

Figure 1.—Location and limits of study area in the western Gulf of Maine.

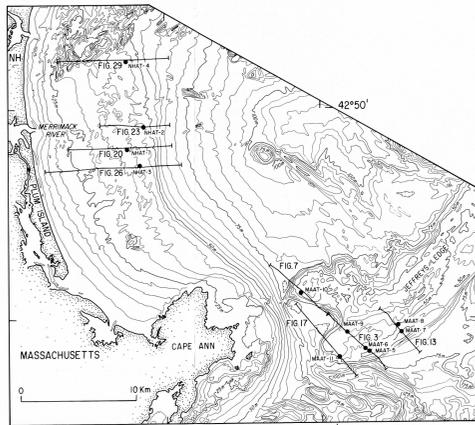


Figure 2.—Index and bathymetric map showing the location of seismic profiles and cores. Contour interval is 5 m.

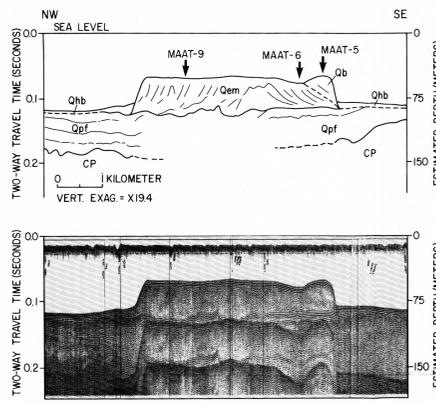


Figure 3.—Interpreted seismic profile showing the submerged end moraine and barrier beach and the location of cores MAAT-5, MAAT-6, and MAAT-9. Letter symbols indicate: CP = coastal plain strata, Qpf = glaciomarine mud, Qem = end moraine deposits, Qhb = marine mud, and Qb = beach deposits.

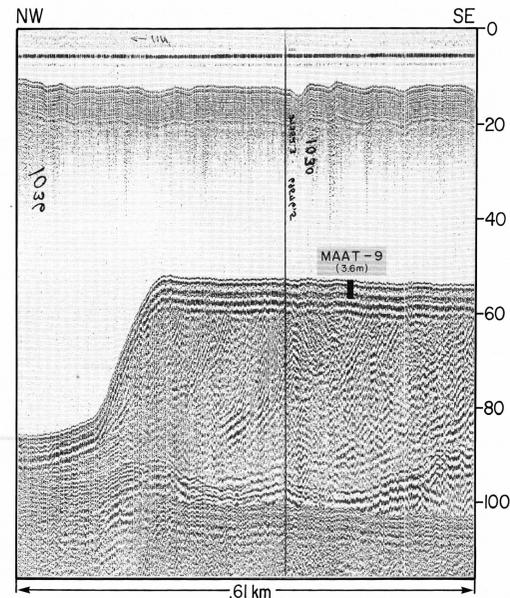


Figure 4.—Enlarged section of seismic profile (fig. 3) showing location of end moraine core MAAT-9.

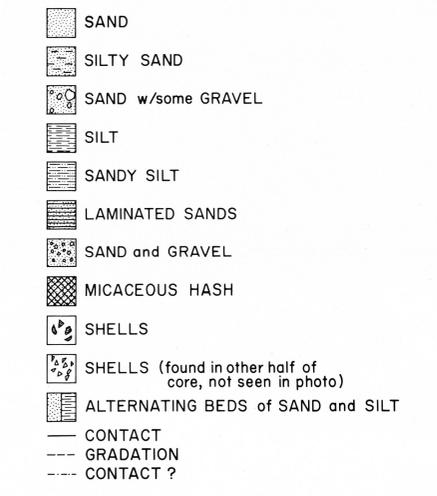


Figure 5.—Key showing symbols used to illustrate lithology of the cores. See figure 5 for key to lithologic symbols. Depth in centimeters.

