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The Woods Hole Oceanographic Institution - U.S. Geological Survey Program for the Atlantic Continental Margin: Status at end of 1965

K. O. Emery

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REPORTS

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K. O. EMERY

Woods Hole Oceanographic Institution, Woods Hole, Mass.

Introduction

Prior to 1962 studies of the geology of the continental margin of the United States were conducted by three main kinds of organizations, government bureaus, industries, and universities. The only general examination of all continental margins of the country was in the form of soundings by the U.S. COAST AND GEODETIC SURVEY. A few interested staff members contoured soundings and made physiographic interpretations for regions that were of interest to them. Navy research facilities made or contracted for topographic and sediment maps to aid in testing of equipment and techniques needed for naval warfare. Studies limited in scope and area were conducted by the U.S. BUREAU OF COMMERICAL FISHERIES for improvement of the fishing industry, by the U.S. ARMY BEACH EROSION BOARD mostly for gaining information about waves, and by the U.S. GEOLOGICAL SURVEY for certain aspects of sedimentology and for local stratigraphy and geological structure. Very little was done by state agencies.

During the same period, prior to 1962, a great amount of geological and geophysical data was obtained by petroleum companies and their service organizations, particularly off the coasts of Louisiana, Texas, and southern California. Most of the information was considered proprietory - to the extent that the same areas were repeatedly shot over by seismic crews and explored by divers of different companies. Some information, especially generalized structure, was published by members of the oil industry who had the interest or position to do so. Offshore geological research by other industries was relatively insignificant.

University faculty members and graduate students led in the disemination of knowledge about the geology of the continental margin. Budget and time factors, however, required their efforts to be restricted to local areas, but there were many of these areas in accordance with the wide distribution of universities. Scarcity of ship facilities required most of the studies to be near shore. Also, the faculties of most universities that owned or controlled ships preferred to investigate the deep-sea floor, so that information about the continental margin was largely incidental to work at greater depth and distance from shore.

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In September 1962 the first study of the general geology of a large segment of the continental margin was begun as a joint five-year program of the WOODS HOLE OCEANOGRAPHIC INSTITUTION and the U.S. GEOLOGICAL SURVEY (EMERY and SCHLEE, 1963). The chosen area extends from Nova Scotia to the tip of Florida (Figure 1), a coastal distance of 2900 km. The continental shelf (plus the Gulf of Maine) has an area of 420,000 sq km. Adjacent to the continental shelf at the south is the Blake Plateau, at 600 to 1100 metres depth and with an area of 180,000 sq km. The next main unit is the continental slope, an area of 62,000 sq km. Still farther seaward is the continental rise, about 1,030,000 sq km, sloping towards associated abyssal plains. The total area of continental shelf, Blake Plateau, continental slope and continental rise off eastern United States is about 1,730,000 sq km, somewhat more than the area of all states east of the Mississippi-Ohio river system. This area is great in comparison with funds, time, and staff; accordingly, a decision was made to study the entire region in a reconnaissance fashion with progressively greater density of data at shallower depth. This decision was based upon the probable continuity of land geology and shelf geology, the probable greater diversity of shelf geology than of deep-sea geology, and the much lesser cost of shallower work. However, detailed investigation of the shore zone and of estuaries and lagoons were to be avoided, largely because many small laboratories are studying or can study these areas with inexpensive equipment and boats. Their work and ours should supplement rather than duplicate each other.

During 1963, 1964 and 1965 a total of 474 ship days were spent collecting samples and data for the program. Most, 338, of the days were aboard WHOI's R/V Gosnold, a 30-metre converted army freighter. A smaller (13-metre) WHOI ship, R/V Asterias, accounted for 81 days. Additional collections were made aboard WHOI's C-54Q research airplane and submarine Alvin, and on a cooperative basis aboard the Bureau of Commercial Fisheries' R/V Albatross IV, the REYNOLD ALUMINUM COMPANY's submarine Aluminaut, and the offshore drilling ship Caldrill I.

