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DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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SEDIMENTS, STRUCTURAL FRAMEWORK, PETROLEUM POTENTIAL, ENVIRONMENTAL CONDITIONS, AND OPERATIONAL CONSIDERATIONS OF THE UNITED STATES NORTH ATLANTIC OUTER CONTINENTAL SHELF.

BY

U.S. GEOLOGICAL SURVEY

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SEDIMENTS, STRUCTURAL FRAMEWORK, PETROLEUM POTENTIAL, ENVIRONMENTAL CONDITIONS, AND OPERATIONAL CONSIDERATIONS OF THE UNITED STATES NORTH ATLANTIC OUTER CONTINENTAL SHELF

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1975

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Sediments, Structural Framework, Petroleum Potential, Environmental Conditions, and Operational Considerations of the United States North Atlantic Outer Continental Shelf

By the U.S. Geological Survey

ABSTRACT

The area designated for possible oil and gas lease sale as modified from BLM memorandum 3310 #42 (722) and referred to therein as the North Atlantic Outer Continental Shelf (OCS) contains about 58,300 sq km of shelf beneath water depths of less than 200 m and lies chiefly within the Georges Bank basin. The oldest sediments drilled or dredged on the bordering Continental Slope are sandstone, clay, and silt of Upper Cretaceous age. In Upper Cretaceous exposures, on Marthas Vineyard and nearby New England islands, the predominant lithology appears to be clay. About 125 km northeast of the eastern tip of Georges Bank, the Shell B-93 well penetrated clays and silts of Upper and Lower Cretaceous age above dense Jurassic carbonate rocks which overlie a basement of lower Paleozoic slate, schist, quartzite, and granite.

Structurally, the Georges Bank basin is a westerly trending trough which opens to the west-southwest. Post-Paleozoic sediments are more than 8 km thick in parts of the basin. Major structural features appear to be directly related to basement structures. Local anticlines, probably caused by differential compaction over basement flexures and horst blocks or by later uplift along basement faults are reflected principally in Lower

Cretaceous and older sediments, though some of these features continue upward to within 0.7 of a second (about 650 m) of the seafloor.

Tertiary deposits in the Georges Bank basin are probably up to a kilometre thick and are made up of poorly consolidated sand, silt, and clay. The Cretaceous section is inferred to be up to 3.5 km thick and to be mainly clastics -- shale, siltstone, calcareous shale, changing to limestone in the lowest part of the system. Jurassic rocks in the deepest part of the basin appear to be about 3.6 to 4.0 km thick and probably consist mainly of dense carbonates.

Potential source rocks in the Georges Bank basin may include organic-rich Cretaceous shale and carbonaceous Jurassic limestone. By analogy with the Scotian Shelf, Cretaceous sandstones are considered to be potential reservoir rocks. Local zones of porous dolomite are believed to be present in carbonate rocks of Jurassic age and should not be overlooked as potential reservoirs.

Structural highs related to draping and differential compaction over basement blocks could be important potential petroleum traps. Additional traps may include reef structures near the shelf edge, updip pinchouts, and stratigraphic traps in both clastic and carbonate sediment.

A statistical mean for the undiscovered recoverable petroleum resources is calculated to be 0.9 billion barrels of oil and 4.2 trillion cubic feet of gas. At the 5 percent probability level (1 in 20 chance) the undiscovered recoverable petroleum resources are calculated to be 2.4 billion barrels of oil and 12.5 trillion cubic feet of gas. These undiscovered recoverable petroleum resources are those quantities of oil and gas that may be reasonably expected to exist in favorable settings, but which have not yet been identified by drilling. Such estimates, therefore, carry a high degree of uncertainty.

Environmental studies of Georges Bank indicate a low-moderate risk from petroleum development. However, the risk estimate is based on very limited data. Drift bottle returns used to infer oil spill trajectories show about a 2% overall recovery rate. Meteorologic data comes mainly from nearby land areas and from ships attempting to avoid storms. Seismicity on Georges Bank is low. This may reflect, in large part, the difficulty of land-based stations in recording earthquakes far from the coast. Direct data on the engineering properties of shallow buried sediment comes mainly from two Texas Tower surveys of limited areas on Georges Shoal and Nantucket Shoals made in the early 1950's. The 17 holes (most less than 30 m deep) reveal some silty layers below loose sand and much lateral variability in sediment type over short distances.

The technology for exploration at the required water depths (20 m - 200 m) is available. Mobil drilling units are in great demand around the world and will have to be brought in from other areas along with skilled manpower. Our highest estimates indicate 50 platforms, 800 producing wells, 1,100 km of pipeline, and 5 onshore terminals may be needed. The time frame for production, using our high estimates (5% probability) for the undiscovered recoverable resources, could include 4-5 years for significant development, 6-7 years until production commences, and 18 years until peak production.

INTRODUCTION

This report was compiled in answer to the Bureau of Land Management (BLM) memorandum 3310 #42 (722) requesting, from the U.S. Geological Survey (USGS), a summary of the geology, potential mineral resources, estimated oil and gas resources, potential environmental hazards, and operational considerations for a possible oil and gas lease sale in the United States North Atlantic Outer Continental Shelf (OCS) area. The report brings together the geologic research done in this area over the past century, beginning with the work of A. E. Verrill in the late 19th century (Schopf, 1968) and continuing on up to the present studies of deep crustal configuration of the area through use of common depth point (CDP) seismic reflection profiles. Researchers from academic institutions, government agencies and industry have studied the area and it is from their published knowledge and the ongoing USGS research and field projects that this synthesis is made.

In plate 1, the area designated for possible oil and gas lease sale as modified from BLM memorandum 3310 #42 (722), and referred to herein as the North Atlantic OCS area, is outlined by a dashed line. This area lies chiefly within Georges Bank. Georges Bank is a large, submerged platform of about 37,000 square kilometres (sq km) located on the Continental Shelf east-southeast of New England. But in a larger structural-stratigraphic sense, is is a broad trough of Mesozoic and Cenozoic sedimentary rocks that underlies the platform and adjacent areas. This broad structural depression has been termed the Georges Bank trough by Maher (1971) and the Georges Bank basin by Schultz and Grover (1974). Because of its broad width, we prefer the designation of Georges Bank basin. The general outline of the Georges Bank basin is shown by a dashed line on plate 1. The basin encompasses an area of about 65,300 sq km and includes all of the topographic platform called Georges

Bank, plus Great South Channel, Nantucket Shoals, and part of the Continental Slope (the major topographic incline to the deep ocean where the sea floor falls away from 200 metres (m) depth to 2,000 m depth over a distance of a few kilometres. The area under consideration for oil and gas lease sales (58,300 sq km), however, includes only those areas of Georges Bank basin on the Atlantic Outer Continental Shelf (OCS) that lie in water depths of less than 200 m (pl. 1).

PHYSIOGRAPHY

The area (pl. 1) is a broad shelf extending east-southeast from New England about 350 km. It is marked by extensive areas of sand shoals, channels, and featureless flat shelf. The physiography of the shelf area is dominated by two main features, Nantucket Shoals and Georges Bank (pl. 1). A broad channel (Great South Channel) 35 km wide and slightly more than 80 m deep divides the two areas. Georges Bank, in turn, is separated from the Scotian Shelf to the northeast by Northeast Channel a deep water passage 40 km wide and 230 m deep, that extends from the Gulf of Maine across the Continental Shelf. Uchupi (1968, p. C5) describes Georges Bank as "an immense barrier flanking the seaward side of the Gulf of Maine... This topographic high 150 km wide, and 280 km long, is one of a chain of banks extending from Nantucket Island to the Grand Banks". The northern half of the Bank is a vast complex of shoals (fig. 1) enclosed in less than 60 m water depth. The shoals consist of several arcuate NW-SE trending broad sand ridges up to several kilometres wide and several tens of kilometres long; they trend parallel to the main direction of tidal flow across the bank. Their surface is crenulated with second order sand waves (Uchupi, 1968), 10-20 m high, 100-700 m apart, and as much as 10 km long. The second order features can parallel the general trend of the shoal or be perpendicular to the shoal axis.

Nantucket Shoals (covering an area of 6,400 sq km) has the same general arrangement of sand shoals and higher ordered waves on their surface. Here, however, the shoals trend in broad arcuate patterns NE to SW and are developed from the shallow water depths adjacent to Nantucket Island out 85 km to the southeast in 40 m of water. The shoals are arcuate features 10-20 km long,

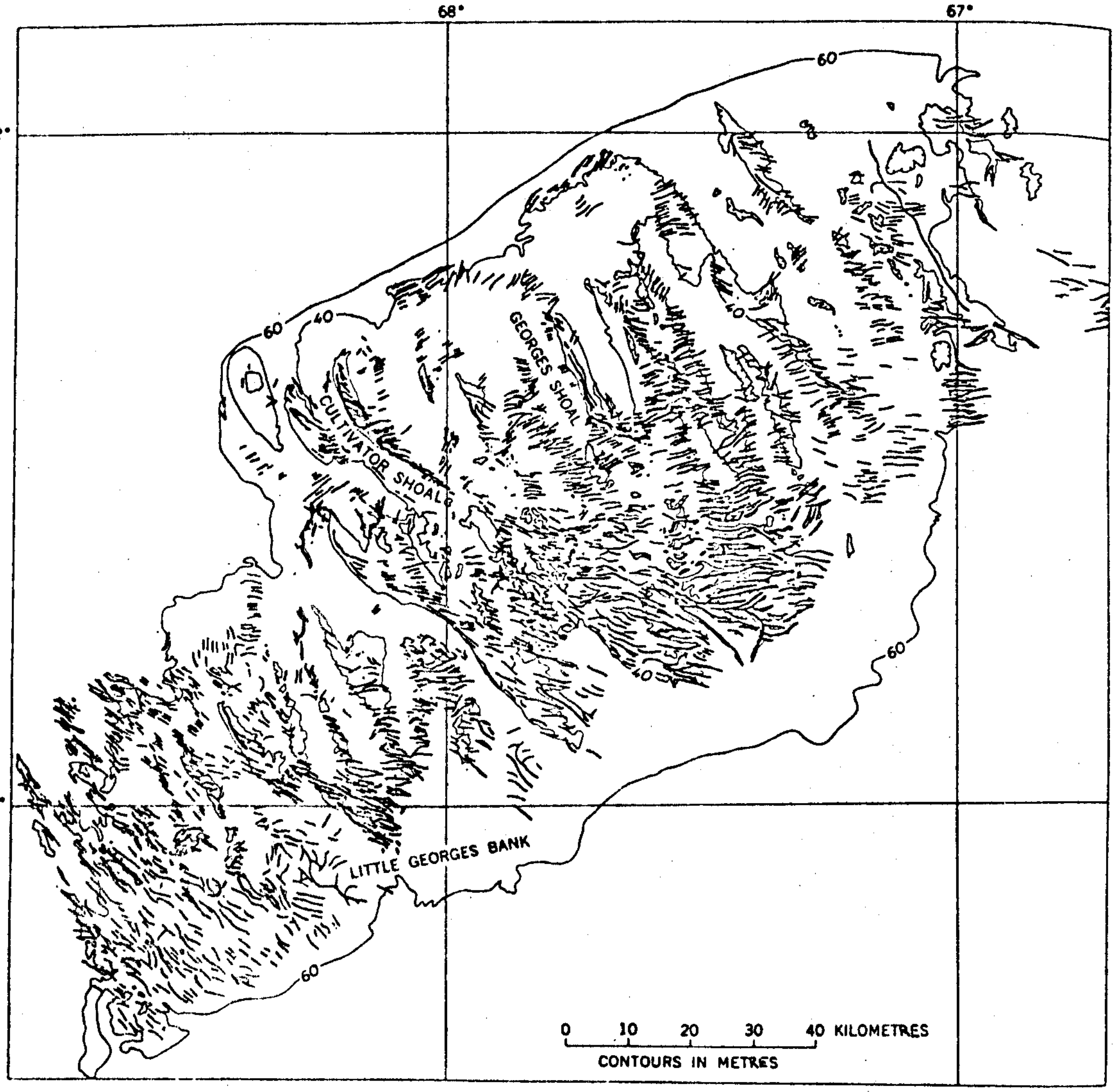


FIGURE 1 —Distribution of sand waves on Georges Bank. Curved lines indicate crests of sand waves. Based on soundings from U.S. Coast and Geodetic Survey hydrographic surveys. (After Uchupi, 1968)

2-4 km across, and asymmetrical in cross section (steep southeast side and a relief of 15-20 m). The channels between the shoals are broad (2-8 km) and crenulated by second order sand waves 1-2 km long, 3-4 m high, and less than 1/4 km across; the second order features trend normal to the shoals and channels and merge with the gentle northwest flanks of the shoals. Nantucket Shoals are obviously a current dominated area -- a subaqueous dune field shaped by the strong tidal currents that traverse it. The complexity of the bathymetry can be appreciated by references to C. and G. S. Chart 0708N-52 (Nantucket Shoals - Scale 1:125,000) published by the National Ocean Survey .

The shelf area south of the Georges Bank shoals is a flat sand covered surface similar to the shelf area south of Nantucket Shoals; it slopes from 60 m to 100 m over a distance of 50-75 km (0°3'). Some profiles across this area (Schlee, 1973, p. 15) show a hard, well defined reflector (with multiple echos) with no relief -- a sand plain. Apparently, some of the submarine canyons that indent the southern edge of the Bank have shelf extensions, a shelf valley 1-2 km wide, and with a relief of 2-4 m.

South of Georges Bank, the Continental Slope covers an area (9,000 sq km) where the sea floor deepens to slightly more than 2 km over a distance of 20-25 km, approximately 6° slope. The Continental Slope is the major physiographic feature of the area and marks the transition to the deep Continental Rise over a hummocky and gullied terrane, interrupted by several major submarine canyons, whose dimensions are hundreds of kilometres long, a few kilometres wide, and several hundred metres deep. The southern edge of the Bank is indented up to 25 km, by six major submarine canyons (from west to east, Hydrographer, Welker, Oceanographer, Gilbert, Lydonia and Corsair) plus several smaller unnamed canyons (pl. 1). The canyons were probably eroded in the Quaternary and late Tertiary during glacial stages when sea level stood at the present shelf edge. Glacial melt water streams would have delivered copious amounts of sediment to the upper slope; and as the sediments moved downslope from these point sources, the canyons were scoured out.

Intersecting the Continental Slope at about 68°W longitude is the New England Sea Mount Chain -- a series of 60 Mesozoic (?) volcanic cones (basalt) that stretch in a chain from the flanks of Georges Bank, southeast 1,200 km. Two of these (Bear and Physalia) are situated within 100 km of the shelf edge, where they project 1.5 and 1.9 km, respectively, above the sea floor. Two of the sea mounts (Bear and Mytilus) appear to have a thin sediment cap, from which Cretaceous and Eocene fossils were dredged (see a discussion of the sea-mount chain by Emery and Uchupi, 1972).

North of Georges Bank is the Gulf of Maine, a rectangular shaped area approximately 450 km by 230 km (pl. 1). Topographically, the Gulf of Maine is a series of broad basins and banks with irregular hummocky areas in between. There are 21 basins, from as little as 30 sq km in area to slightly more than 10,000 sq km. These basins occupy 30 percent of the Gulf (Uchupi, 1968), are nearly flat-floored features, 64 m to 377 m in depth. Many of the basins are compound depressions, in that two or more may be linked together with only low sills between. Banks and ledges can rise to within a few tens of metres of sea level and some are flat-topped.

GEOLOGY OF GEORGES BANK BASIN

Surficial Sediment

Georges Bank is covered by quartzose sand, medium to coarse-grained, with small amounts of gravel (Schlee, 1973, pl. 1; Trumbull, 1972; Milliman and others, 1972). The coarsest sediment is associated with interareas between shoals (Schlee and Pratt, 1970, p. 434) where quartzose gravel forms a lag; coarse to medium sand makes up the ridges (Stewart and Jordan, 1964). The sand is light brown (Stanley, 1969) quartzose well sorted sediment (pl. 2).

Over the Georges Bank, the sand fraction is 94 to 100 percent quartz and feldspar (Trumbull, 1972) with minor amounts of glauconite, heavy minerals, shell fragments, and rock fragments. Feldspar to feldspar and quartz ratio (1/8 - 1/4 mm size fraction - fine sand) is 5-10 percent (Milliman and others, 1972), pointing to the dominance of quartz. Shell fragments are mainly mollusks, though in the south central part of the Bank echinoids dominate; mollusks are prevalent again on the southern edge of the Bank (Milliman and others, 1972, fig. 7). The percent of iron oxide stained grains is low (5-25 percent) along the northern part of the Bank and becomes higher (25-50 percent) in the southern part, away from the shoals. Heavy minerals are less than 2 percent of the total sand; these are mainly opaques (mean of 40 percent of the total heavy mineral suite), altered heavy minerals (mean of 18.9 percent of the total heavy mineral fraction), and nonopaque heavy minerals. Garnet (40.7 percent - mean mineral percentage of the nonopaque part of the heavy minerals), staurolite (14.4 percent), and amphiboles (10.7 percent) are the main suites on Georges Bank with minor amounts of augite and epidote (Ross, 1970). Dark green to black grains of glauconite occur on Nantucket Shoals and parts of Georges Bank (trace to 2 percent, Trumbull, 1972, fig. 7); anomalous amounts (up to 15 percent of glauconite are reported in places from the gentle flanks of Georges Bank and are thought to represent contribution from eroded Coastal Plain formations that underlie Nantucket Shoals and Georges Bank.

In overall composition, the sands are orthoquartzitic to subarkosic (Milliman, and others, 1972), a compositional maturity that indicates a Coastal Plain source. This sedimentary source is given additional support by the inference from reflection profiles that Tertiary and Cretaceous sediments underlie the Bank and extend up into the Gulf of Maine (Uchupi, 1970; Weed and others, 1974) and by the presence of Tertiary fossils dredged from the Bank (Gibson, 1965). In addition, the patchy anomalies of detrital glauconite (Trumbull, 1972) already mentioned point to a nearby source of Tertiary green sand or clay. The close association of sand with coarse gravel (Schlee and Pratt, 1970) on the northern part of the Bank and in Nantucket Shoals suggests that while the source of the sediment may be from Tertiary and Cretaceous sedimentary rocks, the sediment was probably transported by glacial processes as outwash along the northern edge of the Bank, Great South Channel, and Nantucket Shoals from ice sheets that lay to the north (Pratt and Schlee, 1969).

Though composition of the sand remains uniform over much of Georges Bank, it becomes finer grained toward the south. Median grain size is in the 1/4 to 1/16 mm range (fine to very fine sand size) south of Nantucket Shoals and along the southern edge of Georges Bank. Principal size modes are in the 1/4 to 1 mm range (medium to coarse sand size) over most of the Shoals and Bank; modes become finer in the same southern area where median grain size decreases. Gravel occurs mainly on the northern half of the Bank in the vicinity of the shoals. It can be found to the south but only in small anounts (Schlee and Pratt, 1970, fig. 1). Both of the changes point to a broad north-south gradation in grain size over the Bank. A similar one exists to the southwest of Nantucket Shoals, though here the gradation is from gravelly sand to sandy silt.

The main change in sediment type is off the Bank, on to the Continental Slope and into the Gulf of Maine where the amount of silt and clay more than balance the sand and gravel fractions. On the Slope and in the canyons, silty sand and sandy silt dominate. In Georges Basin and on the northern flank of Georges Bank, sand mixed with some silt and clay are present. Apparently, the strong tidal flow across the bank has winnowed fine sand on-to the northern flank where it is mixed with fine grained sediment settling out of the water column.

The thickness of the unconsolidated sedimentary cover is poorly known. Only 17 holes have been drilled on Georges Bank and Nantucket Shoals (Anderson-Nichols and Company; Moran, Proctor, Mueser, and Rutledge, 1954). These were drilled in connection with the erection of two Texas Towers, one on Nantucket Shoals and the other on Georges Bank (pl. 1). In 1954, two sets of four holes were drilled from an anchored barge on Nantucket Shoals (lat 41°01.1'N., long 69°27.7'W., lat 40°58.4'N., long 69°23.0'W.); one hole from each set was summarized by Emery and Uchupi (1972, fig. 78). Groups of holes were drilled about 7 1/2 km apart, one on Fishing Rip and the other on Middle Rip. The Fishing Rip holes encountered mainly yellowish-gray medium-grained well sorted sand, with a few thin beds of gravelly sand in the top 18 m; below that are 2 m of gravelly sand followed by 19 m of yellowish-gray fine sand becoming silty toward the bottom. The holes were drilled in about 21 m of water. To the southeast on Middle Rip, the holes went through coarse sand in the top 6 m, medium sand in the next 21 m and clayey silt to the bottom of the hole at 46 m.

On Georges Shoal, an additional eight holes were bored from two barge sites in 1954. The next year a ninth hole was put down at the Texas Tower site. The northernmost group of four holes (lat 41°42.3'N., long 67°45.6'W.) encountered yellowish-brown coarse grained sand in the top 6 m that gave way to yellowish-gray medium-grained sand, with stringers of gravelly sand at 14 m and 21 m below the sea floor; some silty layers are associated with the gravelly sand. From 35 to 49 m (bottom of hole), the sand is fine-grained and mixed with some silt. From the Texas Tower, (lat 41°41.3N., long 67°45.6'W., 17 1/2 m water depth), the hole went through 36 m of grayish-olive medium-grained sand with a gravelly sand at 23 m and sandy clayey silt at the bottom of the hole (37 m). The southernmost barge site (lat 41°30.2'N., long 67°53.5'W.) encountered mostly yellowish-gray medium-grained sand with a silty fine-grained sand 3 m thick, about 19 m below the sea floor (20 m). The deepest hole penetrated 30 m below the sea floor.

From these few holes, one can see that the upper part is mainly sand; in the lower part of the deeper holes, finer-grained sediment, is encountered. The upper sand ranges from 15 m - 27 m thick -- a spread of values that encompasses the height of most of the sand shoals above adjacent troughs. Thus, the sand shoals appear built over a substrate of finer sediment and if Stewart and Jordan (1964) are correct, the shoals are migrating across a base of finer silty sand or a gravelly, poorly sorted lag deposit (Schlee, 1968; Emery, Wigley and Rubin, 1965).

A general summary of drilling results in the Georges Bank area by Anderson-Nichols Company; Moran, Proctor, Mueser, and Rutledge (1954) for the Navy is included in this report in Appendix I.

Onshore Stratigraphy

The character, thickness, and age of Coastal Plain formations along the Atlantic Coast has been summarized recently by Minard and others (1974), Perry and others (1974), and Weed and others (1974). Northeast of Long Island, Coastal Plain stratigraphy is fragmentary because of the limited outcrops, which are mostly on islands.

Upper Cretaceous sediments are exposed in several places along the bluffs of Block Island (Quinn, 1971, p. 46). Here the exposed Cretaceous beds are reported to consist of red, white, gray, and black clays and sand. The dark clays contain lignite and nodules of siderite and pyrite. Quinn (1971) assigns these beds to the Raritan Formation (?), whereas Woodworth and Wigglesworth (1934) term these beds "Magothy clay", admittedly based on little evidence. Sirkin (1974, p. 437) sampled "lignite seams in the lower levels of two beach cliff sections" for his palynological studies. These seams are biostratigraphic equivalents of the South Amboy Fire Clay Member of the Raritan Formation and therefore upper Cenomanian (to Turonian?) in age. Unconsolidated sediments extend as much as 305 m (1,000 ft) or more under Block Island according to Hansen and Shiner (1964) and Quinn (1971).

Glacially deformed Cretaceous sediments have been reported from Gay Head on Marthas Vineyard. These are assigned to the Raritan Formation (?) by Kaye (1964) who reports Cretaceous carbonate rocks at this locality. Berry (1915) concluded that the "leaf-bearing Cretaceous of Marthas Vineyard [correlates] with the Magothy formation" rather than the Raritan. The section of Upper Cretaceous beds exposed at Gay Head has been described by Woodworth and Wigglesworth (1934), who found "quartz-bearing kaolinite at the top,...

merging into cross-bedded quartz gravel below". This upper unit, classified as marine, based on the presence of a pelecypod, overlies red and white clays containing carbonized leaves (unit 2), which in turn overlies lignitic clay and lignite. The contortion and faulting of the beds at this locality renders the above described sequence somewhat suspect. However, the similarity of the succession to that in the upper part of the Cretaceous sequence of Long Island (Perlmutter and Todd, 1965) lends it credibility. Younger Upper Cretaceous marine sands and clays are not exposed at Gay Head but are found locally further inland, especially at Indian Hill, ten miles to the northwest. Stephenson (in Woodworth and Wigglesworth, 1934) regarded these marine deposits as Matawan in age (and thus Campanian).

Hollick (1901, p. 387-418) discovered deposits of the leaf-bearing Cretaceous clay beds (unit 2 of Gay Head) on Nonamesset Island. These beds are probably equivalent to the Magothy (or upper Raritan) Formation as are similar deposits at Gay Head.

In Upper Cretaceous exposures, on Marthas Vineyard and the nearby islands, sands do not appear to be the predominant lithofacies. Northeast of Georges Bank, the Shell Mohawk B-93 well on Browns Bank encountered principally clays and silts in the Cretaceous. The geophysical bore-hole logs from this well showed essentially no sands of Cretaceous age above the dense Jurassic carbonate rocks.

Tertiary units are described from three areas, Gay Head on Marthas Vineyard, Nonamesset Island near Woods Hole, and Scituate, south of Boston. Fossiliferous Miocene green sand 3 m thick, unconformably overlies Cretaceous clay at Gay Head cliffs on the southwestern tip of Marthas Vineyard. They yielded an abundant marine fauna of mollusks, foraminifera, crabs, and whale vertebrae (Woodworth and Wigglesworth, 1934). At Lakeys Bay on Nonamesset Island (part of the Elizabeth Islands), a thin layer of yellowish- green sand of Miocene age was found at beach level beneath Pleistocene deposits. At Third Cliff on the western side of Cape Cod Bay (near Scituate), Chute (1965) reports a gray clay of Eocene (?) age (based on pollen flora) overlain by glauconitic sand and fine gravel of late Tertiary (?) age. From this brief review, it is obvious that Coastal Plain units are patchy and thin in southern New England. The Tertiary and Cretaceous section probably was more extensive but glaciation has eroded the poorly consolidated units and incorporated them in the till and outwash that mantles Cape Cod and the offshore islands.

Offshore Stratigraphy

The type and ages of rocks encountered in the Georges Bank - Nantucket Shoals area have been summarized by Uchupi (1970), Emery and Uchupi (1972), and Weed and others (1974). The oldest sedimentary rocks drilled and dredged from the Continental Slope are glauconitic sandstone, brown and gray silty clay, and micaceous silt of late Cretaceous age (Stetson, 1949; Gibson and others, 1968). Faunal examination of most of these samples by Gibson and others (1968) seems to suggest that the sediment was deposited in bathyal depths. Samples containing microfossils of Paleocene, Eocene, and Oligocene were also dredged from the submarine canyons that indent the shelf south of Long Island and southern New England; they are clayey foraminiferal-coccolith oozes that accumulated in water depths similar to where they are now found. The Lower Tertiary rocks may thin on the slope south of Georges Bank as suggested by the paucity of this age rock recovered from dredging (Weed and others, 1974; Gibson and others, 1968). Miocene and younger sandstone, mudstone, and silty clay have been dredged from the sites of Hydrographer, Lydonia, and Corsair Canyon, and Miocene pebbly sandstone containing mollusks has been dredged by fishermen from the surface of Georges Bank (Gibson, 1965; Weed and others, 1974).

The closest shelf drill hole information comes from Browns Bank -- Shell's Mohawk B-93 well (McIver, 1972). From the southern part of McIver's schematic diagram, one can get an idea of the type and age of rock drilled 125 km from the eastern end of Georges Bank. On this basis, Schultz and Grover (1974) projected a probable stratigraphic section for Georges Bank based mainly on the Scotian Shelf exploratory holes. Their column shows poorly consolidated sands and mud for the Tertiary section, a dominantly noncarbonate clastic section (mudstone, sandstone, and chalk) for the Cretaceous, and dolomite or limestone section for the Jurassic, overlying a basement of lower Paleozoic slate, schist, quartzite, and granite (Meguma group). Figure 2 shows possible stratigraphy and lithology of the Georges Bank area based on a seismic velocity analysis of CDP records by Mattick and others (written communication).

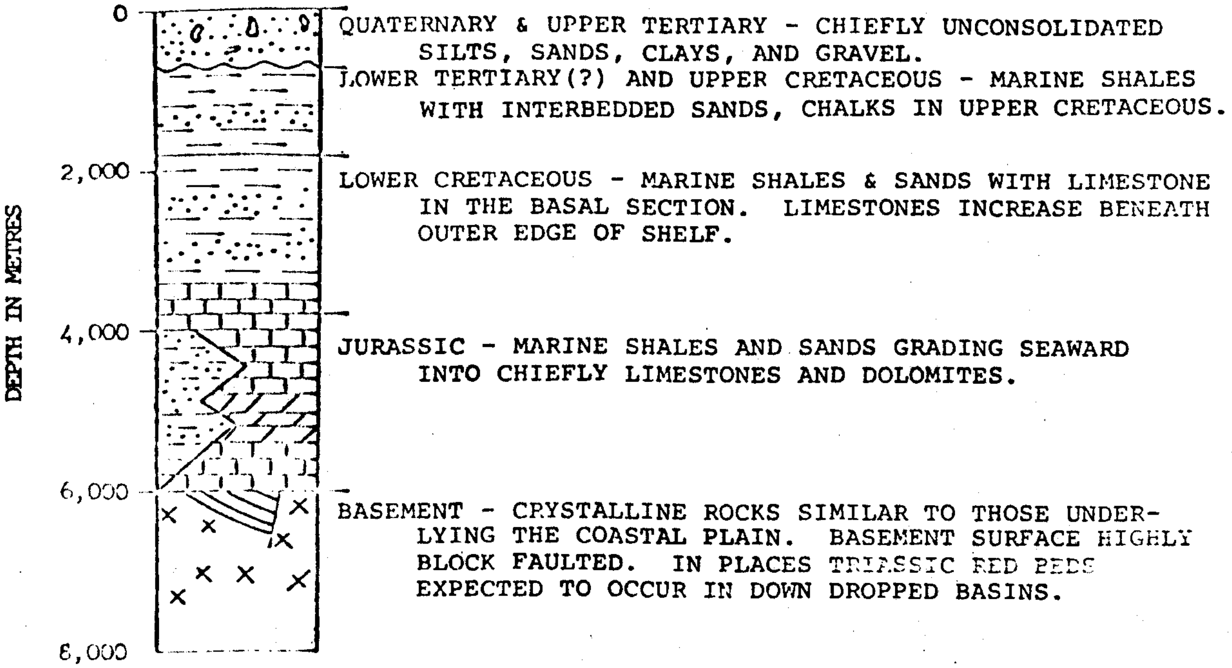


Figure 2.-- Possible stratigraphy and lithology of the Georges Bank basin.

GEOLOGY OF THE GULF OF MAINE

The sedimentary sequence overlying the basement in the Gulf of Maine averages about 50 m. This consists of a few isolated Coastal Plain erosional remnants with a thin veneer of Pleistocene glacial deposits.

According to Ballard and Uchupi (1974), the Gulf of Maine area has experienced a complex geological history. The oldest basement unit, the Avalon platform, was involved in orogenic activity 560 million years ago. The land masses adjacent to the Avalon platform experienced two major diastrophic events, the Taconic and Acadian orogenies of Middle Ordovician and Late Devonian time. Both events were characterized by intense folding, thrust faulting, regional metamorphism and intrusions.

The Avalon platform contains many fault basins of probable Triassic age. Two major erosional surfaces are indicated from seismic profiles. The second period of erosion (Pliocene) removed most of the Coastal Plain sedimentary rocks and the first major erosional surface (Early-Middle Jurassic) was exhumed and partly eroded.

Pleistocene glaciers, which extended across the Gulf to Georges Bank, modified the Pliocene fluvially carved surface. As a consequence of these two erosional cycles, the sediment blanket on top of the Avalon platform-Triassic basement complex is less than 50 m thick.

Neither the igneous and metamorphic rocks nor the thin sedimentary cover are considered prospective for hydrocarbons.

GEOPHYSICS OF GEORGES BANK BASIN

Regional Structure

Georges Bank basin is one of several deep sedimentary basins that underlie the United States and Canadian Atlantic Outer Continental Shelf (pl. 3). Georges Bank basin is bounded to the northeast by the Yarmouth Arch. To the southwest, the basin is separated from the deeper Baltimore Canyon trough by the Long Island Platform.

Generalized structure contour maps of Georges Bank reveal a westerly trending trough opening out to the west-southwest and encompassing an area from Brown Bank (Scotian Shelf) to Nantucket Shoals (Drake and others, 1959; Maher, 1971, Schultz and Grover, 1974; Mattick and others, 1974; Emery and Uchupi, 1972; Uchupi, 1971, Ballard, 1974). Both Schultz and Grover (1974) and Ballard (1974) show a structure contour map of the pre-Jurassic and pre-Mesozoic basement -- respectively, figures 3 and 4. For the shallow waters of Georges Bank, these are essentially isopach maps of sediment thickness above "basement". Schultz and Grover's (1974) map shows in excess of 3.1 km (10,000 ft) of post-Paleozoic sedimentary rock covering the northern part of the Bank. The section increases to over 7.6 km (25,000 ft) along the southern part of the Bank and is broadly warped by the southerly plunging Yarmouth Arch -- an uplift 75 km across that affects older rock (inferred to be Jurassic carbonates) and extends across the eastern end of the Bank. Ballard (1974) shows a similar thickness of sediment (using an average velocity of 3.9 km/sec) for Jurassic and younger sequence (fig. 4). He implies a southwest trend to the Yarmouth Arch and the deepest part of the basin to be fairly restricted beneath the southern edge of the Bank. A tectonic map of pre-Jurassic basement (fig. 5) is given by Ballard (1974).

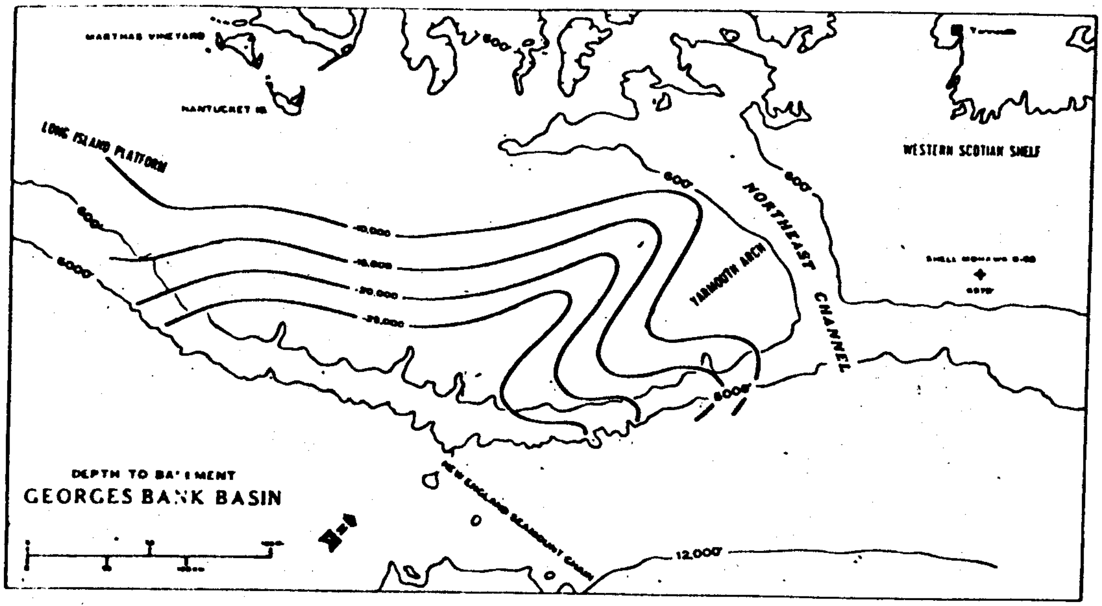


Figure 3. -- Structure contour map of depth to pre-Mesozoic basement. Contour interval 5,000 ft. (from Schultz and Grover, 1974).

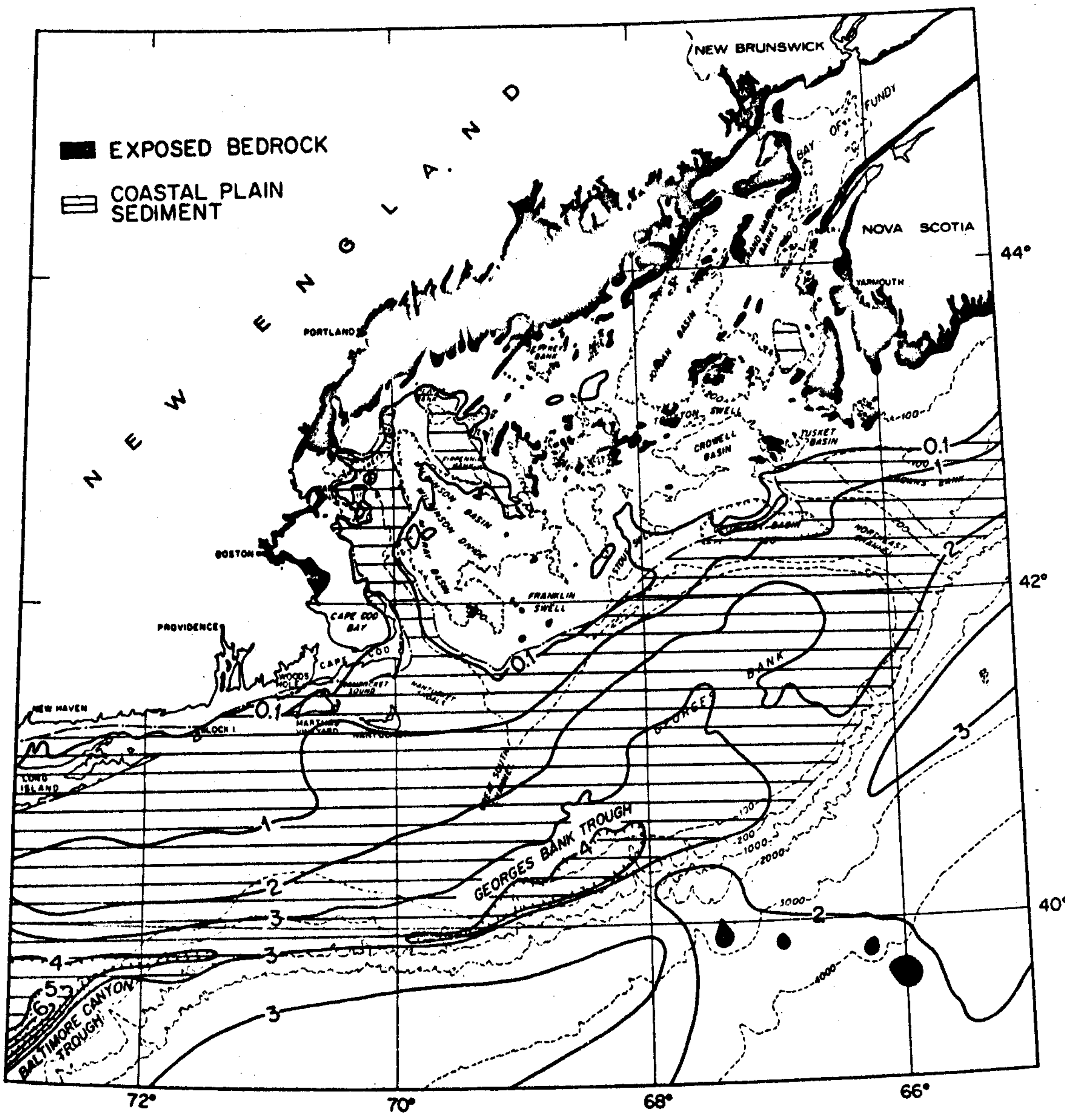


Figure 4.--Isopach map of total sediment.
Solid Line = Reflection time (sec's).
Dashed line = Bathymetry in metres.
(From Ballard, 1974)

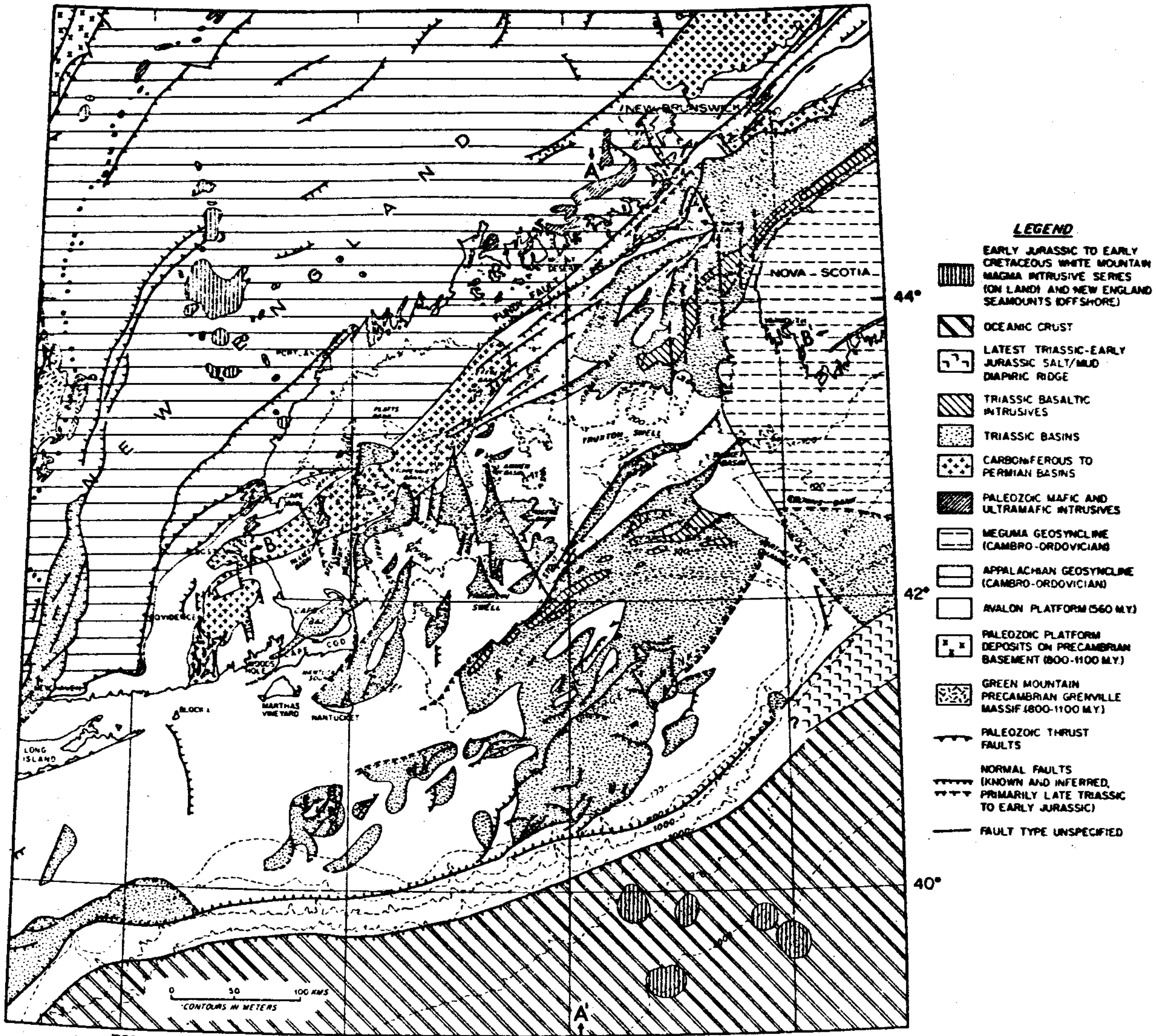


Figure 5.--Tectonic map of pre-Jurassic basement for Georges Bank, Gulf of Maine and eastern New England (from Ballard, 1974).

