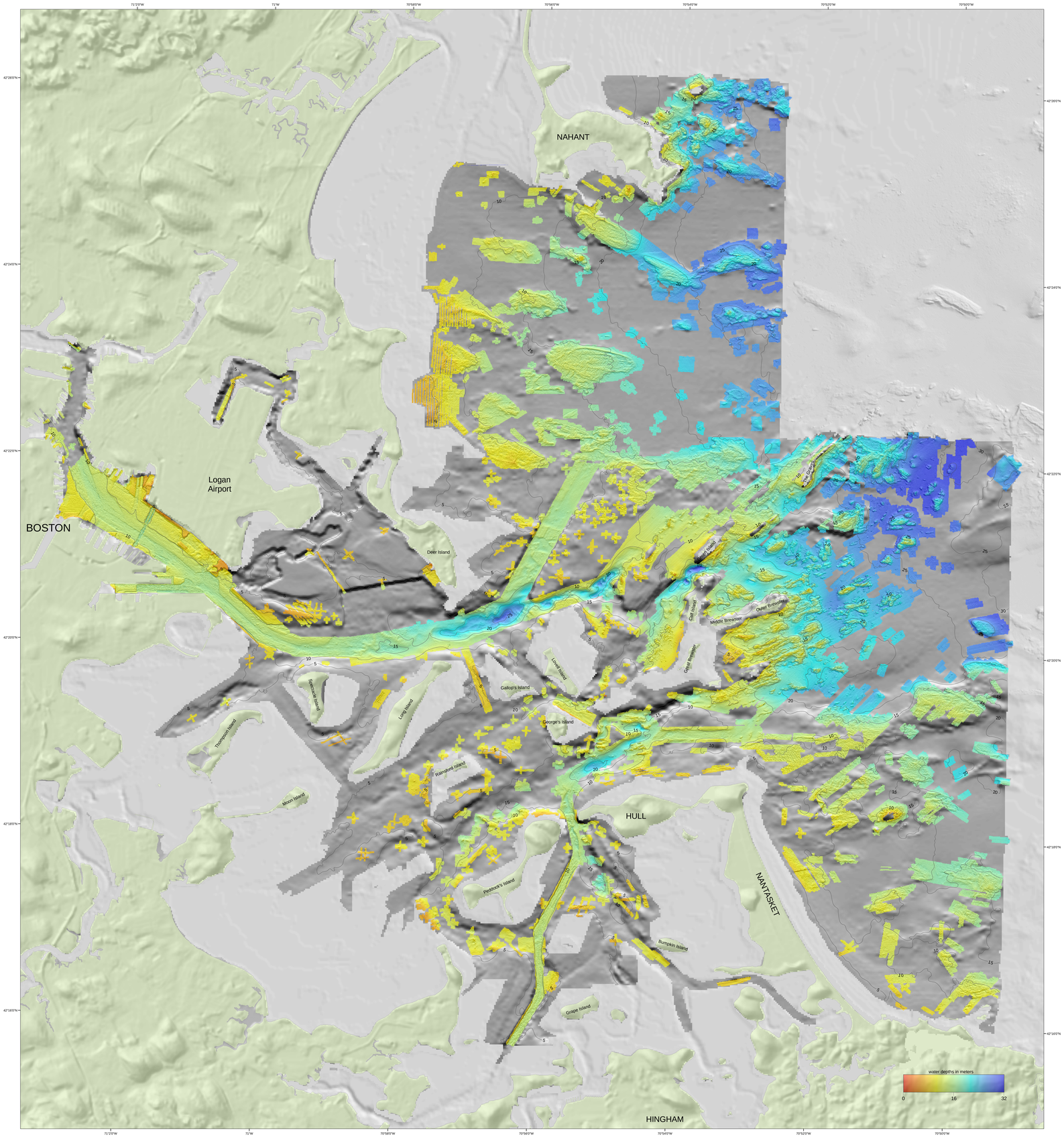
Prepared in cooperation with the
MASSACHUSETTS OFFICE OF COASTAL ZONE MANAGEMENT



Projection: UTM
Zone: 19
Datum: WGS84

NOT FOR NAVIGATIONAL USE

1:25,000

1 CENTIMETER ON THE MAP EQUALS 250 METERS ON THE SEAFLOOR

Kilometers

BATHYMETRIC CONTOURS IN METERS BELOW MEAN LOWER LOW WATER (MLLW)

HIGH-RESOLUTION GEOLOGIC MAPPING OF THE INNER CONTINENTAL SHELF: BOSTON HARBOR AND APPROACHES, MASSACHUSETTS

Sheet 2. Shaded-relief topography of the seafloor (grayscale) with areas surveyed by multibeam colored by water depth.

