



The Legacy of Contaminated Sediments in Boston Harbor

"Contamination of sediments in Boston Harbor, particularly by metals, is so widespread that its effects may be felt long after the sources of contamination are shut off. Where are toxic concentrations of metals located today? How did they get there? How will they move? These are questions that must be answered in detail before we can properly estimate risk in the environment."

—Dr. Frank Manheim,
U.S. Geological Survey

Ample data exist to complete a comprehensive toxicity analysis of Boston Harbor sediments, but until recently these data have not been integrated.

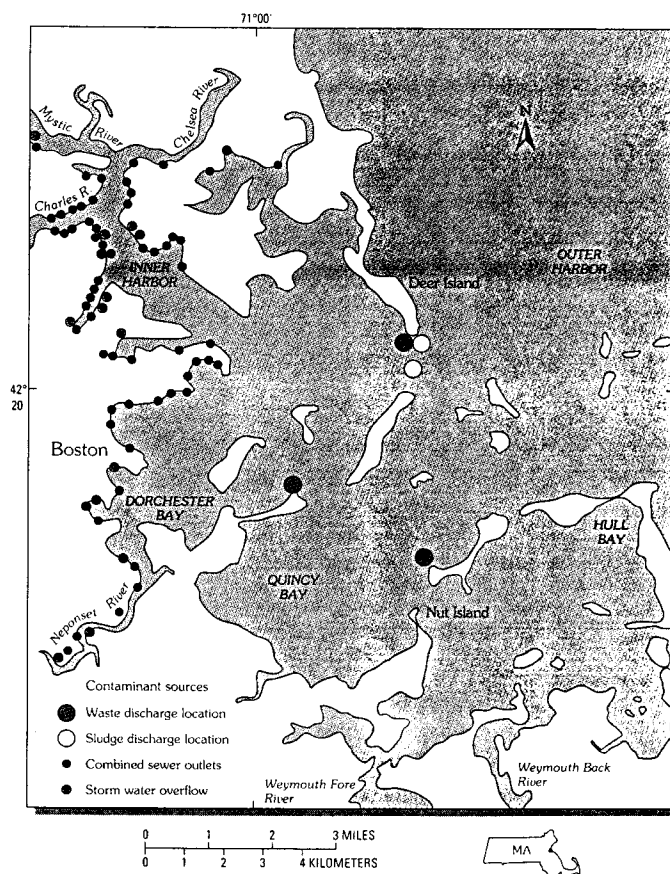
Scientists at the U.S. Geological Survey (USGS) have assembled a significant body of data that is now in a usable form. The USGS adopted an interdisciplinary approach to begin the pioneering effort at data rescue. This work involved collaboration with the Environmental Protection Agency (EPA), the U.S. Army Corps of Engineers (USACE), the Massachusetts Water Resources Authority (MWRA), Massachusetts Coastal Zone Management, and the National Oceanic and Atmospheric Administration (NOAA). More than 100,000 sediment chemistry analyses from over 1,500 samples were gleaned from 500 references, compiled, and scientifically edited by the USGS and other workers for use in studies of the distribution and fate of contaminants.

USGS studies have documented toxic levels of metal contaminants in Boston Harbor sediments.

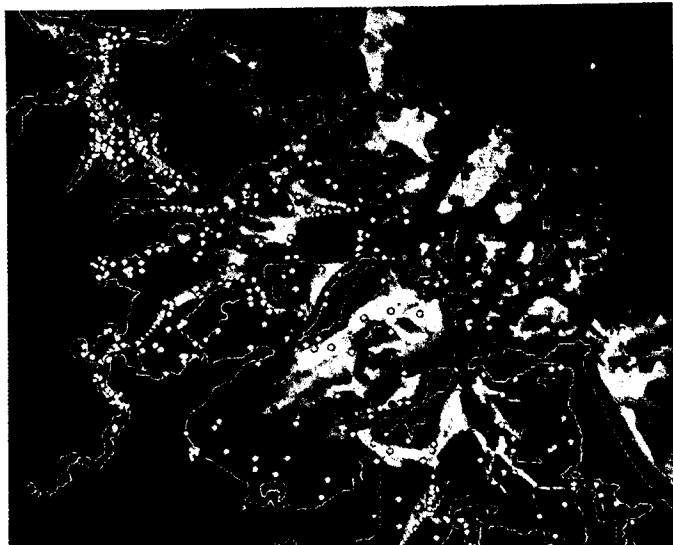
At least 50 percent of the surface sediment samples taken from Boston Harbor have concentrations that exceed NOAA's lowest effects-based toxicity thresholds for 6 of the 14 metals having sufficient analyses. Mercury (Hg) is potentially the most serious contaminant since nearly all the surface samples in the harbor have concentrations higher than NOAA's screening threshold. Lead (Pb) concentrations also exceed minimum threshold levels, but the contamination is neither as widespread nor as severe. Contamination may not be restricted to surface layers, but virtually all sediment layers near the top have much higher concentration levels of all metals than do the deeper, pre-industrial layers.

Toxicity criteria for sediments are not well established and must be used with caution.

Toxicity criteria are determined by exposing biota to varying levels of contaminants in sediments and comparing responses. However, unpolluted sediments can occasionally have metal (nickel and chromium, for example) concentrations greater than or equal to the lowest recommended toxicity thresholds. Adverse effects in organisms may also depend on factors other than concentrations. USGS database and mapping efforts help establish natural variations in background levels of potentially toxic metals and organic contaminants, as well as sediment properties, so that each area under investigation can be considered on its own geochemical terms.



Boston Harbor, the largest shipping port in New England, is surrounded by Boston and its suburbs. Map shows waste discharge locations prior to current remediation programs.



Samples from the USGS-Woods Hole Contaminated-Sediments Database (white and black points) superimposed on a shaded relief map of NOAA bathymetry. Colors denote mean low-water depths: blue, >40'; green, 30-40'; yellow, 20-30'; orange, 10-20'; red, <10'.

Contaminants are not distributed randomly, but follow patterns that are consistent with sedimentary environments.

USGS work has provided details of the areal distribution of contaminants and their concentrations in harbor sediments. A critical factor in understanding how contaminants move and where they ultimately come to rest is knowledge of the sedimentary environments, such as areas of erosion and deposition, and the type of sediment that contaminants are usually associated with. Cores taken in the harbor and Massachusetts Bay provide an important historical record of sediment contamination levels in the marine environment. They also reveal the thickness of contaminated layers.

A key issue facing environmental scientists, planners, and regulators is the mobility of contaminants in the sediments.

