



# **Sidescan Sonar Imagery, Multibeam Bathymetry, and Surficial Geologic Interpretations of the Sea Floor in Rhode Island Sound, off Sakonnet Point, Rhode Island**

By Katherine Y. McMullen, Lawrence J. Poppe, Erin R. Twomey, William W. Danforth, Todd A. Haupt, and James M. Crocker

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# Contents

Contents.....	iii
Introduction .....	1
Geologic Setting.....	1
Data Acquisition and Processing.....	2
Bathymetry .....	3
Sidescan Sonar Imagery .....	3
Rocky and Bouldery Areas.....	3
Sand-wave Fields.....	3
Hummocky Areas.....	4
Tabular Erosional Outliers.....	4
Small Hills and Scarps .....	5
Trawl Marks.....	5
Sedimentary Environments .....	5
Erosion or Nondeposition.....	5
Coarse-Grained Bedload Transport .....	6
Sorting and Reworking.....	6
Discussion.....	6
Summary.....	7
GIS Data Catalog .....	7
Sidescan Sonar Imagery.....	8
Bathymetric Imagery .....	8
Bathymetric Grids.....	9
Interpretive Data.....	9
Basemap Data .....	9
Acknowledgements .....	9
Contacts .....	10
References Cited .....	11

# Figures

<b>Figure 1.</b> Location map of NOAA Survey H11320 (red polygon) in Rhode Island Sound. Location of stratigraphy profile A-A' from figure 3 is also shown. ....	13
<b>Figure 2.</b> Location of figures (red polygons), bathymetric profiles (green lines), historic seismic-reflection profiles (blue lines, O'Hara and Oldale, 1980), and sand (yellow circles) and rocky (red circle) sediment samples (Poppe and others, 2003) within the study area. ....	14
<b>Figure 3.</b> Interpreted stratigraphy of Rhode Island Sound from O'Hara and Oldale (1980). Acoustic units include: PzZ - Proterozoic to Paleozoic bedrock, Ku - Cretaceous coastal plain sediments, Qdo - Wisconsin glacial drift deposits, Qdm - Buzzards Bay moraine deposits, Qfe - Holocene fluvial and estuarine deposits, and Qm - Holocene quiet-water marine deposits. Boundaries are dashed where inferred. Vertical exaggeration: 40X. Location of stratigraphy profile shown as A-A' in figure 1. ....	15
<b>Figure 4.</b> Map showing the location of end moraines (solid black polygons) in southern New England and New York. The Ronkonkoma-Nantucket moraine shows the maximum extent of the Laurentide ice sheet 20 ka, while the Harbor Hill-Roanoke Point-Charlestown-Buzzards Bay moraine shows a retreated position of the ice sheet around 18 ka (Uchupi and others, 1996).	

Submarine ridges (dotted lines) mark the underwater extensions of the moraines. H11320 study area shown as a gray polygon. Modified from Gustavson and Boothroyd (1987). ..... 16

**Figure 5.** Photo of NOAA Ship RUDE (courtesy of NOAA). ..... 17

**Figure 6.** Hill-shaded bathymetry of the study area. Four areas outlined in black show multibeam bathymetry from H11320, while the rest of the bathymetry is from the NGDC Coastal Relief Model. Multibeam bathymetric data have been gridded at 4 m and depths represent mean lower low water level in multibeam data and either mean low water or mean lower low water in Coastal Relief Model data (Divins and Metzger, n.d.). ..... 18

**Figure 7.** Sidescan sonar imagery of NOAA Survey H11320. Darker regions represent low backscatter and generally finer grained sediments; lighter regions represent high backscatter and generally coarser grained sediments. .... 19

**Figure 8.** Interpretation of sidescan sonar imagery and multibeam bathymetry showing areas of rocky and gravelly sediment, sand waves and crest orientations, sediment transport direction, hummocky sea floor, tabular erosional outliers, small hills and scarps, and trawl marks. .... 20

**Figure 9.** Detailed sidescan sonar imagery and bathymetry illustrating the relatively smooth central basin floor scattered with rocks and boulders in the south and adjacent ridge to the north. Sand waves are located on the ridge and a scarp crosses the ridge in an east-west direction. Sand waves have curved crests oriented east-west and wavelengths of 40 to over 100 m in the west and about 50 m in the east. High-resolution multibeam bathymetry has been overlaid on bathymetry from the NGDC Coastal Relief Model. Figure location is shown in figure 2. .... 21

**Figure 10.** Bathymetric profiles of sand waves showing slip faces oriented northward. Profile C-C' is of sand waves in the eastern field of east-west oriented crests, which have wavelengths of about 50 m. Profile D-D' is of sand waves in the northwestern corner of the study area where wavelengths are also about 50 m. Location of profiles shown in figure 2. .... 22

**Figure 11.** Detailed view of sidescan sonar imagery showing mottled backscatter and corresponding bathymetry. Mottled backscatter in the sidescan sonar data is caused by the hummocky surface of moraines and glacial till inconsistently reflecting backscatter due to the variable topography and sediment distribution. Note: black line outlines high-resolution multibeam bathymetry which overlies bathymetry from the Coastal Relief Model. Figure location is shown in figure 2. .... 23

**Figure 12.** Sidescan sonar imagery and Boomer seismic-reflection profile (O'Hara and Oldale, 1980) and interpretation through an area of mottled backscatter. Right side of sidescan sonar image shows mottled backscatter (top image). Seismic profile shows Cretaceous coastal plain sediments overlain by Wisconsin glacial drift and Holocene fluvial and estuarine sediments. Mottling tends to occur in areas where glacial moraine sediments are either exposed or near the surface. Vertical exaggeration: 13X. Depths are based on the assumed compressional wave velocity of 1500 m/s. Location of seismic line shown in figure 2. .... 25

**Figure 13.** Detailed area of sidescan sonar image showing low-backscatter targets. These features show no relief in the bathymetry data and are thought to be patches of fine-grained sediment within larger areas of coarser grained sediment. Figure location shown in figure 2. .... 26

**Figure 14.** Detailed view of sidescan sonar imagery and corresponding hill-shaded bathymetry showing tabular erosional outliers. Curvilinear shadows in the sidescan sonar imagery correspond to the outline of small plateaus in the bathymetry. Boulders are visible in both images, on the sidescan sonar imagery as light-toned targets with dark shadows and within the bathymetry as dark targets. The area of boulders in the lower right corner of both images shows an exposure of till. Lighter backscatter between the erosional outliers is from coarse-grained, bouldery sediment. Images are in UTM. Location of figure shown in figure 2. .... 27

**Figure 15.** Sidescan sonar imagery, Boomer seismic-reflection profile (O'Hara and Oldale, 1980), and interpretation through an area of tabular erosional outliers. Top image shows location of the seismic profile on the sidescan sonar data and erosional outliers in the center. Lower images of seismic profile and interpretation show stratified sediments, possibly from a small glacial lake or pond, below the erosional outliers. Note irregular sea floor and estuarine sediments above laminations, likely due to prior erosion of lacustrine sediments. Boulders can be seen rising above the sea floor. Vertical exaggeration: 16X. Depths are based on the assumed compressional wave velocity of 1500 m/s. Figure location shown in figure 2. ....28

**Figure 16.** Bathymetric profiles across study area from north to south. Location of profiles shown in figure 2. Profile A-A', located in the southwestern part of the study area, crosses a bathymetric high with deeper basins to the north and south. Profile B-B', located in the eastern part of the study area, crosses a bathymetric high in the north, central basin, and moraine in the south. Arrows point to changes in slope interpreted to represent paleoshorelines. ....30

**Figure 17.** Sidescan sonar imagery, Boomer seismic-reflection profile (O'Hara and Oldale, 1980), and interpretation of an area with small scarps of outcropping strata. Top image shows scarp and location of seismic line on sidescan sonar mosaic. Bottom images of seismic line and interpretation show Pleistocene glacial drift overlain by Holocene fluvial and estuarine sediments. The small scarp displayed within the sidescan sonar mosaic is presumed to correspond to the prominent reflector between the fluvial sediments and glacial drift as it nears the surface. Vertical exaggeration: 15X. Depths are based on the assumed compressional wave velocity of 1500 m/s. Location of seismic line shown in figure 2.....31

**Figure 18.** Detailed view of sidescan sonar imagery showing long lines of low backscatter interpreted to be trawl marks from fishing boats. Figure location is shown in figure 2.....33

**Figure 19.** Map showing sedimentary environments in study area characterized by erosion or nondeposition, coarse-grained bedload transport, and sorting and reworking. ....34

## Conversion Factors

Multiply	By	To obtain
Length		
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
Area		
square kilometer (km <sup>2</sup> )	247.1	acre

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83). Vertical datum, as used in this report, refers to mean lower low water.

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## **Introduction**

The U.S. Geological Survey (USGS) is working with the National Oceanic and Atmospheric Administration (NOAA) to interpret the surficial geology in estuaries and sounds along the northeastern coast of the United States. This report interprets the area covered by NOAA Survey H11320, about 72 km<sup>2</sup> of sea floor in eastern Rhode Island Sound (RIS), located about 8 km south of Sakonnet Point, Rhode Island (fig. 1). Previous work in RIS includes studies of both sea-floor processes and subsurface geologic framework. McMaster (1960) mapped surficial sediment samples in Narragansett Bay and RIS and McMaster and others (1968) conducted a seismic-reflection survey in Block Island Sound and RIS. O'Hara and Oldale (1980) collected seismic-reflection profiles, sidescan sonar data, and vibracores in eastern RIS (fig. 2). They interpreted the geologic history, assessed sand and gravel resources, and evaluated the mining impact of these resources. McMaster's (1960) interpretation of the surficial sediment within this study area consisted of sand with several isolated areas of gravel. Several other sediment samples were previously obtained within the study area: three National Oceanographic Data Center (NODC) dredge samples from 1942 consisted of sand and one National Ocean Service (NOS) sample from 1939 was rocky (fig. 2; Poppe and others, 2003). The purpose of this report is to define the sea-floor morphology and sedimentary environments and interpret processes occurring on the sea floor using sidescan sonar imagery, multibeam bathymetry, and historic seismic-reflection profiles.

## **Geologic Setting**

Rhode Island Sound (RIS) is located offshore of Rhode Island and southeastern Massachusetts between Block Island and Martha's Vineyard (fig. 1). It covers an area of over 2500 km<sup>2</sup> to the east of Block Island Sound and reaches depths of about 60 m.

The stratigraphy underlying RIS is composed of a Proterozoic to Paleozoic basement of gneiss and schist with pegmatite and granitic intrusives, overlain by Upper Cretaceous coastal plain and continental shelf sediments in the south and Wisconsin glacial deposits throughout the region, topped by Holocene estuarine and marine sediments (fig. 3; McMaster and others, 1968; O'Hara

and Oldale, 1980). A cuesta formed from the northern terminus of the Upper Cretaceous sediments crosses the southern part of the study area (O'Hara and Oldale, 1980). The uppermost Wisconsin glacial deposits and Holocene sediments are further subdivided based on our interpretations of seismic-reflection data and those of O'Hara and Oldale (1980).

The surficial geology in the study area consists of glacial drift, including moraine, outwash and glaciolacustrine deposits, and fluvial and estuarine sediments. Two end moraines cross RIS and are evident as bands of gravelly sediment and submarine ridges (fig. 4; McMaster, 1960). The Ronkonkoma-Nantucket Moraine represents the maximum extent of the Laurentide ice sheet at around 20 ka (Uchupi and others, 2001). The Harbor Hill-Roanoke Point-Charlestown-Buzzards Bay Moraine represents the retreated ice sheet position at about 18 ka (Uchupi and others, 2001). The southwestern segment of the Buzzards Bay Moraine, which crosses the southern part of our study area, is thought to be composed of proglacial deltaic and lacustrine sediments capped by a thin subglacial till, similar to the Buzzards Bay Moraine (Oldale and O'Hara, 1978; O'Hara and Oldale, 1980). Offshore, the moraines in RIS are capped by a lag deposit of sand, gravel, and boulders resulting from winnowing of the till by marine processes (O'Hara and Oldale, 1980). The northern part of the study area has patches of exposed glacial drift and outwash plain deposits of sands and gravels as well as glaciolacustrine silts and clays, thought to be deposited by meltwater streams from the Buzzards Bay ice lobe (O'Hara and Oldale, 1980) or from the drainage of Lake Cape Cod Bay (Uchupi and others, 2001). Much of our study area was mapped by O'Hara and Oldale (1980) as having a surface consisting of Holocene fluvial and estuarine deposits of sands, gravels, and muds up to 16 m thick. The fluvial sediments were deposited during subaerial exposure of the shelf after glacial retreat and during the drainage of glacial lakes, while estuarine sediments were deposited during the northward transgression of the shoreline across the sound.

