Distribution of Economic Heavy Minerals in Sediments of Saco Bay, Maine

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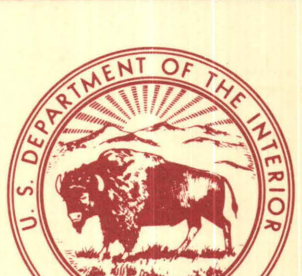

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By GRETCHEN LUEPKE and ANDREW E. GROSZ

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By Gretchen Luepke *and* Andrew E. Grosz

Abstract

The heavy-mineral assemblage in sediments of 12 vibracore samples from Saco Bay, Maine, is dominated by garnet and pyroboles (pyroxenes and amphiboles). Minerals occurring in lesser abundance are sillimanite, andalusite, epidote, tourmaline, and staurolite. Minerals of economic value--ilmenite, leucoxene, rutile, zircon, and aluminosilicates (sillimanite and andalusite)--constitute an average of about 14 percent of the heavy minerals in the analyzed sediments and an average of about 0.1 percent of the bulk samples. No large qualitative variations were found in the mineral assemblages within or among the core sediments analyzed. However, significant quantitative differences occur that are related to the texture of the sediments; increasing percentages of silt and clay correlate strongly with decreasing percentages of total heavy minerals.

With one exception, the uppermost parts of the cores are coarser and commonly contain over 1 percent heavy minerals. These coarser sediments extend to an average depth of about 1.6 m and have a higher heavy-mineral concentration than the basal silt and clay that they almost invariably overlie. Weight percentages of magnetite, pyrite, and limonite increase with depth, while those of economically important minerals decrease. To a lesser extent, weight percentages of garnet increase with depth, while the reverse is true for pyroboles.

The general scarcity of economic mineral species, low total heavy-mineral percentages, and relative thinness of deposits limit the potential for heavy-mineral resources in the Saco Bay area.

INTRODUCTION

As part of the U.S. Geological Survey's effort to assess the mineral potential of the continental shelves for placer deposits within the U.S. Exclusive Economic Zone, 12 vibracore samples from Saco Bay, Maine, were analyzed for their heavy-mineral content.

In the United States, chemically stable heavy minerals such as ilmenite, leucoxene (altered ilmenite), rutile, zircon, and monazite have been concentrated along fossil beaches, alluvial floodplains, and present-day shorelines. Major onshore deposits are located in the coastal-plain sediments of New Jersey (Markewicz and others, 1958), the Carolinas (Force and others, 1982), and Georgia and Florida (Pirkle and Yoho, 1970; Garnar, 1972). Economic concentrations of heavy minerals may also be associated with former shoreline and fluvial deposits now submerged on the continental shelf. Still, the nation's demand for many of these minerals, particularly ilmenite and rutile, exceeds the domestic supply (L.E. Lynd, U.S. Bureau of mines, oral commun., 1985).

The Atlantic Continental Shelf (ACS) of the United States has an area of approximately 3.91×10^5 km^2 and contains an estimated 8.30×10^{11} m^3 (about 42 percent by volume) of sand and gravel, assuming a 5-m average thickness across the shelf (OCS Mining Policy Phase II Task Force, 1979). From these data, the amount of heavy-mineral sand of variable composition and grade on the ACS has been estimated to be about 1.30×10^9 m^3, which is about 0.16 percent of the estimated volme of sand and gravel on the shelf. Sand bodies are present at the surface throughout most of the ACS at water depths ranging from an average of about 20 m near shore to 80-140 m near the shelf edge (Milliman, 1972). The surficial sands appear to consist of ancient shoreline deposits that were formed during the regression of the sea during the recent glacial epoch (Emery, 1966). Submerged terraces and beach ridges on the shelf add to evidence for a subaerial environment of deposition (Uchupi, 1968). Although not all shoals are submerged shoreline features (Duane and others, 1972) but may in fact be Holocene nearshore deposits (Swift and others, 1972), concentrations of heavy minerals may nonetheless be associated with them (Everts, 1972; Goodwin and Thomas, 1973).

Acknowledgments

We thank John D'Agostino and Ricardo Lopez for assistance with the labor-intensive wet-milling process, Robert Oscarson for analyses with the SEM

and EDAX, and Lisa Morgenson, for preparing the samples for X-ray diffraction analysis.

PREVIOUS WORK

Although an extensive literature describes the nature and distribution of sediments on the ACS, little has been written about the economic potential of heavy-mineral concentrations within these sediments. Many ACS studies broadly refer to economic potential but provide insufficient information for making quantitative resource estimates (for example, Stetson, 1938; Gorsline, 1963; Pilkey, 1963; Emery and Noakes, 1968; Stone and Siegel, 1969; Ross, 1970). Identified economic heavy minerals from the ACS include ilmenite, rutile, monazite, zircon, cassiterite, gold, kyanite, sillimanite, garnet, and staurolite (Gorsline, 1963; Emery and Noakes, 1968; Goodwin and Thomas, 1973; Grosz and Escowitz, 1983). Ilmenite, rutile, and zircon, in places reaching unusually high grade, are relatively widespread off the southeastern United States coast. Ilmenite, leucoxene, and zircon have been mined onshore for more than 40 years from elevated Pleistocene sand bodies in Florida, Georgia, and New Jersey. Significant concentrations of these minerals are also found in coastal Georgia, South Carolina, and North Carolina.

Previous work on heavy minerals in sediments of offshore Maine was part of an overall study of the Gulf of Maine by Ross (1970). That study, based on analyses of heavy minerals from ocean-floor grab samples, was conducted primarily to clarify the source and postglacial geologic history of heavy minerals in the area. A map by Folger and others (1975) of general characteristics of bottom sediments on the continental shelf of the northeastern United States includes Saco Bay.

