DEPARTMENT OF THE INTERIOR
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PREPARED IN COOPERATION WITH
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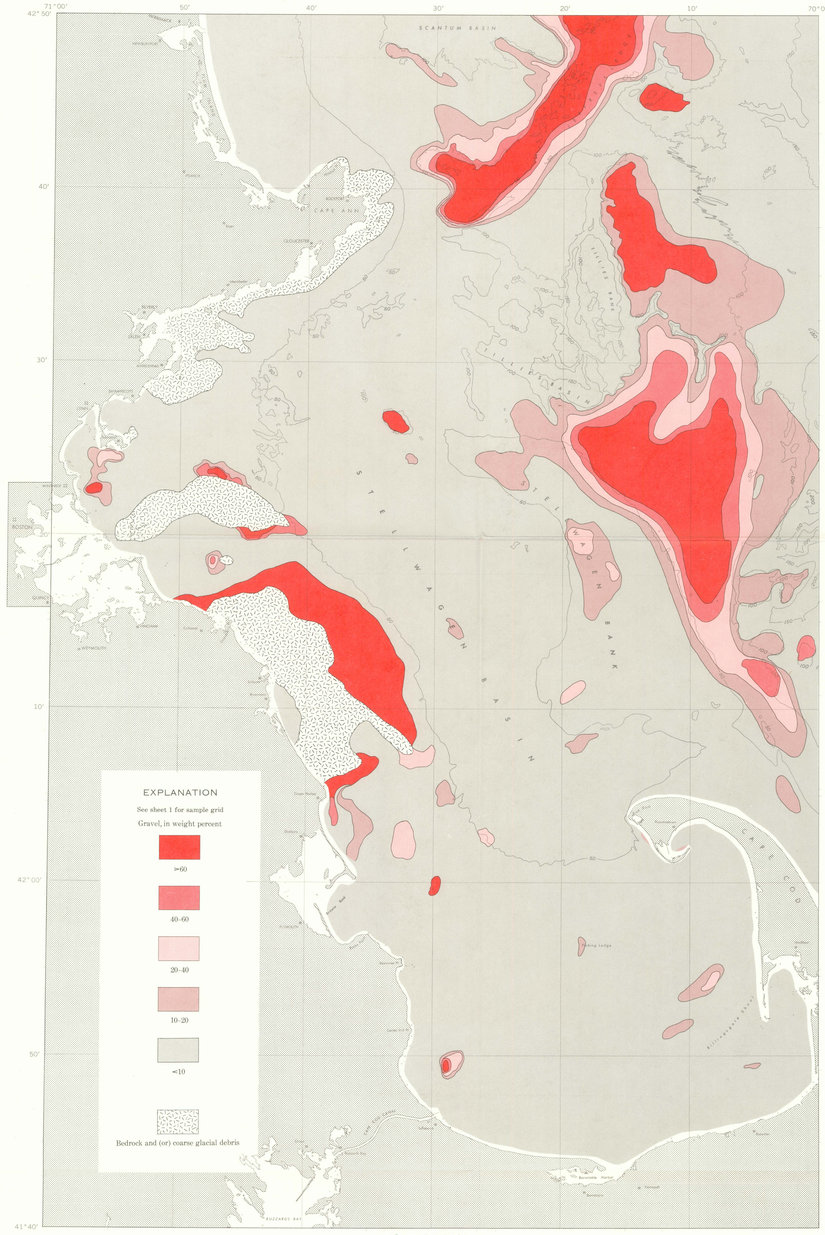
DEPARTMENT OF PUBLIC WORKS
AND
THE WOODS HOLE OCEANOGRAPHIC INSTITUTION

MISCELLANEOUS GEOLOGIC INVESTIGATIONS
MAP I-746 (SHEET 2 OF 2)