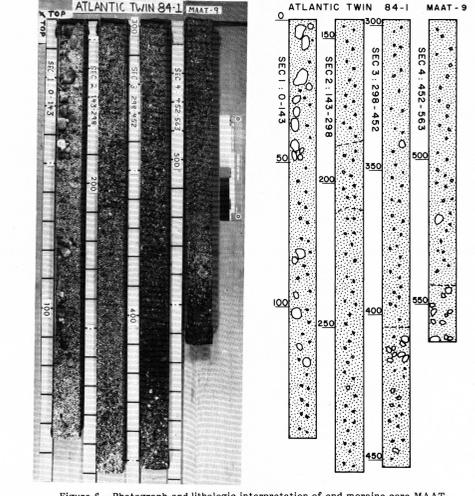


Figure 6.—Photograph and lithologic interpretation of end moraine core MAAT-5. See figure 5 for key to lithologic symbols. Depth in centimeters.

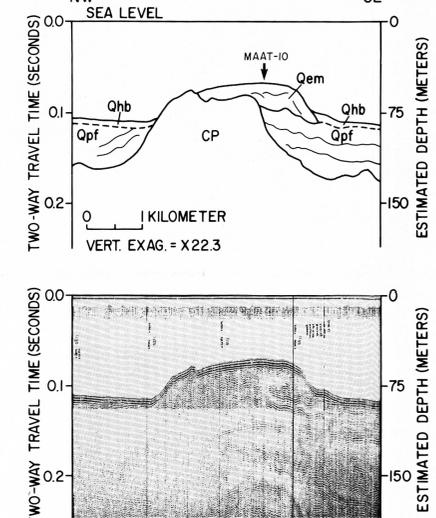


Figure 7.—Interpreted seismic profile showing submerged end moraine and the location of core MAAT-10. See figure 3 for meaning of letter symbols.

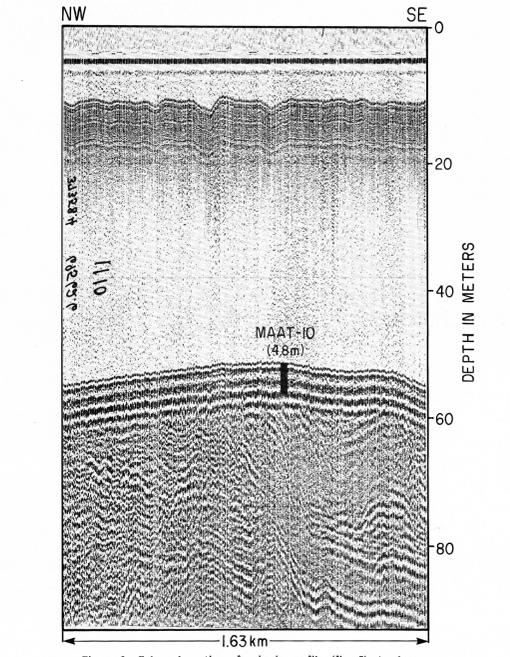


Figure 8.—Enlarged section of seismic profile (fig. 7) showing location of end moraine core MAAT-10.

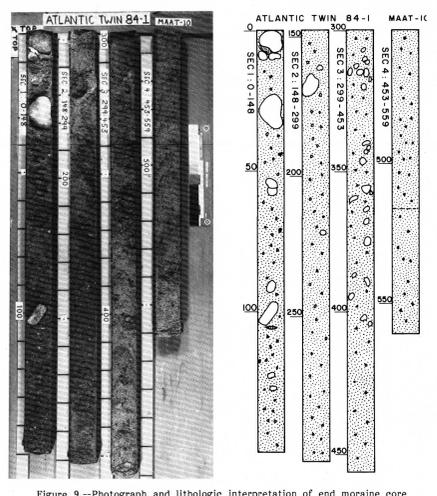


Figure 9.—Photograph and lithologic interpretation of end moraine core MAAT-10. See figure 5 for key to lithologic symbols. Depth in centimeters.

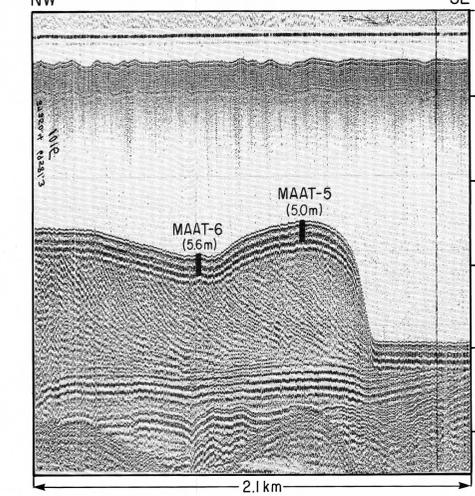


Figure 10.—Enlarged section of seismic profile (fig. 3) showing location of barrier beach core MAAT-5 and lagoon core MAAT-6.

