# Sidescan-Sonar Imagery and Surficial Geologic Interpretations of the Sea Floor in Western Rhode Island Sound

By K.Y. McMullen, L.J. Poppe, T.A. Haupt, and J.M. Crocker

Open-File Report 2008-1181

**U.S. Department of the Interior**
**U.S. Geological Survey**

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U.S. Geological Survey, Reston, Virginia 2009

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Suggested citation:
McMullen, K.Y., Poppe, L.J., Haupt, T.A., and Crocker, J.M., 2009, Sidescan-Sonar Imagery and Surficial Geologic Interpretations of the Sea Floor in Western Rhode Island Sound: U.S. Geological Survey Open-File Report 2008-1181, DVD-ROM. Also available online at http://pubs.usgs.gov/of/2008/1181/.

## Contents



## Figures

## Conversion Factors, Datum, and Abbreviations

| Multiply | By | To obtain |
|---|---|---|
| Length | | |
| centimeter (cm) | 0.3937 | inch (in.) |
| meter (m) | 3.281 | foot (ft) |
| kilometer (km) | 0.6214 | mile (mi) |
| Area | | |
| square kilometer ($km^2$) | 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.

Abbreviations used include: KHz – kilohertz, one thousand periods per second, and Hz – periods per second.

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## Abstract

The U.S. Geological Survey (USGS) and National Oceanic and Atmospheric Administration (NOAA) have been working together to interpret sea-floor geology along the northeastern coast of the United States. In 2004, the NOAA Ship RUDE completed survey H11322, a sidescan-sonar and bathymetric survey that covers about 60 square kilometers of the sea floor in western Rhode Island Sound. This report interprets sidescan-sonar and bathymetric data from NOAA survey H11322 to delineate sea-floor features and sedimentary environments in the study area. Paleozoic bedrock and Cretaceous Coastal Plain sediments in Rhode Island Sound underlie Pleistocene glacial drift that affects the distribution of surficial Holocene marine and transgressional sediments. The study area has three bathymetric highs separated by a channel system. Features and patterns in the sidescan-sonar imagery include low, moderate, and high backscatter; sand waves; scarps; erosional outliers; boulders; trawl marks; and dredge spoils. Four sedimentary environments in the study area, based on backscatter and bathymetric features, include those characterized by erosion or nondeposition, coarse-grained bedload transport, sorting and reworking, and deposition. Environments characterized by erosion or nondeposition and coarse-grained bedload transport are located in shallower areas and environments characterized by deposition are located in deeper areas; environments characterized by sorting and reworking processes are generally located at moderate depths.

## Introduction

The U.S. Geological Survey (USGS) has been working with the National Oceanic and Atmospheric Administration (NOAA) to interpret areas of the sea floor along the northeastern coast of the United States. In July 2004, NOAA completed hydrographic survey H11322 in Rhode Island Sound, about 8 km southeast of Point Judith, Rhode Island, and 12 km east of Block Island (fig. 1). Sidescan-sonar and bathymetric data obtained during the survey were used to delineate sea-floor features and sedimentary environments. This report documents the interpretation of 60 $km^2$ of sea floor covered by NOAA survey H11322. This information is useful for studying benthic habitats and provides a framework for future studies.

Prior work in this area includes studies of the sea-floor characteristics and stratigraphy to determine active sediment processes and geologic history. McMaster (1960) mapped the sediment distribution of Narragansett Bay and Rhode Island Sound. He classified and mapped the surficial sediments in the current study area as mostly sand, with silty sand in the northwest and gravel scattered throughout the west (McMaster, 1960). McMaster and others (1968) outlined the northern boundary of Cretaceous Coastal Plain sediments and mapped buried stream valleys. Knebel and others (1982) used sidescan sonar to map features of the sea floor in Rhode Island Sound, such as areas of sand waves and sediment accumulation. Needell and others (1983a) identified sedimentary units in the stratigraphic framework of Rhode Island Sound. Four sediment samples from the National Ocean Service (NOS) Hydrographic Database and one sample from the Hathaway 71 data set fall within the boundary of NOAA survey H11322: three samples of sand or fine sediment are from the east and one sample of mud and one of gravel are from the central part of the study area (fig. 2; Poppe and others, 2003).

Two recent studies that interpret NOAA hydrographic surveys in Rhode Island Sound were conducted east of this study area (fig. 1; McMullen and others, 2007; McMullen and others, 2008). These studies delineate sea-floor features including rocky areas, sand waves, a hummocky recessional moraine, glaciolacustrine erosional outliers, and a series of scarps and benches interpreted to be paleoshorelines. The eastern border of the present study area overlaps the western boundary of these studies (McMullen and others, 2008).

## Geologic Setting

Glacial sediments that were reworked as a result of marine transgression during the Holocene Epoch dominate the Rhode Island Sound sea floor. The stratigraphy in the sound consists of a Paleozoic basement of mostly gneiss and schist overlain by Cretaceous Coastal Plain sediments in the south and Pleistocene glacial drift and Holocene deposits throughout the Sound (fig. 3; McMaster, 1960; McMaster and others, 1968; Needell and others, 1983a). The northern boundary of the Cretaceous Coastal Plain sediments forms a northward-facing cuesta that crosses the sound (McMaster and others, 1968; Needell and others, 1983a). The southern extent of the glacial deposits is marked by the Ronkonkoma-Block Island-Nantucket end moraine, dating to about 20,000 years ago, whereas a retreated ice position, dating to about 18,000 years ago, is represented by the Harbor Hill-Roanoke Point-Charlestown-Buzzards Bay moraine (fig. 4; Uchupi and others, 1996). During glacial recession, pro-glacial lakes formed between the previous morainal position and the retreating ice front in present Long Island Sound, Block Island Sound, and Narragansett Bay (Uchupi and others, 2001). The glacial lakes also extended into Rhode Island Sound (Needell and others, 1983a). During and after lake drainage, the area occupied by the present-day shelf was exposed to subaerial erosion, and fluvial channels cut into the glacial drift (Needell and others, 1983a). As sea level rose, Holocene marine and transgressive sediment sequences including fluvial, estuarine, and beach sediments were deposited and subsequently reworked and eroded by waves and currents (Needell and others, 1983a).

## Data Acquisition and Processing

Sidescan-sonar and bathymetric data were collected aboard the NOAA Ship RUDE during July 2004 (fig. 5). NOAA hydrographic surveys provide 200-percent sidescan-sonar coverage of the sea floor by collecting two overlapping sets of sidescan-sonar data (each with a 200-m swath width and about 180-m trackline spacing) that are offset by about 90 m to ensure coverage of the nadirs. Sonar lines from one set of sidescan-sonar data were used in this study. Sidescan-sonar data were acquired with a Klein 5500 towfish (455 kHz) and recorded using Triton ISIS software in extended Triton format (xtf). Sidescan-sonar data were processed using USGS software packages Xsonar and ShowImage (Danforth, 1997). A median filtering routine was applied to the data to remove speckle noise. Sonar data were corrected for slant-range and radiometric distortion inherent in the data and towfish layback. The data were mosaicked using XSonar, resulting in an enhanced, geographically referenced, sidescan-sonar mosaic with 1 meter/pixel resolution.

Bathymetric data consisted mostly of vertical-beam echo-sounder data, with single-frequency multibeam data collected only in several areas of interest. The vertical-beam echo-sounder data were acquired during sidescan-sonar acquisition with an Odom Echotrac dual-frequency echo-sounder (24 and 200 kHz) and logged by Coastal Oceanographics Hypack Max software. Shallow-water multibeam data (455 kHz) were collected with a Reson SeaBat 8125 and logged by Triton ISIS software. Bathymetric data were integrated and processed using CARIS HIPS/SIPS software. Depths were corrected for tides and represent mean lower low water level. The integrated vertical-beam and multibeam data were imported into IVS Fledermaus to create a bathymetric surface with 45-m horizontal resolution. Detailed information on the instruments and software used on the NOAA Ship RUDE can be found in the NOAA Data Acquisition and Processing Report (National Oceanic and Atmospheric Administration, 2004).

Seismic-reflection data were collected by the USGS aboard the Research Vessel NEECHO in 1980 (Needell and others, 1983b, 1983c). These data were attained with an EG&G Uniboom system, which filtered to a 400- to 4,000-Hz bandpass and recorded at a quarter-second sweep rate (Needell and others, 1983b). The seismic data have 1- to 2-m vertical resolution.

## Bathymetry

The study area consists of bathymetric highs, located in the northwest, southwest, and northeast, and a system of elongate, interconnected bathymetric lows that deepen southward and westward (fig. 6). The lows trend toward the southwest between the northern highs and toward the west in the south. The northwestern high is the shallowest part of the study area, with depths as shallow as 25 m. The northeastern high, where depths are as shallow as 29 m, contains a shallow depression about 35 m deep that is oriented north-northwest to south-southeast. The southwestern part of the channel system, where depths reach as much as 40 m, is the deepest part of the study area.

