USGS
science for a changing world

Terrain Ruggedness Analysis and Distribution of Boulder Ridges in the Stellwagen Bank National Marine Sanctuary Region

Boulder Ridges and Bedrock Outcrops

by Page C. Valentine, Lian A. Scully, and Sarah J. Fuller; U.S. Geological Survey, Woods Hole, Massachusetts

METHODS

- Boulder ridges and bedrock outcrops were identified using multibeam topographic imagery and backscatter intensity of the seabed, the Terrain Ruggedness Index (TRI), and video and photographic images.
- Boulder ridge and bedrock features were digitized using ArcMap software editing tools.
- GIS cannot be used to automatically recognize and delineate these features. They must be identified using the above criteria and digitized individually and subjectively by hand.
- Polygon shape files (.shp) of the ridges define ridge areas on the corresponding bathymetric image, from which the range of elevations within each polygon were determined. The range of heights within ridge polygons were calculated using the Zonal Statistics tool from the Spatial Analyst extension for ArcMap.
- The boulder ridges were divided into two classes; those with maximum heights <1 meter, and those with maximum heights ≥1 meter.
- Area statistics for boulder ridges and bedrock outcrops were calculated and entered into Table 1.

SUMMARY

- Seabed geomorphology in the Stellwagen Bank NMS region, off Boston, Massachusetts is highly variable due to its glacial origin. Seabed variability provides the framework for the region's wide range of habitats and high biodiversity.
- This map combines digital sun-illuminated topographic imagery with an interpretation of the distribution of boulder ridges and bedrock outcrops for an area of 3759 sq km. Sun elevation and angle are 45 degrees and 350 degrees, respectively.
- Boulder ridges are elongate features that are accumulations of boulders and cobbles deposited by glacial processes in the form of eskers and moraines.
- Boulder ridges are characterized by piled cobbles and boulders. The cobbles and boulders touch and support each other and are separated by voids (a defining characteristic).
- Voids were produced by erosion of sand and mud from eskers, moraines, and other features during the post-glacial rise in sea level.
- Boulder ridges range up to 10s of meters in width and 100s of meters in length. They are irregular in plan view, have sharply defined crests, and are situated primarily on the tops and upper edges of banks and valleys.
- Boulder ridges are divided into two groups, those less than 1 meter in height and those 1 meter in height or greater. Ridges in the second and larger group have an average height of 2.81 m and a maximum height of 18 m. Boulder ridges lie at water depths of approximately 30 to 90 m.
- Bedrock outcrops form glaciated subcircular hills and submerged coastlines.
- Bedrock outcrops are characterized in sun-illuminated topographic imagery by distinctively uneven surfaces and by joints and fractures that trend in many directions. Bedrock outcrops range from coastal exposures to water depths of 90 m.
- Boulder ridges and bedrock outcrops occupy only 45 sq km (1.2 pct) of the map area. The combination of hard surfaces and voids make them a favorable substrate for attached epifauna and an important habitat for many species of juvenile and adult fish, including redfish, codfish, wolffish, and cunner.

