SURFICIAL SEDIMENTS AND SAND AND GRAVEL DEPOSITS OF INNER MASSACHUSETTS BAY

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INTRODUCTION

Massachusetts Bay is an elongate, arcuate embayment along the southwestern side of the Gulf of Maine bounded by Cape Ann to the North and Cape Cod Bay on the South (Fig. 1). The inner shelf exhibits irregular bathymetry (anon., 1970), particularly off the Boston Basin in the centre of the Bay. North of Boston the coast is characterized by numerous headlands and re-entrants, whereas a relatively straight coastline is found to the south. Our study is focused on sedimentary characteristics of the complex inner shelf of Massachusetts Bay in order to understand better the Holocene history of this heavily glaciated area and the evolution of modern sand and gravel deposits.

Early reconnaissance studies of sedimentation in Massachusetts Bay were undertaken by Trowbridge and Shepard (1932) and Stetson and Schalk (1935). Each concluded that bottom deposits originated as glacial till or glaciofluvial deposits which had been reworked by marine processes. Schlee and Pratt (1970) and Schlee and others (1971) mapped widespread sand and gravel in the nearshore zone and supported the concept of extensively reworked glacial deposits. On the basis of mineralogy, Ross (1970) also favored a glacial origin for surficial marine sediments in western Massachusetts Bay. The source rocks for the offshore sediments were thought both by Schlee and Pratt and by Ross to be crystalline bedrock located northwest of Boston.

A geologic history for Massachusetts Bay was proposed by Oldale and Uchupi (1970) and Oldale and others (1971) wherein the Paleozoic and early Mesozoic crystalline and sedimentary basement underwent three periods of fluvial erosion and two cycles of coastal-plain deposition prior to an early Pleistocene emergence. Later, two to four Pleistocene glaciers advanced through Massachusetts Bay depositing sequences of tills and glaciomarine clays. The last glacial retreat was followed initially by submergence and then emergence before sea level rose to its present position.

Our paper is based upon geophysical and bottom-sampling data collected in the spring of 1972 to assess mineral deposits within the Commonwealth of Massachusetts territorial waters. In addition to delineating several sand and gravel deposits of potential commercial value, the investigation also provided insight into the Holocene geology and surficial sediments of inner Massachusetts Bay. A detailed examination of the nearshore stratigraphy is presently in progress by workers of the U.S. Geological Survey at Woods Hole, Massachusetts where the acoustic data from our study are on file.

Methods

Acoustical data acquired for this study included more than 900 kms of sub-bottom and side-scan profiles, which were complemented by 54 long cores, 66 grab samples, and photographs from 113 sites. Track-line coverage and station positions are shown in Figure 1. Sub-bottom profiling was accomplished utilizing a 300-joule EG&G Uniboom source, Aquadyne hydrophone streamer, and Raytheon shipboard receiver system. Side-scan coverage was obtained with an EG&G side-scan sonar operating at 105 kilohertz and configured to provide a record of bottom texture across a 300-m wide swath centred on the boat trackline. In the physical sampling portion of the program, an Alpine Vibracorer was used to acquire 8.9 cms diameter cores up to 11.6 m long. Additionally, surface sediment samples were taken with a Shipek grab sampler having a capacity of 2832 cm^3, and bottom photographs were taken at each core and grab-sampling site. Navigational control during survey operations was provided by Loran type B hyperbolic radio location.

Visual description and sub-sampling of cores and grabs took place aboard ship, and sub-samples were later analyzed for grain-size distribution. In the laboratory, the areal distribution of bottom sediment types was determined by correlating textural patterns on the side-scan sonar records with bottom samples, underwater photographs, and sub-bottom profiles. The geometry of sand and gravel deposits was delineated by evaluating the acoustic profiles and long cores.

Surficial Sediments

Information on the character of surficial sediments was provided by direct physical sampling, bottom photography, and side-scan sonar. The variable nature of substrates encountered is illustrated by bottom photographs shown in Figure 2 and side-scan sonar records shown in Figure 3. Not only were diverse substrates encountered, but, as indicated by the side-scan sonar records, considerable variation was observed over short distances. Although most sediment distribution maps are based on data from discrete points, an accurate distribution map for complex inner Massachusetts Bay could not have been prepared without the side-scan sonar coverage which extended over 35 percent of the study area.

