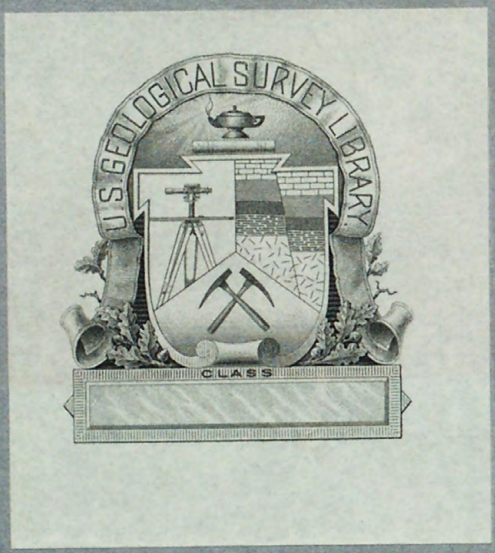
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Bottom sediments on the Continental Shelf of the Northeastern United States: Cape Cod to Cape Ann, Massachusetts

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BOTTOM SEDIMENTS ON THE CONTINENTAL SHELF OF THE NORTHEASTERN UNITED STATES: CAPE COD TO CAPE ANN, MASSACHUSETTS

John Schlee, David W. Folger and Charles J. O'Hara

INTRODUCTION

These reconnaissance maps have been constructed to show the areal distribution of major types of bottom sediment and some of their constituents on the sea floor off Massachusetts between Cape Ann and Cape Cod (41°45'N and 42°50'N and west of 70°-00W). They are intended to serve as a guide to future detailed mapping of gravel, sand, silt clay, and organic carbon. Because sediment texture is in part a reflection of long-term hydrologic conditions, the maps will also help to infer the important sediment transport mechanisms in the area and thus they should be useful in problems relating to disposal of solid and liquid waste offshore.

Unpublished analyses of bottom sediment samples collected during 4 different studies were used to compile the maps. The studies included the current joint investigation of the continental margin of the eastern United States by the Geological Survey and the Woods Hole Oceanographic Institution (WHOI) (218 samples), the Systematics Ecology Program (SEP) of the Marine Biological Laboratory of Woods Hole, Massachusetts (92 samples), the U.S. Army Corps of Engineers Sand Inventory program (92 samples) and the Boston harbor study (110 samples) made at the Massachusetts Institute of Technology by Mencher and others (1968).

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Samples from Cape Cod Bay were collected on a geometric grid with an average spacing of about 3 km. Those to the north and offshore were collected in some areas on the basis of a predetermined grid and in others on the basis of sediment variations that were observed with an acoustic profiler. The net result is an average sample spacing of about 5-6 kilometers. Nearshore sample spacing is variable; the minimum is about 1 km in some areas.

Methods used to analyze the sediment grain size distribution[1/] were as follows: offshore and Cape Cod Bay (USGS-WHOI and SEP)-pipette and Rapid Sediment Analyzer (Schlee, 1966); Boston Harbor (Mencher et al, 1968)-sieve and hydrometer; nearshore (U.S. Army Corps of Engineers)-visual estimate. Of the two components analyzed carbonate was measured by Hulseman's (1967) method and organic carbon according to the method outlined in the Laboratory Equipment Manual (1969). Data have been presented on Coast and Geodetic Survey Chart 0808N-50, Cape Cod to Cape Ann, on which bathymetry is contoured at a 5 meter interval.

1/ Grain size classes follow Wentworth (1922) as follows: gravel > 2mm; sand 2.00-.062 mm; silt .062-.004 mm; clay <.004 mm

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BATHYMETRY

Two broad ridges dominate the sea floor topography in the map area. Stellwagen Bank extends 40 km to the northwest, from Cape Cod toward Cape Ann at depths less than 50 meters; Jeffrey's Ledge extends northeast from Cape Ann at depths of 60 m or less. A smaller, complexly dissected bank (Tillies Bank), oriented approximately north-south, lies between the other two ridges. It rises to within 60 meters of the surface, and is surrounded by a moat with a maximum depth of almost 200 meters. A sub-parallel ridge to the east of Tillies Bank rises abruptly to about 65 meters below the surface. Relatively smooth, gently sloping bottom occupies most of the area shoreward (west) of the Bank-Ledge system, but east of it, bathymetry is more complex and gradients are steeper.