## Historic Seismic-Reflection Data

Five historic seismic-reflection profiles cross the study area (Needell and others, 1983b; 1983c). Seismic-reflection data from the western and southern parts of the study area show horizontal to slightly dipping layered strata filling low areas in a unit of discontinuous reflectors (fig. 7). The layered strata, which coincide with a channel system, are interpreted to be fluvial and estuarine sediments (Needell and others, 1983b). The unit of discontinuous reflectors, which also covers the surface of the central part of the study area, is interpreted to be unstratified glacial drift (Needell and others, 1983b). The easternmost profile shows a unit of faintly stratified sediment overlying a unit of discontinuous reflectors (fig. 8). The stratified unit is interpreted to be composed of glaciolacustrine sediments, like those found east of the study area on the same bathymetric high (McMullen and others, 2008).

## Sidescan-Sonar Imagery

Sidescan-sonar imagery of the study area includes areas of low, moderate, and high backscatter. Bathymetric highs tend to have higher backscatter and bathymetric lows tend to have lower backscatter. Patterns apparent in the sidescan-sonar imagery include those interpreted to be sand waves, scarps, erosional outliers, boulders, trawl marks, and dredge spoils (figs. 2, 9). Areas of backscatter are often gradational, many patterns overlap, and boundaries are inferred.

### Low backscatter

Areas of low backscatter, caused by weak acoustic returns, are the darker tones on the sidescan-sonar mosaic and indicate generally finer grained sediment. Low backscatter is located in deeper water, mainly in the north and west (fig. 9). These areas correspond to the channel system described above.

### Moderate backscatter

Areas of moderate backscatter, characterized by moderate tones on the sidescan-sonar mosaic, are located between areas of low and high backscatter. Moderate backscatter covers most of the eastern and southern parts of the study area (figs. 9, 10).

### High backscatter

Areas of high backscatter, caused by strong acoustic returns, are the lighter tones of the sidescan-sonar mosaic and indicate generally coarser grained sediment. High backscatter is found mostly in the shallower parts of the west and along the southern flanks of the eastern bathymetric high (figs. 9, 10).

### Sand waves

Areas with tiger-striped backscatter tend to be located on bathymetric highs across much of the eastern half of the study area and in areas of the northwest and southwest. This pattern is interpreted to represent sand waves (figs. 2, 9). The sand waves on the eastern bathymetric high are oriented in different directions: in the north and along the southern edge, the crests tend to be oriented north-south, whereas in the central part they tend to be oriented east-west (fig. 10). Sand waves on the northwestern bathymetric high tend to have crests oriented roughly parallel to the sea-floor gradient, ranging from northeast-southwest to north-south. In general, north-south oriented sand waves have wavelengths of about 15 to 30 m; east-west-oriented sand waves have wavelengths of about 200 m. Megaripples, with wavelengths of about 1 to 3 m and crests oriented northwest-southeast, are also found on the northwestern high, indicating active sediment transport to the northeast or southwest (fig. 11). The southwestern areas of sand waves have north-south- and northwest-southeast-oriented crests. Sand-wave asymmetry could not be resolved in the sidescan-sonar or bathymetric data to determine sediment-transport directions.

### Scarps

A continuous, curvilinear pattern of sharply contrasting backscatter is observed along the southern edge of the eastern bathymetric high (figs. 2, 9, 10). This pattern is also present on the southwestern high. These features occur in water depths ranging from 35 m in the east to 37 m in the west and tend to separate areas of higher backscatter from areas of lower backscatter. They are interpreted to be a series of small scarps, hills, and benches. Seismic-reflection data in the area of the scarps show a drop of about 1 m on the sea-floor surface (fig. 8). The bathymetric data show a channel along the northern side of the scarps and hills (fig. 6). Backscatter patterns similar to these are found east of the study area, where high-resolution (1-m) bathymetry shows small scarps, hills, and benches that correspond to the high and low backscatter variations (McMullen and others, 2007; 2008).

### Erosional outliers

The northwestern bathymetric high shows areas of low backscatter surrounded by areas of high backscatter (figs. 2, 11). The high-backscatter areas are coarser grained and contain megaripples with wavelengths of 1 to 3 m. The low-backscatter areas are finer grained bathymetric highs with steep sides and flat tops, up to several hundred meters in diameter. Similar features in eastern Rhode Island Sound were interpreted to be erosional outliers (McMullen and others, 2007). Seismic-reflection data in this area show fluvial and estuarine sediments in the channel to the south that appear to continue northward along the flank of the bathymetric high where these small plateaus, approximately 1 m in height, are visible (fig. 7).

### Boulders

High-backscatter targets with low-backscatter shadows are scattered throughout the study area. These features are interpreted to be boulders, probably glacial erratics, which are up to several meters wide (figs. 9, 11, 12).

### Trawl marks

Thin, linear to curvilinear patterns of either high or low backscatter are seen in the deeper parts of the study area. These lines are interpreted to be trawl marks from fishing boats (fig. 10). Whether this area is a focus of commercial fishing or simply an area where the trawl marks are preserved is uncertain.

### Dredge spoils

About a dozen round to oblong areas of high backscatter are observed in the southwest (fig. 12). These areas are about 20 to 50 m across and appear to be aligned along several lines. Many of the areas show distinctly higher backscatter than their surroundings. Other areas show only slightly higher backscatter than the surrounding sea floor, but appear to contain rocks. A disposal site for dredged material, Site 69b, is located to the south of the study area (U.S. Environmental Protection Agency, 2004). The high-backscatter areas are probably dredge spoils that fell as disposal trails during transport; similar features consisting of areas 12 to 35 m wide and 6 to 18 cm thick, have been reported outside the disposal site (U.S. Army Corps of Engineers, 2004).

## Sedimentary Environments

On the basis of backscatter tones and features observed in the sidescan-sonar imagery, four sedimentary environments can be distinguished in the study area (fig. 13). Lighter backscatter tones tend to indicate higher energy environments and darker backscatter tones tend to indicate lower energy environments. The historic sediment samples from the study area tend to be characteristic of the sedimentary environments from which they were collected; however, boundaries of the environments were not determined using sediment-sample data, as only five samples are available from within the study area. The sedimentary environments are characterized by the processes of erosion or nondeposition, coarse-grained bedload transport, sorting and reworking, and deposition.

### Erosion or nondeposition

Sedimentary environments characterized by processes of erosion or nondeposition are located on the bathymetric highs. These environments produce high backscatter on the sonar image and include areas of rocks and erosional outliers. One historic sediment sample of gravel came from this sedimentary environment located in an area of high backscatter. Processes of erosion and nondeposition are found in higher energy environments where currents tend to winnow away finer grained sediment, leaving a coarser grained lag of sand and gravel.

### Coarse-grained bedload transport

Also on the bathymetric highs are sedimentary environments characterized by the process of coarse-grained bedload transport. This environment exists where sand waves are present. These are relatively high-energy environments where currents maintain sand waves. The three historic samples of sand collected in the study area were from this sedimentary environment.

### Sorting and reworking

Sedimentary environments characterized by sorting and reworking processes are found primarily between bathymetric highs and lows. The sea floor in this environment typically consists of fine sands and mud (Knebel and others, 2000). This environment is characterized by moderate backscatter and tends to be found between environments characterized by the process of deposition and higher energy environments.

### Deposition

Throughout much of the channel and the depression on the northeastern bathymetric high, environments are characterized by fine-grained deposition. One historic sample of mud came from this sedimentary environment, which displays low backscatter in the sidescan-sonar imagery. This low-energy environment with weak currents, if any, allows finer grained sediment, such as muds, to accumulate.

## Sea-Floor Geology

Sidescan-sonar imagery along with bathymetric and seismic-reflection data are useful in interpreting sea-floor geology. The bathymetry in the study area is related to the underlying stratigraphy. Erosional outliers and scarps, which are also found east of the study area, are the results of a lower sea level stand and the various paleoenvironments in the area. Sand waves on the sea floor are used to infer directions of net sediment transport.

The bathymetry in the study area is a surficial expression of the underlying geology. Bathymetric highs are associated with glacial drift, including glaciolacustrine sediments in the east (fig. 8). Linear bathymetric lows in the study area overlie and are surface expressions of the westward-draining fluvial channels that were partially filled during subaerial exposure (fig. 7). In the west, fluvial and estuarine sediments extend from the channel across the southern flank of the bathymetric high and form erosional outliers.

Features with the same backscatter characteristics as the erosional outliers in the western part of the study area were also identified in eastern Rhode Island Sound. These erosional outliers to the east, visible in high-resolution multibeam bathymetry as small plateaus about 0.5 m high, occur over stratified sediments that were interpreted to consist of glaciolacustrine deposits (McMullen and others, 2007). The erosional outliers in the present study area likely consist of fluvial and estuarine sediments that presumably continue from the channel onto the flank of the bathymetric high, as there is no well-defined northern boundary of these sediments (fig. 7). Glaciolacustrine sediments may be located on the bathymetric high and form these outliers; however, well-stratified sediments are not distinguishable in the seismic-reflection profiles. The outliers in both locations were probably formed in the same way; the more readily erodible sediment was removed, leaving plateaus of the more cohesive sediments.