Because of the variable nature of the bottom, it was necessary to classify sediments by common associations. Six distinct substrate types were recognized, including:

1) bedrock or boulders with patches of coarse sediment,

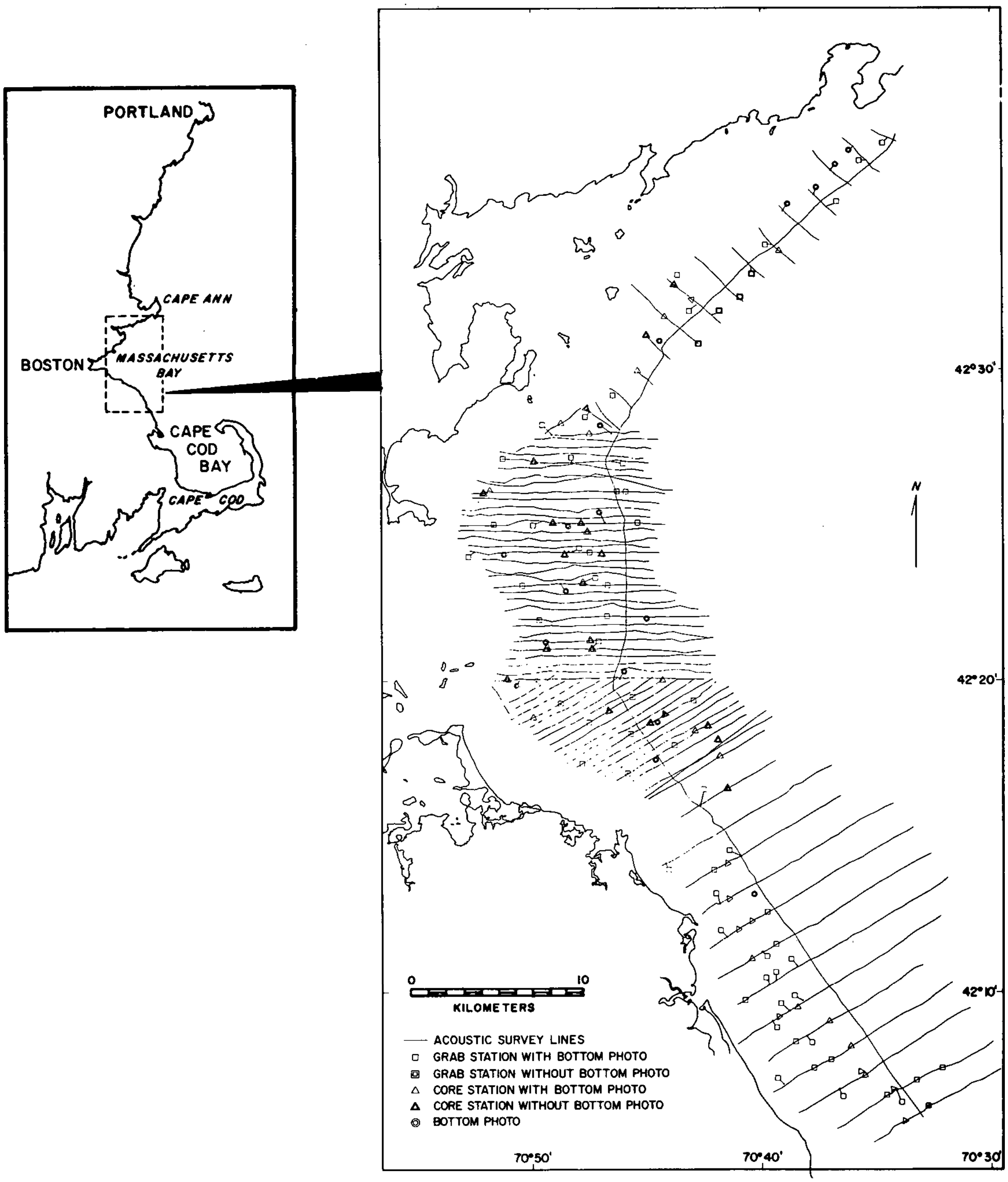


FIG. 1 Location map of inner Massachusetts Bay.

2) cobbles with sand and gravel,
3) sand and gravel,
4) sand,
5) silty sand, and
6) a heterogenous mixture of sediments ranging from cobbles to silt and clay.

The distribution of these surficial sediment zones is shown in Figure 4. This figure exhibits a good correspondence to the sediment texture maps prepared by Schlee and others (1971), although showing considerably more detail based upon the greater volume of data collected in the present study.

The complex distributional pattern of surface sediments reflects the variable nature of sub-bottom geology and effects of sea-level fluctuations. Sub-bottom profiles reveal undulating hard reflectors composed of crystalline bedrock in some areas and glacial till elsewhere. Between frequent outcrops of these reflectors are depressions filled with glaciomarine sands, silts, and clays which are often stratified, exhibit apparent unconformities, and are possibly interspersed with additional till units. The sub-bottom geology of inner Massachusetts Bay is exemplified by the acoustic profiles of Figure 5.