By

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HIGH RESOLUTION GEOLOGIC MAPPING OF THE INNER CONTINENTAL SHELF: BOSTON HARBOR AND APPROACHES, MASSACHUSETTS

U.S. Geological Survey Open-File Report 2006-1008

Map Sheet 2 : Shaded-relief topography of the seafloor (grayscale)
with areas surveyed by multibeam colored by water depth

Introduction

A series of five map sheets shows the sea floor topography and geology of Boston Harbor and Approaches. Sheets 1-4 are at a scale of 1:25,000; Sheet 5 is at a scale of 1:60,000. Sheet 1 shows sea floor topography in shaded-relief, colored by water depth. Sheet 2 shows shaded-relief topography in grayscale with data from high-resolution multibeam surveys superimposed and colored by water depth. Sheet 3 shows sidescan-sonar backscatter intensity in grayscale with high backscatter displayed as light tones and low backscatter as dark tones within the imagery. Sheet 4 shows shaded-relief topography colored by backscatter intensity with red tones representing high backscatter and blue tones representing low backscatter. Sheet 5 shows shaded relief, backscatter intensity and sample locations, sea floor slope, and an interpretive map of sea floor environments. The location of sampling sites referenced in the text below can be found on the sediment texture map on sheet 5.

These maps are produced as part of a cooperative effort by the U.S. Geological Survey (USGS), the Massachusetts Office of Coastal Zone Management (CZM) and the National Oceanic and Atmospheric Administration (NOAA) to systematically map the sea floor geology offshore of Massachusetts and provide geologic framework information for resource management, scientific research, industry and the public. These map sheets are part of an USGS Open File Report (Ackerman and others, 2006) describing data collection, processing, and analysis of geophysical and sample data. The report (on DVD-ROM) also includes all of the data in GIS format and as part of an ESRI ArcMap project.

Data and Methods

The bathymetric and sidescan-sonar data used to generate these maps were collected as part of hydrographic surveys of the navigable areas within Boston Harbor and its approaches carried out by NOAA in 2000 and 2001 (surveys H10990, H01991, H10992, and H10994) by the NOAA ship Whiting and its launches. These cruises acquired sidescan-sonar data over an area of 155 km2 and single-beam bathymetric data over an area of approximately 170 km2. In addition, multibeam echosounder data were acquired over 65 km2 (approximately 37% of the survey area). The multibeam echosounder data were collected in navigation channels and at approximately 450 site-specific locations that were identified as potential hazards to navigation. The most dense multibeam echosounder coverage is within the navigation channels (President Roads, North Channel, South Channel, and Nantasket Roads), Boston Inner Harbor, and east of the outer Boston Harbor Islands. The multibeam echosounder data were reduced to Mean Lower-Low Water (MLLW) using data from tide station 844-3970, Boston, MA. Bottom photographs, video, and grab samples were collected by CZM and the USGS in 2004 in order to guide the interpretation of the geophysical data. See Ackerman and others (2006) for a detailed description of the field program and data processing.

A composite bathymetry grid was created from single-beam and multibeam echosounder data and was used to create the shaded-relief image shown on sheet 1. Multibeam echosounder data were exported at a 2-meter grid interval for each of the four survey areas and single-beam echosounder data from surveys H10990, H10992, and H10994 were exported at a 4-meter grid interval. The single-beam echosounder data from survey H01991 were provided by NOAA as a separate xyz file. Generic Mapping Tools (GMT; http://gmt.soest.hawaii.edu/) was used to create an interpolated bathymetric grid using the "surface" routine with a grid cell size of 30 m and a tension parameter of 0.2.

The hydrographic surveys were designed for target identification and therefore NOAA collects overlapping sidescan-sonar data to ensure complete coverage of the sea floor. An Edgetech model 272-T (100 kHz) and a Klein T-5500 (455 kHz) sonar were used for the sidescan-sonar surveys. System and vessel configurations varied between and within individual surveys. The sidescan-sonar data were processed to correct for radiometric and geometric distortions inherent in sonar data.