Topography

On the sea floor as on land, one must investigate the topography, sediments, rocks, and structure in order to deduce geological history and possible economic resources. To some extent all four investigations can be concurrent, but an early knowledge of topography aids in the efficient collection of other kinds of information. Fortunately, previous work of the Coast and Geodetic Survey yielded a general knowledge of the topography of most of the region, and its detailed soundings provided a basis for rapid preparation of contour charts. Supplementary soundings came from smooth sheets of the CANADIAN HYDROGRAPHIC SERVICE and the files of the LAMONT GEOLOGICAL OBSERVATORY and WHOI. A set of three colored charts prepared by UCHUPI (1965a) extend from land to the upper part of the continental rise (Figure 1) at a scale of 1:1,000,000 and with contour intervals of 20 and 200 metres. They serve both as base maps for other work and as sources of geological hypotheses to be tested in the field. Another chart by PRATT (in press) covers the entire western North Atlantic Ocean at a scale of 1:3,600,000 at Latitude 35° and contour intervals of 50, 100 and 1000 metres. Detailed maps have also been prepared for particular small areas of interest such as sand waves and heads of submarine canyons.

Sediments

Samples of bottom sediments were desired for the clues that they may yield to shallow underlying rocks, as well as for knowledge of the sediments per se. Sediments off this coast have several origins: detrital (glacial, fluviatile, paludal, eolian, and with varying degrees of marine modification), biogenic and authigenic. Some are relict from previous environmental conditions and some are modern. Knowledge of these sediments and their distribution permits the making of inferences about Pleistocene and Recent geological history and also aids proper interpretation of ancient sedimentary strata on the adjacent land.

Samples were desired at about 18-km (10-nautical mile) spacing on the continental shelf and slope; ones at about three times this spacing were considered sufficient on the Blake Plateau and the deep-sea floor. For a reconnaissance study a single sample for each 300 or 400 sq km seems satisfactory, but a closer spacing (even to a few metres) is required for detailed knowledge of complex areas such as hills in the Gulf of Maine, sand waves, and shore zones; such detailed sampling is left to others or to a later phase of this program.

About 400 samples having approximately the desired spacing had previously been collected by the BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY at Woods Hole for its analyses of the relationship between fisheries and bottom sediments; these were made available to our program. An additional 1485 samples obtained during the past three years (Figure 2) nearly completes the necessary sampling program. About 100 of these were obtained with dredges, and about 600 were taken with a 0.1 sq m Smith-McIntyre grab; the rest were with a large heavy camera-grab. As described by EMERY, MERRILL, and TRUMBULL (1965), the camera-grab can photograph the bottom and then collect as much as 0.2 cu m (0.6 sq m) of bottom materials from the area of the photograph. Such a large sample is desirable in order to obtain a large enough sample of gravelly bottom to