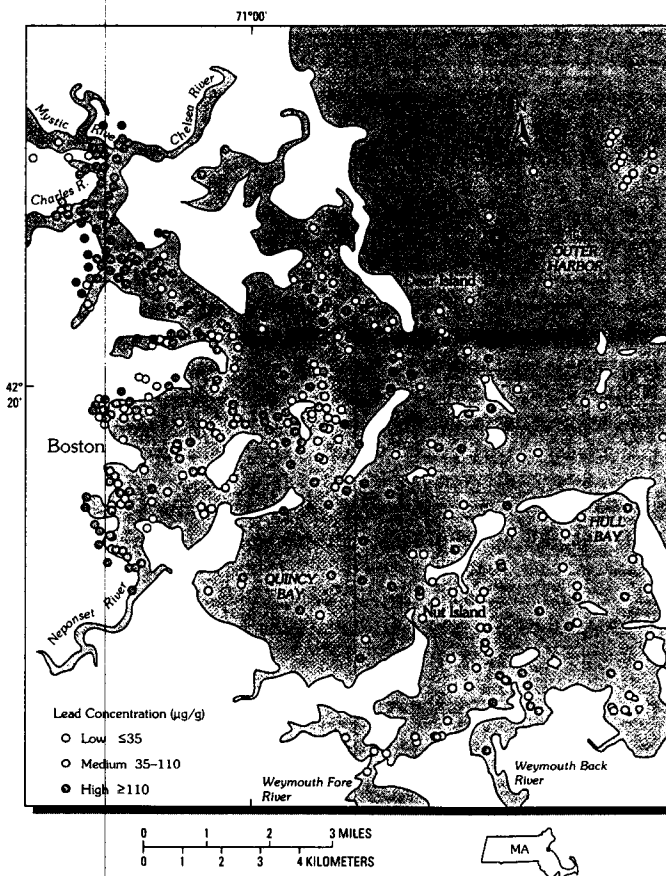
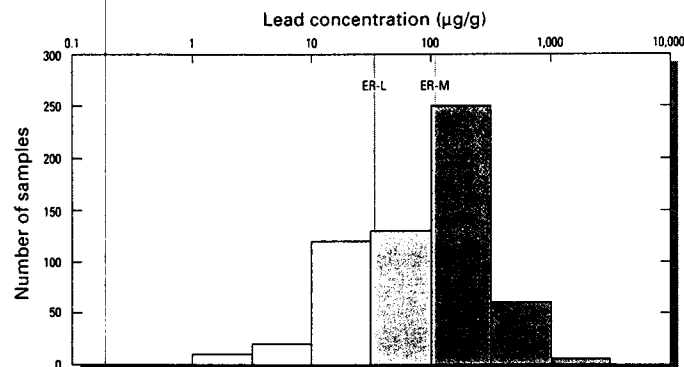
After contaminants are deposited on the sea floor, biological and mechanical mixing of the top few centimeters takes place. Normal biological activity of worms, clams and fish affects the top few centimeters of sediment almost everywhere, although pollutant-tolerant biota replace others where sufficient contamination exists. In some areas, worms may burrow as deep as 30 cm, mixing shallow sediments with more deeply buried sediments. Other episodic changes are created by harbor channel dredging, waste dumping, storm-wave action, trawling, and dredge material disposal. The effects on near-surface sediments are often unpredictable; however, remobilization of sediments in these and other ways can bring contaminants that are associated with sediments back into the water column. These processes affect the rate at which contaminants will be removed from the ecosystem.

USGS studies focus on determining the extent to which Boston Harbor is a net depositional environment.

Many important questions face environmental scientists: how much of the contaminated sediment remains in the harbor and how much moves out into Massachusetts Bay and beyond? Of the material that remains, how much becomes buried deep enough by natural sedimentation to remove it from serious concern and how much is resuspended or transported elsewhere in the harbor? Should some areas of the harbor be considered hazardous and if so, how are they changing with time? Answers to these questions will help determine how long this problem will be with us.

A National Contaminated-Sediments Database is in early stages of development.

The Boston Harbor data form the basis for an in-depth study of contaminated sediments in one area. The National Estuaries Program has identified many fragile environments for further study. USGS scientists have initiated collaborative efforts with EPA, USACE, National Science Foundation, NOAA, a number of universities, and local and State government agencies to assemble, edit, and validate relevant sediment and contaminant data that already exist. Specific projects are underway for Chesapeake Bay, Gulf of Maine, Long Island Sound, and Gulf of Mexico. The necessary data exist so that studies similar to the one in Boston Harbor can be successfully completed, but first the data need to be identified and incorporated into a National Contaminated-Sediments Database.



Map and histogram showing concentration levels and locations of lead (Pb) samples in Boston Harbor that are currently in the database. High metal values are those greater than the ER-M (100 µg/g), the concentration at which 50 percent of test sediments are found to have consistent adverse effects on biota. Low metal values are those less than the ER-L (35 µg/g) the concentration at which 10 percent of test sediments are found to have consistent adverse effects on biota.

West-Central Florida Coast

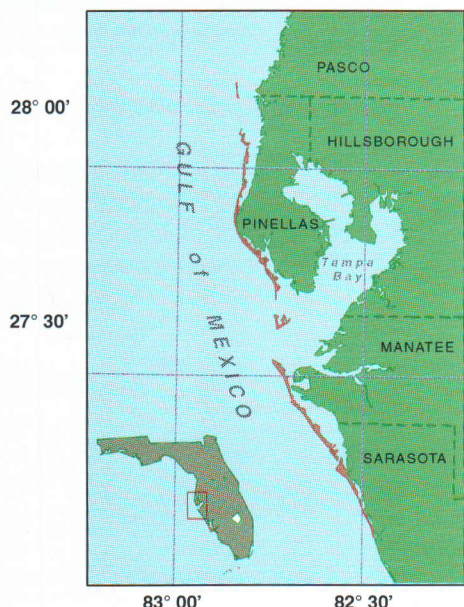
Limited sand resources for eroding beaches

Abby Salinger LIDAR Mapping
Rick Stumpf

Issue

Beach erosion is a major concern on the highly developed west-central Florida coast. The region between Anclote Key in southern Pasco County and Venice Inlet in central Sarasota County contains 18 barrier islands and inlets spanning 130 km of coastline, much of which has undergone significant change within the past century.