## **Data Acquisition and Processing**

Sidescan sonar and multibeam bathymetric data were acquired by NOAA in 2004, during Survey H11320, aboard the NOAA Ship RUDE (fig. 5). A Klein 5500 towfish transmitting at 455-kHz and Triton-Elics ISIS software were used to acquire sidescan sonar data and to archive the data in extended Triton format (XTF). All sidescan sonar data were processed using USGS sidescan sonar processing software packages XSonar and ShowImage. A median filtering routine was applied to the sidescan sonar data to remove speckle noise, resulting in a 0.06-m pixel size. Time-varied gain was applied to sonar data collected on Julian Day 118 and 133 (year 2004), as the dynamic range of these data were low. Sonar data were further processed to correct for slant-range and radiometric distortion inherent in the sonar data. All processed data were mosaicked using XSonar, resulting in an enhanced, geographically correct, sidescan sonar mosaic with 1 meter/pixel resolution. The mosaic was converted to a TIFF image, which was imported into Adobe Photoshop CS2 in order to apply a 'stretch' (i.e. increase the dynamic range of the data) to the image. Within the sidescan sonar imagery light tones represent strong acoustic reflectivity (generally coarser grained sediment) and dark tones represent weak acoustic reflectivity (generally finer grained sediment).

A Reson SeaBat 8125, which operates at 455-kHz, was used to acquire multibeam bathymetric data in areas with possible navigational hazards and along several tie-lines. Multibeam data were processed using CARIS HIPS/SIPS software. Four large areas of complete multibeam bathymetry coverage, totaling 20 km<sup>2</sup>, were separated from the tie-lines and single-beam bathymetric data that were included in the survey's grid, as the single-beam data were vertically offset from the multibeam data. The four areas of multibeam data were gridded at 4-m resolution.

Bathymetry from the Coastal Relief Model created by the National Geophysical Data Center (NGDC) is used in the study area to provide rough bathymetry on which the higher resolution multibeam bathymetry can be overlaid (Divins and Metzger, n.d.). The NGDC Coastal Relief Model bathymetry data from around the study area were downloaded as an ASCII raster grid and converted to a GeoTIFF and Generic Mapping Tools (GMT) grid using FWTools. The GMT grid was resampled at 4 meters and converted back to an ASCII grid and finally a GeoTIFF. Sidescan sonar and bathymetry data were converted to geographic coordinates.

O'Hara and Oldale (1980) collected 670 km of seismic-reflection data in eastern Rhode Island Sound and Vineyard Sound with an EG&G Unit Pulse Boomer during 1974 and 1975, about 30 km of which are within this study area (fig. 2). The transducer was triggered every 0.5 second and the sweep rate was 0.25 second. Seismic-reflection data has 1-1.5 m resolution.

## **Bathymetry**

The bathymetry in the study area consists of basins and ridges with an overall southerly slope (fig. 6). A rounded central basin reaches a depth of about 31 m, while the deepest area is in the southwestern corner of the survey and reaches depths of about 36 m. The basins are surrounded by ridges, with up to 8 m of relief, which coincide with exposures of glacial drift including glaciolacustrine sediments and moraine deposits in the south (O'Hara and Oldale, 1980). Ridges tend to be covered with sand waves, a channel-eroded morphology, or composed of tabular erosional outliers, while the basins tend to have a smooth sea floor with boulders, which are present throughout much of the study area. In the southeast, ridges composed of moraine deposits are oriented northeast-southwest.

## **Sidescan Sonar Imagery**

Bathymetric, seismic-reflection, and sediment data were used to help interpret the sidescan sonar imagery (fig. 7). Six distinctive acoustic backscatter patterns are evident in the sidescan sonar imagery (fig. 8). These patterns delineate rocky and bouldery areas, sand-wave fields, hummocky areas, tabular erosional outliers, small hills and scarps, and trawl marks.

## **Rocky and Bouldery Areas**

Clustered, individual, high-backscatter targets with low-backscatter shadows are widespread throughout the region and are interpreted to be rocky and/or bouldery areas (fig. 9). Some boulders in the study area exceed 10 m in width. The largest areas of rocks and boulders are located in the southeastern, central, and northeastern parts of the study area, and are present both on ridges and in basins.

## **Sand-wave Fields**

Areas of tiger-striped backscatter occur across much of the northern half of the study area and an area near the center of the survey. These areas tend to occur on bathymetric highs in areas of relatively high backscatter and are interpreted to be fields of sand waves (fig. 9). Most of the sand-wave fields are about 1-2 km<sup>2</sup> in area, though one field is over 6 km<sup>2</sup>. A sand-wave field with straight to curved, north-south oriented crests is located in the northeastern corner of the survey. The wavelengths are 10-30 m and are nearly symmetrical. The sand waves in the north-central field have mostly curved and some straight crests that are east-west oriented and have wavelengths of 40



m to over 100 m. Between these two sand-wave fields are sand waves with curved, east-west oriented crests with wavelengths of about 50 m (fig. 9). The slip faces of these waves are oriented toward the north, suggesting a northward sediment transport direction (fig. 10). Another field of sand waves with curved, east-west oriented crests (though some are north-south oriented) is located in the northwest. The bathymetry shows the waves in the northwestern corner have slip faces oriented toward the north (fig. 10). In the north-central part of the study area there are two small sand-wave fields, each less than 0.1 km<sup>2</sup> in area, of sinuous crested waves oriented to the northeast with wavelengths of several meters. The sand waves in the center of the study area have curved crests oriented to the east-northeast.

## **Hummocky Areas**

In the south, north-central, and northeastern corner of the study area, a mottled backscatter pattern appears in the sidescan sonar imagery (fig. 11). The mottled areas in the south-central part of the study area appear in the bathymetry as mounds up to about 1 m in height and generally less than 100 m in width. The mottling covers areas as large as 7 km<sup>2</sup> and tends to coincide with exposures of a glacial moraine in the south and till deposits in the north (fig. 12). Mottled areas around the moraine in the southeast correspond to bathymetry that is cut by channels up to 1 m deep (fig. 11). The most prominent channels are oriented to the west, south, and south-southwest. The northeastern corner of the sidescan sonar imagery shows mottled backscatter corresponding to variable bathymetry. The mottling is interpreted to indicate a hummocky, erosional surface.

Within an area of mottled backscatter along the southern edge of the study area near the southwestern basin is an area with oblong to round, low-backscatter targets (fig. 13). The low-backscatter targets have sharp boundaries and look like acoustic shadows; however, there are no high-backscatter objects to create acoustic shadows. The low-backscatter targets are generally less than 10 m in width and around 10-40 m in length. If these features have relief, it is below the resolution of the multibeam bathymetry and the seismic-reflection data. Rocks and boulders are generally not located within the area of these features, but they exist to the north and east of the area. These features are seen to cross multiple track lines. They are inferred to be caused by patches of fine-grained sediment located within areas of coarser grained sediment.

## **Tabular Erosional Outliers**

The sidescan sonar imagery shows two areas, in the western and eastern parts of the study area, with varied high and low backscatter, while the corresponding bathymetry consists of small plateaus up to several hundred meters across and about 0.5 m high (fig. 14). The western area covers almost 4 km<sup>2</sup> and the eastern area covers about 0.5 km<sup>2</sup>. The plateaus in the eastern part of the study area are eroded by a southerly oriented channel complex. Sidescan sonar data show that in the western area, the tops of the plateaus have lower backscatter and finer grained sediment, whereas the sea floor between the plateaus has higher backscatter and coarser grained, gravelly and bouldery sediment. Seismic data show horizontally stratified sediments that underlie the plateaus and areas to the northwest, which influence the bathymetry of the estuarine surface sediments (fig. 15). The plateaus differ from hummocky areas in that the individual plateaus are larger in area, they have flatter tops, a more drastic change in slope on their sides, and the plateaus are fine-grained with coarse-grained sediment between them.

The plateaus are interpreted to be tabular erosional outliers composed of stratified glacial drift that is inferred to be cohesive glaciolacustrine sediment. The glaciolacustrine sediment onlaps till that is exposed to the southeast of the erosional outliers. Till, containing boulders up to 16 m in

width, is also exposed between the erosional outliers where the thin lake sediments have been eroded away.

## **Small Hills and Scarps**

Discontinuous, curvilinear features of high and low backscatter with sharp boundaries are evident in the sidescan sonar imagery around the edges of the bathymetric lows (fig. 9). The patterns are oriented mostly east-west, perpendicular to the slope and askew to the ship track. Bathymetry in these areas show small hills, up to 0.5 m in height and, in the southwest, a change in slope from less than 0.5 degree to 3 degrees where the features are present (fig. 16). These features are up to 2.5 km long and occur in water depths of 24-27 m in the northeast and 30-35 m in the southwest. The low-backscatter curvilinear features appear to be produced by small, erosional scarps and small, elongate hills on the sloped sea floor. Scarps cause a sharp change in backscatter where the slope changes. The elongate hills run perpendicular to the general slope and create low-backscatter acoustic shadows where they are roughly parallel to the ship track, accounting for the sharp contrasts in backscatter.

Because the hills and scarps in the sidescan sonar imagery tend to coincide with fluvial deposits and drift deposits that have reflectors terminating near the surface (fig. 17) we infer that these paired features were formed by outcropping strata, which are more resistant to erosion than the surrounding sediments. Since these features tend to parallel the bathymetry and are located at depths similar to those of paleoshorelines described in nearby areas, they may mark paleoshorelines.

## **Trawl Marks**

Anthropogenic features are also visible in the sidescan sonar imagery. The central, northeastern, and southwestern areas of the study area contain several long, thin, straight lines of low backscatter, which are interpreted to be trawl marks from fishing boats (fig. 18). They range in length from about 100 m to 1 km.

## **Sedimentary Environments**

The present day sea floor in the study area is interpreted to contain three sedimentary environments characterized by the processes of erosion or nondeposition, coarse-grained bedload transport, and sorting and reworking (fig. 19). These environments are delineated using interpretations of the sidescan sonar, bathymetric, and seismic-reflection data. The boundaries of the sedimentary environments are gradational and borders are inferred.

### **Erosion or Nondeposition**

Environments characterized by erosion or nondeposition, which dominate the sea floor in the study area, are distinguished by the presence of rocks and gravel, tabular erosional outliers, or a hummocky surface. These processes are prevalent on the moraine and flanks of the ridges. These high-energy areas are exposed to currents that winnow away finer grained sediments and leave a coarser grained lag.

## Coarse-Grained Bedload Transport

Environments characterized by coarse-grained bedload transport are located where sand waves are present, which occurs mostly in the northern parts of the study area. The orientations of sand wave crests are generally east-west and tend to parallel the bathymetric contours. In two sand-wave fields the slip faces are oriented northward, suggesting this is the direction of sediment transport. Currents are most likely flowing into and out of the central basin across the northern ridge.

## Sorting and Reworking

Environments characterized by the processes of sorting or reworking are located in the central and western basins and on parts of the northern ridges. These areas have moderate backscatter and lack sand waves and gravelly sediment as indicated in the interpretations of the sidescan sonar imagery. There does not seem to be any fine-grained deposition of sediment in the study area as McMaster (1960) interpreted the area to be sandy with some areas of gravel. Thus, sediments are interpreted to be undergoing processes of sorting and reworking in areas that lack characteristics of erosion and coarse-grained bedload transport.

## Discussion

Erosional outliers and small hills and scarps are distinct features in the study area that have not been previously mapped. They are interpreted to have formed from the deposition of glacial lake sediments and from the erosion of paleoshorelines as sea level transgressed northward.

Glaciolacustrine sediments are thought to have been deposited in the study area during recession of the Laurentide ice sheet. Some theories for the origin of glaciolacustrine sediment in RIS include transport and deposition of the sediment by meltwater streams (O'Hara and Oldale, 1980) or by the catastrophic drainage of glacial lakes (Uchupi and others, 2001). However, in this area, the presence of up to 15 m of stratified drift associated with erosional outliers of cohesive sediments indicates that these are glaciolacustrine sediments deposited in situ. Stratified glaciolacustrine sediments are located in what was likely the ice-distal side of the lake where water energy was low and fine-grained sediment could settle. Stratification of the lake sediments tends to fade to the northwest (fig. 15), suggesting higher energy and ice-proximal environments lay in that direction. Erosion of the till and glaciolacustrine sediment probably occurred during lake drainage and subaerial exposure prior to marine incursion.

After glacial recession, when sea level was at a lower stand than at present, much of what is now Rhode Island Sound was subaerially exposed. As sea level rose, shorelines moved northward across the area, depositing and eroding features in the sea floor. The hills and small scarps in our study area are probably erosional features formed as wave-cut terraces in paleoshorelines that have been preserved because of the sediment's high cohesiveness. The paleoshoreline features at 24-27 m probably formed 8.4-8.7 ka and the features at 30-35 m probably formed between 9.0-9.8 ka based on a sea-level-rise curve for southeastern Massachusetts (Oldale and O'Hara, 1980).

