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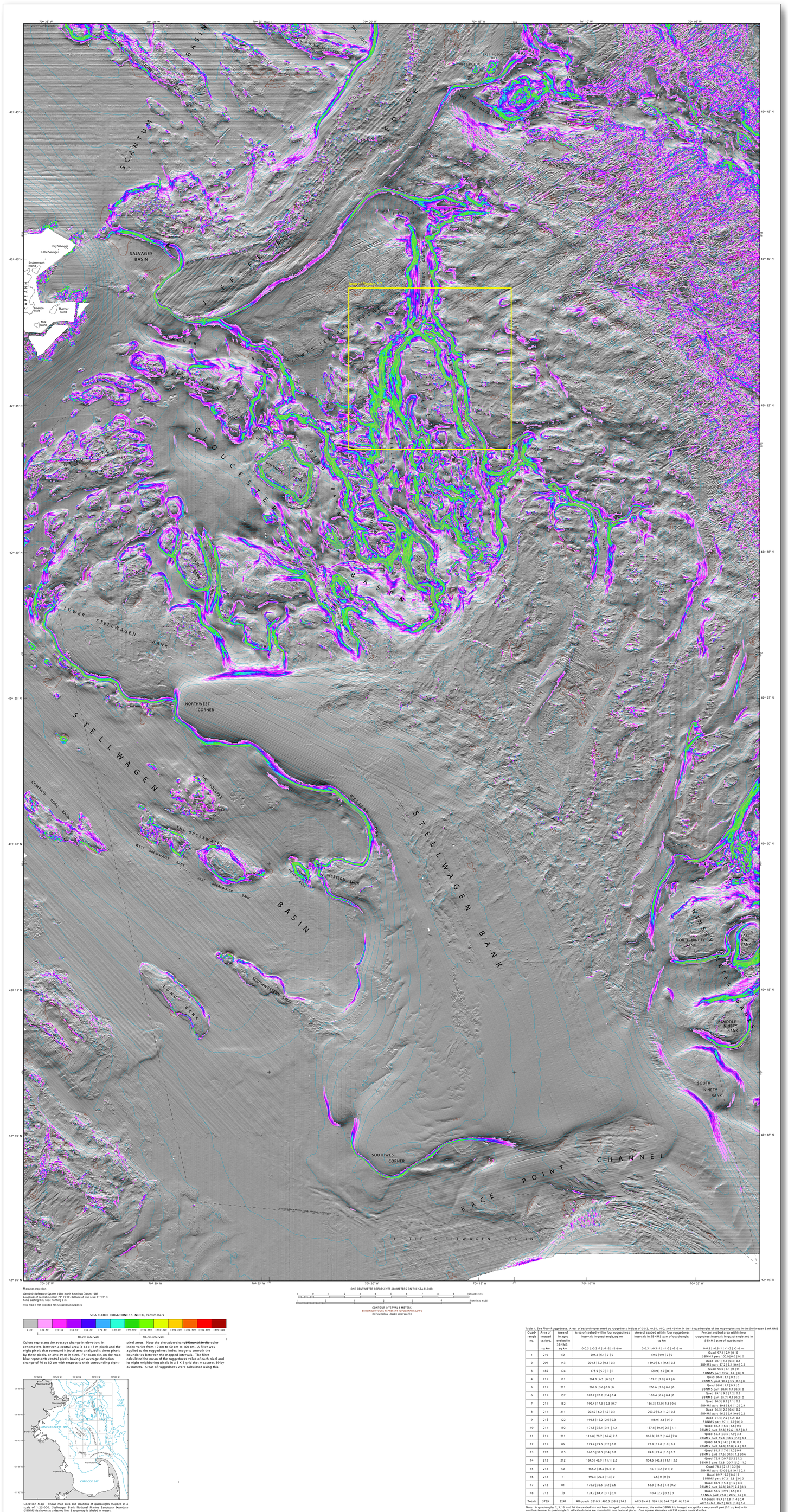
Terrain Ruggedness Analysis and Distribution of Boulder Ridges in the Stellwagen Bank National Marine Sanctuary Region

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



Mercator projection

Geodetic Reference System 1980; North American Datum 1983
Central meridian 70° 7' 30" W.; latitude of true scale 41° 39' N.
False easting 0 m; false northing 0 m

This map is not intended for navigational purposes

SEA FLOOR RUGGEDNESS INDEX, centimeters

0-30	>30-40	>40-50	>50-60	>60-70	>70-80	>80-90	>90-100	>100-150	>150-200	>200-300	>300-400	>400-500	>500-600

