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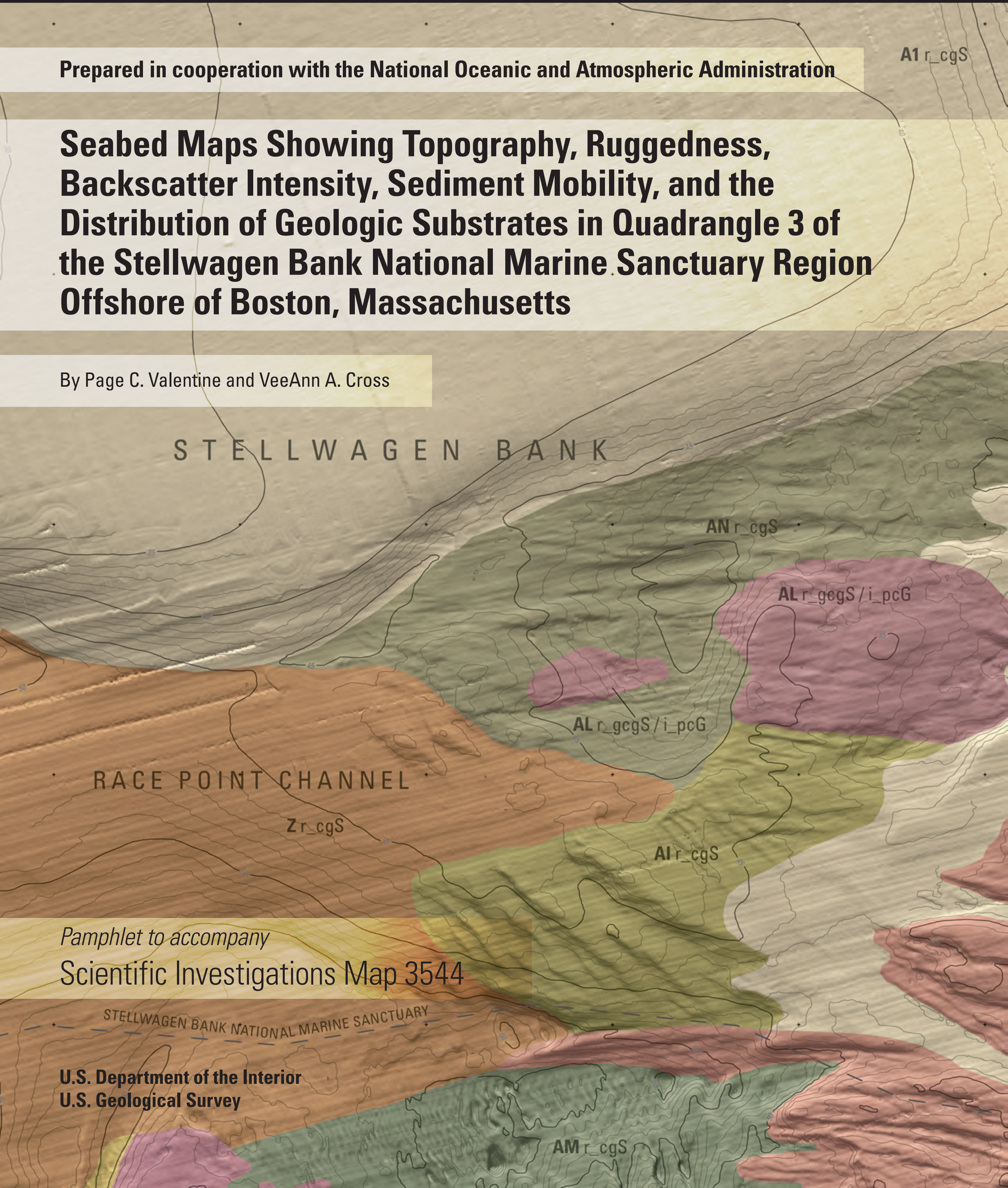
Seabed Maps Showing Topography, Ruggedness, Backscatter Intensity, Sediment Mobility, and the Distribution of Geologic Substrates in Quadrangle 3 of the Stellwagen Bank National Marine Sanctuary Region Offshore of Boston, Massachusetts

By Page C. Valentine and VeeAnn A. Cross



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Scientific Investigations Map 3544

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Cover. The northwestern part of quadrangle 3 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts, showing seabed geology and sun-illuminated topography. For more information, see map D, sheet 2.

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
kilometer (km)	0.5400	mile, nautical (nmi)
	Area	
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
square kilometer (km^2)	0.2916	square nautical mile (nmi^2)

Base-Map Information (Maps A–G)

Mercator projection; Geodetic Reference System 1980; horizontal datum: North American Datum of 1983

Longitude of central meridian 70°19′ W.; latitude of true scale 41°39′ N.

False easting 0 m; false northing 0 m; vertical datum: Mean Lower Low Water

Abbreviations

>	greater than
≥	greater than or equal to
<	less than
≤	less than or equal to
GIS	geographic information system
PDF	Portable Document Format
SBNMS	Stellwagen Bank National Marine Sanctuary
TRI	terrain ruggedness index

Seabed Maps Showing Topography, Ruggedness, Backscatter Intensity, Sediment Mobility, and the Distribution of Geologic Substrates in Quadrangle 3 of the Stellwagen Bank National Marine Sanctuary Region Offshore of Boston, Massachusetts

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Abstract

The U.S. Geological Survey, in cooperation with the National Marine Sanctuary Program of the National Oceanic and Atmospheric Administration, has conducted seabed mapping and related research in the Stellwagen Bank National Marine Sanctuary (SBNMS) region since 1993. The area being mapped using geophysical and geological data includes the SBNMS and the surrounding region, which totals approximately 3,700 square kilometers (km^2) and is subdivided into 18 quadrangles. The seabed is a glaciated terrain that is topographically and texturally diverse. Quadrangle 3, the subject of this scientific investigations map, has a mapped area of 185 km^2 and has water depths that range from about 30 meters (m) on the Stellwagen Bank crest to about 135 m in a basin east of South Ninety Bank, which lies off the eastern margin of Stellwagen Bank. Seven map types, each at a scale of 1:25,000, depict seabed topography, ruggedness, backscatter intensity, distribution of geologic substrates, sediment mobility, distribution of fine- and coarse-grained sand, and substrate mud content. These maps show the distribution of geologic substrates on the southeastern part of Stellwagen Bank, on adjacent banks and basins in deeper water to the east, in the eastern part of Race Point Channel to the south of the bank, and on the northern slope of Cape Cod. Interpretations of multibeam sonar bathymetric and seabed backscatter imagery, photographs, video imagery, and grain-size analyses were used to create the geology-based maps. Data from 309 stations were analyzed, including 279 sediment samples. The geologic substrate maps of quadrangle 3 show the distribution of 21 geologic substrates that represent a wide range of textures, such as rippled sand, immobile sand, immobile muddy sand, sand that partially veneers gravel, and boulder ridges. Mapped substrates are characterized by sediment grain-size composition, surface morphology, substrate layering, the mobility or immobility of substrate surfaces, and water depth range. This scientific investigations map portrays the major geological elements (substrates, topographic features, and processes) of environments in quadrangle 3. It is intended to provide a foundation for research into present and past sediment transport processes in a complex terrain, provide insights into the ecological requirements of invertebrate and vertebrate species that use the various substrates, and support seabed management in the region.

Introduction

The U.S. Geological Survey and the National Marine Sanctuary Program of the National Oceanic and Atmospheric Administration have been cooperating to research and map the Stellwagen Bank National Marine Sanctuary (SBNMS) region since 1993. The SBNMS region lies offshore of Boston, Massachusetts, and extends from Race Point Channel in the south to the southern part of Jeffreys Ledge in the north (fig. 1). This region is subdivided into 18 quadrangles with a combined area of approximately 3,700 square kilometers (km^2). This scientific investigations map (SIM) presents maps of quadrangle 3 at a scale of 1:25,000 (1 centimeter [cm] on the map represents 250 meters [m] on the seabed) that show the physical characteristics of the seabed. Geospatial datasets of seabed topography, sediment mobility, and the distribution of geologic substrates for quadrangle 3 are provided in a data release associated with this report (Valentine and Cross, 2026a). The mapped area (185 km^2) includes the southeastern part of Stellwagen Bank (about 30 m minimum water depth), the adjacent South Ninety Bank (about 90 m water depth), basins in deeper water (about 135 m maximum water depth) to the northeast, the eastern part of Race Point Channel (about 50 m water depth) to the south of the Stellwagen Bank, and the northern slope of Cape Cod (about 30 m minimum water depth).

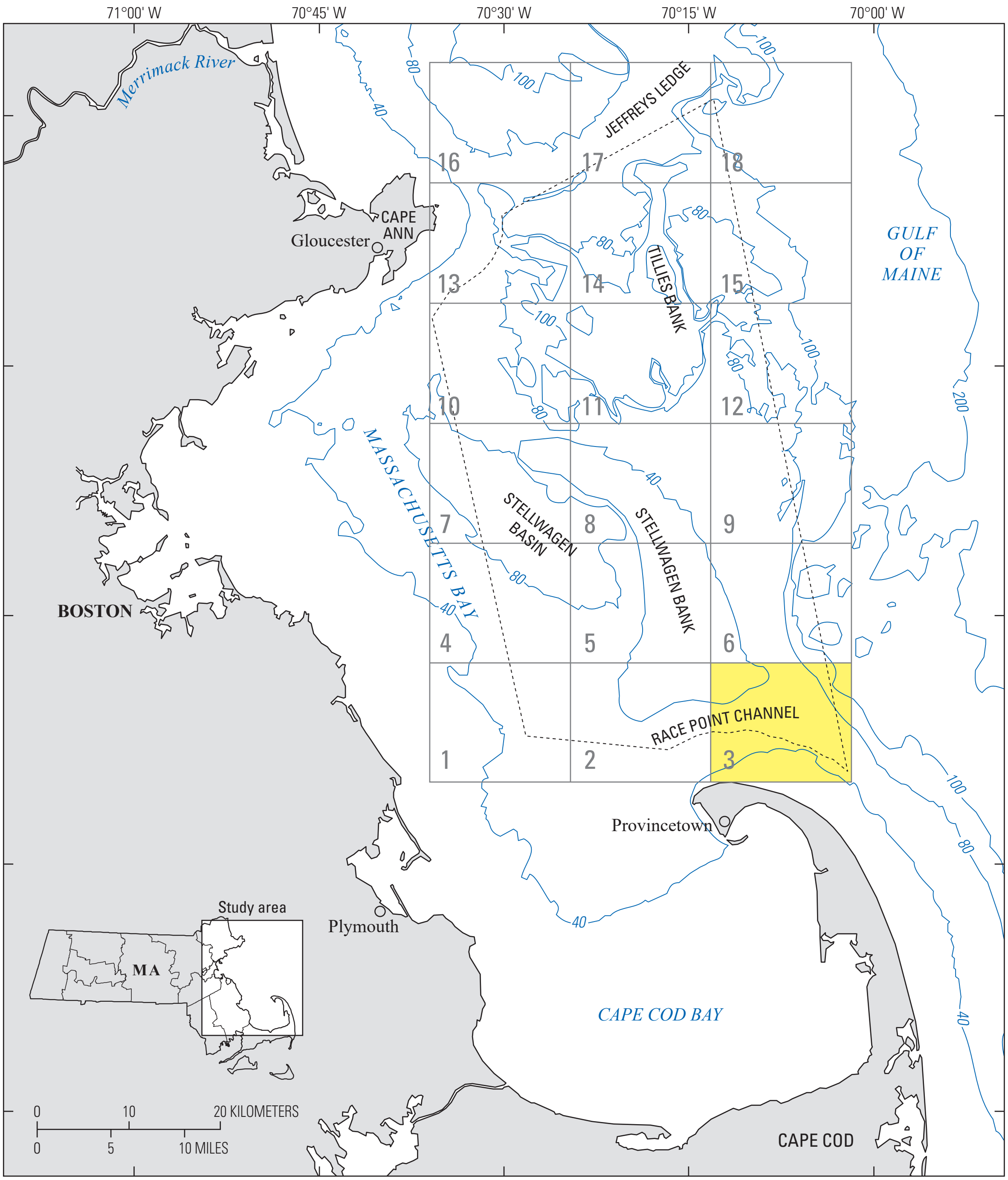

Figure 1. Map showing the location of quadrangle 3 (highlighted in yellow) of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts. The numbered grid indicates the 18 quadrangles of the U.S. Geological Survey multibeam sonar substrate-mapping project. The dashed line represents the Stellwagen Bank National Marine Sanctuary boundary. Bathymetric contours are labeled in meters and the contour interval is variable. Figure modified from Valentine and Cross (2024d).

The Stellwagen Bank region is a glaciated terrain and, as described in Valentine (2019), bank sediments have been reworked during several episodes of submergence and emergence by rising and falling sea level since the Last Glacial Maximum. Present processes of erosion and transport are the result of currents generated by large storms from the northeast (Butman and others, 2008; Warner and others, 2008) that produce bedforms on the seabed of the bank down to about 50 m water depth. Tidal currents are generally too weak (Butman and others, 2007) to move the coarse-grained sand on the bank. Quadrangle 3 lies approximately 65 kilometers (km) east of the Massachusetts coast and just to the north and northeast of Cape Cod's northernmost extent. At present, no sediment is transported from land into the map area except perhaps from the northern margin of Cape Cod onto the southern margin of Race Point Channel.

A geologic substrate is a surface or volume of sediment or rock material where physical and biological processes occur, such as the movement and deposition of sediment, the formation of bedforms, and the settlement, attachment, burrowing, feeding, reproduction, and sheltering of organisms (Valentine, 2019). A sedimentary substrate is characterized and identified by sediment composition (mud, sand, and gravel), the distribution of grain diameters, seabed structures (for example, ripples, burrows, and attached organisms), substrate layering (for example, finer sediment partly veneering coarser sediment), sediment movement, and water depth range. Substrates in quadrangle 3 range in composition from rippled and immobile coarse-grained sand to coarse-grained sand overlying gravel to boulder ridges to muddy, fine-grained sand. Layered substrates are generally in the form of a sand substrate that partially veneers a gravel substrate.

Seabed properties of quadrangle 3 are shown in a series of seven map types. Three maps show seabed topography (map A), ruggedness (map B), and backscatter intensity (map C). The other maps are interpretive and show the distribution of 21 geologic substrates (map D), the mobility or immobility of substrates (map E), the dominance of fine- or coarse-grained sand in substrates (map F), and the mud content of substrates (map G).

Several of the map types in this SIM (A, B, and C) have been published previously as parts of regional maps at a scale of 1:60,000 (Valentine, 2005); they are presented here at higher resolution (1:25,000 scale). Map A was previously published at a scale of 1:25,000 (Valentine and others, 1999, 2010), but it did not show the distribution of boulder ridges. Maps D–G show new interpretations of geologic substrate composition, substrate mobility, sand content, and mud content.

This SIM follows the design of companion SIMs that show the same seabed properties for quadrangle 2 (which adjoins quadrangle 3 to the west; Valentine and Cross, 2024a, c), for quadrangle 5 (which adjoins quadrangle 3 to the northwest; Valentine and Cross, 2024b, d), and for quadrangle 6 (which adjoins quadrangle 3 to the north; Valentine and Gallea, 2015). This SIM for quadrangle 3 and the companion SIMs for quadrangles 2 and 5 use the same wording in some places to describe the study, regional geology, and other shared features.

The purpose of this SIM is to provide a range of information about the distribution of physical attributes of the seabed in the SBNMS region at a scale (1:25,000) that is appropriate for the density of data. High-resolution substrate maps can serve as a foundation for further study of seabed processes (such as present and past sediment transport), support ecological studies of vertebrate and invertebrate species that use these substrates as habitat, and support planning and managing usage of the seabed.