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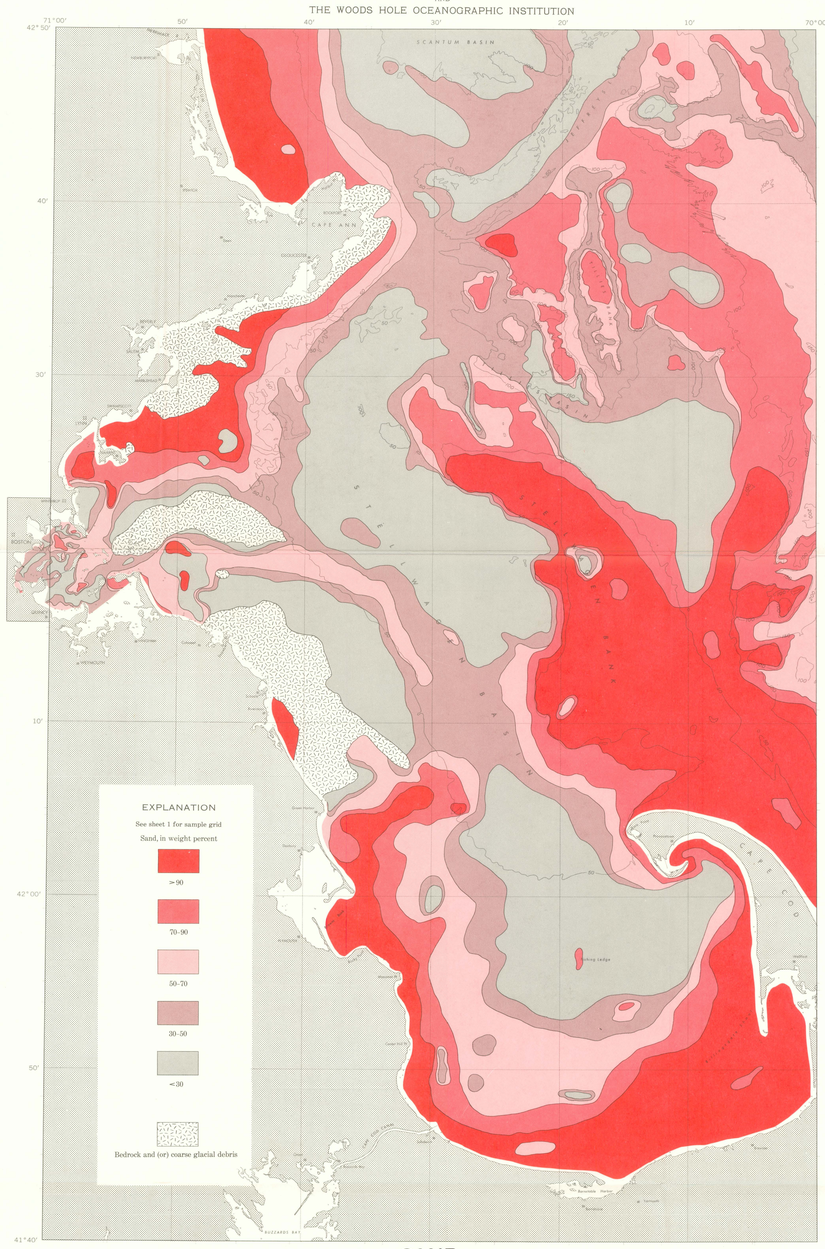

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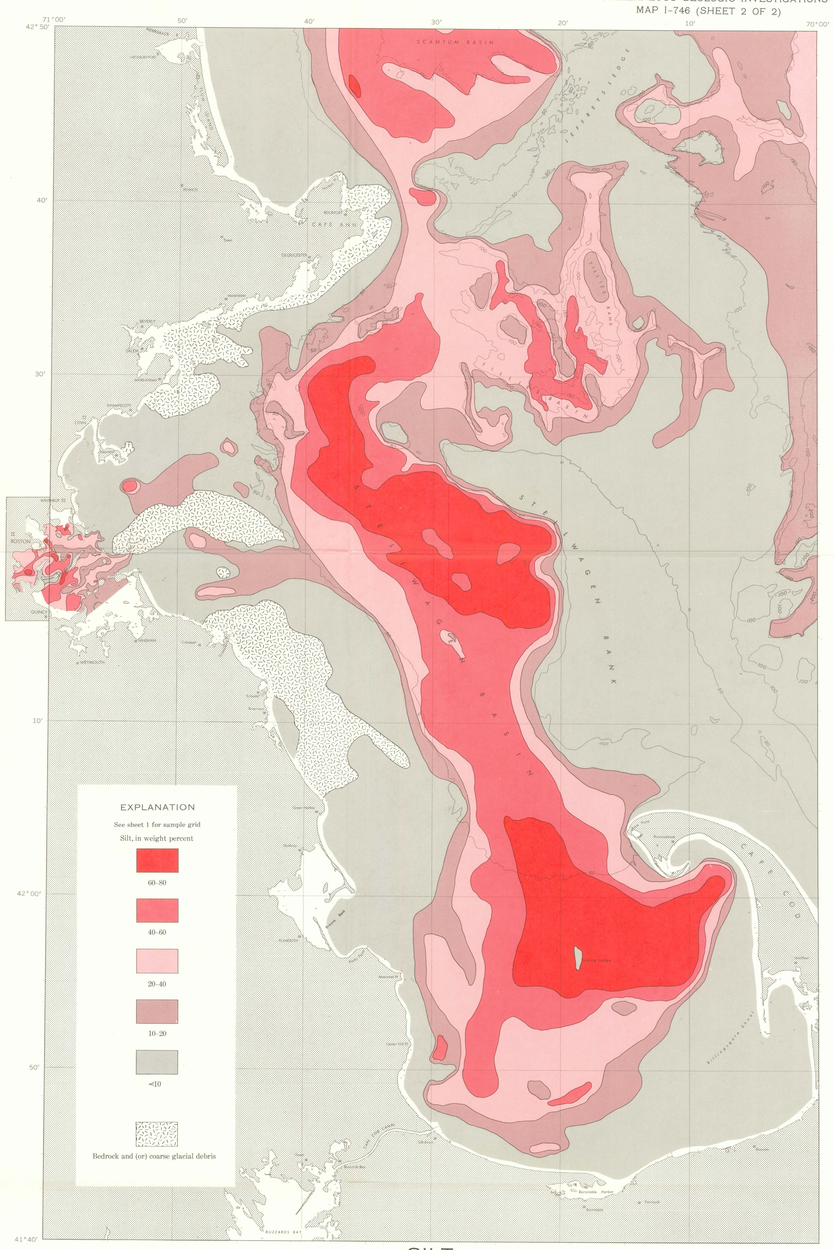