10-cm intervals | 50-cm intervals | 100-cm intervals

ONE CENTIMETER REPRESENTS 600 METERS ON THE SEA FLOOR

1 0 1 2 3 4 5 6 7 8 9 10 KILOMETERS
1 0 1 2 3 4 5 NAUTICAL MILES

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

Colors represent the average change in elevation, in centimeters, between a central area (a 13 x 13 m pixel) and the eight pixels that surround it (total area analyzed is three pixels by three pixels, or 39 x 39 m in size). 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. Note the elevation-change intervals within the color index varies from 10 cm to 50 cm to 100 cm. A filter was applied to the ruggedness index image to smooth the boundaries between the mapped intervals. The filter calculated the mean of the ruggedness value of each pixel and its eight neighboring pixels in a 3 X 3 grid that measures 39 by 39 meters. Areas of ruggedness were calculated using this

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. Sea Floor Ruggedness. Areas of seabed represented by ruggedness indices of 0-0.3, >0.3-1, >1-2, and >2-6 m in the 18 quadrangles of the map region and in the Stellwagen Bank NMS

Quad-rangle no.	Area of imaged seabed, sq km	Area of imaged seabed in SBNMS, sq km	Area of seabed within four ruggedness intervals in quadrangle, sq km 0-0.3 | >0.3-1 | >1-2 | >2-6 m	Area of seabed within four ruggedness intervals in SBNMS part of quadrangle, sq km 0-0.3 | >0.3-1 | >1-2 | >2-6 m	Percent seabed area within four ruggedness intervals in quadrangle and in SBNMS part of quadrangle 0-0.3 | >0.3-1 | >1-2 | >2-6 m
1	210	50	204.2 | 6.1 | 0 | 0	50.0 | 0.0 | 0 | 0	Quad 97.1 | 2.9 | 0 | 0 SBNMS part 100.0 | 0.0 | 0 | 0
2	209	143	204.8 | 3.2 | 0.6 | 0.3	139.0 | 3.1 | 0.6 | 0.3	Quad 98.1 | 1.5 | 0.3 | 0.1 SBNMS part 97.2 | 2.2 | 0.4 | 0.2
3	185	124	178.9 | 5.7 | 0 | 0	120.9 | 2.9 | 0 | 0	Quad 96.9 | 3.1 | 0 | 0 SBNMS part 97.6 | 2.4 | 0 | 0
4	211	111	204.0 | 6.5 | 0.3 | 0	107.2 | 3.9 | 0.3 | 0	Quad 96.8 | 3.1 | 0.2 | 0 SBNMS part 96.2 | 3.5 | 0.3 | 0
5	211	211	206.6 | 3.6 | 0.6 | 0	206.6 | 3.6 | 0.6 | 0	Quad 98.0 | 1.7 | 0.3 | 0 SBNMS part 98.0 | 1.7 | 0.3 | 0
6	211	157	187.7 | 20.2 | 2.4 | 0.4	150.4 | 6.4 | 0.4 | 0	Quad 89.1 | 9.6 | 1.2 | 0.2 SBNMS part 95.7 | 4.1 | 0.2 | 0
7	211	152	190.4 | 17.3 | 2.3 | 0.7	136.3 | 13.0 | 1.8 | 0.6	Quad 90.3 | 8.2 | 1.1 | 0.3 SBNMS part 89.8 | 8.6 | 1.2 | 0.4
8	211	211	203.0 | 6.2 | 1.2 | 0.3	203.0 | 6.2 | 1.2 | 0.3	Quad 96.3 | 2.9 | 0.6 | 0.2 SBNMS part 96.3 | 2.9 | 0.6 | 0.2
9	211	122	192.8 | 15.2 | 2.6 | 0.3	118.0 | 3.6 | 0 | 0	Quad 91.4 | 7.2 | 1.2 | 0.1 SBNMS part 97.1 | 2.9 | 0 | 0
10	211	192	171.5 | 35.1 | 3.4 | 1.2	157.8 | 30.0 | 2.9 | 1.1	Quad 81.2 | 16.6 | 1.6 | 0.6 SBNMS part 82.3 | 15.6 | 1.5 | 0.6
11	211	211	116.8 | 70.7 | 16.6 | 7.0	116.8 | 70.7 | 16.6 | 7.0	Quad 55.3 | 33.5 | 7.9 | 3.3 SBNMS part 55.3 | 33.5 | 7.9 | 3.3
12	211	86	179.4 | 29.5 | 2.2 | 0.2	72.8 | 11.0 | 1.9 | 0.2	Quad 84.9 | 14.0 | 1.0 | 0.1 SBNMS part 84.8 | 12.8 | 2.2 | 0.2
13	197	115	160.5 | 33.5 | 2.4 | 0.7	89.1 | 23.6 | 1.5 | 0.7	Quad 81.5 | 17.0 | 1.2 | 0.4 SBNMS part 77.6 | 20.5 | 1.3 | 0.6
14	212	212	154.5 | 43.9 | 11.1 | 2.5	154.5 | 43.9 | 11.1 | 2.5	Quad 72.8 | 20.7 | 5.2 | 1.2 SBNMS part 72.8 | 20.7 | 5.2 | 1.2
15	212	50	165.2 | 46.0 | 0.4 | 0	46.1 | 3.4 | 0.1 | 0	Quad 78.1 | 21.7 | 0.2 | 0 SBNMS part 93.0 | 6.8 | 0.1 | 0.1
16	212	1	190.3 | 20.6 | 1.3 | 0	0.6 | 0 | 0 | 0	Quad 89.7 | 9.7 | 0.6 | 0 SBNMS part 97.2 | 2.8 | 0 | 0
17	212	81	176.0 | 32.5 | 3.2 | 0.6	62.3 | 16.8 | 1.8 | 0.2	Quad 82.9 | 15.3 | 1.5 | 0.3 SBNMS part 76.8 | 20.7 | 2.2 | 0.3
18	212	13	124.2 | 84.7 | 3.1 | 0.1	10.4 | 2.7 | 0.2 | 0	Quad 58.5 | 39.9 | 1.5 | 0.1 SBNMS part 77.8 | 20.5 | 1.7 | 0
Totals	3759	2241	All quads 3210.3 | 480.5 | 53.8 | 14.5	All SBNMS 1941.9 | 244.7 | 41.0 | 13.0	All quads 85.4 | 12.8 | 1.4 | 0.4 All SBNMS 86.7 | 10.9 | 1.8 | 0.6

