High-Resolution Geologic Mapping of the Inner Continental Shelf: Cape Ann to Salisbury Beach, Massachusetts

U.S. Geological Survey Open-File Report 2007-1373

Map Sheet 5: Geology of the Seafloor

Introduction

A series of five map sheets shows the seafloor topography and geology of the inner continental shelf between Cape Ann and Salisbury Beach, Massachusetts. This map (sheet 5) shows a geologic map of the seafloor and describes how the map was produced. Sheet 1 shows shaded-relief topography in color, sheet 2 shows shaded-relief topography in gray scale, sheet 3 shows gray scale backscatter intensity, and sheet 4 shows shaded-relief topography colored by backscatter intensity. These maps were 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 the Internet and a DVD-ROM that presents a full description of the data collection, processing, and analysis procedures used to create the maps. The report also includes copies of selected data layers in a Geographic Information System (GIS).

Additional data are included on this map to show the regional topography in areas adjacent to the new survey. To the north and west, seafloor topography in shaded-relief view is shown at a reduced resolution of 90 m/pixel on the basis of data from the NGDC Coastal Relief Model (Divins and Metzger, 2007). Hillshaded bathymetry to the east and southeast from Butman and others (2007) is displayed at a resolution of 10 m/pixel. Onshore topography displayed at a resolution of 5 m/pixel is from the Massachusetts Geographic Information System (MassGIS, 2005).

Geologic Mapping

This study integrated remotely sensed geophysical data with data from bottom samples and underwater photography to characterize seafloor geology at a broad, regional scale. The datasets used to construct the map are shown in four small panels (A-D) along the bottom of this sheet. Panel A is an isopach map, which shows the thickness of sediment overlying bedrock in the region. Panel B shows the topography of the seafloor in gray scale shaded relief with locations of bottom photographs and sediment sampling locations. Panel C is a backscatter intensity map, which shows patterns of acoustic reflectivity related to different substrates, and includes sediment sampling locations with pie diagrams depicting sediment texture. Panel D is a map of seafloor slope in degrees, with slopes 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.

The map in panel E is an interpretive geologic map that divides the inner continental shelf into five environments, or physiographic zones. The five zones — Rocky Zones, Nearshore Ramps, Ebb-Tidal Deltas, Shelf Valleys, and Outer Basins— 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). This approach has been used to produce geologic maps at regional scales for other shelf areas in the western Gulf of Maine where seafloor topography and substrates are similar to the inner shelf of northeastern Massachusetts (Kelley and others, 1989; Kelley and Belknap, 1991; Barnhardt and Kelley, 1995).

- Rocky Zones are rugged, high-relief areas dominated by rock outcrops and glacial gravels. Local accumulations of shell-rich sediment are found at the base of rock outcrops and as sediment ponds in small depressions. This environment composes 18.3 km^2 or 5.1% 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 50 m. The seafloor is generally covered with sand-rich sediment, with isolated exposures of ledge, cobbles, and boulders. This environment composes 228.4 km^2 or 63.9% of the mapped area.

- Ebb-Tidal Deltas are lobate deposits of sandy sediment that occur in shallow water seaward of tidal inlets. This environment composes 10.6 km^2 or 3.0% of the mapped area.

- Shelf Valleys are elongate depressions that are partially filled with sandy, gravelly sediment. Rock outcrops are common. The valleys were probably eroded by streams when sea level was lower than at present. This environment covers the least area, only 1.1 km^2 or 0.3% of the mapped area.

- Outer Basins are areas of muddy seafloor that lie seaward of Nearshore Ramps in water deeper than 50 m. They generally have low slopes and few rock outcrops. This environment composes 99.1 km^2 or 27.7% of the mapped area.

Data and Methods

Approximately 325 km^2 of the inner shelf in water depths of 2–92 m were mapped on two separate cruises in 2004 and 2005. Several different geophysical systems were used, including multibeam echosounders and interferometric sonars (bathymetry), sidescan sonars (acoustic backscatter intensity), and chirp seismic-reflection profilers (subsurface stratigraphy and structure). 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. The map sheets and text are part of the Open File Report.