Under natural conditions, barrier islands shift in response to storms, sediment supply, and changes in sea-level. Manmade structures such as sea walls, jettys, and even buildings and roads can alter the influence of these natural processes. Consequently, some areas have experienced rapid beach erosion, resulting in narrow beaches that are insufficient for recreational use or protection of upland properties. Beach erosion and loss of protective dunes have left the coast susceptible to damage from storms and hurricanes. A 1992 report issued by the Florida Department of Natural Resources designated 65% of west Florida beaches as "critical erosion areas." In response, several sections of the coast have undergone nourishment projects to restore beach widths to previous dimensions. This method of beach maintenance is expensive, typically costing well over a million dollars for each mile of beach, and needs to be repeated as often as every 4 years. While beach nourishment is becoming the most common means of addressing beach erosion, it may not provide a cost-effective long-term solution, as sand resources for nourishment are limited along much of the west Florida coast.



Map of study area showing location of barrier islands.



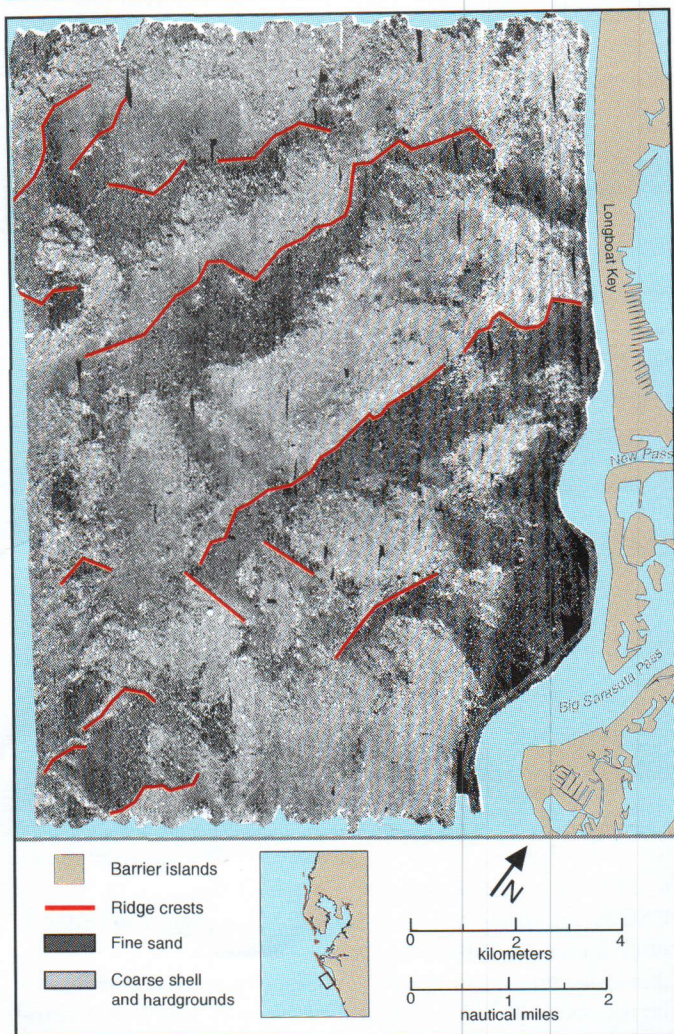
A recent beach nourishment project at Sand Key is an increasingly common countermeasure to beach erosion in highly developed coastal regions.

In 1992, Congress directed the U.S. Geological Survey (USGS) to initiate a 5-year study of this region in order to better understand the recent geologic history of the barrier-island system and the processes that control the distribution and transport of sediment on the inner shelf. The West-Central Florida Coastal Studies Project is a cooperative effort between the USGS, the University of South Florida, and Eckerd College.

Geologic Setting

The west-central Florida coast barrier-island chain sits near the center of a broad, gently sloping carbonate platform. The continental shelf is underlain by limestone bedrock with a thin, discontinuous cover of sand deposits of both quartz and carbonate origin. Prior to the initiation of this project, it was generally believed that sand resources were evenly distributed on the continental shelf. Early results, however, have demonstrated that sand is concentrated in specific, nearshore areas and is of limited thickness.

USGS scientists and collaborators have systematically mapped the thickness of sand deposits near the coast through seismic surveys and jet-probing. The first phase was a regional mapping with widely spaced geophysical and sample data that found that most beach-quality sand is concentrated in active ebb-tidal deltas located just off tidal inlets and in long, linear ridges found on the inner shelf. Across the entire study area, bottom samples and core samples have been collected and are being analyzed to develop a map of sea-floor sediment types. This research indicates that although there is coarse, biogenic carbonate sand being produced in the modern environment, there is little or no modern source of beach-quality quartz sediment in this region.



Sidescan-sonar imagery in an area off Sarasota, Florida, reveals that fine sand (dark gray) is concentrated in long linear ridges and in ebb-tidal deltas located off tidal inlets. Light-gray areas consist of coarse, shelly material or hardgrounds.

In addition to the reconnaissance mapping, USGS scientists and collaborators have completed detailed studies in two localities, one north and one south of the entrance to Tampa Bay. Detailed sidescan-sonar maps were made of localized areas which are being used to understand the variability in sediment distribution of beach-quality sand, carbonate shell material, and hardgrounds and to shed new light on the processes that shape the inner shelf.

Coastal Processes and Morphodynamics

The west-central Florida barrier-island and inlet system is among the most varied in the world. The combination of low wave energy and microtidal conditions produces a wide range of barrier and inlet morphologies. Barrier islands and inlets in this region are affected by a complex suite of processes including sediment availability, impacts of storms and hurricanes, circulation, and underlying geologic control. For example, analysis of core samples and seismic data indicates that, in some areas along the coast, the underlying limestone bedrock exerts a significant control on the location of the barrier islands. Processes affecting the barrier island and inlet

system have been active throughout recent geologic history, as evidenced by the range in ages of barrier islands, from greater than 4,600 years at Siesta Key in the southern part of the study area to less than a decade at 3-Rooker Bar in the north. There is also evidence that the location of some islands has shifted considerably landward over thousands of years.

Researchers are also examining dominant oceanographic processes, how they influence sediment transport, and how they affect sand distribution in this region. Several methods are being utilized to examine circulation patterns on the inner shelf including deploying instruments that measure winds, currents, temperature, and salinity. Early results have demonstrated the importance of seasonal variations in the mean circulation and in sea level and have identified coastal upwelling of colder, deeper water following storms.

Data collected by current meters and satellite imagery are being utilized in the development of three-dimensional numerical circulation models. These models help to describe the responses of the entire west Florida continental shelf circulation and sea level to storms and seasonally varying conditions.



Researchers take vibracore samples to examine sediments lying below the sea floor.

Research Applications

The west-central Florida coast is a highly populated region with an economy closely tied to its natural resources. The results of this project will allow planners and managers to better understand the effects of land-use decisions based upon a scientific understanding of the natural coastal processes.