BOULDER RIDGES ON TILLIES BANK

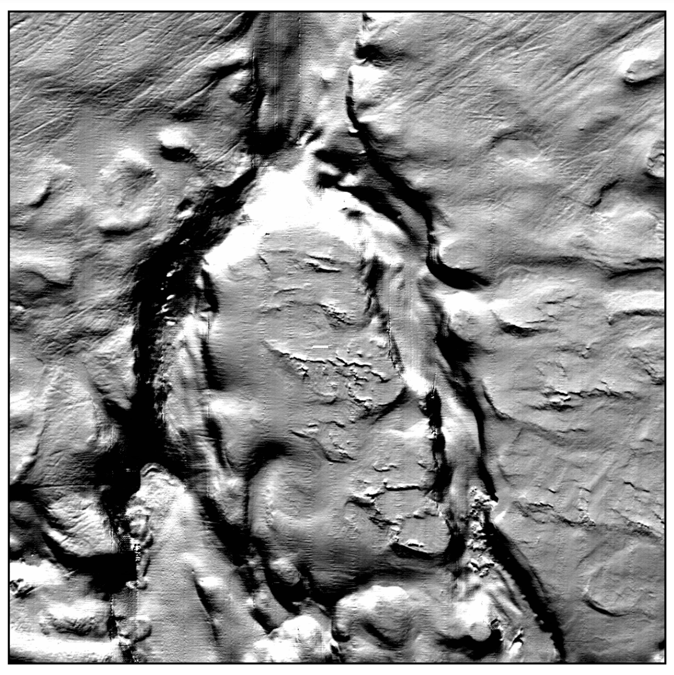


Figure 1. Sun-illuminated topography of the northern part of Tillies Bank showing sharply defined boulder ridges that represent glacial eskers and moraines on the bank top. Vertical exaggeration 4x. Scale 1:60,000

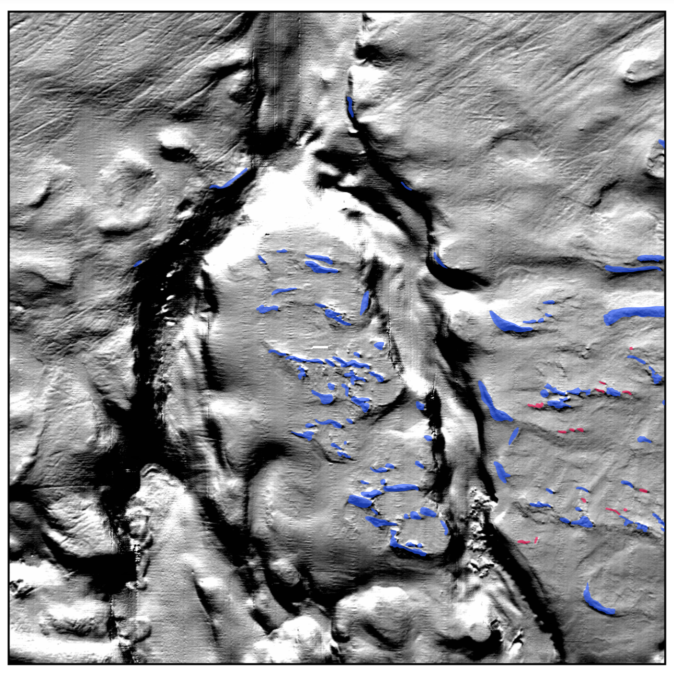


Figure 2. Sun-illuminated topography of the northern part of Tillies Bank showing boulder ridges with maximum heights of <1 meter (red) and ≥1 meter (blue).

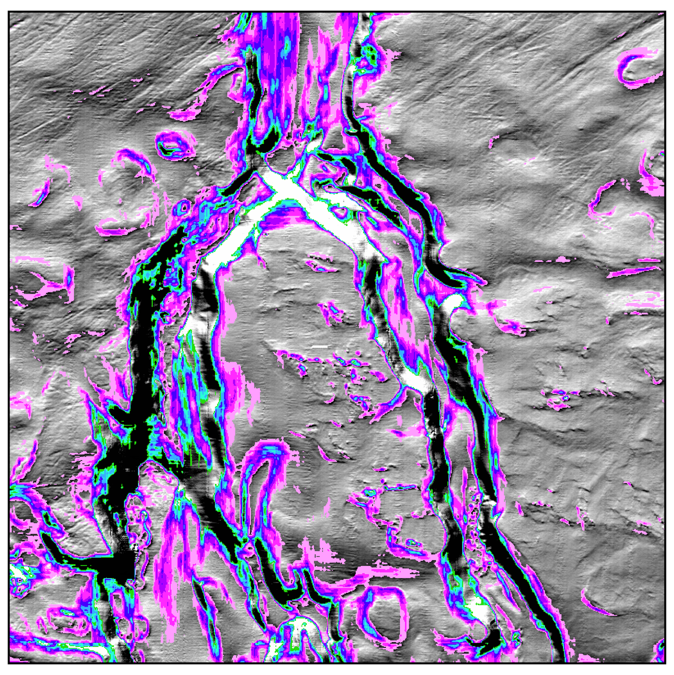
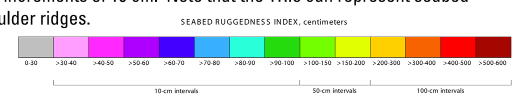


Figure 3. Sun-illuminated topography of the northern part of Tillies Bank showing Terrain Ruggedness Indices (TRIs) that represent average changes in elevation of 30 cm (pink) to 100 cm (green) in increments of 10 cm. Note that the TRIs can represent seabed types other than boulder ridges.



