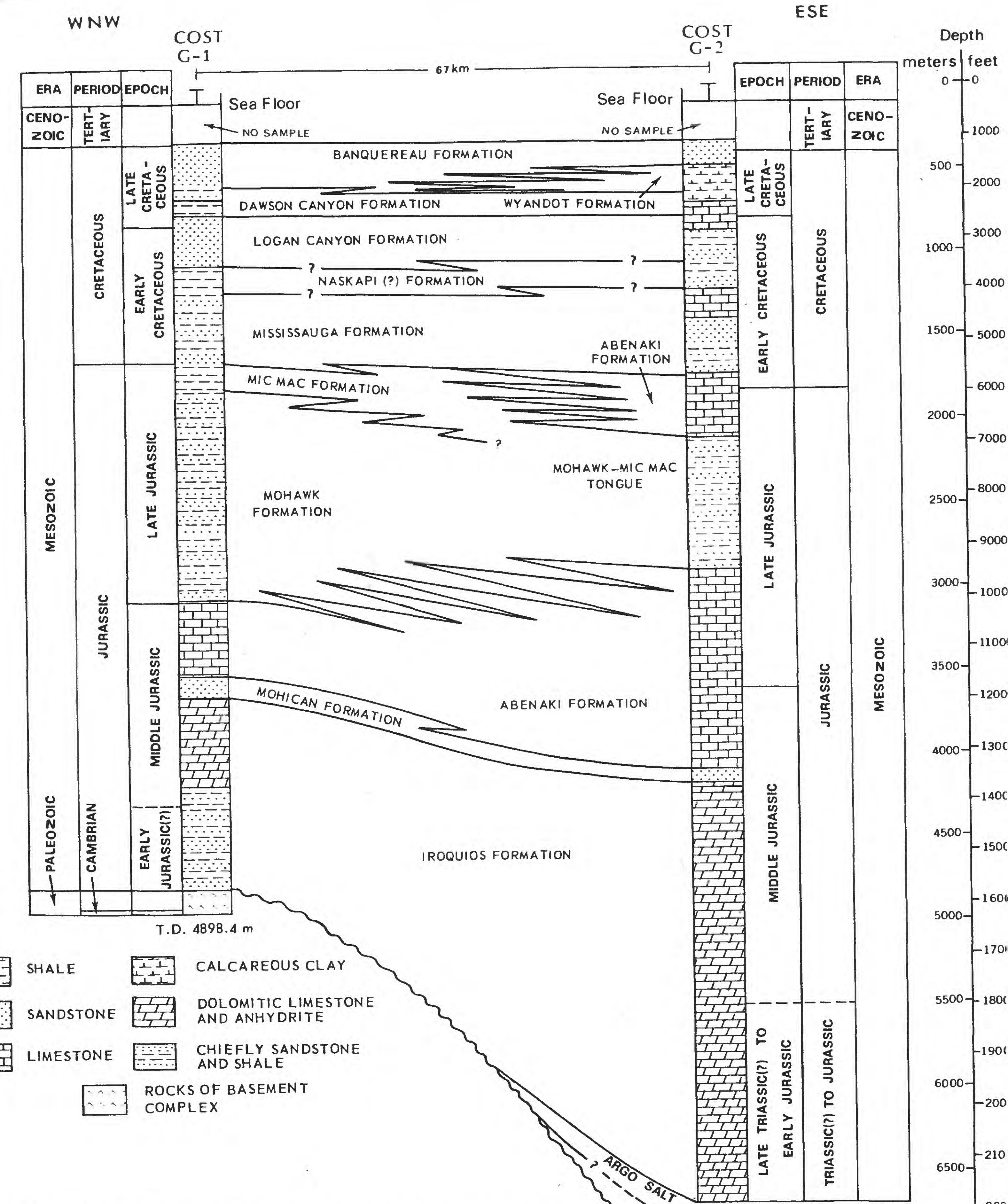


Figure 6-2 Geologic cross section from COST No. G-1 well in Georges Bank Basin. Names of rock-stratigraphic units were adapted from Scotian Shelf of Canada after McIver (1972), and Jansa and Wade (1975). Figure highly generalized from Amato and Simonis (1980, plate 2).

