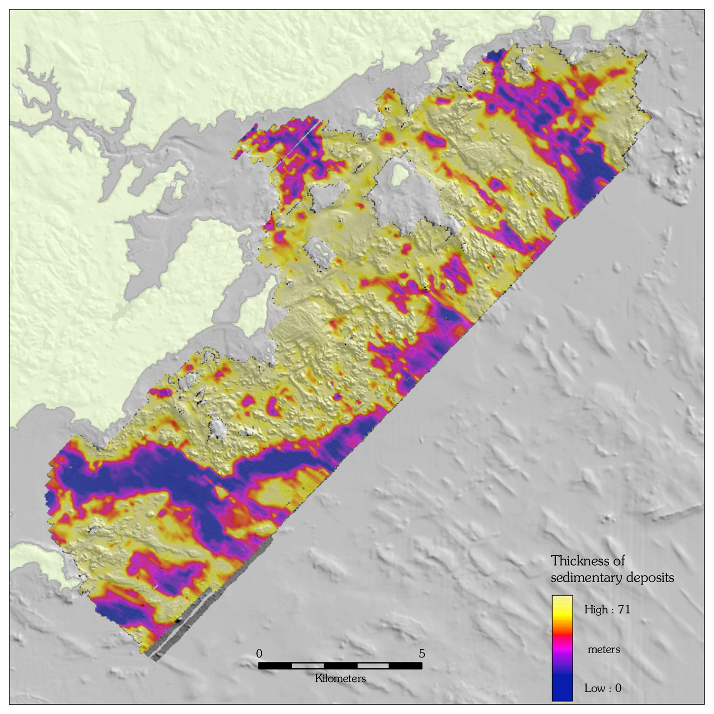
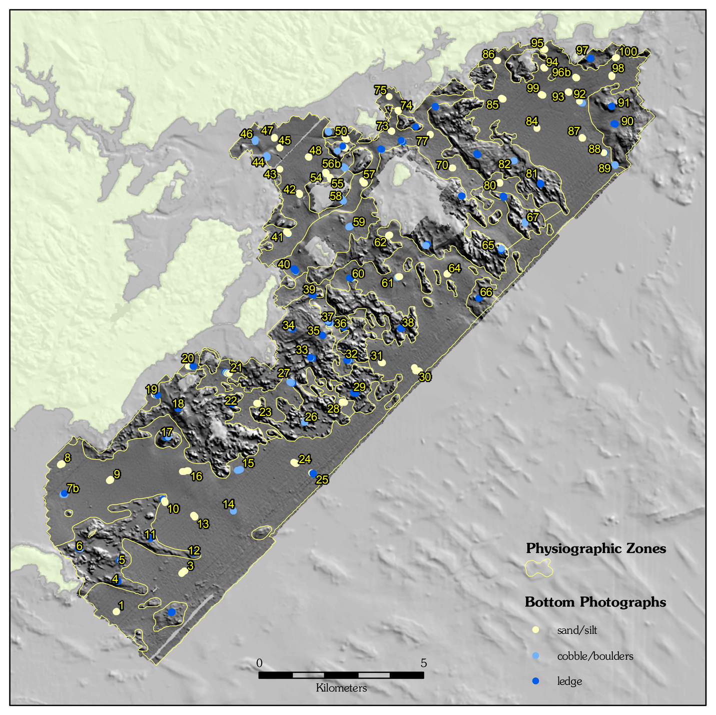
Prepared in cooperation with the
MASSACHUSETTS OFFICE OF COASTAL ZONE MANAGEMENT