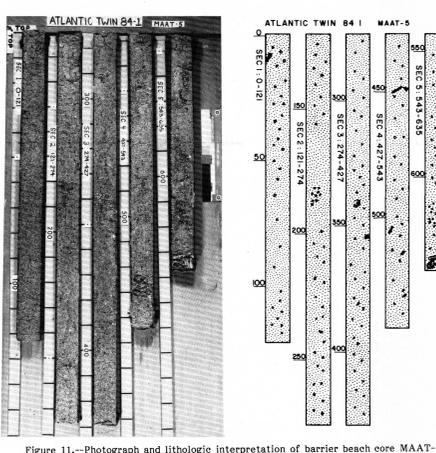


Figure 11.—Photograph and lithologic interpretation of barrier beach core MAAT-5. See figure 5 for key to lithologic symbols. Depth in centimeters.

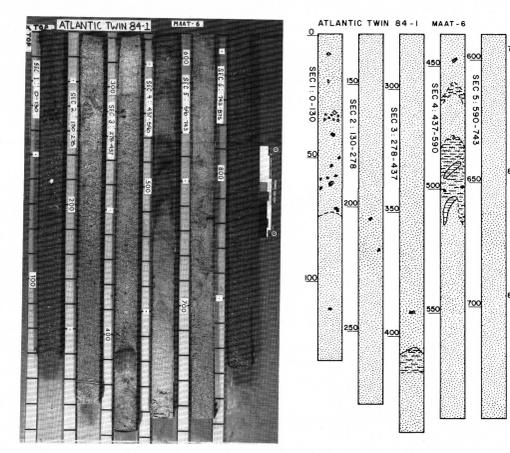


Figure 12.—Photograph and lithologic interpretation of lagoon core MAAT-6. See figure 5 for key to lithologic symbols. Depth in centimeters.

INTRODUCTION

Submerged marine geologic features located in the western Gulf of Maine between Cape Ann, Massachusetts and New Hampshire (fig. 1), were identified from high-resolution seismic-reflection data collected between 1978 and 1988. The features include the following: (1) A pair of end moraines formed during the retreat of the Laurentide ice Sheet from the Gulf of Maine (Oldale, 1985a). (2) A barrier spit and lagoon complex and (3) a paleodelta, both of which formed during a late Wisconsinan lowstand. The barrier spit and lagoon complex formed during the late Wisconsinan lowstand (Oldale and others, 1983; Oldale, 1985b). (4) A wave-cut unconformity that was eroded as the sea transgressed to its present position. (5) A surficial sand deposit that formed atop the unconformity in middle Holocene time. Vibracores (fig. 2) were taken in 1984 to corroborate the interpretations from the seismic data, to determine the sedimentary texture and structure of the features, to identify the nature of the unconformity, and to obtain material for ¹⁴C dating.

ACKNOWLEDGMENTS

Support for the vibracoring was supplied in part by the Commonwealth of Massachusetts and the U.S. Minerals Management Service. Alpine Ocean Seismic Survey, Inc. provided the vibracorer and the R/V Atlantic Twin, from which the vibracores were taken.

GEOLOGIC SETTING

End moraines in the study area were formed below sea level during the retreat of the Laurentide ice Sheet from the Gulf of Maine about 13 ka (Oldale, 1985a). At that time, relative sea level was higher than present (Oldale and others, 1983), the result of glacial isostatic depression of the crust below the late Wisconsinan eustatic sea level. Minor readvances of the Laurentide ice front formed the moraines as it overrode and deformed the glaciomarine mud and deposited till and ice-contact subaqueous outwash (Oldale, 1985a), in a manner described by Rust and Romanelli (1975), Smith (1983), and Smith and Hunter (1983).

