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Acoustical survey of Massachusetts and Cape Cod Bays, western Gulf of Maine.

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U.S. Geological Survey

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5. Acoustical survey of Massachusetts and Cape Cod Bays, western Gulf of Maine, by Brian E. Tucholke, R. N. Oldale, and Charles D. Hollister. 14 p., 1 map and explanation, scale 1:250,000.

6. Interpretive profiles, western Gulf of Maine and southeastern Massachusetts offshore area: sedimentary framework, by R. N. Oldale, Elazar Uchupi, and K. E. Prada. 1 sheet.

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Acoustical survey of Massachusetts and Cape Cod Bays, western Gulf of Maine.

Brian E. Tucholke, R.N. Oldale and Charles D. Hollister

Abstract

The accompanying map shows the amount of acoustic penetration achieved in the sediments of the western Gulf of Maine using a 3.5 kHz echosounding system and illustrates the pronounced control of topography on sediment distribution. Little or no sub-bottom penetration was observed in areas of sand and gravel on the major banks and ledges. Sonic penetration in the silt- and clay-filled basins was to the acoustic basement and in excess of 40 m where the acoustic basement was beyond instrument range. Stratification and unconformities were observed locally in the penetrable sediments. The fine-grained penetrable sediments in the major basins and near the coastline are inferred to originate from two sources: 1) glaciomarine deposits of mostly rock flour deposited during the retreat of the ice from the western Gulf of Maine, and 2) silt and clay winnowed from the banks and ledges and redeposited in the topographic lows during the Holocene lowering and later rise in sea level. The local unconformities, contacts between stratified and non-stratified sediments, and a shallow sub-bottom reflector observed in Cape Cod Bay may have been formed during the Holocene emergence and submergence of the western Gulf of Maine. Changes in sedimentation rates appear to be related to deglaciation, late-glacial submergence, and Holocene sea level changes.

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Introduction

In 1969 the U.S. Geological Survey and the Woods Hole Oceanographic Institution began a detailed study of the western part of the Gulf of Maine as part of a program of geologic mapping offshore. The first area includes the offshore area between Lat. 41°40'N to 44°00'N and Long. 70°00'W to 71°00'W. The 3.5 kHz echosounding data obtained aboard the R/V GOSNOLD, R/V DOLPHIN and R/V VERRILL within this area are summarized in this report.

The authors wish to acknowledge the help of Elazar Uchupi, K.E. Prada, R.W. Ballard, Zvi Ben-Avraham, and Joseph MacIlvaine of the Woods Hole Oceanographic Institution, and J.S. Schlee, D.W. Folger and M.F. Kane of the U.S. Geological Survey in collecting the data. D.A. Ross, J.S. Schlee and Elazar Uchupi critically reviewed the manuscript.

Previous Work

The structure and surface morphology of the Gulf of Maine are characteristic of glaciated continental shelves and have attracted considerable attention from geologists. Johnson (1925) believed the Gulf of Maine to be an inner lowland with a bordering cuesta (Georges Bank), subaerially eroded by streams and later submerged. Formation of the Gulf of Maine by glacial erosion was suggested by Burbank (1929), Shepard and others (1934) and later in a detailed topographic study by Murray (1947). Torphy and Zeigler (1957), Uchupi (1966a and 1966b), and Oldale and Uchupi (1970) have proposed that the Gulf of Maine was formed by Tertiary fluvial erosion and subsequently modified by Pleistocene glacial erosion and deposition.

Drake and others (1954) found a thin veneer of unconsolidated sediment overlying most of the Paleozoic basement in the Gulf. More recently Hathaway and others (1965), Schlee and Pratt (1970) and Schlee (in press), have found that the surficial sediments in the Gulf of Maine include till-like mixtures of sand, gravel, silt and clay; hemipelagic clay in the basins; and sand and gravel on the banks and ledges. Studies of surficial sediment distribution in the western Gulf of Maine have also been conducted by Ross (1967), primarily on the basis of heavy mineral assemblages.