Saco Bay, near the central coast of the Gulf of Maine, is in southern Maine, about 20 km south of Portland (fig. 1). It is about 7 km wide and bounded by two rocky headlands: Prouts Neck at the north and Fletcher Neck at the south. The Saco River, which has its headwaters in the White Mountains of New Hampshire (Farrell, 1972), enters the southern end of the bay. All other drainage into Saco Bay is local. The bay is bordered by beach and dune deposits, behind which are swamps, vegetated dunes, glacial till, and glacial outwash deposits (Prescott, 1963). At the southern end of the bay around Biddeford Pool, the surficial deposits are entirely glacial till. Local bedrock, where present at the surface, consists of metasedimentary rocks (phyllite, schist, and metaquartzite) of Silurian and (or) Devonian ages and some Devonian granitic intrusive rocks (Osberg and others, 1984; J.T. Kelley, University of Maine, oral commun., 1985). Extensive Triassic and Jurassic granitoid intrusives, ranging in composition from granite to gabbro, crop out in the White Mountains of New Hampshire (Cox, 1970). This study of the offshore deposits was designed to evaluate the potential for detrital heavy-mineral resources in the bay.

CORE LITHOLOGY AND STRATIGRAPHY

The lithologies of the cores examined in this study range from very well sorted, very fine sands to pebbly silts and clays. Coarse to medium sands are more widespread in the northern end of Saco Bay, particularly near Stratton and Bluff Islands. In 6 of 12 cores, the sands rest on a layer of silt and clay that may contain angular pebbles and (or) abraded shells at or near the top. On the basis of two cores from southern Saco Bay, a silt-and-clay layer appears to lie at or very near the surface in that part of the bay (fig. 1).

The basal silt-and-clay layer is seen in cores 1215, 1216, 1217, 1240, 1241, and 1242. The upper parts of cores 1215, 1216, and 1242 are silty, fine to very fine micaceous sands with or without pebbles or granules; some cores have well-sorted sands, one has interlayered fine, medium, and coarse sands.

The other six cores do not show a basal silt-and-clay layer, and the size and sorting of the sands vary from core to core. One is well sorted from top to bottom; another has a series of layers; and others have fine-grained, well-sorted micaceous sand.

Detailed descriptions of each core are given in the appendix. The average total length of the six cores without a basal silt-and-clay layer is 1.9 m; in contrast, the average total length of the six cores that show a basal layer is 3.6 m. The fact that the basal parts of cores 1218, 1220, and 1221 show increasing silt content suggests that a basal silt-and-clay layer may lie at some greater depth at these locations. Cores 1212, 1213, and 1214 are all 2.2 m or less in total length; the possible presence of the basal silt-and-clay layer at greater depths at these locations is uncertain.

HEAVY-MINERAL STUDY

Methods

The aim of this study was to establish the relative abundance of broad groups of minerals (garnet, sheet silicates, tourmaline, pyroboles, and others) and the general distribution of economically valuable mineral species. Reconnaissance sample processing and analytical methods were used to identify and quantify the combined heavy-mineral species that accounted for about 95 percent of each heavy-mineral assemblage. There was no attempt to investigate or to document the complete heavy-mineral assemblages.

The vibracore samples used in this study were collected in 1967 by the U.S. Army Corps of Engineers as part of an offshore sand-and-gravel inventory along the eastern coast of the United States (Prins, 1980). The vibracores from Saco Bay were collected in water depths ranging from 7 to 22 m. The cores range in length from 0.9 to 5.2 m. The cores were opened and described (appendix); archival samples were taken of the representative lithologies, and then each core was divided into approximately 152-cm (5-ft) sections, although that interval was not used if a change in