U.S. Geological Survey Open-File Report:
OFR 2005-1293
Sheet 5 of 5

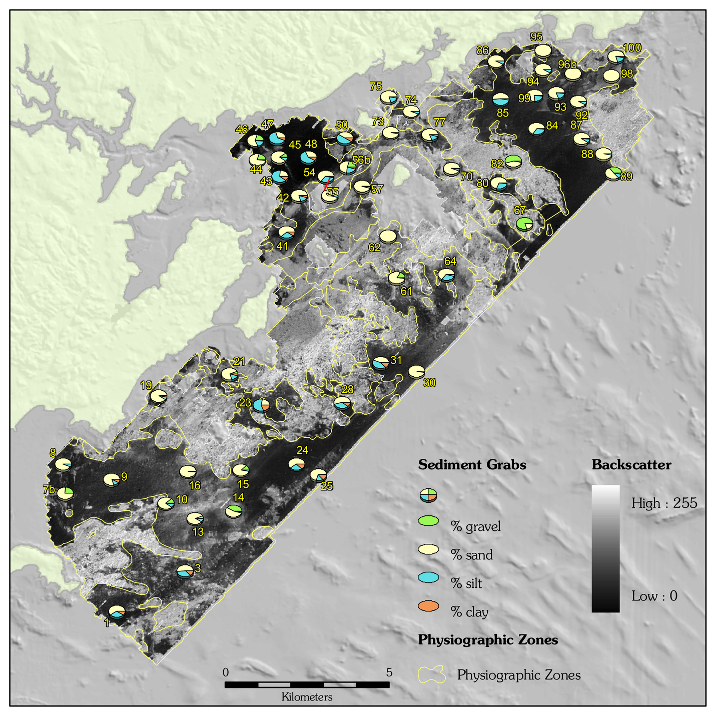
Panel A
Isopach map at 1:120,000 scale showing thickness of sediment deposits overlying bedrock on the inner continental shelf. Darker colors (purple) indicate thick deposits of sediment filling deep, bedrock-framed valleys. Lighter colors (yellow) indicates thin (or absent) deposits of sediment over bedrock. Map was derived using geostatistics (Kriging) to interpolate depth to bedrock from a grid of closely spaced seismic reflection profiles. Distances between seismic profiles is 100 m and the grid resolution of the isopach map is 50 m.



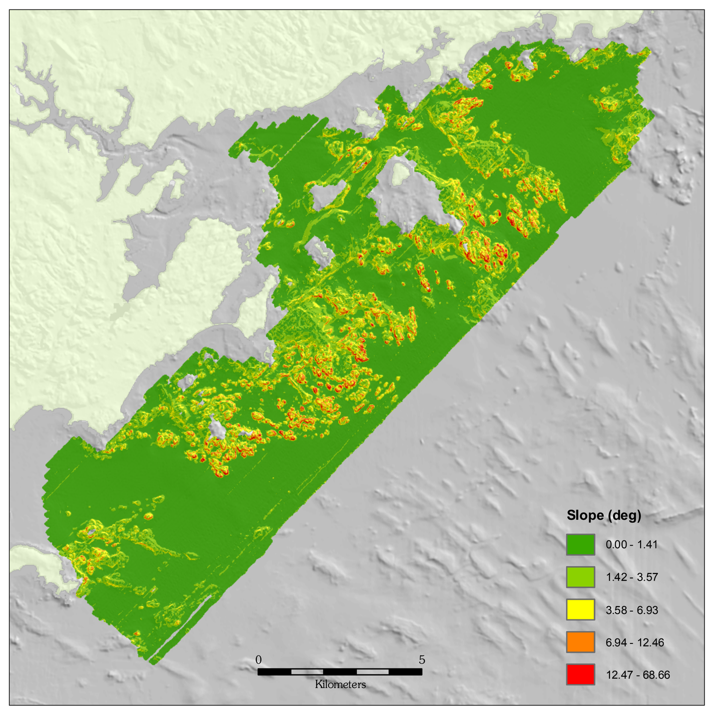
Panel B
Map of shaded-relief topography at 1:120,000 scale. Filled circles represent bottom photographs at stations number 1-100. Circles are color-coded to indicate the general substrate type, based on visual interpretation of photographs. Thin yellow lines indicate boundaries of physiographic zones that are defined on geologic map in panel E (at right). See map sheets 1 and 2 for higher resolution maps of seafloor topography.