Stellwagen Basin is bordered by the Massachusetts coast on the south and west and by Cape Cod and Stellwagen Bank on the east and northeast. It is elliptical in outline and is oriented with a long axis that trends northwest-southeast. Most of the southwest side slopes gently toward the deep axis of the basin at gradients of about 0.1 to 0.5 percent. The northeast side however, dips steeply toward the axis at gradients up to 6 percent. Only in Cape Cod Bay is the nearshore topography smooth. Adjacent to the coast from Plymouth to Boston the bottom is hummocky and rough for distances up to 15 km from shore. The southern part of Scantum Basin north of Cape Ann has a configuration similar to Stellwagen Basin with gentle gradients on the landward side and steeper gradients on the seaward side.

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East of the Bank-Ledge system the bottom dips irregularly seaward and attains a maximum depth in the map area of about 220 meters due east of Boston. The deepest areas are channels leading to the deeper waters of Murray Basin to the east.

In summary, Jeffreys Ledge, Tillies Bank and Stellwagen Bank partially isolate 3 basins from the outer shelf. From north to south these are Scantum Basin, Tillies Basin, and Stellwagen Basin.

SEDIMENT DISTRIBUTION

The map of sediment type is based on a modified version (Schlee, in press) of Shepard's (1954) sediment classification. Each sample was located on two ternary diagrams on the basis of its gravel, sand, silt and clay content. It was then plotted on the map as one of 11 sediment types defined by the ternary diagrams. Several inshore areas are shown as bedrock because the bathymetry is similar to areas where rocky ledges project above sea level as islands and because we were unable to obtain grab samples of sediment there despite repeated attempts.

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Echo sounding (12 khz and 3.5 khz) was used as an aid to locate sediment boundaries over much of the area. This acoustic information plus bathymetry has been used to supplement the textural data to determine approximate boundaries between various sediment types. Sediment texture has been inferred in several banks, basins, and valleys where we collected no samples. This inference has been made because our experience in collecting samples from similar features elsewhere in the area has shown the close relation of sediment texture to different types of physiographic features. Also, in contouring the percentages of gravel, sand, silt and clay, some intermediate contours have been deleted because we lack intermediate values to show their placement.

Clayey silt covers most of the bottom of Stellwagen Basin and Cape Cod Bay. Both areas also have small hillocks of coarser till-like sediment associated with them which could act as local sources of detritus along with the contiguous banks and coastal shelf.

The finest grained sediment is in the Murray-Wilkinson basin area well offshore and to a lesser extent in Scantum Basin (silty clay). The amount of silt and coarser detritus added from Jeffreys Ledge appears to be minor because a gradation toward finer grain size is lacking from this deep water bank toward Scantum Basin; instead the gradation is evident shoreward. Curiously, grain size does decrease to the east of Jeffreys Ledge toward Murray Basin where sand, clay-silt-sand, and clayey silt mark the transition to the basin.

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Shallow banks and ledges are veneered by sand and by mixtures of gravel and sand; Jeffreys' Ledge is mainly gravel or gravelly sand flanked by a sandy apron to the southeast. Stellwagen Bank is mainly sand or pebbly sand flanked to the east by gravel or gravelly sand. A broad area between 60 and 100 m deep between Jeffreys Ledge and Stellwagen Bank and east of Tillies Bank is also covered by sand mixed with some gravel. The sand cover from Stellwagen Bank extends southward into the current-swept channel between the Bank and tip of Cape Cod; from this channel, a cover of silty, clayey sand extends westward and northward into the southern end of Stellwagen Basin.

