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MAPS AND SEISMIC PROFILES SHOWING GEOLOGY OF THE INNER CONTINENTAL SHELF, MASSACHUSETTS BAY, MASSACHUSETTS

By
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Introduction

This report depicts the geology and discusses the geologic history of the Inner Continental Shelf off the central part of the Massachusetts east coast. Massachusetts Bay is located between Cape Cod Bay and Cape Ann, and its eastern limit lies in the vicinity of Stellwagen Basin (figs. 1, 2).

Geologic interpretations are based on about 1,500 kilometers (km) of high-resolution seismic-reflection profiles, on cores, and on published accounts of the geology of the adjacent coast. Massachusetts Bay is underlain by consolidated rock of Precambrian to possibly Triassic age that is locally overlain by unconsolidated coastal plain strata of Cretaceous to Tertiary age. Bedrock types are not delineated by the data and the coastal plain deposits are not well known. These older rocks form the basement for the Pleistocene and Holocene sediments of Massachusetts Bay. Drift of the late Wisconsinan glaciation is underlain in places by older glacial deposits. The upper drift is composed mostly of submarine deposits that were laid down during ice retreat. At that time, ice loading depressed the crust below worldwide (eustatic) sea level. Rebound of the crust following the melting of the ice caused shoreline regression and allowed the exposed drift to be fluvially eroded while deposition continued offshore. As rebound slowed or ceased, the shoreline gradually transgressed to its present position. Marine plantation and the formation of estuaries and beach or bar deposits characterize the most recent episode in the geologic history of Massachusetts Bay.

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Methods

This report is based primarily on three sets of high-resolution seismic-reflection profiles from Massachusetts Bay. The first set was taken in 1972 during a survey made by the Raytheon Co. Company under contract with the Massachusetts Department of Natural Resources. The survey covered the area between lat. 42°50' N. and 42°38' N. and it produced 800 km of high-resolution seismic-reflection and sidescan-sonar profiles, along generally east-trending tracklines up to about 18 km long and spaced approximately 0.5 to 2 km apart. Selected seismic-reflection profiles, spaced about 2 km apart, were used for this report (tracklines are shown in figure 2). In addition to the geophysical profiles, data from the Raytheon survey included vibrocores from 45 sites, bottom grab samples, and bottom photographs. The original navigation log and chart, seismic-reflection profiles, and sidescan-sonar profiles are on file at the U.S. Geological Survey (USGS) office in Woods Hole, Mass. Only selected profiles from the Raytheon survey were used for this report; their tracklines are shown in figure 2.

Two other sets of seismic-reflection profiles were collected by the USGS, as part of a cooperative program between the USGS and the Massachusetts Department of Public Works. Seismic-reflection data were collected aboard the RV *Gilliss* in the spring of 1979 along about 720 km of mostly east-trending tracklines, as part of a survey of Stellwagen Bank and Stellwagen Basin. More data were taken aboard the RV *Asterias* in the summer of 1979 along about 500 km of mostly east-trending tracklines. Tracklines on both cruises were spaced approximately 1.8 km apart.

All subbottom profiles were made using an EG&G Uniboom[1] high-resolution seismic-reflection system. The analog data were displayed on 19-inch paper using a quarter-second sweep. On the RV *Gilliss* and RV *Asterias* cruises, the sound source was triggered every half second, and returning seismic signals were filtered between 400 and 4,000 Hertz (Hz). Records from the Raytheon survey do not include trigger rate or filtering. Generally, on all three surveys, subbottom layers less than about 1 meter (m) thick were not resolved by the seismic system.

Navigation during the Raytheon survey was by LORAC[1], a radiolocation system utilizing three portable land-based transmitting stations. Claimed accuracy was to 8.5 m, but there are indications that those obtained using the LORAC system were considerably less accurate. Navigation systems aboard the RV *Gilliss* included Loran-C and the USGS integrated navigation system. Fixes were automatically recorded at about 20-second (s) intervals. Loran-C was used aboard the RV *Asterias* with manually recorded fixes at 15-minute intervals and at major course changes.

Assumptions as to the geologic nature and age of the seismic reflectors and seismic units (fig. 3) are based on the adjacent subaerial stratigraphy, on information from cores and bottom samples, and on correlation with reflectors and seismic units determined in seismic studies of adjacent offshore areas.

The depths below sea level of major seismic reflectors and the thickness of seismic units are based on inferred sound-velocities of 1.5 km/s for water and for sediments inferred to be of Holocene age, 1.8 km/s for sediments inferred to be of Pleistocene age, and 2.5 km/s for sediments inferred to be of Tertiary or Cretaceous age. The contacts between seismic reflectors and the contacts determined from the cores agree reasonably well and indicate that a sound velocity of 1.5 km/s is appropriate for the glacial marine and Holocene deposits. However, the velocity of 1.8 km/s was assigned to the undifferentiated drift in a compromise that takes into account higher velocities that probably occur in the older glacial deposits. The geologic map (fig. 13) represents the inferred geologic units that, within the resolution of the Uniboom system, crop out at the sea floor. Cross-sections were derived from the geologic map on the basis of depths and thicknesses calculated from the seismic profiles.

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

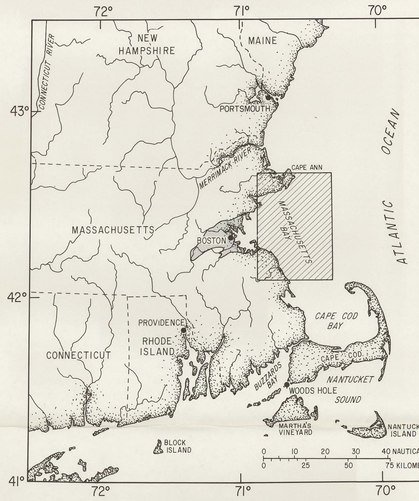

Figure 1.--Index map of southeastern New England showing the study area (ruled pattern). Stippled area shows approximate limit of the Boston basin.

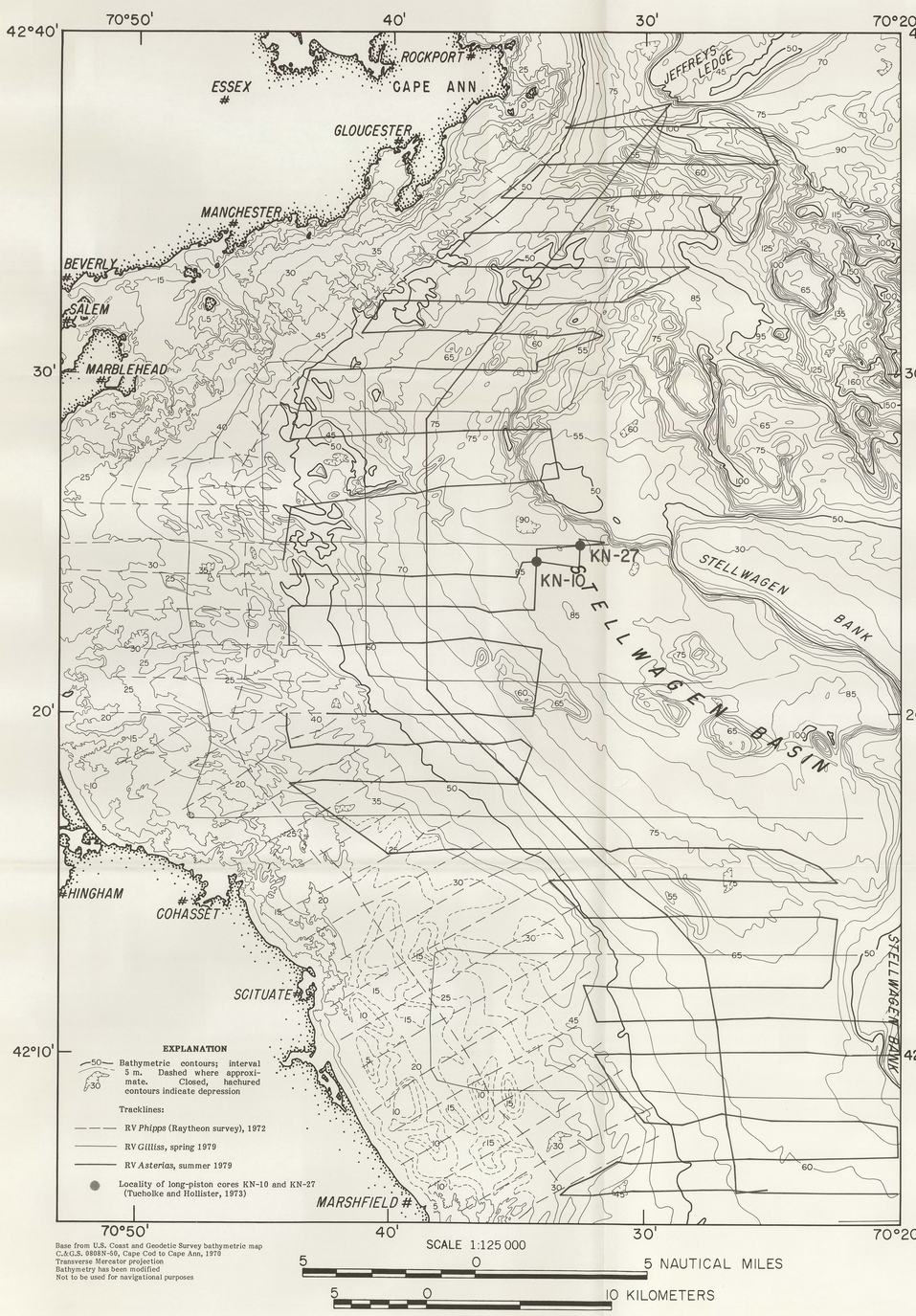

Figure 2.--Bathymetry and tracklines.