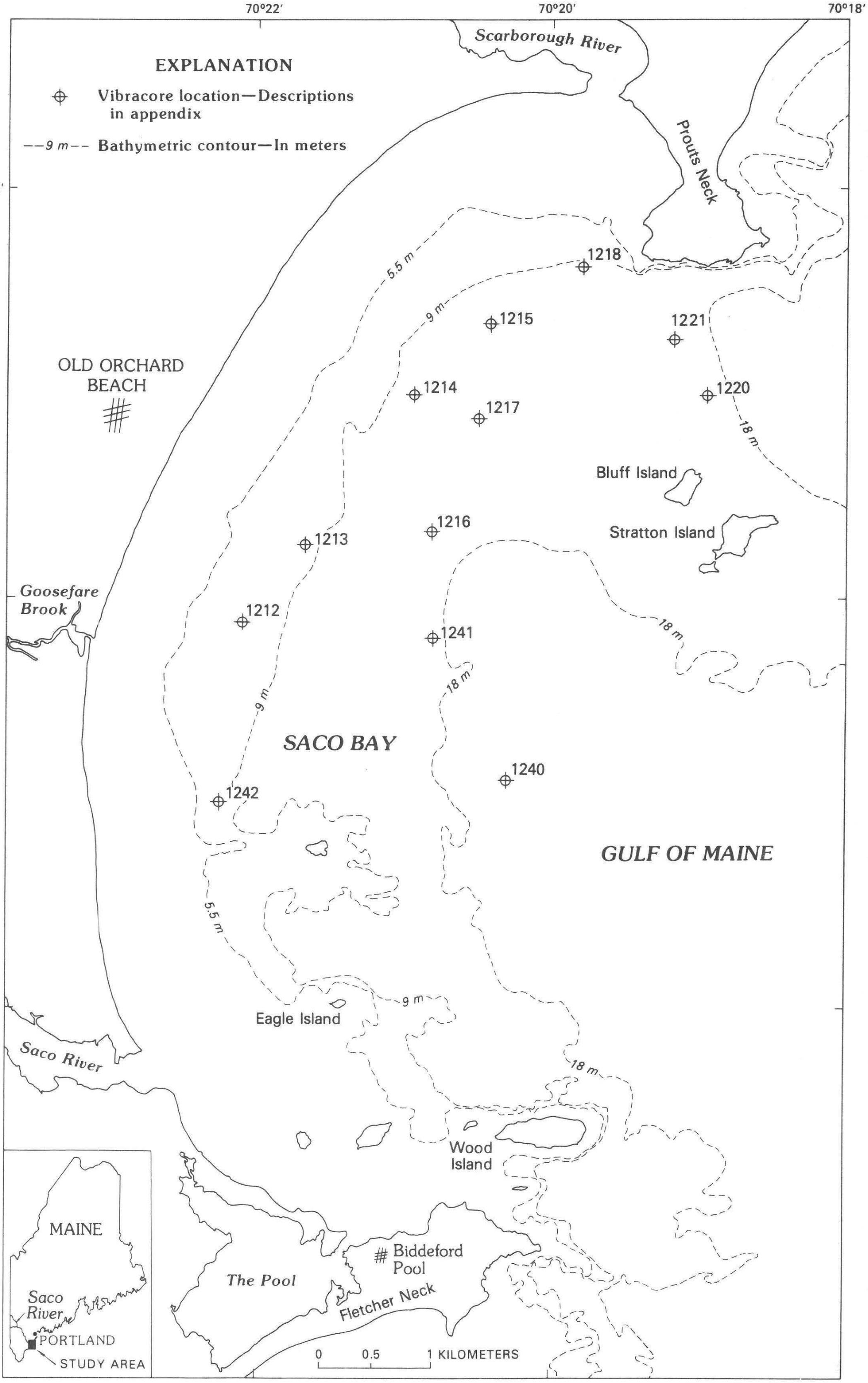

Figure 1. Index map of Saco Bay, Maine, showing core locations. Bathymetry from National Ocean Survey Chart 13287 (Saco Bay and vicinity), 1981, scale 1:20,000.

lithology made a different division more logical. This process yielded 24 samples for analysis.

Each sample was processsed to test and document the variations in heavy-mineral content with depth. Bulk sample sizes ranged from about 3,200 g to 12,300 g. Large sample size reduced possible particle-sparsity biases that can result when a limited number of grains significantly influences the concentration of an economically important mineral species (see Clifton and others, 1969).

After being weighed, each sample was wet sieved through a 2.0-mm (10-mesh) stainless-steel screen to remove pebble- and gravel-sized material. The <2.0-mm (sand-size) fraction was first processed by use of a modified Humphreys[1] three-turn sampling spiral (fig. 2) to obtain an initial heavy-mineral concentrate. The three-turn spiral separates heavy minerals from lighter ones in a laminar-flow process that balances centrifugal against centripetal forces acting on a flowing slurry of water and sand. Most samples were processed through the spiral three times, but samples that were exceptionally silt rich and clay rich went through four times. The fine fraction (<0.062 mm, silt and clay) was discarded with each washing. The light-mineral fraction from the spiral concentrator was then processed by use of a mechanical pan concentrator to recover heavy minerals not separated by the spiral concentrator.

In general, this wet-milling process recovered over 95 percent of the heavy minerals from the Saco Bay samples. In this study, the amount of material allowed to flow into the spiral concentrate was purposefully large; therefore, the percentage of light minerals remaining as part of the concentrate varied from less than 1 to about 60 percent. After the entire wet-mill process, subsamples of the remaining light fraction were taken for determination of the types and quantities of heavy minerals not recovered by the wet-mill process.

Purification of the wet-mill concentrates was conducted in what is referred to as the dry-mill process. Initially, the samples were refined by sink-float separation in tetrabromoethane (specific gravity=2.96). A 12.5-percent split of most of the purified mineral samples was taken for chemical analysis; a second 12.5-percent split was retained as a repository sample for future studies. The remaining 75 percent of the heavy-mineral suite from each sample was magnetically reduced to paramagnetic subfractions, thereby segregating minerals by magnetic susceptibility and facilitating mineral identification. Ferromagnetic and strongly paramagnetic minerals were removed by use of a modified Frantz isodynamic magnetic separator set at vertical (fig. 3). The remaining material was separated into three paramagnetic subfractions (0-0.5, 0.5-1.0, and >1.0 amperes) when the magnetic separator was set at 15 degrees forward with 25-degree side slopes.

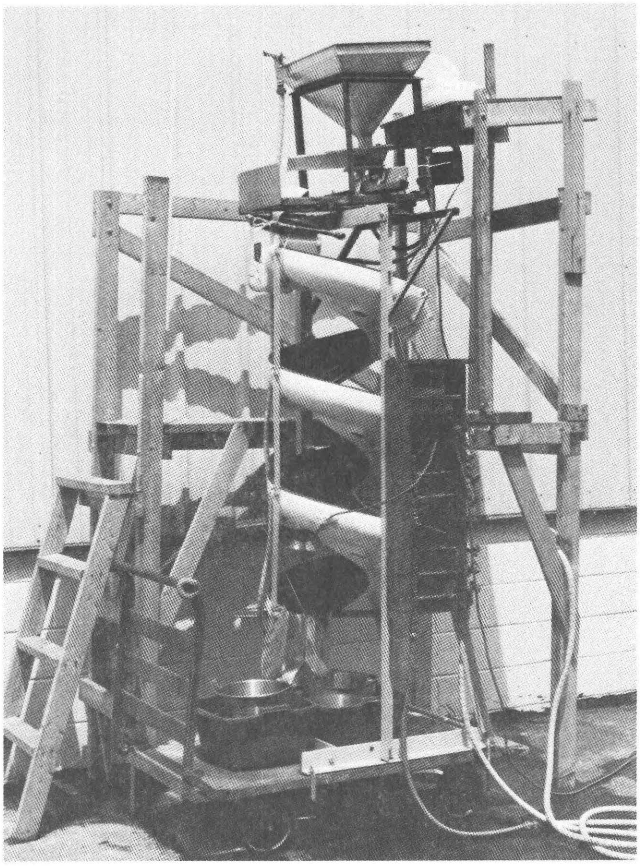

Figure 2. Three-turn sampling spiral used to obtain an initial heavy-mineral concentrate.