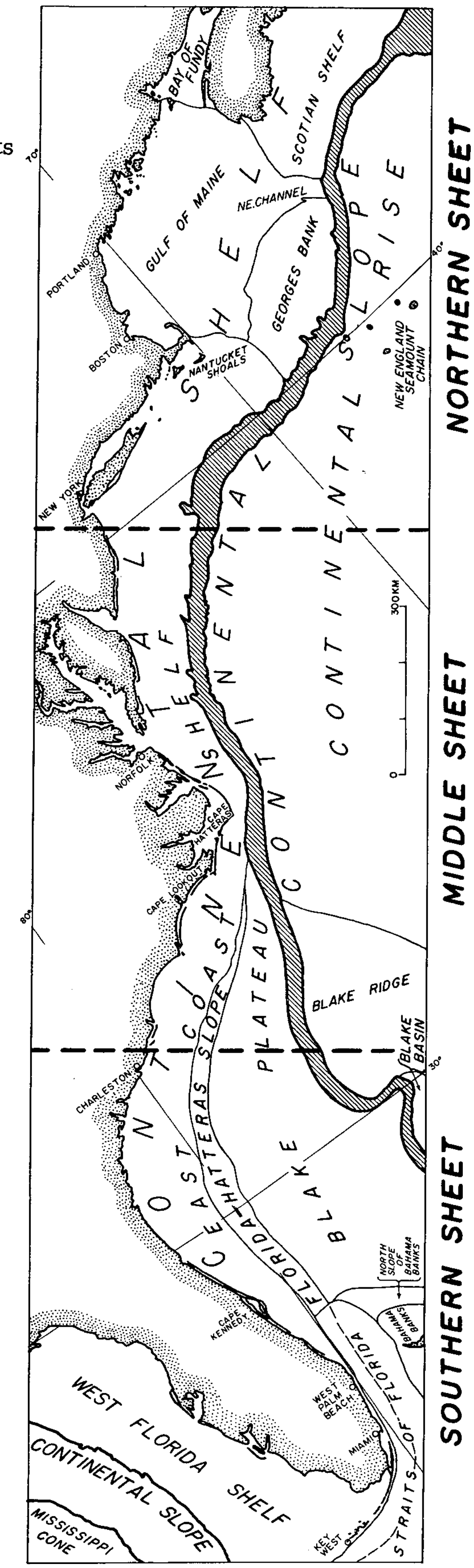

Figure 1. Major topographic features of the Atlantic Continental Shelf, showing areas covered by three map sheets (UCHUPI 1965a).

be statistically significant, and to properly assess the importance of benthic animals in producing and modifying the bottom sediments. Cores have not yet been taken, because they provide little of the third dimension if they are only a few metres long in a region 2900 km long and 350 km wide and where the Pleistocene sediments are commonly several tens of metres thick. Eventually some cores will be obtained for studies of depositional rates and of diagenesis of interstitial waters. Modern techniques of deep-water drilling have supplanted cores for most stratigraphic studies.

Members of the group who are studying sediments are: JOHN SCHLEE, texture; R.M. PRATT, gravel lithology; J.V.A. TRUMBULL, sand fraction; JOBST HÜLSEMAN, carbonate, nitrogen and organic carbon content; J.C. HATHAWAY and P.F. McFARLIN, X-ray mineralogy; D.A. ROSS, optical mineralogy; F.T. MANHEIM, chemical composition; all the preceding being at WHOI. At the USGS in Washington, T.G. GIBSON is studying the foraminifera, and J.E. HAZEL the ostracodes; D.J. STANLEY of DALHOUSIE UNIVERSITY, Halifax, is studying the color. In the BUREAU OF COMMERCIAL FISHERIES, C.SCHELSKE at Beaufort, N.C., is studying gamma activity; the larger benthic organisms separated from the sediments are being cooperatively studied by the Bureau at Woods Hole under the direction of R.L. WIGLEY, and those from the Blake Plateau are being investigated by the SMITHSONIAN SORTING CENTER. Many additional supplementary studies are being conducted by specialists of other organizations. To date, most of the 1000 samples from the northern topographic sheet (Nova Scotia to New York City) have been analyzed in the laboratory and reports are being written for publication.

One interesting aspect of the shelf sediments is the antiquity of the relict material that is iron stained and coarser grained than sediments nearer the shore. It contains shells of the edible shallow-water oyster but now at depths as great as 90 metres; some specimens have been radiocarbon dated at 8,000 to 11,000 years (MERRILL, EMERY and RUBIN, 1965). A similar date was found for a salt-marsh peat now at 59 metres (EMERY, WIGLEY and RUBIN, 1965). Further evidence of inheritance of the sediments from a former dry land bordering shallow water is provided by the presence of at least 20 molars of mammoths and mastodons. A related problem is the question of why the relict sediments have not become buried under a blanket of later sediments. Measurements of transparency and color of the ocean surface indicates the usual much higher concentration of suspended sediments near shore than farther at sea. More precise information is being obtained by G.C. BOND through measurement of total concentration of suspended sediment and its grain-size distribution and general composition in about 500 samples of surface ocean water.

Rocks

Knowledge of the kind and ages of rocks on the continental margin is needed in order to extrapolate the geology of the land to the sea floor. These rocks also provide the data required for an understanding of the pre-Pleistocene geological history of the region.