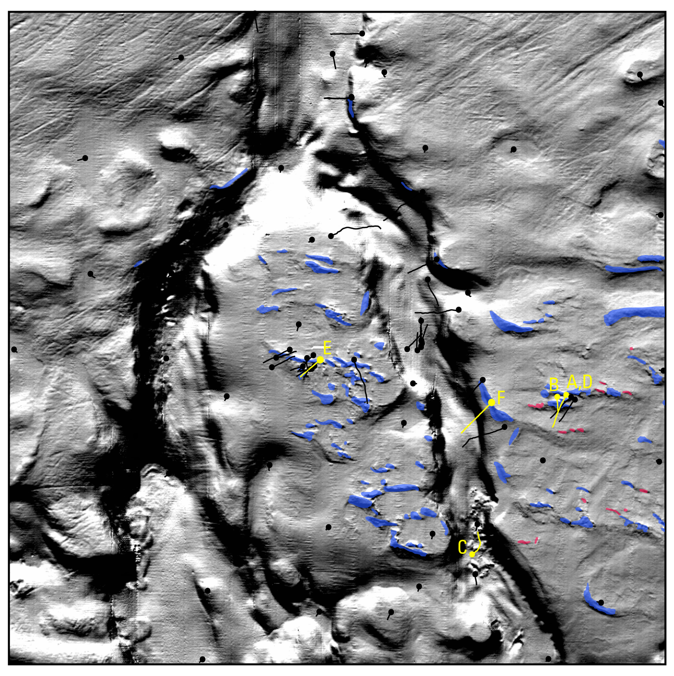
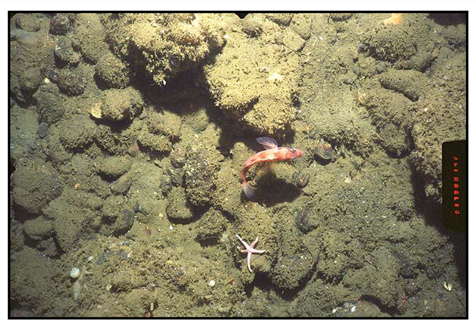


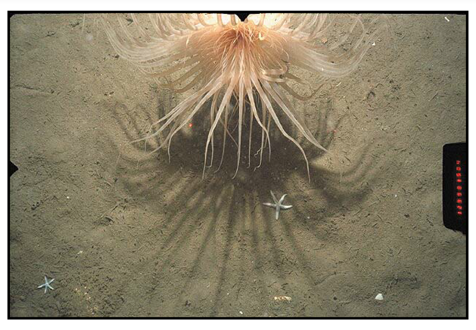
Figure 4. Sun-illuminated topography of the northern part of Tillies Bank showing boulder ridges and the locations of video and photographic transects and seabed photographs A-F (see below).

SEABED PHOTOGRAPHS

Photographs show a seabed area of 51x76 cm.



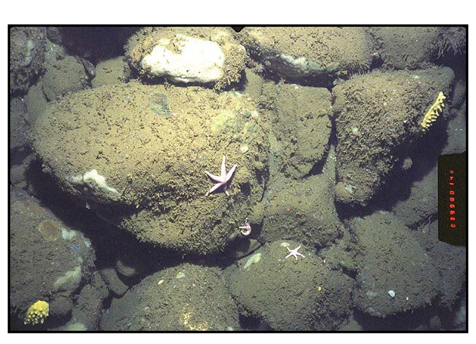
A. Pebbles, cobbles and small boulders at the base of a boulder ridge; encrusted by tunicates, hydroids, and bryozoans. Other fauna: sea star; juvenile Acadian redfish (*Sebastes fasciatus*). TRI of boulder ridge along transect is 30-80 cm. [Station 3142; water depth 76 m].