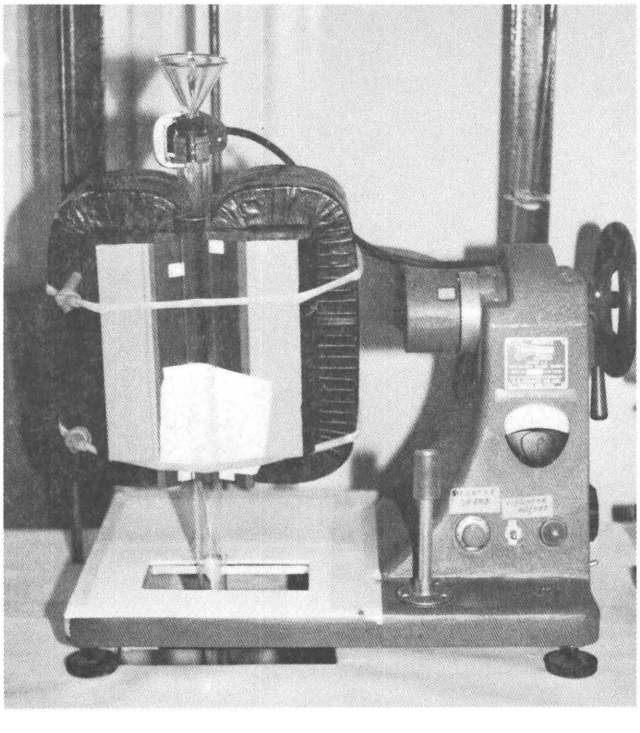

Figure 3. Modified magnetic separator used to recover ferromagnetic and strongly paramagnetic minerals.

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[1] Use of trade names in this report is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

Each magnetic fraction was weighed and studied through binocular and petrographic microscopes. Long-wave and unfiltered short-wave ultraviolet illumination was used with other optical properties to detect zircon and monazite, respectively. X-ray diffraction was used to check the bulk mineralogy of a representative aliquot of each subfraction. Selected mineral grains were examined by use of a scanning electron microscope (SEM) and an energy dispersive X-ray analyzer (EDAX) methods.

Visually estimated percentages of individual mineral species were summed across magnetic fractions and were calculated as percentages of the total heavy minerals in a sample. This method does not take into account the different specific gravities of the mineral species; however, the average of specific gravities of all species in each subfraction are generally similar. Therefore, although the calculated percentages are not true weight percentages, the difference is probably insignificant.

To check the degree of recovery of heavy minerals by the wet-milling process, bulk samples of the light minerals were also processsed in tetrabromoethane. By an analysis of these samples, an average of about 5 percent by weight of the total heavy-mineral content of a sample was not recovered by the wet-milling process. The mineral species in this fraction were micas, pyroboles, epidote, limonite, and altered grains, although small amounts of garnet, sphene, andalusite, sillimanite, staurolite, tourmaline, and apatite were also present. With the exception of garnet, all of these minerals are among the lighter heavy minerals (specific gravity < 3.5).

Grain-size analyses of the samples are given in table 1 and heavy-mineral analyses in table 2; both tables include cumulative statistics. Because silt- and clay-rich sediments pose difficulties in both separation and identification methods, the amounts of ferromagnesian micas and lighter heavy minerals (specific gravity < 3.5) are probably underrepresented in table 2, and higher density minerals such as garnet and zircon may be overrepresented.

Results

The weight percentages of gravel in the Saco Bay samples range from a trace (<0.05) to about 9.5; silt and clay percentages determined by use of rapid sediment analyzer (RSA) data (S.J. Williams, written commun., 1985) range from 1 to about 96 percent. When the percentage of silt and clay is relatively low (less than 11 percent), samples generally contain >1.0 percent heavy minerals (compare tables 1 and 2). When the estimated silt and clay content is relatively higher (11 to 96 percent), the heavy-mineral content is typically < 1.0 percent. Of the 24 Saco Bay samples, 9 contain more than 1 percent heavy minerals in the upper 2.2 m of sediment.

Heavy-mineral species of the Saco Bay sediments, in decreasing order of abundance, include garnet, pyroboles (pyroxenes and amphiboles), sillimanite and andalusite, epidote group, tourmaline, staurolite, ilmenite (with traces of leucoxene), sphene, mica, apatite, zircon, rutile, limonite, magnetite, and pyrite. Monazite was not detected.

Table 1. Grain-size analyses of vibracore samples from Saco Bay , Maine

[T, trace(<0.5 percent); --, value not calculated because it would have been statistically meaningless. Gravel fraction determined from sieving. Sand fraction determined by subtracting gravel and silt plus clay fractions from 100 percent. Silt and clay fraction determined by use of rapid sediment analyzer (RSA) data (S.J. Williams, written commun., 1985).]

Sample number	Latitude[1] N.	Longitude[1] W.	Water depth (m)	Core depth interval (cm)	Weight percent of sample: Gravel (>2.0 mm)	Sand (2.0-0.062 mm)	Silt and clay (<0.062 mm)
1212	43.498	70.368	7.0	0-162	T	97.9	2
1213	43.504	70.360	7.9	0-134	1.7	96.8	1.5
1214	43.516	70.349	10.0	0-223	4.5	90.5	5
1215-1	43.522	70.342	10.4	0-124	T	54.7	45
1215-2				124-332	T	19.8	80
1215-3				332-424	.7	29.3	70
1216-1	43.505	70.347	15.5	0-66	T	75.8	24
1216-2				66-243	T	11.9	88
1217-1	43.514	70.341	12.5	0-180	1.1	88.9	10
1217-2				180-329	1.1	78.9	20
1218	43.526	70.330	9.5	0-94	7.1	87.9	5
1220-1	43.517	70.316	17.4	0-152	3.2	95.8	1
1220-2				152-317	6.4	63.6	30
1221	43.521	70.319	17.1	0-198	2.3	67.7	30
1240-1	43.485	70.338	22.2	0-124	.6	69.4	30
1240-2				124-246	9.4	40.6	50
1241-1	43.497	70.347	16.8	0-91	T	90.9	9
1241-2				91-203	T	24.9	75
1241-3				203-335	T	24.9	75
1241-4				335-434	T	24.8	75
1242-1	43.483	70.370	7.0	0-152	6.2	13.8	80
1242-2				152-305	T	4.9	95
1242-3				305-457	T	3.8	96
1242-4				457-515	T	3.9	96
Minimum value					T	3.8	1
Mean value					1.9	--	--
Maximum value					9.4	97.9	96
Standard deviation					2.7	--	--