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SWASH: A New Method for Monitoring Coastal Erosion

Coastal Erosion and the Shoreline

Coastal erosion is a serious national problem with long-term economic and social consequences. Developed areas are threatened with billions of dollars in property damage as a result of storm impacts and long-term erosion. Over the last few decades, data on the position of the shoreline has emerged as the principal source of information for local, state, and federal government agencies charged with managing coastal erosion. This measure of the shifting land/water interface is also an important source of information for scientific investigations of coastal change, for determinations of the sediment budget, and for conducting numerical simulations of shoreline change.

Despite the importance of this measure of coastal change, the methods available for collecting shoreline position data are very limited. The

most commonly applied method—shoreline interpretation from aerial photography—is expensive, labor-intensive, and involves a considerable amount of subjectivity in identifying the shoreline. There is a significant need for a method that can provide an unambiguous and repeatable measure of shoreline position, can cover large sections of coast within a single low tide period, is inexpensive to operate, and can be used for both long-term monitoring and rapid-response surveys of storm impacts. In response to this need, the USGS developed SWASH, a vehicle-based system for measuring shoreline position which utilizes recent advances in the Global Positioning System (GPS).

The SWASH System

The SWASH system is mounted on a six-wheel amphibious all-terrain vehicle (fig. 1), which is driven

along the beach at low tide. As the vehicle transits the coast, an array of GPS sensors are used to make high-accuracy measurements of horizontal position, vertical position, and beach slope. Following the field survey, position and slope data are combined to compute shoreline position, defined as the horizontal location of a target elevation contour's intersection with the beach (fig. 2). In keeping with historical sources on shoreline information, the Mean High Water contour is usually chosen as the definition of the shoreline.

Tests have demonstrated that the SWASH system can measure the position of the shoreline with an accuracy of about one meter, far exceeding the accuracy of previous methods. Field tests have also shown that SWASH can survey more than 65 km of shoreline within a single low tide period and provide near real-time information on shoreline



Figure 1. The SWASH system vehicle

SWASH: A System for Measuring Shoreline Position

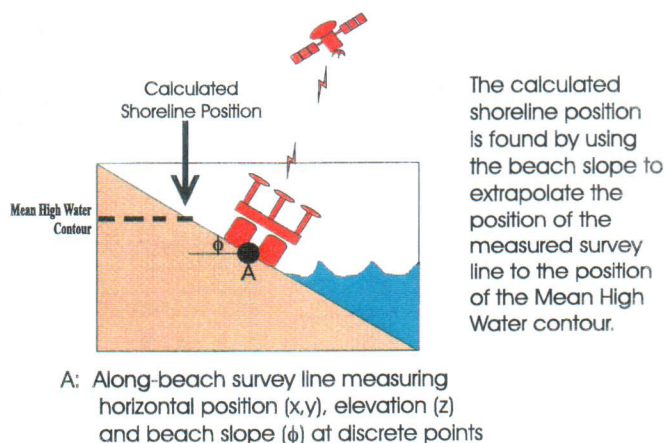


Figure 2. The operating principle of the SWASH system for measuring shoreline position.

changes during storms. SWASH is also very inexpensive to operate relative to previous methods for obtaining shoreline position.

A Northeaster Storm in the Outer Banks

In the Fall of 1997, SWASH was deployed along the Outer Banks of North Carolina to measure storm-induced coastal erosion. The USGS conducted a month of daily shoreline position measurements along 70 km section of coast from Corolla to Oregon Inlet. The response of the shoreline to a moderate Northeaster storm (fig. 3) was extraordinarily non-uniform (fig. 4), with zones of significant erosion (up to 20 m of shoreline recession) alternating with zones of virtual stability (less than 2 m of change). In the period of decreasing waves following the storm, the pattern of change almost entirely reversed, with the erosional zones experiencing strong accretion and the stable zones still showing no significant change (fig. 4). These unexpected results have important management implications in that these erosional "hotspots" correspond to zones where houses and hotels are threatened and frequently lost during storms along this section of the Outer Banks.

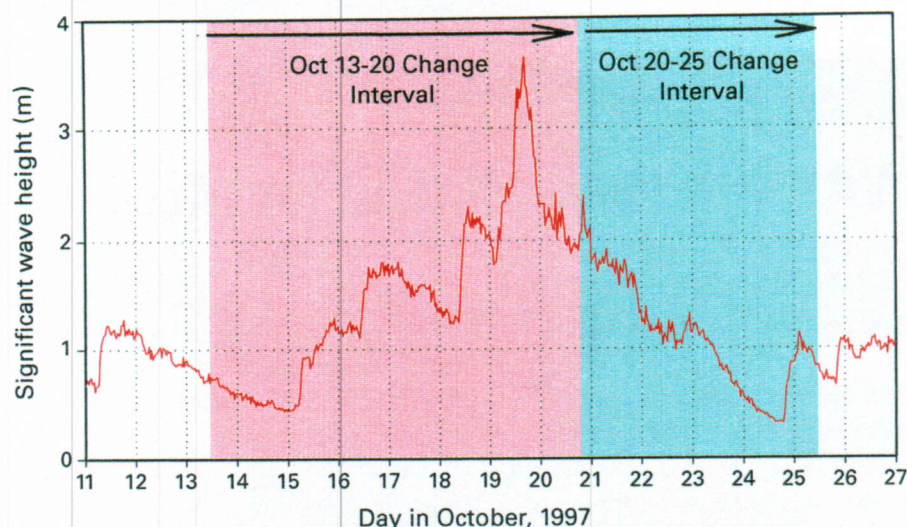


Figure 3. Wave height record showing the Northeaster storm which impacted the Outer Banks of North Carolina from October 15 through October 23, 1997. Color bands give the intervals for the shoreline changes shown in Figure 4.

Prior to the development of SWASH, measurements such as these would have been nearly impossible to obtain. SWASH represents a valuable new tool for both coastal management and scientific investigations of the processes of coastal erosion.

Future Work with SWASH

The USGS will use SWASH to make additional storm measurements, both in North Carolina and on other coasts, to develop a broader understanding of how the shoreline responds to storm impacts. The low cost, ease of deployment, and high-accuracy of SWASH also makes it an

ideal tool for monitoring long-term shoreline change. The USGS plans to target several sites along the U.S. East Coast for long-term shoreline change monitoring with SWASH.