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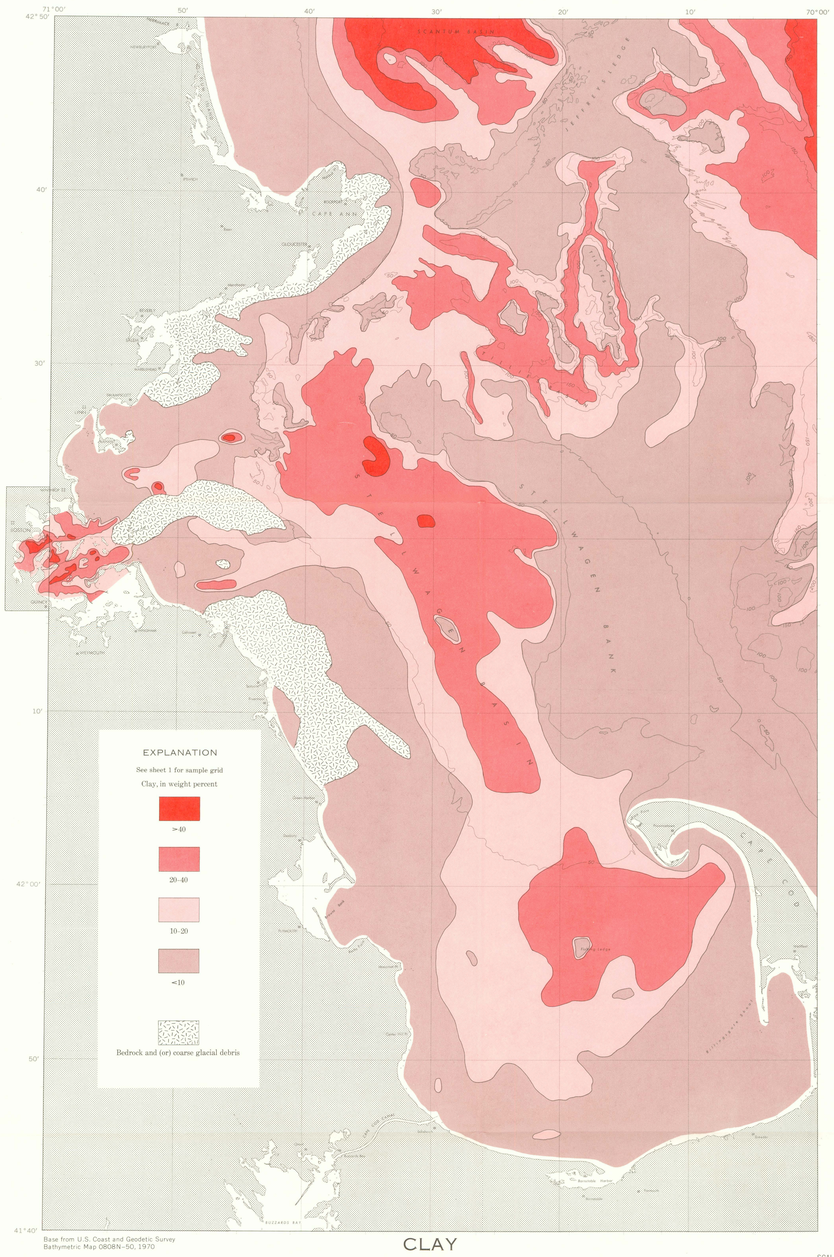