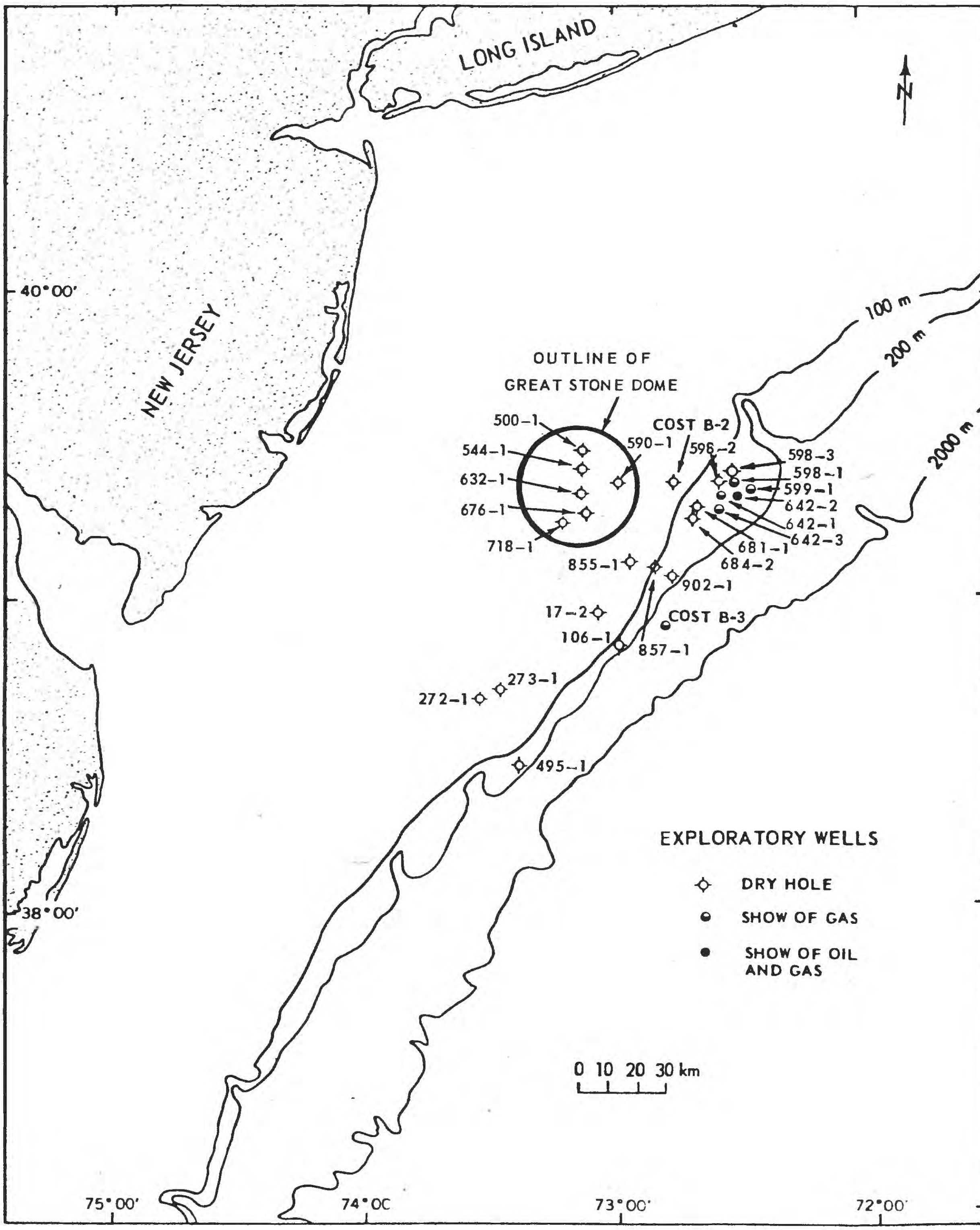
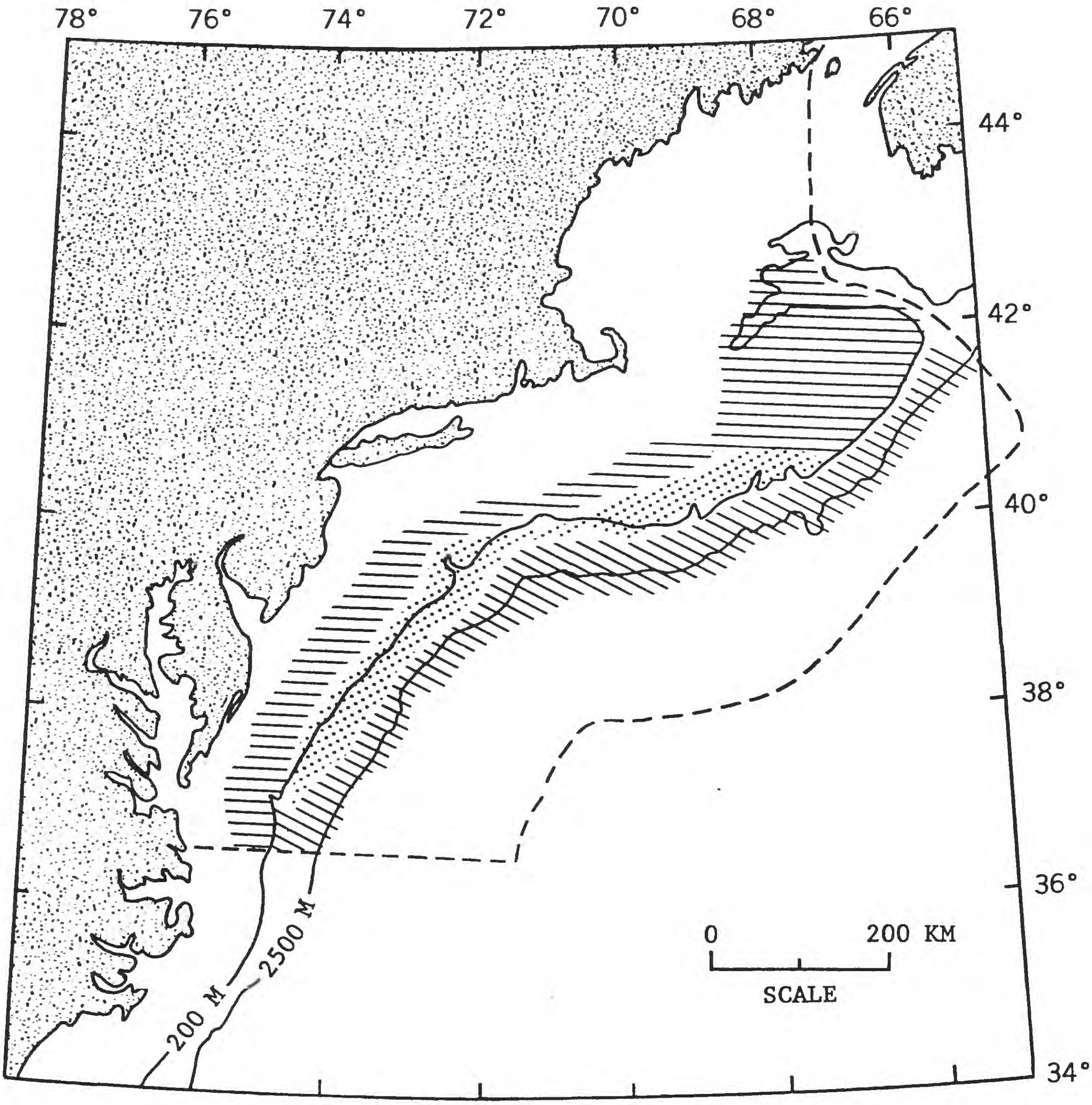