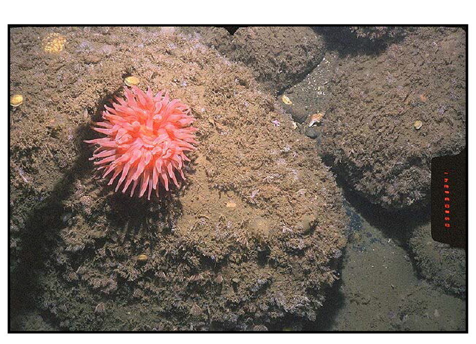
C. Sandy mud overlying mounds of glacial sediment. Fauna: sea stars; burrowing cerianthid anemone. TRI of hummocky seabed along transect is 30-70 cm. [Station 2226; water depth 127 m].

E. Cobbles and boulders at the base of a boulder ridge; encrusted by tunicates, hydroids, and bryozoans. Other fauna: yellow *Polymastia sponge*; juvenile Acadian redfish (*Sebastes fasciatus*). TRI of boulder ridge along transect is 30-80 cm. [Station 3143.1; water depth 63 m].

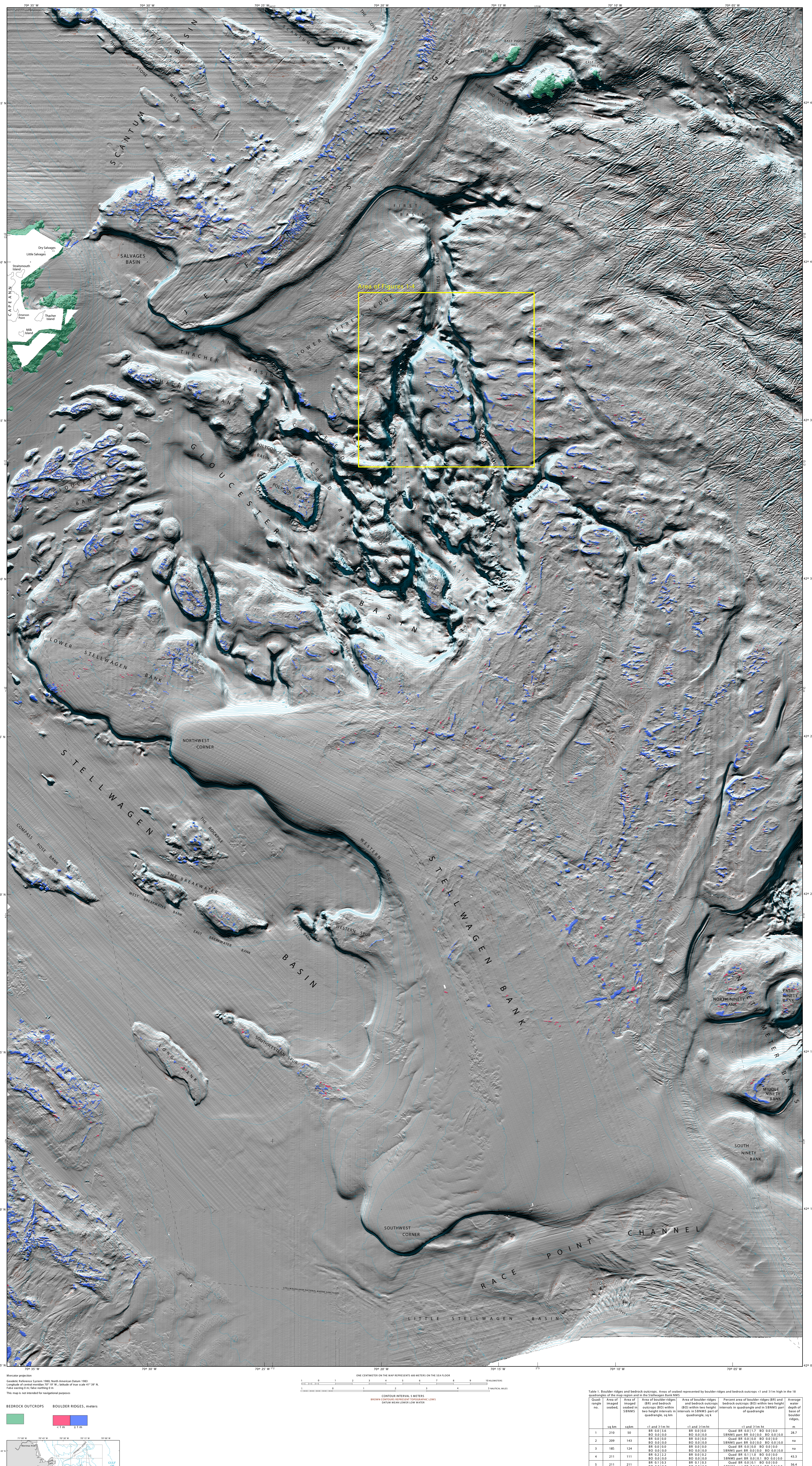
B. Piled boulders separated by voids on a boulder ridge; encrusted by tunicates, hydroids, and bryozoans. Other fauna: attached yellow *Terebratulina* brachiopods; sea stars (including *Porania insignis*). TRI of boulder ridge along transect is 30-50 cm. [Station 3142.7; water depth 67 m].