Depositional paleoshoreline features have been found in other areas near RIS. Profiles of a paleoshoreline located about 24 m below present sea level near Block Island, thought to be from 8.3-9 ka, consist of barrier spit, lagoon, and headland features as well as terraces (McMaster and Garrison, 1967). These features are similar to, although larger than the profiles of the hills and scarps in RIS. A drowned spit off Cape Ann, MA with seaward-dipping reflectors marks a sea level 50 m below present (Oldale, 1985). Though the hills in our study area are similar in profile to the

spits, they are not distinct seismic units with dipping reflectors and they are only about 0.5 m in height on the upslope side. If there were spits or other depositional features associated with the paleoshorelines in RIS, then they would probably not have been preserved owing to their small size. Other previously described paleoshorelines in the region are composed of erosional and depositional features. Paleoshorelines in Long Island Sound, lying under about 15 m of estuarine deposits, show planar, terraced surfaces with lens-shaped seismic units and erosional steps or scarps (Gayes and Bokuniewicz, 1991). The paleoshorelines in Long Island Sound mark shorelines at depths including 25-27 m, thought to have formed 8.5-9 ka, 30 m, and 37-38 m, thought to have formed 10-10.5 ka (Gayes and Bokuniewicz, 1991). South of our study area, on the continental shelf, Garrison and McMaster (1966) found wave cut terraces with scarps and a ridge and depression topography interpreted to be barrier beaches and lagoons that occur at depths including 24 m. Because of their similar depth, we believe that the terraces near Block Island described by McMaster and Garrison (1967) and those on the continental shelf described by Garrison and McMaster (1966) are coeval with the paleoshoreline features at 24-27 m within the study area.

## Summary

An analysis of sidescan sonar data together with bathymetric and seismic-reflection data indicate six backscatter features in the study area including: rocky and bouldery areas, sand-wave fields, hummocky areas, tabular erosional outliers, small hills and scarps, and trawl marks. The bathymetry in the study area is composed of basins in the central and southwestern areas that have a relatively smooth sea floor aside from boulders, which are ubiquitous. Ridges around the basins are composed of glacial drift and have surfaces characterized by sand waves, a hummocky morphology, and erosional outliers (fig. 8). Sand wave fields are mostly located on the northern ridges and wave crests are roughly perpendicular to the slope. The moraine and areas of exposed till have a hummocky erosional surface. Tabular erosional outliers probably consist of cohesive glaciolacustrine sediment deposited in situ. Erosional scarps and small elongate hills, which parallel bathymetric contours and occur at depths similar to paleoshorelines in the region, were probably formed from outcropping strata that are resistant to erosion. Trawl marks are also evident. Sedimentary environments characterized by erosion or nondeposition are located on the moraine and the flanks of the ridges. Processes associated with coarse-grained bedload transport are prevalent along the northern regions; environments characterized by processes associated with sorting and reworking occur variously throughout the region where there are no sand waves or rocky areas.

## GIS Data Catalog

This report contains several data layers (or themes) that show bathymetry and sidescan sonar imagery of Rhode Island Sound. GeoTIFFs produced from grids of the NOAA sidescan sonar and multibeam echo sounder surveys and NGDC Coastal Relief Model are provided in geographic and universal transverse mercator projections, along with the multibeam grids. Available vector data consists of a polygon data layer, nos80k\_84 that provides the coastline for the Rhode Island Sound GIS project area.

Data layers are provided with geographic coordinates to allow the data to be integrated into a Geographic Information System (GIS). Data layers archived here do not require additional processing to be utilized within the Environmental Systems Research Institute's (ESRI) ArcView and ArcGIS software. This does not mean that a user will not wish to do additional processing,

especially if utilizing a different GIS software package or spheroid, but that it is not necessary to do additional processing simply to utilize the data in its minimum archive format.

For those who do not have the ESRI software or a compatible GIS data browser available on their computer, a free viewer, ArcExplorer, is available from ESRI. Please note that the ArcExplorer software is limited to Microsoft Windows operating systems. The key functionality of ArcExplorer is the viewing of spatial data. The user will need to add the selected data layers by using ArcExplorer's add data button.

Each GIS data layer from this publication is cataloged below for easy access. The individual data layers are described below and include the GeoTIFF, grid, or shapefile name (e.g. h11320\_geo\_4m) which is linked to a browse graphic showing the data layer extent and coverage. Selecting the data layer name will result in the browse graphic being displayed in a separate browser window.

Federal Geographic Data Committee (FGDC) metadata for the individual data layers is provided in a text version. Selecting associated metadata files from the table below will open the information in a new browser window.

A 'zip' compressed, downloadable archive file containing the components of the ESRI shapefile for each data layer is also provided. Compressed downloadable files were created using the Windows program WINZIP v9.0. For those users who do not have software capable of uncompressing the archived zip files, they may obtain a free version of the software from Winzip Computing, Inc. or Pkware, Inc.

## Sidescan Sonar Imagery

Data Layer Name and Description	Metadata	Files
<b>h11320_1m_sss_geo_en</b> - inverted and enhanced sidescan sonar imagery of NOAA survey H11320 (geographic)	HTML FAQ txt	zip
<b>h11320_1m_sss_geo</b> - composite sidescan sonar imagery of NOAA survey H11320 (geographic)	HTML FAQ txt	zip
<b>h11320_1m_sss_utm_en</b> - inverted and enhanced sidescan sonar imagery of NOAA survey H11320 (UTM zone 19, NAD83 spheroid)	HTML FAQ txt	zip
<b>h11320_1m_sss_utm19</b> - composite sidescan sonar imagery of NOAA survey H11320 (UTM zone 19, NAD83 spheroid)	HTML FAQ txt	zip

## Bathymetric Imagery

Data Layer Name and Description	Metadata	Files
<b>h11320_geo_4m.tif</b> - multibeam echo sounder data from NOAA survey H11320 (geographic)	HTML FAQ txt	zip
<b>ris_cr_geo_4m.tif</b> - NGDC Coastal Relief Model bathymetric imagery (geographic)	HTML FAQ txt	zip

<b>h11320_utm_4m.tif</b> - multibeam echo sounder data from NOAA survey H11320 (UTM zone 19, NAD83 spheroid)	HTML FAQ txt	zip
<b>ris_cr_utm_4m.tif</b> - NGDC Coastal Relief Model bathymetric imagery (UTM zone 19, NAD83 spheroid)	HTML FAQ txt	zip

## Bathymetric Grids

Data Layer Name and Description	Metadata	Files
<b>h11320_geo_4m</b> - multibeam bathymetric grid of NOAA survey H11320 (geographic)	HTML FAQ txt	zip
<b>h11320_utm_4m</b> - multibeam bathymetric grid of NOAA survey H11320 (UTM zone 19, NAD83 spheroid)	HTML FAQ txt	zip
<b>h11320_1m_UTM19NAD83.txt</b> - space delimited ASCII text file of the bathymetric grid of NOAA survey H11320 (UTM zone 19, NAD83 spheroid)	HTML FAQ txt	zip

## Interpretive Data

Data Layer Name and Description	Metadata	Files
<b>h11320environs</b> - interpretation of the sedimentary environments in NOAA survey H11320 (geographic)	HTML FAQ txt	zip
<b>h11320interp</b> - interpretation of the sidescan sonar and bathymetric imagery from NOAA survey H11320 (geographic)	HTML FAQ txt	zip

## Basemap Data

Data Layer Name and Description	Metadata	Files
<b>nos80k_84</b> - medium resolution digital vector U.S. shoreline shapefile for the Rhode Island Sound GIS project area (geographic)	HTML FAQ txt	zip
<b>h11320outline</b> - outline of sidescan sonar imagery from NOAA Survey H11320 (geographic)	HTML FAQ txt	zip