Sand is the predominant sediment type for the inner shelf off Cape Cod, where it is probably derived from the reworked sandy deposits of Cape Cod. This gives way in deeper water to silty clayey sand, and sand-silt-clay bordering the clayey silt in the center of the basin. The inner shelf north of Plymouth shows a more complex topography that is due in part to outcrops of bedrock on the sea floor. The change in topography also reflects a change of sediment type; gravel is more evident and the bordering area of sand becomes thinner and more discontinuous.

The map shows that broad bathymetric features such as basins and banks relate to sediment type; smaller topographic features such as hillocks, knobs, and swales in the rugged areas bordering coast line have little relation to the sediment type. Here the variety of sediment types is large and lateral changes from one type to another are rapid.

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The map also illustrates that basin sediment type is affected by a close source of coarse-grained sediment. Tillies Basin, for example, is a small narrow depression surrounded by shallow banks and ledges covered by coarse-grained sediment. The probable ease with which the coarse debris can be moved into the adjacent basin appears to be reflected by the presence of sand in the sediments flooring the basin. Nearby coarse grained glacial(?) deposits also may be a source of coarse sediment in Stellwagen Basin and Cape Cod Bay.

Sand and Gravel

The highest concentrations of gravel are on Jeffreys Ledge, the inshore shelf between Hull and Plymouth, and east of Stellwagen Bank. Gravel forms a minor association with sand on Stellwagen Bank and with till-like deposits in places like Fishing Ledge in Cape Cod Bay. On the floors of most of the basins, gravel is absent because it has been covered by silt and clay (Schlee, in press).

Most probably, the gravel was transported to the area by glaciers. It is associated with many sediment types and occurs in different current regimes. Some pebbles are striated. It forms a lag veneer with sand, and marks a late stage of ice deposition; hence we may have a crude guide for detecting the waning stages of ice retreat in the offshore area. If so, Stellwagen Bank and Jeffreys Ledge which are covered by some such coarse detritus, may mark offshore moraines and outwash, later reworked during the post-glacial rise in sea level.

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Sand is most abundant on the inshore shelf, on shallow banks, and in the area of deep water east of Tillies Bank. It forms an irregular belt of deposits stretching southward from Jeffreys Ledge to Cape Cod. It floors deep as well as shallow areas, but is particularly abundant around the periphery of Cape Cod Bay and along parts of the coastal shelf bordering eastern Massachusetts.

Sand distribution is a guide to current activity. Currents are particularly strong on Stellwagen Bank and in the channel between the Bank and the tip of Cape Cod. The inner shelf is also an area of strong coastal currents and wave action, and if sand is available as on Cape Cod, the contiguous Bay sediments will contain abundant sand. Areas of sand also occur next to banks composed in part of glacial deposits, such as Jeffreys Ledge. Current-deposited sand apparently smooths the bottom of the inner shelf north of Cape Ann, where bathymetric contours are widely spaced.

Silt and clay

Silt and clay are the dominant fractions of sediment in offshore basins and in sheltered bays and estuaries. Relatively weak currents allow deposition of the fine detritus, though the process is one interrupted by periodic resuspension (Spencer and Sachs, 1970).

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Silt is a major constituent of sediments in the inshore basins where glacial debris is close by and where the basins are not far from the coast. Clay apparently is more abundant in basins well offshore, and in some nearshore basins where perhaps the currents are so weak that the detritus has time to settle out. Silt and clay apparently are covering older glacial(?) deposits in the basins (Schlee and Pratt, 1970, fig. 3; Tucholke and others, 1970) at a rate of approximately 40 cm/1000 years.*

* A piston core collected in July 1969 from Tillies Basin (Lat. 42°32.1' N, Long. 70°22.2'W in 75 fms) gave a radiocarbon date of 6130 ± 130 years BP on sediment obtained from the 230-240 cm interval below the sea floor.

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Organic Carbon

About 90 of the samples collected between Cape Ann and Cape Cod were analyzed for organic carbon. Concentrations of 0.5, 1.0, and 2.0 percent were contoured on the map. Bathymetry and variations in sediment type were used to aid the positioning of contours between control points. Where data are sparse and bathymetry complex, the map is doubtless oversimplified.