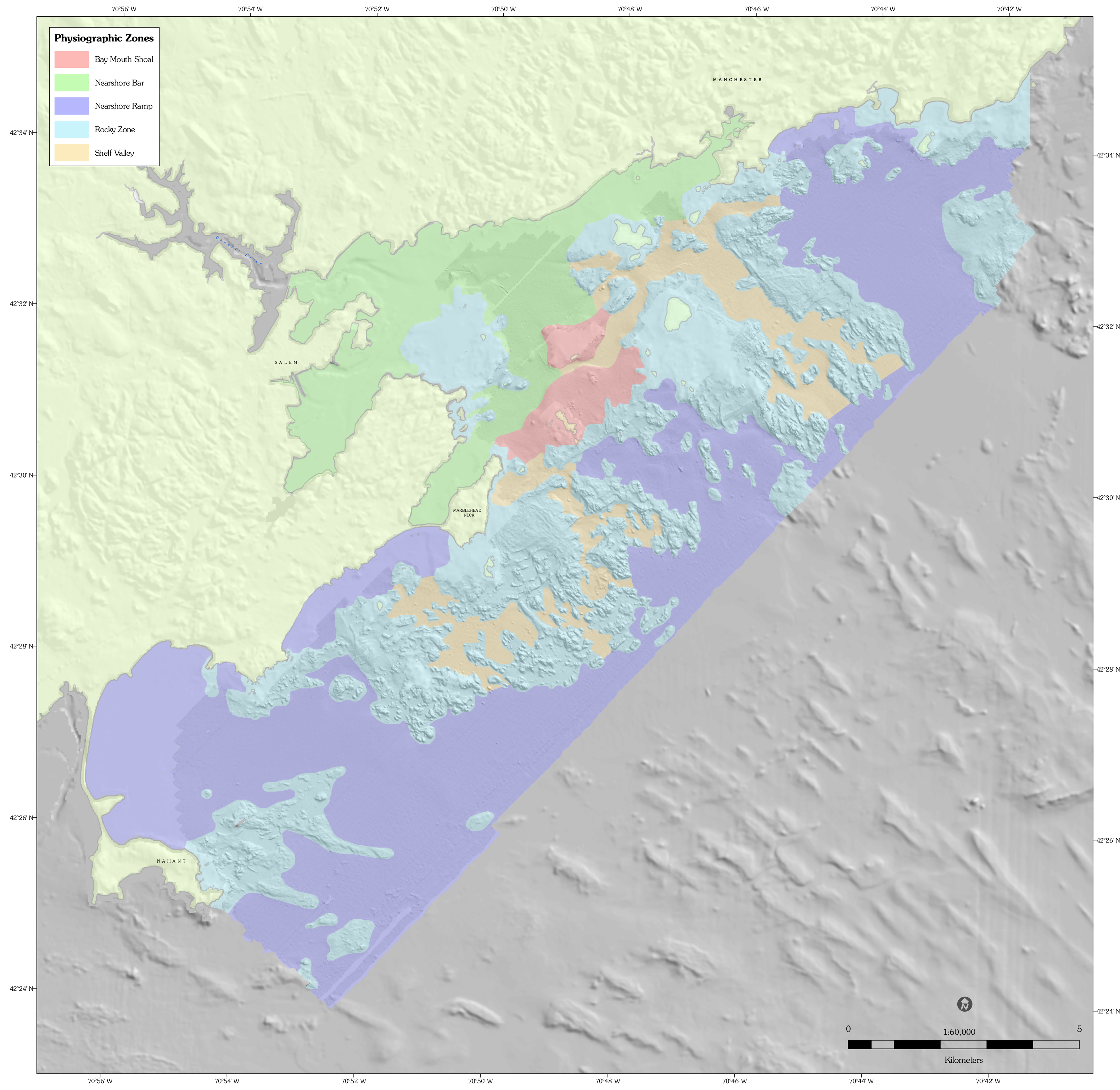


Panel C
Map of acoustic backscatter intensity at 1:120,000 scale. Backscatter intensity is represented by 256 shades of gray. High backscatter values, depicted by lighter shades, suggest that the seafloor in those areas is covered with coarse sand, gravel, cobbles, boulders and rock. Low values, depicted by lighter shades, indicate sandy mud or mud. Interpretation of substrate properties from backscatter data was validated by sampling, shown here as pie diagrams depicting sediment grain size. Thin yellow lines indicate boundaries of physiographic zones that are defined on geologic map in panel E (at right). See map sheets 3 and 4 for higher-resolution maps of acoustic backscatter.