The sidescan sonar data were mosaicked using PCI Geomatics and exported as georeferenced TIFF image files at 1 meter/pixel resolution. Tone-matching was applied in order to correct for the variations in dynamic range of the sidescan-sonar data collected within individual surveys.

Map Sheets

The shaded-relief bathymetric maps (sheets 1 and 2) were created by vertically exaggerating the sea floor topography ten times and artificially illuminating the relief by a light source positioned 45° above the horizon from an azimuth of 0° (due north). Topographic features, such as channel boundaries or submarine ridges, are enhanced by strong illumination on north-facing slopes and by shadows cast on south-facing slopes. The shaded-relief image accentuates small features that could not be effectively shown by contours alone at this scale. The water depth, using a color scale from red (shallow) to blue (deep), is superimposed on the sun-illuminated topography. Smoothed topographic contours at 5-m intervals are shown. The shaded relief imagery is derived from 2-m multibeam echosounder data merged with the composite 30-m bathymetry described above. The locations of the multibeam echosounder data are shown in sheet 2. Gridded single-beam echosounder data display smoothed topography due to wide-line spacing and interpolation. Multibeam echosounder data reveal more detailed sea floor topography. Boundaries between datasets are delineated by sharp transitions from smooth to detailed topography (sheet 2). The channels northeast of George's Island (multibeam echosounder) and Gallop's Island (single-beam echosounder) exemplify the rough and smooth sea floor, respectively.

Sheets 3 and 4 display sidescan-sonar backscatter intensity. Backscatter intensity is a relative measure of the reflectivity of the material on the sea floor. The intensity of acoustic backscatter is represented by 256 shades of gray, ranging from lighter shades (representing high backscatter values) to darker shades (representing low backscatter values). Shadows appearing in the sonar imagery can be useful in the identification of features and objects on the sea floor. Direct sampling of the sea floor sediments, bottom photography and video are needed to accurately interpret sidescan-sonar backscatter intensity. In general high backscatter corresponds to areas of coarse sand, gravel, cobbles, boulders and rock within Massachusetts Bay. Moderate backscatter corresponds to sand or muddy sand. Low backscatter is associated with sandy mud or mud.

Some artifacts are present within the data. These include small highs and lows, and unnatural-looking patterns oriented parallel or perpendicular to survey tracklines. Artifacts may be due to environmental conditions or result from data collection and processing. Tracklines were generally run parallel to the major channels in Boston Harbor and around the Harbor Islands. They were predominantly north-south in the harbor approaches. Slight mismatches in the grayscale tones in the sidescan-sonar (sheet 3 and 4) are also artifacts of data collection and processing. These occur where acquisition parameters in one swath are different from the adjacent swath, making it difficult to match the grayscale tone along the entire length of those lines. Areas that could not be surveyed because they were too shallow (typically less than a few meters deep) are shown in light gray.

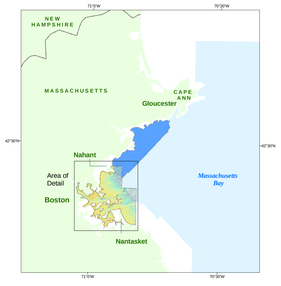
Additional data are included on all sheets to show the regional topography in areas adjacent to the survey. To the east, offshore of the new survey area, sea floor topography in shaded-relief view is shown at a resolution of 6 m/pixel (Butman and others, 2004). Inshore of the survey area and to the east, sea floor topography generated from the NOAA/NOS estuarine bathymetry database (NOAA, 1998) is shown in shaded-relief view at a resolution of 30 m/pixel. Onshore topography was extracted from Massachusetts Geographic Information System (MassGIS, 2005) displayed at a resolution of 20 m/pixel.

