Department of the Interior

U.S. Geolgical Survey

Summary Report of the sediments, structural framework, petroleum potential, and environmental conditions of the United States Mid-Atlantic continental margin in area of proposed Oil & Gas Lease Sale No. 59.

by

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

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INTRODUCTION AND SUMMARY

This report has been compiled to update and summarize the geological information concerning the area of the Atlantic continental margin off the U.S. Mid-Atlantic proposed for Oil and Gas Lease Sale No. 59 (fig. 1). The region of interest lies between 35° and 41° N and 70.5° and 76° W. The north-south dimension is about 660 km (356 nautical miles, 410 statute miles) and the maximum east-west dimension is approximately 250 km (135 nautical miles, 155 statute miles). The area is centered toward the outer Continental Shelf off Delaware and contains more than 154,000 km^2 (38,000,000 acres) off the coasts of North Carolina, Virginia, Maryland, Delaware, New Jersey and New York. Water depths within the region range from 20 to slightly more than 4,000 m (fig. 1).

This report begins with a discussion of the regional geology and geophysics, followed by a description of the oil and gas potential and potential environmental hazards.

Our main conclusions are: (1) a thick sedimentary basin containing a buried carbonate-reef complex underlies the outer shelf, slope and upper Continental Rise; (2) source rock capable of generating hydrocarbons and structures, reservoirs, and seals capable of trapping commercial quantities of hydrocarbons are present; (3) the quantities of resources for the Mid-Atlantic Continental Shelf and Slope corresponding to the .95 and .05 probabilities and the calculated statistical means are:

	.95	.05	Mean
Oil (billion barrels)	0	2.1	0.5
Gas (trillion cubic feet)	0	10.9	4.1

Recently available data from the COST B-3 well, confirming the presence of hydrocarbons on the slope, would suggest that these estimates may be somewhat conservative in spite of the great uncertainties of future economic recovery; (4) potential environmental hazards include: strong currents and mobile surface sediments on the shelf, and slumps and channel fill on the slope. Currents on the Continental Slope are generally less than 50 cm/s (1 knot) and are caused by Gulf Stream eddies and storms.

Owing to the paucity of data both for resource calculations and environmental analyses, the Geological Survey cannot at this time judge the advisability of lease sales in areas included under water depths > 2,000 m.

by

John S. Schlee

Since publication of the last Summary Report (Mattick and others, 1976) for the Mid-Atlantic area, the Continental Offshore Stratigraphic Test (COST) B-3 well has been drilled on the Continental Slope, and 18 exploratory wells have been or are being drilled on the outer shelf and slope. Within the nomination area, 4,875 km of multichannel profiles have been collected by the U.S. Geological Survey between 1973 and 1978 (fig. 1).

Analyses of approximately 3,000 km of multichannel seismic profiles over the shelf area reveal (fig. 2) a broad basin (the Baltimore Canyon Trough) widening and deepening seaward of New Jersey where the maximum sediment thickness is greater than 15 km (Schlee and others, 1976, 1977; Grow and others, 1979; Klitgord and Behrendt, 1979). The irregularity of the isopachs toward Long Island and Cape Hatteras probably indicates that the basement is block faulted where the basin merges with the Long Island Platform (northeast) and the Carolina Platform (southwest).

Acoustic basement is not discernible underneath the outer edge of the shelf and slope. There, the presence of what appears to be a buried carbonate platform prevents deep penetration of seismic energy. Analysis of the pattern of magnetic anomalies, however, does allow us to extrapolate a general outline of the basin (fig. 3).

The depths to magnetic basement shown in figure 3 were calculated using the Werner deconvolution method (Klitgord and Behrendt, 1979). It indicates that the deepest depth to magnetic basement (>12 km) within the lease area is under the shelf as a part of the Baltimore Canyon Trough. A belt of lower (6-8 km) values characterizes the slope and upper Continental Rise in the vicinity of the East Coast Magnetic Anomaly (ECMA). Seaward, basement deepens to over 11 km below sea level, and then shoals to the southeast beneath the Continental Rise. A comparison of magnetic and seismic data (fig. 4) for the two cross-margin profiles

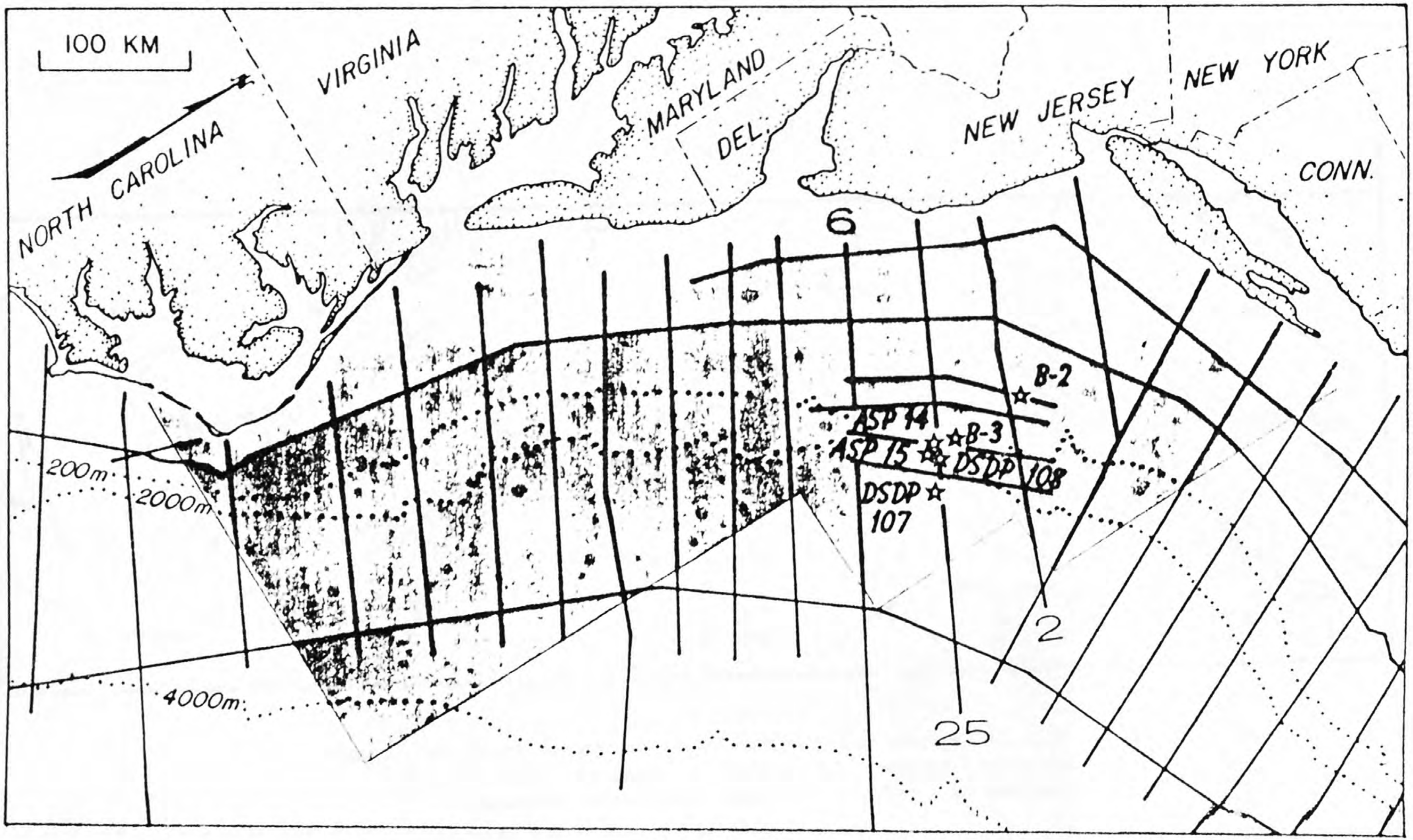


Figure 1.--Map of the Mid-Atlantic area showing selected wells and location of multichannel reflection profiles. Area of proposed oil and gas lease sale is shaded. Seismic profiles discussed in text are numbered. Bathymetric contours are shown by dotted lines.

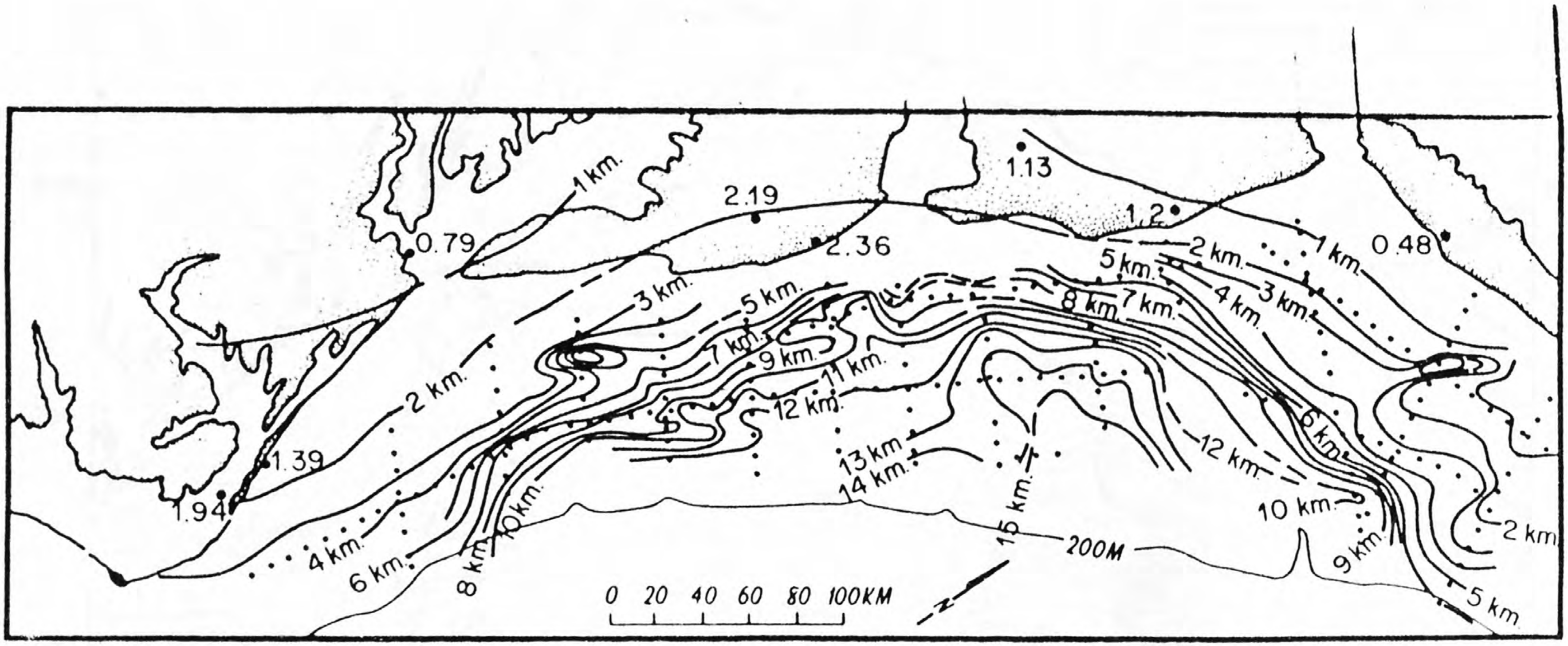


Figure 2.--Isopach map of total sediment thickness in the Baltimore Canyon Trough area. Dotted lines show location of seismic control (Schlee, in preparation).