After deglaciation, the crust rebounded and relative sea level fell to about 50 m below present sea level (Oldale and others, 1983). Timing of this lowstand is not well established, but it may have occurred about 11 ka (Oldale and others, 1987). The barrier spit and lagoon complex and the paleodelta are inferred to have formed at this time (Oldale and others, 1983; Oldale, 1985b). Following the formation of these features, the sea transgressed to its present position forming a widespread wave-cut unconformity overlain by a discontinuous surficial sand deposit that is middle Holocene and younger in age (Edwards and Oldale, 1988).

METHODS

Interpreted high-resolution seismic-reflection profiles were used to select the vibracore sites (fig. 2 and table 1). Profiles across the moraines and the barrier beach and lagoon complex were obtained using a Del Norte sparker. Core sites MAAT-5, MAAT-6, MAAT-9, and MAAT-10 were located with the locations of Del Norte seismic profiles in which the seismic returns were filtered between 280 to 1,600 Hz and recorded at a 0.5 sec sweep. Core sites NHAT-1 through NHAT-4 are on the Merrimack River paleodelta and were selected using interpreted Uniboom seismic profiles. The Uniboom seismic returns were filtered between 400 and 4,000 Hz and recorded at a 0.25 sec sweep.

Depths shown on the seismic profiles were determined using an assumed seismic velocity of 1.5 km/sec for the water column and sediment.

The cores (table 1) were taken using an Alpine Ocean Seismic Survey Vibracore capable of obtaining cores 8.0 cm in diameter and 9.1 m long. Penetration ranged from 3.7 to 8.4 m. Recovery probably ranged from 15 to 100 percent, although this is uncertain because of expansion within the core liner. The retrieved cores were cut into 1.5 m lengths, split, photographed, and described.

The core sites were located by reoccupying LORAN C fixes recorded during the original seismic survey. During the coring cruise, a seismic reflection profile was made over the core site to insure that the ship had arrived at the selected target.

END MORAINES

Two cores (MAAT-9 and MAAT-10) were taken in the end moraines located off Cape Ann and at the southwest end of Jeffreys Ledge (fig. 2). The moraines are characterized seismically by positive relief, deformed internal reflections indicating folding and faulting, and deformed internal reflections in the glaciomarine mud beneath the moraine (figs. 3, 4, 7, and 8). The cores indicate that the feature is in part underlain by sand containing abundant pebbles to cobble-sized elasts, and by pebbles to cobble-gravel (figs. 6 and 9). Core MAAT-10 (fig. 9) has a shell fragment in the upper part of the core and may include marine deposits of Holocene age.

BARRIER SPIT AND LAGOON

The barrier spit and lagoon complex is located on the southeastward flank of Jeffreys Ledge (fig. 2). The barrier spit is characterized seismically by a lens-shaped cross section with seaward-dipping internal reflections (figs. 3, 10, 15, 14, and 18) and bathymetrically by contours that depict a barrier ridge and lagoon (fig. 2). Three cores (MAAT-5, MAAT-6, and MAAT-11) penetrated the barrier spit (table 1) and indicate that the barrier is underlain by well-sorted, medium to very coarse sand with scattered pebbles, shell fragments, and layers of shell hash (figs. 11, 15, and 19).

Two cores (MAAT-8 and MAAT-10) penetrated sediments inferred, on the basis of the morphology (figs. 2, 10, 13, and 14), to have been deposited in a lagoon behind the barrier (Oldale, 1985b). Both cores consist mostly of very coarse to medium sand (figs. 12 and 16). They also contain layers of fine sand to silt, and scattered shell fragments. Core MAAT-6 also had contains two shell hash layers (fig. 12).

MERRIMACK RIVER PALEODELTA

A paleodelta is located approximately 8 km seaward of the mouth of the Merrimack River (fig. 2). The delta parallels the coast and is about 50 km long and 7 km wide. The major seismic characteristic of this feature consists of internal reflections that dip steeply seaward (figs. 20, 21, 23, 24, 26, 27, 29, and 30). The internal reflections are inferred to represent delta foreset beds.