Previous work

Many previous studies have outlined the geology and geologic history of the region. Offshore seismic-reflection surveys have defined the major stratigraphic units and unconformities (Oldale and others, 1973). Two long-piston cores from Stellwagen Basin (fig. 2) provided information on the nature and age of the postglacial sediments (Tucholke and Hollister, 1973). Tracklines on both cruises were spaced approximately 1.8 km apart.

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Geologic setting

The bedrock geology of the Massachusetts east coast is complex and probably representative of the bedrock beneath Massachusetts Bay. South of the Boston basin, the rocks are mostly granites of Precambrian age, although near Marshfield (fig. 2), Pennsylvanian clastic rocks of the Narragansett basin occur (Zen, 1983). Within the Boston basin, bedrock consists mostly of volcanic and sedimentary rocks of Precambrian to earliest Cambrian age (Zen, 1983; Kaye, 1984). The rocks along the coast north of the Boston basin are mostly granites of Precambrian age, and Cape Ann is underlain by granite of Ordovician to Silurian age (Zen, 1983). Formational contacts and faults in coastal Massachusetts generally strike northeast (Zen, 1983), and presumably these trends continue beneath Massachusetts Bay. Sedimentary and igneous rocks of Triassic age may occur locally offshore; Kaye (1982a) identified a small Triassic basin about 18 km northwest of Marblehead (fig. 2). Unconsolidated sedimentary rocks of Mesozoic age containing reworked pollen of Late Cretaceous, Paleocene, and Eocene age (Kaye, 1982b) occur atop bedrock in the vicinity of Marshfield. Similar deposits have been inferred to occur offshore in the western Gulf of Maine (Oldale and others, 1971). The fluvial unconformity atop bedrock (including Triassic rocks) is variable in age. Where the unconformity is overlain by Miocene deposits, it is Paleogene or older. The unconformable surface atop the bedrock and coastal plain deposits is late Tertiary or early Quaternary in age. This younger fluvial unconformity was modified by glacial erosion at least twice (Kaye, 1976; Hanson, 1984).

Deposits of Quaternary age along the east coast of Massachusetts provide a stratigraphic framework for understanding the Quaternary deposits in Massachusetts Bay. A lower till characterized by deep weathering occurs mostly in drumlins (Kaye, 1976; Hanson, 1984). The till is considered to be pre-Wisconsinan (Oldale and Eakenasy, 1983) or early Wisconsinan (Koteff and Pessl, 1985) in age. A thin sandy till of late Wisconsinan age caps bedrock in many places. South of the Boston basin, the late Wisconsinan drift consists mostly of glaciofluvial and glaciolacustrine deposits (Chute, 1965a,b). These deposits may have been associated with a glacial lake that occupied Cape Cod Bay and possibly southernmost Massachusetts Bay (Oldale, 1982; Stone and Peper, 1982). Along the coast from Boston northward, glacial drift consists mostly of coarse ice-contact and outwash deposits of submarine origin and fine-grained glacial-marine deposits. These deposits are related to a marine incursion that was synchronous with the retreat of the late Wisconsinan ice (Hanson, 1984; Stone and Peper, 1982).

The late-glacial and postglacial history of sea-level change for Massachusetts' east coast is complex. South of the Boston basin, submergence followed deglaciation by a considerable amount of time (Redfield and Rubin, 1962; Oldale and O'Hara, 1980). From Boston northward, ice retreat and submergence were contemporaneous and were followed shortly by rapid regression of the shoreline as the crust rebounded due to the release of the ice load. As sea level fell below present sea level by tens of meters (Kaye and Barghoorn, 1964; Oldale and others, 1983), the exposed glacial drift was fluvially eroded to form a regressive unconformity. Sediments that were deposited during this early Holocene lowstand formed a now-submerged delta (Oldale and others, 1983) and spit (Oldale, 1985a) that occur north of Cape Ann. Transgression to the present shoreline followed the lowstand (Oldale, 1985b). As sea level rose, estuarine deposits formed in the valleys. As the surf zone crossed the landscape, glacial deposits and estuarine deposits were eroded to form a transgressive unconformity that in many places extends to the present shore. Beach or bar deposits formed atop the transgressive unconformity both offshore and along the coast.

Interpretation of the seismic data

Photographs and matching line drawings (fig. 3) illustrate our geologic interpretation of the seismic data. The stratigraphically lowest reflector in the profiles represents the bedrock surface (unit Pz). It can be traced landward to where bedrock crops out along the shore. Where this reflector coincides with the sea floor, bedrock can be identified by joining that is clearly displayed by sidescan-sonar profiles. We infer that the bedrock beneath Massachusetts Bay is similar to that of adjacent areas on land. The depth to the bedrock surface increases from a few tens of meters nearshore to more than 280 m east of Cape Ann (fig. 4).

Bedrock is overlain by a discontinuous seismic unit (fig. 3, top in profiles B, D, C, E, and F) that occurs mostly east of Cape Ann (fig. 5). The base of this unit is not revealed by seismic data in most places. The unit is inferred to represent coastal plain deposits of Tertiary and Late Cretaceous age, perhaps similar to the Miocene deposits that crop out near Marshfield (Kaye, 1982b). Depths to the surface atop coastal plain deposits, and to the bedrock surface where not overlain by coastal plain deposits, are shown by contours in figure 6. We infer that this surface (fig. 3) is a fluvial unconformity carved during a low eustatic sea-level stand that occurred in late Tertiary time (Vail and others, 1977). Later the fluvially carved surface was modified by glacial scour two or more times. Ancestral stream valleys are not clearly delineated by the structure contours in figure 6; however, this may be because their drainage basins were small and were occupied by minor river systems, as is the present landscape (Upson and Spencer, 1964).

A sparsely distributed and discontinuous seismic unit (fig. 3, unit Qdo in profiles A, C, and E) overlies the bedrock and coastal plain deposits. The unit does not crop out at the sea floor and generally lies deeply buried by upper Wisconsinan glacial-marine silt and clay. It is inferred to be mostly upper Wisconsinan drift, including stratified ice-contact and outwash sand and gravel and till deposited at the sea floor beneath and adjacent to the ice. It may also be, in part, drift of an earlier glaciation similar to the older till that underlies drumlins onshore. The older drift was sampled by long-piston cores (KN-18 and KN-27, figs. 3 (profile C) and 7). Core KN-27 penetrated about 24 m below the sea floor where it was stopped by a compact gravely layer that corresponded to the reflector at the top of the older drift. Core KN-18 was stopped by a similar layer at about 19 m. The sediment in the lower two meters of core KN-27 was a silty, sandy clay containing angular to poorly rounded, striated pebbles (Tucholke and Hollister, 1973).

Then thick, widespread seismic unit Qd (fig. 3) is a glacial-marine deposit laid down as the late Wisconsinan ice retreated from the Gulf of Maine and eastern Massachusetts. It can be correlated to the glacial-marine silty clay and coarse glacial drift onland (Kaye, 1976; Hanson, 1984). Offshore, the vibrocores that penetrated the unit showed it to be mostly clay or silty clay locally containing some sand and minor amounts of gravel (fig. 7). The long-piston cores from Stellwagen Basin (KN-10 and KN-27, figs. 3 (profile C) and 7) are believed to have penetrated the entire unit, and show the glacial-marine deposits to be a nearly uniform silty clay containing minor silt and silty sand lenses (Tucholke and Hollister, 1973). Seismically, the glacial-marine clay can be separated into two facies (fig. 3, profile C). The lower facies is characterized by reflections that mimic the surface of the underlying geologic unit. The upper facies is conformable, but the reflections tend to be more nearly horizontal. Possibly, the lower facies was deposited beneath floating ice in water devoid of currents and the upper facies was deposited in open water following the retreat of the ice, but at a time when abundant sediment-laden meltwater was still being discharged into Massachusetts Bay.

Figure 8 shows the thickness of undifferentiated glacial drift (Qdo and Qd). The glacial deposits are generally a few tens of meters thick from Boston to the coast, and thicker offshore. Maximum thicknesses of up to 120 m occur in depressions in the preglacial surface.

The map showing the depth to the top of the drift (fig. 9) represents a complex surface. In deep water, the drift surface is conformably overlain by Holocene deposits. In shallower water and adjacent to the coast, the drift surface is a complex unconformity, in part fluvially cut (represented by reflector ru in profiles B-H, fig. 3), and in part wave cut (represented by reflector tu in profiles D and F, fig. 3). Depths to the drift surface vary from generally less than 20 m along the shore to more than 100 m east of Cape Ann. Fifty-meter-deep depressions just east of outer Boston Harbor may represent the course of a major stream that drained the Boston basin before the Holocene submergence.

Seismic reflectors and seismic units above the glacial drift are Holocene in age. The oldest reflector (ru in profiles B-H, fig. 3) represents, in the deep offshore basins, a conformable contact between glacial-marine and nonglacial-marine deposits (Tucholke and Hollister, 1973). Closer to shore, this reflector is a regressive unconformity atop glacial drift and older rocks, locally preserved beneath marine transgressive deposits (Qfe in profiles D, F, and H, fig. 3). The thickest and most extensive seismic unit consists of sediments deposited in the deep basins (Qm in profiles B, C, and E-G, fig. 3). Long-piston cores from Stellwagen Basin show the deep-water marine deposits to be mostly silty clay (Tucholke and Hollister, 1973). The long-piston core adjacent to Stellwagen Bank (KN-27, fig. 7) shows a significant increase in the sand fraction from 3 m to 7 m below the sea floor; at 5 m, the core is 50 percent sand (Tucholke and Hollister, 1973). The sand influx most likely represents marine transgression of the bank, during which waves and currents carried sand off the bank and into the adjacent basin. Silt and clay again become dominant in the upper part of core KN-27 as the increasing water depth over the bank diminished wave erosion.