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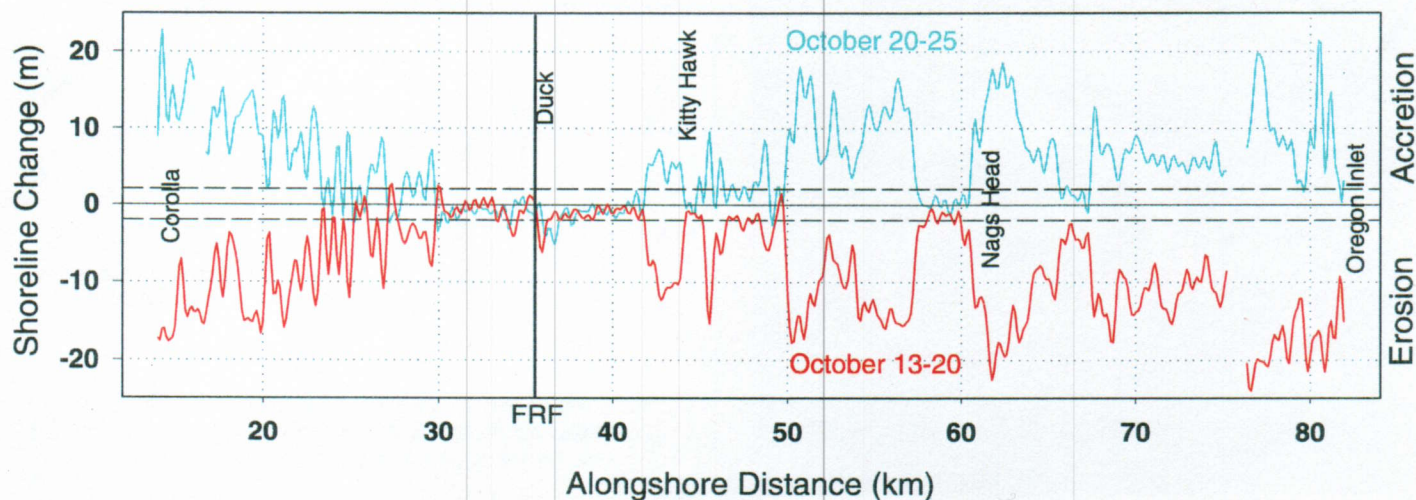


Figure 4. Shoreline erosion in response to increasing wave height (October 13-20) and shoreline accretion in response to decreasing wave height (October 20-25) as measured by SWASH in the Outer Banks of North Carolina in 1997. Parts of the coast experienced over 20 m of erosion during a moderate Northeaster storm, followed by a nearly equivalent amount of accretional recovery in the post-storm period.

MAPPING THE SEA FLOOR OFF THE U.S. EAST COAST

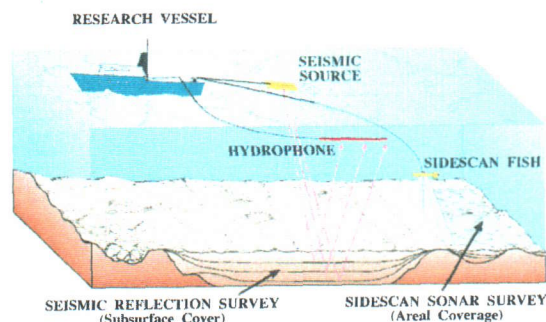
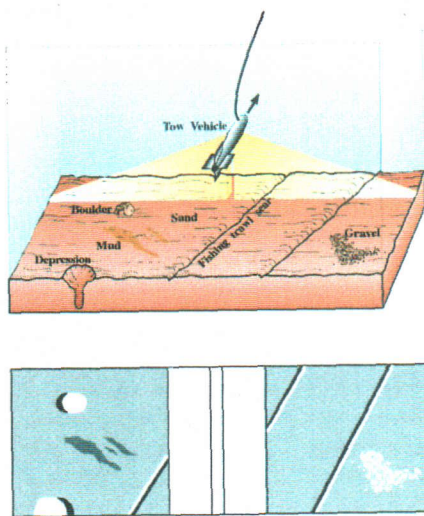
New detailed images of the sea floor are improving our understanding of the coastal ocean and providing a regional framework for addressing a wide range of critical issues such as polluted sediments, coastal erosion, biological habitats, and long-term environmental change.

Interpretive maps of the sea-floor geology provide a fundamental framework for research and management in the coastal ocean. They show the composition of the seabed and the shape (topography) of the sea floor; they show areas of present and past accumulation of sediment and pollutants; they provide information on the transport of sediment; and they help to define biological habitats as well as locations and impacts of human activities. This information can be used to develop predictive models to guide habitat and resource management, monitoring strategies, and other research studies.

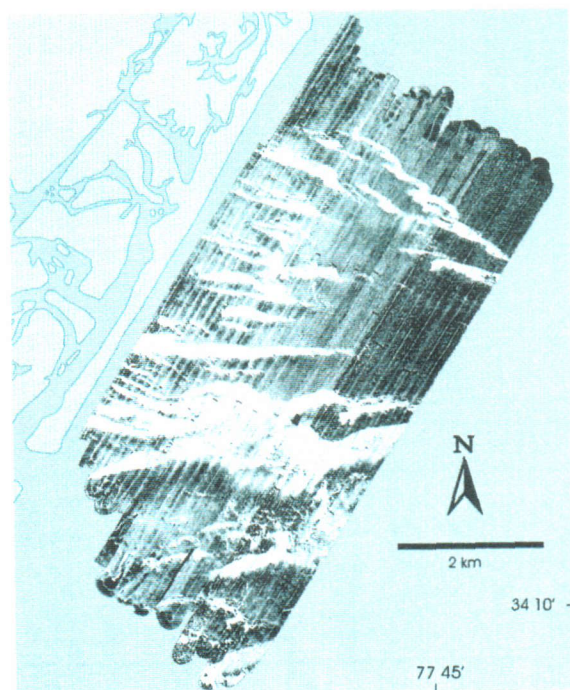
Modern oceanographic surveys use remote sensing techniques (sidescan-sonar, multibeam bathymetry, and high-resolution seismic reflection profiling), direct sampling, and visual observations to characterize the sea floor. The surveys provide a new, highly detailed view of the sea floor. In contrast to previous maps that were based on widely-spaced data, the new digital images are similar in detail to an aerial photograph and show the changes of seabed features over a wide range of scales. The locations and effects of human activities, such as ocean waste disposal and bottom trawling, are often clearly observed. Sedimentary features such as bedforms provide information about the transport and fate of sediments and pollutants and about the importance of the underlying geologic structures and the geologic history in controlling the present distribution of surface sediments.

Top: A sidescan-sonar 'fish' towed behind a vessel surveys the sea floor by sending sound to either side of the ship's path. Typical survey swaths are a few hundred meters wide.

