Announcement M13AS00014: Hurricane Sandy Coastal Recovery and Resiliency - Resource Identification, Delineation and Management Practices

Cooperative Agreement: M14AC00011 University of Rhode Island
Identification of Sand/Gravel Resources in Rhode Island Waters While working Toward a Better Understanding of Storm Impacts on Sediment Budgets

Deliverable J:
FINAL TECHNICAL REPORT, Phase I
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Prepared By: Brian Caccioppoli, Jeffrey Gardner, Carol Gibson, John King, Bryan Oakley, David Robinson

Principal Investigator:
John King
Professor of Oceanography
Graduate School of Oceanography
University of Rhode Island
Narragansett, RI 02881
(401) 874-6182
jwking@uri.edu

Senior Advisor:
Grover Fugate
Executive Director
Coastal Resources Management Council
Wakefield, RI 02879
(401) 783-3370
gfugate@crmc.gov

Co-Principal Investigators:
Jon Boothroyd*
Former Professor Emeritus and
Rhode Island State Geologist
Department of Geosciences
University of Rhode Island

Bryan Oakley*
Assistant Professor of Environmental Geoscience
Eastern Connecticut State University
(860) 465-0418
Oakleyb@easternct.edu

ArcGIS Technical Specialist:
Carol Gibson
Marine Research Specialist
Graduate School of Oceanography
University of Rhode Island
(401) 874-6182
cgibson@uri.edu

*** Note:** The project team was deeply saddened by the loss of Co-PI Dr. Jon C. Boothroyd, who passed away unexpectedly before the conclusion of this project. Dr. Bryan Oakley, a former PhD student and close colleague of Boothroyd's, assumed his responsibilities on this project.

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1. INTRODUCTION AND PROJECT BACKGROUND

This document represents Deliverable D of Cooperative Agreement Award M14AC00011 between BOEM and the Graduate School of Oceanography, University of Rhode Island (GSO-URI), entitled "Identification of Sand/Gravel Resources in Rhode Island Waters While Working Toward a Better Understanding of Storm Impacts on Sediment Budgets." The purpose of this deliverable is to present the Draft Technical Report for the project.

1.1 Project Overview

This project represents a collaborative effort between GSO-URI, the Rhode Island Coastal Resources Management Council (RI CRMC), and the Narragansett Indian Tribal Historic Preservation Office (NITHPO). The overall goal of the project is to identify sand and gravel deposits in federal waters 3-8 nautical miles offshore of Rhode Island (Figure 1) that may be appropriate for use as beach replenishment material, and to assess whether the identified borrow areas could contain culturally sensitive archaeological sites. The project consisted of four major components: (1) compiling and converting existing, publicly-available geophysical and geological data in the area of interest into standard ArcGIS-compatible databases and maps; (2) leveraging information from the ongoing RICRMC Shoreline Change Special Area Management Plan ("Beach SAMP") study to estimate sand resource needs for beach replenishment in Rhode Island; (3) leveraging information from the ongoing BOEM-URI-NITHPO “Submerged Paleocultural Landscapes Project” to identify and protect ancient Native American cultural resources within the potential borrow areas; and (4) conducting new geophysical surveys to identify and delineate potential sediment borrow areas located within 3 – 8 nautical miles offshore of the State of Rhode Island.

1.2 Geologic Setting of the Study Area

The south coast of Rhode Island trends southwest by northeast for approximately 33 km (20 mi), and consists of a system of headlands and barrier spits (Figure 2). The headlands are comprised of eroding till, and stratified sand and gravel deposited during the late Wisconsinan deglaciation. Barrier spits 0.5 to 5 mi (0.8 to 8 km) in length and 600-900 ft (175 to 300 m) in width connect the headlands. The south coast is a micro-tidal [mean range 3.6 ft (1.1 m); spring range 5.2 ft (1.6 m)], wave-dominated, mixed energy coast according to the classification of Hayes (1979). Mean wave height is 2.6 ft (0.8 m) (Boothroyd et al., 1985), although storm waves in excess of 25 ft (8 m) can be expected during storm conditions (Spaulding and Grilli, 2008, personal communication).

1.2.1 Geologic Environments

The present day geomorphology of the shoreface/inner shelf of the Rhode Island south shore is largely the result of the advance and retreat of the late Wisconsinan Laurentide Ice Sheet. While Coastal Plain sediment of Cretaceous to Tertiary age likely covered southern New England, all in-place evidence of the Coastal Plain sediment has been eroded. Glacially transported Cretaceous sediment has been sampled in discrete blocks in terminal moraines at Block Island, Rhode Island (Sirkin, 1976; Stone and Sirkin, 1996), and Coastal Plain sediment has been interpreted in seismic reflection data from Rhode Island Sound, south of Narragansett Bay (Needell et al., 1983). The Late

Wisconsinan Laurentide Ice Sheet reached its terminal position south of Block Island at the last glacial maximum, coinciding with the low-stand in eustatic sea level around 26,000 yBP, before beginning to retreat northward (Boothroyd and Sirkin, 2002; Dyke et al., 2002; Peltier and Fairbanks, 2006; Stone and Borns jr., 1986). As the glacier retreated, melt-water issuing from the ice deposited sediment in a variety of depositional environments (Gustavson and Boothroyd, 1987; Stone and Stone, 2005) on what is now the southern Rhode Island shoreface and outer continental shelf. Of particular interest to this study are previously identified large glacial deltas, which underlie the modern coastal lagoons and extend south into Block Island Sound (Figure 3). These deltas were deposited into Glacial Lake Block Island sometime before 21,000 yBP (Oakley and Boothroyd, 2013; Oakley, 2012), prior to sea level inundating the study area. Sub-bottom seismic reflection profiles collected by Oakley (2012) from the present upper shoreface and inner continental shelf showed southerly dipping (5 - 15º) reflectors offshore of the Rhode Island south shore, interpreted to have been deposited in a delta slope depositional environment (Figure 4) (Oakley, 2012), These were hypothesized to contain significant volumes of sand and gravel. Characterizing the location, sedimentology, and volume of these deltas was a primary focus of this study.

1.2.2 Benthic Geologic Habitats in the Study Area

A benthic geologic habitat or depositional environment is a spatially recognizable area with geologic characteristics that are distinctly different from surrounding areas (Oakley et al., 2012). In order to identify submerged habitats, distinct facies and facies boundaries are typically identified from side-scan and sub-bottom sonar records aided by underwater video-imagery, bathymetry, surficial sediment samples, sediment-profile images and/or sediment core data. Previous investigations in the vicinity of the study area were focused either on the upper and lower shoreface (Klinger, 1996; Boothroyd and Klinger, 1998; Brenner, 1998; Zitello, 2002; Oakley et al., 2009) or areas of potential development for wind turbines south and east of Block Island (LaFrance et al., 2010, 2014; Oakley et al., 2010a, 2010b). Recent projects (Boothroyd and Oakley, 2007, 2009) utilized a naming convention that combined the interpreted geologic habitat/depositional environment, surface sediment grain size information, and other identifiable characteristics. The following relevant general environments were identified in previously- studies:

1. ***Depositional platform sand sheet (DP ss)*** **–** This habitat was identified as a fairly featureless light return on the side-scan record. Representative sediment samples of this facies are fine to very fine sand (0.0625 - 0.25 mm). The sand sheet extends from the shoreline out approximately 328 to 656 ft (100 to 200 m) on the upper shoreface. The offshore extent of the sand sheet throughout areas studied thus far corresponds to a water depth of approximately 23 ft (7 m) (Klinger 1996; Oakley et al., 2007; Oakley et al., 2009). Sand sheet varies in thickness from 0.3–3 ft (0.1–1m) (Brenner, 1998; J.P. Klinger, personal communication, 2006).

2. ***Cross-shore swaths with small dunes (CSS sd)*** **–** This habitat, characterized by a dark side-scan return with distinct patterns of 2D-bedforms with a spacing of 1.6-4.3 ft (0.5 – 1.3 m) (ripples to small dunes in the classification of Ashley et al. 1990) occurs on the upper and middle shoreface. CSS sd forms mostly shore-perpendicular swaths that extend seaward on the shoreface beyond the seaward limit of most areas studied thus far. These swaths probably represent areas of downwelling that are active during storm events (Hequette and

Hill, 1993). As a result, they indicate areas of high rates of offshore sediment transport. Grain size from samples collected in this habitat ranged from well-sorted medium sand (0.25 – 0.5 mm), to moderately sorted coarse sand (0.5 – 1 mm) to gravel (1 - 4 cm).

3. ***Depositional Cobble gravel pavement (Dpv gp)*** **-** This geologic habitat has been identified by a dark (hard) return on the side-scan record. The cobble pavement forms large, relatively featureless areas on the shoreface seaward of the sand sheet (DP ss) and contains mostly cobbles [10-15 cm intermediate axis diameter]. This habitat formed in areas occupied by glacial alluvial fans and/or large glacial lacustrine deltas as the surf zone swept over the area during post-glacial sea-level rise. The cobbles are only moved during major storm events, such as severe extra-tropical cyclones and hurricanes, when wave-orbital motion is robust enough for cobble transport (Klinger, 1996).

4. ***Glacial Outcrop boulder gravel concentrations (GO bgc)*** **-** This habitat is readily identifiable by concentrations of large boulders, easily distinguished on the side-scan sonar record. Individual boulders range from 3-13 ft (1-4 m) diameter. The boulder concentrations (GO bgc) are the result of wave erosion at the shoreline of drumlins, headlands comprised of till or glacial ice-marginal fluvial deposits containing beds of debris-flow till or end moraine deposits. The boulders are located very close to where they were originally deposited by glacial action. They crop out (protrude through) later deposits such as the sand sheet (Dp ss) and cobble pavement (DPv gp).

5. ***Glacial delta plain (various facies) (GDP xxx)*** **–** These habitats were identified in two areas mapped southeast of Block Island as part of the Ocean Special Area Management Plan (Oakley et al., 2010a, b), and are interpreted to be reworked sediment on the former delta plain. These deltas graded into glacial lakes during late Wisconsinan deglaciation, prior to marine transgression in the Holocene. These deltas would be similar in morphology and orientation as those interpreted in the present study area (Oakley, 2012) and elsewhere in New England (Gustavson and Boothroyd, 1987; Koteff and Pessl, 1981; Stone and Stone, 2005). The surface sediment distribution mapped by Oakley et al., (2010a, b) follows the same naming convention as the shoreface units above (Glacial delta plain GDP) and an abbreviation for sediment type. Some examples include; boulder concentrations (GDP bgc), sand sheet (GDP ss) and cobble pavement (GDP cgp). The presence of sandwaves (GDP sw) and other active bedforms (small dunes) (GDP csd) indicate extensive transport of sediment across these surfaces. It is interpreted that the original delta plain surfaces were highly modified during mid to late Holocene marine transgression and continue to be altered, particularly during large storm events.

6. ***Glacial Lakefloor basin (various facies) (GLF xxx)*** **-** These habitats were identified in two areas mapped south east of Block Island as part of the Ocean Special Area Management Plan (Oakley et al., 2010a, b), and are interpreted to be sediment deposited in the basin in former glacial lakes during late Wisconsinan deglaciation. In the present study area, this would be the former Glacial Lake Block Island. The surface sediment distribution mapped by Oakley et al., (2010a, b) follows the same naming convention as the shoreface units (1-4 above), using the interpreted depositional environment (Glacial lakefloor basin GLF) and an abbreviation for sediment characteristics (grainsize + descriptor). Some examples include;

Glacial Lakefloor basin sand sheet with gravel sheet (GLF ssg), Glacial lakefloor basin fine sand (GLF fs) and Glacial lakefloor basin coarse silt (GLF sic). The presence of sandwaves (GLF sw) and other active bedforms (small dunes) (GLF csd) indicate extensive transport of sediment across these surfaces. The presence of finer-grained sediment (coarse silt and silt) indicates some deeper portions of the basins are sediment sinks for modern marine mud deposited from suspension.

1.2.3 Sediment Transport

The shoreface and inner shelf of Rhode Island is a dynamic environment characterized by oceanographic processes that affect the type and geographic distribution of benthic sediment. The following processes dominate the study area (Boothroyd and Oakley, 2007, 2009; Oakley et al., 2009):

1. ***Onshore sediment transport*** **-** Sediment transport on the depositional platform (DP ss) is controlled by wave orbital motion that transports sediment onshore and combined flows that transport sediment offshore. Transport of sediment on the sand sheet occurs at least 90 days/year during periods of post-storm recovery through long-term depositional stages, and 30 of those days can be attributed to southwest, sea-breeze generated waves ($T=2.7$ s and $H = 0.4$ m) (Klinger, 1996). The seaward limit of onshore sediment transport during fair-weather conditions is known as the return depth. Klinger (1996) calculated the return depth for the south coast of Rhode Island at 39 ft (12 m) below mean lower low water (MLLW). Sediment transported seaward of the return depth is considered to be lost from the shoreline system and is not returned to the active beach.

2. ***Offshore sediment transport*** - Offshore migration of sand across the shoreface is dominated by storm-generated combined flows, which are the result of storm induced downwelling and asymmetric wave orbital motion. During storms, the asymmetric wave-orbital motion (offshore stroke) sweeps sand-sized sediment up over the crest of bedforms where it can be transported offshore as bedload by a downwelling return flow generated by set-up (storm surge) along the shoreline (Clifton, 2006; Hequette and Hill, 1993; Suter, 2006). The downwelling flow seems to follow topographic lows in the cross-shore swaths, which are aligned perpendicular to the trend of the shoreline and extend offshore to at least 65.6 ft (20 m) water depth (Oakley et al., 2009). Transport of coarse sand in the CSS sd swaths on the shoreface occurs only during storm events, ~ 2.5-4 days/yr in 39.3 (12 m) of water (Klinger 1996).

3. ***Longshore sediment transport*** – Rates of longshore sediment transport can be estimated based on historical dredging records from Pt. Judith Pond and from measured vertical sediment accumulation rates within the Pt. Judith Harbor of Refuge. It was estimated that the sediment accumulation rate is about 14,387 y^3yr^{-1} (11,000 m^3yr^{-1}) for the Pt. Judith-Potter Pond complex (Friedrich, 1982). The primary source of this material is sediment transported alongshore by predominantly eastward longshore current flow.

2.0 PROJECT METHODOLOGY

2.1 Data Synthesis

2.1.1 Objective and Geographic Area of Interest

The primary goal of the data synthesis component of this project was to locate publicly available geological and geophysical data that had been collected in the study area over the past several decades, and to compile these data into an ArcGIS-compatible dataset with an associated reference map. This synthesis was intended to serve as a user-friendly compilation of relevant data for BOEM, and also to provide a general geologic and geophysical characterization of study area for the project team. The data compilation effort focused on data collected between 3 - 8 nautical miles offshore of the state of Rhode Island (Figure 1). Individual datasets that were located within the project area, but also extended outside its geographic boundaries, were also included in their entirety in order to facilitate the most accurate and complete interpretations of available data. Datasets that did not intersect or cross the study area in any way were not included.