Four cores (NHAT-1, NHAT-2, NHAT-3, and NHAT-4) were taken in the Merrimack River paleodelta (table 1). All of these cores penetrated the surficial sand deposit, the wave-cut unconformity, and the foreset beds of the delta. The delta deposits are finer grained than those of the surficial sand deposit and generally consist of interbedded silt to medium sand that coarsens upward to mostly medium sand (figs. 22, 25, 28, and 31).

WAVE CUT UNCONFORMITY

The wave cut unconformity is represented in the seismic data by a smooth reflection that defines the top of the delta deposits (figs. 20, 23, 26, and 29). In the cores, the unconformity is marked by a sharp lithologic change that in many places is overlain by a shell hash layer. The unconformity separates the delta deposit from the surficial sand deposit or forms the sea floor (figs. 22, 25, 28, and 31).

SURFICIAL SAND DEPOSIT

The surficial sand deposit was difficult to resolve in the seismic records because in many places it was thinner than the resolving power of the seismic system. The surficial sand deposit was more easily identified by side-scan sonar that showed it to form a discontinuous sand sheet of low relief and locally linear ridges up to 6 m high (Edwards, 1988). In cores (figs. 22, 25, 28, and 31), the surficial sand deposit is generally characterized by medium to very coarse sand with some pebbles and pebble gravel. Scattered shells and layers of shell hash were found at the base and within the deposit. Two shell hash layers in core NHAT-3 were ¹⁴C dated (Edwards and Oldale, 1988). The basal shell hash layer was dated 5,069 ± 200 yrs BP (W-5645), and the upper shell hash layer was dated 4,190 ± 190 yrs BP (W-5648) (fig. 28).

DISCUSSION

Cores from the end moraines off Cape Ann (Oldale, 1985a) show them to be composed of stratified gravely sand and gravel. The deposits are similar to ice-contact stratified drift found in emerged submarine end moraines in Maine (Smith, 1982; Smith and Hunter, 1983). The end moraines also include deformed glaciomarine mud as indicated by the seismic profiles (figs. 3 and 7) and probably till, deposited as the glacier overrode the moraines (Oldale, 1985a). They are similar to submarine end moraines, now emerged, at Cambridge, Mass. (Chute, 1959) and in Maine (Bloom, 1963; Smith, 1982; Thompson and Smith, 1983; Smith and Hunter, 1983). The submarine moraines were formed along the calving front of the marine-based Laurentide ice Sheet (Oldale, 1985a). The cores from the moraines did not contain datable materials. However, the moraines are located between the Cambridge moraine that formed about 14 ka (Kaye and Barbour, 1964) and the Kennebec moraine in southern Maine dated at 13.2 ka (Borns, 1973). Thus, they are likely to be intermediate in age.

The well-sorted, shaly, pebbly, medium to very coarse sand in the barrier spit and the finer-grained shaly sediments in the cores from the lagoon support the earlier interpretations of these features based on seismic data (Oldale, 1985b). The barrier spit may have an emerged analogue in the beach at an elevation of about 16 m above sea level in the Merrimack Valley, that formed as sea level fell from the late Wisconsinan marine limit (Edwards, 1988). The silt to medium sand composition of cores NHAT-1 to NHAT-4 is consistent with the interpretation from the seismic data (Oldale and others, 1983) that the delta is a delta. A nearby delta, that formed as the sea regressed from the late Wisconsinan marine limit, is a delta in the Merrimack Valley at about 16 m above sea level. Exposures in this delta show it to be composed of fine to medium sand (Edwards, 1988). The submerged barrier beach and lagoon complex on Jeffreys Ledge and the submerged Merrimack River paleodelta have not been dated as yet. However, they probably were formed during the 50 m lowstand inferred to have occurred about 11-10.5 ka (Oldale and others, 1983, Oldale, 1985b; Oldale and others, 1987).

The wave-cut unconformity is a time-transgressive feature that represents the passage of the sea floor from the late Wisconsinan lowstand to the present shore. Wave erosion probably removed the topset beds of the paleodelta and supplied the sediments for the surficial sand deposit. The ¹⁴C dates from core MAAT-3 indicate that the surficial sand deposit formed during middle Holocene time as the shoreface of a barrier spit migrated shoreward to its present position off Plum Island (fig. 2) (Edwards, 1988). Modern northeast storms may modify the surficial sand deposit.