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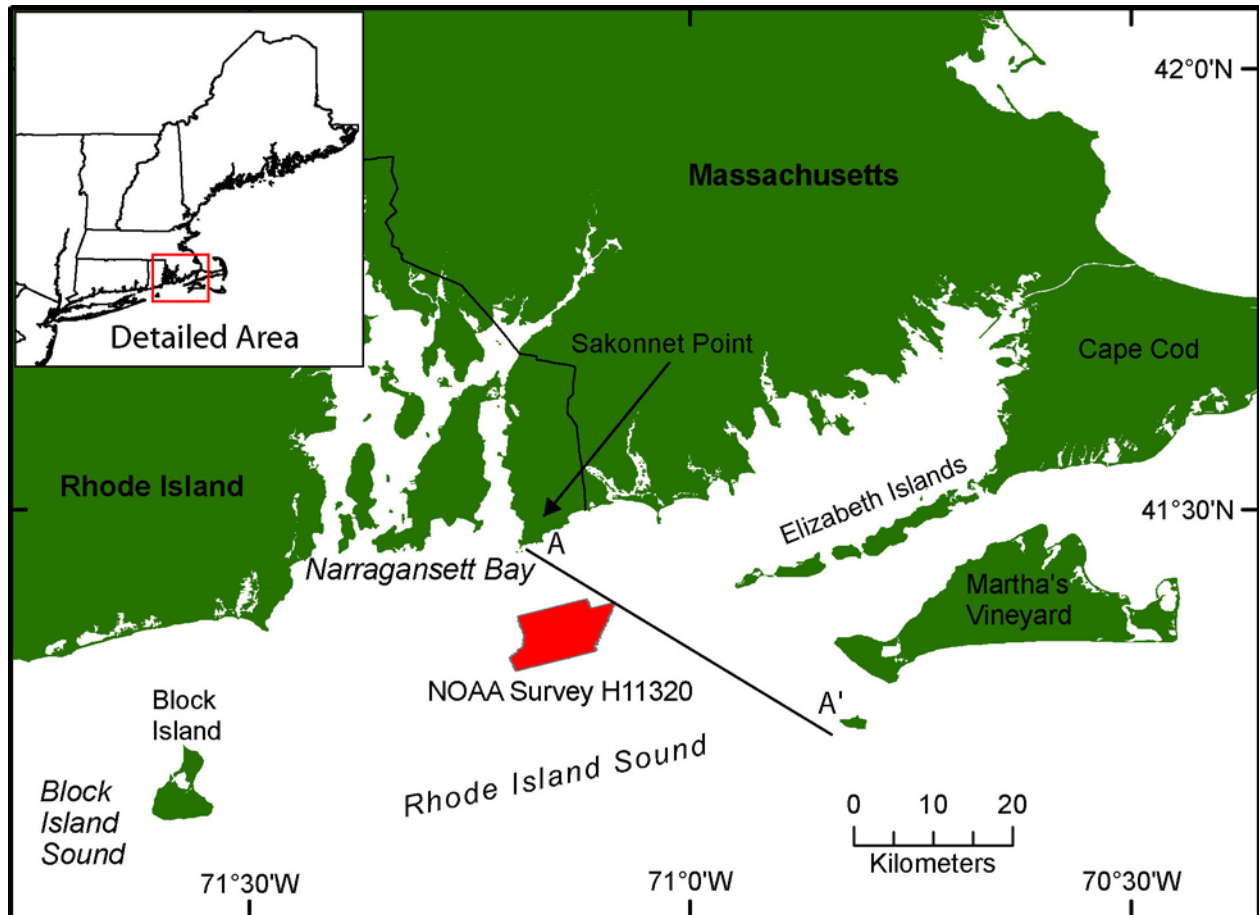
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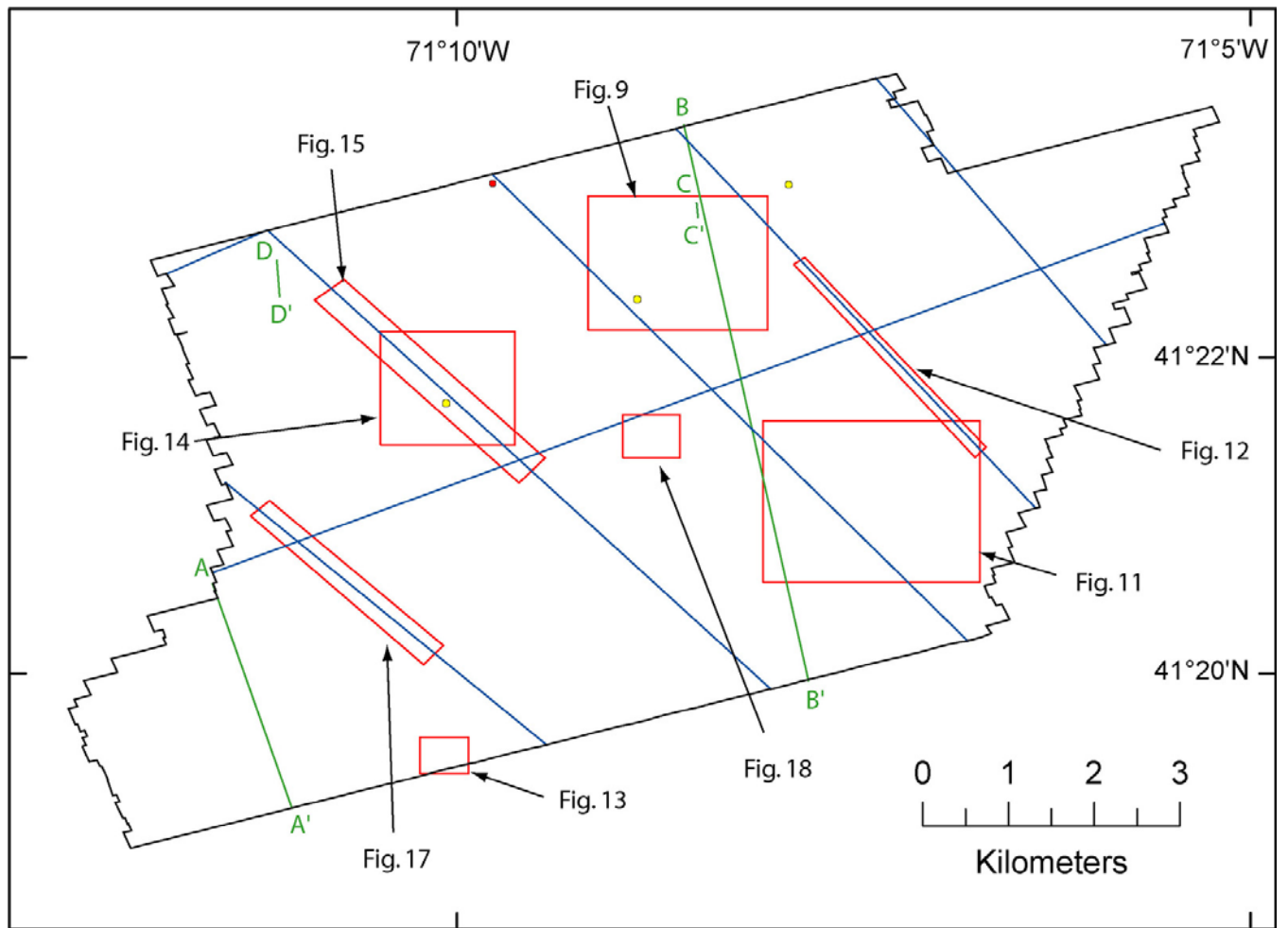
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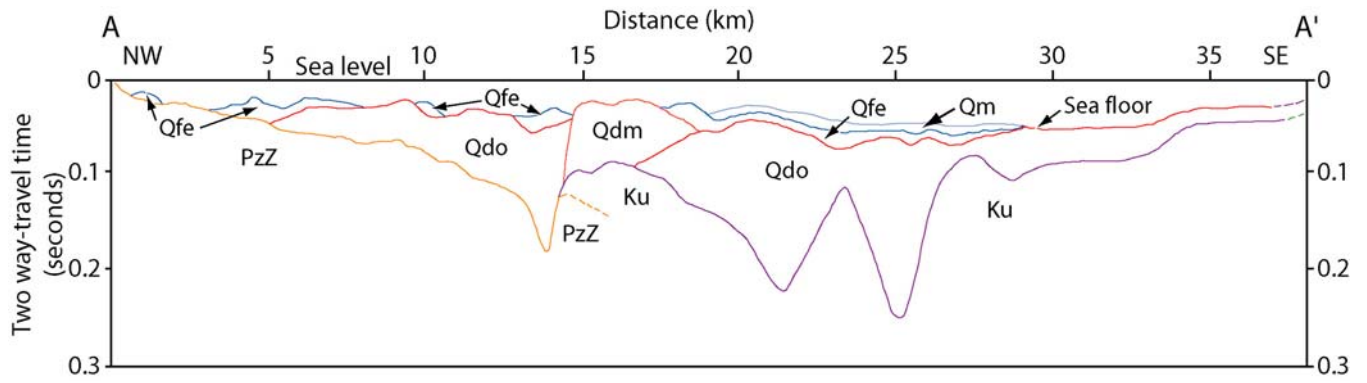
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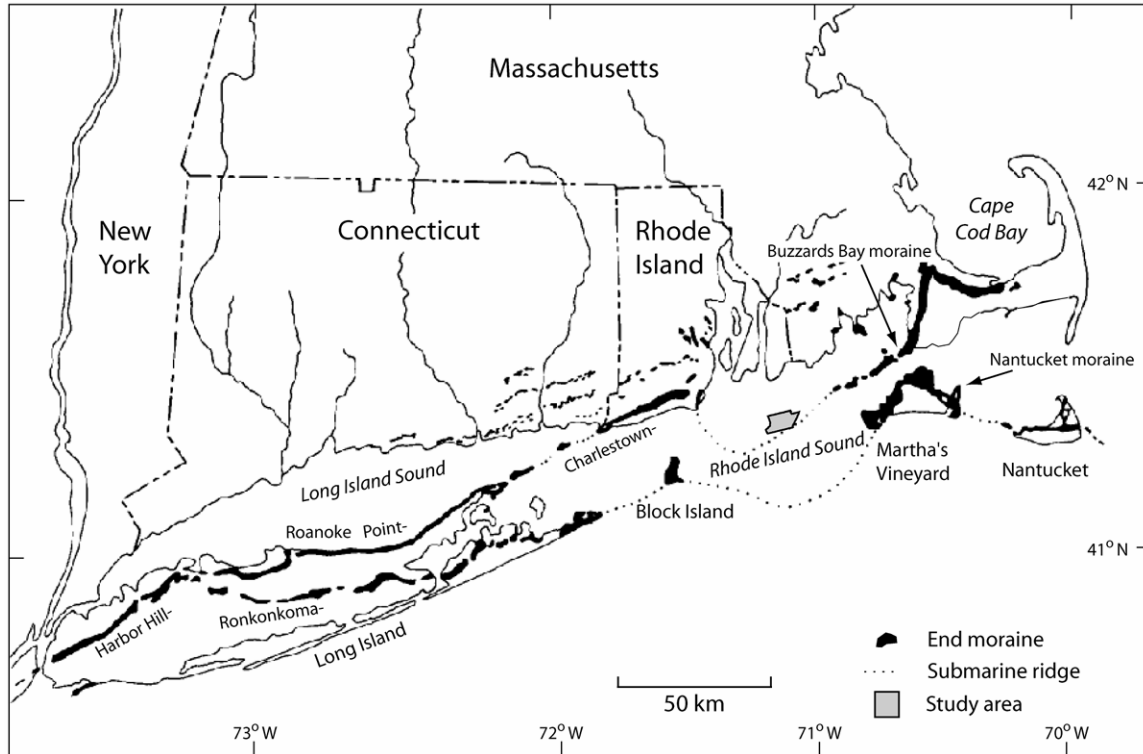
**Figure 1.** Location map of NOAA Survey H11320 (red polygon) in Rhode Island Sound. Location of stratigraphy profile A-A' from figure 3 is also shown.



**Figure 2.** Location of figures (red polygons), bathymetric profiles (green lines), historic seismic-reflection profiles (blue lines, O'Hara and Oldale, 1980), and sand (yellow circles) and rocky (red circle) sediment samples (Poppe and others, 2003) within the study area.



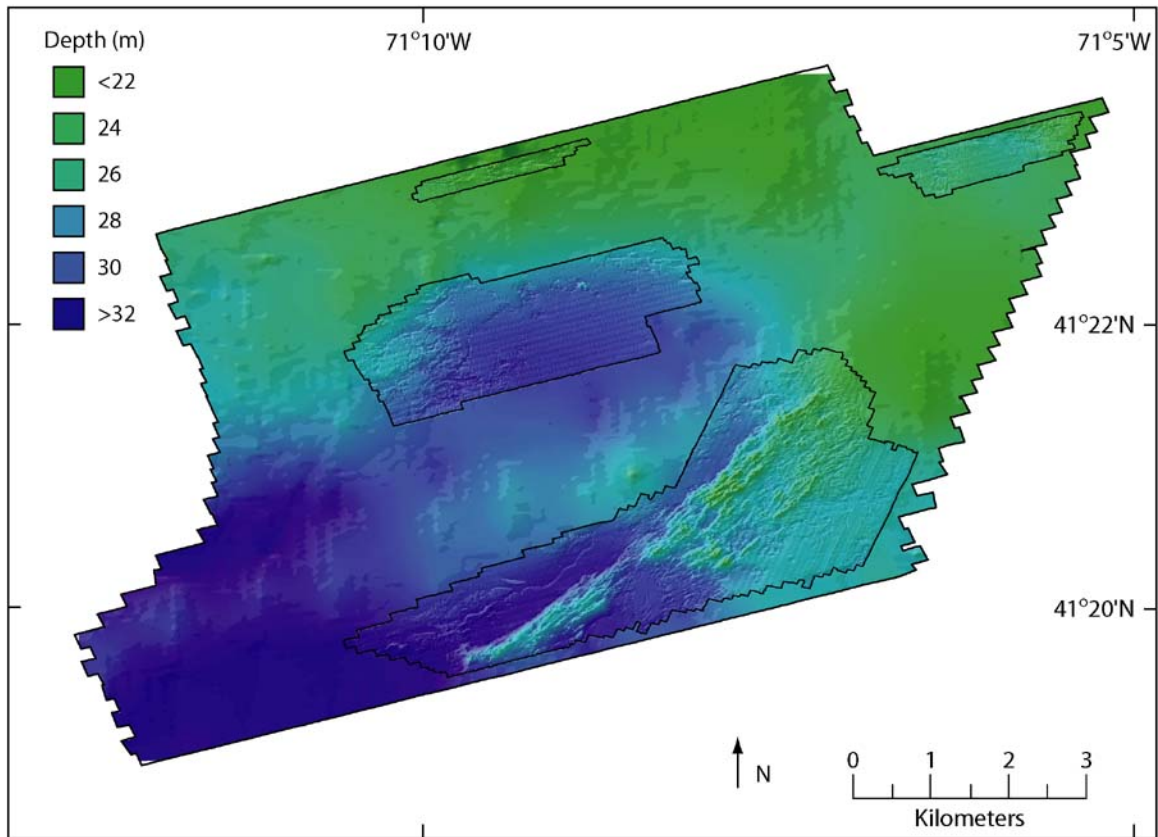
**Figure 3.** Interpreted stratigraphy of Rhode Island Sound from O'Hara and Oldale (1980). Acoustic units include: PzZ - Proterozoic to Paleozoic bedrock, Ku - Cretaceous coastal plain sediments, Qdo - Wisconsin glacial drift deposits, Qdm - Buzzards Bay moraine deposits, Qfe - Holocene fluvial and estuarine deposits, and Qm - Holocene quiet-water marine deposits. Boundaries are dashed where inferred. Vertical exaggeration: 40X. Location of stratigraphy profile shown as A-A' in figure 1.