In 1973, the U.S. Geological Survey shot a common depth point (CDP) seismic profile across Georges Bank which extended out onto the Continental Slope and Rise (figs. 6, 7, and p. 4). The location of this profile is shown on plate 1. The illustrations show a broad basin with almost 4 seconds (two way travel time) of sedimentary section (about 7.5 km) above an irregular basement. Figure 6 shows an irregular diffuse acoustic basement high about 20 km across beneath the outer edge of the Continental Shelf -- a high that appears to come within 3 km of the sea floor under the shelf and 1 km under the slope.

The seismic data indicate that, in general, major structural features within the sedimentary section in Georges Bank trough are directly related to basement structures. Jurassic sediments appear to have been deposited on a highly irregular basement surface deformed by local and regional flexures and block faulting. In some cases, faulting may have continued **during Jurassic** time, as appears to be the case at shotpoint 1040. Major faulting does not appear to have significantly effected post-Jurassic sediments. Local anticlines, probably caused by differential compaction over basement flexures and horst blocks, can be seen across the entire record section. Although most of these anticlinal features are limited to the Lower Cretaceous and older sediments, some appear to continue upward to within 0.7 of a second (about 650 m) from the water bottom. An example of the latter occurs at shotpoint 1360.

The diffused buried ridge bounding the southern edge of the basin (fig. 6) is a double-humped feature, 20 km across at depth and narrowing to two poorly defined highs (fig. 6), one of which overlies the shelf

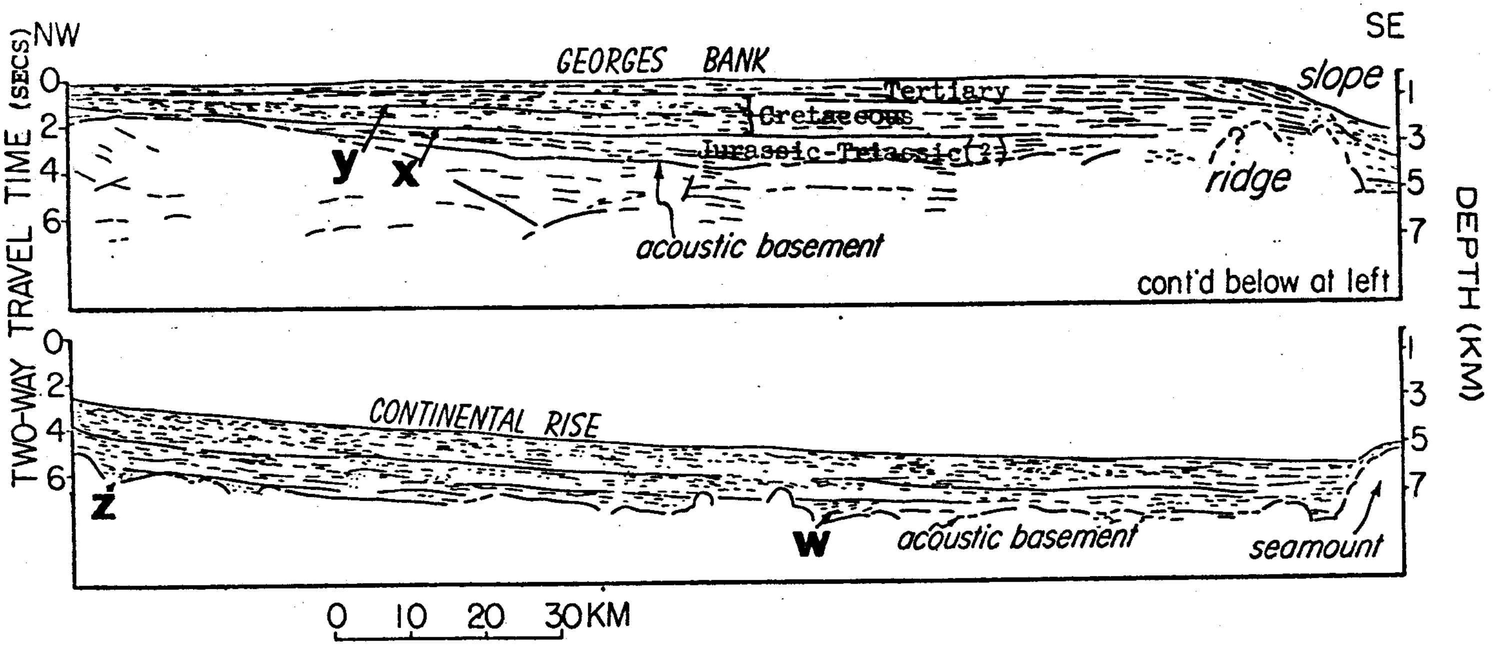


Figure 6.-- Interpretive section along USGS-CDP profile. Heavey lines mark prominent reflectors. Lighter lines give the fabric of less prominent reflectors. Some of the stronger reflections from below acoustic basement are shown. Letters on profile are referred to in the text. Vertical exaggeration of topography approximately 4:1.

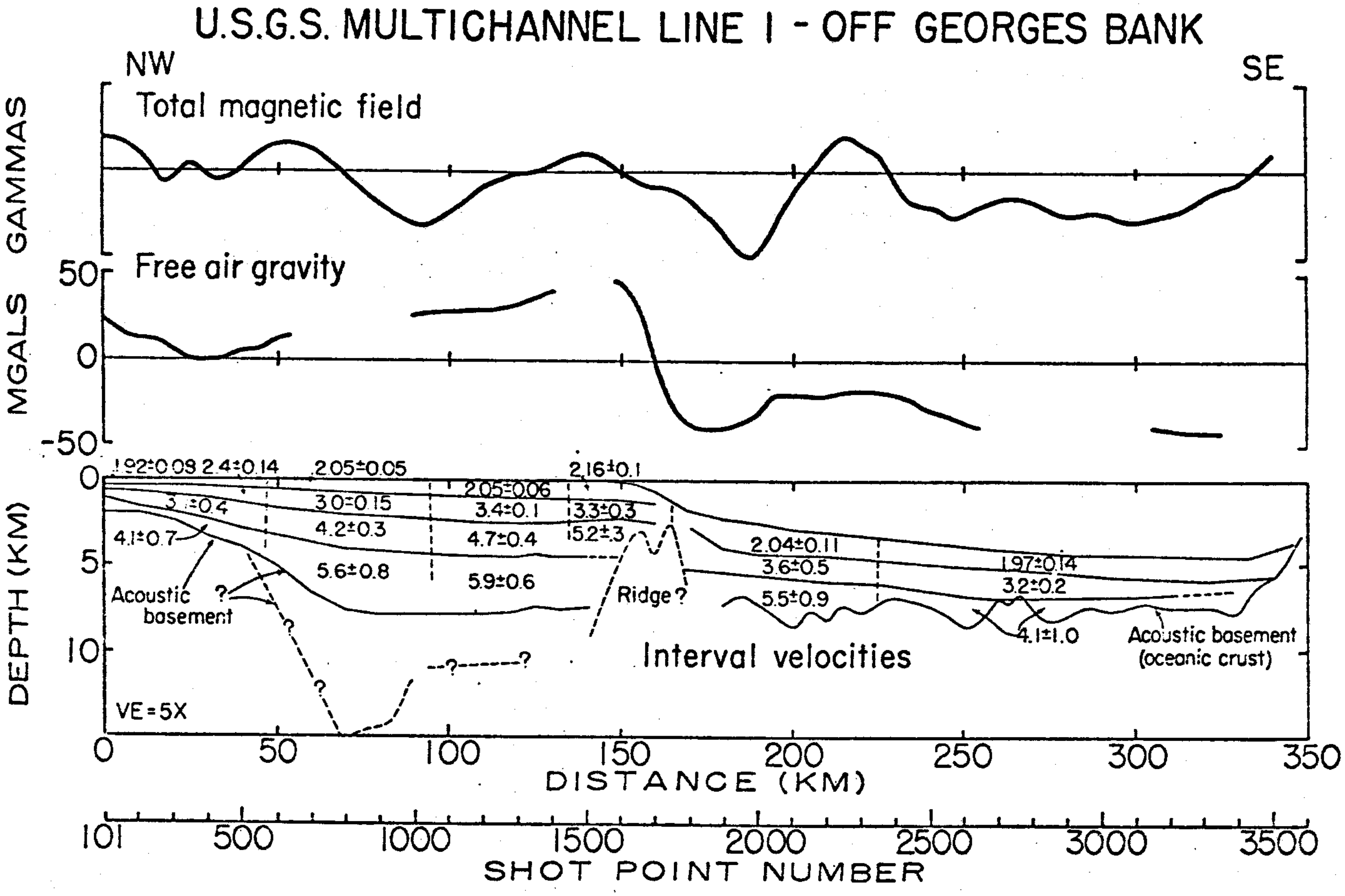


Figure 7.-- A generalized structural profile across Georges Bank using the CDP stacked recorded section shown in plate 4. Note the change in appearance of older units beneath basin as compared with figure 6, after time is converted to depth. Gravity and magnetic data are from the R/V LYNCH cruise in 1973.

edge (6 km across and buried by about 2 1/2 km of sediment) and the second of which overlies the slope (3 km in width and covered by 1.3 km of sediment). In the upper 2 - 2 1/2 seconds of the record (fig. 6), many of the subhorizontal reflectors from the middle acoustic units continue over the buried "ridge" to the upper slope where they are cut off by the sediment prism that makes the slope and Continental Rise. Over the shelf portion of the "ridge", these subhorizontal reflectors are less continuous and more diffuse than either to the northwest or to the southeast (outer shelf edge - upper part of the Continental Slope). The magnetic slope anomaly and free-air gravity highs both occur over the outer shelf edge but are offset slightly landward from the ridge observed in the seismic data (fig. 7). Note the increase in interval velocities on the north side of this apparent ridge. The magnetic data do not show short wave-length anomalies over the ridge and suggest a deeper source for the slope anomaly. While free-air gravity anomalies over continental margins usually have positives near the shelf edge and negatives over the slope (due to the topography and changing crustal thickness), the increase in sediment velocities near the outer shelf indicate significant lateral density increases within the sedimentary strata over the outer shelf. These may infer a transition from clastic to carbonate dominated lithology in the deeper strata beneath the outer shelf.

The structural nature of the "ridge" has been subject to several interpretations. Mattick and others (1974) infer the ridge to be a southward extension of the Yarmouth Arch -- an upfaulted structural crystalline basement high extending southward from the inner Scotian Shelf into the seaward edge of Georges Bank; Schultz and Grover (1974) infer it to be about 6.5 km down. Ballard (1974) infers a narrow spur of the Yarmouth Arch to continue along the southern edge of Georges Bank upper Continental Slope, and to be buried by less than 3 seconds (5000 m) of sediment in the vicinity of the USGS-CDP line (fig. 4 and 6). Following the lead of Emery and Uchupi (1972), he infers the ridge to be a horst formed through the intrusion of oceanic basalt that moved in during the pull apart of Africa and North America. Scott and Cole (1975) show a rise in the basement beneath the seaward edge of Georges Bank and a deeply buried fault zone bridging the transitional area of continental and oceanic crust; they infer a carbonate facies built above the uplifted basement and adjacent to the deeply buried fault zone.

The presence of an irregular, weakly defined narrow ridge on the CDP data combined with the broad magnetic slope anomaly and a broad gravity high suggest in general that a volcanic or basement ridge could be present. However, there are no short wave-length magnetic anomalies and gravity anomalies that could in large measure be explained by increasing sediment densities near the outer shelf (i.e., increasing velocities). Nevertheless, since the CDP line is near where the New England seamounts intersect the continental margin, the ridge in this case could easily be related to a deeper volcanic structure. The ridge complex is buried by a portion of the sediments to a maximum depth of

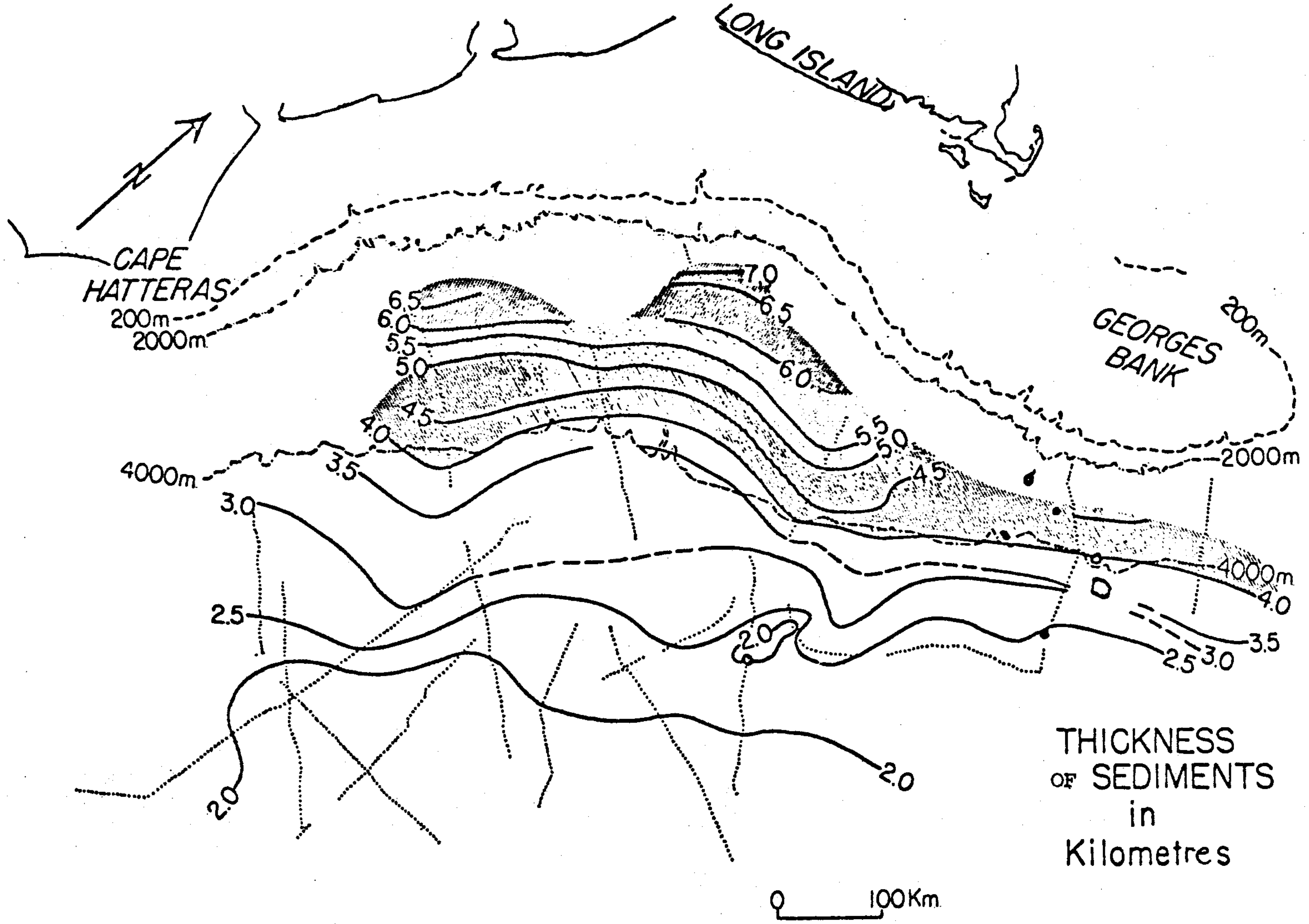


Figure 8. -- Isopach map above acoustic basement. Cruise tracks used to make the estimates are shown as dotted lines. Shaded areas show thicknesses in excess of 4 km on the Continental Rise.

4 to 5 km that postdate the late Triassic-early Jurassic breakup-up of North America and Africa. It is possible that intrusives were emplaced along the zone of translation where the contiguous portions of rifting continents slid past each other. The slope south of Georges Bank (where the northeast-southwest trend of the margin changes to an east-west trend) is one such area, and the slope south of the Grand Banks is another; interestingly, Keen and Keen (1974) infer a similar intrusive ridge in this area.

Both Georges Bank and the Grand Banks are marked by the intersection of seamount chains that acted as partial barriers to the prograding wedge of sediment along the zone of intersection; the seamounts may be overtopped and buried by a sedimentary prism to give the appearance of an indistinct ridge as off eastern Canada. Perhaps the southern margins off Georges Bank and the Grand Banks have a similar history, and that in the case of Georges Bank, we see a block-faulted intruded edge of the margin, much as the investigators cited show. The slivered end of the Yarmouth Arch is intruded to give rise to a barrier, now covered by sedimentary deposits of varying thickness.

Seaward of the Georges Bank ridge (fig. 7), the sedimentary section thins from 4-5 km under the slope to less than 3 km (fig. 8) at the south-east end of the line. The Continental Rise wedge is built over an irregular oceanic basement, and the section is not marked by strong continuous acoustic reflectors (fig. 6). Reflectors split and merge in an anastomosing manner, particularly in the upper 1-2 km of sediment. Discontinuities suggestive of low angle unconformities extend a few kilometres laterally before they are lost. Only out at the seaward end of the line are the reflectors even and more continuous, and these terminate abruptly against the seamount.

Acoustic basement in the deep ocean is represented by a gently undulating irregular reflector that is buried by at least 7 km of sediment beneath the upper Continental Rise (fig. 7). It is more deeply buried to the south, seaward of the Baltimore Canyon trough, than it is to the northeast off the Georges Bank basin. In a curious way, the inferred sediment thickness on the shelf is a guide to the off-shelf sediment thickness. Oceanic basement can be traced on the Georges Bank line right up to the base of the Continental Slope (fig. 7) where the sediment cover is estimated to be about 4-4.5 km thick. Before it is masked, acoustic basement comes within a few kilometres of the ridge that underlies the Continental Slope, and appears to dip moderately toward the ridge (fig. 6, point Z). Evidence for a thick belt of sediment beneath the lower slope and upper Continental Rise is lacking on the Georges Bank line. Seaward, acoustic basement is irregular, with a relief of several hundred metres over a distance of only a few kilometres. Nestled within sharply defined lows in acoustic basement, are small sediment-filled grabens (point W, fig. 6). They have a relief up to 1 sec and extend laterally as much as 7 1/2 km.

Seismic Stratigraphy

Combining seismic reflection characteristics, velocity studies, and stratigraphy, several investigators (Ballard, 1974; Foote and others, 1974; Scott and Cole, 1975; Mattick and others, 1974; Schultz and Grover, 1974; Mattick and others, written commun.; Schlee and others, written commun.; Taylor and others, written commun.) have attempted to infer the ages and lithologies of the sediments in Georges Bank basin. Table 1 summarizes the ages, lithologies, velocities, and thickness ranges of these "stratigraphic" units. From this table can be seen a general clustering of velocity data, thicknesses, and lithologies. In general, the authors agree that Tertiary deposits are up to a kilometre thick, have velocities around 2 km/sec, and are made up of poorly consolidated sand, silt, and clay. The thickness figures for the Cenozoic (Schultz and Grover, 1974; Schlee and others, written commun.) are about 1 1/4 to 2 times those shown by Emery and Uchupi (1970) derived from single channel continuous seismic profile (CSP) data, collated with dredge hauls. Weed and others (1974), also using dredge data, infer a Tertiary-Cretaceous boundary on the slope in about 800 m water depth; hence the figure of one kilometre may be somewhat high. Mattick and others (written commun.) show on plate 4 the prograded nature of post-horizon 1 units which they infer to be Quaternary and Middle Tertiary age.

The Cretaceous system is inferred to be up to 3.3-3.5 km thick and based on results of logs from holes on the Scotian Shelf, to be mainly

Table 1 -- Summary of seismic units beneath Georges Bank

Source	Designation and Thickness	Age	Velocities	Lithology
Ballard (1974)	Unit 1 0-4 sec (7.5 km)	post late Triassic	average 3.7 km/sec	Early Jurassic-thru Early Cretaceous- limestone, dolomite, shale, and evaporites Cretaceous - Terrigenous clastics
Schultz and Grover (1974)	0-1 km	Tertiary	-	Unconsolidated sand and mud
	0.2-1.1 km	Upper Cretaceous	-	Mudstone with minor sandstone and chalk
	0.5-2.0 km	Lower Cretaceous	-	Shale with imbedded sandstone and shale
	0.5-4.0 km	Jurassic	4.7 km/sec	Limestone, dolomite, with salt(?) toward base
		Basement (lower Paleozoic)	-	Slate, schist, quartzite, granite
Mattick and others (1974)	0.1-1.0 km	Pliocene, Miocene Oligocene(?)	-	
	0- 3.4 km	Cretaceous	-	
	0- 2.0 km	Jurassic	-	
	0- 1.8 km	Triassic	-	Arkose, shale, tuff, and basalt
Mattick and others(written commun.)	0.6 km-2.4 km	Cenozoic and Upper Cretaceous	1.6-4.3 km/sec	Sand, silt, clay in upper part and chalk in lower part
Taylor and others(written commun.)	0.6-2.3 km	Lower Cretaceous	2.7-4.9 km/sec	Calcareous sandstone, siltstone, and shale
		Jurassic	4.1-7.9 km/sec	Limestone and dolomite
		Basement		

Table 1 cont.

Schlee and others	0.3- 1.1 km	Cenozoic	1.9-2.2 km/sec	Silt, sand, gravel and clay
	0.2- 1.5 km	Upper Cretaceous	2.4-3.3 km/sec	Marine shale and sand changing laterally to carbonate
	0.5- 2.0 km	Lower Cretaceous	3.1-5.2 km/sec	
	0.4- 3.6 km	Jurassic and Triassic	4.1-5.9 km/sec	Dense carbonates
		Basement		

clastics -- shale, siltstone, and sandstone, changing to limestone in the lowest part of the system toward the soutern part of Georges Bank. Acoustically, this interval is marked by crenulations and bifurcations along the northern part of the profile (pl. 4). To the south, crenulations give out and distinct discontinuous horizontal reflectors appear; a particularly strong reflector marks the base of the zone at 2.9 seconds (X in fig. 6). Within the Cretaceous interval, one horizon (in fig. 6) appears to stand out on the northern part of the profile; we used this reflector to subdivide the Cretaceous into an upper and lower series. Though not continuous over the southern half of the profile, we used it as a "boundary" because a few weak reflectors appear to intersect it at a low angle suggesting that it could represent a disconformity. Mattick and others (written commun.) label it horizon II on plate 4 and infer that Lower Tertiary and Upper Cretaceous sediments (analogous to the Dawson Canyon Shale, and Logan Canyon sand and shale) are above the horizon and sands and shales of lower Cretaceous age are below it. Schlee and others (written commun.) found a fairly marked change in velocity at this horizon shown in figure 7 (i.e., from 2.4-3.1 km/sec at the inshore end and 3.3-5.2 km/sec under the southern part of the shelf). These changes suggest a substantial change in lithology, both vertically and laterally within the Cretaceous. The critical question is to what?

Both vertical and lateral changes in lithology are documumented farther notth in the vicinity of Browns Bank on the Scotian Shelf. In this area, McIver (1972) shows a north to south lateral change from dominantly sandstone to shale within the Cretaceous system and a vertical change, in the same direction from interbedded clastics to limestone (Upper Jurassic). If the lithologies encountered beneath Browns Bank carry south to Georges Bank basin, then the lateral change in signature of reflectors (already discussed) from a broad collection of discontinuous crenulated reflectors between shot points 101 and about 800 in plate 4, to stronger more continuous reflectors from shot point 800 to 1600 may reflect a lithofacies change from an abridged section of shallow marine and non-marine clastics marked by disconformities to a more complete evenly bedded marine section attended by a 5 fold increase in thickness. Is the thickened section marine shale or is there substantial sand present? If the trend portrayed under the Scotian Shelf is right (McIver, 1972), it is shale (Schultz and Grover, 1974, fig. 7) with interbedded sandstone and siltstone. However Mattick and others (written commun.) show a significant amount of sand in the Lower Cretaceous section beneath Georges Bank (fig. 2). Their interpretation is based on analogy (velocity) with the central Scotian Shelf rather than the southern Scotian Shelf where well B-93 is located. According to Mattick and others (written commun.), the B-93 well is too near the shelf edge to be representative of the Georges Bank section. In addition, these authors imply that during Cretaceous time the Yarmouth Arch would have acted as a barrier to sedimentation from the Scotian Shelf area.

The vertical increase in velocity from about 3.3 to 5.2 km/sec as shown in figure 7 near the shelf edge could represent a change in lithology within the Cretaceous system from dominantly marine clastic to limestone and dolomite.

Based on analogy with drill hole data on the Scotian Shelf and velocity data, Jurassic and Triassic rocks in the deepest part of Georges Bank basin are inferred to be about 3.6 to 4.0 km thick and to consist mainly of dense carbonates (table 1). On plate 4, this interval is between horizons III and V -- a sequence thought by Mattick and others (written commun.) to be Jurassic limestone and dolomite (fig. 2). The high velocity obtained for this acoustic unit ranges up to 7.9 km/sec (Taylor and others, written commun.) though values are more typically between 4-6 km/sec. The high velocity values and the fairly strong returns of some reflectors, suggest a section of dolomite and limestone (similar to what has been drilled on the Scotian Shelf as the Abenaki Formation - McIver, 1972). McIver (1972, fig. 5) also indicates some sandstone and shale (up to 3500' thick - Mohawk Formation), dolomite (up to 650' thick - the Iroquois Formation) and salt (greater than 3000' - the Argo Salt) beneath the Abenaki Formation. Whether all these units extend under Georges Bank is unknown. We see no evidence on the one CDP profile of salt diapirs, nor did Schultz and Grover (1974) in their examination of CDP data.

The CDP line across the Bank (pl. 4) shows no clear evidence of Triassic sediment-filled grabens. Schultz and Grover (1974, fig. 6), Mattick and others (1974, fig. 10), and Ballard (1974, fig. 7), do infer such features under Georges Bank basin.

GEOLOGIC HISTORY

Opening of the North Atlantic, probably during the Triassic (Hallam, 1971), initiated an interval of block faulting, volcanism, uplift, and later subsidence (Sanders, 1963). The early Mesozoic history was likely similar to Cenozoic history in the Red Sea (Ross and Schlee, 1973; Lowell and Genik, 1972) where pre-Miocene uplift and lateral extension resulted in crustal thinning and formation of the Red Sea Basin. Eventually, during the Miocene, the flanks sagged and subsided in a block-faulted basin in which volcanics were extruded and evaporites formed. Using the idea of Falvey (1974), the initial uplift may have related to thermal expansion and to a migration of the phase boundary in the lithosphere. Later crustal subsidence would be due to a thinned crust riding lower -- because of the effects of erosion and because of thermal metamorphic phase changes at the base of the thinned crust. Oldest block-fault deposits would be continental sandstones and shales similar to those described by Sanders (1963) and in Triassic grabens of the northeastern U. S. and Bay of Fundy (Klein, 1962).

Nonmarine conditions gave way to a shallow marine environment in the Jurassic. During an interval of considerable subsidence, paralic sands and shale accumulated to the north and limestone accumulated out in the main and southern part of the Basin; on some of the tilted and elevated blocks, reefs may have been established to act as a partial barrier to a newly formed Atlantic Ocean. This phase of offshore carbonate shelf deposition may well have extended into the early Cretaceous to judge from inferred early Cretaceous reefs off Cape Hatteras (Emery and Uchupi, 1972, p. 435) and the presence of shallow limestone of the same age underlying the seaward edge of the Blake Plateau (Heezen and Sheridan, 1966).

During the Cretaceous, diminished sedimentation occurred in the northern part of the basin and a thicker section was deposited in the central part of the Georges Bank Basin. The crenulated discontinuous nature of the reflectors and the presence of at least one disconformity in the northern part of the CDP profile (pl. 4) suggest that along the northwestern edge of the basin, interbedded sands and muds accumulated in a transitional zone bridging a fluvial-littoral-shallow shelf environment. Farther offshore, marine clastics were likely deposited over the remainder of the basin. Eventually, in the middle or late Cretaceous, the sediment wedge built over the reef-ridge (?) area to disperse marine clays directly on to the ancestral continental slope.

Structural movement during late Cretaceous helped create a major unconformity over much of Georges Bank. This hiatus was followed by deposition of a progradational sequence of Tertiary marine sands, clays, and siltstone. Uplift during Pliocene and early Pleistocene caused erosion of the Bank (Oldale and others, 1974) and led to the formation of an interior lowland (present site of the Gulf of Maine and a large crustal cut in Tertiary and Cretaceous sedimentary rocks) along the northern edge of Georges Bank. Pleistocene glaciers enlarged the valleys within the Gulf of Maine and delivered large quantities of coarse glacial debris to the northern part of the Bank as a series of moraines and outwash plains. As shown by Knott and Hoskins (1968), the Pleistocene deposits on the Bank are a thin blanket of reworked glacial outwash that was dispersed southward across the Bank in a complex system of now buried channels. During the Pleistocene, these channels were sediment dispersal ways to the many submarine canyons that served as conduits for the coarse sediment delivered to the Continental Rise. The Holocene rise in sea level has caused a reworking and redistribution of much of the glacial debris which has given rise to a series of shoals. The reworking continues, particularly in the shoals and in the heads of submarine canyons.

RESOURCES (OTHER THAN PETROLEUM)

The "total resources", as defined by U.S. Geological Survey (GS) and U.S. Bur. Mines (BuM) Committee (1973), of the U.S. Atlantic OCS are judged to be very large. GS and BuM include as reserves all the naturally occurring materials -- those known and those yet unidentified but expected to exist based on geologic evidence. Thus "total resources" would include materials such as oil and gas (these are discussed in a separate section of this report), hard minerals (placer-type deposits), sand and gravel, and minerals either dissolved in or precipated from seawater. An over-whelmingly large amount of the total resources of the United States Atlantic OCS are "undiscovered resources" and correspondingly few resources lie within the definitions of "identified" and "demonstrated" resources (GS and BuM, 1973). Even a smaller part of the identified resources can be classified as a "reserve" (GS and BuM, 1973).

Because the surface of the United States Atlantic OCS area has been sampled about as intensely as any part of the Continental Shelf off the United States, the general paucity of "reserves" of hard minerals appears to result not from insufficient sampling, but from an actual dearth of such minerals in the area. Nevertheless, lack of detailed sampling of various areas known to contain hard subeconomic mineral deposits, places most of the minerals present in the "Identified subeconomic resources classification" (GS and BuM, 1973).

The materials listed in table 2 with their corresponding data have been encountered on or within the seabed of the United States Atlantic OCS. All these materials except sand, gravel, and mud are placed in the "Identified-subeconomic resources" category (GS and BuM, 1973).

Sand and gravel, and perhaps the ceramic muds (Manheim, 1972) represent, among the materials listed in table 2, those resources most intensively, but not yet fully, investigated. Nevertheless resource estimates show economic deposits exist and sand and gravel resources at present can be established as "economic reserves" (GS and BuM, 1973). Sand and gravel deposits most likely available now for economic extraction are large, so that, even though only partly evaluated, the indicated reserves on the United States Atlantic OCS (including the Georges Bank area) are at least 450 billion tons of dry sand and at least 1.4 billion tons of gravel. The total gravel amount may exceed 50 billion tons and the inferred sand resources are probably 10 or more times greater than now estimated.

Table 2.--Data sources for resources (other than oil and gas) for the United States Atlantic OCS

Material	Selected Data Sources
Phosphorite	Stanley and others, (1967); McKelvey and Wang, (1969), p. 10, pls. 1 and 4; Manheim, (1972, p. 11-13); Milliman (1972); McKelvey and others (1969, p. 5A53-5A57)
Anhydrite	McKelvey and Wang (1969, pl. 4)
Manganese nodules - including trace elements: Ni, Cu, Co, Sn, Fe, Zn, Ag, Ba, Al, B, Ti, V, Ar, and many others	McKelvey and Wang (1969, p. 11 pl. 1); Horn, Horn and Delach (1973); Mero (1965, p. 180); Horn (1972, p. 10); Manheim (1972, p. 11)
Ilmenite, monazite, zircon, rutile staurolite, kyanite, sillimanite, and garnet	Trumbull and others (1958, p. 52-53); McKelvey and Wang (1969); Emery and Noakes (1968); Hathaway (1971); Manheim (1972, p. 7-11); Ross (1970); McKelvey and others (1969, p. 5A1-5A117); Manheim (1972, p. 2, 11)
Copper and zinc (chalcopyrite and sphalerite minerals)	Manheim (1972, p. 2, 11)
Sand, gravel and mud	Manheim (1972, p. 13-18; 22) Schlee (1964; 1968); Schlee and Pratt (1970); Emery (1965); Duane (1968); Davenport (1971); Taney (1971); Economic Associates Inc. (1968); Milliman (1972); Ross (1970); McKelvey and Wang (1969, p. 10); McKelvey and others (1969, p. 5A64); Nossaman and others (1969); Doumani (1973); Rexworthy (1968)
Glauconite	McKelvey and others (1969, p. 5A91)
Carbonate	Hulsemann (1967); Milliman (1972, p. J7)

Petroleum Geology

What is involved in evaluating the petroleum potential of an offshore area such as Georges Bank basin, which to date has not been deeply drilled? Certainly the technological and engineering capibilities to drill on continental shelves have been demonstrated throughout the world including the Gulf of Mexico, the North Sea, and the nearby Scotian Shelf off Canada. We may conclude then that the real questions, those related to the petroleum potential of Georges Bank basin, are the same as those posed by any other prospective area -- offshore or onshore. However, in the development stage, the greater expense involved in offshore drilling and production will eliminate the commercial development of some small fields that otherwise could be developed if located onshore.

In general, an evaluation of an unexplored basin should include answers or at least partial answers to questions pertaining to : (1) source rocks, (2) reservoir rocks, (3) timely development of effective traps.

It is generally thought that the source of most of the world's petroleum was organic-rich rocks commonly referred to as source rocks. The original organic matter was probably deposited as fine-grained carbonaceous sediment in a marine environment where the sedimentation rate was rapid enough to prevent complete oxidation of the organic matter. Maturation of the original organic matter occurred as the sediments were subjected to the effects of temperature, pressure, and time. Finally, overburden pressure facilitated the expulsion of waters containing oil and gas.

If petroleum is expelled during compaction of sediments, it must be able to migrate to a readily available porous and permeable reservoir in order to accumulate. According to Hedberg (1964), "if there are no reservoirs to catch this [escaping] fluid, any petroleum expelled will only go back into the depositing medium where it will either rise to the surface and be oxidized...[or] remain locked up in the compacting mud". The most common reservoir rocks are sandstone and porous limestone (both of which are believed to be present beneath the Georges Bank area).

In addition to the porosity and permeability requirements of reservoir rocks, it follows that petroleum will not accumulate unless the reservoir is sufficiently sealed so that further migration is halted -- thereby providing a petroleum trap. Leverson (1954) has classified traps into three categories: structural traps, stratigraphic traps, and combination traps -- a combination of the two. Seismic evidence indicates that in the Georges Bank basin, potential structural traps include large domal structures over uplifted basement blocks. Stratigraphic traps in Georges Bank basin may include reef structures, updip pinchouts, and porosity and permeability changes in both clastic and carbonate rocks.

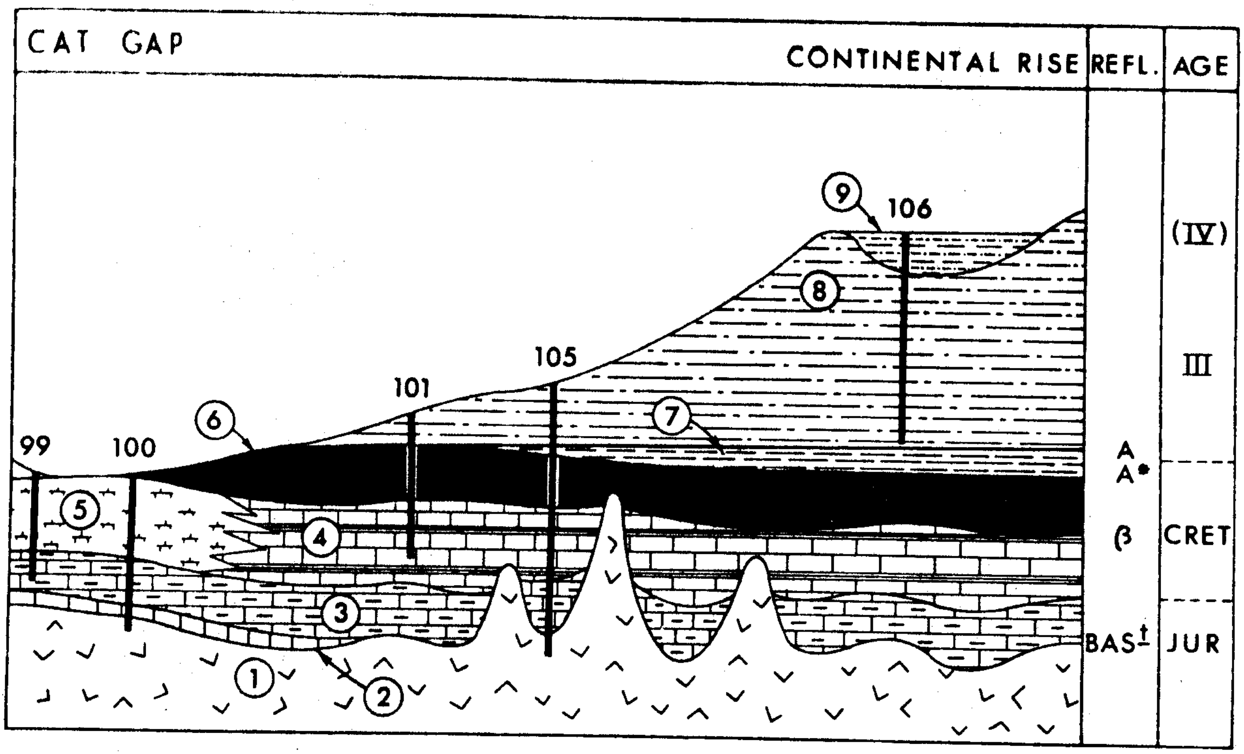
The timing of the trap development is critical in evaluating the hydrocarbon potential of a structure. For example, if a particular structure was formed long after generation and migration of petroleum, the chance of it containing commercial hydrocarbons is diminished. In the case of anticlinal structures over basement blocks in the Georges Bank area, seismic evidence suggests that these structures developed by draping and differential compaction with some continued uplift of the basement blocks along the controlling faults. Hence, the structures would have been developed at the time of generation and migration of petroleum and therefore are considered potential hydrocarbon traps.