In general, the continental shelves and slopes of the world contain outcrops of rock similar to those of the adjacent land and completely

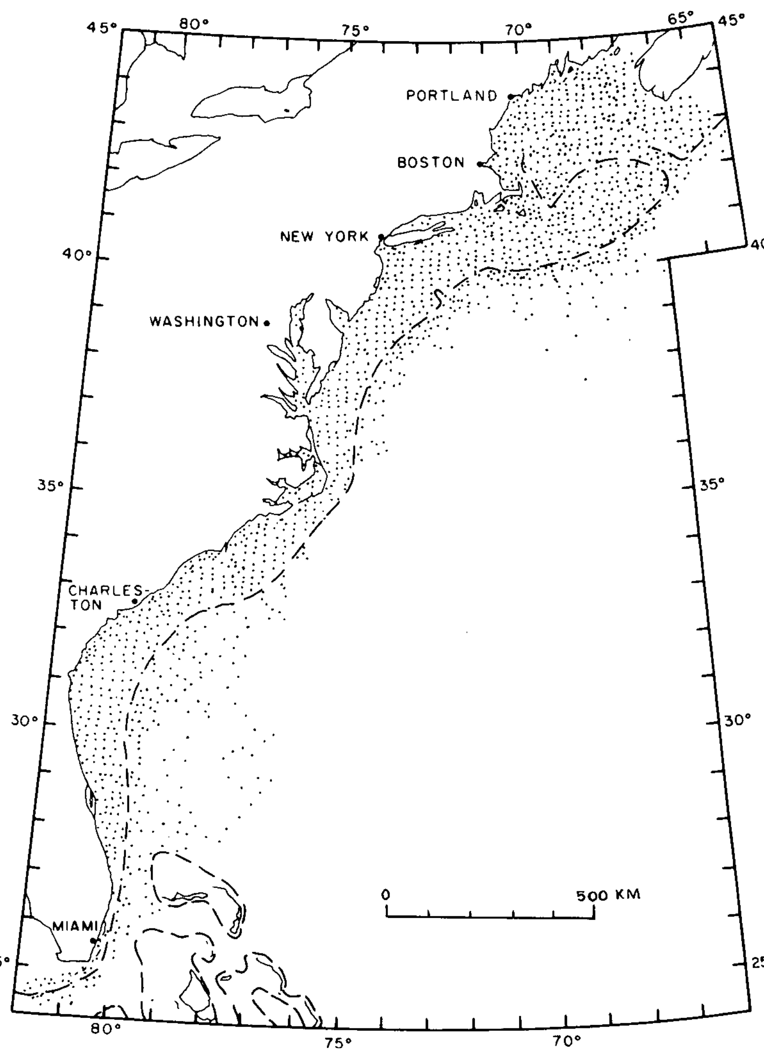

Figure 2. Positions of bottom samples taken up to the end of 1965.

