Section 2: High-Resolution Geologic Maps of the Sea Floor

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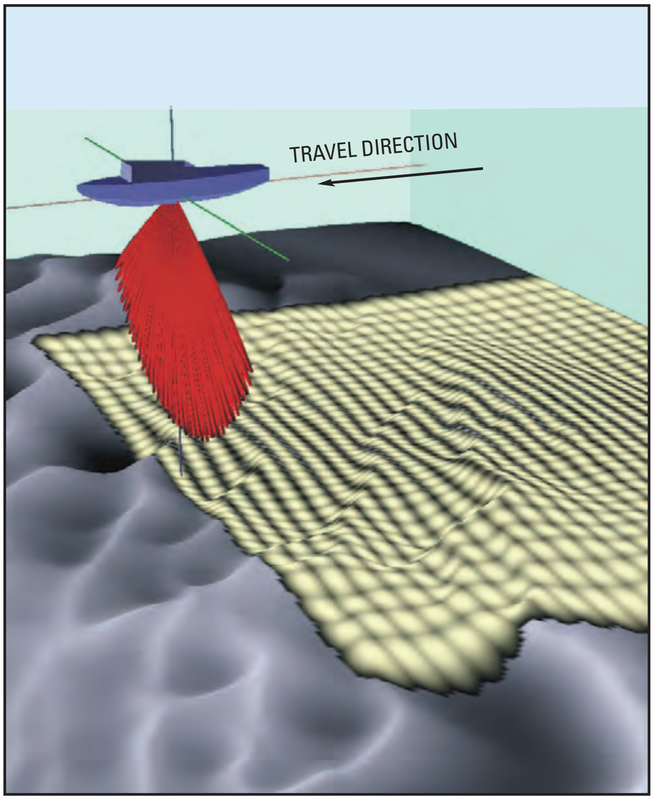
Maps of the sea floor provide information on the topography and geology for scientific, management and commercial activities. Massachusetts Bay and the Stellwagen Bank National Marine Sanctuary were mapped from 1994 to 1998 using a high-resolution multibeam mapping system (figs. 2.1A, 2.1B), providing topography and backscatter intensity measurements at a horizontal resolution of 6–10 m (figs. 2.2A, 2.2B, Butman and others, 2004b; Valentine and others, 2001, 2003a–c). Although the water depth in this area was relatively well-known, the backscatter-intensity observations provide, for the first time, a measure of the surficial sediment properties at the same resolution and location (co-registered) as bathymetry. Previous maps of surficial sediment properties were based on widely spaced samples.

Direct observations with bottom photography, video, grab sampling (fig. 2.3), and coring have been made to assist in interpretations of the backscatter-intensity data, which are a measure of sediment texture and bottom roughness. High backscatter intensity is generally associated with rock or coarse-grained sediment such as gravel and coarse sand. Low backscatter intensity indicates finer grained sediments such as fine sand and mud.

The location and water depths of the major bathymetric features of the sea floor, such as banks and basins, are unchanged in the new maps. However the new backscatter intensity and the improved spatial resolution of the co-registered bathymetry and backscatter-intensity data sets provide a new view of the surface topography and geology. One of the most striking aspects of the sea floor shown by these data is the variation in bottom morphology and texture over scales of a few kilometers or less. This variation is caused by both natural and anthropogenic processes.

The major topographic features in Massachusetts Bay were formed by glacial processes in several stages. Ice containing rock debris moved across the region,

Figure 2.1 ***(A).*** Canadian Hydrographic Service vessel *Frederick G. Creed* that surveyed the Stellwagen Bank National Marine Sanctuary and western Massachusetts Bay using a multibeam sea-floor mapping system.



Courtesy of Ocean Mapping Group,
University of New Brunswick, Canada

Figure 2.1 ***(B).*** The operation of a multibeam sea-floor mapping system. The Simrad EM1000 mapping system used to map Massachusetts Bay generated an array of 60 acoustic beams, that survey a strip of sea floor measuring in width approximately 7.5 times the water depth. The system is mounted on a vessel that steams over the sea floor in parallel lines. In Massachusetts Bay, the survey lines were typically spaced 100–200 m apart. The horizontal spatial resolution of the data is about 10 m and the vertical accuracy is approximately 50 cm. The footprint of the acoustic beams on the sea floor increases with distance from the ship.

sculpting its surface and depositing sediment to form the large basins, banks, ridges, and valleys that characterize the region. The ice melted and the sea floor was submerged between 18 and 14 thousand years ago (ka); the resulting high stand of relative sea level was approximately 33 m above modern sea level at about 14 ka (Oldale and others, 1993). The relative sea level dropped to a low stand of approximately 45 m below modern sea level at about 12 ka as the earth's crust rebounded from ice loading. Thus, the sea floor of Massachusetts Bay in water depths shallower than about 45 m was reworked during the marine transgression between 18 and 14 ka, again during a sea-level regression between 14 and 12 ka, and finally during the transgression between 12 ka and the present. Today, the surficial sediments and features continue to be reworked and shaped by tidal and storm-generated currents, which erode and transport sediments from the shallow areas into the deeper basins. Over time, the shallow areas affected by these processes have become coarser as sand and mud are removed and gravel remains, and the deeper basins have been built up as they receive the winnowed sand and mud.