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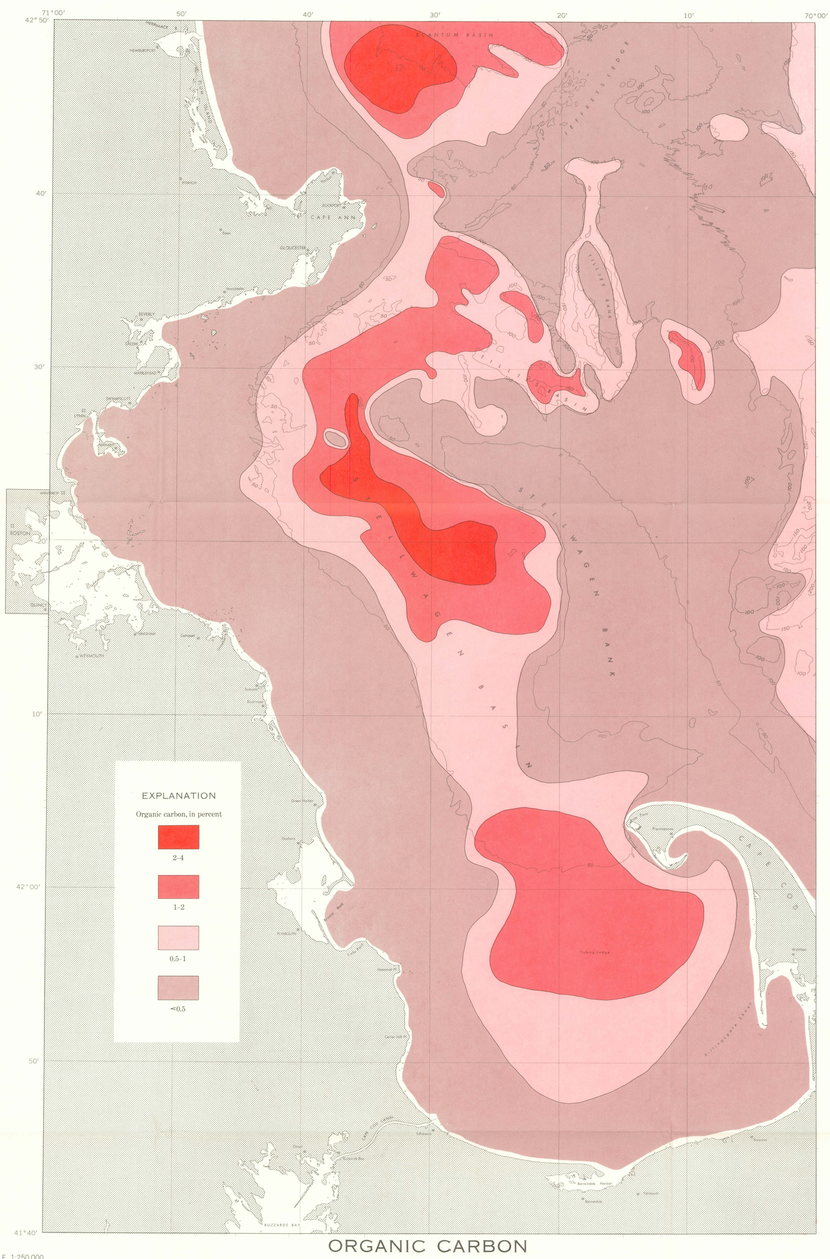

ORGANIC CARBON

Base from U.S. Coast and Geodetic Survey
Bathymetric Map 0808N–50, 1970

SCALE 1:250 000

BATHYMETRIC CONTOUR INTERVAL 50 METERS
DATUM IS MEAN LOW WATER

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

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

1973

INTRODUCTION[1]

These reconnaissance maps 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° W.). 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 be helpful in deducing 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 four 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 U.S. Geological Survey (USGS) 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, Copland, and Payson (1968).

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 km, Nearshore sample spacing is variable; the minimum is about 1 km in some areas.