Landward of Stellwagen Basin, the Holocene deposits are thinner and less extensive. The older deposits represented by seismic unit Qfe (profiles D, F, and H, fig. 3) are generally confined to valleys in the presubmergence surface. Numerous vibrocores up to 6 m long (Malsberger, 1976) indicate that the deposits are highly variable vertically and horizontally and that they vary from gravel to clay, with either sand or clay being dominant in any one place. The deposits are fluvial valley-fill and estuarine sediments laid down as the shoreline transgressed in response to the Holocene rise in sea level.

Holocene marine transgression of the nearshore part of Massachusetts Bay resulted in a widespread wave-cut unconformity (tu, fig. 3) that truncates glacial drift and Holocene valley-fill deposits. The wave-cut unconformity is time transgressive and its present position is along the open ocean shoreline. Offshore, the unconformity coincides with the sea floor in most places. Locally, the wave-cut unconformity is overlain by a generally lens-shaped seismic unit (Qb in profiles D, E, F, and H, fig. 3). The unit has been extensively cored because it is composed of sand and gravel (Setlow, 1973; Meisburger, 1976) and has considerable potential as an offshore source of aggregate. The sand and gravel are inferred to be beach deposits, formed along an older shoreline, or bar deposits, formed below sea level as waves and currents reworked the underlying glacial drift. The lens-shaped bodies represent a local thickening of an extensive sheet of sand and gravel. Though not resolvable in the seismic record, this sheet makes up the nearshore sea floor in most places (Setlow, 1973; Meisburger, 1976).

Two maps show the thickness and distribution of the Holocene-age deposits. The first (fig. 10) combines all of the Holocene deposits and includes the deep-water offshore sediments, the transgressive fluvial and estuarine deposits, and the beach or bar deposits. Figure 11 shows the thickness and distribution of the beach or bar deposits alone.

The bathymetric map (fig. 2) represents the morphology of the sea floor, a surface generated by past depositional and erosional events and by modern sea-floor processes. Preglacial fluvial erosion and glacial scour of bedrock and coastal plain deposits produced major bathymetric lows such as Stellwagen Basin and the seaward part of Boston basin and left large-scale morphologic highs, including Stellwagen Bank and Jeffreys Ledge, east of Cape Ann. Within the basins, the sea floor is locally underlain by a veneer of thick accumulations of glacial and postglacial silt and clay that in places lay a few places deeply bury the pre-Pleistocene erosion surface. On Stellwagen Bank outside the map area, thick accumulations of Holocene sand make the bank-top smooth. The nearshore zone is characterized by small-scale morphologic features. Bathymetric highs there are mostly bedrock outcrops or erosional remnants of more resistant glacial drift, such as drumlins; smaller bathymetric highs are composed of accumulations of sand and gravel reworked from the glacial drift. Areas of smooth sea floor in the nearshore zone are underlain by fine-grained deposits laid down in depressions in the bedrock surface or by thin accumulations of sand and gravel atop the Holocene transgressive unconformity. Smooth sea floor also occurs just seaward of barrier beaches and sea cliffs cut in thick sandy glacial drift.

Total sediment thickness (fig. 12) is dominated by deposits of pre-Pleistocene age that underlie the complex of banks and ledges southeast of Cape Ann and the large bathymetric highs that interrupt the floor of Stellwagen Basin. Coastal plain deposits also represent much of the total sediment thickness in a few places in the nearshore area off outer Boston Harbor. In areas where coastal plain sediments occur, total thickness is as much as 200 m offshore and as much as 60 m just seaward of outer Boston Harbor. Thick accumulations of glacial and postglacial deposits in Stellwagen Basin account for a total thickness as great as 90 m. Values of a few tens of meters occur along the shore where bedrock lies at relatively shallow depths.

The geologic map and cross sections (fig. 13) show the distribution of the geologic units that crop out at the sea floor or are overlain by younger sediments too thin to be resolved by the seismic profiles. In most places in Stellwagen Basin, the sea floor is composed of silt and clay of Holocene age (Qm). Coastal plain deposits (Tcp) and glacial drift (Qd) crop out locally where bathymetric highs interrupt the basin floor. Landward of the basin, the geologic map becomes much more complex where the transgressive unconformity forms the sea floor and cuts across many geologic units. In this region, glacial drift (Qd) is exposed at the sea floor in most places. Bedrock outcrops (Pz) are abundant, and coastal plain deposits (Tcp) occur locally. Fluvial and estuarine deposits (Qfe), truncated by the transgressive unconformity, are exposed at the sea floor in many places. Locally, the sea floor consists of beach or bar deposits (Qb) that overlie the transgressive unconformity.

Cross sections A-A' and B-B' illustrate the stratigraphic position of the geologic units. In the cross sections and on the geologic map, the drift (Qd) is undifferentiated and includes the glacial-marine silty clay and the older glacial drift (Qdo).

Geologic history

For the most part, the bedrock geology beneath Massachusetts Bay represents tectonic events of late Precambrian and early Paleozoic age (Barosh, 1984). Seaward of the Boston basin, the bedrock may indicate volcanic activity and shallow-water marine conditions during latest Precambrian and earliest Cambrian time (Kaye, 1984). Fault basins filled with nonmarine clastic sediments may have developed during the Pennsylvanian and Triassic Periods (Kaye, 1982a; Barosh, 1984). Coastal plain deposits may represent a nearshore marine environment during Tertiary time (Behlke and Cheetham, 1967; Folger and others, 1978; Kaye, 1982b) or subaerial depositional environments during the Cretaceous (Folger and others, 1978; Hall and others, 1980). The fluvial unconformity atop both bedrock and coastal plain strata is evidence of a long episode of subaerial erosion that probably occurred during a late Tertiary lowstand of sea level (Vail and others, 1977). Maximum depths to the unconformity (fig. 6) may indicate the course of pre-Pleistocene streams, ancestral to the modern drainage.

The Quaternary history of Massachusetts Bay is represented by glacial drift and by deposits associated with the Holocene marine transgression. The older drift (Qdo) may be composed in part of New England "lower till" that is thought to have been deposited during an Illinoian (Oldale and Eakenasy, 1983) or early Wisconsinan (Koteff and Pessl, 1985) glaciation. The late Quaternary history of Massachusetts Bay may have been very complex because the bay is located between regions that underwent different modes of ice retreat and late Quaternary sea-level change. South of the bay, on Cape Cod for example, ice retreat was subaerial and the drift was deposited under glaciofluvial or glaciolacustrine conditions (Oldale, 1982). To the north, ice retreat and marine transgression were contemporaneous and glacial deposition occurred in a marine environment (Stone and Peper, 1982). The upper Wisconsinan deposits in Massachusetts Bay are interpreted to be of glacial-marine origin. However, the change to subaerial drift may occur just to the south of the map area inasmuch as glaciofluvial and glaciolacustrine deposits occur along the coast just 9 km south of Marshfield, Mass. (Chute, 1965a). The older drift (Qdo) may include upper Wisconsinan subaqueous sand, gravel, and till deposited on the sea floor along the ice front in the same manner as that described by Rust and Romanelli (1975) for subaqueous ice-contact and outwash deposits in the Ottawa Valley, Canada, that were associated with the Champlain Sea. The coarse glacial drift (Qd) in the nearshore zone of Massachusetts Bay had a similar origin. In the deep offshore basins, fine-grained sediments, mostly rock flour, were deposited as the ice floated off the sea floor. In the quiet environment beneath the floating ice, the sediments formed a blanket that mimicked the underlying morphology. Later, the sea surface was exposed as the ice front retreated landward. The glacial-marine sediments, subject to currents, formed a nearly flat-bedded deposit of silt and clay in the basins, and, in the nearshore zone, atop the subaqueous coarse drift. Shortly after the ice front retreated across the present shoreline, about 14,000 years before present (Kaye and Barghoorn, 1964), sea level began to fall as the crust rebounded. Regression continued and the sea fell below its present level. The magnitude and timing of sea-level lowering in Massachusetts Bay are not well established, but off Cape Ann, the lowstand was about 50 m below present sea level and probably occurred about 10,500 years before present (Oldale, 1985a). Fluvial erosion of the exposed glacial drift produced the regressive unconformity (ru), and the reworked drift was deposited offshore. At this time Stellwagen Bank was probably subaerial; shortly thereafter, the sea began to transgress as isostatic rebound slowed or ceased and the worldwide postglacial sea-level rise continued. The rising sea drowned the landscape, and fluvial and estuarine deposits (Qfe) were laid down in the valleys. Wave erosion during the transgression trimmed the glacial drift and more recent fluvial and estuarine deposits to form the transgressive unconformity (tu). This surface forms the present sea floor in most places. Locally, beach or bar deposits (Qb) were laid down atop the transgressive surface and were subsequently drowned by the continued rise in sea level. The marine transgressive unconformity (tu) and the fluvial and estuarine deposits (Qfe) are time-transgressive features that are now forming along the modern shore. In the deep basins offshore, sedimentation has continued uninterrupted from late Wisconsinan time. The influx of sand into the eastern part of Stellwagen Basin (Tucholke and Hollister, 1973) probably represents the change from subaerial to marine conditions atop Stellwagen Bank, perhaps about 9,000 years before present.