We see that the problem of correctly evaluating the future energy resources of Georges Bank basin involves not only a knowledge of the geologic processes presently operating on the shelf, but also a knowledge of how these processes varied in the past. With this in mind, it is helpful to compare Georges Bank basin with similar shelf basins where the geology is better known. For these reasons, we have arranged the discussion of petroleum geology of Georges Bank basin as follows: (1) a reconstruction of the history of the basin as it relates to petroleum potential; (2) geologic analogies with other shelf basins; (3) a discussion of potential source rocks and reservoir rocks by age; (4) a discussion of the timely development of potential traps; and (5) an estimate of the undiscovered recoverable oil and gas resources of the basin.

Geologic History Related to Petroleum Resources

Although a geologic history of the Western Atlantic Ocean was presented earlier in the geologic section of this report, we feel it is worthwhile to repeat and detail those aspects of that history that pertain to Georges Bank basin and in particular to the basin's petroleum potential.

Initial rifting at the Mid-Atlantic Ridge resulted in a narrow, relatively shallow ocean basin in which circulation may have been greatly restricted. The earliest sediments deposited on the oceanic basement (based on DSDP data) were Jurassic shallow-water fossiliferous carbonates, possibly containing intercalated evaporite sequences in areas marginal to initial rift zones (fig. 9). Carbonate deposition gradually ceased as the early Atlantic floor continued to sink below carbonate compensation depth and septic bottom conditions were inaugurated. Stagnation and deep-water deposition of several hundred metres of Early Cretaceous black, carbonaceous hemipelagic clays dominated this state of the development of the western North Atlantic. The reducing environment, though in many places sharply defined from the earlier shallow-water depositional stage by acoustic horizon B, continued from Neocomian (Lower Cretaceous) to early Cenomanian (Upper Cretaceous) time. Again, during this time-period, black sapropelic clays filled remaining irregularities in the basement floor of the deep ocean. Toward the end of this time-period, a modest amount of bottom circulation took place, for "normal" deep sea brown sediments lie conformably on the black clay



1. Basalt
2. Callovian -?- Oxfordian greenish-gray limestone
3. Late Jurassic red clayey limestone
4. Tithonian-Neocomian white and gray limestone
5. Tithonian-Neocomian calcareous ooze and chalk
6. Cretaceous black clay
7. Late Cretaceous -?- Early Tertiary multicolored clay
8. Tertiary hemipelagic mud
9. Quaternary terrigenous sand and clay

Figure 9.-- Synthetic sketch based on data from drilling and seismic profiler records in the North Atlantic basin during JOIDES Leg II. Note Cretaceous clay in black. From Lancelot and others (1972). Location of drill holes shown in figure 10.

Figure 10.-*Physiographic diagram of a portion of the western North Atlantic (Heezen and Hays, 1968) with locations of Leg 11 drilling sites.*

sequence, suggesting a heralding of the end of rather complete deoxygenated bottom-water conditions in late Albian or earliest Cenomanian time. Elsewhere, particularly to the south, bottom currents were apparently stronger and some erosion of the black clay sequence occurred. The top of this sequence is marked by the acoustic reflector horizon A* (earliest Cenomanian). Nevertheless, deep-water conditions prevailed, so that it seems quite likely that the increased bottom circulation followed a major increase in areal extent of the North Atlantic basin beginning in Late Cretaceous time, as seafloor spreading between Europe and North America effected a route by which Arctic bottom waters could reach the western North Atlantic basin adjacent to the Georges Bank area.

Whereas, the above geologic history of the western Atlantic can be reconstructed from scattered deep well data (fig. 9), there are few documented facts to reveal the geologic history of the shelf area--especially the Georges Bank basin; the following discussion is our present interpretation based on the data and inferences presented earlier in the geologic section of this report.

Opening of the western North Atlantic, probably during Triassic (Hallam, 1971), initiated a period of block faulting in the Georges Bank area. Basement blocks, up to 20 km across, were uplifted as much as 2 km (Schültz and Grover, 1974, fig. 5). Mattick and others (1974) speculate that, in places, a thick section (up to 2 km) of continental derived Triassic rocks consisting of red arkose, sandstone, shale, tuff, and basalt flows - in places intruded by diabase - were preserved in the large down-faulted grabenlike structures between the uplifted basement blocks. This early basin, at or near the active rift zone, would have experienced above normal geothermal temperatues and the first marine deposits may have been Jurassic evaporites. These deposits would have been laid down in localized downfaulted sub-basins. Inasmuch as the initial basin water-depths were shallow, marine waters may have been restricted behind a tectonic dam at the shelf edge and by the Yarmouth arch and Long Island platform to the northeast and southwest respectively, possibly leading to hypersaline conditions and evaporite deposition.

As the basin continued to sink, evaporite deposition may have gradually halted, and fossiliferous shallow-water carbonates which included tephra and turbidites were probably deposited over much of the basin floor during Late Jurassic (Oxfordian-Kimmeridgian) time. Seismic evidence (pl. 4) indicate that these deposits were draped over a yet highly block-faulted and irregular basin floor. In places, basement blocks apparently were still adjusting to continental separation, as evidenced by continued Jurassic faulting (pl. 4). Later, in Jurassic (Tithonian) to early Cretaceous (Neocomian time), as the Atlantic became deeper and less restricted areally, thin to moderately thick-bedded, dense limestones or dolostones were probably deposited over much of the central and seaward part of the Georges Bank basin; whereas shoreward, paralic marine shales and sands were probably deposited. A reduction in the amount and size of drape structures (or differential compaction) suggests that by Neocomian time, much of the basin-forming activity had ceased and that most of the block structures and basin-floor irregularities had been filled by sediments.

At this time, on some of the remaining tilted and elevated blocks near the shelf edge, reefs may have been established (discussed on pages 40 and 41 of this report) to act as a partial barrier to the juvenile Atlantic Ocean. As such, reefs would have permitted only modest interchange of pelagic life between the basin and the Atlantic Ocean proper. It would have restricted the circulation between the two regions and enhanced and possibly maintained anaerobic conditions. Also, continued tilting and floundering of the Continental Margin would have permitted extensive transgression of ocean onto the land, shifting the shoreline west of the basin area, and thereby reducing the amount of terrigenous sediment contributed to the basin. During earliest Cretaceous time, carbonate sedimentation probably prevailed over most of the basin area (consistent with the seismic data), whereas, during the remainder of the Lower Cretaceous, carbonate deposition was restricted to areas in the southeastern part of the basin along the shelf edge. Along the northwestern edge of the basin, interbedded sands and muds probably accumulated. In the central part of the basin, marine clastics were deposited possibly interbedded or interfingered with the shelf-edge carbonates.

The eastern boundary (reef?) of the basin was apparently destroyed before the end of the Cretaceous, and perhaps, turbidites flowed onto the ancestral Continental Slope and even onto the Rise where they formed a thickening drape above black clays and carbonate sediments.

Deposition rates slowed in Upper Cretaceous time and the basin is therfore filled chiefly with Jurassic and older Cretaceous deposits. New cycles of deposition, chiefly marine shales and sands, occurred during latest Cretaceous and early Tertiary (Paleocene-Eocene) time. At this time, the geomorphic form of the Continental Shelf and Slope was well established by normal oceanic circulation patterns. Thermohaline circulation carried oxygenated waters to the abyssal deeps and probably oxidized most of the organic components of the sediments prior to their burial. Exception to these oxidizing conditions occurred--turbidites and mud flows on the Continental Slope may have provided quick-burial of reduced organic material (Emery, 1963).

A widespread erosional unconformity developed on the Continental Shelf at the end of the Eocene which continued throughout the Oligocene on this part of the North Atlantic margin. Upper Tertiary deposits, less than a kilometre thick, consist chiefly of unconsolidated silts, sands, clays, and gravel.

What can be summarized, at least in general terms, about the petroleum potential of Georges Bank basin from its geologic history? Apparently the basin was restricted or partly restricted throughout the Jurassic and Lower Cretaceous. In addition, we suspect that during Jurassic and Lower Cretaceous times temperature gradients in the Georges

Bank basin were higher than at present. Carbonate deposition prevailed during the Jurassic in contrast to clastic deposition during the Cretaceous. We might predict therefore, that carbonaceous Jurassic limestone and organic-rich Lower Cretaceous shale are potential source rocks. Fractured limestone and porous dolomite could provide potential reservoirs in Jurassic rocks; whereas reservoir rocks in the Cretaceous section are more likely to be sandstone. Jurassic and Lower Cretaceous reefs located near the shelf edge may provide additional reservoirs. Block faulting during the Triassic and possible continued movement along these faults during the Jurassic suggest that large structural highs, caused by draping and differential compaction over basement blocks, will occur in the Jurassic and Lower Cretaceous sections. Whereas in the Upper Cretaceous section these structures, if they exist, will have very little relief.

These conclusions are encouraging as far as the future petroleum potential of Georges Bank basin. Are the results substantiated when we compare the basin with similar offshore basins?

Geologic Analogies

As noted by Rouse (1971), "it is hard to find a seaboard or offshore producing area comparable to the Atlantic province". In their classification of hydrocarbon basins, Halbouty and others (1970) classify basins of the Atlantic shelf as type V characterized by stable coastal basins representing the end phase of cratonic-rifting where seafloor spreading probably separated or pulled apart the initial rift basins to oceanic proportions. Most of these basins have an offshore basement ridge that acts as a dam to contain shore-derived sediments. The average estimated recovery of oil per cubic km of sediment for a type V basin is 4,318 bbls (Halbouty and others, 1970). These authors list only one type V basin with giant fields--the Cabinda embayment of Angola-Congo. The two giants are Cabinda "B" and Emeraude Marin with estimated reserves of 1.2 billion and 500 million bbls of oil, respectively. Both fields are anticlines on the Continental Shelf and produce from sandstones. Cabinda "B" produces from the Cretaceous and Miocene from an average depth of 3,048 m. Emeraude Marin produces from the Tertiary, between 548 and 610 m. Although Georges Bank basin and Cabinda embayment are both type V basins, this may not be a good analogy because Georges Bank basin has a thin, possibly non-prospective Tertiary section in comparison to the latter.

If one appeals to recent concepts of continental drift, Georges Bank area might be compared with the northwest coast of Africa. Rona (1970) has compared the North and South Atlantic (Southeast Georgia embayment area) with the pre-drift opposing continental margin off Africa (Senegal Basin) and noted that they appear symmetrical with respect to late Precambrian, Paleozoic, and Mesozoic tectonic framework and early and middle Paleozoic, Mesozoic, and Cenozoic stratigraphic frameworks. He states:

> "Mesozoic and Cenozoic mean rates of subsidence and sequences of gross lithology generally correlate between the opposing continental margins. Similarities in the stratigraphic records of the opposing continental margins have behaved as if vertically, as well as horizontally, coupled to the ocean basin."

The pre-continental drift reconstruction of Briden, Dewey, and Smith (1974) places Georges Banks opposite the coast of Morocco. To date, exploration on the northwest coast of Africa, both onshore and offshore has been very disappointing (Aymé, 1965; Alem, 1974; and Levy and others, 1975).

Moroccan offshore exploration began in 1967 and since then, concessions have been granted out to the 500 m isobath. As of 1972, ten wells have been drilled offshore Morocoo, three of which had hydrocarbon shows. One well "showed occurrences of poor quality, heavy, viscous oil in the Jurassic", and another was reported to have "excellent oil traces in the Middle and Lower Cretaceous" (Levy and others, 1975). Cumulative production through 1973 for Morocco has been 15.4 million bbls of oil and 14 billion cubic feet of gas with daily production of only 879 bbls of oil 8,110 million cubic feet of gas for 1973 (Alem, 1974). All the Moroccan oil fields are near depletion (Alem, 1974).

In terms of geographic proximity to Georges Bank basin, the nearest explored offshore area is the Scotion shelf located less than 100 km to the northeast. Schultz and Grover (1974) and Scott and Cole (1975) suggest similarities between the two areas. At present the only available data on the physical properties of the deeply buried sediments in Georges Bank basin are from seismic velocities. Comparison of these velocities with those obtained on the Scotian Shelf provide a basis, although limited, for comparison of the two offshore areas.

In figure 11 (Mattick and others, written communication) interval velocities from the Scotian Shelf, Georges Bank, Baltimore Canyon trough, and the Gulf of Mexico are shown. The Scotian Shelf data are from well logs of Shell Naskapi N-30 and Shell Oneida 0-25 wells. The Georges Bank velocities were computed from the seismic reflection data discussed earlier, and the Baltimore Canyon trough velocities are from results of two additional profiles shot in that area.

The most striking feature of figure 11 is that the curves from the Georges Bank area and the Scotian Shelf are almost identical In contrast, the curve representing velocities in the Baltimore Canyon area is well below the former and the Gulf of Mexico velocities even lower. According to Faust (1951) velocities in sedimentary rocks depend on depth of burial, age, and lithology. Mattick and others (written communication) have interpreted these results as indicating that the lithology and stratigraphy of the Scotian Shelf and Georges Bank basin sediments are similar. Other authors including Schultz and Grover (1974), and

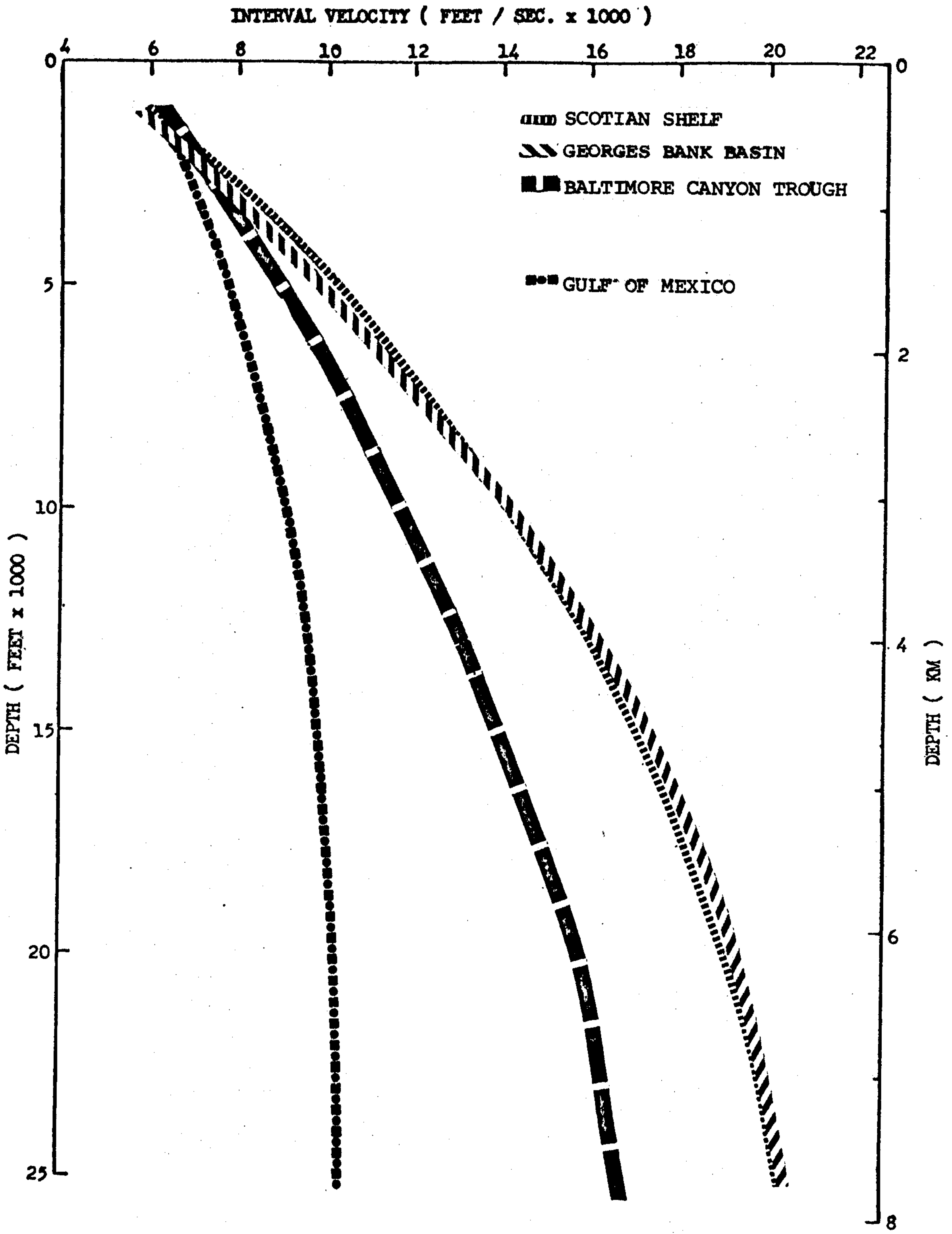


Figure 11.-- Comparison of velocities computed in Georges Bank area with velocities reported from other nearby areas.

Scott and Cole (1975) have made analogies between the two areas.

What have been the results of recent Scotian Shelf exploration? Exploration began on the Sootion Shelf in 1967. To date 45 wells have been drilled on the Scotian Shelf, six of which have been "small discoveries" all within 50 km of Sable Island (Sherwin, 1975).

The best results reported to data have been from the Mobil-Tetco Sable Island E-48-drilled over the West Sable Island structure--a deep salt dome (fig. 12). In this well 247 m of pay (individual pay zones range in thickness from less than a metre to about 10 m) were encountered over the interval 1,350 m to 2,370 m in sands of the Dawson Canyon and Logan Canyon formations of Cretaceous age (Smith, 1975). The following is a summary of the completion history for E-48 (Marrow, Harris, and Warden, 1972):

> "Subsequent to reaching a total depth of 11,820 ft (3503 m), 22 intervals were tested through perforations between 3752 ft (1144 m) to 7502 ft (2297 m). Seven of these tests yielded oil and gas in amounts varying from 370 BOPD plus .2 MMCFGPD to 790 BOPD plus 1 MMCFGPD. Ten of the tests yielded gas and NGLs with the gas varying from .7 MMCFGPD to 10.5 MMCFGPD, and the NGL varying from 127 BPD plus 2.8 MMCFGPD to 1660 BPD plus 7 MMCFGPD. Three of the tests yielded gas only at rates varying from 2.45 MMCFGPD to 5.55 MMCFPD.
>
> The well was completed flowing at the rate of 2880 BOPD and 1.3 MMCFGPD from perforations 4790 ft (1460 m) - 4795 ft (1462 m) on October 15, 1971 and shut-in."

It should be noted that the above test periods varied from less than 3 hours to 12 hours. After the E-48 well was drilled seven additional wells were drilled over the salt dome. Five of these wells have been listed as suspended oil and gas wells, one as a dry hole, and one, the 0-47 drilled on the east flank of the salt dome encountered 20 m of gas

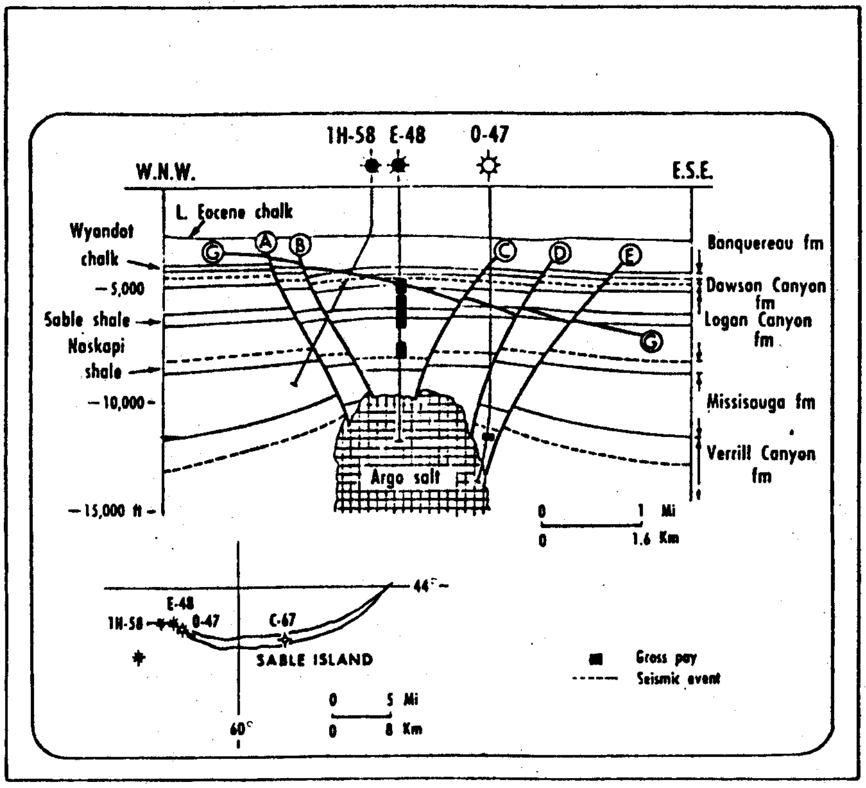


Figure 12.-- West Sable structure as indicated by well data. From Smith (1975).

pay in a deeper sand zone in the Verrill Canyon Formation of Upper Jurassic age (Sherwin, 1975). The completion history of the O-47 is summarized as follows (Dawson, 1974):

> "Six successful drillstem tests were run in open hole. DST #8 (12,369 ft (3770 m) - 12,775 ft (3894 m)) flowed gas at rates up to 14 MMcf/d. on 1/2 inch choke.
>
> Subsequant to reaching a final total depth of 13,775 ft (4199 m) measured 5 1/2 inch production liner was run from 12,900 ft (3932 m) to surface. Five (5) production tests were run over the gross interval 11,906 ft (3392 m) to 12,498 ft (3809 m). Production test #5 (over the perforated intervals 12,498 ft (3809 m) to 12,492 ft (3809 m) and 12,485 ft (3805 m) to 12,477 ft (3803 m) yielded 9.2 MMcf/d. and 1/2 bbl. condensate on a 9 hour test.
>
> The well was completed as a suspended gas well and rig released July 1, 1972."

Figure 13 shows the location of other wells drilled in the vicinity of Sable Island. In the Shell Onondaga E-84 well, located approximately 30 km southeast of Sable Island, a number of sandstones were encountered in the gross interval between 2,702 m and 2,824 m (Lower Cretacous Missisouga Formation) and interpreted to be gas bearing on the basis of open hole logs and shows in the drilling mud returns. Two subsequent wells were drilled on the deep seated salt dome but encountered only minor amounts of gas.

The Shell Primrose located about 65 km east of Sable Island, drilled on a shallow piercement salt dome, recovered oil and gas on production tests of the intervals 1,371 m - 1,379 m, 1,391 m - 1,400 m, 1,498 m - 1,532 m, and 1,594 m - 1,650 m. Drilling of two delineation wells have indicated insufficient reserves to warrent commercial development at the present time (Sherwin, 1975).

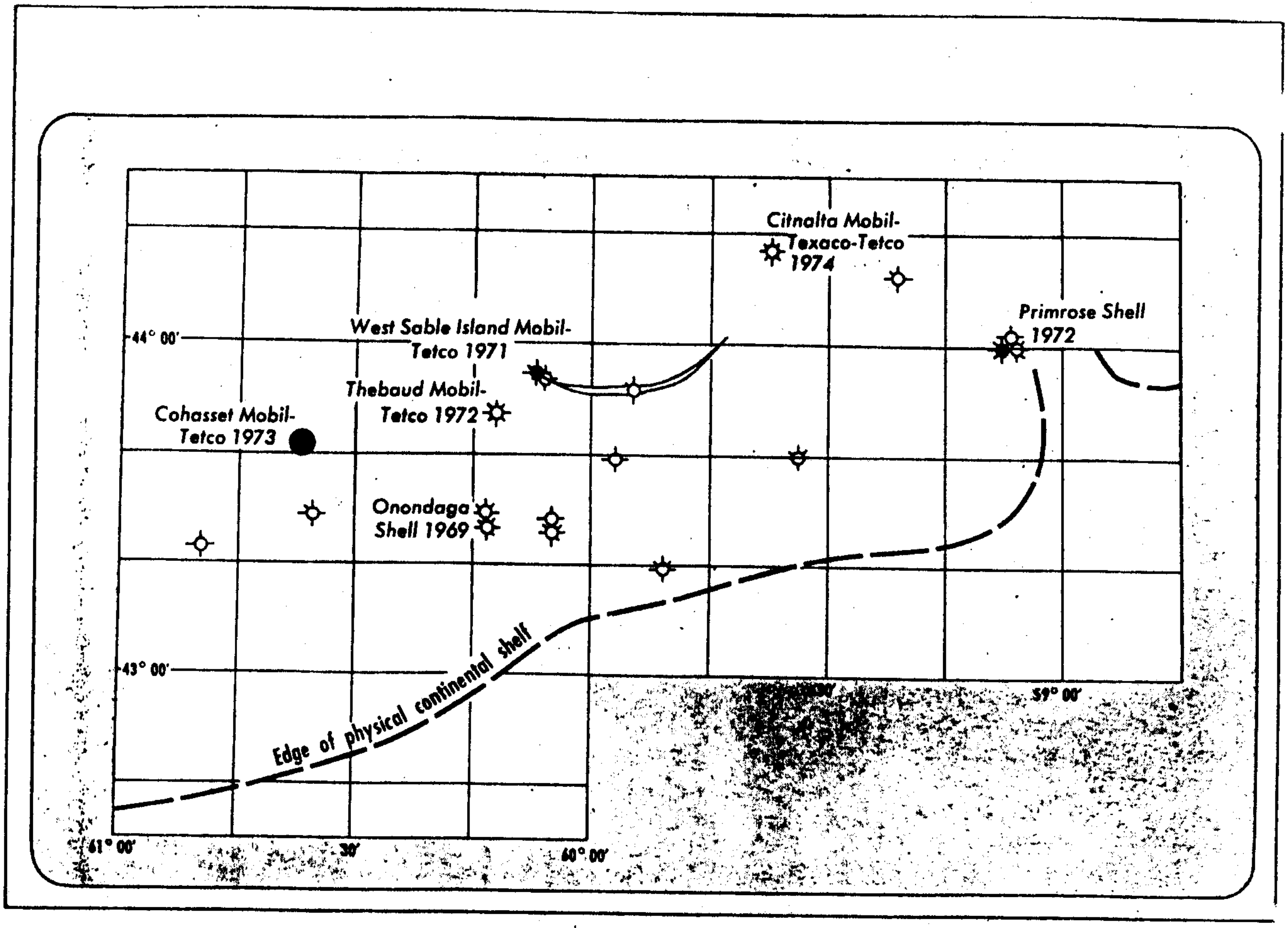


Figure 13.-- Location of wells on the Scotian Shelf. From Sherwin (1975).

Another discovery, the Mobil-Tetco Thebaud P-84 was drilled on a salt generated domal structure located about 10 km southwest of the Mobil-Tetco Sable Island E-48. The well bottomed at 4,115 m when an over-pressured shale section was encountered. The well completion history is summarized as follows (deJonge, Prior, and Harris, 1973):

> "One successful drillstem test was run in open hole. This DST flowed gas at a rate of 10.6 MMcf/d on a 32/64 inch choke.
>
> Twelve production tests were run over the gross interval 10,300 ft (3,139 m) to 13,235 ft (4,034 m). Five of these tests yielded gas with condensate at varying rates.
>
> The well was completed as a suspended gas well on October 11, 1972."

The Mobil-Tetco Cohasset D-42, located about 40 km west of Sable Island, recovered high-gravity oil from three to five zones tested between 1,800 and 3,700 m (Sherwin, 1975).

The Mobil Citnolta I-59 well, located approximately 15 km northeast of Sable Island recovered gas and condensate from three relatively thin zones tested below 3,700 m with other untested hydrocarbon-bearing zone indicated on the log (Sherwin, 1975). Three other wells, located north of Sable Island, have encountered significant but non-commercial shows of oil (Sherwin, 1975).

The petroleum potential of Georges Bank basin, on the basis of geologic analogies, can be summarized as follows: Halbouty and others (1970) estimate that Atlantic type basins contain the lowest quantities (4,318 bbls per cubic km) of recoverable oil even though the Cabina embayment of Angola-Congo has two giant fields. If we assume that the petroleum potentials of opposing margins of Africa and North America are similar (based on a similarity in gross lithology and stratigraphic records) then we might compare Georges Bank basin with Morocco and its offshore area where cummulative production through 1973 was 15.4 million bbls of oil and 14 billion cubic feet of gas. On the basis of geographic proximity (less than 100 km) and possible similarities in stratigraphy and lithology we might compare the petroleum geology of Georges Bank with the Scotian Shelf, If this last analogy is really valid then the data suggest that source rocks and reservoir rocks will be present in the Georges Bank basin. Thick pay zones with substantial flow rates of both oil and gas are reported from at least one well on the Scotian Shelf. Well data from the Sable Island structure on the Scotian Shelf indicate that the pay zones are thick but lack latteral continuity--whether this problem will exist in the Georges Bank basin is not known at present. In the case of the Scotian Shelf most of the "significant" discoveries have been from structures associated with salt diapirism; however, Burke (1975) indicates that extensive thick salt deposits do not extend as far west as Georges Bank. Nevertheless, large drape structures present in Georges Bank basin may provide the necessary traps.

Based on the information presented in the geologic and geophysical sections of this report, together with the above discussions on geologic history and geologic analogies, it is possible to comment more specifically on potential source rocks and reservoir rocks by geologic age.

Potential Source Rocks and Reservoir Rocks by Geologic Age

Pre-Triassic.--Unmetamorphosed pre-Triassic rocks have not been reported north of the Southeast Georgia embayment on the United States continental margin. Although Mattick and others (1974) discuss the possibility of unmetamorphosed pre-Triassic sediments in the Baltimore Canyon trough at depths greater than 13 km, seismic evidence given earlier in this report (pl. 4) and the results of Schultz and Grover (1974) indicate that pre-Triassic rocks underlying Georges Bank basin have been highly metamorphosed. It is most unlikely therefore, that pre-Triassic rocks beneath the Georges Bank basin contain hydrocarbons, except where intensely fractured basement rocks may lie in fault contact with petroliferous sediments.

Triassic.--Most Triassic rocks (red beds) of the eastern United States have little hydrocarbon generating potential--the Continental Shelf should prove no different. These rocks were deposited in a continental to brackish water oxidizing environment and therefore, most of the available organic material was removed before burial. The humic and lignitic material escaping oxidation might have generated small quantities of gas. The chance of gas generation would be increased in Triassic grabens that have been intruded with dikes and sills.

Jurassic.--The Jurassic section, at depths of 3-6 km, in the Georges Bank area is probably greater than 2 km thick (Scott and Cole, 1975;

Schultz and Grover, 1974; Mattick and others, 1974; and pl. 4)--essentially compring about one-third of the total sedimentary section beneath Georges Bank area (fig. 2). The Jurassic section is a prolific producer in the Gulf Coast and in the giant Jay Field in Northwest Florida. Jurassic rocks are expected to consist of chiefly limestones and dolomites in the central and southeast part of the basin and marine shales and sandstone in the northwest. In reference to Jurassic reservoirs beneath the shelf off the United States Mid-Atlantic, Maher (1971) states:

> "The possibility of carbonate reservoirs beneath the Continental Shelf in the vicinity of the Hatteras Light well is suggested by porous zones in limestone and dolomite beds in pre-Upper Cretaceous rocks. The upper part of a 100-foot carbonate sequence at the top of rocks of Late Jurassic or Early Cretaceous (Neocomian) age (8,750 feet) contains oolitic limestone, porous granular dolomite, and anhydrite. The porosity of these beds is slight compared to the sandstones discussed previously, but it bears on the probability that thicker units of porous dolomite and oolitic limestone beds may be expected offshore."

Even though high seismic velocities suggest that Jurassic carbonates consist overall of dense limestones and dolomites, the possibility of zones of high porosity should not be overlooked. Carbonate rocks (oolitic limestones, calcarenites, and coquinas) commonly possess high initial porosity and permeability and are considered potential reservoir rocks. Dolomitization can occur shortly after deposition of calcium carbonate and provide a very timely effective secondary reservoir porosity. Likewise, because of their brittle character, consolidated carbonates are susceptible to the formation of secondary fracture reservoirs for oil and gas. It should be noted that in comparing the nature of reservoirs of giant fields on a world-wide basis, Moody (1975, pg. 310) reports that carbonates contain almost as much total oil as sandstones.

Significant Jurassic reservoir rocks may be encountered beneath the northwest part of the basin where Jurassic rocks appear to have low velocities and are relatively shallow (less than 3 km). As stated earlier, the low velocities could be indicative of Jurassic sandstone and shale. In Mobil-Tetco 0-47 on Sable Island, hydrocarbons were reported in Verrill Canyon sandstones of Jurassic age at a depth of about 3.65 km (Smith, 1975).

Direct evidence as to the presence of potential Jurassic source rocks is not available. Such information can come only from deep wells, outcrops, or petroleum seeps. Indirect evidence from geophysical data (velocity and density) which sometimes can be used to predict reservoir properties cannot distinguish rocks, rich in organic materials, from those that are not. Thick marine shales generally regarded to be the most important hydrocarbon generators, are reported from the nearby Scotian Shelf. McIver (1972) states that the Verrill Canyon shale at the Shell Oneida 0-25 well is 368 m thick and consists of medium gray to brown, carbonaceous, splintery shale. These shales probably were the source rock for the pay zone penetrated in Verrill Canyon sandstone at 0-47 on Sable Island. Jurassic organic-rich carbonate rocks, provided they were not oxidized before burial, should not be overlooked as potential source rocks; especially considering that the basin during early Jurassic, may have been highly restricted so as to provide reducing bottom conditions favorable for the preservation of organic matter and at the same time have provided a trap for abundant plankton. In this respect the previously mentioned early Jurassic evaporite may be important. Hedberg (1964, pg. 1772) has stated:

> "The common occurrence of evaporite deposits in the stratigraphic sections of oil-field areas is impressive. Moody (1959) has commented that of 39 major petroleum provinces in the free world 17 are known to show significant associations between evaporites and important oil reservoirs. The reason for the association is probably not that evaporite deposition has any direct relation to oil genesis, but rather that both evaporites and petroleum are common products of restricted basins."

Lower Cretaceous.--At this time, without the benefit of drill data, Lower Cretaceous rocks beneath the Georges Bank area are considered to have the best hydrocarbon potential. Not only is the Lower Cretaceous section thick (in excess of 2 km), but these rocks are at depths of between one and 4 km. These depths are important if we reflect on the statistics of Moody (1975) -- as far as giant oil fields are concerned, the major accumulations of oil are infrequent below depths of about 3.7 km. (Note... a number of large(?) fields have been recently found in the Gulf Coast below 3.7 km). The varied lithology of the Lower Cretaceous section (marine sandstone, shale, and limestone) is expected to provide ample probabilities for potential reservoir rocks and source rocks.

Both north and south of Georges Bank potential Lower Cretaceous reservoir sands have been penetrated by the drill. To the north, at least one pay zone was encountered in Lower Cretaceous sandstone of the Logan Canyon Formation at the Sable Island E-48 well on the Scotian Shelf (Smith, 1975). (A detailed discussion of the Scotian Shelf is given elsewhere in this report.)

To the south, thirty-seven porosity and permeability measurements of Lower Cretaceous rocks from the Hatteras Light 1 well on Cape Hatteras, North Carolina show that the average porosity and permeability of these rocks are 26.1 % and 487 millidarcys respectively (Maher, 1971). Beneath the Georges Bank area itself, downdip Lower Cretaceous carbonates are potential reservoirs. Within the Lower Cretaceous Sunniland Limestone near Miami, porosity ranges from 6.5 to 23.3% and permeability between 0 and 2.3 darcys (Meyerhoff and Hatten, 1974). Potential Cretaceous reservoir sands in the Georges Bank area probably coalesce updip to the north where they abut the regional unconformities along the northern margin of the area, analogous to the Hatteras area further south. However no hydrocarbon seeps are known from this area based on available data. Fault traps do not appear likely in this part of the section (Mattick and others, 1974, fig. 10; Schultz and Grover, 1974, fig. 5).

Mattick and others (1974) have speculated on the possibility of Lower Cretaceous reef reservoirs occurring along the shelf edge in the Baltimore Canyon trough. Seismic evidence indicates that reefs could occur along the shelf edge in the Georges Bank area also. The importance of reefs in petroleum accumulation apparently is due to the fact that they furnished timely, high porosity reservoirs near favorable source areas (Hedberg, 1964). In this case, shelf edge reefs might be potential reservoirs, not only for petroleum generated on the shelf, but also, if we appeal to the concept of long distance migration, for petroleum generated on the slope. In this connection, the suggestion of Emery (1963), that sediment slides to the foot of the slope might create rich source material, should be considered. Conversely however, Meyerhoff and Hatten (1974) are not impressed with the reservoir potential of shelf edge reefs off Florida. According to these authors, the Atlantic Ocean has been able to flush the exposed reefs of the Bahamas area since early in its history.

In general, environmental conditions during Lower Cretaceous time could have been exceptionally compatible with a world-wide production of potential source rocks. Fischer and Arthur (1975) suggest that Albian, and to a lesser degree Aptian, was a time of deposition of extremely non-oxidized sediments. It may have been a time of reduced oceanic circulation or a time when high rates of organic productivity overwhelmed the available oxygen. In connection with the latter, flourishing marine organisms could have created their own bottom-reducing conditions (Hedberg, 1964, p. 1770). The data of Fischer and Arthur indicate that this was a time of warmer temperatures, high faunal diversity, and heavy carbonate carbon isotopes.

Well data from the nearby Scotian Shelf indicate that Lower Cretaceous shales are abundant (McIver, 1972); and probably the petroleum from Lower Cretaceous rocks in Sable Island E-48 is due to source beds in some of these shales. Lower Cretaceous fore-reef deep-water shales and/or limestones must be considered also as potential source rocks as suggested for the Golden Lane Fields of Mexico by Meyerhoff and Hatten (1974). Deep-water Early to Middle Cretaceous Tamabra Limestone and Tamaulipas Limestone of the Tampaco Embayment of Mexico (Coogan and others, 1972) possibly contained the original organic materials that were transferred into petroleum for the giant reserves in the Golden Lane Fields which produce from the shallow-water reef limestone of the El Abra Formation (Meyerhoff and Hatten, 1974). However, available data from the Georges Bank area limits Cretaceous reef development to areas of deeper water (greater than 200 m) off the present shelf edge.

Whether Lower Cretaceous reefs could or could not have generated petroleum is open for debate. As to reef generation is general, Rainwater (1971) has stated:

> "Though enormous quantities of organic material are generated in reefs, most of it probably is oxidized. Only in the adjacent backreef protected area is there preservation of both indigenous and reef organic matter. If this material is converted to petroleum and is squeezed out of the fine-grained backreef sediment into the porous reef rock, it will not be trapped unless the reef is covered by impervious beds such as anhydrite or clay. Inasmuch as conditions favorable for anhydrite deposition are not likely to develop quickly in a barrier-reef environment, the most likely seal is clay. Only during regressive periods of abundant supply of terrigenous sediments from bordering lands are the reefs likely to be smothered with clay and silt".

In connection with this, Cretaceous marine clays are reported from both onshore outcrops and in Scotian Shelf wells (pgs. 15-16, this report).

One of the most interesting speculations as far as potential Lower Cretaceous source rocks, is whether the thick (200-300 m) Albian through Cenomanian black, hemipelagic organic-rich clays, encountered during the Deep Sea Drilling Program (DSDP), might extend to the base of the shelf or possibly even beneath the shelf itself in the Georges Bank area. (See figures 9 and 10). Lancelot and others (1972) have discussed the organic matter of these muds from DSDP holes 101 and 105:

> "The total organic carbon content, as determined on 34 samples from this part of the section, shows several values around 3 per cent. One value from Core 9 of Site 105 reaches 14.8 per cent. Concentration of carbon was high enough so that one sample could be burned aboard the ship. Detailed analyses of the organic matter from the carbonaceous clays are published elsewhere in this volume (Simoneit et al.); they indicate relatively low contribution from plant-derived organic debris."

The large geographic separation (over 1,000 km) between DSDP holes 101 and 105 suggest broad areal distribution of Lower Cretaceous sapropel (potential petroleum source beds) in the western North Atlantic. But whether or not these beds are buried beneath the base of the Continental Shelf and, by appeal to long distance migration, could have been a source of petroleum for shelf edge reservoirs in the Georges Bank area, can only be answered by deep drilling. It should be added that the quantity of organic-carbon content of a rock by itself does not assure its source rock properties (Fuloria, 1967)--the convertibility of the organic matter to petroleum and the efficiency of oil expulsion are also important. The authors are not aware of evidence that indicates that these Lower Cretaceous deep-water, clay deposits of the Western North Atlantic are associated with any commercial accumulations of hydrocarbons.