Methods used to analyze the sediment grain size distribution (grain-size classes follow Wentworth (1922)—gravel > 2 mm; sand 2.00–0.062 mm; silt 0.062–0.004 mm; clay < 0.004 mm) were as follows: offshore and Cape Cod Bay (USGS-WHOI and SEP)—pipette and Rapid Sediment Analyzer (Schlee, 1966); Boston Harbor (Mencher and others, 1968)—sieve and hydrometer; nearshore samples from 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 instruction manual of the Laboratory Equipment Corporation (1959). Data have been presented on U.S. Coast and Geodetic Survey Bathymetric Map C. & G.S. 0808N–50, Cape Cod to Cape Ann, on which bathymetry is contoured at a 5 m interval.

ACKNOWLEDGEMENT

We are indebted to the staff at the Woods Hole Oceanographic Institution, and the Marine Biological Laboratory for their assistance and cooperation, and to the Department of Public Works of the Commonwealth of Massachusetts for partial support. In particular, R.L. Burroughs, J.R. Heirtzler, M.R. Carriker, R.H. Meade, J.D. Milliman, B.E. Tucholke, C.D. Hollister, Joseph McIlvaine, R.N. Oldale, Christopher Lambertsen, and L.G. Toner were most generous of their time and assistance. Students from Middlebury College (W. Aubrey, B. Beyer, D. Carrillo, P. Carroll, P. Cashman, S. Cashman, S. Calabi, L. Collister, S. Colwell, A. Gilbert, F. Gutowski, M. Higgins, K. Hindert, R. McGirr, V. Milkey, M. Nevell, C. Parmenter, G. Sedgwick, P. Smith, S. Webel) ran many of the textural and compositional analyses and plotted the data. To Captain H.H. Seibert and the crew of the R/V GOSNOLD, Peter Graham and Francis Doohan of the R/V A.E. VERRILL, and to Captain Landvik and the crew of the R/V DOLPHIN, we are indebted for their aid and assistance on the numerous cruises to the area during 1968 and 1971. Several persons generously provided data from their own studies, in particular, Dr. D.K. Young (University of South Florida), Dr. D.B. Duane (Coastal Engineering Research Center, Army Corps of Engineers), and Ely Mencher (City College of New York). The Cartographic Section of the U.S. Coast and Geodetic Survey kindly provided advanced copies of bathymetric map 0808N–50 prior to its publication.

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 m; Jeffreys 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 m of the surface, and is surrounded by a moat with a maximum depth of almost 200 m. A subparallel ridge to the east of Tillies Bank rises abruptly to about 65 m 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; its long axis trends northwest. 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 of as much as 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 of as much as 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.

East of the bank-ledge system the bottom dips irregularly seaward and attains a maximum depth in the map area of about 220 m 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 partly isolate three 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 terrary 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.

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.

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 to 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 the coastline 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.

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 Cohasset and Plymouth, and east of Stellwagen Bank. Minor amounts of gravel are associated 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 has been covered by silt and clay (Schlee, in press).

Most probably, the gravel material was transported to the area by glaciers. Gravel is associated with many sediment types and occurs in different current regimes, Some pebbles are striated. Gravel 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 coarse detritus, *may* mark offshore moraines and outwash, later reworked during the post-glacial rise in sea level.

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 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 interrupted by periodic resuspension (Spencer and Sachs, 1970).

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/1,000 years. (A piston core collected in July 1969 from Tillies Basin (lat 42°22.1' 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.)

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 mostly in the basins. Highest concentrations (not shown) are in Boston harbor where Mencher, Copeland, and Payson (1968) found in excess of 15 percent 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.

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 Jeffreys Ledge and 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; 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.

Some indications of bottom drift have been obtained from about 1,000 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 are being prepared. 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.

The 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 Hjulstrom'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 exceed 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.

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 near shore 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 percent, and mostly <0.5 percent) throughout the area.

REFERENCES CITED

Bigelow, H.B., 1927, Physical oceanography of the Gulf of Maine: U.S. Bur. Fisheries Bull., 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. Geog. Soc. Serial Atlas Marine Environment Folio 7.

Graham, J.J., 1970, Coastal currents of the western Gulf of Maine: Internat. 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.

Halpern, David, 1969, Observations of short period internal waves in Massachusetts Bay: Cambridge, Mass., Massachusetts Inst. Technology, unpub. Ph.D. thesis, 110 p.

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

Hülsemann, Johst, 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: St. Joseph, Mich., Laboratory Equipment Corp., 20 p.

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

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

———, 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.

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.

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. Geology, v. 30, p. 377–392.

[1] Contribution 2716 of the Woods Hole Oceanographic Institution.

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