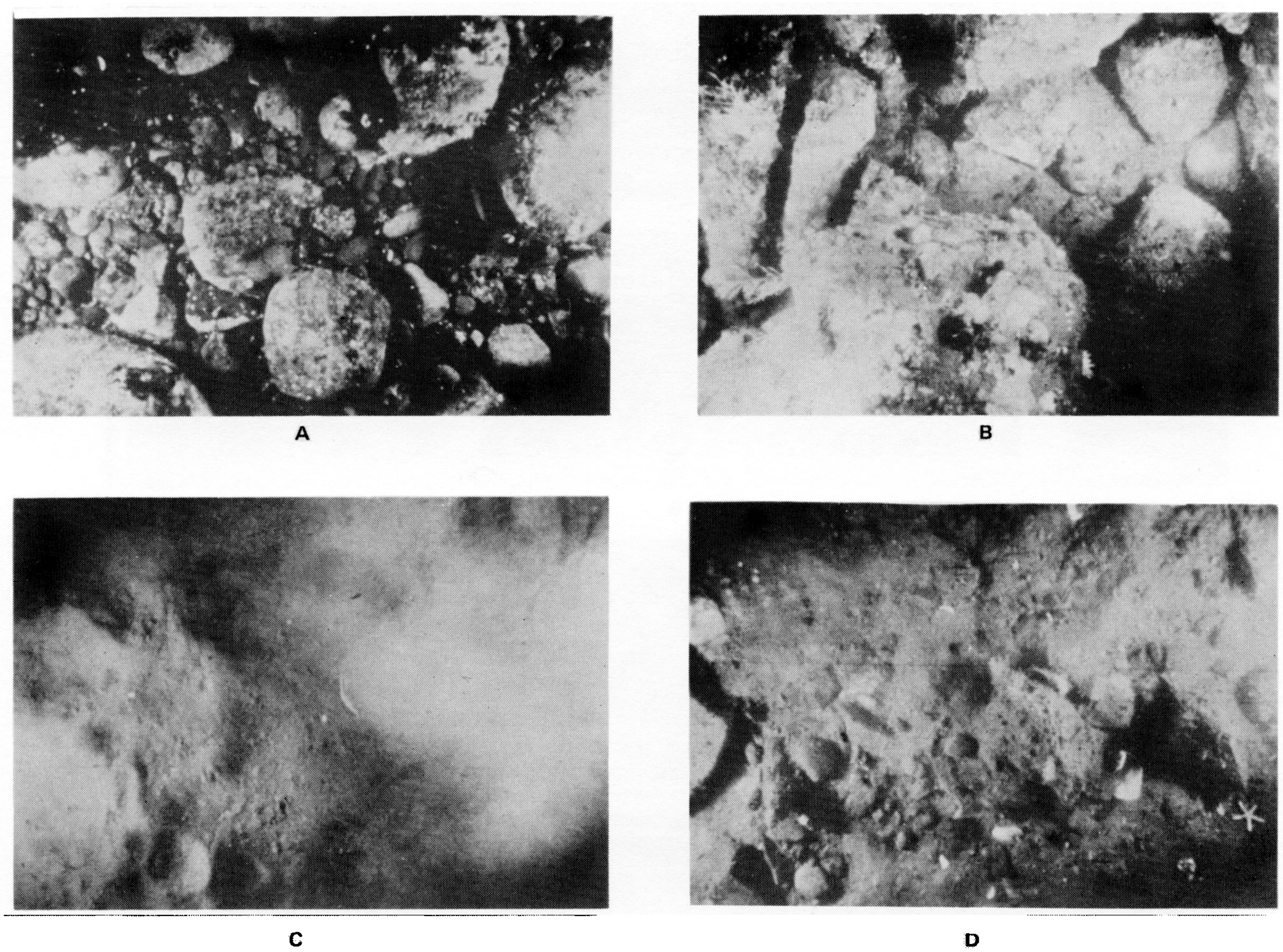


FIG. 2 Photographs from inner Massachusetts Bay showing 40 by 60 - cm portions of the bottom: A -- cobbles interspersed with gravel; B -- boulders or bedrock; C -- silty sand; D -- sand and gravel.

East and southeast of Boston Harbor, much of the sea floor consists of either bedrock outcrops or mixtures of boulders and cobbles. The boulders and cobbles represent a lag deposit inferred to result from marine reworking, which began during the Holocene emergence and is presently continuing by wave and tidal-current action. This reworking has also created a thin, continuous sheet of sand and gravel over much of the southern central region of the study area. Following the terminology of Swift and others (1971), these sediments constitute palimpsest deposits. Variations in the texture of this sheet are interpreted to reflect the characteristics and proximity of source till exposures on the sea floor.