2.1.2 Data Sources

A thorough internet search and literature review was conducted to identify pertinent digital and analog data. Only datasets that were of high enough resolution to contribute to a robust geologic and geophysical characterization of the project area were selected for inclusion in this compilation. Publicly available data were the primary focus of the compilation effort, although a small amount of privately held data was accessed through the archives at GSO-URI, or through collaboration with the project team's colleagues. The compilation effort focused on data that was available in some type of digital format. Analog data or printed material was considered for inclusion only if it was deemed to provide a significant contribution to the geological characterization of the project area. In cases were multiple datasets of the same type were available, such as bathymetry collected by NOAA's hydrographic survey program over several decades, only the most recent or highest resolution dataset was chosen for inclusion in the compilation.

2.1.3 Data Synthesis and Formatting

Once located, digital data were downloaded from their original sources to a local high-capacity hard drive, and converted to ArcGIS geodatabases organized by data type. In some cases, such as with USGS Open File Reports, datasets were already in ArcGIS-compatible "shapefile" or "grid" format, and only needed to be converted to a standardized geographic coordinate system and exported to subject-specific geodatabases. In other cases, data were digitally available as spreadsheets or as non-GIS compatible graphics files, which required conversion to the correct format through use of import, conversion, and/or georegistration tools available in the ArcGIS software. Analog data of particular significance were hand digitized in ArcMap and converted to geodatabase format.

Data were compiled into an ArcMap (v. 10.2.2) "project" (*. mxd) and associated "file geodatabases" (*. gdb files), with all datalayers standardized to the UTM19N, NAD83 projection system. FDGC-compliant metadata for each datalayer was created in ArcCatalog (see section 2.1.4 of this report) and appended to each file. File geodatabases are organized into seven categories: 1) Avoidance areas; 2) interpretative data regarding benthic geologic environments; 3) vibracores; 4) sub-bottom sonar survey tracklines and, included within file metadata, online links to the associated sub-bottom profiles where available; 5) sidescan sonar data (including new data collected for this project); 6) bathymetry; and 7) basemaps (state outlines and other general geographic data). Two additional geodatabases containing new data collected for this project were included in the final spatial data transfer: 1) URI Surveys 2015 and 2016; and 2) Potential Resource Areas. Unprocessed data were not included in the compilation of previously-collected data. (Note that raw and processed geophysical survey data collected by the project team in 2015 and 2016 were included in folders separate from the GIS-compatible data with the final spatial data transfer at the conclusion of the project.)

2.1.4 Metadata creation for previously collected data

Metadata was developed for all previously collected data included in the digital data synthesis using ESRI's ArcCatalog software. (See section 2.3.5 of this report for a description of metadata creation for newly collected data.) Because the data compiled for this project were obtained from a variety of sources, the amount and type of metadata associated with the original data source varied considerably. All metadata were standardized into FGDC CSDGM format, and was created with one of three methods:

1. If a dataset was included in the compilation in its original format with no modification by the project team, and associated metadata was available, the original metadata provided by the source organization was standardized to FDGC-compliant format with no modification. In cases where additional explanatory information required by the FDGC format was also available from the originator, the original metadata was amended with this additional information. NOAA and USGS datasets are examples of this type of metadata.

2. If a dataset was substantially modified for use in the project, new metadata was created even if the source metadata was available. A description of the methods used to modifiy the original dataset was included in the new metadata, and online links were included to the original metadata. An example of this process is the NOAA Multibeam Bathymetry Mosaic layer, which was created by merging several individual NOAA bathymetric datasets into one raster layer. Each original dataset was associated with detailed metadata from the originator, however the merge process modified the original datasets. The metadata associated with this layer describes the individual datasets, how they were merged, and provides online links to the original metadata associated with each dataset that contributed to the final mosaic.

3. If no metadata was available for a dataset, the project team provided as much information in FGDC format as possible, with citations to the original source material. This situation occurred in cases where data was not available in digital format, such as the McMaster, et. al. (1968) sub-bottom trackline data layer.

2.2 Leveraging Data from Concurrent Projects

At the time this project was being conducted, two additional research efforts were underway that provided valuable data for identifying optimal sand and gravel borrow areas in the study area. Specifically, the project team utilized data from two concurrent projects to calculate Rhode Island's sand resource needs for beach replenishment projects, and to provide a preliminary assessment of the potential for paleolandscape preservation in the target area.

2.2.1 Shoreline Change Special Area Management Plan (RICRMC)

A primary goal of the current project was to quantify the volume of sand available in target offshore borrow areas, and to provide an estimate of Rhode Island's sand resource needs. The project team accessed data from the Shoreline Change Special Area Management Plan, ("Beach SAMP"), a multidisciplinary project facilitated by the Rhode Island Coastal Resources Management Council (CRMC), the University of Rhode Island Coastal Resources Center, and Rhode Island Sea Grant to develop an estimate of the sand resources that will be needed for beach replenishment projects in Rhode Island. The amount of sand needed to replenish Rhode Island beaches was calculated as the volume of sand (y^3) per yard [(m^3) per meter] of shoreline length, excluding several barriers that will remain undeveloped in the near future in accordance with current coastal regulations and property ownership. See Section 3.2.1 of this report for a more detailed discussion of the methodology used for these calculations, and a discussion of the results.

2.2.2 Submerged Paleolandscapes Project (BOEM-URI-NITHPO)

At the time the current research was being conducted, the project team was participating in an additional study in partnership with BOEM and the Narragansett Indian Tribal Historic Preservation Office (NITHPO). This project, entitled "Developing Protocols for Reconstructing Submerged Paleocultural Landscapes and Identifying Ancient Native American Archaeological Sites in Submerged Environments" (the "Submerged Paleolandscapes Project," BOEM-URI Cooperative Agreement M14AC00011) attempted to develop a "best practices" modeling approach to predict the locations of ancient Native American cultural and archaeological sites on the Outer Continental Shelf (OCS) that have been submerged by post-glacial sea level rise. Since sand and gravel extraction activities have significant impact on the seafloor and could cause severe damage to submerged culturally sensitive sites, the information resulting from the Submerged Paleolandscapes Project is particularly pertinent to targeting locations for sand and gravel resources. However, at the time this report was written, the cultural sensitivity model associated with the Submerged Paleolandscapes Project was still under development, and could not be leveraged for a definitive assessment of the geographic locations discussed in this report. The project team's preliminary assessment regarding paleolandscape preservation in the target areas is discussed in Section 5 of this report.

2.3 New Geophysical Surveys

2.3.1 Identification of target survey area

New geophysical surveys were conducted after the data compilation effort (Section 3.1) was completed. The analysis of the compiled data, which included prior Boomer sub-bottom work by the USGS and CHIRP sub-bottom work by Project Co-PIs Bryan Oakley and Jon Boothroyd, indicated that the highest potential borrow sites that met the project criteria were the glacial deltaic deposits located in an area south of Charlestown, Rhode Island, that straddled the state/federal waters boundary (Figure 3). The major criteria used to select this location were its: (1) location in federal or adjacent state waters; (2) location in water depths between 35-90 ft (10.6-27.4 m); (3) potential for a large volume of sand and gravel with low amounts of organic matter and fine sediment; and (4) location near [(3-6 miles)(4.8–9.6 km)] the south shore beaches of Rhode Island. Survey efforts for this project were focused in this area. Figure 5 shows the area targeted for geophysical surveying, superimposed on the generalized glacial geology of the area.

2.3.2 Geophysical data collection

The Phase 1 reconnaissance study was accomplished during two periods, 23-28 August 2015 aboard the *R/V Endeavor*, and 13-23 May 2016 aboard the *R/V Shanna Rose*. The planned hiatus allowed review of geophysical data to develop suggestions for expanding the original transects into surrounding areas where seismic profiles indicated the potential for suitable surficial material. A total of 29 transects were surveyed in 2015 (3 parallel and 26 perpendicular to shore) while 40 transects were run in 2016 (4 parallel and 36 perpendicular to shore). Nominal spacing between transects was 4.921 ft (1,500 m) for lines parallel to the coast and 984-1968.5 ft (300-600 m) for shore perpendicular lines The total trackline mileage was approximately 237 miles (381 km). Figure 6 illustrates the location and spacing of all transects surveyed for this project. Figures 7 and 8 show enlarged views of tracklines surveyed in 2015 and 2016 respectively, with line labels corresponding to sub-bottom profile images.

The seismic profiler was used during both investigations while the side scan sonar-swath bathymetry system was only available for the 2016 cruise. Survey equipment utilized to complete the investigations is detailed below.

2.3.2.1 Navigation and Positioning Systems

A Hemisphere Crescent VS101 global positioning system (GPS) using SBAS (satellite-based augmentation system, such as WAAS and others) for differential corrections and Hypack V2015 navigation software were used to accurately locate the vessel and geophysical sensors during the data acquisition program. Manufacturer's stated position accuracy is less than 0.6 meter 95% of the time using the SBAS mode. Dual GPS antennas on this system also provide heading and can output some motion parameters depending upon antenna configuration on the vessel; roll measurements obtained with antennas aligned side-to-side (for this survey), pitch values output when antennas mounted along the vessel centerline fore to aft. The system features heading accuracies of 0.1° with update rates of all measurements of up to 20 Hz. Position data formats conform to NMEA standards and can be modified to interface with other survey equipment requirements.

2.3.2.2 Benthos C3D-LPM Side Scan Sonar-Swath Bathymetry System (2016 only)

Side scan sonar imagery of the bottom were acquired using a C3D sonar system (pole mounted) operating at a frequency of 200 kHz, perfect for the combination of extended range and resolution for a reconnaissance level investigation. As such, full bottom coverage was not intended nor required to gain a sufficient understanding of the seafloor conditions. The system is an interferometric sonar with co-located side scan and swath bathymetry acquired simultaneously, and features 1000 data points per channel with up to 5 cm resolution. The sonar was controlled by GeoDAS software (Ocean Imaging Consultants, Inc.), which was interfaced to the GPS as well as a

TSS DMS-05 motion sensor and Teledyne Citadel CTD profiler for sound speed input. The program automatically saved a new digital sonar file every 15 minutes (OIC proprietary format). Swath bathymetry data were collected as backup, since NOAA previously covered the survey area with fairly high-resolution multibeam coverage that will be used to represent the seafloor topography.

Project Specific Sonar Parameters:

- 200 m sweep range

2.3.2.3 HMS-620 Bubble Gun Seismic Reflection Profiler

Exploration of the subsurface was accomplished with a bubble gun profiler operating in the 70-700 Hz frequency range, designed for penetration through coarser surficial sediment and increased depths below the seafloor. The system consists of the bubble gun sound source (electromagnetic, contained air) mounted below a catamaran, powered by the HMS-620 transceiver including single or dual power supplies and a single channel receiver. A 24-element hydrophone array or streamer is interfaced to the receiver for input of reflected acoustic signals. The receiver features basic signal functions including initial gain amplification and a bandpass filter with low and high cutoff options. The sound source and streamer are towed astern of the vessel and outside the propeller wash to minimize ambient noise on the hydrophones and interference to the bubble gun transducer.

Seismic data were recorded (SEG Y format) together with GPS positions by SonarWiz Version 5 acquisition software on a topside notebook computer. The computer was interfaced to the HMS-620 transceiver for triggering and data transfer via a Chesapeake Technologies, Inc. (CTI) analog interface console. Specific acquisition settings are provided below.

Project Specific Seismic Parameters:

- 250 ms trigger rate
- 125 ms record length
- 9-12 dB initial gain amplification
- Filter open (no bandpass)

2.3.3 Data processing

After completion of the 2016 field effort, both the 2015 (*R/V Endeavor*) and 2016 (*R/V Shanna Rose*) data files were processed together using the same sequence of algorithms to develop consistent sonar imagery and ensure a coherent final dataset. A synopsis of the processing completed on the side scan sonar and seismic datasets is provided below.

2.3.3.1 Side Scan Sonar Imagery

To develop an acoustic mosaic of the seafloor, the sonar imagery from each trackline were imported to OIC's CleanSweep software for editing and merging into a cumulative plan view plot. CleanSweep provides a means of manipulating large datasets with many processing functions including batch processing options to expedite data transformations. The software features an advanced interferometric package with 3D editor and visualization, feature-based navigation correction tool, powerful automated bottom tracking algorithm, multiple along and across track gain normalization options, and the ability to export data in any common format to work seamlessly with other industry standard data and presentation software packages.

The following general processing sequence was completed for this dataset:

1. File import and conversion to individual swaths for processing
2. Navigation check on each file (including offset and layback applied), smoothing and editing if necessary
3. Bottom tracking of each individual sonar file; this step is critical to developing a high quality mosaic
4. Application of gain curves to normalize the data across the full sweep range and over the duration of the field program
5. Draft mosaic generated to check gain settings, bottom tracking, image quality and resolution
6. Manual editing of applied functions if necessary
7. Export of the sonar mosaic in format suitable for graphics software

For this project, a geo-referenced TIF image was exported out of CleanSweep for import and presentation in ArcMap GIS software (ESRI). Review and analysis of the side scan sonar imagery revealed areas of coarser material (sand and gravel) on the seafloor of interest to this project. This surficial information can then be correlated with the shallow subsurface results obtained from interpretation of the seismic profiles.

2.3.3.2 Sub-bottom Profile Data

Subsurface data was processed and analyzed using SonarWiz Version 6 (Chesapeake Technologies, Inc.) sub-bottom software package. The program is a powerful software package that allows the user full control over signal processing functions such as filtering, stacking, a variety of gain adjustments, and other file manipulation options. SonarWiz also features 3D visualization (fence diagrams) for inspection of profile intersections and sub-bottom data trends, and the capability of plotting with bathymetry and side scan sonar surfaces to provide a comprehensive review of geophysical data in the survey area.

Since the vertical axis of the seismic records is signal travel time and not material thickness, a conversion from time to depth was performed using an average sediment velocity of 5,000 ft s^{-1} (1,524 m s^{-1}). This value is typical for saturated, unconsolidated marine sediment in the shallow subsurface. Given the reconnaissance level nature of this study, vertical adjustments for tide (~3 ft [0.9m] tide range) were done manually within SonarWiz to check intersections. A general sequence of algorithms applied to each file is summarized below.

Seismic processing steps performed on the files include:

1. File import and conversion to SonarWiz working format (CSF): SEGY formatted reflection shot point files were imported
2. Geometry/navigation checks: Verification of all survey geometry parameters contained in the file headers

3. Band Pass Filtering: A 1-D bandpass filter (~100-1,000 Hz) was applied to all traces to increase the signal/noise ratio improving the interpretability of reflected arrivals.
4. Bottom Tracking: Automated function to accurately track the seafloor for static corrections
5. Gain Application: Automatic gain control (AGC) and time variable gain (TVG) functions are available to compensate for signal attenuation with depth
6. Swell Filtering: A low pass filter in the distance dimension was applied to eliminate fluctuations in the x-direction smaller than a chosen wavelength. This step was used for smoothing the data to remove the effect of sea conditions. Sensor Offset and Layback Applied
7. Seismic midpoint position applied to each individual file; intersections checked to verify proper layback/offset achieved
8. Static Corrections
9. A muting curve above the seafloor was defined to set all data points in the water column to zero amplitude. This was done to clear out all reflections produced in the water column improving visualization and interpretability of the profiles.
10. Trace Editing, Merging, and Interpolation
11. Processing features in this function include combining multiple profiles into one file, trimming overlap from combined profiles, flipping profiles end to end so all are viewed from the same direction, and more.
12. Export of final processed seismic file and interpretation
13. A variety of formats are available for export of the digital processed file and interpreted data (reflectors, layer thickness, etc.)