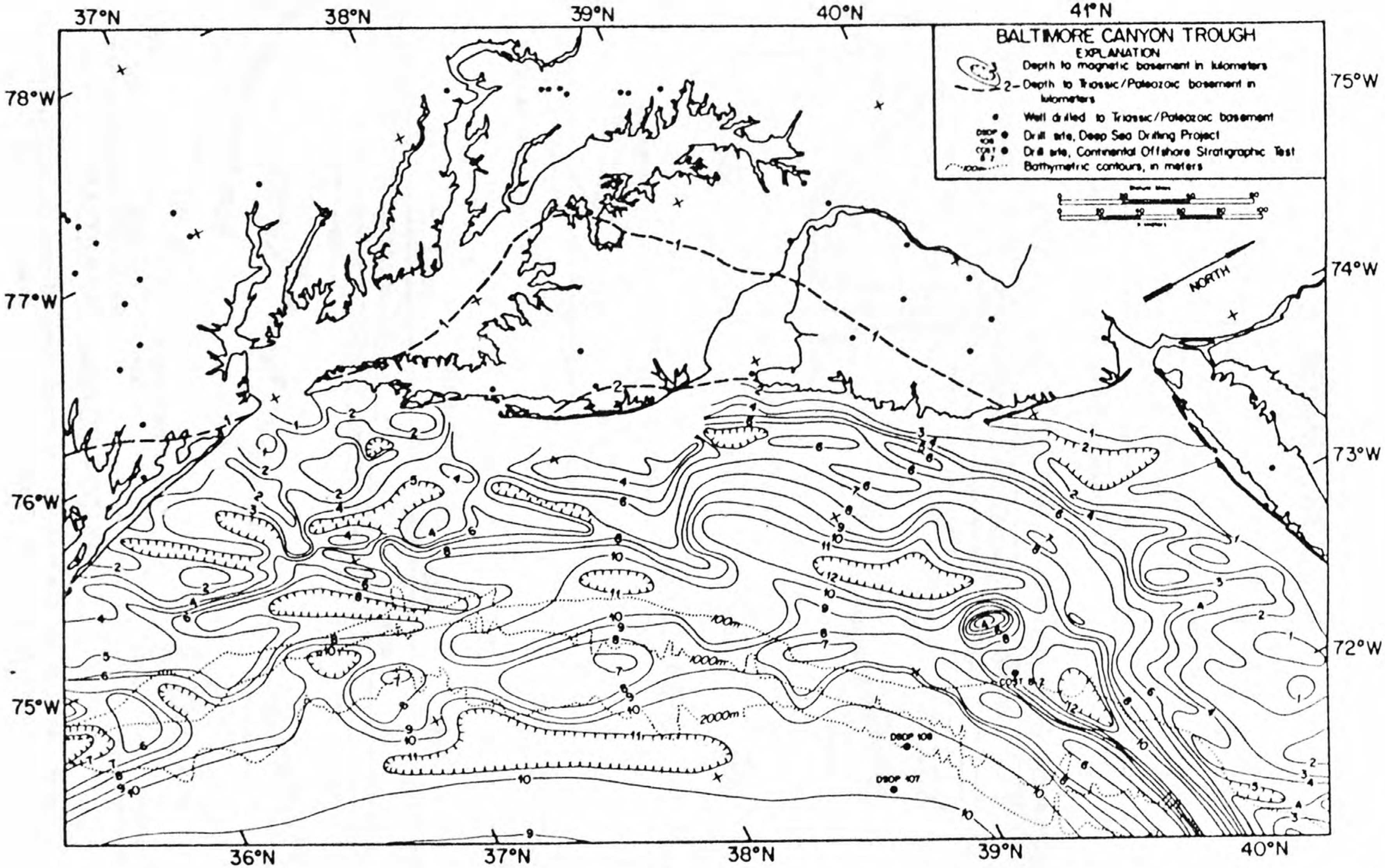


Figure 3.--Contour map, calculated from magnetic data, showing depth to basement in the Baltimore Canyon Trough area (from Klitgord and Behrendt, 1979).

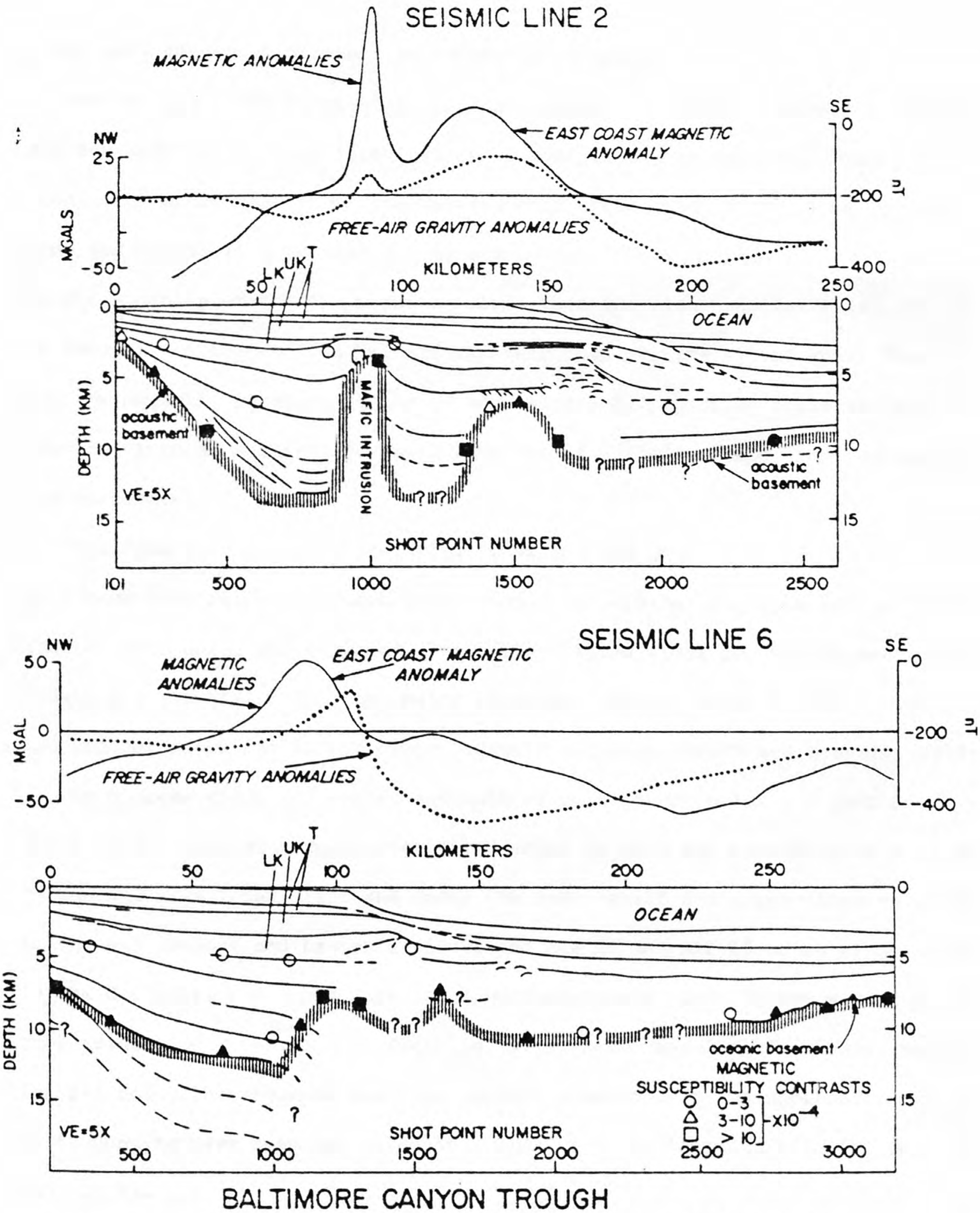


Figure 4.--Comparison between depths to basement calculated from magnetic data and multichannel seismic reflection data (Klitgord and Behrendt, 1979).

shows good agreement between the two types of data.

The nature of the basement ridge area beneath the slope is unknown. Klitgord and Behrendt (1979) postulate that it is most likely an uptilted block of oceanic(?) crust that forms the seaward edge of the Baltimore Canyon Trough. Grow and others (in preparation) made a detailed analysis of line 25 (fig. 1) in the vicinity of the slope, and conclude that the ridge may not exist or, if it does, it is deeper (~13 km) and narrower than originally thought. The shallow magnetic basement estimates may be caused, in part, by sills and dikes intruded into an earliest Jurassic sequence of redbeds, evaporites, volcanics, and carbonates.

Data from two deep offshore holes (COST B-2 and COST B-3, fig. 1) in the area have been released. Each penetrated about 4.8 km below sea level. When the two COST holes are compared with wells drilled along the New Jersey coast (Amato and Simonis, 1979), the major thickness changes (fig. 5) are in the Miocene and younger rocks and in the Upper Jurassic sequence (Amato and Simonis, 1979).