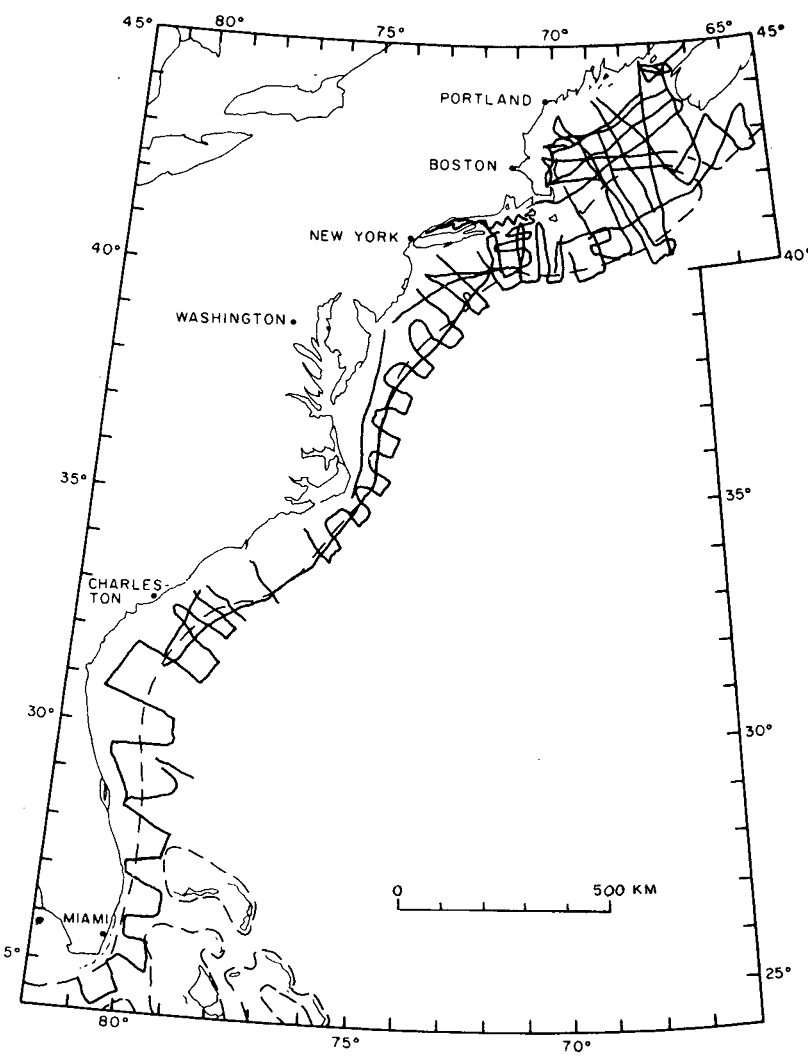

Figure 3. Positions of continuous seismic profiles up to the end of 1965.

different from those of the deep-sea floor. Outcrops on the Atlantic continental shelf and slope are uncommon because of burial beneath Pleistocene and Recent sediments. They are restricted to areas of slopes so steep that later sediments were never deposited or were subsequently eroded away. Outcrops on the shelf are largely restricted to hills in the irregular Gulf of Maine and to the shelf-break. On the continental slope, they are most common at the sides of submarine canyons, although locally they also occur on some of the steeper slopes between canyons.

Rocks have been obtained from about 200 localities through use of dredges and the camera-grab. Additional dredging is planned for the summer of 1966. Most of the rocks from the Gulf of Maine were brought by Pleistocene glaciers from New England and Canada; they are being studied by R.M. Pratt. Those of the shelf-break and the continental slope are from outcrops and drill holes ashore.

A generalized geological map that ignores the mantle of Pleistocene and Recent sediments has been prepared. It shows the presence of Paleozoic, Triassic, Cretaceous and Early Tertiary rocks in the Gulf of Maine. Miocene and Pliocene rocks occur along the entire length of the shelf-break between Nova Scotia and the tip of Florida. Outcrops of Miocene and Oligocene rocks are common atop the Blake Plateau. Where outcrops are present on the continental slope and its submarine canyons, they consist of Early Tertiary to Late Cretaceous rocks. The continental rise has such a thick cover of sediments that rock samples are not available, but one can reasonably speculate that a succession of Pliocene to older strata lie beneath these sediments.

A better method of obtaining rock samples than the dredging of outcrops is provided by drilling. During 1964 an association named JOIDES (Joint Oceanographic Institutions Deep Earth Sampling) program was organized by the directors of WOODS HOLE OCEANOGRAPHIC INSTITUTION, LAMONT GEOLOGICAL OBSERVATORY, UNIVERSITY OF MIAMI and SCRIPPS INSTITUTION OF OCEANOGRAPHY. Its first operation was the drilling of six holes in the continental margin off Florida (BUNCE et al, 1965). These holes penetrated almost the entire Tertiary section on the continental shelf and the Blake Plateau (Figure 4). Benthic foraminifera, mollusks, and calcareous algae showed that the entire sequence on the shelf was deposited in shallow water and that on the Blake Plateau was in deep water. The shelf sediments are dominated by detritus from land, whereas those of the Blake Plateau are chiefly biogenic calcareous debris. These relationships show that the Blake Plateau did not form during the Tertiary, but it dates from an earlier time.

