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GEOLOGICAL SURVEY CIRCULAR 870

U.S. Geological Survey Program of Offshore Resource and Geoenvironmental Studies, Atlantic–Gulf of Mexico Region, from September 1, 1976, to December 31, 1978

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By David W. Folger and Sally W. Needell

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By David W. Folger and Sally W. Needell

ABSTRACT

Mineral and energy resources of the continental margins of the United States are important to the Nation's commodity independence and to its balance of payments. These resources are being studied along the continental margins of the Atlantic Ocean and the Gulf of Mexico in keeping with the mission of the U.S. Geological Survey "to survey the geologic structures, mineral resources, and products of the national domain." (Organic Act of 1879).

An essential corollary to these resource studies is the study of potential geologic hazards that may be associated with offshore resource exploration and exploitation. In cooperation with the U.S. Bureau of Land Management, the Geological Survey, through its Atlantic-Gulf of Mexico Marine Geology Program, carries out extensive research to evaluate hazards from sediment mobility, shallow gas, and slumping and to acquire information on the distribution and concentration of trace metals and biogenic and petroleum-derived hydrocarbons in sea-floor sediments. All these studies are providing needed background information, including information on pollutant dispersal, on the nearshore, estuarine, and lacustrine areas that may be near pipeline and nuclear powerplant sites. Users of these data include the Congress, many Federal agencies, the coastal States, private industry, academia, and the concerned public.

The results of the regional structural, stratigraphic, and resource studies carried out under the Atlantic-Gulf of Mexico Marine Geology Program have been used by the Geological Survey and the Bureau of Land Management to select areas for future leasing and to aid in the evaluation of tracts nominated for leasing.

Resource studies have concentrated mostly on the Atlantic Outer Continental Shelf frontier areas. Geologic detailing of five major basins along the U.S. Atlantic margin, where sediments are as much as 14 km thick, have been revealed by 25,000 km of 24-and 48-channel common-depth-point seismic data, 187,000 km of aeromagnetic data, and 39,000 km of gravity data, plus 10,000 samples and logs obtained from U.S. Geological Survey and industry drilling (for example, coreholes of the Atlantic Slope Program, Joint Oceanographic Institutions Deep Earth Sampling, Continental Offshore Stratigraphic Tests, and the Atlantic Margin Coring Program). A sedimentary section of Jurassic and Cretaceous age grades from terrigenous clastic rocks nearshore to carbonate rocks offshore; this section is part of an extensive buried bank-platform complex that could contain large reserves of natural gas and oil.

The volume of sediment deposited offshore far exceeds the volume deposited onshore where extensive accumulations of oil, gas, and minerals have been found. Commercial exploratory drilling offshore thus far has been limited to the Baltimore Canyon Trough area off New Jersey, where at least two holes have found gas; leasing has taken place in the Southeast Georgia Embayment, where drilling was scheduled to begin in 1979, and is imminent in the Georges Bank area off New England.

In addition, hydrogeologic and hydrochemical data obtained from the drilling studies have delineated freshwater-bearing submarine extensions of land aquifers that are important coastal ground-water resources.

Hazards in the Georges Bank area include sand mobility associated with strong currents and storm-driven waves; high concentrations of suspended sediment in the water column that, when mixed with spilled oil, may sink to the bottom; and slumping along the upper slope. In the Baltimore Canyon, high sediment mobility accompanies major winter storms, and slumped material may cover as much as 20 percent of the upper slope. Potentially unstable slope areas are being studied in great detail to provide data on timing, triggering mechanisms, and rates of sediment movement. In the Southeast Georgia Embayment and Blake Plateau Basin, strong Gulf Stream flow poses a major problem to all offshore operations.

In the Gulf of Mexico, studies of Holocene stratigraphy and structure, trace-metal distribution, and recent faulting have provided important data to environmental studies being conducted on the South Texas Outer Continental Shelf and the upper Continental Slope. Concentrated studies of geologic hazards in the Mississippi Delta area by a U.S. Geological Survey-Louisiana State University-Texas A&M University cooperative group have shown wide areas of unstable sea floor, even though slopes are commonly less than 1°. This instability arises in areas marked by high sedimentation rates, fine-textured materials, and abundant biogenic gas; it has resulted in widespread failure of structures and pipelines in the area. USGS studies are documenting the rates, character, and causes of movement.

Scientific results of these studies conducted in 1977 and 1978 have been published as abstracts, articles in professional journals, and U.S. Geological Survey Professional Papers, Bulletins, Circulars, Miscellaneous Field Studies Maps and Open-File Reports.

During the next 5 years, emphasis will shift from resource and environmental surveys of the Atlantic and Gulf of Mexico Continental Shelves to similar studies of the Continental Slope and Rise. Nearshore research probably will increase also through the 1980's.

INTRODUCTION

Of major importance in the fight against inflation is the development of natural resources in the United States and the concomitant reduction of our dependence on foreign markets. New offshore sources of hydrocarbons, uranium, thorium, manganese, titanium, and sand and gravel for construction will help to reestablish our commodity independence, strengthen the dollar, and reduce unemployment. An essential corollary to exploration for and exploitation of our continental margin frontier areas is the proper evaluation of associated environmental hazards and early application of appropriate measures to reduce them.

The U.S. Geological Survey is studying the U.S. continental margins in keeping with its mission "to survey the geologic structures, mineral resources, and products of the national domain." (Organic Act of 1879). These studies provide information required to carry out responsibilities delegated to the USGS for the management of exploration for and development of mineral and energy resources beneath the Nation's Continental Shelves and adjacent Continental Slopes.

Extensive offshore resource and geoenvironmental studies and topical investigations along the Atlantic and Gulf of Mexico coasts are conducted under the Atlantic-Gulf of Mexico Marine Geology Program of the USGS (fig. 1). This report describes the scope and goals of these studies, relates the studies to activities associated with other Geological Survey functions and Federal Programs, and records selected accomplishments of the 2 years from September 1, 1976, to December 31, 1978. It partly replaces and updates USGS Open-File Report 77-320 (Behrendt, 1977), which provided comparable data on activities of the Atlantic-Gulf of Mexico Marine Geology Program before 1977.

RESOURCE EXPLOITATION ON THE U.S. ATLANTIC AND GULF OF MEXICO CONTINENTAL MARGINS

The amount of oil produced from United States wells exceeded the amount of oil discovered domestically each year from 1945 to 1977, except 1948, 1949, and 1968 (Moody, 1978). The cumulative reduction in our reserves by 1977 was about 37 billion barrels. We are using up domestic oil found before 1945 and are dependent, to a larger and larger extent, on imported oil. One effect on the entire economy of the resulting trade deficit has been serious inflation. Potentially productive offshore area almost equals productive onshore area in the United States, but 90 percent of the onshore area is leased and only 2 percent of the offshore area is leased. Obviously, we need to exploit the frontier offshore areas where large reserves of oil and gas may exist.

The production values of minerals and energy resources extracted from the U.S. Outer Continental Shelves have risen every year since 1947 when oil was first discovered 20 km off the coast of Louisiana; the resources produced in 1978 were worth more than $7 billion. The bulk of these resources has continued to come from the shelf off the Gulf of Mexico coast where an increasing proportion of the Nation's oil and gas is being pumped from deposits that lie below the sea floor. The recovery of oil and gas, as well as salt and sulfur, from this area has given us high hopes of finding resources elsewhere on the Continental Shelves of the United States.

Two of the first ten holes drilled in the Baltimore Canyon Trough off the Middle Atlantic States by January 1979 have significant shows of hydrocarbon (fig. 2). Because the normal success ratio is 1:19 for exploratory offshore holes in unproven areas (Tucker, 1978), the results are encouraging for the entire Atlantic margin. However, no commercial production has been established as yet.

Mineral-resource development on the Continental Shelves, like that on land, has occasionally been marred by accidents that resulted in loss of life and property and contamination of the environment. Many of these accidents had natural causes, such as foundation failures due to unstable subsurface sediments, high waves, and strong currents. Prior to extensive development of the frontier areas, potential natural hazards must be assessed properly to minimize the loss of natural resources and to protect the environment. An increasing population density along the Atlantic and Gulf of Mexico coasts, active fisheries, and diverse recreational activities mandate that the "Federal government must assume responsibility for the minimization or elimination of any conflict associated with such exploitation" (43 U.S. Code 1804).

PURPOSE

The purpose of this report is to describe our resource- and environmental-assessment programs (those that are mainly associated with oil and gas ex-

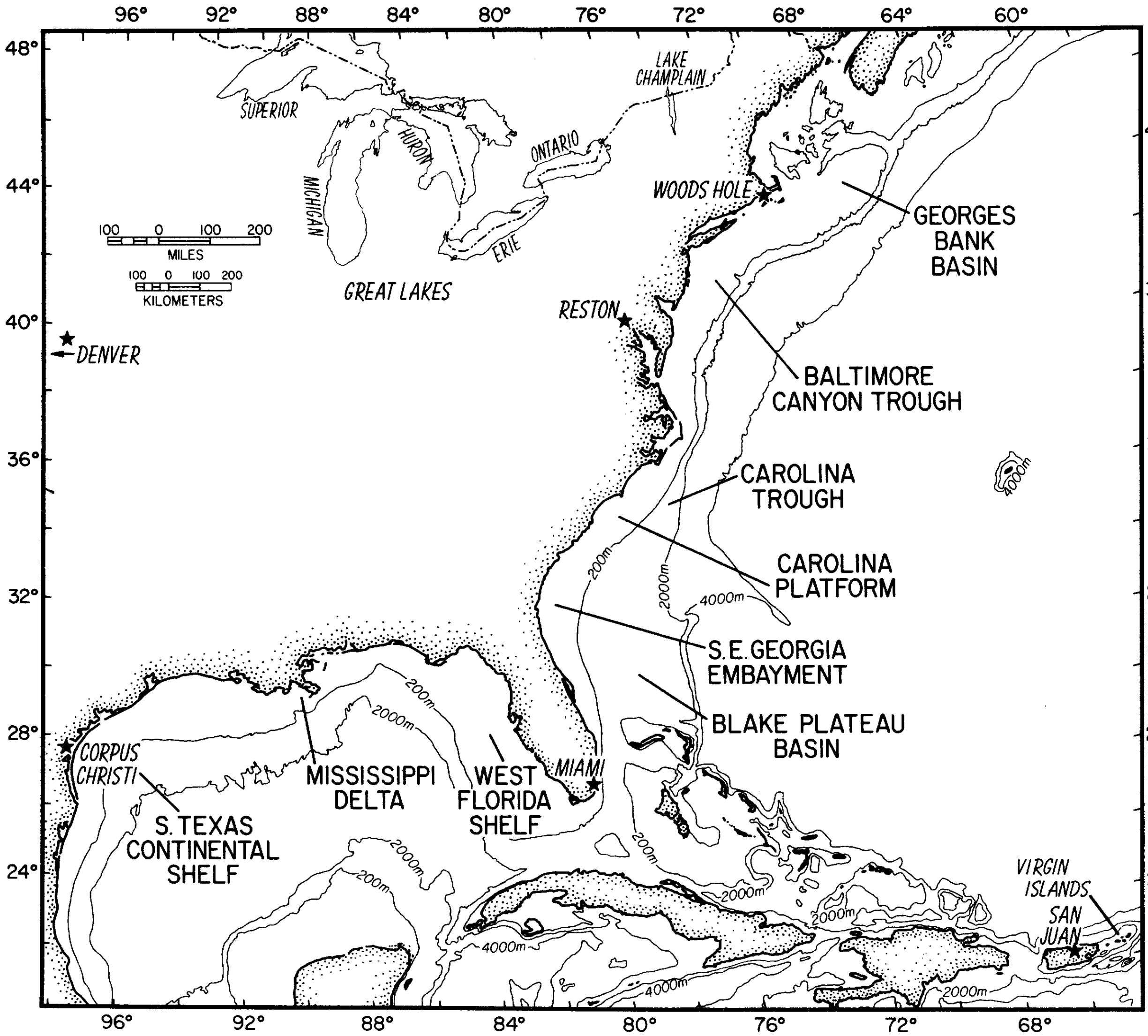


FIGURE 1.—Locations of program personnel (starred locations) and principal offshore operating areas of the Atlantic-Gulf of Mexico Marine Geology Program.

ploration and development) and our basic research in marine geology. All this work is essential to determine the processes responsible for the accumulation of mineral reserves and the potential natural hazards associated with their recovery. Thus, this document is intended to provide Government agencies, Congress, State agencies, private industry, academia, and the concerned public with a clear outline of our activities and their relation to other programs. For example, as part of the USGS Geologic Division, we work closely with the USGS Conservation Division in the selection and withdrawal of lease tracts; with the U.S. Bureau of Land Management on environmental geologic hazards; with the U.S. Department of Energy on improving equipment; with such States as Texas, Georgia, and Massachusetts, with the Commonwealth of Puerto Rico, and with the U.S. Virgin Islands on estuarine and inner shelf research; with industry to devise new methods and techniques; and with many university and college groups performing research in the earth sciences.

HISTORY

The U.S. Geological Survey began marine geology studies of the Atlantic continental margin during

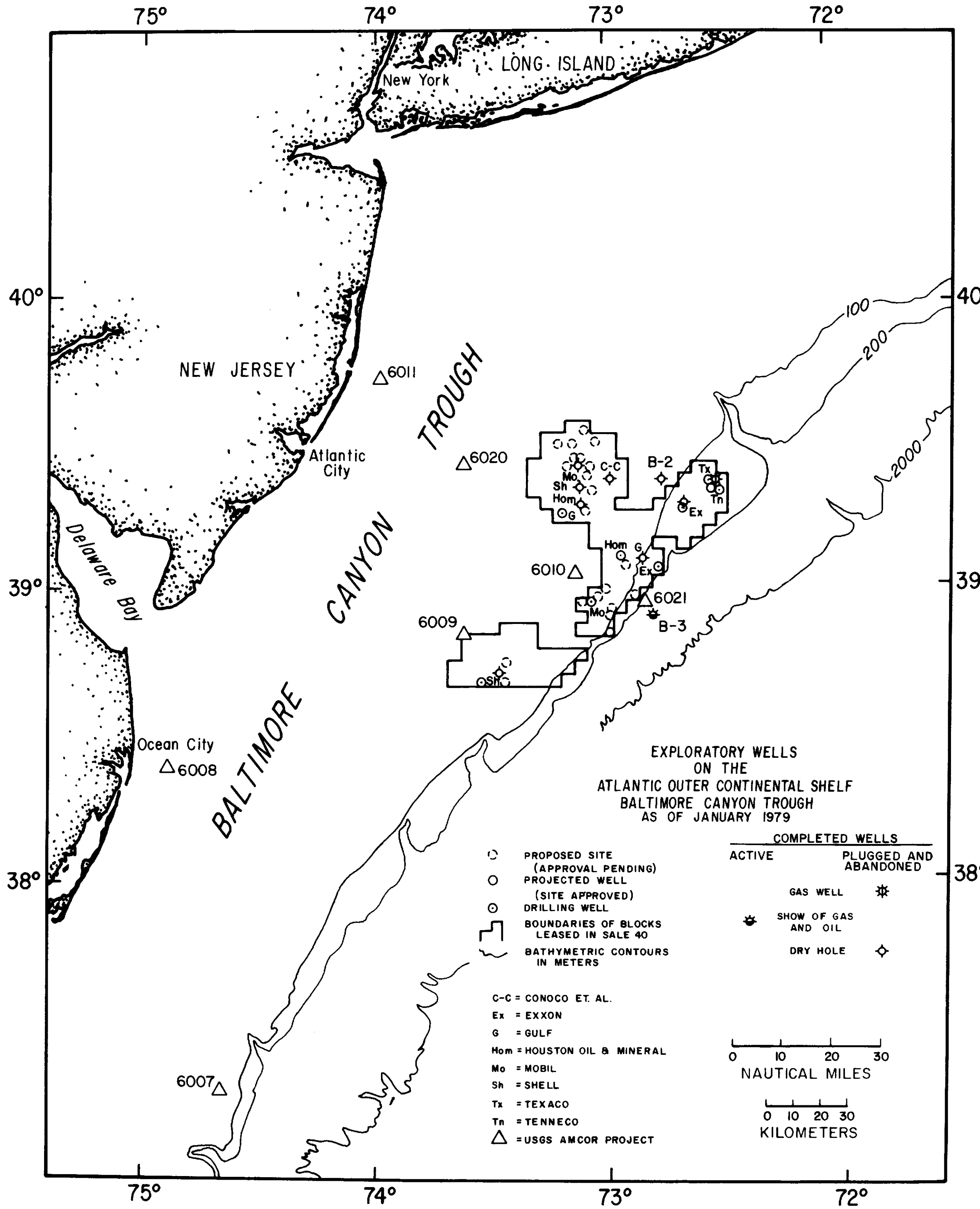


FIGURE 2.—Locations of exploratory wells on the U.S. Atlantic Outer Continental Shelf, Baltimore Canyon Trough area. AMCOR, U.S. Atlantic Margin Coring Program; B-2, B-3, Continental Offshore Stratigraphic Tests.

1962 and of the Gulf of Mexico margin during 1967. These regional studies encompassed bathymetry, physical and chemical characteristics of surficial sediments, high-resolution and single-channel geophysical data, and some biology. The early work was accomplished off the Atlantic and Gulf coasts in close cooperation with the Woods Hole Oceanographic Institution under the leadership of K. O. Emery. Such cooperation was endorsed subsequently by a Commission of the House of Representatives in January 1969 in House Document No. 91–42 entitled "Our Nation and the Sea", which notes (p. 29): "In recent years Federal marine-oriented laboratories have been located near universities with strong marine programs. In fact, this is a statutory requirement of the Federal Water Pollution Control Administration. Active cooperation between the university and Federal laboratory usually has resulted in the benefit of both. Such location and cooperation, of course, should be encouraged further." This effort at Woods Hole was noted in the annual report of the President to the Congress on Marine Resources and Engineering Development (U.S. National Council on Marine Resources and Engineering Development, 1970, p. 71): "The Geological Survey began concerted offshore mapping in 1962 by sponsoring a cooperative program with Woods Hole Oceanographic Institution on the Atlantic continental margin."

In 1973, the 10 USGS research scientists at Woods Hole and the 8 at Corpus Christi were combined with 4 others from Washington, D.C., to form the Branch of Atlantic-Gulf of Mexico Geology. As the necessity for energy-resource assessment and environmental-hazard studies became clearer, this program was expanded substantially so that, at the present time, it includes almost 200 people in Woods Hole, Mass.; Corpus Christi, Texas; Reston, Va.; San Juan, Puerto Rico; and Denver, Colo. They include representatives from other branches of the USGS (such as Regional Geophysics, Oil and Gas Resources, and Paleontology and Stratigraphy) who contribute to the program.

ACKNOWLEDGMENTS

The material used to compile this report was written by many people within the USGS and by some outside sources. Only the outside sources have been referenced within the text. Other material was taken, some of it verbatim, from reports, papers, and abstracts that are included in the bibliography (p. 58) and thus is representative of most aspects of the program activity.

FUNDING, COOPERATIVE PROGRAMS, AND USERS OF MARINE GEOLOGY PROGRAM PRODUCTS

COOPERATIVE PROGRAMS AND FUNDING

Principal funding to carry out program objectives for FY 78 (fiscal year 1978) and FY 79 came from four sources: the Geologic Division, USGS (56 percent); the U.S. Bureau of Land Management (BLM) (33 percent); the Conservation Divison, USGS (7 percent); and the U.S. Department of Energy (3 percent). The U.S. Bureau of Mines, the Water Resources Divison of the USGS, the Department of Natural Resources of the Commonwealth of Puerto Rico, and the Department of Public Works of the Commonwealth of Massachusetts have contributed or will contribute about 1 percent of the annual budget as matching funds for USGS input to cooperative programs (fig. 3). In addition, other Federal agencies such as the U.S. National Oceanic and Atmospheric Administration (NOAA) and the Nuclear Regulatory Commission have provided funding, data input, or vessel support.

Cooperation with other program elements in the USGS extends to several areas. The Earthquake Hazards Program provides direct support for studies of coastal or lacustrine areas adjacent to powerplant sites; personnel from the Branch of Paleontology and Stratigraphy extend regional stratigraphic correlations offshore as more data are gathered by drilling; and the Oil and Gas Resources Program processes some offshore seismic data and uses Marine Geology Program data to estimate resources.

Interaction involving varying levels and kinds of support for State and private universities is extensive (fig. 3). Cooperation with industrial groups, aside from those contracted for services, mainly involves platform stability.

RELATION OF PROGRAMS TO FEDERAL INITIATIVES

The U.S. Geological Survey has a statutory responsibility to classify the public lands and to examine the geological structures, mineral resources, and products of the National domain (43 U.S. Code 31(a)) and in areas outside the National domain that are "determined by the Secretary [of the Interior] to

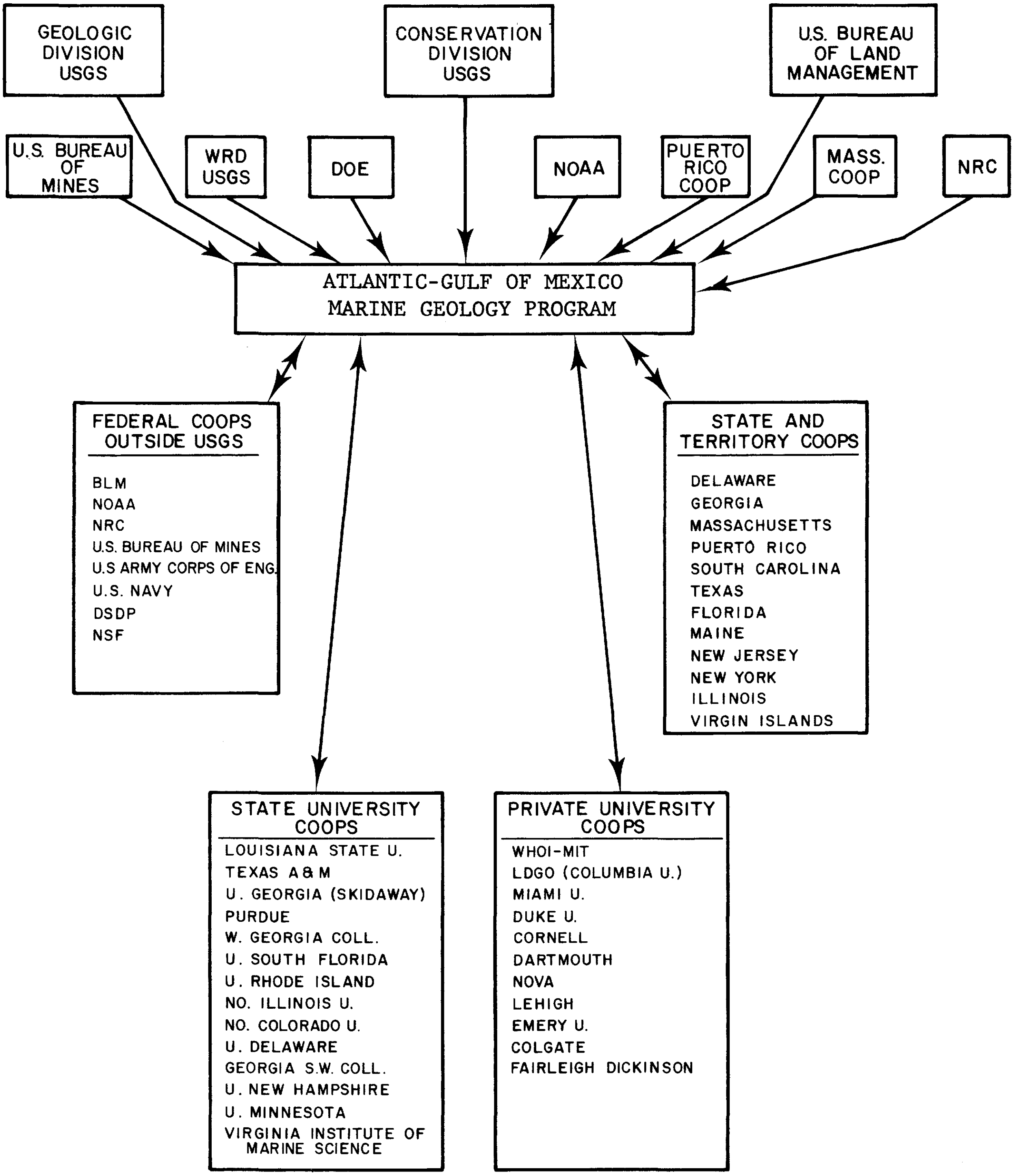


FIGURE 3.—Funding sources (above) and cooperators (below) of the Atlantic-Gulf of Mexico Marine Geology Program during fiscal years 1978 and 1979. BLM, U.S. Bureau of Land Management; COOP, Cooperative Program; DOE, U.S. Department of Energy; DSDP, Deep Sea Drilling Project; LDGO, Lamont-Doherty Geological Observatory; MASS. COOP, Massachusetts Cooperative Program; NOAA, U.S. National Oceanic and Atmospheric Administration; NRC, U.S. Nuclear Regulatory Commission; NSF, National Science Foundation; WHOI-MIT, Woods Hole Oceanographic Institution-Massachusetts Institute of Technology; and WRD, Water Resources Division of USGS.

be in the national interest" (43 U.S. Code 31(b)). Specific Geological Survey responsibilities for the Outer Continental Shelf are described in documents such as the Memorandum of Understanding among the USGS, BLM, and NOAA (May 19, 1975). This Memorandum describes USGS responsibilities as follows: "1) to obtain a fundamental knowledge of regional marine geologic conditions and the processes involved in the formation of hydrocarbon deposits in order to increase capability for resource production and evaluation; 2) to identify potential areas for mineral exploration and development; and 3) to provide geologic information on resource(s) . . . that is needed by Federal, State, local and private planners, managers, and others."

For environmental programs, the Outer Continental Shelf Hazards Act of 1953 and subsequent amendments (for example, that of 1968 (43 U.S. Code 1804) charged the Secretary of the Interior with responsibility for leasing and regulating the exploration and development of the submerged lands of the Continental Shelf seaward of lands belonging to the coastal States. The National Environmental Policy Act of 1969 requires analysis of the potential effects of every proposed Federal project that alters the quality of the human environment.

USER GROUPS

Data produced under the Atlantic-Gulf of Mexico Marine Geology Program are used by a broad spectrum of the Federal, State, academic, and industrial communities. Many users are involved directly in the program either through input of funding or participation in program planning and execution (fig. 3). The USGS Conservation Division and the U.S. Bureau of Land Management use these data to select lease areas and to prepare environmental impact statements. Federal cooperator-users include the Department of Energy, which is funding part of our instrument research, and the National Oceanic and Atmospheric Administration, which is supporting construction and deployment of ocean-bottom seismometer systems and which has participated in sediment-stability studies of the Mississippi Delta. In FY 79, the Water Resources Division of the USGS will continue to fund some seismic surveys and sediment collection in the Potomac River estuary, and the U.S. Bureau of Mines will be funding research on seismic systems capable of analyzing geologic hazards to mines below bodies of water.

Input from other program elements of the Geological Survey includes support from the Earthquake Hazards Analysis Program for assessment of earthquake hazards in coastal areas and lakes, support from the Oil and Gas Resources Program for research on geopressured reservoirs, support from the Regional Geophysics Program for tectonic studies, and manpower support from the Branch of Paleontology and Stratigraphy for study of problems in offshore stratigraphy. The U.S. Nuclear Regulatory Commission has provided funding for earthquake-hazards research; the U.S. Army Corps of Engineers has funded surveys to locate disposal sites for dredge spoil; and the National Science Foundation (NSF) allows the USGS to use NSF-sponsored University National Oceanographic Laboratory System (UNOLS) vessels.