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 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 and, 1983). Erosion-resistant granitic rocks form rugged headlands and submarine shoals that define the northern and southern margins of the study area. Glaciation and relative sea-level change are the most important processes to have acted on the region and have produced a heterogeneous mix of bottom types on the inner continental shelf. Late Pleistocene glaciers reached their maximum extent south of Cape Cod about 21,000 years before present (yrs B.P.) (Balco and others, 2002) and retreated northward as the climate warmed. The retreating ice margin passed the present coast of Cape Ann about 14,500 yrs B.P. (Kaye and Barghoorn, 1964). The glaciers smoothly eroded the underlying bedrock and largely buried it with bouldery till and muddy glacial-marine sediment (Stone and others, 2006). Thick deposits of coarser grained fluvial, deltaic and littoral sediment accumulated above the glacial deposits and masked the underlying topography beneath a generally smooth, seaward-dipping seafloor. These younger sediment accumulations represent the variety of different environments that existed on the inner shelf subsequent to the end of the last Ice Age.

Large excursions in relative sea level, primarily due to a combination of global climate change and local isostatic effects, have driven profound changes in the position of the coastline and strongly influenced the geologic evolution of the region. Relative sea level fell from a highstand of +33 m at 14,500 yrs B.P. to a lowstand of about -50 m at 12,000 yrs B.P. (Stone and Peper, 1982; Oldale and others, 1993). As isostatic rebound decreased, relative sea level rose at different rates to the present elevation. The ongoing Holocene transgression (landward migration of the coast) has reworked a wide expanse of the inner shelf, and eroded a prominent unconformity overlain by relatively thin, discontinuous deposits of mobile sand. Large mounds of boulder-sized clasts represent the remnants of ice-contact deposits such as drumlins and moraines, which have been eroded by marine and terrestrial processes. In water depths greater than about 50 m, below the sea-level lowstand, the generally smooth seafloor is dominated by fine-grained marine mud interrupted by a few widely separated outcrops of ledge and boulders. Scoured moats around these deep-water outcrops indicate persistent erosion by bottom currents.

The Merrimack River, which drains a large area of Massachusetts and New Hampshire, enters the Gulf of Maine just north of Cape Ann. Sediment supplied by the river and derived from erosion of coastal and inner shelf deposits has built the longest chain of sandy barriers in the Gulf of Maine (FitzGerald and others, 1994). The barrier islands and spits are pinned to bedrock or glacial promontories along the coast and stretch approximately 30 km from Ipswich Bay to the New Hampshire border.

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Panel A

Map showing the total thickness of sediment between subsurface bedrock and the seafloor. Small, isolated exposures of bedrock (dark gray shading) are covered with sediment less than 0.5-m thick. Sediment-thickness values were interpreted from closely spaced seismic-reflection profiles. In the nearshore area, measured values were used to generate an interpolated grid, but in the offshore area, values are displayed only as discrete points along the widely spaced seismic-reflection tracklines. Map scale is 1:120,000.

Panel B

Map showing the locations of sediment-sampling sites and photography/video transects superimposed on gray scale, shaded-relief topography. Each numbered circle indicates a station where bottom photographs, video, and/or sediment samples were collected to validate interpretations of geophysical data. Map scale is 1:120,000. See map sheets 1 and 2 for higher resolution maps of seafloor topography.

Panel C

Map showing acoustic backscatter intensity, which is a measure of the hardness or roughness of the seafloor. In general, high backscatter values (lighter tones) indicate that the seafloor is covered with coarse sand, gravel, cobbles, boulders, and rock. Lower backscatter values (darker tones) indicate finer sandy and muddy sediment. The locations of sediment-sampling sites are shown here as pie diagrams that indicate grain-size distribution. Map scale is 1:120,000. See map sheets 3 and 4 for higher resolution maps of acoustic backscatter.

Panel D

Map showing seafloor slope in degrees, with slopes derived from the 5-m bathymetric grid in map sheet 1. The map was colored using a Natural Breaks Method (Jenks) with five classes to symbolize slope. Map scale is 1:120,000.

Panel E

Interpretive geologic map showing five physiographic zones on the inner continental shelf, including Rocky Zones, Nearshore Ramps, Ebb-Tidal Deltas, Shelf Valleys, and Outer Basins. The physiographic zones were delineated based on seafloor topography, seafloor slope, and sediment thickness, composition, and texture (panels A-D below). See main text at right for descriptions of physiographic zones.