Many analyses are being made of samples from the six holes by the same group that is analyzing the surface sediments, and by others of many different organizations. The success of this venture probably will lead to the drilling of additional holes for geological information off Miami, Cape Hatteras, New York, and Georges Bank possibly during 1968.

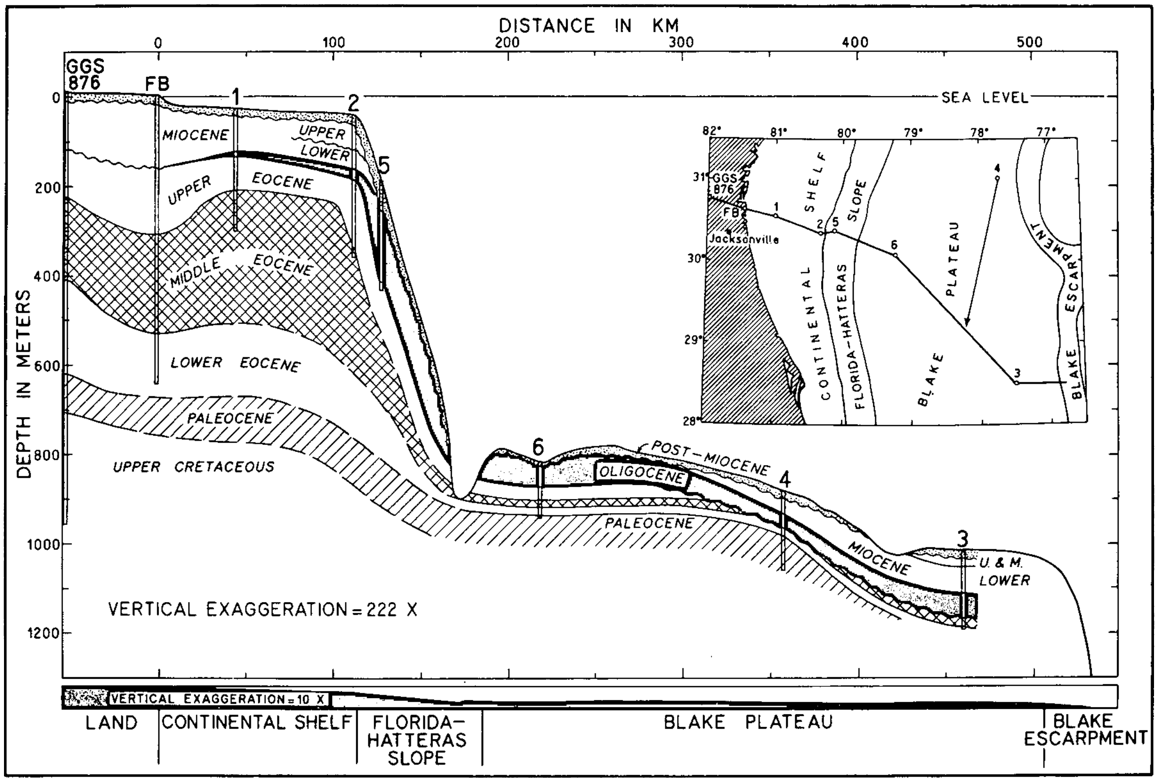

Figure 4. Section through the continental shelf and Blake Plateau as revealed by the JOIDES drill holes.

Structure

The deep structure of the continental margin holds the evidence for the origin of this feature and it has been investigated by MAURICE EWING, CHARLES DRAKE and their associates at Lamont Geological Observatory, and by BRACKETT HERSEY and his associates at WHOI using deep seismic refraction, magnetics, and gravity measurements. The present program is more concerned with the structure of the top few hundred to one thousand metres - the thickness of the Pleistocene, Tertiary, and the top of the Cretaceous strata. Investigations of this zone have been accomplished by use of a 10,500-joule sparker, a modification by R.K. PAUL of others in use at WHOI and elsewhere. About 16,000 km of continuous seismic reflection profiles have been run with this device (Figure 3) and about 400 km are planned for 1966.