The shallow banks and ledges are typically floored with high backscatter-intensity material and the deep basins with low backscatter-intensity material, consistent with the surficial sediment distribution based on analysis of sediment samples. Bottom photographs show a range of bottom sediment types on the crest of Stellwagen Bank (figs. 2.4A, 2.4B, and 2.4C), boulders in some areas on the eastern flank of Stellwagen Bank (fig. 2.4D), a muddy burrowed sea floor in Stellwagen Basin (fig. 2.4E), and boulders and outcropping rock along the western shore (fig. 2.4F). Current research focuses on combining the topography, backscatter intensity, photographs, and other data about the sea floor to define and map the distribution of bottom types.

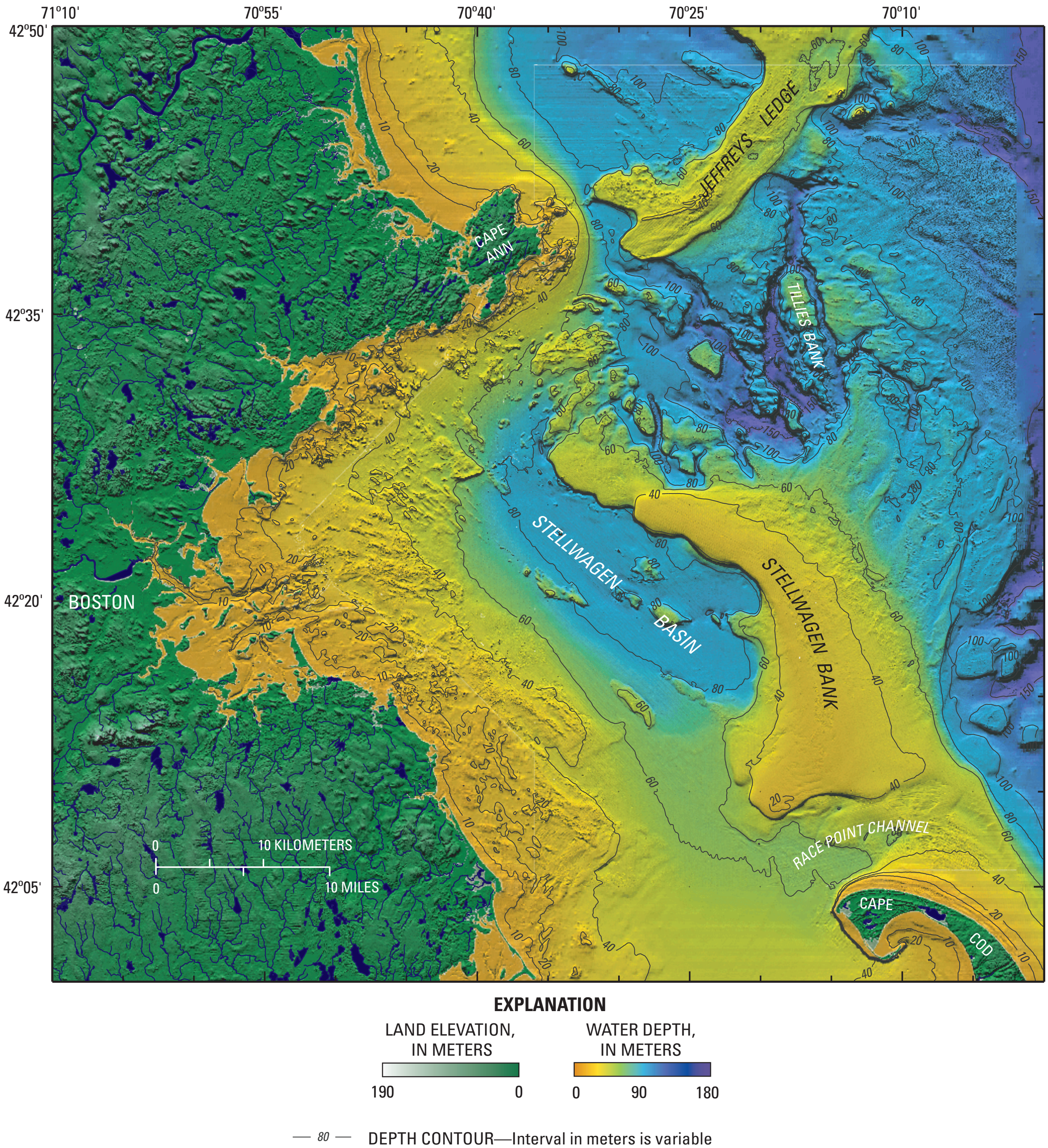


Figure 2.2 ***(A).*** Topography of Massachusetts Bay, in shaded-relief view, colored by water depth, based on multibeam surveys and the National Oceanic and Atmospheric Administration Coastal Relief Model (Modified from Butman and others, 2004b.) The onshore topography is from the U.S. Geological Survey Digital Elevation Model. The image was created by vertically exaggerating the topography four times and then artificially illuminating the relief by a light source positioned 45 degrees above the horizon from an azimuth of 350 degrees. In the resulting image, topographic features are enhanced by strong illumination on the northward-facing slopes and by shadows cast on southern slopes. The image accentuates small features that could not be effectively shown by contours alone at this scale. Selected bathymetric contours (black lines) are labeled in meters.