The scarps, hills, and benches, which are at depths of 35 to 37 m, are probably records of a paleoshoreline. These features stretch across Rhode Island Sound in a curvilinear pattern parallel to the present shoreline at a relatively constant depth that becomes slightly shallower to the east (McMullen and others, 2007; 2008). The morphologies and depth of the scarps, hills, and benches are similar to those of paleoshorelines found in nearby areas, which have been previously dated based on sea-level-rise curves. In Long Island Sound, paleoshoreline features including small steps, lensoidal beach deposits, and erosional benches or terraces have been found at 37 to 38 m and were suggested to have formed 10,000 to 10,500 years ago (Gayes and Bokuniewicz, 1991). A 15-m-high, 1.5-km-wide, mid-shelf scarp located off New Jersey in water depths between 37 and 52 m was interpreted as a shoreline that formed around 10,500 years ago (Duncan and others, 2000). Although it is shallower than the features in our study area, a submerged barrier spit at 24 m was interpreted to represent a paleoshoreline from 8,300 to 9,000 years ago southwest of the study area, off the southern coast of Block Island (McMaster and Garrison, 1967). The scarps identified in Rhode Island Sound are thought be coeval with the paleoshoreline features in Long Island Sound and off the New Jersey coast due to their similar depths.

Sand-wave orientation in the study area is used to determine net sediment-transport directions, as water currents in the study area are not known. Sand waves in the northeastern part of the study area are generally oriented with their crests perpendicular to the sea-floor gradient. Therefore, net sediment transport is most likely parallel to the slope in this area. However, sand-wave crests on the northwestern bathymetric high are oriented parallel to the bathymetric gradient, implying that net sediment transport is around the high and that the sediment transport may be helping to maintain the feature.

## Summary

Sidescan-sonar imagery and bathymetric data collected in 2004 as part of NOAA survey H11322, along with seismic-reflection data collected by the USGS in 1980, are used to interpret the sea-floor geology and sedimentary environments in western Rhode Island Sound. Bathymetric highs in the study area tend to be associated with moderate to high backscatter, sand waves, and, on the western bathymetric high, erosional outliers. The southern edge of the eastern bathymetric high is flanked by scarps. The bathymetric highs tend to be composed of glacial drift at the surface, which in the east includes glaciolacustrine sediments. Sedimentary environments characterized by erosion or nondeposition and coarse-grained bedload transport are located on bathymetric highs and sedimentary environments characterized by sorting and reworking processes are located on their flanks. Bathymetric lows tend to have low backscatter and are commonly composed of fluvial sediments. Sedimentary environments characterized by fine-grained deposition are located in deeper parts of the study area. Trawl marks also tend to be found in the bathymetric lows. Boulders are scattered throughout the study area and dredge spoils are located in the southwest.

## Geographic Information System Data Catalog

This report contains both raster and vector data from western Rhode Island Sound. The raster data consist of bathymetry (available in both color-hillshade relief GeoTIFF images and Environmental Systems Research Institute's (ESRI) binary grids) and sidescan-sonar GeoTIFFs. The vector data are in ESRI shapefile format and include a NOAA polygon shoreline, a polygon outline of the study area, and two interpretive polygon layers. The raster data are provided in both a Geographic Coordinate System and a Universal Transverse Mercator (UTM) zone 19 projection, whereas the vector data are available in a Geographic Coordinate System only. In addition, a text file containing the original NOAA bathymetry data is made available (positions are UTM, zone 19). Geographic data layers are provided in the WGS84 datum and UTM data layers are provided in the NAD83 datum in order to be consistent with the preferences of collaborators.

When accessing this report from the DVD-ROM, the top level of the report contains an ArcView 3.3 project file (h11322.apr) and an ESRI ArcMap document (h11322.mxd) created in ArcMap 9.2, but saved as an ArcMap 9.0/9.1 document to make it accessible in older versions. These files contain the data layers of this report already loaded. If the user does not have access to the ESRI software or a compatible GIS data browser, a free viewer, ArcExplorer, is available from ESRI (www.esri.com).

Each GIS data layer from this publication is cataloged below for easy access. The individual data-layer name is linked to a browse graphic which will open a separate browser window displaying an image of the data layer. Federal Geographic Data Committee (FGDC) metadata for the individual data layers are provided in HTML, FAQ HTML, and text versions. 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 each data layer is also provided. Compressed downloadable files were created using the Windows program WINZIP v9.0. Users who do not have software capable of uncompressing the archived Zip files can obtain a free version of the software from Winzip Computing, Inc., or Pkware, Inc.

### Sidescan-Sonar Imagery

| Data-Layer Name and Description | Metadata | Files |
|---|---|---|
| **h11322_1m_sss_geo_str** - stretched sidescan-sonar imagery of NOAA survey H11322 (geographic, WGS84) | HTML<br>FAQ<br>txt | Zip |
| **h11322_1m_sss_geo** - composite sidescan-sonar imagery of NOAA | HTML | Zip |

| | | |
|---|---|---|
| survey H11322 (geographic, WGS84) | FAQ<br>txt | |
| **h11322_1m_sss_utm_str** - stretched sidescan-sonar imagery of NOAA survey H11322 (UTM zone 19, NAD83) | HTML<br>FAQ<br>txt | Zip |
| **h11322_1m_sss_utm** - composite sidescan-sonar imagery of NOAA survey H11322 (UTM zone 19, NAD83) | HTML<br>FAQ<br>txt | Zip |

## Bathymetric Imagery

| Data-Layer Name and Description | Metadata | Files |
|---|---|---|
| **h11322_geo.tif** - representation of bathymetric data from NOAA survey H11322 (geographic, WGS84) | HTML<br>FAQ<br>txt | Zip |
| **h11322_utm.tif** - representation of bathymetric data from NOAA survey H11322 (UTM zone 19, NAD83) | HTML<br>FAQ<br>txt | Zip |

## Bathymetric Grids

| Data-Layer Name and Description | Metadata | Files |
|---|---|---|
| **h11322_geo45m** - bathymetric grid of NOAA survey H11322 (geographic, WGS84) | HTML<br>FAQ<br>txt | Zip |
| **h11322_utm45m** - bathymetric grid of NOAA survey H11322 (UTM zone 19, NAD83) | HTML<br>FAQ<br>txt | Zip |
| **h11322_1m_utm19nad83.txt** – space-delimited ASCII text file of the bathymetric grid of NOAA survey H11322 (UTM zone 19, NAD83) | HTML<br>FAQ<br>txt | Zip<br>(19MB) |

## Interpretive Data

| Data-Layer Name and Description | Metadata | Files |
|---|---|---|
| **h11322environs** - interpretation of the sedimentary environments in NOAA survey H11322 (geographic, WGS84) | HTML<br>FAQ<br>txt | Zip |
| **h11322interp** - interpretation of the sidescan sonar and bathymetric imagery from NOAA survey H11322 (geographic, WGS84) | HTML<br>FAQ<br>txt | Zip |

### Base-map Data

| Data-Layer Name and Description | Metadata | Files |
|---|---|---|
| **nos80k_84** - medium resolution digital vector U.S. shoreline shapefile for the Rhode Island Sound GIS project area (geographic, WGS84) | HTML<br>FAQ<br>txt | Zip |
| **h11322outline** - outline of sidescan sonar imagery from NOAA Survey H11322 (geographic, WGS84) | HTML<br>FAQ<br>txt | Zip |

## Acknowledgments

We appreciate the shipboard support provided by the crew of the National Oceanic and Atmospheric Administration Ship RUDE. Critical reviews by VeeAnn Cross, Ben Gutierrez, Elizabeth Pendleton, and Dale Simmons (all of the USGS) improved this report.

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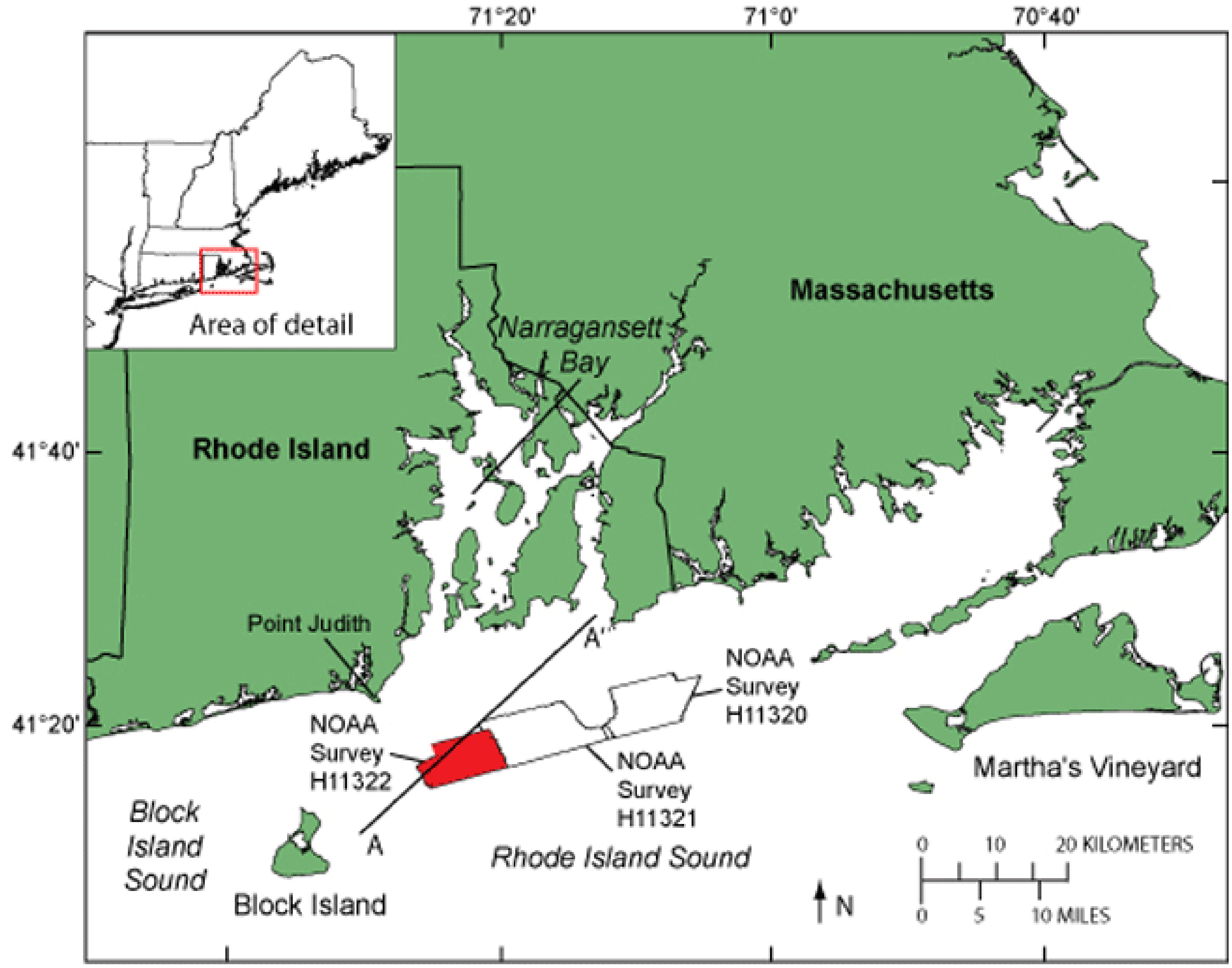