Figure 6-3 Locations of deep exploratory wells drilled in the Baltimore Canyon trough.



---- Approximate seaward extent of Lease Sale 82.

Areas of Continental Shelf that have prospects for finding natural gas deposits.

Areas of Continental Shelf and Slope where shelf facies have prograded over slope and basin facies. These areas have good potential for oil and natural gas.

Areas of the Continental Slope where prospective hydrocarbon targets occur in reef and forereef facies.

Figure 6-4 Map showing areas with petroleum potential in Lease Sale 82

Petroleum Potential and Resource Assessment

by

R. B. Powers and A. S. Khan

Introduction

The area proposed ICS lease sale #82 includes the Baltimore Canyon trough (Mid-Atlantic) and the Georges Bank Basin (North Atlantic) provinces, and extends to water depths in excess of 14,764 ft (4,500 m) in places (fig. 7-1). The sale area includes parts of three physiographic units - the continental shelf, the continental slope, and the continental rise, and covers approximately 195,985 mi^2 (507,601 km^2). The estimates made here of undiscovered recoverable total crude oil and total natural gas are for the Continental Shelf and the continental slope to 2500 m (Figs. 7-2, 7-3, and 7-4). No resource assessments are made for the area greater than 2500 m water depth due to the absence of adequate data. Earlier estimates of undiscovered oil and gas resources in the Mid-Atlantic and North Atlantic provinces were made by Miller and others (1975); U.S. Geological Survey (1975); Mattick and others (1975); Powers (1979); and most recently by Dolton and others (1981).

Estimates of undiscovered recoverable oil and gas resourcers for the Mid-Atlantic and North Atlantic were made by using direct subjective probability methods as described by Miller and others (1975), Dolton and others (1981), Powers and Pike (1981), and Crovelli (1981). Separate estimates of total crude oil and total gas for the shelf and slope of the Mid-Atlantic and the North Atlantic are aggregated by a Monte Carlo procedure to arrive at total resource estimates for the entire sale area. These estimates are based on the assumption that resources may be found under conditions represented by a continuation of present price-cost relationships and technological trends.

In frontier areas, such as the sale area where there has been minimal or no drilling, there is a risk that no commercially recoverable oil or gas exists. Therefore, the likelihood of any commercially recoverable resource being present was estimated and called the marginal probability (MP) (figs. 7-2, 7-3, 7-4). The marginal probability was applied to the corresponding conditional probability distribution of the quantity of undiscovered recoverable resource. From this distribution the final low (F_{95}), high (F_5), and mean estimates were obtained.

Continental Shelf Drilling History and Traps

In the Mid-Atlantic, 27 exploratory wells and one COST (Continental Offshore Stratigraphic Test) well (B-2) have been drilled on the shelf and on COST Well (B-3) has been drilled on the slope during the past four years. Twenty-three of the exploratory wells have been plugged and abandoned and five have recovered appreciable amounts of gas and condensate, indicating a possibility of commercial production. However, the five apparent discovery wells appear to be confined to a single, segmented structure which covers approximately 10 square miles within Blocks 598, 599, and 642. Details of production tests in these wells are described more fully by Mattick and Ball (this report). Some observers feel that the hydrocarbon reservoirs in the vicinity of Block 598 are highly variable in thickness, areal extent, porosity and permeability and make reservoir analysis difficult (Ocean Oil Weekly Report, 1981). Although commercial prospects of the Block 598,599,642 structure are still undetermined, Texaco, Tenneco and Exxon have filed to unitize and extend the leases on Blocks 598, 599, 642 and 643. Elsewhere, the results of exploratory drilling on the shelf proved to be disappointing.

The Great Stone Dome, the largest individual structure in the shelf (sale #82 area) off New Jersey proved to be dry after the drilling of seven wildcat tests centered around Block 588 (Powers, 1979). Leases on Blocks 718 and 719 on the southern flank of this feature have been relinquished by the Gulf-Conoco partnership. In addition, Shell Oil Company relinguished leases on Blocks 184, 228, 229, 232 272,and 273, on a structure further south of the Great Stone Dome. On the basis of the rather negative results of exploration activity on the central part of the shelf, it would appear that the only area with petroleum potential is confined to a zone narrow near the margin of the shelf, close to the 200 meter isobath.