Features

This study encompasses Boston Inner Harbor, Boston Outer Harbor, the northern approaches to Boston Harbor (Broad Sound; north of the Harbor Islands to Nahant), and the southern approaches to Boston Harbor (outer Harbor Islands and nearshore east of Nantasket Beach). The bathymetry and sidescan-sonar data show natural features and sea floor modification from anthropogenic activities. Dredging and other anthropogenic activities are generally focused in the shipping channels. Evidence of dredging is visible within the imagery as straight-sided channels, unnatural-appearing roughness and/or linear features on the sea floor that are typically oriented parallel to a channel. Disposal of dredged material is clearly displayed within the multibeam echosounder data as rounded mounds; often occurring in a straight line. Some have a central high and a surrounding moat thought to be created as the material was deposited on the sea floor. The mounds sometimes are identified in the sidescan-sonar by high backscatter intensity, but are not always resolved. Other anthropogenic features on the sea floor include wrecks of small boats and barges, pipelines, and piles of debris. Almost all of the Inner Harbor from Castle Island to Long Wharf was mapped by multibeam echosounder. In the Outer Harbor and the Harbor Approaches, the 2-m resolution multibeam echosounder data are displayed with the 30-m resolution single-beam echosounder data; interpretation of features and their spatial extent is limited by these mixed observations.

The seafloor landscape varies from gently sloping sub-tidal flats to areas of rugged elevation exhibiting as much as 7 m of local relief (sheet 1). The acoustic backscatter intensity (sheet 3) illustrates the general distribution of surficial sediment. The approaches to Boston Harbor and the dredged navigation channels around the Harbor Islands are generally characterized by high backscatter, bedrock, boulder, cobbles, or dense shell beds. The Inner and Outer Harbor are primarily composed of fine-grained sediments, such as fine sand or mud, which displays as low backscatter within the sidescan-sonar imagery.

Sea-floor topography and surficial character in the study area vary at scales of several meters and less. For example, high relief bedrock and bouldery glacial deposits (till) are commonly exposed on the sea floor in close proximity to flat-lying deposits of finer sediment (sand, mud). Rocky areas sometimes contain isolated accumulations of shelly sediment that are ponded in small cracks or low-lying areas between rock outcrops.



Map of other adjacent seafloor mapping projects. Area to the north in blue is the Nahant to Gloucester area (Barnhardt and others 2006) and offshore in light blue is Massachusetts Bay (Butman and others 2004).

Features (continued)

Boston Inner Harbor

The bathymetry and surficial character of the sea floor within the Inner Harbor reflect a long history of dredging in the study area (for example, see the circular features near 42° 20' 51", 71° 0' 40.8" W and the trapezoidal area centered near 42° 20' 40.2", 71° 0' 45" W). The north side of the main navigation channel south of Logan Airport is dredged to a depth of 35' (about 10.7 m) and the south side to a depth of 40' (about 12 m) (NOS Chart 13272). The Ted Williams Tunnel runs under the navigation channel between South Boston and Logan Airport. On the sea floor, the tunnel is marked by a depression about 50 m wide that is a few m deeper than the navigation channel; on the northern side of the channel, the tunnel depression has a central high and channels about 2-4 m deeper along the western and eastern edges. The multibeam echosounder data do not extend over the Callahan or Sumner Tunnel. The sea floor of the Reserved Channel and a trapezoidal area across the main channel to the east of the Reserved Channel (centered near 42° 20' 40.2" N, 71° 0' 45" W, dredged to 40') have a rough appearance, in contrast to the relatively smooth main channel. A linear feature about 5 m wide and less than 1 m deep runs east-west across the main channel near 42° 20' 33" N, 71° 0' 30" W; this feature is in a cable area (NOS Chart 13272). Throughout the inner harbor the sea floor is marked by numerous linear features, presumably scours from wire and anchor drags. There are also some depressions (for example near 42° 21' 34.8' N, 71° 2' 25.8" W), typically less than 20 m in spatial extent and a few m deep, thought to be caused by dredging.

Low backscatter intensity material covers most of the Inner Harbor, representing fine-grained sediments (sheets 3, 4 and 5). Moderate backscatter intensity occurs in the shipping channel east of Castle Island and in the northern part of the Inner Harbor east of Boston. The cover of the Ted Williams tunnel is moderate backscatter. The finest sediments sampled in this survey, at the mouth of the Mystic River, contained over 40% clay.