Lower Tertiary (?) and Upper Cretaceous.--Stable shallow-water conditions persisted throughout most of Upper Cretaceous time. Sedimentation rates were much slower than during Lower Cretaceous time. These two factors are not conducive to hydrocarbon generation. Whatever organic matter was deposited, either land derived or marine, was probably oxidized before it could be preserved. As noted by Ernst (1974) "...sediments (carbonates, orthoquartzites, etc.) on continental shelves of the Atlantic type accumulate in an environment that promotes oxidation and solution of unstable lithic, biogenic, and mineral grains and the formation of secondary quartz and carbonates."

Offshore of Cape Hatteras, the reservoir characteristics of Upper Cretaceous rocks may not be as good as in onshore wells. Maher (1971) compared the Hatteras Light well with updip wells and noted that "rocks of Woodbine age may be considerably less porous and permeable a short distance offshore than they are beneath the Atlantic Coastal Plain". However, on the Scotian Shelf, sands of the Dawson Canyon and Logan Canyon formations and the Wyandot Chalk are considered potential reservoir rocks.

Maher (1971) is optimistic in his overall assessment of the Upper Cretaceous hydrocarbon potential. He believes that thick marine source rocks may be expected beneath the shelf and went on to say:

> "Upper Cretaceous rocks have good possibilities for oil and gas production beneath the Continental Shelf, but they have only fair possibilities, chiefly for gas, in the Coastal Plain."

The most optimistic predictions concerning the Upper Cretaceous potential reservoirs of the Georges Bank area would have to be based on a comparison with the Sable Island area of the Scotian Shelf. Smith (1975) has reported that the Mobil-Tetco Sable Island E-48 well encountered 247 m of pay in sands of the Dawson Canyon and Logan Canyon formations with substantial flow rates of both oil and gas before being shut-in. (A more detailed description of the Scotian Shelf exploration is given elsewhere in this report.)

It should be noted that some Upper Cretaceous rock units are exposed on the Continental Slope (Weed and others, 1974). In reference to this Johnston and others (1959) say..."this structural setting need not be a deterrent to petroleum accumulation, for in the Appalachian Plateau, petroleum is produced within a few miles of the outcrop of permeable reservoirs."

Upper Tertiary.--The Upper Tertiary strata of the Continental Shelf offers little hope for commercial quantities of petroleum. These deposits, less than a kilometre thick in the Georges Bank area, consist chiefly of unconsolidated silts, sands, clays, and gravel. Reported shows of oil and gas in the Tertiary of Florida are rare (Winston, 1971). In three JOIDES holes drilled offshore of Jacksonville, Fla., "oil odors and specks" have been reported (Schlee and Gerard, 1965; and Emery and Zarudski, 1967). Hollister and others (1972) reported "a substantial amount of gas, consisting primarily of methane with a trace of ethane" for DSDP hole 103 (fig. 10). According to Meyerhoff and Hatten (1974), there is a lack of sealing beds within the Tertiary. Maher (1971) has stated that "Tertiary rocks exhibit very good reservoir and source rock characteristics" but are less promising than Cretaceous rocks.

Potential Traps

The diagrammatic cross-section shown in figure 14 illustrates our interpretation and inferences concerning possible petroleum traps in the Georges Bank basin. The cross-section is based primarily on the seismic profile shown in plate 4.

Drape structures--The largest and most important potential petroleum traps in the Georges Bank basin could be structural highs associated with draping and differential compaction over basement blocks. One of these structures is labled "A" in figure 14. The structure is approximately 20 km wide near the top of the Jurassic and if it is roughly symmetrical, 80,000 acres may be under closure--a sizeable structure. Although these features appear to be the result of draping and differential compaction, part of the relief may be due to continued uplift of basement blocks during Jurassic time or even in Cretaceous time.

Drape structures such as these have provided substantial petroleum traps in other parts of the United States such as the giant Panhandle-Hugoton Field of Texas, Oklahoma, and Kansas (Pippin, 1970). In the Georges Bank area, these drape structures could have provided "timely" traps for hydrocarbons that may have been generated

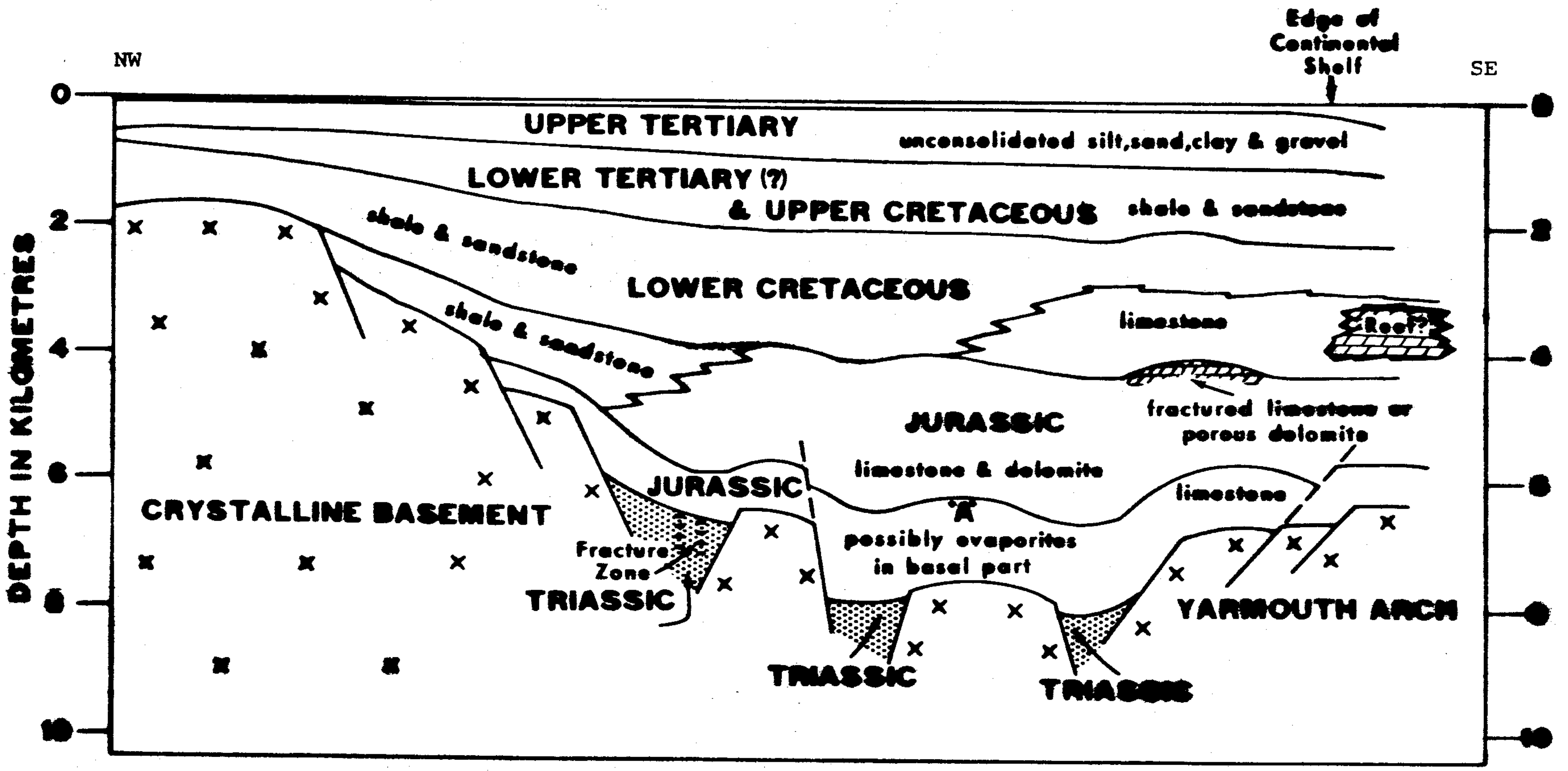


Figure 14.--Diagrammatic cross-section illustrating potential traps in the Georges Bank basin.

in Jurassic or Lower Cretaceous rocks.

Fault traps.--Continued movement of basement blocks during Jurassic and possibly during Lower Cretaceous time may have resulted in potential fault traps. If such fault traps exist, they are probably in the lower part of the sedimentary section.

Stratigraphic traps in carbonate sediment.--The thick marine carbonates of Jurassic and Lower Cretaceous age could contain abundant buried reefs and dolomites. These rocks, sometimes extremely porous and permeable, are potential stratigraphic traps, especially near the shelf edge.

Stratigraphic traps associated with facies changes.--Downdip facies changes from marine clastics to carbonates and from marginal marine sandstone to shale in Jurassic and Cretaceous rocks should provide stratigraphic traps. Although difficult to locate, these traps could be numerous.

Updip wedgeouts.--Updip wedgeouts of Jurassic and Cretaceous units offer promising possibilities as stratigraphic traps.

Fracture zones in Triassic basins.--Possible fracture zones in Triassic sandstone could be potential gas traps; however, these traps, if they exist, would be deeply buried.

Unconformities.--Although unconformities are not shown in figure 14, they have been suggested as possible hydrocarbon traps. According to Maher (1971) unconformities separating sequences assigned to Late Jurassic or Early Cretaceous may exist beneath the Continental Shelf.

Estimate of Undiscovered Recoverable Oil and Gas Resources

Undiscovered recoverable resources are those economic resources, yet to be discovered, which are estimated to exist in favorable geologic settings (Miller and others, 1975). As a part of the recent study for the Federal Energy Administration (FEA) by the Resource Appraisal Group of the Geological Survey (summarized in Geological Survey Circular 725), estimates of undiscovered recoverable oil and gas resources of the North Atlantic Shelf have been prepared as follows: (1) by carefully reviewing the available geological and geophysical data, gathered by area specialists, (2) by applying a variety of resource appraisal techniques to this data, and (3) through group appraisals involving subjective probabilities and the application of appropriate statistical procedures (Raiffia, 1968).

The proposed lease area (pl. 1) within the confines of the North Atlantic shelf province is estimated to contain 95% of the undiscovered recoverable resources of the province. The lognormal distributions for, respectively, oil and gas within the total U.S. North Atlantic shelf province, following the statistical methods of Kaufman (1962), are shown in figure 15. Based on available geologic factors, a marginal probability of 60% was assigned to the occurrence of any recoverable quantities of oil and gas in this province. In other words, a subjective decision, based on geologic factors, was reached that there existed a 40% chance that no commercially recoverable oil and gas would be found in the province. This marginal probability may

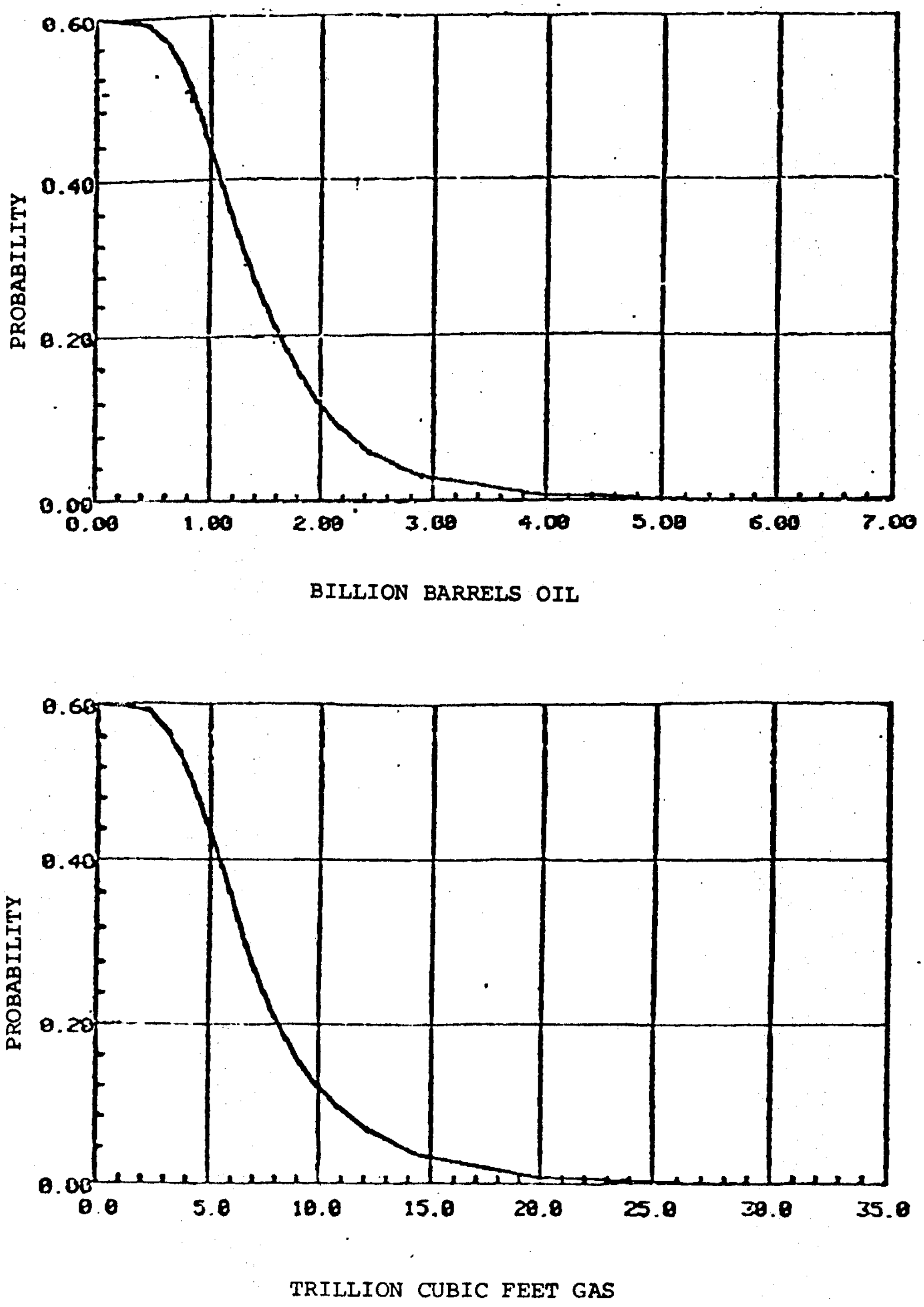


Figure 15.-- Lognormal distributions for oil and gas within the U.S. North Atlantic shelf province.

be revised at a later date as more data become available,

For the proposed lease area the estimated undiscovered recoverable resources at the 5% probability level (1 in 20 chance of occurrence) are 2.4 billion barrels of oil and 12.5 trillion cubic feet of gas. The estimated undiscovered recoverable petroleum resources at a one percent probability (1 in 100 chance) of at least that amount are about 3.8 billion barrels of oil and about 19 trillion cubic feet of gas. The statistical mean, derived from the lognormal distributions for oil and gas, adjusted to the lease area, is 0.9 billion barrels of oil and 4.2 trillion cubic feet of gas.

ENVIRONMENTAL CONSIDERATIONS

We examined the Georges Bank environment from three main aspects, the weather, oceanic circulation, and geologic hazards. The main driving force of water circulation and ultimately sediment movement is the weather--particularly winter storms. Storms also pose a slight potential danger to offshore rigs (CEQ 1974, figure 5-2) on the Bank. Oceanic circulation is important in dispersal of pollutants from a potential oil spill. Where are they likely to end up and how will they affect the fisheries? Shifting sediment through a quake or through migration of sand waves could prove hazardous to a platform or a pipeline. What are the likelihoods and upon what are they based?

Several studies have examined the possible impact of oil development on Georges Bank (Ahern, 1973; Offshore Oil Task Group, 1973; CEQ, 1974; Trigom-Parc, 1974) and have reached a variety of conclusions. Trigon-Parc (1974) presented a socio-economic and environmental inventory of the northeastern Atlantic region. Ahern (1973) concludes that petroleum could be developed at a moderate cost with a negligible damage to fisheries from spills. The MIT study, looking at spill probabilities, concluded that a spill from Georges Bank would have only a few percent chance of reaching shore and if it did, the oil would be well weathered. The CEQ report (1974, p. 1-8) assigns a low to moderate environmental risk to the Georges Bank area from OCS development. Most of these studies are cautiously optimistic about risks to the environment from oil development. In part, the cautious view results from a data base that is sparse in its coverage. We wish to examine the base and the natural phenomena operating on Georges Bank in more detail.

The climate is an important factor in water circulation on Georges Bank and adjacent shoals because they are shallow exposed areas. For much of the year, weather effects are superimposed on strong tidal currents that cross the Bank, however, periodically, storms are the major driving force in water movement. The climate for the area is summarized in table 3, and figures 10 and 11. During the summer, winds of force 3 are from the southwest 20-25% of the time; calm or light variable airs 6-9% of the time. Storm tracks cross through the area from southwest to northeast. Fog can cover the Bank 5-10% of the time and air temperature averages between 64-68°F. During the fall, a transition to strong winds from west and northwest takes place, with a force of 5 (fresh breeze). Temperatures drop into the 48° - 52°F range and storm tracks have similar orientation, though are more frequent in September. In the winter, winds of force 5 are out of the northwest quadrant and calm intervals prevail only a small part (1-2%) of the time. Air temperatures average 32° - 36°F and major storm tracks cross the Bank with increased frequency compared to the fall. During the spring, winds come mainly from the west at a diminished force, and temperature moderates.

Anderson-Nichols and Company; Moran, Proctor, Mueser and Rutledge (1954) have summarized data on maximum winds, waves, swell, tidal currents, and icing; their data are quoted below:

"Maximum Winds and Waves

A study of weather maps for the last twenty years has yielded the results shown...[below]. The wave predictions...[below] are based on a study made at New York University for the Bureau of Aeronautics U. S. Navy, the results of which are contained in "Practical Methods for Observing and Forecasting Ocean Waves," July 1953.

Table 3.--Summation of meteorological data adjacent to Georges Bank from U. S. Coast Pilot, U.S. Department of Commerce (1974)

NANTUCKET, MASSACHUSETTS (Memorial Airport) 41°15'N., 70°04'W. Elevation (ground) 43 feet. WB-1969

	Air temperature (°F.)					Precipitation (inches)			Humidity (percent)		Wind (knots)					Mean number of days						
	Normal			Extreme												Sunrise to sunset						
Month	Daily maximum	Daily minimum	Monthly	Record highest	Record lowest	Normal total	Maximum 24 hrs.	Snow, sleet mean total	7 a.m. EST	1 p.m. EST	Mean speed	Prevailing direction	Maximum speed and direction	Percent of possible sunshine	Mean sky cover sunrise to sunset	Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, sleet 1.0 inch or more	Thunderstorms	Heavy fog
(a)	(b)	(b)	(b)	4	4	(b)	23	23	4	4	22	14	23	23	23	23	23	23	23	23	22	22
Jan.	39.2	26.8	33.0	63	2	4.22	2.82	8.7	79	67	12.8	NW	51NW	42	7.0	7	6	18	13	2	*	5
Feb.	38.1	24.6	31.4	54	5	3.76	2.32	10.6	79	67	13.2	WNW	57NW	48	6.9	6	6	16	12	2	*	5
Mar.	42.5	29.6	36.1	60	10	4.54	2.92	7.5	80	67	13.2	NW	63N	56	6.5	8	8	15	12	2	1	6
Apr.	50.6	38.0	44.3	69	23	3.76	4.48	0.9	80	65	12.7	WSW	55N	56	6.5	7	8	15	12	*	2	8
May	59.9	45.3	52.6	77	32	2.88	6.53	0.0	80	69	11.3	SW	43N	59	6.7	7	8	16	10	0	3	10
June	67.8	54.8	61.3	89	40	2.92	3.02	0.0	88	76	10.4	SW	34NE	61	6.6	7	8	15	8	0	3	12
July	74.3	61.7	68.0	90	50	2.71	2.65	0.0	87	76	9.6	SW	36S	60	6.8	6	9	16	8	0	4	15
Aug.	74.4	61.7	68.1	86	46	3.68	3.67	0.0	89	75	9.5	SW	63SE	60	6.4	8	8	15	9	0	3	13
Sept.	69.3	56.4	62.9	83	36	3.51	5.05	0.0	87	71	10.3	SW	63SE	60	6.1	9	8	13	8	0	2	7
Oct.	60.8	47.8	54.3	77	22	3.70	3.21	T	82	67	11.2	SW	60E	58	5.8	10	8	13	9	0	1	7
Nov.	52.3	39.5	45.9	68	20	4.05	4.95	0.3	80	71	11.6	NW	61NW	42	7.1	5	8	17	12	*	1	5
Dec.	42.5	29.6	36.1	58	4	3.93	4.26	6.8	78	69	12.3	WNW	50W	41	7.0	6	8	17	13	2	*	4
Year	56.0	43.0	49.5	90	2	43.68	6.53	34.8	83	70	11.5	SW	63SE	55	6.6	86	93	186	125	8	20	98

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest temperature 95 in August 1948; lowest temperature -6 in February 1918; maximum speed and direction of wind 79E in March 1914.

METEOROLOGICAL TABLE FOR COASTAL AREA OFF MASSACHUSETTS, NEW HAMPSHIRE, AND MAINE

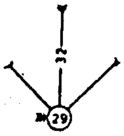
Boundaries: From 42°N. northward to coast, and from 66°W. westward to coast

	Weather Elements	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Percentage frequency	Wind ≥ 34 knots	10.5	10.3	3.4	1.5	0.1	0.0	0.0	0.2	1.0	3.5	4.3	10.7
	Wave height ≥ 10 feet	13.3	13.8	4.5	1.9	0.8	0.2	0.0	0.1	1.8	6.4	8.3	11.3
	Visibility < 2 naut. mi.	8.3	8.5	5.4	8.6	12.1	16.8	22.7	17.4	10.0	6.1	5.2	7.1
	Precipitation	21.7	23.7	15.3	11.7	9.8	8.0	4.7	6.9	7.2	7.0	13.2	22.1
	Sky overcast or obscured	49.6	44.3	35.0	34.5	34.1	31.1	31.1	30.8	28.9	28.8	40.8	47.0
	Thunder and lightning	0.0	0.1	0.0	0.1	0.1	0.4	0.5	0.5	0.3	0.1	*	0.0
	Temperature ≥ 85°F	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Temperature ≤ 32°F	40.9	45.8	22.3	2.9	0.0	0.0	0.0	0.0	0.0	0.1	1.7	26.6
	Mean temperature (°F)	34.1	32.7	36.4	41.5	47.3	54.8	61.2	62.0	58.8	53.1	45.7	37.9
	Mean relative humidity (%)	79	79	78	80	85	86	88	88	84	81	78	80
	Mean cloud cover (eighths)	6.0	5.6	4.7	4.5	4.7	4.6	4.7	4.4	4.0	4.2	5.3	5.9
Millibars	Mean sea-level pressure	1014	1013	1013	1015	1015	1014	1015	1015	1018	1017	1016	1016
	Extreme maximum sea-level pressure	1052	1042	1040	1042	1038	1033	1030	1037	1041	1039	1041	1045
	Extreme minimum sea-level pressure	976	970	977	980	990	994	994	992	988	973	980	971

*0.0-0.05%

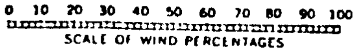
These data are based upon observations made by ships in passage. Such ships tend to avoid bad weather when possible, thus biasing the data toward good weather samples.

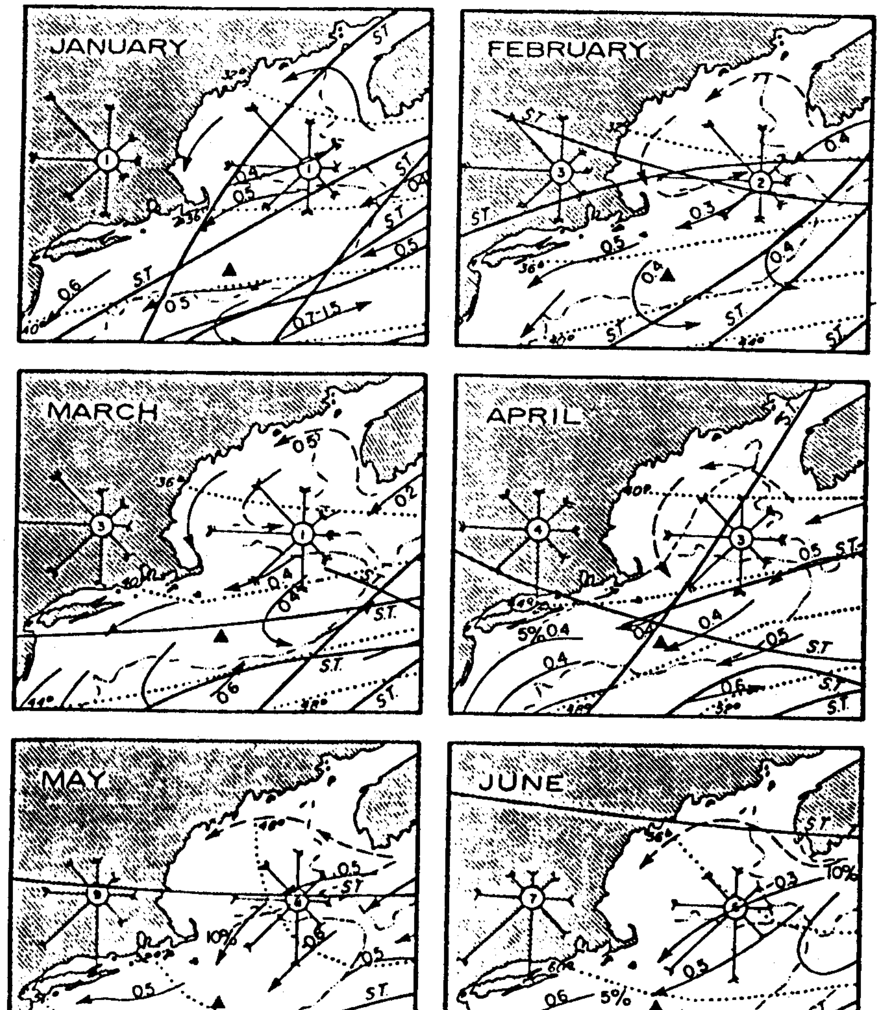
EXPLANATION OF WIND ROSES



PREVAILING WINDS AND CALMS.—The wind rose, in blue, in each 5-degree square shows the character of the winds that have prevailed within that square. The wind percentages are concentrated upon eight points. The arrows fly with the wind. The length of the arrow, measured from the outside of the circle on the attached scale, gives the percent of the total number of observations in which the wind has blown from or near the given point. The number of feathers shows the average force of the wind on the Beaufort scale. When arrow is too short, feathers are shown beyond its end. The figure in the center of the circle gives the percentage of calms, light airs, and variable winds. When the arrow is too long to be shown conveniently, the shaft is broken and the percentage is indicated by numerals.

FOR EXAMPLE: The attached wind rose should be read thus: In the recorded observations the wind has averaged as follows: From N. 32 percent, force 4; from NE. 20 percent, force 3; from W. 1 percent, force 6; from NW. 18 percent, force 2; calms, light airs, and variables, 29 percent.





▲ Nantucket Shoals Light Station

Figure 16.-- Excerpts from monthly pilot charts showing wind roses data for January through June in the Georges Bank area. Wind roses are summations for a 5 degree square. Heavy lines are major storm tracks. Light lines indicate geostrophic current drift in knots. Dotted lines are isotherms of average air temperatures in degrees Fahrenheit (Defense Mapping Agency Hydrographic Center, 1974-1975).

EXPLANATION OF WIND ROSES

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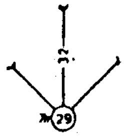
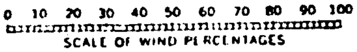




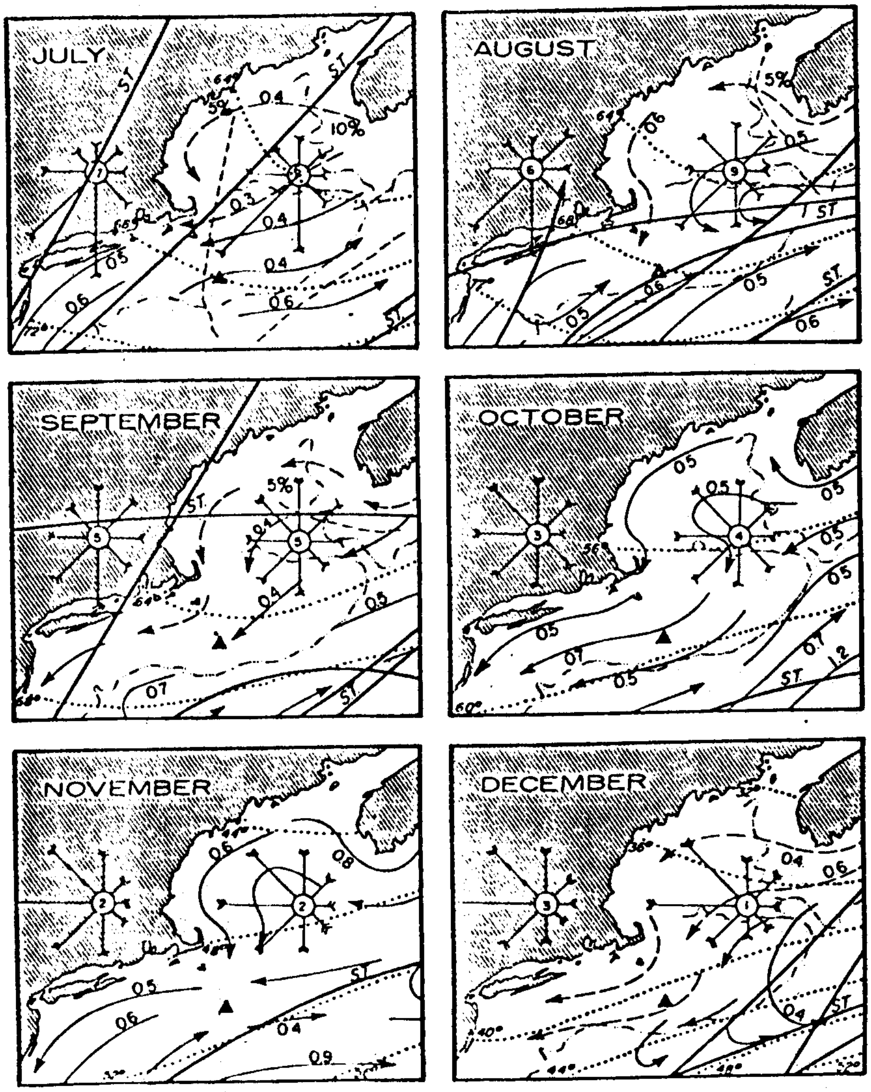


Figure 17.-- Excerpts from monthly pilot charts showing wind roses data for July through December in the Georges Bank area. Wind roses are summations for a 5 degree square. Heavy lines are major storm tracks. Light lines indicate geostrophic current drift in knots. Dotted lines are isotherms of average air temperature in degrees Fahrenheit (Defense Mapping Agency Hydrographic Center, 1974-1975).

ANALYSES OF MAXIMUM STORM WIND AND WAVES

Type	Date	Dir.	Winds: Ave. Vel. Mph.	Winds: Duration Hrs.	Winds: Fetch Mi.	Winds: Max. Vel. Mph.	Wave Height* Ave. of 10% Highest Ft.
Hurricane	Sept. 21,'38	SSE	90	8	400	120	50
Hurricane	Oct. 4, '51	S	45	30	500	70	43
Storm	Dec. 3-4,'37	NE	55	30	600	65	48
Storm	Nov.29-30,'45	E	70	30	600	75-90	66
Storm	Sept. 22,'53	S	40	24	600	50	32
Storm	Nov. 7, '53	E	60	30	600	70	48

*Note: During these maximum storms 80% of all waves will be less than 0.7 times these heights but single maximum wave may be 1.5 times heights listed.

It will be noted ··· that the maximum wind occurred during a hurricane at a velocity of 120 miles per hour and that the computed average height of the 10% highest waves is 66 ft. during an easterly storm. The computed wave heights are based on a statistical procedure of analysis applied to wave spectra conforming closely to actual sea waves. This theoretical method has been checked for sea conditions where the maximum height of waves is approximately 20 ft. No checks are yet available for higher sea conditions. According to the statistical theory most of the waves in a storm will be considerably lower in height than the average of the 10% highest waves, but, theoretically, one wave in one-thousand during maximum storm will have a height 1.5 times the height of the average of the 10% highest and one wave in twenty thousand may be even higher.

Refraction and Focusing of Swells

Severe wave conditions can result from refraction and focusing effects of long period swells as they approach shoal water. Such swells are the result of a major storm the boundaries of which may be several hundred miles away from the location being investigated. The following discussion of such swells is quoted from a preliminary report by Woods Hole Oceanographic Institution:

> "Very long period swells of any considerable amplitude are rare off New England but even quite low swells is not to be discounted because the energy can become focused through refraction effects. This is the chief disadvantage of building on top of a shoal. Cashes Ledge, although protected by George's and Brown's Bank is sufficiently shoal to cause regeneration of swell. This would appear to be a less serious factor at the deeper Brown's Bank site. It is reasonable to believe that, through a skillful selection of the exact building location, some protection from storm waves can be gained on George's and probably also off Nantucket but at the present stage of our investigation these locations seem very unfavorable from the standpoint of swell to be a factor. The reaction of swell arriving occasionally at the relatively well protected Minot's Light should be carefully considered."

To date no reasonably reliable analyses for possible regeneration and focusing of swells at proposed sites have been obtained. It is believed that our proposed design criteria, platform type and height provide adequate protection against any possible swell condition that may occur at the proposed sites. Nevertheless, the factor of possible regeneration and focusing of swells presents sufficient uncertainties to make a conservative selection of design criteria and platform heights desirable.

Tides and Tidal Currents

The Woods Hole Oceanographic Institution has estimated that the maximum astronomical tides at George's Bank and Nantucket Shoals will be in the order of 2 feet above and below mean sea level. This estimate has been confirmed exactly by tide cycle measurements made from the fixed platform of the drill barge during boring operations at these locations. It is possible that the astronomical tide may be somewhat greater at Cashes Ledge and somewhat less at Brown's Bank and the location off New York. The charts of Georges Bank and Nantucket Shoals show tidal currents up to velocities of 5 knots varying in all directions with the stage of the tide. Observations during the drilling operations confirmed these tidal currents which maintained almost constant velocity although shifting in direction over the tidal cycle. Both the charts and observations during the drilling operations show heavy tidal rips over or near the shallowest portions of the shoal areas. Further, the Woods Hole geologists who investigated the bottom conditions in these areas by skin diving, report that the five to ten feet of water immediately above sea bottom is full of swirling sand "resembling a driving snow storm." This swirling sand is moved and held in suspension by the tidal currents. The Woods Hole Oceanographic Institution has estimated that meteorological tides may amount to as much as 6 feet and that they are likely to coincide with severe storms.

Icing, Corrosion and Scour

At the outset of this investigation it was obvious that corrosion of structural elements in sea water and extending through the sea water surface would be a serious problem. The problem of corrosion protection in the zone immediately above low water and in the spray zone is further complicated by the possibility of icing in northern waters. The Woods Hole Oceanographic Institution has reported that in general freezing temperatures should not be expected at the offshore locations being studied. However, they report that there have been two bad winters off New England in the last forty years, namely, 1918 and 1934. Severe icing would have occurred in both years at all of the proposed sites but it would have been worse off New York and at Cashes Ledge because of the shorter over water passage of the cold northwest winds. During the winter of 1934 air temperatures of 13 degrees F. were recorded at Nantucket Shoal Lightship. If icing occurs, the ice formed by spray on the structural elements will fall into the sea with a rise in temperature. Unless a reasonably heavy sea is running, such ice will churn around the structural elements passing through the sea surface causing damamge to corrosion protection elements not having large mechanical strength.

It was further realized at the beginning of this investigation that scour in the ocean bottom around supporting structural elements extending into the ocean bottom was a definite possibility. The Woods Hole Oceanographic Institution informed us that Georges Bank is covered with a realtively thin but variable thickness layer of shifting sand. Nantucket Shoals were believed by them to consist of a considerably thicker deposit of sands in which shoal areas may be moving at the rate of 5 or 10 yards per year. In view of the relatively high velocity tidal currents in these areas and the bottom currents which will probably be induced by severe waves and storms, it seems possible that scour around objects penetrating the sea bottom will occur in these sands to depths corresponding to the thickness of any loose shifting sands unless adequate protective measures are employed.

Thus, the problem of providing a reasonably permanent structure supported from the ocean bottom requires complete protection against corrosion with particular attention to the zone extending from about 5 feet below mean low water to 20 feet above mean sea level in which zone the most severe corrosion attack always occurs and in which zone the effects of icing and mechanical wear of floating ice make necessary the use of corrosion protective materials with large mechanical strength. A definite possibility of scour exists where the sea bottom consists of loose or shifting sands and protection against mechanical wear by sand grains swirling in the ocean water must be provided for a height of at least 10 feet above the ocean bottom."

The meteorlogical data is probably biased toward less than extreme conditions in part because of the way it is collected and presented. The data given in table 3 comes mainly from the Nantucket Airport and from ships passing through the area. The data are probably biased toward less extreme values because, (1) ships at sea usually try to avoid storms if possible and (2) land observations usually tend to be diminished when compared to light-ship observations a few kilometres away (Butman, unpublished data). Further, the data presented in the Pilot Charts (figures 10 and 11) are monthly averages over 5 degree squares--again supplied by vessels trying to avoid adverse weather.

Water Circulation - Oil Spill Trajectory

Most studies of hazards to the Georges Bank environment focus on oil spill trajectories--dispersal patterns largely dependent on the water circulation there. This has been done most recently by Bumpus (1973). Unlike the Baltimore Canyon area to the south, current meter observations are lacking. In a USGS-MIT coop, we recently deployed one array of four current meters on the southerr part of the Bank to make observations over several months.

The water circulation as deduced from drift bottles and sea-bed drifters suggests the presence of a large clockwise gyre over surface waters of the Georges Bank at least part of the year (Bumpus, 1973); the seasonal changes in this gyre are not well defined because of limited returns. Bottom drift over Georges Bank follows a clockwise rotation around the shoals but with a net drift to the west across Great South Channel. The drift patterns are given in Appendix II (figs. 1-24), as well as the recovery rates and the net drift rate for drift bottles. Several thousand drift bottles released over a 10 year period are summarized by months (Appendix II, figs. 1-12). A dot is in the center of each 10 minute rectangle from which bottles drifted to an overseas location. An arrow shows the inferred direction of drift from each rectangle and the length of the arrow reflects the fastest drift recovered.

The first feature to note on these diagrams is the poor recovery rate of drift bottles, except for coastal areas. Only during the months of March and April, do rates reach the interval of 1-10%. This means that for most of the area, the record is missing! In March and April there is southwesterly drift across Nantucket Shoals. During the summer, the northwest drift across Nantucket Shoals toward land continues. During fall and winter, returns are too fragmentary to discern a trend.

Surface drift, as discerned from ship's logs (figs. 10 and 11), show mainly a southwest drift at 0.4-0.7 knots (nautical miles per hour) and a suggestion of a surface gyre during March and the summer months.

Sea-bed drifter records of bottom movement (Appendix II, figs. 12-24) are even more fragmentary. On these diagrams, the same symbols prevail as on the surface drift diagrams, except that contours of recovery rate are 10, 20, 30, 40, 50 and 60%, and arrow lengths do not signify a rate of movement, only a direction. Recovery rates are less than 10% except for coastal areas of Cape Cod and Nantucket Shoals. In a patchy pattern, the drifters show a clockwise pattern around Georges Bank in the winter, with transport to the northeast on the northern part of the Bank and to the southwest over the central and southwest over the central and southern parts; over Nantucket Shoals, it is to the west and northwest. The clockwise gyre appears to be more pronounced in the spring and summer over Georges Bank, and to be more of a southwest drift in the fall and early winter (November). A westerly and inshore (NW) drift pattern appears to persist south of Cape Cod.

With the fragmentary returns of drift bottles (2% overall), the Offshore Oil Task Group (1973) from MIT attempted to model the trajectories of 200 simulated spills emanating from four launch points on Georges Bank (fig. 12). They assumed a geostrophic drift pattern as shown in figure 13, and during two seasons (spring and summer) found some likelihood of trajectories from a spill reaching the south coasts, of Cape Cod, Rhode Island, and Connecticut (fig. 14, 15, 16, 17, and 18). For the four seasons, they used a nine-state (eight compass directions and calm) Markov process for modeling the wind, with a three hour transition period for new wind directions. They conclude that:

"1) The probability of a Georges Bank spill coming ashore in New England is highly variable, varying from nil in the winter to as high as 5% in the summer. The northwesterly component of winter winds makes it extremely difficult for any cold season Georges Bank spill to reach shore under a wide range of possible current pattens.

2) Any spill reaching shore will take at least 30 days to reach shore and will probably require 60 days.

3) Under current assumptions consistent with the drift bottle data, almost all spills which come ashore in New England will do so on the western and southern shore of Cape Cod.