Methods

The process of mapping geologic substrates in quadrangle 3 followed the principles of substrate characterization and identification as described in Valentine (2019). Geologic substrates were identified by analyzing video imagery of the seabed, multibeam sonar and backscatter imagery of the seabed, and grain sizes of sediment samples. The collection and processing of the multibeam sonar bathymetric and backscatter data presented here are described in Valentine (2005). The locations of stations (areas where data such as sediment samples or video imagery were collected) were digitally plotted on a multibeam sonar image of sun-illuminated seabed topography in a Portable Document Format (PDF). The boundaries of geologic substrates were digitally drawn by hand on this image based on the interpretation of the data described in this SIM. After the geologic substrates were identified, they were digitized in a geographic information system (GIS) and were then used to create three other interpretive maps. These maps characterize the substrates on the basis of the mobility or immobility of their surfaces, the dominance of fine- or coarse-grained sand, and the mud content. Table 1.1 in appendix 1 lists new data layers and previously published data that were used to compile the maps for quadrangle 3.

Grain-size classifications for sediment as used in this study are given in table 1. Composite grain-size classifications for sediment as used in this study are given in table 2.

Naming and abbreviation conventions for components of sediment and nonsediment classes and the mobility and layering properties of substrates are given in table 3 and are described below (from Valentine [2019], table 5). A sediment class based on grain-size analysis contains one or more aggregates and (or) composite grades (Valentine, 2019, table 1). For example, a muddy, gravelly, coarse-grained sand (mgcgS) is a sediment class containing three components: mud (an aggregate), gravel (an aggregate), and coarse-grained sand (a composite grade), in order of increasing weight percent. A sediment class based on a visual analysis of seabed imagery would be, for example, a pebble, cobble gravel (pcG), a sediment class consisting of pebbles and cobbles (each a composite grade), not in order of increasing abundance. A nonsediment class, also based on a visual analysis of seabed imagery, contains components such as shell deposits, rock outcrops, or semiconsolidated mud. Properties of seabed mobility (presence or absence of ripples) and substrate layering are also based on a visual analysis of seabed imagery. An unlayered substrate contains one sediment class (for example, muddy, fine-grained sand [mfgS]) or one nonsediment class (for example, rock outcrop [R]). A layered substrate contains at least two sediment classes or a sediment class and a nonsediment class (for example, a rippled, coarse-grained sand; partial veneer on immobile, semiconsolidated mud [r_cgS / i_scM]). In the present approach to substrate identification, the need to construct two-part names that are both informative and brief can produce names for two (or more) substrates in which geologic substrate symbols are unique but the abbreviations for the descriptive parts of the names are identical, for example A1 r_cgS and Y r_cgS.

Table 1. Grain-size classifications for sediment as used in this study of quadrangle 3 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts.

[To convert particle diameter (D) in millimeters (mm) to phi units (φ): $\varphi = -\log_2 D = -3.3219 \log_{10} D$. To convert particle diameter in phi units to mm: $D = 2^{-\varphi}$. Table from Valentine and Cross (2024d)]

Grade[1]	Grain size	
	Particle diameter range[1] (millimeters)	Phi grade scale[2]
Gravel, boulder	256 to <4,096	−8 to −11
Gravel, cobble	64 to <256	−6 to −7
Gravel, very coarse pebble	32 to <64	−5
Gravel, coarse pebble	16 to <32	−4
Gravel, medium pebble	8 to <16	−3
Gravel, fine pebble	4 to <8	−2
Gravel, granule	2 to <4	−1
Sand, very coarse	1 to <2	0
Sand, coarse	0.5 to <1	1
Sand, medium	0.25 to <0.5	2
Sand, fine	0.125 to <0.25	3
Sand, very fine	0.062 to <0.125	4
Silt	0.004 to <0.062	5 to 8
Clay	<0.004	9 and higher
Mud (silt and clay)	<0.062	5 and higher

[1]Described in Udden (1914), Wentworth (1922), Folk (1954), and Blair and McPherson (1999).

[2]Described in Krumbein (1936).

Table 2. Composite grain-size classifications for sediment as used in this study of quadrangle 3 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts.

[To convert particle diameter (D) in millimeters (mm) to phi units (φ): $\varphi = -\log_2 D = -3.3219 \log_{10} D$. To convert particle diameter in phi units to mm: $D = 2^{-\varphi}$. Table from Valentine and Cross (2024d)]

Composite grade	Grain size	
	Particle diameter range (millimeters)	Phi grade scale
Composite grade based on grain-size analysis		
$Gravel_2$ (G_2)	8 to <64	−3, −4, and −5
$Gravel_1$ (G_1)	2 to <8	−1 and −2
Coarse-grained sand (cgS)	0.25 to <2	2, 1, and 0
Fine-grained sand (fgS)	0.062 to <0.25	4 and 3
Composite grade based on visual analysis		
Boulder gravel (bG)	256 to <4,096	−8 to −11
Cobble gravel (cG)	64 to <256	−6 to −7
Pebble gravel (pG)	2 to <64	−1 to −5

Table 3. Naming and abbreviation conventions for components of sediment and nonsediment classes and the mobility and layering properties of substrates in quadrangle 3 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts.

[Not all of the terms in this table are applicable to quadrangle 3. See tables 1 and 2 for grain-size classifications of sediment class components. Table from Valentine (2019, table 5). Terms: >, greater than; ≥, greater than or equal to; <, less than; ≤, less than or equal to]

Name	Abbreviation	Portion of sediment, in weight percent
Sediment class components (aggregates and composite grades) based on grain-size analysis		
Mud	M	M≥50
Muddy	m	M≥10 to <50
Sand	S	S≥50
Sandy	s	S≥10 to <50
Fine-grained sand	fgS	fgS≥50
Fine-grained sandy	fgs	S≥10 to <50; fgS>cgS, fgS–cgS is >10
Coarse-grained sand	cgS	cgS≥50
Coarse-grained sandy	cgs	S≥10 to <50; cgS>fgS, cgS–fgS is >10
Coarse- and fine-grained sand	cgfgS	S≥50; fgS>cgS, fgS–cgS is ≤10
Coarse- and fine-grained sandy	cgfgs	S≥10 to <50; fgS>cgS, fgS–cgS is ≤10
Fine- and coarse-grained sand	fgcgS	S≥50; cgS>fgS, cgS–fgS is ≤10
Fine- and coarse-grained sandy	fgcgs	S≥10 to <50; cgS>fgS, cgS–fgS is ≤10
Gravel	G	G≥50
Gravelly	g	G≥25 to <50
Sediment class components (aggregates and composite grades) based on visual analysis of seabed imagery		
Gravel	G	Presence of gravel
Pebble gravel	p	Presence of pebbles
Cobble gravel	c	Presence of cobbles
Boulder gravel	b	Presence of boulders
Nonsediment class components based on visual analysis of seabed imagery		
Rock outcrop	R	Presence of rock outcrop
Shell deposit	Sh	Presence of shell deposit
Shelly	sh	Presence of shells
Semiconsolidated mud	scM	Presence of semiconsolidated mud outcrop
Properties of substrate mobility and layering based on visual analysis of seabed imagery		
Rippled	r	Presence of rippled sediment, implies mobility
Immobile	i	Presence of sediment with no ripples, implies no movement
Rippled and immobile	r_i	Presence of both rippled and immobile sediment
"Partial veneer on"	/	Indicates layered substrates. For example, "r_cgS / i_pcbG" means "rippled, coarse-grained sand; partial veneer on immobile, pebble, cobble, boulder gravel"

Map A. Sun-Illuminated Topography and Boulder Ridges

Map A shows seabed topographic imagery of quadrangle 3, which is a glaciated terrain modified by postglacial sediment-transport processes. This imagery is derived from multibeam sonar bathymetric data contoured at a 5-m interval. Water depths range from about 30 m on the southern part of Stellwagen Bank (northwest corner of quadrangle 3) to about 135 m in a basin east of South Ninety Bank (northeast corner of quadrangle 3). There are five boulder ridges in the mapped area, which are ≥1 m in height and are shown as semitransparent polygons overlying topographic imagery. Four boulder ridges are located on the southern margin of Race Point Channel and one is located on the western margin of South Ninety Bank. These ridges represent a combined area of 0.7 km^2 in this quadrangle (table 4).

The relatively smooth surface of the southeastern part of Stellwagen Bank (based on interpretation of multibeam topographic imagery) slopes eastward from a water depth of about 30 m on the bank to about 60 m at the bank margin; this surface then extends southward along the bank margin and across the eastern entrance of Race Point Channel. To the east of the bank lies a region of banks and basins that reaches a water depth of about 135 m east of South Ninety Bank. The eastern and central parts of Race Point Channel lie south of Stellwagen Bank in quadrangle 3; the western part of the channel lies south of the bank in quadrangle 2 to the west (Valentine and Cross, 2024c). The channel is oriented east-west, separates the bank from the northern margin of Cape Cod, and reaches water depths of 45 to 60 m along its axis in quadrangle 3. The channel floor displays a range of features which include a field of bedforms oriented across the channel axis, areas of gravel partially veneered by sand, and a large area of northwest trending, curvilinear ridges and troughs that are interpreted to represent keel marks produced by the keels of icebergs that grounded in the relatively shallow waters of the entrance to Race Point Channel. These keel marks have persisted since the disappearance of glaciers after the Last Glacial Maximum (Valentine, 2019). There are other linear depressions in the seabed located in the northern part of the channel, south of the southern margin of Stellwagen Bank, that also appear to represent keel marks that have been partially filled by sediment transported onto them from the bank. Iceberg keel marks are present in abundance in quadrangles 12, 15, and 18 in the northeastern part of the SBNMS region (Valentine, 2005).

To view maps and descriptions of glacial and postglacial seabed topography and the distribution of boulder ridges and bedrock outcrops in the entire SBNMS region, see maps A, B, and F of Valentine (2005). For further description of topographic features in this quadrangle, see the map and explanation of sun-illuminated topography in Valentine and others (1999, 2010).

Topographic contours were generated at 5-m and 1-m intervals from bathymetric data collected by a Simrad EM1000 multibeam sonar echo sounder that was used in the mapping survey (Valentine and others, 1998). The 5-m contours accurately represent the morphology of topographic features such as large and small banks and valleys. However, because they do not adequately show the irregular relief of the seabed in some areas, they are supplemented by 1-m contours on maps B and D–G. In areas of relatively featureless seabed where only minor changes in water depths occur, the 1-m contours are not shown because the process of contouring produces incoherent patterns of lines that misrepresent the topographic complexity (Valentine, 2019).

Three possible shipwrecks are present in quadrangle 3. Two of these are on Stellwagen Bank (at lat 42°11.12′ N., long 70°12.06′ W. and at lat 42°11.87′ N., long 70°11.03′ W.) and one is in Race Point Channel (at lat 42°06.74′ N., long 70°06.50′ W.).

Table 4. Area of the seabed mapped as boulder ridges in quadrangle 3 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts.

[Boulder ridges are segregated into two height categories, <1 meter (m) in height and ≥1 m in height. Data in columns 3 and 4 are rounded to one decimal place. Areas of the seabed mapped as boulder ridges and bedrock outcrops in all 18 quadrangles in the Stellwagen Bank National Marine Sanctuary region are listed in table 1 of map F of Valentine (2005). Table format from Valentine and Cross (2024d). Terms: ≥, greater than or equal to; <, less than; km^2, square kilometer]

Region	Area (km^2)	Area of boulder ridges that are <1 m or ≥1 m in height (km^2)		Area of boulder ridges that are <1 m or ≥1 m in height (percent)	
		<1 m	≥1 m	<1 m	≥1 m
Quadrangle 3	185	0.0	0.7	0.0	0.4

Map B. Seabed Ruggedness

Map B shows the results of an analysis of multibeam sonar bathymetric data to calculate seabed ruggedness, which is a measure of changes in elevation (water depth) over small areas. This kind of analysis is useful for identifying steep features where ruggedness values rapidly increase over short distances, and for delineating features in relatively smooth areas that are subtly expressed by seabed topography. The seabed ruggedness measure is based on a terrain ruggedness index (TRI) developed by Riley and others (1999) to quantify topographic heterogeneity on land. The TRI of Riley and others (1999) measures the sum change in elevation between a central grid cell (pixel) and its eight neighboring grid cells, which is computed by squaring the eight differences in elevation, summing the squared differences, and taking the square root of the sum. Here, a seabed ruggedness index is used to measure changes in elevation more directly by calculating the average change in elevation between a central pixel and its eight neighbors, which is computed by averaging the absolute values of the eight differences in elevation (see map D of Valentine [2005]). Comparing the two methods, a central pixel (representing a positive feature) with an elevation (water depth) value of 10 m and eight neighboring pixels with values of 15 m would have a TRI sum change value of 14.1 m using the method of Riley and others (1999), and a seabed ruggedness of 5.0 m using the method employed here.

For map B, seabed ruggedness values were calculated as the average change in water depth between a central 13-m pixel and the eight pixels that surround it, an area measuring 39 × 39 m. Subsequently, a smoothing filter was applied to the ruggedness index image. This filter calculated the mean of the seabed TRI value of each pixel and its eight neighboring pixels. On map B, the seabed ruggedness index values are represented by 13 colors ranging from lavender to dark red. Map colors represent the average change in elevation, in centimeters, and are shown in 10-cm increments in the >30- to 100-cm range (7 colors), in 50-cm increments in the >100- to 200-cm range (2 colors), and in 100-cm increments in the >200- to 600-cm range (4 colors). For example, on the map, blue represents central pixels having an average elevation change of >70 to 80 cm with respect to their surrounding eight-pixel areas. Average changes in elevation of less than or equal to 30 cm are not shown in color.

Table 5 shows the area of seabed that is represented by two seabed ruggedness intervals. Ruggedness values in the 0 to 30 cm range represent an area of approximately 179 km^2 (97 percent) of the total 185 km^2 mapped area of quadrangle 3. Ruggedness values reach a high of >30 to 100 cm in only approximately 5.7 km^2 (3 percent) of the mapped area of the quadrangle, which includes the following areas: along the deep southeastern flank of Stellwagen Bank southwest of South Ninety Bank; on the eastern margin of South Ninety Bank and on the crest of the small, unnamed bank to the southeast of South Ninety Bank; in the large field of sand waves in Race Point Channel where the highest values occur; and on the southern margin of Race Point Channel in the southwestern corner of the mapped region. Of the five boulder ridges present in quadrangle 3, the ruggedness analysis identified only the one surrounded by substrate AP (a rippled, coarse-grained sand that partially veneers cobble, boulder gravel in Race Point Channel) in the southern part of the quadrangle. To view maps and a description of seabed ruggedness and slope angle of the entire SBNMS region, see maps D and E, respectively, of Valentine (2005).

Table 5. Area of the seabed represented by ruggedness intervals in quadrangle 3 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts.

[Areas of seabed are represented by two ruggedness intervals of 0–30 centimeters (cm) and >30–100 cm in quadrangle 3. Data in columns 3 and 4 are rounded to one decimal place. Areas of seabed represented by ruggedness intervals in all 18 quadrangles of the Stellwagen Bank National Marine Sanctuary region are listed in table 1 of map D of Valentine (2005). Table format from Valentine and Cross (2024d). Terms: >, greater than; km^2, square kilometer]

Region	Area (km^2)	Area of seabed within four ruggedness intervals (km^2)				Area of seabed within four ruggedness intervals (percent)			
		0–30 cm	>30–100 cm	>100–200 cm	>200–600 cm	0–30 cm	>30–100 cm	>100–200 cm	>200–600 cm
Quadrangle 3	185	178.9	5.7	0	0	96.9	3.1	0	0

Map C. Backscatter Intensity and Sun-Illuminated Topography

Map C shows imagery of seabed backscatter intensity and sun-illuminated topography derived from multibeam sonar data. Backscatter intensity is a measure of the strength of sound waves reflected from the seabed. Hard substrates reflect sound waves more strongly than soft substrates. When color coded and mapped, backscatter intensity reveals patterns that are a useful preliminary guide for delineating the geographic extent of substrates. On map C, the backscatter intensity index shows values represented by an eight-color range from blue to red (1–8). Values from 1 to 3 (blue to blue-green) represent relatively soft substrates, values from 3 to 6 (blue-green to yellow) represent substrates of intermediate hardness, and values from 6 to 8 (yellow to red) represent relatively hard substrates. Backscatter intensity patterns, when used in concert with sediment grain-size analyses and interpretations of video and photographic imagery of the seabed, can be used to characterize and identify geologic substrates. It is not possible to recognize the substrates mapped in quadrangle 3 by relying on backscatter intensity alone. Some of the consistently narrow bands are artifacts of the multibeam survey and were possibly caused by ship motion that was not fully accounted for by the attitude sensors of the sonar system.