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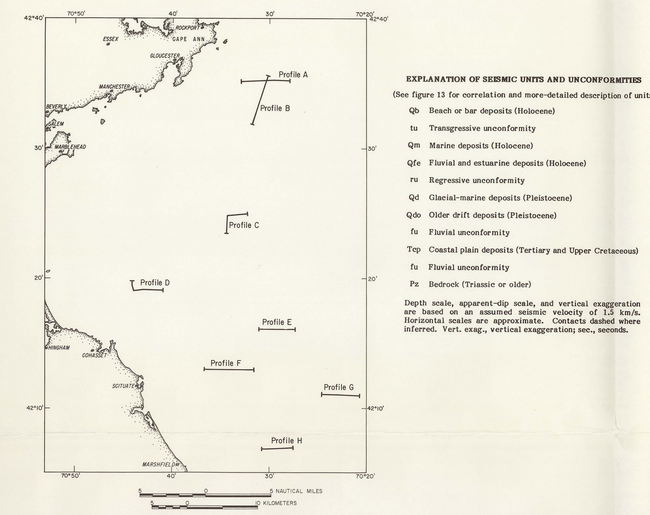

LOCATION MAP

EXPLANATION OF SEISMIC UNITS AND UNCONFORMITIES

(See figure 13 for correlation and more-detailed description of units)

- Qb Beach or bar deposits (Holocene)
- tu Transgressive unconformity
- Qm Marine deposits (Holocene)
- Qfe Fluvial and estuarine deposits (Holocene)
- ru Regressive unconformity
- Qd Glacial-marine deposits (Pleistocene)
- Qdo Older drift deposits (Pleistocene)
- fu Fluvial unconformity
- Tcp Coastal plain deposits (Tertiary and Upper Cretaceous)
- fu Fluvial unconformity
- Pz Bedrock (Triassic or older)

Depth scale, sound-velocity scale, and vertical exaggeration are based on an assumed seismic velocity of 1.5 km/s. Horizontal scales are approximate. Contacts dashed where inferred. Vert. exag., vertical exaggeration;

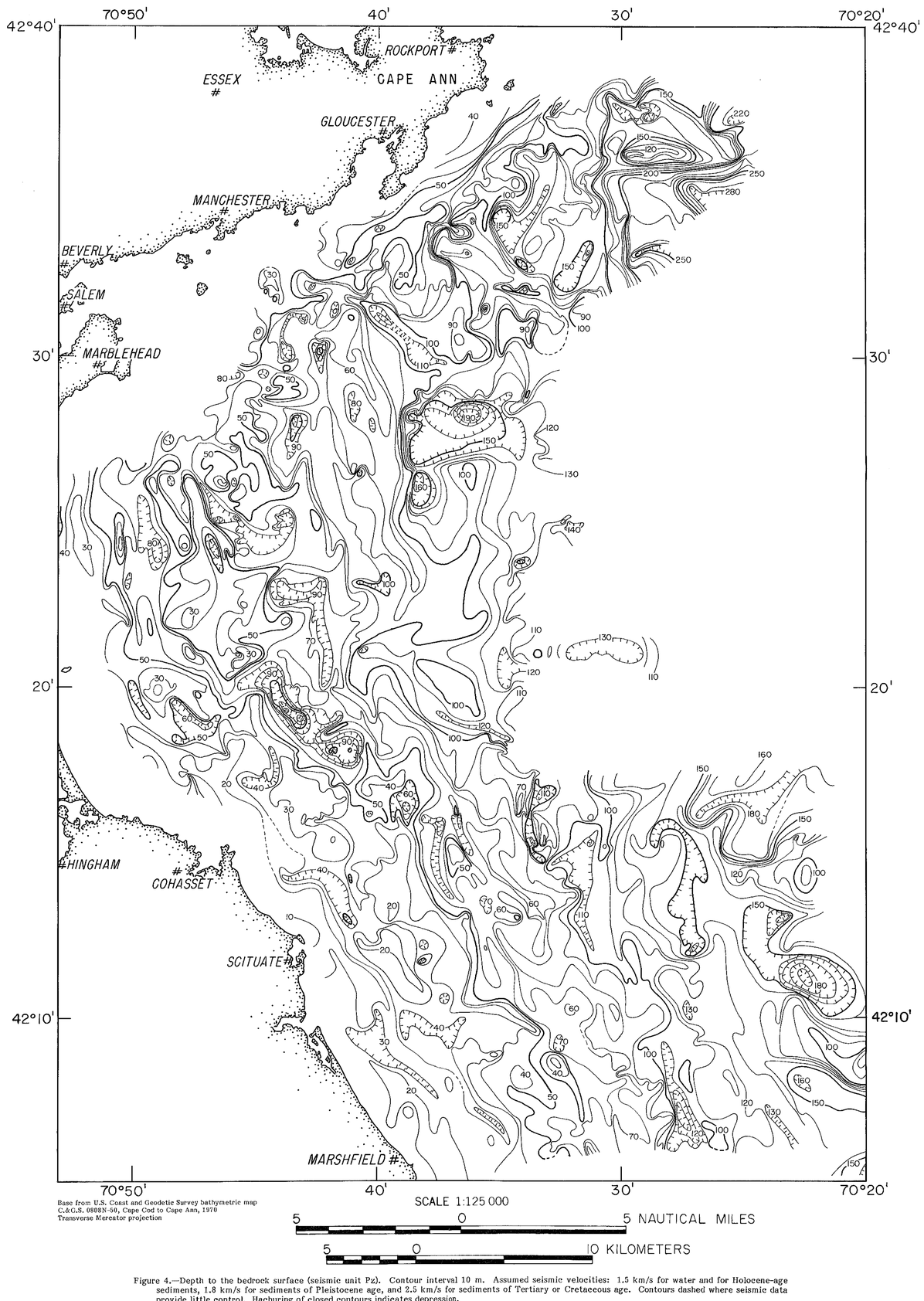

Figure 4.--Depth to the bedrock surface (seismic unit Pz). Contour interval 10 m. Assumed seismic velocities: 1.5 km/s for water and for Holocene-age sediments, 1.8 km/s for sediments of Pleistocene age, and 2.5 km/s for sediments of Tertiary or Cretaceous age. Contours dashed where seismic data provide little control. Hachuring of closed contours indicates depression.

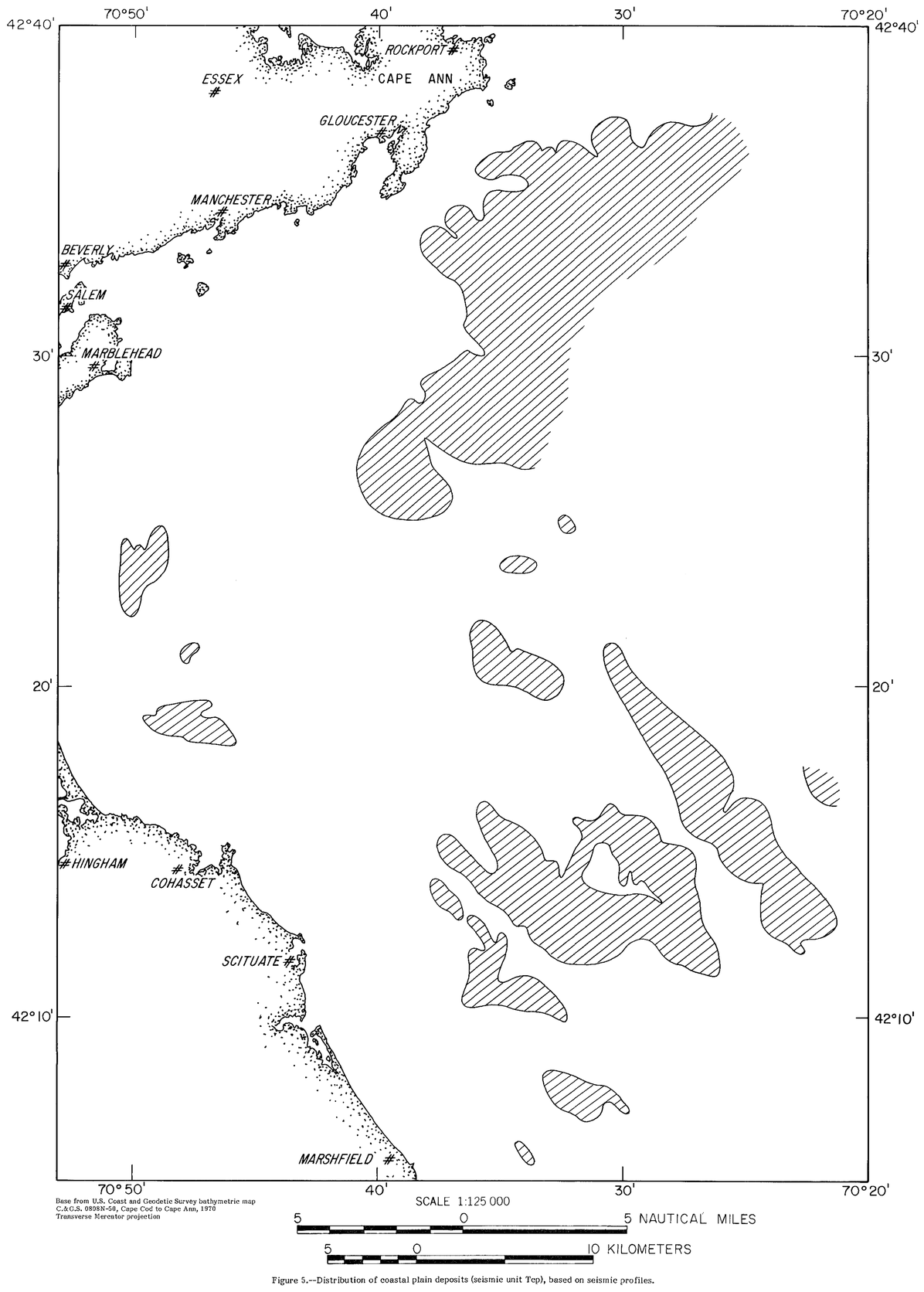

Figure 5.--Distribution of coastal plain deposits (seismic unit Tcp), based on seismic profiles.