In addition to those mentioned, other States cooperate in the program. Delaware provides data for geophysical studies; Georgia was involved in coastal plain resource studies; Florida and South Carolina provide well data; Maine has participated in estuarine and nearshore research; New York has participated in Lake Ontario and Lake George studies; and Illinois and Minnesota are involved in Great Lakes studies.

Industrial cooperatives have centered mainly around problems of rig and pipeline stability. Both oil-producing companies and the petroleum industry service companies have shown great interest in USGS studies, particularly those being carried out in the Gulf of Mexico, where rigs are numerous and where stability problems are severe.

State universities such as Louisiana State University and Texas A&M University have provided an enormous amount of research on the design and deployment of instruments to monitor changes in sediment stability and on the study of Gulf Coast sedimentation in general. The University of Georgia (Skidaway Institute) and University of South Carolina have carried out extensive surveys of hardgrounds and geologic hazards in the Southeastern Georgia Embayment. Georgia College, Georgia Southwestern College, and Emory University have produced maps summarizing the petroleum potential of the Georgia coastal plain.

The University of South Florida has participated in surveys of suspended matter and bottom sediment in the Southeast Georgia Embayment and Baltimore Canyon Trough areas. The University of Texas at Galveston has collected CDP (common-depth-point) seismic data for use in regional gulf tectonic synthesis, and the University of Texas at Austin has been a major cooperator on Gulf Coast nearshore and estuarine studies. University of Rhode Island (URI) students carry out various aspects of our program; equipment is often shared with URI, and in FY 79, URI will provide significant ship and personnel support.

Northern Illinois University has aided us in the interpretation of our CDP seismic data. University of Northern Colorado personnel have led submersible cruises, interpreted seismic records, and synthesized environmental data. University of Delaware personnel have interpreted seismic records and collaborated with our geophysicists on studies of continental margin evolution. Cooperative gravity studies have been carried out with the University of New Hampshire, and seismic data will be collected jointly in FY 79.

Corpus Christi State University is the host for our Corpus Christi office. The Woods Hole Oceanographic Institution (WHOI) is host for the Woods Hole office and also provides extensive computer, technological, shop, ship, and other support services. Many scientists at WHOI also work on joint projects with USGS scientists.

Among other private academic institutions, Lamont-Doherty Geological Observatory of Columbia University will be involved with the USGS in a joint study of deep-sea stratigraphy. Recently, the University of Miami has provided most of our ship support for acquisition of geophysical data. Duke University has been involved in environmental studies off the Southeastern and Middle Atlantic States. Cornell and Lehigh Universities have provided valuable geotechnical advice for activities concerned with sediment instability. Nova University has carried out virtually all the current-meter preparation for our 10 bottom tripods used for studies of bottom-sediment dynamics. Colgate University faculty and students have provided assistance in a variety of resource and environmental studies. Similarly, personnel from the West Indies Laboratory of Fairleigh Dickinson University have provided support for, and have participated in, several studies off St. Croix Island.

PROGRAM ACTIVITIES

OVERVIEW

Research activities being conducted under the Atlantic-Gulf of Mexico Marine Geology Program are studies related to offshore oil and gas, environmental investigations, and studies in marine geology. Within that framework, the objectives of the offshore geologic surveys are:

(1) To provide publicly available oil- and gas-resource data in support of the U.S. Department of Interior's oil and gas leasing program on the Outer Continental Shelf (OCS).

(2) To determine areas that have significant petroleum potential for future OCS sales.

(3) To provide resource data and analysis to the Federal government, coastal States, and the concerned public for long-term planning and for international boundary determinations, and for Law of the Sea negotiations.

(4) To conduct environmentally related geologic research that will characterize regionally the nature of offshore hazards and provide information necessary for the safe exploration and development of oil and gas resources on the Atlantic and Gulf of Mexico OCS.

(5) To evaluate subsea hydrogeology, with special reference to coastal ground-water supplies.

(6) To locate and study deposits of sand, gravel, phosphorite, and other minerals on the Continental Shelves and in the deep ocean basins.

(7) To conduct geologic research on coastal, estuarine, and lacustrine processes in support of all USGS stratigraphic investigations and State coastal zone activities.

Regional resource studies of the Atlantic margin have been underway since 1973. From 1976 to 1978, the data collected have been of sufficient quantity and quality to produce an integrated synthesis of margin geology and evolution that has no parallel in the public sector. The broad resource implications of these studies include (1) the delineation of four major sedimentary basins and the discovery of a fifth, (2) the location of what appears to be a shelf-edge paleoreef complex, which could contain petroleum, along much of the Atlantic margin, (3) the locus of probable salt-piercement structures that elsewhere in the world are associated commonly with petroleum accumulation, and (4) the outline of structural features near the present shelf edge similar to those where oil and gas shows have been common in other areas. Further work is designed to study areas within the basins where structural and stratigraphic relations are complex, but where oil and gas potential may be high.

Synthesis of the regional structure in the entire Gulf of Mexico has been underway for several years and will serve as the basis for future data collection. New resource studies on the west Florida shelf and slope are outgrowths of this work. To date, petroleum exploration in this area has been neither extensive nor successful.

Environmental studies in areas where leasing has taken place (Baltimore Canyon Trough and Southeast Georgia Embayment) or is about to take place (Georges Bank Basin) have been pursued vigorously on the Atlantic margin since 1975 (fig. 1). These studies have focused on surficial sediment dynamics, composition and chemistry of surficial sediment, geotechnical sediment characteristics, petrogenic and biogenic gas content of subbottom sediments, heavy $C_{15}+$ hydrocarbon geochemistry, shallow stratigraphy, and faulting, all of which relate to the safe operation of marine facilities used in the exploration and development of natural gas and liquid hydrocarbon reserves. Present emphasis now is shifting to the Continental Slope, where sediment stability may be a major potential geologic hazard.

Since 1974, Gulf Coast environmental studies have been keyed to management of the extensive hydrocarbon resources on the Continental Shelf. The two main study areas have been the South Texas Outer Continental Shelf (where topics of study include the geochemistry of the sediments, the nature and movement of suspended sediments, and shallow stratigraphy and structure) and the Mississippi Delta area (where topics of investigation include submarine landslides, the role of biogenic methane in sediment instability, storm waves as triggers for sediment failure, and the internal characteristics of weak, unstable subbottom sediments in areas of rapid deposition). Many environmental problems associated with petroleum and natural-gas development can be studied in the delta area, where production is extensive and where rigs, pipelines, and platforms are abundant.

In addition, a major reconnaissance survey of geologic hazards on the Gulf of Mexico upper Continental Slope north of lat 26° N. and between water depths of 100 and 1,000 m was completed. During this study, more than 25,000 km of high-resolution seismic data were gathered.

Analyses of pore water in cores recovered during the Atlantic Margin Coring Program revealed that fresh to brackish waters are common beneath much of the Continental Shelf. The results of this regional survey will guide future, more detailed studies of offshore freshwater resources.

Studies of offshore aggregate reserves will be increasingly important as land deposits are exhausted and (or) covered by housing developments. Cooperative studies of offshore sand and gravel are underway presently in Massachusetts, Puerto Rico, and the Virgin Islands. Other studies of hard minerals (phosphates, manganese, uranium, and thorium) in the area off Florida and elsewhere in the United States' exclusive economic zone are ready to be initiated when funding is available.

Studies of estuarine, inner shelf, and lake environments will be expanded during the next few years in response to growing pressure for multiple use of these areas. Present studies address earthquake hazards and powerplant siting, mining hazards, pipeline routes, and pollutant distribution.

In summary, Atlantic resource studies are now reaching the stage of regional synthesis based on extensive grids of CDP seismic, gravity, and magnetic data and data from many drill holes. No further contract 48-channel seismic data collection is contemplated for the next year or two. However, a cooperative 24-channel seismic survey by the Bundesanstalt für Geowissenschaften and Rohstoffe (Geological Survey of the Federal Republic of Germany) will help to fill in the existing grid. New in-house 12-channel work will focus on detailed structure and stratigraphic problems that relate to potential resource areas, and an excellent synthesis of the drilled stratigraphy has been conducted by members of the USGS at Woods Hole. Resource studies in the Gulf will focus on the west Florida shelf and slope where production is yet to be established.

For environmental studies in the Gulf of Mexico, the focus of regional studies will shift from the South Texas Shelf to the middle and northern gulf. Mississippi Delta studies will continue, but more emphasis will be placed now on in situ gas studies; data will be collected by a pressure core barrel and a geophysically instrumented sediment probe. In the Atlantic, sediment-mobility studies on the shelf will continue off the entire U.S. coast during FY 79, and then emphasis probably will shift to the Continental Slope, where additional information is needed to evaluate the effects of storms, currents, and internal waves as potential causes of sediment mass movement. On both the Atlantic and Gulf Continental Slopes, new emphasis will be placed on the nature of slumps and on the mechanisms that cause them.

PROGRAM PRODUCTS

Research results are reported in a variety of publications. Publication form depends upon the nature of the research, the urgency of the need for it, and the audience for which it is intended. These results range in sophistication from raw data deposited with NOAA's Environmental Data Service (EDS) to USGS Professional Papers and equivalent publications in outside professional journals. Thirty days after a ship returns, cruise reports are submitted to EDS in a Report of Observations/Samples Collected by Oceanographic Programs form. After some cruises, sample-inventory reports are submitted as a followup Second Level Inventory Report. Geophysical data are normally submitted as a Marine Geophysical Data Inventory to the National Geophysical and Solar-Terrestrial Data Center of EDS after 1 year, and sample data are submitted as available. Thus, information becomes available for public use as soon as it is processed to the point of being manageable.

Specific reports about lease areas are required by mutual agreement between the USGS Geologic Division (GD) and the USGS Conservation Division (CD). The Branch of Atlantic-Gulf of Mexico Geology selects areas having the potential to produce petroleum and recommends them to the CD and BLM. Prior to a Call for Lease Nominations, GD and CD prepare a short summary of the geologic, resource, and environmental characteristics of the area. Subsequently, an extensive summary of all the available data in the area is prepared for use in the draft environmental impact statement issued by the BLM. Following lease-tract selections, members of the CD and GD meet to assess the environmental hazards in the area and to withdraw or place stipulations on hazardous tracts.

Reports are presented in a variety of USGS formats. The simplest is the USGS Open-File Report, which receives a minimum of editing and is designed mainly to get information before the public quickly. Other USGS publications, in order of increasing sophistication, include Miscellaneous Field Studies Maps, Circulars, Bulletins and Professional Papers. All are used extensively, but those requiring less time for publication are more appropriate avenues for information on leasing and environmental hazards that must be available for Federal and State decisionmaking.

Publication in professional journals is the route preferred by most program scientists because there the work receives wide exposure to the scientific community. During 1977 and 1978, more than 125 journal articles were published as a result of this program.

Participation in national and regional professional society meetings serves as one of the most rapid methods to disseminate findings. Program scientists have convened, chaired, and participated in many symposia concerned with resource, environmental, and marine geologic problems on the Atlantic and Gulf of Mexico margins. Many abstracts were published during 1977–78 for these meetings and symposia.

SUMMARY OF PROGRAM RESULTS IN FISCAL YEARS 1977 AND 1978

RESOURCE ASSESSMENT

ATLANTIC

For the entire Atlantic margin, the integration of magnetic and multichannel seismic-reflection data shows that basin and platform locations in the North American and African margins were influenced strongly by the initial rifting patterns in the Early Jurassic, which are evident in depth-to-magnetic-basement maps as small initial offsets (about 10–30 km); these offsets are propagated as fracture zones in the adjacent oceanic crust. The outer edges of the deep, sediment-filled basins such as the Georges Bank Basin, the Baltimore Canyon Trough, and the Carolina Trough are marked by a magnetic basement high along the East Coast Magnetic Anomaly (ECMA) (fig. 4). The area of this anomaly is evident on seismic profiles as a region of carbonate bank or reefal buildup and is the location of most of the diapirs found south of the Gulf of Maine.

Data from the U.S. Geological Survey's 1974–76 digital, high-sensitivity aeromagnetic survey were used to study the ECMA. This anomaly marks the seaward edge of the deep, sediment-filled basins that parallel the continental margin and the landward edge of oceanic crust (fig. 4). The Jurassic magnetic quiet zone seaward of the ECMA is interpreted to be underlain by oceanic crust because of the character of the 10- to 50-nT (nanotesla) linear magnetic anomalies and the acoustic character of the seismic basement. Depths to magnetic basement calculated by the Werner deconvolution method suggest that a ridge or dike complex underlies the ECMA at a depth ranging from 6 to 8 km and that it extends more or less continuously from the Georges Bank area south to the Blake Spur fracture zone off Charleston, S.C. Source of the ECMA appears to be the combination of shortwave-length anomalies caused by this basement ridge and an edge effect due to the contrast of the oceanic crust seaward of the ECMA with flat-lying adjacent nonmagnetic sedimentary rocks (as

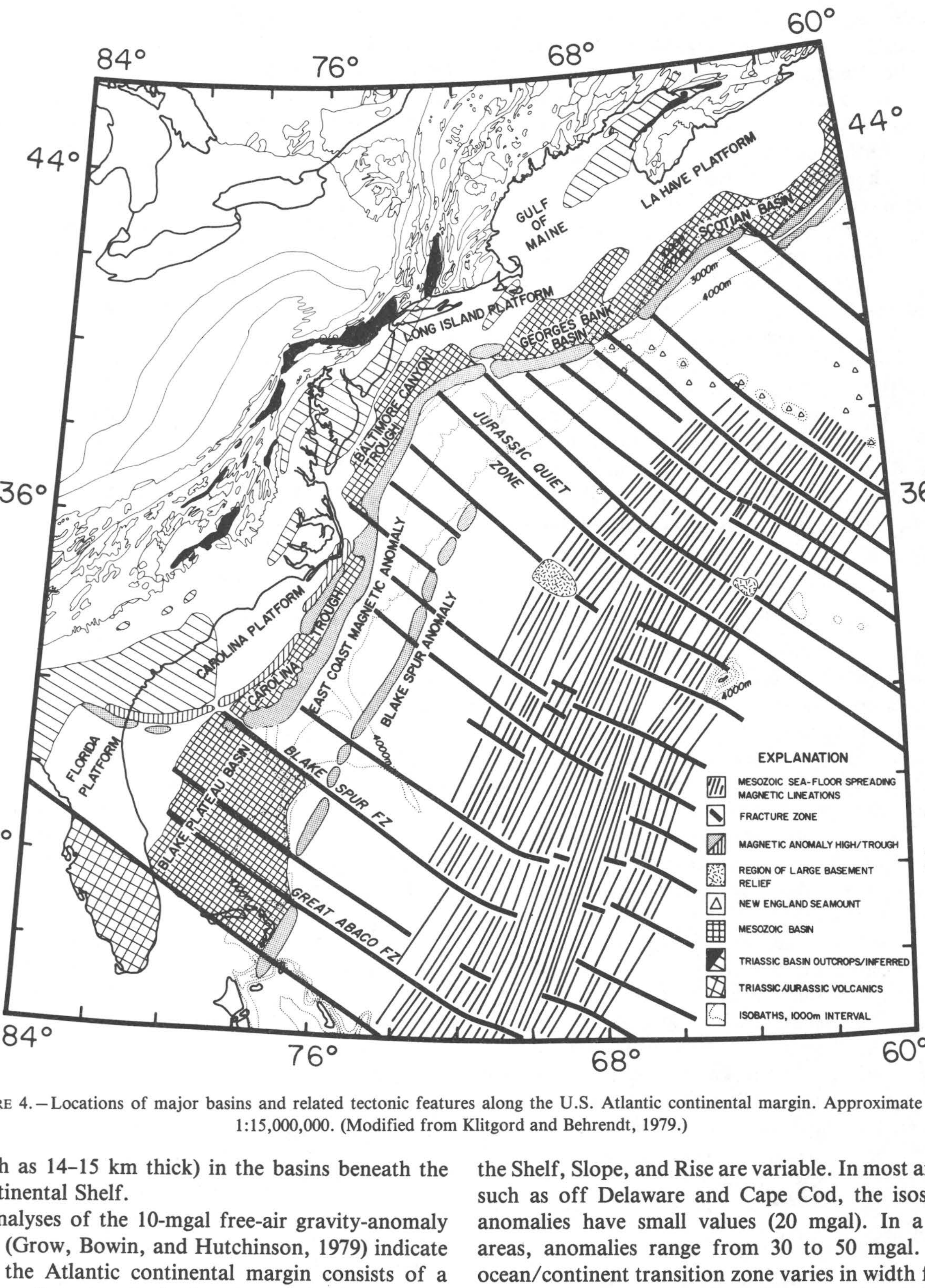


FIGURE 4.—Locations of major basins and related tectonic features along the U.S. Atlantic continental margin. Approximate scale 1:15,000,000. (Modified from Klitgord and Behrendt, 1979.)

much as 14–15 km thick) in the basins beneath the Continental Shelf.

Analyses of the 10-mgal free-air gravity-anomaly map (Grow, Bowin, and Hutchinson, 1979) indicate that the Atlantic continental margin consists of a series of regional platforms and basins. Major sedimentary basins contain 10 to 14 km of sediments and are characterized by regional free-air gravity lows of −10 to −20 mgal. Isostatic anomalies across the Shelf, Slope, and Rise are variable. In most areas, such as off Delaware and Cape Cod, the isostatic anomalies have small values (20 mgal). In a few areas, anomalies range from 30 to 50 mgal. The ocean/continent transition zone varies in width from 80 km off Cape Cod to about 200 km off the Middle Atlantic States.

In 1976, the Atlantic Margin Coring (AMCOR) Program was completed. During this program, boreholes penetrated to depths of as much as 310 m at 19 sites along the Continental Shelf and Slope (fig. 5*A*). The drilling program delineated rocks from Pleistocene to Late Cretaceous age, encompassing phosphoritic Miocene strata, widespread Eocene carbonate beds that account for strong seismic-reflection horizons, and several regional unconformities. Two sites off Maryland and New Jersey showed light-hydrocarbon gases having a molecular composition and stable isotope ratios in the range of those of mature petroleum (fig. 5*B*). Pore-fluid studies showed that relatively fresh to brackish waters are present beneath much of the Atlantic Continental Shelf (fig. 5*C*). However, off Georgia and the Florida-Hatteras Slope, high salinity of pore waters suggests buried evaporitic strata. Analyses of engineering properties of sediment cores demonstrated that sediments range from those having good foundation strength to those having potential for severe loss of strength under cyclic loading conditions.

North Atlantic (Georges Bank Basin)

In the Georges Bank Basin, 5,000 km of 48-channel CDP seismic data were collected during 1977 and 1978 (fig. 6). Interpretation of these data delineated four major stratigraphic units: (1) a probable terrigenous clastic evaporite volcanic sequence (Triassic to Lower Jurassic) associated with deeply buried fault blocks, (2) a carbonate platform and reef sequence that formed during Jurassic time along the ancestral shelf/slope break, (3) a marine/nonmarine sequence built over the carbonate rocks as the shelf prograded seaward during Cretaceous time, and (4) a moderately thick prism of sediments of Tertiary and younger age that formed the Continental Rise. Much of the present Continental Slope is an erosional surface cut into lower Tertiary and Upper Cretaceous strata during Tertiary marine regressions as sediment moved downslope to build the Rise. The total section is approximately 8 to 10 km thick and is composed mostly of Jurassic sedimentary rock; Cretaceous rocks are less than one-fourth as thick as those of the Jurassic and Triassic sequence (fig. 7). Potential hydrocarbon traps are most likely to be on drape structures above deeply buried fault blocks, diapirs, and buried reef structures.

Middle Atlantic (Baltimore Canyon Trough)

Analyses of approximately 9,600 km of multichannel seismic-reflection data collected over the Continental Shelf, Slope, and Rise between Cape Hatteras and Long Island reveal that the history of rifting and subsidence during the Mesozoic in this area is similar to the Mesozoic history of the North Atlantic. Three thousand kilometers of data collected in 1978 are being analyzed now (fig. 6). These data are being tied to the stratigraphy penetrated in COST (Continental Offshore Stratigraphic Test) B-2 and COST B-3 wells (fig. 2), and the sonic logs run in these holes are being used for better velocity control. The data reveal several large, deeply buried fault blocks and broad arches in addition to a Jurassic and Cretaceous shelf-edge carbonate(?) complex that extends 20 km seaward of the present shelf edge to the present Continental Slope. Total sediment section under the Continental Shelf exceeds 14 km in the deepest part of the basin and is composed predominantly of Jurassic nonmarine, evaporitic, and carbonate sedimentary rocks. Under the Slope, the depth to basement exceeds 12 km, and some structures identified in seismic data may be hydrocarbon traps (fig. 8). The recent discovery of gas in the COST B-3 well is good evidence for this conclusion. The middle Cretaceous black shales beneath the Continental Rise may be source beds for Atlantic margin oil and gas reserves.

Analyses of cores, well cuttings, and electric logs in the COST B-2 well reveal potential reservoir sands having porosities as high as 40 percent in the section between 1,000 m and 4,300 m. Organic geochemistry studies reveal that several Cretaceous units are possible source beds for natural gas because of their high (as high as 12 percent) organic carbon content that is due to coaly kerogen types. However, the organic matter is not yet thermally mature, though natural gas is forming. Original estimates of an 85 percent marginal probability that liquid petroleum and natural gas in commercially recoverable quantities will be found have not as yet been substantiated. However, significant occurrences of gas have been found under both the outer shelf and upper slope.

South Atlantic (Southeast Georgia Embayment)

Nine thousand kilometers of 48-channel CDP seismic data (fig. 6), gravity data, and magnetic data reveal that the continental margin off the Southeastern United States consists of the Carolina Trough, a narrow basin containing 10 to 11 km of Jurassic to Holocene sedimentary rocks (fig. 9), and a large broad basin to the south (Blake Plateau Basin) containing as much as 14 km of post-Triassic sedimentary rocks (fig. 10). The basin center is beneath the inner Blake Plateau. The continental margin in this area began to form during the Triassic as rifting of the continental crust began.

In the Early Jurassic (185 m.y. (million years) to 175 m.y. ago), intrusions and extrusions of mafic material extensively mixed with continentally derived sediments to form new transitional basement beneath the Blake Plateau; marine waters flooded the subsiding zone, and reefs began to form on fault-block highs. About 175 m.y. ago, reorganization of plate movement resulted in a 200-km eastward jump of the spreading center, closer to the African continent. About 140 m.y. ago, a reef began to develop at the location of the Blake Escarpment; the reef grew upward for 5 km before dying out in the Early Cretaceous. A broad carbonate platform behind this reef, and, after it died, another reef formed 70 km west of the initial one. The second reef died at the end of Early Cretaceous time. During Late Cretaceous and Paleocene time, quiet-water deposition of chalk and terrigenous mud characteristic of slope depths covered the plateau and Outer Continental Shelf. In post-Paleocene time, sediments were extensively eroded because the Gulf Stream began to flow across the inner Blake Plateau. The present Continental Shelf has been constructed largely through sedimentary outbuilding; its seaward edge reflects the interplay of sedimentation coupled with periodic erosion by the Gulf Stream.

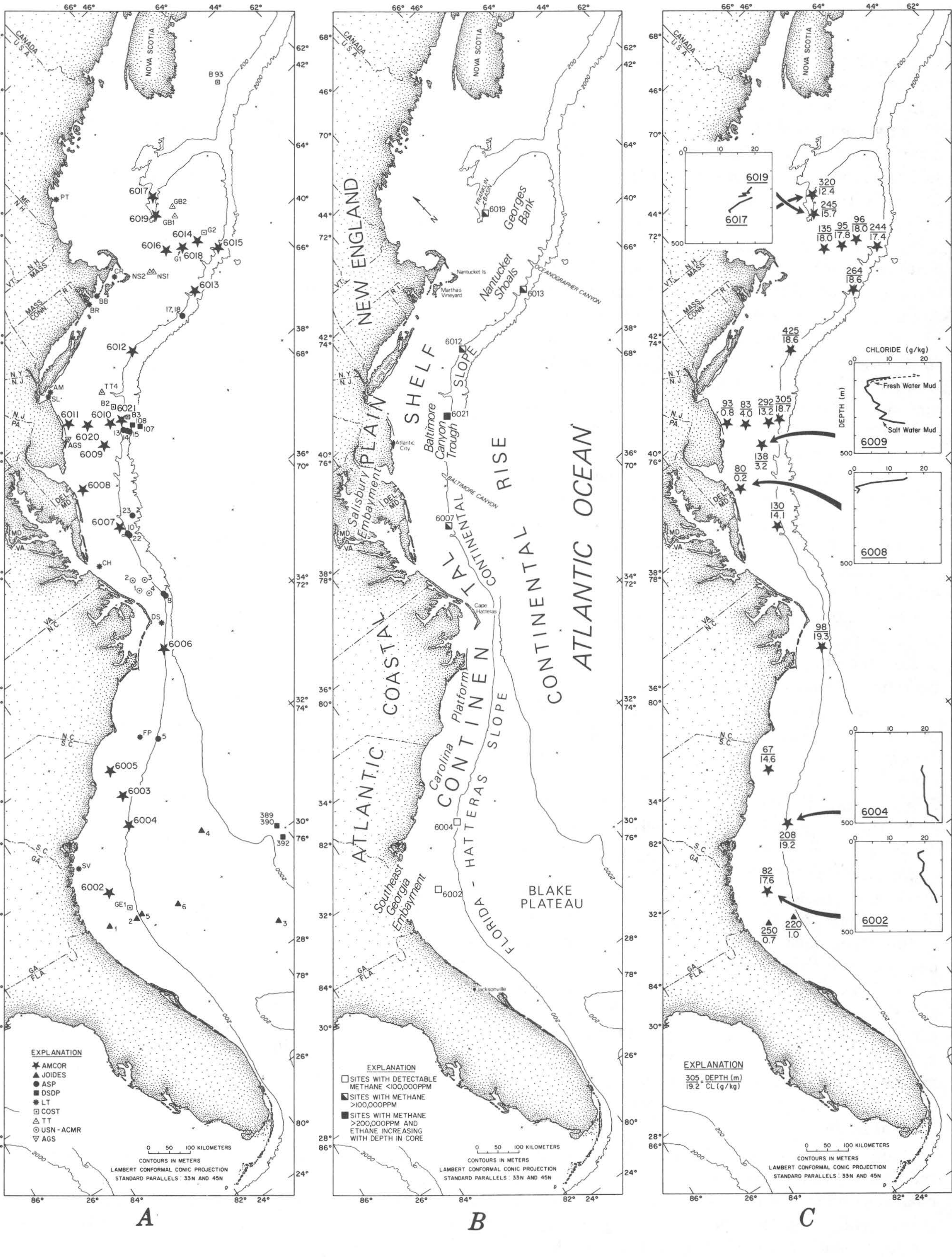
Data from thermal measurements, color alteration of kerogen, temperature of maximum pyrolysis yield, carbon-preference index, and primary vitrinite reflectance from the COST GE-1 well in the Southeast Georgia Embayment (see fig. 6) indicate that source-rock organic material is thermally immature at depths less than 3,000 m as far as liquid gaseous hydrocarbon generation is concerned. Below this depth, the sedimentary rocks are largely nonmarine to nearshore, and, although they are thermally mature, they must be viewed as having little or no potential as petroleum source rocks because of their low organic carbon content. Sandstone and limestone reservoirs having good porosity and permeability are present in the section between 1,700 m and 3,000 m. If these sandstones interfinger with mature marine shales seaward, excellent potential for oil and gas accumulation may exist in the Blake Plateau Basin.