Processed seismic profiles were reviewed and interpreted for thicker, laterally expansive surficial sand bodies and mapped in plan view. Characteristics of the seismic signatures representative of the desired material (sand and gravel), context with surrounding geologic units, and position relative to adjacent inner continental shelf paleo-environments were all considered during the analysis and interpretation of these data.

2.3.3.2 Sub-bottom Profile Data

After the full processing sequence was applied to each seismic profile in SonarWiz, the bottom tracking was converted to a seafloor reflector. The base of the surficial sand unit was then interpreted over large, laterally continuous areas, and mapped as a subsurface reflector where a change in acoustic returns is apparent. This horizon may represent a transition to a different seismic facies below. Using a sediment velocity of 500 ft s^{-1} (1,524 m s^{-1}) suitable for saturated medium grained sediments, the depths of these two interfaces were used to calculate the thickness of the surficial sand layer. Thickness values were then exported out of SonarWiz for all areas identified which included xyz points at a 3.2 ft (1 meter) spacing along each profile crossing the resource area.

The geo-referenced xyz files were imported to Global Mapper for creation of isopach contours and color shaded relief. A boundary was drawn around each area where significant unit thickness was interpreted, and a zero value was assigned to the boundary line. This was necessary to provide a more accurate volume estimate defined by the resource area limits. Contours were generated [(6.6 ft) (2 m) interval)] from a 16.4 ft (5 m) gridded dataset thereby interpolating between the fairly wide reconnaissance line spacing surveyed. The contours were splined during generation to produce a smoother result. A color gradient shader was used to highlight the layer thickness for visual effect and presentation. Finally, a volume was calculated for that region of the subsurface bounded by the seafloor and boundary line (zero values) down to the thickness values interpreted from the seismic profiles and gridded by Global Mapper.

A digital graphic image of the final contours and color-shaded relief of each area was captured for developing the figure presented later in this report.

2.3.4 Geospatial visualization of data

ESRI's ArcGIS Desktop suite of software (ArcInfo license level) was used for representation and analysis of all geospatial data collected for this project. ArcMap v. 10.2.2 was used for visualization and analysis, and ArcCatalog 10.2.2 was used for data organization and metadata creation.

2.3.5 Metadata creation for newly collected data

This project generated two types of data: 1) geospatial data that were visualized using ESRI's ArcGIS software, such as geophysical survey tracklines or sidescan sonar mosaics; and 2) geophysical survey data and data products that were not imported into ArcGIS, such as raw geophysical data, data processed using other software, or sub-bottom profile images. Metadata was created for all newly acquired data. For ArcGIS files, metadata was developed using the metadata editor in ArcCatalog. For non-GIS files, metadata were generated using templates downloaded from the USGS site below, and edited utilizing Microsoft XML Notepad 2007.

- https://www2.usgs.gov/datamanagement/describe/metadata.php#advanced-users

All metadata files have been created to conform to the FGDC (Federal Geographic Data Committee) standards. For ArcGIS files, metadata is viewable using the File Description tab in ArcCatalog, whereas for non-GIS files, metadata is presented in standalone XML format.

3. RESULTS AND DISCUSSION

3.1 Digital Data Synthesis

The digital database resulting from this project represents an ArcGIS-compatible synthesis of geological and geophysical data collected in collected federal waters between 3-8 nautical miles offshore of the state of Rhode Island, and in state waters immediately south of Rhode Island's southwest coast. FGDC-compliant metadata is included for each dataset. Two categories of data are included in the digital synthesis:

1. Previously acquired data: Prior to the initiation of this study, a significant amount of high quality geological and geophysical data had been collected in the waters off of Rhode Island. Much of the data was publicly available through various organizations and institutions, but had not been compiled in ArcGIS format in a centralized location. In addition, prior to this

study, metadata for these datasets was either not readily available, or not standardized into a format compatible with ArcGIS software. The synthesis effort conducted for this project resulted in a standardized digital database consisting of ArcGIS geodatabases accompanied by an associated index map. This compilation provides an excellent reconnaissance-level characterization of the geologic and geophysical characteristics of the study area, and was used by the project team to target the geographic area chosen for additional surveying, and to plan the data acquisition effort.

2. Newly acquired data: In addition to previously acquired data, the digital database also contains ArcGIS files representing newly acquired geophysical data obtained for this project. Feature classes representing a side scan sonar mosaic, and seismic reflection profile tracklines are included in the appropriate geodatabase in combination with previously acquired data. Since seismic reflection images cannot be easily represented in ArcMap, these images are included in a dedicated folder with filenames corresponding to the survey trackline file visualized with ArcGIS.

3.1.1 Data Format and Organization

Both previously-collected and newly-collected data were compiled onto a dedicated external hard drive at the conclusion of the project and delivered to BOEM personnel for review. All data that could be converted to Arc-GIS compatible formats were organized into an ArcMap (v. 10.2.2) project, entitled "URI_BOEM_M14AC000011.mxd" and associated "File Geodatabases" (*.gdb files). Each datalayer stored in the File Geodatabases is listed in the catalog tree of the ArcMap project, and can be checked or unchecked for display purposes. All datalayers are standardized to the UTM 19N, NAD 83 projection system. Metadata for each feature class is viewable though the ArcCatalog "Description" tab.

File geodatabases are organized into the following seven categories:

1. **Avoidance areas**: Geographic areas in which dredge disposal operations have occurred, and are therefore not appropriate target areas for sand and gravel extraction.

2. **Interpretive data**: Interpretations of the benthic geologic environment, based primarily on side scan and grab sample data. These data describe benthic processes, such as erosion or deposition, and/or surficial sediment type.

3. **Vibracores**: Location of vibracores within the project study area, and links (within the layer metadata) to sources of written core descriptions.

4. **Sub-bottom tracklines**: Location of seismic reflection tracklines within the study area, and links (within the layer metadata) to associated digital seismic reflection profile files and interpretations.

5. **Side scan sonar data**: Processed side scan sonar images. This geodatabase also includes the side scan sonar mosaic developed from geophysical surveys conducted for this project.

6. **Bathymetry**: Full coverage, seamless elevation-bathymetry grid (3 arc-second resolution) for Rhode Island and offshore waters, and high-resolution multibeam mosaic grids where available.

7. **Basemaps**: Polygons representing state outlines, the project study area, and NOAA Survey outlines.

8. **URI Surveys 2015 and 2016:** Polygons and polyline files showing the target study area and ship tracklines resulting from the geophysical survey conducted by the Coastal Mapping Laboratory, GSO-URI during 2015 and 2016 for this project.

9. **Resource Areas:** Polygons illustrating the geographic locations of potential resource areas identified as the result of geophysical surveying conducted for this project.

Data that could not be converted to ArcGIS-compatible formats, such as sub-bottom profile imagery and raw geophysical survey data, are included in separate folders on the dedicated hard drive. Stand-alone metadata files are included with these data in *.XML format.

3.2 Leveraging Data from Other Sources

3.2.1 Rhode Island Beach Replenishment Requirements

The Rhode Island Coastal Resources Management Council (CRMC), the University of Rhode Island Coastal Resources Center, and Rhode Island Sea Grant are currently undertaking a multidisciplinary science-based coastal management project known as the Shoreline Change Special Area Management Plan, (aka The "Beach SAMP"). The main goals of the Beach SAMP are to gather new data on impacts of sea level rise, storm surge and coastal erosion, provide educational outreach to the public and municipalities, create a policy framework for dealing with shoreline change, and develop tools and best practices to deal with shoreline change in Rhode Island. As part of the evaluation of best practices to mitigate the impacts of shoreline change, estimations of the sediment volume needed to replenish beaches along the Rhode Island south shore were calculated. Data collected by the Beach SAMP project provide valuable information regarding the characteristics required for potential offshore sand and gravel borrow areas that could meet Rhode Island's resource needs.

3.2.1.1 Volume calculation methodology

The volume of sand needed to replenish the beaches along the Rhode Island south shore was calculated as a simple volume of sand yd^3 (m^3) per yard (meter) of shoreline length. While the entire shoreline between Napatree Point and Point Judith (Figure 9) encompasses approximately 24 miles (38 km) of linear shoreline, the undeveloped barriers (Napatree, Mashaug, Quonochontaug, East Beach, Quonochontaug and Moonstone [(9 miles) (14.5 km)] were excluded from the volume calculations in this report. Under the current coastal regulations and property ownership, these barriers will remain undeveloped in the near future, and natural processes should be allowed continue to operate on these barriers without replenishment. The till boulder and discontinuous bedrock headlands, [(3.4 miles) (5.5 km)] (Weekapaug, Green Hill, Point Judith and portions of Watch Hill and Quonochontaug) were also excluded. Additionally, while not part of the Rhode Island south shore, Scarborough State Beach [(3.4 miles) (1.5 km)] and the portion of the Narragansett Barrier that encompasses Narragansett Town Beach [(0.6 miles) (1 km)] were included in this analysis as beaches possibly replenished in the future. Taken together, this represents potentially replenished shoreline length of approximately 12.4 miles (20 km).

Various levels of replenishment, ranging from small-sale replenishment (widening the berm with no significant additions to the foredune/dike), to large-scale projects (constructing dikes and significant berm widening) were considered. The small-scale, berm only replenishment was based on the average alongshore volume of sand placed on Misquamicut State Beach in May 2014 ([85 yd^3 yd^{-1}] [65 m^3 m^{-1}]). Large-scale replenishment was considered as significant widening of the berm and enlargement of the foredune/dike, similar to the model presented for Mantoloking, NJ (USACE, 2013b), and represents an increase in 400 yd^3 yd^{-1} (305 m^3 m^{-1}). A 'moderate' scale replenishment volume with an arbitrary volume of 200 yd^3 yd^{-1} (150 m^3 m^{-1}) was included in the subsequent calculations.

Project cost was estimated based on the two possible sources of sediment using recent local and regional projects, and were averaged as a 'total cost' (i.e. the project cost/volume of sand). The cost for upland sources was based on the 2014 replenishment of Misquamicut State Beach \$36 yd^{-3} (\$47 m^{-3}). Costs for offshore sources of replenishment sand vary from \$5 to \$15 yd^{-3} (\$6.5 to \$20 m^{-3}) (Kana, 2012). Recent projects in New Jersey utilizing offshore sources have averaged \$12 to 15 yd^{-3} (\$16 to \$20 m^{-3}) (Keiser, 2009). The cost for offshore sources was assumed to be \$15 yd^{-3} (\$20 m^{-3}) for this report.

3.2.1.2 Volume calculation results

The small scale, berm-only level of replenishment extrapolated over the 12.4 mi (20 km) of shoreline likely to be replenishment requires 1,700,335 yd^3 (1,300,000 m^3) of sand. Large-scale replenishment would require 7,978,495 yd^3 (6,100,000 m^3) of sand for the same area. Estimated costs vary depending on sediment source and cost per yard; for upland sources, the total cost range from \$61,100,000 to \$287,000,000 for small-scale or large-scale replenishment respectively. Total estimated costs range from \$26,000,000 to \$122,000,000 utilizing offshore sources of sand. Table 1 summarizes the alongshore-average volume, total volume and assumed cost for the three replenishment scenarios. We used these estimates to formulate a preliminary hypothesis that the target areas identified off the southwest coast of Rhode Island (Figure 5) contain enough sand to meet Rhode Island's beach replenishment needs. However, additional geophysical surveying, geotechnical sampling, and refined volume calculations are required to test this hypothesis, and will be conducted in Phase II of this project.

Table 1:
Average replenishment volume, total sand volume and estimated project costs for the three replenishment scenarios.

Scenario	**Average Replenishment Volume yd^3 yd^{-1} (m^3 m^{-1})**	**Total Volume (yd^3)**	**Total Volume (m^3)**	**Cost (upland source; \$36 yd^{-3} (\$47 m^{-3})**	**Cost (offshore source; (\$15 yd^{-3}) (\$20 m^{-3})**
Low	85 (65)	1,700,335	1,300,000	\$61,100,000	\$26,000,000
Moderate	200 (150)	3,923,850	3,000,000	\$141,000,000	\$60,000,000
High	400 (305)	7,978,495	6,100,000	\$286,700,000	\$122,000,000

3.2.1.3 Discussion

Nationally, beach replenishment has been conducted most extensively along barrier islands and spits along the Mid-Atlantic and southern East Coast of the United States, with total replenishment volumes an order of magnitude larger than New England shorelines (Trembanis, 1999). Replenishment remains the most common mitigation technique in response to coastal storms and subsequent erosion (Trembanis et al., 1999). Replenishment is widely viewed as the most effective response to maintaining the shoreline in response to accelerating sea level rise (ASBPA, 2012; Houston, 2016). Despite this widespread view, the effectiveness of replenishment in a period of accelerating sea level rise and the potential for increased storminess remains in question, and is a subject of much debate within the scientific literature. A full discussion of this debate is outside the scope of this document. Briefly, Houston (2016) ascertains that replenishment can continue to maintain beaches (on the east coast of Florida) through the end of the century under most sea-level rise scenarios. These assumptions are based on the 'Bruun Rule' (Bruun, 1962), which itself is controversial (i.e. Cooper and Pilkey, 2004). Leonard et al., (1990) conclude that replenished beaches erode 1.5 to 12 times faster than non-replenished beaches, and while widely cited, this is also controversial (Houston, 1990; Houston, 1991; Pilkey and Leonard, 1990, 1991). However, many replenishment projects lack proper monitoring to evaluate the long-term erosion rate and lifetime of the project (Pilkey, 1990; Marine Board, 1995) and this monitoring remains a vital aspect of any future replenishment projects.

While common elsewhere, replenishment at a large scale has been rare in Rhode Island, with most projects placing a volume < 1,000 yd^3 (800 m^3) (Haddad and Pilkey, 1998). Replenishment will likely become a more common practice as shoreline change continues to affect developed shorelines. The USACE replenished a 1 km long segment of the Misquamicut Barrier (Misquamicut State Beach) in May 2014. This project entailed a nominal volume of 86,000 yd^3 (65,000 m^3) (USACE, 2013a) and represents the largest direct placement replenishment project in Rhode Island within the last several decades (a similar volume of sediment was added to the Matunuck, RI (Figure 9) shoreface in 2007 as beneficial reuse from a nearby dredging project). Misquamicut was also replenished following Hurricane Carol (1954), with approximately 80,000 yd^3 (60,000 m^3) placed in 1960 (Dixon and Pilkey, 1998). On-going monitoring of the Misquamicut replenishment project suggests that as of March, 2015, 35% of the added volume has been removed from the beach (Oakley et al, 2015, 2016). The high cost of the recent project on Misquamicut (3.1 million dollars; \$36 yd^{-3} (\$47 m^{-3}) was due to the sediment source (upland glacial stratified deposits). With the exception of beneficial reuse of sediment dredged from tidal inlets and tidal deltas, offshore sources have not been utilized in RI. Because of the high cost and increasingly limited availability of upland sources, any consideration of future large-scale replenishment projects as a response to storm-driven shoreline change and sea level rise will require the identification of feasible offshore sediment sources.