**Figure 1.** Location of National Oceanic and Atmospheric Administration (NOAA) survey H11322 study area (red polygon) in Rhode Island Sound, southeast of Point Judith, Rhode Island. Also shown are locations of NOAA surveys H11320 and H11321 and the seismic profile A-A' presented in figure 3. Inset shows location of study area off the northeastern United States.

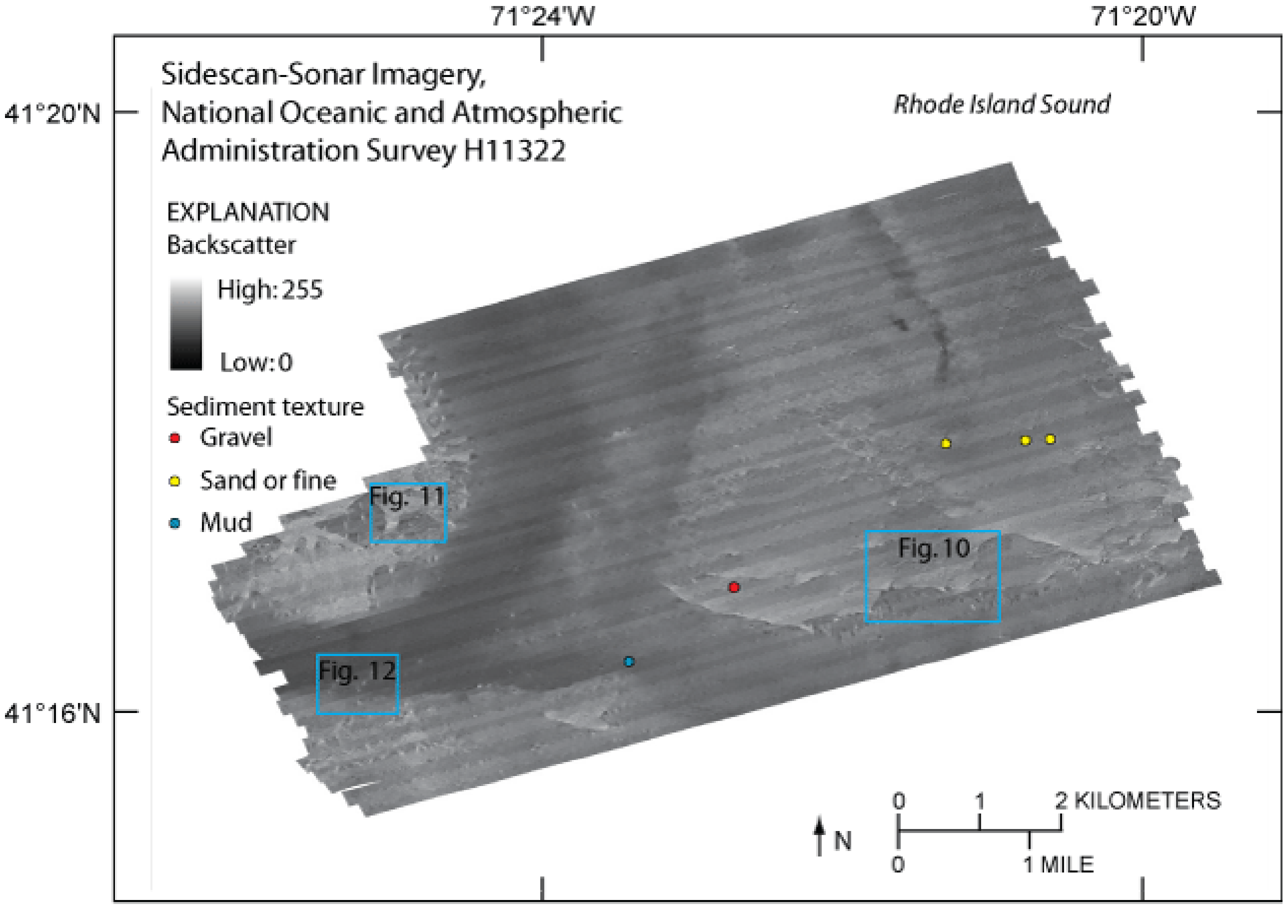


**Figure 2.** Sidescan-sonar image of National Oceanic and Atmospheric Administration survey H11322 in western Rhode Island Sound. Areas of high backscatter (lighter tones associated with generally coarser grained sediment) are observed on the bathymetric highs in much of the eastern, northwestern, and southwestern parts of the study area. Areas of low backscatter (darker tones associated with generally finer grained sediment) are observed in the troughs in the western and southern parts of the study area. Also shown are sediment sample locations (red, yellow, and blue circles) and locations of figures 10, 11, and 12 (blue rectangles). Area of image is shown in figure 1.

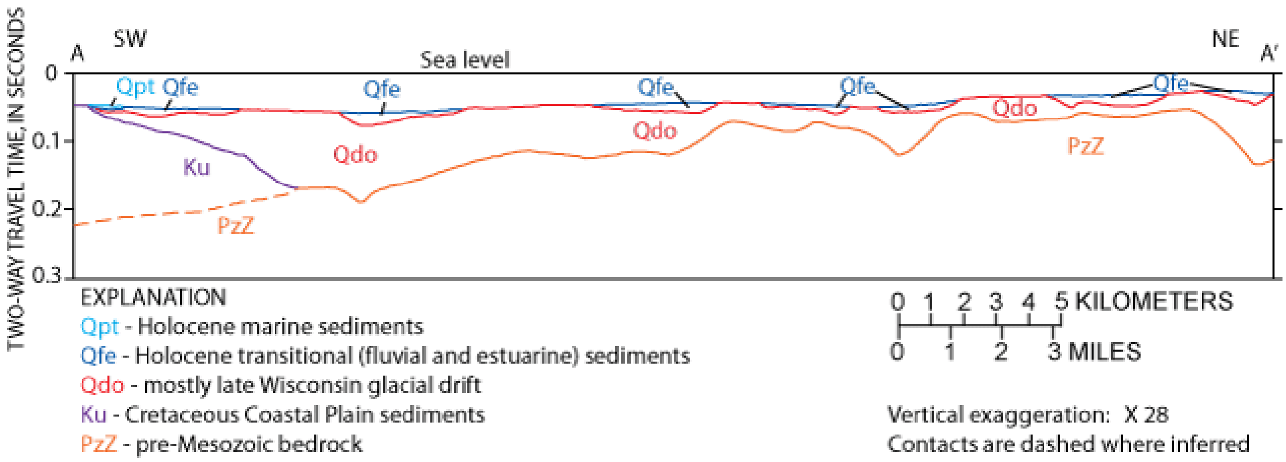


**Figure 3.** Stratigraphy interpreted from seismic subbottom profile across Rhode Island Sound. (Modified from Needell and others, 1983b, location of profile shown in figure 1.)