Unpublished data of T. M. Chowns (1976) show that the subsurface of the Georgia coastal plain is characterized by five terranes: (1) a medium- to high-grade metamorphic terrane representing the subsurface continuation of the Piedmont Province that extends 10 to 12 km southeast of the Fall Line, (2) a red-bed association intruded by numerous dolerites inferred to be of Triassic age and occupying a complex graben beneath the Apalachicola Embayment, (3) a group of fossiliferous Lower Ordovician to Upper Devonian sandstones and shales that form the nucleus of the peninsular arch of Florida and extend into the southern part of Georgia, (4) a lower Paleozoic felsic volcanic terrane and associated granite plutons that underlie the Suwanee Saddle and Southeast Georgia Embayment and appear to correlate with similar rocks on the south side of the peninsular arch and in the Apalachicola Embayment, and (5) an area of very mafic crust causing high-amplitude gravity and magnetic anomalies in a zone extending along the northeastern margin of the Triassic red beds in South Carolina.

GULF OF MEXICO

A tectonic map of the Gulf of Mexico is being prepared by members of the USGS; the map will portray the structure and geologic framework of the Continental Slope of the northern Gulf of Mexico. The slope is the seaward face of the petroleum-rich Gulf Coast Continental Shelf and includes all the steeply sloping floor from the shelf edge (at 200 m below sea level) to the Abyssal Plain (at 3,200 m). Structural grain and topography of the slope are controlled primarily by salt movement; virtually the entire province is underlain by salt stocks and pillowlike swells. Areas between salt domes commonly contain as much as 3.5 km of sediment, most of which is muddy slump deposits containing a few sandy turbidite zones. Despite the apparently low incidence of turbidite sands, those of reservoir quality are probably present in intraslope basins, especially in Pleistocene strata that accumulated when shorelines and sediment sources were close to the present shelf edge. Prospects in the upper slope province include strata of Pliocene and Pleistocene age in the area seaward of the Mississippi Delta and strata of mainly Pleistocene age elsewhere. Potential reservoirs are expected in regressive wedges of neritic sand; in turbidite accumulations; along the shelf-edge, where they may be bounded by growth faults; and on the flanks of salt structures.

New resource data acquired in 1977–78 to be used in compiling the regional tectonic map of the gulf included 7,600 km of multichannel CDP-processed seismic data recorded in the north-central and eastern Gulf of Mexico (fig. 11). These data were procured


NOVA SCOTIA
CANADA
U.S.A.
6017
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6016
6018
6015
G1
G2
B 93
NS2
NS1
6013
17,18
6012
TT4
AM
SL
B2
B3
6021
108
107
6011
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EXPLANATION
AMCOR
JOIDES
ASP
DSDP
LT
COST
TT
USN - ACMR
AGS
0 50 100 KILOMETERS
CONTOURS IN METERS
LAMBERT CONFORMAL CONIC PROJECTION
STANDARD PARALLELS : 33N AND 45N
NEW ENGLAND
Georges Bank
Nantucket Shoals
OCEANOGRAPHER CANYON
Nantucket Is
Marthas Vineyard
6019
6013
6012
SLOPE
SHELF
PLAIN
6021
Baltimore Canyon Trough
Atlantic City
Salisbury Embayment
BALTIMORE CANYON
RISE
ATLANTIC OCEAN
CONTINENTAL
6007
COASTAL
Cape Hatteras
CONTINENTAL
Carolina Platform
ATLANTIC
6004
HATTERAS
SLOPE
FLORIDA
Southeast Georgia Embayment
6002
BLAKE PLATEAU
Jacksonville
EXPLANATION
SITES WITH DETECTABLE METHANE <100,000PPM
SITES WITH METHANE >100,000PPM
SITES WITH METHANE >200,000PPM AND ETHANE INCREASING WITH DEPTH IN CORE
6019
6017
320/12.4
245/15.7
135/18.0
95/17.8
96/18.0
244/17.4
264/18.6
425/18.6
CHLORIDE (g/kg)
DEPTH (m)
Fresh Water Mud
Salt Water Mud
6009
93/0.8
83/4.0
292/13.2
305/18.7
138/3.2
80/0.2
6008
130/14.1
98/19.3
67/14.6
6004
208/19.2
82/17.6
6002
250/0.7
220/1.0
EXPLANATION
305/19.2 = DEPTH (m)/CL (g/kg)

A *B* *C*

from the University of Texas Marine Science Institute at Galveston.

ENVIRONMENTAL ASSESSMENT

ATLANTIC

Environmental assessment studies of the Atlantic continental margin have concentrated largely on sediment mobility and stability characteristics. The emphasis of these studies has been slightly different in each of the three main lease areas (fig. 12) because of differences in the relative magnitude of various hazards. For example, instrumented tripods (fig. 13) have revealed that, in the Georges Bank region of the Continental Shelf, high tidal currents and, to a lesser extent, major storms are responsible for most of the vigorous circulation that redistributes sediment either in the water column or as large mobile sand waves. In the Baltimore Canyon Trough on the shelf, storms are responsible for most sediment movement. On the upper Continental Slope, slumping may be a major potential hazard in some lease tracts. Insufficient data concerning the geometry, mechanisms, and timing of slumps resulted in the withdrawal of 27 lease tracts from Lease Sale 49. In the Southeast Georgia Embayment, the strong currents associated with the Gulf Stream constitute a hazard to the many operational activities associated with exploration and development and to bottom stability; bottom scour has been well documented. The ubiquitous distribution of hardgrounds, which are typically populated by concentrations of benthic organisms and fish, constitutes a further limit on the location of drilling and development activities.

North Atlantic (Georges Bank Basin)

Research cruises to the Georges Bank areas have included studies ranging from studies of suspended-matter distribution to single-channel seismic surveys. Figures 14*A*, *B*, and *C* show tracklines along which data were collected in 1977–79, and table 1 summarizes the kinds of data collected by scientists on USGS cruises in the Atlantic and Gulf of Mexico in 1976–78.

Concentrations of particulate matter in the waters of the Georges Bank area are typically between 0.05 and 1.0 mg/L. However, concentrations as high as 15 mg/L were measured south of Nantucket during a winter storm. Such high levels are significant because they exceed the estimated levels of suspended-matter concentration (3–5 mg/L) necessary to cause crude oil to sink to the bottom. Current measurements and preliminary carbon-14 and lead-210 data from the cores collected south of Martha's Vineyard (fig. 14*C*) suggest that fine-grained sediment is actively accumulating there. This large area of clay and silt may not be relict, as previous reports have indicated, but may have been derived from fine-grained material being winnowed from the Georges Bank/Nantucket Shoals area (fig. 14*C*). This area of fine-grained sediment appears to be the principal site on the Continental Shelf off the Northeastern United States where pollutants introduced by offshore development activity in the Georges Bank area may actually concentrate. In part, the reason for this phenomenon is the clockwise residual water flow around Georges Bank and westward flow along the Continental Shelf.

In the bottom sediment of Georges Bank, total concentrations of iron, lead, zinc, barium, copper, nickel, vanadium, chromium, and cadmium and leachable concentrations of zinc, copper, and chromium are low and are characteristic of areas having uncontaminated coarse-grained sediment. Profiles of the concentrations of these elements and sediments near the water/sediment interface give no indication of recent trace-metal accumulation.

Vibracores collected in till-like material near the presumed Pleistocene ice limit south of Nantucket Island and west of Great South Channel reveal carbon-14 dates between 20,000 and 30,000 years B.P. (before present). These dates indicate that the till was dropped by ice in the glacial late Wisconsinan Stage.

Preliminary analysis of high-resolution seismic-reflection profiles on the Continental Slope off Georges Bank indicates that slumping and mass movement of material have taken place in this area and that the scale of the mass movement ranges from small to large; styles range from simple creep to major dislocation and translation. However, sophis-

FIGURE 5.—Locations of geologic and geographic features and drilling sites along the U.S. Atlantic continental margin and light-hydrocarbon and hydrologic data for AMCOR sites. *A*, Locations of drilling sites on the U.S. Atlantic continental margin. AMCOR, Atlantic Margin Coring Program; JOIDES, Joint Oceanographic Institutions Deep Earth Sampling; ASP, Atlantic Slope Project; DSDP, Deep Sea Drilling Project; LT, Light Tower; COST, Continental Offshore Stratigraphic Test; TT, Texas Tower; USN-ACMR; United States Navy-Air Combat Maneuvering Range; and AGS, Atlantic Generating Station. *B*, Geologic and geographic features and light-hydrocarbon data for AMCOR sites. *C*, Hydrologic data for AMCOR sites. Insets show chlorinity variations with depth below sea level of selected sites. Numbers accompanying each site show the minimum chlorinity value and the depth below sea level at which that value existed. (Modified from Hathaway and others, 1979.)

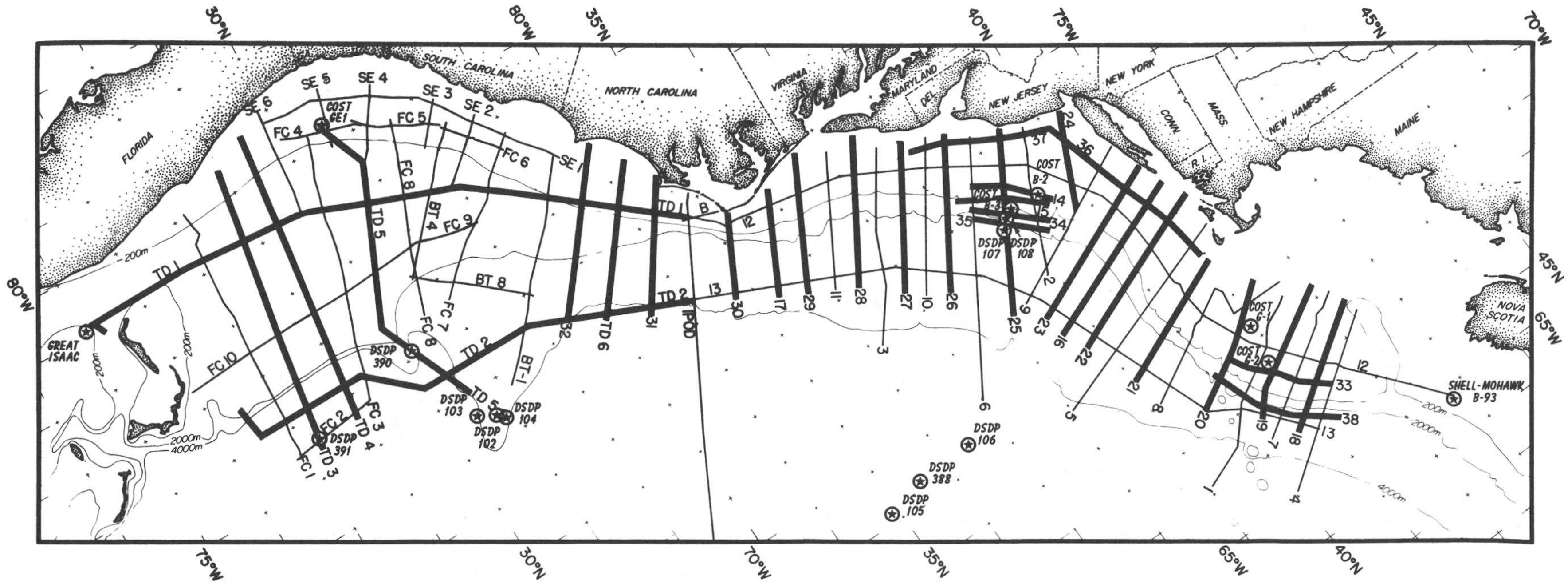


FIGURE 6.—Locations of tracklines along which common-depth-point seismic profiles were collected for resource studies of the U.S. Atlantic continental margin. Heavy lines indicate data collection sites for 1977 and 1978. Some wells (starred locations) are shown for reference: DSDP, Deep Sea Drilling Project; COST, Continental Offshore Stratigraphic Test. Approximate scale 1:13,750,000. (Modified from Folger and others, 1979.)

ticated analysis of the data is continuing because masses may be easily confused with unconformities or with acoustical artifacts in terrain cut by submarine canyons.

In situ observations of the Outer Continental Shelf and upper Continental Slope south of Georges Bank reveal small slump scars characterized by slopes of 20° to 45°, by clay outcrops, and by burrows and depressions inhabited by a diversity of megabenthic organisms. Step topography, reverse slopes, and hummocky sea floor were observed below the scars. Areas where slumps are absent are characterized by smooth, gently dipping sea floor and sparse fauna.

Middle Atlantic (Baltimore Canyon Trough)

Most of the detailed seismic profiling on the Shelf in the Baltimore Canyon Trough was carried out prior to the time covered by this report. Surveys conducted along tracklines shown in figures 15*A* include mainly submersible, suspended-matter, sidescan-sonar, and single-channel seismic surveys (table 1).

Seismic surveys of the Slope were initiated in 1978 along tracklines shown in figure 15*B*. Measurements during FY 77 and FY 78 of bottom currents, temperature, turbidity, and suspended matter and photographs of the bottom demonstrate that, in this area, surficial bottom sediment moves primarily in response to winter storms, surface waves, and tidal currents in waters as much as 60 to 80 m deep. These agents cause transport along the shelf ranging from 10 to 20 km and transport cross the shelf ranging from 5 to 10 km; thus, fine material probably can be distributed over wide areas of the shelf each year. The consistency of measurements taken by identical tripod systems spaced far apart on the shelf suggests that instruments on one tripod can monitor conditions over a large area of the Continental Shelf.

Seismic investigations of shallow strata have previously indicated that well-defined sand waves are present only in the area near the head of Wilmington Canyon (fig. 15*A*). The bedforms there are 1 to 8 m high, and crests having wavelengths of 100 to 600 m are oriented northwest-southeast. The bedforms are symmetrical to the southwest and show internal southwest-dipping foreset beds. These waves are close to a lease area and would pose a potential stability problem for pipelines. The best evidence to date suggests that these beds are not in motion or that they move only in response to extremely large storms.

Vibracores of the upper few meters of sediment have revealed that silty-clayey strata underlie the surficial sand sheet across most of the shelf in the Baltimore Canyon Trough area. Information from drilling during the AMCOR Program suggests that this fine-textured sediment unit is as much as 300 m thick under the Continental Shelf. Measurements of cores from the unit indicate that, on the Continental Shelf, much of this fine-textured material is overconsolidated, probably owing to ground-water circulation when sea level was much lower.

Many of the high-resolution seismic profiles collected on the Continental Slope reveal possible slumping or mass movement. Within a closely surveyed area (fig. 15*B*), possible slumped sediments constitute about 15 percent of the area. Submersible observations of small slumps in the area reveal steep slopes and outcrops of stiff clay, heavily burrowed by benthic fauna, at the slump heads. Downslope from the slump scars, blocks of sediment and step topography are common. Outside the slump areas, the sea floor is smooth, and megabenthic fauna are sparse. The potential hazard from slumping has yet to be fully determined because the geometry, age, and frequency of slumping are not well documented. If the slumping was all associated with the last sea-level lowering and preceding sea-level lowerings, then it probably will not constitute a major problem. On the other hand, if much of the sediment on the upper slope does move during earthquakes, as it did off the Grand Banks of Newfoundland in 1929, then slumping may be an important hazard.

As part of an effort to characterize the background geochemical character of surficial sediment in the Middle Atlantic area, we have shown that the $C_{15}+$ heavy hydrocarbon (paraffin) concentration flux correlates with the seasonal changes in the intensity of sediment transport motion along and across the shelf. Other factors that are known to influence the natural seasonal flux distribution and the fate of the component hydrocarbons are (1) the chemical, biological, and microbial degradation in situ, (2) the influence of temperature, salinity, and pressure gradients on the residence time of particulate matter that carries sorbed hydrocarbons, (3) the sorption of hydrocarbons by humic and fulvic acids, (4) circulation envelopes, (5) clay-mineral type, composition,

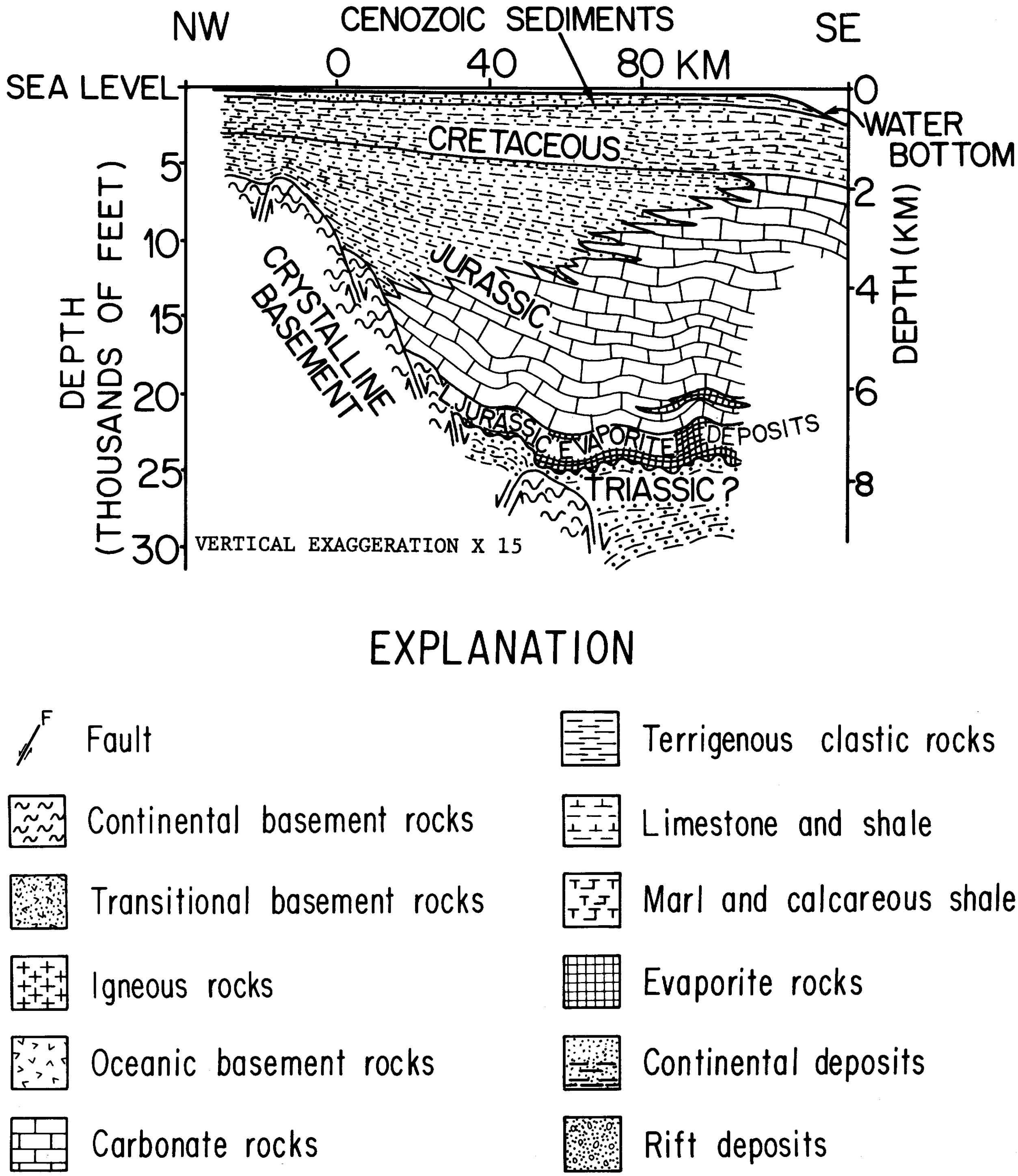


FIGURE 7.—Diagrammatic cross section along common-depth-point line 1 across central Georges Bank showing a thick sequence of Jurassic and Cretaceous sedimentary rocks overlying Triassic and Jurassic red beds(?) and faulted crystalline basement. The location of line 1 is shown in figure 6. Explanation applies to figures 7 to 10. (Modified from Schlee, 1978.)

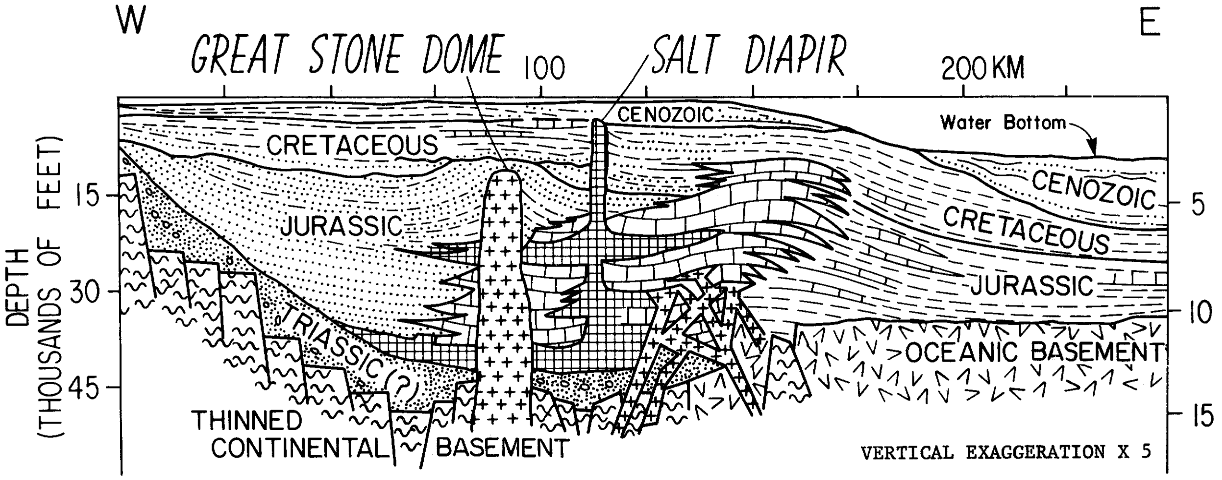


FIGURE 8.—Diagrammatic cross section along common-depth-point line 25 of the Baltimore Canyon Trough. The location of line 25 is shown in figure 6. Potential hydrocarbon traps include the arched sediments associated with the Great Stone dome and salt diapir and also the structural and stratigraphic traps in the carbonate (reef) complex. See explanation of lithologic units in figure 7. (Modified from Grow, Mattick, and Schlee, 1979.)

and charge deficiency, and (6) the bottom topography.

The concentrations of the saturated paraffin (aliphatic) hydrocarbons are generally less than 1 μg/g (1.0 ppm, parts per million) and are predominantly biogenic rather than anthropogenic. The aromatic hydrocarbons, also less concentrated than 1 μg/g (1.0 ppm), are believed to have a source different from that of the aliphatics; possibly they are associated with atmospheric particulate matter.

South Atlantic (Southeast Georgia Embayment)

Single-channel seismic and sidescan-sonar surveys plus tripod observations, bottom-sediment coring, and submersive observations were carried out in 1977 and 1978 on the U.S. South Atlantic continental margin (figs. 16*A*, *B*; table 1). These observations indicate that the major environmental hazard to mineral exploration on the Blake Plateau is strong currents associated with the Gulf Stream that cause extensive bottom scour, steep bathymetry, and cut and fill on many unconformity surfaces. No major faulting was found in the Blake Plateau or Slope; small faults, delineated by using high-resolution seismic data, appear to be related to differential compaction or slumping.

Piston coring and rock dredging on the Blake Plateau reveal that most surface areas are covered by lag phosphorites or manganese nodules. Large living coral reefs, mounds, and thickets (ahermatypic varieties of coral) are ubiquitous, particularly under the Gulf Stream. Steep escarpments appear to be topped by lag gravels, reefs, and indurated rock. Reefs and hardgrounds associated with abundant benthic and demersal activity are discontinuous on the shelf. These reefs and hardgrounds are of three general morphotypes: (1) generally flat-lying low-relief (0.5 m) rock outcrops, which are periodically covered and uncovered by a layer of surficial sand, (2) attached reefs and areas having 2 m or more of relief, which consist of interfingered ridges and troughs of micrite-cemented sand or shelly rocks, and (3) shelf-edge reefs having 5 to 30 m of relief, which are discontinuous along the shallow part of the Continental Slope. Hardgrounds (probably relict beach rock or shelf-edge reefs) are least common off the central Georgia coast and are more common both to the south off Florida and to the north off South Carolina.

Benthic and demersal productivity on the Blake Plateau appears to be related to relief; productivity is low in areas of low relief, and hard and soft corals, sea whips, sponges, and algae are abundant in higher relief areas.

GULF OF MEXICO

South Texas Outer Continental Shelf

During 1977 and 1978, extensive studies for the U.S. Bureau of Land Management on the South Texas OCS were completed and synthesized by the USGS. These studies included the interpretation of 20,000 km of high-resolution seismic data and

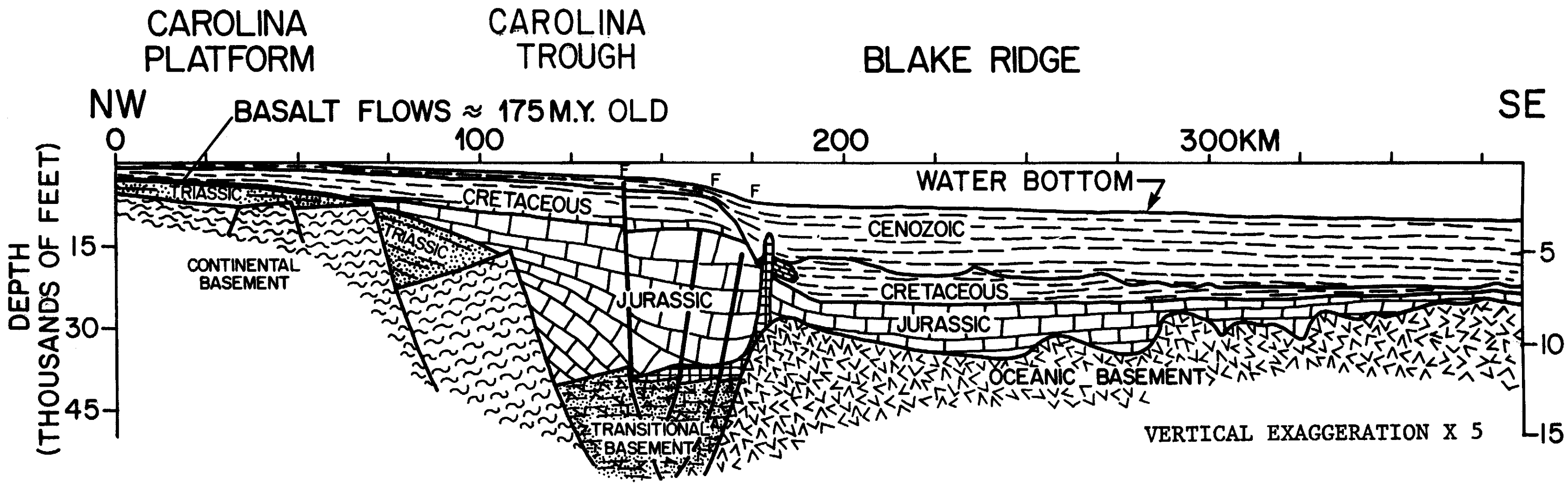


FIGURE 9.—Diagrammatic cross section based on common-depth-point line BT-1 across the Carolina Platform and Carolina Trough. The location of line BT-1 is shown in figure 6. See explanation of lithologic units in figure 7. (Modified from Folger and others, 1979.)