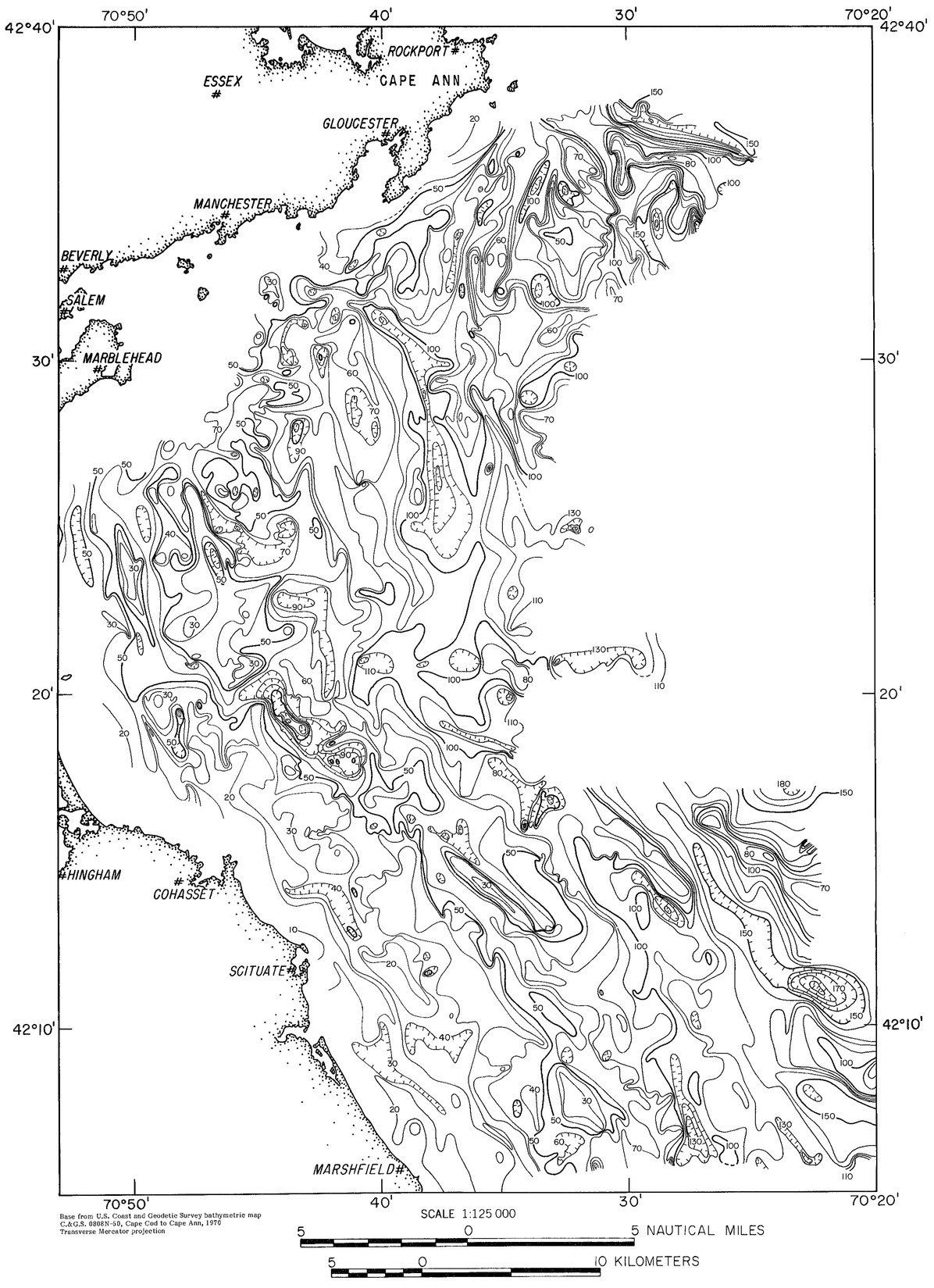

Figure 6.--Depth to seismic reflector (fu) which marks the surface of bedrock (Pz) or coastal plain deposits (Tcp). Contour interval 10 m. Assumed seismic velocities: 1.5 km/s for water and for sediments of Holocene age, and 1.8 km/s for sediments of Pleistocene age. Contours dashed where seismic data provide little control. Hachuring of closed contours indicates depression.

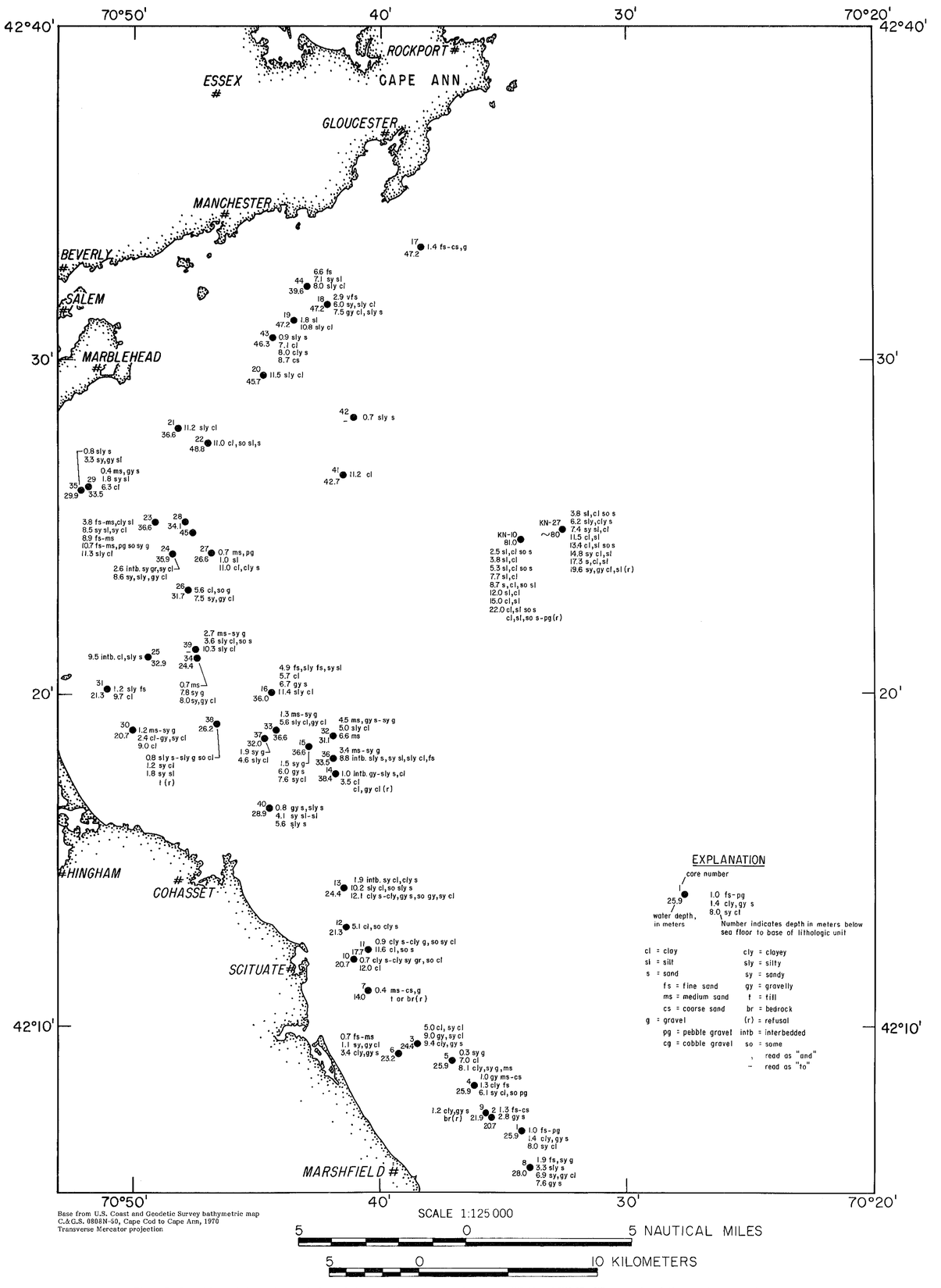

Figure 7.--Localities and lithologic descriptions of vibracores 1-45 and long-piston cores KN-10 and KN-27. Vibracore descriptions are based on information provided by Raytheon Oceanographic and Environmental Services (1972). Long-piston core descriptions are modified from Tucholke and Hollister (1973).