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Surface Morphology and Geologic Setting

On the basis of previous echosounding and seismic profiling surveys (Oldale, Uchupi and Prada, unpub. data) the study area can be divided into several topographic provinces. To the south is the flat-floored Cape Cod Bay with 40 to 80 m of unconsolidated sediment over crystalline basement. The region near the coastline from Cape Cod Bay north to the Merrimack River is characterized by an irregular, glacially scoured, crystalline basement locally covered by a thin layer of dominantly sand and gravel. North of the Merrimack River this coastline province exhibits a highly irregular glacially scoured rock surface and intervening sediment-filled valleys and small basins. A group of deep (120-180 m), relatively flat-bottomed basins lie seaward of the coastline province. In these basins basement outcrops are rare, but the sediment is usually not of sufficient thickness to mask the gross morphology of the basement surface. East of the basins are the flat-topped banks, Stellwagen Bank and Jeffreys Ledge, with depths of less than 60 m. These features, like most of Cape Cod, are underlain by thick Pleistocene drift and localized coastal plain deposits of Tertiary(?) age. East of Stellwagen Bank and Jeffreys Ledge, a broad topographically high area deepens to the east in a series of basins. Geologically this area is similar to the region of banks and ledges and has thick drift and coastal plain sediments over crystalline basement. Depths range from about 75 m on the broad high to over 180 m in the basins on the eastern border of the area.

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Methods

Murray (1947) published 16, 17.5 and 20 kHz echograms showing acoustic penetration in the basin sediments of the western Gulf of Maine. This characteristic penetrability of the fine-grained sediments was used in the present investigation to aid in determining surficial sediment distribution and shallow subsurface structure. Acoustic profiling was conducted using a towed, 3.5 kHz, two element transducer manufactured by Ocean Research Equipment, Inc., an EDO model 248-A transceiver, a precision graphic recorder (PGR) and a recorder designed and built by K.E. Prada of the Woods Hole Oceanographic Institution. Depending on the depth of water, sweep lengths of 100 to 200 fms were used during the survey; pulse lengths were from 2 to 5 ms. The low frequency of this echosounding system offered better penetration in fine-grained sediments and improved resolution of sub-bottom features when compared to previously used higher frequency systems.

Profiling was supplemented by bottom sampling with dredges and grab buckets, and in areas of fine-grained sediment, by coring. In addition, bottom photographs were taken at 59 stations.

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Acoustic Profiling

The results of the 3.5 kHz acoustic profiling are shown on the map as the depth to the deepest observed reflector. In most places this datum was the acoustic basement, defined as the lowest, relatively strong, coherent reflector exclusive of the reflectors within the penetrable sediments. Variations were observed in the reflectivity of the acoustic basement, and they probably indicate changes in the composition of both this reflector and the overlying sediments. Where no penetration was achieved the acoustic basement by definition coincides with the sea floor. In other places acoustic basement was not observed and penetration was measured to the deepest observed reflector within the penetrable unit. In Cape Cod Bay acoustic basement is a flat, poorly defined, but continuous layer that occurs at shallow depths, generally less than 10 m.

Depth values on the map do not constitute an isopach map of any specific sediment type but only reflect the ability of the 3.5 kHz acoustic signal to penetrate the sediments. Penetration correlates well with sediment texture; generally sand and coarser sediments reflect most of the acoustic signal while silt and clay allow increasing penetration. Penetration in admixtures of coarse and fine sediments appears to increase as the fraction of fine material increases. Instrument variables may also affect sub-bottom penetration; however, attempts were made to minimize this effect, and it is felt that the penetration results are geologically significant.

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King (1967) and Schlee (in press) correlated the strength and character of the bottom echo with surficial sediment type. Although this approach to surficial sediment identification is dependent on such instrument variables as gain and pulse length, certain bottom echoes in the records do appear to be characteristic of specific sediment types. Clay and admixtures of silt and clay typically exhibit weak bottom echoes. As the sand fraction increases, the bottom return becomes stronger, and the bottom remains relatively smooth. Gravel and coarser sediments show up as strong echoes in areas of often irregular bottom topography. Echoes from bedrock and probably from compact till are most often the strongest and most prolonged, and the bottom is usually extremely irregular. These echo characteristics also apply to the acoustic basement of bedrock, glacial till, or outwash sand and gravel.

Broadly, the penetration values on the map emphasize the topographic control on sediment distribution. Elevated areas such as banks usually show no penetration, indicating the absence of silt and clay. The greatest penetration is observed in basins and channels where clay and silt are abundant.

In the zone of transition between the basins and banks, reflectors within the penetrable unit usually can be seen to rise and crop out when approaching a bank. In some places, however, rising sub-bottom reflectors become very weak or disappear near the bank. This is interpreted as a possible facies change due to an increase in the amount of coarse sediment in the section toward the bank. Bottom samples in these transitional areas substantiate this view.

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Several localized areas exhibit little or no penetration within the basins. These represent near surface approaches or actual outcrops of basement material rather than a change in the penetrability of the basin sediments.

The topographically complex northern coastal section shown on the map is equally complex in sediment distribution. This area is characterized by closely spaced outcrops of till or bedrock separated by ponded fine-grained sediments. Penetration of as much as 40 meters was obtained in the sediment ponds.