Local variation in shoreline configuration and modification of the profile by anthropogenic activities (infrastructure, sand fencing, dikes etc.) would result in each segment of the shoreline having a different design profile, however the volume of sand needed to replenish the profile either at the berm-only scale or at a larger scale would be similar along the various segments of the Rhode Island shoreline. While each beach has associated shape and morphology which is a function of grain size and wave height (Bascom, 1951), it was assumed in this report that the same volume would be spread evenly alongshore. Comparing the design profile for Mantoloking, NJ (USACE, 2013b) to the profile configuration at Misquamicut State Beach (Figure 11) and Narragansett Town Beach (Figure 12) gives some context for what a large-scale replenishment project would look on two different profile configurations along the Rhode Island shoreline.

The volumes presented here 7,978,495 yd^3 (6,100,000 m^3) are similar to the volumes being replenished for other shorelines in the northeastern United States. Along the 13.7 mi (21 km) segment of the New Jersey shoreline between Manasquan Inlet and the northern end of Island Beach State Park, a total of 10,700,000 yd^3 (8,200,000 m^3), and on Long Beach Island (18 mi; 29 km) total volume of 11,000.000 yd^3 (8,400,000 m^3) will be placed (NJDEP, 2016). It should be noted that the projects in New Jersey each have scheduled maintenance cycle of approximately 2,000,000 yd^3 (1,500,000 m^3) every seven years, to be maintained until 2065 (NJDEP, 2016). A similar maintenance schedule in Rhode Island would require identification of an additional 14,000,000 yd^3 (10,500,000 m^3) of sand.

Total costs of replenishment presented here are based on recent local and regional projects. Similar costs to the 2014 Misquamicut State Beach replenishment project for future upland sourced replenishment remains a valid cost estimate, given the likely distance between upland (glacial) sources of sand and replenished beaches along the south shore. The estimate for offshore sources of sand are at the upper end of recent projects [(\$15 yd^{-3}) (\$20 m^{-3})], however, given the lack of established offshore sources at similar distances offshore and lack of project precedent in Rhode Island, it is felt this is a fair assumption. This analysis omits mobilization costs that have ranged between \$3 - 5 million on recent projects (J. Waldner, personal communication, August 2016). Mobilization costs would be mitigated either by bundling and building several smaller projects within a region, or by undertaking larger projects.

3.2.2 Paleolandscape Preservation in Target Areas

In 2012, the project team entered into a Cooperative Agreement with BOEM and the Narragansett Indian Tribal Preservation Office (NITHPO) entitled "Developing Protocols for Reconstructing Submerged Paleocultural Landscapes and Identifying Ancient Native American Archaeological Sites in Submerged Environments" (BOEM Award Number M12AC00016) ("The Submerged

Paleolandscapes Project"). Multidisciplinary field investigations of one near-shore area in Rhode Island, and three locations off the coast of Rhode Island are currently being conducted as part of the project to develop and test best practices for identifying, avoiding or mitigating adverse effects to submerged Native American cultural and archaeological sites caused by development on the outer continental shelf. One of the primary goals of the Submerged Paleolandscapes Project is to develop and test an archaeological predictive model that can help assess cultural and archaeological sensitivity in submerged environments. At the time this report was written, development of this model was incomplete, and therefore could not be applied to the designated sand and gravel resource borrow areas identified during the Phase I investigation. However, sub-bottom sonar imagery resulting from the Phase I geophysical survey provided an initial assessment regarding the presence or absence of relict paleolandscape features in the targeted resource areas.

3.2.2.1 Geological processes affecting paleolandscape preservation in submerged areas

The chronology, rate, and magnitude of relative sea level rise following glacial retreat is a function of the relationship between eustatic flooding, sedimentation and isostatic rebound as a result of glacial melting (McMaster 1984). Initially, the rate of sea level rise in the study area was relatively fast. At about 11,500 B.P., sea level was estimated to have reached a point about 165 ft (50 m) lower than today. Just 1,500 years later, sea level had risen more than 65 ft (20 m) to a level about 98 ft (30 m) lower than present. Therefore at about 10,000 years ago, the coastline off of southern Rhode Island was located near the foot of the large deltaic deposits that we have identified as potential sand and gravel borrow areas. The general trend of rapid sea level rise during this period did not follow a smooth curve, but instead fluctuated and was punctuated by episodes of still-stand and negative sea level oscillations during times of climatic cooling and glacial advance (Rampino and Sanders 1980). As glacial ice volumes decreased, the rate of sea level rise gradually slowed.

In general, episodes of marine transgression are frequently periods of erosion, a destructive process that creates less than ideal depositional sequences from an archaeological perspective. Marine transgression can be thought of as proceeding in one of two basic ways: 1) by “shoreface” retreat, when the coastline slowly regresses inland; or 2) by “stepwise” retreat, when in- place drowning of coastal features occurs (Waters 1992). Shoreface retreat describes the erosion of previously deposited sediments by wave and current processes as the shoreline transgresses, and is the dominant inundation regime during the marine transgression process (Waters 1992). As the glaciers melted and sea level rose, shoreface erosional zones sequentially passed across the subaerially exposed portions of the harbor floor. Older sediments that had been deposited in coastal and terrestrial environments inland of the shoreline would have been reworked, first by the swash and backwash processes of the beachface, then by waves and currents. The erosion of the shoreface associated with transgression would have reworked these deposits into a thin unconformable geological unit of transgressive lag (i.e., gravel and coarse sand deposits) forming the top of a time-transgressive geological unit known as a marine unconformity (i.e., the surface defined by the top of the buried paleosol and the base of the overlying marine deposit). Reworking terrestrial and coastal sediments are referred to as palimpsest sediments (Swift et al. 1971), and the erosional surface, marked by the depth of the maximum disturbance by transgression, is called the ravinement surface. This surface often shows up quite clearly in sub-bottom profiler data and can be a useful indicator for the potential presence of relict paleolandforms below it (Waters 1992). We interpret the ravinement and the sediments just below the ravinement as areas of potential paleocultural sensitivity. Shoreface retreat is usually the prevailing marine transgressive regime, especially during stillstand episodes, and after about 5,000 years ago, when the regional rate of sea level rise appears to have slowed considerably.

Alternatively, marine transgression may occur by the process of stepwise retreat, which is the sudden inundation or in-place drowning of coastal landforms and sediments. Stepwise retreat most commonly occurs at times and in areas of rapidly rising sea level, where the coast is quickly subsiding and the gradient of the transgressed surface is shallow. In this case, instead of the waves and currents of the shoreface sequentially reworking older sediments during transgression, the shoreline zones jump from the active shoreline to a point farther inland, submerging the older coastal landforms and sediments in an area seaward of the more destructive shoreface zones. The shoreface's wave zones then stabilize and develop a new shoreline farther inland. Instances of in-place drowning during stepwise retreat, preserving forested topographic lows, river and pond margins, marshes and swamps, paleochannels and other relict paleolandscape features, have been documented in a variety of places along the Atlantic coast, including in Rhode Island off of Cedar Tree Beach in Greenwich Bay and in nearshore waters off of the west side of Block Island by the BOEM-URI Submerged Paleolandscapes Project team. Relict paleolandscape features are potential areas of cultural sensitivity, since these areas were subaerially exposed and available for human habitation.

3.2.2.2 Potential for palelandscape preservation in Phase I resource areas

The project team conducted a preliminary examination of all sub-bottom profile images obtained during the 2015 and 2016 survey seasons. The relatively steep topography characteristic of the deltaic deposits in these profiles strongly favors the shoreface retreat model discussed above, and the associated erosional processes suggest that limited intact paleolandscapes may be preserved. For example, the dipping forset beds shown in Figure 13 are clearly truncated by erosion, and the topset beds appear to have been removed. Examining glacial deltas in central New England, Koteff, et al. (1993) assumed that < 6.6 ft (2 m) of the deltaslope beds had been removed based on a detailed examination of borrow pit exposures. In addition, the ravinement surface occurs only sporadically preserved within the study area, and relict paleolandscape features appear limited to a few paleochannels. Figure 14 illustrates a representative west-to-east transect obtained in the central portion of the target area. The ravinement surface is not immediately visible in this profile and may not be preserved, suggesting that extensive reworking of marine sediments is occurring in the study area.

Research from the Submerged Paleolandscapes project will be completed in late 2017, and will be available for use in Phase II of this project.

3.3 New Geophysical Surveys

Investigations conducted in August 2015 and May 2016 provide recent nearsurface geological information to support the mapping of potential sediment resource areas offshore of Rhode Island. The surveys cover portions of state and federal waters offshore between Quonochontaug and Point Judith Harbor of Refuge. These data were acquired as part of the Phase 1 reconnaissance level study to identify larger, more extensive potential resources to be further investigated during the subsequent detailed Phase 2 study. Wider (i.e. not full coverage) trackline spacings utilizing larger sonar sweep ranges is a typical approach for such studies to cover more ground and provide a broad overview of the shallow geologic units.

All the processed data, including bathymetry (NOAA), side scan sonar, and sub-bottom profiles, were reviewed and analyzed to develop an understanding of current conditions on the OCS in the area investigated. Interpretation of the geophysical data correlate well with a number of previous studies of the area, and suggest a sequence of recent sand on the seafloor, often reworked from Holocene fluvial and older glacial material, overlying glacial deltaic deposits (i.e. glacial fluvial outwash) which overlie glacial lacustrine deposits that outcrop farther offshore in deeper water. This is a simplified version of the near-surface stratigraphy, but it explains the abundance of surficial sand and larger sediment sizes on the OCS given the past environments that have occupied the region.

Results from this study include maps and profiles that support an assessment of the surficial and subsurface geology in the area investigated, and more specifically provide geophysical data to interpret potential resource borrow areas on the OCS. A reconnaissance level side scan sonar mosaic of the seafloor reveals general reflectivity patterns and hence possible surficial sediment types and/or benthic substrate. These data are supplemented by sub-bottom profiles that penetrate over 98-131 ft (30-40 m) below the seafloor and reveal seismic facies indicative of sand and gravel size sediment targeted for this project. Select profiles were chosen and annotated to show the seismic stratigraphy apparent in each of the areas discussed in the next section. The interpreted sand and gravel layer (predominantly glacial deltaic deposits and overlying recent sediment) within the four resource areas was mapped on all profiles and contoured to develop a unit thickness. The resulting sediment isopach was used to calculate estimated volumes of material available to borrow.

3.3.1 Sub-bottom Profile Interpretation

Approximately 237 line-miles (381.4 km) of sub-bottom profile images resulting from geophysical surveying conducted in 2015 and 2016 were examined to provide a preliminary characterization of the subsurface geology of the target area. Changes in seismic stratigraphy and the interpreted depositional environments were described for several representative sub-bottom profiles. Four of the interpreted profiles were segments of north-south oriented sub-bottom profiles, each transecting a potential resource area (See section 4 of this report for additional discussion regarding identified resource areas). Additionally, a west-east sub-bottom profile was selected for interpretation to identify any paleochannels or buried terrestrial deposits that could suggest intact paleolandscape preservation. The following discussion provides a summary of the most prominent features visible in these images.

3.3.1.1 Crystalline Bedrock / Coastal Plain Sediment and Fluvial Unconformity

Differentiating coastal plain sediment from underlying crystalline bedrock is not critical for the purposes of identifying offshore sand and gravel deposits. Crystalline bedrock does not outcrop at or near the seafloor and holds no potential for sand or gravel resources. Coastal plain sediment also underlies glacial deposits within the study area, making it inaccessible for dredging. For this reason, the interpreted figures do not explicitly differentiate these seismic units. A brief description of regional crystalline bedrock and coastal plain sediment is provided below.

Early subsurface investigations from Block Island Sound (e.g. McMaster et al., 1968; Garrison, 1970) report crystalline bedrock as the deepest regional seismic reflector. The seismic characteristics have been described as a south-southeast dipping surface with steepening of the slope occurring several kilometers north of Block Island, RI. The bedrock surface has been described as an irregular, continuous surface with prominent channels forming a south trending bedrock drainage surface (McMaster and Ashraf, 1973a). The age of the rocks has been constrained as pre-Mesozoic based on southern New England bedrock studies. Much like the onshore bedrock geology of southeastern New England, the bedrock geology underlying Block Island Sound is inferred to consist of gneisses and granites associated with the Paleozoic accretion of the microcontinent of Avalonia (Lewis and Stone, 1991).

Many regional geological studies have reported the presence of unconsolidated to semi-consolidated sediment underlying Quaternary glacial deposits in the mid-Atlantic and southern New England (e.g. McMaster et al., 1968; Needell and Lewis, 1984). Referred to as coastal plain sediment of the Atlantic coastal margin, these sediment are composed of both non-marine and marine interbedded sands, gravels and clays, deposited with the outbuilding of the passive margin since continental rifting formed the proto-Atlantic Ocean. These sediments have been constrained to Late Cretaceous to Tertiary in age. In seismic stratigraphy, the coastal plain dips to the southeast and is deeply incised by north draining channels. This prominent fluvial unconformity truncates the coastal plain, and represents a long period of fluvial erosion due to subaerial exposure. In Block Island Sound, the northern extent of the remnant coastal plain is demarcated by an irregular, north facing cuesta (Needell and Lewis, 1984). The absence of coastal plain sediment north of the cuesta created an inner lowland that influenced subsequent glacial deposition. Some isolated erosional remnants of the coastal plain have been mapped north of the cuesta.

The coastal plain and bedrock surface is most easily identified in the W-E sub-bottom lines. The surface is highly irregular, with deep channels and steep to rounded interfluvs. Channel depths often exceed 295 ft (90 m) below sea level (Figure 15, Figure 16). Towards the eastern end of the survey, the coastal plain rises close to the seafloor, with lower amplitude channels (Figure 17). The contact between the coastal plain and overlying glacial deposits is marked by a prominent fluvial unconformity.

3.3.1.2 Glaciodeltaic Sediment and Glaciofluvial Erosion

Glaciolacustrine sediment includes sediment deposited in a proglacial lakefloor setting as ice margin retreated towards the north from the terminal moraine position. Meltwater from the retreating glacier generally drained towards the south, filling pre-glacial topographic lows and forming Glacial Lake Block Island. Drainage to a eustatically lowered sea level was largely prevented by the terminal moraines, except at spillways (Oakley, 2012). Sediment cores from Block Island, Rhode Island and Long Island Sounds have provided physical samples of the sediment, and has been described as rhythmically layered silt and clay couplets and clay concretions (Frankel and Thomas, 1966; Bertoni et al., 1977).

The seismic characteristics of glaciolacustrine sediment are consistent with previous studies and are easily identified by laterally continuous, closely spaced, rhythmically layered reflectors that drape the underlying topography. Glaciolacustrine sediment is seen in all the interpreted sub-bottom profiles with the exception of Figure 18. Where the underlying topography is deeply incised, glaciolacustrine sediments exceed 50 m thicknesses (Figure 19). Glaciolacustrine sediment is most ubiquitous where water depths exceed 40 m (131 ft) within Block Island Sound.

The fine-grained nature of glaciolacustrine sediment makes it an area of low interest for potential sand and gravel resources.

3.3.1.3 Glaciodeltaic Sediment and Glaciofluvial Erosion

A prominent reflector separates glaciolacustrine lake deposits and overlying glaciodeltaic deposits. This reflector forms an irregular surface that is laterally continuous, with shallow v-shaped channels. This reflector is a discontinuity associated with glaciofluvial erosion during the formation of glacial lake deltas.