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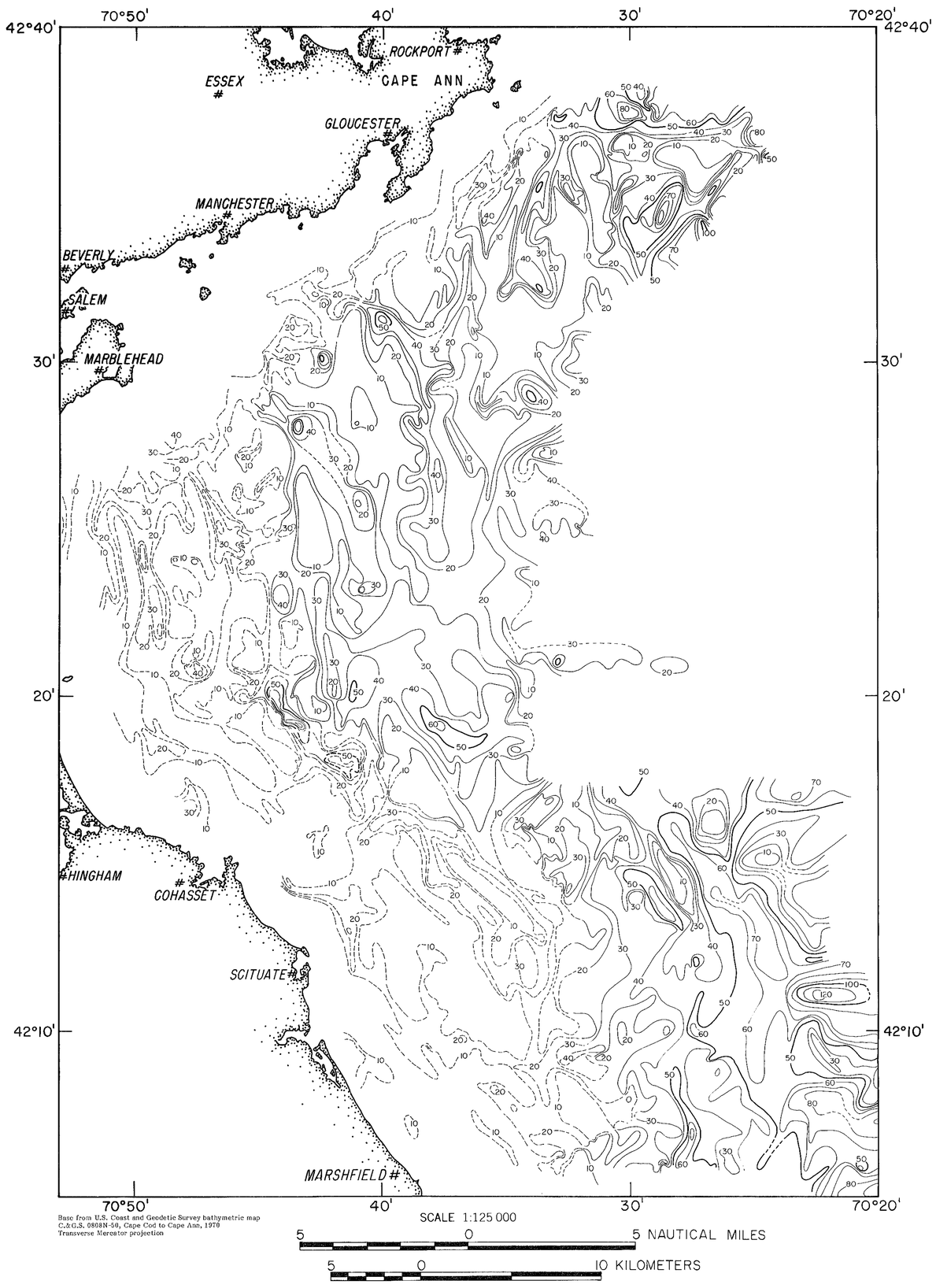
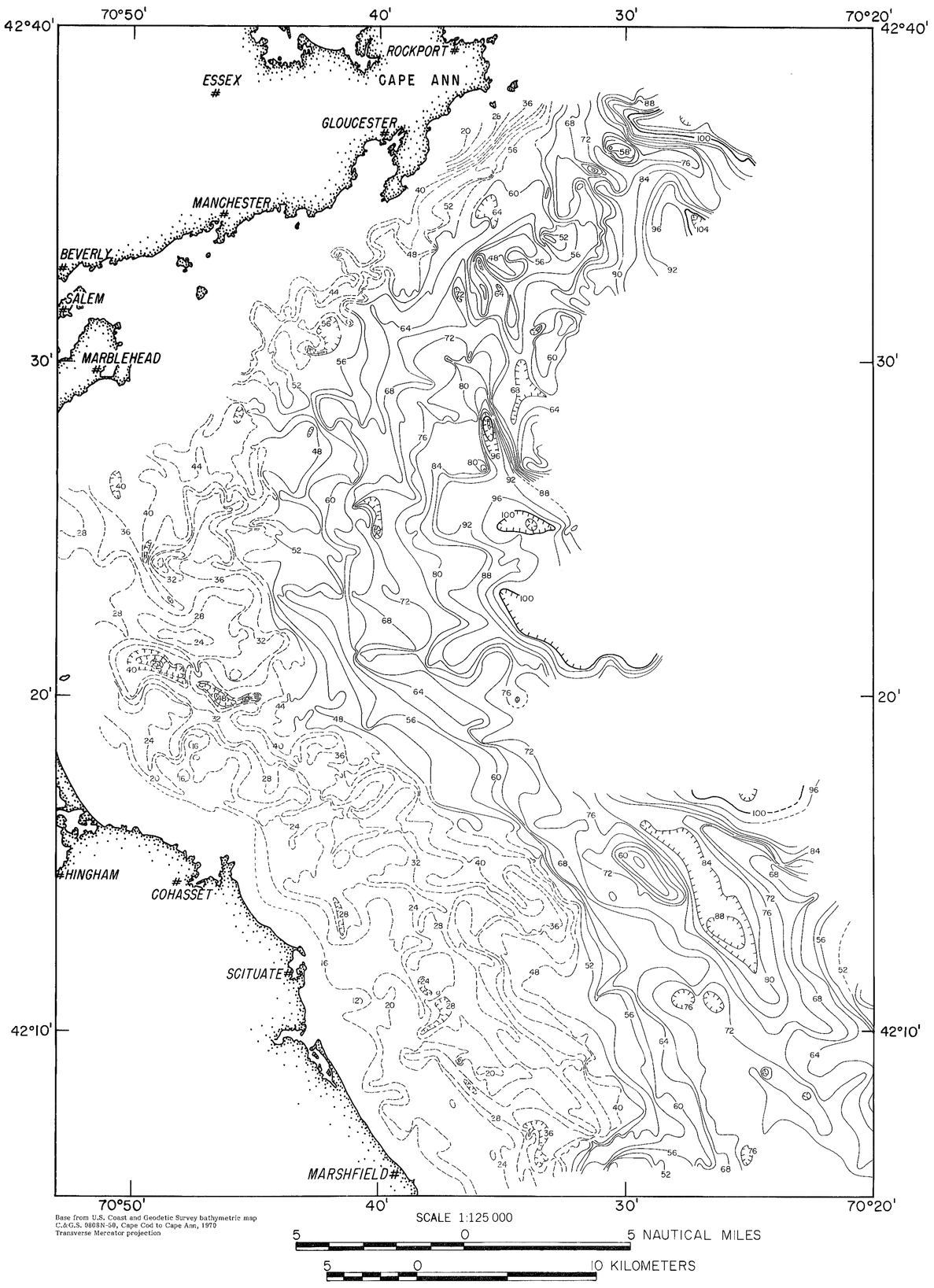


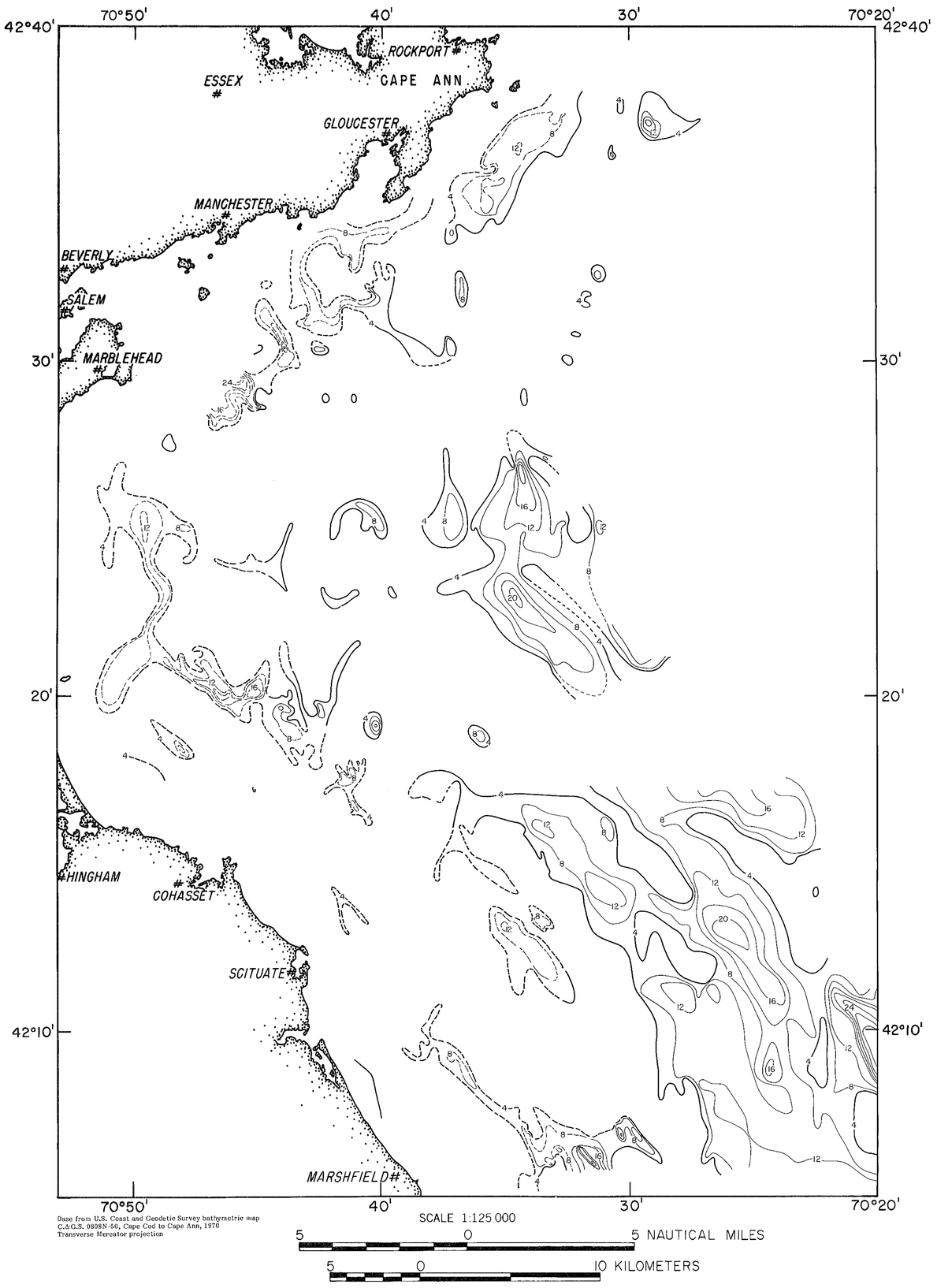
Base from U.S. Coast and Geodetic Survey bathymetric map C.&G.S. 0808N-50, Cape Cod to Cape Ann, 1970
Transverse Mercator projection

Figure 8.--Combined thickness of the glacial marine deposits and older drift deposits (seismic units Qd and Qdo, respectively; see figures 3 and 13). Contour interval 10 m. Thickness based on an assumed seismic velocity of 1.8 km/s. Contours dashed where seismic data provide little control.