Boulders and outcrops are less common north of Boston Harbor, with much of the bottom covered by a thin layer of uniform silty fine sand. The texture and geometry of this sand suggest that is is a modern deposit originating from coastal erosion and input from local streams. We speculate that erosional and stream sediments undergo sorting in the surf zone which provides silty sand to the nearshore zone, and the silty sand has prograded seaward by the diffusion mechanism described in Swift (1970).

Previous investigators have speculated upon the origin of the belt labelled bedrock or boulders on Figure 4 which lies parallel with the shoreline south of Boston Harbor. Trowbridge and Shepard (1932) and Schlee and others (1971) identified these bottom materials as bedrock, whereas Stetson and Schalk (1935) and Hough (1942) recovered coarse sediments in this zone which they interpreted as reworked glacial drift. We interpret this belt to consist primarily of bedrock because side-scan sonar records indicate a rough bottom texture, rock surfaces appear in bottom photographs, and minimal sediment was retrieved by grab and core sampling in this zone. The pebbles reported by the latter investigators probably occur as a patchy veneer over the bedrock surface.

Mineralogical analysis were not performed on the sediment samples collected during the present study, but it was observed that the coarse fractions consisted primarily of an arkosic to subarkosic mixture of feldspar and quartz as noted by Milliman and others (1972). Observations during this study also supported the conclusion reached by Ross (1970) that the hornblende and garnet heavy mineral assemblage occurring in Massachusetts Bay is not concentrated in any area or horizon.