Georges Bank (North Atlantic) is a relatively unexplored basin. Prior to an OCS lease sale in December 1979, two COST tests (G-1 and G-2) were drilled on the shelf in Blocks 79 and 141 to 16,071 ft (5,357 m), and 21,874 ft (7,291 m) respectively. A geological and operational evaluation of the above tests is discussed in detail in two USGS Open-File reports, Open-File 80-268 (Amato and Bebout, 1980) and Open-File 80-269 (Amato and Simonis, 1980).

In addition to the COST wells, Exxon recently completed a 14,118 ft wildcat hole on Georges Bank in 230 ft (70 m) water depth in Block 133. Exxon, after plugging and abandoning this well as a dry hole, is planning to move a semi-submersible drilling rig to a new location in block 975 to drill a 15,000 ft wildcat. Also on Georges Bank, Shell Oil Company is currently drilling at 12,500 ft at its 15,500 ft wildcat well in 492 ft (150 m) water depth in block 410.

Estimates of Petroleum Resources for Shelf Areas

Estimates of aggregated total undiscovered resources for the the shelf part of Sale Area 82 are summarized in the following table:

Lease Sale 82 Shelf (D-200 m) (Fig. 7-2)

	F_{95}	F_5	Mean	M.F.
Oil (Billions of barrels)	0	3.79	1.23	0.82
Gas (Trillions of cubic feet)	1.89	17.49	8.06	0.99

Continental Slope Drilling History and Possible Traps

The only well drilled on the Mid-Atlantic Slope was the COST B-3 which was completed at a total depth of 15,820 ft (4,822 m) in January 1979, in 2,686 ft (819 m) of water. Results of this test have been described in detail by Scholle (1980) and Powers (1981). A second well (COST B-4) on the slope which was approved to drill to 20,000 ft (6,096 m) in 4,300 ft (1,311 m) water depth was cancelled due to the unavailability of a drilling rig (Powers, 1981). The abandoned B-4 location is 33 mi (53 km) northeast of the B-3 and 21 mi (34 km) southeast of the Block 598-642 gas and oil discoveries on the Mid-Atlantic shelf. It is believed that the well would have penetrated the crest and fore-reef zones of an inferred Late Jurassic-Early Cretaceous reef complex which lies 9 mi (15 km) seaward of the COST B-3 well (Grow, 1980).

Regional geophysical studies, in addition to data from the B-3 well, have delineated this inferred southeastward prograding carbonate bank or reef complex. This feature is inferred to form the Late Jurassic-Early Cretaceous shelf edge beneath the present Continental Slope, from Cape Hatteras to Georges Bank (Grow, 1981). Previous studies also show the presence of trapping structures associated with this shelf margin carbonate buildup, and block-faulting in the area of the B-3 well (Scholle, 1980), as well as seaward dipping growth faults that may tie into bedding plane faults along the Jurassic slope (Grow, 1980). Stratigraphic traps should have significant - potential in the area between the B-3 well and the carbonate bank buildup at the Jurassic-Cretaceous shelf edge, as indicated by the rapid facies changes of sandstones, shales, and limestones in the lower sections fo the B-2 and B-3 wells. The wire-line tests that were run in the B-3 well at 15,750 ft (4,800 m) recovered rich methane gas from coarse-grained, well-sorted sandstone. Since thte test was confined to a small interval of snadstone, it is probable that zones of more permeable gas-bearing sandstone are present in similar settings in this area. The potential for undiscovered recoverable hydrocarbon resources in this part of the sale area is considered to be favorable.

Analogs considered particularly applicable to the Continental Slope in Sale Area 76 are the Cretaceous Edwards reef trend on the Texas Gulf Coast and the El Abra-Tamaulipas reef complex of the Reforma-Chiapas area in Mexico. These analogous producing areas represent minimum and maximum volumetric hydrocarbon yields.

Estimates of Petroleum Resources for Slope-Upper Rise areas

Estimates of aggregated total undiscovered resources for the slope part of Sale Area 82 (Fig. 7-3) are summarized in the following table.

Lease Sale 82 Slope (200-2500 m) (Fig. 7-3)

	F_{95}	F_5	Mean	M.P.
Oil (Billion barrels)	0	9.21	3.21	0.79
Gas (Trillion cubic feet)	1.32	26.91	11.86	0.97

Estimates of Petroleum Resources for Proposed Sale Area

Aggregated total estimates of undiscovered recoverable oil and gas resources in the proposed sale area from 0 to 2500 m water depth (Fig. 7-4) are shown in the following table:

Lease Sale #82 Shelf and Slope (0-2500 m) (Fig. 7-4)

	F_{95}	F_5	Mean	M.P.
Oil (Billion barrels)	0.33	10.66	4.44	0.96
Gas (Trillion cubic feet)	6.87	37.48	19.92	1.0