The highest backscatter values are located on two slightly elevated features in an area south of Stellwagen Bank in the northern part of Race Point Channel in 45 m water depth. They represent substrate AL, a rippled, gravelly, coarse-grained sand partial veneer on pebble, cobble gravel (for descriptions of substrates, see the section “Map D. Distribution of Geologic Substrates” below). Substrate AL is located in the shallowest part of Race Point Channel, and the exposure of gravel is likely caused by strong storm-wave generated currents that prevent sand from covering the gravel. Moderately high backscatter values are located in several other areas of Race Point Channel. Substrate AK (about 60 m water depth), an immobile, coarse-grained sand that forms a very thin partial veneer on pebble, cobble, boulder gravel, lies in the southwestern part of quadrangle 3. It has a hummocky surface, and it surrounds an east-west oriented boulder ridge (substrate C). Two boulder ridges (substrate C) surrounded by rippled coarse-grained sand (substrate AO) are present along the southern margin of Race Point Channel near the southern limit of the mapped area. Substrate AP is a large region that displays moderately high backscatter in the southeastern part of the eastern entrance to Race Point Channel; it is a rippled, coarse-grained sand that partially veneers cobble, boulder gravel. The seabed of substate AP is a series of arcuate ridges and troughs that represent the keel marks of grounded icebergs (see the discussion of map A above). The seabed on the top of South Ninety Bank, located in the northeast part of quadrangle 3, also displays moderately high backscatter produced by substrate F, an immobile, coarse-grained sand that partially veneers pebble, cobble, boulder gravel and that surrounds a boulder ridge (substrate C).

The seabed in the remainder of quadrangle 3 (primarily in Stellwagen Bank, its eastern flank, and the deep entrance to Race Point Channel) displays intermediate backscatter values that represent sand substrates. An exception is the area occupied by substrate AM, a rippled, coarse-grained sand that lies in the middle to southern part of Race Point Channel. The surface of substrate AM in multibeam topographic imagery displays bedforms of varying wavelengths whose crests are consistently oriented to the northwest. Small bedforms (50-m wavelength) of moderate backscatter are located in the northern part of the substrate, and large bedforms (100–200-m wavelength) of low backscatter are located in the southern part. The differences in backscatter strength of the bedform populations are not related to sediment grain size, but possibly to bedform wavelength size, with smaller bedforms producing higher backscatter values than larger bedforms.

Map D. Distribution of Geologic Substrates

Map D shows the distribution of 21 geologic substrates characterized by grain-size composition, the distribution of grain diameters in the sediment, surface morphology, substrate layering, the mobility or immobility of the substrate surfaces, and water depth range. Bathymetric contours are drawn at 5-m intervals, except in some areas of complex seabed with low relief where they are drawn at 1-m intervals.

Data from 309 stations were analyzed, including 279 sediment samples. Map D, sheet 1 shows the distribution of geologic substrates and the locations of stations where sediment samples were collected or the locations of the ends of video drifts if no sediment was collected. Sediment was usually collected at the end of video drifts. Map D, sheet 2 shows the distribution of geologic substrates and sun-illuminated topography, but not the locations of data stations. Data from these stations were used to identify and map the substrate polygons.

See Valentine and Cross (2026b) for the results of grain-size analyses of sediment samples and the assignment of stations to substrates. See tables 6 and 7 (which follow the “References Cited”) for descriptions and comparisons of substrate properties, water depth ranges, and substrate areas. See Valentine (2019) for a complete description of the methodology developed for sediment classification and for substrate characterization, identification, and mapping.

The geologic substrates of quadrangle 3 were formed by the glacial processes of erosion and deposition, were subsequently modified by the effects of rising postglacial sea level, and are presently affected by storm-wave generated currents (Valentine, 2019). A discussion of the morphology and origin of topographic features in this quadrangle can be found in Valentine and others (1999, 2010).

Substrates range widely in character in quadrangle 3. The shallow surface of Stellwagen Bank and its upper eastern flank are covered by mobile, coarse-grained sand; the lower eastern flank of the bank is covered by immobile, coarse-grained sand. In Race Point Channel, south of the bank, and on the northern margin of Cape Cod, the seabed displays a range of substrates, including mobile, coarse-grained sand; mobile, fine-grained sand; mobile, coarse-grained sand partially veneering gravel; and several boulder ridges. East of Stellwagen Bank in deeper water is a terrain of small banks and basins where substrates vary from immobile, coarse-grained sand that partially veneers gravel on bank tops to immobile, muddy, fine-grained sand in the basins.

The quality of substrate identification and mapping depends on the spatial density of samples and observations available to interpret multibeam sonar imagery. Fewer samples are required to identify substrates where the substrate boundaries align with topographic features and sonar backscatter intensity patterns. More samples are required where multibeam imagery indicates seabed features and substrates are complex, and also where they are relatively uniform but are present in an area of changing water depths.

Substrates are mapped in three ways, depending on the density of the data. First, substrates are mapped as irregular-sided polygons (in this context meaning polygons with many vertices and smooth edges) if the density of data allows for their extent to be mapped with some confidence. In quadrangle 3, 20 of 21 substrates are mapped as irregular-sided polygons. Second, substrates are mapped as straight-sided polygons (in this context meaning angular polygons with relatively few vertices and sides) if transitions between substrates are ambiguous because data are sparse. The straight-sided polygons alert the user that there is uncertainty as to the areal extents of the substrates. In quadrangle 3, no substrates are mapped as straight-sided polygons. Contacts are not drawn for irregular-sided or straight-sided polygons because contacts indicate a degree of certainty that is usually not warranted in marine substrate mapping. Third, deposits of substrates that occur within the bounds of other mapped substrates and that are too few to be mapped as coherent units at 1:25,000 scale are shown as magenta square symbols on map D, sheet 1, and are identified in Valentine and Cross (2026b). In quadrangle 3, deposits of substrate A3 are only shown as magenta square symbols and these occur within the areas mapped as substrates A1, Z, and AN.

Description of Map Units (Substrates)

[The grain sizes of sediment samples collected from each substrate are given as mean weight percents for each aggregate (mud, sand, and gravel) and composite grade (fine-grained sand, coarse-grained sand, $gravel_1$, and $gravel_2$). See Valentine (2019) for descriptions of aggregates and composite grades. Weight percent values were rounded and may not add up to 100 or other summed values, for example, sand, 88 (fgS, 69; cgS, 20). Aggregates and composite grades are abbreviated and given in order of increasing weight percent in the name of each substrate. For example, a muddy, fine-grained sand (mfgS) contains more fine-grained sand than mud. Sand is divided into two composite grades: fine-grained sand (fgS; 0.062 to <0.25 millimeters [mm]) and coarse-grained sand (cgS; 0.25 to <2 mm). Fine-grained sand (3 and 4 phi combined) is transported as suspended load, and coarse-grained sand (0, 1, and 2 phi combined) is transported as bed load (Valentine, 2019). Gravel is also divided into two composite grades: $gravel_1$ (G_1; 2 to <8 mm) and $gravel_2$ (G_2; 8 to <64 mm). Gravel (in the form of pebbles, cobbles, and boulders) that could not be sampled was identified using visual analysis of video and photographic imagery. Grain-size characteristics for the four layered substrates (F, AK, AL, and AP) represent the sampled sediment that partially veneers gravel. Substrate unit names describe the mobility or immobility of their surfaces, sediment grain-size composition, and sediment layering. For example, the notation "r_cgS / i_pcbG" means "rippled, coarse-grained sand; partial veneer on immobile, pebble, cobble, boulder gravel." See table 3 for further explanation]

A1 r_cgS—Rippled, coarse-grained sand.—Substrate A1 is a mobile, coarse-grained sand deposit that covers the southeastern part of Stellwagen Bank and its flank, as well as the eastern approaches to Race Point Channel. Its mapped area is 74.7 km^2, or 40.4 percent of the mapped area in quadrangle 3. The water depths of the stations range from 32 to 59 m and the water depth of the mapped substrate ranges from 30 to 60 m. Mean weight percents of aggregates and composite grades are as follows: mud, <1; sand, 94 (fgS, 2; cgS, 92); gravel, 6 (G_1, 6; G_2, <1). The substrate extends westward onto the southwestern part of the bank in quadrangle 2 (Valentine and Cross, 2024c), and northward onto the eastern flank of the bank in quadrangle 6 (Valentine and Gallea, 2015). Substrate A1 is dominantly coarse-grained sand and is very low in mud and fine-grained sand content. Its surface is smooth, as observed in multibeam topographic imagery, but video imagery reveals that sand ripples with wavelengths of 0.5 to 1.0 m are present on the surface; the orientation of ripple crests varies from north-south to northwest-southeast. The ripples are symmetrical and well-shaped (sometimes with narrow, sharply defined crests and sometimes with broad crests hosting secondary ripples) when first formed by storm-wave generated currents, but they are subsequently rounded by faunal disturbance and flattened by bottom-tending fishing gear such as dredges and trawls. Those stations that occur in the A1 polygon that are not documented with video imagery or that do not display sand ripples because they have been disturbed by fishing gear are nevertheless characterized as "rippled" by analogy to the many nearby stations in A1 that exhibit ripples in video imagery. Substrate A1 is texturally similar to substrate Z, which is recognized as a separate substrate because it lies in deeper water in Race Point Channel south of Stellwagen Bank and contains slightly more fine-grained sand. Substrate AB, a rippled, fine-grained sand, is adjacent to substrate A1 along the western boundary of quadrangle 3 in a small area on the southern margin of Stellwagen Bank, as well as in quadrangle 2 (Valentine and Cross, 2024c) where it covers much more area. Substrate A1 is similar to substrate A3 in that they both have similar mud and overall sand content, and both have rippled surfaces. However, substrate A3 contains more fine-grained sand (13 weight percent) and each sample from substrate A3 generally contains 10 weight percent or more of fine-grained sand, mostly as 3-phi sand.

A2 i_cgS—Immobile, coarse-grained sand.—Substrate A2 is an immobile, coarse-grained sand deposit that lies along the southeastern flank of Stellwagen Bank and in the deeper eastern approaches to Race Point Channel. Its mapped area is 10.7 km^2, or 5.8 percent of the mapped area in quadrangle 3. The water depths of the stations range from 59 to 73 m and the water depth of the mapped substrate ranges from about 55 to 80 m. Mean weight percents of aggregates and composite grades are as follows: mud, 1; sand, 98 (fgS, 10; cgS, 88); gravel, 2 (G_1, 2; G_2, 0). Substrate A2 is dominantly coarse-grained sand and is very low in mud and fine-grained sand content. Its surface is unrippled in contrast to the adjacent mobile substrate A1, which lies in shallower water depths (30–60 m) to the west and contains less fine-grained sand (2 weight percent). Substrate A2 is bounded in deeper water to the east by substrate E (also an immobile, coarse-grained sand) and by substrate G1 (a muddy, fine-grained sand). Substrates A2, E, and G1 all extend northward into the adjoining quadrangle 6 (Valentine and Gallea, 2015).

A3 r_cgS—Rippled, coarse-grained sand.—Substrate A3 is a collection of mobile, coarse-grained sand deposits that lie within the areas occupied by substrates A1, Z, and AN. The water depths of the stations range from 42 to 55 m. Mean weight percents of aggregates and composite grades are as follows: mud, <1; sand, 98 (fgS, 13; cgS, 85); gravel, 2 (G_1, 2; G_2, 0). It is also present as scattered deposits on the crest and western flank of the bank in the adjoining quadrangle 5 to the northwest (Valentine and Cross, 2024d). Substrate A3 is texturally similar to substrate A1 in that it has a very low mud content. It differs from A1 in that it has more fine-grained sand (each sample generally contains 10 weight percent or more of fine-grained sand, mostly as 3-phi sand) and that its surface ripples are much smaller, with wavelengths of 10 to 20 cm. Substrate A3 is also similar to substrate A2; they both contain more fine-grained sand than substrate A1, but A2 has less fine-grained sand than A3, is immobile, and lies at greater water depths (55–80 m). Samples of substrate A3 were collected from within the area mapped as substrates A1, Z, and AN, but they are not mappable as coherent units at 1:25,000 scale; the locations of these samples are shown by magenta square symbols on map D, sheet 1, and are identified in Valentine and Cross (2026b).

C i_cbG —Immobile, cobble, boulder gravel.—Substrate C is represented by five boulder ridges (piled cobbles and boulders) that occur in four locations in quadrangle 3. The mapped area of these ridges is 0.7 km^2, or 0.4 percent of the mapped area in quadrangle 3. It is represented by only one station (number 4986, 57 m water depth) in quadrangle 3. The water depth of the mapped substrate ranges from >25 to 87 m. Weight percents of aggregates and composite grades of the one sample that was collected at the base of a boulder ridge are as follows: mud, 18; sand, 66 (fgS, 4; cgS, 62); gravel, 16 (G_1, 3; G_2, 13). The shape and relief of the boulder ridges are based on interpretation of multibeam topographic imagery and on the substrate's high reflectivity in backscatter imagery, which is typical of boulder ridges mapped in quadrangles 5 (Valentine and Cross, 2024d) and 6 (Valentine and Gallea, 2015).

A sinuous boulder ridge with an east-west orientation is present in the southern part of Race Point Channel. It is approximately 1.5 km long and 0.1 km wide, lies in water depths of >55 to 58 m, and is surrounded by gravelly substrate AK. The only station for substrate C lies within the bounds of this boulder ridge (table 6). Two adjacent boulder ridges are present on the southern margin of Race Point Channel near the southern limit of the quadrangle 3 mapped area. The westernmost ridge is 0.5 km long and 0.1 km wide and is oriented approximately east-west. The easternmost ridge extends southward past the map boundary, is at least 0.7 km long and 0.2 km wide, and is oriented northwest to southeast. These two ridges lie in water depths of >25 to <35 m and are surrounded by substrate AO. A single boulder ridge is present on the southern flank of Race Point Channel in water depths of <30 to 36 m. The feature is approximately 0.5 km long, 0.2 km wide, and is oriented northeast to southwest (which is normal to the trend of the sediment ridges of substrate AP which surrounds it). Another boulder ridge forms a low feature that trends northwest to southeast along the southwest margin of South Ninety Bank in water depths of 85 to 87 m; it is surrounded by substrate F which occupies the summit of South Ninety Bank.

E i_cgS—Immobile, coarse-grained sand.—Substrate E is an immobile, coarse-grained sand deposit that lies in a shallow valley between the southeastern flank of Stellwagen Bank and the western flank of South Ninety Bank. Its mapped area is 0.3 km^2, or 0.2 percent of the mapped area in quadrangle 3. It is not represented by any stations in quadrangle 3. The water depth of the mapped substrate ranges from 75 to 80 m. Mean weight percents of aggregates and composite grades of the samples collected from substrate E in quadrangle 6 (66 to 122 m water depth) are as follows: mud, 4; sand, 82 (fgS, 18; cgS, 64); gravel, 14 (G_1, 9; G_2, 5) (Valentine and Gallea, 2015). Substrate E separates substrate A2 to the west from substrate G1 that lies on the western flank of South Ninety Bank in deeper water to the east. Substrate E is interpreted to be a short extension (1.5 km) of substrate E mapped in the adjoining quadrangle 6 to the north and to be texturally similar to that deposit. Its occurrence in quadrangle 3 is based on interpretation of multibeam topographic and backscatter imagery.