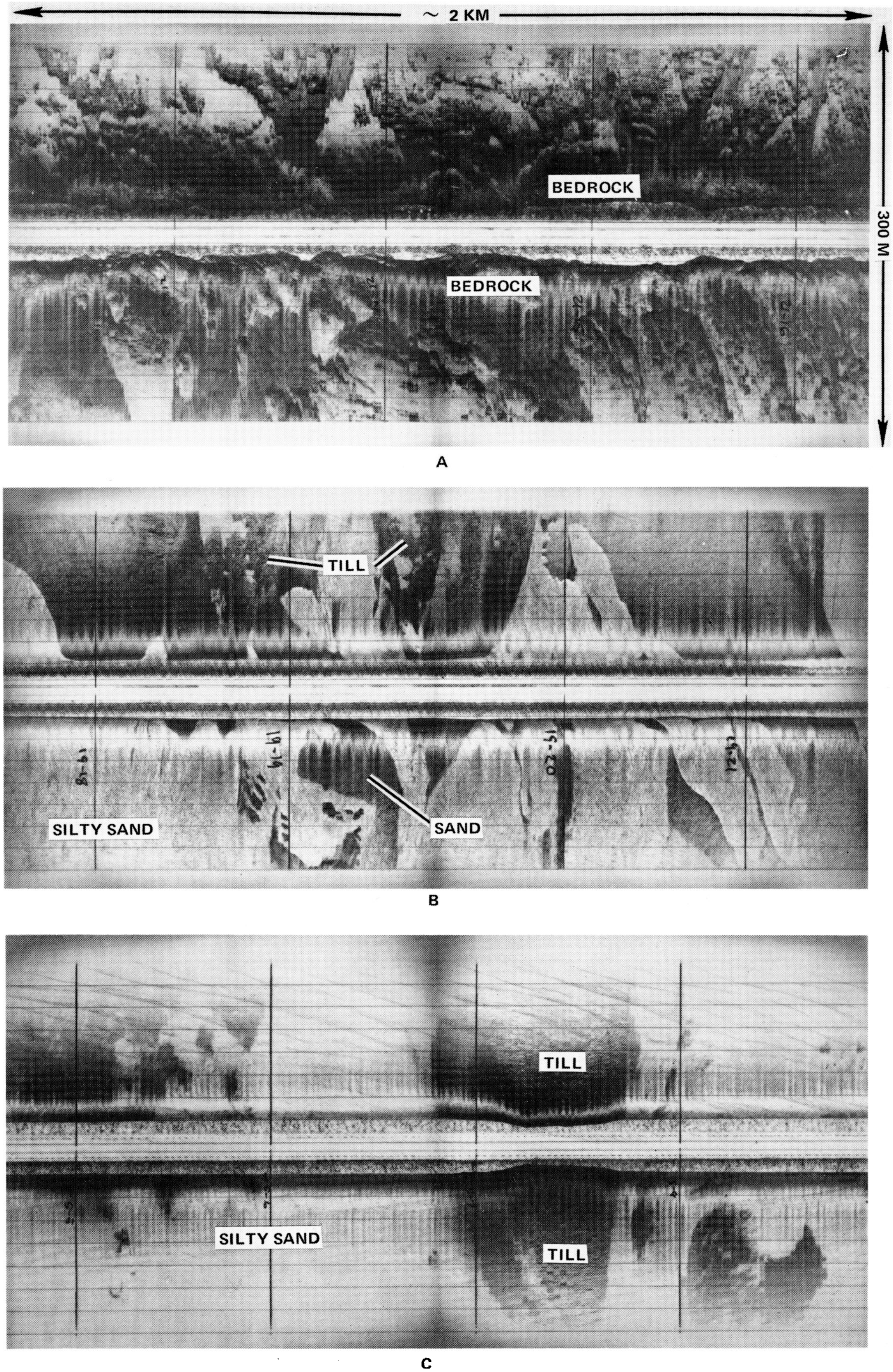


FIG. 3 Side-scan sonar records from inner Massachusetts Bay: A -- bedrock outcropping; B -- till surrounded by sand (note rippling) and silty sand; C -- silty sand with zones of exposed till.