The Miocene sands and shales encountered in offshore holes are part of a shelf progradational sequence deposited under deltaic and near-deltaic environments in the B-2 area (Poag, 1978) and under the outer-shelf and upper-slope environments in the B-3 (Bebout and Lachance, 1979) and ASP 14 and ASP 15 holes (Poag, 1978). In the B-2 hole, the Upper Jurassic sandstone, shale, and lignite were deposited in a transitional environment (Scholle, 1977; Amato and Simonis, 1979); but in the B-3 hole, the sequence contains oolitic limestone in the uppermost part that is thought to have been deposited in a tidal bar environment (Adinolfi and Jacobson, 1979).

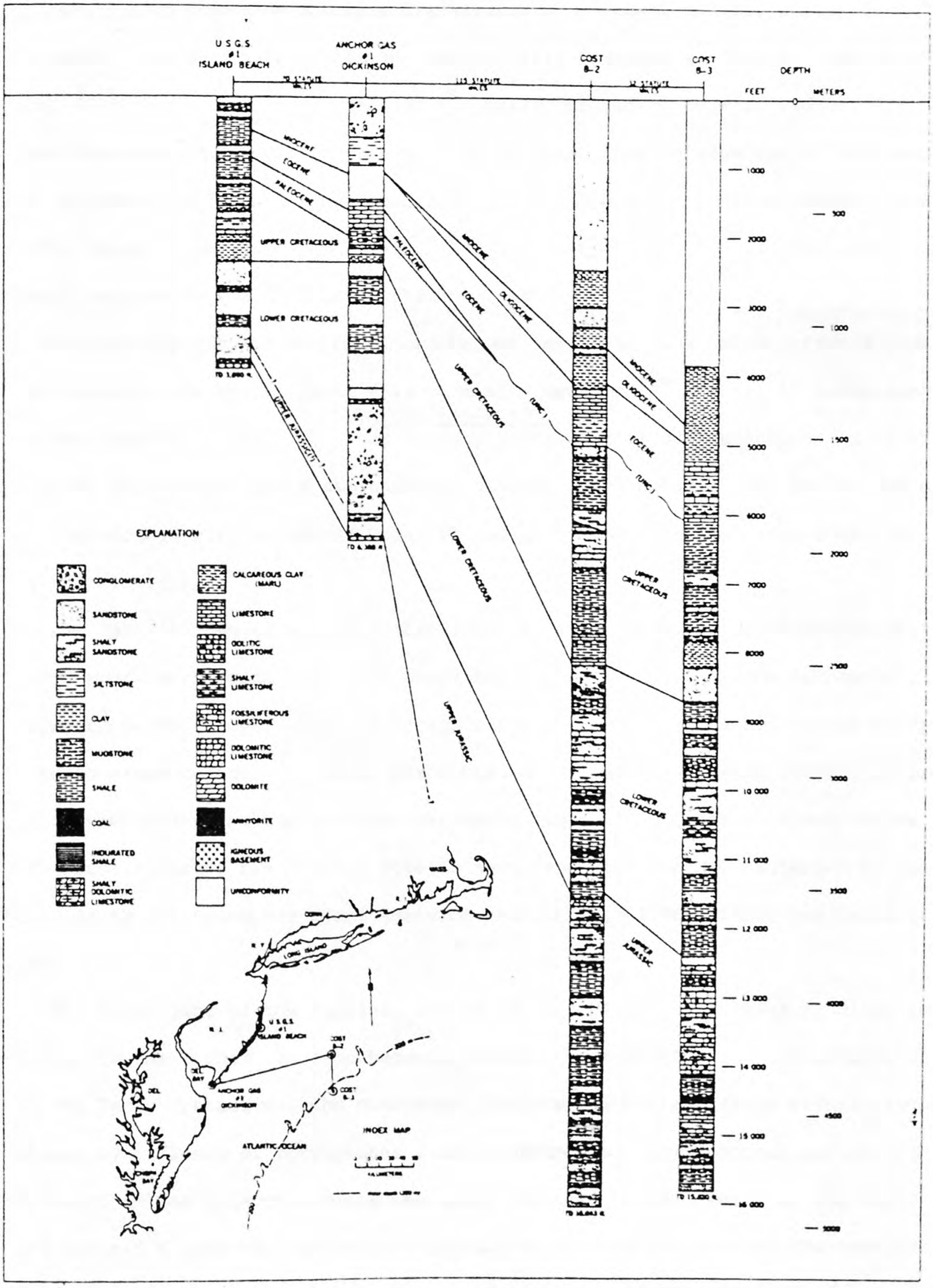


Figure 5.--Cross section through the Baltimore Canyon Trough (from Adinolfi and Jacobson, Pl. 4, 1979).

The COST holes show changes from mainly nonmarine conditions in the oldest (Kimmeridgian) rocks to a marine transgression (in the B-3 hole) during latest Jurassic, followed by a regression during Early Cretaceous (Adinolfi and Jacobson, 1979) as an influx of sand and mud built prograding deltaic wedges. In the Late Cretaceous and early Tertiary, a major transgression resulted in the deposition of calcareous mudstone, limestone, and sandstone under bathyal conditions (Poag, 1978; Adinolfi and Jacobson, 1979). A major hiatus characterizes the outer shelf section at the Tertiary-Cretaceous boundary.

The stratigraphy of the Baltimore Canyon Trough below 5 km is inferred from the seismic data and summarized in schematic cross section (fig. 6) taken along seismic profile 2 (fig. 1). On the landward side, the oldest, thickest part of the section is inferred to be Lower and Middle Jurassic nonmarine, clastic, sedimentary rocks built over an earlier-formed rift sequence, Upper Triassic red beds, and volcanic rocks (Schlee, in preparation).

The Jurassic sequence changes laterally to a sequence of limestones/dolomites and evaporites beneath the outer shelf and slope. Seaward of the carbonate platform, fore-reef slope facies of Jurassic and Early Cretaceous age mantle older oceanic crust beneath the slope and Continental Rise (Schlee and others, in press). It is the interfingering of these carbonate deposits with anoxic black shales of the North Atlantic basin which seem to have generated the most interest as potential deep water stratigraphic traps (Mattick and others, 1978; Arthur and Schlanger, 1979).

The lower part of the Jurassic system is thought to be intruded by dikes and sills in the transition zone between thinned continental crust and oceanic crust. In the Early Cretaceous, the carbonate platform was buried during several regressive phases by influxes of terrigenous clastic sediments. A widespread marine transgression in the Late Cretaceous and early Tertiary broadly built up the shelf, and created a subdued, gently-inclined slope. During the rest of the Tertiary and Quaternary, relative sea level began to fall (Vail and others, 1977; Pitman, 1978).

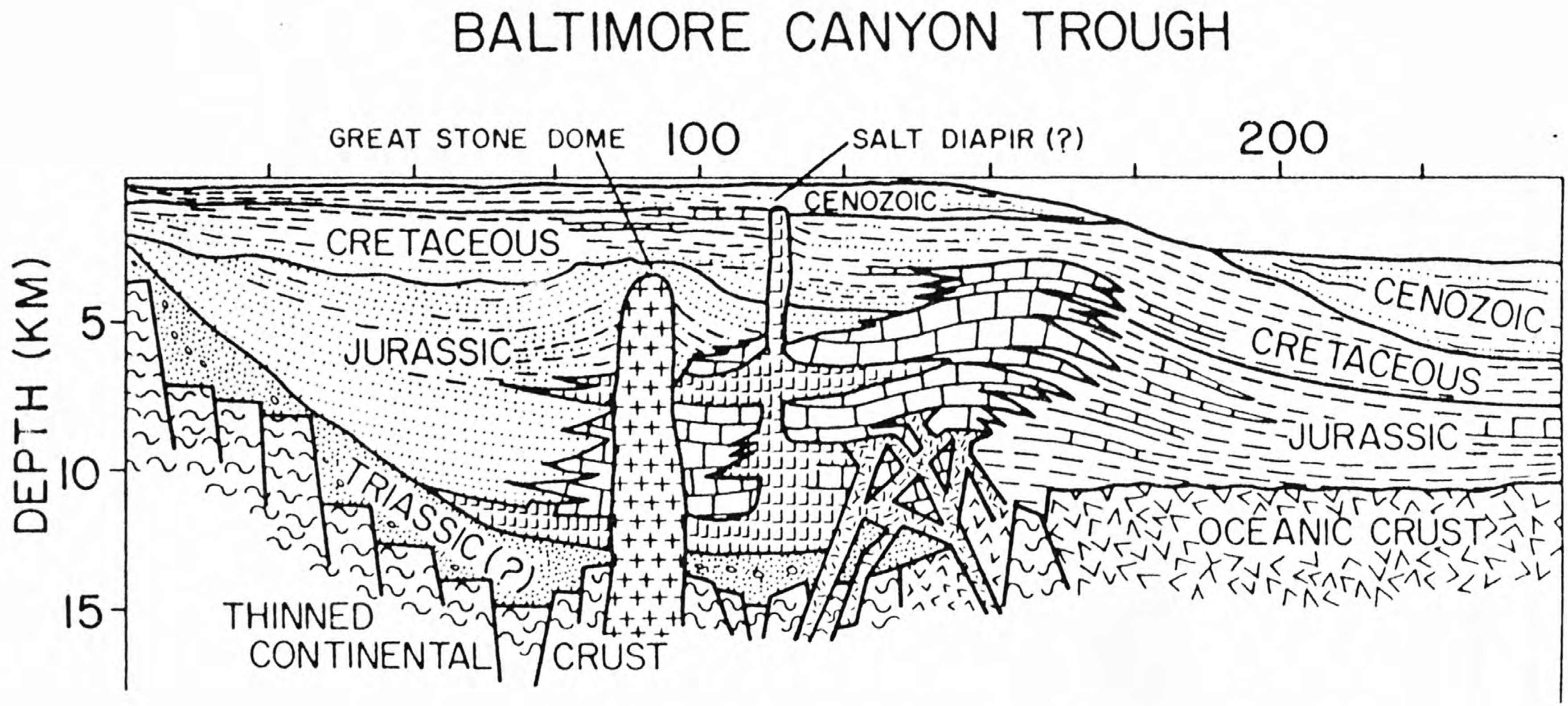


Figure 6.--Schematic cross section of the Mid-Atlantic margin. Location of section is along seismic reflection profile 2 (fig. 1).