F i_cgS / pcbG—Immobile, coarse-grained sand; partial veneer on pebble, cobble, boulder gravel.—Substrate F is a layered substrate of immobile, coarse-grained sand that partially veneers pebble, cobble, boulder gravel. It lies on the southern part of the top of South Ninety Bank. Its mapped area is 3.1 km^2, or 1.7 percent of the mapped area in quadrangle 3. It is represented by only two stations (numbers 1443 and 1444) in quadrangle 3. The water depths of the stations range from 87 to 97 m and the water depth of the mapped substrate ranges from 85 to 115 m. Mean weight percents of aggregates and composite grades of the two samples from the sediment partial veneer that overlies gravel are as follows: mud, 5; sand, 56 (fgS, 40; cgS, 16); gravel, 39 (G_1, 15; G_2, 24). The high gravel content is interpreted to represent gravel particles that were inadvertently collected from the gravel substrate located below the partial veneer of sand.

The seabed on the northern part of the top of South Ninety Bank lies in the adjoining quadrangle 6 and was mapped as substrate F (Valentine and Gallea, 2015). The seabed on the southern part of the bank top lies in quadrangle 3 and is also mapped here as substrate F; however, the assignment of this area to substrate F requires explanation. On the northern part of the bank, the grain size of sand is variable; coarse-grained sand is dominant on the bank top (3 stations) and fine-grained sand content (2 stations) increases with water depth on the bank's flank (Valentine and Gallea, 2015). By contrast, on the southern part of the bank top in quadrangle 3, in the two samples collected, the content of fine-grained sand is greater than coarse-grained sand. Nevertheless, this area is identified as substrate F because sediment texture data here are variable and sparse; it is unlikely that the northern and southern parts of this relatively smooth and flat bank top are occupied by different substrates, as the multibeam sonar bathymetric and backscatter imagery (Valentine, 2005) show the seabed on the bank top to be of similar character in both quadrangles. More sediment sampling is required to verify this interpretation.

G1 i_mfgS—Immobile, muddy, fine-grained sand.—Substrate G1 is an immobile, muddy, fine-grained sand deposit that lies on the southern flank of South Ninety Bank and in the deeper waters of the basins to the east and south of it. Its mapped area is 17.8 km^2, or 9.6 percent of the mapped area in quadrangle 3. This substrate has been mapped in a similar topographic setting on the northern flank of South Ninety Bank and in its adjacent basins in quadrangle 6 to the north (Valentine and Gallea, 2015). The water depths of the stations range from 78 to 126 m and the water depth of the mapped substrate ranges from 70 to 135 m. Mean weight percents of aggregates and composite grades are as follows: mud, 6; sand, 88 (fgS, 69; cgS, 20); gravel, 6 (G_1, 3; G_2, 3). Substrate G1 in quadrangle 3 contains only 6 mean weight percent mud, which is less than the ≥10 weight percent threshold (table 3) required for it to be characterized as a muddy sediment (Valentine, 2019). However, because the mud composition of the 9 samples collected from substrate G1 in quadrangle 3 (range of 1–16 and mean of 6 weight percent) is very similar to that of the 39 samples collected from substrate G1 in quadrangle 6 (range of 2–18 and mean of 10 weight percent; Valentine and Gallea, 2015), and because of its similar topographic setting, the substrate mapped as G1 in quadrangle 3 is identified as a muddy, fine-grained sand for consistency with its occurrence in the adjoining quadrangle 6 to the north.

Y r_cgS—Rippled, coarse-grained sand.—Substrate Y is a mobile, coarse-grained sand deposit that lies in the in the southern part of Race Point Channel in the southwestern part of the mapped area. Its mapped area is 2.0 km^2, or 1.1 percent of the mapped area in quadrangle 3. The water depths of the stations range from 62 to 63 m and the water depth of the mapped substrate ranges from 60 to 63 m. Mean weight percents of aggregates and composite grades are as follows: mud, 3; sand, 96 (fgS, 36; cgS, 60); gravel, 1 (G_1, 1; G_2, 0). Substrate Y lies in the southwestern part of quadrangle 3 and extends westward into quadrangle 2 (Valentine and Cross, 2024c). It lies to the west of substrate AC, in somewhat deeper water, and contains more fine-grained sand (36 weight percent) than substrate AC (12 weight percent). Substrate Y is bounded to the south by the northern margin of Cape Cod, which is occupied by substrates AG and AQ.

Z r_cgS—Rippled, coarse-grained sand.—Substrate Z is a mobile, coarse-grained sand deposit that lies in Race Point Channel at the base of Stellwagen Bank. Its mapped area is 13.5 km^2, or 7.3 percent of the mapped area in quadrangle 3. The water depths of the stations and the mapped substrate range from 43 to 62 m. Mean weight percents of aggregates and composite grades are as follows: mud, 1; sand, 97 (fgS, 5; cgS, 91); gravel, 3 (G_1, 2; G_2, 1). Substrate Z is bounded to the north by substrate A1 on Stellwagen Bank and is differentiated from it because it lies in somewhat deeper water in Race Point Channel and because it contains more fine-grained sand (5 weight percent) than substrate A1 (2 weight percent). As observed in multibeam topographic imagery, substrate Z has a relatively smooth surface. In Race Point Channel, it is bounded by a range of sand substates including substrates AI and AN to the east, AC and AM to the south, and a small portion of AB to the west which extends into quadrangle 2 (Valentine and Cross, 2024c). Also, to the south, it abuts substrate AK, a layered substrate of sand that partially veneers gravel. Substrate Z extends westward from quadrangle 3 into quadrangle 2 (Valentine and Cross, 2024c).

AB r_fgS—Rippled, fine-grained sand.—Substrate AB is a mobile, fine-grained sand deposit that lies in a small part of Race Point Channel on the southern flank of Stellwagen Bank along the western margin of quadrangle 3. Most of the substrate lies in the adjoining quadrangle 2 to the west (Valentine and Cross, 2024c). Its mapped area is <0.1 km^2, or <0.1 percent of the mapped area in quadrangle 3. Substrate AB is not represented by any stations in quadrangle 3. The water depth of the mapped substrate in quadrangle 3 is about 49 to 55 m. Mean weight percents of aggregates and composite grades of the samples collected from substrate AB in quadrangle 2 (44 to 63 m water depth) are as follows: mud, 4; sand, 96 (fgS, 71; cgS, 25); gravel, <1 (G_1, <1; G_2, 0) (Valentine and Cross, 2024c). Substrate AB in quadrangle 3 is bounded to the north on the bank by the rippled, coarse-grained sand of substrate A1 and to the east and south in Race Point Channel by the rippled, coarse-grained sand of substrate Z. The contacts between substrate AB and substrates A1 and Z in quadrangle 3 were mapped on the basis of interpretation of seabed topography and the grain texture of nearby sediment samples in substrates A1 and Z. The fine-grained sand that characterizes substrate AB likely has been transported southward from Stellwagen Bank by storm-wave generated currents from the north and northeast.

AC r_cgS—Rippled, coarse-grained sand.— Substrate AC is a mobile, coarse-grained sand deposit that lies in the southern part of Race Point Channel. Its mapped area is 1.4 km^2, or 0.8 percent of the mapped area in quadrangle 3. It is represented by only one station (number 1254) in quadrangle 3. The water depth of the one station is 59 m and the water depth of the mapped substrate ranges from 59 to 60 m. Weight percents of aggregates and composite grades of the one sample are as follows: mud, 2; sand, 98 (fgS, 12; cgS, 86); gravel, <1 (G_1, <1; G_2, 0). The substrate's surface displays bedforms (50–100 m wavelength) that are observable in multibeam topographic imagery. These bedforms trend northwest to southeast, approximately normal to the trend of Race Point Channel, and resemble bedforms present in the northern part of substrate AM to the east. Substrate AC is bounded to the east by substrate AK and to the west by substrates Y and Z, whose surfaces are smooth as observed in multibeam topographic imagery. Based on the presence of its distinctive bedforms, substrate AC is mapped as extending westward for a short distance into quadrangle 2 (Valentine and Cross, 2024c).

AG r_cgS—Rippled, coarse-grained sand.— Substrate AG is a mobile, coarse-grained sand deposit that lies on the southern flank of Race Point Channel in the southwestern part of the mapped area and extends westward into quadrangle 2 (Valentine and Cross, 2024c). Its mapped area is 0.3 km^2, or 0.2 percent of the mapped area in quadrangle 3. It is not represented by any stations in quadrangle 3. The water depth of the mapped substrate ranges from about 50 to about 60 m. Mean weight percents of aggregates and composite grades of the samples collected from substrate AG in quadrangle 2 (55 to 58 m water depth) are as follows: mud, <1; sand, 100 (fgS, 5; cgS, 95); gravel, 0 (G_1, 0; G_2, 0) (Valentine and Cross, 2024c). Substrate AG is interpreted to be a short extension of substrate AG from the adjoining quadrangle 2 to the west. Its occurrence in quadrangle 3 is based on interpretation of multibeam topographic and backscatter imagery. Storm-wave generated sand ripples are present on the surface of substrate AG. To the east, along the northern slope of Cape Cod, it abuts substrate AQ, a rippled, fine-grained sand.

AI r_cgS—Rippled, coarse-grained sand.— Substrate AI is a mobile, coarse-grained sand deposit that lies in the central part of Race Point Channel between Stellwagen Bank to the north and Cape Cod to the south. Its mapped area is 4.4 km^2, or 2.4 percent of the mapped area in quadrangle 3. The water depths of the stations range from 43 to 49 m and the water depth of the mapped substrate ranges from 43 to 55 m. Mean weight percents of aggregates and composite grades are as follows: mud, <1; sand, 90 (fgS, 4; cgS, 85); gravel, 10 (G_1, 6; G_2, 5). Substrate AI is characterized by areas of smooth seabed separated by areas of subparallel ridges aligned dominantly northwest to southeast, as observed in multibeam topographic imagery. Two samples collected from the ridges are gravelly, coarse-grained sand, suggesting that just below the surface substrate the ridges are gravelly and possibly represent partially buried iceberg keel marks (see the comment on the origin of the keel marks in the description of substrate AP below). Substrate AI is bounded to the north by substrates AL and AN, to the east by substrate A1, to the south by substrate AP, and to the west by substrate Z.

AJ i_cgS—Immobile, coarse-grained sand.— Substrate AJ is an immobile, coarse-grained sand deposit that lies on the top of a small, unnamed bank located southeast of South Ninety Bank. Its mapped area is 0.2 km^2, or 0.1 percent of the mapped area in quadrangle 3. It is represented by only one station (number 1446) in quadrangle 3. The water depth of the one station is 111 m and the water depth of the mapped substrate ranges from 110 to 111 m. Weight percents of aggregates and composite grades of the one sample are as follows: mud, 9; sand, 88 (fgS, 29; cgS, 59); gravel, 3 (G_1, 3; G_2, 0). It is surrounded in deeper water by substrate G1.

AK i_cgS / pcbG—Immobile, coarse-grained sand; partial veneer on pebble, cobble, boulder gravel.— Substrate AK is a layered substrate of immobile, coarse-grained sand that partially veneers pebble, cobble, boulder gravel. It lies in the southcentral part of Race Point Channel. Its mapped area is 2.7 km^2, or 1.4 percent of the mapped area in quadrangle 3. The water depths of the stations range from 57 to 61 m and the water depth of the mapped substrate ranges from 55 to 61 m. Mean weight percents of aggregates and composite grades of the very thin sediment partial veneer that overlies gravel are as follows: mud, 2; sand, 84 (fgS, 12; cgS, 72); gravel, 13 (G_1, 5; G_2, 9). The substrate is interpreted to be immobile because only 2 of 10 stations with video imagery show ripples, and they are very poorly developed in the thin, patchy sand that veneers the gravel at some stations. The gravel element of the substrate is documented by video imagery. The substrate's hummocky surface, as observed in multibeam topographic imagery, exhibits high reflectivity in backscatter imagery, which is typical of a hard substrate. Multibeam topographic imagery is the basis for the mapped geographic extent of the substrate. Substrate AK surrounds an east-west trending boulder ridge (substrate C). Substrate AK is bounded on all sides by substrates of rippled sand, which include substrate Z to the north, substrate AM to the east and southeast, substrate AQ to the south, and substrate AC to the west.

AL r_gcgS / i_pcG—Rippled, gravelly, coarse-grained sand; partial veneer on immobile, pebble, cobble gravel.— Substrate AL is a layered substrate of mobile, gravelly, coarse-grained sand that partially veneers immobile, pebble, cobble gravel. It lies in two separate areas on topographic highs in the northeastern part of Race Point Channel, south of Stellwagen Bank. Its mapped area is 2.9 km^2, or 1.6 percent of the mapped area in quadrangle 3. The water depths of the stations range from 46 to 53 m and the water depth of the mapped substrate ranges from 45 to 53 m. Mean weight percents of aggregates and composite grades of the sediment partial veneer that overlies gravel are as follows: mud, <1; sand, 56 (fgS, 17; cgS, 39); gravel, 44 (G_1, 5; G_2, 39). Pebbles and cobbles are identified based on video imagery. At some stations, substrate AL is a gravel pavement with little or no sand veneer. Multibeam backscatter imagery is the basis for the mapped geographic extent of this substrate. The substrate's surface exhibits high reflectivity in multibeam backscatter imagery, which is typical of a hard substrate. The western part of substrate AL is surrounded by substrate AN. The eastern part of substrate AL is bounded to the north and west by substrate AN, to the east by substrate A1, and to the south by substrate AI.

AM r_cgS—Rippled, coarse-grained sand.—Substrate AM is a mobile, coarse-grained sand deposit that lies in the southern part of Race Point Channel, north of Cape Cod. Its mapped area is 8.0 km^2, or 4.3 percent of the mapped area in quadrangle 3. The water depths of the stations range from 45 to 64 m and the water depth of the mapped substrate ranges from 40 to 64 m. Mean weight percents of aggregates and composite grades are as follows: mud, 1; sand, 98 (fgS, 4; cgS, 94); gravel, 1 (G_1, 1; G_2, <1). The substrate surface displays large bedforms (100–200 m wavelength) in the south and small bedforms (50–100 m wavelength) in the north, as observed in multibeam topographic imagery. The bedforms trend northwest to southeast, approximately normal to the trend of Race Point Channel. The small bedforms in the northern part are similar in wavelength and orientation to those present in substrate AC to the west. Substrate AM is bounded to the north by substrates Z and AP, to the east by substrate AP, to the south by substrate AO, and to the west by substrate AK.

AN r_cgS—Rippled, coarse-grained sand.—Substrate AN is a mobile, coarse-grained sand deposit that lies along the northern margin of Race Point Channel and the southern margin of Stellwagen Bank. Its mapped area is 7.3 km^2, or 3.9 percent of the mapped area in quadrangle 3. The water depths of the stations range from 48 to 50 m and the water depth of the mapped substrate ranges from 45 to 50 m. Mean weight percents of aggregates and composite grades are as follows: mud, <1; sand, 99 (fgS, 32; cgS, 67); gravel, 1 (G_1, 1; G_2, 0). Substrate AN is similar in mobility and sand content to adjacent substrate A1 to the north and east and to substrate Z to the west, but substrate AN has a much higher fine-grained sand content (32 weight percent) compared to that of A1 (2 weight percent) and Z (5 weight percent). It is likely that the fine-grained sand in substrate AN has been winnowed and transported by storm-wave generated currents from substrate A1 on Stellwagen Bank, which abuts AN to the north. Also, the surface of substrate AN displays ridge-like features in multibeam topographic imagery that are interpreted to be partially buried iceberg keel marks (see the comment on the origin of the keel marks in the description of substrate AP below); in contrast, the surfaces of substrates A1 and Z are smooth in multibeam topographic imagery. To the south, substrate AN abuts the eastern deposit of substrate AL and surrounds the western deposit of substrate AL.