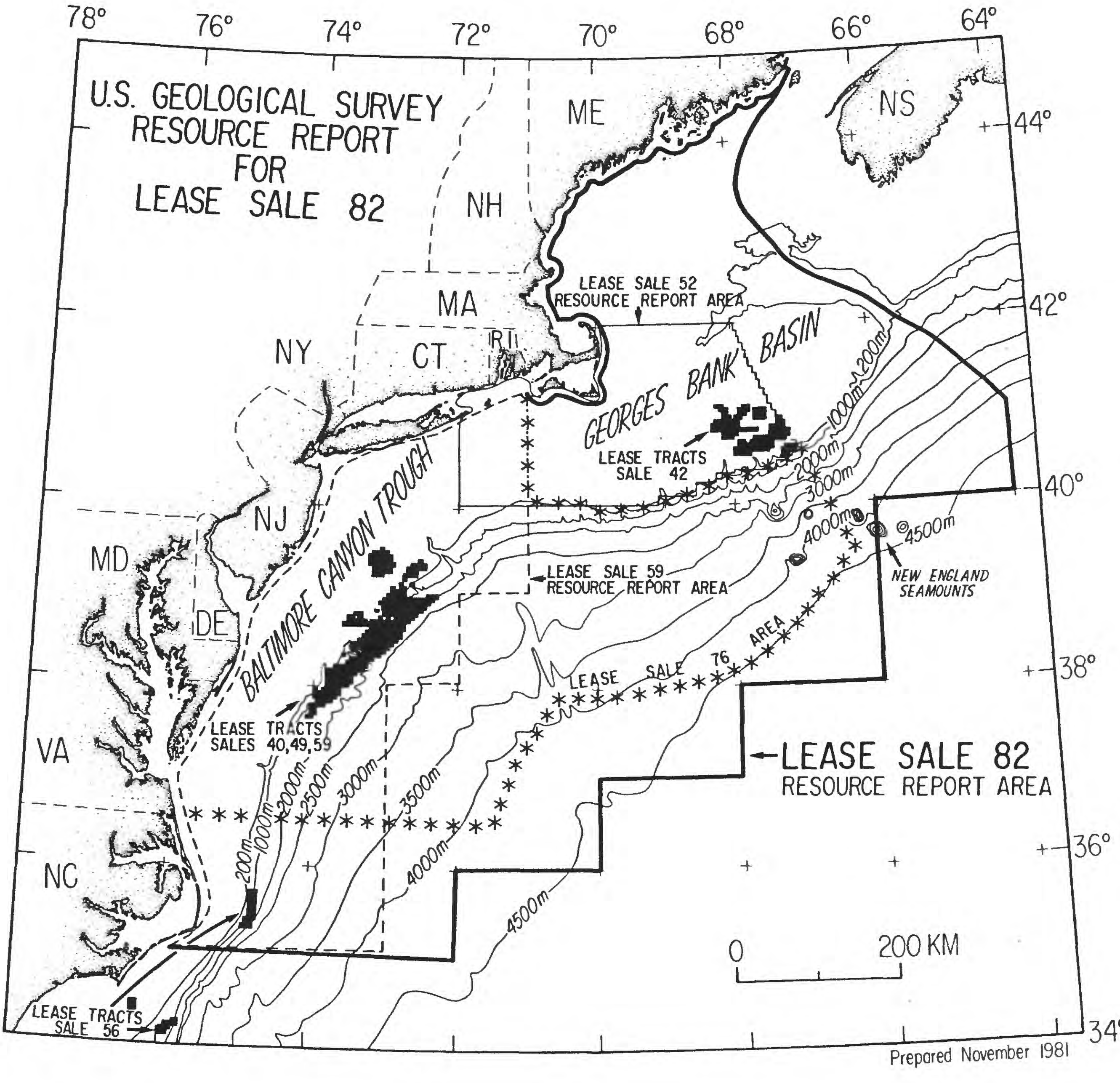
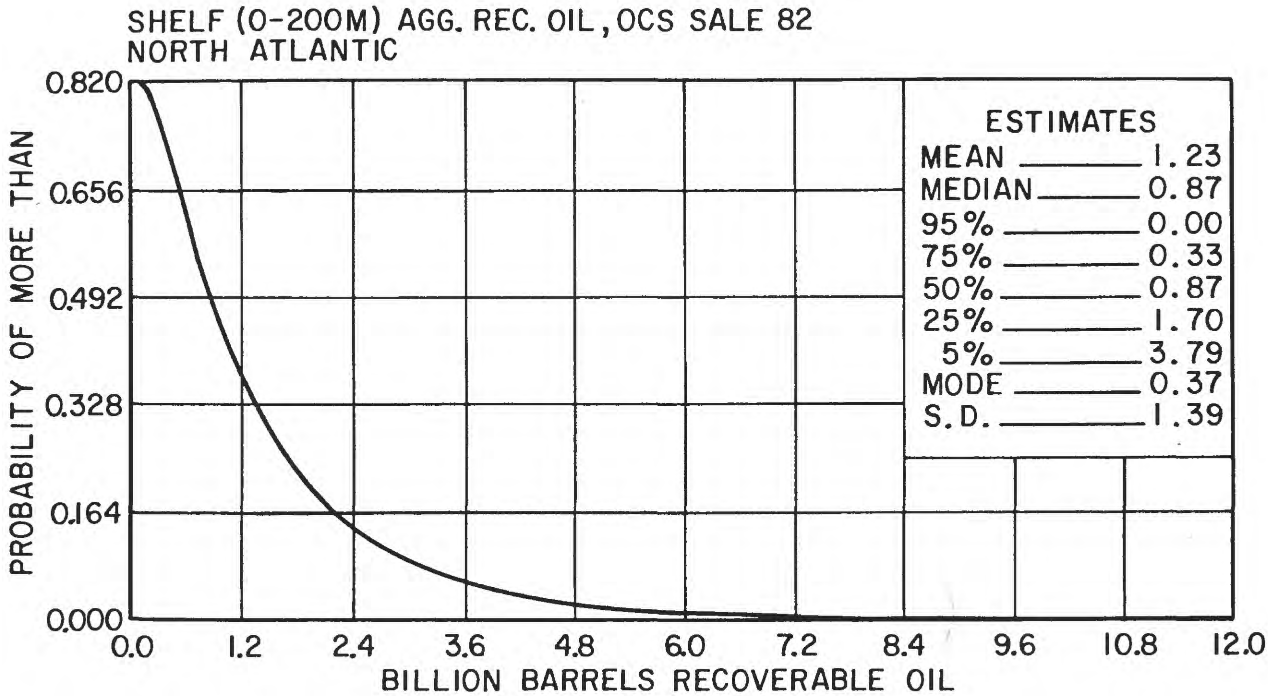