Glaciodeltaic sediment was deposited in a prograding glacial lake delta depositional environment as sediment-laden meltwater discharged from the retreating glacier in braided streams. As sediment-laden meltwater reached Glacial Lake Block Island, the finer grained fraction of sediment remained suspended in the water column, later to be deposited by turbidity currents or settlement due to a lower flow regime as glaciolacustrine silts and clays. At the proximal lake margin, coarser sediment including sand and gravel was deposited by fluvial deposition forming the coarse topset and foreset beds.

The seismic characteristics of the glaciodeltaic deposits vary depending on the location along the delta as well as the angle that the sub-bottom lines transect the deltaic deposits. In N-S sub bottom profiles, steeply dipping reflectors are interepreted as foreset beds composed of sand and gravel (Figure 13). The foreset-bottomset bedding contact represents a transition to finer grained sediments including fine sand and silt. In other N-S sub-bottom profiles (e.g. Figure 19), glaciodeltaic sediment is more acoustically transparent, with a near absence of internal reflectors. In sub-bottom lines oriented parallel to the delta front, flat-lying to low-angle dipping reflectors are observed (Figure 15). Despite some differences in seismic characteristics, the thickness of glaciodeltaic deposits in the study area is typically 33-50 ft (10 to 15 m).

Glaciodeltaic sediment is the most significant source of sand and gravel resources within the study area. The seismic characteristics are consistent with deltaic deposits composed of sand and gravel, though targeted sediment cores would help to characterize the thickness and suitability for beach replenishment.

3.3.1.4 Paleochannels

Several paleochannels were observed within the study area (Figure 14, Figure 18). For the purposes of this report, a paleochannel is differentiated from glaciofluvial erosion. Unlike glaciofluvial erosion, which was contemporaneous with the formation of glacial deltas, paleochannels are not overlain by glaciodeltaic deposits. Paleochannels were cut into glaciodeltaic and glaciolacustrine deposits as Glacial Lake Block Island drained prior to marine inundation. The seismic characteristics of paleochannels are shallow, u-shaped and v-shaped channel cuts. The channels are filled with sediments, sometimes with crude stratification (Figure 18). Due to the potential for preserved terrestrial landscapes, paleochannels should be closely considered for paleocultural sensitivity.

3.3.1.5 Ravinement, Reworked / Marine Sediment and Modern Scour

Within the study area, the ravinement surface, also referred to in regional studies as the marine unconformity, represents the eroded surface flooded by the transgressing sea during the Holocene (Needell and Lewis, 1984). The ravinement surface is best seen in (Figure 13), where glaciodeltaic foreset beds are truncated. In most sub-bottom profiles within the study area, the ravinement surface is thought to be unpreserved or only a few yards/meters at most below the seafloor, making it unobservable due to a strongly reflective seafloor.

Overlying the ravinement surface is a surficial layer of marine sediment and sediment reworked by modern inner shelf tidal and storm induced currents. Since the deposit is only a few yards/meters thick, the seismic characteristics are poorly resolved.

In several locations within the study area, shallow troughs (3-4 m) cut into glaciodeltaic deposits (Figure 15). Identified as modern scour, these troughs are likely caused by modern bottom currents, either tidal or induced by storm events.

3.3.1.6 Sources of Sand and Gravel

Sub-bottom profiles reveal that glaciodeltaic deposits are the predominant source of sand and gravel resources within the study area. This conclusion is drawn due to several factors. Glaciodeltaic deposits are either surficially exposed or very shallowly buried by a veneer of marine sediment, making them easily accessible. The deposits are spatially continuous and in many places exceed 33 ft (10 m) thickness. The seismic characteristics and geomorphology of these deposits suggest that the sediment is predominantly sand and gravel, however, geotechnical data is critical for verifying this interpretation. Other identified deposits are deeply buried and thus inaccessible (coastal plain sediment and bedrock), have a low fraction of sand and gravel (glaciolacustrine sediment, bedrock) or require closer inspection due to the potential presence of intact paleolandscapes (paleochannels) and possible associated paleocultural sensitivity.

4. RECOMMENDED BORROW AREAS

Prior to the initiation of this study, the project team hypothesized that sand and gravel resources were located in four broad depositional environments on the Rhode Island OCS: (1) the distal delta plains and slopes of the large glacial lacustrine deltas deposited in former Glacial Lake Block Island (2) the alluvial fans deposited at outlet channels through the outer Late Wisconsinan moraine; (3) the coarse sand sheets common on the OCS and (4) the depositional platform sand sheet. The data synthesis and new geophysical surveys conducted as part of this reconnaissance study suggest that there are areas of the OCS that contain significant quantities of sand and gravel sized material. An unbiased approach was taken such that the interpretation of the geophysical data was the only factor considered to identify potential resource areas. Seismic characteristics suggestive of sand and gravel sized sediment were interpreted, with laterally continuous and extensive surficial facies mapped for this study. Any areas exhibiting the presence of paleochannels or other geologic features that might make the surficial sand sheet discontinuous and contribute unsuitable material were not included. The types of sub-bottom signal returns are grouped into three primary categories:

1. Acoustically transparent; often indicative of massive, possibly homogenous sand deposits void of internal layering and hence reflectors;
2. Steeply dipping reflectors; commonly represent cross bedding, foreset bedding, or other remnant sand dominated depositional feature; and
3. Chaotic reflections and diffractions; can be due to the presence of coarse material including gravel, cobbles, and boulders.

It is important to note that there has been no geotechnical data (vibracores) collected yet to verify sediment composition. The delineation of potential resource areas is based solely on geophysical interpretation. The following discussion provides a review of the four potential resource areas identified and highlights other potentially significant factors that might impact the suitability of each area as a borrow source. Figure 20 presents a location map of the four areas.

4.1 Resource Area 1

Area 1 (Figure 20) is the most extensive and covers the seaward slope of interpreted glacial deltaic deposits and possibly glacial fluvial sediment locally. In general, the seafloor slopes down offshore from less than 65 ft (20 m) to over 115 ft (35 m) of water across this bathymetric feature. A northwest-southeast trend in the seafloor topography is evident in the east-central portion of the area. Side scan sonar imagery show slightly higher reflectivity associated with surficial sediment in Area 1, particularly compared to seafloor areas to the south. A wedge of interpreted suitable sediment occupies the slope (Figure 19) that pinches out in places at the seafloor along its seaward edge where glacial lacustrine deposits outcrop discontinuously. Sub-bottom images reveal steeply dipping reflectors as well as acoustically transparent surficial units characteristic of a sand dominated environment. Over 80% of Area 1 is located in federal waters with the thickest sequence of material in the eastern half of the site. This portion of the area is also void of charted man-made obstructions compared to the west, where a submarine cable going in/out of Green Hill and a cable corridor trending offshore from Quonochontaug (Figure 9) exist. Two charted shipwrecks were recorded on the side scan sonar imagery that will have to be avoided and/or inspected in this area.

4.2 Resource Area 2

Area 2 (Figure 20) is located directly adjacent to and landward of Area 1 in state waters, subdivided by the types of seismic returns and position on the inner shelf (Figure 13). Water depths in this portion of the Sound vary from approximately 50 – 80 ft (15-24 m) with the seafloor sloping to the south and west. Possibly related to antecedent geomorphic features, two or more linear ridges of material trend in a northwest-southeast orientation through the site and continue to the northwest into Area 4 and to the Quonochontaug (Figure 9) shoreline. In the subsurface, seismic returns are characterized by dipping reflectors over much of the area and chaotic reflections locally. Some nearly ideal examples of interpreted foreset beds representing the frontal slope of glacial deltaic deposits were recorded in this area. Area 2 is generally void of man-made obstructions with only one charted cable passing through the site (landfall at Green Hill, Figure 9), oriented in a northeast-southwest direction. This area contains the second largest volume of possibly suitable material in the offshore region investigated.

4.3 Resource Area 3

Area 3 (Figure 20) is a smaller site south of Nebraska Shoals in the eastern portion of the survey area, where water depths ranging from approximately 35 – 85 ft (11-26 m) exist. Bathymetry and side scan data indicate some possible harder bottom conditions, such as a coarser material lag deposit in the northern half of this area. Sonar imagery suggests there is a patchy distribution of the coarser material (gravel, cobbles, boulders) interspersed with sandy sediment. Seismic characteristics of the subsurface (Figure 18) include chaotic and variable reflections indicative of sand and coarser sediment, with a reasonably thick surficial layer apparent. Unfortunately, there is a high concentration of man-made obstructions in this area, with multiple submarine cables charted in/out of Green Hill and a cable corridor trending offshore from Matunuck (Figure 9). Research and surveys would be required to identify active and abandoned cables, and then determine if their presence is too much of a deterrent to dredging. Area 3 is also entirely within state waters.

4.4 Resource Area 4

Area 4 (Figure 20) is in state waters close to the shoreline in the northwestern corner of the survey area. The landward edge of this area is positioned 0.9-1.5 mi (1.5-2.5 km) from the beach. Water depths vary from 32-80+ ft (10-24 m) and the seafloor slopes down toward the south. A more pronounced steeper slope in some places 66-79 ft (20-24 m) depths, although abrupt, creates a shallow wedge of sediment similar to Area 1. Side scan sonar imagery reveals an abundance of sand waves/ridges in this area creating some topographic relief on the seafloor. Larger sand ridges trend in a northwest-southeast direction (crest-trough axis) while smaller amplitude sand waves are oriented generally due north-south. Seismic facies (Figure 21) contain steeply dipping reflectors and acoustically transparent sections suggestive of the target material and may represent more glacial deltaic deposits. Area 4 completely covers a charted cable corridor that runs offshore from Quonochontaug (Figure 9), thus creating some potential hazard to dredging as well as risk to the existing submarine cables during those activities. Further research and additional field surveys will be necessary to map these transmission and/or telecommunication lines for avoidance.

4.5 Resource Area Summary

Large quantities of potential sand and gravel resources are apparent on the continental shelf in Block Island Sound. Three of the four resource areas are in state waters (Areas 2, 3, and 4) however, as the nearshore region of the shelf stores most of the material suitable for beach replenishment. Area 1 is predominantly in federal waters except for the westernmost portion, and contains an estimated volume of over 98 million y^3 (75 million m^3) of material beyond the three nautical mile limit. Contoured isopach maps were produced for each of the resource areas, showing the spatial variability in sand and gravel thickness (Figure 22). The breakdown of sand and gravel volumes is included in the table below.

Table 2. Estimated Volumes of Sand and Gravel Available. Values calculated using Global Mapper (Blue Marble Geographics)

Resource Area	Surface Area	Thickness Range	Estimated Volume
1	4.01 mi^2 (10.51 km^2)	10-62 ft (3-19 m)	119.9 $x10^6$ yd^3 (91.7 $x10^6$ m^3)
2	2.34 mi^2 (6.07 km^2)	20-56 ft (6-17 m)	92.5 $x10^6$ yd^3 (70.7 $x10^6$ m^3)
3	1.25 mi^2 (3.23 km^2)	16-36 ft (5-11 m)	35.9 $x10^6$ yd^3 (27.5 $x10^6$ m^3)
4	1.42 mi^2 (3.69 km^2)	13-46 ft (4-14 m)	42.1 $x10^6$ yd^3 (32.2 $x10^6$ m^3)

5. RECOMMENDATIONS FOR PHASE II DATA ACQUISITION

Initially, results from these studies need to be considered concurrently with other factors influencing the selection of resource areas. Some of these factors include but are not limited to, the amount of beach replenishment material needed, suitable water depth for dredging, proximity to shore for transferring dredged sediment, clearance from existing man-made features (submarine cables, cable areas, traffic lanes, etc.), avoidance of sensitive benthic habitats/fisheries/cultural resources, potential jurisdictional and associated regulatory issues, and time and cost of future operations to complete the project.

Once the number of resource areas for future study has been decided and sites delineated and selected, plans for the next phase of work can be formulated. The Phase 2 detailed survey of the potential resource areas should include high-resolution geophysical surveying at a closer line spacing, combined with geotechnical assessments of near-surface sediments. Line spacing for the detailed investigation will be dictated by marine archaeological requirements to document the presence or absence of submerged cultural sites on the OCS prior to dredging. This spacing is dependent upon water depth and may vary from 49 ft (15 m) in shallow water to 98 ft (30 m) farther offshore.

Typical equipment employed for the detailed investigations normally includes:

- Single or multibeam/swath bathymetry system
- High frequency side scan sonar
- Marine magnetometer with altimeter
- 50-4,000 Hz sub-bottom profiling system

The lower frequency sub-bottom system is necessary to penetrate through surficial coarse sediment (sand-gravel and larger) to image the base of the suitable material layer and underlying stratigraphy. These data will be used to help delineate the resource areas in much more detail, but also support the archaeological review for shipwrecks and paleolandscapes within the depth of interest for the project.

In addition to the high-resolution geophysical acquisition, geotechnical information is critical to determine sediment grain sizes present in the surficial layer of each area. This knowledge can be gained via vibratory coring and subsequent analysis of the core samples (geologic log, coarse fraction grain size analysis, etc.). Results from these analyses could target and prioritize specific geographic areas based on the suitability of the surficial sediment.

Ultimately, these scientific results combined with the weighting of the environmental, logistical, operational, and regulatory factors will indicate the most suitable resource area(s) to meet the project objectives.

Based on the Phase I results discussed above, the project team plans to obtain additional vibracores (using a P-3 Rossfelder system) from areas that are in suitable locations based on sub-bottom stratigraphy, water depth, proximity to the coast, preferably in federal waters, and with low potential for stakeholder conflict. After analyzing the vibracores for sand resource quality, more detailed high-resolution geophysical surveys will be conducted in areas that contain high-quality sand. These surveys will include interferometric sonar using an Edgetech 6205 system, sub-bottom sonar using a FSI bubblepulser (single source) system, and magnetometer using a Geometrics 882 system. Groundtruth studies will be done using grab samples and underwater video in addition to the vibracores. These studies will produce data on the location, volume and quality of the sand resource, and data on the potential for user conflict with Tribes and the fishing community. In addition, best practices and a refined archaeological predictive model resulting from the ongoing Submerged Paleolandscapes Project will be utilized to provide a preliminary assessment regarding potential archaeological sensitivity of the targeted resource areas.