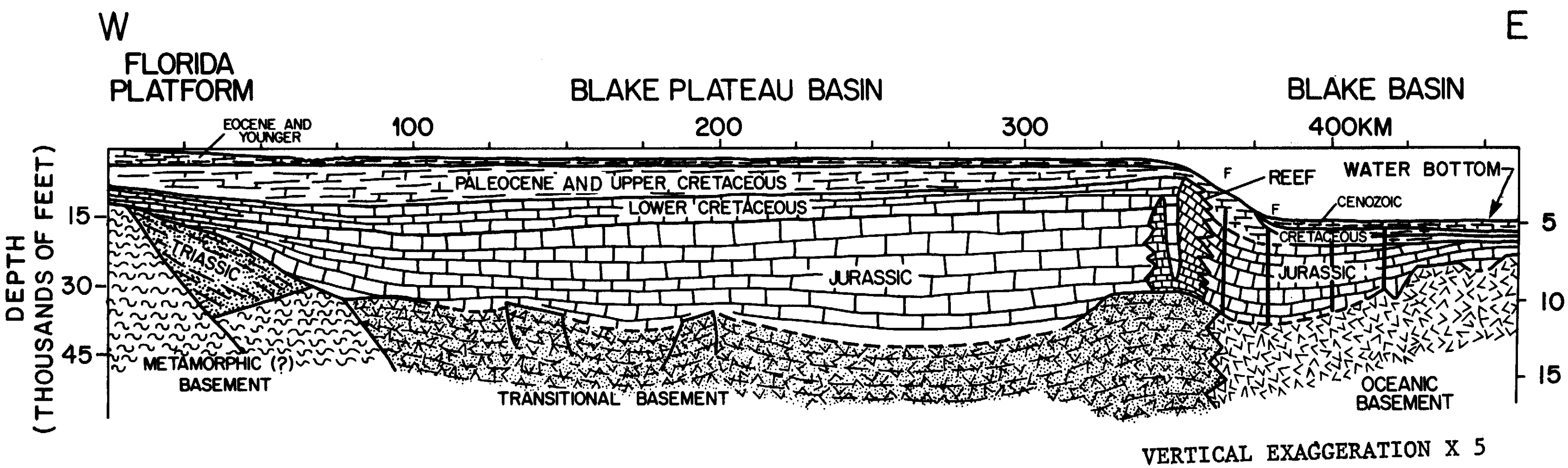


FIGURE 10. — Diagrammatic cross section based on common-depth-point line FC-3 across the Blake Plateau Basin. The location of line FC-3 is shown in figure 6. See explanation of lithologic units in figure 7. (Modified from Folger and others, 1979.)

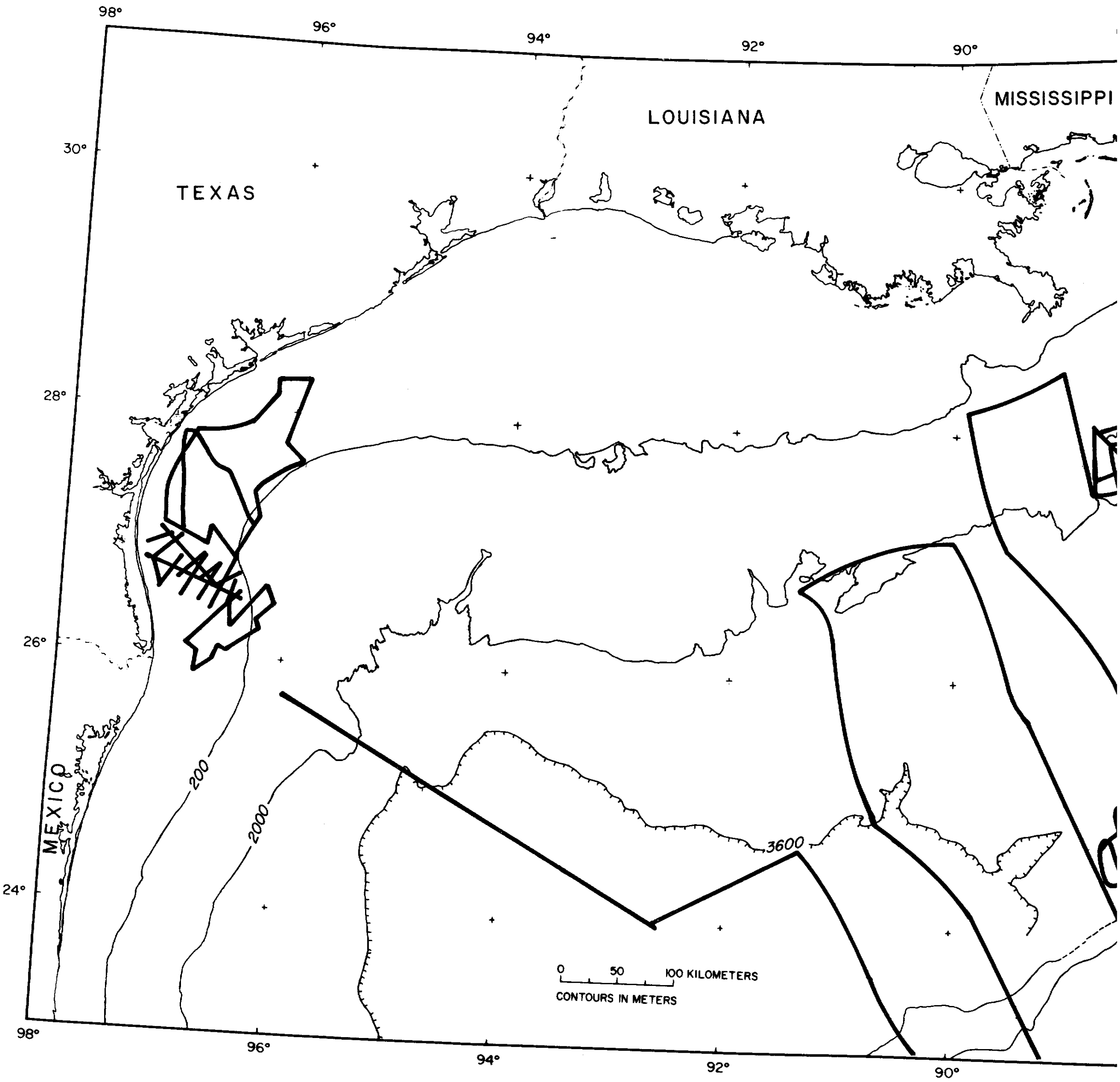
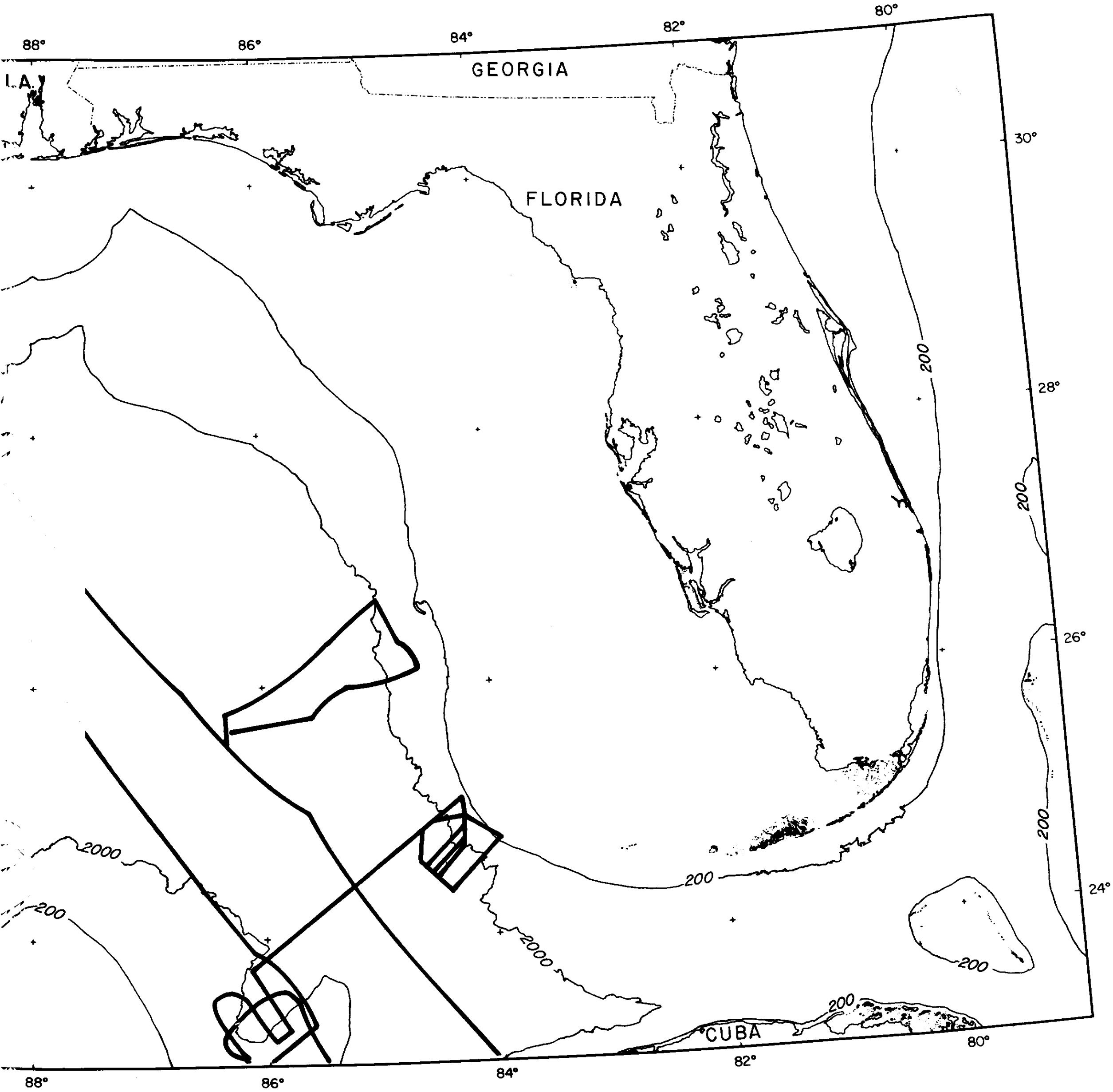


FIGURE 11.—Tracklines along which common-depth-point seismic data were collected in the Gulf of Mexico. These data were acquired

analysis of 234 samples of suspended matter and 66 piston cores (figs. 17*A*, *B*).

Concentrations of suspended sediment (mainly quartz, montmorillonite, and illite) were highest over the north and inner central parts of the shelf. Principal sources apparently were the inlets along the northern part of the South Texas OCS, the Mississippi River, and smaller rivers. The dispersal patterns of trace metals were similar to dispersal patterns of total suspended matter. The trace metals in suspension on the inner shelf are associated with the common terrestrially derived particulate matter and the large amounts of suspended biological constituents. High concentrations of trace metals on the outer shelf probably are due to specific biological components but may be due in part to natural-gas seepage.

Bottom sediments can be classified on the basis of textural analyses into three classes: relict deposits of the ancestral Rio Grande, redeposited relict sediments, and modern deposits transported to the shelf during Holocene time. Widespread discrete sand layers show that large quantities of coarse sediment are carried periodically seaward beyond mid-



from the University of Texas Marine Science Institute to be used in compiling a regional tectonic map of the Gulf of Mexico.

shelf, probably during hurricanes that floor the bays and cause strong ebbtides that transport turbid water and sand across the shelf.

Studies of lead-210 dates indicate that rates of sedimentation on the shelf during the last 150 years have ranged from 0 to 9 mm/yr. Highest rates were measured in sediments deposited on the northern part of the shelf.

Isopachs of the shallow strata define areas of variable uplift and subsidence due to diapirism, sediment loading, and fluctuations in sea level due to glaciation. The main depocenter has migrated northward since early Holocene time from just north of the ancestral Rio Grande delta to its present position on the northern part of the OCS. Faulting has been continuous since late Pleistocene time and has migrated seaward across the shelf.

Mississippi Delta

Studies of bottom-sediment instability on the Continental Shelf and Slope off the Mississippi Delta since 1974 have revealed a complex of slumps and slides. The documentation of these features has

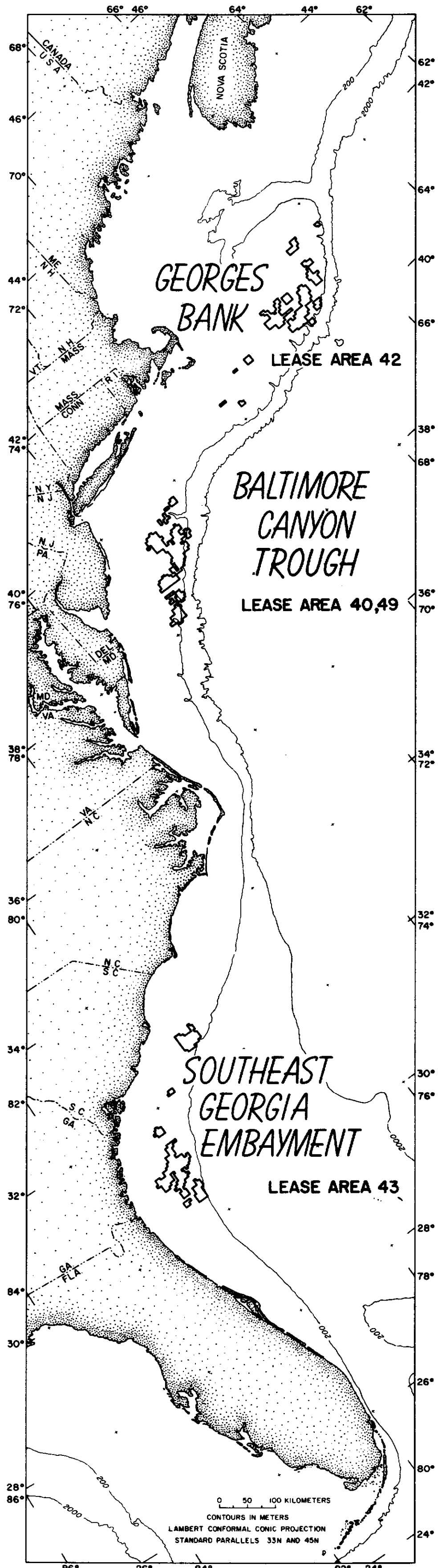


FIGURE 12.—The three main lease areas on the U.S. Atlantic Continental Margin.

steadily improved as more sophisticated techniques and better equipment have been brought to bear on the problem (figs. 18*A*, *B*, *C*). Instability of various types is common off the modern Mississippi Delta complex. The instability is due mainly to the high rates of sedimentation (as high as 80 m/100 yr), to weak clays having water contents in excess of 100 percent, and to differential loading of clay sediments. The kinds of instabilities that now have been documented include:

(1) Peripheral slumping, which may cover an area 200 m by 100 m in a stairstep configuration; downslope movement may be as much as 700 m/yr.
(2) Shallow diapiric intrusions ranging in diameter from a few hundred meters to 2 km and having vertical displacements from 200 to 500 m at rates of several meters per year.
(3) Radial grabens 200 to 800 m wide and several kilometers long showing downslope movement of as much as 5 m/yr.
(4) Circular collapse depressions having diameters of 50 to 500 m.
(5) Surface mudflows that commonly are more than 35 m thick and extend for distances of as much as 100 km as a complex of lobes that move as fast as several hundred meters per year.
(6) Shelf-edge arcuate slumps having 100 m of displacement.
(7) Deep-seated faults.

All these features may result in failure of support for platforms or pipelines constructed on or near them. Of greatest concern are the submarine landslides, which are especially destructive. These slides take place on slopes having inclinations as low as 0.2° to 1.5° and in water 5 to 100 m deep. They include collapse depressions, bottleneck slides, elongate slides and slumps, mudflow gullies, and overlapping mudflow lobes. The basic mechanism of movement is the downslope translation of thin slabs of sediment debris. Movement rates of several hundred meters per year have been documented. Large surges of these features may result from complex temporal and spatial relations of wave-induced stresses, sediment loading, and inherent loss of shear strength due to high pressures of pore water and methane gas.

LAKE STUDIES

To serve as a basis for future Great Lakes studies, all the publicly available geological and geophysical data have been assembled in a series of USGS Miscellaneous Field Studies Maps (Hutchinson and Wold, 1979a, b; Wold and Hutchinson, 1979a, b, c). During compilation of available data already acquired on the geology of central Lake Michigan (fig. 1), a fault in east-central Lake Michigan was discovered on seismic profiles. The fault has more than 100 m of offset.

Analysis of seismic-reflection data collected in central Lake Ontario (fig. 19) shows that a bathymetric ridge having 30 m of relief crosses the lake and is controlled by underlying bedrock. Magnetic data collected from the lake, and magnetic and gravity data collected earlier in western New York, show that the bathymetric ridge and the Clarendon-Linden structure coincide with a linear magnetic trough and the west flank of a series of circular Bouguer gravity highs. The source of these geophysical anomalies appears to be in the Proterozoic crystalline basement; thus, the deformation observed in the Paleozoic carbonate rocks may be inherited from a preexisting structure in the Proterozoic rocks. Although the unconsolidated lake sediments show no evidence of Holocene movement on the fault, the magnetic and gravity evidence indicates that the Clarendon-Linden structure continues across central Lake Ontario.

A survey of Lake George, which is south of Lake Champlain (fig. 1), was undertaken mainly to investigate the possibility that recent uplift of the adjacent Adirondack Mountains massif has produced faulting in recent sediments. Leveling studies have shown that the Adirondacks are possibly rising at a rate of about 3.7 mm/yr (Isachsen, 1975). This survey, which included both high-resolution geophysical data and coring, may provide evidence to support or disprove this theory.

INNER SHELF STUDIES

Studies in Massachusetts coastal waters (figs. 20*A*, *B*) reveal that parts of the Buzzards Bay and Sandwich moraines appear to have been formed when advancing ice dragged and thrust glacial and fluvial-lacustrine deposits upward and laterally to their present position. The moraine on Nantucket also is glaciotectonic in origin, but it was not overridden by ice and consists of glacial lacustrine deposits displaced by ice push when the ice front was north of the island. Seismic records reveal that, off Cape Ann, a bathymetric high is underlain by deformed beds that overlie undeformed ponded deposits. The high is inferred to be a glaciotectonic end moraine formed when ice readvanced during the late Wisconsinan

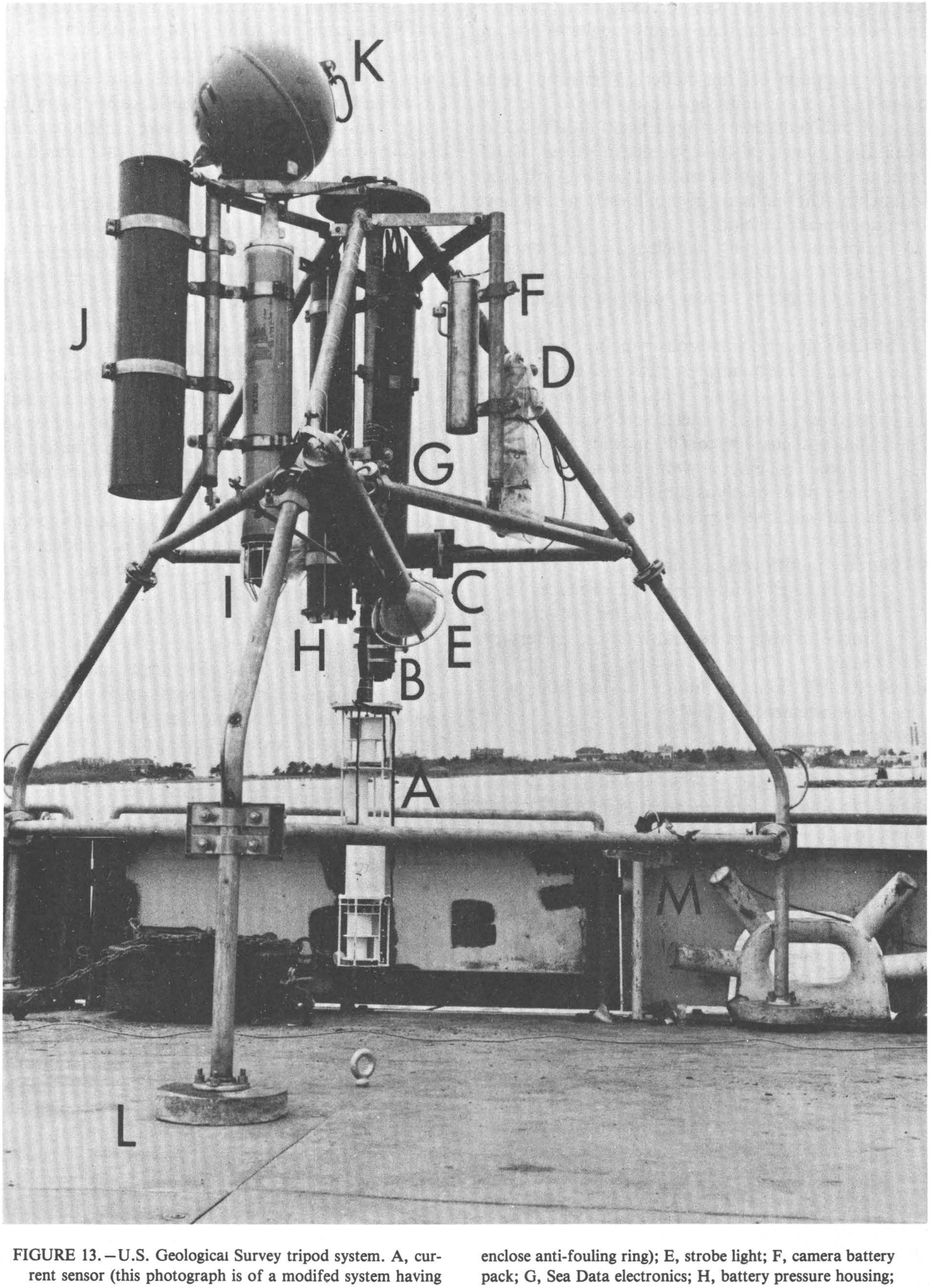


FIGURE 13.—U.S. Geological Survey tripod system. A, current sensor (this photograph is of a modifed system having two savonius rotors); B, pressure sensor; C, transmissometer; D, camera (wrapped in protective plastic bag to enclose anti-fouling ring); E, strobe light; F, camera battery pack; G, Sea Data electronics; H, battery pressure housing; I, acoustic release transponder; J, rope canister; K, recovery float; L, lead anchor feet; M, current vane.

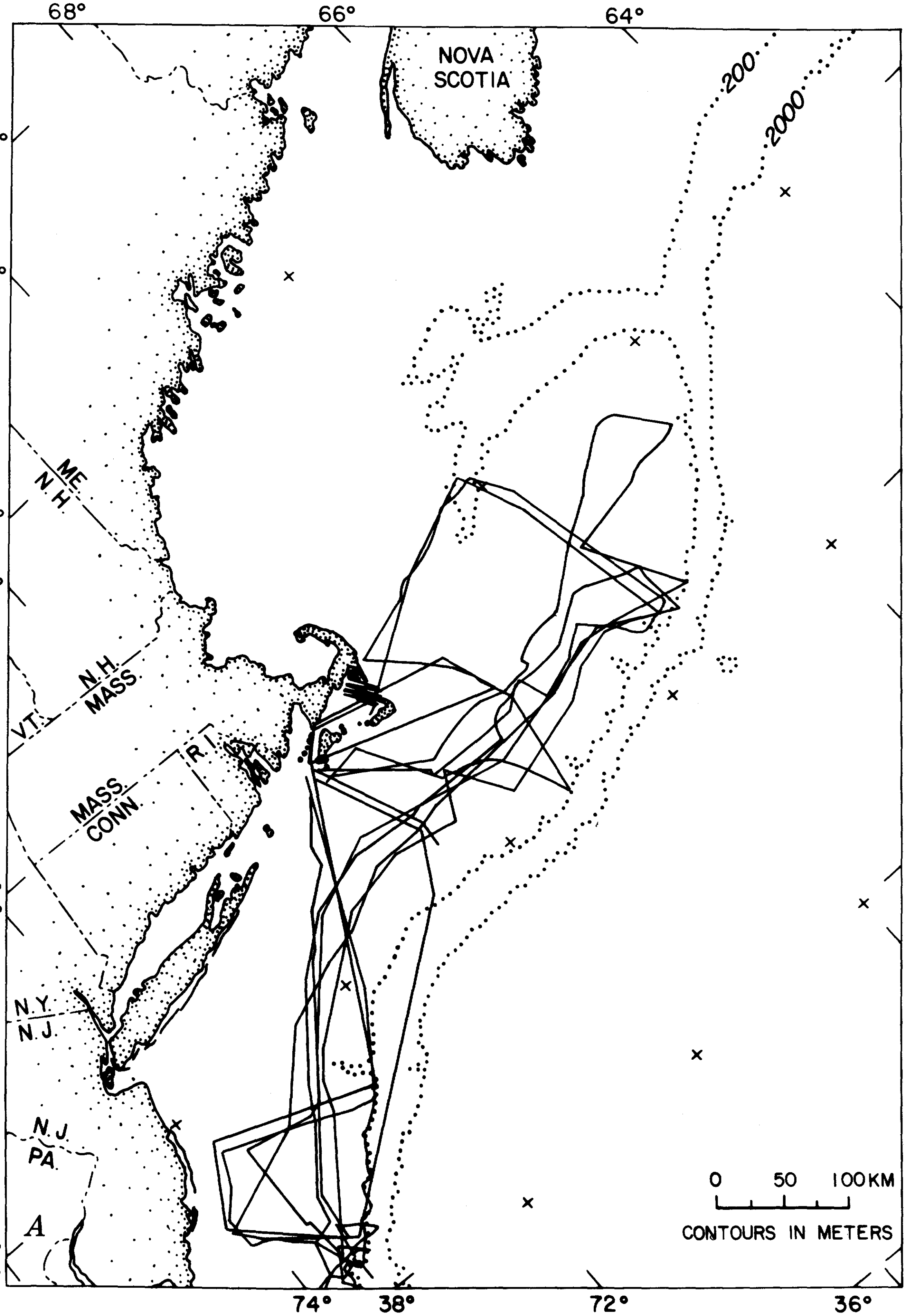


FIGURE 14.—Tracklines over the U.S. North Atlantic continental margin along which data were collected by the USGS in 1977–79. *A*, 1977.