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.

METHODS

The Terrain Ruggedness Index (TRI) shows the average change in elevation between a center cell (pixel) and its eight neighboring cells (pixels). On this map, pixel size is 13 meters square. Therefore, the TRI shows the average change in elevation between an area measuring 13 x 13 m and a surrounding area measuring 39 x 39 m. Average changes in elevation are shown here in ten-centimeter increments in the 0.3 to 1.0 meter range, in half-meter increments in the 1.0 to 2.0 meter range, and in one-meter increments in the 2.0 to >6.0 meter range. Average changes in elevation less than 30 centimeters are not shown.

The Terrain Ruggedness Index developed for this map is based on an index described by Riley and others (1999) that calculated the sum change in elevation between a grid cell and its eight neighboring grid cells by squaring the eight differences in elevation, summing the squared differences, and taking the square root of the sum. Here, the index has been modified to calculate the average of the absolute values of the eight differences in elevation, an approach we consider to be more straight forward than the method of Riley and others (1999). By comparison, a cell with an elevation value of 10 meters, and neighboring grid cells with values of 11, 12, 13, 14, 15, 16, 17 and 18 would have a TRI value of 4.50 meters with the new method, rather than 14.28 with the Riley and others (1999) method. An example of the TRI equation used here is given in Figure 1.

TRI = [abs{grid(0,0) - grid(-1,-1)}+ abs{grid(0,0) - grid(0,-1)}+
abs{grid(0,0) - grid(1,-1)}+ abs{grid(0,0) - grid(1,0)}+
abs{grid(0,0) - grid(-1,1)}+ abs{grid(0,0) - grid(0,1)}+
abs{grid(0,0) - grid(-1,0)}+ abs{grid(0,0) - grid(1,1)}] / 8

-1,-1	0,-1	1,-1
-1,0	0,0	1,0
-1,1	0,1	1,1

Figure 1: Terrain Ruggedness Index (TRI) for the Stellwagen Bank NMS region. If each square on the grid represents the location of a corresponding pixel value on the bathymetric image, then the TRI can be described by the above equation. Note: abs = absolute value; grid( ) = the pixel's value from the given grid location.