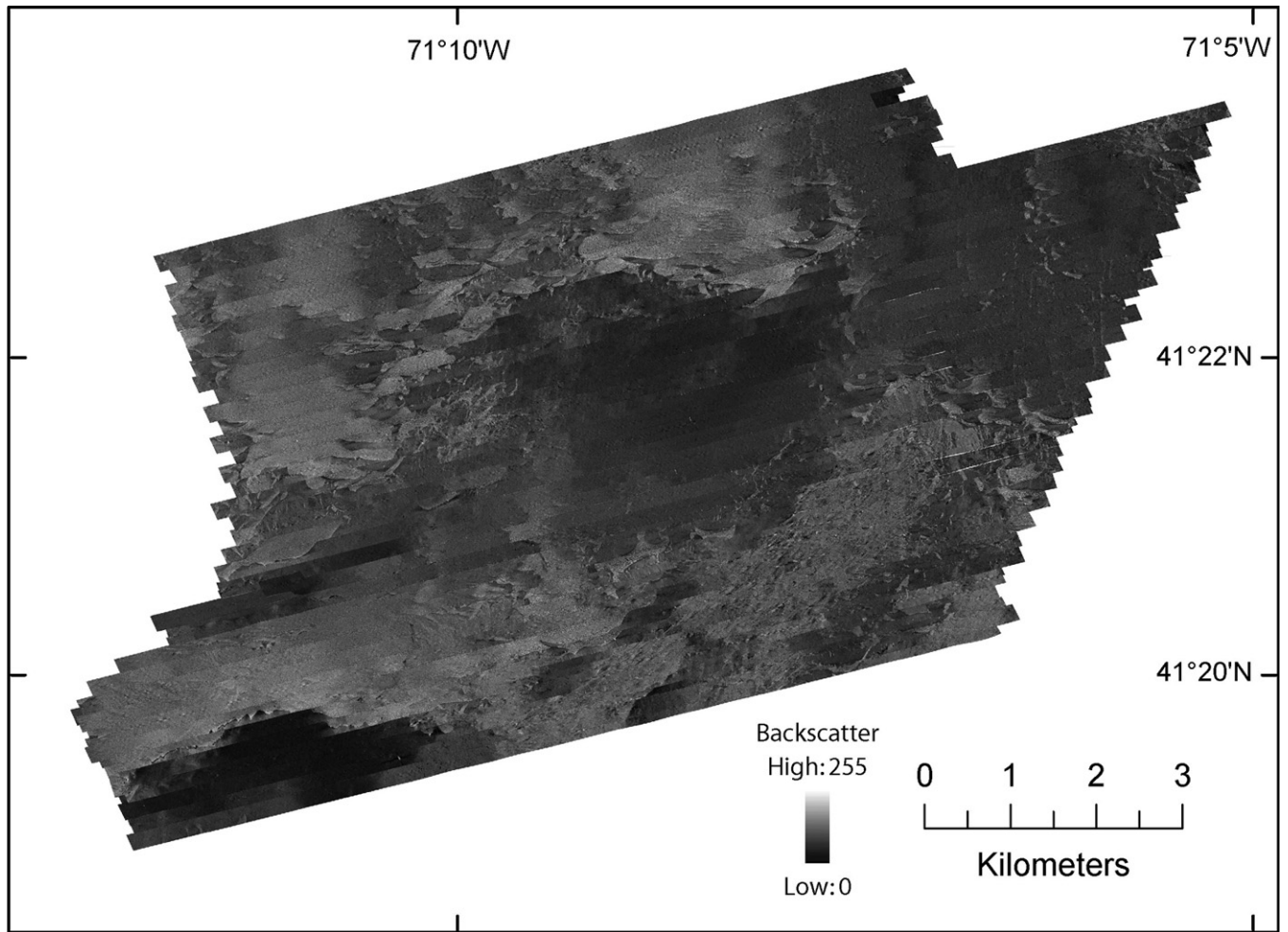
**Figure 4.** Map showing the location of end moraines (solid black polygons) in southern New England and New York. The Ronkonkoma-Nantucket moraine shows the maximum extent of the Laurentide ice sheet 20 ka, while the Harbor Hill-Ronkonkoma Point-Charlestown-Buzzards Bay moraine shows a retreated position of the ice sheet around 18 ka (Uchupi and others, 1996). Submarine ridges (dotted lines) mark the underwater extensions of the moraines. H11320 study area shown as a gray polygon. Modified from Gustavson and Boothroyd (1987).



**Figure 5.** Photo of NOAA Ship RUDE (courtesy of NOAA).

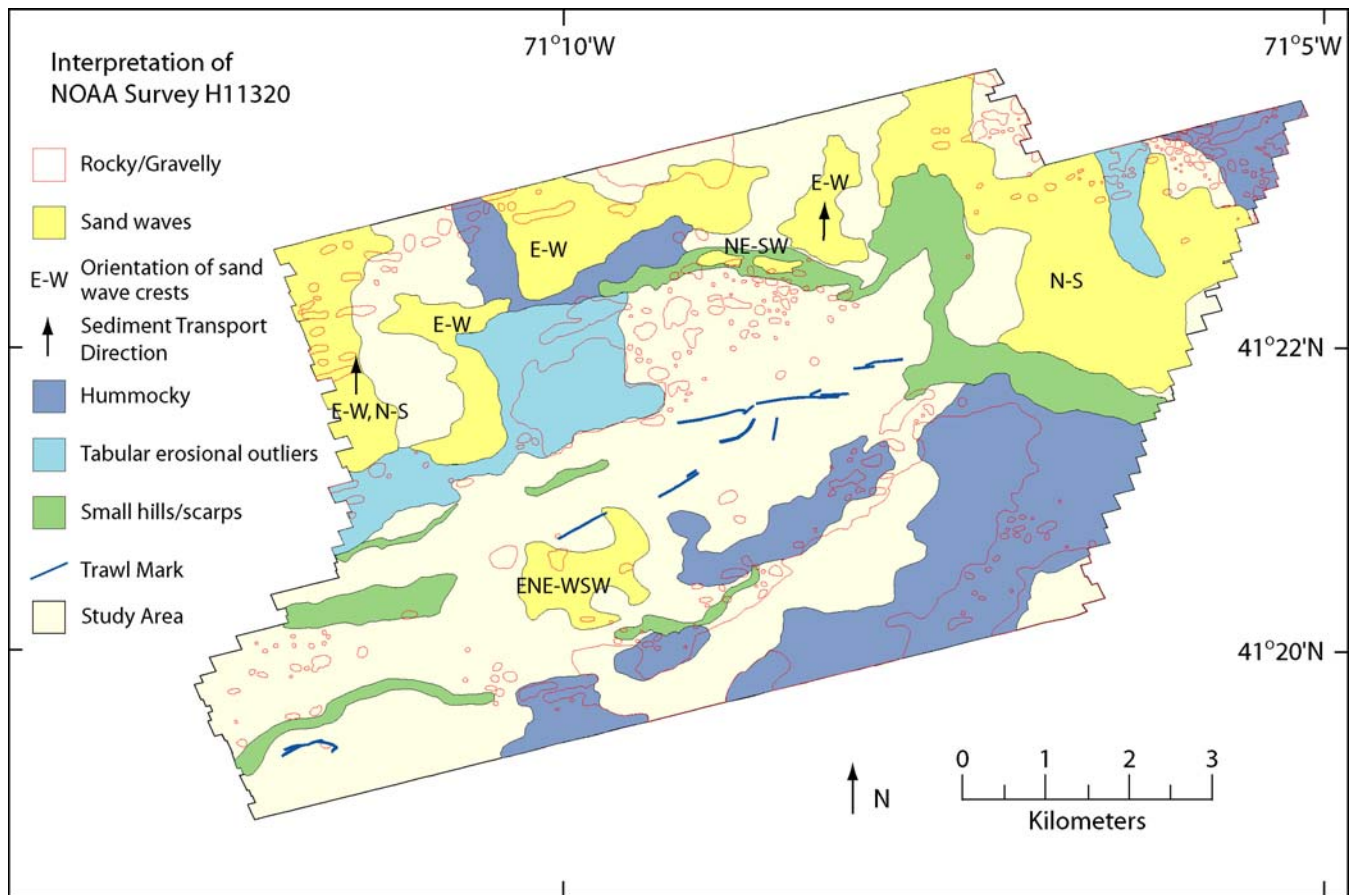


**Figure 6.** Hill-shaded bathymetry of the study area. Four areas outlined in black show multibeam bathymetry from H11320, while the rest of the bathymetry is from the NGDC Coastal Relief Model. Multibeam bathymetric data have been gridded at 4 m and depths represent mean lower low water level in multibeam data and either mean low water or mean lower low water in Coastal Relief Model data (Divins and Metzger, n.d.).

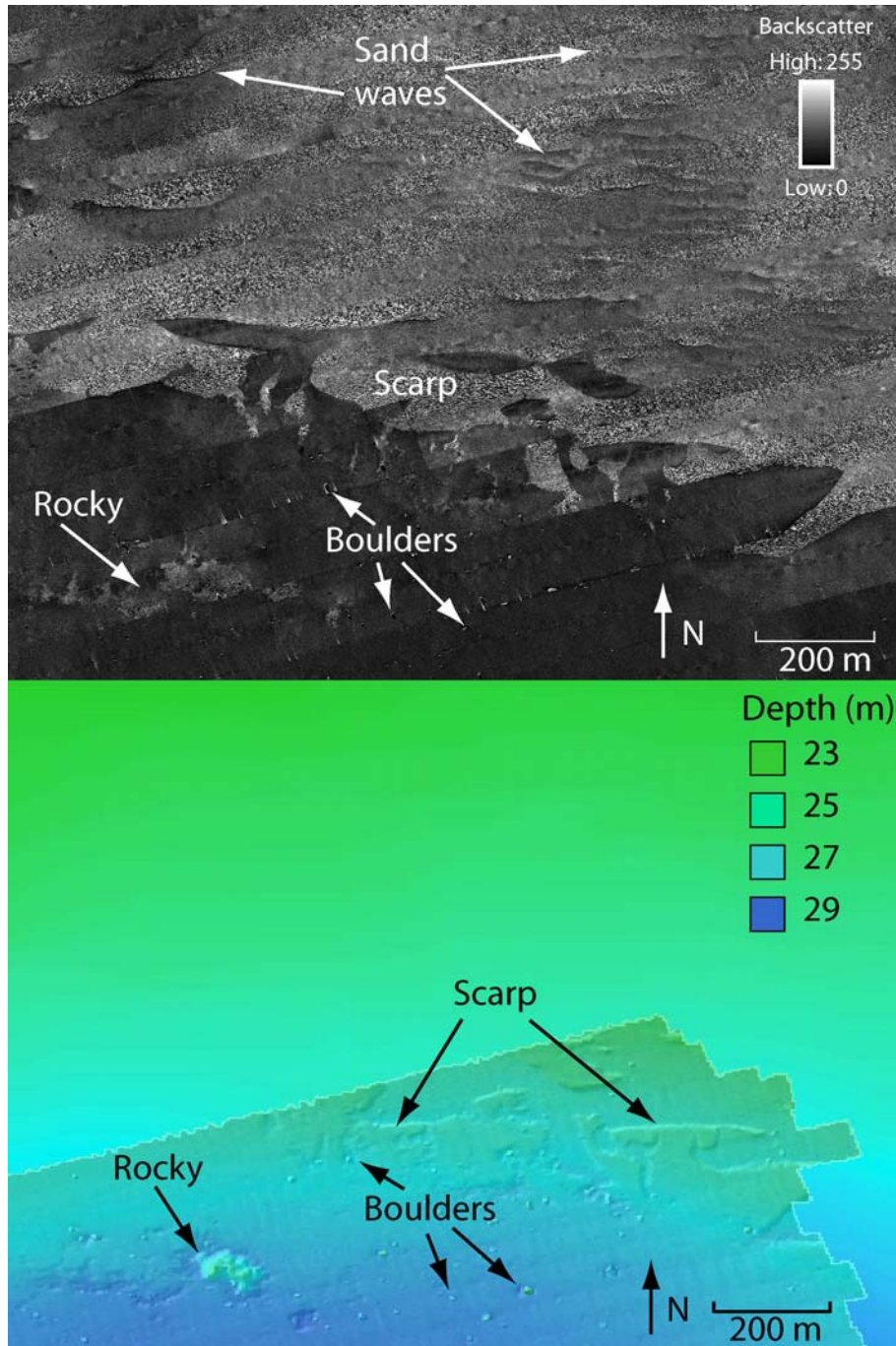


**Figure 7.** Sidescan sonar imagery of NOAA Survey H11320. Darker regions represent low backscatter and generally finer grained sediments; lighter regions represent high backscatter and generally coarser grained sediments.