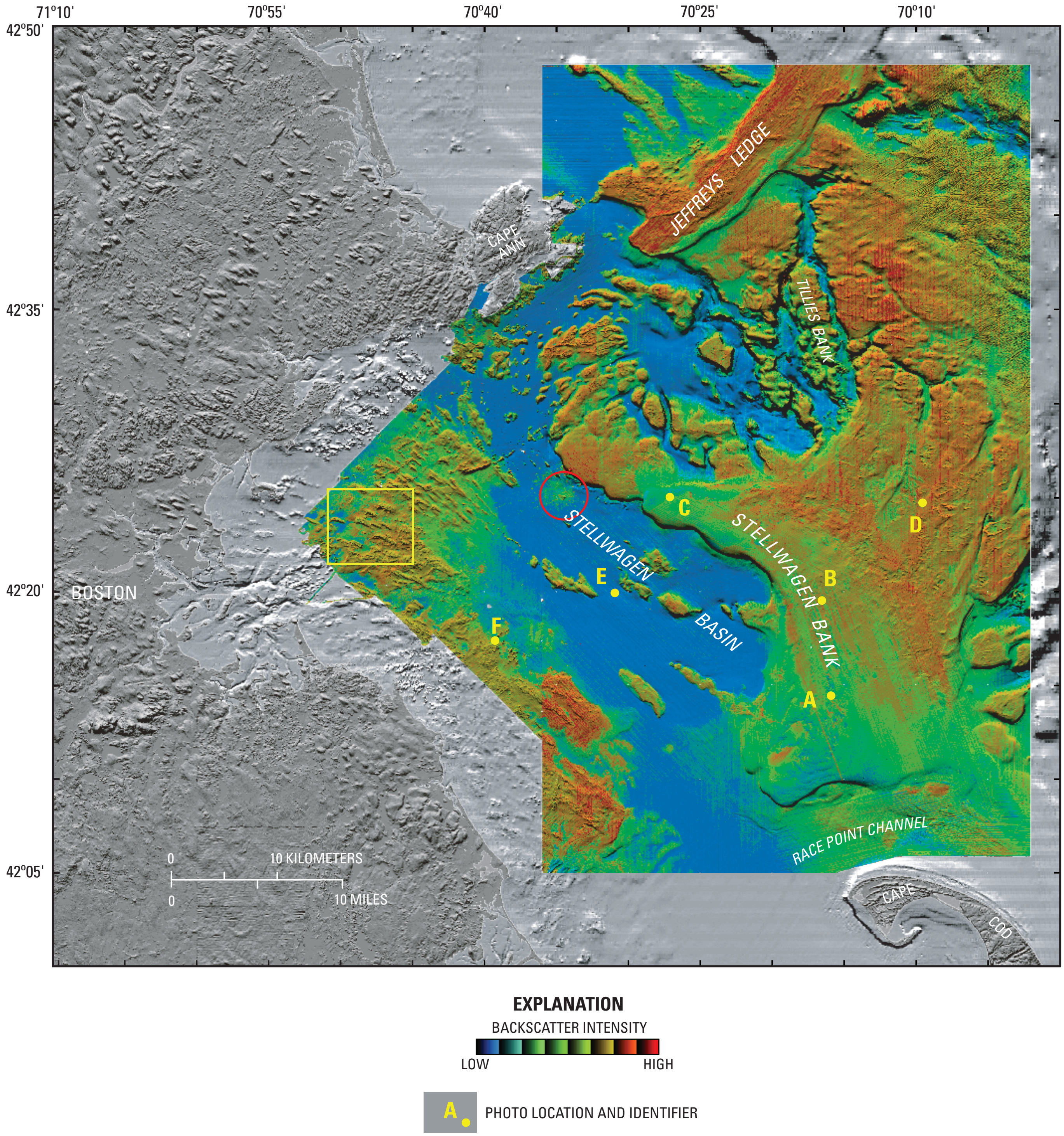
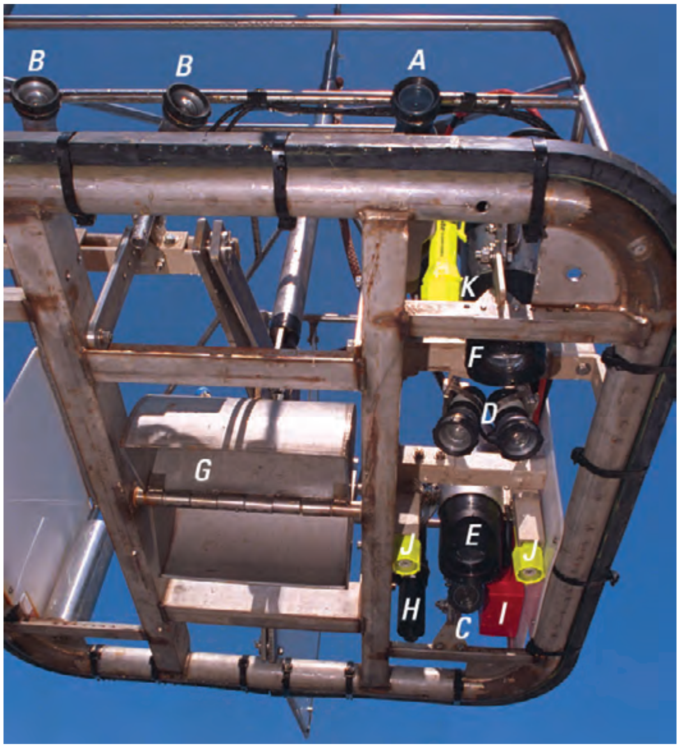
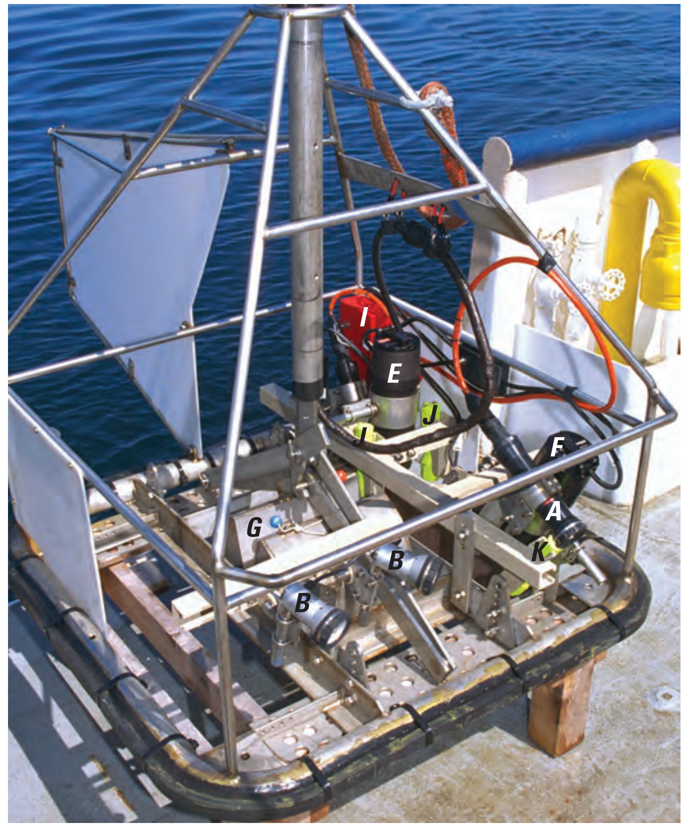