[1] Latitude and longitude expressed in degrees to the nearest thousandth.

The ratio of pyroxenes to amphiboles in all samples is approximately equal. Pyroxene species include hypersthene, augite, and rare aegerine-augite; amphiboles are dominated by blue-green and green hornblende. Brown hornblende is present, basaltic hornblende and riebeckite are also present but very rare. The epidote group includes both epidote and clinozoisite. Sillimanite occurs in slightly greater amounts than andalusite. Most tourmaline is brown, but some is blue.

Pyrite and anatase appear to be of authigenic origin because of unweathered crystal facets, but they may also be detrital, considering the rapidity with which periglacial sediments are deposited. Limonite most commonly appears as a coating on other grains. Ilmenite shows minor alteration to leucoxene.

Apatite and sphene occur in strongly subequal amounts; no immediate explanation for this is available. Zircon and rutile are relatively scarce; the latter is generally in trace quantities. Other trace minerals (<0.5 percent of the heavy minerals) were anatase, corundum, olivine(?), and chloritoid. In addition, most samples also contain at least trace amounts of altered grains that are included in the "Other minerals" column in table 2.

Little evidence for dissolution of unstable to moderately stable minerals has been found in nearshore areas of the Gulf of Maine (Ross, 1970). Our volumetrically large samples confirm this interpretation for Saco Bay. Ross (1970) found that garnet, amphibole, augite, epidote, and staurolite constituted more than 75 percent of the nonopaque heavy minerals in the Gulf of Maine. These minerals constitute an average of about 69 percent of the total heavy-mineral fraction in the present study.

The mineralogic differences indicated by the data given on table 2 show an increase of magnetite, pyrite, and limonite coupled with a decrease in the EHM/T with depth. To a lesser degree, pyroboles

Table 2. Heavy-mineral analyses of vibracore samples from Saco Bay, Maine

[T, trace (<0.1 in EHM/T column, <0.5 in other columns); N, not detected; S.G., specific gravity; --, value not calculated because it would have been statistically meaningless]

Sample number	Weight percent of sample having S.G.>2.96	Weight percent of minerals having S.G.>2.96																		
		Magnetite	Ilmenite	Luecoxene	Pyrite	Limonite	Mica	Garnet	Staurolite	Epidote group[1]	Pyroboles[2]	Sillimanite and andalusite	Tourmaline	Sphene	Apatite	Rutile	Zircon	Other minerals[3]	EHM/C[4]	EHM/T[5]
1212	1.91	T	5.0	T	T	T	5.9	21.8	3.6	9.4	26.2	9.7	8.1	3.4	1.9	T	2.9	1.2	17.8	0.26
1213	3.16	T	3.7	T	T	T	1.1	28.3	4.2	11.4	25.2	8.2	8.5	3.2	1.8	T[6]	2.8	.9	15.1	.37
1214	1.20	T	6.1	T	T	T	0.9	48.9	4.7	6.8	16.8	4.8	5.3	1.9	.7	.5[6]	1.6	.8	17.3	.12
1215-1	1.91	T	3.4	T	N	T	4.2	24.7	3.5	9.2	33.5	9.3	5.1	1.7	1.7	T	1.7	1.8	14.6	.22
1215-2	.31	T	3.1	T	N	T	1.5	35.6	5.2	9.1	23.1	9.5	5.9	1.7	1.7	T	1.7	1.5	14.5	.03
1215-3	.17	T	2.9	T	T	T	.6	32.5	4.7	10.7	22.7	10.8	5.9	1.4	3.1	T	2.1	2.0	15.9	.02
1216-1	1.49	T	2.6	T	N	T	1.2	29.8	5.6	8.8	25.3	11.3	9.6	1.7	1.7	T	1.2	.7	15.3	.17
1216-2	.26	0.7	3.1	T	N	T	1.3	35.7	4.9	9.3	19.2	10.3	7.5	3.1	1.3	T	2.8	.5	16.4	.03
1217-1	1.44	T	2.5	T	T	T	1.6	28.7	6.1	6.7	29.4	7.9	11.5	1.9	1.4	T[6]	1.4	T	12.2	.14
1217-2	.82	T	3.0	T	T	T	1.3	34.5	3.9	6.9	28.3	7.0	10.0	2.4	.9	T[6]	.9	T	11.3	.07
1218	1.31	T	3.0	T	T	0.9	.7	50.5	4.7	4.8	20.7	4.2	6.4	.9	.7	.5	.9	1.0	8.6	.09
1220-1	1.56	T	3.9	T	T	T	T	28.9	6.8	9.3	28.9	6.8	10.6	.9	.9	T	.9	1.4	11.7	.14
1220-2	.77	T	4.9	T	T	T	1.2	37.1	8.2	6.1	25.2	5.3	6.7	1.2	.9	T[6]	1.2	1.5	11.6	.07
1221	.86	T	3.4	T	T	T	1.2	27.0	4.7	9.8	27.1	12.3	7.2	2.2	1.6	T[6]	1.1	1.8	17.0	.11
1240-1	.47	1.0	2.6	T	T	T	.9	29.9	6.8	6.3	26.8	10.6	6.2	2.1	2.1	T	2.1	2.2	15.5	.06
1240-2	.43	4.0	2.1	T	6.0	1.6	T	33.7	5.5	5.6	17.1	9.3	5.0	2.5	2.5	T	1.2	3.3	12.8	.04
1241-1	1.81	T	4.5	T	T	T	2.3	19.3	2.8	10.9	35.9	10.7	3.8	3.1	2.1	T	3.1	.6	18.5	.26
1241-2	.88	.9	4.7	T	T	.8	2.9	22.4	5.0	8.6	30.3	9.4	4.9	3.1	3.1	T	2.1	1.3	16.4	.11
1241-3	.13	2.0	1.7	T	T	1.2	1.7	28.1	4.8	9.1	27.0	9.7	6.8	2.9	1.8	T	1.4	1.5	13.0	.01
1241-4	.05	7.0	2.5	T	T	8.8	2.5	27.4	4.2	7.4	22.4	5.3	6.3	2.1	1.4	T	1.0	1.4	9.2	T
1242-1	.19	.7	4.9	T	T	T	2.9	33.3	7.9	4.7	21.3	8.8	7.6	2.5	1.7	.8[6]	1.2	.8	15.7	.02
1242-2	.02	5.4	4.5	T	T	2.3	2.9	31.2	4.5	6.2	22.9	7.6	5.7	2.2	2.2	.7	.7	T	13.5	T
1242-3	.02	5.3	2.4	T	2.4	1.0	2.9	32.7	4.3	7.2	20.3	7.7	5.8	1.9	2.4	T	1.4	1.5	11.7	T
1242-4	.11	2.0	3.7	T	T	19.0	2.0	25.4	3.9	7.4	19.7	8.9	2.7	1.5	1.5	T	1.0	.7	13.8	.01
Minimum value	.02	T	1.7	--	N	T	T	19.3	2.8	4.7	16.8	4.2	2.7	.9	.7	T	.7	T	8.6	T
Mean value	.89	--	3.5	--	--	--	1.8	31.1	5.0	8.0	24.8	8.6	6.8	2.1	1.7	T	1.6	1.2	14.1	.10
Maximum value	3.16	7.0	6.1	--	6.0	19.0	5.9	50.5	8.2	11.4	35.9	12.3	11.5	3.4	3.1	.8	3.1	3.3	18.5	.37
Standard deviation	.81	--	1.1	--	--	--	1.3	7.3	1.3	1.9	4.9	2.1	2.1	.7	.7	--	.7	.7	2.6	.10