Boston Outer Harbor

The Outer Harbor contains the Harbor Islands and major shipping channels that provide access to the Port of Boston and the communities of Quincy, Weymouth, and Hingham. The northern part of the Outer Harbor contains the sub-tidal Governors Island Flats and Deer Island Flats (east of Logan Airport), bounded to the south by President Roads and the President Roads Anchorage. The sediments on the flats are characterized by low backscatter intensity. A series of irregularly-shaped dredged areas with linear edges are located south and east of Logan Airport and continue to the north into Winthrop Bay. The area centered near 42° 20' 45.6" N, 70° 59' 57.6" W is 4-6 m deep with an irregular sea floor; the area centered near 42° 21' 10.8" N, 70° 59' 3.6" is about 6 m deep with a nearly flat sea floor. The deepest water in Boston Harbor, about 28 m deep, occurs in a depression about 2 km long and 200 m wide located south of Deer Island. Along the northern side of this depression, the sea floor is shaped in a series of sand waves about 10 m in wavelength and less than a meter high. These sand waves coalesce and disappear at about 14-15 m water depth. Three additional depressions, with water depths in excess of 20 m, trend east-northeast from the low south of Deer Island along the axis of the south Channel. Backscatter intensity changes from low in the inner harbor to high from this point eastward in the north and south channels and into the Approaches.

In the southern part of the Outer Harbor, bathymetric and sidescan-sonar mapping were conducted mostly in water depths greater than 6 meters and focused in Nantasket Roads and the smaller navigation channels around the Harbor Islands and those leading into Quincy and Hingham and Hull Bays. The deepest water occurs in two natural lows, one in Nantasket Roads north of Hull and centered near 42° 18' 48" N, 70° 55' 6" W, 22 m deep, and one south of Hull and centered near 42° 17' 36" N, 70° 55' 6" W, 18 m deep. High backscatter intensity material is found in Nantasket Roads, on the topographic high (Hospital Shoal) east of Rainsford Island, in the channel between Rainsford and Long Island, to the west and southwest of Peddocks Island, and in the low south of Hull. Bottom photographs in these areas show a gravel pavement on the sea floor. The areas south of Long Island, in the entrance to Quincy Bay and southeast of Peddocks Island in the entrance to Hingham Bay, exhibit low backscatter intensity. Sediment texture analyses at station 63 (south of Long Island) and 61 southeast of (Peddocks Island) reveal clayey silt and sandy silty clay, respectively (sheet 5). On the margins of the navigation channels and where the surveys extend into the sub-tidal flats of Hull, Hingham, Quincy Bays, the sea floor is covered with fine muddy sediment that shows low backscatter intensity.

Approaches to Boston Harbor

The Approaches to Boston Harbor are characterized by areas with rough topography (sheet 1 and 2), elevated sea floor and high backscatter intensity (sheet 3 and 4) and areas of smooth topography and low backscatter intensity. The high-backscatter intensity areas are typically covered by outcropping rock, boulders, cobbles and gravel; the low backscatter intensity areas are typically covered by sandy sediments.

The sea floor in President Roads and in the North and South channels is characterized by high backscatter. Bottom photographs and video at stations 44, 53, 54 (sheet 5) show mostly cobbles that were too coarse for retrieval; no sediment samples were collected in these areas. At station 50 in the South Channel the sea floor was a dense bed of mussel shells. Rippled sands are found within a low backscatter region at station 45, southeast of Deer Island and north of the navigation channel.

In Broad Sound there are features elevated 4-5 m from the surrounding sea floor, characterized by rough topography and high backscatter (e.g. centered near 42° 23' 6" N, 70° 55' 18" W and near 42° 24' 30" N, 70° 55' 6" W). The north or northeast facing side of these features rises abruptly about 3 m above the surrounding sea floor. Photographs show these features to be covered by gravel, cobbles and boulders. These features are most likely drumlins that were eroded and reworked during the last rise in sea level, leaving behind the coarse sediments.

A series of high backscatter outcropping ledges lie east of the Brewster Islands, for example near 42° 20.1' N, 70° 52.6' W. These ledges are bounded to the north by the Graves and to the south by Nantasket Roads and cover approximately 15 km2. The ledges trend east-northeast - west-southwest and have 4-7 m of local relief.

East of Nantasket there are two areas characterized by variable topography (up to 4 m of local relief) and high backscatter intensity. Based on bottom photographs and video, the local highs show with algae-covered rock outcrops and boulder- to cobble-sized sediment. These outcrop areas are separated by an approximately 700-m wide band characterized by uniform low backscatter; sediment samples and bottom photographs obtained show the area is composed of well-sorted fine sand.