Figure 7-1. -- Index map outlining area for proposed North Atlantic OCS Lease Sale 82.



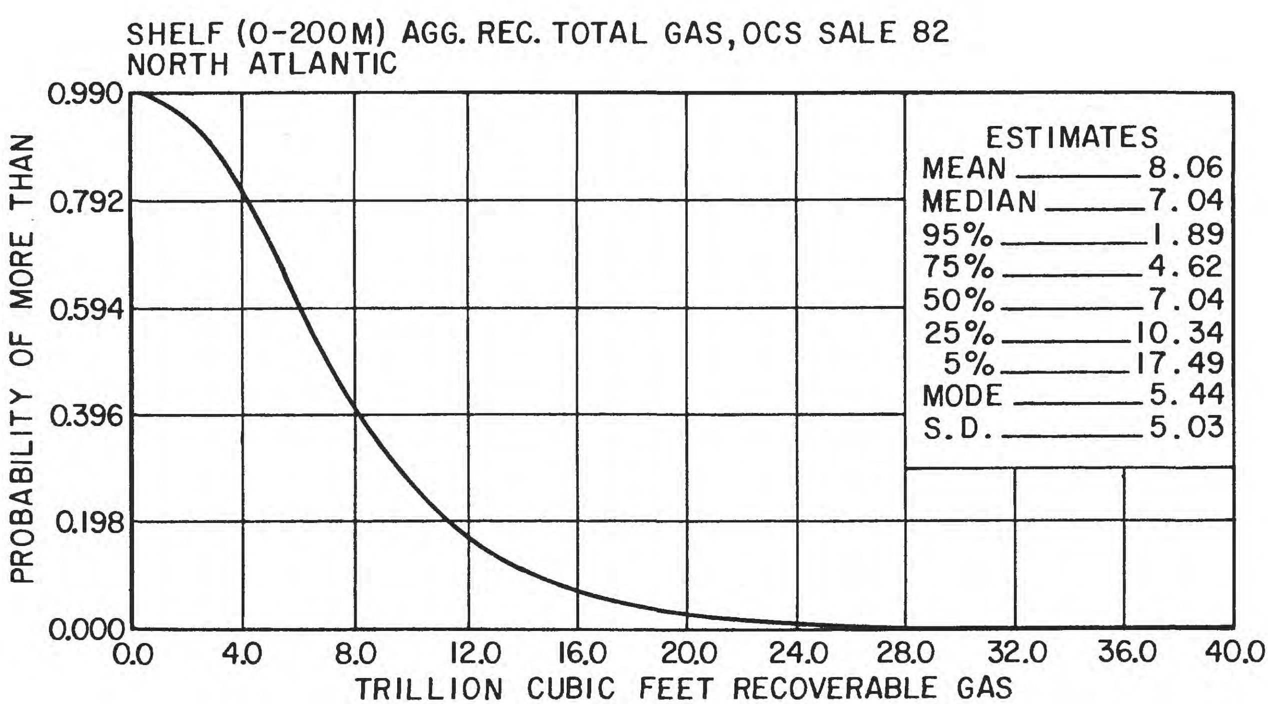
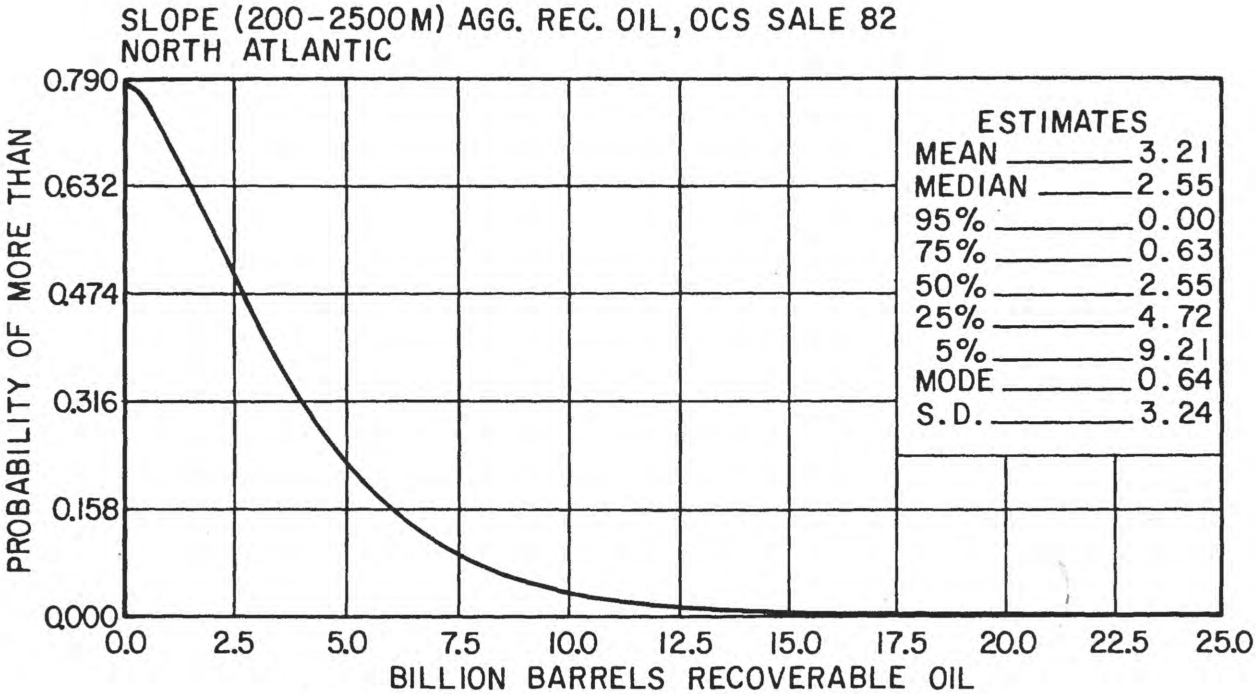