Bottom: The intensity and pattern of sound reflected from the ocean floor provide information on the composition of sediments and the topography. Strong reflections from boulders, gravel, and the walls of trawl grooves appear as light tones on this data record; weak reflections from finer sediments or shadows behind vertical features are dark. A composite image (see example to right), pieced together from multiple survey strips, provides an image of the sea floor similar in detail to an aerial photograph.

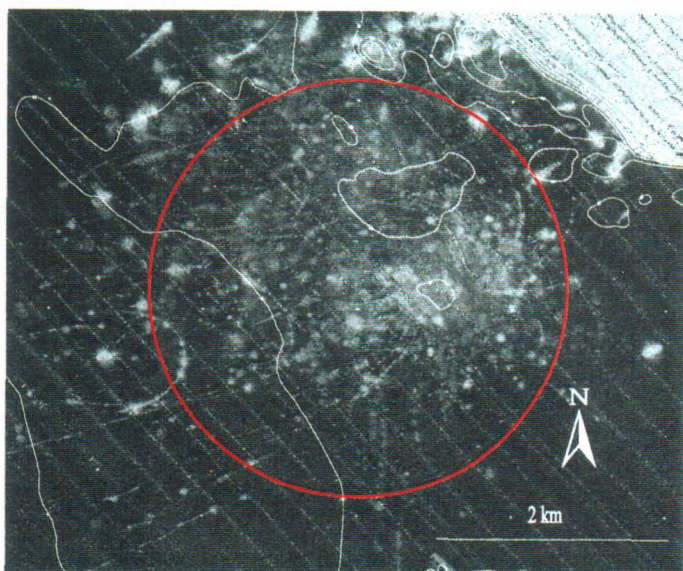
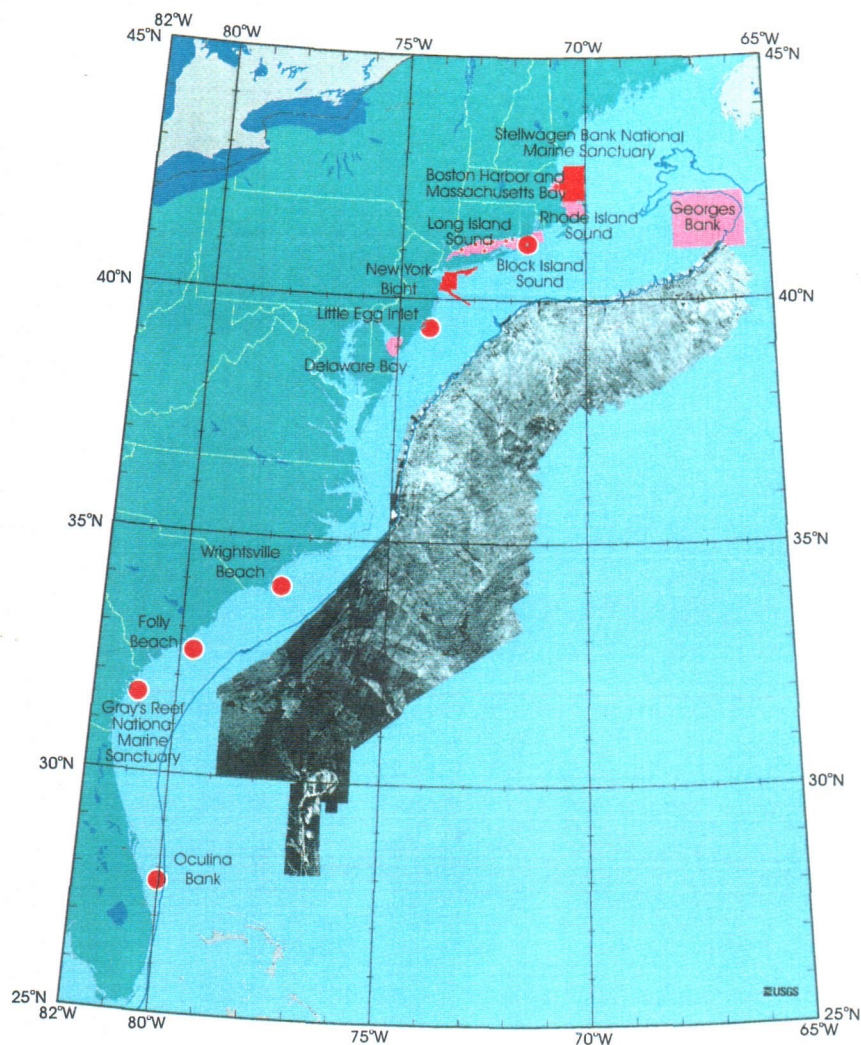


The sea floor is remotely mapped by sidescan-sonar and high-resolution seismic reflection profiling. These systems use the strength of reflected sound to characterize the sea floor and sediments below it.



Sidescan-sonar image off Wrightsville Beach, N.C. The light features in this image are bed forms extending from the beach and indicate an erosional pattern resulting from the transport of sand from the beach offshore to the continental shelf. This type of information has important implications for identifying possible sources of sand used in beach replenishment, and for understanding how beaches erode in response to hurricanes and large storms.

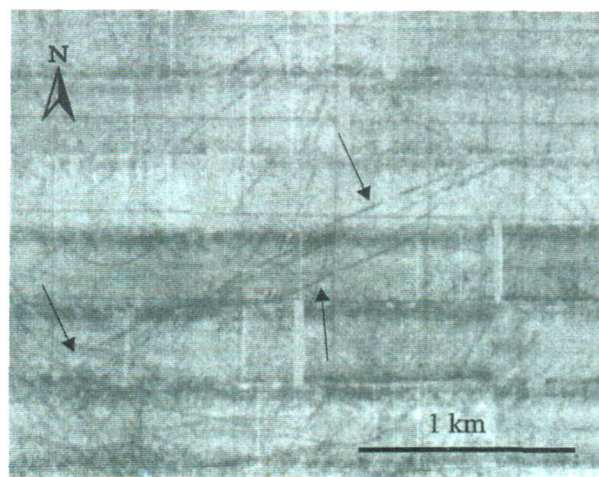
Right: The USGS and collaborators are undertaking a national effort to map and characterize the sea-floor geology of the coastal ocean. Reconnaissance mapping of the deepwater portion of the U.S. Exclusive Economic Zone (EEZ), begun in 1984 shortly after proclamation of the U.S. EEZ, has been completed (water depths deeper than 200 m, gray image in this figure). USGS efforts now focus on the shallow areas of the EEZ. Because only a narrow band of sea floor can be imaged during each pass of the ship in shallow water, systematic (that is 100 percent coverage) mapping of the shallow EEZ (as was done in deeper water) is too time consuming to be presently feasible. Present mapping is carried out in urbanized and (or) sensitive areas of the coastal ocean as part of studies that address issues of polluted sediments, coastal erosion, biological habitats, and sand and gravel resources. Dark red areas indicate 100 percent coverage with either sidescan-sonar or multibeam systems; pink areas indicate regional coverage (typical line spacing of a few kilometers). Dots indicate locations of smaller, detailed surveys.