AO r_cgS—Rippled, coarse-grained sand.—Substrate AO is a mobile, coarse-grained sand deposit that lies along the southern margin of Race Point Channel and the northern margin of Cape Cod. It likely represents a sand apron that extends northward from Cape Cod into Race Point Channel. Its mapped area is 5.9 km^2, or 3.2 percent of the mapped area in quadrangle 3. The water depths of the stations range from 28 to 49 m and the water depth of the mapped substrate ranges from 28 to 55 m. Mean weight percents of aggregates and composite grades are as follows: mud, 1; sand, 97 (fgS, 3; cgS, 94); gravel, 2 (G_1, 2; G_2, 1). The surface of substrate AO is smooth as observed in multibeam topographic imagery. By contrast, it is bounded to the north by substrate AM, to the east by substrate AP, and to the west by substrate AQ, all of which are mobile sand substrates that collectively display surfaces of bedforms, ridges, troughs, and hummocks in multibeam topographic imagery. Substrate AO is similar in grain-size composition to other rippled, coarse-grained sand substates (A1, Y, and Z) that display a smooth surface in multibeam topographic imagery in quadrangle 3. Two boulder ridges (substrate C) are present within the southern part of substrate AO.

AP r_cgS / i_pcbG—Rippled, coarse-grained sand; partial veneer on immobile, pebble, cobble, boulder gravel.—Substrate AP is a layered substrate of mobile, coarse-grained sand that partially veneers immobile, pebble, cobble, boulder gravel. It lies in the southeastern part of Race Point Channel. Its mapped area is 27.2 km^2, or 14.7 percent of the mapped area in quadrangle 3. The water depths of the stations range from 34 to 51 m and the water depth of the mapped substrate ranges from 30 to 51 m. Mean weight percents of aggregates and composite grades of the sediment partial veneer that overlies gravel are as follows: mud, <1; sand, 92 (fgS, 3; cgS, 89); gravel, 8 (G_1, 5; G_2, 3). Substrate AP exhibits relatively high reflectivity in multibeam backscatter imagery, which is typical of coarse sediment. Cobbles and boulders are identified based on video imagery. The substrate's surface topography, as observed in multibeam topographic imagery, is a series of subparallel, arcuate troughs and ridges that trend northwestward. Both substrate layers are visible on the ridges, but only the upper layer (the rippled, coarse-grained sand) is visible in the troughs. The troughs are <5 m deep and are interpreted to be iceberg keel marks that were formed during the last deglaciation (Valentine, 2019) by the grounding of icebergs as they drifted westward into the channel from deeper water to the east. The keel marks are present beginning at 45 to 50 m water depth in the east and extend westward in the channel until the water depth increases to >50 m. Substrate AP surrounds a boulder ridge (substrate C). Substrate AP is bounded to the north and west in Race Point Channel by substrates A1, AO, AM, and AI, all of which are rippled, coarse-grained sand. Substrate AP is bounded to the east, in the open Atlantic Ocean, by substrate A1.

AQ r_fgS—Rippled, fine-grained sand.—Substrate AQ is a mobile, fine-grained sand deposit that lies along the southern margin of Race Point Channel in the southwestern part of the mapped area. Its mapped area is 1.2 km^2, or 0.6 percent of the mapped area in quadrangle 3. The water depths of the stations range from 54 to 61 m and the water depth of the mapped substrate ranges from 50 to 61 m. Mean weight percents of aggregates and composite grades are as follows: mud, 3; sand, 96 (fgS, 62; cgS, 34); gravel, 1 (G_1, <1; G_2, <1). Storm-wave generated sand ripples are present on the surface of substrate AQ. It is bounded to the north by substrates Y, AC, and AK, to the east by substrates AM and AO, and to the west by substrate AG. Substrate AQ likely extends southward into an unmapped area of shallowing water depths on the northern margin of Cape Cod.

Map E. Sediment Mobility

Map E shows the distribution of 21 geologic substrates of map D grouped into four substrates based on surface mobility, as determined by the presence or absence of sand ripples observed in video, photographic, and multibeam topographic imagery (tables 6 and 7; Valentine and Cross, 2026b). The four mapped substrates are (1) mobile sediment (unlayered sand substrates with rippled surfaces), (2) mobile and immobile sediment (layered substrates of mobile sand that partially veneers immobile gravel), (3) immobile sediment (unlayered sand substrates with immobile surfaces), and (4) boulder ridges ≥1 m in height.

Some stations have been fished using otter trawls and scallop dredges. These activities temporarily disturb and flatten sand ripples so that video and photographic imagery sometimes show no evidence of sand ripples at the time of acquisition. The sand ripples are later re-formed by storm-wave generated currents. The presence of broken shells is often an indicator of fishing disturbance. When a site that occurred within an area mapped as a rippled substrate did not display ripples at the time of imaging due to fishing disturbance, that site is still interpreted to be a rippled substrate under natural conditions.

In quadrangle 3, substrate mobility decreases with increasing water depth eastward from Stellwagen Bank and the eastern part of Race Point Channel. The boundary between mobile substrate A1 and immobile substrate A2 lies at approximately 55 to 60 m water depth along the eastward transition into deeper water. In the southeastern part of the quadrangle, in substrate A2, seabed features resembling bedforms are interpreted to be relict and are of unknown origin. There is no evidence of present-day sediment movement (for example, ripples) in the area occupied by substrate A2 and in deeper water to the east.

On the southeastern part of Stellwagen Bank and in Race Point Channel, 13 substrates (A1, Y, Z, AB, AC, AG, AI, AL, AM, AN, AO, AP, and AQ) have mobile surfaces in water depths that reach a maximum of 60 m. Substrate A3, a mobile substrate, occurs as small, unmappable deposits within the areas occupied by substrates A1, Z, and AN. The only immobile substrates in the channel are the boulder ridges of substrate C and the layered substrate AK where immobile sand is very sparsely present on the underlying pebble, cobble, boulder gravel. Substrate AK is surrounded by substrates with rippled sand surfaces, and the absence of ripples in the sand at most stations of AK is likely because there is too little sand lying amongst the gravel particles for ripples to form.

In quadrangle 3, mobile substrates are found at the maximum depth of 60 m in Race Point Channel. This depth is greater than the maximum depths of mobile substrates found at 50 to 55 m on the western flank of Stellwagen Bank in the adjoining quadrangle 5 to the northwest (Valentine and Cross, 2024d) and on the eastern flank of the bank in the adjoining quadrangle 6 to the north (Valentine and Gallea, 2015).

In the eastern and northeastern parts of quadrangle 3, where deep banks and basins are present and water depths reach about 135 m, all substrates (A2, C, E, F, G1, and AJ) have immobile surfaces.

Map F. Distribution of Fine- and Coarse-Grained Sand and Boulder Ridges

Map F shows the distribution of fine- and coarse-grained sand that characterize the composition of unlayered (or the upper layer of layered) geologic substrates shown on map D. There are two substrate groups in which either fine- or coarse-grained sand dominate the sand fraction (table 6).

The fine-grained sand group consists of three substrates (G1, AB, and AQ) that have ≥50 mean weight percent sand, of which the largest portion is fine-grained sand (3 and 4 phi combined). Substrate G1 is a muddy, fine-grained sand that occurs in relatively deep water (70–135 m) in the basins between Stellwagen Bank and South Ninety Bank in the eastern part of the quadrangle and extends northward into quadrangle 6 (Valentine and Gallea, 2015). Substrate AB occurs in a very small area (45 to 55 m water depth) in Race Point Channel along the southern margin of Stellwagen Bank. Most of substrate AB occurs in the adjoining quadrangle 2 to the west (Valentine and Cross, 2024c). Substrate AQ occurs in the southwestern part of the quadrangle along the northern margin of Cape Cod in relatively shallow water depths of 50 to 61 m.

The coarse-grained sand group consists of seventeen substrates (A1, A2, A3, E, F, Y, Z, AC, AG, AI, AJ, AK, AL, AM, AN, AO, and AP) that have ≥50 mean weight percent sand, of which the largest portion is coarse-grained sand (0, 1, and 2 phi combined). These substrates occur on the eastern flank of Stellwagen Bank to a water depth of 50 m, in Race Point Channel to its maximum depth of 60 m, in the eastern entrance of Race Point Channel to a depth of 70 m, on the top of South Ninety Bank at a depth of 85 to 90 m, and on the top of the small unnamed bank to the southeast of South Ninety Bank at a depth of 110 m. Coarse-grained sand substrates that occur on Stellwagen Bank and in Race Point Channel are mobile; substrates that occur in deeper water to the east (A2, E, F, and AJ) are not.

Also shown on the map is substrate C, which is represented by five boulder ridges. Four ridges occur in Race Point Channel and one lies on the southwestern edge of the top of South Ninety Bank.

Map G. Distribution of Substrate Mud Content and Boulder Ridges

Map G shows the mud content of the 20 sedimentary substrates of map D grouped using a seven-tier scale based on mean weight percent mud content (table 6). The seven ranges of mud content, in mean weight percent, are as follows: <1; 1 to <5; 5 to <10; 10 to <20; 20 to <50; 50 to <90; and ≥90. Mud content is <1 weight percent on Stellwagen Bank and in the eastern part of Race Point Channel, it is <5 weight percent in the western part of Race Point Channel, and it increases to a maximum of <10 weight percent on the banks and in the basins in deeper water to the east of Stellwagen Bank. Also shown on the map are boulder ridges (equivalent to substrate C).

Substrate mud contents and their equivalent geologic substrates from map D, water depths, and locations are listed below:

- Seven substrates contain <1 weight percent mud (A1, A3, AG, AI, AL, AN, and AP; 30–60 m water depth). Five of these substrates (A1, AI, AL, AN, and AP) occupy the southeastern part of Stellwagen Bank and the eastern part of Race Point Channel. Substrate AG lies in the southwestern part of quadrangle 3 on the slope that extends from Cape Cod northward into Race Point Channel; it extends into quadrangle 2 to the west where it was sampled (Valentine and Cross, 2024a, c). Substrate A3 also contains <1 weight percent mud, but it occurs as unmappable deposits within substrates A1, Z, and AN.

- Ten substrates contain 1 to <5 weight percent mud (A2, E, Y, Z, AB, AC, AK, AM, AO, and AQ; 28–80 m water depth). Two substrates (A2 and E) occupy the deep eastern slope of Stellwagen Bank. Eight substrates (Y, Z, AB, AC, AK, AM, AO, and AQ) lie in the western part of quadrangle 3, in the central part of Race Point Channel. The mud content of substrate AC is based on one sample.

- Three substrates contain 5 to <10 weight percent mud (F, G1, and AJ; 70–135 m water depth). These three substrates are all associated with the small banks and deep basins located in deep water in the eastern part of quadrangle 3. The mud content of substrate AJ is based on one sample.

- No substrates contain 10 or more weight percent mud.

- Substrate C contains 0 weight percent mud and is shown as boulder ridges ≥1 m in height on map G.

The compilation of substrate maps for the Stellwagen Bank region began with mapping quadrangle 6 (Valentine and Gallea, 2015). In map G of the SIM for quadrangle 6, sedimentary substrates were grouped using a five-tier scale based on mean weight percent mud content. The five classes of mud content used in quadrangle 6 are as follows: ≤1; >1 to 5; >5 to 10; >10 to 20; and >20 to 50 (the maximum mud content that occurs in quadrangle 6 substrates).

Subsequently, during the compilation of related maps of quadrangles in the Stellwagen Bank region, the mud content of sedimentary substrates was portrayed using a slightly different scale that experience has shown to be a better method for mapping mud content (Valentine, 2019). The new seven-tier scale based on mean weight percent mud content employs seven classes of mud content as follows: <1; 1 to <5; 5 to <10; 10 to <20; 20 to <50; 50 to <90; and ≥90. The new scale modified the definition of the mud content classes by changing the placement of the less than (<) and the greater than (>) symbols, and it also increased the number of classes from 5 to 7. This new approach for mapping substrate mud content was employed for the SIMs for quadrangle 5 (Valentine and Cross, 2024d) and quadrangle 2 (Valentine and Cross, 2024c) and is also followed here for quadrangle 3.

Quadrangles 3 and 6 share a northern-southern border, with quadrangle 3 to the south and quadrangle 6 to the north. Substrate mud content was mapped in quadrangle 3 and in quadrangle 6 using the different mud content scales described above, which has resulted in a mismatch at the border where the contact of the substrate containing <1 mean weight percent present in quadrangle 3 is not mapped northward into quadrangle 6. The practical result is that two substrates in quadrangle 6 mapped as containing ≤1 and >1 to 5 mean weight percent mud are equivalent to two substrates in quadrangle 3 mapped as containing <1 and 1 to <5 mean weight percent mud. This discrepancy represents only a few weight percent mud content but should be taken into account when utilizing the information on the distribution of substrate mud content provided by these maps.

References Cited

Blair, T.C., and McPherson, J.G., 1999, Grain-size and textural classification of coarse sedimentary particles: Journal of Sedimentary Research, v. 69, no. 1, p. 6–19. [Also available at https://doi.org/10.2110/jsr.69.6.]

Butman, B., Sherwood, C.R., and Dalyander, P.S., 2008, Northeast storms ranked by wind stress and wave-generated bottom stress observed in Massachusetts Bay, 1990–2006: Continental Shelf Research, v. 28, nos. 10–11, p. 1231–1245. [Also available at https://doi.org/10.1016/j.csr.2008.02.010.]

Butman, B., Signell, R.P., Warner, J.C., and Alexander, P.S., 2007, Oceanographic setting, *in* Bothner, M.H., and Butman, B., eds., Processes influencing the transport and fate of contaminated sediments in the coastal ocean—Boston Harbor and Massachusetts Bay: U.S. Geological Survey Circular 1302, p. 26–33. [Also available at https://doi.org/10.3133/cir1302.]

Folk, R.L., 1954, The distinction between grain size and mineral composition in sedimentary-rock nomenclature: Journal of Geology, v. 62, no. 4, p. 344–359. [Also available at https://www.jstor.org/stable/30065016.]

Krumbein, W.C., 1936, Application of logarithmic moments to size frequency distributions of sediments: Journal of Sedimentary Petrology, v. 6, no. 1, p. 35–47. [Also available at https://doi.org/10.1306/D4268F59-2B26-11D7-8648000102C1865D.]

Riley, S.J., DeGloria, S.D., and Elliot, R., 1999, A terrain ruggedness index that quantifies topographic heterogeneity: Intermountain Journal of Sciences, v. 5, nos. 1–4, p. 23–27. [Also available at http://download.osgeo.org/qgis/doc/reference-docs/Terrain_Ruggedness_Index.pdf.]

Udden, J.A., 1914, Mechanical composition of clastic sediments: Bulletin of the Geological Society of America, v. 25, no. 1, p. 655–744. [Also available at https://doi.org/10.1130/GSAB-25-655.]

Valentine, P.C., ed., 2005, Sea floor image maps showing topography, sun-illuminated topography, backscatter intensity, ruggedness, slope, and the distribution of boulder ridges and bedrock outcrops in the Stellwagen Bank National Marine Sanctuary region off Boston, Massachusetts: U.S. Geological Survey Scientific Investigations Map 2840, 12 sheets, scale 1:60,000, 1 DVD-ROM. [Also available at https://doi.org/10.3133/sim2840.]

Valentine, P.C., 2019, Sediment classification and the characterization, identification, and mapping of geologic substrates for the glaciated Gulf of Maine seabed and other terrains, providing a physical framework for ecological research and seabed management: U.S. Geological Survey Scientific Investigations Report 2019–5073, 37 p., accessed June 14, 2023, at https://doi.org/10.3133/sir20195073.

Valentine, P.C., Baker, J.L., Unger, T.S., and Polloni, C., 1998, Sea floor topographic map and perspective view-imagery of Quadrangles 1-18, Stellwagen Bank National Marine Sanctuary off Boston, Massachusetts: U.S. Geological Survey Open-File Report 98–138, 1 CD-ROM. [Also available at https://doi.org/10.3133/ofr98138.]

Valentine, P.C., Baker, J.L., and Unger, T.S., 1999, Sun-illuminated sea floor topography of quadrangle 3 in the Stellwagen Bank National Marine Sanctuary off Boston, Massachusetts: U.S. Geological Survey Geologic Investigations Series Map I–2703, 1 sheet, scale 1:25,000. [Also available at https://doi.org/10.3133/i2703.]

Valentine, P.C., and Cross, V.A., 2024a, Geospatial datasets of seabed topography, sediment mobility, and the distribution of geologic substrates in quadrangle 2 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts: U.S. Geological Survey data release, accessed December 16, 2024, at https://doi.org/10.5066/P9UL3LWN.