Records of the continuous seismic profiles are being analyzed by ELAZAR UCHUPI, A.R. TAGG and K.O. EMERY. Several small studies in the region of the Gulf of Maine have been completed: basins of the Gulf (UCHUPI, 1965b), Georges Bank (EMERY and UCHUPI, 1965), Northeast Channel (UCHUPI, in press), and the Triassic Trough (TAGG and UCHUPI, in press).

The results of these studies have been compiled and supplemented in a general summary of the entire Gulf of Maine by UCHUPI (in press). Also, a compilation of 45 profiles across the shelf-break and down the continental slope between Nova Scotia and the tip of Florida was prepared by UCHUPI and EMERY (in press).

The seismic profiles, supported by inferences from dredgings and the section from the JOIDES drill holes, show that the Pleistocene is commonly several tens of metres thick and the Tertiary several hundreds of metres thick. Both are generally flat-lying across the continental shelf, and they steepen at the continental slope. Among most of the continental slope the Tertiary bedding is parallel to or slightly less steep than the face of the continental slope itself. Locally, the Tertiary beds continue into the continental rise, but in many places its seaward continuation is buried beneath a thick wedge of later sediments. At no place do the continuous seismic profile records clearly depict a fault at the continental slope. Yet the continental slope is broadly curved, as expected of a fault origin, and it separates basement rocks and structures having different characteristics on either side. Accordingly, we must suppose that the tectonic activity that probably produced the original continental slope and probably also the Blake Plateau ceased during the Cretaceous. Subsequent deposition on the continental slope has caused a progradation of 5 to 10 km during the Tertiary. An even greater progradation of at least 35 km has occurred for the gentle slope that separates the continental shelf from the Blake Plateau.

Economic Resources

The sea floor off the Atlantic coast contains several potential economic resources (EMERY, 1965b). Chief of these is petroleum, which may be found in each of several areas of complex structure indicated by Figure 5. Altogether about $1,700 million of petroleum (one-sixth of the total production in the United States) presently comes from offshore Louisiana, Texas, and California each year. None is yet produced from the Atlantic shelf, although several petroleum companies are conducting geophysical investigations. Company interest reached the stage of exploratory drilling during 1965 off Newfoundland.

A somewhat related resource is fresh water, aside from direct distillation of sea water. The JOIDES test hole closest (45 km) to shore off Florida encountered an aquifer having a pressure head of 10 metres (JOIDES - BUNCE, et al, 1965), and subsequent analyses by Manheim have shown potable interstitial water throughout most of the 277-metre section that was represented by samples. Probably many such reservoirs of fresh water exist beneath the continental shelf ready to be tapped, if recovery of the water is considered economic; this probability is promoted by the presence of several known offshore springs along the southern coast. Even at Cape Cod measurements of inflow into a small estuary by Emery suggest that the average leakage of near-surface ground water amounts to 2000 cu m/day along a 1-km section of shore. One of the major efforts of the program is the compilation of an atlas of runoff from segments of the coast by R.H. MEADE in collaboration with other members of the WATER RESOURCES DIVISION of the USGS and of other organizations. When completed, this atlas may provide the information needed for better utilization of surface water and ground water along the entire coast.