[1] Includes epidote and clinozoisite.

[2] Pyroxenes plus amphiboles.

[3] May include corundum, chloritoid, altered grains, and unknown minerals.

[4] Sum of percentages of ilmenite, leucoxene, rutile, zircon, and sillimanite and andalusite in S.G.>2.96 concentrate.

[5] Weight percentage of economic heavy minerals in the total sample.

[6] Anatase seen in this sample.

decrease, and garnet increases with depth. Greater than trace amounts (0.5 percent or more) of magnetite, pyrite, and (or) limonite appear to correlate somewhat with relatively high amounts of silt and clay in a sample (see table 1); of 11 samples containing >0.5 percent of these minerals, only one sample contains less than 25 percent silt and clay.

CONCLUSIONS

The nine samples containing more than 1 percent heavy minerals represent core intervals from the upper 2.2 m. The economically important minerals of the Atlantic Contintental Shelf are ilmenite, leucoxene, aluminosilicates, zircon, rutile, and monazite (Grosz and Escowitz, 1983). The weight percentages of the economically important minerals (EHM/T column, table 2) in the sediments of Saco Bay constitute an average of 0.1 percent of whole samples, ranging from <0.01 to 0.37 percent, or 8.6 to 18.5 percent of the heavy-mineral fraction (EHM/C column, table 2). For comparison, EHM/T and EHM/C values are about 2.5 and 70 percent, respectively, in commercial deposits in northeastern Florida. Thus the Saco Bay deposits have little economic importance.

Saco Bay bottom sediment has been characterized as a well-sorted sand, uniformly distributed over wide areas in water depths from 4 to 21 m (Farrell, 1972). Folger and others (1975) supported this conclusion, although they indicated coarse glacial debris and (or) bedrock in the northern part of Saco Bay and around Bluff, Stratton, and Eagle Islands (fig. 1). These previous studies examined only the uppermost centimeters of bottom sediment. Our study shows sands in the uppermost parts of the cores range from very well to very poorly sorted, and it indicates that coarse glacial debris is more prevalent in surficial sediments of Saco Bay than was previously thought. In the 12 cores examined, sand thicknesses range from 0.5 to 3.2 m and average 1.6 m. Furthermore, from examination of cores with deeper penetrations (>2 m), this widespread sand appears to rest upon an equally widespread silt and clay substrate which is at least as thick (see appendix).

The heavy-mineral assemblages of Saco Bay, Maine, are generally uniform both laterally and vertically. Although surficial samples contain more than 1 percent heavy minerals, the dominant species, garnet and pyroboles, are not highly valued minerals. The same species persist to depth in all 12 cores, but samples rich in silt and clay contain significantly lower percentages of heavy minerals. On the basis of the samples analyzed, the potential for thick sand deposits with significant economic heavy-mineral concentrations in Saco Bay appears to be small.