CONCLUSIONS

Sediments recovered in vibracores from five marine geologic features in the western Gulf of Maine support the initial interpretations of these features based on high-resolution seismic-reflection data. The submarine end moraines formed during ice front fluctuations of the marine-based Laurentide ice Sheet during its retreat from the Gulf of Maine. The Merrimack River paleodelta and the barrier spit and lagoon complex were formed during the low sea-level stand that occurred about 11 ka following the retreat of the Laurentide ice. The wave cut unconformity stop the delta formed during the Holocene transgression of the shoreline, and the surficial sand deposit may have formed in middle Holocene time at the shore face of a barrier spit that migrated landward during transgression.

REFERENCES CITED

Bloom, A.L., 1963, Late-Pleistocene fluctuations of sea level and postglacial crustal rebound in coastal Maine. *American Journal of Science*, v. 261, p. 828-878.

Borns, H.W., 1973, Late Wisconsinan fluctuations of the Laurentide ice Sheet in southern and eastern New England. In Black, R.F., and others, eds., *The Wisconsinan Stage*. Geological Society of America Memoir 136, p. 37-45.

Chute, N.E., 1959, Glacial geology of the Mystic Lakes-Fresh Pond area, Massachusetts. U.S. Geological Survey Bulletin, 191F, p. 187-218.

Edwards, G.B., 1988, Late Quaternary geology of northeastern Massachusetts and the Merrimack embayment, western Gulf of Maine. Unpublished M.S. thesis, Boston University, 337 p.

Edwards, G.B., and Oldale, R.N., 1986, Evidence for Holocene erosional shoreface retreat in a linear ridge system offshore Merrimack River, Massachusetts. *Geological Society of America Abstracts with Programs*, v. 16, n. 1, p. 14.

Kaye, C., and Barbour, E.S., 1964, Late Quaternary sea-level change and crustal rise at Boston, Massachusetts, with notes on the autocorrelation of peat. *Geological Society of America Bulletin*, v. 75, p. 63-80.

Oldale, R.N., 1985a, Upper Wisconsinan submarine end moraines off Cape Ann, Massachusetts. *Quaternary Research*, v. 24, p. 187-196.

Oldale, R.N., 1985b, A drowned Holocene barrier spit off Cape Ann, Massachusetts. *Geology*, v. 13, p. 375-377.

Oldale, R.N., Whitmore, T.C., and Grimes, J.R., 1987, Elephant teeth from the western Gulf of Maine, and their implications: *National Geographic Research*, v. 3, p. 439-446.

Oldale, R.N., Womack, J.E., and Whitney, A.B., 1983, Evidence for a postglacial low relative sea-level stand in the drowned delta of the Merrimack River, western Gulf of Maine. *Quaternary Research*, v. 19, p. 325-338.

Rust, B.R., and Romanelli, Richard, 1975, Late Quaternary subaqueous outwash deposits near Ottawa, Canada. In Hopkins, A.V., and MacDonald, B.C., eds., *Glaciofluvial and glaciolacustrine sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication 22*, p. 177-193.

Smith, G.W., 1982, End moraines and the pattern of ice retreat from central and south coastal Maine. In Larson, G.J., and Stone, G.D., eds., *Late Wisconsinan glaciation of New England*. Dubuque, Iowa, Kendall/Hunt, p. 195-209.

Smith, G.W., and Hunter, L.L., 1983, Late Wisconsinan deglaciation of coastal Maine. In Tucker, R.G., and Marvinney, R.G., eds., *Studies in Maine Geology*, Vol. 6. *Quaternary Geology*. Maine Geological Survey, Augusta, p. 13-22.

Thompson, W.B., and Smith, G.W., 1983, Pleistocene stratigraphy of the Augusta and Waldoboro areas, Maine. *Maine Geological Survey Bulletin* 27, 37 p.

CORES FROM MARINE GEOLOGIC FEATURES IN THE WESTERN GULF OF MAINE

By
Robert N. Oldale¹ and Gerald B. Edwards²
1990

¹U.S. Geological Survey, Woods Hole, Mass.
²Chambers M. Montgomery Consulting Engineers, Inc., Herndon, Va.