4) The key impact of our uncertainty regarding current pattern is on the Bay of Fundy area. Rather minor changes in the current pattern can increase the number of spills reaching the Bay of Fundy during spring and summer from 0% to 10%. Under those current and season assumptions which yield the high rate of return to the Bay of Fundy, 1-2% of the spills will reach the northern New England coast."

These same fragmentary returns were used to predict oil spill trajectories by the MIT Group for the Council on Environmental Quality Report (1974) and this time probability of oil impacting Nantucket and the south coast of Cape Cod rose to as much as 65% (table 4). The data were keyed to areas where oil development could occur; three of the four sites were postulated to be on the south side of Georges Bank and the fourth was in the southern part of Nantucket

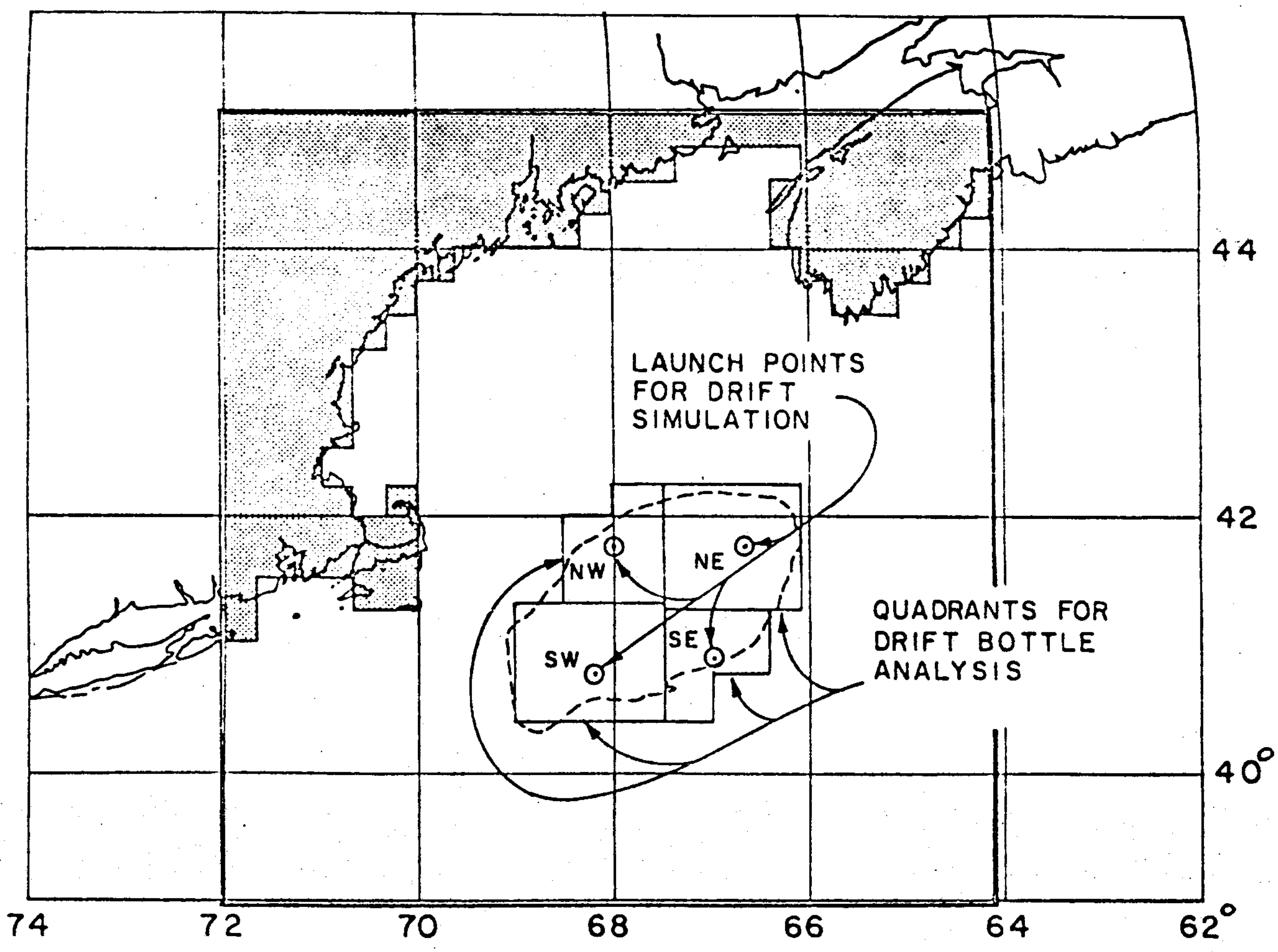


Figure 18.--Outline of New England used in computer simulation by MIT (Offshore Oil Task Group, 1973).

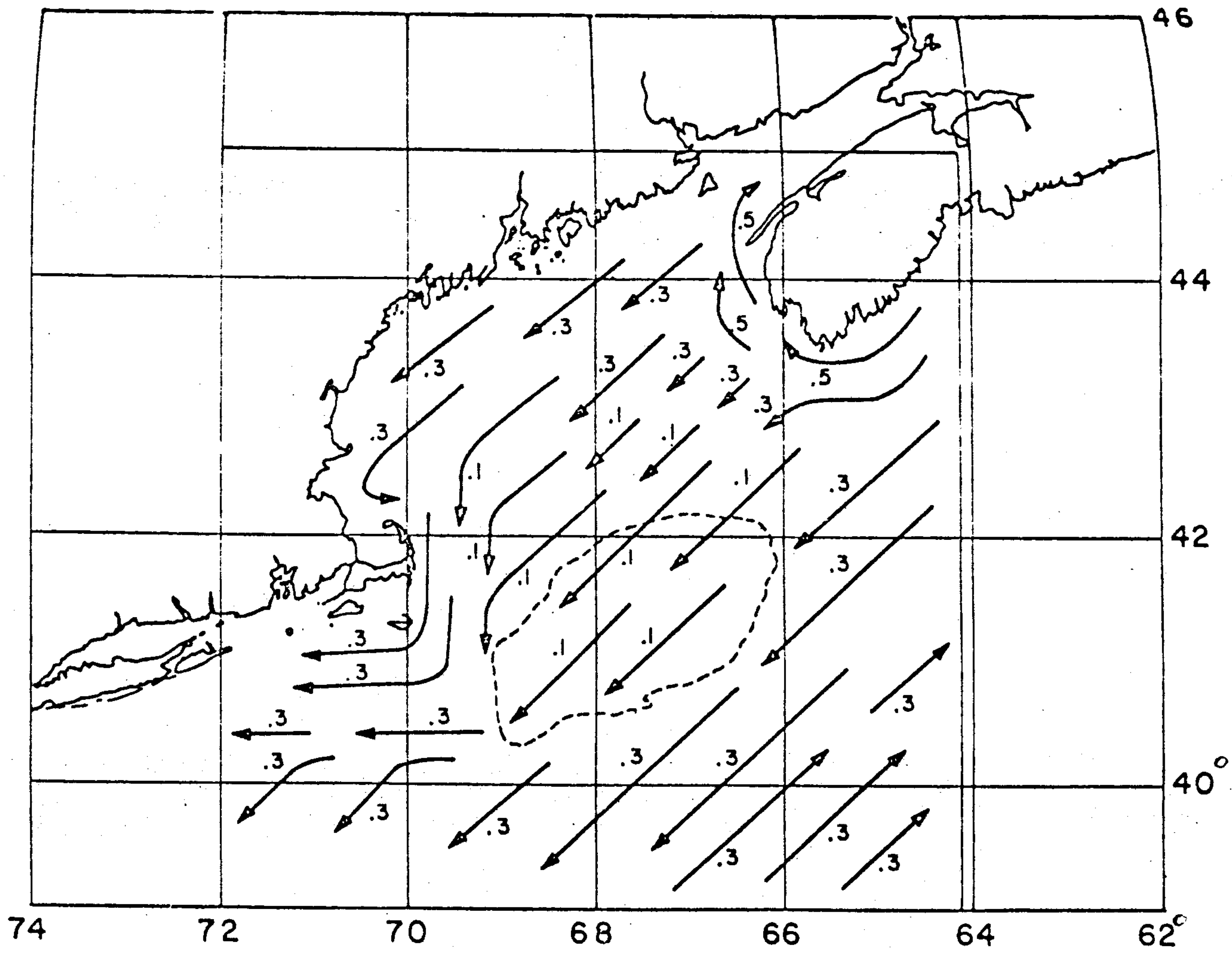
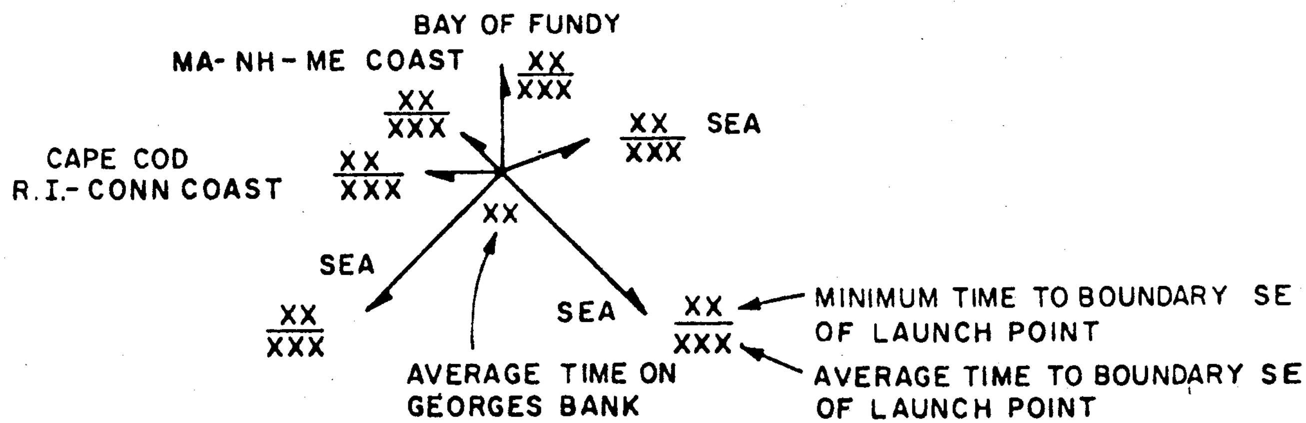


Figure 19.--Geostrophic drift pattern used by MIT in computer simulation (Offshore Oil Task Group, 1973).

1. ARROW INDICATES PERCENT TRAJECTORIES TERMINATING IN REGION ARROW POINTS TO, SCALE INDICATED ON DRAWING.

2. FRACTIONAL NUMBER AT TIPS OF ARROWS INDICATE = $\left\{\frac{\text{MINIMUM TIME TO REGION}}{\text{AVERAGE TIME TO REGION}}\right\}$ IN DAYS.

3. NUMBER DIRECTLY BELOW LAUNCH POINT INDICATES AVERAGE TIME SPENT BY SPILL ON THE WATERS OVER GEORGES BANK, IN DAYS.



4. IF THERE ARE NO FRACTIONAL NUMBERS, THEN NO TRAJECTORIES TERMINATED IN THAT DIRECTION.

5. THE DRIFT BOTTLE DATA IS SUMMARIZED SIMILARLY, THE TIME AT SEA IS NOT A WELL SUBSTANTIATED NUMBER SO ONLY THE MEDIAN TIME IS INDICATED.

Figure 20.-- Explanation of symbols for figures 15, 16, 17, and 18.

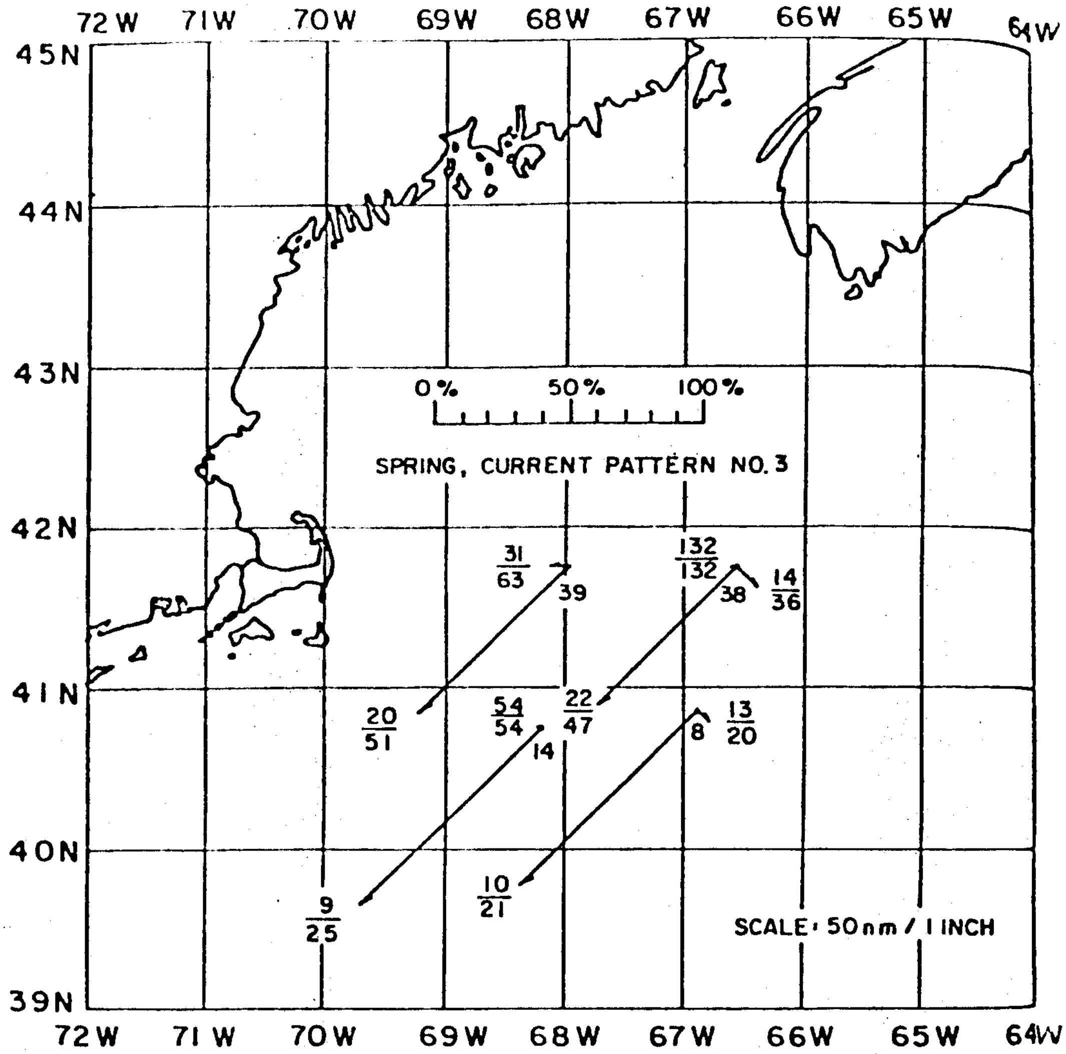


Figure 21.--Summary of trajectory probabilities for spring.

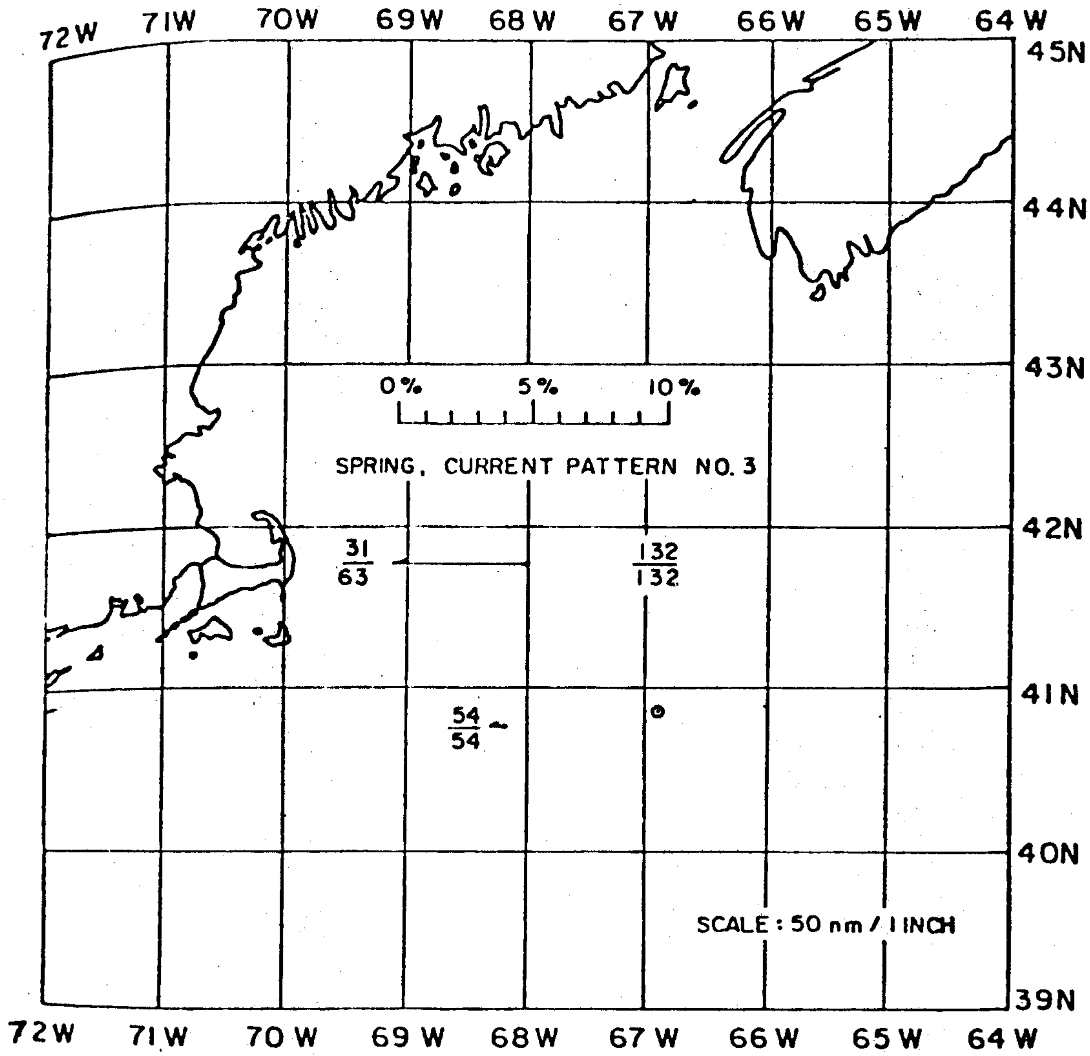


Figure 22.--Expanded scale summary of trajectories terminating on New England or Bay of Fundy shores in spring.

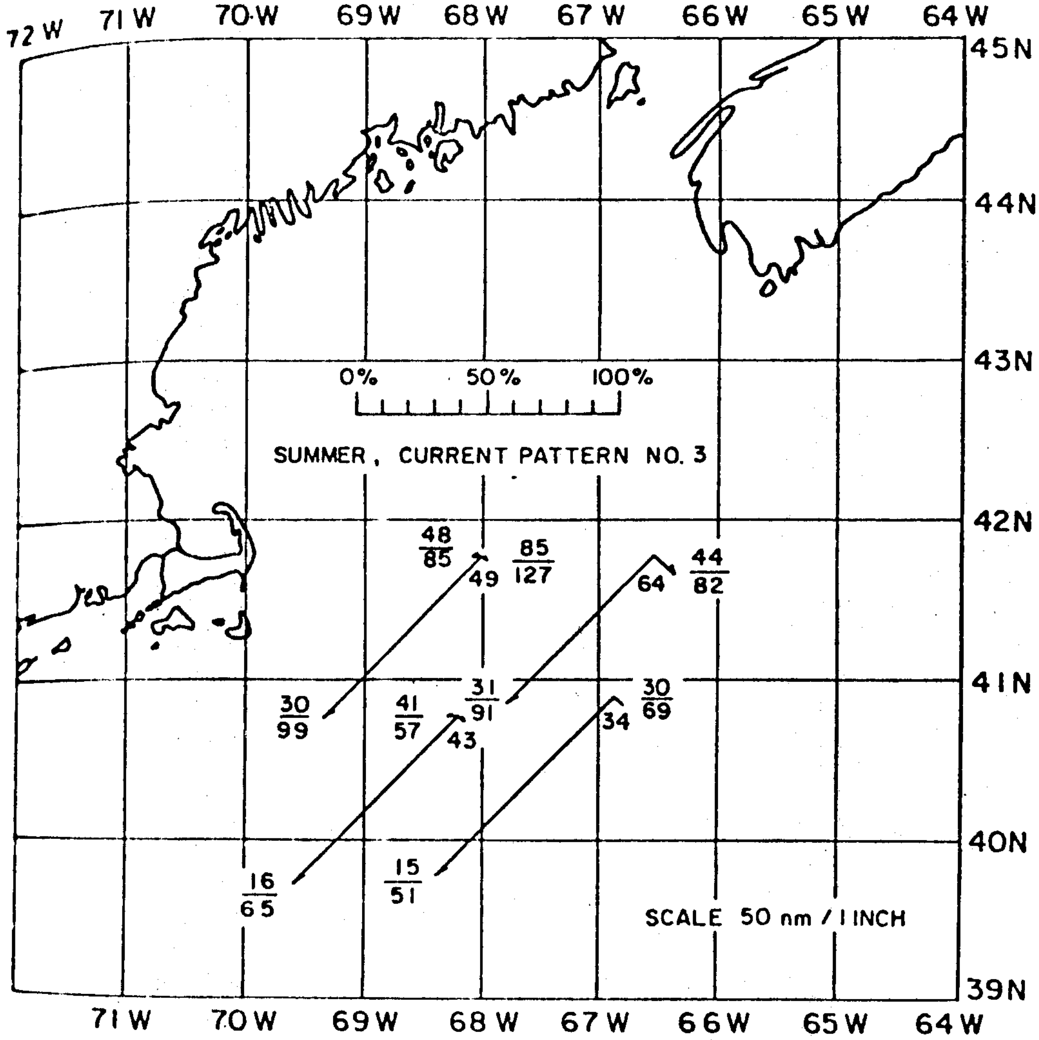


Figure 23.--Summary of trajectory probabilities for summer.

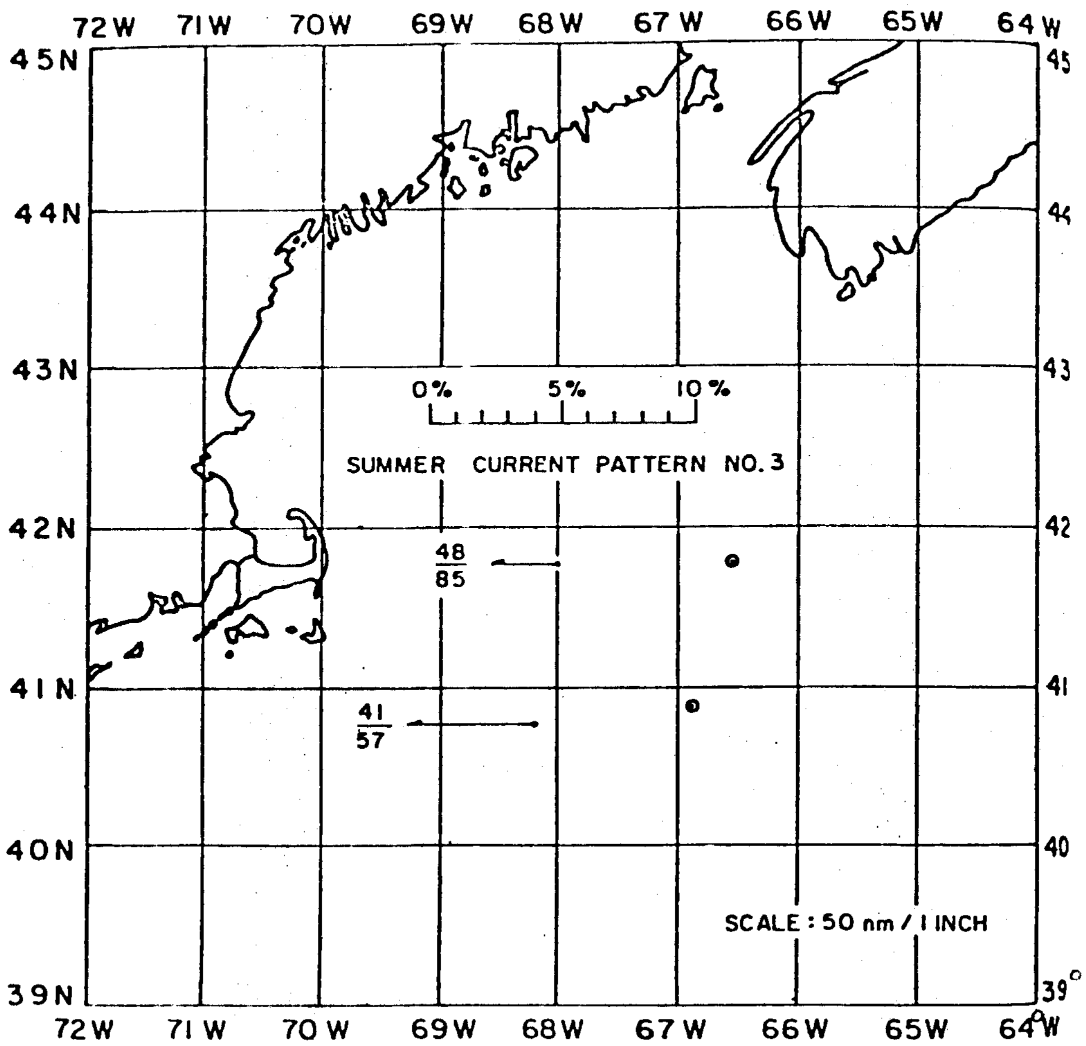


Figure 24.--Expanded scale summary of trajectories terminating on New England or Bay of Fundy shores in summer.

TABLE 4 (CEQ, 1974)

Probabilities of Oil Spills Coming Ashore from Hypothetical Spill Sites in the Atlantic Ocean

Shore point	Season[1]	Distance from shore						Center of EDS
		10 miles east	25 miles east	50 miles east	75 miles east	100 miles east	125 miles east	
Nantucket	Spring	65%	45%	30%	25%	20%	20%	15% (EDS 1)
	Autumn	30	10	5	0-5	0-5	Near 0	Near 0 (EDS 1)
Nantucket Shoals	Spring	50	50	35	30	20	20	20 (EDS 2) 35 (EDS 3)
	Winter	5	5	5	5	5	4-5	Near 0 (EDS 2) Near 0 (EDS 3)

[1]Two seasons are listed for each area. In the first season, oil spilled has the highest probability of reaching shore; in the second season, oil spilled has the lowest probability. Probabilities are intermediate in the unlisted seasons.

Source: The Massachusetts Institute of Technology Department of Ocean Engineering.

Shoals. This reappraisal by CEQ is significant because they modeled data on projected spills as close as 10 miles to the Nantucket Coast. The lease area boundary (plate 1) is within 15 miles of the south shore of Nantucket and the nearest potential structure is about 30 miles southeast of Nantucket (CEQ, 1974, fig. 2-1). Hence, values given in table 4 give a general idea of the risk to southern New England. The risk is low from Georges Bank sites but rises for the sites southeast of Nantucket, particularly in the spring.

Lacking in the oil spill studies are data on the fate of oil on the Bank. The first MIT study illustrates the high residency time of a potential spill on Georges Bank (a range of 8-64 days in the spring and summer, and 3-31 days in the fall and winter) during which time some of the oil could sink to the bottom as has occurred in coastal spills such as the West Falmouth oil spill. Indeed the whole topic of subsurface movement of oil is ignored in MIT studies probably bacause data on bottom flow are even more sketchy than drift bottom returns.

In summary, only a very general outline of water movement off the northeastern United States can be given. Needed are long term current-meter measurements and drogue-tracking in selected areas to chart the seasonal configuration of the clockwise gyre, and the interaction of it with water from the Gulf of Maine, and from the Continental Slope. The measurements bear not only on possible pollutant trajectories, but on seafloor sediment movement and larvae transport as well.

Geologic Hazards

Potential geologic hazards include: (1) seismic risks, (2) sediment movement, (3) stability of shallowly buried sediment, (4) geopressure, (5) shallow gas, and (6) dredging.

Seismic risks.-- An examination of earthquake epicenters (figures 19 and 20) and seismic activity level (Hadley and Devine, 1974) shows (1) very few epicenters off eastern New England, and (2) moderate to high level of seismic activity in the coastal area of southeastern New England. Hadley and Devine (1974) indicate a level 2 for much of the coastal area signifying "seismic frequency is generally more than 8 and less than 32, and no earthquake in the area has had a maximum epicentral intensity greater than Modified Mercalli (MM) IV". The coastal area is one in which "major faults are known but epicentral distribution does not indicate that they are the source of recorded earthquakes." According to Howell (1973) Georges Bank may have a hazard index between the rough average of 6.94 ± 1.18 of the Continental Shelf and 6.07 ± 1.18 for the Maritime Province. The expected intensity is below VII--the level at which appreciable damage to building of normal construction is common.

Few earthquake epicenters have been located offshore, a condition that probably reflects the difficulty of shore-based seismographs in focusing on offshore quakes unless they are major or within a few kilometres of the coast. Conjecturally, offshore-onshore trends of seismically active zones are postulated to cross the western part of the Georges Bank Basin. Sbar and Sykes (1973) project the Boston-Ottawa seismic belt southeastward to the

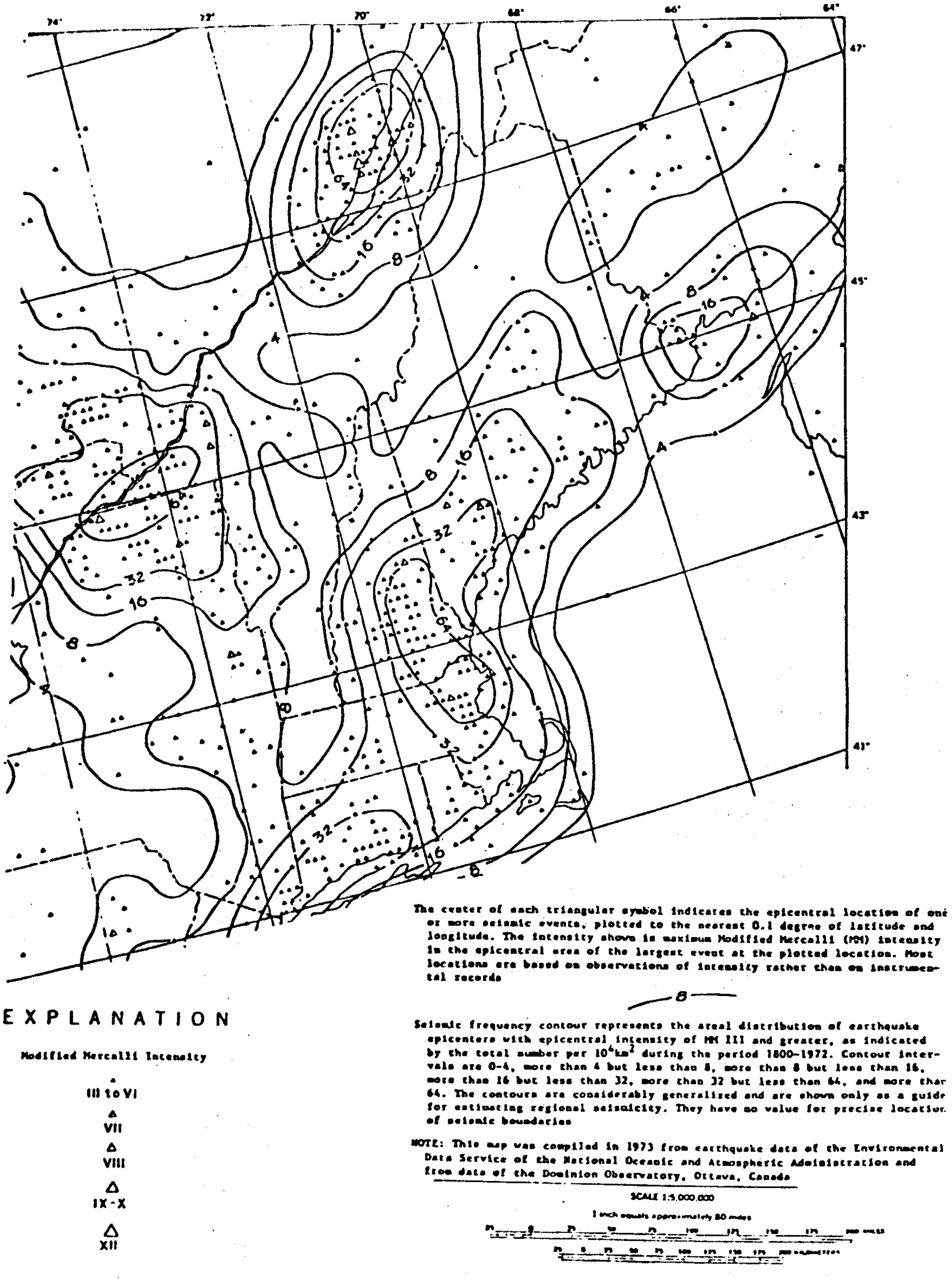


Figure 25.-- Earthquake epicenters recorded between 1800 and 1972. From Hadley and Devine (1974).

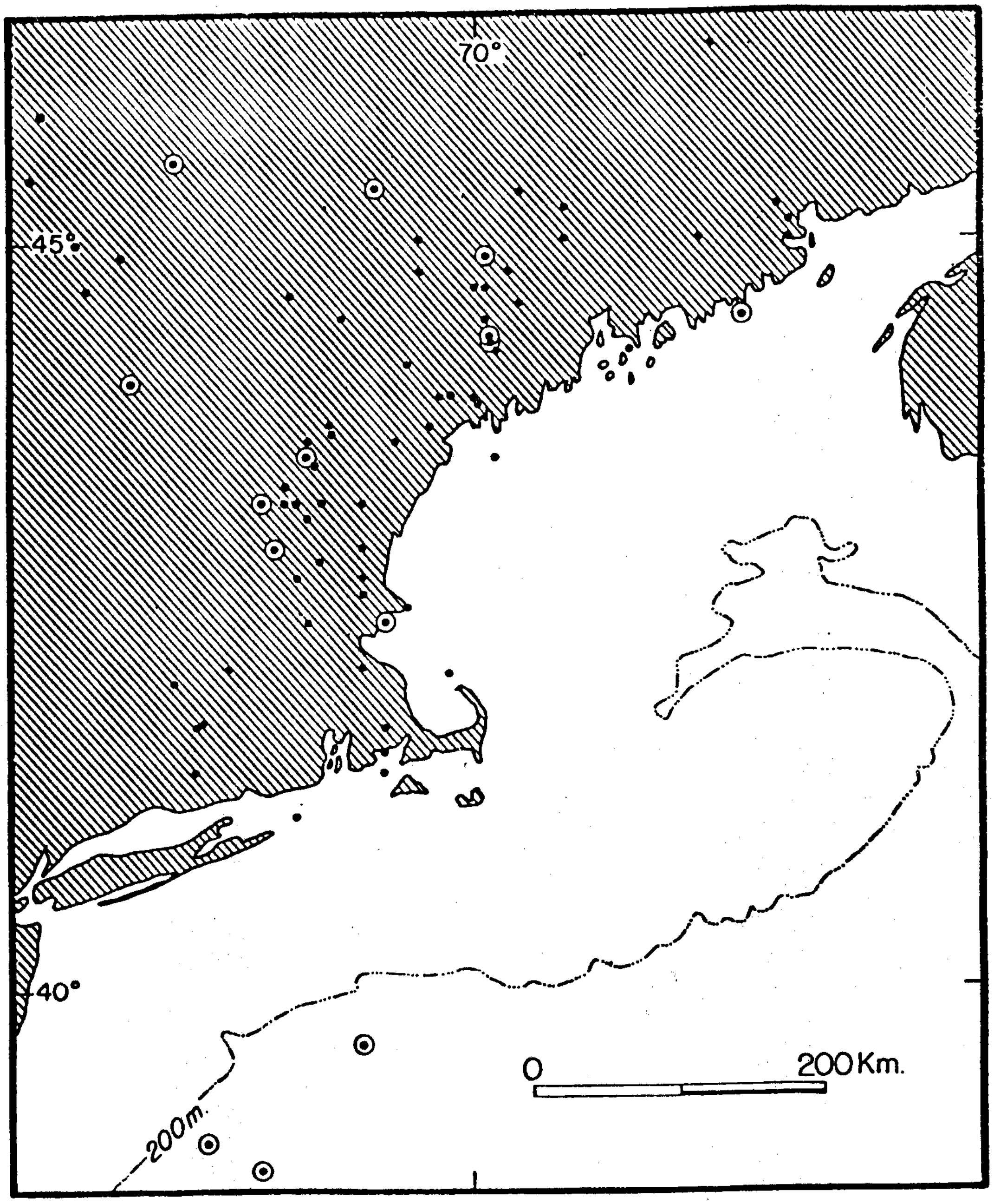


Figure 26.-- Earthquake epicenter map of all earthquakes recorded between 1900 and 1974. Double circles show epicenters recorded between 1961 and 1974. (From NOAA Earthquake Information Center, Boulder, Colorado, Written Communication).

New England Seamount Chain, noting that the trend of the belt and the Chain are along the same small circle about a pole of rotation between Africa and North America. As a comment on this trend, Ballard's map (fig. 5) shows inferred structural trends connected with faulting that attended formation of the Triassic rift basins; the trends are mainly NE-SW and the zones became inactive after the Triassic. He also shows the NE-SW trending basement horst under the slope -- again thought to be a seismically "dead" feature. Shown elsewhere in Ballard's thesis is the same NW-SE shear zone Sbar and Sykes (1973) project across the western Georges Bank area to tie together the White Mountain Magma intrusive series of New Hampshire. Ballard (1974) considers this zone to be the complimentary set of fractures to be the NE-SW shear set in the western Gulf of Maine, and to be the active one at present. Sheridan (1974, fig. 1) postulates the White Mountain fault to trend nearly N-S (instead of NW-SE) and to cross the margin south of Nantucket at the western end of the Georges Bank basin. This fault along with a parallel fault, 150 km to the east, he postulates to be shear zone faults in the White Mountain stress system and possibly could be active at present. Surface indication of faulting in the Georges Bank area is lacking. Based on several hundred kilometres of single channel seismic reflection profiles in the Georges Bank area, Oldale and others (1974), Knott and Hoskins (1968), and Uchupi (1968) do not indicate any evidence for shallow faulting. McMaster (1971) does report shallow faulting, but well to the west, off Eastern Long Island.

Roberson (1964) indicates folding due to slumping adjacent to Oceanographer Canyon.

Sediment movement.--Sediment transport studies have not been done in any systematic way on the Georges Bank-Nantucket Shoals area. Both of these areas have been of danger to shipping because of the shifting dune fields. The only study we know of that attempted to assess the rate of shoal migration was Stewart and Jordan's (1964) contribution that showed sand ridges (features average 7 km long and 8 m high) in Georges Shoal had migrated a maximum net distance of 300 m to the west over a period 25 to 28 years. They went on to measure tidal currents of up to 2 kts over the shoal and noted that the major axis of the tidal ellipse parallel the axis of sand ridge. The sediment moved as a sheet of sand one metre thick at the ridge crest. The main effect of the tides was to move the sand back and forth but not to the west. From wave hindcast data they report that 54% of the time, waves approach from the east-northeast and east, and these they feel are causing the ridge migration. Needed beyond this study are figures on sediment accumulation and erosion over Georges Bank and the Nantucket Shoals.

Emery and Uchupi (1972) confirm the mobility of bottom sands by noting that sand levels around the legs of the Texas Towers deepened enough to weaken the structures, leading eventually to their abandonment and salvage in 1964 (location shown in plate 1).