This general trend, coupled with several short term sea level shifts (Vail and others, 1977), caused the slope to be eroded and cut back, exposing older Eocene (DSDP hole 108) and Cretaceous rocks. Debris moved downslope to build an enormous continental wedge as thick as 3 km.

ESTIMATES OF UNDISCOVERED RECOVERABLE OIL AND GAS RESOURCES

by

Richard B. Powers

Earlier estimates of the oil and gas potential of the Mid-Atlantic area were made by Miller and others (1975), U.S. Geological Survey (1975), and Mattick and others (1976). These estimates, however, were made prior to the drilling of the COST wells and the recent wildcat discoveries.

The proposed sale area (fig. 1) includes parts of three physiographic provinces: the Continental Shelf (0 m to 200 m), the Continental Slope (200 m to 2,000 m), and the Continental Rise (2,000 m to 5,000 m). The total sale area comprises approximately 154,200 km^2: 82,800 km^2 (54%) on the shelf, 19,700 km^2 (13%) on the slope, and 51,700 km^2 (33%) on the rise.

Undiscovered recoverable resources are those resources, yet to be discovered, which are estimated to exist in favorable geologic settings. Because undiscovered resources are uncertain quantities, estimation of their amounts is best stated as ranges of values corresponding to different probabilities of occurrence. Estimates are made at the 95% (low), 5% (high), and "most likely" probabilities. The estimates are then statistically analyzed by a Monte Carlo simulation procedure. The final computerized values are processed and displayed as probability distributions by lognormal curves which show the entire range of probabilities and a statistically-calculated mean estimate. Although it is assumed that oil and gas occurs in commercial amounts in making these estimates, this assumption cannot be made with any certainty in areas, such as the Mid-Atlantic, where no commercial quantities of oil or gas have been discovered. Because of this uncertainly, an additional estimate is made of the probability of finding commercial quantities of oil or gas. The "marginal probability" is included in the Monte Carlo procedure and processed with the other probabilities to arrive at final estimates.

Separate estimates of undiscovered recoverable oil and gas resources in the proposed lease sale area are made for the shelf and slope. These estimates are based on assumptions that resources will be found under conditions represented by a continuation of present price-cost relationships and technological trends. No resource estimates are made for the Continental Rise because of the sparcity of geologic data in that area and the fact that industry has not yet developed production capabilities for such water depths.

Shelf

To date, 18 wildcat wells have been drilled or are in the process of being drilled (fig. 7) on the shelf. Two discoveries have been made near the edge of the shelf. The first direct evidence of hydrocarbons in the Baltimore Canyon area was Texaco's 598-1 discovery (Oil and Gas Journal, 1978). A lower, 11.5 m-interval, below 3,960 m, yielded natural gas at the rate of 7.5 MMcf/d (212,000 m^3/d) (Oil and Gas Journal, 1978). A confirmation well - Texaco's 598-2 - located one mile west was dry, however, indicating that the trapping structure may not be as extensive as originally thought.

In May, 1979, Tenneco - referring to their Block 642-1 well - announced that natural gas had been recovered from a 4.5 m-interval in Jurassic sand at 4,020 m; the initial flow rate was 12 MMcf/d (346,000 m^3/d) plus condensate at the rate of 100 bbl/d (Oil and Gas Journal, 1979). A second test at 3,860 m flowed gas at the rate of 1 MMcf/d (28,300 m^3/d) and 500 bbl/d of salt water. A third test at 2,535 m flowed 48.4°-gravity oil at the rate of 630 bbl/d from a thin Lower Cretaceous sand. The Block 642-1 well is located 2 miles south of the Texaco Block 598-1 well, and is apparently on the same general structural complex, but probably located along a separate fault.

The recovery of hydrocarbons from the two wells is significant; however, only additional drilling can determine if resources in commercially recoverable quantities exist.

Exploratory drilling on the "Great Stone Dome," centered around Block 588, had

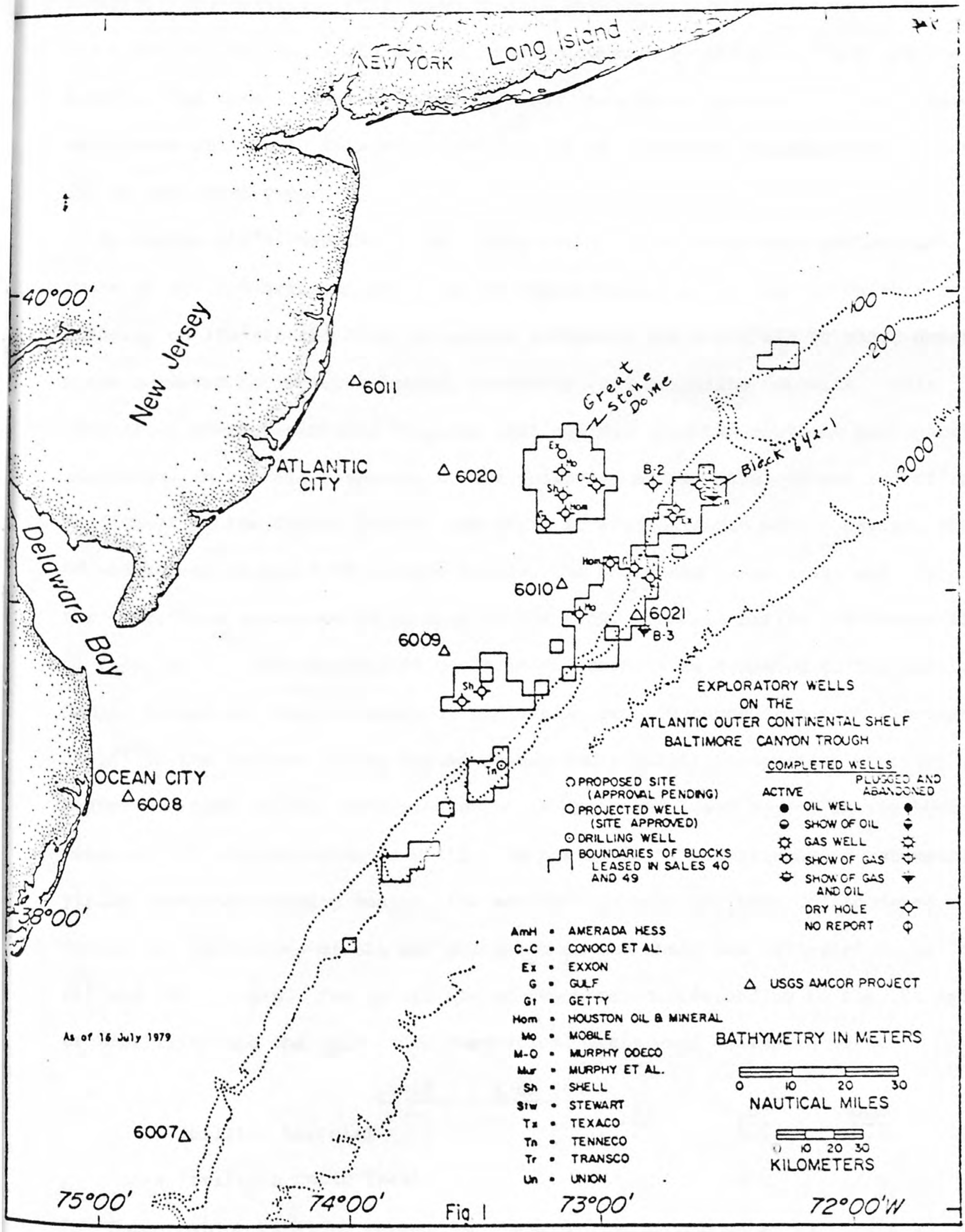


Figure 7.--Map showing location of exploratory wells drilled in the Baltimore Canyon Trough area.

disappointing results. This broad feature appeared to be the largest single structure on the shelf, and the most promising as a potentially-giant gas field based on its areal size (about 400 km^2) and structural closure (>200 m). Five wells were drilled on this structure and all were plugged and abandoned with no oil or gas shows reported.

As Dolton (1979) has indicated, Upper Jurassic and Cretaceous sedimentary rocks of the Mid-Atlantic shelf can be characterized as a wedge of deltaic sediments bordered on its seaward flank by marine sediments and underlain by older Jurassic rocks believed to include clastic, carbonate, and evaporite deposits. This simplified characterization suggests that the Mid-Atlantic could be geologically analagous, in certain respects, to the following areas: the onshore and offshore Gulf Coast of the United States, the North African Atlantic margin basins, the offshore Scotian Shelf of eastern Canada, the Mackenzie Delta area, and, in part, the Cretaceous sequences of several of the Rocky Mountain basins. Although all of these areas have significant geologic differences as compared to the Baltimore Canyon Trough and their commercial production records range from zero (Scotian Shelf) to the highest in the United States (Gulf Coast), comparison of these analog basins were made to help determine probable upper and lower bounds on the hydrocarbon potential of the Mid-Atlantic shelf. On the basis of comparisons of volumetric yields from these analog basins, the marginal probability that undiscovered commercial quantities of oil and gas exist on the shelf was estimated to be .50 for oil and .85 for gas. The quantities of resources corresponding to the .95 and .05 probabilities and the calculated statistical means were estimated to be:

<u>Shelf - 0 m to 200 m</u>

	.95	.05	Mean
Oil (billion barrels)	0	1.6	0.4
Gas (trillion cubic feet)	0	8.1	2.6

The lognormal probability curves for these estimates are shown in figure 3.