Figure 2.2 ***(B).*** The topography of Massachusetts Bay in shaded-relief view, colored by backscatter intensity in the area of the multibeam survey (Modified from Butman and others, 2004b.) In the image shown here, the backscatter intensity is represented by a suite of eight colors ranging from blue, which represents low intensity (fine-grained sediments such as fine sand and mud), to red, which represents high intensity (rock outcrops and coarse-grained sediments such as gravel and coarse sand). Within each color band, the intensity of the color is shaded according to the shaded-relief image. Shaded-relief topography in the area surrounding the multibeam data is based on the NOAA Coastal Relief Model and shown without coloring for backscatter intensity by the gray tones. The yellow rectangle is the area around the new ocean outfall shown at higher resolution in figure 2.5. The red circle outlines the Massachusetts Bay Disposal Site. Locations of bottom photographs in figure 2.4 are shown as yellow circles labeled A–F.

A



B



EXPLANATION

SEABOSS SENSORS

A – Forward-looking video camera
B – Lights for forward-looking video camera
C – Downward-looking video camera
D – Lights for downward-looking video camera
E – 35-millimeter still camera
F – Strobe light for still camera
G – Modified Van Veen grab sampler
H – Depth sensor
I – Junction box
J – Parallel lasers for scale
K – Angled laser for range

Figure 2.3. The USGS SeaBed Observation and Sampling System (SEABOSS) used to obtain still photographs, videos, and samples of the sea-floor sediments. These observations are used to help interpret the backscatter intensity obtained in the multibeam surveys. The SEABOSS is lowered to within about a meter of the bottom and obtains photographs and videos as the ship drifts over the sea floor. A single sample of the bottom sediments may be obtained during the photographic transect. *(A)* View of the SEABOSS from below, and *(B)* SEABOSS aboard ship.