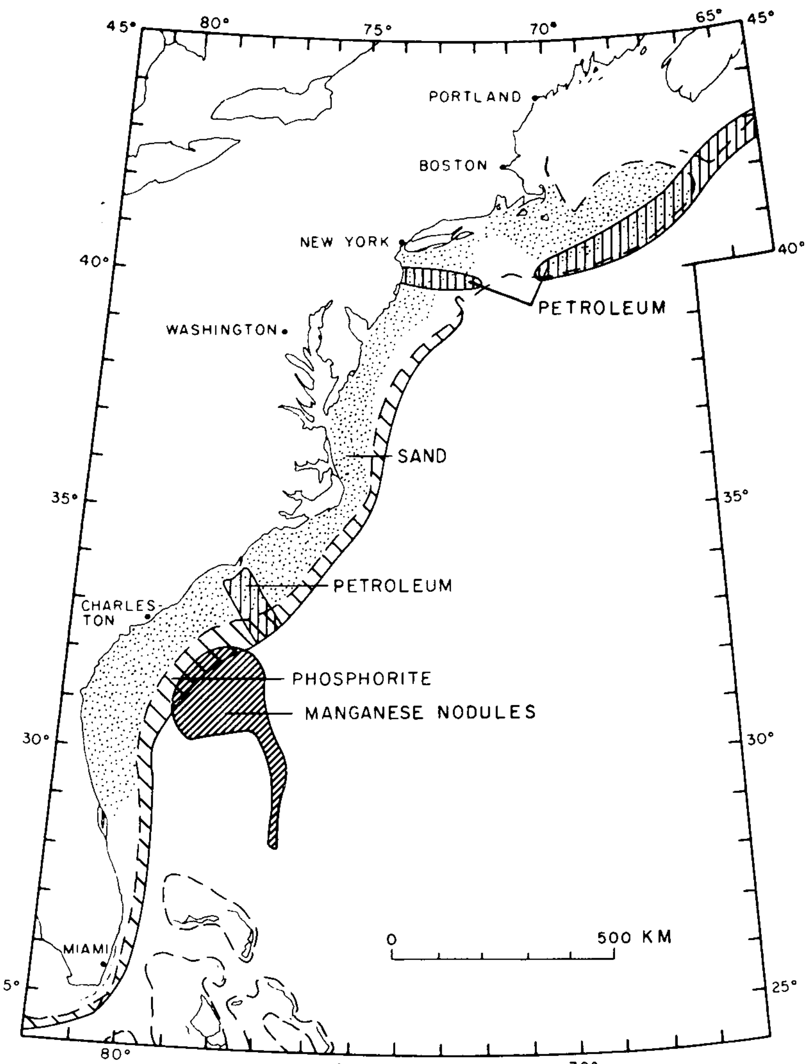

Figure 5. Most favorable areas for some potential economic resources.

The third most favorable economic resource appears to be sand and gravel, particularly that of the relict sediment that covers most of the continental shelf (Figure 5). Increasing demands for sand and gravel for widening of beaches and for engineering construction purposes appears to be outpacing the development of new supplies. Easy access and cheap barge transportation from source to destination may support an offshore sand and gravel industry (SCHLEE, 1964).

Two other resources are among those that are most frequently mentioned in semi-popular literature on the ocean. One is phosphorite, which is known to occur at or near outcrops of Miocene strata along much of the shelf-break (Figure 5). The cost of transportation of phosphorite from extensive mines on shore in Florida and neighboring states and even larger reserves in the Idaho-Wyoming region generally is the major part of its total cost to the user. At present the value of phosphorite from these areas is about $140 million per year. The second related resource is manganese oxide in the form of nodules that are abundant on part of the Blake Plateau (MANHEIM, 1965; PRATT and McFARLIN, in press). However, the total value of manganese of comparable low concentration that was mined in the United States during 1961 was only $1.5 million (EMERY, 1965b). It seems evident that no great fortune is likely to be made from an unsubsidized offshore mining operation for manganese, or for its associated small concentrations of copper and nickel.

Conclusions

The field work for the WHOI-USGS study during the first five-year portion of the investigation of the continental margin off the Atlantic coast has largely been completed. The chief remaining job is to complete the laboratory analyses of the results and to prepare the material for publication. The results of an integrated study of topography, sediments, rocks, and structure (with associated studies of biology and water) of a large segment of the continental margin are far greater than could be expected for unrelated and unintegrated studies during the same period. Similar programs may be developed for other continental margins of the United States, such as the Gulf of Mexico and the Pacific. They may also be initiated in other countries, as indicated by the development of a somewhat similar program for the continental margin off the Atlantic coast of Canada by the BEDFORD INSTITUTE OF OCEANOGRAPHY and DALHOUSIE UNIVERSITY.

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