D. Piled boulders separated by voids on a boulder ridge; encrusted by tunicates, hydroids, and bryozoans. Other fauna: sea stars; yellow *Polymastia* sponge. TRI of boulder ridge along transect is 30-80 cm. [Station 3142; water depth 76 m].



F. Piled boulders separated by voids on a boulder ridge; encrusted by tunicates, hydroids, and bryozoans. Other fauna: attached pink anemone; yellow *Polymastia* sponge; yellow *Terebratulina* brachiopod. TRI of boulder ridge along transect is 30-150 cm. [Station 3954; water depth 65 m].

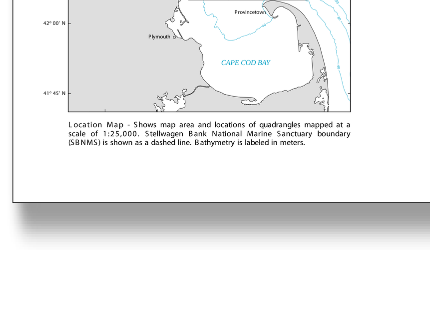


Mercator projection
Geodetic Reference System 1980; North American Datum 1983
Longitude of central meridian 70° 19' W.; latitude of true scale 41° 39' N.
False easting 0 m; false northing 0 m
This map is not intended for navigational purposes

ONE CENTIMETER ON THE MAP REPRESENTS 600 METERS ON THE SEA FLOOR
0 1 2 3 4 5 6 7 8 9 10 KILOMETERS
0 1 2 3 4 5 NAUTICAL MILES

CONTOUR INTERVAL 5 METERS
BROWN CONTOURS REPRESENT TOPOGRAPHIC LOWS
DATUM MEAN LOWER LOW WATER

BEDROCK OUTCROPS   BOULDER RIDGES, meters
< 1 m   ≥ 1 m



Location Map - Shows map area and locations of quadrangles mapped at a scale of 1:25,000. Stellwagen Bank National Marine Sanctuary boundary (SBNMS) is shown as a dashed line. Bathymetry is labeled in meters.

Table 1. Boulder ridges and bedrock outcrops. Areas of seabed represented by boulder ridges and bedrock outcrops <1 and ≥1m high in the 18 quadrangles of the map region and in the Stellwagen Bank NMS