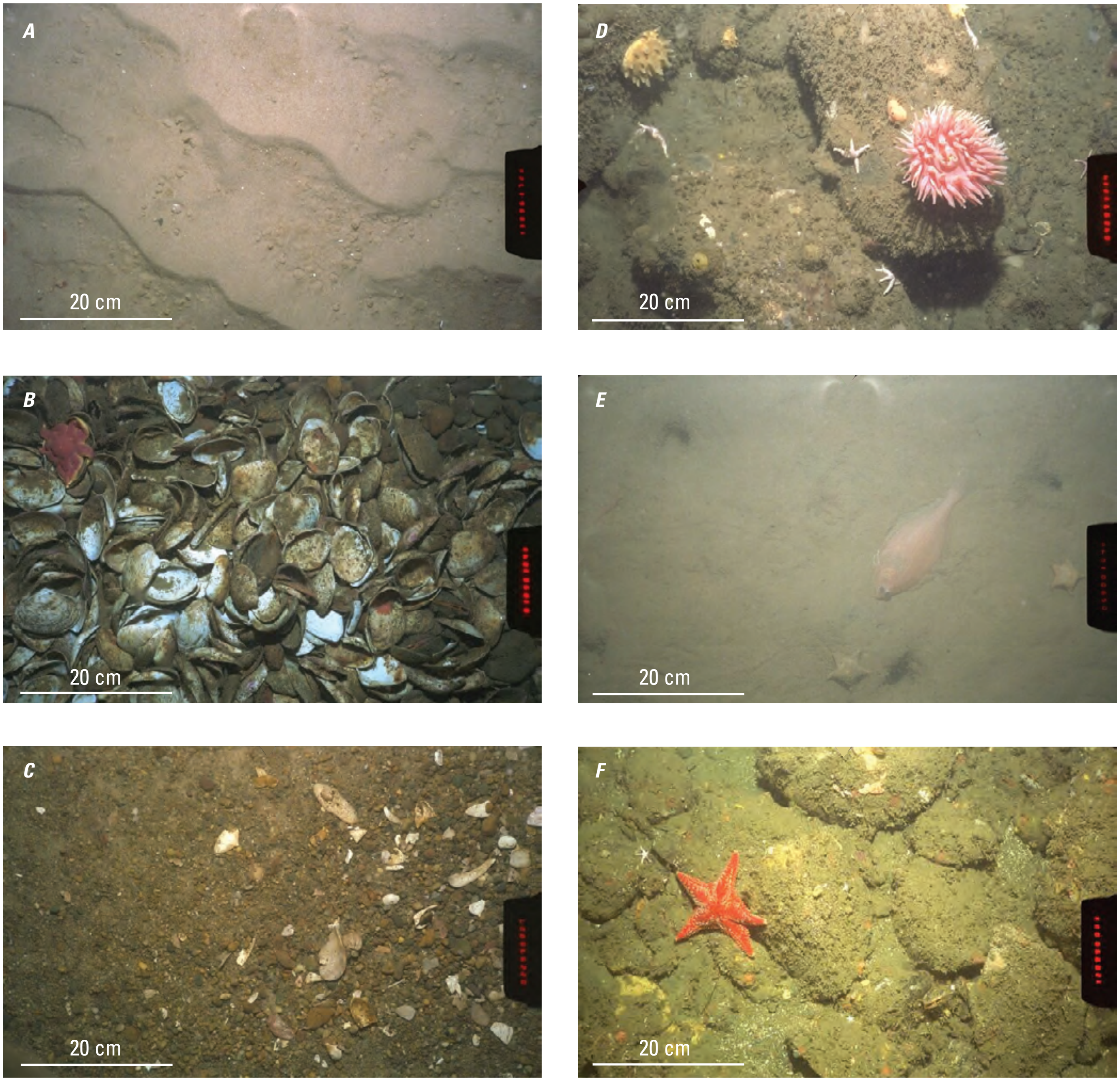


Figure 2.4. *(A)* The sea floor on the crest of Stellwagen Bank at a water depth of about 27 m (see fig. 2.2B for location). At this location, the sandy sediments are shaped into ripples. The black rectangle on the right side of the images is a photo identifier. *(B)* The sea floor on the crest of Stellwagen Bank at a water depth of about 33 m (see fig. 2.2B for location). At this location, the sea floor is covered with clam shells. *(C)* The sea floor on the northern end of Stellwagen Bank at a water depth of about 31 m (see fig. 2.2B for location). At this location, the sea floor is covered with pebbles, coarse sand and shell hash. *(D)* The sea floor on a boulder ridge to the east of Stellwagen Bank at a water depth of about 78 m (see fig. 2.2B for location). A yellow sponge (left) and pink anemone are attached to the boulders. *(E)* The sea floor in Stellwagen Basin at a water depth of about 89 m, an area of fine-grained sediments (see fig. 2.2B for location). The fish is a flounder. *(F)* The sea floor on the western side of Massachusetts Bay at a water depth of about 40 m (see fig. 2.2B for location). The sea floor at this location is covered with boulders and cobbles.

In western Massachusetts Bay, the sea floor in the vicinity of the new ocean outfall is shaped into a series of northwest-southeast-trending features (figs. 2.5A, 2.5B). They are approximately 1–2 km long and 0.5 km wide, and they typically rise 5 to 10 m above the surrounding sea floor. Oldale and others (1994) examined 11 of these features, originally mapped by Bothner and others (1992), and hypothesized that they are glacial drumlins formed during the last glaciation and submerged during the rise in sea level after the glaciers melted. The tops of these features are covered by boulders, cobbles, and pebbles (fig. 2.6A). The areas between the topographic highs range from mud (fig. 2.6C) to sand (fig. 2.6B) and gravel (fig. 2.6F). The backscatter-intensity image (fig. 2.5B) shows that bottom types often change over short distances (figs. 2.6E, 2.6F).

Some areas of the sea floor show the effects of past disposal of anthropogenic material. These sites are often identified in the shaded-relief topography (fig. 2.5A) by a low mound having an unnatural-appearing roughness that results from numerous individual dumps of material. In the backscatter-intensity image (fig. 2.5B) the sites are often characterized by numerous small high backscatter-intensity features resulting from individual dumps. Bottom photographs show cobbles and boulders at some of these sites (fig. 2.6D). The dumpsites are often most apparent in areas where high backscatter-intensity material has been placed on low backscatter-intensity sediments. For example, a circle of medium backscatter-intensity material (light green in fig. 2.2B) marks the Massachusetts Bay Disposal Site in the northern part of Stellwagen Basin (Valentine and others, 1996).

The new multibeam mapping included the area surrounding the ocean outfall that discharges treated sewage effluent from the Boston metropolitan region into western Massachusetts Bay (figs. 2.5A, 2.5B). The outfall extends along a northeast-southwest-trending line between 42º 23.06’ N., 70º 48.23’ W. and 42º 23.33’ N., 70º 46.81’ W. The outfall is located in 30 to 35 m of water in a topographic low bounded by west-northwest-trending ridges to the north and south that rise to about 25 m below the sea surface. The outfall is composed of 53 individual diffuser heads. Two parallel rows of mounds of material, discarded on the sea floor from the 130-ft vertical shafts drilled to the tunnel below for the risers (fig. 1.3), appear as a narrow east-northeast trending double line about 2 km long (figs. 2.5A, 2.5B). The diffuser heads between the disposal mounds are not resolved at the 6-m horizontal resolution of the multibeam survey.