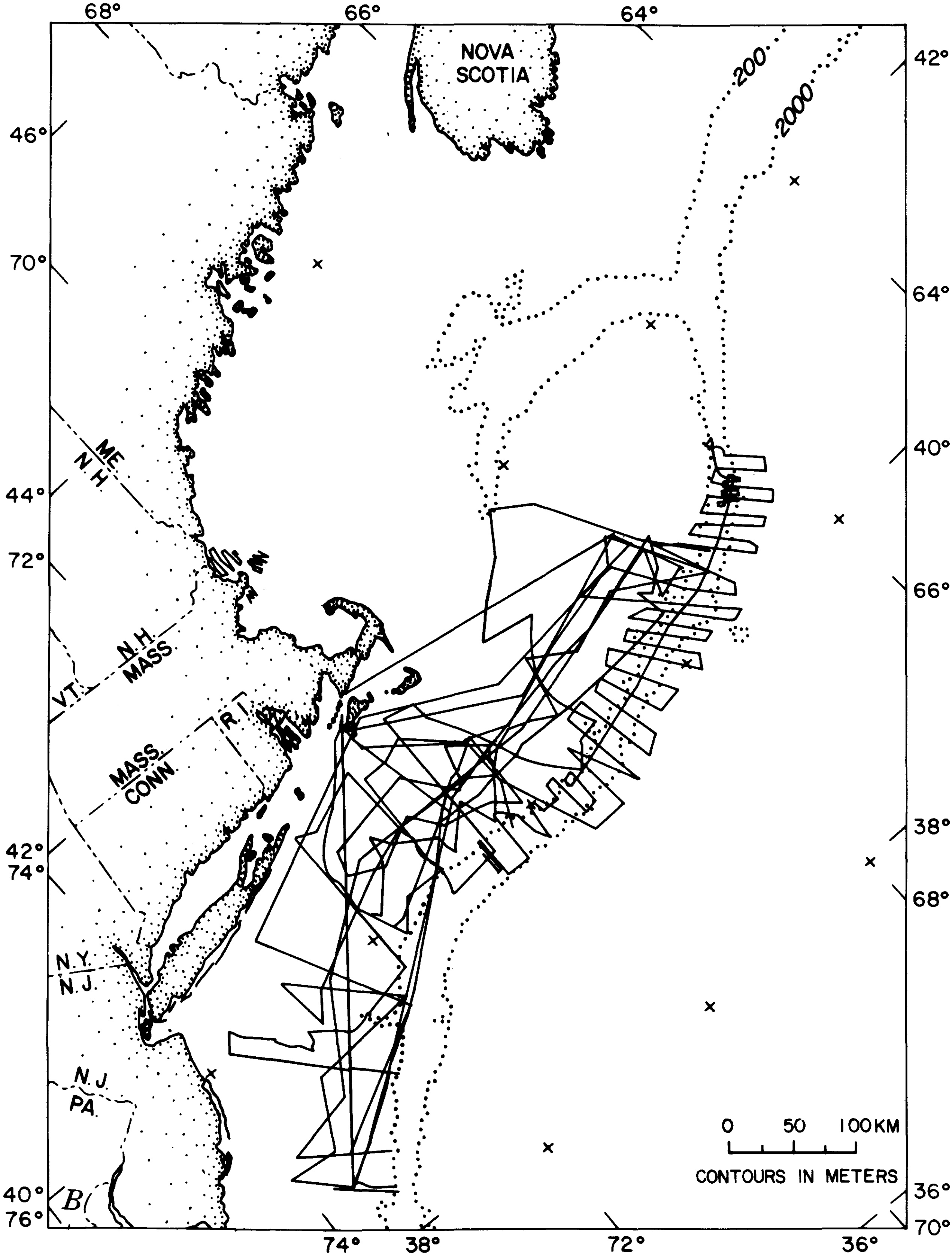


FIGURE 14.—Tracklines over the U.S. North Atlantic continental margin along which data were collected by the USGS in 1977–79—Continued. *B*, 1978.

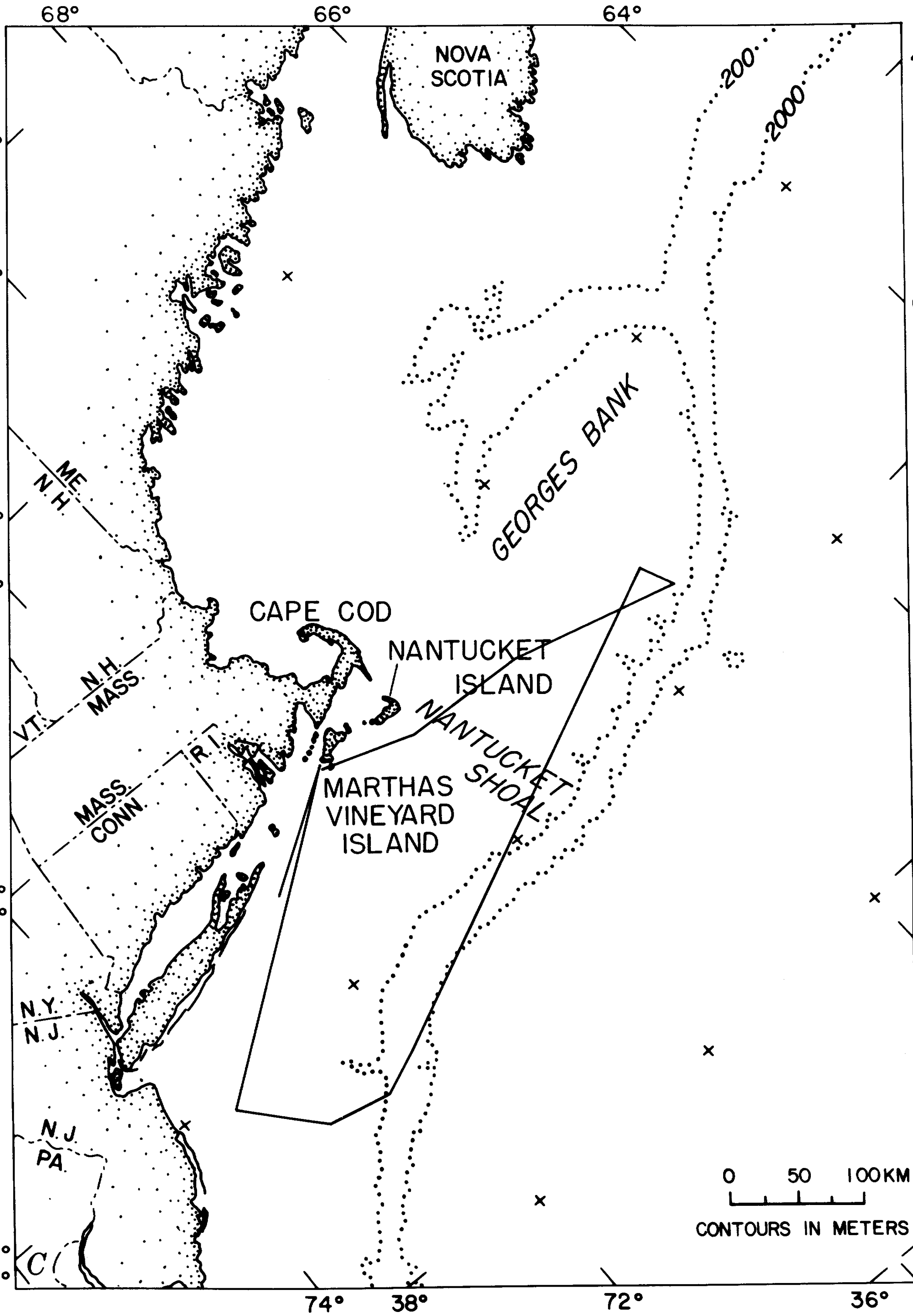


FIGURE 14.—Tracklines over the U.S. North Atlantic continental margin along which data were collected by the USGS in 1977–79—Continued. *C*, 1979.

TABLE 1.—*Cruises conducted in the Atlantic and Gulf of Mexico by the U.S. Geological Survey from September 1976 to December 1978 and types of data collected*

[XBT, expendable bathythermograph cast. CTD, conductivity-temperature depth]

Cruise Number	Date	Location of cruise	Name of vessel	USGS Man-days at sea	Multichannel (km)	Single-channel sparker/air gun (km)	Uniboom (km)	Minisparker (km)	7 or 200 kHz (km)	3.5 or 12 kHz (km)	Sidescan sonar (km)	Gravity (km)	Magnetics (km)	Grab samples	Vibracores	Gravity and piston cores	Bottom camera stations	Seston samples	XBT and CTD	Temperature and salinity measurements	Tripod deployments	Submersible dives	Transmissometer current meters deployed	Scuba dives	Current meter deployed/recovered
025	9–21–76 to 10–10–76	South Atlantic	*Fay*	266	----	3310	----	3310	----	----	----	5560	3310	----	----	----	----	----	----	----	----	----	----	----	----
	10–04–76 to 10–16–76	Coastal Massachusetts	*Asterias*	16	----	----	250	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
77–1	10–05–76 to 10–08–76	Puerto Rico	*Jean A*	12	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	16	----
	10–16–76 to 10–22–76	Lake George	*Seabiskit*	9	----	----	110	----	110	----	----	----	110	----	----	----	----	----	----	----	----	----	----	----	----
026	10–16–76 to 10–25–76	South Atlantic	*Fay*	60	----	----	----	----	----	----	108	----	----	----	18	16	----	----	----	----	----	----	----	----	----
77–2	10–18–76 to 10–21–76	Puerto Rico	*Jean A*	12	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	19	----
	10–26–76 to 10–31–76	North and Middle Atlantic	*Whitefoot*	10	----	----	----	----	----	----	----	----	----	----	----	----	----	----	21	----	----	----	2	----	----
	10–29–76 to 11–03–76	South Texas OCS	*Ida Green*	55	----	----	----	----	----	----	----	----	----	----	----	----	----	78	----	26	----	----	26	----	----
017	12–03–76 to 12–10–76	North Atlantic	*Oceanus*	48	----	----	----	----	----	----	----	----	----	----	----	----	----	65	83	95	2	----	22	----	----
	12–17–76 to 12–29–76	North Atlantic	*Whitefoot*	6	----	----	----	----	----	----	----	----	----	2	----	----	----	----	----	----	1	----	1	----	----
77–3	1–21–77 to 1–22–77	Puerto Rico	*Jean A*	6	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2/2
	1–25–77	Puerto Rico	*Jean A*	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2/2
	2–18–77	Puerto Rico	*Jean A*	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2/2
	2–14–77 to 2–16–77	Puerto Rico	*Eastward*	6	----	----	----	----	----	40	----	----	----	----	----	12	----	----	----	----	----	----	----	----	----
	3–08–77 to 3–17–77	North Atlantic	*Whitefoot*	53	----	----	----	----	----	----	----	----	----	----	----	----	----	----	41	41	3	----	3	----	----
	3–16–77	Puerto Rico	*McKee*	4	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	3–17–77 to 3–21–77	Gulf of Mexico	*Decca Profiler*	60	----	----	----	----	----	----	----	----	----	----	----	----	----	78	----	----	----	----	----	----	----

77–4	3–31–77 to 4–10–77	Puerto Rico	*Jean A*	29	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	4–05–77 to 5–06–77	Gulf of Mexico	*Chem-Mist*	76	----	----	----	1125	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	4–19–77 to 5–02–77	Middle Atlantic	*SubSig II*	140	----	----	----	----	----	----	----	----	----	----	----	----	----	306	154	----	----	----	80	----	----
77–6	5–13–77 to 5–21–77	St. Croix, U.S. V.I.	*Jean A*	15	----	----	----	220	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	5–24–77 to 5–27–77	South Texas OCS	*Decca Profiler*	44	----	----	----	----	----	----	----	----	----	----	----	----	----	78	----	26	----	----	26	----	----
	5–28–77 to 6–05–77	South Texas OCS	*Decca Profiler*	90	----	----	----	500	----	600	----	----	----	----	----	50	----	----	----	----	----	----	----	----	----
027	6–08–77 to 6–14–77	Middle Atlantic	*Oceanus*	72	----	----	643	----	----	558	740	----	----	----	----	----	----	----	----	----	----	----	----	----	----
77–7	6–15–77 to 7–01–77	Puerto Rico	*Jean A*	47	----	----	----	----	----	----	----	----	----	38	----	----	----	----	----	----	----	----	12	18	----
029	7–06–77 to 7–13–77	North and Middle Atlantic	*Oceanus*	56	----	----	----	----	----	----	----	----	----	----	----	----	----	----	209	8	4	----	5	----	----
	7–22–77 to 7–27–77	Coastal Massachusetts	*Asterias*	16	----	----	181	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	8–03–77 to 8–06–77	North Atlantic	*Eileen B*	32	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	8–05–77 to 8–07–77	South Atlantic	*Advance II*	4	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1	----	----	----	----
	8–19–77 to 10–29–77	Middle and South Atlantic	*Coral Seal*	151	4500	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	9–07–77 to 9–23–77	South, Middle and North Atlantic	*Advance II*	50	----	----	----	----	----	----	----	----	----	----	----	----	----	----	179	----	----	----	9	----	----
	9–13–77 to 10–01–77	Virgin Islands	*Alianora*	90	----	----	----	1260	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
1–77	9–18–77 to 9–25–77	Middle Atlantic	*Annandale*	42	----	----	----	377	----	----	----	----	----	----	20	----	----	----	----	----	----	----	----	----	----
2–77	9–27–77 to 10–02–77	Coastal Massachusetts	*Annandale*	25	----	----	----	----	----	----	----	----	----	----	20	----	----	----	----	----	----	----	----	----	----

TABLE 1.—*Cruises conducted in the Atlantic and Gulf of Mexico by the U.S. Geological Survey from September 1976 to December 1978 and types of data collected*—Continued

Cruise Number	Date	Location of cruise	Name of vessel	USGS Man-days at sea	Multichannel (km)	Single-channel sparker/air gun (km)	Uniboom (km)	Minisparker (km)	7 or 200 kHz (km)	3.5 or 12 kHz (km)	Sidescan sonar (km)	Gravity (km)	Magnetics (km)	Grab samples	Vibracores	Gravity and piston cores	Bottom camera stations	Seston samples	XBT and CTD	Temperature and salinity measurements	Tripod deployments	Submersible dives	Transmissometer current meters deployed	Scuba dives	Current meter deployed/recovered
77–09	11–07–77 to 11–16–77	Puerto Rico	*McKee*	20	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
78–2	12–05–77 to 12–07–77	Puerto Rico	*Jean A*	20	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	16/16
78–3	12–15–77 to 12–17–77	Puerto Rico	*Jean A*	12	----	----	----	90	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
038	1–19–78 to 1–26–78	North and Middle Atlantic	*Oceanus*	63	----	----	----	----	----	----	----	----	----	6	----	----	----	----	127	130	4	----	3	----	----
039–1	2–02–78 to 2–06–78	North, Middle and South Atlantic	*Oceanus*	40	----	----	----	----	----	----	----	----	----	3	----	----	----	----	----	95	2	----	----	----	----
78–4	2–06–78 to 2–15–78	Puerto Rico	*Jean A*	50	----	----	----	200	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	6	----
039–2	2–07–78 to 2–15–78	Virgin Islands	*Oceanus*	88	----	----	----	600	----	400	----	----	600	----	----	----	----	----	----	----	----	----	----	----	----
	2–16–78 to 2–25–78	Virgin Islands	*Sarima*	40	----	----	----	----	----	240	160	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	3–18–78 to 3–28–78	St. Thomas, U.S. V.I.	*Caribe Diver*	110	----	----	----	----	----	----	----	----	----	18	----	----	----	----	----	----	----	----	----	----	----
E2E–78	4–02–78 to 4–13–78	South Atlantic	*Eastward*	55	----	----	----	----	----	----	----	----	----	----	----	51	----	----	----	----	----	----	----	----	----
045	5–10–78 to 5–18–78	North and Middle Atlantic	*Oceanus*	81	----	----	----	----	----	----	----	----	----	6	----	10	----	----	138	121	6	----	5	----	----
039–4	5–14–78 to 5–24–78	South and North Atlantic	*Westward*	10	----	----	----	----	----	----	368	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	5–15–78 to 5–20–78	North Atlantic	*Cape Henlopen*	10	----	----	941	----	941	----	673	----	----	----	----	----	----	----	----	----	----	----	----	----	----
78–1	5–20–78 to 5–25–78	Middle Atlantic	*Captain John Smith*	16	----	----	----	115	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

	5-22-78 to 6-02-78	South Texas OCS	*Egret*	48	—	—	—	700	—	—	—	—	—	—	—	6	—	—	—	—	—	—	—	—	—
	5-29-78 thru 11-06-78	North, Middle and South Atlantic	*Carino and Gyre*	4813	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
78-6	6-01-78 to 8-10-78	Puerto Rico	*Zodiac*	54	—	—	—	—	—	—	—	—	—	114	—	—	—	—	—	—	—	—	—	26	—
	6-19-78 to 6-20-78	Texas OCS	*Longhorn*	8	—	—	—	—	—	—	—	—	—	4	4	—	—	—	—	—	—	—	—	—	—
	7-07-78 to 7-18-78	South Atlantic	*Whitefoot*	10	—	—	—	—	—	—	—	—	—	2	—	—	—	—	10	10	3	—	—	—	—
78-1 and 78-2	7-30-78 to 8-09-78	Middle and North Atlantic	*State Arrow*	80	—	—	—	564	—	28	—	—	—	6	—	—	4	—	—	—	—	24	—	—	—
78-5	7-11-78 to 7-13-78	Puerto Rico	*Jean A*	15	—	—	—	—	45	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
78-3	8-15-78 to 8-19-78	South Atlantic	*State Arrow*	24	—	—	—	—	—	—	—	—	—	—	—	—	—	—	38	44	—	22	—	—	—
7-78-1	8-18-78 to 9-04-78	Middle Atlantic	*Iselin*	216	—	2050	—	2100	—	2100	22	—	—	—	—	—	—	—	—	—	—	—	—	—	—
78-G7	8-19-78 to 9-01-78	Middle Atlantic	*Gyre*	117	—	—	—	—	—	—	—	—	—	8	—	3	—	286	—	—	—	—	—	—	—
78-7	9-05-78 to 9-08-78	Puerto Rico	*Jean A*	12	—	—	—	—	—	—	—	—	—	42	—	—	—	—	—	—	—	—	—	—	—
7-78-2	9-08-78 to 9-27-78	North Atlantic	*Iselin*	198	—	2142	—	2669	—	218	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	9-11-78 to 9-21-78	Coastal Massachusetts	*Asterias*	56	—	—	—	250	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
78-8	9-18-78 to 9-22-78	Puerto Rico	*Jean A*	20	—	—	—	—	64	—	—	—	—	48	—	—	—	—	—	—	—	—	—	—	—
103	9-28-78 to 10-05-78	Middle and North Atlantic	*Atlantis II*	88	—	—	—	—	—	—	18	—	—	7	—	—	—	—	94	—	5	—	6	—	—

TABLE 1.—*Cruises conducted in the Atlantic and Gulf of Mexico by the U.S. Geological Survey from September 1976 to December 1978 and types of data collected*—Continued

Cruise Number	Date	Location of cruise	Name of vessel	USGS Man-days at sea	Multichannel (km)	Single-channel sparker/air gun (km)	Uniboom (km)	Minisparker (km)	7 or 200 kHz (km)	3.5 or 12 kHz (km)	Sidescan sonar (km)	Gravity (km)	Magnetics (km)	Grab samples	Vibracores	Gravity and piston cores	Bottom camera stations	Seston samples	XBT and CTD	Temperature and salinity measurements	Tripod deployments	Submersible dives	Transmissometer current meters deployed	Scuba dives	Current meter deployed/recovered
7–78–3	9–29–78 to 10–19–78	South Atlantic	*Iselin*	200	----	3570	----	3487	----	3565	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	10–17–78 to 10–20–78	Potomac River	*Orion*	24	----	----	----	----	----	----	----	----	----	----	----	17	----	----	33	33	----	----	----	----	----
	10–30–78	North Atlantic	*Whitefoot*	4	----	----	----	----	----	----	----	----	----	----	----	----	----	----	4	4	1	----	1	----	----
	10–30–78	Puerto Rico	*Jean A*	6	----	----	----	----	----	----	----	----	----	109	----	----	----	----	----	----	----	----	----	----	----
	11–01–78 to 11–18–78	St. Croix, U.S. V.I.	*Sarima*	80	----	----	50	----	----	----	26	----	----	25	----	----	----	----	----	----	----	----	----	----	----
001	11–26–78 to 12–07–78	Lake George	*Neecho*	72	----	37.2	----	----	130	----	14.4	----	----	5	----	15	----	----	----	----	----	----	----	----	----
	12–12–78 to 12–14–78	South Atlantic	*Whitefoot*	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1	----	----	----	----

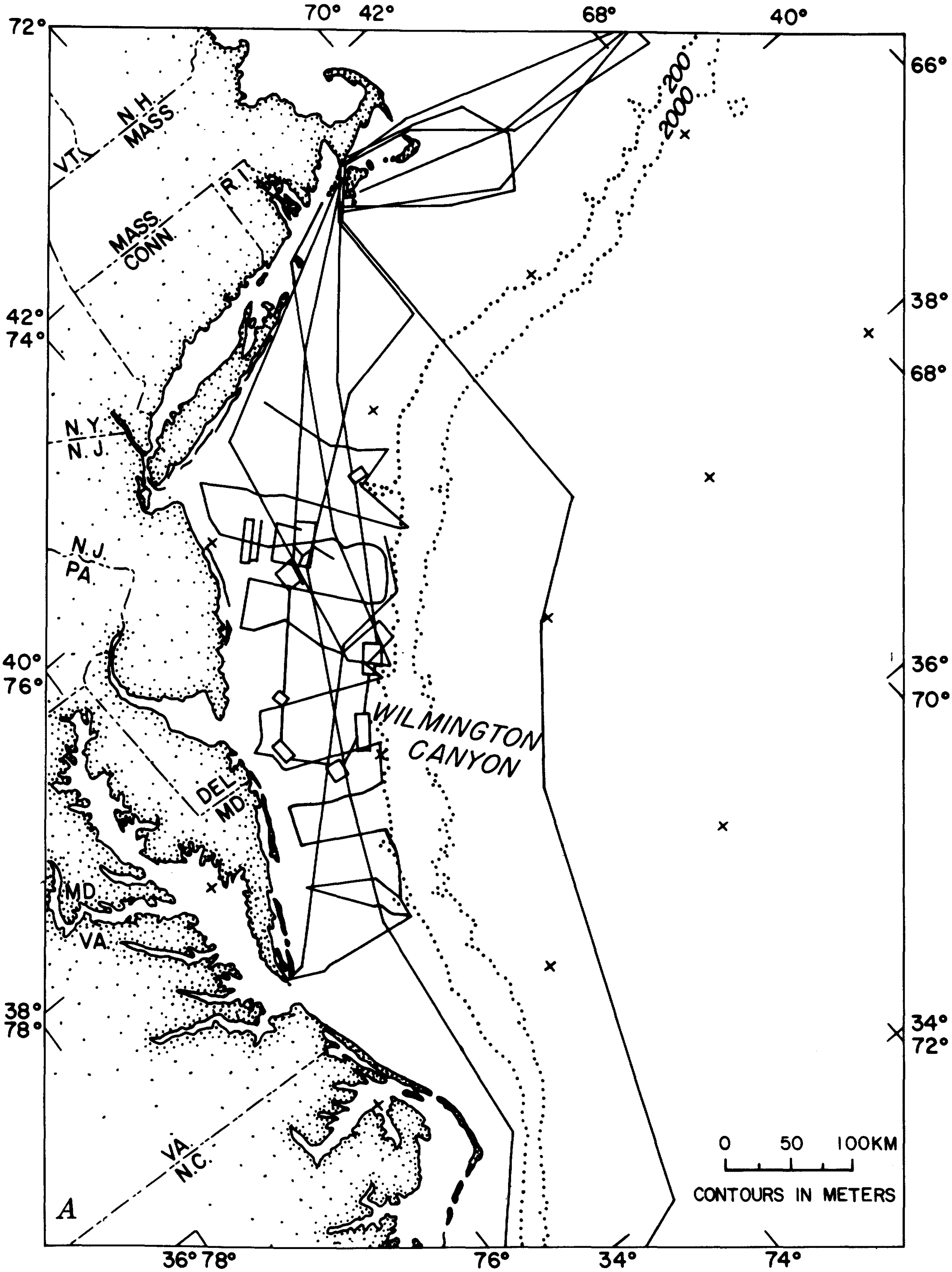


FIGURE 15.—Tracklines over the U.S. Middle Atlantic continental margin along which data were collected by the USGS in 1977-78. *A*, 1977.

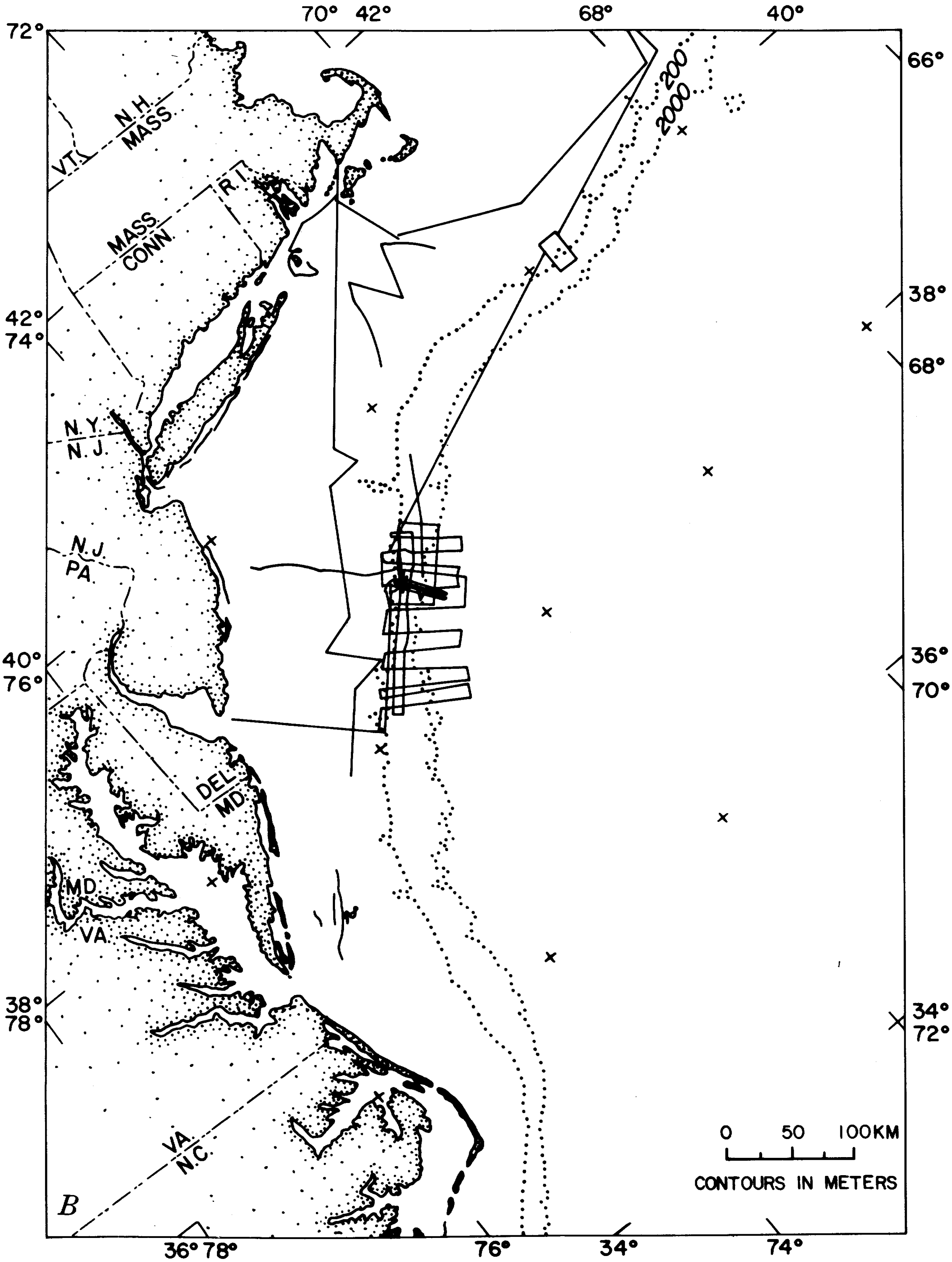


FIGURE 15.—Tracklines over the U.S. Middle Atlantic continental margin along which data were collected by the USGS in 1977-78—Continued *B*, 1978.