Numerous individual high backscatter targets in the Approaches, which are 4-6 m in length and less than a meter high, are interpreted to be individual boulders and are observed in nearly all of the areas outside the harbor with rough sea floor topography. Although the multibeam echosounder data resolves individual boulders in the Harbor Approaches, the boulders are not observed in the sandy sediments immediately adjacent to these areas. The boulders are likely to be associated with glacial deposits. There are fewer similar targets within the Harbor; however, additional sampling is needed in order to assess similarities with targets within the Harbor Approaches.

Sea-floor units

Six sea-floor units defined by bottom slope, backscatter intensity, surficial sediment texture and anthropogenic activity were distinguished within the study area (sheet 5): High-relief bedrock and boulder, Medium-relief boulder and cobble, Low-relief gravel and sand, Low-relief sand, Low-relief mud, and Anthropogenic modification areas. These zones were delineated qualitatively at a scale of 1:30,000 in areas where both new sidescan sonar and bathymetric data are available (about 155 km2). Bottom slope was calculated from the 30-m gridded bathymetry as the average slope between the central pixel and the surrounding 8 pixels. Areas smaller than about 200 meters were not delineated.

High-relief bedrock and boulder areas are characterized by local slopes of 4 to 30 degrees and high backscatter intensity. Bottom photographs and video in these areas show the sea floor covered by cobbles, boulders or outcropping bedrock; no sediment samples could be obtained in these rocky areas. Most of the high-relief bedrock and boulder area occur between the outermost Harbor Islands and the rocky ledges farther offshore to the east.

Medium-relief boulder and cobble areas are characterized by local slopes of 1 to 4 degrees and high backscatter intensity. Bottom photos and video in these areas show the sea floor covered by gravel, cobbles and boulders. Most of the medium-relief boulder and cobble area occurs in the harbor approaches.

Low-relief gravel and sand areas are characterized by a local slope of less than 1 degree and either high or mottled (patches of high/low) backscatter intensity and sandy sediments (e.g. stations 14, 15 and 92; see sheet 5). Bottom photographs and video obtained in areas near these sandy samples show gravel and cobble-sized sediment on a sandy or muddy substrate.

Low-relief sand areas are characterized by local slope of less than 1 degree, predominately low backscatter intensity and uniform sandy sediments, confirmed by the sampling survey. Low-relief, low-backscatter sandy environments dominate the approaches to Boston Harbor.

Low-relief mud areas are characterized by local slope of less than 1 degree, predominately low backscatter intensity, and fine-grained muddy sediments, confirmed by the sampling survey. Low-relief muddy environments lie within Boston Harbor.

Anthropogenic modification areas have been altered by human activity. The most easily identified man-made artifacts are dredged channels and anchorage areas. The sea floor of Boston Harbor has been influenced by other activities, including the disposal of dredge spoils, placement of artificial reefs, construction of piers, laying of pipelines, and submerged wrecks. Areas of Anthropogenic Modification comprise all five sea-floor environments described above; however, the overprint of man-made artifacts dominates the other natural characteristics.

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References

Ackerman, S., Butman, B., Barnhardt, W.A., Danforth, W.W., and Crocker, J.M., 2006, High-resolution geologic mapping of the inner continental shelf; Boston Harbor and Approaches. U.S. Geological Survey Open-File Report OF2006-1008. 1 DVD-ROM.

Butman, B., Valentine, P.C., Danforth, W.W., Hayes, L., Serrett, L.A., and Middleton, T.J., 2004, Shaded relief, backscatter intensity and sea floor topography of Massachusetts Bay and the Stellwagen Bank region, offshore of Boston, Massachusetts: U.S. Geological Survey Geologic Investigation Map I-2734, scale 1:125,000, 2 sheets. Available online at http://pubs.usgs.gov/imap/i2734/.

MassGIS, 2005, Massachusetts Geographic Information System, Statewide Digital Elevation Model (1:5000) February 2005, Available online at http://www.mass.gov/mgis/img_elev5k.htm.

NOAA, 1998, National Oceanic and Atmospheric Administration, National Ocean Survey, Special Projects Office, 1998, Estuarine Bathymetry, NOS Special Projects website at http://sposerver.nos.noaa.gov:16080/bathy/index.html.