Left: A sediment backscatter image of the Massachusetts Bay Disposal Site, offshore Boston, shows individual dumps of coarse-grained material (high-backscatter, light spots) clearly visible against the finer muddy sediments that cover this region of the sea floor (low-backscatter, dark background). The dumped material sometimes outlines a ship track (arcuate and linear features) and occurs both inside and outside the designated disposal site (red circle). The light region in the northeast corner of the image is the sandy edge of Stellwagen Bank. The evenly-spaced diagonal stripes indicate the track of the survey ship.

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Right: Sidescan-sonar mosaic showing linear scour marks (arrows), attributed to bottom trawling, in the New York Bight. Additional processing of this image will reduce the tone differences between survey stripes.



Mapping the Sea Floor and Biological Habitats of the Stellwagen Bank National Marine Sanctuary Region

National Marine Sanctuaries are marine and coastal areas of special biological significance. The Stellwagen Bank National Marine Sanctuary lies off the Massachusetts Coast and supports active commercial and recreational fisheries. It also serves as a habitat for marine mammals, including endangered species of whales, and draws 1.5 million visitors a year, many of whom are whale watchers. The Sanctuary abuts the Massachusetts Bay Disposal Site, which serves as a repository for material dredged from the harbors of Boston and surrounding cities and towns. It is near Boston's new ocean outfall that will discharge treated sewerage effluent into Massachusetts Bay beginning in 1998. Sanctuary habitats are disturbed by dredging and trawling by fishing gear, and by bottom currents generated by large storms.

The sea floor of the Stellwagen Bank National Marine Sanctuary was surveyed using a multibeam sea-floor mapping system that utilized sound to measure the water depth and sediment characteristics as the ship steamed over the area of interest. This system provided a new and highly detailed view of the sea floor at a spatial resolution of a few meters. During the survey, the mapping system was mounted on the Canadian Hydrographic ship *Frederick G. Creed*, a Small Waterplane Twin Hull (SWATH) vessel specially designed and equipped for multibeam surveying. Guided by these detailed images, we are using extensive bottom sampling, video and photographic observations to define and map biological habitats.

The maps of the sea floor produced by this project will be a basis for scientists, policy makers, and managers to understand this complex ecosystem and to monitor and manage its economic and natural resources. The maps provide information essential for:

- Determining the distribution of biological habitats and living resources and understanding the natural processes that affect them

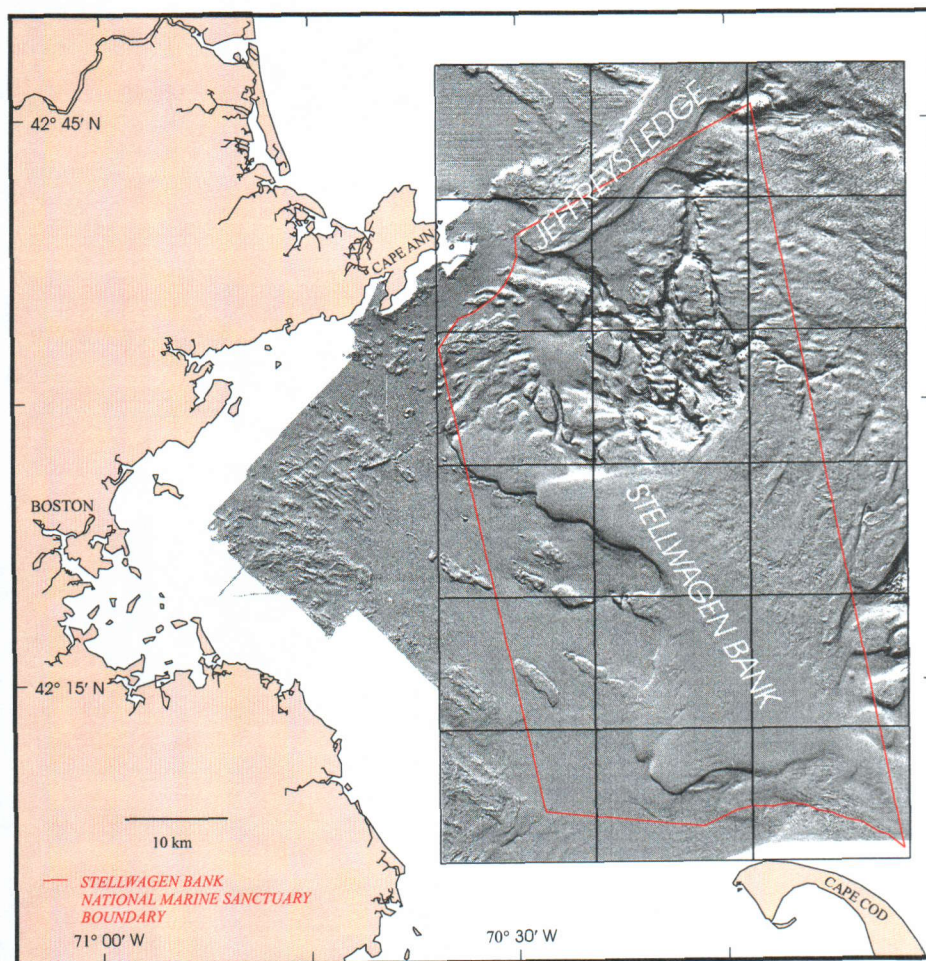


Figure 1. The USGS Stellwagen Bank Mapping Project is producing a series of maps (18 quadrangles at a scale of 1:25,000) that depict topography, backscatter, and the distribution of sedimentary environments and biological habitats in the Stellwagen Bank National Marine Sanctuary region, as well as overview maps at scales of 1:60,000. In this figure, the grid for the 1:25,000 map series is superimposed on the sun-illuminated topography of the region. This plan view was created by vertically exaggerating the topography and artificially illuminating the relief (in this case with a sun from the north). The image accentuates the small scale variability of the topography that would be difficult to show in a traditional contour map.