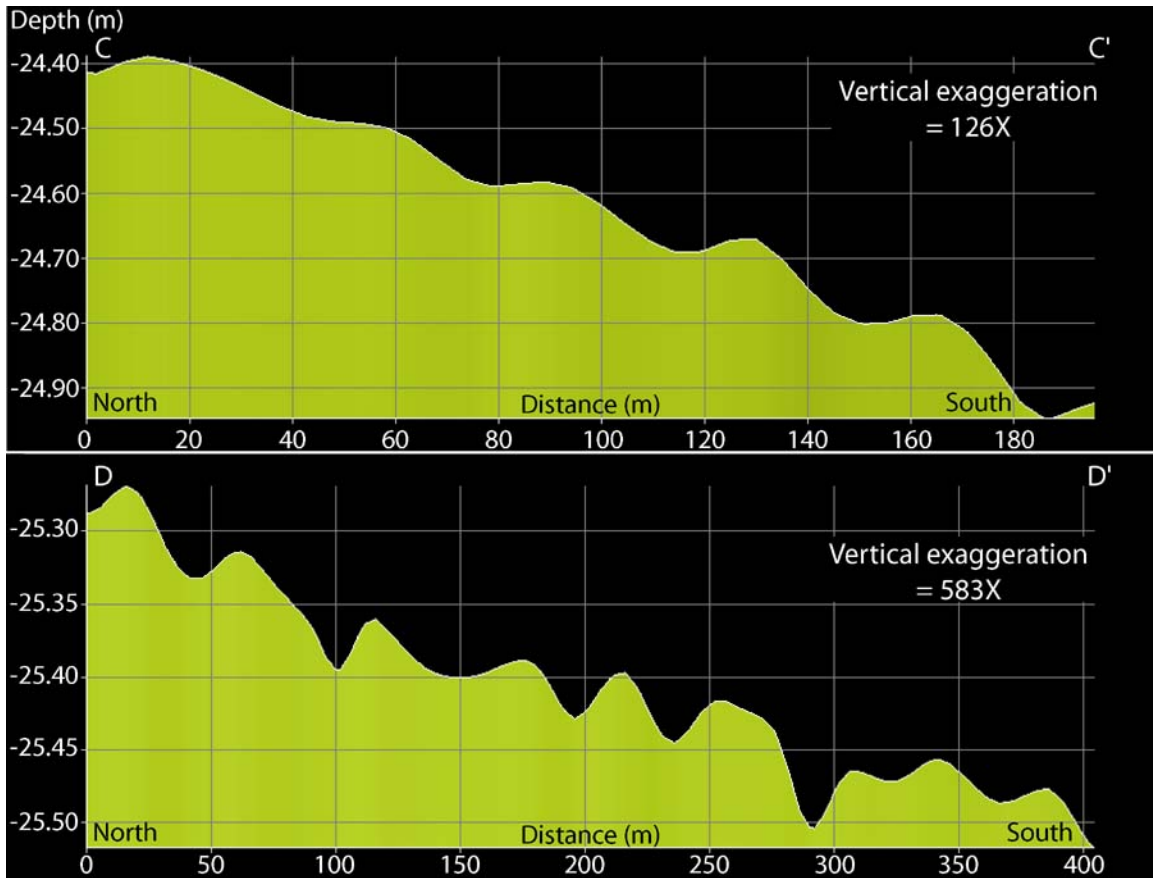




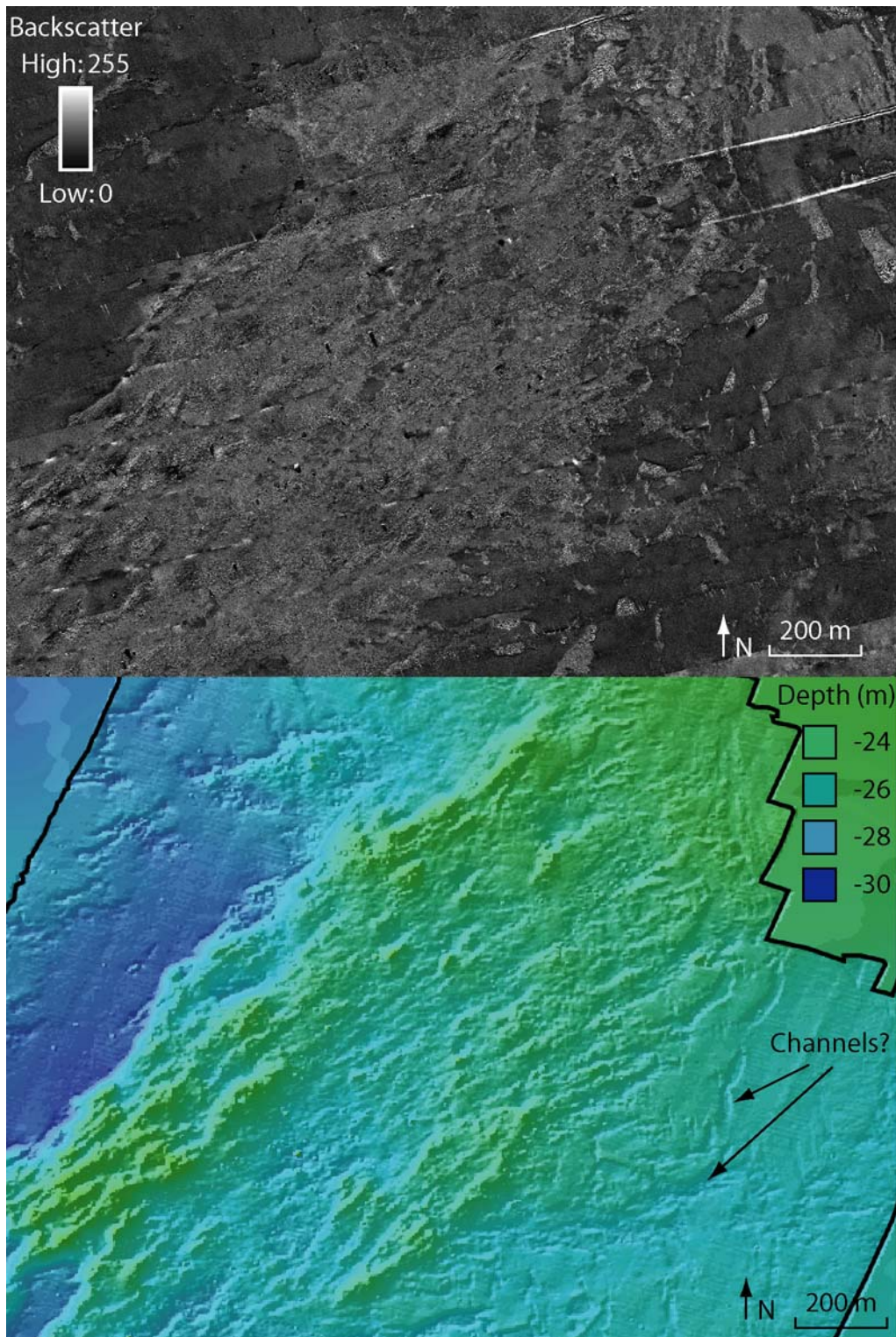
**Figure 8.** Interpretation of sidescan sonar imagery and multibeam bathymetry showing areas of rocky and gravelly sediment, sand waves and crest orientations, sediment transport direction, hummocky sea floor, tabular erosional outliers, small hills and scarps, and trawl marks.



**Figure 9.** Detailed sidescan sonar imagery and bathymetry illustrating the relatively smooth central basin floor scattered with rocks and boulders in the south and adjacent ridge to the north. Sand waves are located on the ridge and a scarp crosses the ridge in an east-west direction. Sand waves have curved crests oriented east-west and wavelengths of 40 to over 100 m in the west and about 50 m in the east. High-resolution multibeam bathymetry has been overlaid on bathymetry from the NGDC Coastal Relief Model. Figure location is shown in figure 2.

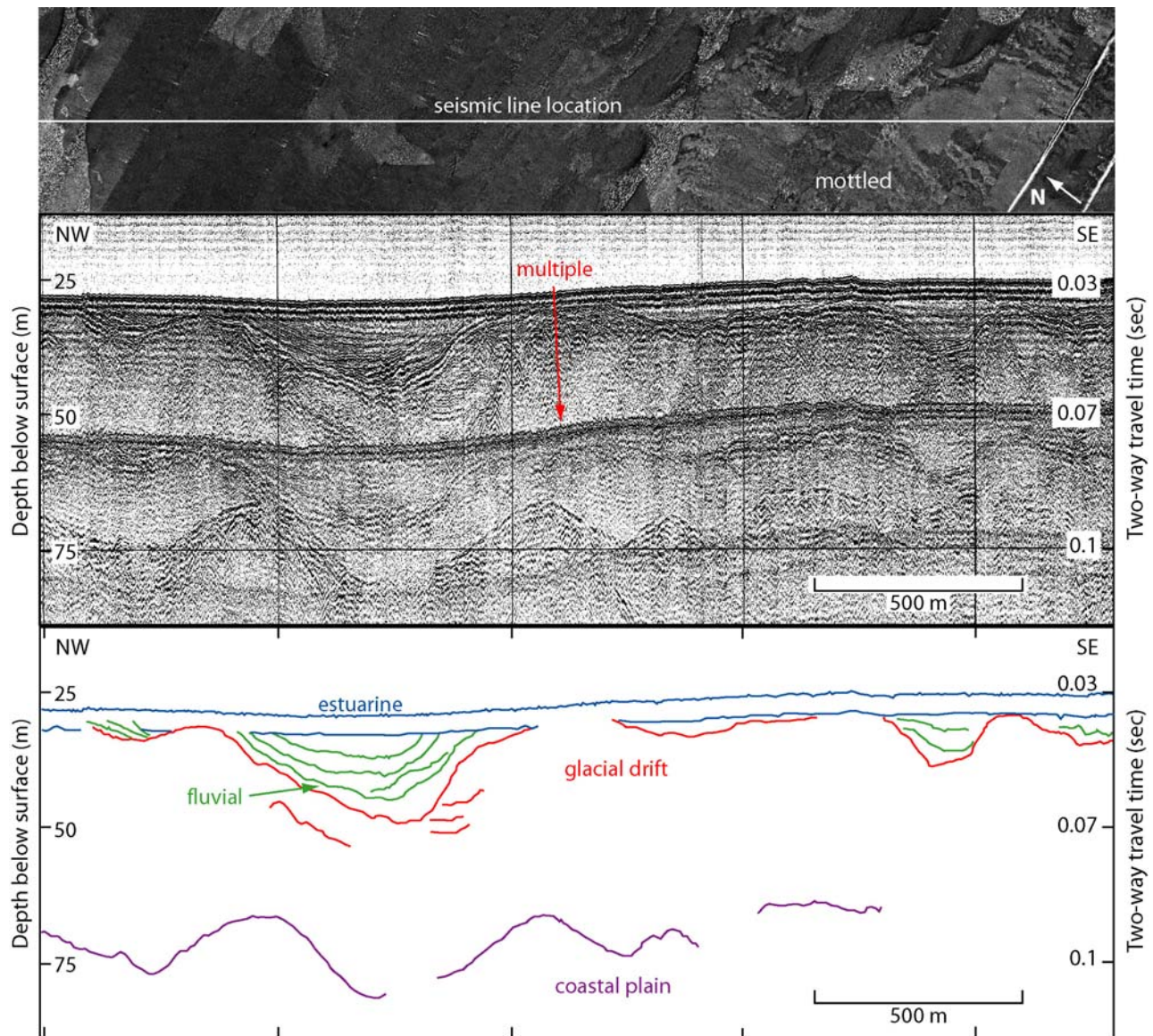


**Figure 10.** Bathymetric profiles of sand waves showing slip faces oriented northward. Profile C-C' is of sand waves in the eastern field of east-west oriented crests, which have wavelengths of about 50 m. Profile D-D' is of sand waves in the northwestern corner of the study area where wavelengths are also about 50 m. Location of profiles shown in figure 2.

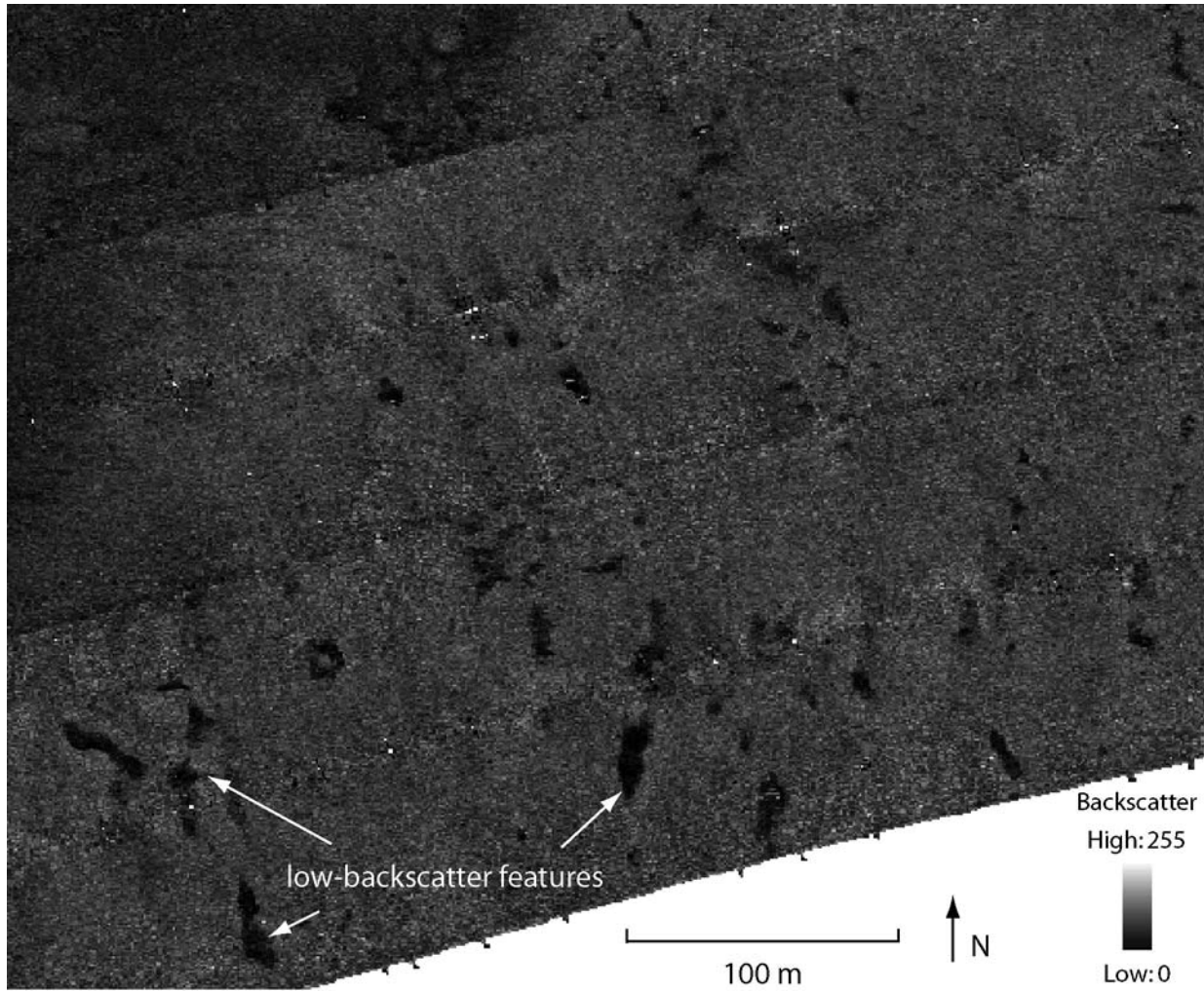


**Figure 11.** Detailed view of sidescan sonar imagery showing mottled backscatter and corresponding bathymetry. Mottled backscatter in the sidescan sonar data is caused by the hummocky surface of moraines and glacial till inconsistently reflecting backscatter due to the variable topography and sediment distribution. Note: black line outlines high-