The USGS established a long-term sediment sampling site in the fine-grained sediments to the west of the ocean outfall and a site for moored oceanographic observations to the south of the outfall (fig. 2.5B). Samples and observations were obtained at these sites from 1989 until 2006. The fine-grained sediments are inferred to be in an area of sediment deposition and thus a good location to monitor for long-term change of sediment properties and contaminants (see Section 7). The oceanographic observations (see Section 3 and Section 4) help to identify key processes that cause sediment resuspension and transport, and provide data for developing and testing predictive numerical models for sediment transport and fate (see Section 6).

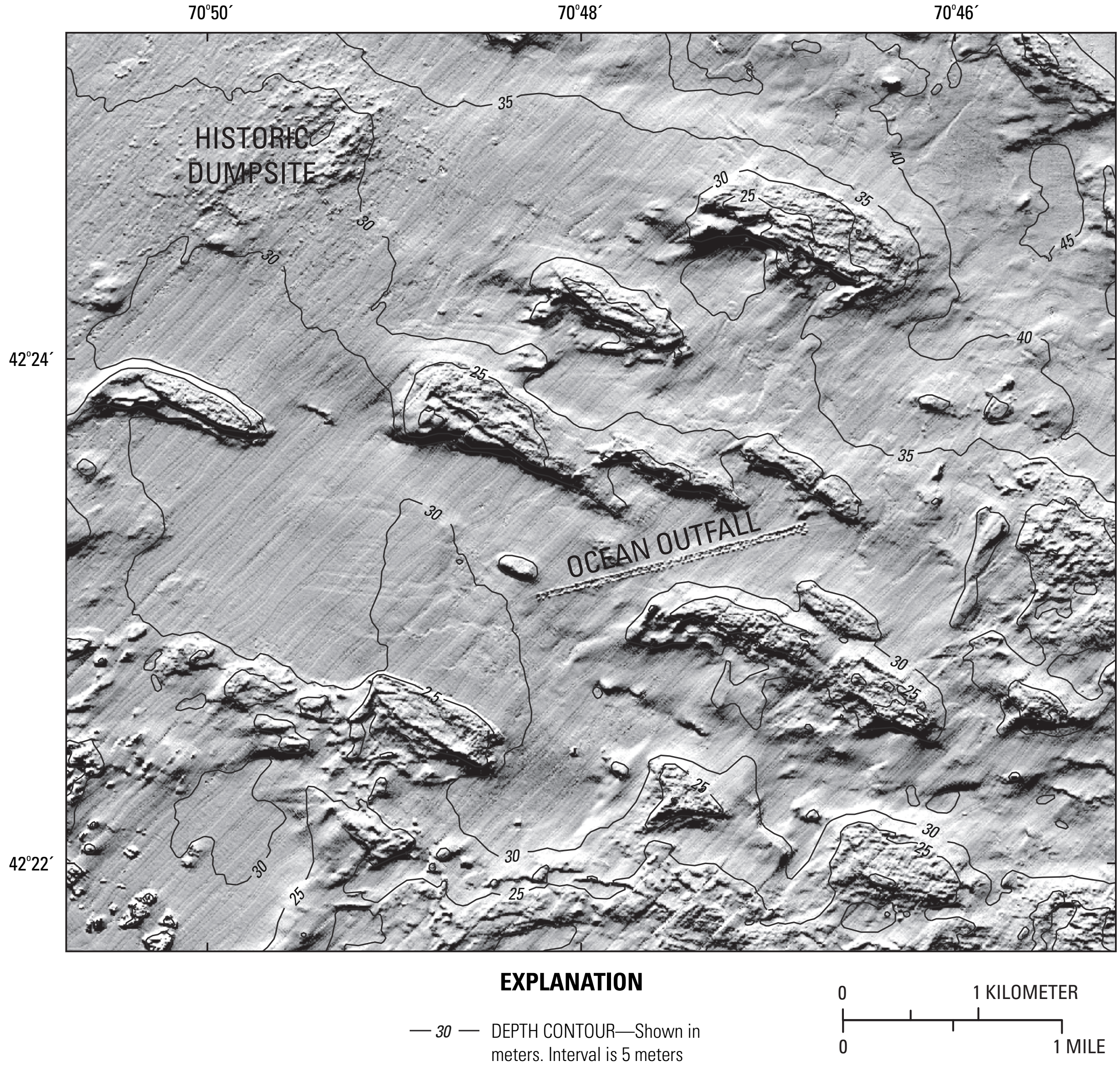


Figure 2.5 ***(A).*** Topography in shaded-relief view of western Massachusetts Bay around the new ocean outfall, based on the multibeam survey, with 5-m contours superimposed (From Butman and others, 2003c). The shaded-relief image was created by vertically exaggerating the topography four times and then artificially illuminating the relief by a light source positioned 45° above the horizon from an azimuth of 350°. In the resulting image, topographic features are enhanced by strong illumination on the northward-facing slopes and by shadows cast on southern slopes. The image accentuates small features that could not be effectively shown by contours alone at this scale. The faint parallel lines running northeast-southwest are parallel to the ship track and are artifacts of the data. The two parallel rows of mounds were formed from material discarded on the sea floor from the shafts drilled for the 55 individual diffuser heads (53 currently in use) that compose the new ocean outfall. Depth contours are shown in black and labeled in meters.