Stability of shallow sediment.--The properties of shallowly buried sediment is poorly known. Except for the report on the Texas Tower sites, data is lacking. From their borings, Anderson-Nichols and Company; and Moran, Proctor, Mueser and Rutledge (1954) concluded:

"Georges Bank and Nantucket Shoals

The foundation conditions at these two sites are essentially the same. The conditions consist of a relatively thin layer, up to 10 to 15 ft. in thickness, of medium loose sand overlying 50 to 80 ft. of compact to very compact sand which, in turn, overlies medium compact sand to depths of at least 120 ft. However, scattered through this area there are lenses and pockets of organic clayey silts and silty clays up to maximum thicknesses of 45 ft., as shown at Location No. 1 on Nantucket Shoals. For the locations explored, these deposits begin at depths of 60 to 90 ft. below the ocean bottom. The locations of these deposits cannot be predicted because they were formed by old salt marshes and ponds in the geologic development of the area. On the basis of borings at four locations there is a 50 per cent chance of encountering such undesirable layers at new locations. We have estimated, on the basis of determinations of water content and Atterberg plasticity limits on these soils, that a thickness of 40 ft. of such material beginning at a depth of 20 ft. below the bottom of one leg of a triangular tower structure may cause settlements as much as six inches under the dead and static live loads of the structure. Inasmuch as the thickness of these compressible layers is extremely variable, it is probable that, if encountered, the thickness would not be the same under three legs of a tower structure and that the compressible deposit might be present under only one or two of the legs. The result would be undesirable tilt and distortions of the structure. Therefore, it is believed essential that the structures be located in areas where there is reasonable assurance that organic silt or clay interbedding will not be present in the sand. This restricts the locations of the structures to areas immediately adjacent to Location No. 2 at each of Georges Bank and the Nantucket Shoals, on the basis of information now available. If the permanent structures are moved more than 1000 ft. from the locations where borings show definitely that no compressible soils are interbedded in the underlying sands, we believe that additional borings should be made during or prior to construction operations. It is suggested that the proposed design makes this operation feasible in that drill rigs can be mounted on the structure and the drilling can be done immediately after the structure is raised on its temporary legs and before the sinking of the permanent legs to final position begins. If undesirable subsoil conditions are found by this process, the structure can be moved and the operation repeated before sinking the permanent legs. If assurance can be obtained that no compressible clays or organic soils are interbedded in the sands, the safe bearing

> capacity of the compact sands 30 ft. or more below the sea bottom is estimated to be 12 tons per square foot for continuously applied static loads and 16 tons per square foot for dynamic and transient loads. It is proposed that the final designs will be prepared on this basis. These values require that a cover of at least 30 ft. of sand be maintained. This will be accomplished by placing the bearing level of the permanent legs at a greater depth than 30 ft. to provide for possible scour of the upper medium compact sand and by providing stone riprap protection around the legs. For resistance to lateral loadings caused by pretensioning of diagonal bracing by wave forces, the compact sand can safely be assumed to have an angle of internal friction of 35 degrees. This provides large resistance against lateral loads and our analyses demonstrate that the lateral loads can safely be carried by the caisson legs in the sand."

The similarity in the logs in two widely spaced groups of borings shows that there is substantial lateral variability in the sediment and that placement of rigs will depend in part on either anchoring below clayey layers or in avoiding zones of finer grained buried sediment. Similar borings will be needed away from the shoals, to evaluate stratigraphic variability, and geotechnical properties of the upper 20-40 m of sediment.

Geopressure.--Geopressures (abnormally high fluid pressures), caused by rapid sedimentation, compaction, diagensis, shale and salt diapirs, and faulting may lead to blowouts if proper precautions are not taken during drilling. Geopressures are commonly reported in the Tertiary and Mesozoic sequences of the Gulf Coast. However, in that area, geopressures are handled successfully on a routine basis. A mud weight of 15.5 lbs, was required for one Sable Island test, and another east coast Canadian well encountered gradients of 0.73 psi/ft. A gradient of 0.465 psi/ft, and 9 lbs/gal mud weight are considered normal. Abnormally high fluid pressures at depth are commonly associated with velocity inversions. The authors did not encounter evidence of significant velocity inversions in the Georges Bank area.

Shallow gas.--In the Gulf of Mexico, blowouts have occurred from encountering gas at shallow depths before surface casing or conductor pipe has been installed. In addition hydrogen sulfide (H_2S) has been encountered while drilling Mesozoic rocks in the Gulf of Mexico and at times has been a serious problem there, but no problems with H_2S have been reported from drilling operations on the Scotian Shelf. It is expected that high resolution seismic surveys over expected drilling sites and proper surface casing will eliminate problems from shallow gas.

Dredging.--Dredging for minerals can pose certain problems. When heavy minerals are separated from the sediment in which they occur on the site, and this sediment is returned to the sea floor, only a few percent of the total dredged material is removed from the bottom, and the equilibrium between the sea bottom and the ocean currents is not disturbed. But if sand and gravel are being mined, 100% of the dredged material is removed and the equilibrium is disturbed. Under these conditions, coastal features such as bars and beaches could be altered during restoration of equilibrium.

OPERATIONAL CONSIDERATIONS

Technology

The technology required for exploration of areas in the North Atlantic OCS is available, much of it having been recently demonstrated in the North Atlantic off the coast of Canada. By April, 1975, 89 wells had been drilled (53 on the Scotian shelf and 36 on the Grand Banks) (Oil and Gas Journal, 1975). New techniques for measuring and predicting maximum environmental forces are continually improving overall capability and reliability for design of offshore equipment.

Mobile drilling units for exploratory drilling are in great demand and must be obtained from the Gulf of Mexico or other parts of the world. A recent offshore mobile rig count showed 275 total units in operation, 13 idle and 5 in transit, with an additional 163 units under construction or planned including 41 drill ships or drill barges, 63 Jack-ups, and 59 semi-submersibles (Offshore Magazine, 1975). It is estimated that 133 offshore rigs will be completed in 1975, and 126 in 1976 (Ocean Oil Weekly Report 1975, and see Table 5).

Table 5.--Size of drilling rigs under construction and projected from Ocean Oil Weekly Report, 1975.

Size	1974		1975 (estimate)		1976 (estimate)	
	Land	Offshore	Land	Offshore	Land	Offshore
5,000-10,000 ft	25	8	44	6	45	13
10,001-18,000 ft	42	22	40	37	45	17
18,001-and over	10	50	17	90	29	96
TOTALS	77	80	101	133	119	126

Offshore areas in the North Atlantic OCS are 300-500 km from the shore in water depths up to 200 m (pl. 1). Technology is presently available for construction of platforms for development drilling and production facilities and for the construction of pipelines for operating at these water depths and distances from shore (see figs. 27 and 28).

Manpower

Most of the skilled manpower for exploratory drilling will have to come from other areas such as the Gulf of Mexico. Also, the reservoir of skilled manpower for operations other than exploratory drilling, such as development and production, including the installation of platforms, pipelines and onshore facilities, is relatively small due to the lack of previous petroleum development in the North Atlantic coastal states. Although the skilled manpower for most of the operations will have to be moved from other areas, there should be adequate manpower in the North Atlantic coastal states available for training. After the first leasing of the U.S. Mid-Atlantic OCS, the expected influx of experienced personnel may provide some of the core needed for training personnel to work in the U.S. North Atlantic OCS.

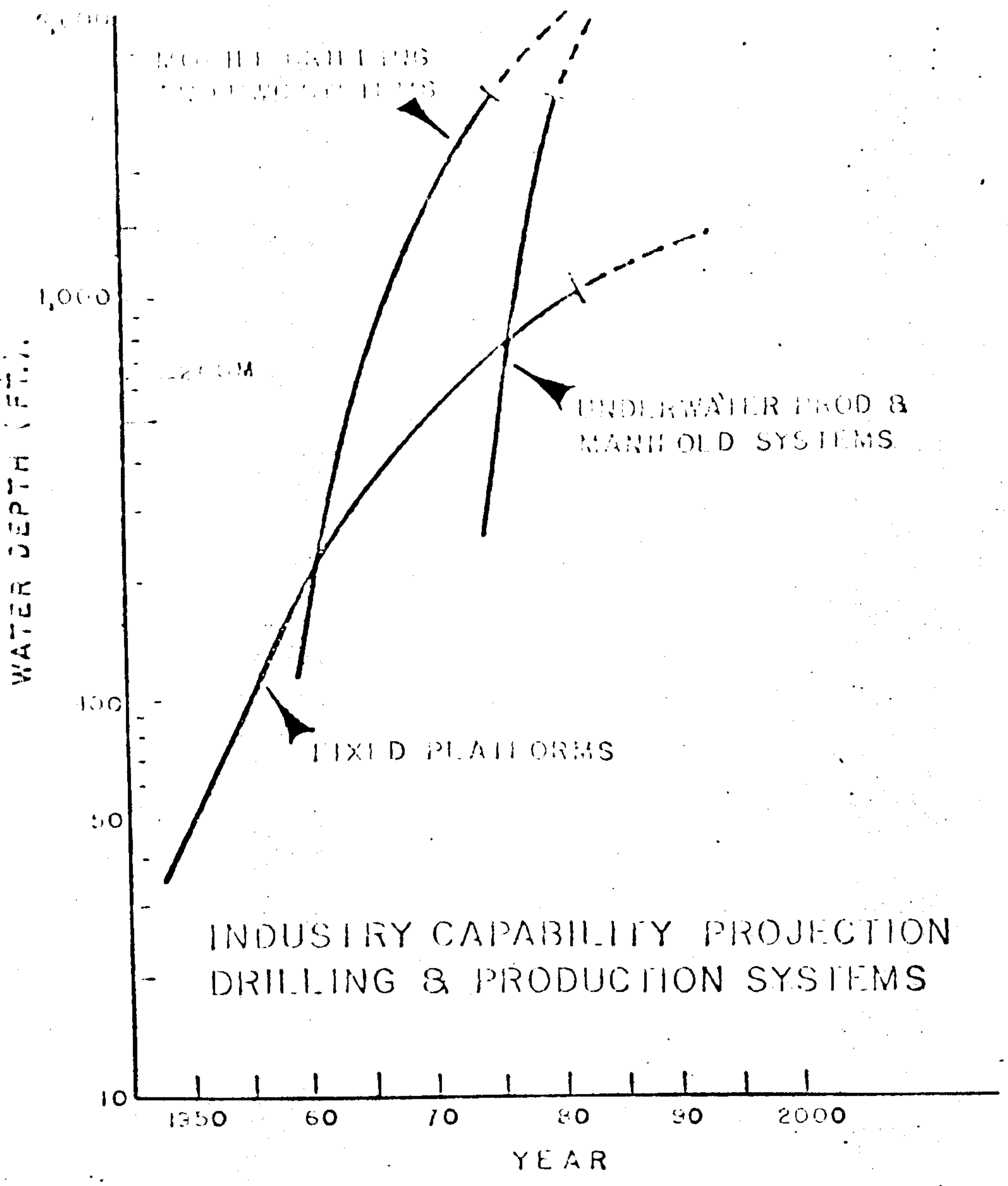


Figure 27--- Projection of drilling and production capability. From Greer, 1973.

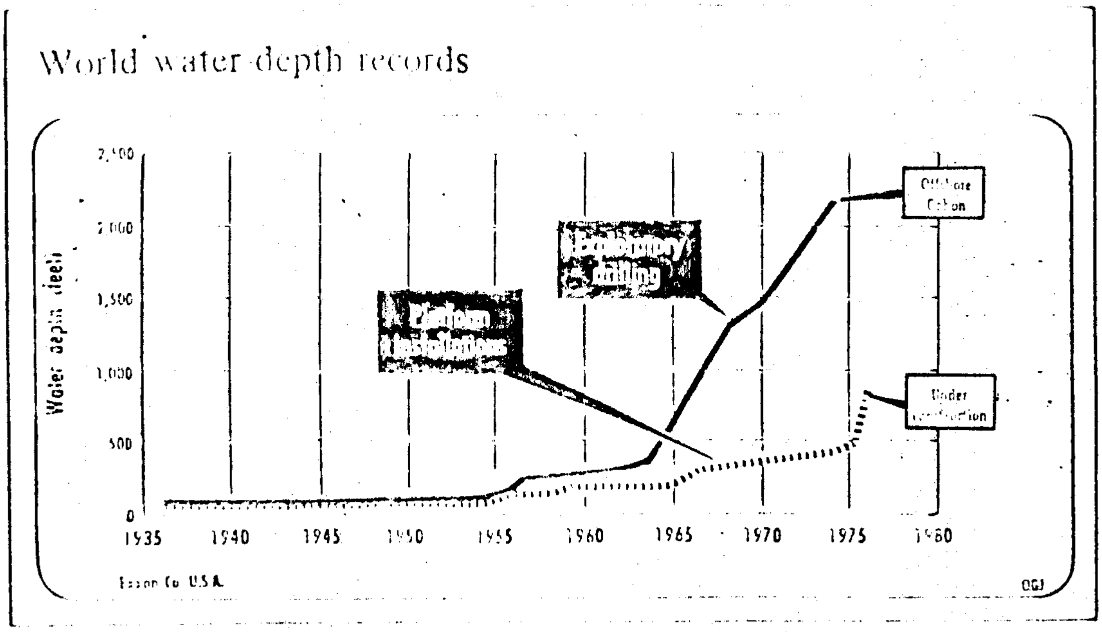


Figure 28.-- World water-depth drilling records. From Oil and Gas Journal, 1975.

Time Frame

If we assume that commercial quantities of oil and gas will not be discovered, a drilling "boom" cannot be anticipated even though initial exploratory drilling may be commenced within months after a lease sale. If this is the case, we foresee an initial flurry of drilling activity after leasing that will decelerate after several dry holes are drilled -- much as did activity on the Outer Continental Shelf off Oregon and Washington following the leasing of 580,853 acres in 1964. Exploratory drilling on acreage leased at such a sale should be largely completed at the end of the initial 5 year lease term.

If we assume that the undiscovered recoverable petroleum resources equal or exceed 2.4 billion barrels of oil and 12.5 trillion cubic feet of gas (5% probability or 1 in 20 chance as discussed previously in this report), the time frame for significant development may be 4 to 5 years subsequent to a sale with initial drilling starting within months after a lease approval. In this case it is estimated that it will be 6 to 7 years after a sale before production commences and 18 years until peak production is attained.

Infrastructure

Preliminary estimates of peak production and facilities necessary are highly speculative in the absence of demonstrated reserves of oil and gas. Based on the 5% probability that the undiscovered recoverable petroleum resources will equal or exceed 2.4 billion barrels of oil and 12.5 trillion cubic feet of gas (as discussed previously in this report), about 700 oil wells, some of which will produce appreciable amounts of gas, and 100 gas wells, contributing a significant amount of condensate and NGL, or 800 producible wells, will be needed, along with an additional 100 or more exploratory wells which will be dry holes. Assuming 20 wells per platform, this means that there will need to be 40 drilling and production platforms, about 1,100 km (700 mi) of large diameter pipelines, and 5 onshore terminals. Peak production may reach 400,000 barrels of oil per day and 2.0 billion cubic feet of gas per day. These estimates are based on production over a 35 year period following the date of initial production from development wells drilled to an average depth of 4,570 m (15,000 ft) at an average distance of 200 km (125 mi) from shore.

If we assume that there will not be a commercial discovery of oil or gas in the North Atlantic OCS, there would be no need for construction of drilling and production platforms, pipelines, or onshore terminals. Several conditions of non-discovery must be assumed - first, that if all wells are dry with no "shows" of oil or gas, the number of exploratory wells drilled will be quite small. Our existing knowledge of the Georges Bank area in the North Atlantic OCS does not identify many anomalous structures in the most prospective portions; so it is valid to assume that not over 2 dry, "no show" wells would be drilled per structure, plus 10 more in other as-yet-unknown prospective areas. This results in the drilling of no more than 30 wildcat wells to condemn the entire North Atlantic OCS, with depths averaging 4,570 m (15,000 ft) and lying an average distance of 200 km (125 mi) from shore. Second, if we assume that most of the exploratory wells encounter favorable shows of oil and gas, or even indicate that they are capable of producing oil and/or gas in less than commercial quantities, the number of exploratory wells will double or triple from the above. Thus, under these conditions, 60 or more wells could be drilled in the North Atlantic OCS before it is actually condemned. The time needed to drill a valid exploratory test in this area could be 6 months or longer for the deepest wells drilled. Based on a 6 months per well figure, the number of wells needed to adequately evaluate the North Atlantic OCS, and the number of drilling rigs estimated to be simultaneously working in the area, we foresee that exploratory drilling will be largely completed in 5 years.

SUMMARY

The area designated for possible oil and gas lease sale as modified from BLM memorandum 3310 #42 (722) and referred to therein as the North Atlantic Outer Continental Shelf (OCS) contains about 58,300 sq km of shelf beneath water depths of less than 200 m and lies chiefly within Georges Bank basin. The area is a broad shelf extending east-southeast from New England about 350 km. It is marked by extensive areas of sand shoals, channels, and featureless flat shelf. The physiography of the shelf is dominated by two main features, Nantucket Shoals and Georges Bank.

Georges Bank is covered by quartzose sand, medium to coarse-grained, with small amounts of gravel. The coarsest sediment is associated with interareas between shoals, coarse to medium sand makes up the ridges. Though composition of the sand remains fairly uniform over much of Georges Bank, it becomes finer grained twoard the souther part. Gravel occurs mainly on the northern half of the Bank. Both of these changes point to a broad north-south gradation in grain size over Georges Bank. A similar gradation exists southwest of Nantucket Shoals, though here the gradation is from gravelly sand to sandy silt.

Within the Georges Bank basin area no deep drilling information is available. The oldest sedimentary rocks drilled on the bordering Continental Slope are glauconitic sandstone, silty clay, and micaceous silt of late Cretaceous age probably deposited in bathyal depths. Exposed Upper Cretaceous sediments on Block Island are sands and lignitic clays

of Upper Cenomanian age. In Upper Cretaceous exposures, on Marthas Vineyard and the nearby islands, the predominant lithology appears to be clay. About 250 km northeast of Georges Bank, the Shell Mohawk B-93 well located near the Continental Slope on Browns Bank penetrated principally clays and silts of Upper and Lower Cretaceous age above dense Jurassic carbonate rocks which overlie a basement of lower Paleozoic slate, schist, quartzite, and granite (Meguma group).

In the Gulf of Maine located west of Georges Bank, the sedimentary sequence is about 50 m thick and consists of isolated Coastal Plain erosional remnants with a thin veneer of Pleistocene glacial deposits.

Structurally the Georges Bank basin is a westerly trending trough opening out to the west-southwest containing about 3.1 km of post-Paleozoic sedimentary rock in the northern part. The section increases to over 8 km along the southern part and is broadly warped by the southerly plunging Yarmouth Arch -- an uplift 75 km across that affects older Jurassic carbonates. Seismic data indicate that, in general, major structural features within the sedimentary section are directly related to basement structures. Jurassic and Triassic (?) sediments were deposited on a highly irregular basement surface deformed by local and regional flexures and block faulting. In some cases faulting may have continued during Jurassic time. Major faulting does not appear to have affected post-Jurassic sediments. Local anticlines, probably caused by differential compaction over basement flexures and horst blocks, are principally reflected in Lower Cretaceous and older sediments, though some of these features continue upward to within 0.7 of a second from the water bottom.

Seismic data indicate that a poorly defined buried ridge bounds the southern edge of the Basin. Associated magnetic and gravity data suggest that the ridge may reflect a deeper intrusive feature associated with the New England seamounts. We speculate that intrusives were emplaced along a zone of translation as contiguous portions of rifting continental masses slid past each other. The ridge (Yarmouth arch) would be a block-faulted intruded, slivered edge of margin that subsided and was covered by sedimentary deposits. Seaward of the ridge, the sedimentary section thins from 4-5 km under the slope to less than 3 km to the southeast.

Combining reflection characteristics, velocity studies, and stratigraphy presented by several investigators, Tertiary deposits in the Georges Bank Basin are probably up to a kilometre thick, have velocities around 2 km/sec and are made up of poorly consolidated sand, silt, and clay. Based on the results of the Shell Mohawk B-93 well drilled on the Scotian Shelf, the Cretaceous system is inferred to be up to 3.4-3.5 km thick and to be mainly clastics -- shale, siltstone, and calcareous shale, changing to limestone in the lowest part of the system toward the southern part of the basin. Mattick and others (written commun.) however, have indicated that the Lower Cretaceous section contains sands. A vertical increase in velocity from about 3.3 to 5.2 km/sec near the shelf edge could represent a change in lithology from dominantly marine clastics to limestone and dolomite within the Cretaceous. Jurassic rocks in the deepest part of the basin are inferred to be about 3.6 to 4.0 km thick and to consist mainly of dense carbonates. Although some authors have suggested the possibility of salt and evaporites in the basal part of the sedimentary section based on analogy with the Scotian Shelf, the present authors could find no seismic evidence of either basal evaporites or salt diapirs.

The general paucity of "reserves" of hard minerals (other than oil and gas) on the U.S. Atlantic OCS area appears to result not from insufficient sampling, but from an actual dearth of such minerals. Sand and gravel deposits most likely available now for economic extraction are large--even though only partly evaluated, reserves on the U.S. Atlantic OCS (including the Georges Bank area) are at least 450 billion tons of dry sand and at least 1.4 billion tons of gravel. The total gravel amount may exceed 50 billion tons and the inferred sand resources are probably 10 or more times greater than now estimated.

The Georges Bank bank basin appears to have the necessary elements for hydrocarbon production. Potential source rocks in the Georges Bank basin may include organic rich Cretaceous shale and carbonaceous Jurassic limestone. By analogy with the Scotian Shelf, Cretaceous sandstones are considered to be potential reservoir rocks. Local zones of poreous dolomite are believed to be present in carbonate rocks of Jurassic age and should not be overlooked as potential reservoirs.

Structural highs related to draping and differential compaction over basement blocks could be important potential petroleum traps. Additional traps may include reef structures near the shelf edge, updip pinchouts, and stratigraphic traps in both clastic and carbonate sediments.

A statistical mean for the undiscovered recoverable petroleum resources is calculated to be 0.9 billion barrels of oil and 4.2 trillion cubic feet of gas. These undiscovered recoverable petroleum resources are those quantities of oil and gas that may be reasonably expected to exist in favorable settings, but which have not yet been identified by drilling. Such estimates, therefore, carry a high degree of uncertainty.

Available environmental data are insufficient to evaluate hazards connected to petroleum development. Studies that have used data presently on hand suggest a low to moderate risk to the environment. Data on water circulation (and oil spill trajectories) are based on an overall 2% return of the drift bottles. Using the computed trajectories, most danger seems to be in the spring and summer, and to the southern coast of New England. Seismic risk appears to be low offshore, but a part of the diminished risk may be due to the difficulty of land-based seismographs in locating offshore epicenters from other than major earthquakes. Speculatively, Sbar and Sykes (1973) project the Boston-Ottawa seismic trend southeast through the western part of the Georges Bank basin to connect it to the New England Seamount Chain. Howell (1973) estimates the seismic index hazard at 6.94± 1.18 for Georges Bank, or slightly below the level at which appreciable damage to building of a normal construction is common. Evidence for shallow faulting is lacking based on 2,200 km of single channel reflection profiles. Sediment dynamics have been studied for only one set of shoals on northern Georges Bank. Emery and Uchupi (1972), however, confirm the mobility of bottom sands by noting that sand levels around the legs of the Texas Towers deepened enough to weaken the structures, leading eventually to their abandonment. Although the properties of shallowly buried sediment is poorly known, logs in two widely spaced groups of borings show that there is substantial lateral variability on the sediment and that placement of rigs will depend in part on either anchoring below clayey layers or in avoiding zones of finer grained buried sediment. Geopressures are often encountered in Cenozoic and Mesozoic sediments of the Gulf Coast; in the Sable Island area geopressures are common below 3.5 km. In the Gulf of Mexioc, there have been occasional problems from encountering gas at shallow depths before surface casing or conductor pipe has been installed. This problem has not been encountered, at least to date, on the Scotian Shelf. Velocity data from Georges Bank does not indicate any substantial velocity inversion commonly associated with geopressures.

Mobil drilling units for exploration are in great demand around the world and will have to be brought in from other areas along with skilled manpower. Our highest estimates indicate 40 platforms, 800 producing wells, 1,100 km of pipeline, and 5 onshore terminals may be needed. The time frame for production, using our high estimates (5% probability) of the undiscovered recoverable resources, could include 4-5 years for significant development, 6-7 years until production commences, and 18 years until peak production.

Oil and Gas Possibilities in the Georges Bank basin

1. Georges Bank basin is prospective for oil and gas.
2. About 58,300 sq km (under water depths of less than 200 m) are underlain by Mesozoic and Cenozoic sediments between 1.0 and 7.5 km thick which are believed to contain petroleum reservoir rocks, source rocks, and potential traps.
3. Cretaceous rocks and possibly Jurassic rocks are considered most prospective.
4. Statistical means for undiscovered recoverable petroleum resources in Georges Bank basin are:

   0.9 billion barrels of oil
   4.2 trillion cubic feet of gas

   At the 5 percent probability level (1 in 20 chance) the undiscovered recoverable petroleum resources are:

   2.4 billion billion barrels of oil
   12.5 trillion cubic feet of gas

5. The Gulf of Maine is not prospective for oil and gas.

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Appendix I.--A general summary of drilling results in the Georges Bank area.

A general summary of drilling results are given by Anderson-Nichols; Moran, Proctor, Mueser, and Rutledge (1954) for the Navy.

> "Georges Bank .... The drilling operations disclosed the following subsoil conditions below the sea bottom. At both locations a layer 10 to 15 feet thick of medium compact light brown, medium to coarse sand was found. At Location No. 1 this sand is underlaid by a compact to very compact light gray medium to fine sand with traces of silt, coarse sand and fine gravel. This sand persisted to the full depths of the borings varying from 80 ft. to 120 ft. below the ocean bottom. However, at depths of approximately 60 to 80 ft. two layers of dark gray clayey silt were found interbedded in the sand. The upper layer varies from 5 to 10 ft. in thickness and the lower layer from 1 to 5 ft. in thickness. These layers are distinctly less compact and are more compressible than the sand materials. At location No. 2 the thickness of the compact to very compact light gray medium to fine sand with traces of silt, coarse sand and fine gravel varies between 55 ft. and 70 ft. Below this layer a medium compact dark green fine sand containing some silt and traces of medium sand was found. The dark green sand persisted to the full depths of the borings which extended from 90 ft. to 120 ft. below the ocean bottom. No soft or compressible materials were encountered in the borings at Location No. 2."

The Woods Hole Oceanographic Institution has submitted the following geologic evaluation of the results of these borings:

> "In general one may think of the stratigraphic section penetrated by the wells as being Pleistocene and Pre-Pleistocene. Wells drilled at Location No. 2 on Georges Bank proved the most simple stratigraphic picture, gray and white quartz sands overlying "greensands". Cores of the greensands are unfossiliferous and probably are Miocene or Cretaceous, inasmuch as the most common greensands of the northeastern coastal plain are Miocene and Cretaceous. The overlying quartz sands, therefore, represent deposits acacumulated during all four glacial and inter-

> glacial ages. The environment of deposition of the upper sands can be inferred to be glacial outwash plains because larger detritus is lacking. Furthermore, the area must have been above sea level when the glaciers were active or ice rafted boulders would be abundant in the sands. When sea level rose after each of the glacial maxima, part or all of the outwash plains were inundated and reworked by the sea. The sorting coefficients of the samples indicate that reworking was not uniform. Some of the sands were not reworked very much. One may imagine that the areas were low sandy islands, such as Sable Island, where wind piled the sand into dunes and rounded many of the smaller fragments. Local salt marshes or ponds were very likely present on the islands."

"It is well possible that the dark gray clayey silt found in the sands at Location No. 1 were deposited in one of the ponds described in the geological evaluation. On this basis, similar interbedding of silt or organic materials is possible any place within the general area. No boulders were encountered in any of the borings and it is not probable that boulders will be found in the general area covered by the exploration. However, boulders may be encountered in any of the deeper water areas of Georges Bank and are definitely indicated east of Georges Bank where the water depth reaches 30 fathoms.

Nantucket Shoals.--At Nantucket Shoals two locations were also explored in detail by drilling operations. Location No. 2 is approximately 4.5 miles west-northwest of Location No. 1. The results of all on-site investigations at these two locations are shown on Drawing Nos. 627-424 and 425 in the same form as the drawings for Georges Bank.

The general stratigraphy of the subsoils below the ocean bottom is very similar to that at Georges Bank. The upper medium compact sand varies in thickness from 3 ft. to 10 ft. At Location No. 1 the total thickness of the compact to very light gray medium to fine sand is 80 to 85 ft. Underlying this sand are layers of medium consistency, greenish gray organic silty clay with some layers of mottling by black organic clays. The thickness of this deposit ranges from 25 ft. to 45 ft. This is definitely a questionable stratum in terms of possible settlements that might be caused by it. This deposit is probably the result of salt marshes and ponds, as previously described, and represents an undesirable condition which, if possible, must be avoided in the locations of the proposed structures. The greenish gray organic silty clay is underlaid by grayish green fine to medium sand with some very stiff grayish green fine sandy clay indicated in one boring at a depth of approximately 145 ft. below sea bottom. At Location No. 2 the compact to very compact sands persist for the full depths of the borings which varied from 90 to 130 ft. below the sea bottom. Location No. 2 thus presents distinctly better foundation conditions."

Appendix II.-- Inferred surface and bottom drift in Georges Bank area (figures 1-24).

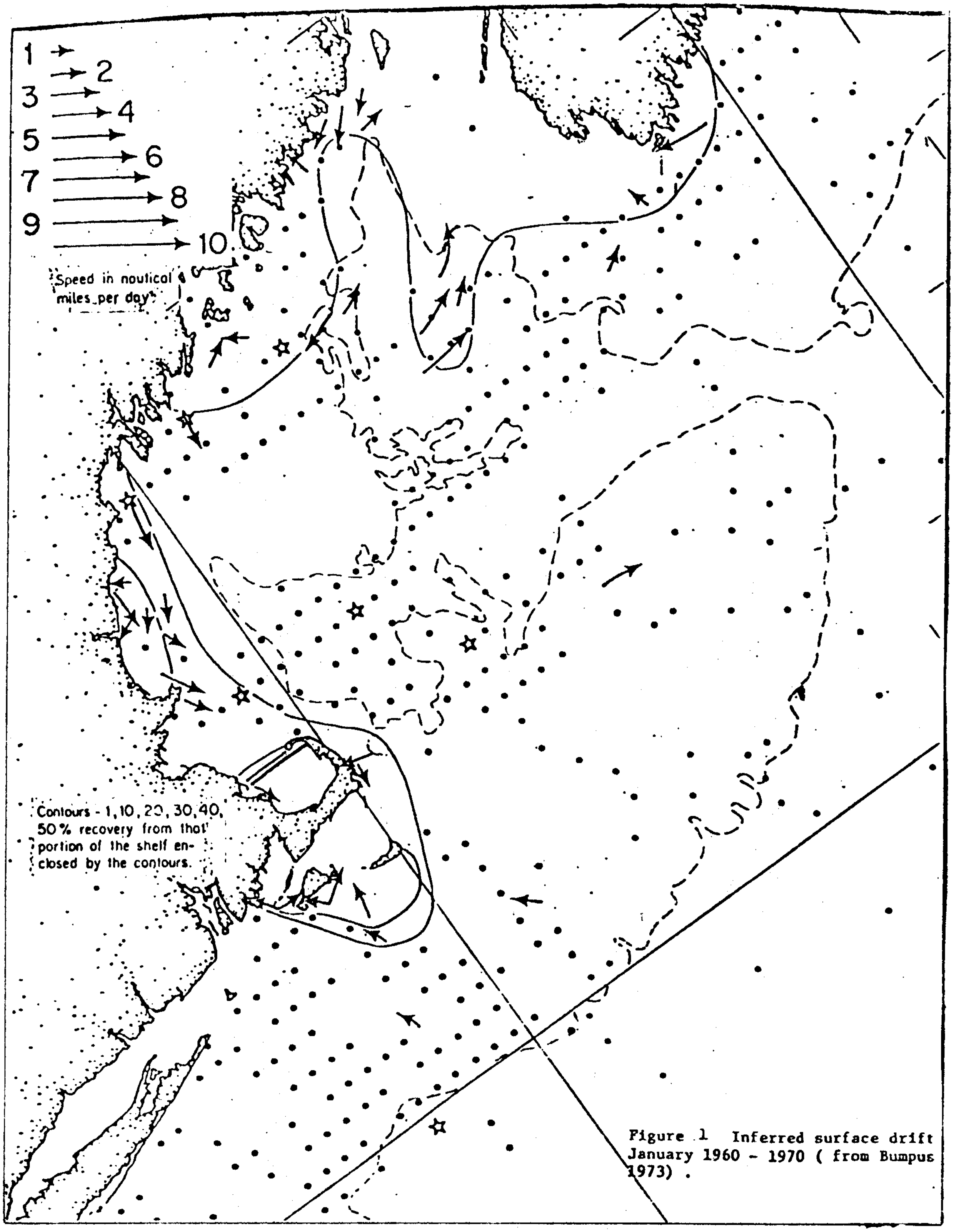

Figure 1 Inferred surface drift January 1960 - 1970 (from Bumpus 1973) .

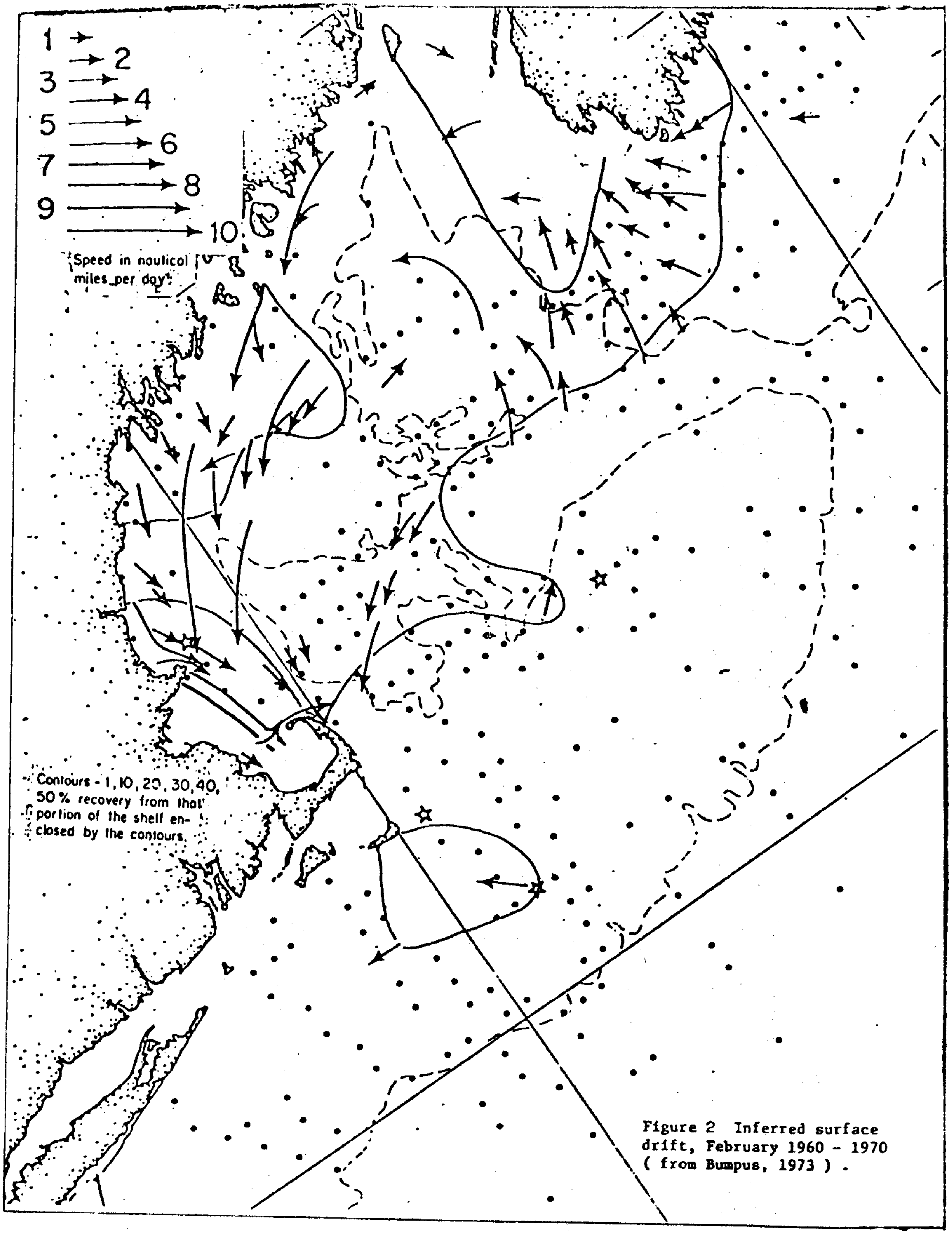

Figure 2 Inferred surface drift, February 1960 - 1970 (from Bumpus, 1973) .

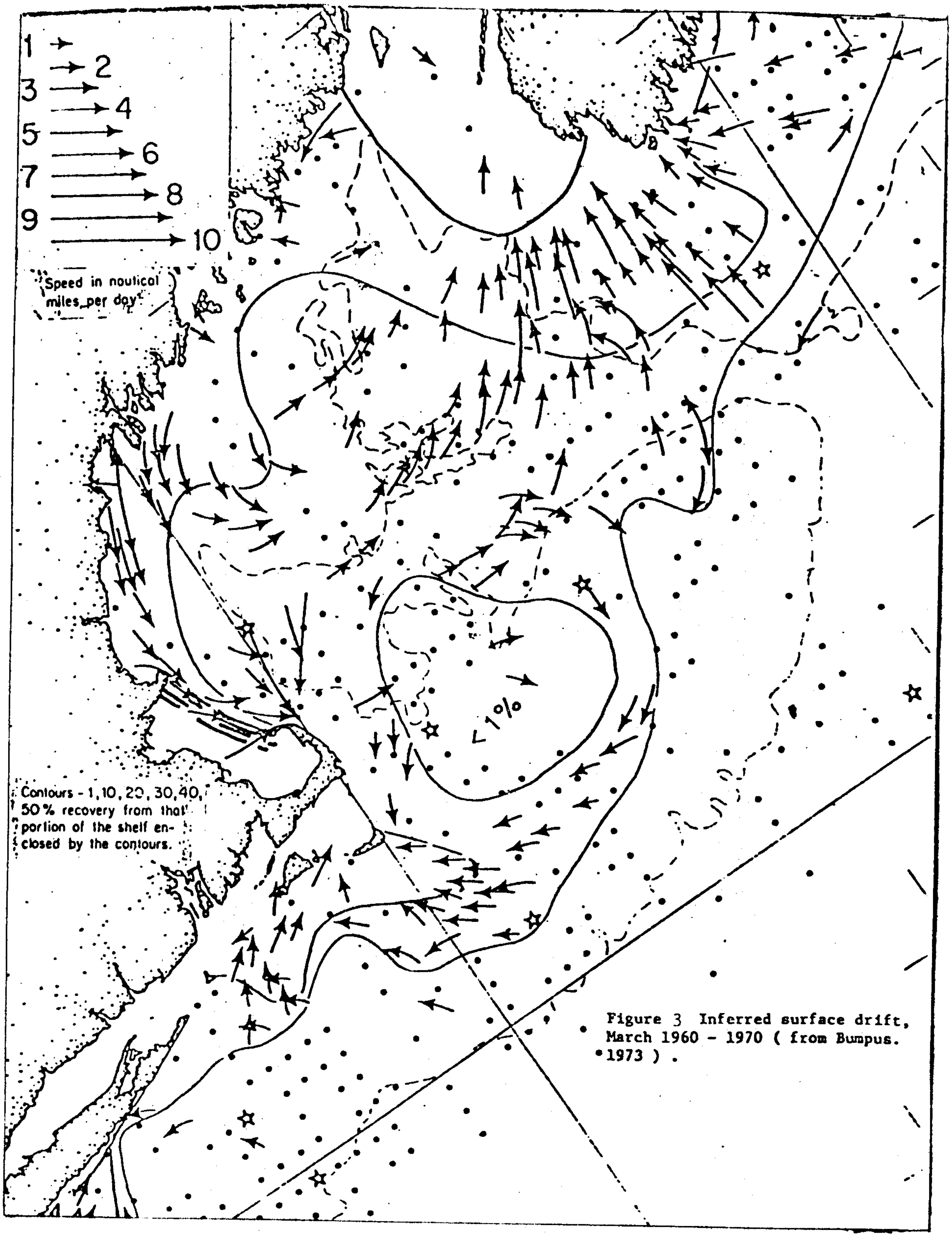

Figure 3 Inferred surface drift, March 1960 - 1970 (from Bumpus. 1973) .