- The TRI was applied to the digital bathymetric grids of the seafloor by running a macro in ArcMap's Visual Basic editing environment. The macro contained equivalent Visual Basic code for the equation shown in Figure 1.
- Artifacts of data collection were removed by hand editing and by applying a "mean" filter on the ruggedness image (Compare Figures 3, 5). The Neighborhood Statistics function in Spatial Analyst was used to calculate a mean TRI for a 3 x 3 pixel template of TRI values centered over each pixel in the image.
- The total areas of classes were calculated using the Histogram Tool in Spatial Analyst. This tool reports the number of pixels in each ruggedness class on the image. Average changes in elevation were shown in ten-centimeter increments in the 0.3 to 1.0 meter range (Fig. 4); in half-meter increments in the 1.0 to 2.0 meter range (Fig. 6); and in one-meter increments in the 2.0 to >6.0 meter range (Fig. 7). Total areas for each class can be determined by multiplying the number of pixels in the class by the image pixel size of 13 meters x 13 meters. Area statistics for classes in the Stellwagen Bank NMS region were totaled and entered into Table 1.

Reference: Riley, S.J., DeGloria, S.D., and Elliot, R., 1999, A terrain ruggedness index that quantifies topographic heterogeneity: Intermountain Journal of Sciences, Vol. 5, No 1-4, p. 23-27.

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 analysis of seabed ruggedness for an area of 3759 sq km. Sun elevation and angle are 45 degrees and 350 degrees, respectively.
- The Terrain Ruggedness Index (TRI) calculates the average difference in elevation between a small area (a central pixel of 13 x 13 m) and its surrounding area (8 neighboring pixels).

1	2	3
4		5
6	7	8

- In order to delineate small features from large features, average differences in seabed elevation are shown on the map as follows: in 10-cm increments in the >0.3 to 1 m range
in 50-cm increments in the >1 to 2 m range
in 100-cm increments in the >2 to 6 m range

SEA FLOOR RUGGEDNESS INDEX, centimeters

0-30	>30-40	>40-50	>50-60	>60-70	>70-80	>80-90	>90-100	>100-150	>150-200	>200-300	>300-400	>400-500	>500-600

10-cm intervals | 50-cm intervals | 100-cm intervals

- Gray tones on the map have low TRIs of 0 to 30 cm.
- TRIs in the >0.3 to 1 m range (Fig. 4) represent small scale features such as: boulder ridges; mud-draped gravel mounds; elongate iceberg scours; sand dunes; and gentle slopes of banks, valleys, and basins.
- TRIs in the >1 to 2 m range (Fig. 6) represent flanks of banks and bedrock hills and a few boulder ridges.
- TRIs in the >2 to 6 m range (Fig. 7) represent the steepest flanks of banks and bedrock hills.
- The resolution of bathymetric data determines the resolution of seabed features that can be recognized using TRI analysis. TRIs derived from 13-meter pixel data are not comparable with TRI values of the same magnitude derived from 10-meter pixel data.
- Seabed terrains with similar TRIs do not necessarily represent similar bottom types. See the companion "Boulder Ridges and Bedrock Outcrops" poster.
- Without supporting video and photographic imagery, the Terrain Ruggedness Index does not allow reliable interpretation or comparison of seabed features.

SEABED RUGGEDNESS OF TILLIES BANK

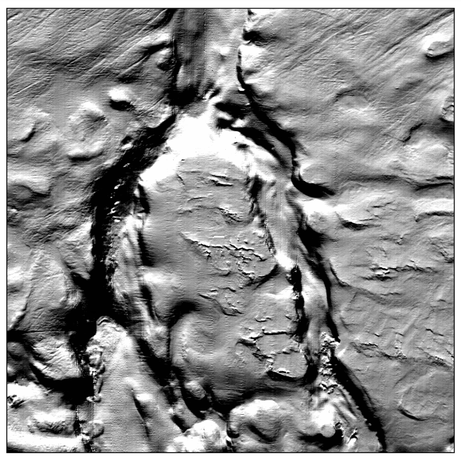


Figure 2: Sun-illuminated topography of the northern part of Tillies Bank showing rugged glaciated terrain. Vertical exaggeration 4x. Scale 1:60,000.

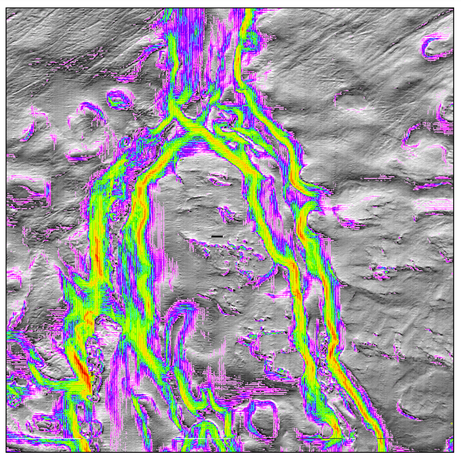


Figure 3: Sun-illuminated topography of the northern part of Tillies Bank with Terrain Ruggedness Indices (TRIs) before removal of artifacts with a "mean" filter. Compare to Figure 5.