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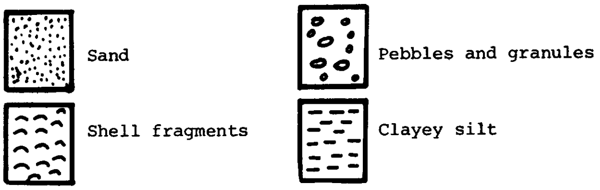
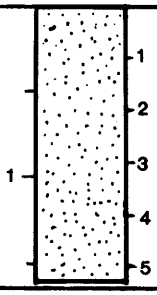
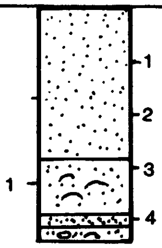
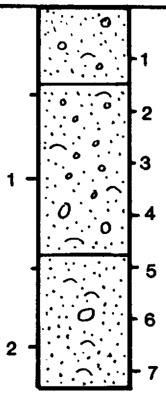
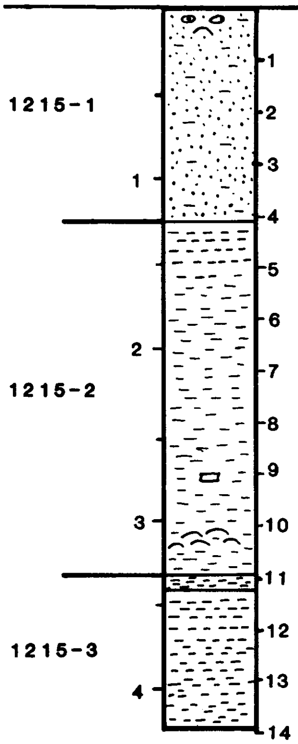
Appendix. Megascopic descriptions of vibracores from Saco Bay, Maine, showing division of cores into samples for heavy-mineral analysis. Location of cores shown on figure 1.

EXPLANATION



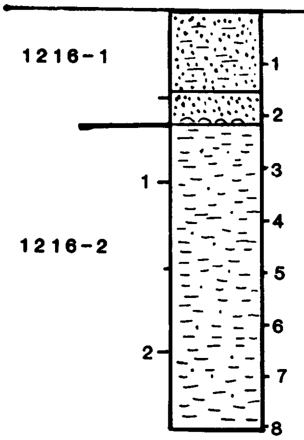
Sample number	Core depth (meters) (feet)	Lithic-unit depth (centimeters)	Description
			USGS 1212, water depth 7 m (23 ft)
1212		0-162	Sand, very light gray, very fine, very well sorted, micaceous; minor amounts of sand-dollar fragments and tiny pelecypod shells.
			USGS 1213, water depth 7.9 m (26 ft)
1213		0-87	Sand, very light gray, very fine, well-sorted; includes sand-dollar fragments.
		87-119	Same as above, but also includes salt-and-pepper colored, medium-grained sand, large pelecypod shell fragments, and small whole turritellid gastropod shells.
		119-127	Same as 0- to 87-cm interval.
		127-134	Sand, salt-and-pepper colored, medium-grained; includes large, irregularly shaped angular rock fragments and minor amounts of shell and sand-dollar fragments.
			USGS 1214, water depth 10 m (33 ft)
1214		0-43	Sand, gray, medium-grained; includes a few granules and rare shell fragments.
		43-144	Sand, gray, coarse; includes large shell fragments (including one sand dollar), granules, and flat pebbles as long as 2.5 cm; gravel >10 percent.
		144-223	Sand, light-gray, fine, well-sorted; includes large shell fragments, large mica flakes, and one subrounded pebble 4 cm long.

USGS 1215, water depth 10.4 m (34 ft)



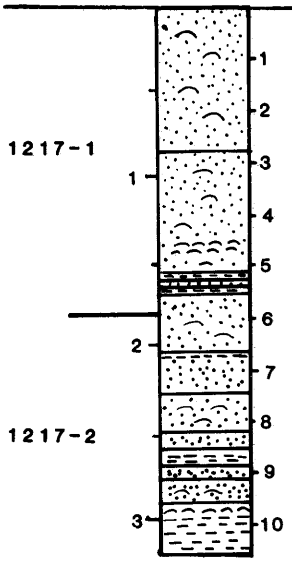
0-124	Silty sand, gray, very fine, micaceous; two subrounded pebbles and one shell fragment at top of unit.
124-332	Clayey silt, light-gray; wood fragment at 277 cm; large shell fragments at 312 cm.
332-342	Clayey silt, dark-purplish-gray; rich in organic matter.
342-424	Clayey silt, light-gray.

USGS 1216, water depth 15.5 m (51 ft)



0-45	Silty sand, medium-gray, very fine, micaceous; no shells or pebbles.
45-66	Sand, gray, very fine, micaceous; abraded shell fragments at base of unit.
66-243	Clayey silt, gray, with randomly distributed yellowish-brown mottling.

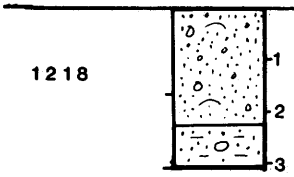
USGS 1217, water depth 12.5 m (41 ft)



0-83	Sand, gray, fine; includes shell and sand-dollar fragments.
83-156	Sand, salt-and-pepper colored, medium-grained; moderately sorted; pelecypod shells concentrated at 138-145 cm; shells, shell fragments, and sand-dollar fragments scattered throughout remainder of unit.
156-160	Silty clay lens, gray, micaceous.
160-165	Sand, gray, medium-grained; includes shells.
165-169	Silty clay lens, gray, micaceous; shell fragments at base of lens.
169-203	Sand, gray, fine; includes few shell fragments.
203-227	Sand, gray, medium-grained, micaceous; includes minute shell fragments; 0.5-cm silty clay lens at top of unit.
227-250	Sand, salt-and-pepper colored, medium-grained; includes shell fragments.
250-259	Sand, yellowish-gray, coarse; includes rare shell fragments.
259-269	Clayey silt lens, gray, micaceous; includes shell fragments.
269-278	Same lithology as 227- to 250-cm interval.
278-292	Same lithology as 250- to 259-cm interval.
292-323	Clayey silt, gray; includes shells at top of unit.