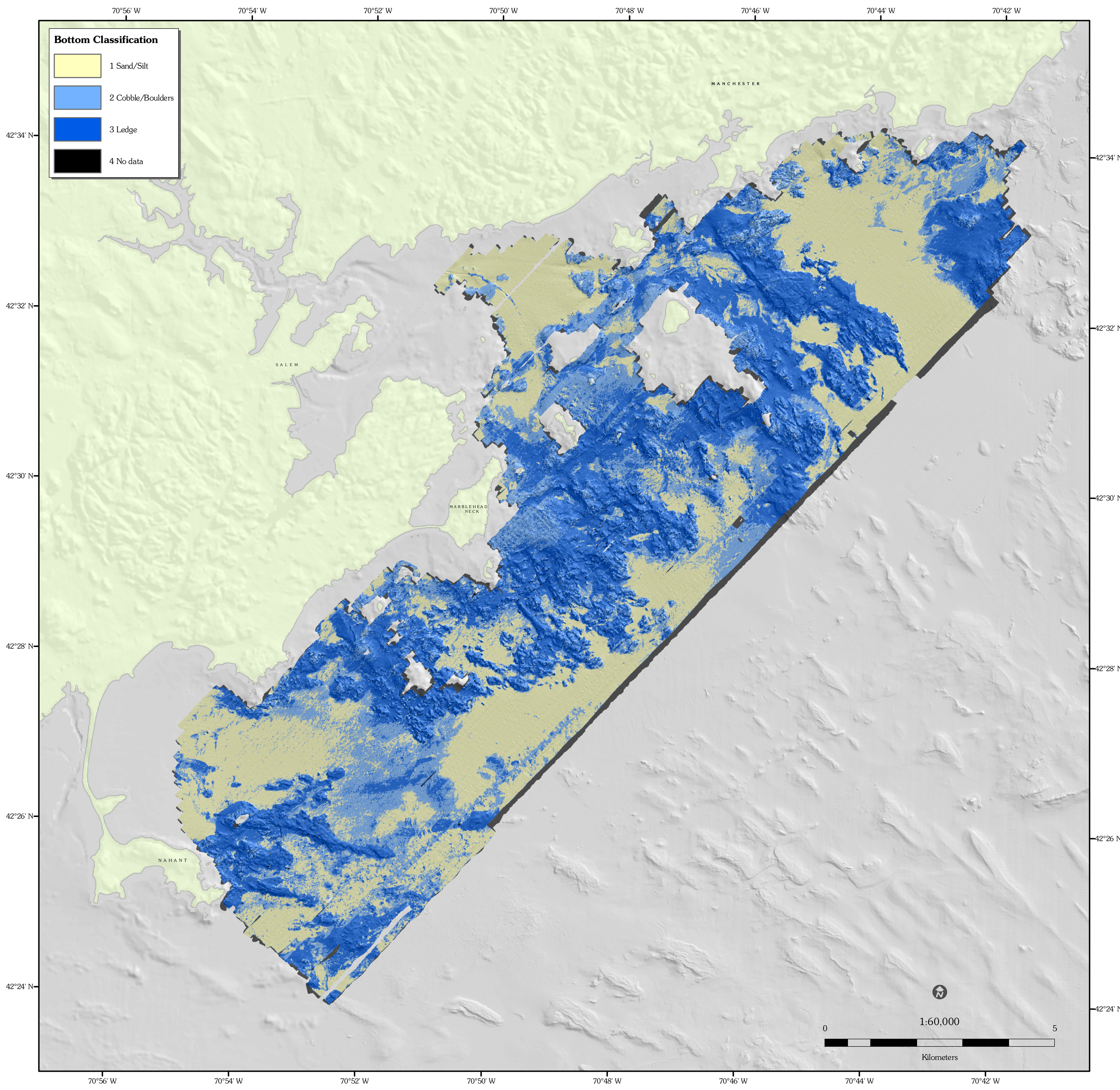


Panel D
Map of seafloor slope in degrees at 1:120,000 scale derived from 5-m bathymetric grid in panel B. The map is colored using a Natural Breaks Methods (Jenks) with 5 classes to symbolize slope. The mean slope is 1.59 degrees. Areas of low slope (0-1.4 deg) are displayed in dark green; areas of steep slope (12.47-68.66 deg) are displayed in red.





Panel E
Map of seafloor environments at 1:60,000 scale. Interpretation of geophysical and sampling data in panels A-D (at left) support geologic mapping of seafloor (above). The seafloor in the study area is divided into five environments, or physiographic zones, which are delineated based on seafloor morphology and the dominant characteristics of surficial materials. See main text (at right) for description of



Panel F
Map of generalized bottom type at 1:60,000 scale. Bottom type was calculated using ISO (Iterative Self Organizing) method to group depth, slope, and backscatter into 4 general classes. See main text (at right) for description of the method used to produce this map

HIGH-RESOLUTION GEOLOGIC MAPPING OF THE INNER CONTINENTAL SHELF: NAHANT TO GLOUCESTER MASSACHUSETTS

Map Sheet 5: Geologic maps of the seafloor

Introduction

A series of five map sheets shows the seafloor topography and geology of the inner continental shelf between Nahant and Gloucester, Massachusetts including Salem Sound and parts of western Massachusetts Bay. This map (sheet 5) shows geologic maps of the seafloor and summarizes how they were produced. Sheet 1 shows shaded-relief topography in color, sheet 2 shows shaded-relief topography in grayscale, sheet 3 shows grayscale backscatter intensity, and sheet 4 shows shaded-relief topography colored by backscatter intensity. These maps are produced as part of a cooperative effort by the U.S. Geological Survey (USGS) and the Massachusetts Office of Coastal Zone Management (CZM) to systematically map the seafloor geology offshore of Massachusetts. This map sheet is accompanied by a more extensive report on DVD-ROM that presents a description of the data collection, processing, and analysis procedures used to create these maps. The DVD-ROM also includes copies of all data layers in GIS format, and the original data used to validate the geologic interpretations.