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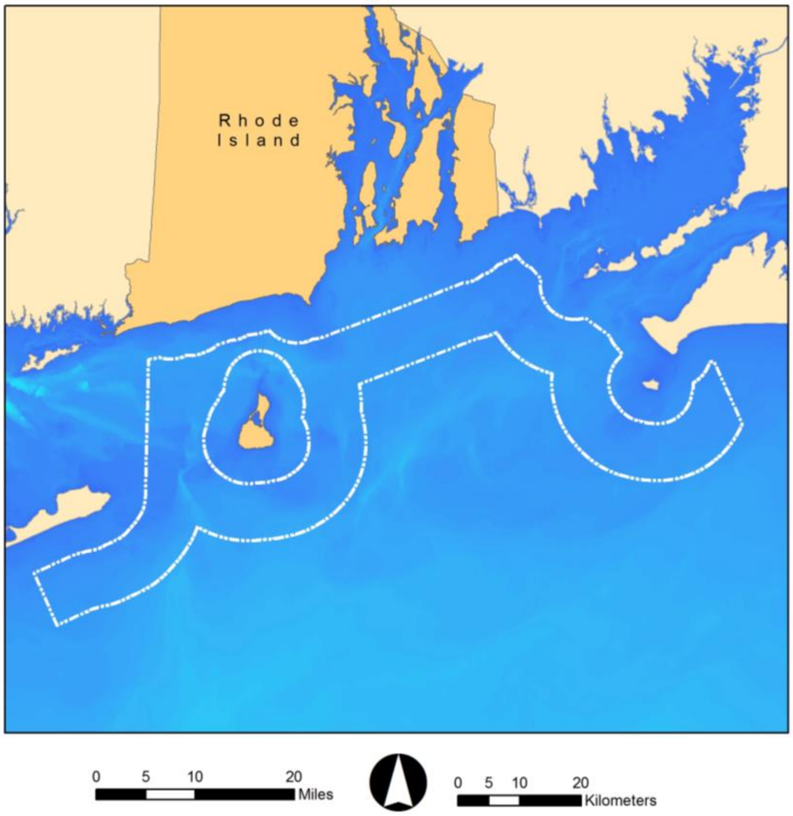

Figure 1. Map showing the primary project study area. The region between 3 - 8 nautical miles offshore of the state of Rhode Island is outlined in white.

Figure 2. Index map (left) and orthophotograph (right) showing the configuration of headlands and barrier spits that characterize the southwest coast of Rhode Island.

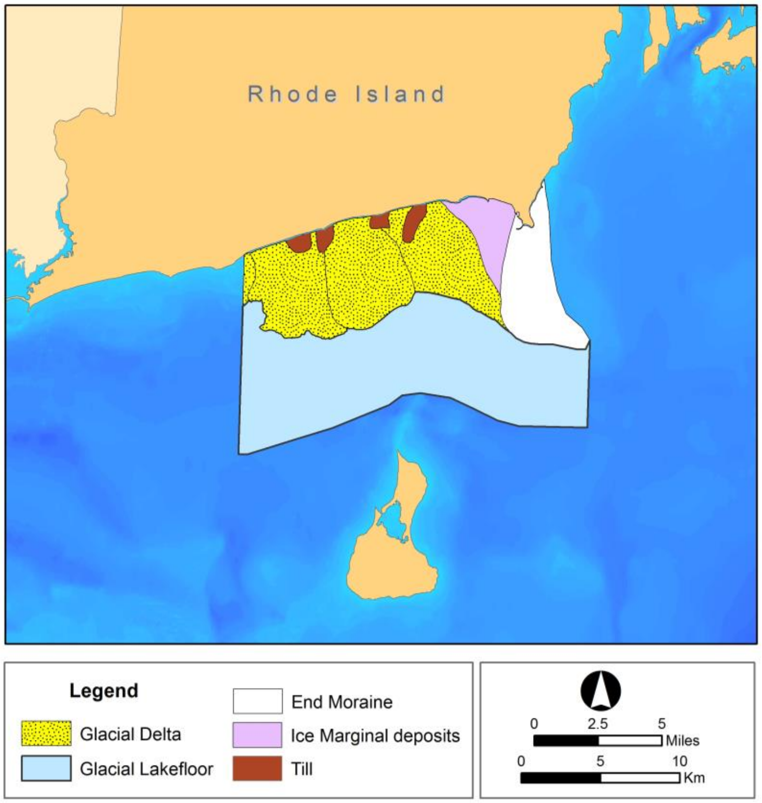

Figure 3. Generalized Quaternary geology off the south coast of Rhode Island. Of particular interest to this project are the glacial deltaic deposits, illustrated with stippled yellow shading. (Modified from Oakley, 2012 and Needell and Lewis, 1984).

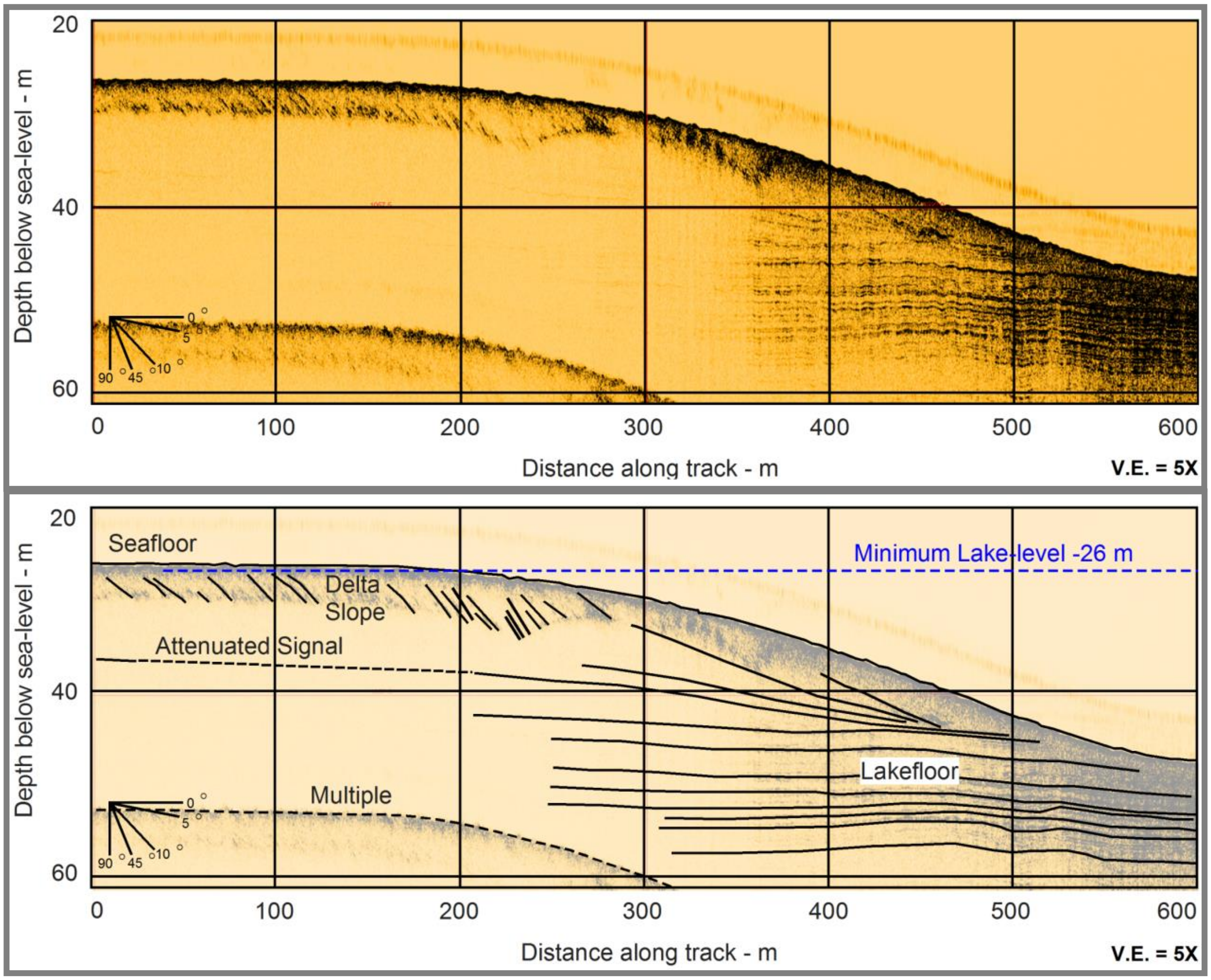

Figure 4. Representative CHIRP seismic image of a Glacial Lake Block Island lacustrine delta, collected prior to the initiation of this study. The "minimum lake level" label refers to Glacial Lake Block Island. Target areas for the current project were the delta slope beds, and the overlying Holocene sand identified in these reconaissance surveys. (Oakely, 2012)

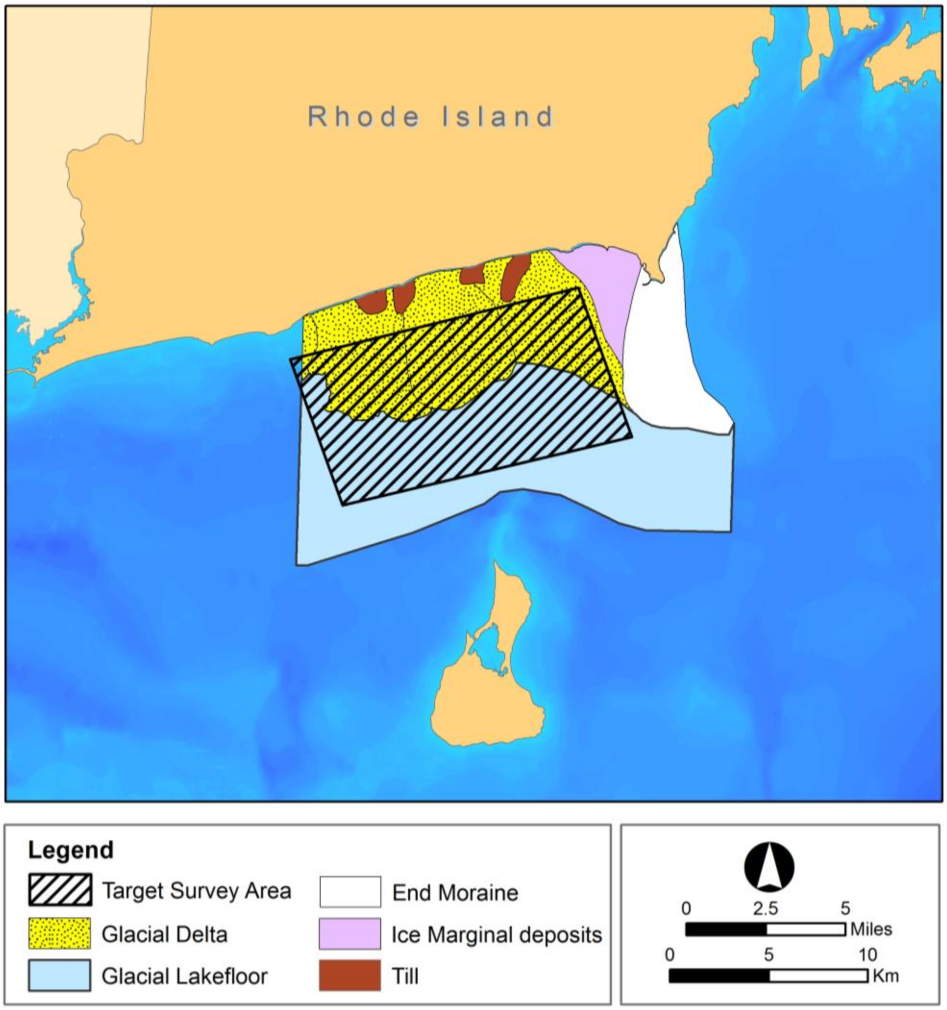

Figure 5. Target area for additional geophysical surveying, superimposed on the generalized Quaternary geology off the south coast of Rhode Island. (Geology modified from Oakley, 2012 and Needell and Lewis, 1984).

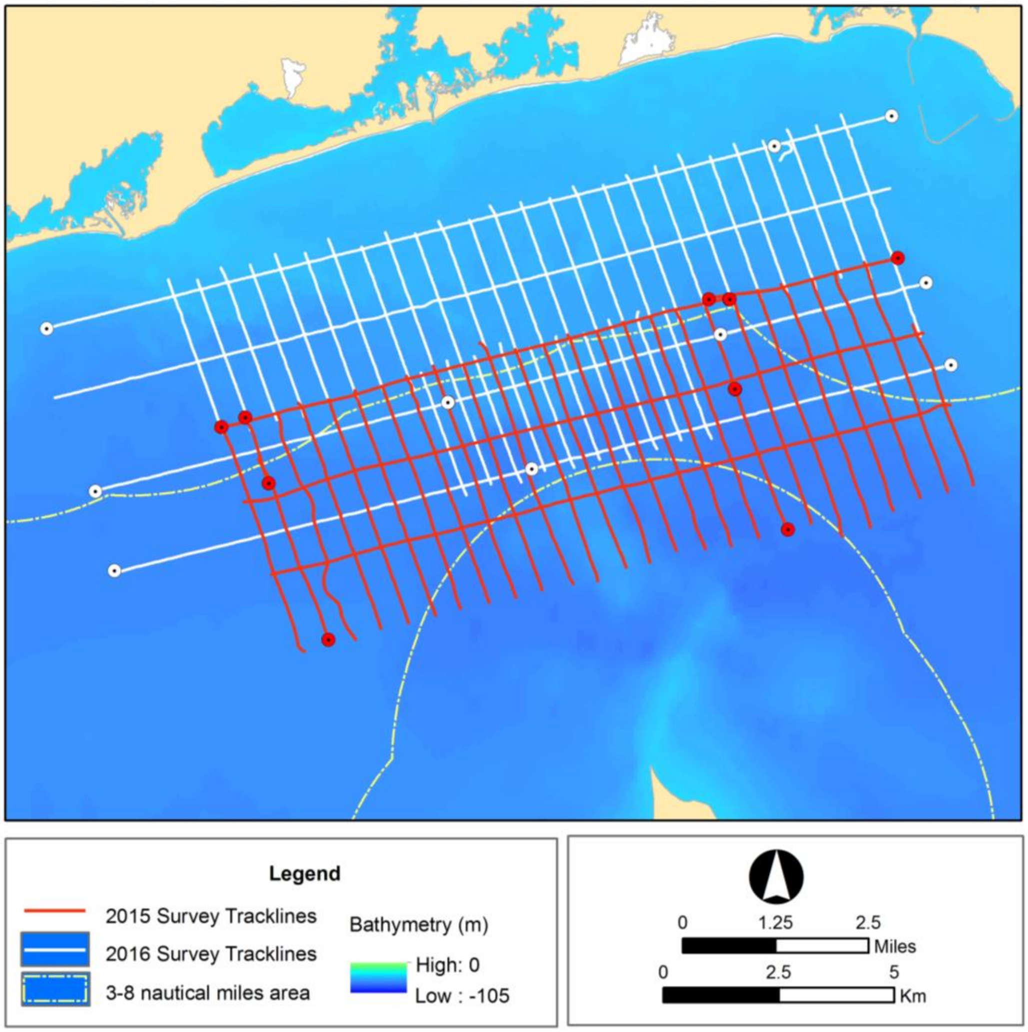

Figure 6. Location of geophysical survey tracklines from 2015 (red) and 2016 (white) in the target study area. A small number of tracklines were run in segments. In these cases, red and white dots illustrate the endpoints of individual segments.