<table>
<tr><th>Quad-rangle no.</th><th>Area of imaged seabed, sq km</th><th>Area of imaged seabed in SBNMS sqkm</th><th>Area of boulder ridges (BR) and bedrock outcrops (BO) within two height intervals in quadrangle, sq km
<1 and ≥1m ht</th><th>Area of boulder ridges and bedrock outcrops (BO) within two height intervals in SBNMS part of quadrangle, sq k
<1 and ≥1m ht</th><th>Percent area of boulder ridges (BR) and bedrock outcrops (BO) within two height intervals in quadrangle and in SBNMS part of quadrangle
<1 and ≥1m ht</th><th>Average water depth of base of boulder ridges, m</th></tr>
<tr><td>1</td><td>210</td><td>50</td><td>BR 0.0 | 3.6
BO 0.0 | 0.0</td><td>BR 0.0 | 0.0
BO 0.0 | 0.0</td><td>Quad BR 0.0 | 1.7 BO 0.0 | 0.0
SBNMS part BR 0.0 | 0.0 BO 0.0 | 0.0</td><td>28.7</td></tr>
<tr><td>2</td><td>209</td><td>143</td><td>BR 0.0 | 0.0
BO 0.0 | 0.0</td><td>BR 0.0 | 0.0
BO 0.0 | 0.0</td><td>Quad BR 0.0 | 0.0 BO 0.0 | 0.0
SBNMS part BR 0.0 | 0.0 BO 0.0 | 0.0</td><td>na</td></tr>
<tr><td>3</td><td>185</td><td>124</td><td>BR 0.0 | 0.0
BO 0.0 | 0.0</td><td>BR 0.0 | 0.0
BO 0.0 | 0.0</td><td>Quad BR 0.0 | 0.0 BO 0.0 | 0.0
SBNMS part BR 0.0 | 0.0 BO 0.0 | 0.0</td><td>na</td></tr>
<tr><td>4</td><td>211</td><td>111</td><td>BR 0.2 | 2.2
BO 0.0 | 0.0</td><td>BR 0.0 | 0.2
BO 0.0 | 0.0</td><td>Quad BR 0.1 | 1.0 BO 0.0 | 0.0
SBNMS part BR 0.0 | 0.1 BO 0.0 | 0.0</td><td>43.3</td></tr>
<tr><td>5</td><td>211</td><td>211</td><td>BR 0.1 | 0.3
BO 0.0 | 0.0</td><td>BR 0.1 | 0.3
BO 0.0 | 0.0</td><td>Quad BR 0.0 | 0.1 BO 0.0 | 0.0
SBNMS part BR 0.0 | 0.1 BO 0.0 | 0.0</td><td>56.4</td></tr>
<tr><td>6</td><td>211</td><td>157</td><td>BR 0.5 | 2.5
BO 0.0 | 0.0</td><td>BR 0.4 | 1.9
BO 0.0 |0.0</td><td>Quad BR 0.2 | 1.2 BO 0.0 | 0.0
SBNMS part BR 0.2 | 1.2 BO 0.0 | 0.0</td><td>71.5</td></tr>
<tr><td>7</td><td>211</td><td>152</td><td>BR 0.0 | 0.9
BO 0.0 | 0.0</td><td>BR 0.0 | 0.5
BO 0.0 | 0.0</td><td>Quad BR 0.0 | 0.4 BO 0.0 | 0.0
SBNMS part BR 0.0 | 0.3 BO 0.0 | 0.0</td><td>58.7</td></tr>
<tr><td>8</td><td>211</td><td>211</td><td>BR 0.3 | 1.0
BO 0.0 | 0.0</td><td>BR 0.3 | 1.0
BO 0.0 | 0.0</td><td>Quad BR 0.1 | 0.5 BO 0.0 | 0.0
SBNMS part BR 0.1 | 0.5 BO 0.0 | 0.0</td><td>55.9</td></tr>
<tr><td>9</td><td>211</td><td>122</td><td>BR 0.2 | 4.2
BO 0.0 | 0.0</td><td>BR 0.2 | 2.4
BO 0.0 | 0.0</td><td>Quad BR 0.1 | 2.0 BO 0.0 | 0.0
SBNMS part BR0.1 | 1.9 BO 0.0 | 0.0</td><td>75.3</td></tr>