Valentine, P.C., and Cross, V.A., 2024b, Geospatial datasets of seabed topography, sediment mobility, and the distribution of geologic substrates in quadrangle 5 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts: U.S. Geological Survey data release, accessed March 21, 2024, at https://doi.org/10.5066/P9W9BN3S.

Valentine, P.C., and Cross, V.A., 2024c, Seabed maps showing topography, ruggedness, backscatter intensity, sediment mobility, and the distribution of geologic substrates in quadrangle 2 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts: U.S. Geological Survey Scientific Investigations Map 3530, 8 sheets, scale 1:25,000, 27-p. pamphlet, accessed December 16, 2024, at https://doi.org/10.3133/sim3530.

Valentine, P.C., and Cross, V.A., 2024d, Seabed maps showing topography, ruggedness, backscatter intensity, sediment mobility, and the distribution of geologic substrates in quadrangle 5 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts: U.S. Geological Survey Scientific Investigations Map 3515, 8 sheets, scale 1:25,000, 27-p. pamphlet, accessed March 21, 2024, at https://doi.org/10.3133/sim3515.

Valentine, P.C., and Cross, V.A., 2026a, Geospatial datasets of seabed topography, sediment mobility, and the distribution of geologic substrates in quadrangle 3 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts: U.S. Geological Survey data release, https://doi.org/10.5066/P13PVHRI.

Valentine, P.C., and Cross, V.A., 2026b, Station locations in quadrangle 3 in Stellwagen Bank National Marine Sanctuary offshore of Boston, Massachusetts where video, photographs and sediment samples were collected by the U.S. Geological Survey from 1993–2021 - includes sediment sample analyses and interpreted geologic substrate, *in* Geospatial datasets of seabed topography, sediment mobility, and the distribution of geologic substrates in quadrangle 3 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts: U.S. Geological Survey data release, https://www.sciencebase.gov/catalog/item/65d7c9e6d34ec3e1801d814f.

Valentine, P.C., and Gallea, L.B., 2015, Seabed maps showing topography, ruggedness, backscatter intensity, sediment mobility, and the distribution of geologic substrates in quadrangle 6 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts: U.S. Geological Survey Scientific Investigations Map 3341, 10 sheets, scale 1:25,000, 21-p. pamphlet, accessed June 14, 2023, at https://doi.org/10.3133/sim3341.

Valentine, P.C., Gallea, L.B., Blackwood, D.S., and Twomey, E.R., 2010, Seabed photographs, sediment texture analyses, and sun-illuminated sea floor topography in the Stellwagen Bank National Marine Sanctuary region off Boston, Massachusetts: U.S. Geological Survey Data Series DS–469, accessed June 14, 2023, at https://doi.org/10.3133/ds469.

Warner, J.C., Butman, B., and Dalyander, P.S., 2008, Storm-driven sediment transport in Massachusetts Bay: Continental Shelf Research, v. 28, no. 2, p. 257–282. [Also available at https://doi.org/10.1016/j.csr.2007.08.008.]

Wentworth, C.K., 1922, A scale of grade and class terms for clastic sediments: Journal of Geology, v. 30, no. 5, p. 377–392. [Also available at https://www.jstor.org/stable/30063207.]

Tables 6 and 7

[Appendix 1 follows table 7]

Table 6. Properties of geologic substrates in quadrangle 3 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts.

[Textural properties for the unlayered substrates (A1, A2, A3, E, G1, Y, Z, AB, AC, AG, AI, AJ, AM, AN, AO, and AQ) are based on grain-size analysis. Textural properties for the layered substrates (F, AK, AL, and AP) are based on grain-size analysis of the upper substrate that partially veneers the lower substrates. The lower substrates are identified on the basis of video imagery and are combinations of pebble, cobble, and boulder gravel. Weight percent values may not add to 100 due to rounding; <1 means >0 and ≤0.5 weight percent. A sand (4, 3, 2, 1, and 0 phi), mud (>4 phi), or gravel (−1, −2, −3, −4, and −5 phi) grain size is termed "significant" in a substrate if its mean weight percent for all samples of a substrate type is ≥10. See tables 1 and 2 for grain-size classifications for sediment. Sediment components of an unlayered substrate (or the upper substrate of a layered substrate) are listed in order of increasing weight percent in the sediment class name. Sediment components of the lower substrate indicate presence/absence and are not listed in order of increasing areal coverage in the sediment class name. See table 3 for an explanation of characters used in substrate names to describe their physical attributes. For stations that represent substrates that could not be mapped as coherent units (A3), the water depth range of stations is the same as that of the mapped substrate. See Valentine and Cross (2026b) for the results of grain-size analyses of sediment samples and the assignment of stations to substrates. Table format from Valentine and Cross (2024d). Grain-size abbreviations: cgS, coarse-grained sand (2, 1, and 0 phi combined); fgS, fine-grained sand (4 and 3 phi combined); G_1, gravel$_1$ (−1 and −2 phi combined); G_2, gravel$_2$ (−3, −4, and −5 phi combined). Other terms: ~, about; >, greater than; ≥, greater than or equal to; <, less than; ≤, less than or equal to; φ, phi; All, total number of stations; m, meter; max, maximum; min, minimum; mm, millimeter; nd, no data; NS, number of stations with only video or photograph imagery; S, number of stations with sediment grain-size analysis]

Substrate name	Substrate name translation	Number of stations	Station water depth range; mean [mapped substrate depth range] (m)	Significant sediment grain sizes		Weight percent of aggregates (mud, sand, and gravel), phi grades (4 phi and 3 phi), and composite grades (fgS, cgS, G_1, and G_2) that occur in each substrate									
				Phi grade (mean weight percent)	Min and max grain diameter (mm); max difference	Samples	Mud	4 phi	3 phi	fgS	cgS	Sand	G_1	G_2	Gravel
A1 r_cgS	A1—Rippled, coarse-grained sand	S, 154; NS, 25; All, 179	32–59; 41 [30–60]	2φ (18), 1φ (48), 0φ (25); Total (91)	0.25–<2.0; ~1.75	Range	0–8	0–1	<1–9	<1–9	69–98	72–100	<1–24	0–8	<1–28
						Mean	<1	<1	2	2	92	94	6	<1	6
A2 i_cgS	A2—Immobile, coarse-grained sand	S, 7; NS, 0; All, 7	59–73; 64 [~55–80]	2φ (19), 1φ (49), 0φ (19); Total (87)	0.25–<2.0; ~1.75	Range	<1–1	0–3	2–18	2–20	76–96	96–99	<1–3	0–0	<1–3
						Mean	1	1	8	10	88	98	2	0	2
A3 r_cgS	A3—Rippled, coarse-grained sand	S, 9; NS, 0; All, 9	42–55; 50 [42–55]	3φ (12), 2φ (38), 1φ (39); Total (89)	0.125–<1.0; ~0.875	Range	<1–1	0–2	9–21	10–23	76–90	88–100	0–11	0–0	0–11
						Mean	<1	1	12	13	85	98	2	0	2
C i_cbG	C—Immobile, cobble, boulder gravel	S, 1; NS, 0; All, 1	57 [>25–87]	2φ (18), 1φ (41), −3φ (13); Total (72)	0.25–<16.0; ~15.75	Range	18	<1	4	4	62	66	3	13	16
						Substrate C is represented by boulder ridges (piled cobbles and boulders) that occur in four locations in quadrangle 3. One boulder ridge is surrounded by substrate AK and lies in water depths of >55 to 58 m. A single sediment sample (from station 4986, 57 m water depth) was collected at the base of this ridge. Two adjacent boulder ridges are surrounded by substrate AO and lie in water depths of >25 to <35 m. One boulder ridge is surrounded by substrate AP and lies in water depths of <30 to 36 m. One boulder ridge is surrounded by substrate F and lies in depths of 85 to 87 m. The identification of the boulder ridges is based on their shape and relief in multibeam topographic imagery and their high reflectivity in backscatter imagery, which is typical of boulder ridges mapped in quadrangles 5 (Valentine and Cross, 2024d) and 6 (Valentine and Gallea, 2015).									
E i_cgS	E—Immobile, coarse-grained sand	S, 0; NS, 0; All, 0	[75–80]	nd	nd	The presence of substrate E in quadrangle 3 is speculative as no samples were collected from this area (a shallow valley between Stellwagen Bank and South Ninety Bank). Substrate E occurs in the adjoining quadrangle 6 to the north (Valentine and Gallea, 2015), extends southward to the northern boundary of quadrangle 3, and is assumed to extend southward a short distance into quadrangle 3 and that it similarly is an immobile, coarse-grained sand.									
F i_cgS / pcbG	F—Immobile, coarse-grained sand; partial veneer on pebble, cobble, boulder gravel[1]	S, 2; NS, 0; All, 2	87–97; 92 [85–115]	3φ (35), −2φ (13), −3φ (24); Total (72)	0.125–<16; ~15.875	Range	4–5	5–6	31–38	37–43	12–20	55–57	13–16	23–25	38–40
						Mean	5	6	35	40	16	56	15	24	39
G1 i_mfgS	G1—Immobile, muddy, fine-grained sand[2]	S, 9; NS, 0; All, 9	78–126; 97 [70–135]	4φ (12), 3φ (56), 2φ (15); Total (83)	0.062–<0.5; ~0.438	Range	1–16	3–42	34–76	40–85	<1–41	68–99	0–15	0–12	0–28
						Mean	6	12	56	69	20	88	3	3	6

Table 6. Properties of geologic substrates in quadrangle 3 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts.—Continued

[Textural properties for the unlayered substrates (A1, A2, A3, E, G1, Y, Z, AB, AC, AG, AI, AJ, AM, AN, AO, and AQ) are based on grain-size analysis. Textural properties for the layered substrates (F, AK, AL, and AP) are based on grain-size analysis of the upper substrate that partially veneers the lower substrates. The lower substrates are identified on the basis of video imagery and are combinations of pebble, cobble, and boulder gravel. Weight percent values may not add to 100 due to rounding; <1 means >0 and ≤0.5 weight percent. A sand (4, 3, 2, 1, and 0 phi), mud (>4 phi), or gravel (−1, −2, −3, −4, and −5 phi) grain size is termed “significant” in a substrate if its mean weight percent for all samples of a substrate type is ≥10. See tables 1 and 2 for grain-size classifications for sediment. Sediment components of an unlayered substrate (or the upper substrate of a layered substrate) are listed in order of increasing weight percent in the sediment class name. Sediment components of the lower substrate indicate presence/absence and are not listed in order of increasing areal coverage in the sediment class name. See table 3 for an explanation of characters used in substrate names to describe their physical attributes. For stations that represent substrates that could not be mapped as coherent units (A3), the water depth range of stations is the same as that of the mapped substrate. See Valentine and Cross (2026b) for the results of grain-size analyses of sediment samples and the assignment of stations to substrates. Table format from Valentine and Cross (2024d). Grain-size abbreviations: cgS, coarse-grained sand (2, 1, and 0 phi combined); fgS, fine-grained sand (4 and 3 phi combined); G_1, gravel$_1$ (−1 and −2 phi combined); G_2, gravel$_2$ (−3, −4, and −5 phi combined). Other terms: ~, about; >, greater than; ≥, greater than or equal to; <, less than; ≤, less than or equal to; φ, phi; All, total number of stations; m, meter; max, maximum; min, minimum; mm, millimeter; nd, no data; NS, number of stations with only video or photograph imagery; S, number of stations with sediment grain-size analysis]

Substrate name	Substrate name translation	Number of stations	Station water depth range; mean [mapped substrate depth range] (m)	Significant sediment grain sizes		Weight percent of aggregates (mud, sand, and gravel), phi grades (4 phi and 3 phi), and composite grades (fgS, cgS, G_1, and G_2) that occur in each substrate									
				Phi grade (mean weight percent)	Min and max grain diameter (mm); max difference	Samples	Mud	4 phi	3 phi	fgS	cgS	Sand	G_1	G_2	Gravel
Y r_cgS	Y—Rippled, coarse-grained sand	S, 3; NS, 0; All, 3	62–63; 62 [60–63]	3φ (33), 2φ (34), 1φ (19); Total (86)	0.125–<1.0; ~0.875	Range	3–3	2–5	22–47	25–51	45–70	95–96	<1–2	0–0	<1–2
						Mean	3	3	33	36	60	96	1	0	1
Z r_cgS	Z—Rippled, coarse-grained sand	S, 16; NS, 1; All, 17	43–62; 52 [43–62]	2φ (30), 1φ (50), 0φ (11); Total (91)	0.25–<2.0; ~1.75	Range	<1–2	0–2	1–19	1–20	78–98	83–100	<1–7	0–9	<1–16
						Mean	1	<1	5	5	91	97	2	1	3
AB r_fgS	AB—Rippled, fine-grained sand	S, 0; NS, 0; All, 0	[~49–55]	nd	nd	Substrate AB is a mobile, fine-grained sand that lies on the southern flank of Stellwagen bank. No samples were collected from this substrate in quadrangle 3. Substrate AB lies principally in quadrangle 2 to the west (Valentine and Cross, 2024c).									
AC r_cgS	AC—Rippled, coarse-grained sand	S, 1; NS, 0; All, 1	59 [59–60]	3φ (11), 2φ (44), 1φ (38); Total (93)	0.125–<1.0; ~0.875	Range	2	1	11	12	86	98	<1	0	<1
						Substrate AC lies principally in quadrangle 3, but only one sample was collected. It extends a short distance into quadrangle 2 to the west (Valentine and Cross, 2024c) where no samples of it were collected.									
AG r_cgS	AG—Rippled, coarse-grained sand	S, 0; NS, 0; All, 0	[~50–~60]	nd	nd	Substrate AG is a mobile, coarse-grained sand deposit that lies on the southern flank of Race Point Channel (north of Cape Cod). No samples were collected from this substrate in quadrangle 3. Substrate AG lies principally in quadrangle 2 to the west (Valentine and Cross, 2024c).									
AI r_cgS	AI—Rippled, coarse-grained sand	S, 7; NS, 0; All, 7	43–49; 46 [43–55]	2φ (32), 1φ (57); Total (89)	0.25–<1.0; ~0.75	Range	<1–1	<1–1	0–14	1–14	69–97	71–99	<1–15	0–15	<1–28
						Mean	<1	<1	4	4	85	90	6	5	10
AJ i_cgS	AJ—Immobile, coarse-grained sand	S, 1; NS, 0; All, 1	111 [110–111]	3φ (21), 2φ (19), 1φ (31), 0φ (10); Total (81)	0.125–<2.0; ~1.875	Range	9	8	21	29	59	88	3	0	3
						The only grain-size analysis from this substrate is an immobile, coarse-grained sand that lies on the top of a small bank located southeast of South Ninety Bank.									
AK i_cgS / pcbG	AK—Immobile, coarse-grained sand; partial veneer on pebble, cobble, boulder gravel	S, 10; NS, 1; All, 11	57–61; 59 [55–61]	3φ (10), 2φ (32), 1φ (35); Total (77)	0.125–<1.0; ~0.875	Range	2–3	<1–2	5–15	6–18	55–81	67–97	<1–8	0–29	<1–31
						Mean	2	1	10	12	72	84	5	9	13
AL r_gcgS / i_pcG	AL—Rippled, gravelly, coarse-grained sand; partial veneer on immobile, pebble, cobble gravel	S, 9; NS, 1; All, 10	46–53; 49 [45–53]	3φ (16), 2φ (14), 1φ (16), −3φ (15), −4φ (15); Total (76)	0.125–<32; ~31.875	Range	<1–1	<1–3	3–33	3–34	2–94	8–97	<1–14	0–92	3–92
						Mean	<1	1	16	17	39	56	5	39	44
AM r_cgS	AM—Rippled, coarse-grained sand	S, 11; NS, 0; All, 11	45–64; 55 [40–64]	2φ (32), 1φ (57); Total (89)	0.25–<1.0; ~0.75	Range	<1–2	0–2	1–5	1–7	89–98	94–100	0–5	0–1	<1–5
						Mean	1	1	3	4	94	98	1	<1	1