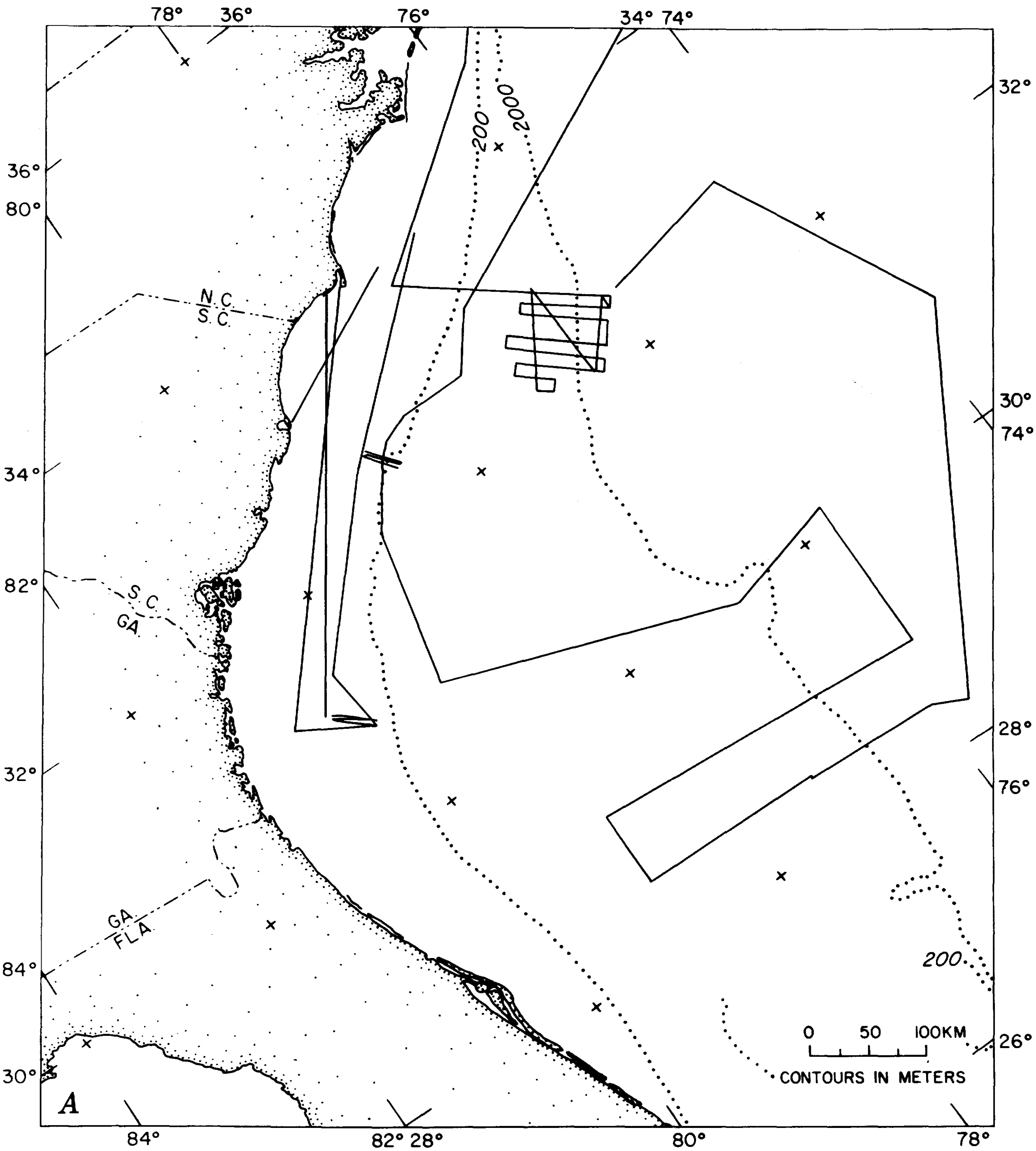


FIGURE 16.—Tracklines over the U.S. South Atlantic continental margin along which data were collected by the USGS in 1977–78. *A*, 1977.

glaciation. Understanding the glaciotectonic history of the upper Pleistocene deposits along the Massachusetts coastal zone is essential for distinguishing such structures from those that could have been produced by recent earth movements and, hence, that would be a major concern in nuclear-plant siting.

Recently obtained radiocarbon dates from southeastern Massachusetts offshore areas combined with previously published dates indicate that relative sea

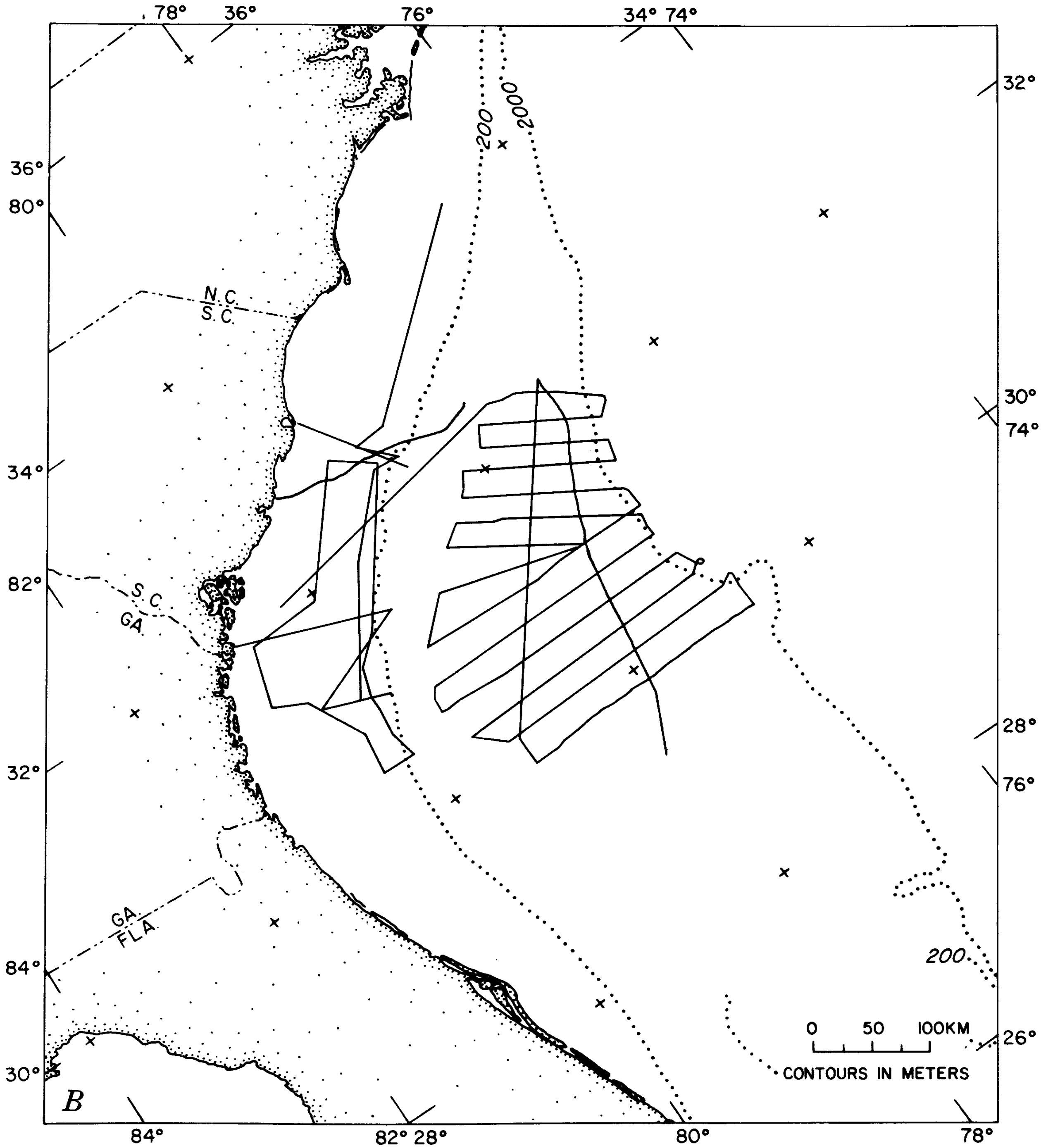


FIGURE 16.—Tracklines over the U.S. South Atlantic continental margin along which data were collected by the USGS in 1977–78—Continued B, 1978.

level 12,000 years ago was 70 m below its present level. From that time to 10,000 years ago, sea level rose at a rate of 1.7 m per 100 years. Between 10,000 years ago and 6,000 years ago, the rate of sea-level rise dropped gradually to about 0.3 m per 100 years; that rate persisted until about 2,000 years ago.

In support of interdisciplinary investigations of the Potomac River and estuary, 17 cores (fig. 21) were collected in October 1978 from fluvial, transitional, and estuarine zones of the system between Washington, D.C., and the Chesapeake Bay. The sediment cores were analyzed to determine sedimen-

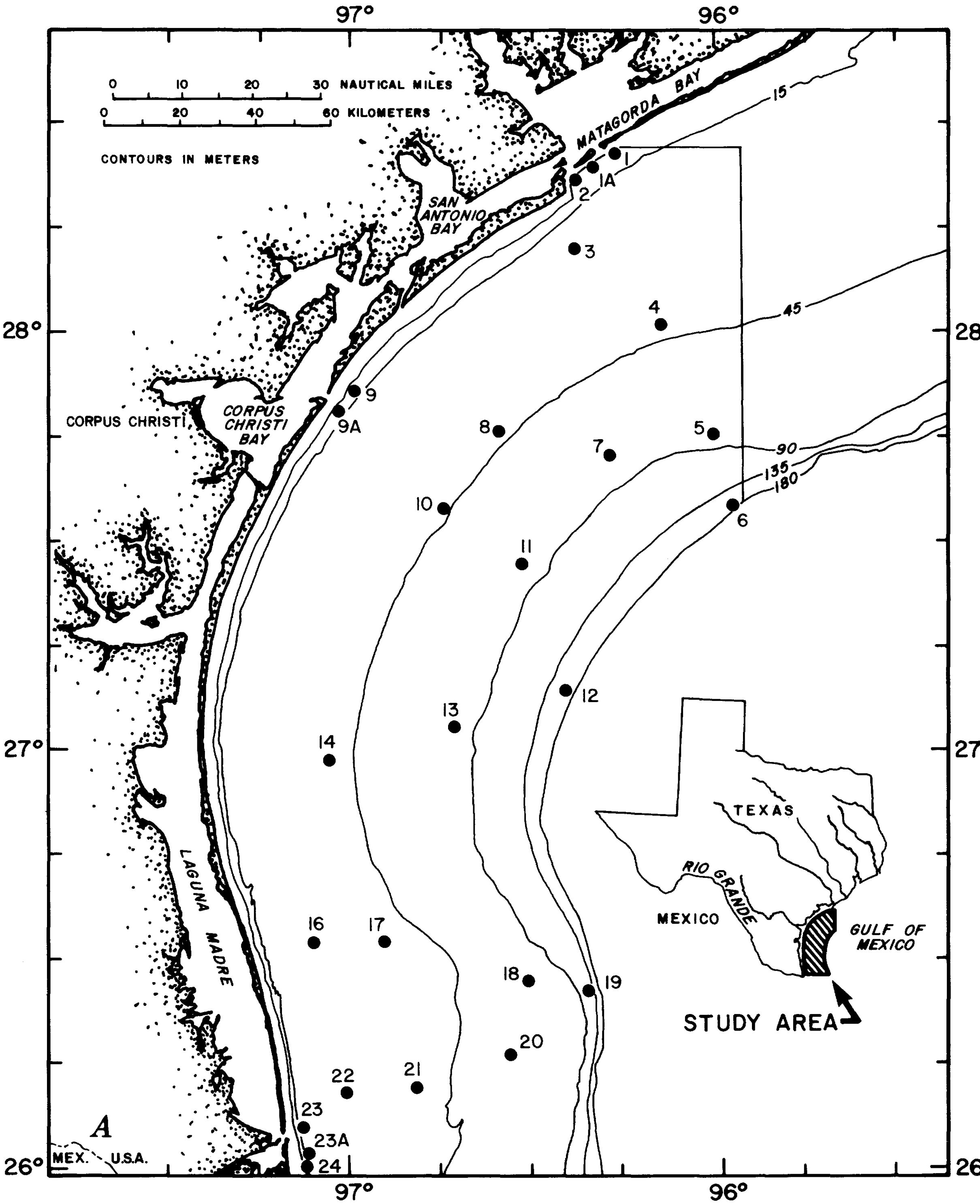


FIGURE 17.—Locations of sampling stations, South Texas Outer Continental Shelf. *A*, Suspended-matter sampling stations. Bathymetry in meters.

tation rates and stratigraphic distribution of selected trace metals. X-radiographs were made of each core, and they were subsampled at 2-cm intervals for analyses by atomic absorption of selected trace metals (Pb, Cd, Cu, Zn, Mn, and Fe) and for lead-210 activity. Most of these analyses are com-

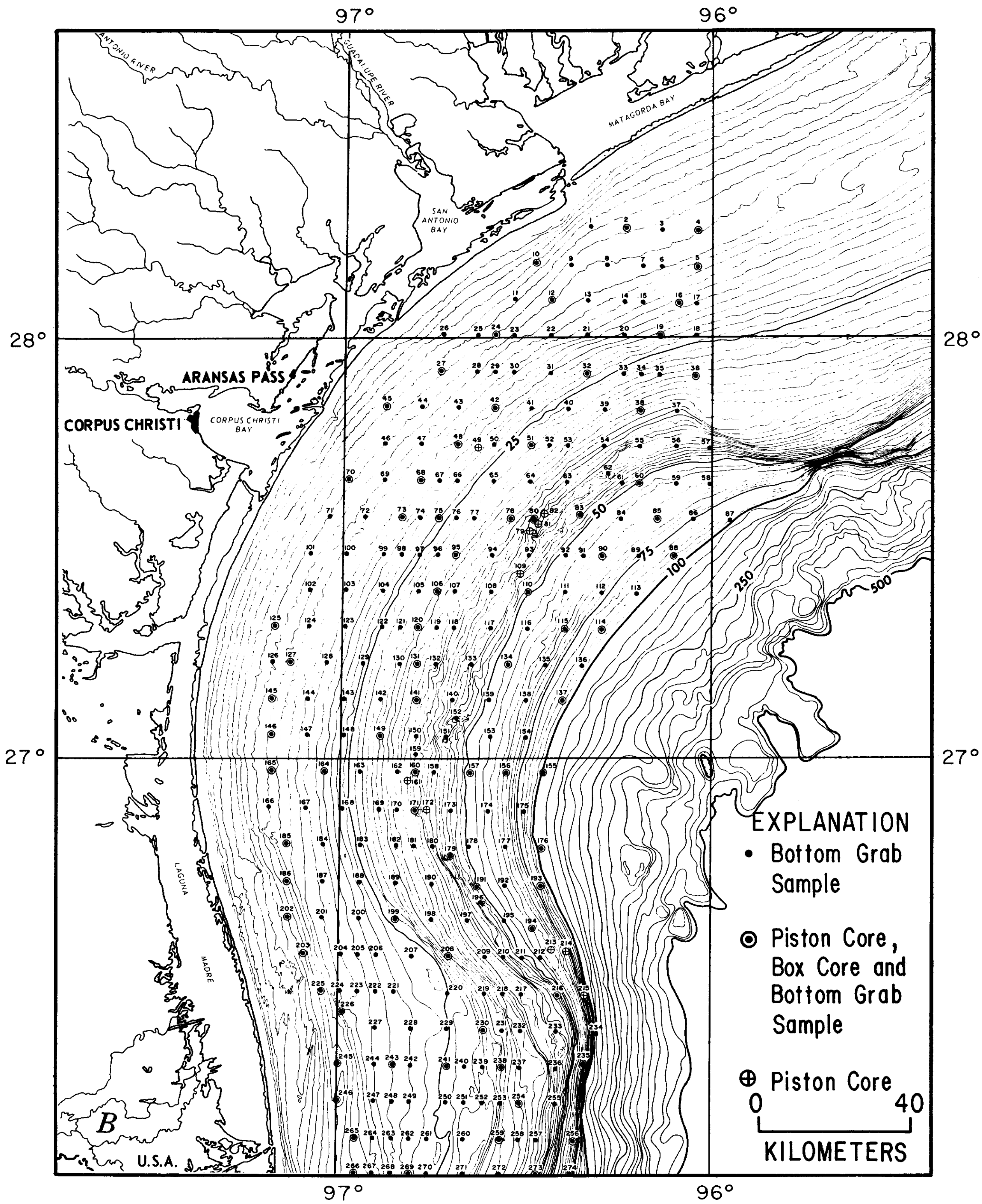


FIGURE 17.—Locations of sampling stations, South Texas Outer Continental Shelf—Continued. *B*, Piston core, box core, and bottom grab-sample stations. Bathymetry in meters.

plete, and more cores will be collected in midsummer 1979. The results of this study will be incorporated into an overall Potomac ecosystem model that will describe the response of the system to both physical and chemical changes.

Studies of the insular shelf around Puerto Rico (figs. 22*A*, *B*, *C*) revealed several large sources of sand that may be used in the future for construction and road building. For example, in the Cabo Rojo area, off the southwest corner of the island (fig. 22*A*), mapping has delineated a large area of clean, coarse, calcareous sand. Coring and seismic work show that the sand averages 5 m in thickness in an area >9 km^2. Bulk samples of the sand have been tested and found to be entirely satisfactory for concrete manufacturing. Although beach sands in the area are mainly biogenic detritus, the composition and grain size of the offshore sands are different. Apparently, the two areas are sedimentologically separate, and mining of the offshore sand probably will not adversely affect the shoreline and beaches. The results of these studies could assure Puerto Rico of a long-term solution to its problem of diminishing resources of construction sand.

Geologic investigations of the northern Puerto Rican insular shelf conducted in cooperation with Duke University have shown the sedimentation processes to be different from those common on the many Puerto Rican continental and insular shelves of the world. Most deposits on the Puerto Rican insular shelf are not in equilibrium with present conditions; they include relict deposits whose characteristics were determined by subaerial exposure during the last sea-level lowering and the subsequent sea-level rise. However, on the narrow north shelf of Puerto Rico, clayey, silty, and sandy sediment has originated under present conditions. Seismic profiling clearly reveals that the modern sediment is deposited on the rougher premodern surface. The profiles also indicate that the sediments in some areas of the upper insular slope off the northern coast are unstable. This slope instability will need detailed investigation prior to exploitation if the petroleum exploration planned by the Commonwealth of Puerto Rico is successful.

Studies of sedimentation off the Virgin Islands (fig. 23) began in September 1977 as a search for offshore sand sources. Three of the seven target areas were examined in detail, and two were found to contain significant deposits of sand. The textural signature of these deposits is very close to that of the sand found on the beaches, which has been used in the past for construction. The deposits are apparently relict and show no recent additions within the last 800 years.

Studies of Corpus Christi Bay and Nueces Bay, Tex. (fig. 24), reveal the presence of the filled ancient valley of the Nueces River 20 to 30 m below present sea level. Apparently this valley filled when sea level rose rapidly and extensive oyster reefs formed. Rapid deposition of sediment resulted in incomplete compaction and, therefore, in low shear strengths that could be hazardous when the material is subjected to loading.

Studies of the water column in Corpus Christi Bay show that sediment is being redistributed primarily in response to wind conditions, runoff from adjacent fluvial systems, and shelfward incursion of open Gulf Waters. Wind seems to be the primary factor in the distribution of material from source areas throughout Corpus Christi Bay.

Geochemical studies along the Texas coast reveal clear evidence of the effect of urbanization (increases in lead and cadmium) in many bays and estuaries. The areas of increased lead and cadmium concentrations are enlarging across the shelf at a rate of 2 km per year.

FUTURE PROGRAMS

Whatever the outcome of present exploration efforts on the Atlantic Continental Shelf, resource studies there will decline continuously during the next 3 to 4 years in favor of Continental Slope and Rise evaluations. Research in those important areas also will increase in the Gulf of Mexico. Major impetus to slope and rise studies will come from the International Phase of Ocean Drilling-II drilling initiatives in 1981 as site surveys begin. Additional project input will come in 1984 or 1985 when drilling begins. Presumably, technologic problems associated with deep-water drilling will be solved in the next few years, and the possible traps beneath the upper Continental Slope of the Middle Atlantic States will be drilled.

The utility of the CDP data collected thus far will be enhanced greatly by advanced processing carried out by contract groups and by use of the USGS' PHOENIX computer in Denver. The acquisition of a more sophisticated supplementary computer system during the next 5 years will strengthen the Geological Survey's capability in this important area.

During the next 5 years, environmental shelf studies will probably decline whereas the fairly high level of Continental Slope and Rise study that is already underway will be maintained (fig. 25). Certainly, the next 5 years will be needed to explore

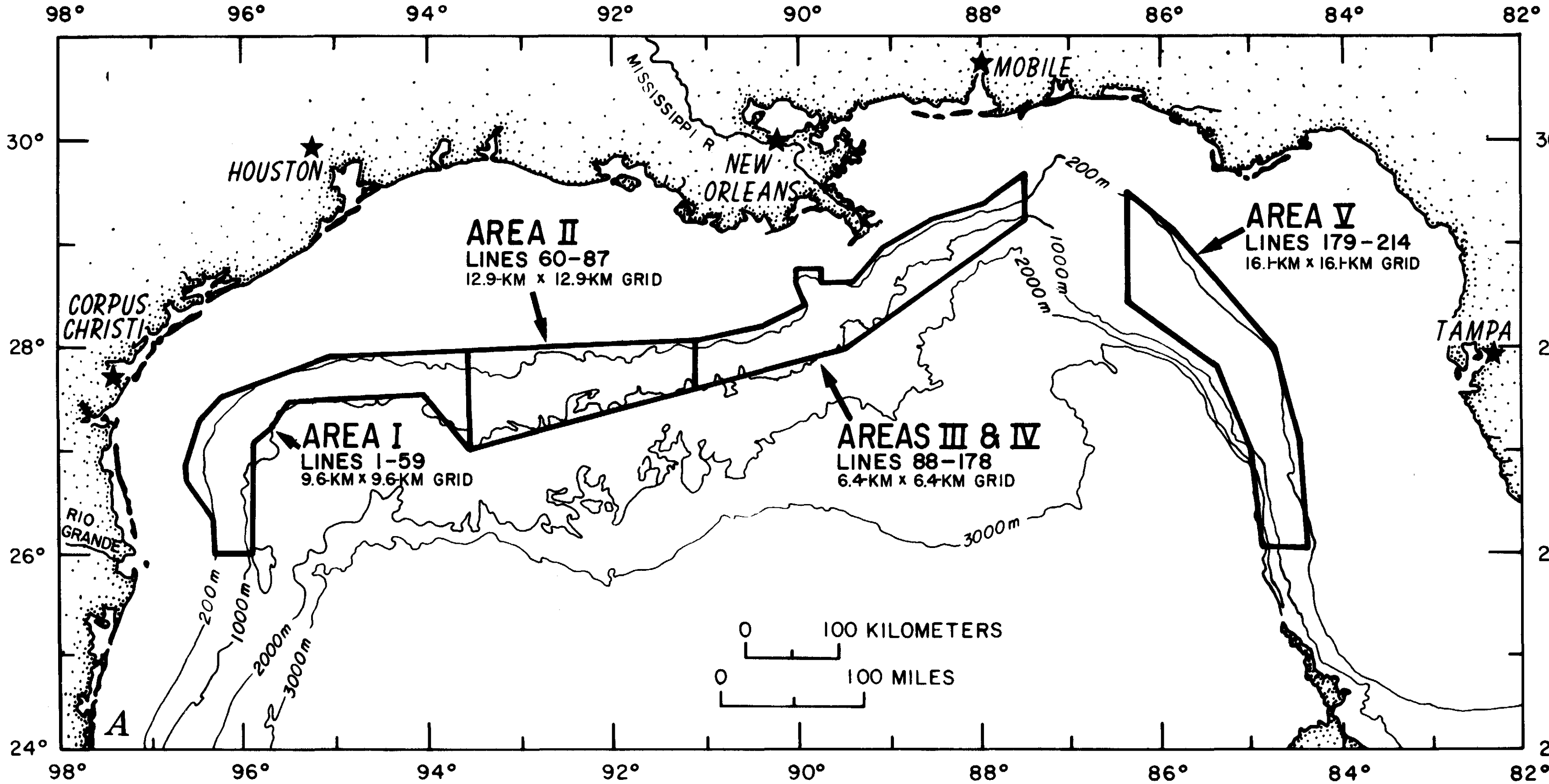


FIGURE 18.—Areas in northern part of the Gulf of Mexico where seismic data have been collected for the U.S. Geological Survey Continental Slope Project, areas where sediment is unstable, and locations of unstable features common off the Mississippi River complex. *A*, Areas I–V are areas where seismic data were collected at different intervals.

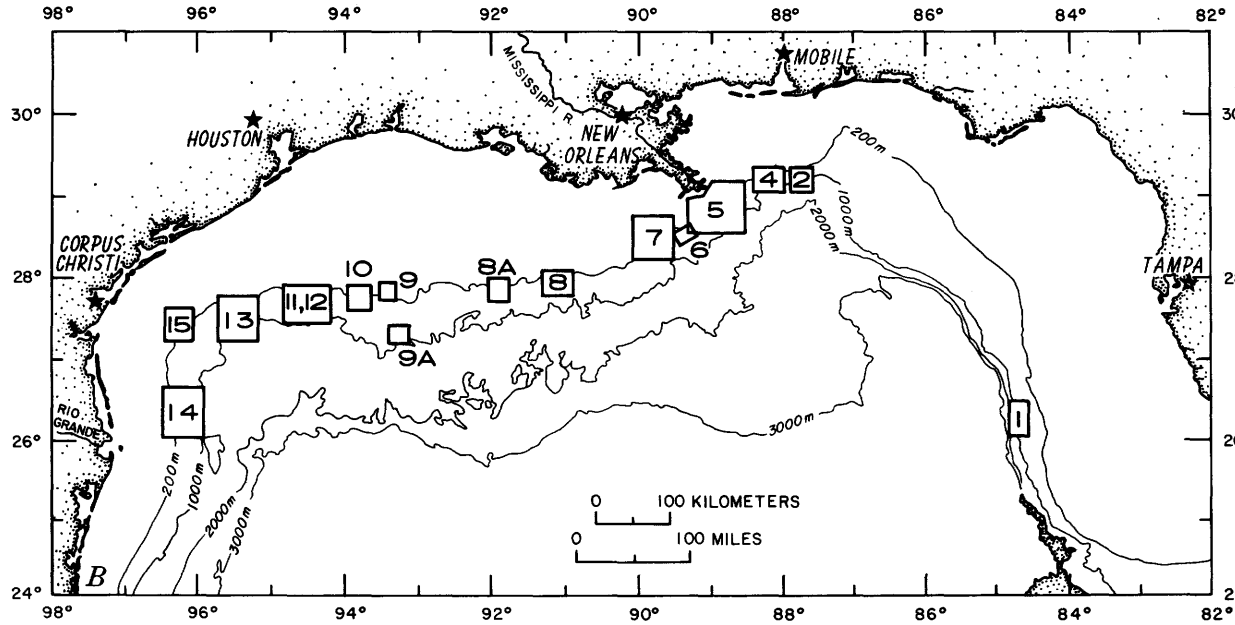


FIGURE 18.—Areas in northern part of the Gulf of Mexico where seismic data have been collected for the U.S. Geological Survey Continental Slope Project, areas where sediment is unstable, and locations of unstable features common off the Mississippi River complex—Continued. *B*, Areas 1, 2, 4–8, 8A, 9, 9A, and 10–15 are areas of sediment instability.