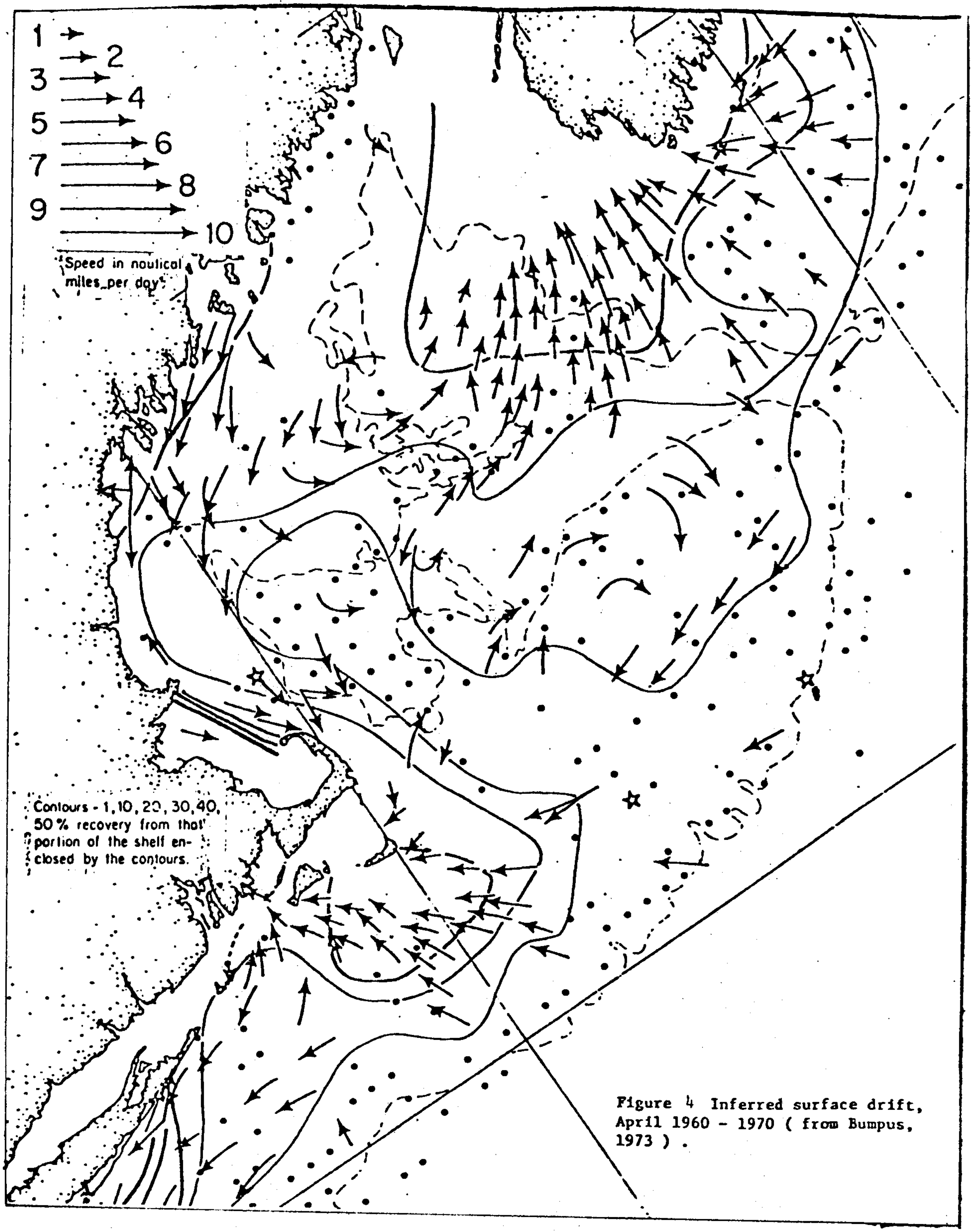

Figure 4 Inferred surface drift, April 1960 - 1970 (from Bumpus, 1973) .

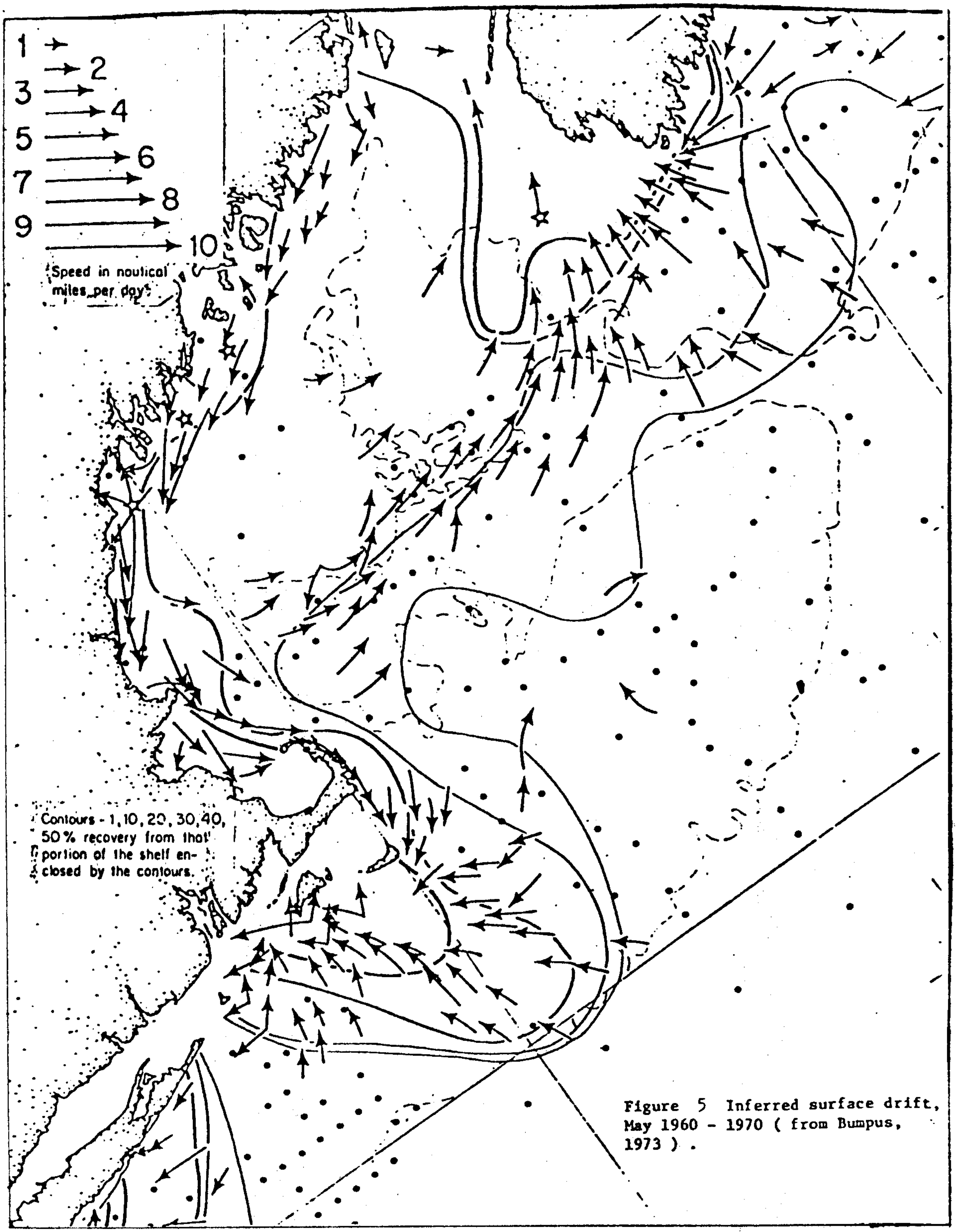

Figure 5 Inferred surface drift, May 1960 - 1970 (from Bumpus, 1973) .

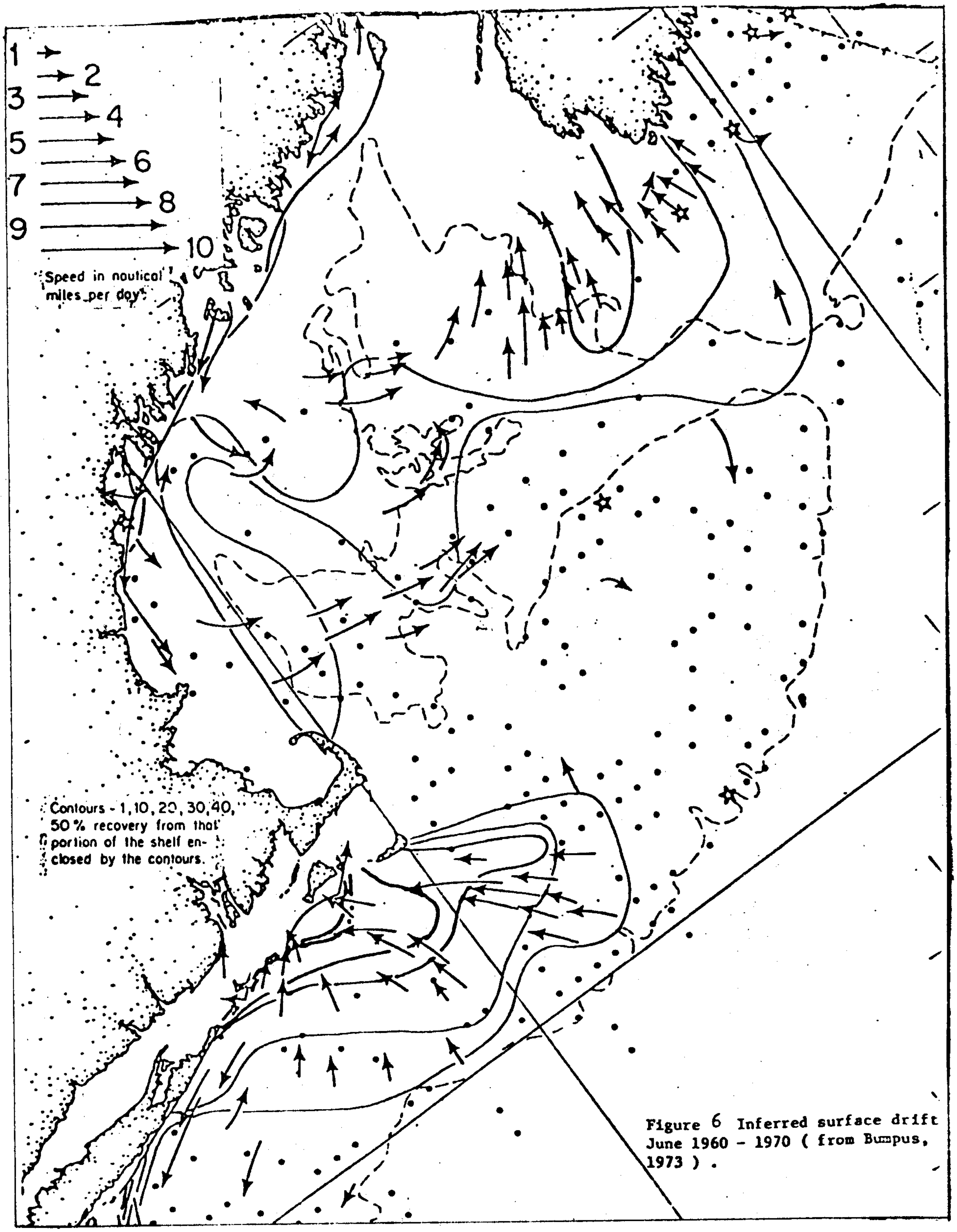

Figure 6 Inferred surface drift June 1960 - 1970 (from Bumpus, 1973) .

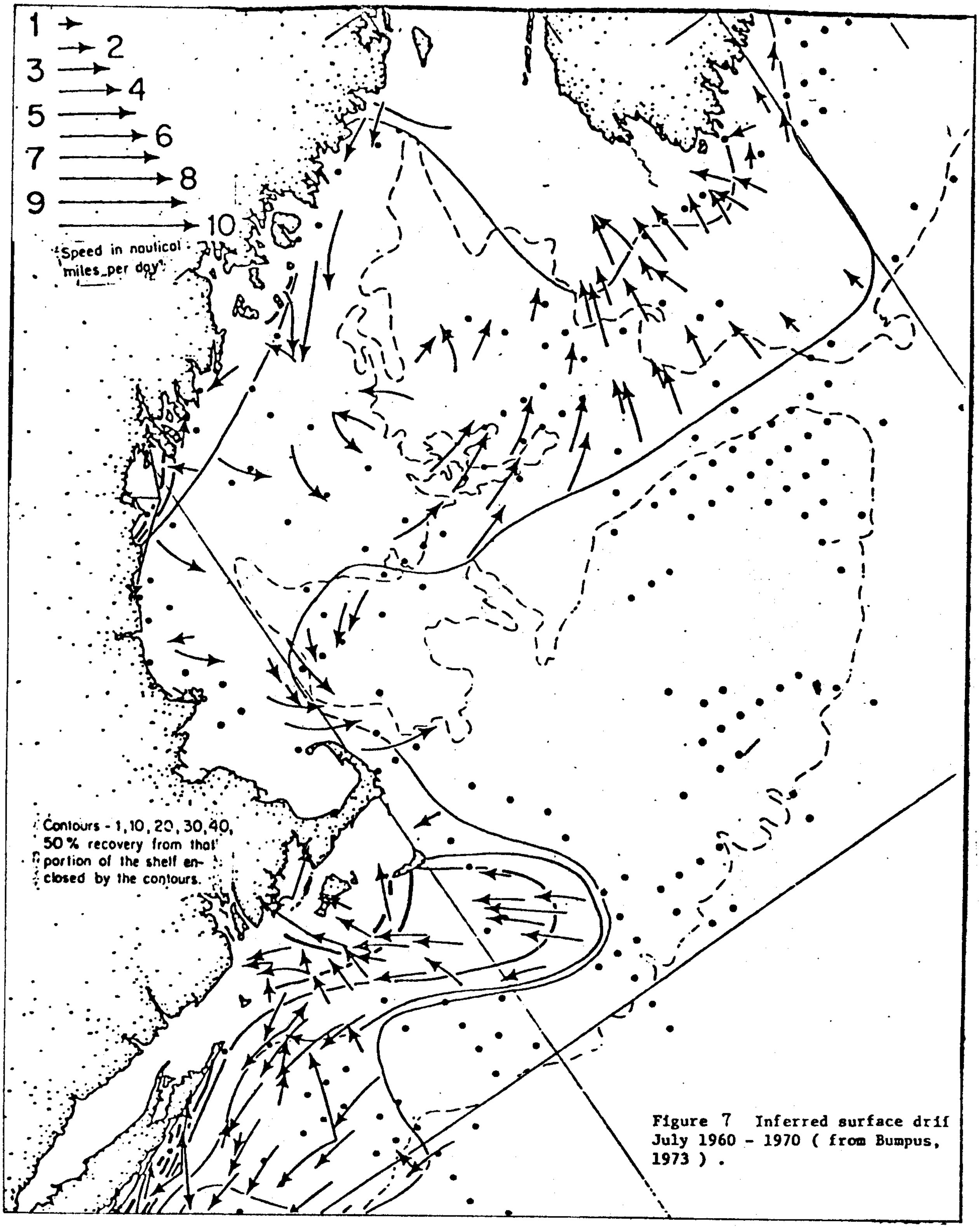

Figure 7 Inferred surface drif
July 1960 - 1970 (from Bumpus, 1973) .

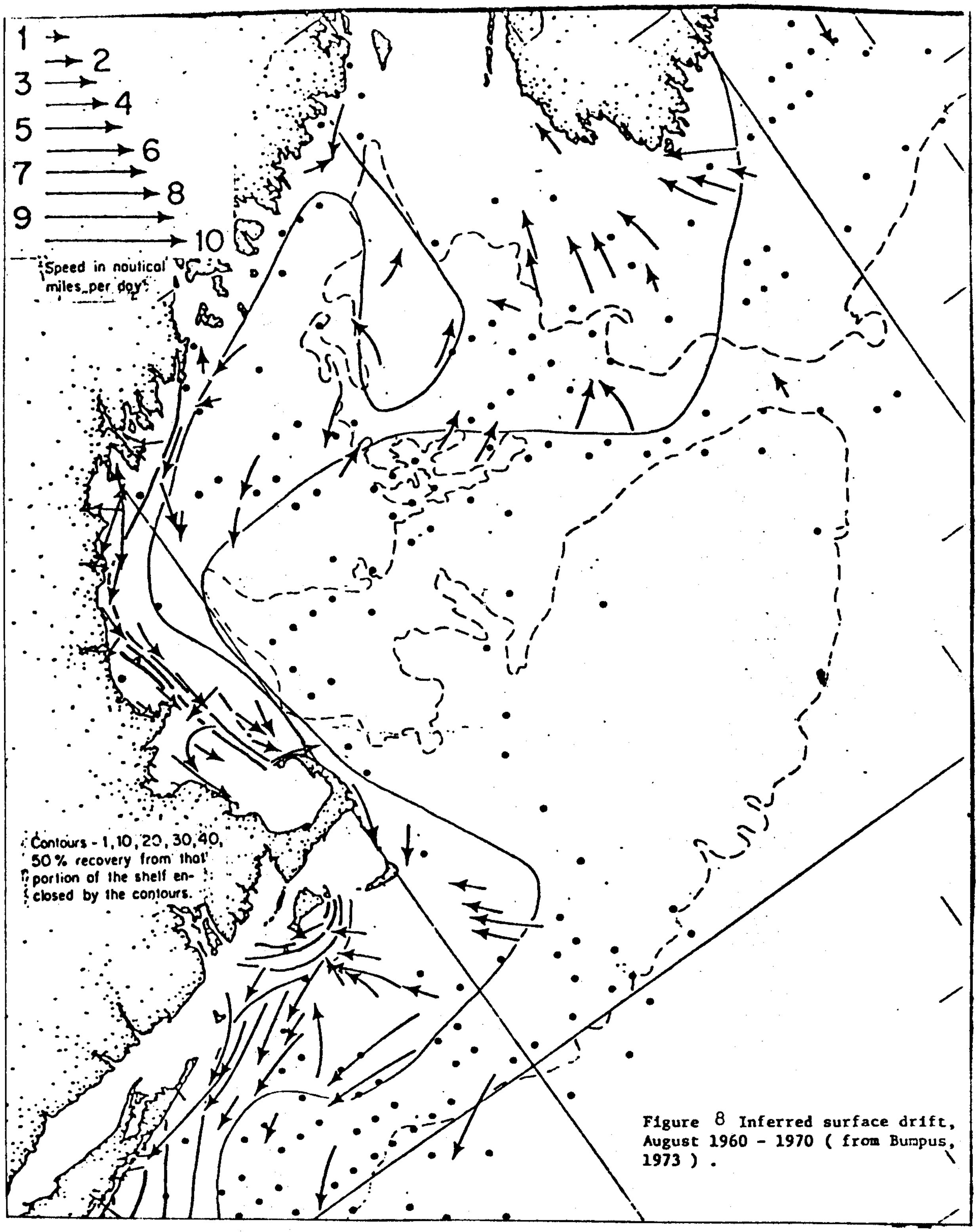

Figure 8 Inferred surface drift, August 1960 - 1970 (from Bumpus, 1973) .

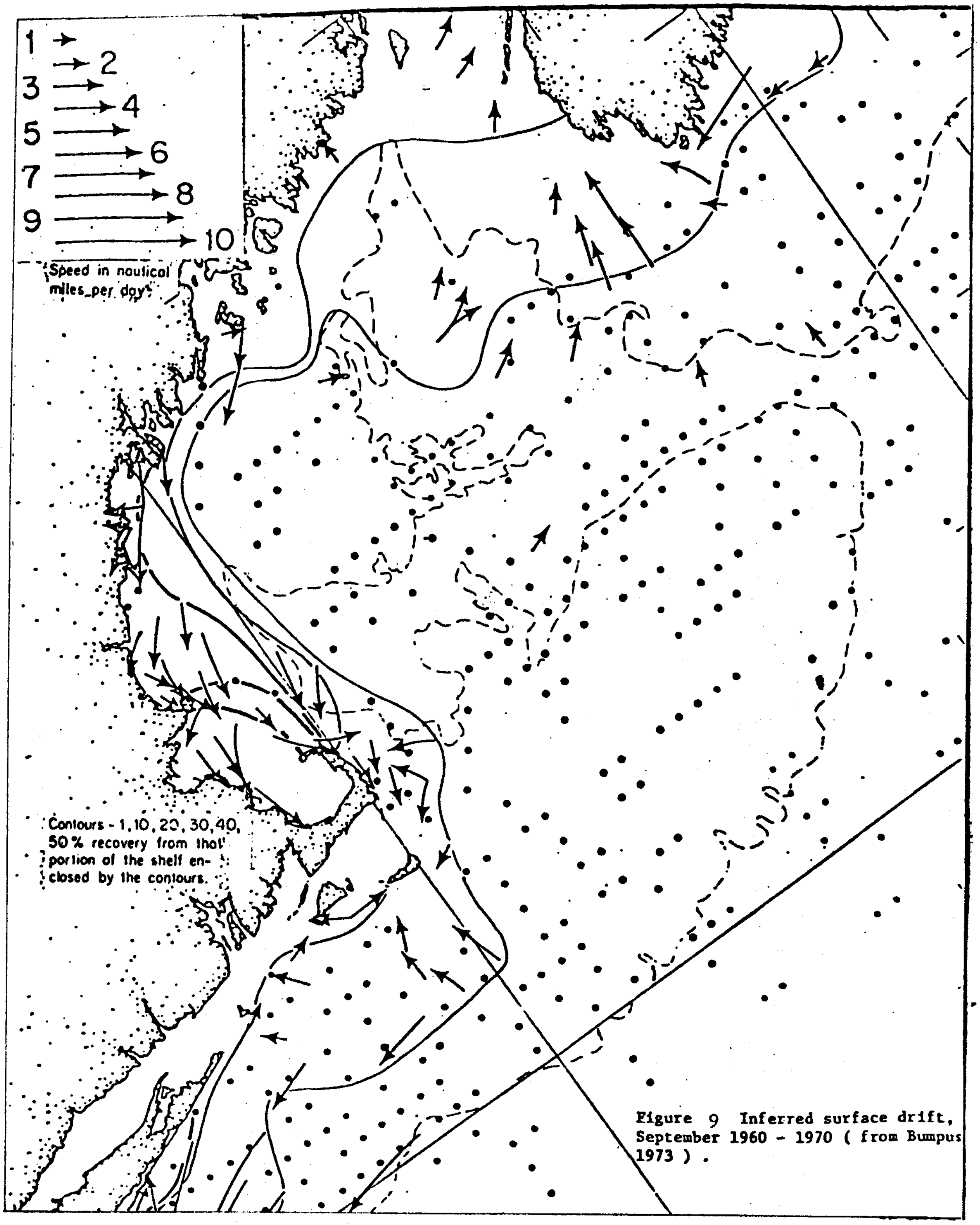

Figure 9 Inferred surface drift, September 1960 - 1970 (from Bumpus 1973) .

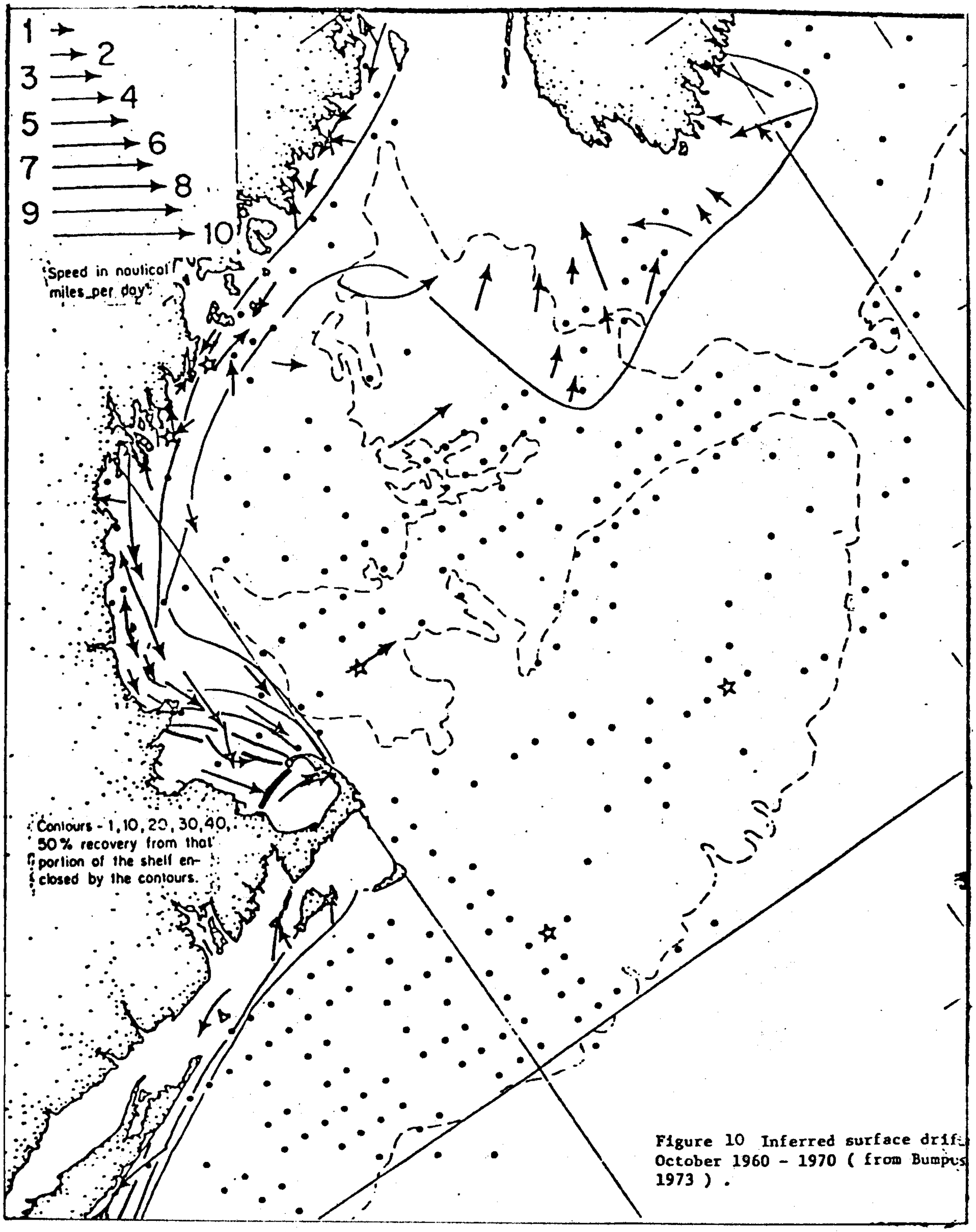

Figure 10 Inferred surface drift October 1960 - 1970 (from Bumpus 1973) .

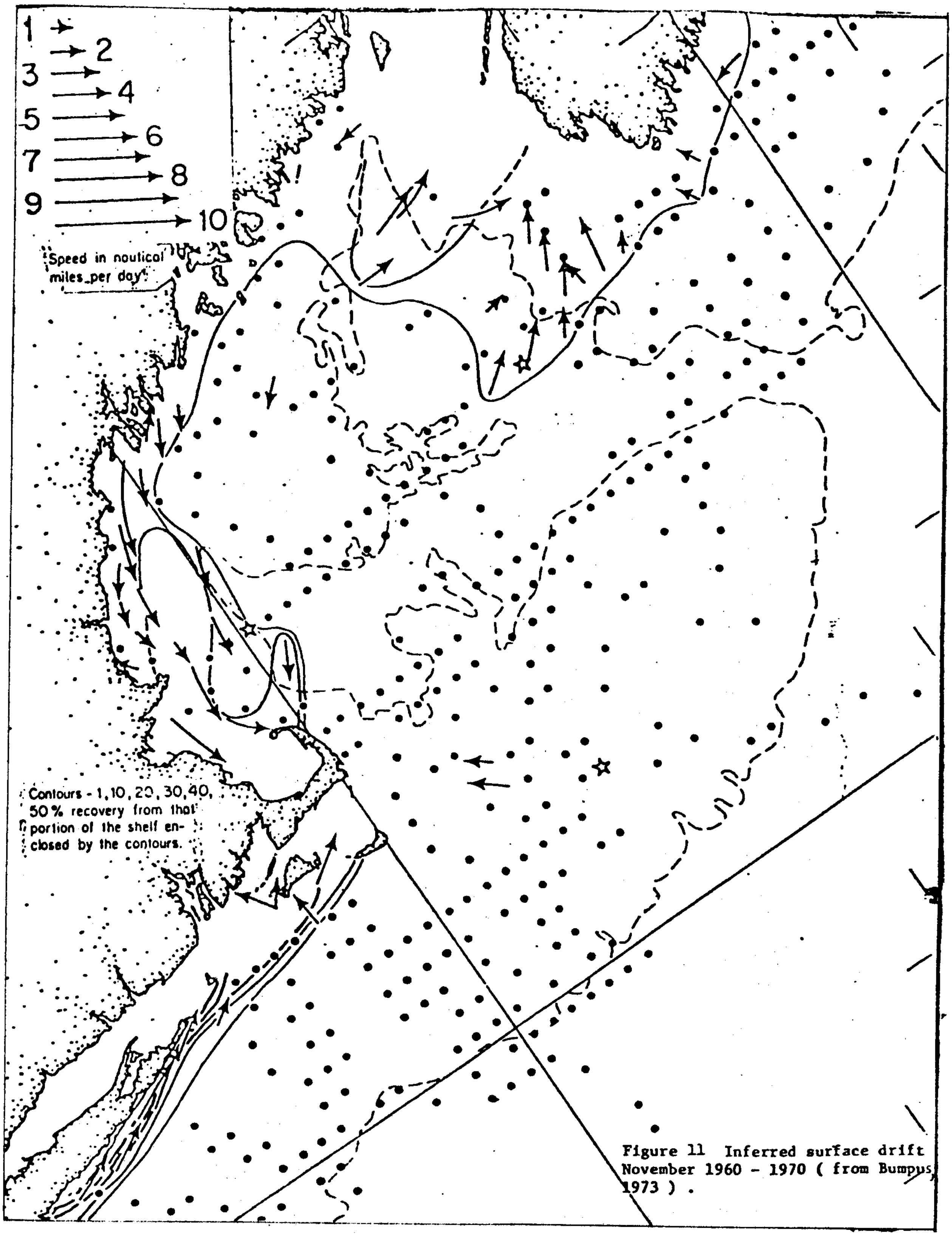

Figure 11 Inferred surface drift November 1960 - 1970 (from Bumpus 1973) .

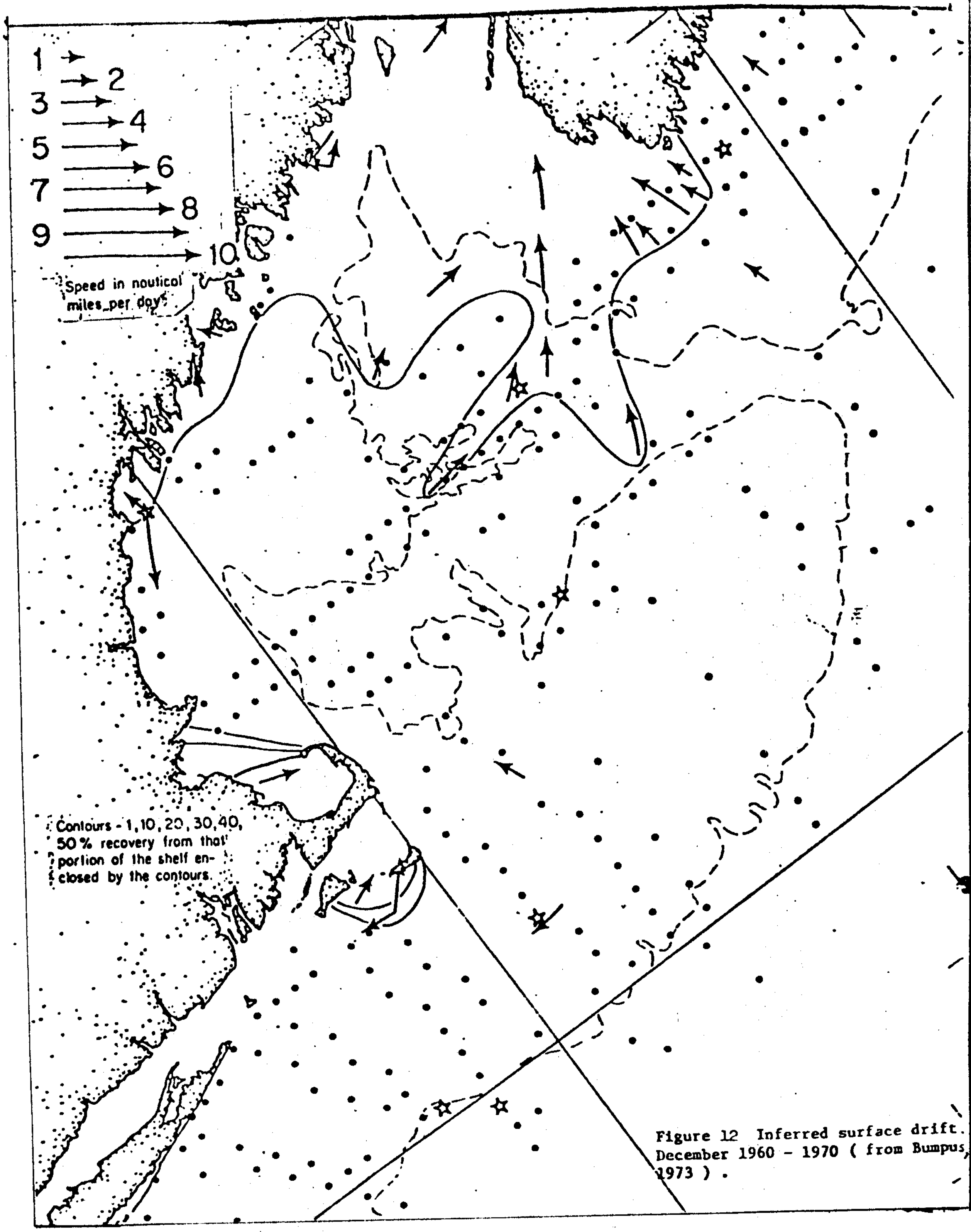

Figure 12 Inferred surface drift. December 1960 - 1970 (from Bumpus, 1973) .

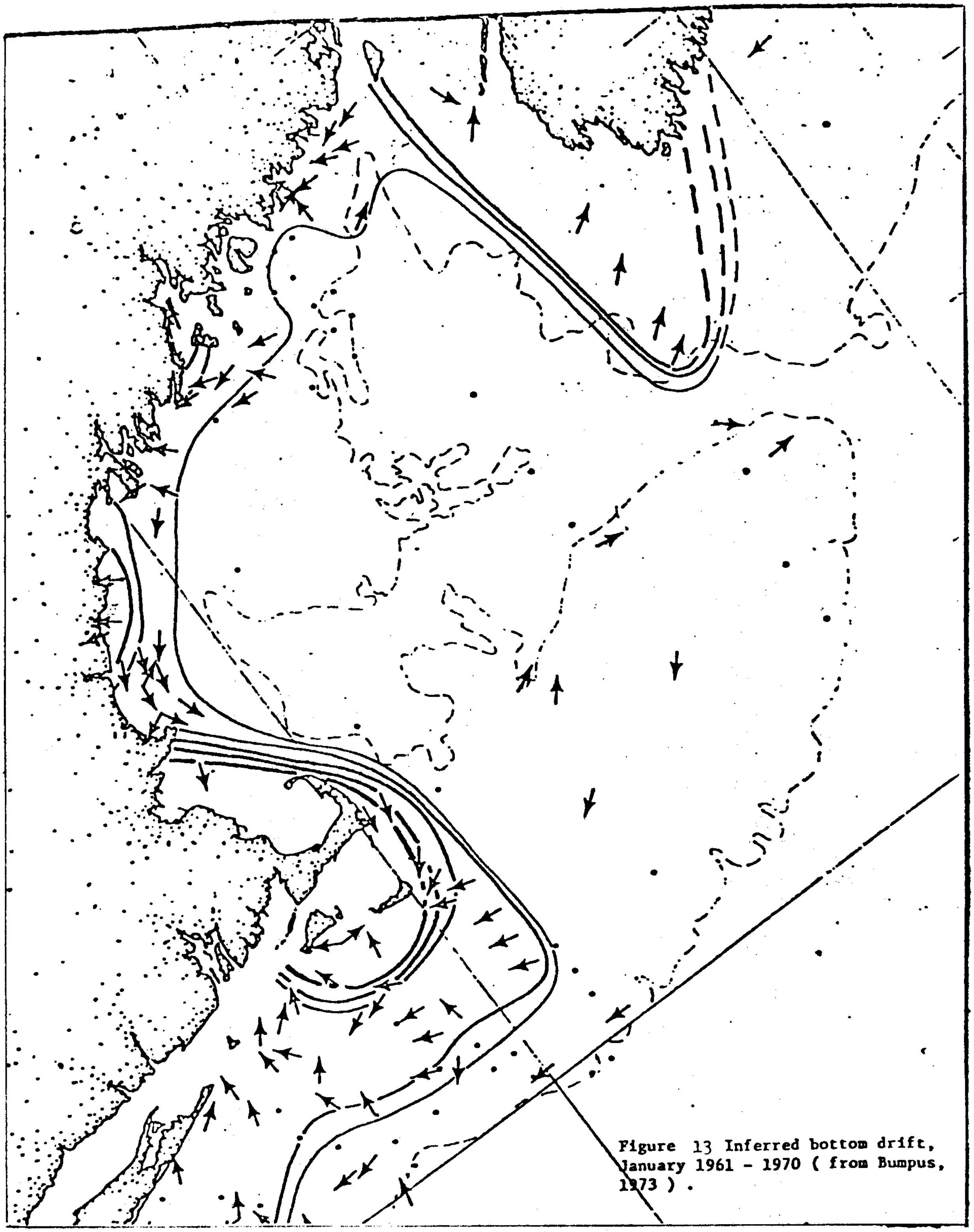

Figure 13 Inferred bottom drift, January 1961 - 1970 (from Bumpus, 1973) .

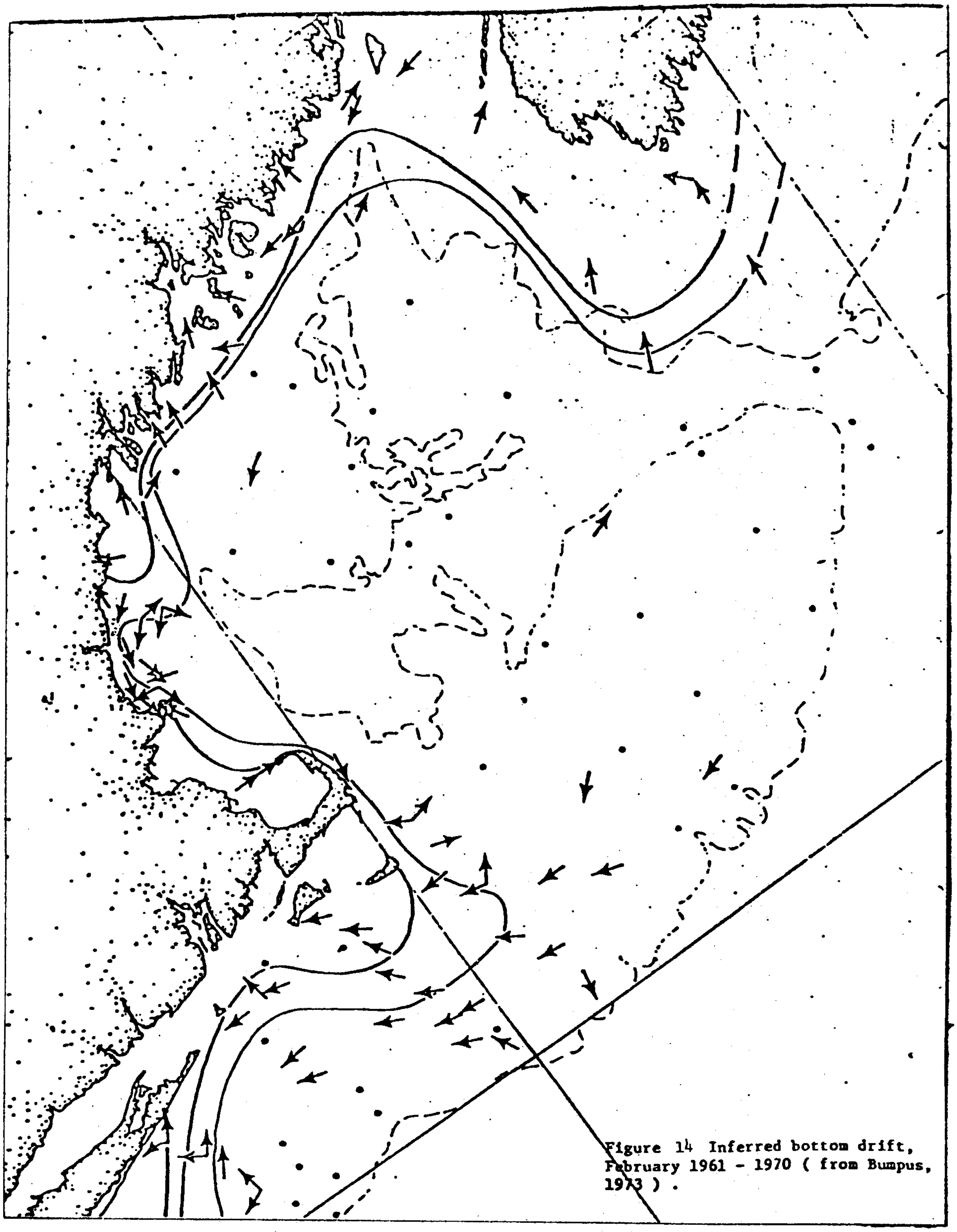

Figure 14 Inferred bottom drift, February 1961 - 1970 (from Bumpus, 1973) .