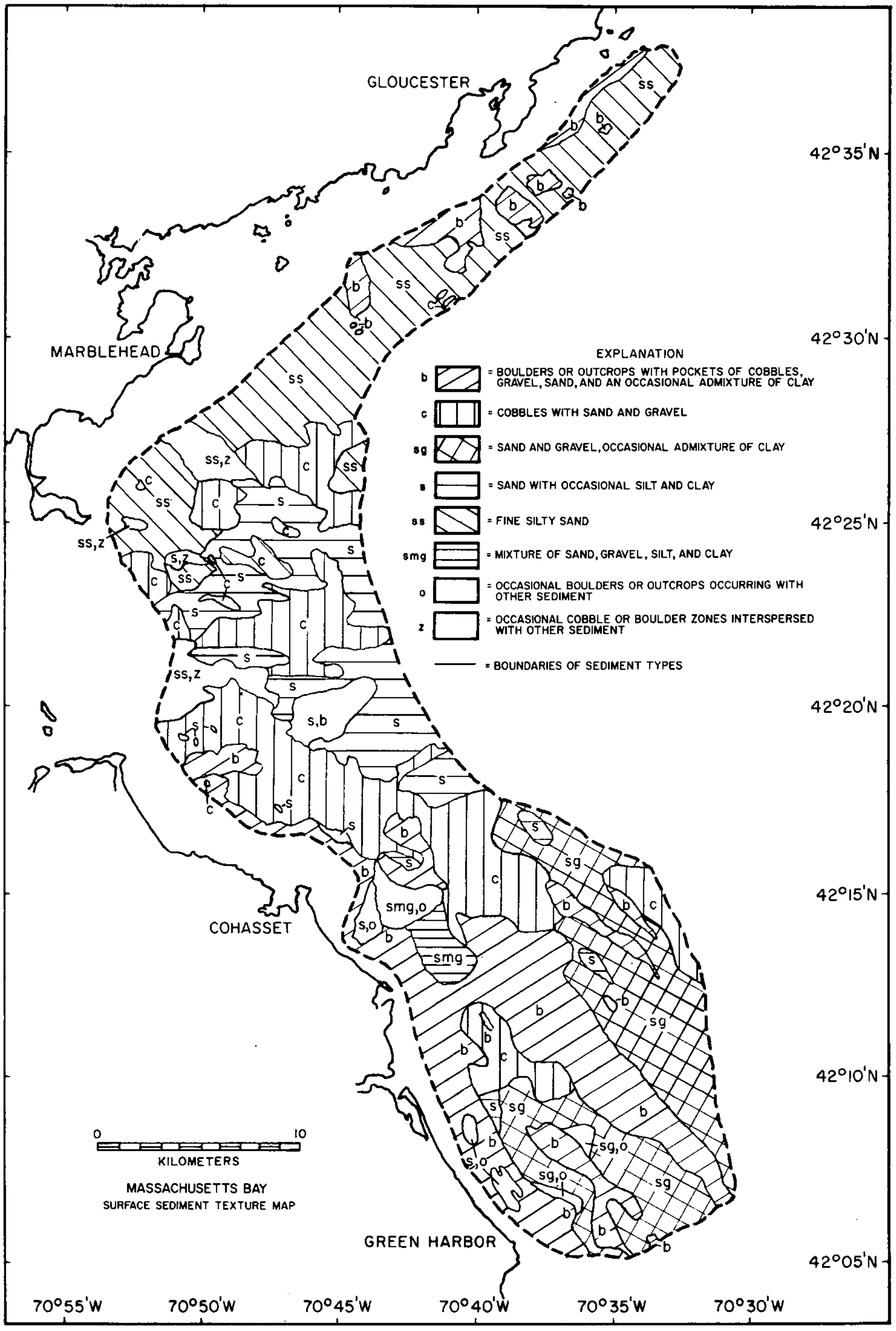
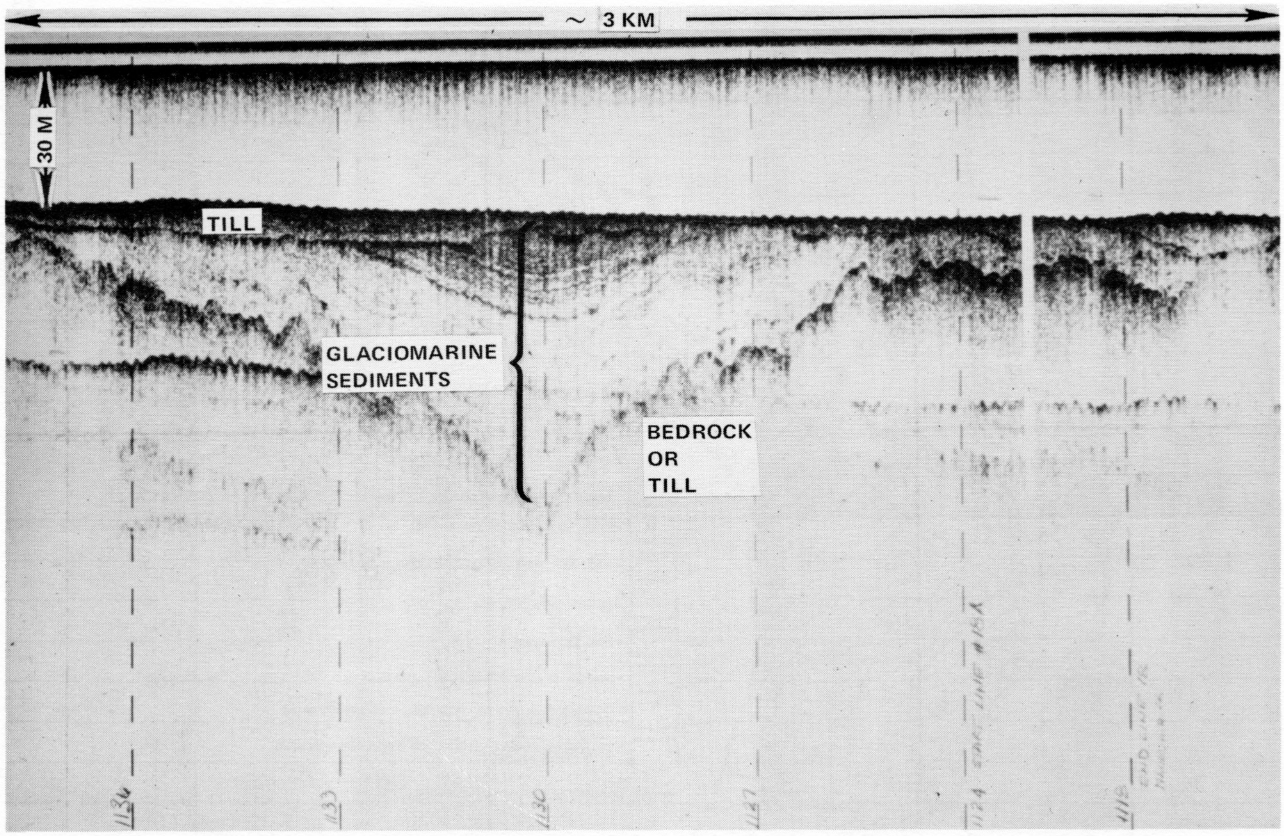
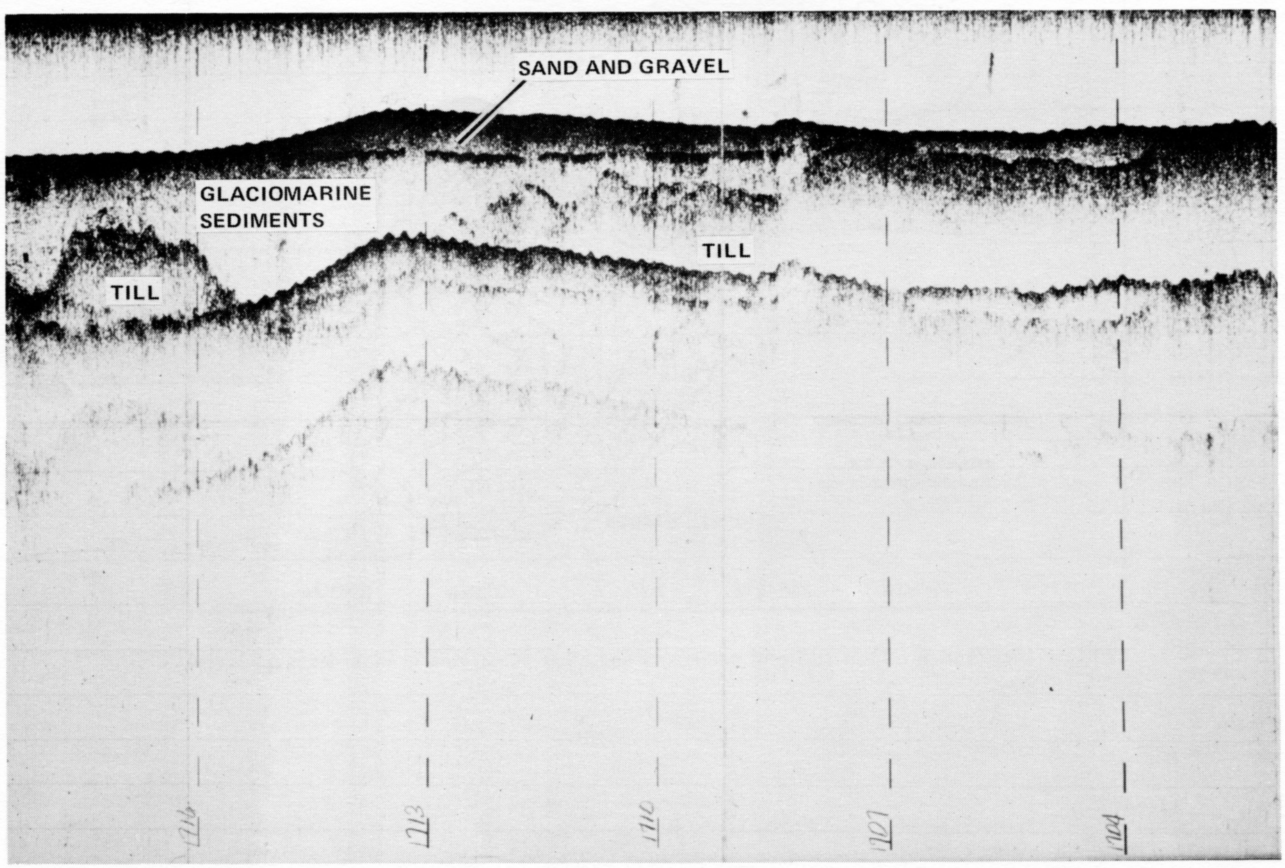