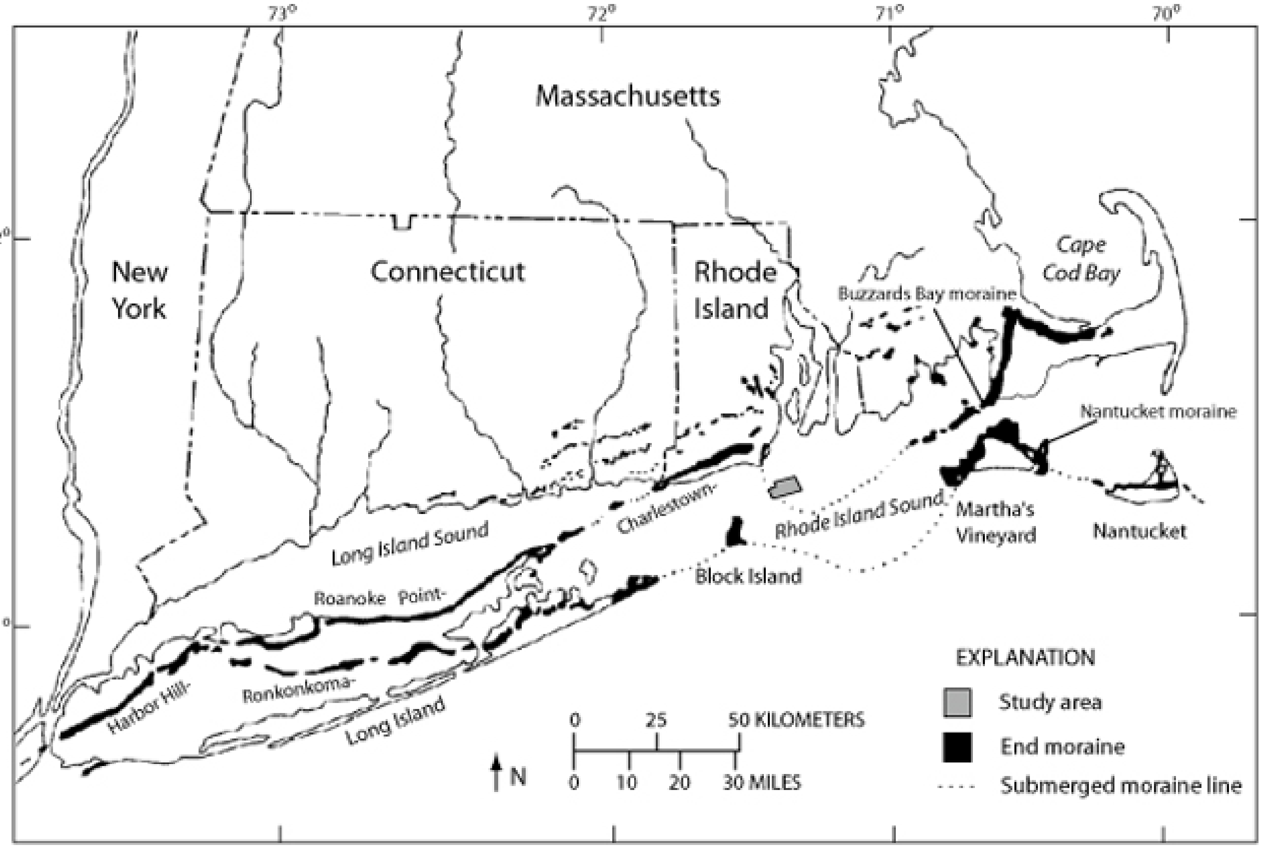


**Figure 4.** Location of end moraines (black polygons) and submarine ridges (dashed lines) in southern New York and New England (modified from Gustavson and Boothroyd, 1987) and location of study area (gray polygon). The Ronkonkoma-Nantucket end moraine represents the maximum advance of the Laurentide Ice Sheet about 20,000 years ago and the Harbor Hill-Roanoke Point-Charlestown-Buzzards Bay end moraine represents a retreated ice-sheet position from about 18,000 years ago (Uchupi and others, 1996).


**Figure 5.** Photograph of National Oceanic and Atmospheric Administration Ship RUDE at sea. (Photograph by NOAA.)

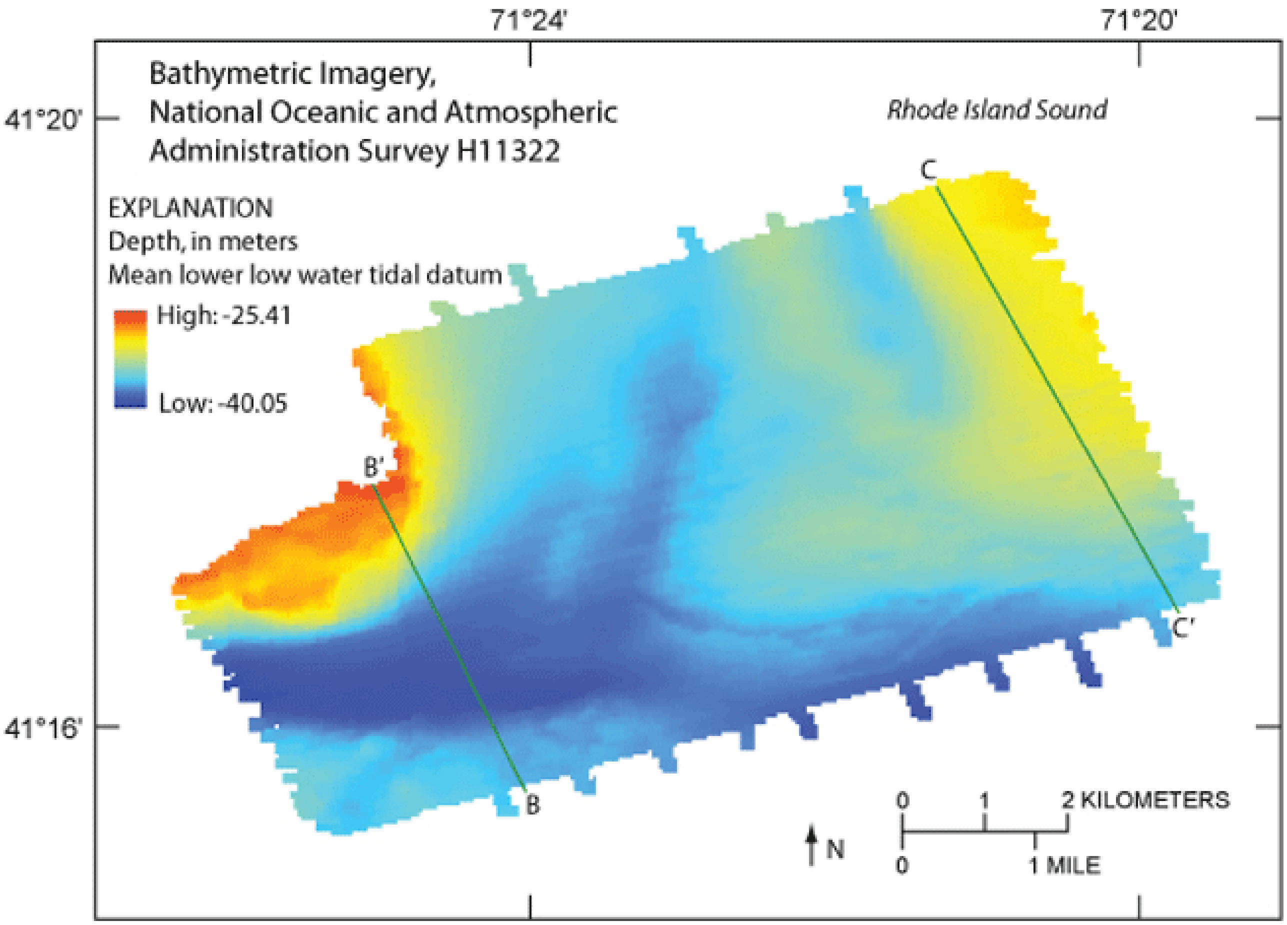


**Figure 6.** Bathymetric image of National Oceanic and Atmospheric Administration survey H11322 in western Rhode Island Sound. Bathymetric highs are located in the northwest, northeast, and southwest. Channels lie between the northern bathymetric highs and across their southern boundaries. Green lines indicate locations of seismic-reflection profiles B-B' and C-C', shown in figures 7 and 8, respectively.