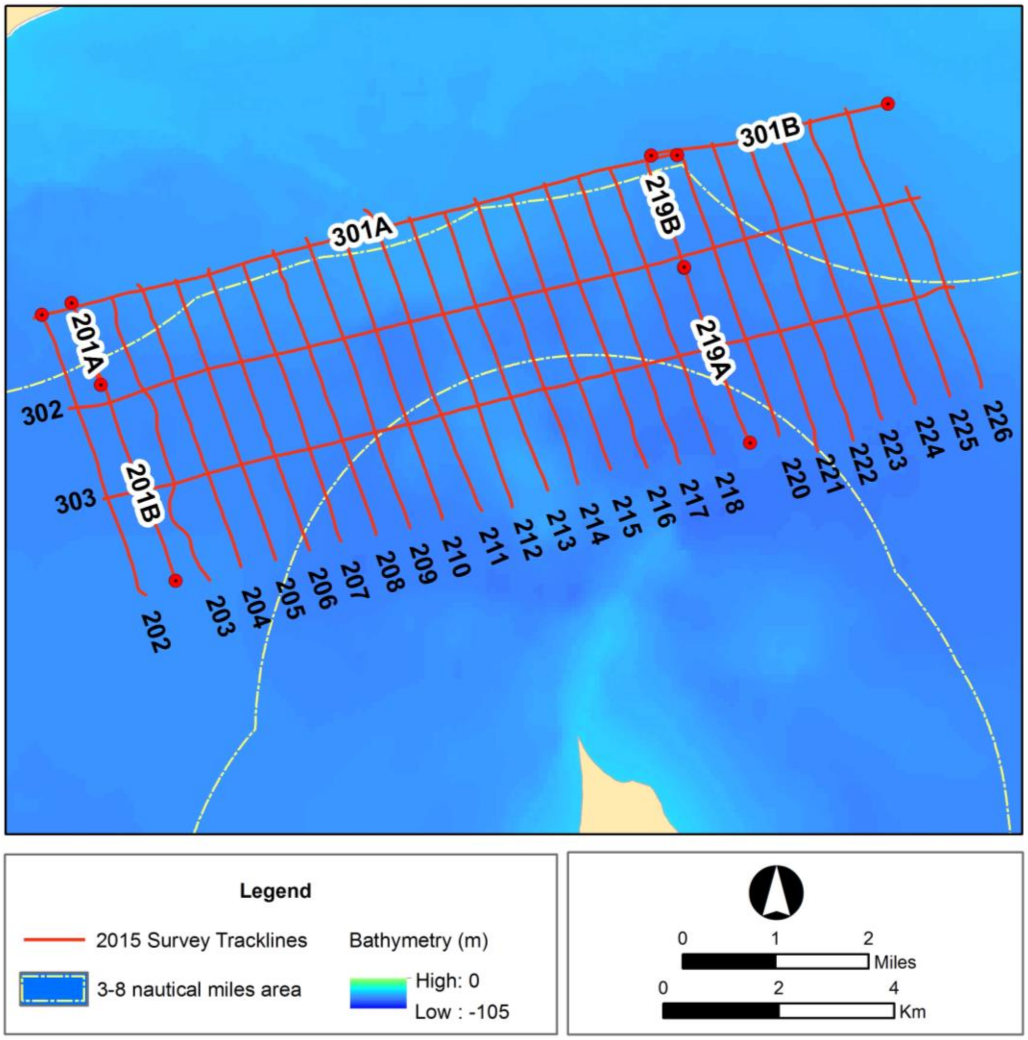

Figure 7. Location of geophysical survey tracklines from 2015, with labels corresponding to sub-bottom profile images. Labels with white halos indicate that a line was surveyed in segments, with red dots illustrating the endpoints of each segment.

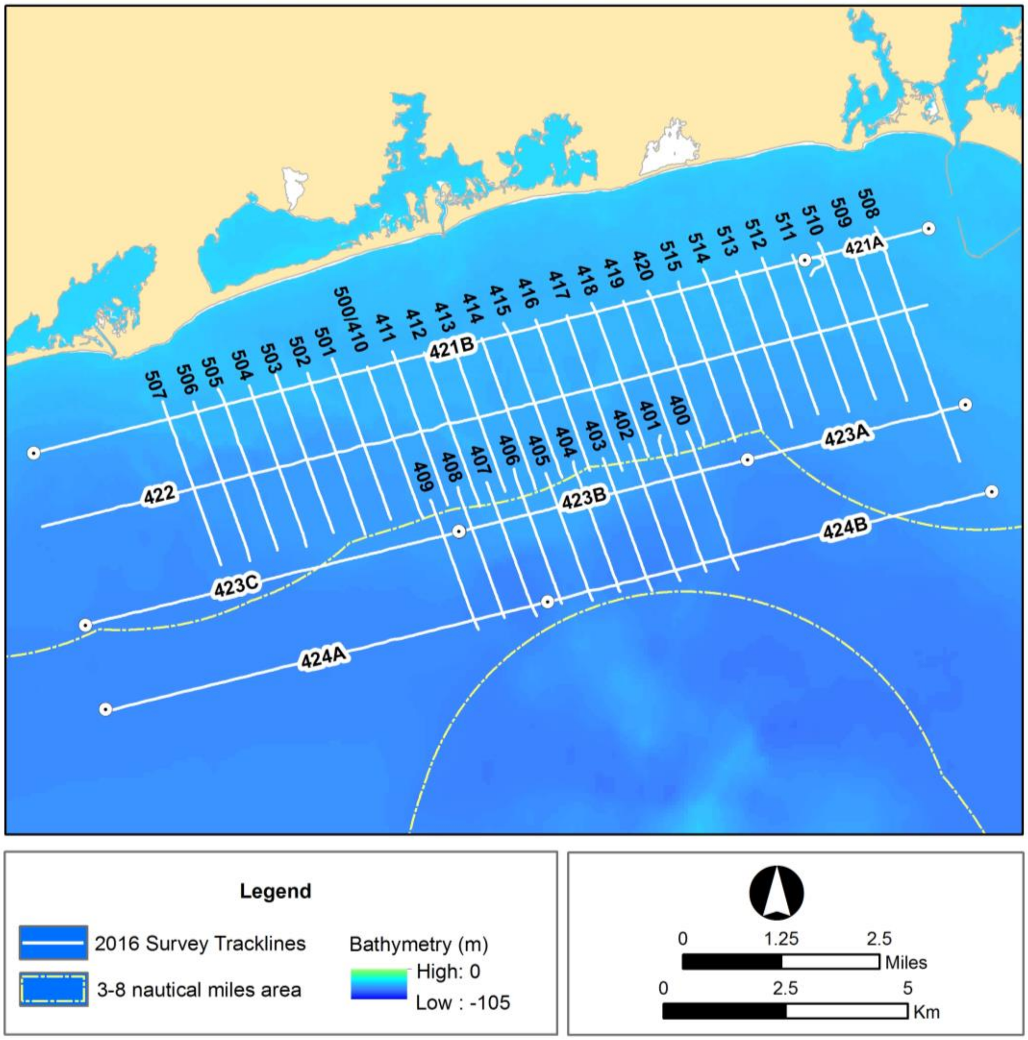

Figure 8. Location of geophysical survey tracklines from 2016, with labels corresponding to sub-bottom profile images. Labels with white halos indicate that a line was surveyed in segments, with white dots illustrating the endpoints of each segment.

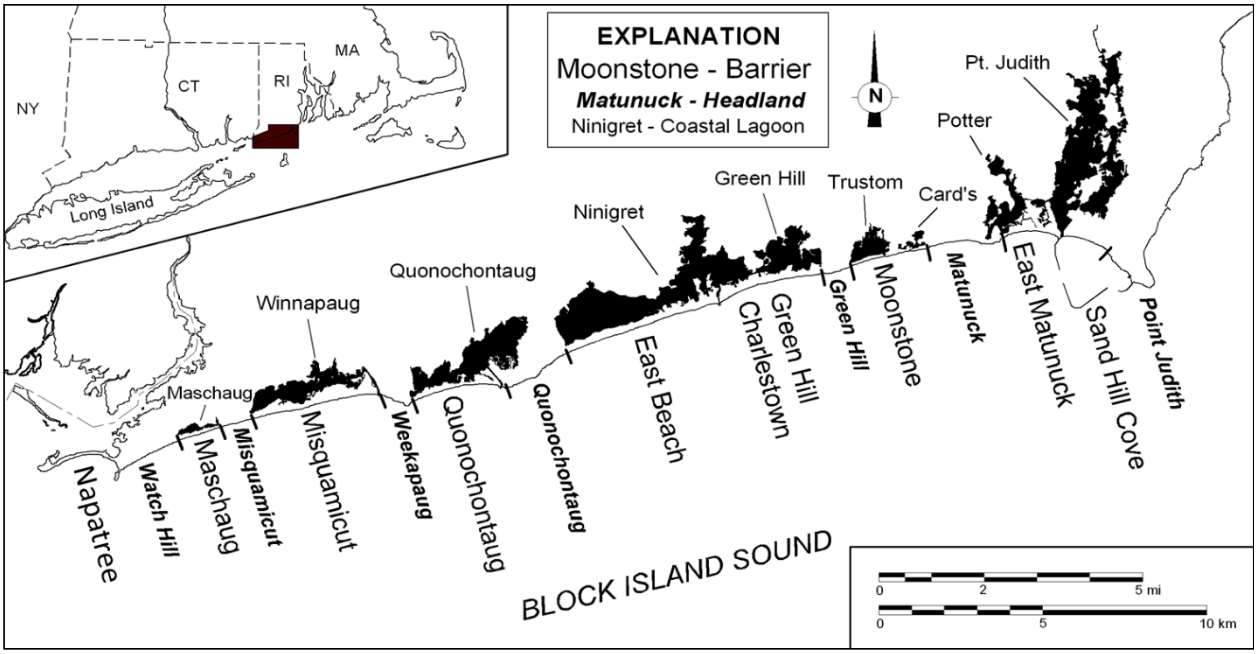

Figure 9: Barriers and headlands of the Rhode Island South Shore (modified from Boothroyd et al., 1998).

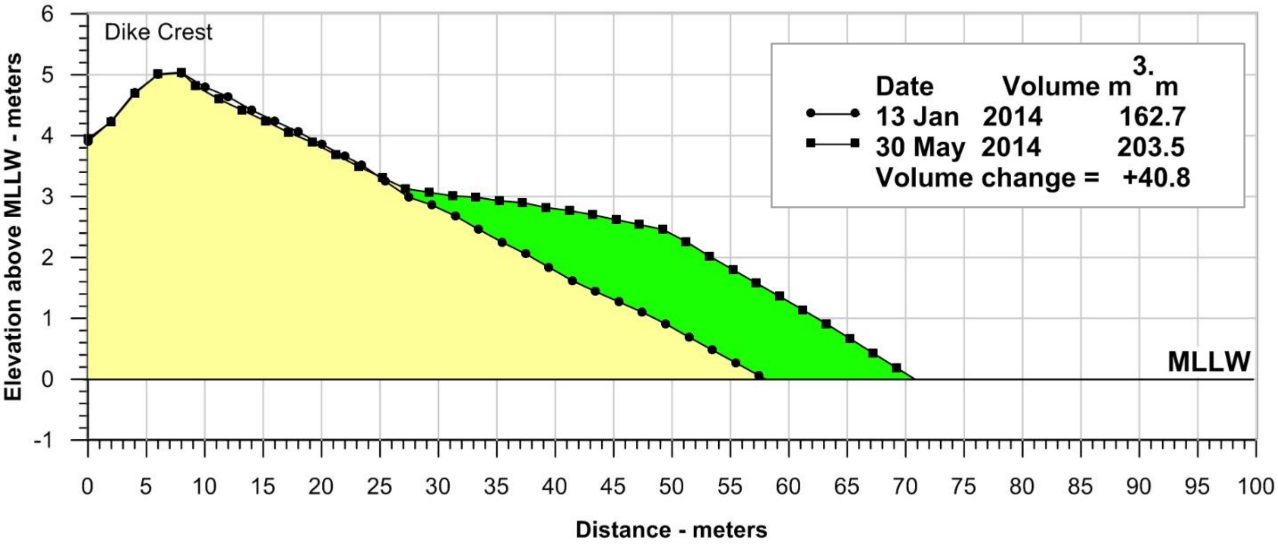

Figure 10: Measured profile for Misquamicut State Beach prior to (13 Jan 2014) and immediately following beach replenishment (30 May 2014). Green filled area represents the replenished volume at this profile. This volume/configuration is the basis for the small-scale replenishment (Table 1).

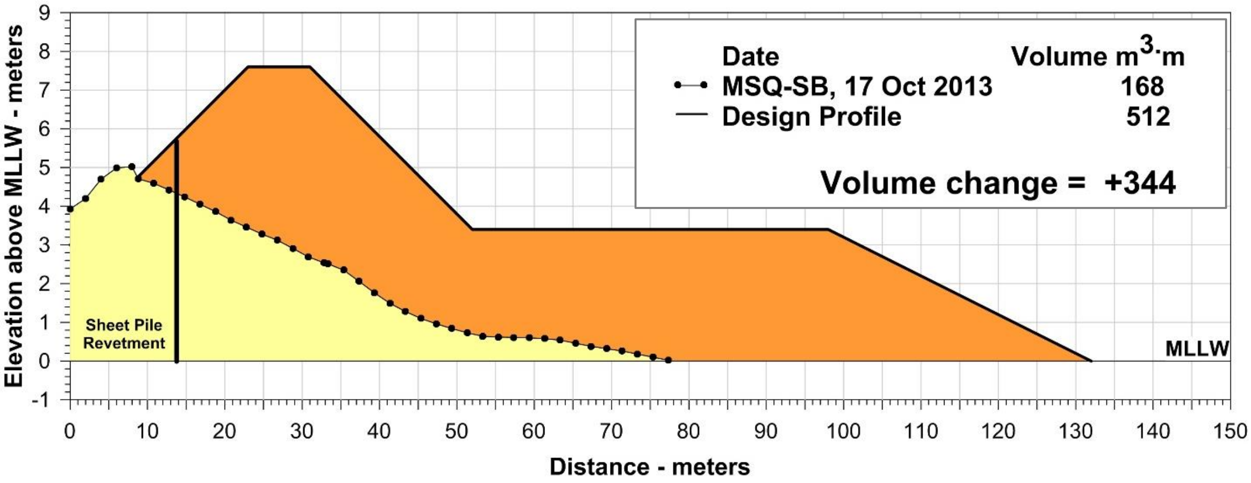

Figure 11: Pre-replenishment (2013) profile at Misquamicut State Beach plotted against a profile design (with sheet pile revetment) for Mantoloking, NJ (USACE, 2013b). The net increase in profile volume here is 344 m^3 m^{-1}. This volume/configuration is the basis for the large-scale replenishment (Table 1).

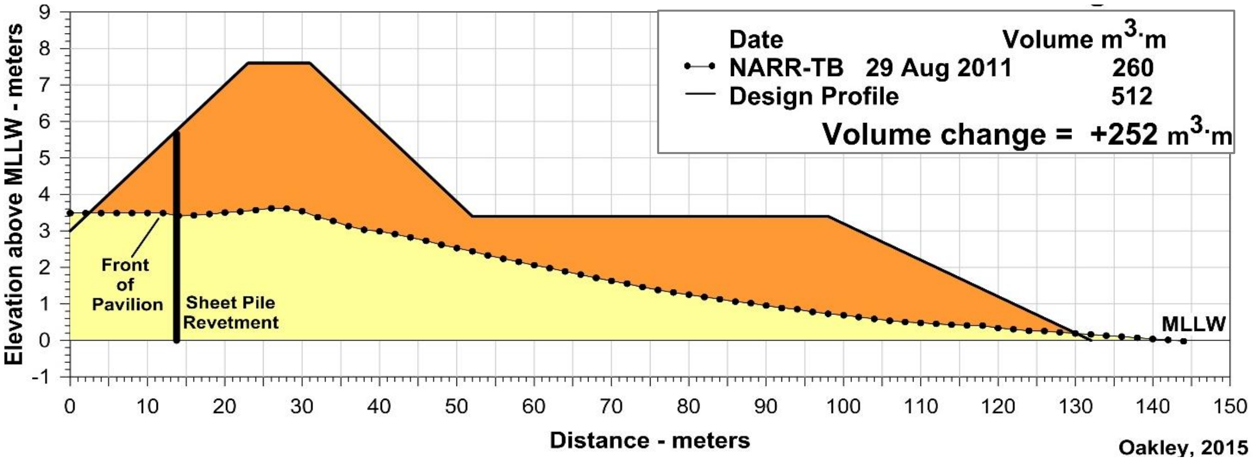

Figure 12: Pre-replenishment (2013) profile at Narragansett Town Beach plotted against the design profile (with sheet pile revetment) for Mantoloking, NJ (USACE, 2013b). The net increase in profile volume here is 252 m^3 m^{-1}. This volume/configuration is the basis for the large-scale replenishment (Table 1).