Figure 7-2.--Aggregate unconditional probability distribution curves for total undiscovered recoverable oil and gas resources (Shelf, 0-200 m), marginal probability (oil = .82, gas = .99) and standard deviation (SD) for OCS Sale 82



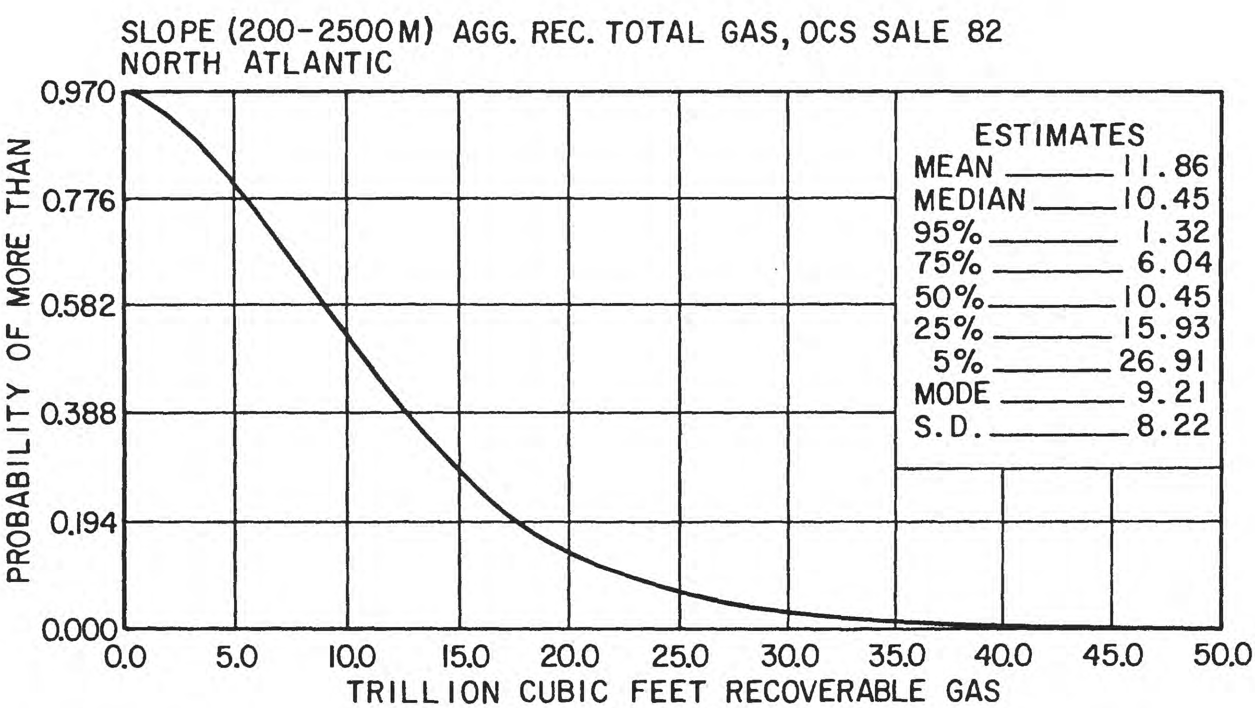
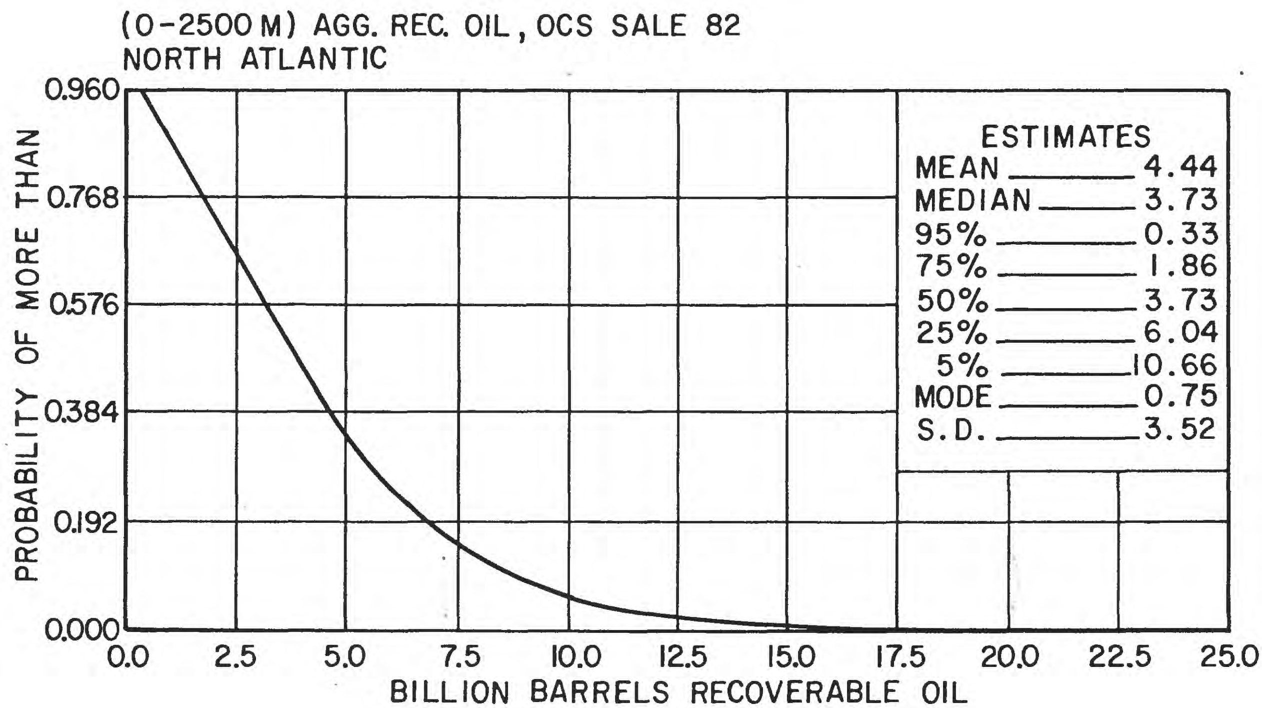