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Structure

Reflectors within the penetrable sediments are highly variable in character. In places they are well-defined and multilayered, but in other areas are weak or absent. The most commonly observed relationship is well stratified sediments above the basement overlain by a structureless unit that continues upward to the sea floor. Reflectors are generally flat or gently dipping, although most steeply dipping forset(?) layers have been observed. They sometimes appear to be subparallel to the irregular basement surface, perhaps as a result of differential compaction. In most cases, however, the reflectors appear to represent actual bedding. Parabolic echos within the penetrable sediments probably represent ice-rafted glacial boulders or lenses of gravel. Unconformities were recognized within the penetrable sediments, but they could not be traced or correlated for any great distance. In a few places, mostly on the banks and ledges, small valleys filled with stratified sediments were observed.

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Sedimentation Rates

A sedimentation rate for the upper part of the penetrable sediments in Tillies Basin was determined by Carbon-14 dating on one piston core (42°32.1'N, 70°22.2'W). Dates obtained were 1860 ± 120 years B.P. and 6130 ± 130 years B.P. for the depths 0-10 cm and 230-240 cm respectively, yielding an average rate of accumulation of 50 to 60 cm per 1000 years for this interval. This rate is not valid for the whole section as over 40 meters of fine-grained sediment has accumulated in Tillies Basin since the glacier retreated from this area about 12,300 years ago (Kaye and Barghoorn, 1964). This thickness of sediment requires an average rate of accumulation in excess of 325 cm per 1000 years. The difference is probably best explained by the large initial influx of fine-grained sediments during the glacial retreat, followed by decreasing rates of accumulation as this source became less significant.

Recent sedimentation rates on the topographic highs are unknown but are probably considerably lower than those in the basins. Bottom photographs often show a few millimeters of silt and clay over the coarse bank-top sediments, indicating that deposition is occuring in these areas. This material must be removed periodically, possibly during major storms, or a thick blanket of silt and clay would now cover the banks and ledges.

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Discussion and Conclusions

The complementary techniques of bottom sampling, bottom photography and 3.5 kHz echosounding have proved most useful in interpreting the surficial sediment distribution, depositional history and shallow structure of the study area.

Observed penetration in the 3.5 kHz echosounding records rapidly emphasizes the pronounced control of submarine topography on the distribution of fine-grained sediments in this area and delineates their thickness and internal structure. Unfortunately, the 3.5 kHz signal will not penetrate coarse-grained and indurated sediments, and the system is therefore ineffective in evaluating the thickness of the sand and gravel resources of the area. Under closely controlled instrument conditions, however, interpretation of the bottom echo appears to have merit in delineating the areal extent of these resources, especially in conjunction with bottom sampling and photography.

The great difference between the sedimentation rate determined from the Carbon-14 dates on the core in Tillies Basin and that based on the time since the last ice retreat suggests that much of the penetrable unit is composed of late-glacial marine clay and silt. This view is also supported by the late glacial rock flour sediments now exposed along the coast from Boston northward in the Presumpscot Formation (Bloom, 1960) and in the acoustically penetrable sediments of Boston Harbor (Burroughs, personal comm., 1970). Therefore, deposition of the penetrable sediment probably began during the retreat of the last ice sheet in the western part of the Gulf of Maine. Melt-water streams deposited thick accumulations of fine-grained sediment in the basins along with probably much thinner accumulations on the tops of the submerged banks and ledges.

Eventually glacial meltwater ceased to flow into the western Gulf of Maine and lower sedimentation rates predominated. At this time the thin veneer of rock flour on the banks and ledges and the silt and clay in the glacial drift probably became the major sources of fine-grained sediment for the basins. This material was transported to the basins by wave and current action, especially during the post-Pleistocene lowering of sea level which resulted from the isostatic rebound of the crust. The sedimentation rate (50-60 cm per 1,000 years) for the Tillies Basin core probably reflects this process. Still lower sedimentation rates appear to predominate in the basins at present due to the near absence of fine-grained material available from the topographic highs.

The post-Pleistocene low stand of sea level resulting from the isostatic rebound of the crust was up to 25 m in Boston (Kaye and Barghoorn, 1964) and up to 3 m along the coast of Maine (Bloom, 1960) and may be represented by several features of the penetrable unit. Some of the local unconformities were possibly cut at this time. The nearly flat sub-bottom at shallow depths in Cape Cod Bay may be an extensive erosional surface developed when much of the bay was exposed, and the small sediment-filled erosional channels on the banks and ledges may represent former stream valleys.

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