<tr><td>10</td><td>211</td><td>192</td><td>BR 0.3 | 4.7
BO 0.0 | 0.0</td><td>BR 0.3 | 4.5
BO 0.0 | 0.0</td><td>Quad BR 0.2 | 2.2 BO 0.0 | 0.0
SBNMS part BR 0.2 | 2.4 BO 0.0 | 0.0</td><td>55.7</td></tr>
<tr><td>11</td><td>211</td><td>211</td><td>BR 0.1 | 1.6
BO 0.0 | 0.0</td><td>BR 0.1 | 1.6
BO 0.0 | 0.0</td><td>Quad BR 0.0 | 0.8 BO 0.0 | 0.0
SBNMS part BR 0.0 | 0.8 BO 0.0 | 0.0</td><td>68.7</td></tr>
<tr><td>12</td><td>211</td><td>86</td><td>BR 0.2 | 2.7
BO 0.0 | 0.0</td><td>BR 0.2 | 1.5
BO 0.0 | 0.0</td><td>Quad BR 0.1 | 1.3 BO 0.0 | 0.0
SBNMS part BR 0.2 | 1.7 BO 0.0 | 0.0</td><td>77.1</td></tr>
<tr><td>13</td><td>197</td><td>115</td><td>BR 0.0 |2.1
BO 0.0 | 7.2</td><td>BR 0.0 | 1.9
BO 0.0 | 7.2</td><td>Quad BR 0.0 | 1.0 BO 0.0 | 3.4
SBNMS part BR 0.0 | 1.7 BO 0 | 6.3</td><td>50.1</td></tr>
<tr><td>14</td><td>212</td><td>212</td><td>BR 0.1 | 2.4
BO 0.0 | 0.0</td><td>BR 0.1 | 2.4
BO 0.0 | 0.0</td><td>Quad BR 0.0 | 1.1 BO 0.0 | 0.0
SBNMS part BR 0.0 |1.1 BO 0.0 | 0.0</td><td>64.3</td></tr>
<tr><td>15</td><td>212</td><td>50</td><td>BR 0.1 | 0.8
BO 0.0 | 0.0</td><td>BR 0.1 | 0.7
BO 0.0 | 0.0</td><td>Quad BR 0.0 | 0.4 BO 0.0 | 0.0
SBNMS part BR 0.1 | 1.5 BO 0.0 | 0.0</td><td>71.8</td></tr>
<tr><td>16</td><td>212</td><td>1</td><td>BR 0.1 | 2.9
BO 0.0 | 0.9</td><td>BR 0.0 | 0.1
BO 0.0 | 0.9</td><td>Quad BR 0.1 | 1.4 BO 0.0 | 0.4
SBNMS part BR 0.0 | 10.8 BO 0 | 143.2</td><td>54.4</td></tr>
<tr><td>17</td><td>212</td><td>81</td><td>BR 0.0 | 2.5
BO 0.0 | 0.6</td><td>BR 0.0 | 0.6
BO 0.0 | 0.2</td><td>Quad BR 0.0 | 1.2 BO 0.0 | 0.3
SBNMS part BR 0.0 | 0.8 BO 0.0 | 0.2</td><td>50.7</td></tr>
<tr><td>18</td><td>212</td><td>13</td><td>BR 0.0 | 0.0
BO 0.0 | 1.7</td><td>BR 0.0 | 0.0
BO 0.0 | 0.5</td><td>Quad BR 0.0 | 0.0 BO 0.0 | 0.8
SBNMS part BR 0.0 | 0.0 BO 0.0 | 4.0</td><td>na</td></tr>
<tr><td>Totals</td><td>3759</td><td>2241</td><td>All quads BR 2.4 | 34.5
All quads BO 0.0 | 10.5</td><td>All SBNMS BR 1.8 | 19.7
All SBNMS BO 0.0 | 8.9</td><td>All quads BR 0.1| 0.9 BO 0.0 | 0.3
All SBNMS BR 0.1 | 0.9 BO 0.0 | 0.4</td><td>na</td></tr>
</table>

Note : In quadrangles 2, 3, 15, and 16, the seabed has not been imaged completely. However, the entire SBNMS is imaged except for a very small part (0.2 sq km) in its southeast corner in Quadrangle 3. All calculations are rounded to one decimal place. One square kilometer = 0.291 square nautical miles.