Table 6. Properties of geologic substrates in quadrangle 3 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts.—Continued

[Textural properties for the unlayered substrates (A1, A2, A3, E, G1, Y, Z, AB, AC, AG, AI, AJ, AM, AN, AO, and AQ) are based on grain-size analysis. Textural properties for the layered substrates (F, AK, AL, and AP) are based on grain-size analysis of the upper substrate that partially veneers the lower substrates. The lower substrates are identified on the basis of video imagery and are combinations of pebble, cobble, and boulder gravel. Weight percent values may not add to 100 due to rounding; <1 means >0 and ≤0.5 weight percent. A sand (4, 3, 2, 1, and 0 phi), mud (>4 phi), or gravel (−1, −2, −3, −4, and −5 phi) grain size is termed "significant" in a substrate if its mean weight percent for all samples of a substrate type is ≥10. See tables 1 and 2 for grain-size classifications for sediment. Sediment components of an unlayered substrate (or the upper substrate of a layered substrate) are listed in order of increasing weight percent in the sediment class name. Sediment components of the lower substrate indicate presence/absence and are not listed in order of increasing areal coverage in the sediment class name. See table 3 for an explanation of characters used in substrate names to describe their physical attributes. For stations that represent substrates that could not be mapped as coherent units (A3), the water depth range of stations is the same as that of the mapped substrate. See Valentine and Cross (2026b) for the results of grain-size analyses of sediment samples and the assignment of stations to substrates. Table format from Valentine and Cross (2024d). Grain-size abbreviations: cgS, coarse-grained sand (2, 1, and 0 phi combined); fgS, fine-grained sand (4 and 3 phi combined); G_1, $gravel_1$ (−1 and −2 phi combined); G_2, $gravel_2$ (−3, −4, and −5 phi combined). Other terms: ~, about; >, greater than; ≥, greater than or equal to; <, less than; ≤, less than or equal to; φ, phi; All, total number of stations; m, meter; max, maximum; min, minimum; mm, millimeter; nd, no data; NS, number of stations with only video or photograph imagery; S, number of stations with sediment grain-size analysis]

Substrate name	Substrate name translation	Number of stations	Station water depth range; mean [mapped substrate depth range] (m)	Significant sediment grain sizes		Weight percent of aggregates (mud, sand, and gravel), phi grades (4 phi and 3 phi), and composite grades (fgS, cgS, G_1, and G_2) that occur in each substrate									
				Phi grade (mean weight percent)	Min and max grain diameter (mm); max difference	Samples	Mud	4 phi	3 phi	fgS	cgS	Sand	G_1	G_2	Gravel
AN r_cgS	AN—Rippled, coarse-grained sand	S, 6; NS, 0; All, 6	48–50; 49 [45–50]	3φ (31), 2φ (44), 1φ (18); Total (93)	0.125–<1.0; ~0.875	Range	<1–1	1–2	19–44	21–45	54–77	97–100	0–2	0–0	0–2
						Mean	<1	1	31	32	67	99	1	0	1
AO r_cgS	AO—Rippled, coarse-grained sand	S, 7; NS, 0; All, 7	28–49; 37 [28–55]	2φ (37), 1φ (48); Total (85)	0.25–<1.0; ~0.75	Range	<1–2	0–<1	<1–6	<1–6	87–98	89–100	<1–9	0–2	<1–11
						Mean	1	<1	3	3	94	97	2	1	2
AP r_cgS / i_pcbG	AP—Rippled, coarse-grained sand; partial veneer on immobile, pebble, cobble, boulder gravel	S, 22; NS, 2; All, 24	34–51; 44 [30–51]	2φ (20), 1φ (53), 0φ (16); Total (89)	0.25–<2.0; ~1.75	Range	<1–1	0–1	0–8	1–8	47–98	50–100	<1–12	0–45	<1–50
						Mean	<1	<1	2	3	89	92	5	3	8
AQ r_fgS	AQ—Rippled, fine-grained sand	S, 4; NS, 0; All, 4	54–61; 57 [50–61]	3φ (58), 2φ (29); Total (87)	0.125–<0.5; ~0.375	Range	2–5	1–6	49–80	51–86	12–46	94–98	0–1	0–2	0–2
						Mean	3	4	58	62	34	96	<1	<1	1

[1]The assignment of the area mapped as substrate F was made for consistency with its occurrence in quadrangle 6 to the north because data are sparse in quadrangle 3. See the section "Description of Map Units (Substrates)" for details.

[2]Substrate G1 is identified as a muddy, fine-grained sand for consistency with its occurrence in the adjoining quadrangle 6 to the north even though the threshold of ≥10 weight percent mud (Valentine, 2019) is not met in quadrangle 3. See the section "Description of Map Units (Substrates)" for details.

Table 7. Geologic substrate symbols, names, areas, and brief comparisons to other substrates in quadrangle 3 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts.

[See table 3 for an explanation of characters used in substrate names to describe their physical attributes. Areas were calculated from substrate polygons (Valentine and Cross, 2026a) using Esri's ArcMap program, version 10.8.1. Quadrangle 3 has a total mapped area of 185 km^2. The area could not be determined for substrate A3 because it is represented by few samples and is not mappable as a coherent unit at 1:25,000 scale. Table format from Valentine and Cross (2024d). Terms: <, less than; km^2, square kilometer; m, meter; nd, no data; wt. pct., weight percent]

Geologic substrate symbol	Substrate name	Substrate name translation	Area of substrate in quadrangle 3 (km^2)	Area of substrate in quadrangle 3 (percent)	Brief description and (or) comparison to other substrates
A1	A1 r_cgS	A1—Rippled, coarse-grained sand	74.7	40.4	Substrate A1 (30–60 m water depth) lies on the southeastern part of Stellwagen Bank and its adjacent flank as well as on the eastern approaches to Race Point Channel. The substrate extends westward onto the southwestern part of the bank in quadrangle 2 (Valentine and Cross, 2024c) and northward onto the eastern part of the bank in quadrangle 6 (Valentine and Gallea, 2015). Substrate A1 is texturally similar to substrate Z, which is recognized as a separate substrate because it lies in deeper water in Race Point Channel south of Stellwagen Bank and contains slightly more fine-grained sand (5 wt. pct.) than A1 (2 wt. pct.). Substrate A1 is also similar in texture to substrate AC that lies in the central part of Race Point Channel and whose surface is characterized by subparallel ridges covered by sand. Substrate A1 is similar in its mud and overall sand content to substrate A3; however, substrate A3 contains more fine-grained sand (13 wt. pct.). Substrate A1 is texturally similar to immobile substrate A2 which lies at greater water depths (about 55–80 m) on the lower eastern flank of Stellwagen Bank and contains more fine-grained sand (10 wt. pct.).
A2	A2 i_cgS	A2—Immobile, coarse-grained sand	10.7	5.8	Substrate A2 (about 55–80 m water depth) lies along the southeastern flank of Stellwagen Bank and in the deeper eastern approaches to Race Point Channel. Its surface is unrippled in contrast to adjacent mobile substrate A1, which lies in shallower water depths (30–60 m) to the west and contains less fine-grained sand (2 wt. pct.). Substrate A2 extends northward into the adjoining quadrangle 6 (Valentine and Gallea, 2015).
A3	A3 r_cgS	A3—Rippled, coarse-grained sand	nd	nd	Substrate A3 (42–55 m water depth, for the stations) is similar to mobile substrate A1, but A3 has a higher fine-grained sand content than A1. Substrate A3 also occurs in quadrangles 2 (Valentine and Cross, 2024c) and 5 (Valentine and Cross, 2024d). Deposits of substrate A3 could not be mapped as a coherent unit and are shown by magenta square symbols on map D, sheet 1 (see Valentine and Cross, 2026b); these deposits occur within the areas mapped as substrates A1, Z, and AN. Substrate A3 is texturally similar to substrate A1 in that it has a very low mud content; however, it contains more fine-grained sand (13 wt. pct.) than A1. Substrate A3 is also similar to substrate A2. They both contain more fine-grained sand than substrate A1, but A2 contains less fine-grained sand (10 wt. pct.) than A3, is immobile, and lies at greater water depths (about 55–80 m).

Table 7. Geologic substrate symbols, names, areas, and brief comparisons to other substrates in quadrangle 3 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts.—Continued

[See table 3 for an explanation of characters used in substrate names to describe their physical attributes. Areas were calculated from substrate polygons (Valentine and Cross, 2026a) using Esri's ArcMap program, version 10.8.1. Quadrangle 3 has a total mapped area of 185 km². The area could not be determined for substrate A3 because it is represented by few samples and is not mappable as a coherent unit at 1:25,000 scale. Table format from Valentine and Cross (2024d). Terms: <, less than; km², square kilometer; m, meter; nd, no data; wt. pct., weight percent]

Geologic substrate symbol	Substrate name	Substrate name translation	Area of substrate in quadrangle 3 (km²)	Area of substrate in quadrangle 3 (percent)	Brief description and (or) comparison to other substrates
C	C i_cbG	C—Immobile, cobble, boulder gravel	0.7	0.4	Substrate C is represented by five boulder ridges (piled cobbles and boulders) that occur in four locations in quadrangle 3. The identification of boulder ridges is based on interpretation of multibeam topographic imagery and on the substrate's high reflectivity in backscatter imagery, which is typical of boulder ridges mapped in quadrangles 5 (Valentine and Cross, 2024d) and 6 (Valentine and Gallea, 2015). A sinuous boulder ridge (>55 to 58 m water depth) is present in the southern part of Race Point Channel. Two adjacent boulder ridges (>25 to <35 m water depth) are present on the southern margin of Race Point Channel. A single boulder ridge (<30 to about 36 m water depth) is present on the southern flank of Race Point Channel. A boulder ridge (about 85 to 87 m water depth) forms a low, hummocky feature that is present along the southwest margin of South Ninety Bank.
E	E i_cgS	E—Immobile, coarse-grained sand	0.3	0.2	Substrate E (75–80 m water depth) lies in a shallow valley between the southeastern flank of Stellwagen Bank and the western flank of South Ninety Bank. Substrate E is not represented by any samples in quadrangle 3, and its mapped extent is speculative. Its occurrence in quadrangle 3 is based on interpretation of multibeam topographic and backscatter imagery. It is interpreted to be a short extension (1.5 kilometers) of substrate E from the adjoining quadrangle 6 to the north (Valentine and Gallea, 2015).
F	F i_cgS / pcbG	F—Immobile, coarse-grained sand; partial veneer on pebble, cobble, boulder gravel	3.1	1.7	Substrate F (85 to 115 m water depth) lies on the southern part of the top of South Ninety Bank. The northern part of South Ninety Bank lies in quadrangle 6 (Valentine and Gallea, 2015) and the southern part in quadrangle 3.
G1	G1 i_mfgS	G1—Immobile, muddy, fine-grained sand	17.8	9.6	Substrate G1 (70–135 m water depth) lies on the southern flank of South Ninety Bank and in deeper waters of the basins to the east and south. This substrate has been mapped on the northern flank of South Ninety Bank in the adjoining quadrangle 6 to the north (Valentine and Gallea, 2015).
Y	Y r_cgS	Y—Rippled, coarse-grained sand	2.0	1.1	Substrate Y (60–63 m water depth) lies in southern part of Race Point Channel (in the southwestern part of the mapped area in quadrangle 3) and extends westward into quadrangle 2 (Valentine and Cross, 2024c). It lies to the west of substrate AC, in deeper water, and contains more fine-grained sand (36 wt. pct.) than substrate AC (12 wt. pct.).

Table 7. Geologic substrate symbols, names, areas, and brief comparisons to other substrates in quadrangle 3 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts.—Continued

[See table 3 for an explanation of characters used in substrate names to describe their physical attributes. Areas were calculated from substrate polygons (Valentine and Cross, 2026a) using Esri's ArcMap program, version 10.8.1. Quadrangle 3 has a total mapped area of 185 km^2. The area could not be determined for substrate A3 because it is represented by few samples and is not mappable as a coherent unit at 1:25,000 scale. Table format from Valentine and Cross (2024d). Terms: <, less than; km^2, square kilometer; m, meter; nd, no data; wt. pct., weight percent]

Geologic substrate symbol	Substrate name	Substrate name translation	Area of substrate in quadrangle 3 (km^2)	Area of substrate in quadrangle 3 (percent)	Brief description and (or) comparison to other substrates
Z	Z r_cgS	Z—Rippled, coarse-grained sand	13.5	7.3	Substrate Z (43–62 m water depth) lies in Race Point Channel at the base of Stellwagen Bank. It is bounded to the north in shallower water on Stellwagen Bank by substrate A1, which contains less fine-grained sand (2 wt. pct.) than substrate Z (5 wt. pct.). Substrate Z extends westward from quadrangle 3 into quadrangle 2 (Valentine and Cross, 2024c).
AB	AB r_fgS	AB—Rippled, fine-grained sand	<0.1	<0.1	Substrate AB (about 49 to 55 m) lies in a very small area of the northern part of Race Point Channel on the southern flank of Stellwagen Bank and it extends westward into quadrangle 2 (Valentine and Cross, 2024c). It is not represented by sediment stations in quadrangle 3, but its grain size composition is interpreted to be the same as it is in quadrangle 2. The extent of substrate AB in quadrangle 3 was determined on the basis of interpretation of seabed topography and the grain texture of nearby sediment samples.
AC	AC r_cgS	AC—Rippled, coarse-grained sand	1.4	0.8	Substrate AC (59–60 m water depth) lies in the southern part of Race Point Channel and extends westward into quadrangle 2 (Valentine and Cross, 2024c). The substrate's surface displays bedforms (50–100 m wavelength) that resemble bedforms present in the northern part of substrate AM to the east. Substrate AC is bounded to the west by substrates Y and Z, whose surfaces are smooth as observed in multibeam topographic imagery.
AG	AG r_cgS	AG—Rippled, coarse-grained sand	0.3	0.2	Substrate AG (about 50 to about 60 m water depth) lies on the southern flank of Race Point Channel (north of Cape Cod) and extends westward into quadrangle 2 (Valentine and Cross, 2024c). It is not represented by sediment stations in quadrangle 3, but its grain size composition is interpreted to be the same as it is in quadrangle 2. Its occurrence in quadrangle 3 is based on interpretation of multibeam topographic and backscatter imagery. To the east, along the northern slope of Cape Cod, it abuts substrate AQ, a rippled, fine-grained sand.
AI	AI r_cgS	AI—Rippled, coarse-grained sand	4.4	2.4	Substrate AI (43–55 m water depth) lies in the central part of Race Point Channel between Stellwagen Bank to the north and Cape Cod to the south. Substrate AI is characterized by areas of smooth seabed separated by areas of subparallel ridges. Two samples collected from the ridges are gravelly, coarse-grained sand, suggesting that just below the surface the ridges are gravelly and possibly represent partially buried iceberg keel marks. Substrates AN and AP also display iceberg keel marks.
AJ	AJ i_cgS	AJ—Immobile, coarse-grained sand	0.2	0.1	Substrate AJ (110–111 m water depth) lies on the top of a small, unnamed bank located southeast of South Ninety Bank. The unnamed bank is surrounded by substrate G1, a muddy, fine-grained sand.