FIG. 4 Distribution map of surficial sediments and other substrates in inner Massachusetts Bay.



A



B

FIG. 5 Sub-bottom acoustic profiles from inner Massachusetts Bay: A -- basin with complex sequence of tills and glaciomarine sediments; B -- till basement partially overlain by glaciomarine sediment, with sand and gravel composing the asymmetric rise at the sea floor.

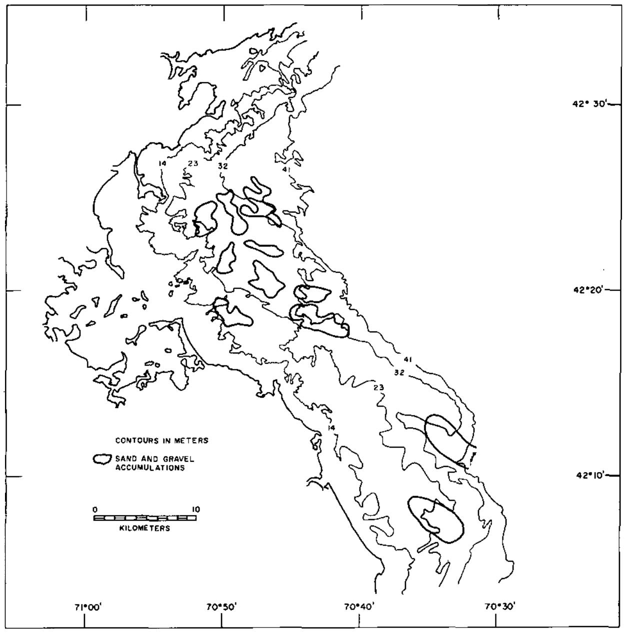


FIG. 6 Locations of sand and gravel deposits in inner Massachusetts Bay.

Sand and Gravel Deposits

Figure 6 shows the locations of volumetrically significant surface accumulations of sand and/or gravel within the study area. These accumulations represent local increases in the thickness of the pervasive coarse palimpsest sediment sheet with maximum thicknesses of individual deposits generally less than 10 m. Although the deposit shown in cross section in Figure 5 has positive relief, most of the accumulations have no marked bathymetric expression. These bodies can thus be geometrically described as lenses. In this sense, it should be noted that the deposit boundaries shown in Figure 6 have been arbitrarily established at the 1-m isopach as an illustrative aid.