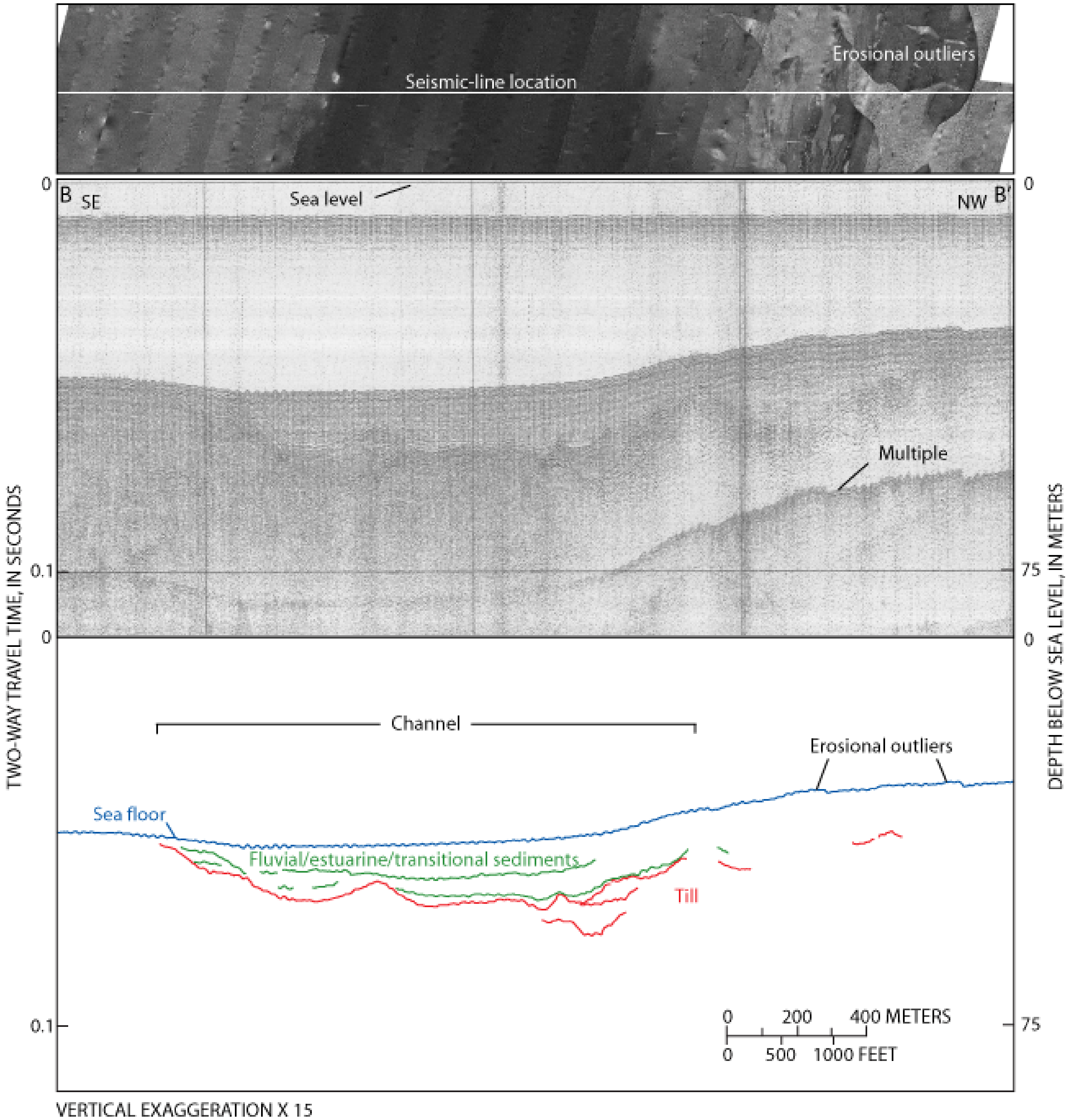


**Figure 7.** (Top) sidescan-sonar imagery from the western part of the study area, (middle) in the area of seismic-reflection profile B-B' (from Needell and others, 1983b) extending southeast to northwest, (bottom) with interpretation. Fluvial, estuarine, and transitional sediments overlie till in the channel and along the southern flank of the northwestern bathymetric high. The bathymetric high also shows small plateaus, which are visible as patches of high and low backscatter in the sidescan-sonar imagery and are interpreted to be erosional outliers. Location of seismic-reflection profile is shown in figure 6.

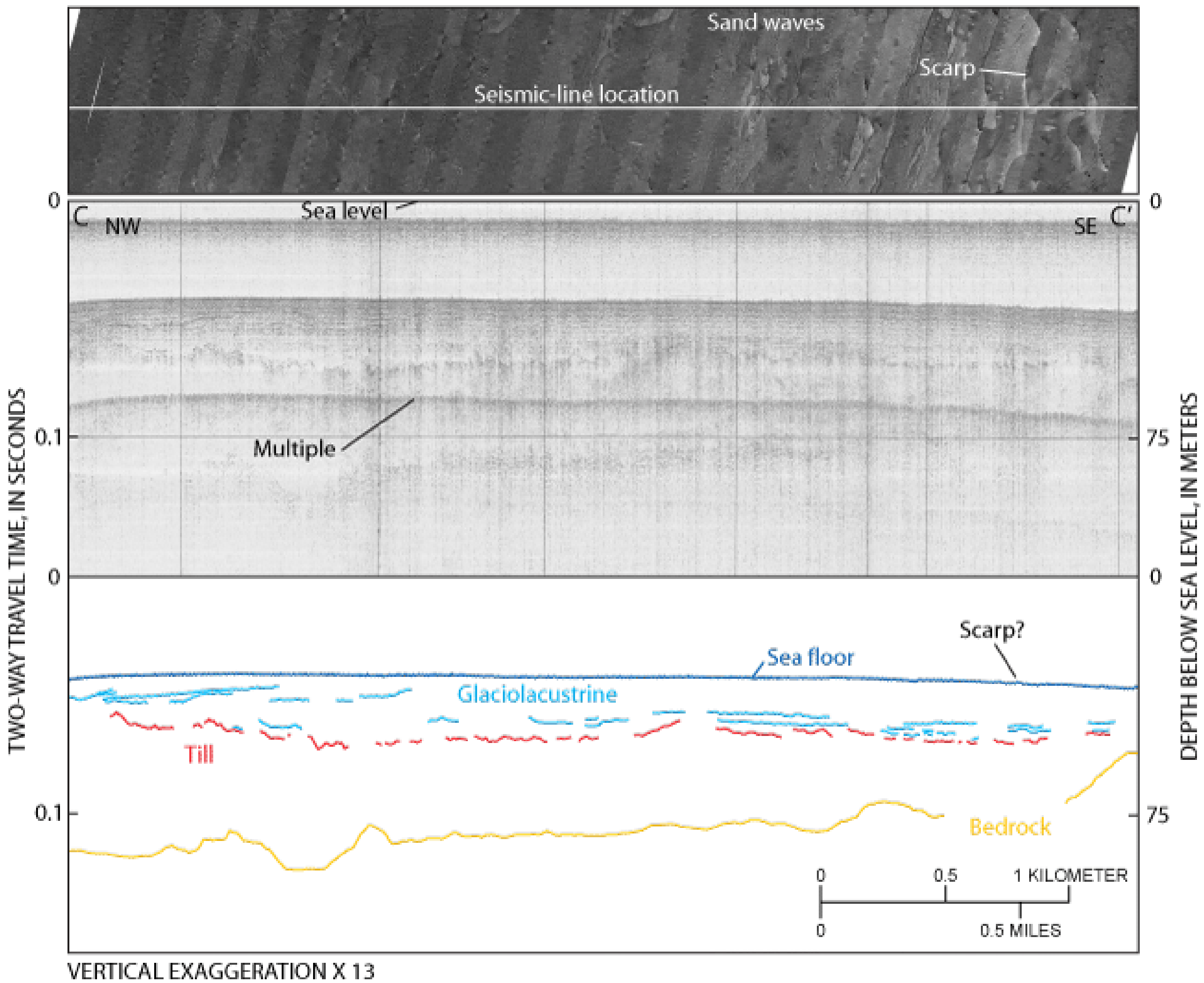


**Figure 8.** (Top) sidescan-sonar imagery associated with (middle) seismic-reflection profile C-C' (from Needell and other, 1983b) and (bottom) interpretation. The uppermost unit is composed of horizontal to gently dipping stratified sediments, interpreted to be glaciolacustrine deposits, which overlie till and bedrock. A small dip in the sea floor in the southern part of the profile occurs where small scarps cross the region. Sand waves are visible in the sidescan-sonar imagery northwest of the scarp. Location of seismic-reflection profile is shown in figure 6.