Table 7. Geologic substrate symbols, names, areas, and brief comparisons to other substrates in quadrangle 3 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts.—Continued

[See table 3 for an explanation of characters used in substrate names to describe their physical attributes. Areas were calculated from substrate polygons (Valentine and Cross, 2026a) using Esri's ArcMap program, version 10.8.1. Quadrangle 3 has a total mapped area of 185 km². The area could not be determined for substrate A3 because it is represented by few samples and is not mappable as a coherent unit at 1:25,000 scale. Table format from Valentine and Cross (2024d). Terms: <, less than; km², square kilometer; m, meter; nd, no data; wt. pct., weight percent]

Geologic substrate symbol	Substrate name	Substrate name translation	Area of substrate in quadrangle 3 (km²)	Area of substrate in quadrangle 3 (percent)	Brief description and (or) comparison to other substrates
AK	AK i_cgS / pcbG	AK—Immobile, coarse-grained sand; partial veneer on pebble, cobble, boulder gravel	2.7	1.4	Substrate AK (55–61 m water depth) lies in the southcentral part of Race Point Channel. Only 2 of 10 stations with video imagery display ripples, which are very poorly developed and occur in the sand veneer that barely veneers the gravel at a few stations. The substrate is interpreted to be immobile. The substrate's hummocky surface exhibits high reflectivity in backscatter imagery, which is typical of a hard substrate. Substrate AK surrounds an east-west trending boulder ridge (substrate C).
AL	AL r_gcgS / i_pcG	AL—Rippled, gravelly, coarse-grained sand; partial veneer on immobile, pebble, cobble gravel	2.9	1.6	Substrate AL (45–53 m water depth) lies in two separate areas on topographic highs in the northeastern part of Race Point Channel south of Stellwagen Bank. At some stations, substrate AL is a gravel pavement with little or no sand veneer. The substrate's surface exhibits high reflectivity in multibeam backscatter imagery, which is typical of a hard substrate.
AM	AM r_cgS	AM—Rippled, coarse-grained sand	8.0	4.3	Substrate AM (40–64 m water depth) lies in the southern part of Race Point Channel, north of Cape Cod. The substrate surface displays areas of large bedforms (100–200 m wavelength) in the south and areas of small bedforms (50–100 m wavelength) in the north. The smaller bedforms in the northern part are similar in wavelength and orientation to those present in substrate AC to the west.
AN	AN r_cgS	AN—Rippled, coarse-grained sand	7.3	3.9	Substrate AN (45–50 m water depth) lies along the northern margin of Race Point Channel south of Stellwagen Bank. Substrate AN is similar in mobility and sand content to adjacent substrate A1 to the north and east and to substrate Z to the west, but substrate AN has a much higher fine-grained sand content (32 wt. pct.) compared to that of A1 (2 wt. pct.) and Z (5 wt. pct.). The surface of substrate AN displays ridge-like features in multibeam topographic imagery that are interpreted to be partially buried iceberg keel marks. Substrates AI and AP also display iceberg keel marks.
AO	AO r_cgS	AO—Rippled, coarse-grained sand	5.9	3.2	Substrate AO (28–55 m water depth) lies along the southern margin of Race Point Channel, north of Cape Cod. The surface of substrate AO is smooth as observed in multibeam topographic imagery. By contrast, it is bounded to the west by substrate AQ, to the north by substrate AM, and to the east by substrate AP, all of which are mobile sand substrates that collectively display surfaces of bedforms, ridges, troughs, and hummocks.

Table 7. Geologic substrate symbols, names, areas, and brief comparisons to other substrates in quadrangle 3 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts.—Continued

[See table 3 for an explanation of characters used in substrate names to describe their physical attributes. Areas were calculated from substrate polygons (Valentine and Cross, 2026a) using Esri's ArcMap program, version 10.8.1. Quadrangle 3 has a total mapped area of 185 km^2. The area could not be determined for substrate A3 because it is represented by few samples and is not mappable as a coherent unit at 1:25,000 scale. Table format from Valentine and Cross (2024d). Terms: <, less than; km^2, square kilometer; m, meter; nd, no data; wt. pct., weight percent]

Geologic substrate symbol	Substrate name	Substrate name translation	Area of substrate in quadrangle 3 (km^2)	Area of substrate in quadrangle 3 (percent)	Brief description and (or) comparison to other substrates
AP	AP r_cgS / i_pcbG	AP—Rippled, coarse-grained sand; partial veneer on immobile, pebble, cobble, boulder gravel	27.2	14.7	Substrate AP (30–51 m water depth) lies in the southeastern part of Race Point Channel. It is a layered substrate, but only the upper layer (the rippled, coarse-grained sand) is visible in the troughs. The substrate's surface topography, as observed in multibeam topographic imagery, is a series of subparallel, arcuate troughs and ridges that trend northwestward along the southeastern part of the channel. The troughs are <5 m deep and are interpreted to be iceberg keel marks that were formed by the grounding of icebergs as they drifted westward into the channel from deeper water to the east. The keel marks are present beginning at 45 to 50 m water depth in the east and they extend westward in the channel until the water depth increases to >50 m. Substrates AI and AN also display iceberg keel marks.
AQ	AQ r_fgS	AQ—Rippled, fine-grained sand	1.2	0.6	Substrate AQ (50–61 m water depth) lies along the southern margin of Race Point Channel on the slope that separates the channel from Cape Cod to the south. It extends along the northern slope of Cape Cod and is bounded to the east and west by coarse-grained sand substrates AO and AG, respectively.

Appendix 1. Data Layers and Data for Quadrangle 3

Data used to compile the quadrangle 3 maps of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts, include new data layers and previously published data, as listed in table 1.1 below. The new data layers are available in a data release associated with this report (Valentine and Cross, 2026a).

Table 1.1. Data layers and data used to compile maps for quadrangle 3 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts.

[Table format from Valentine and Cross (2024). Terms: ≥, greater than or equal to; <, less than; CSV, comma separated values; GeoTIFF, Geographic Tagged Image File Format; JPEG, Joint Photographic Experts Group; m, meter; NAD 83, North American Datum of 1983; TIFF, Tagged Image File Format]

Data-layer name and (or) description	Location of data and associated metadata	Source
q3_geologic_interp—Polygon shapefile of the geologic substrate interpretation of the seabed in quadrangle 3. Attribute fields can be used to symbolically illustrate the seven maps presented in this publication	https://www.sciencebase.gov/catalog/item/65d7c931d34ec3e1801d8149	Valentine and Cross (2026a)
q3_1m_contours—Polyline shapefile of the 1-m contours in quadrangle 3. These contours are used in some areas to reveal small features not shown by 5-m contours	https://www.sciencebase.gov/catalog/item/65d7c877d34ec3e1801d813e	Valentine and Cross (2026a)
q3_13mbathy—32-bit GeoTIFF image of the 13- × 13-m cell-size bathymetry of quadrangle 3 used as a basis for the generation of the 1-m contours and the terrain ruggedness analyses	https://www.sciencebase.gov/catalog/item/65d7caaad34ec3e1801d8158	Valentine and Cross (2026a)
q3_stations_geology—Point shapefile of station locations and Excel and CSV files of sediment grain-size analyses and assignment of stations to substrate types	https://www.sciencebase.gov/catalog/item/65d7c9e6d34ec3e1801d814f	Valentine and Cross (2026b)
2013-044-FA_video_driftlines.zip—Video transects of the sea floor on Stellwagen Bank during U.S. Geological Survey field activity 2013-044-FA, aboard the R/V *Auk*, November 5, 15, and 21, 2013	https://doi.org/10.5066/P9N8YJL1	Valentine and Cross (2019)
2014-015-FA_video_driftlines.zip—Video transects of the sea floor on Stellwagen Bank during U.S. Geological Survey field activity 2014-015-FA, aboard the R/V *Auk*, May 22–23 and 29–30, 2014	https://doi.org/10.5066/P93OZR8C	Valentine and Cross (2020b)
2014-066-FA_video_driftlines.zip—Video transects of the sea floor on Stellwagen Bank during U.S. Geological Survey field activity 2014-066-FA, aboard the R/V *Auk*, November 10, 2014	https://doi.org/10.5066/P9EQM8MK	Valentine and Cross (2020d)
2015-017-FA_video_driftlines.zip—Video transects of the sea floor on Stellwagen Bank during U.S. Geological Survey field activity 2015-017-FA, aboard the R/V *Auk*, May 18–19, 29, and June 3, 2015	https://doi.org/10.5066/P9BG490P	Valentine and Cross (2020c)
2015-062-FA_video_driftlines.zip—Video transects of the sea floor on Stellwagen Bank during U.S. Geological Survey field activity 2015-062-FA, aboard the R/V *Auk*, October 21–22 and November 3–4, 2015	https://dx.doi.org/10.5066/F7N015FS	Valentine and Cross (2017)
2016-038-FA_video_driftlines.zip—Video transects of the sea floor on Stellwagen Bank during U.S. Geological Survey field activity 2016-038-FA, aboard the R/V *Auk*, September 16 and 19, 2016	https://doi.org/10.5066/P91MNNSN	Valentine and Cross (2020e)

Table 1.1. Data layers and data used to compile maps for quadrangle 3 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts.—Continued

[Table format from Valentine and Cross (2024). Terms: ≥, greater than or equal to; <, less than; CSV, comma separated values; GeoTIFF, Geographic Tagged Image File Format; JPEG, Joint Photographic Experts Group; m, meter; NAD 83, North American Datum of 1983; TIFF, Tagged Image File Format]

Data-layer name and (or) description	Location of data and associated metadata	Source
2019-008-FA_video_driftlines.zip—Video transects of the sea floor on Stellwagen Bank during U.S. Geological Survey field activity 2019-008-FA, aboard the R/V *Auk*, July 30–31 and August 1, 2019	https://doi.org/10.5066/P93ATKSC	Valentine and Cross (2020a)
Seabed observation stations—Video drift track locations, Stellwagen Bank National Marine Sanctuary region	https://doi.org/10.3133/sim2840	Valentine (2005)
Seabed observation stations—Sediment sample locations and Excel file of grain-size analyses, Stellwagen Bank National Marine Sanctuary region	https://doi.org/10.3133/sim2840	Valentine (2005)
Photographic images of the seabed—Locations of individual photographs, Stellwagen Bank National Marine Sanctuary region	https://pubs.usgs.gov/ds/469/DataCatalog/sb_photolocs.zip	Valentine and others (2010)
JPEG images of the seabed from quadrangles 1–18 in medium and high resolution, Stellwagen Bank National Marine Sanctuary region	https://pubs.usgs.gov/ds/469/html/DataCatalog.html	Valentine and others (2010)
Sun-illuminated sea-floor topography and TIFF world file, Stellwagen Bank National Marine Sanctuary region	https://doi.org/10.3133/sim2840	Valentine (2005)
Bathymetric contours, Stellwagen Bank National Marine Sanctuary region	https://doi.org/10.3133/sim2840	Valentine (2005)
Backscatter intensity, sun-illuminated sea-floor topography, and TIFF world file, Stellwagen Bank National Marine Sanctuary region	https://doi.org/10.3133/sim2840	Valentine (2005)
Sea-floor ruggedness and TIFF world file, Stellwagen Bank National Marine Sanctuary region	https://doi.org/10.3133/sim2840	Valentine (2005)
Esri binary grid used as the basis for the terrain rugged analyses, Stellwagen Bank National Marine Sanctuary region	https://doi.org/10.3133/sim2840	Valentine (2005)
Sea-floor slope and TIFF world file, Stellwagen Bank National Marine Sanctuary region	https://doi.org/10.3133/sim2840	Valentine (2005)
Boulder ridges <1 meter in height, Stellwagen Bank National Marine Sanctuary region	https://doi.org/10.3133/sim2840	Valentine (2005)
Boulder ridges ≥1 meter in height, Stellwagen Bank National Marine Sanctuary region	https://doi.org/10.3133/sim2840	Valentine (2005)
Bedrock outcrops, Stellwagen Bank National Marine Sanctuary region	https://doi.org/10.3133/sim2840	Valentine (2005)
Boundary, Stellwagen Bank National Marine Sanctuary	https://doi.org/10.3133/sim2840	Valentine (2005)
Quadrangle boundaries, Stellwagen Bank National Marine Sanctuary region	https://doi.org/10.3133/sim2840	Valentine (2005)

References Cited

Valentine, P.C., ed., 2005, Sea floor image maps showing topography, sun-illuminated topography, backscatter intensity, ruggedness, slope, and the distribution of boulder ridges and bedrock outcrops in the Stellwagen Bank National Marine Sanctuary region off Boston, Massachusetts: U.S. Geological Survey Scientific Investigations Map 2840, 12 sheets, scale 1:60,000, 1 DVD-ROM. [Also available at https://doi.org/10.3133/sim2840.]

Valentine, P.C., and Cross, V.A., 2017, Sea floor sediment samples, seabed imagery, and CTD data collected in Stellwagen Bank National Marine Sanctuary, MA in 2015, U.S. Geological Survey Field Activity 2015-062-FA: U.S. Geological Survey data release, accessed June 14, 2023, at https://doi.org/10.5066/F7N015FS.

Valentine, P.C., and Cross, V.A., 2019, Sea-floor sediment samples, seabed imagery, and CTD instrument data collected on Stellwagen Bank in November, 2013, U.S. Geological Survey Field Activity 2013-044-FA: U.S. Geological Survey data release, accessed June 14, 2023, at https://doi.org/10.5066/P9N8YJL1.

Valentine, P.C., and Cross, V.A., 2020a, Sea-floor sediment samples, seabed imagery, and CTD instrument data collected on Stellwagen Bank in July and August, 2019, U.S. Geological Survey Field Activity 2019-008-FA (ver. 1.1, May 2023): U.S. Geological Survey data release, accessed June 14, 2023, at https://doi.org/10.5066/P93ATKSC.

Valentine, P.C., and Cross, V.A., 2020b, Sea-floor sediment samples, seabed imagery, and CTD instrument data collected on Stellwagen Bank in May, 2014, U.S. Geological Survey Field Activity 2014-015-FA: U.S. Geological Survey data release, accessed June 14, 2023, at https://doi.org/10.5066/P93OZR8C.

Valentine, P.C., and Cross, V.A., 2020c, Sea-floor sediment samples, seabed imagery, and CTD instrument data collected on Stellwagen Bank in May and June, 2015, U.S. Geological Survey Field Activity 2015-017-FA: U.S. Geological Survey data release, accessed June 14, 2023, at https://doi.org/10.5066/P9BG490P.

Valentine, P.C., and Cross, V.A., 2020d, Sea-floor sediment samples, seabed imagery, and CTD instrument data collected on Stellwagen Bank in November, 2014, U.S. Geological Survey Field Activity 2014-066-FA: U.S. Geological Survey data release, accessed June 14, 2023, at https://doi.org/10.5066/P9EQM8MK.

Valentine, P.C., and Cross, V.A., 2020e, Station information, seabed and sample imagery, and CTD instrument data collected on Stellwagen Bank in September, 2016, U.S. Geological Survey Field Activity 2016-038-FA: U.S. Geological Survey data release, accessed June 14, 2023, at https://doi.org/10.5066/P91MNNSN.

Valentine, P.C., and Cross, V.A., 2024, Seabed maps showing topography, ruggedness, backscatter intensity, sediment mobility, and the distribution of geologic substrates in quadrangle 5 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts: U.S. Geological Survey Scientific Investigations Map 3515, 8 sheets, scale 1:25,000, 27-p. pamphlet, accessed March 21, 2024, at https://doi.org/10.3133/sim3515.

Valentine, P.C., and Cross, V.A., 2026a, Geospatial datasets of seabed topography, sediment mobility, and the distribution of geologic substrates in quadrangle 3 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts: U.S. Geological Survey data release, https://doi.org/10.5066/P13PVHRI.

Valentine, P.C., and Cross, V.A., 2026b, Station locations in quadrangle 3 in Stellwagen Bank National Marine Sanctuary offshore of Boston, Massachusetts where video, photographs and sediment samples were collected by the U.S. Geological Survey from 1993-2021 - includes sediment sample analyses and interpreted geologic substrate, *in* Geospatial datasets of seabed topography, sediment mobility, and the distribution of geologic substrates in quadrangle 3 of the Stellwagen Bank National Marine Sanctuary region offshore of Boston, Massachusetts: U.S. Geological Survey data release, https://www.sciencebase.gov/catalog/item/65d7c9e6d34ec3e1801d814f.

Valentine, P.C., Gallea, L.B., Blackwood, D.S., and Twomey, E.R., 2010, Seabed photographs, sediment texture analyses, and sun-illuminated sea floor topography in the Stellwagen Bank National Marine Sanctuary region off Boston, Massachusetts: U.S. Geological Survey Data Series DS–469, accessed June 14, 2023, at https://doi.org/10.3133/ds469.

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