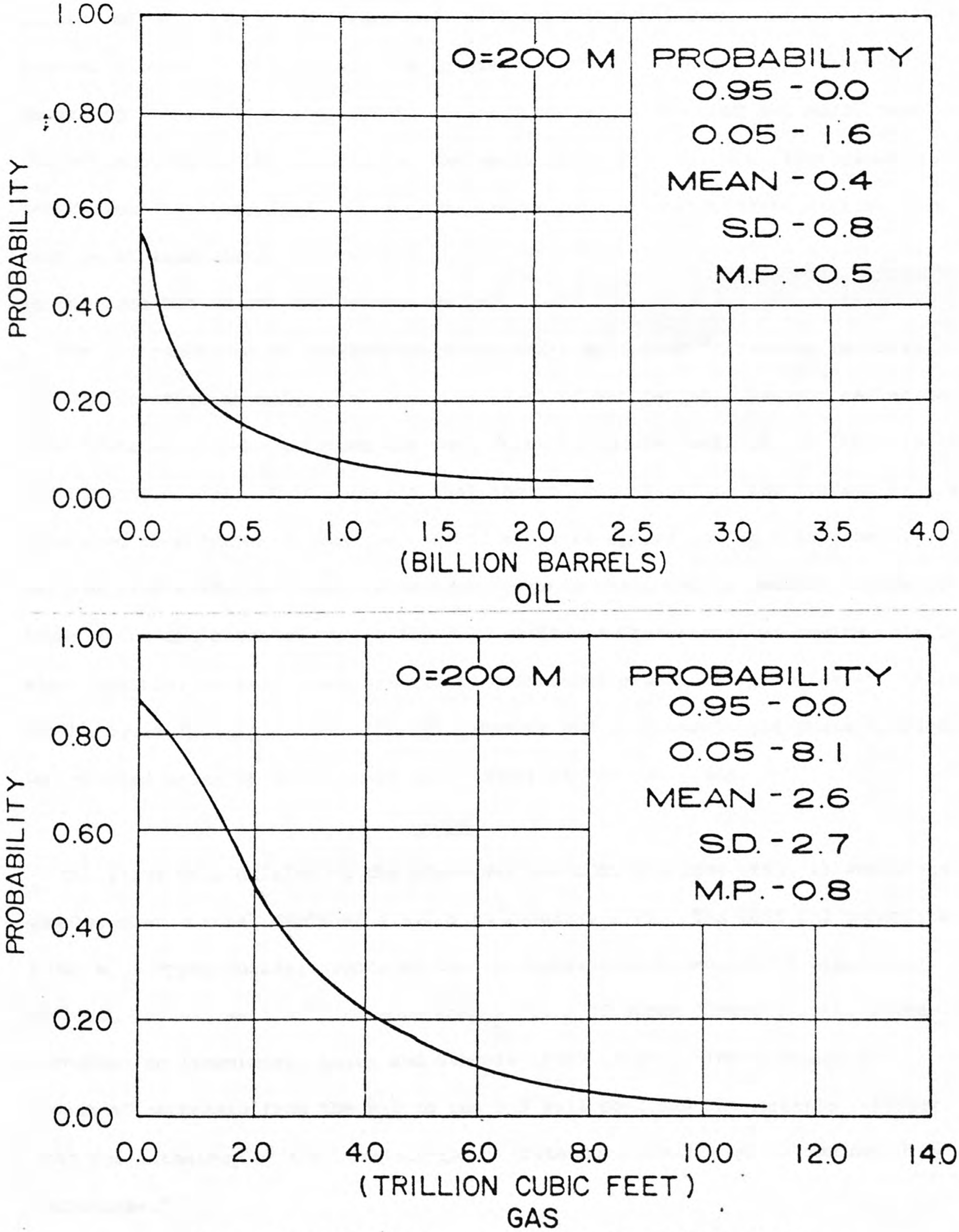


Figure 8.--Probability distribution for undiscovered recoverable oil and total (associated/dissolved and non-associated) gas on the Mid-Atlantic shelf. Marginal Probability: M.P.; Standard Deviation: S.D.

In the COST B-2 well, data from color alteration of visible organic matter, pyrolytic-decomposition temperatures, carbon-preference index, and vitrinite reflection indicate the Tertiary and Cretaceous section, down to about 2,400 m, is thermally immature and is unlikely to yield hydrocarbons other than biogenically-generated methane (Scholle, 1977). Below 2,400 m, in the COST B-2 well, there is disagreement as to the maturity of the sediments with respect to liquid-hydrocarbon generation (Scholle, 1977, p. 8). The deeper part of the Jurassic section, however, must be at least marginally mature as indicated by the flow of liquids in addition to gas from the Texaco and Tenneco wells.

The oil recovered at the Tenneco Block 642-1 well from Cretaceous rocks at 2,535 m presents an enigma in regard to level of maturation. Organic matter recovered from Cretaceous rocks at about the same depth in the B-3 well appear immature (Amato and Simonis, 1979). This suggests that the oil discovered in the Tenneco well was generated much deeper in the section and migrated upward, or that it possibly derived from a thermally-mature source in organic-rich, deeper basinal facies of the lower slope and migrated vertically into shallower Cretaceous reservoirs. It is also possible, however, that associated Cretaceous organic-rich shales at shallow depths could locally achieve thermal maturity and generate liquid-phase hydrocarbons in selected areas (possibly near salt domes) at the shelf edge.

Slope

The first well drilled on the slope was the COST B-3 test (fig. 1) which was completed at a total depth of 4,822 m in January, 1979. The COST B-3 penetrated 1,040 m of Upper Jurassic rocks containing considerable amounts of limestone; whereas, the B-2 well drilled more than 1,200 m of Upper Jurassic rocks which contained no limestone. Amato and Simonis (1979) state, "The increase in amount of carbonate from the B-2 to the B-3 well confirms the seismic interpretation that the lithology of the Jurassic-Early Cretaceous shelf edge is dominated by carbonates."

A pronounced drilling break occurred in the interval from 4,800 m to 4,811 m. In this interval, significant amounts of gas were detected by the mud-logging unit (up to 2,900 units) in a friable sandstone (Nichols, 1979). Log interpretation identified a 3-m gas sand between 4,798 m and 4,801 m which had 12% porosity, low water saturation (32%), but low permeability. A wireline test was run 4 times in this interval, recovering small volumes of methane-rich gas and heavier hydrocarbons. According to Nichols (1979), "The B-3 apparently encountered a small stratigraphic trap which could not be predicted from seismic data over the drillsite."

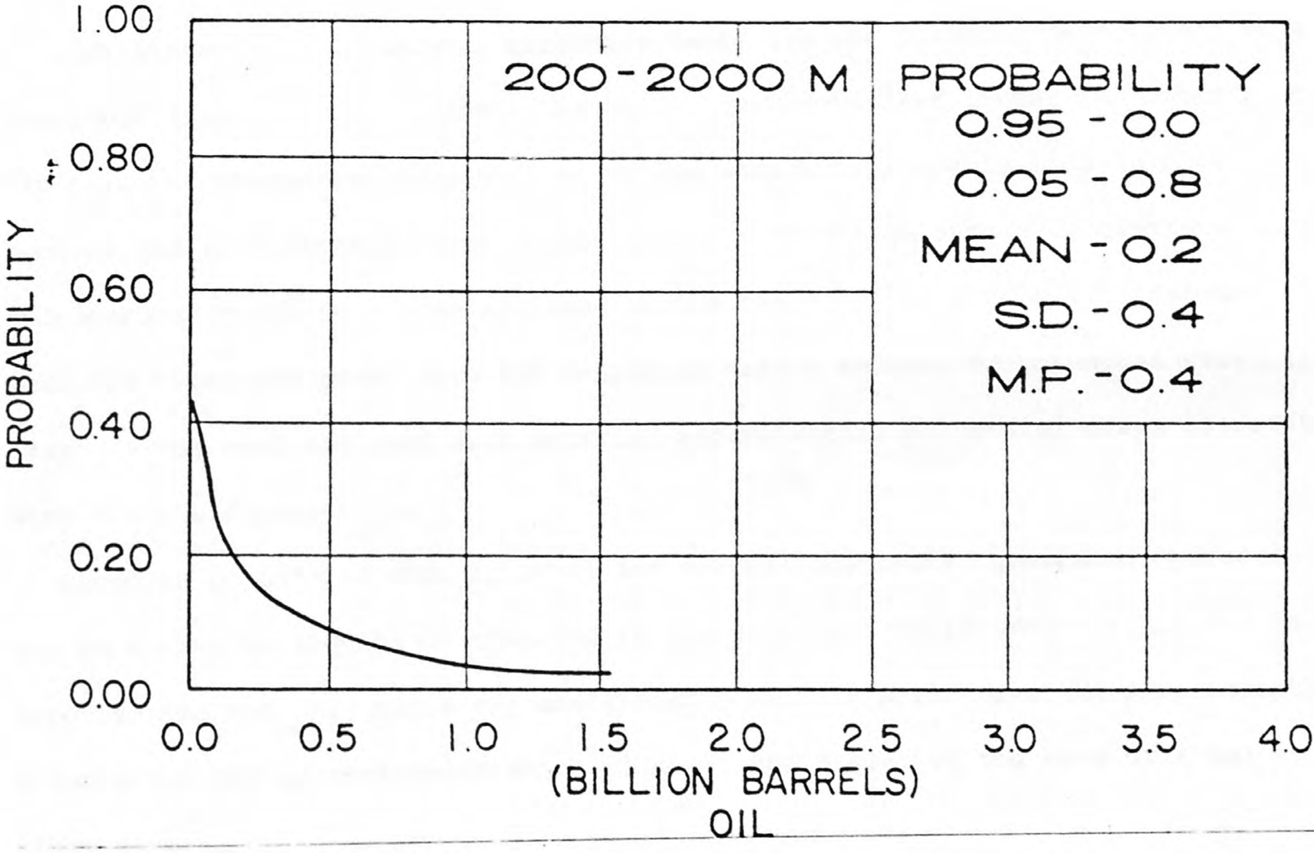
The estimated resource potential of the Mid-Atlantic slope is shown in figure 9. The marginal probability that undiscovered commercial quantities of oil and gas exist beneath the slope was estimated to be .40 for oil and .80 for gas. The quantities at the .95 and .05 probabilities together with a calculated statistical mean were estimated to be:

Slope - 200 m to 2,000 m

	.95	.05	Mean
Oil (billion barrels)	0	0.8	0.2
Gas (trillion cubic feet)	0	5.2	1.5

Data available at the time that these estimates were made allowed only volumetric calculations based on yields from other regions, including the Gulf Coast as a whole. These calculated values were analyzed as scaling factors considering the known geology of the Atlantic slope. Recently-available data from the COST B-3 well, confirming the presence of hydrocarbons on the slope, would suggest that these estimates may be somewhat conservative in spite of the great uncertainties of future economic recovery.