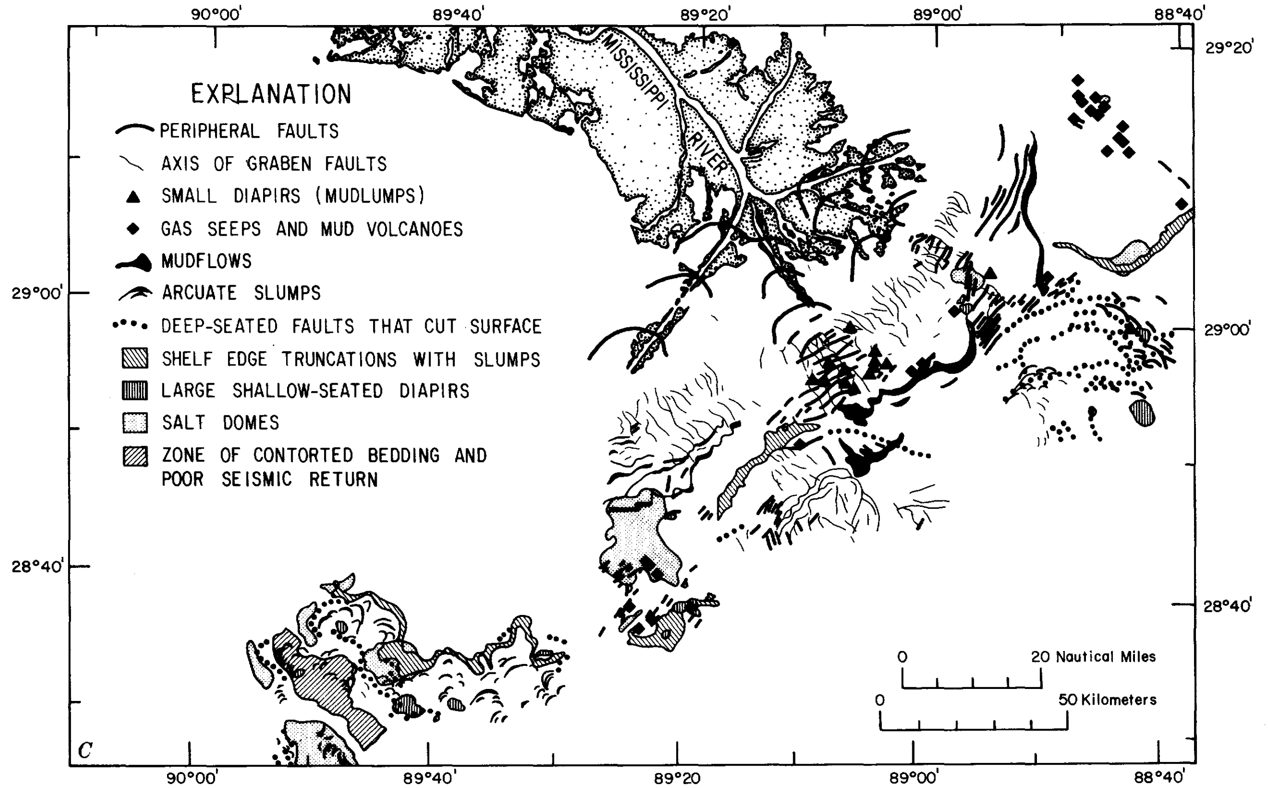


FIGURE 18.—Areas in northern part of the Gulf of Mexico where seismic data have been collected for the U.S. Geological Survey Continental Slope Project, areas where sediment is unstable, and locations of unstable features common off the Mississippi River complex—Continued. *C*, Types of instability common off the Mississippi River complex.

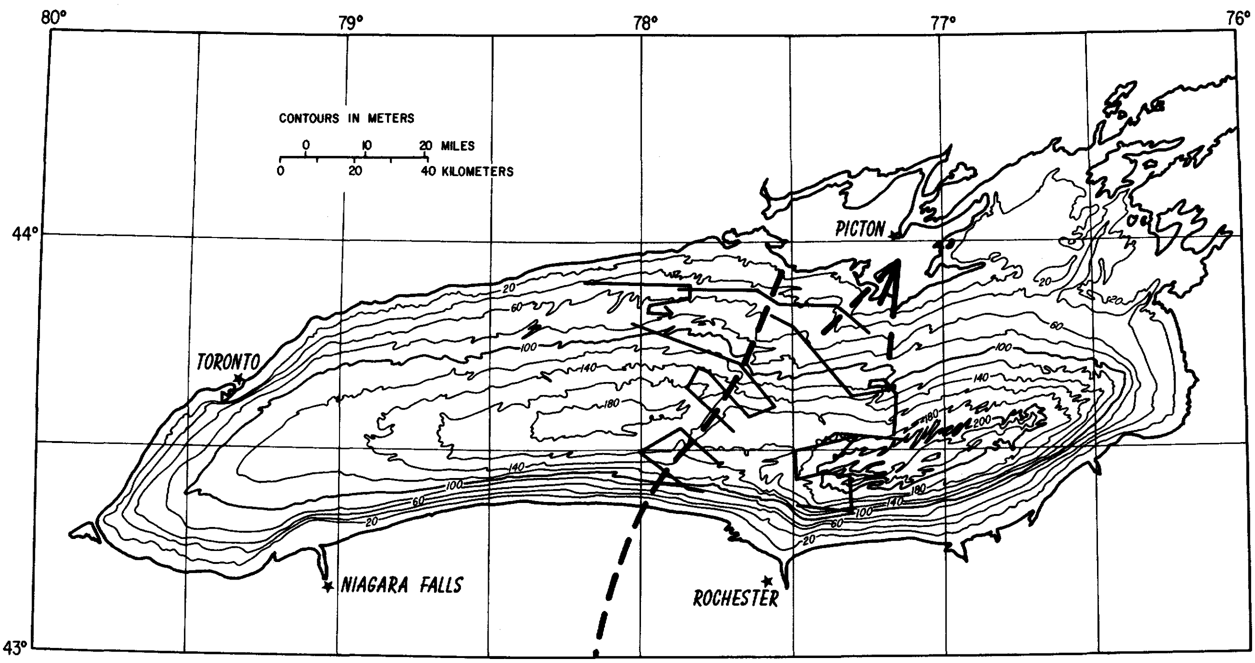


FIGURE 19.—Bathymetry of Lake Ontario (modified from Canadian Hydrographic Service, 1970; Thomas and others, 1972) and superimposed U.S. Geological Survey-New York State Geological Survey cruise tracks (solids lines) and fault structures under investigation (dashed lines). (From Hutchinson and others, 1979.)

thoroughly the Atlantic and Gulf of Mexico Continental Slopes. If significant amounts of petroleum are found and can be produced, activity will obviously have to be expanded.

Surveying on the inner shelf, estuaries, and lakes will probably continue at present levels until about 1981 when National priorities may shift to problems in these areas. At that time, more information will probably be needed for environmental hazards studies associated with reactors, pipeline routes, mine safety, sand and gravel mining, phosphorite mining, and tracking of pollutants. These studies will be carried out in consultation and close cooperation with State agencies.

The Marine Geology Program has provided regional data for input to assessments of mineral resources and potential resources along the Atlantic, Gulf of Mexico, and Puerto Rico/Virgin Islands continental margins; these assessments will be used by a U.S. Department of the Interior task force. The task force is conducting a study that will contribute to policy decisions on the possible end of a 10-year moratorium on the leasing of offshore tracts for mineral exploration.

If leasing is implemented, some of the vast sand and building aggregate resources on the shelf will be among the first materials sought as environmental problems and the competition for land rapidly shrink supplies along populated coastal areas. Leases for other resources, such as ferromanganese concretions on the Blake Plateau (fig. 26), will probably follow.

NEW CAPABILITIES

As a result of a Memorandum of Understanding with the National Science Foundation, the USGS can transfer as much as $1 million per year for ship time aboard UNOLS vessels. Because contracting for vessels from the private sector has met with but limited success, access to UNOLS ships represents a major breakthrough in operating capability. Not only are the vessels designed and maintained primarily for research, but also crews have gained the experience and capabilities necessary to make cruises far more cost effective. From a fleet, the proper-sized vessel usually can be selected for the specific research task, making data collection more efficient and cost effective. At present, UNOLS vessels from Woods Hole Oceanographic Institution, University of Miami, Duke University, Texas A&M University, University of Texas, and University of Rhode Island are being used in research from the nearshore region to the deep sea.

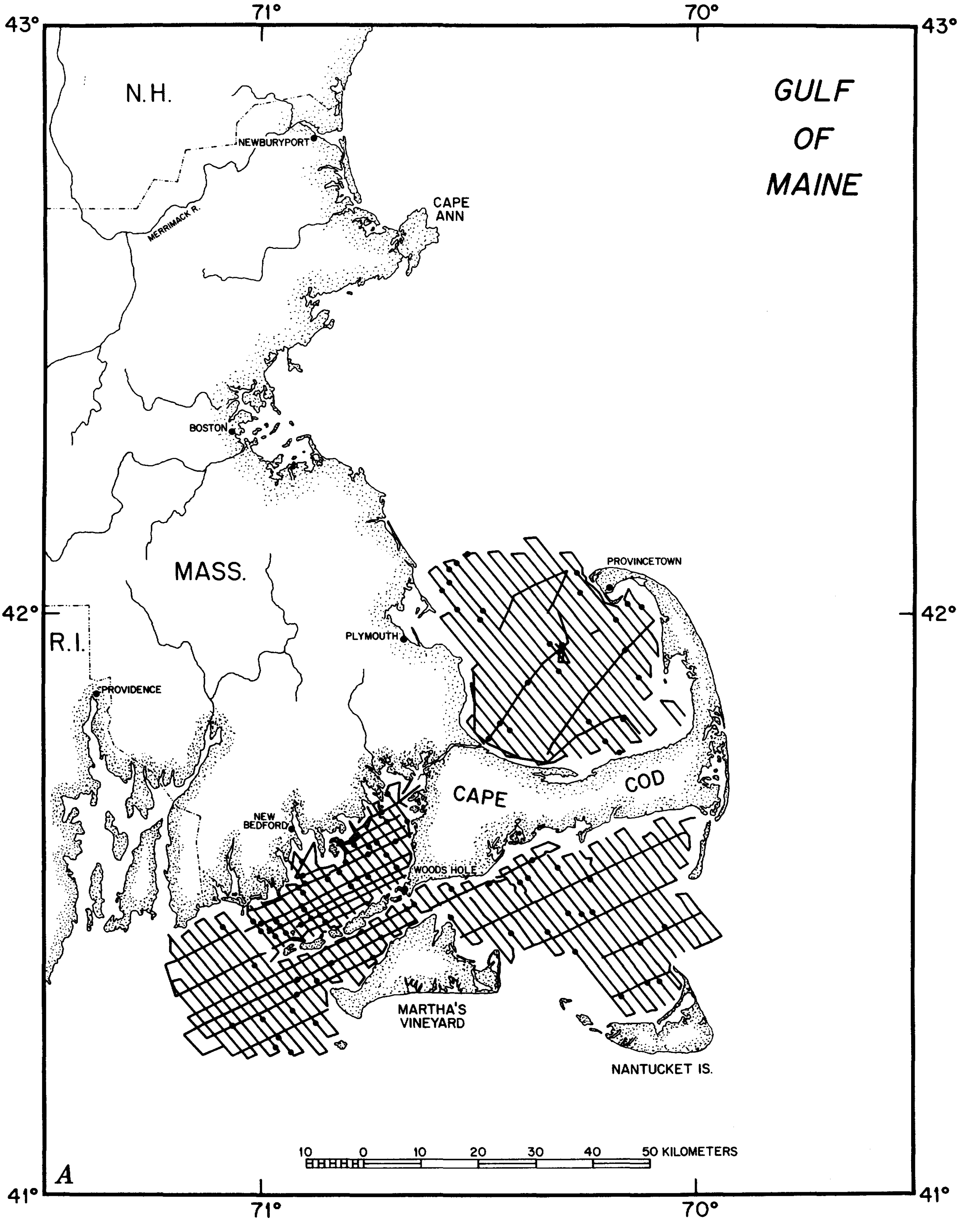


FIGURE 20.—Locations of seismic profiles and vibracores offshore north and south of Cape Cod, Massachusetts, and glacial moraines onshore coastal Massachusetts. *A*, Locations of 3,000 km of high-resolution seismic profiles and 100 vibracores (dots) obtained in Cape Cod Bay, Buzzards Bay, eastern Rhode Island Sound, Vineyard Sound, and Nantucket Sound, Massachusetts. (From O'Hara and Oldale, 1979.)

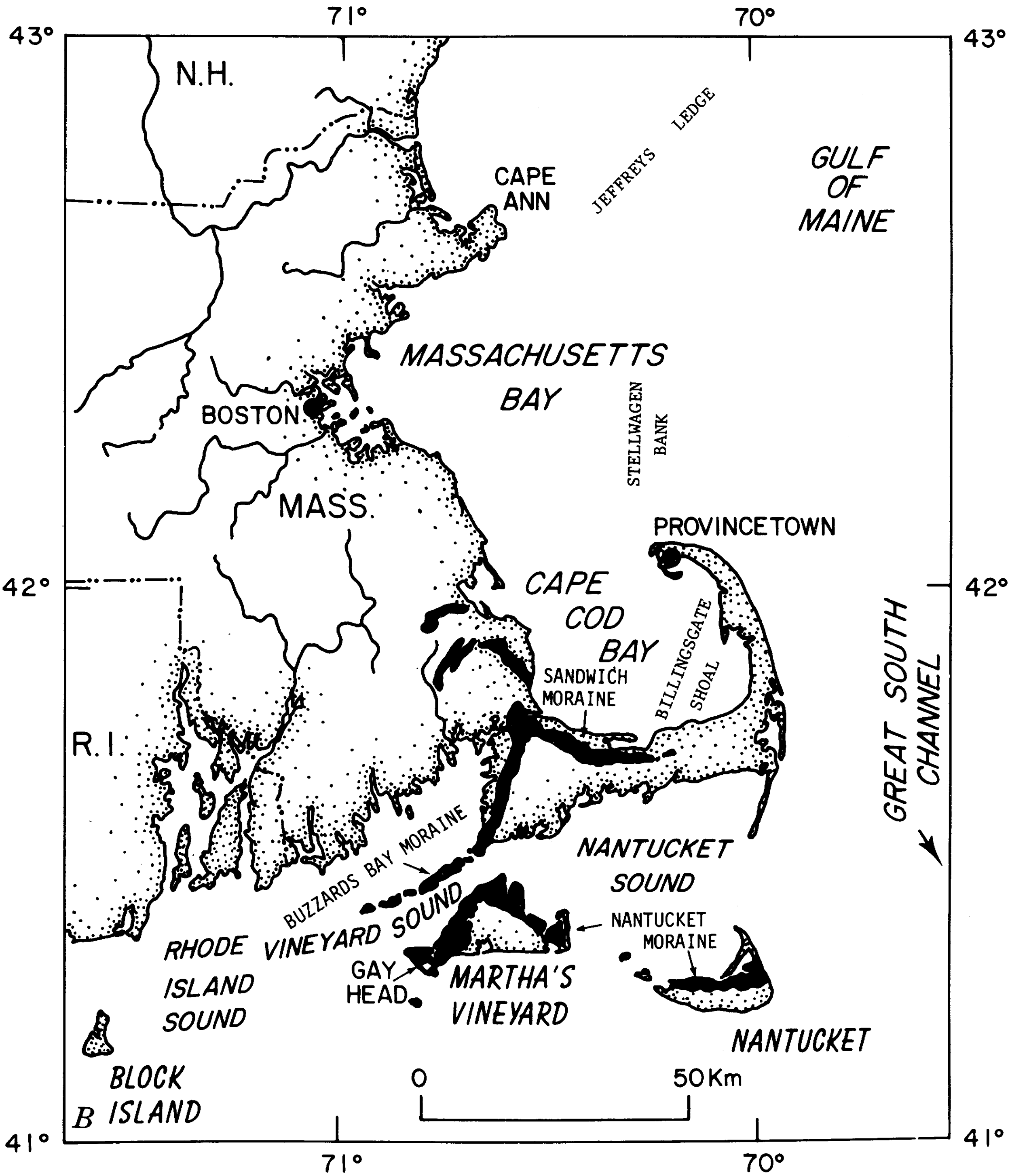


FIGURE 20.—Locations of seismic profiles and vibracores offshore north and south of Cape Cod, Massachusetts, and glacial moraines onshore coastal Massachusetts—Continued. *B*, Glacial moraines (black) of coastal Massachusetts. (From O'Hara and Oldale, 1979.)

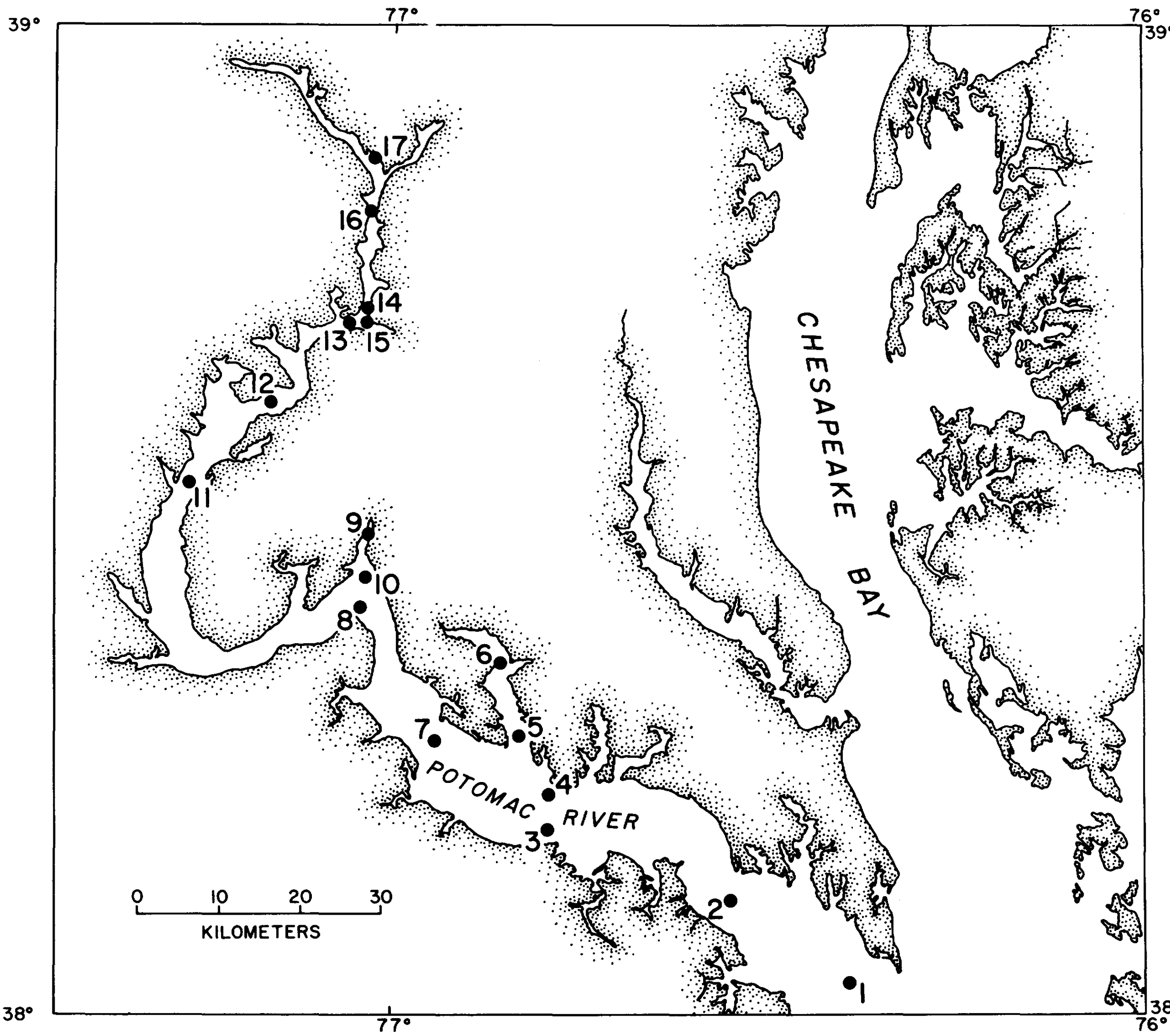


FIGURE 21.—Locations where 17 cores were collected on the Potomac River in October 1978.

During 1977–78, 31 different vessels were used in the program. These ranged in size from motorboats (7 m long) to the research vessel (R/V) *Atlantis* (70 m long). Many of these vessels are shown in figure 27.

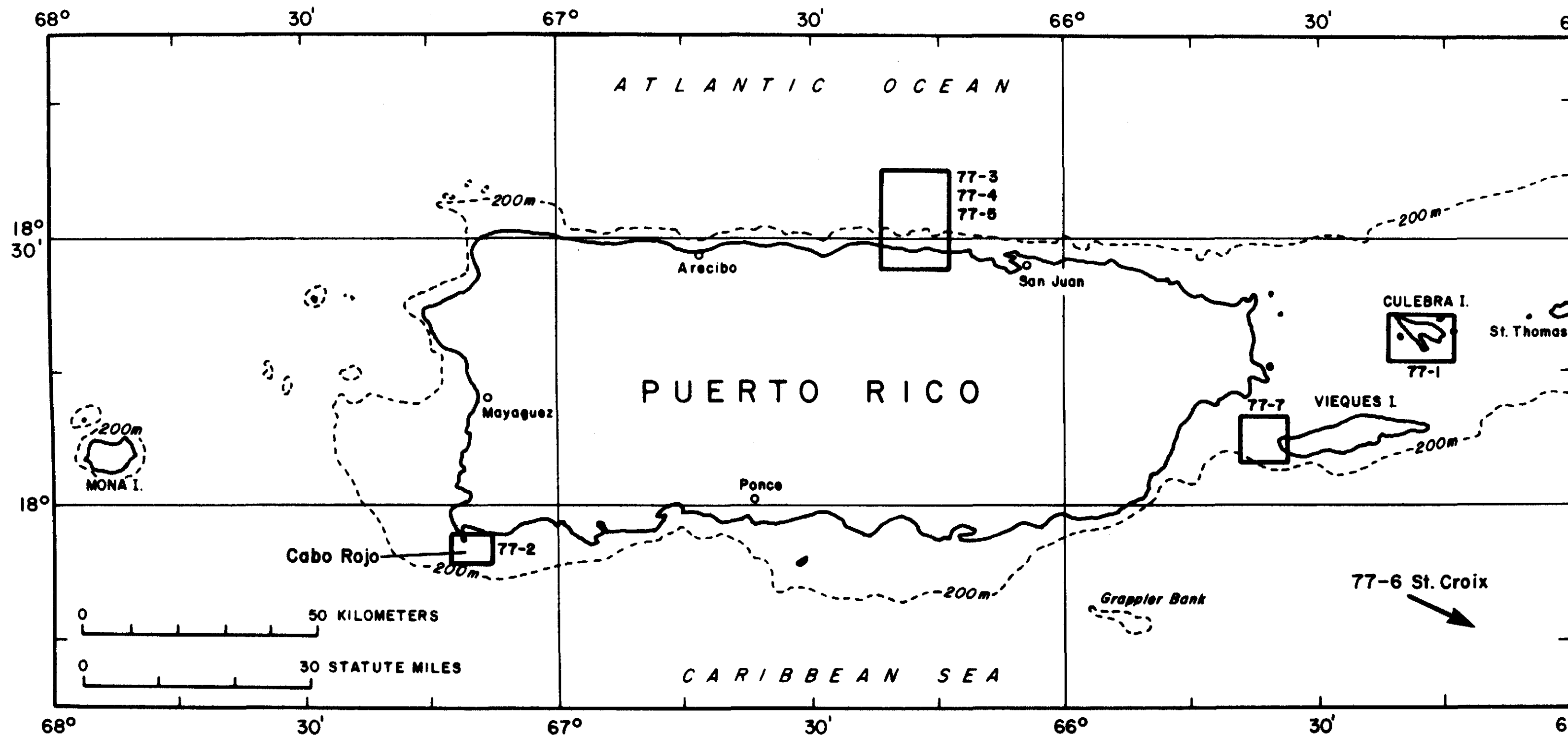
A totally new capability has been added to the Marine Geology Program's inventory of equipment through the acquisition of a 12-m-long nearshore research craft, the R/V *Neecho* (fig. 28).

The vessel can be put on a trailer and moved quickly from estuary to estuary or to inland lakes. It is fully equipped with instruments for geophysical and geological surveys in restricted waters and will be used in investigations of shallow structures, stratigraphy, and geochemistry in response to needs for earthquake-hazard assessment, drilling- and mining-hazards assessment, and pollutant tracking.

A smaller boat (9 m long) for studies of Gulf Coast estuaries has been acquired recently from the Coast Guard. It will replace the aging 7-m craft that has been used for the past 8 years for nearshore studies.

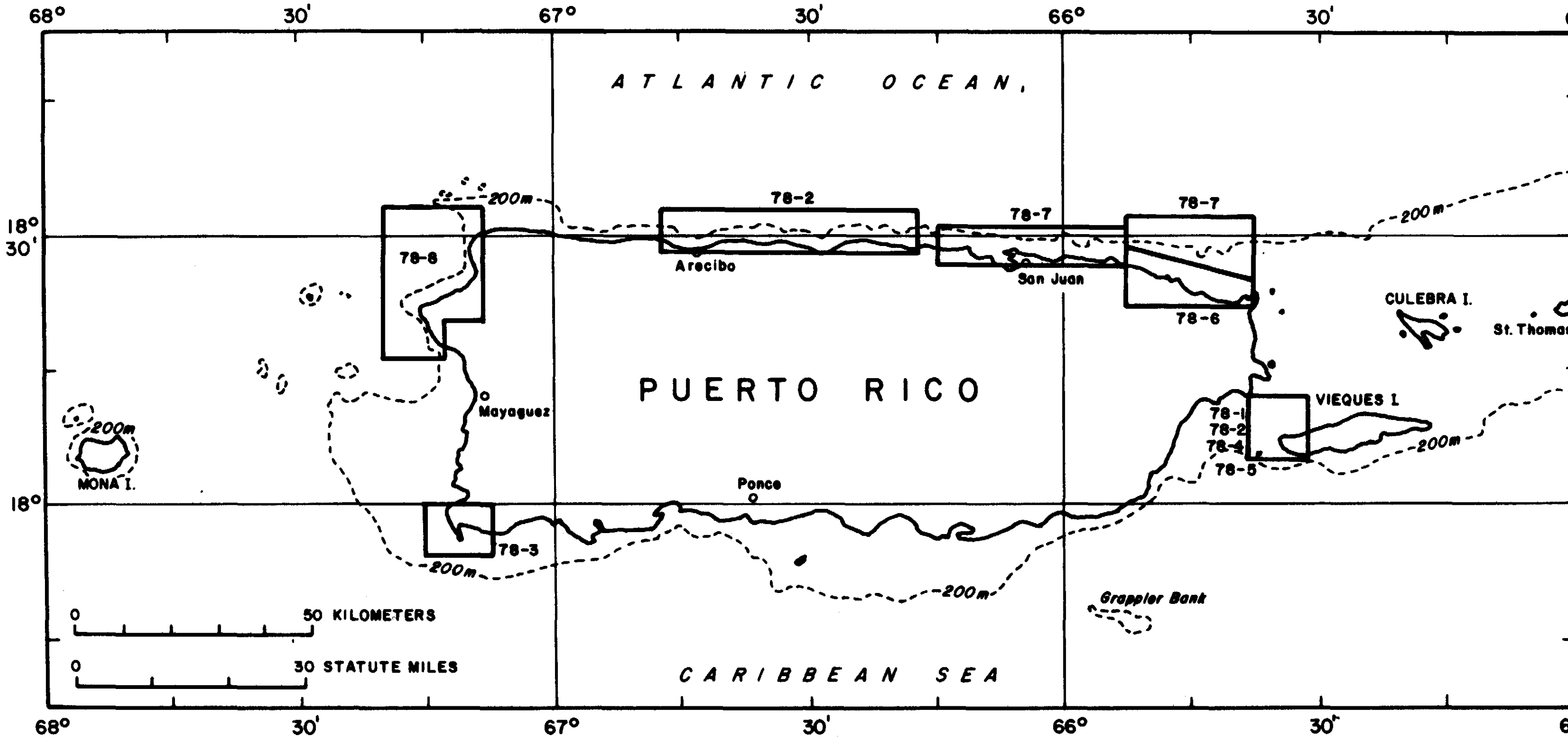
The capabilities of the marine geotechnical laboratory in the Corpus Christi office are being expanded so that equipment in the laboratory can be used to assess the engineering properties of bottom sediments from areas where petroleum is being, or may be, produced. This will be the first laboratory of its kind in the Geological Survey, and it will serve as a research center for government, academic, and industry geotechnical problems.