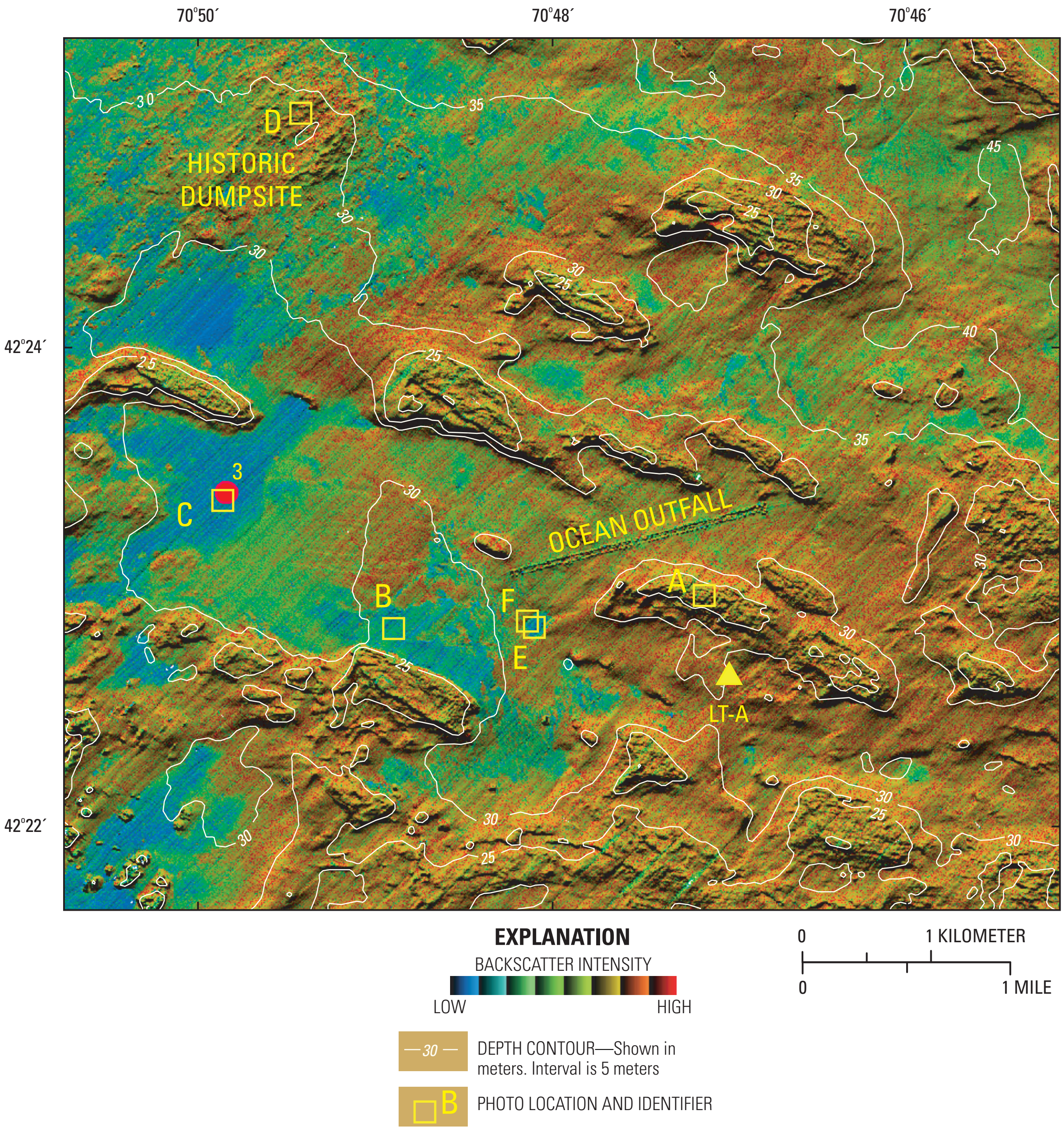


Figure 2.5 ***(B)*.** Topography in shaded-relief view, colored by backscatter intensity, in western Massachusetts Bay around the new ocean outfall (see Butman and others, 2003a). The red tones represent areas of high backscatter intensity, usually indicating boulders or gravel (fig. 2.6A), and typically occur on the crests of the topographic highs. The blue tones represent areas of low backscatter intensity, usually indicating fine-grained sediments (fig. 2.6C), and typically occur in the topographic lows. The green and yellow colors represent areas of intermediate backscatter intensity, typically sand with varying amounts of gravel (figs. 2.6B, 2.6E, and 2.6F). The faint stripes that run northeast-southwest about 100 m apart are parallel to the ship track and are artifacts of the data. The two parallel rows of mounds were formed from material discarded on the sea floor from the shafts drilled for the 55 diffuser heads that compose the diffuser of the new ocean outfall. Long-term sampling of the surficial sediments was carried out by the USGS in an area of fine-grained sediments to the west of the ocean outfall (Station 3 in about 33 m water depth, shown as a red circle; see Section 7). Long-term oceanographic measurements were carried out at a site to the south of the outfall in 33 m water depth (LT-A, shown as a yellow triangle; see Sections 3, 4, and 6). Locations of bottom photographs in figure 2.6 are shown as yellow squares and labeled A–F. Depth contours are shown in white and labeled in meters.