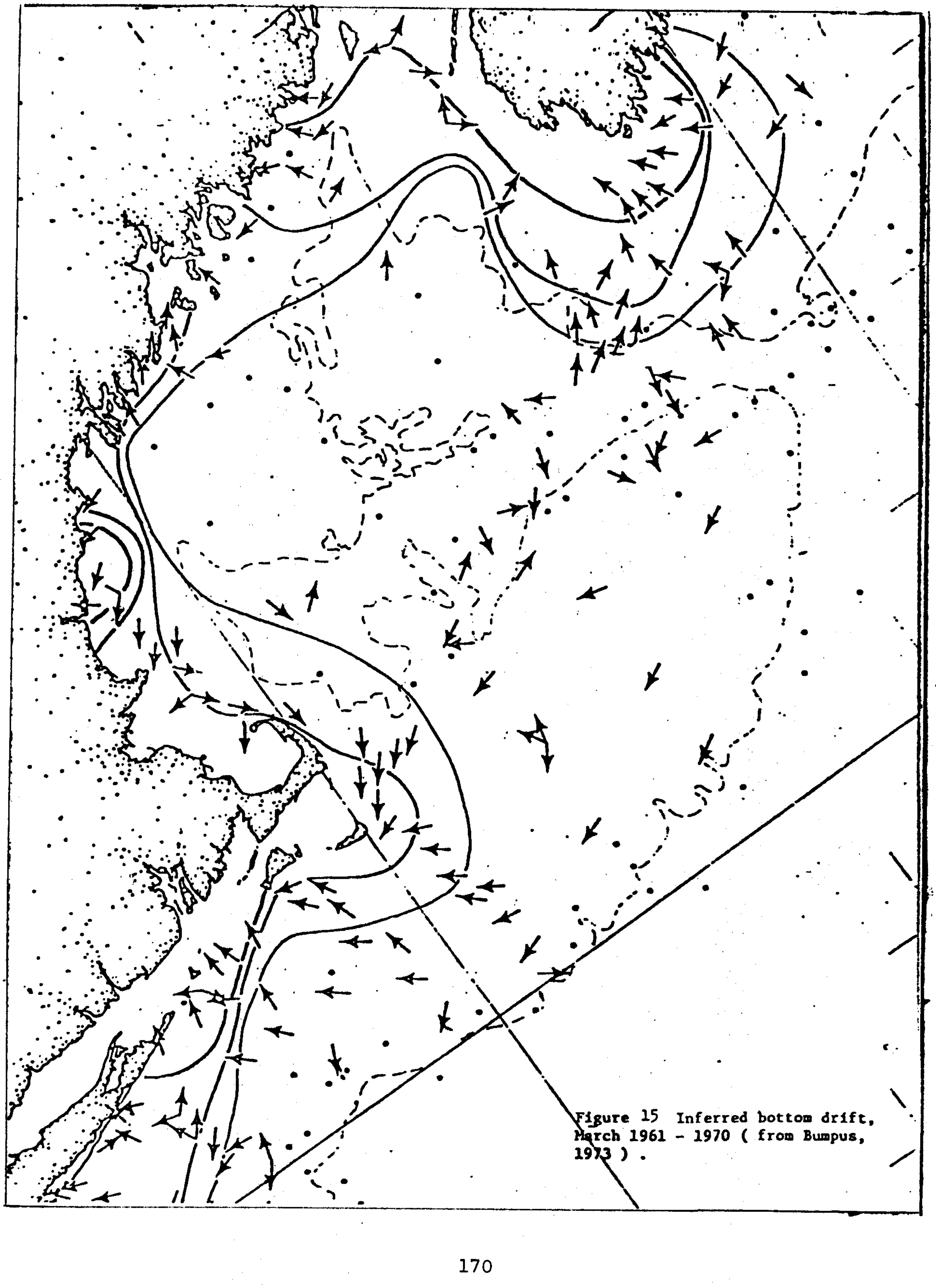

Figure 15 Inferred bottom drift, March 1961 - 1970 (from Bumpus, 1973) .

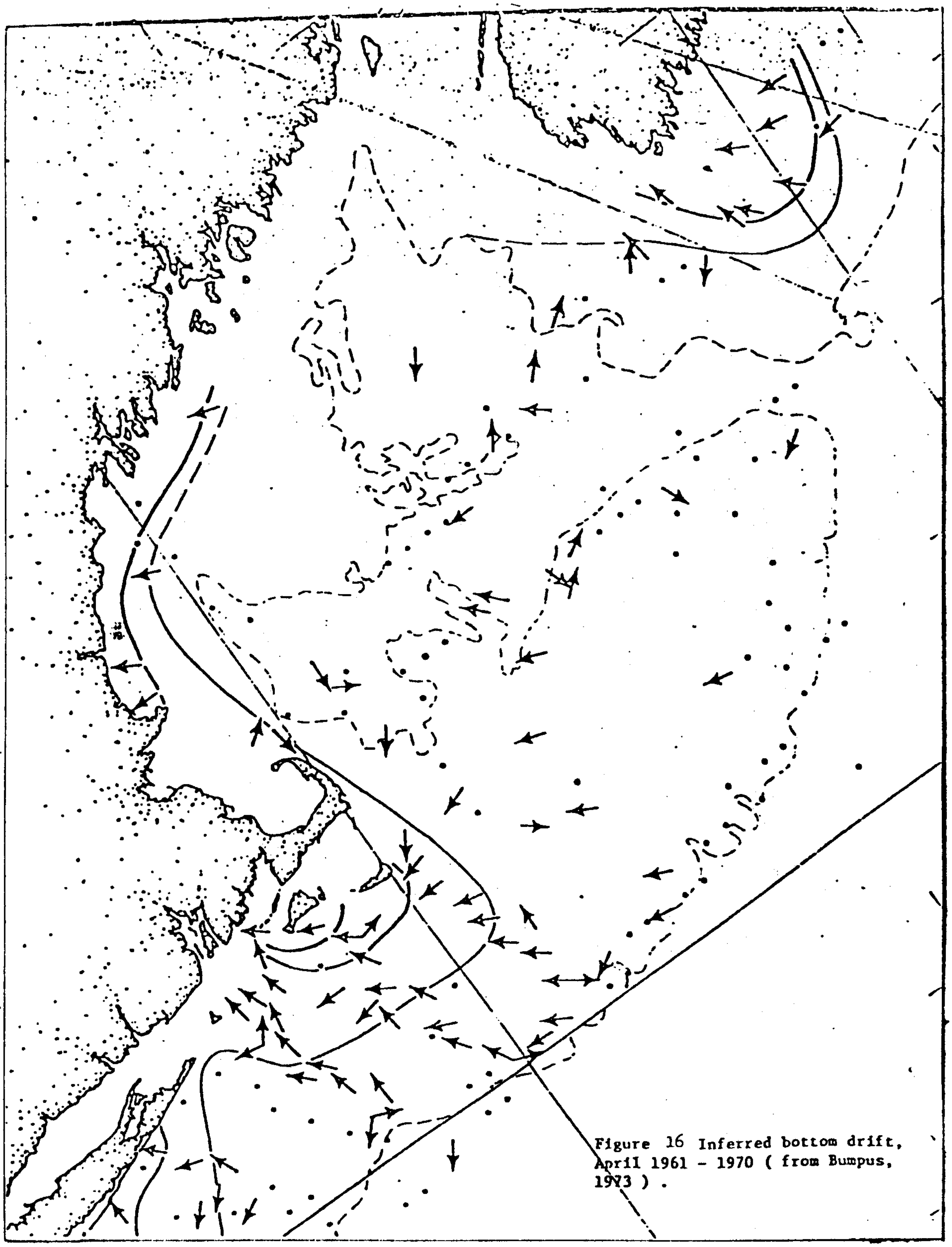

Figure 16 Inferred bottom drift, April 1961 - 1970 (from Bumpus, 1973) .

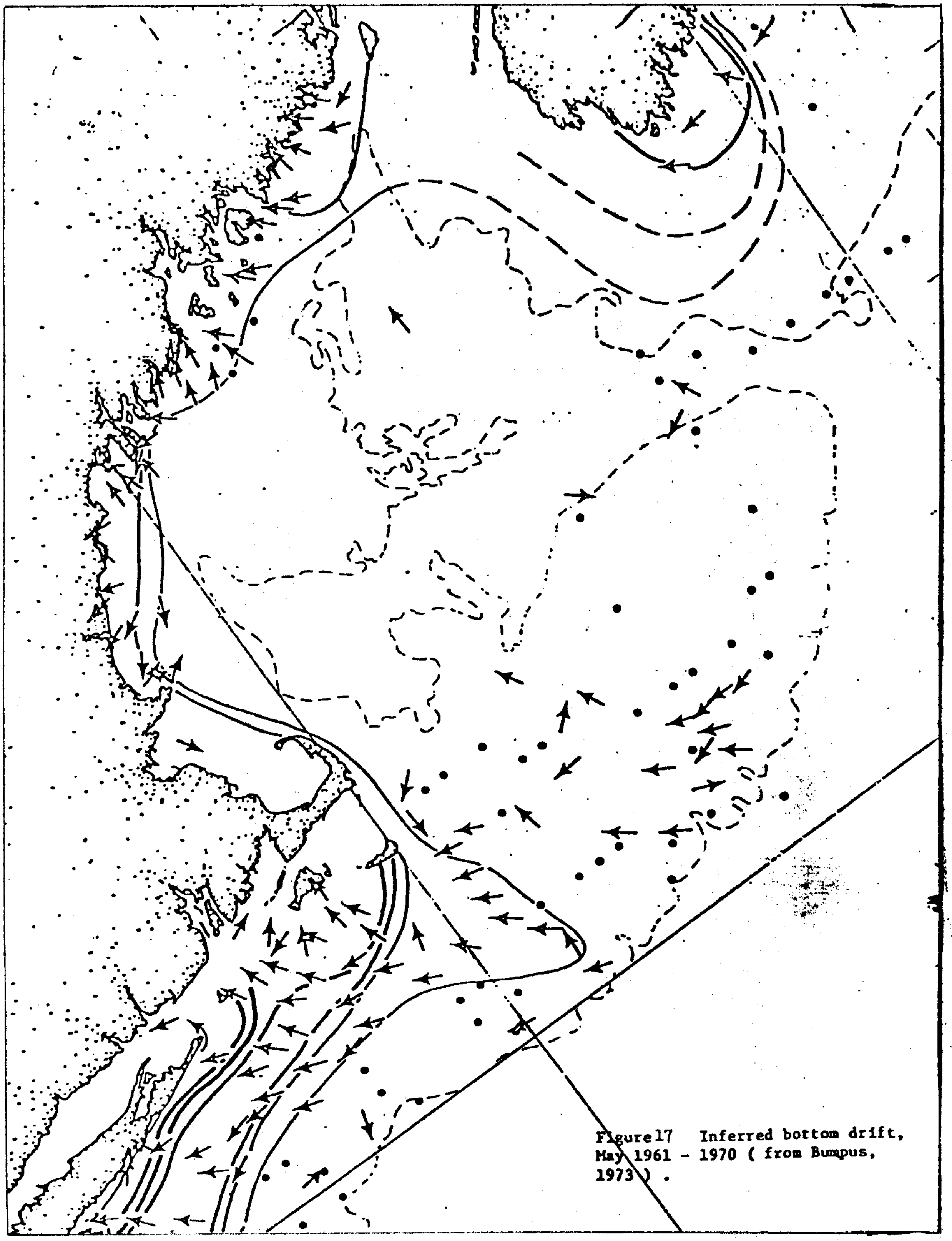

Figure 17 Inferred bottom drift, May 1961 - 1970 (from Bumpus, 1973) .

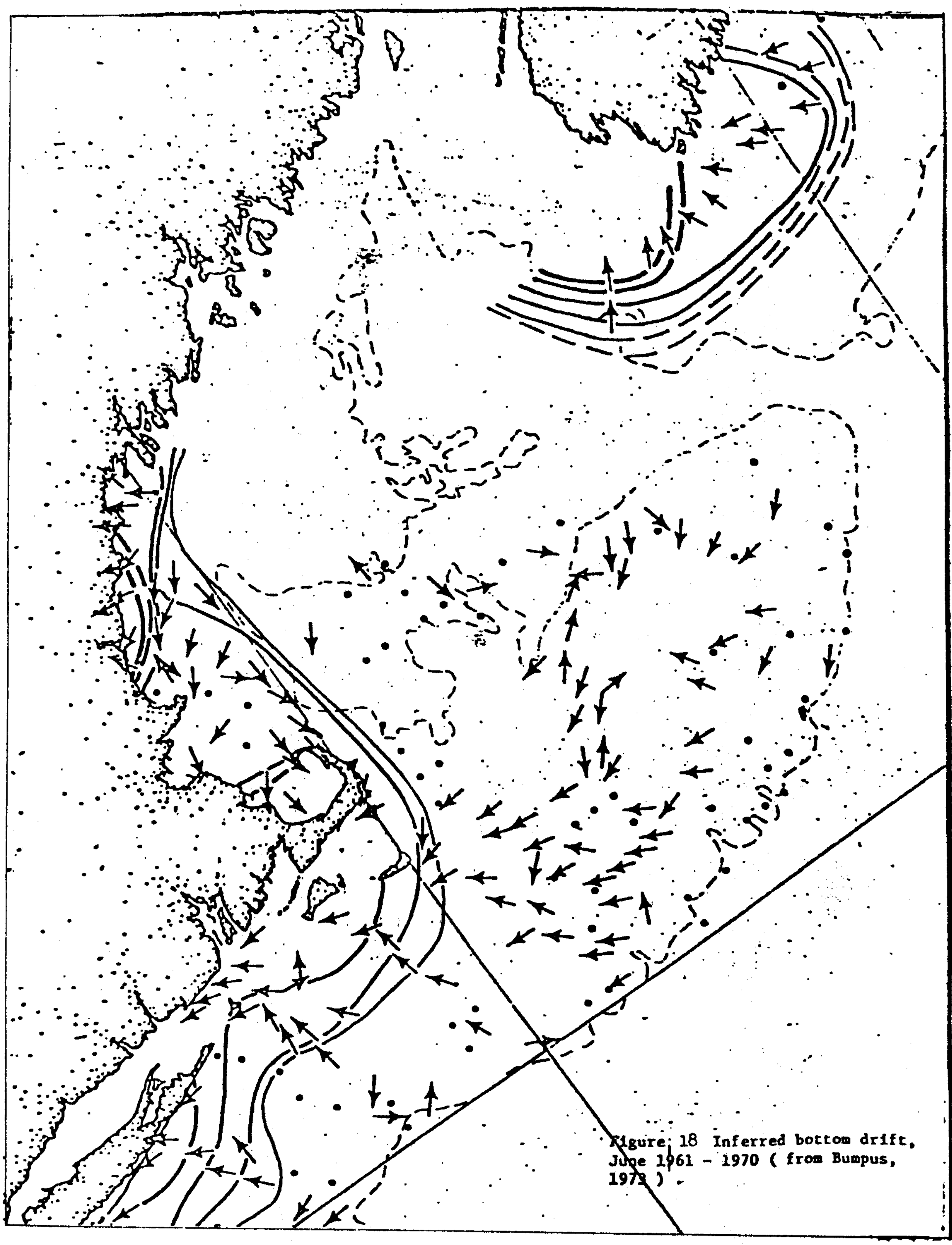

Figure 18 Inferred bottom drift, June 1961 - 1970 (from Bumpus, 1973)

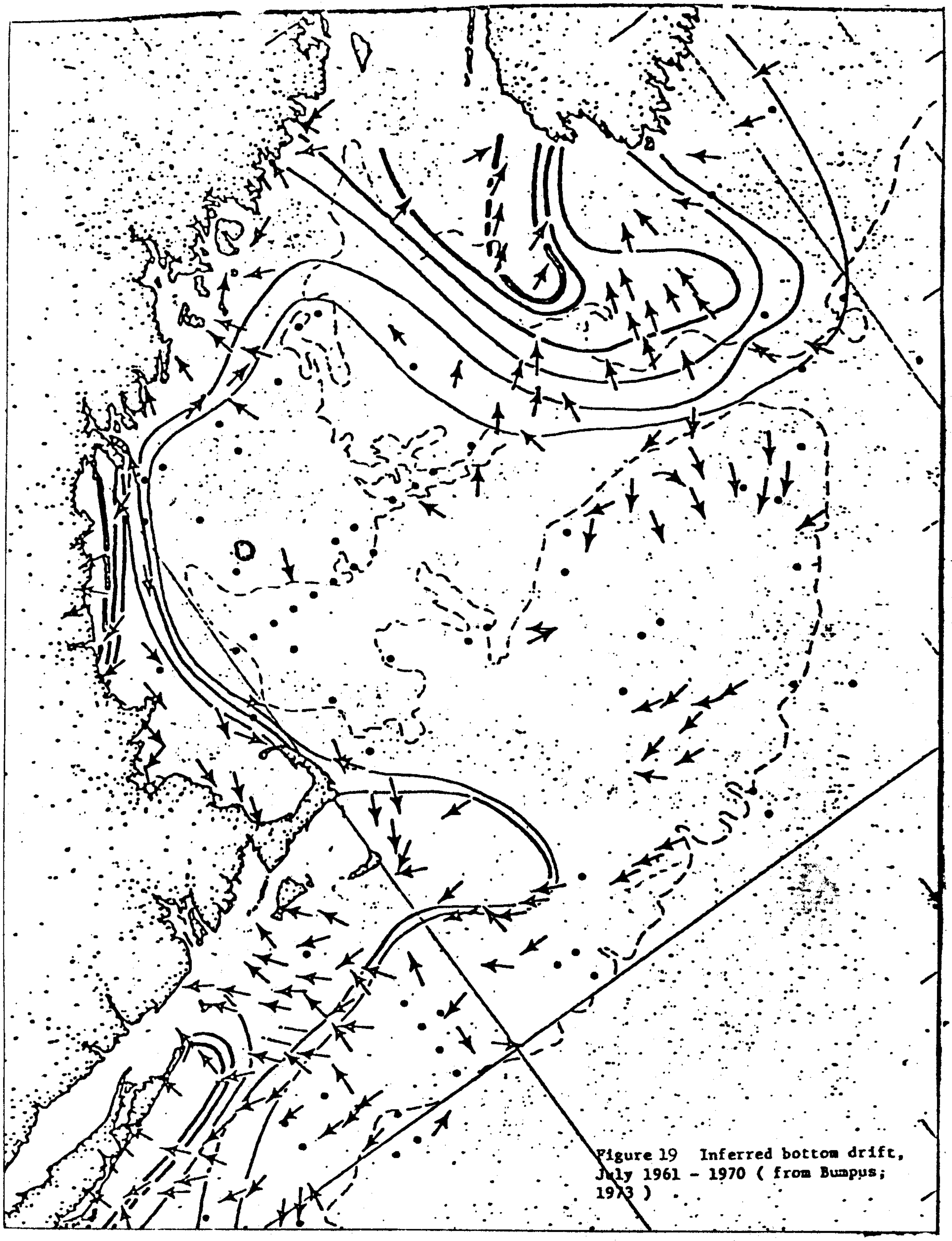

Figure 19 Inferred bottom drift, July 1961 - 1970 (from Bumpus; 1973)

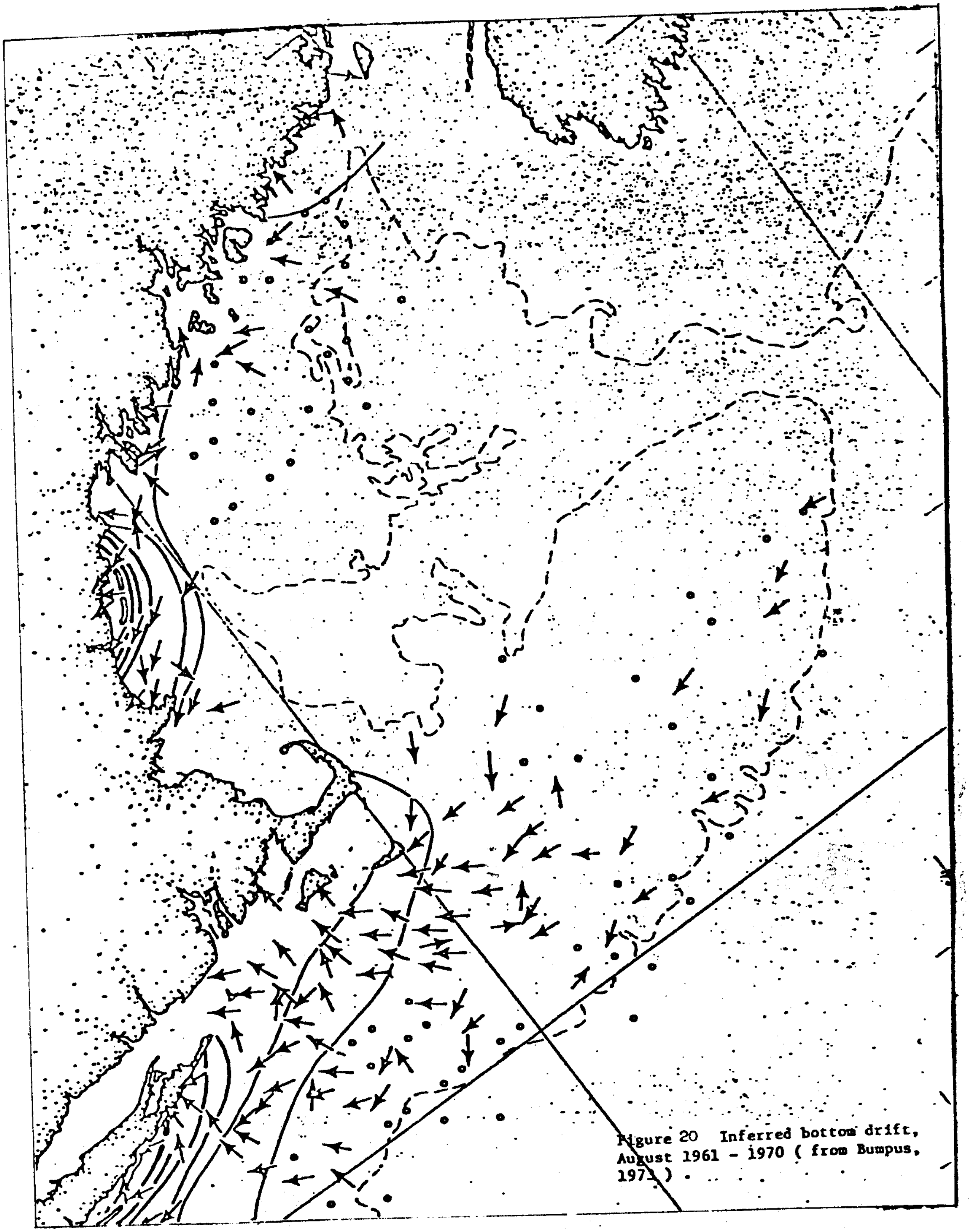

Figure 20 Inferred bottom drift, August 1961 - 1970 (from Bumpus, 1973)

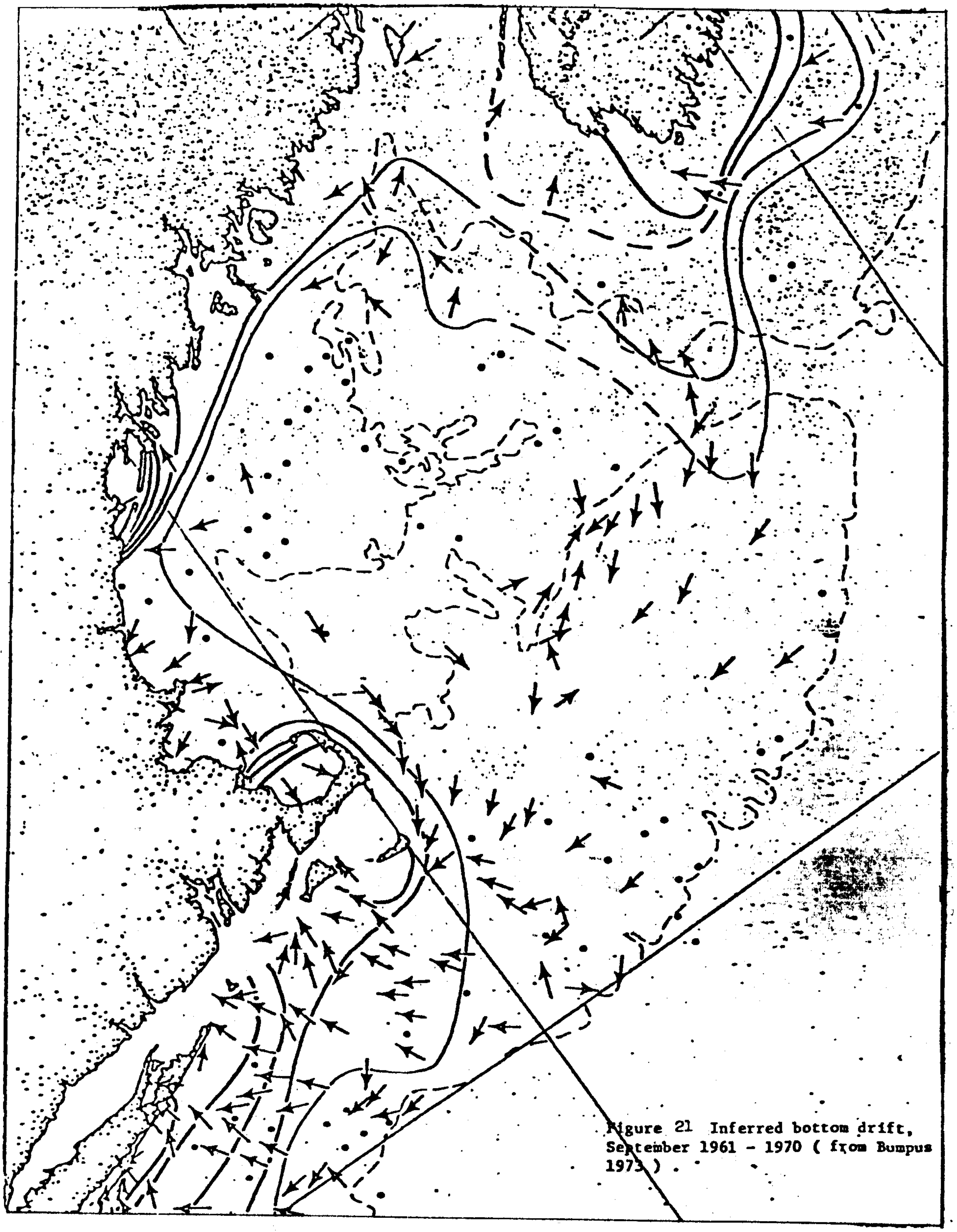

Figure 21 Inferred bottom drift, September 1961 - 1970 (from Bumpus 1973) .

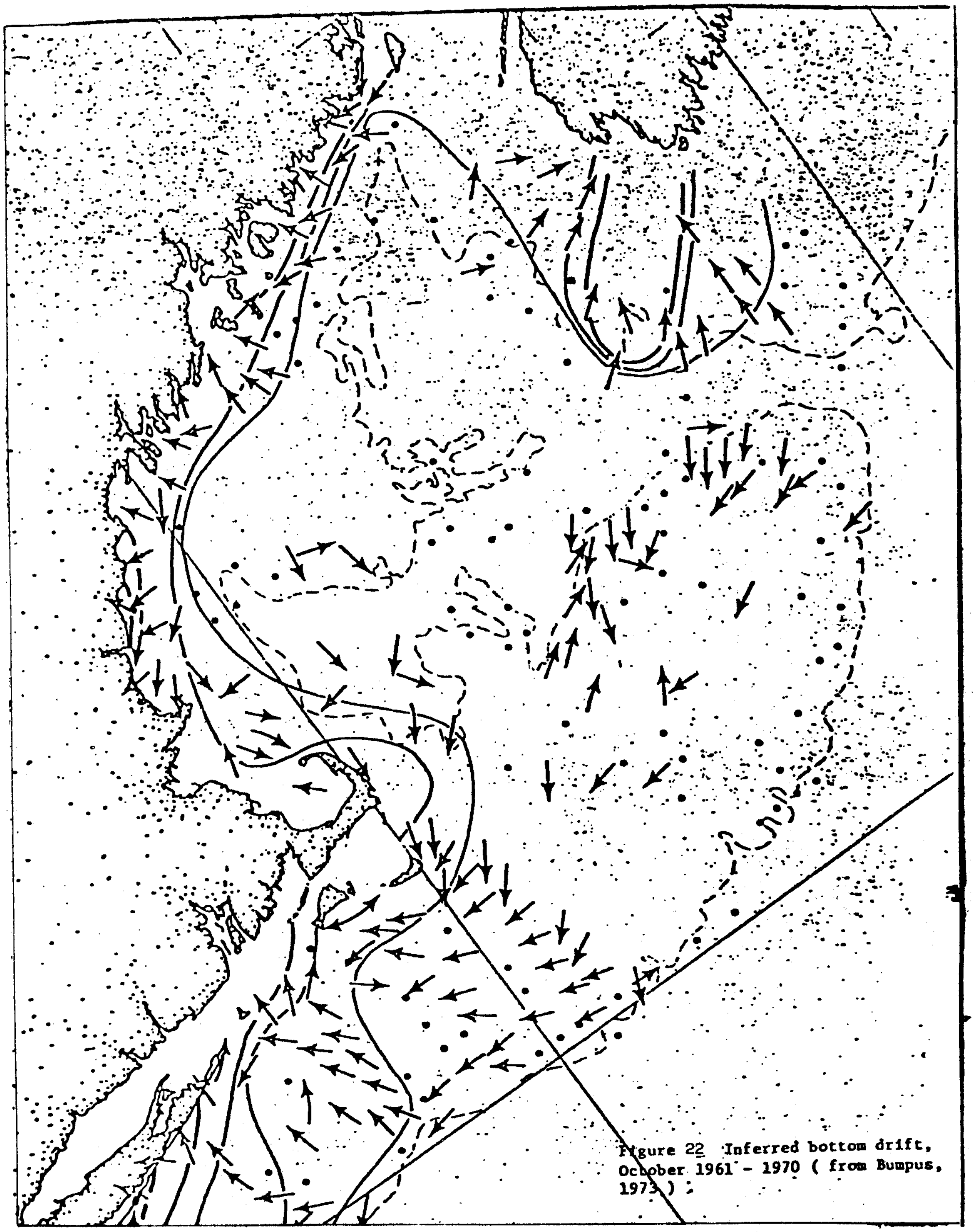

Figure 22 Inferred bottom drift, October 1961 - 1970 (from Bumpus, 1973).

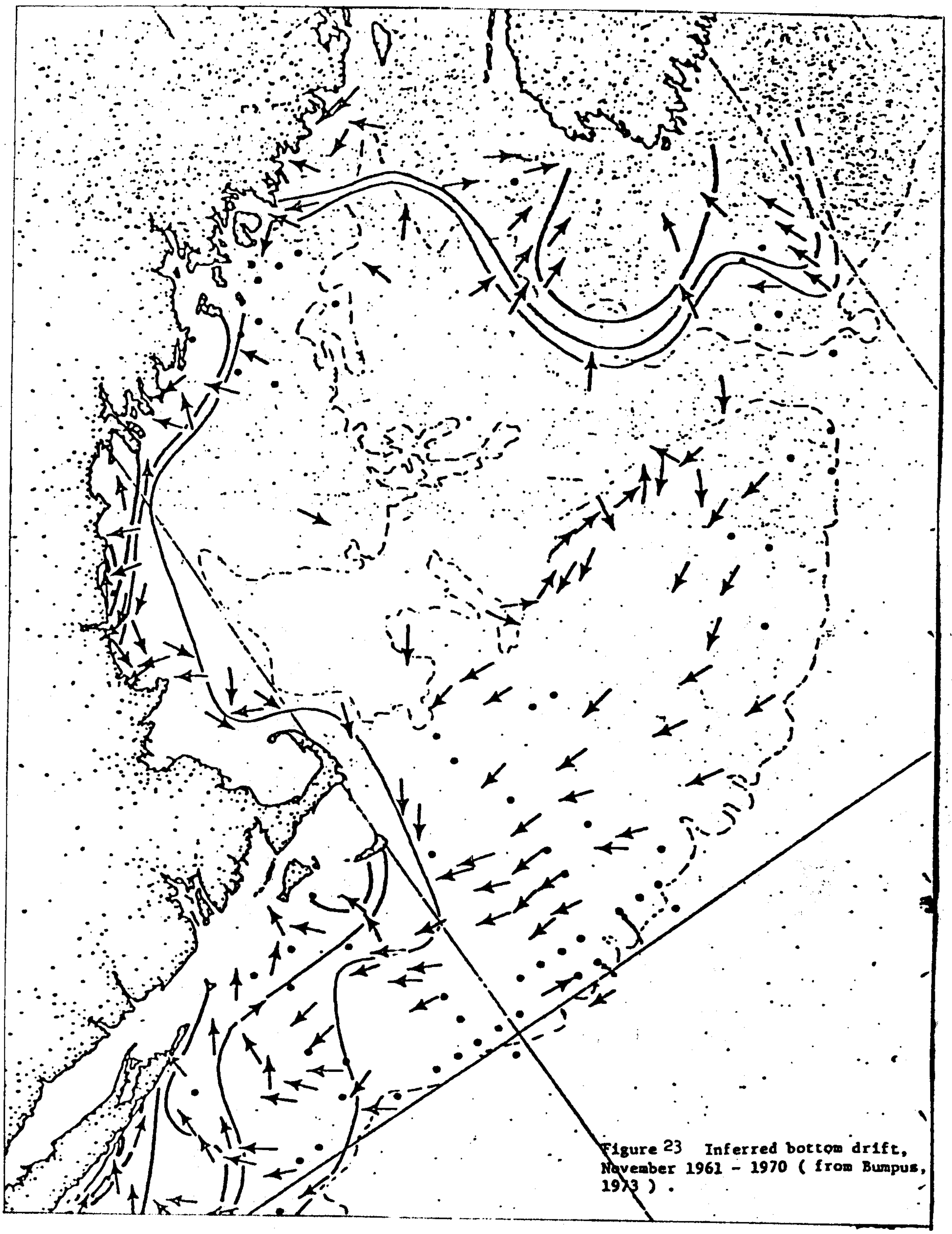

Figure 23 Inferred bottom drift, November 1961 - 1970 (from Bumpus, 1973) .

Figure 24 Inferred bottom drift, December 1961 - 1970 (from Bumpus, 1973) .

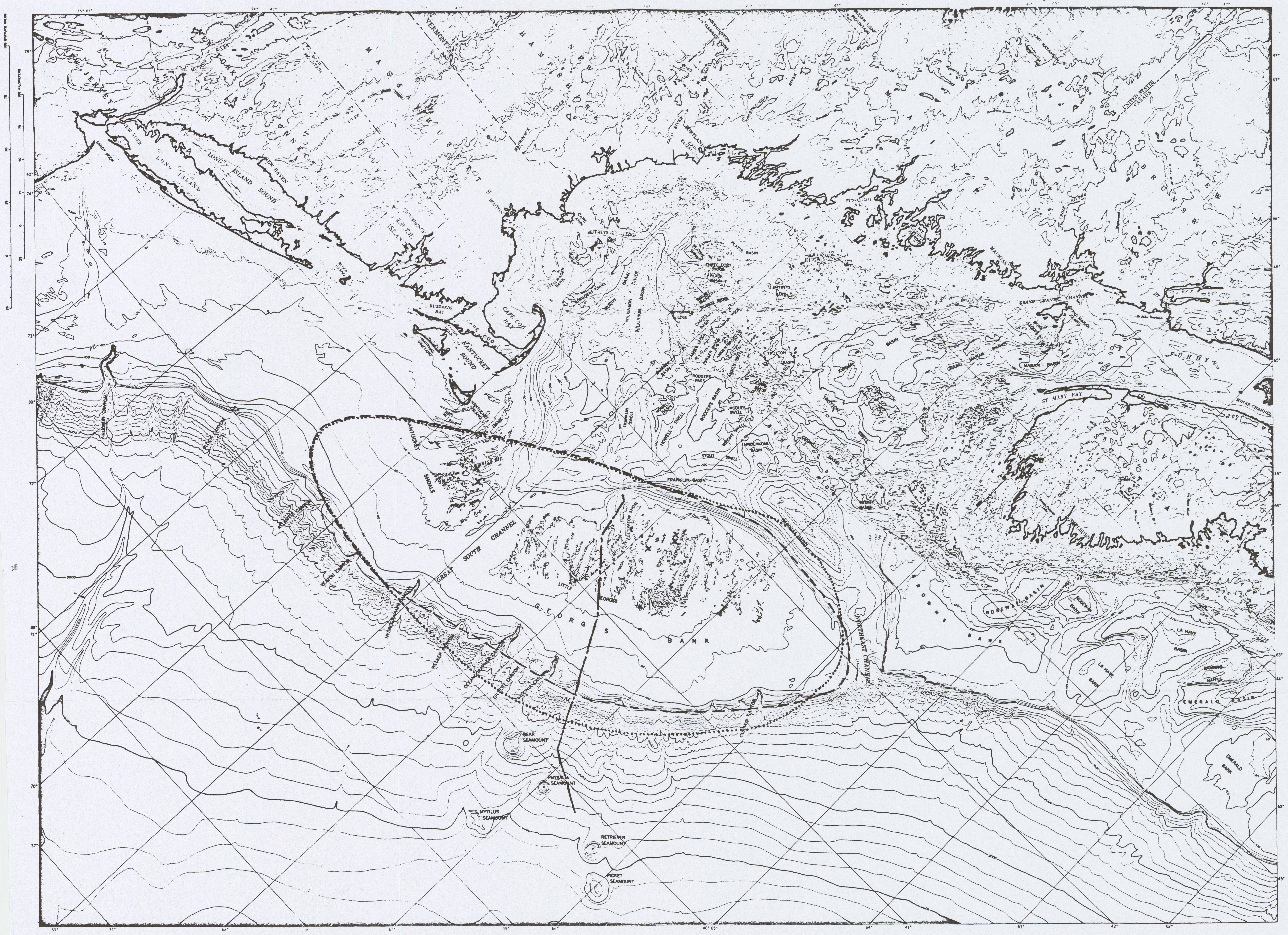

Plate 1.--Map showing bottom topography of the Continental Margin of Georges Bank and adjacent areas. The area designated for possible oil and gas lease sale is outlined by a dashed line. The general outline of Georges Bank basin is shown by a dotted line. Crosses mark locations of the Texas Tower drilling sites. Location of USGS CDP seismic reflection profile is shown by a dash-dot line.

EXPLANATION

Classification modified from Shepard (1954). Gravel is material coarser than 2mm; sand, 0.062 to 2 mm; silt, 0.004 to 0.062 mm; clay, finer than 0.004 mm

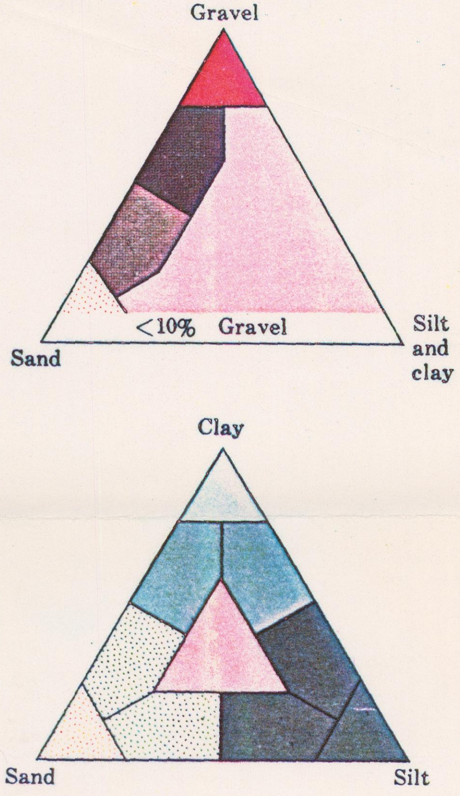

Plate 2.--Map showing sediment type on the continental margin off the northeastern United States from (Schlee, 1973).

EXPLANATION

SECTION 17S TAKEN FROM HERSEY, GSA BULLETIN 70, APRIL, 1959
SECTION 15 TO A MODIFIED FROM MATTICK, USGS OPEN FILE REPORT, 1973

Plate 3. -- Diagrammatic cross section along United States Atlantic Outer Continental Shelf from east Scotian Shelf showing structural framework of the shelf area. Line of section is roughly parallel to the coast line and located at about the center of the Continental Shelf

Plate 4.-- Part of a common depth point (CDP) profile recorded on Georges Bank by USGS in 1973. Record has been processed 12 fold (1200%). Horizon I was mapped on an unconformity thought to be of mid-Tertiary age; horizon II represents a reflector thought to be near the Upper Cretaceous-Lower Cretaceous boundary; horizon III represents the top of Jurassic carbonates; horizon IV represents an unknown Jurassic or Triassic(?) reflector; and horizon V corresponds to acoustic basement--probably crystalline rocks similar to those underlying the Coastal Plain. Note highly block faulted basement surface.