Concentrations of organic carbon ranged from zero in coarse textured material (sand and gravel) to about 2.5 percent in finest grained offshore sediment. Low values, generally less than 0.5 percent, characterize the nearshore region, banks, and ridges; values greater than 0.5 percent are located mostly in the basins. Highest concentrations (not shown) are in Boston harbor where Mencher and others (1968) found in excess of 15% organic carbon in the sediment.

Samples containing more than 2 percent organic carbon were found only in the northern part of Stellwagen Basin and in the southern part of Scantum Basin. Near the mouth of Cape Cod Bay and in Tillies Basin concentrations are mostly between 1 and 2 percent. Along the westernmost part of the map area concentrations increase to almost 1 percent in deeper water.

The magnitude and distribution of organic carbon are similar to values that have been measured in nearby areas such as Buzzards Bay and Narragansett Bay. Most of it is probably derived from indigenous organisms.

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Calcium Carbonate

Concentrations of calcium carbonate are so low in the bottom sediments of the area that a map of their areal variation is not included in this report; values do not exceed 5 percent in any of the samples that were analyzed and generally are less than 1 percent. Most of the calcium carbonate appears to be derived from shell detritus. Highest values (4-5 percent) occur sporadically along the western flank of Stellwagen Bank; and only there, on the northwestern flank of Jeffrey's Ledge and to the east of the bank ridges are concentrations greater than 1 percent, and then only rarely. Throughout most of the area, calcium carbonate constitutes less than 0.5 percent of the sediment.

CURRENT DISTRIBUTION

Past and present studies of the Gulf of Maine have delineated major water flow patterns (Bigelow, 1927), (Bumpus and Lauzier, 1965), (Haight, 1942), Halpern (1969, Unpubl. Ph.D. Diss., Mass. Inst. Technology), and Graham (1970). East of Stellwagen Bank, the net surface currents move to the southeast at 1.8-9.3 km/day (2-10 cm/sec); west of the Bank, surface current flow is southerly in western Cape Cod and Massachusetts Bay and northerly in eastern Cape Cod Bay.

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Some indications of bottom drift have been obtained from about 1000 bottom drifters of the type described by Bumpus and Lauzier (1965) that were released in the Gulf of Maine during 1970-71. Tracks of 45 that have been recovered thus far are consistent with tracks of those few that have been released previously in the Gulf of Maine. Residual bottom water flow over Stellwagen Bank is southeasterly. Many drifters released near the Bank crest were recovered on the eastern side of Cape Cod as far south as Nantucket Sound. Bottom flow in much of the area west of Stellwagen Bank is most often southerly into Cape Cod Bay. Drifters released within about 15 km of shore commonly were recovered on the beach nearest to their release point; this pattern suggests that any material dumped on the bottom that is capable of being moved by existing bottom flow may eventually reach the beaches of the area.

Tidal flow dominates the daily water movement -- particularly for nearshore stations, according to measurements carried out as a part of this study; detailed results will be published later. Measurements from the Boston Lightship (10 km east of the entrance to Boston Harbor) by Haight (1942) show current flow dominantly toward Boston Harbor before high water and to the east away from the harbor after high water; similar results were noted near Nantasket Roads at the entrance to Boston Harbor. Even on Stellwagen Bank, currents move mostly east and west at maximum velocities of 10-45 cm/sec.

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The wide range of bottom current velocities show some relation to the bottom sediment type and to the sea floor bathymetry. Bottom velocities measured on Stellwagen Bank (maximum 45 cm/sec) are adequate to move coarse sand according to Hjülstrom's curve (1939); similar maximum velocities were noted in the broad sandy covered channel that separates Stellwagen Bank from the tip of Cape Cod. Within Stellwagen Basin and in the passage southeast of Cape Ann, maximum bottom current velocities seldom exceeded 18 cm/sec. These spot checks of bottom velocity indicate that any fine material on bank tops probably is winnowed, and redeposited in the adjacent basins.