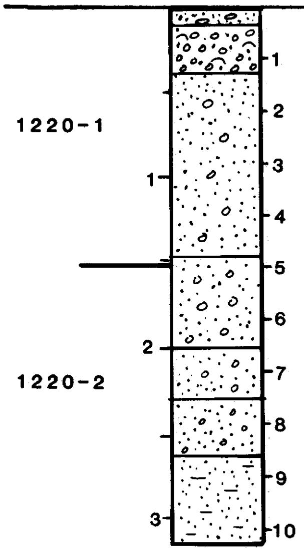
Note: All silty clay lenses contain small amounts of organic matter.

USGS 1218, water depth 9.5 m (31 ft)



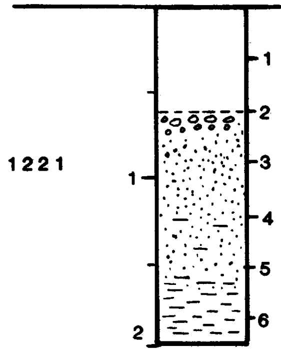
0-68	Sand, tannish-brown, medium-grained, poorly sorted; includes granules and subangular pebbles as long as 5 cm; shell and sand-dollar fragments; gravel >5 percent.
68-94	Silty sand, gray, very fine; includes etched and dissolved shell fragments and one rounded, encrusted pebble 3 cm in diameter.

USGS 1220, water depth 17.4 m (57 ft)



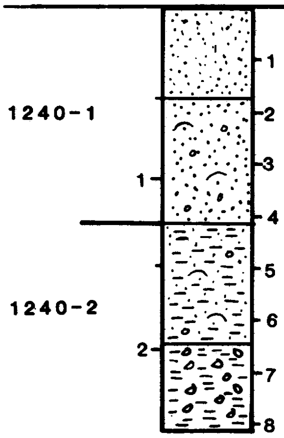
0-12	Sand, salt-and-pepper colored, medium-grained; includes few granules.
12-40	Pebbles, brownish-gray, very fine, maximum long diameter 5 cm; matrix of very coarse to coarse sand with shell fragments; unit is very poorly sorted; gravel >10 percent.
40-147	Same lithology as 0- to 12-cm interval.
147-200	Sand, salt-and-pepper colored, medium-grained, with granules and subrounded pebbles, maximum 2.5 cm in diameter; poorly sorted; gravel >10 percent.
200-231	Sand, salt-and-pepper colored, coarse, with granules and subrounded pebbles, maximum 2.5 cm in diameter; gravel >10 percent.
231-264	Same lithology as 147- to 200-cm interval, except gravel <10 percent.
264-317	Silty sand, gray, very fine, micaceous; unit is finely stratified, bioturbated in part.

USGS 1221, water depth 17.1 m (56 ft)



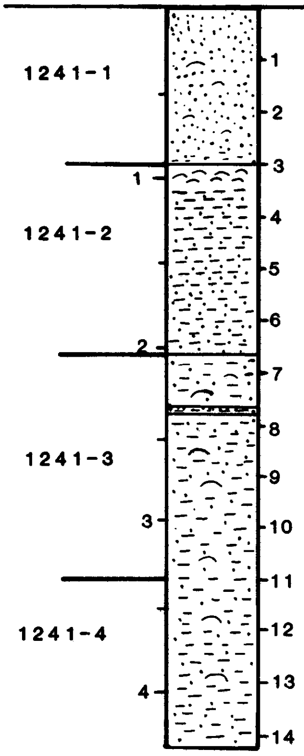
0-61	Core missing.
61-198	Sand, light-tan, medium-grained at top; grades downward through very fine sand to light-gray, coarse silt at base; abundant mica throughout; pebbles, maximum diameter 4 cm; gravel >10 percent at top of recovered core; evidence for fine stratification.

USGS 1240, water depth 22.2 m (73 ft)



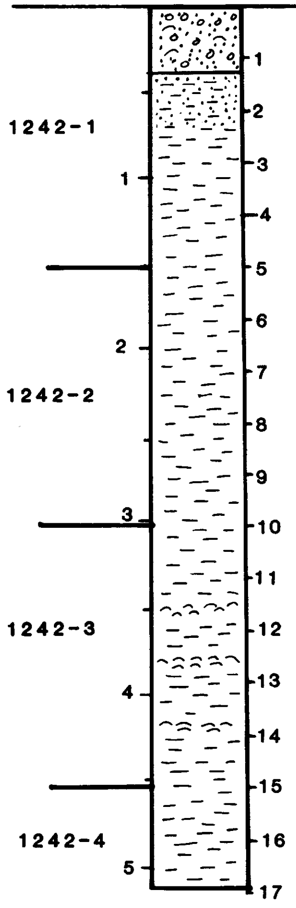
0-50	Sand, light-gray, very fine, very well sorted, micaceous; no shells.
50-124	Sand, light-gray, very fine; includes a few abraded shell fragments and subrounded to rounded pebbles, maximum diameter 2 cm.
124-195	Sandy silt, light-gray, similar to 50- to 124-cm interval.
195-246	Clayey silt, light-gray, very compact; subangular granules and angular, fresh pebbles; gravel >10 percent.

USGS 1241, water depth 16.8 m (55 ft)



0-91	Sand, light-gray, very fine, slightly silty at base, well-sorted; includes delicate shell fragments.
91-203	Sandy silty clay, gray; abraded shell fragments at top of unit.
203-434	Same lithology as 91- to 203-cm interval except for rare shell fragments scattered throughout this unit; light-gray, silty, very fine sand lens at 234-236 cm.

USGS 1242, water depth 7 m (23 ft)



0-38	Silty sand, light-gray, fine, very poorly sorted; granules, fresh shell fragments, and subangular pebbles, maximum diameter 5 cm; gravel >10 percent
38-515	Clayey silt, light-gray, sandy in upper 23 cm; shell fragments at 249 cm, 350 cm, 381 cm, and 414 cm.

Note: Extremely long core recovery suggests that clayey silt was very soft when core was taken.