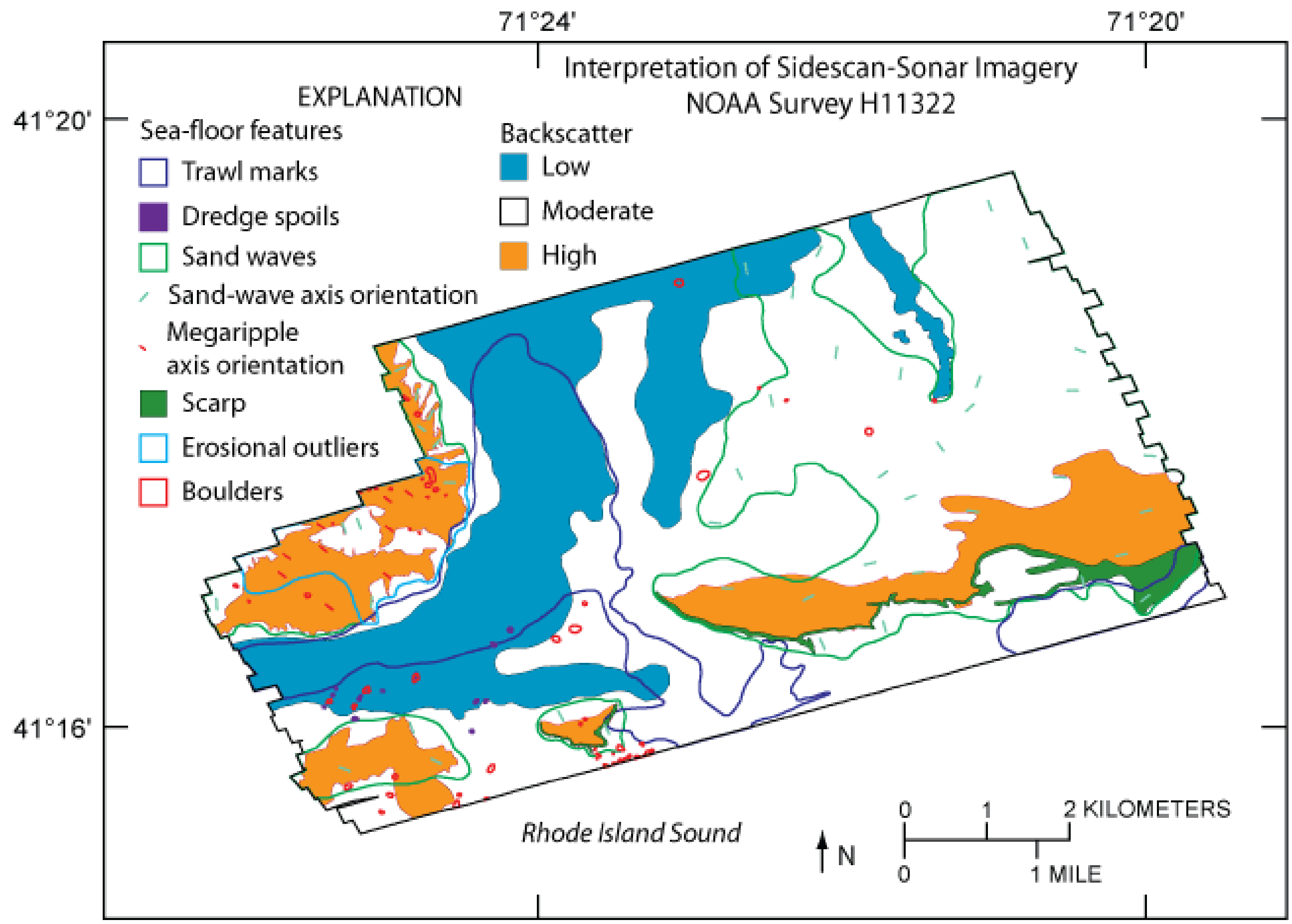


**Figure 9.** Interpretation of sidescan-sonar imagery of study area including low, moderate, and high backscatter; sand waves; sand-wave and megaripple axis orientation; scarps; erosional outliers; boulders; trawl marks; and dredge spoils. Location of study area shown in figure 1.

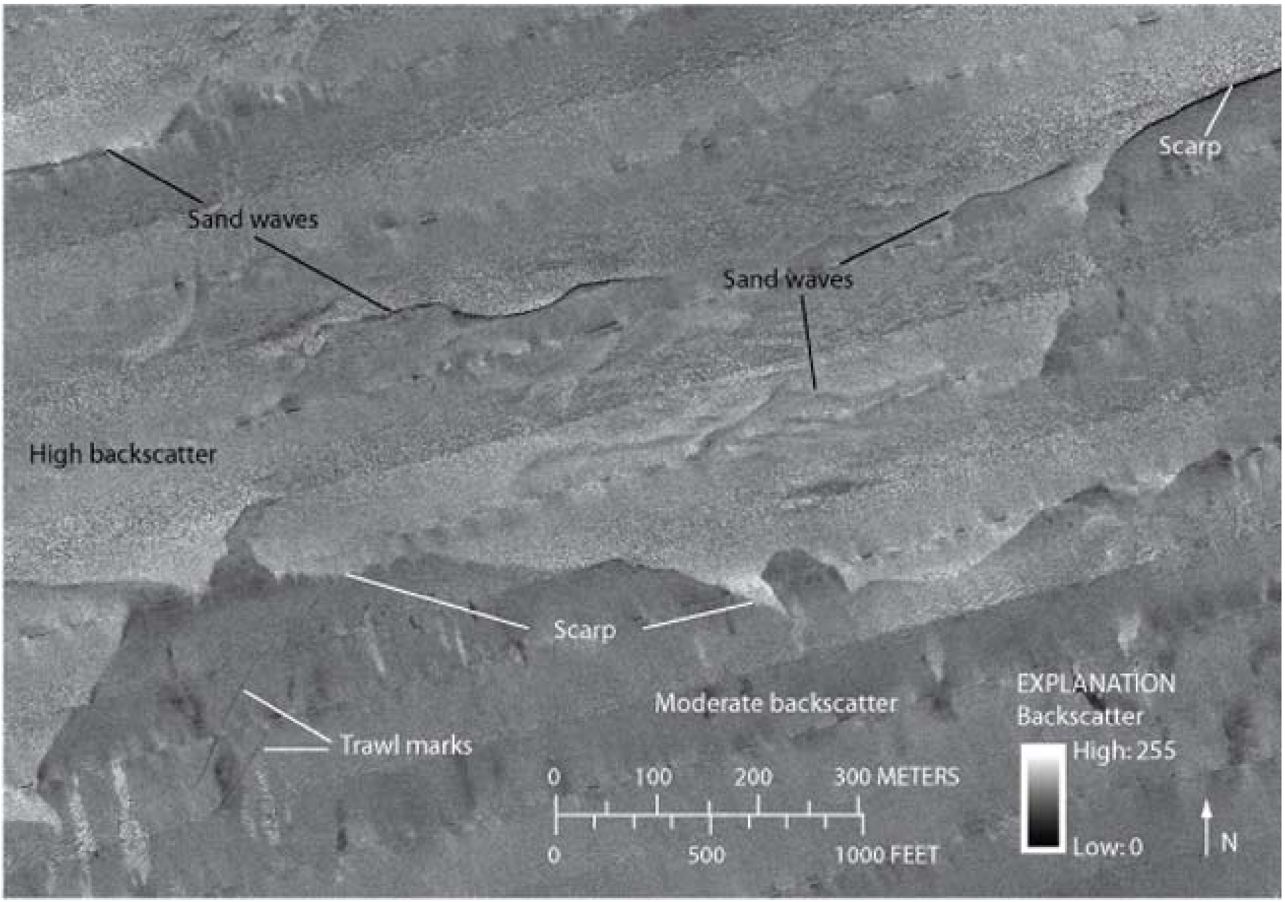


**Figure 10.** Detailed sidescan-sonar image of an area containing scarps, which show a sharp contrast in backscatter that continues along most of the southern slope of the eastern bathymetric high. Sand waves, oriented generally east-west, and higher backscatter are observed north of the scarp. Trawl marks can be seen in the area of moderate backscatter south of the scarp. Location of image shown in figure 2.

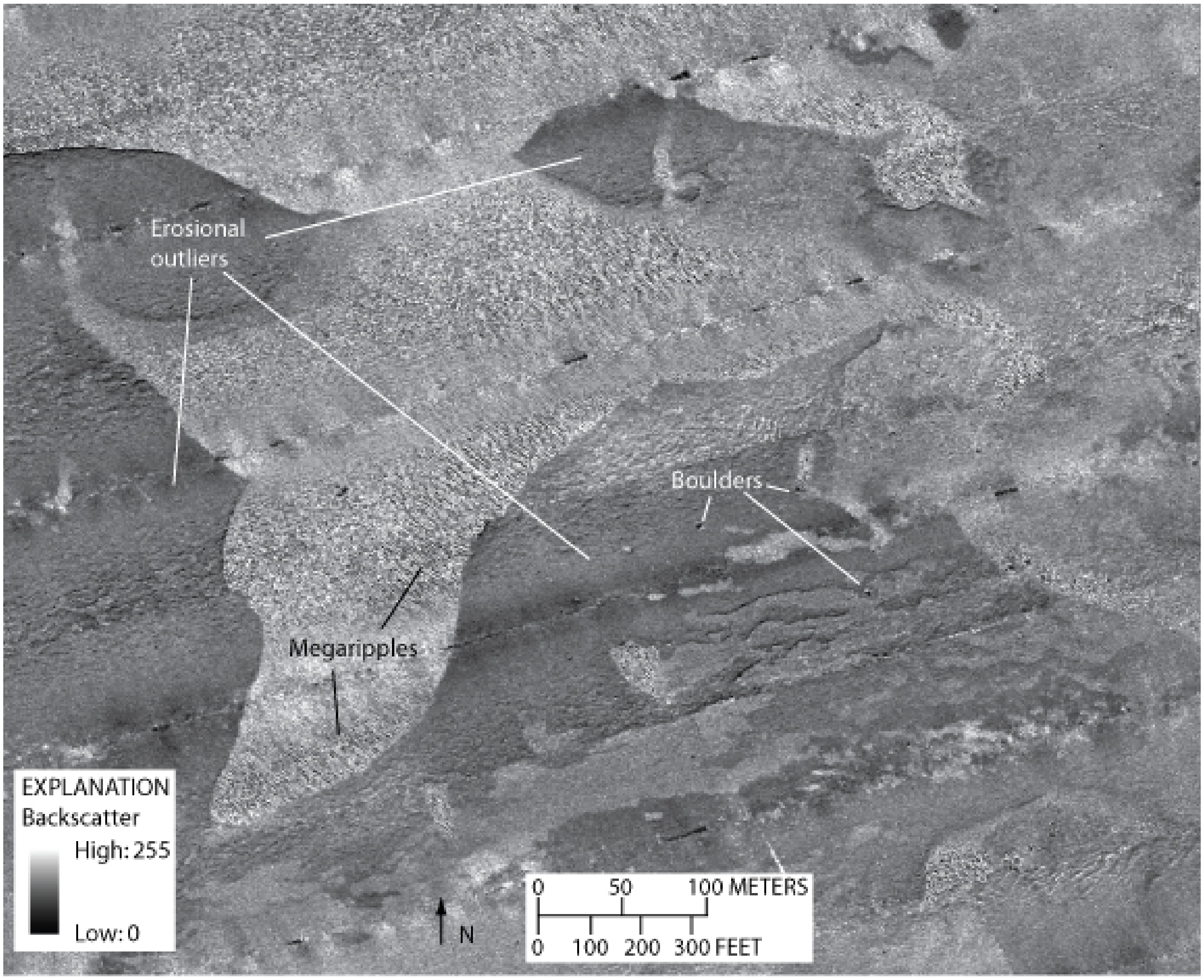


**Figure 11.** Detailed sidescan-sonar image showing erosional outliers in the northwestern part of the study area. Erosional outliers are characterized by low backscatter, presumably representing fine-grained fluvial and estuarine sediment, which form small plateaus about 1 meter high. Areas of high backscatter and megaripples are found between the erosional outliers. Location of image shown in figure 2.