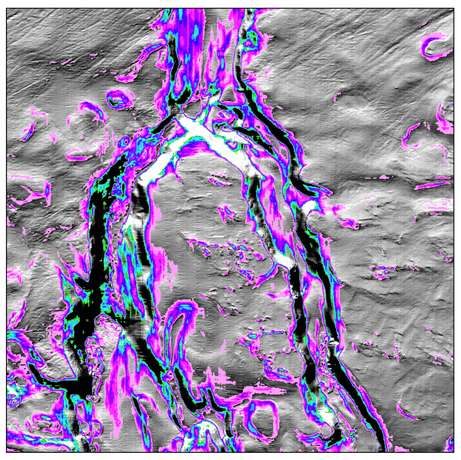


Figure 4: Sun-illuminated topography of the northern part of Tillies Bank with Terrain Ruggedness Indices (TRIs) representing average changes in elevation in 10-cm increments in the 30 to 100 cm range. Boulder ridges are the dominant features on the top of the bank. Most boulder ridges in the Stellwagen Bank NMS region have TRIs in the 30 to 100 cm range.

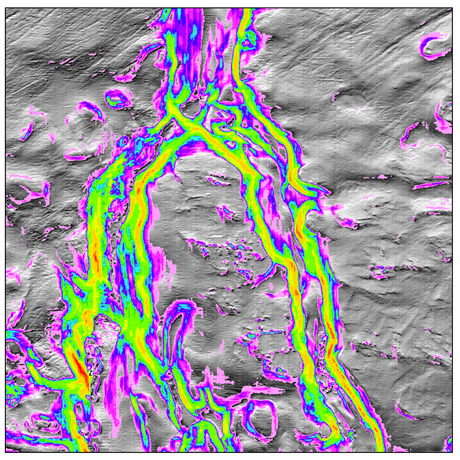


Figure 5: Sun-illuminated topography of the northern part of Tillies Bank with Terrain Ruggedness Indices (TRIs) after removal of artifacts with a "mean" filter. Compare to Figure 3.

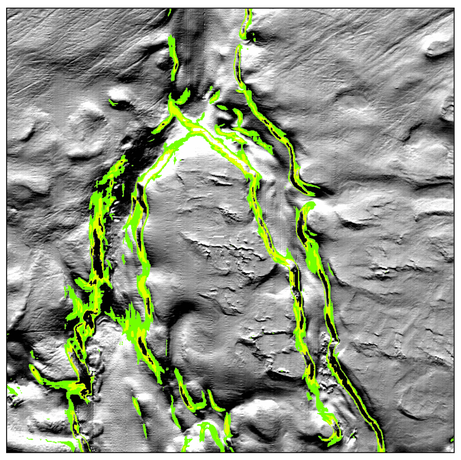


Figure 6: Sun-illuminated topography of the northern part of Tillies Bank with Terrain Ruggedness Indices (TRIs) representing average changes in elevation in 50-cm increments in the 100 to 200 cm range. There are only a few boulder ridges in the image with TRIs in the 100 to 200 cm range.

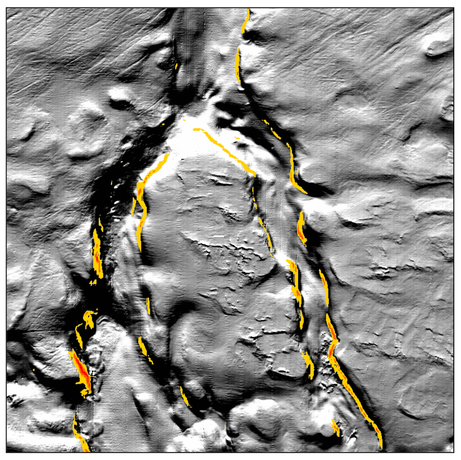


Figure 7: Sun-illuminated topography of the northern part of Tillies Bank with Terrain Ruggedness Indices (TRIs) representing average changes in elevation in 100-cm increments in the 200 to 600 cm range. They are located on the steepest flanks of the bank and adjacent valleys. There are no boulder ridges with TRIs in this range.