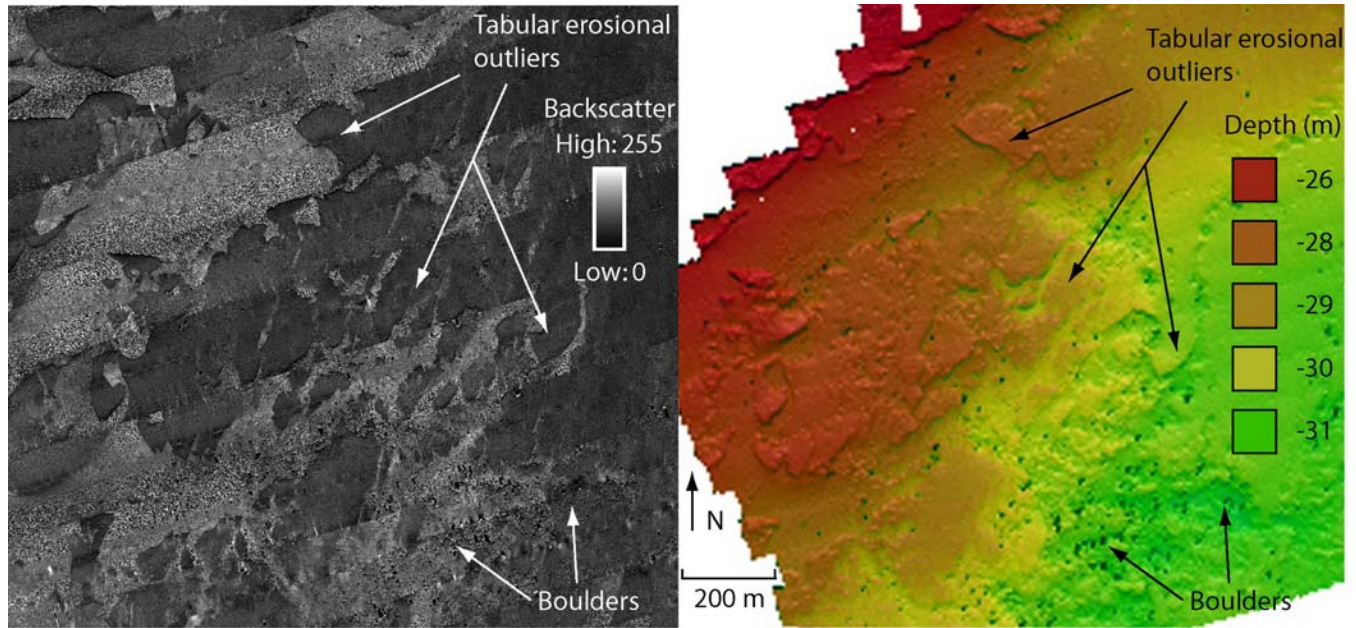
resolution multibeam bathymetry which overlies bathymetry from the Coastal Relief Model. Figure location is shown in figure 2.



**Figure 12.** Sidescan sonar imagery and Boomer seismic-reflection profile (O'Hara and Oldale, 1980) and interpretation through an area of mottled backscatter. Right side of sidescan sonar image shows mottled backscatter (top image). Seismic profile shows Cretaceous coastal plain sediments overlain by Wisconsin glacial drift and Holocene fluvial and estuarine sediments. Mottling tends to occur in areas where glacial moraine sediments are either exposed or near the surface. Vertical exaggeration: 13X. Depths are based on the assumed compressional wave velocity of 1500 m/s. Location of seismic line shown in figure 2.

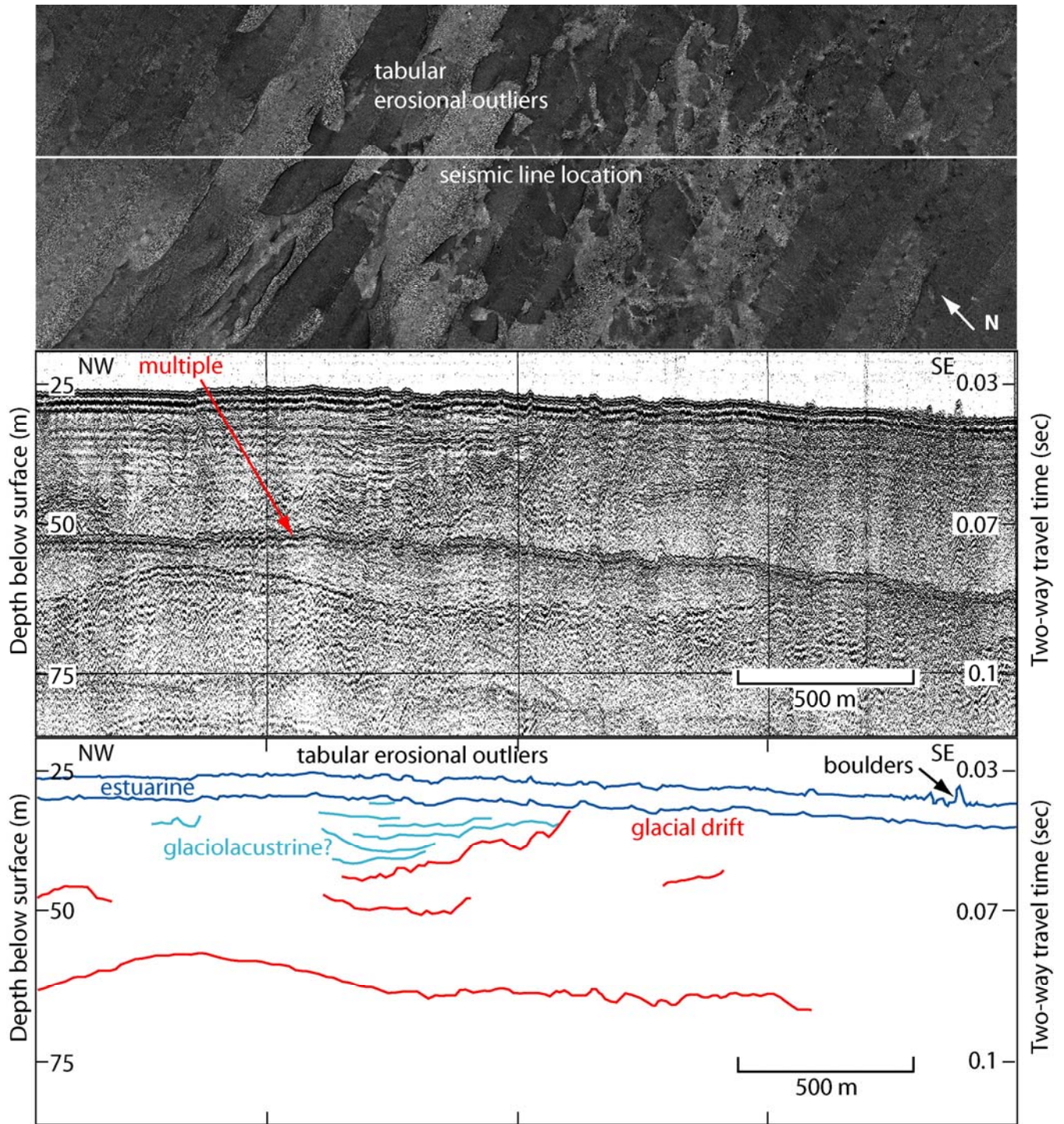


**Figure 13.** Detailed area of sidescan sonar image showing low-backscatter targets. These features show no relief in the bathymetry data and are thought to be patches of fine-grained sediment within larger areas of coarser grained sediment. Figure location shown in figure 2.



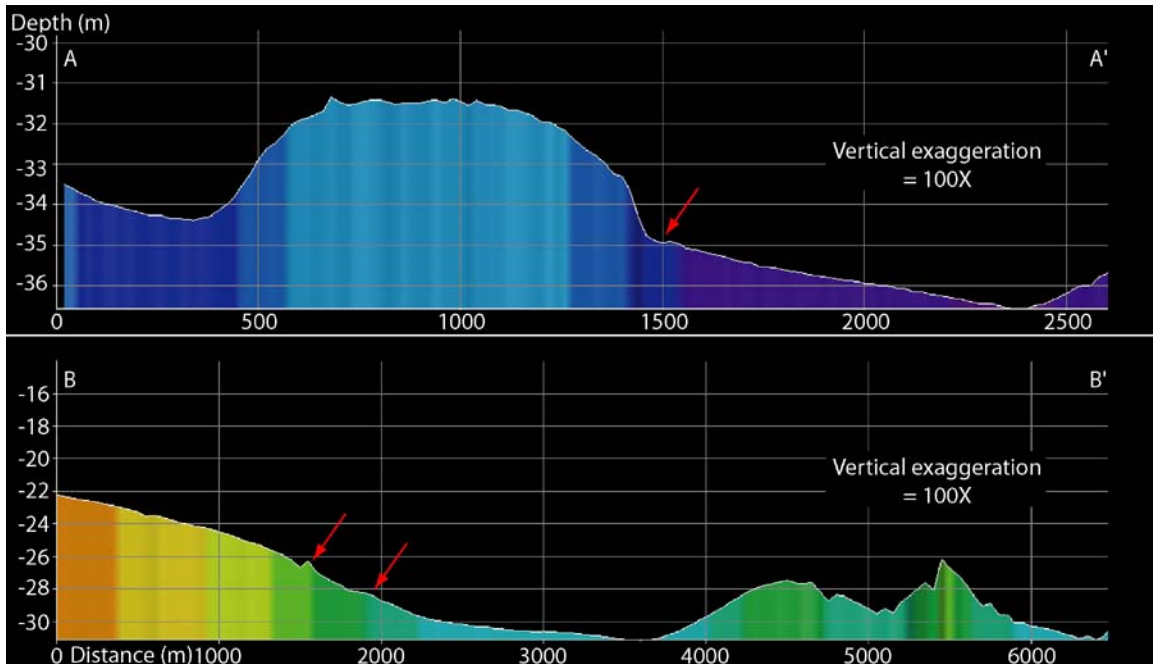
**Figure 14.** Detailed view of sidescan sonar imagery and corresponding hill-shaded bathymetry showing tabular erosional outliers. Curvilinear shadows in the sidescan sonar imagery correspond to the outline of small plateaus in the bathymetry. Boulders are visible in both images, on the sidescan sonar imagery as light-toned targets with dark shadows and within the bathymetry as dark targets. The area of boulders in the lower right corner of both images shows an exposure of till. Lighter backscatter between the erosional outliers is from coarse-grained, bouldery sediment. Images are in UTM. Location of figure shown in figure 2.