With regard to origin, three characteristics of these deposits merit attention: most are concentrated off the Boston Basin where thick sequences of glacial sediments have been recorded on land (Schafer and Hartshorn, 1965); most of the deposits also lie between the 23 and 32-m isobaths, a location which appears to correlate with the post-glacial emergent shoreline (Kaye and Barghoorn, 1964; Tucholke and Hollister, 1973);and lastly, the orientation of the long axes of these deposits trends consistently northwest-southeast. This alignment corresponds to the direction of glacial advance as indicated by linear features on land (La Forge, 1932) and by the mineralogic resemblance of Massachusetts Bay sediments to crystalline bedrock northwest of Boston (Shclee and Pratt, 1970; Ross, 1970). The northwest-southeast elongation of the sand and gravel deposits also parallels the trend of bathymetric features as well as the long axes of depressions in the offshore basement surface.

We postulate that the sand and gravel deposits represent reworked glacial drift because they are well-sorted, exhibit textural similarity to the contiguous palimpsest sediment sheet, and have the geometry of lenses. Although the deposit shown in Figure 5 has a somewhat drumlinoid cross-section, the absence of boulders and fines and the lack of bathymetric expression demonstrated by other deposits indicate that the sand and gravel accumulations are not drumlins. The general lack of bathymetric expression also argues against morphologic and genetic similarity to the linear sand ridges of the North American Middle Atlantic Bight (Swift and others, 1973).

Our concept of the origin and development of the sand and gravel deposits includes the following sequence of events. The deposits originated as the most recent glacial drift deposited in Massachusetts Bay which may be correlative with either the onshore Drumlin Till (drift III) or Lexington Outwash (drift IV) of the Pleistocene stratigraphic sequence developed for Boston by Kaye (1961). The final retreat of the Wisconsin glacier was followed originally by submergence, then the emergence at 10,000 years B.P. when sea level fell to -23 m.

Intensive reworking of the drift took place during this emergence, particularly off the Boston Basin where abundant drift was exposed to the action of shoaling waves on a broad inner shelf. Reworked coarse sediments were deposited as nearshore sands which were concentrated as beaches and fill in bathymetric lows, resulting in the northwest-southeast lineation. Some of these features were in turn reworked as sea level rose to its present position.

At the present time, currents related to waves and tides are sufficiently strong to rework Massachusetts Bay bottom sediments into ripple marks (which appeared in bottom photographs and side-scan sonar records) and prevent the accumulation of fine-grained sediments which are being generated in Boston Harbor (Mencher and others, 1968). No large-scale current-related bedforms, such as sand waves or linear shoals, have been observed on the Bay floor.

Other investigators have correlated deposits of sand on continental shelves with low stands of sea level off other portions of the New England coast. Schnitker (1974) used a well-preserved submerged beach developed on a till surface to identify the maximum post-glacial emergence off Maine. McMaster and Garrison (1967) reported on a submerged barrier spit associated with a former Holocene shoreline near Block Island, Rhode Island. The Massachusetts Bay sand and gravel deposits, by comparison, have been geometrically modified by reworking since their littoral genesis such that their specific depositional characteristics have been obscured. Lateral sediment redistribution, resulting from the reworking, limits the usefulness of these deposits as primary indicators of the maximum post-glacial emergence off Massachusetts although their location supports the sea-level curve proposed by Kaye and Barghoorn (1964).

Summary

Massachusetts Bay is representative of a mid-latitude inner continental shelf on which glacial deposition has been followed by a partial emergence and associated marine reworking. Resulting substrate types include exposed bedrock and till, several coarse palimpsest sediment associations, and modern fine sand which is prograding seaward. These substrates are distributed in a complicated fashion related to bathymetry, the location of bedrock and till outcrops, characteristics and proximity of source tills for palimpsest materials, and production of fine sand by shore erosion. In this variable sedimentary environment, accurate substrate distribution maps can be most efficiently prepared if physical sampling is accompanied by intensive side-scan sonar surveying.

Surface sand and gravel accumulations occur in numerous locations on the inner shelf, particularly off the Boston Basin and between the 23 and 32-m isobaths. These deposits are lenses which grade into the palimpsest sediment sheet at their boundaries. The deposits are thought to have originated as the most recent drift which was initially reworked into beach and nearshore sediments during the post-glacial 23-m emergence. These sediments have in turn been redistributed by waves and currents as sea level rose to its present position.

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