Geologic Mapping

This map sheet summarizes two approaches to mapping the seafloor geology offshore of Massachusetts. The datasets used to construct the geologic maps are shown in four small panels (A-D) along the left margin of this sheet. Panel A is an isopach map, which shows the thickness of sediment overlying bedrock in the region. Panel B is a bathymetric map, which shows the topography of the seafloor in grayscale shaded relief and the locations of bottom photographs. Panel C is a backscatter intensity map, which shows patterns of acoustic reflectivity related to different substrates, and includes bottom sample locations with pie diagrams depicting sediment texture. Panel D is a map of seafloor slope in degrees, derived from the 5 m bathymetric grid in panel B. Additional information about the data displayed in these four panels can be found in the main text of the report and on map sheets 1-4. Interpretations of the data in panels A-D resulted in two geologic maps, shown in two large panels (E, F) at the center of this sheet.

The map in panel E is an interpretative geologic map that divides the inner continental shelf into five environments, or physiographic zones. The five zones are Nearshore Basin, Rocky Zone, Shelf Valley, Nearshore Ramp, and Bay-Mouth Shoal, which are described below. They are delineated based on sediment thickness (isopach, panel A), seafloor morphology (topography, panel B), substrate type (backscatter and grain size, panel C), and seafloor slope (panel D). Using this approach, geologic maps have been produced at regional scales for other shelf areas in the western Gulf of Maine where seafloor topography and substrates are similar to the inner shelf offshore of northeastern Massachusetts (Kelley and others, 1989; Kelley and Belknap, 1991; Barnhardt and Kelley, 1995).