The important geologic features of the slope, as they pertain to petroleum potential and as identified or confirmed by the more recent work, are discussed by



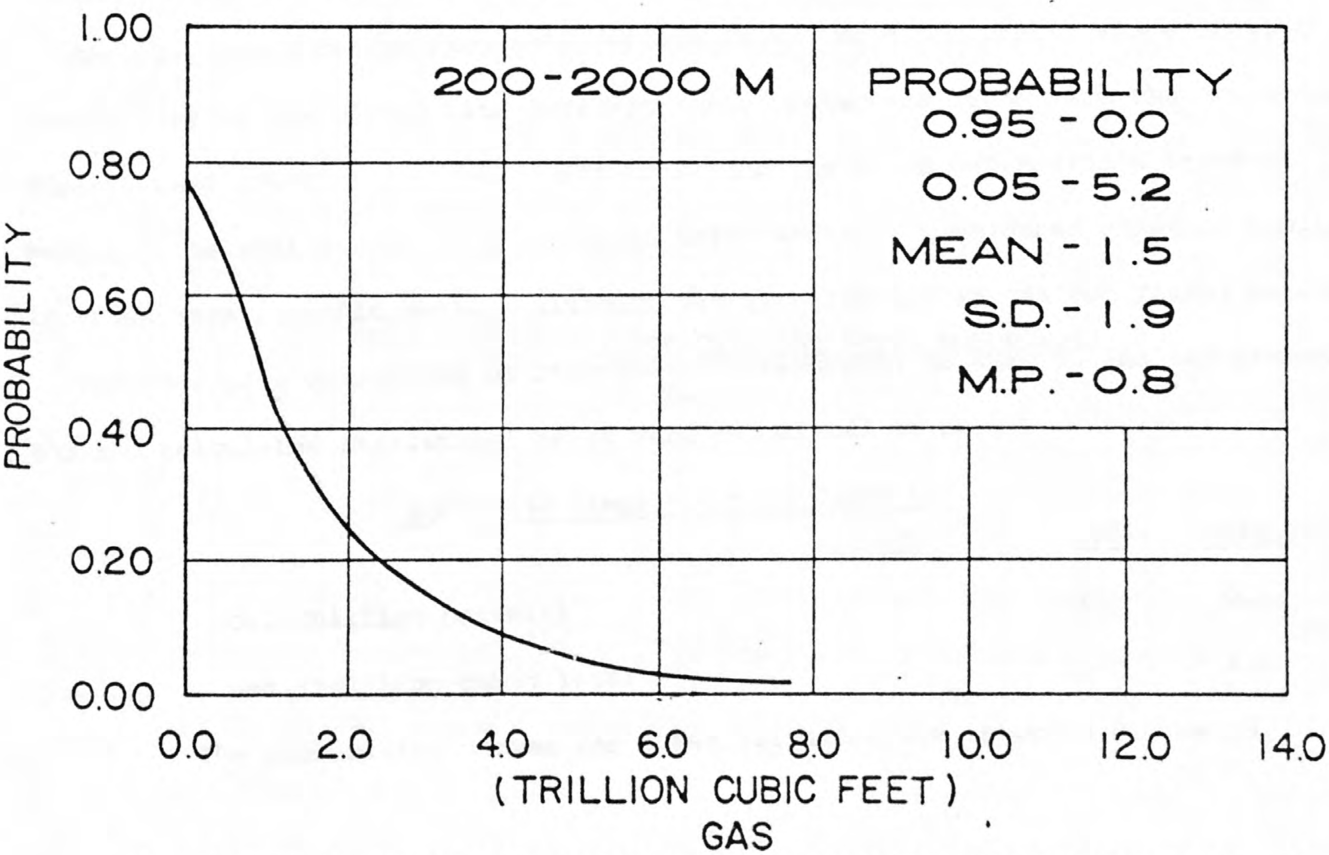


Figure 9.--Probability distribution for undiscovered recoverable oil and total (associated/dissolved and non-associated) gas on the Mid-Atlantic slope.
Marginal Probability: M.P.; Standard Deviation: S.D.

Mattick and others (1978) and summarized as follows: (1) the existence of a major "high" beneath the upper slope and shelf margin; (2) the development on this high of a Jurassic-Early Cretaceous carbonate bank; (3) the probable development of a large but discontinuous Jurassic and Early Cretaceous reef trend; (4) a thick down-dip prism of deepwater, fine-grained marine sediments probably rich in organic content and sufficiently thick so that temperatures high enough to generate liquid hydrocarbons could have been achieved in the deeper parts of the section; and (5) possible migration paths from the deepwater marine section to potential stratigraphic traps in the reef and reef bank material and potential structural traps associated with the shelf margin high.

Based on postulated organic types and thermal gradients, generated hydrocarbons may be richer in liquids as compared to the adjoining shelf area. Traps may be hypothesized not only above the shelf margin high in structural and stratigraphic situations, but in reservoirs which pinchout updip against the base of a paleo-shelf as well.

Analogs considered particularly applicable to the Mid-Atlantic slope area, as they relate to the buried Late Jurassic-Early Cretaceous trend, are the Cretaceous Edwards reef trend of the Texas Gulf Coast and the El Abra-Tamaulipas trend of Mexico. The reef trends of the Permian basin might be considered somewhat similar in gross stratigraphic setting although vastly different in age and faunal makeup.

The aggregate quantities of resources, for both the shelf and slope, corresponding to the .95 and .05 probabilties and the calculated statistical means were calculated to be:

Shelf and Slope - 0 m to 2,000 m

	.95	.05	Mean
Oil (billion barrels)	0	2.1	0.5
Gas (trillion cubic feet)	0	10.9	4.1

The probability curves for these estimates are shown in figure 10.

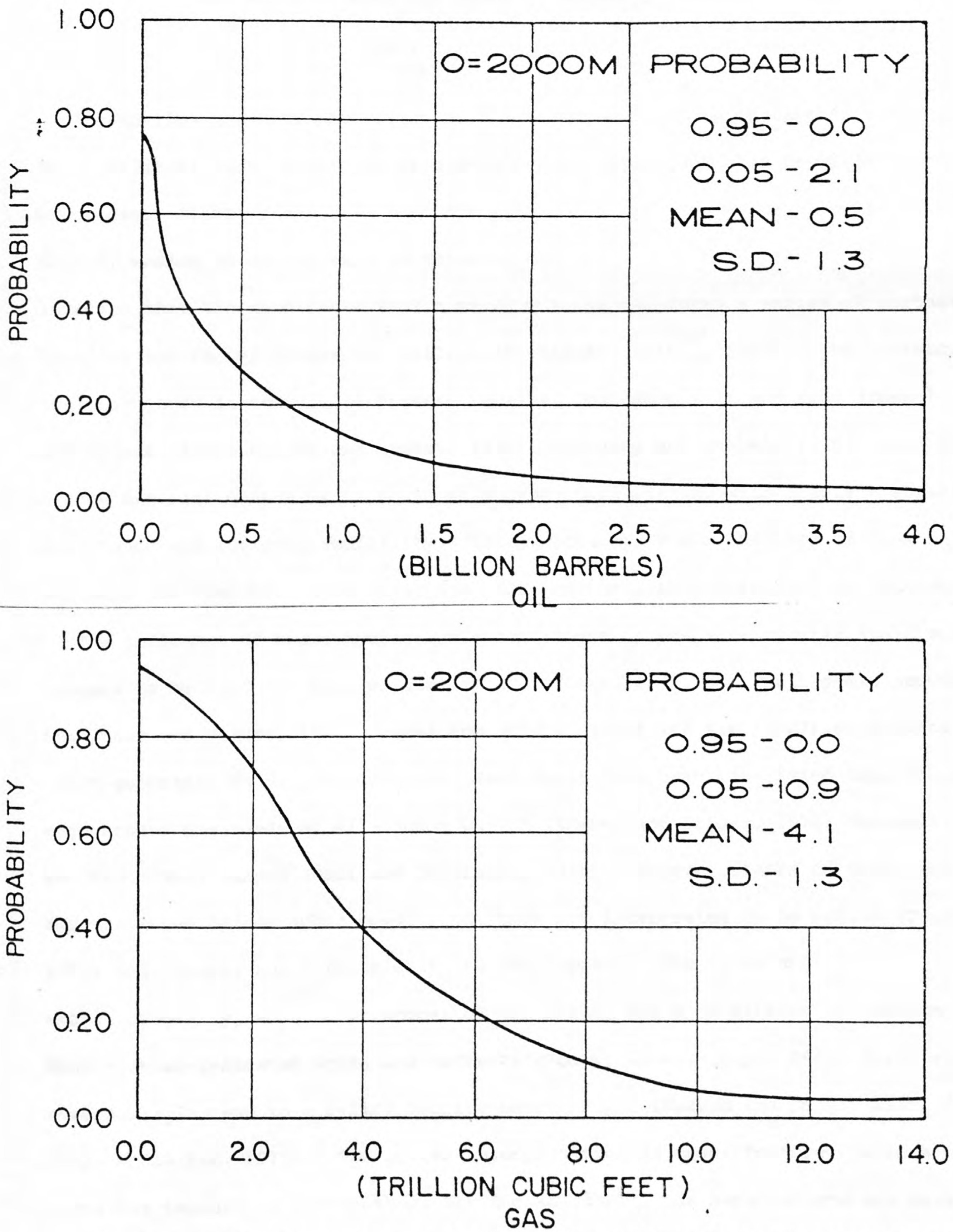


Figure 10.--Aggregated probability distribution for undiscovered total oil and total gas (associated/dissolved and non-associated) on the Mid-Atlantic shelf and slope.

POTENTIAL GEOLOGIC HAZARDS

by

James M. Robb and David C. Twichell

Shelf

The shallow stratigraphy of the Middle Atlantic shelf is 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 valleys (Knebel and Spiker, 1977). The Pleistocene-age clay layer is texturally diverse locally, including silt and sand (Knebel and Spiker, 1977; Folger and others, 1978). Sangrey and Knebel (1978) found this clayey material generally to be heavily over-consolidated, with adequate shearing resistance and low compressibility. Except locally, where the clay is weak and 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 present storm-generated waves and currents. 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, they are interpreted to be relict (Twichell, 1979) and, hence, not 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 (Moody, 1964; Uchupi, 1960; 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 bedforms are buried by as much as 14 m of Holocene-age silt and clay (Twichell and McClennen, 1979).