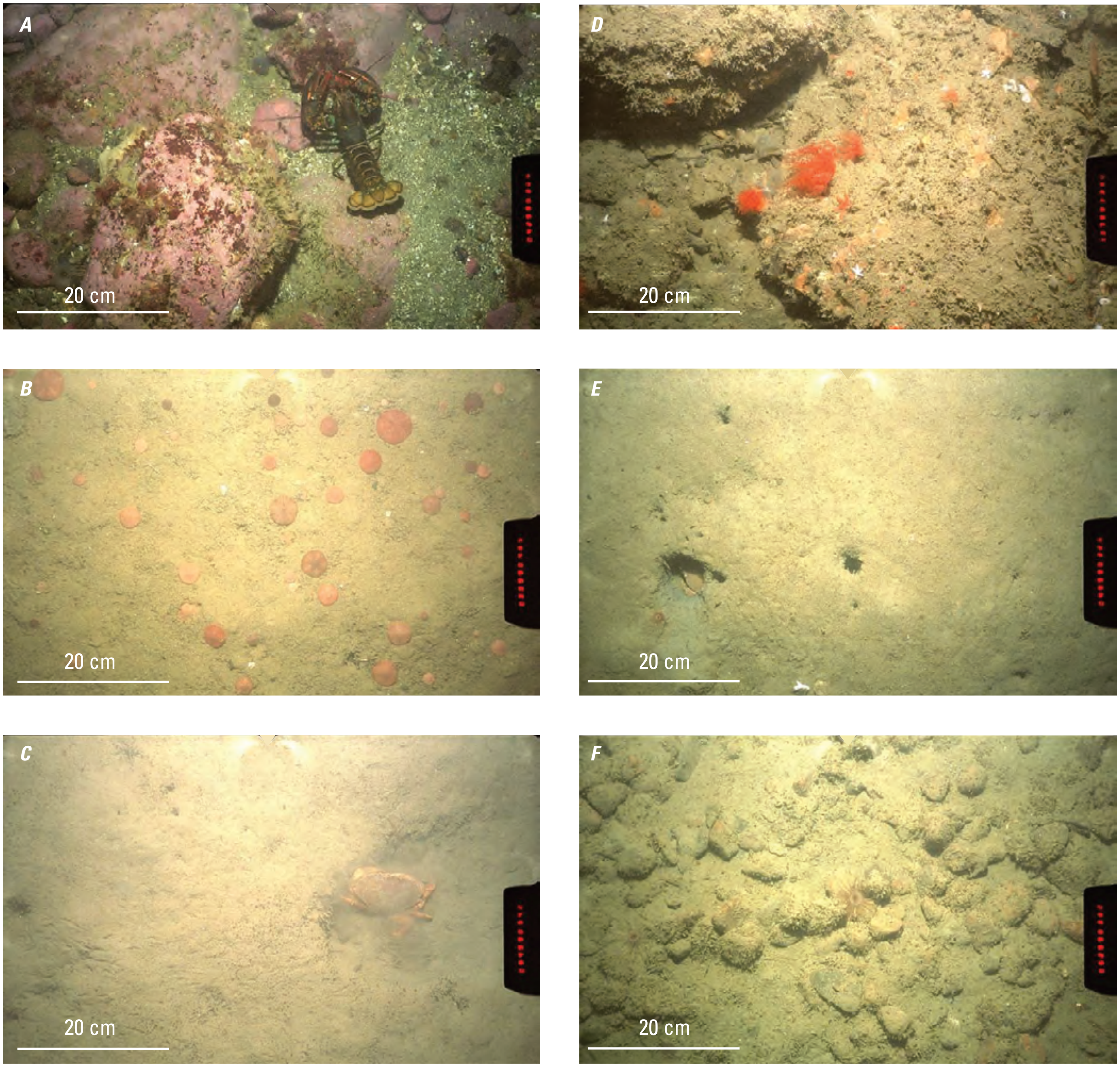


Figure 2.6. *(A)* The sea floor on the crest of the ridge south of the new ocean outfall at a water depth of about 24 m (see fig. 2.5B for location). The pink on the boulders is calcareous algae, typically found in water depths shallower than about 25 m. The sea floor at this location is devoid of any fine-grained sediments. The black rectangle on the right side of the images is a photo identifier. *(B)* The sea floor to the west of the new ocean outfall at a water depth of about 29 m in an area of sandy sediments (see fig. 2.5B for location). In this picture, the sea floor is covered with sand dollars. *(C)* The sea floor to the west of the new ocean outfall at a water depth of about 33 m in an area of muddy sediments (see fig. 2.5B for location). A cancer crab is burrowing in the sediment. This is the site of long-term sediment sampling (see Section 7). *(D)* The sea floor to the northwest of the new ocean outfall in an old dumpsite area at a water depth of about 28 m (see fig. 2.5B for location). *(E)* and *(F)* The sea floor in a small local depression to the south of the new ocean outfall at a water depth of about 34 m (see fig. 2.5B for location). These photographs, taken about 80 m apart, illustrate changes in bottom characteristics over short distances. Photograph E was obtained in an area characterized by low backscatter-intensity material (blue in fig. 2.5B) and shows fine-grained sediments burrowed by a cancer crab. Photograph F was obtained in an area characterized by moderate backscatter-intensity material (green to yellow in fig. 2.5B) and shows the sea floor covered by pebbles and cobbles beneath a thin veneer of fine-grained sediment.