Three systems for acquisition of geophysical data have been improved during 1977 and 1978. The first is a geophysically instrumented sediment probe



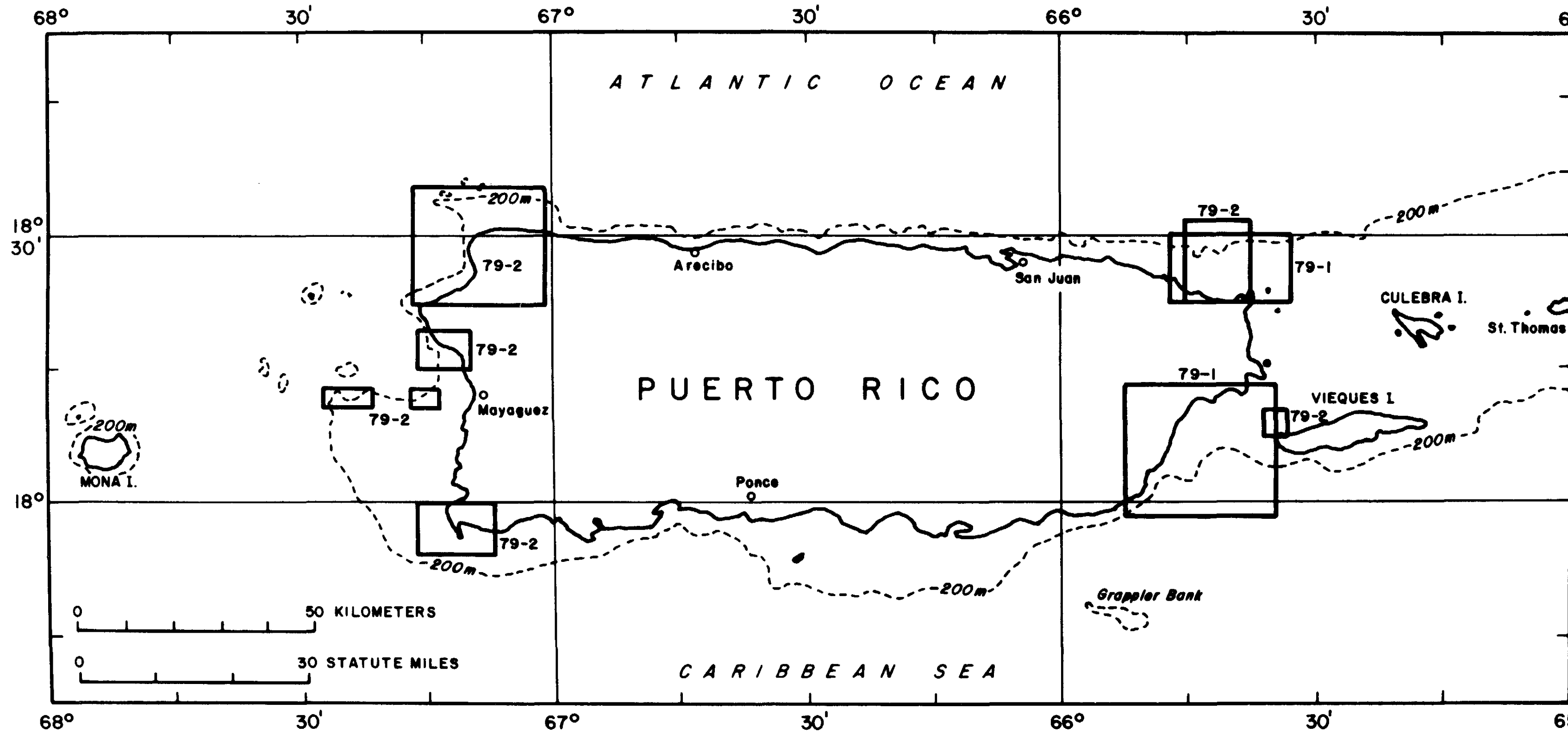
A

FIGURE 22. — Working areas, Puerto Rico Marine Geology Cooperative Project, fiscal years 1977, 1978, and 1979 (through March 1979). *A*, 1977.



B

FIGURE 22.—Working areas, Puerto Rico Marine Geology Cooperative Project, fiscal years 1977, 1978, and 1979 (through March 1979)—Continued. *B*, 1978.



C

FIGURE 22.—Working areas, Puerto Rico Marine Geology Cooperative Project, fiscal years 1977, 1978, and 1979 (through March 1979)—Continued. *C*, 1979 (through March 1979).

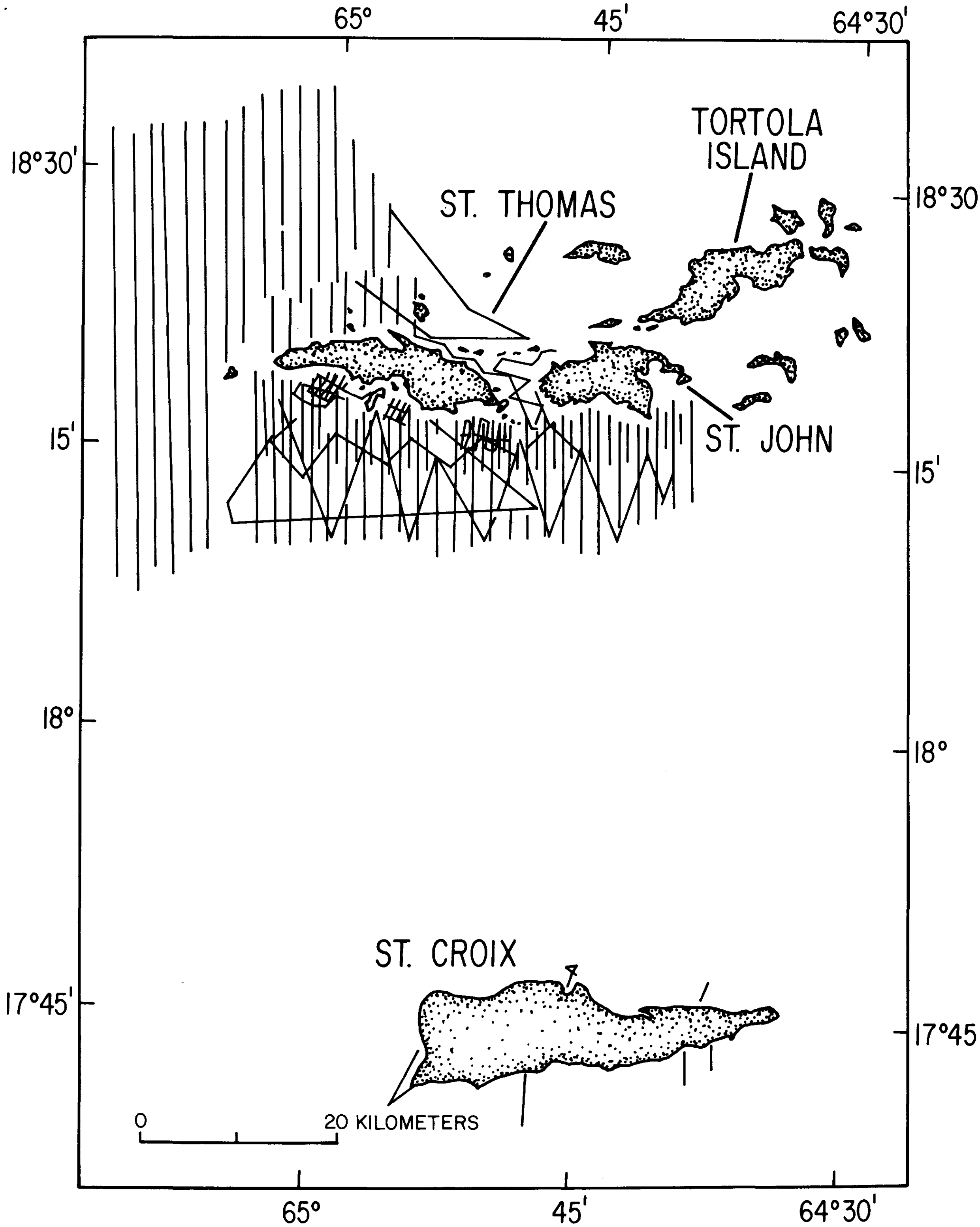


FIGURE 23.—Tracklines along which submarine geologic data were collected around the Virgin Islands during 1977–79.

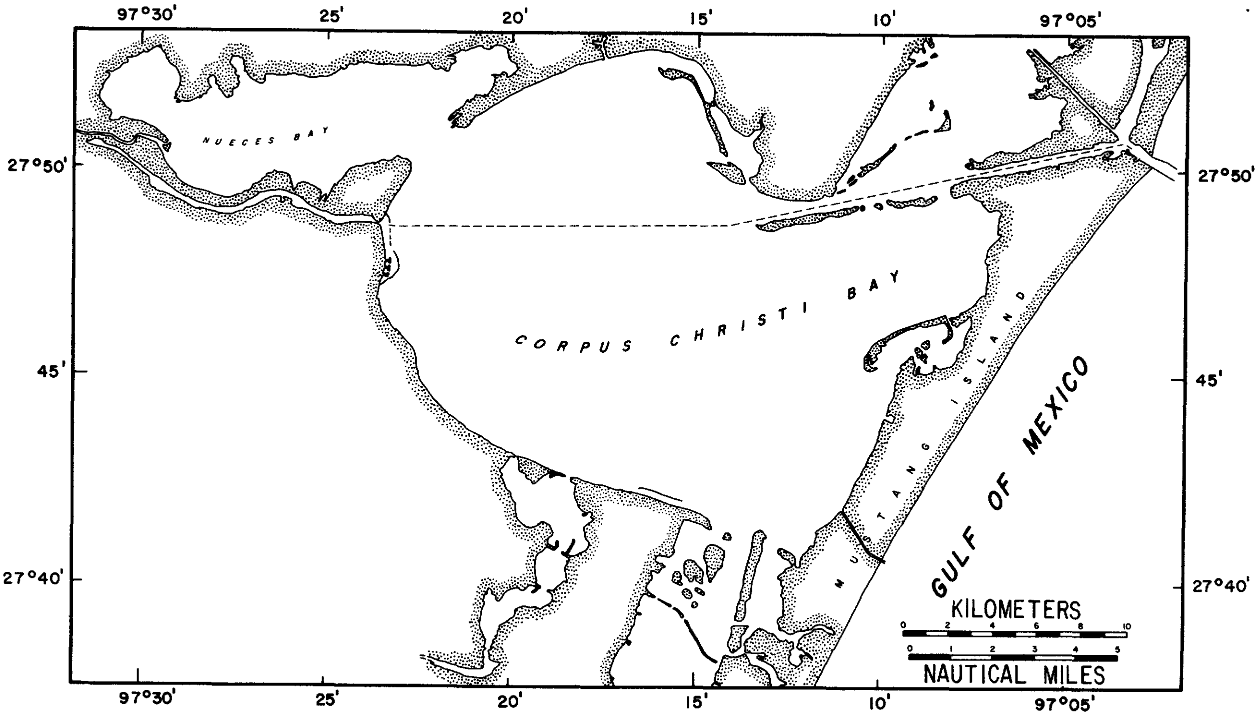


FIGURE 24.—Corpus Christi Bay and Nueces Bay, Texas.

(GISP) that will monitor sediment stress as a function of depth. The GISP system consists of a 10-m probe having pressure transducers (piezometers) at depths of 0, 3, 7, and 10 m and a recorder/electronics package that is commanded to the surface after a 30- to 40-day deployment. The record from these systems will yield a scalar stress measurement (modulus of stress vector) as a function of time at four depths. Sediment overpressure and shear stress, both leading to instability, can be assessed by these measurements. Five GISP's will be ready for deployment in 1980.

The second, an ocean-bottom seismometer, is a device to record earthquakes. Five systems were deployed recently on the Continental Shelf off Charleston, S.C. Five more instruments will be deployed off the Aleutian Islands during the summer of 1979.

The third, a 12-channel CDP seismic-reflection system, will be used to conduct detailed surveys on areas of the Continental Shelf and Slope where our regional 40-km-spaced grid suggests possible oil and gas accumulation. A modification of the system will be used for high-resolution multichannel surveys in shallow waters. Such a system is essential to resolve details of shallow structure that may be critical to reactor siting and mining safety. A pressure core barrel, which has been worked on since 1976, has been tested recently. It is designed to study the in situ characteristics of gas-charged sediments common on the Mississippi Delta and on Continental Slopes; the texture and structure of these sediments normally change when a conventional sediment core is brought to the surface where it releases its gas at atmospheric pressure.

During 1977–78, nine tripods bearing instruments have been designed and constructed to measure in situ current speed and direction, wave height, temperature, and water turbidity and to take continuous bottom photographs. These systems have produced an enormous amount of new information concerning shelf sediment dynamics that is pertinent to rig, platform, and pipeline design in the potentially productive areas of the OCS.

Additional equipment acquired in 1977 and 1978 includes a variety of geophysical gear such as air guns, sparkers, tuned transducer systems, sidescan sonars, seismic streamers, various flat-bed recorders, navigation systems such as loran receivers, satellite navigators and radar, a variety of winches, and supporting equipment such as generators.

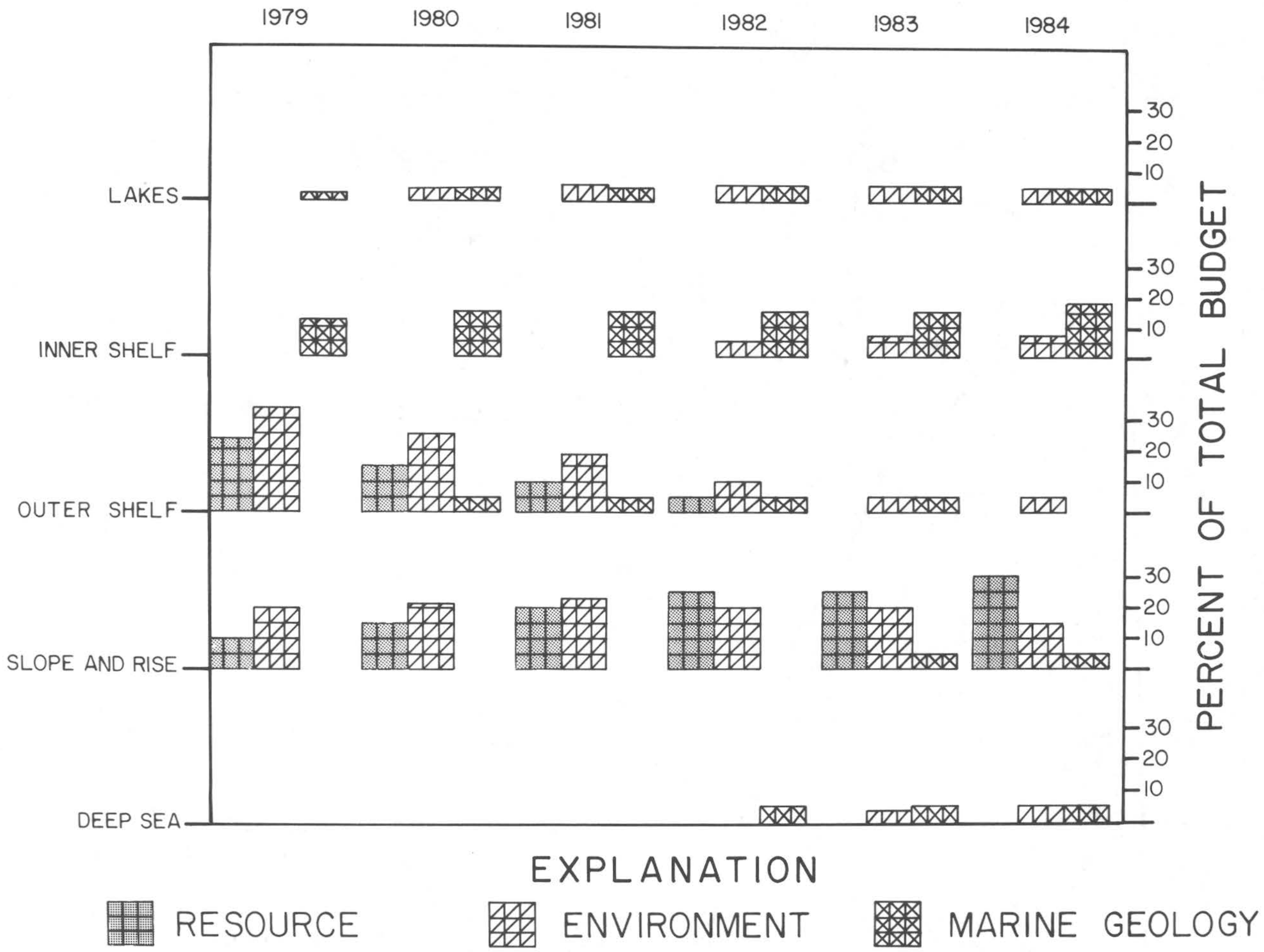


FIGURE 25.—Percentages of the budget of the Atlantic-Gulf of Mexico Marine Geology Program for 1979–84 being allocated for resource, environmental, and marine geology studies of different environments in and off the Eastern United States.

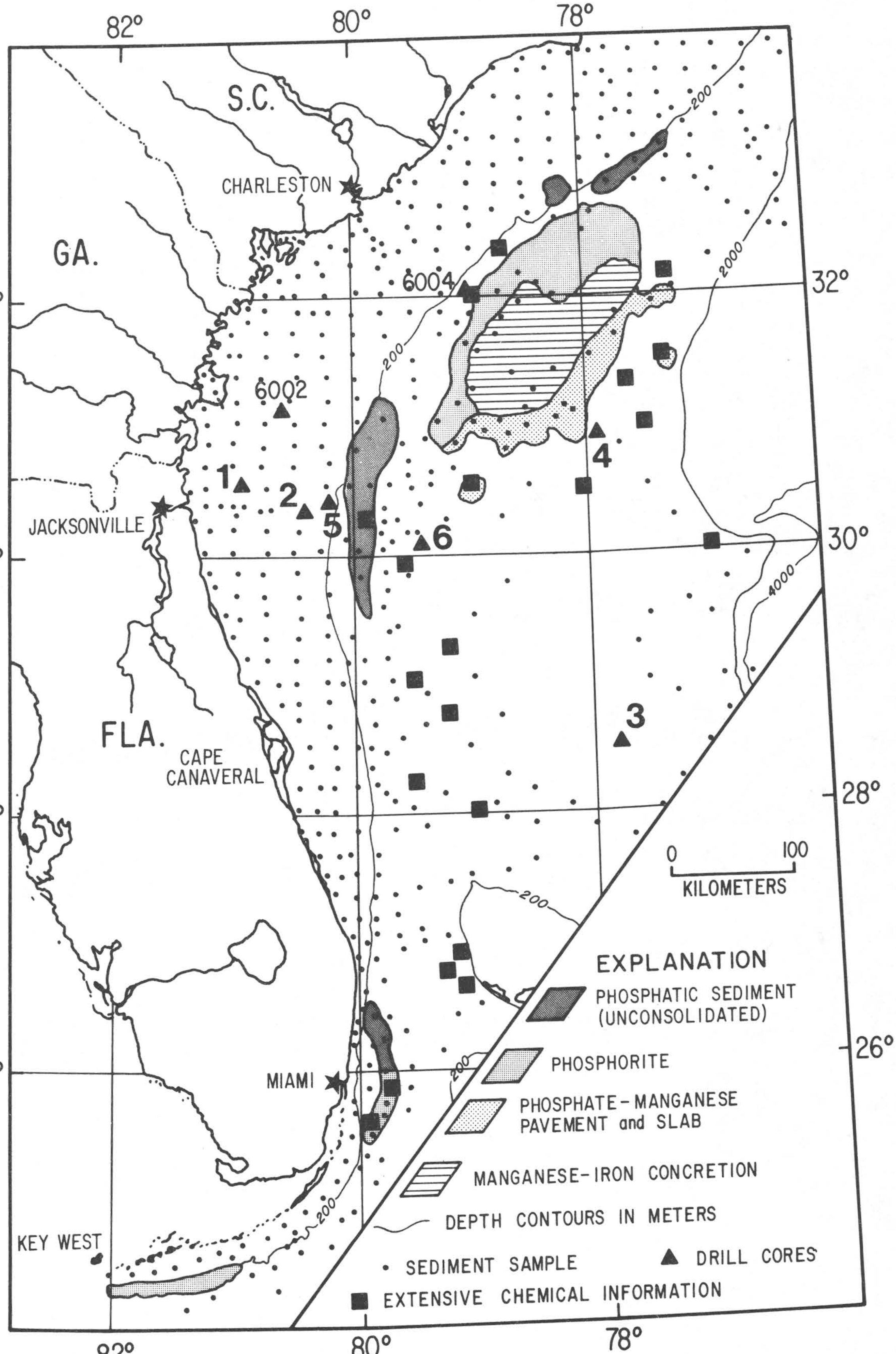


FIGURE 26.—Sample sites and locations of mineral resources on the U.S. South Atlantic continental margin. Bathymetry in meters.

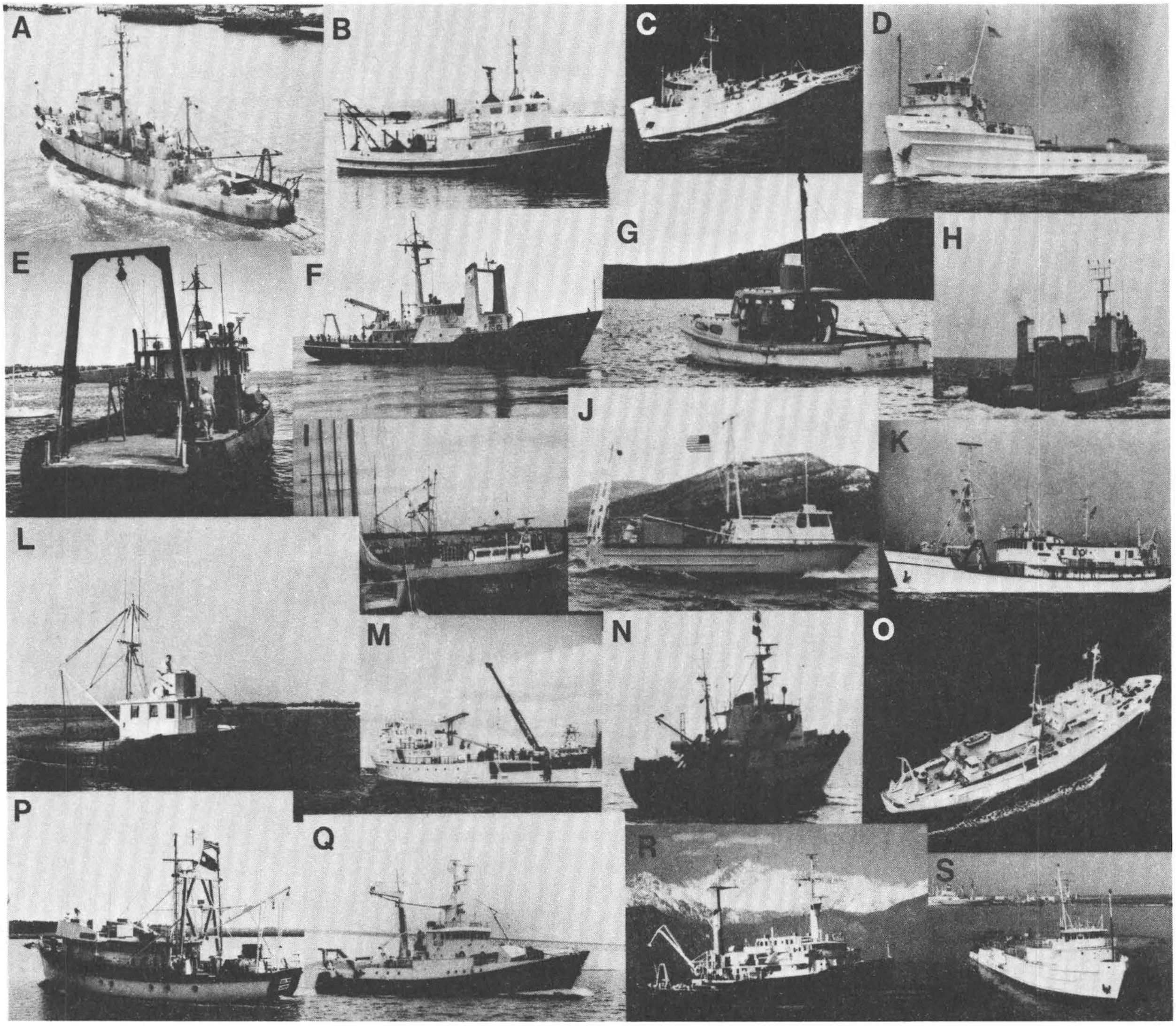


FIGURE 27. — Some of the vessels that were used in the Atlantic-Gulf of Mexico Marine Geology Program for fieldwork in 1977 and 1978. *A*, R/V *Advance II; B*, R/V *Jean A; C*, R/V *Columbus Iselin; D*, *State Arrow; E*, Tug *Whitefoot; F*, R/V *Oceanus; G*, R/V *Sarima; H*, R/V *Decca Profiler; I*, R/V *Orion; J*, R/V *Neecho; K*, R/V *Eastward; L*, R/V *Asterias; M*, R/V *Fay; N*, R/V *Annandale; O*, R/V *Gillis; P*, R/V *Bluefin; Q*, R/V *SubSig II; R*, R/V *Atlantis II;* and *S*, R/V *Coral Seal.*

FIGURE 28.—Research vessel *Neecho*.

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