Shallow faulting has been identified in a localized area near the shelf edge 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 for OCS Sale 49 were addressed 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 and shallow gas deposits. Few occurrences of such hazards were located. Constraints included erosion and scour, filled channels, relict lagoon deposits, and gas-charged sediments, which relate to the stability of bottom-sited facilities and should be investigated on a site-specific basis.

Slope

The Continental Slope is cut by several major canyons and dissected by numerous valleys in between. The surface slopes between 4° and 15°, commonly 7° to 8°; but locally, the inclination may be nearly vertical at canyon or valley walls or at some intercanyon outcrops of consolidated rocks.

Shallow stratigraphic coreholes (Poag, 1978; Hathaway and others, 1976) show more than 300 m of generally fine-textured Pleistocene sediments near the top of the slope, thinning to less than 20 m at mid-slope depths (above 1,000 m water depth). These somewhat chaotically-bedded Pleistocene sediments overlie nearly flat-lying sedimentary rocks of Eocene to Miocene age (Grow and others, 1979) which crop out locally on the lower slope and in canyons and intercanyon areas. The Pleistocene sediments are complex in their sedimentary structures, showing slumps and slides, cut and fill (or channel fills), and depositional features such as leveed valleys.

Potential geologic hazards or constraints on the Continental Slope area include slumps or slides, channel fill, faulting, and erosion and scour.

Slumps or slides have been recognized as a problem, and have been described and discussed by Uchupi (1967), McGregor and Bennett (1977), Embley and Jacobi (1977), and Knebel and Carson (1979). At least 2 and perhaps 3 large slump features have been located in the Mid-Atlantic area (McGregor and Bennett, 1977; Embley and Jacobi, 1977; Robb, unpublished data, 1979). Knebel and Carson (1979) describe smaller slumps 10 m to 90 m deep and 1.7 km to 7.2 km in length. As a result of studies reported by Hall and Ensminger (1979), 27 lease tracts lying on the upper Continental Slope were withdrawn from Lease Sale 49 because they included areas possibly subject to slumping. Features resulting from slumps or slides can be identified on about 30% of the USGS high-resolution seismic lines crossing the Continental Slope.

The ages of slump features, the stability of slope sediments, and the forces necessary to initiate slope failures on the Mid-Atlantic slope are currently under study by the USGS. It is generally thought that small-scale slumping is a currently active process in many places on the slope (certainly in submarine canyons). Controversy exists, however, regarding large-scale slumps (involving seafloor blocks as much as several kilometers in length and width) which may be relict, having occurred during or shortly after the Pleistocene low stand of sea level. These possibly resulted from rapid deposition triggered by storms or earthquakes; waves and storm surges, in particular, exerted greater force on the bottom when sea level was lower.

Though the immediate area dealt with in this report shows few historical earthquake epicenters, the risk of significant slumps or slides resulting from an earthquake occurring in the Cape Ann area or elsewhere is not well known but at the present time is thought to be minimal. However, an earthquake of magnitude 7.2 (Richter scale), such as triggered a slump and turbidity flow on the Grand Banks slope in 1929, might result in a similar instability on the Mid-Atlantic slope.

As seen in high resolution seismic records of the upper slope, filled Pleistocene channel deposits may present problems to bottom structures due to differential bearing strengths of the fill and surrounding material. Filled channels are also observed in rocks of Miocene age, although few are exposed.

Evidence of shallow faulting has been observed below the lower Continental Slope between Carteret and Lindenkohl Canyons (J. Robb, unpublished data). These faults are generally low angle normal growth faults striking northeast in rocks of Cretaceous to Miocene age. In some places they appear to have topographic expression, which probably results from some erosional process acting along their zone of weakness. Kelling and Stanley (1970) report a fault below Wilmington Canyon that may have exercised structural control on the location of that feature.

Considerable erosion has taken place on the lower Continental Slope, to judge by valley erosion and by a general truncation of inferred Miocene and Eocene rocks. This erosion presumable occurred during or before the Pleistocene when sea level was lower and turbidity currents coursed the ravines and canyons. The strength and frequency of present day turbidity currents on the Continental Slope is not known, although such currents and rapid erosion have been described in canyons off the coast of California by Shepard and others (1974). Richard Slater (personal communication, 1978) described being caught in a small turbidity current in Lydonia Canyon while in a research submersible. These observations point up the fact that facilities placed on the Continental Slope should not be sited in canyons or valley channelways.

Rise

The Continental Rise is characterized by subdued topography. Although few data are available, hazards and constraints there will include filled channels, currents and scour, and shallow gas or clathrates.

CURRENTS AND ASSOCIATED SEDIMENT MOTION

by

Bradford Butman

Few direct current observations have been made on the Outer Continental Shelf and the Continental Slope. Currents in this region of the continental margin are complex because they are associated with oceanic circulation as it interacts with the Continental Slope topography, with storms (surface currents only), with the water density distribution, with Gulf Stream eddies, and with other forcing mechanisms. Currents may be particularly complex in submarine canyons.

A near-bottom array of instruments on the slope south of Cape Cod from 1,000 m to 2,500 m water depth showed low frequency currents (periods of 2 to 10 days) of 5-10 cm/s which were very similar (coherent) along a depth contour, but dissimilar (incoherent) across depth contours (Schmitz, 1974). Maximum bottom currents were typically 20 cm/s (Wunsch and Hendry, 1972), and the associated bottom stress was not sufficient to move bottom sediment. Near-bottom current measurements reported by McGregor (1979), in approximately 800 m of water off Delaware, showed maximum bottom currents of 30 cm/s with typical speeds of 3-4 cm/s. McGregor (1979) concluded that bottom sediment might be occasionally scoured. Currents in shallower water on the upper slope and Outer Continental Shelf may be somewhat stronger. Butman and others (1979) reported near-bottom currents of 37 cm/s in winter in water 85-m deep. On the upper slope, internal waves may be sufficient to scour bottom sediments (Butman and others, 1979; Cacchione and Southard, 1974). Flagg (1977) reported typical mean current velocities of 10 cm/s, with standard deviation of 10 cm/s, at the 100-m isobath south of Cape Cod. Surface currents associated with Gulf Stream eddies or meanders may reach 50 cm/s to 100 cm/s as they impinge on the slope (EG&G, 1978). Currents in the numerous canyons may be sufficient to scour the bottom sediments, and the canyons may transport material off the shelf into the deep ocean (Keller and Shepard, 1978).

In summary, currents on the slope are generally less than 50 cm/s (1 knot), and are caused by several processes. Maximum currents will probably be associated with Gulf Stream eddies and with storms. The surface sediments may be scoured occasionally.

LITERATURE CITED

Adinolfi, F., and Jacobson, S. S., 1979, Geologic correlation with other wells: in Amato, R. V., and Simonis, E. K., eds., Geological and operational summary, COST No. B-3 well, Baltimore Canyon Trough area, Mid-Atlantic OCS: U.S. Geological Survey Open-File Report 79-1159, p. 32-39.

Amato, R. V., and Simonis, E. K., eds., 1979, Geological and operational summary, cost no. B-3 well, Baltimore Canyon Trough area, Mid-Atlantic OCS: U.S. Geological Survey Open-File Report 79-1159, 118 p.

Arthur, M. A., and Schlanger, S. O., 1979, Cretaceous "Oceanic anoxic events" as causal factors in development of reef-reservoired giant oil fields: American Association of Petroleum Geologists Bulletin, v. 63, no. 6, p. 870-885.

Bebout, J. W., and Lachance, D. J., 1979, Depositional environments: in Amato, R. V., and Simonis, E. K., eds., Geological and operational summary, COST No. B-3 well, Baltimore Canyon Trough area, Mid-Atlantic OCS: U.S. Geological Survey Open-File Report 79-1159, p. 40-48.

Bennett, R. H., Lambert, O. N., and Hulbert, M. H., 1977, Geotechnical properties of a submarine slide area on the U.S. Continental Slope northeast of Wilmington Canyon: Marine Geotechnology, v. 2, p. 245-261.

Butman, Bradford, Noble, Marlene, and Folger, D. W., 1979, Long-term observations of bottom current and bottom sediment movement on the Mid-Atlantic Continental Shelf: Journal of Geophysical Research, v. 94, p. 1187-1205.

Cacchione, D. A., and Southard, J. B., 1974, Incipient sediment movement by shoaling internal gravity waves: Journal of Geophysical Research, v. 79, p. 2237-2242.

Cousins, P. W., Dillon, W. P., and Oldale, R. N., 1977, Shallow structure of sediments of the United States Atlantic Shelf, Long Island, N.Y., to Norfolk, Va.: in Folger, D. W., ed., Middle Atlantic Outer Continental Shelf environment studies, Vol. 3, Geologic Studies: Virginia Institute of Marine Sciences, Gloucester Point, Va., Chapter 11.

Dolton, Gordon L., 1979, Estimated undiscovered recoverable oil and gas resources: in Mattick, Robert E., ed., Geologic setting, sediments, petroleum potential, environmental considerations and operational consideration pertaining to proposed oil and gas lease sale No. 49 on the U.S. Mid-Atlantic Outer Continental Shelf and Slope: U.S. Geological Survey Circ. (in press).

EG&G, 1978, Data report surface currents deployment, November 1977, Appendix A of Seventh Quarterly Progress Report, New England Outer Continental Shelf Physical Oceanography Program, Contract AA550-CT-6-50: Waltham, Mass., EG&G Environmental Consultants.

Embley, R. W., and Jacobi, R. D., 1977, Distribution and morphology of large submarine sediment slides and slumps on Atlantic continental margins: Marine Geotechnology, v. 2, p. 205-228.

Flagg, C., 1977, The kinematics and dynamics of the New England Continental Shelf and Shelf/Slope front: Cambridge, Mass., Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Joint Program, Ph.D. thesis, 207 p.