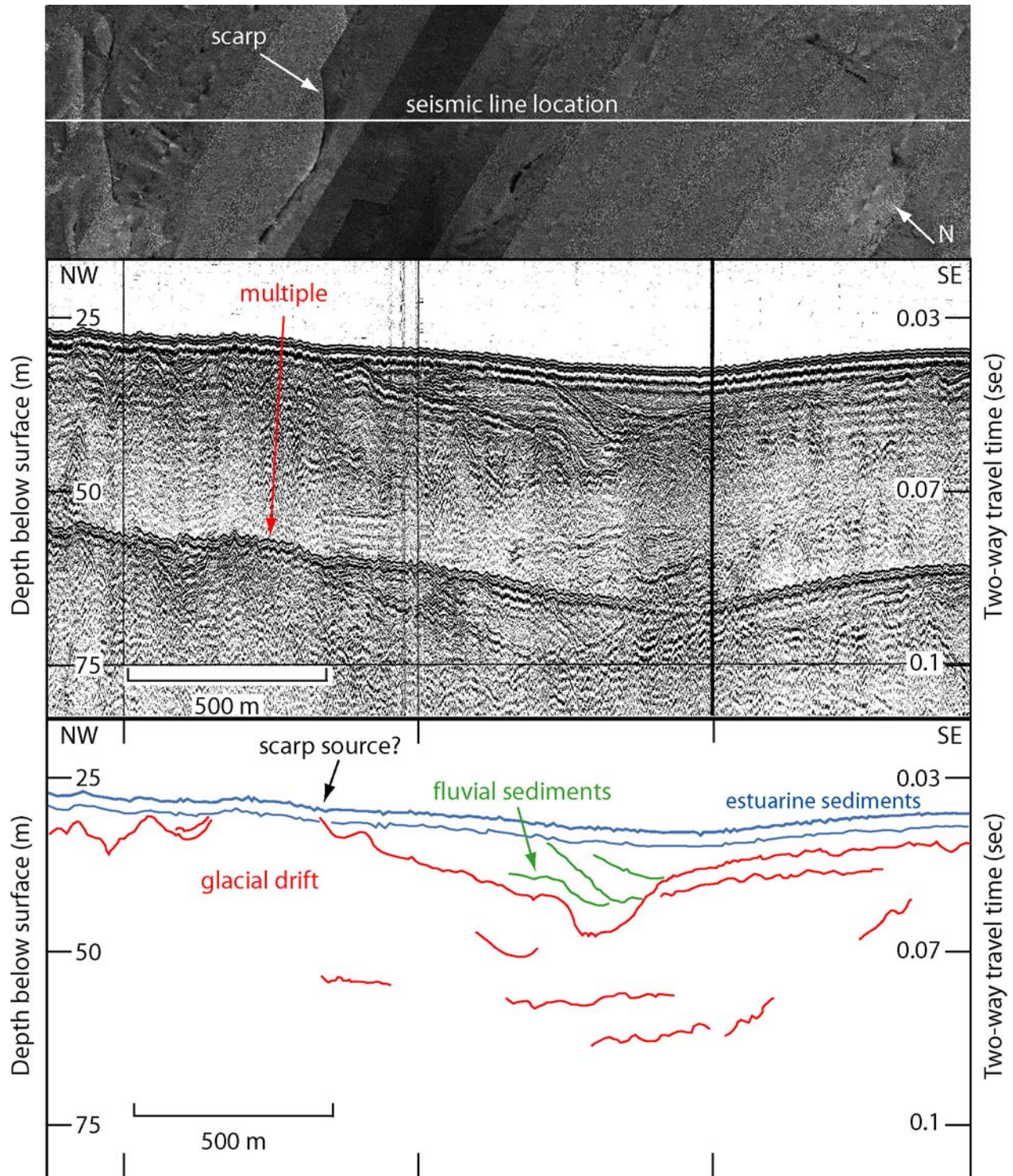


**Figure 15.** Sidescan sonar imagery, Boomer seismic-reflection profile (O'Hara and Oldale, 1980), and interpretation through an area of tabular erosional outliers. Top image shows location of the seismic profile on the sidescan sonar data and erosional outliers in the center. Lower images of seismic profile and interpretation show stratified sediments, possibly from a small glacial lake or pond, below the erosional outliers. Note irregular sea floor and estuarine sediments above laminations, likely due to prior erosion of lacustrine sediments. Boulders can be seen rising above the sea floor. Vertical exaggeration: 16X.

Depths are based on the assumed compressional wave velocity of 1500 m/s. Figure location shown in figure 2.

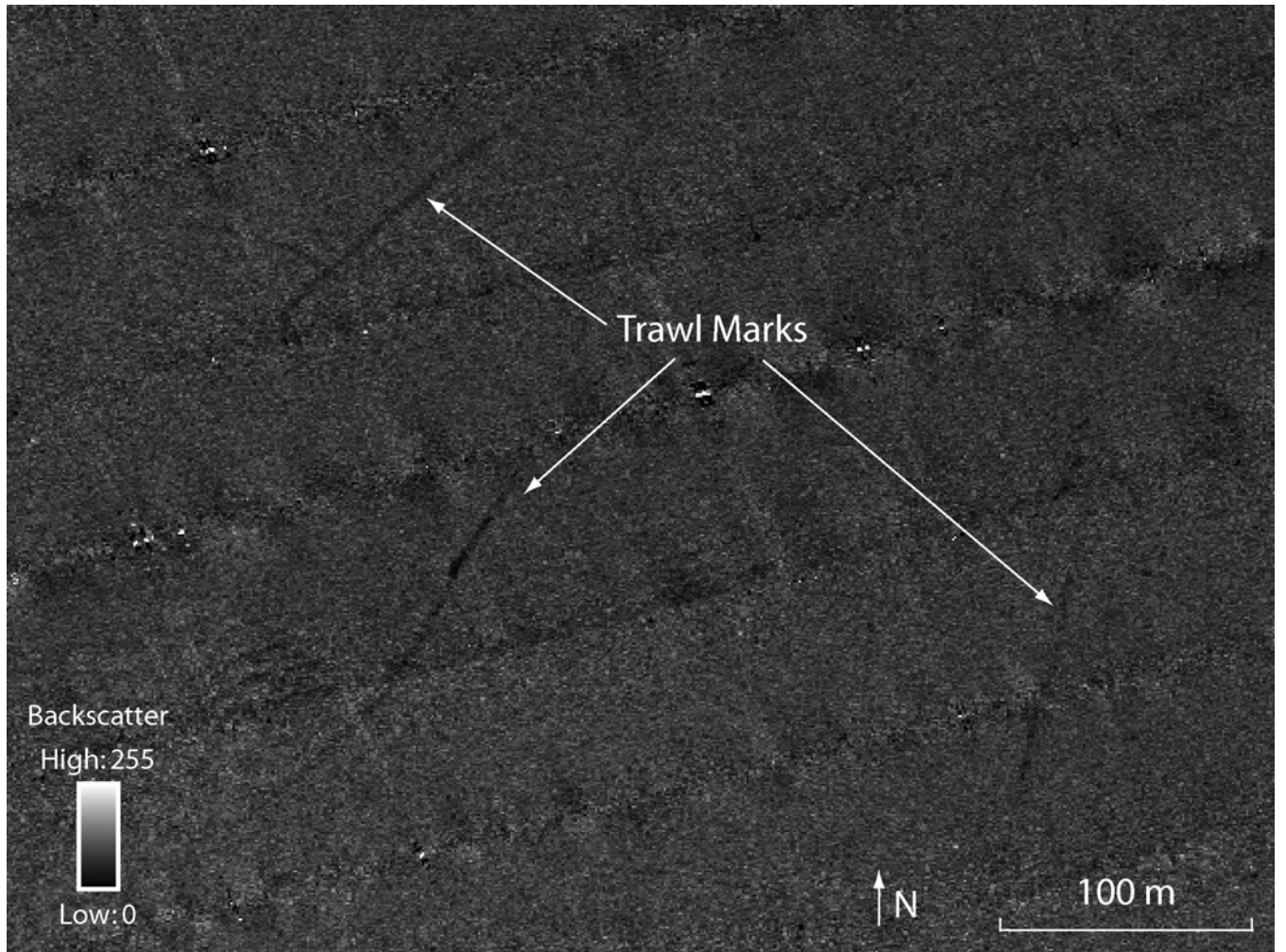


**Figure 16.** Bathymetric profiles across study area from north to south. Location of profiles shown in figure 2. Profile A-A', located in the southwestern part of the study area, crosses a bathymetric high with deeper basins to the north and south. Profile B-B', located in the eastern part of the study area, crosses a bathymetric high in the north, central basin, and moraine in the south. Arrows point to changes in slope interpreted to represent paleoshorelines.

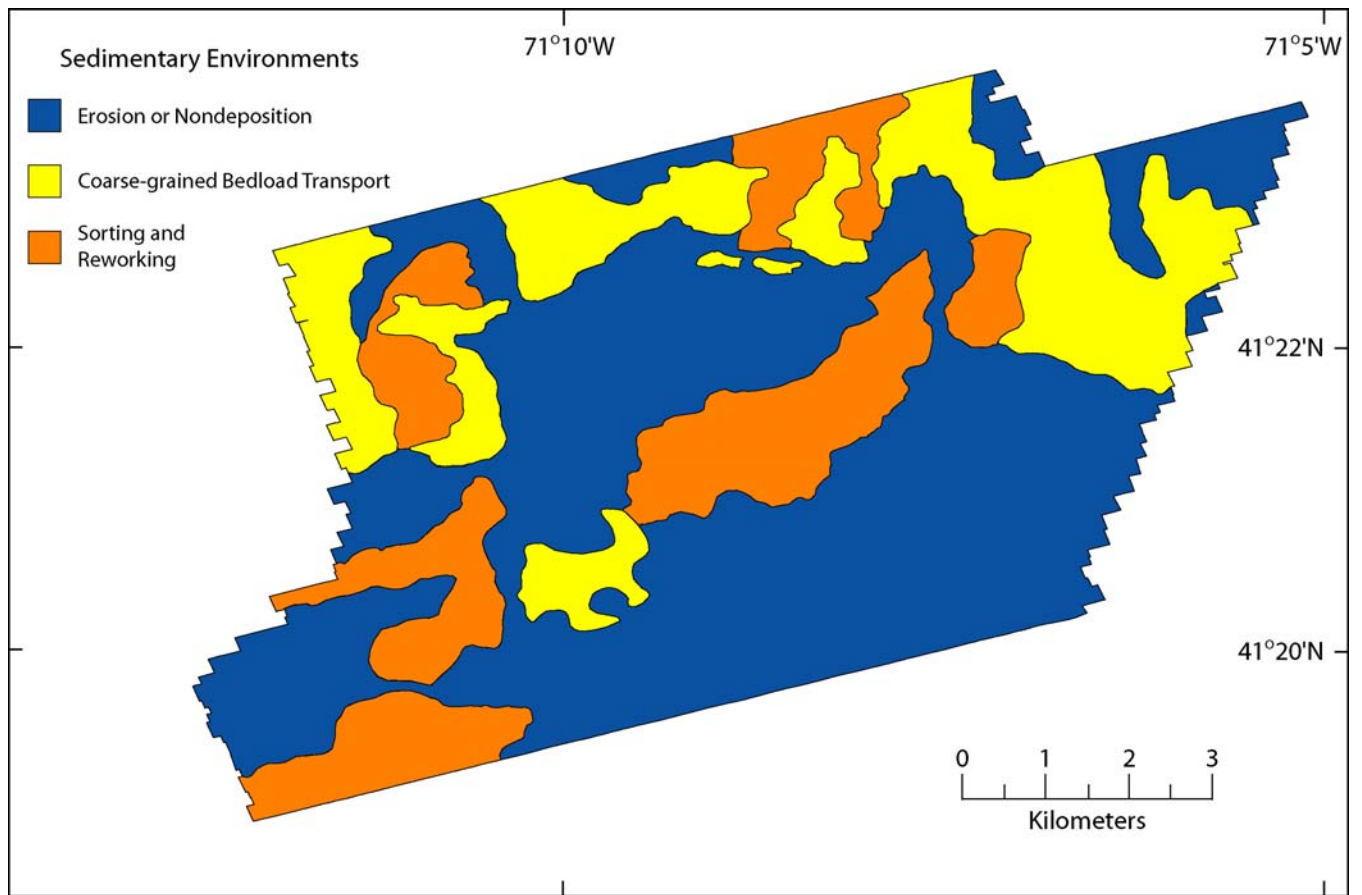


**Figure 17.** Sidescan sonar imagery, Boomer seismic-reflection profile (O'Hara and Oldale, 1980), and interpretation of an area with small scarps of outcropping strata. Top image shows scarp and location of seismic line on sidescan sonar mosaic. Bottom images of seismic line and interpretation show Pleistocene glacial drift overlain by Holocene fluvial and estuarine sediments. The small scarp displayed within the sidescan sonar mosaic is

presumed to correspond to the prominent reflector between the fluvial sediments and glacial drift as it nears the surface. Vertical exaggeration: 15X. Depths are based on the assumed compressional wave velocity of 1500 m/s. Location of seismic line shown in figure 2.



**Figure 18.** Detailed view of sidescan sonar imagery showing long lines of low backscatter interpreted to be trawl marks from fishing boats. Figure location is shown in figure 2.



**Figure 19.** Map showing sedimentary environments in study area characterized by erosion or nondeposition, coarse-grained bedload transport, and sorting and reworking.