Figure 7-3.--Aggregate unconditional probability distribution curves for total undiscovered recoverable oil and gas resources (Slope, 200-2500 m), marginal probability (oil = .79, gas = .97) and standard deviation (SD) for OCS Sale 82.



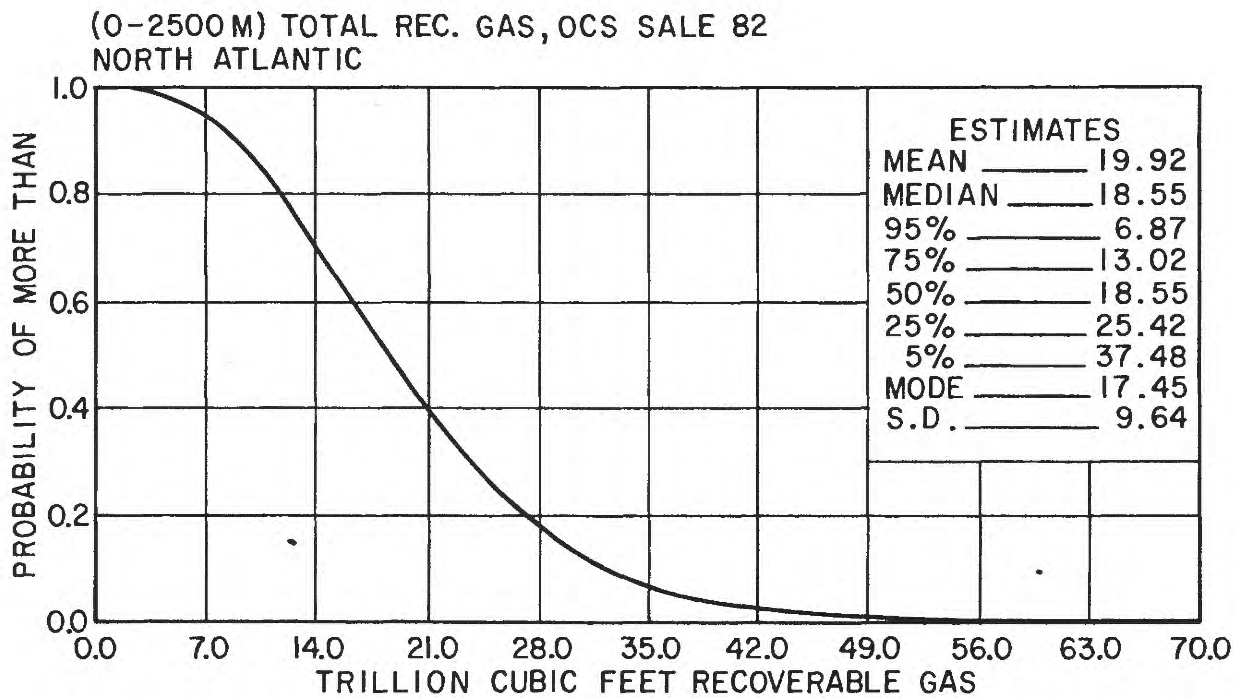


Figure 7-4.--Aggregate unconditional probability distribution curves for total undiscovered recoverable oil and gas resources (Shelf and Slope, 0-2500 m), marginal probability (oil = .96, gas < 1.0) and standard deviation (SD) for OCS Sale 82.

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