Folger, D. W., Butman, B., Knebel, H. J., and Sylwester, R. J., 1978, Environmental hazards on the Atlantic Outer Continental Shelf of the United States: Offshore Technology Conference Paper 3313, p. 2293-2298.

Grow, J. A., Mattick, R. E., and Schlee, J. S., 1979, Multichannel depth sections over Outer Continental Shelf and upper Continental Slope between Cape Hatteras and Cape Cod: in Watkins, J. S., Montadert, L., and

Dickerson, P. W., eds., Geological and Geophysical investigations of the continental margins: American Association of Petroleum Geologists, Memoir 29, p. 65-83.

Grow, J. A., Schlee, J. S., Dillon, W. P., Klitgord, K. D., Hutchinson, D. R., Mattick, R. E., and Bayer, K. C., in preparation, Multichannel seismic investigations off the east coast of the United States: Interunion Commission on Geodynamics.

Hall, R. W., and Ensminger, R. F., eds., 1979, Potential geologic hazards and constraints for blocks in proposed Mid-Atlantic OCS Oil and Gas Lease Sale 49: U.S. Geological Survey Open-File Report 79-264.

Hathaway, J. C., Schlee, J. S., Poag, C. W., Valentine, P. C., Weed, E. G. A., Bothner, M. H., Kohout, F. A., Manheim, F. T., Schoen, Robert, Miller, R. E., and Schultz, D. M., 1976, Preliminary summary of the 1976 Atlantic margin coring project of the U.S. Geological Survey: U.S. Geological Survey Open-File Report No. 76-844, 217 p.

Keller, George H., and Shepard, Francis P., 1978, Currents and sedimentary processes in submarine canyons: in Stanley, D. J., and Kelling, C., eds., Sedimentation in submarine canyons, fans, and trenches: Stroudsburg, Pa., Dowden, Hutchinson, and Ross.

Kelling, G., and Stanley, D. J., 1970, Morphology and structure of Wilmington and Baltimore submarine canyons, eastern United States: J. Geology, v. 78, p. 637-660.

Knebel, H. J., and Carson, Bobb, 1979, Small-scale slump deposits, Middle Atlantic Continental Slope off eastern United States: Marine Geology, v. 29, p. 221-236.

Knebel, H. J., and Folger, D. W., 1976, Large sand waves on the Atlantic Outer Continental Shelf around Wilmington Canyon, off eastern United States: Marine Geology, v. 22, p. M7-M15.

Knebel, H. J., and Spiker, E. C., 1977, Thickness and age of surficial sand sheet, Baltimore Canyon Trough area: American Association of Petroleum Geologists, v. 61, p. 861-871.

Knebel, H. J., Butman, Bradford, Folger, D. W., Cousins, P. W., and McGirr, R. R., 1976, Map and graphic data related to geologic hazards in the Baltimore Canyon trough area: U.S. Geological Survey Misc. Field Studies Map MF 828, 3 sheets.

Klitgord, K. D., and Behrendt, J. C., 1979, Basin structure of the United States continental margin north of Cape Hatteras: in Watkins, J. S., Montadert, L., and Dickerson, P. W., eds., Geological and geophysical investigations of the continental margins: American Association of Petroleum Geologists Memoir 29, p. 85-112.

Mattick, Robert E., Folger, David W., Foley, Neil T., Dolton, Gordon L., and Bayer, Kenneth C., 1976, Summary report of the sediments, structural framework, petroleum potential, environmental conditions, and operational considerations of the United States Mid-Atlantic Continental Shelf: U.S. Geol. Survey Open-File Report 76-532, 26 p.

Mattick, R. E., Girard, O. W., Scholle, P. A., and Grow, J. A., 1978, Petroleum potential of the United States Atlantic slope, rise, and Abyssal Plain: American Association of Petroleum Geologists Bulletin, v. 62, no. 4, p. 592-608.

McClennen, Charles E., 1973, Nature and origin of the New Jersey Continental Shelf topographic ridges and depressions: Kingston, R.I., University of Rhode Island, Thesis, 93 p.

McGregor, Bonnie A., 1979, Current meter observations on the U.S. Atlantic Continental Slope--Variation in time and space: Marine Geology, v. 29, p. 209-219.

McGregor, B. A., and Bennett, R. H., 1977, Continental Slope sediment instability northeast of Wilmington Canyon: American Association of Petroleum Geologists, v. 61, p. 918-928.

McKinney, T. F., Stubblefield, W. L., and Swift, D. J. P., 1974, Large-scale current lineations on the central New Jersey shelf: Investigations by sidescan sonar: Marine Geology, v. 17, p. 79-102.

Miller, Betty M., Thomsen, Harry L., Dolton, Gordon L., Coury, Anny B., Hendricks, Thomas A., Lennartz, Frances E., Powers, Richard B., Sable, Edward G., and Varnes, Katharine L., 1975, Geological estimates of undiscovered recoverable oil and gas resources in the United States: U.S. Geological Survey Circ. 725, 78 p.

Moody, D. W., 1964, Coastal morphology and processes in relation to the development of submarine sand ridges off Bethany Beach, Delaware: Baltimore, Johns Hopkins University, Ph.D. Thesis, 167 p.

Nichols, Renny R., 1979, Interpretation of Geophysical Logs: in Amato, R. V., and Simonis, E. K., eds., Geological and operational summary, COST No. B-3 well, Baltimore Canyon Trough area, Mid-Atlantic OCS: U.S. Geological Survey Open-File Report 79-1159, p. 57-63.

Oil and Gas Journal, 1978, Texaco has "significant" gas reserves at find off east coast: Oil and Gas Journal, August 28, 1978, p. 52.

Oil and Gas Journal, 1979, Tenneco tests oil in Baltimore Canyon strike: Oil and Gas Journal, June 11, 1979.

Pitman, W. C., 1978, Relationship between eustacy and stratigraphic sequences of passive margins: Geologic Society of America Bulletin, v. 89, no. 9, p. 1389-1403.

Poag, C. Wylie, 1978, Stratigraphy of the Atlantic Continental Shelf and Slope of the United States: Annual Review of Earth and Planetary Sciences, v. 6, p. 251-280.

Sanders, J. E., 1962, North-south trending submarine ridges composed of coarse sand off False Cape, Virginia (abs.): American Association of Petroleum Geologists, v. 46, p. 278.

Sangrey, D. A., and Knebel, H. J., 1978, Geotechnical engineering studies in the Baltimore Canyon Trough area: Draft final report for the period 1976-1977, A report to the Bureau of Land Management, Chapter 7, 26 p.

Schlee, J. S., in preparation, Seismic stratigraphy of the Baltimore Canyon Trough.

Schlee, J. S., Behrendt, J. C., Grow, J. A., Robb, J. M., Mattick, R. E., Taylor, P. T., and Lawson, B. J., 1976, Regional framework off northeastern United States: American Association of Petroleum Geologists Bulletin, v. 60, no. 6, p. 926-951.

Schlee, J. S., Martin, R. G., Mattick, R. E., Dillon, W. P., and Ball, M. M., 1977, Petroleum geology on the United States Atlantic-Gulf of Mexico margins: Proc. Southwestern Legal Foundation, Exploration and economics of the petroleum industry, v. 15, p. 47-93.

Schlee, J. S., Dillon, W. P., and Grow, J. A., in press, Structure of the Continental Slope off the eastern United States: Society of Economic Paleontologists and Mineralogists Special Paper, p. 95-118.

Schmitz, W. J., 1974, Observations of low-frequency current fluctuations on the Continental Slope and Rise near Site D: Journal of Marine Research, v. 32, no. 2, p. 233-251.

Scholle, Peter A., 1977, Data summary and petroleum potential: in Scholle, P. A., ed., Geological studies on the COST No. B-2 well, U.S. Mid-Atlantic Outer Continental Shelf area: U.S. Geological Survey Circular 750, p. 8-14.

Shepard, F. P., Marshall, N. F., and McLoughlin, P. A., 1974, Currents in submarine canyons: Deep Sea Research, v. 21, p. 691-706.

Sheridan, R. E., and Knebel, H. J., 1976, Evidence for post-Pleistocene faults on the New Jersey Atlantic Outer Continental Shelf: American Association of Petroleum Geologists, v. 60, p. 1112-1117.

Swift, D. J. P., Kofoed, J. W., Saulsburg, F. P., and Sears, P., 1972, Holocene evolution of the shelf surface, central and southern Atlantic shelf of North America: in Swift, D. J. P., Duane, D. B., and Pilkey, O. H., eds., Shelf sediment transport: Process and Pattern, Stroudsburg, Pa., Dowden, Hutchinson, and Ross, p. 499-574.

Twichell, D. C., 1979, Medium-scale potentially mobile bed forms on the Mid-Atlantic Continental Shelf: in Middle Atlantic Outer Continental Shelf Environmental Studies, Geologic Studies v. III: Final Tech. Report to the Bureau of Land Management for the period October 1, 1976 to September 30, 1977, prepared for the Virginia Institute of Marine Science, Gloucester Point, Va., p. 5-1 to 5-20.

Twichell, D. C., and McClennen, 1979, Anomalous fine sediments on the southern New England Continental Shelf (abs): Geological Society of America, Abstracts with Program, v. 11, p. 56.

Uchupi, Elazar, 1967, Slumping on the continental margin southeast of Long Island, New York: Deep Sea Research, v. 14, p. 635-639.

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

U. S. Geological Survey, 1975, Sediments, structural framework, petroleum potential, environmental conditions, and operational considerations of the Mid-Atlantic area: U.S. Geological Survey Open-File Report 75-6, 45 p., 14 figs.

Vail, P. R., Mitchum, R. M., and Thompson, S. III, 1977, Seismic stratigraphy and global changes of sea level, part 4: Global cycles of relative changes in sea level: in Payton, C. E., ed., Seismic stratigraphy -- applications to hydrocarbon exploration: American Association of Petroleum Geologists Memoir 29, p. 83-97.

Veatch, A. C., and Smith, P. A., 1939, Atlantic submarine valleys of the United States and the Congo submarine valleys: Geologic Society of America Special Paper No. 7, 101 p.

Wunsch, C., and Hendry, R., 1972, Array measurements of the bottom boundary layer and the internal wave field on the Continental Slope: Geophysical Fluid Dynamics, v. 4, p. 101-145.