Nearshore Basins are areas of shallow, low-relief seafloor adjacent to the mainland and separated from offshore areas by islands and shoals. They are found in the sheltered environment of Salem Sound and contain the only significant deposits of muddy sediment in the mapped area. This environment comprises 22.4 km2 or 13.1% of the mapped area.

Rocky Zones are rugged, high-relief areas dominated by rock outcrops and glacial gravels. Accumulations of shell-rich sediment locally occur at the base of rock outcrops and as sediment ponds in small depressions. The abundant shelly material probably results from high productivity of calcareous epifauna on the extensive areas of hard substrate. This environment comprises 63.4 km2 or 37.0% of the mapped area.

Shelf Valleys consist of 1) elongate depressions that extend offshore from the coast, and 2) irregularly shaped areas of small, interconnected depressions. The former probably originated as stream channels that formed when sea level was lower, and the latter as a series of kettles that formed in glacial drift. Both types have been modified by erosion and are partially filled with sandy, gravelly sediment; rock outcrops are common. This environment comprises 12.5 km2 or 7.3% of the mapped area.

Nearshore Ramps, the largest of the mapped zones, are smoothly sloping regions that extend offshore from the coast to depths of about 40 m. The seafloor is generally covered with sand-rich sediment, with isolated exposures of glacial-marine clay, ledge, cobbles and boulders. This environment comprises 68.6 km2 or 40% of the mapped area.

Bay-Mouth Shoals are shallow, flat-topped features covered with sand and gravel that occur at the entrance to Salem Sound. The shoals are elevated above the surrounding shelf, with relatively steep slopes along their margins, and locally emerge above sea level as small islands. Reworking by waves and currents have produced large fields of bedforms. This environment is the least abundant zone, and comprises 4.4 km2 or 2.6% of the mapped area.

The map in panel F is a second, more quantitative approach to seafloor mapping that characterizes the distribution of substrate types in the study area. This map shows the preliminary results of an ongoing effort to develop semi-automated methods of describing the spatial variability of geological materials on the seafloor. The method is based on multivariate statistics, a technique that is commonly used in aerial remote sensing of terrestrial environments. The inputs for this unsupervised classification are seafloor morphology (bathymetry, panel B), substrate type (backscatter, panel C), and seafloor slope (panel D). The isopach map in panel A was used after the classification to help constrain areas of ledge (i.e., sediment thickness ~ 0 m) in the multivariate analysis.

The statistical analysis in panel F delineates substrates into three general classes: sand/silt, cobbles/boulders, and ledge (rock). Areas that are shaded black around the edges of the map were lacking one or more of the three data types, and therefore are mapped as "no data". The map shows areas of high relief and hard bottom as consisting of cobbles/boulders (reworked glacial sediment) and ledge (bedrock outcrops). Bottom samples and photography confirm the computer-generated interpretations. These areas of ledge and cobble/boulder generally correlate to Rocky Zone in Panel E (above), and also include Bay-Mouth Shoal and limited parts of Shelf Valley. Smooth and gently sloping areas of Nearshore Basins, Shelf Valleys and Nearshore Ramps are mapped as sand/silt. Locally, parts of Nearshore Ramp are mapped as cobbles/boulders where sorted bedforms and exposures of underlying glacial-marine sediment occur on the seafloor.

Data and Methods

Mapping of the seafloor was carried out in the nearshore region between the 5 and 40 meter isobaths. Approximately 134 km2 of the inner shelf were mapped using interferometric sonar (seafloor topography), sidescan sonar (backscatter intensity), and chirp seismic-reflection profiling (sediment thickness). The three mapping systems were simultaneously deployed from the RV Rafael, a 25-ft research vessel outfitted for mapping in shallow water. Samples of the surficial sediments and bottom photographs were used to validate interpretations of the remotely-sensed data. For additional information on the methods used in this project, see map sheets 1-4 and the DVD-ROM that accompanies this map.