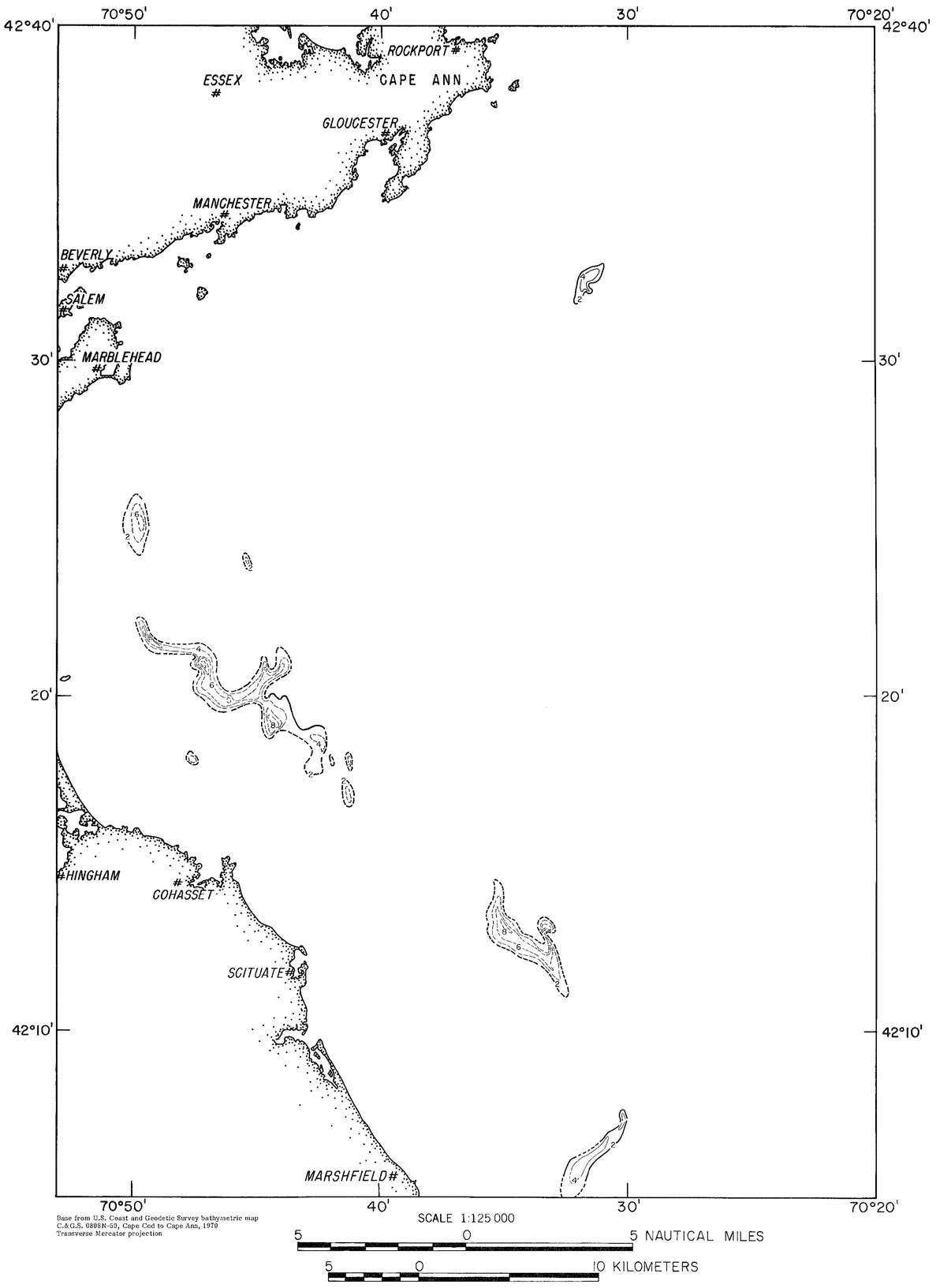
Base from U.S. Coast and Geodetic Survey bathymetric map C.&G.S. 0808N-50, Cape Cod to Cape Ann, 1970
Transverse Mercator projection

Figure 9.--Depth to the glacial drift surface (seismic units Qd and Qdo). Contour interval 4 m. Based on an assumed seismic velocity of 1.5 km/s for water and for sediments of Holocene age. Contours dashed where seismic data provide little control. Hachuring of closed contours indicates depression.



Base from U.S. Coast and Geodetic Survey bathymetric map C.&G.S. 0808N-50, Cape Cod to Cape Ann, 1970
Transverse Mercator projection

Figure 10.--Thickness and distribution of deposits of Holocene age (seismic units Qfe, Qm, and Qb; see figures 3 and 13). Contour interval 4 m. Based on an assumed seismic velocity of 1.5 km/s. Contours dashed where seismic data provide little control.



Base from U.S. Coast and Geodetic Survey bathymetric map C.&G.S. 0808N-50, Cape Cod to Cape Ann, 1970
Transverse Mercator projection

Figure 11.--Thickness and distribution of beach or bar deposits (seismic unit Qb; see figures 3 and 13). Based on an assumed seismic velocity of 1.5 km/s. Contour interval 2 m. Contours dashed where seismic data provide little control. Beach or bar deposits represent potential sources of sand and gravel.

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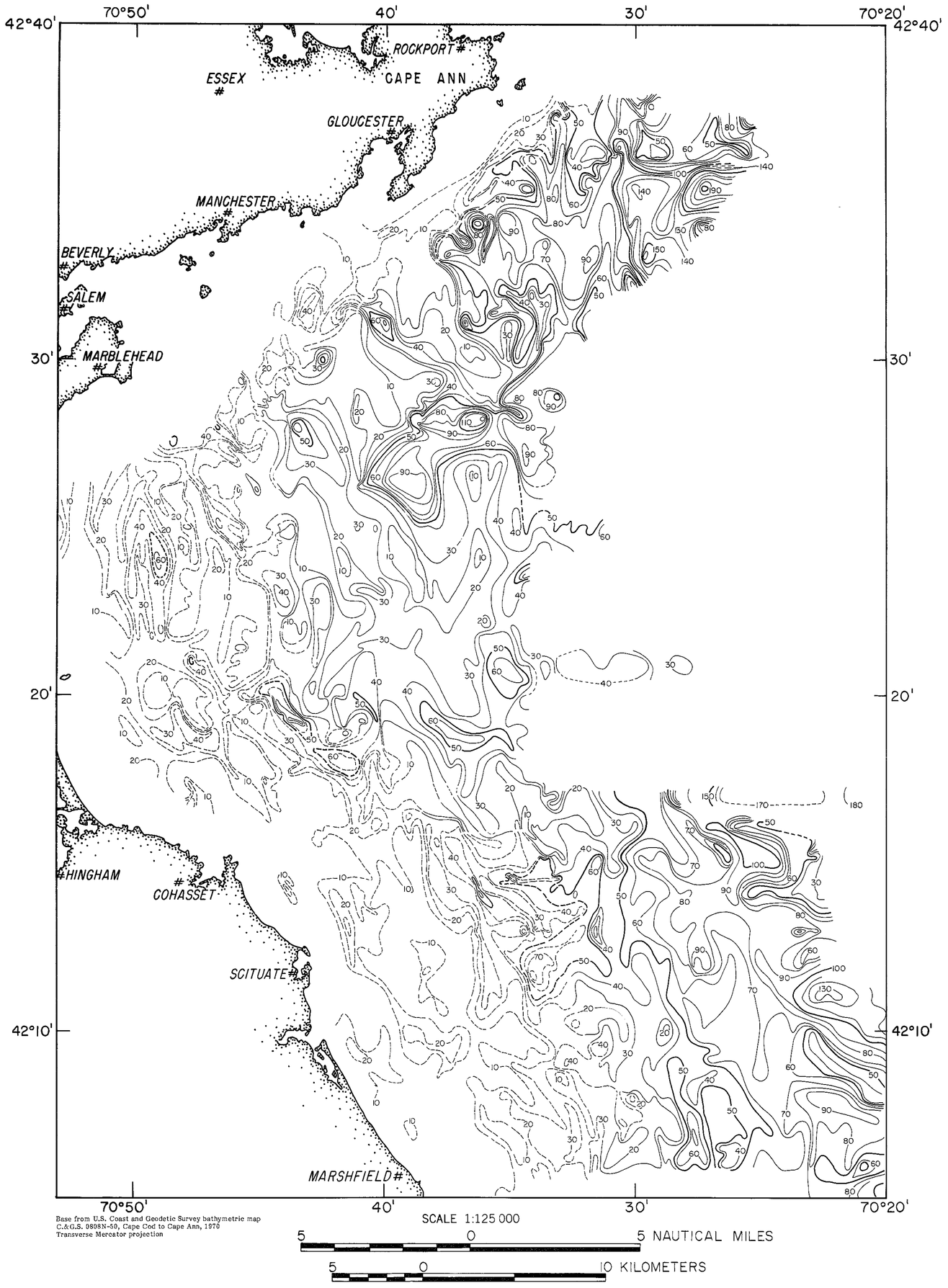
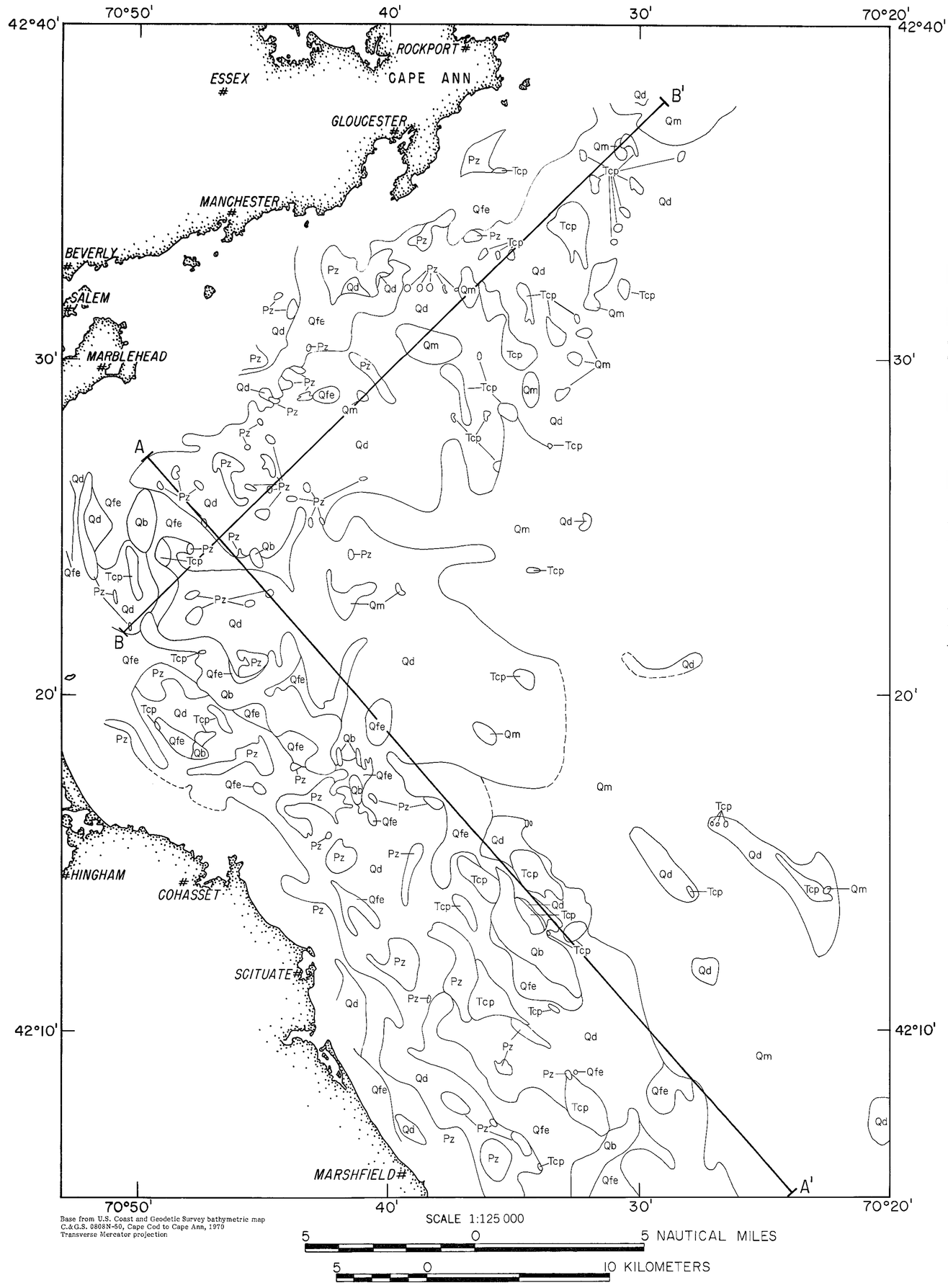