SUMMARY

The distribution of sediment on the sea floor between Cape Ann and Cape Cod is related to bathymetry, currents, and source areas. Nearshore and on banks where current flow is greatest, gravel and sand predominate. Much fine detritus apparently is swept from the shallow areas into the basins where current flow is weaker. There, silt and clay are most abundant although sand is common near elevated features. These recent sediments appear to be burying the lag deposits that are relict from the last glaciation.

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Bottom currents are mainly tidal and flow over banks at maximum velocities capable of transporting coarse sand (45 cm/sec). Residual bottom current flow is generally southward except nearshore where shoreward motion predominates. The basins are typified by relatively sluggish bottom water velocities of only a few centimeters per second.

Organic carbon is most concentrated (2-3 percent) in the fine basin sediments and is sparse (<0.5 percent) in sands on banks and basin flanks. Calcium carbonate, present mostly as patches of shell detritus, is sparse (all <5%, and mostly <0.5%) throughout the area.

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867-100

REFERENCES

Bigelow, H.B., 1927, Physical oceanography of the Gulf of Maine: Bull. U.S. Bureau of Fisheries, v. 40, p. 511-1027.

Bumpus, D.F., and Lauzier, L.M., 1965, Surface circulation on the continental shelf off eastern North America between Newfoundland and Florida: Am. Geogr. Soc. Serial Atlas of the Marine Environment Folio 7.

Graham, J.J., 1970, Coastal currents of the western Gulf of Maine: Internatl. Comm. Northwest Atlantic Fisheries Research Bull. 7, p. 19-31.

Haight, F.J., 1942, Coastal currents along the Atlantic coast of the United States: U.S. Coast and Geod. Survey Spec. Pub. 230, 73 p.

Hjülstrom, Filip, 1939, Transporation of detritus by moving water, in Trask, P.D., Recent marine sediments: Tulsa, Okla., Am. Assoc. Petroleum Geologists, p. 5-31.

Hulsemann, Jobst, 1967, The continental margin off the Atlantic coast of the United States: Carbonate in sediments, Nova Scotia to Hudson Canyon: Sedimentology, v. 8, p. 121-145.

Laboratory Equipment Corporation, 1959, Instruction manual for operation of LECO carbon analyser: Laboratory Equipment Corp., St. Joseph, Michigan, 20 p.

Mencher, Ely, Copland, R.A., and Payson, H., 1968, Surficial sediments of Boston Harbor, Massachusetts: Jour. Sed. Petrology, v. 38, p. 79-86.

U. S. GOVERNMENT PRINTING OFFICE : 1959 O - 511171

Schlee, John, 1966, A modified Woods Hole rapid sediment analyser: Jour. Sed. Petrology, v. 36, p. 403-413.

Schlee, John and Pratt, R.M., 1970, Atlantic Continental Shelf and Slope of the United States: Gravels of the Northeastern Part: U.S. Geol. Survey Prof. Paper 529-H, 39 p.

Schlee, John, in press, Atlantic Continental Shelf and Slope of the United States: Sediment texture of the northeastern part: U.S. Geol. Survey Prof. Paper 529-L.

Shepard, F.P., 1954, Nomenclature based on sand-silt-clay ratios: Jour. Sed. Petrology, v. 24, p. 151-158.

Spencer, D.W., and Sachs, P.L., 1970, Some aspects of the distribution, chemistry, and mineralogy of suspended matter in the Gulf of Maine: Marine Geology, v. 9, p. 117-136.

Tucholke, B.E., Oldale, R.N., and Hollister, C.D., 1970, Acoustical survey of Massachusetts and Cape Cod Bays, western Gulf of Maine: U.S. Geol. Survey Open File Report, 14 p.

Wentworth, C.K., 1922, A scale of grade and class terms for clastic sediments: Jour. Geol., v. 30, p. 377-392.

U. S. GOVERNMENT PRINTING OFFICE : 1959 O - 511171
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