Features

Maps depicting topography and surficial materials on the inner continental shelf play an important role in understanding the region's geologic history and the ongoing processes that have shaped the seafloor. Igneous and metamorphic rocks spanning millions of years of Earth history control the overall geometry of the coast and inner continental shelf (Zen et al., 1983). Erosion resistant intrusive rocks form rugged coastal headlands and some of the submarine shoals. Glaciation and relative sea-level change are the most important processes to act on the region, and have produced a heterogeneous mix of bottom types on the inner continental shelf.

Rock outcrops and coarse-grained glacial sediment form the rugged, irregular topography that characterizes the seafloor in much of the study area. Deposits of glacial till and outwash partially mantle the rocks with a wide range of particle sizes from fine-grained mud to large boulders. Glaciers produced a prominent series of boulder-covered ridges or moraines southeast of Marblehead Neck, in shallow water just outside the entrance to Salem Sound. These relic features are arcuate and convex seaward in planform, with each moraine marking a former position of the ice-sheet margin as it progressively retreated across the region at the end of the last Ice Age. Sandy sediment fills several small, closed depressions in the vicinity of the moraines, which probably represent kettles that formed in glacial drift and have been modified by erosion. An elongate valley with rocky walls extends offshore from Salem Sound, passing between Little Misery and Bakers Islands. The valley exhibits a pattern of tributaries and a main channel that were probably eroded by the ancestral Danvers River when relative sea level was lower than today.

No major rivers presently deliver significant amounts of sediment to the area, so reworking of existing deposits has largely determined the observed distribution of bottom sediment. Modern processes interact with bedrock and glacial deposits to create the sandy beaches and other coastal landforms extant along the present shoreline. Sandy sediment, derived from reworked glacial sediment, has also accumulated on the surface of broad, gently sloping areas of seafloor in Nahant Bay in the southwestern part of the map, and offshore of Manchester in the northeastern part of the map. Thick deposits of muddy sediment primarily occur in Salem Sound, where islands and shoals at the estuary mouth provide shelter from large waves out of the northeast and create a depositional environment. More details on the geologic framework and evolution of the region are found in the report that accompanies this map.

Acknowledgements

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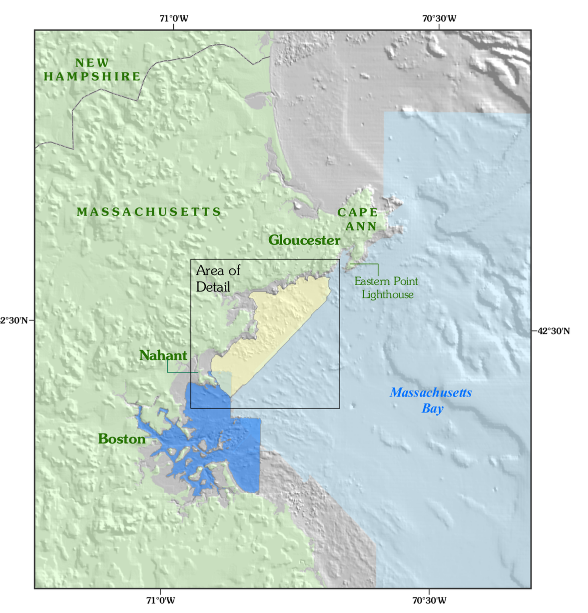

Map of other adjacent sea floor mapping projects. Area to the south in blue is Boston Harbor and approaches (in press). area offshore in light blue is Western Massachusetts Bay (Butman and others 2004).

Projection: UTM
Zone: 19
Datum: WGS84

HIGH-RESOLUTION GEOLOGIC MAPPING OF THE INNER CONTINENTAL SHELF: NAHANT TO GLOUCESTER MASSACHUSETTS

Sheet 5. Geologic maps of seafloor.

By

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