- Assessing natural and human disturbance of habitats and resources
- Identifying areas where contaminants might accumulate

Environmental mapping of sea-floor habitats requires a multidisciplinary approach. This project is being conducted with the cooperation and support of agencies of the National Oceanic and Atmospheric Administration (Sanctuaries and Reserves Division; National Marine Fisheries Service; National Ocean Service; National Undersea Research Program), the Environmental Protection Agency, the

Canadian Hydrographic Service, and the University of New Brunswick. These agencies have provided ships, equipment, and expertise in the collection and interpretation of sea-bed imagery and biological observations.

For more information visit the Stellwagen Bank Information System at <http://vineyard.er.usgs.gov>

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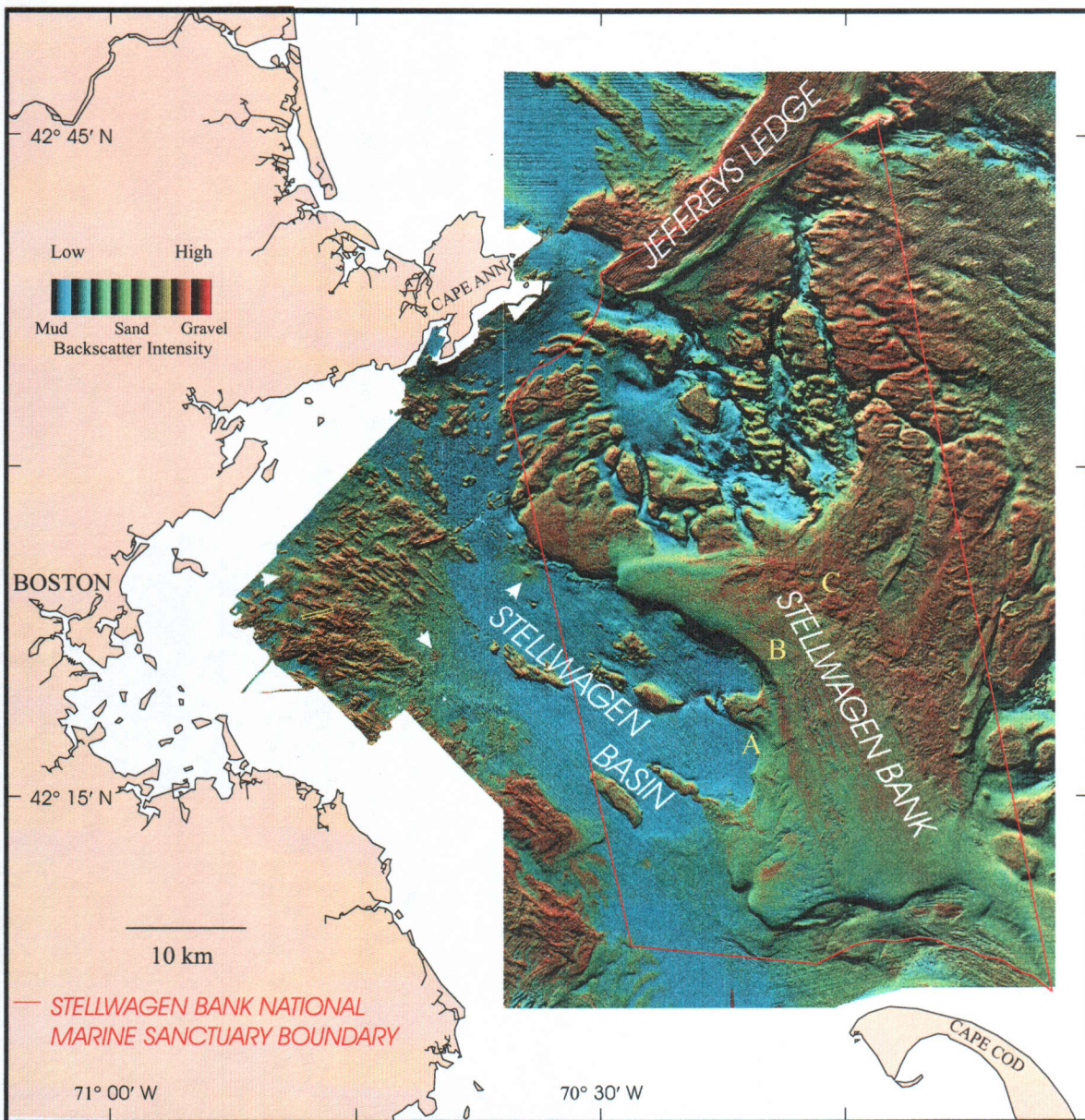


Figure 2. Sun-illuminated map of Stellwagen Bank National Marine Sanctuary and Massachusetts Bay with backscatter intensity draped over the topography. Red indicates high backscatter material including coarse sand, gravel and rock; green indicates sand; blue indicates mud. Within each backscatter color interval, the intensity varies from dark to light depending on the sun illumination. The image illustrates the wide variety of sedimentary environments in this region of the coastal ocean. The transitions between sediment types are often very sharp. Topographic features observed here were formed for the most part by glacial processes. Glacial ice containing rock debris moved across the region, sculpting its surface and depositing sediment to form basins, knolls, banks and other features. Later, many of the smaller features were formed during a final period of ice stagnation and melting. Today, the sea floor is mainly modified by storm currents and waves from the northeast. These currents erode sand and mud from the shallow banks and transport them into the basins. Stellwagen Bank and Jeffreys Ledge are shallow banks (20-40 m water depth) covered with sand and gravel. Stellwagen Basin (80-100 m) is floored with mud. In deeper water (85-140 m) to the northeast of Jeffreys Ledge, the fine hummocky pattern on the sea floor are gouges (5-10 m deep and up to 120 m wide) caused by icebergs that grounded in the muddy sand at the close of the last period of glaciation. Present and past disposal sites (white arrows) are characterized by high backscatter material and are especially distinct when the background material is fine grained sediment, such as in Stellwagen Basin. The easternmost arrow points to the presently active Massachusetts Bay Disposal Site. The yellow rectangle in the western part of the map is the location of the new ocean outfall that will discharge treated sewage effluent from the Boston metropolitan area into Massachusetts Bay. Letters A, B, and C indicate locations of bottom photos in Figure 3.



Figure 3. Photographs of the sea floor illustrating some bottom environments. See Figure 2 for locations. **A:** Muddy sea floor on the eastern edge of Stellwagen Basin at 79 m water depth showing cerianthid burrowing anemones, shrimp, and fish or crab burrows. **B:** Coarse sand with flounder at 37 m. **C:** Pebbles and cobbles in sand with cerianthid burrowing anemone at 58 m.