Base from U.S. Coast and Geodetic Survey bathymetric map C.&G.S. 98883N-50, Cape Cod to Cape Ann, 1970
Transverse Mercator projection

Figure 12.—Total sediment thickness above the bedrock surface. Contour interval 10 m. Based on assumed seismic velocities of 2.5 km/s for coastal plain sediments, 1.8 km/s for sediments of Pleistocene age, and 1.5 km/s for sediments of Holocene age. Contours dashed where seismic data provide little control.



Base from U.S. Coast and Geodetic Survey bathymetric map C.&G.S. 98883N-50, Cape Cod to Cape Ann, 1970
Transverse Mercator projection

CORRELATION OF GEOLOGIC UNITS

Qb	Holocene	QUATERNARY	
Qm	Unconformity (tu)		
Qfe			
Unconformity (ru)			
Qd	Pleistocene (Wisconsinan)		
Qdo			
Unconformity (fu)			
Tcp	Pre-Pleistocene	PRE-QUATERNARY	
Unconformity (fu)			
Pz			

DESCRIPTION OF GEOLOGIC UNITS

Qb — **Beach or bar deposits (Holocene)**—Mostly sand; may include some gravel. Unit generally less than 6 m thick. Forms sand ridges and waves atop the transgressive unconformity (tu; see figure 3, profiles D, F, G, and H)

Qm — **Marine deposits (Holocene)**—Mostly silt and clay; includes sand and possibly gravel. Unit up to 28 m thick. Occurs offshore in deep water. Conformably overlies glacial-marine silt and clay

Qfe — **Fluvial and estuarine deposits (Holocene)**—Sand, silt, and clay. May include some gravel and freshwater and saltwater peat. Unit generally less than 15 m thick. Deposited in valleys drowned by the Holocene rise in sea level. Unconformably overlies drift and older geologic units

Qd — **Glacial-marine deposits (Pleistocene)**—Mostly silt and clay with minor sand; may contain more sand and possibly gravel adjacent to bathymetric highs. May include subaqueous stratified ice-contact and outwash deposits and till or pre-upper Wisconsinan drift near the base. Unit generally less than 50 m thick, although is up to 120 m thick in deeply scoured glaciated valleys. Unconformably overlies older drift (Qdo), coastal plain deposits, and bedrock

Qdo — **Older drift deposits (Pleistocene)**—May include till and coarse stratified drift of late or pre-late Wisconsinan age. May be as much as 30 m thick. Unconformably overlies coastal plain deposits and bedrock. Shown on interpreted seismic profiles only (fig. 3, profiles A, C, and E)

Tcp — **Coastal plain deposits (Tertiary and Upper Cretaceous)**—Inferred to be unconsolidated to consolidated gravel to clay similar to coastal plain and continental shelf deposits exposed on Fippennies Ledge in the Gulf of Maine and in the subsurface of southeastern Massachusetts including Martha's Vineyard and Nantucket (Schlee and Cheetham, 1967; Kaye, 1982b; Hall and others, 1980; Folger and others, 1978). Generally less than 100 m thick; maximum thickness about 200 m. Unit unconformably overlies bedrock

Pz — **Bedrock (Triassic or older)**—Igneous, metamorphic, and sedimentary rock similar to that exposed on land adjacent to the map area

Contact—Dashed where approximately located or where inferred

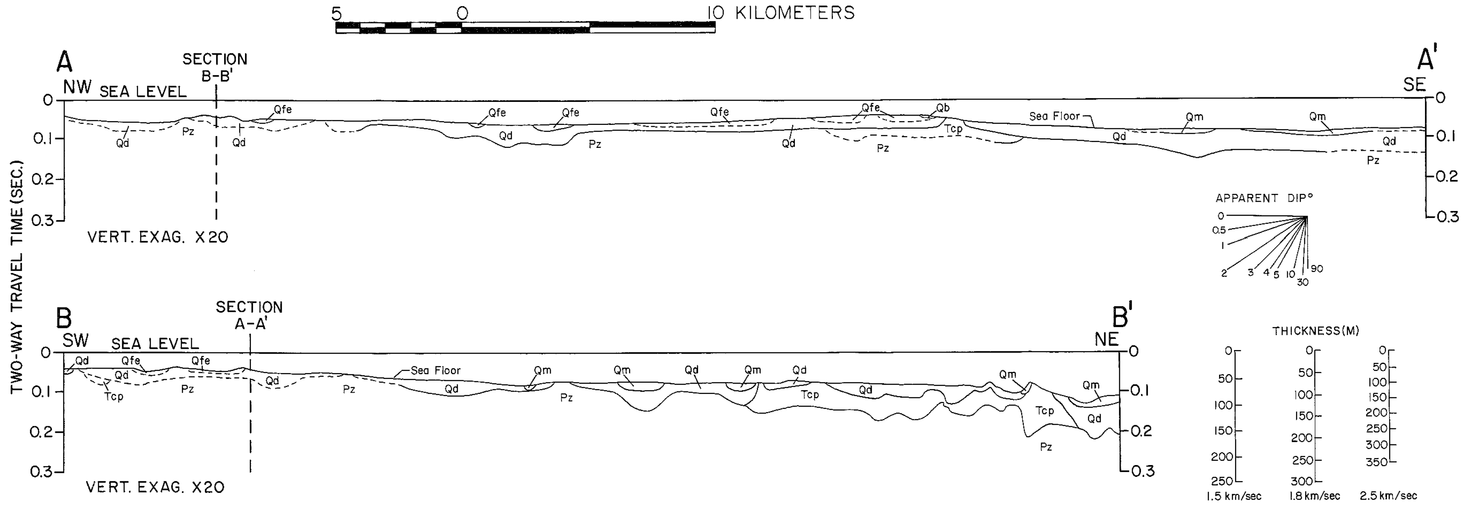


Figure 13.—Map and cross sections showing the distribution and stratigraphic position of the geologic units. The distribution and lithology of the geologic map units are based, in part, on the acoustic nature of the seismic reflection data and, in part, on the vibracore data. Units shown crop out at the sea floor or are overlain by younger deposits too thin to be resolved in the seismic data. Seismic velocity assumptions: 1.5 km/s for water and for sediments of Holocene age, 1.8 km/s for sediments of Pleistocene age, and 2.5 km/s for sediments of Tertiary or Cretaceous age. In cross sections, apparent-dip scale and vertical exaggeration are based on a seismic velocity of 1.5 km/s. Vert. exag., vertical exaggeration; sec., seconds.

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