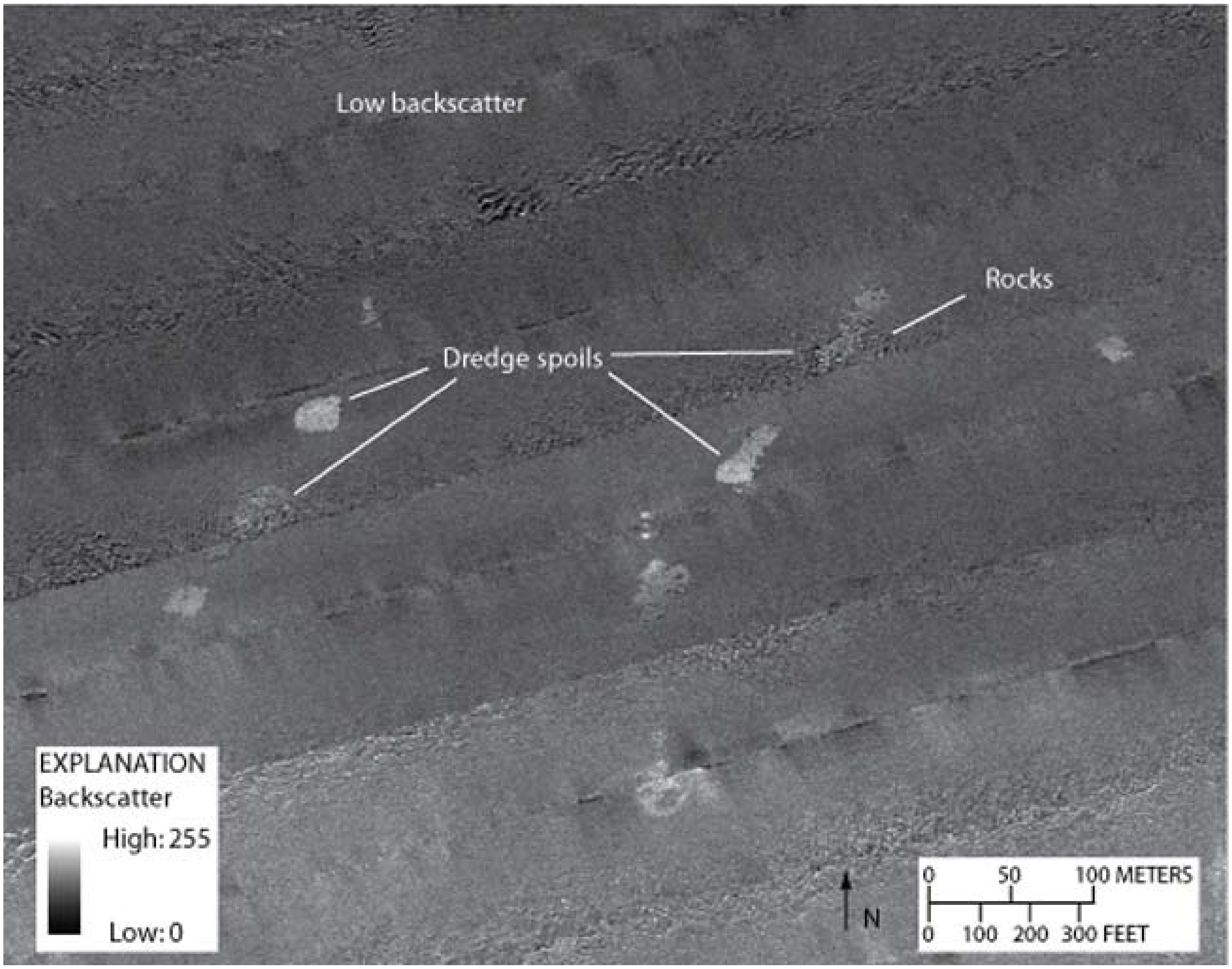


**Figure 12.** Detailed sidescan-sonar image showing dredge spoils in the southwestern part of the study area. An area of low backscatter can be seen in the northern part of the image. Boulders, characterized by high-backscatter targets with low-backscatter shadows, comprise some of the dredge spoils. Location of image shown in figure 2.

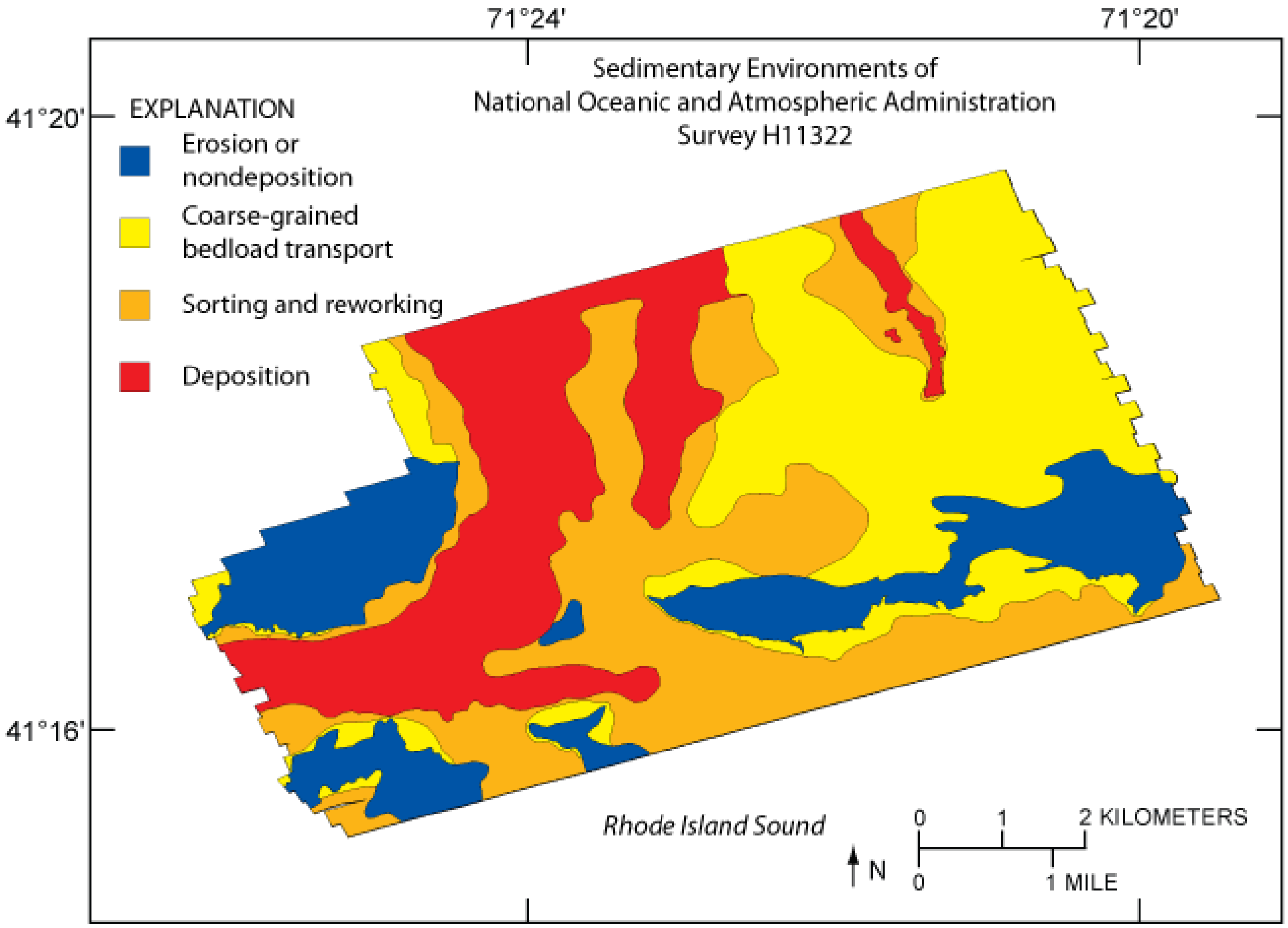


**Figure 13.** Sedimentary environments found in the study area include those characterized by processes of erosion or nondeposition, coarse-grained bedload transport, sorting and reworking, and deposition. Location of study area shown in figure 1.