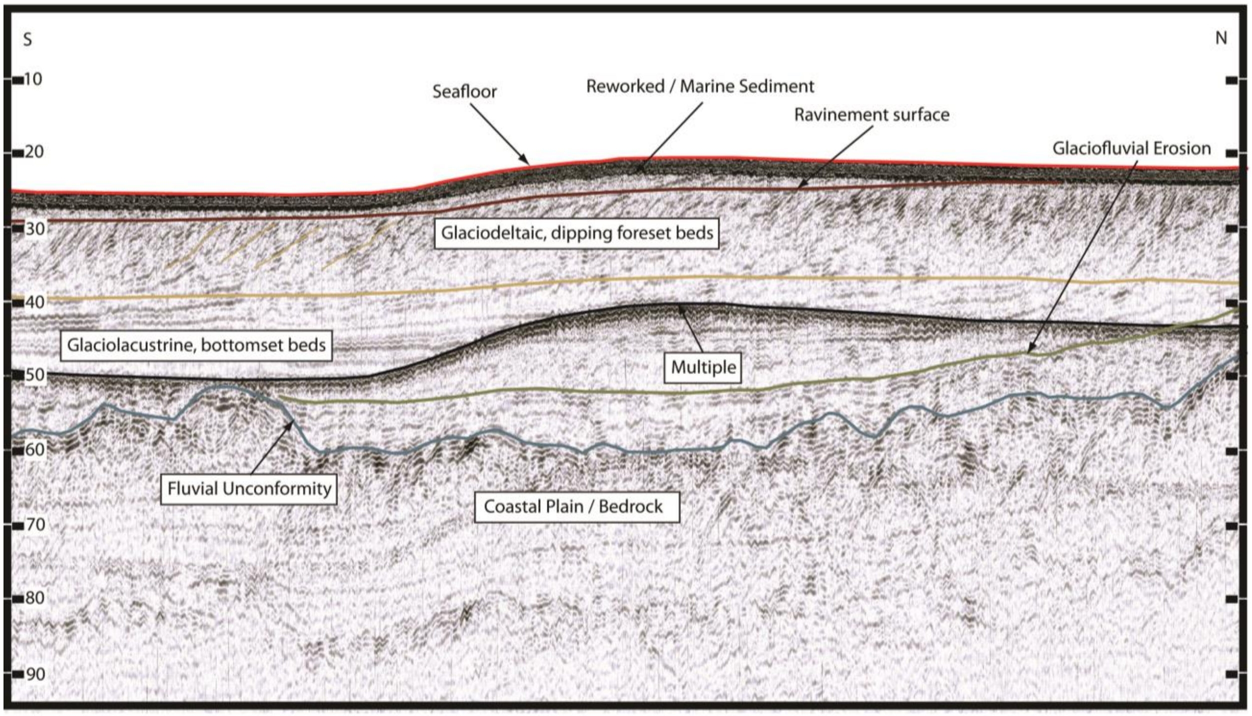

Figure 13: Portion of representative north (left) to south (right) sub-bottom profile image (line 413, see Figure 8 for line location) obtained in the target area, transecting Resource Area 2. Note the eroded glaciodeltaic forset beds visible in the upper part of the image. See sections 3.3.1 of this report for additional discussion about this image. Depth is reported in meters below sea surface with an assumed sound velocity of 1524 m s^{-1}.

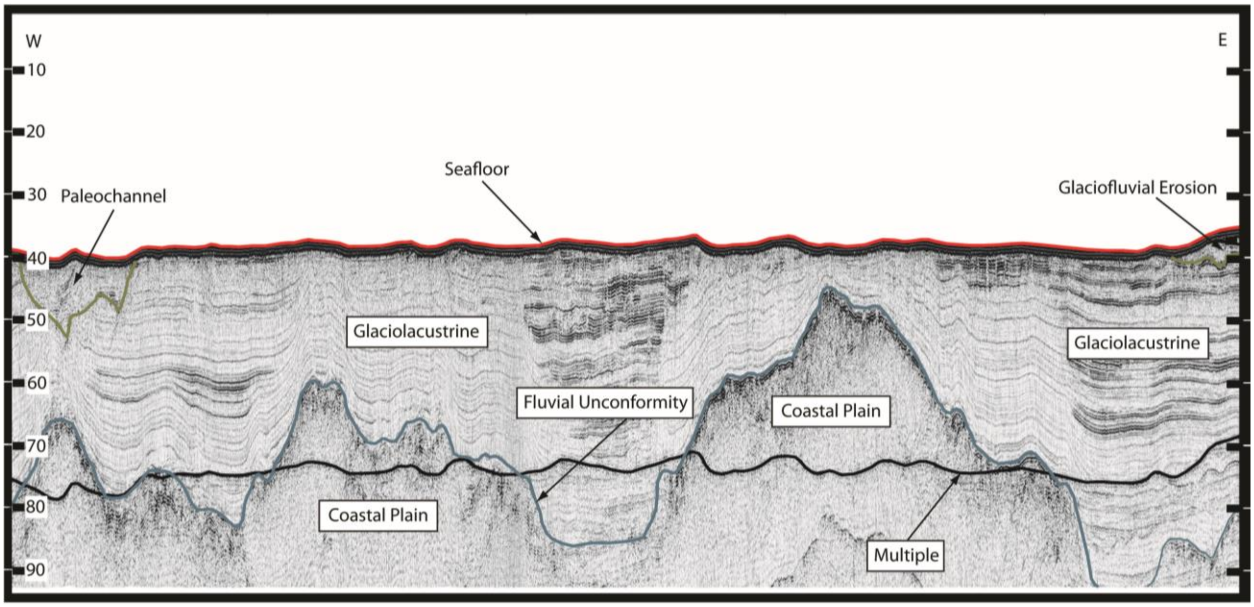

Figure 14: Portion of representative west (left) to east (right) sub-bottom profile image (line 423, see Figure 8 for line location) obtained in the target area, transecting westernmost Resource Area 1. Note the absence of an identifiable ravinement surface. See sections 3.3.1 of this report for additional discussion about this image. Depth is reported in meters below sea surface with an assumed sound velocity of 1524 m s^{-1}.

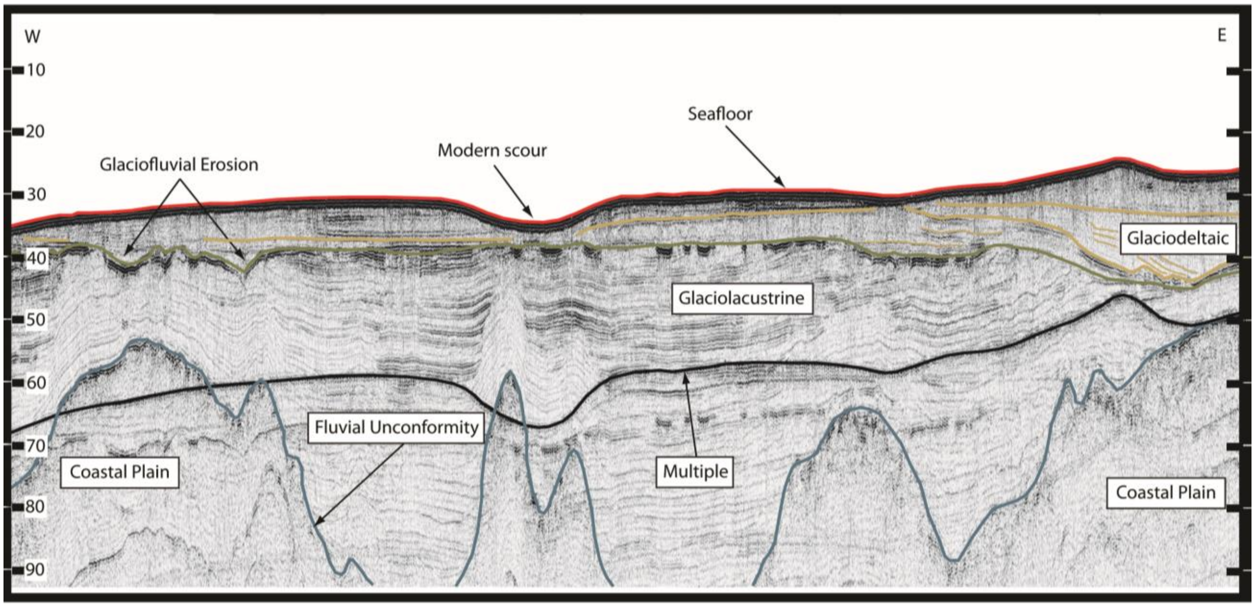

Figure 15: Interpreted section of sub-bottom profile 423, transecting Resource Area 1 (See Figure 8 for line location). The image shows the east end of the sub-bottom profile towards the right. Changes in depositional environments and unconformities are labeled and delineated. See text for detailed descriptions. Depth is reported in meters below sea surface with an assumed sound velocity of 1524 m s^{-1}.

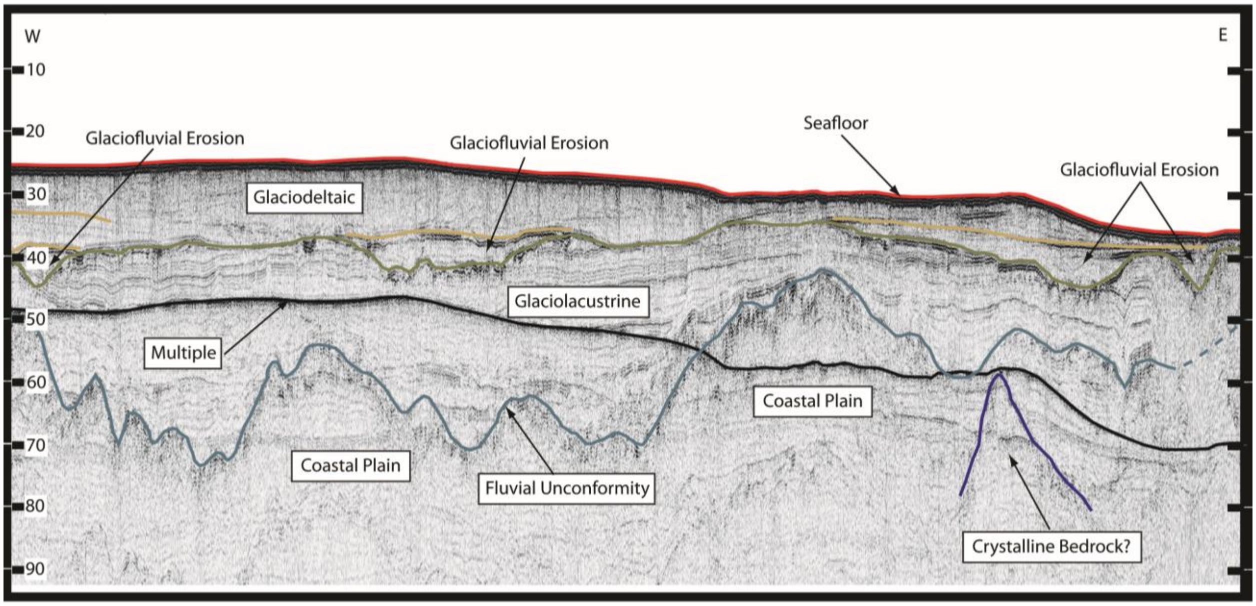

Figure 16: Interpreted section of sub-bottom profile 423, transecting the easternmost portion of Resource Area 1 (See Figure 8 for line location). The image shows the east end of the sub-bottom profile towards the right. Changes in depositional environments and unconformities are labeled and delineated. See text for detailed descriptions. Depth is reported in meters below sea surface with an assumed sound velocity of 1524 m s^{-1}.

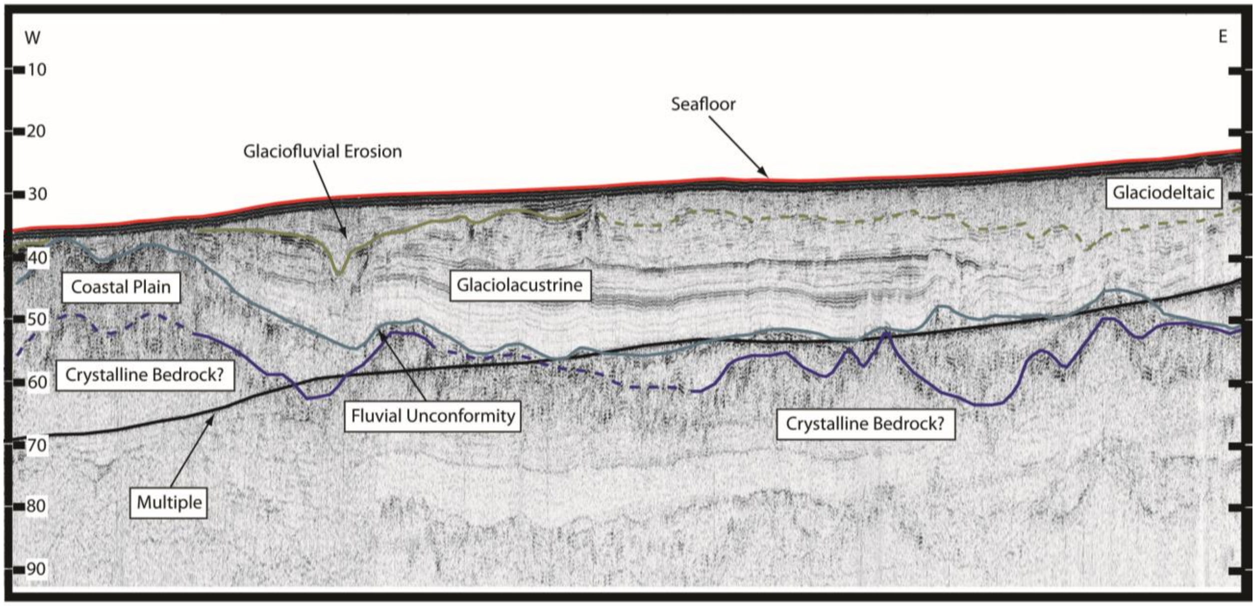

Figure 17: Interpreted section of sub-bottom profile 423 (See Figure 8 for line location). The image shows the east end of the sub-bottom profile towards the right. Changes in depositional environments and unconformities are labeled and delineated. See text for detailed descriptions. Depth is reported in meters below sea surface with an assumed sound velocity of 1524 m s^{-1}.

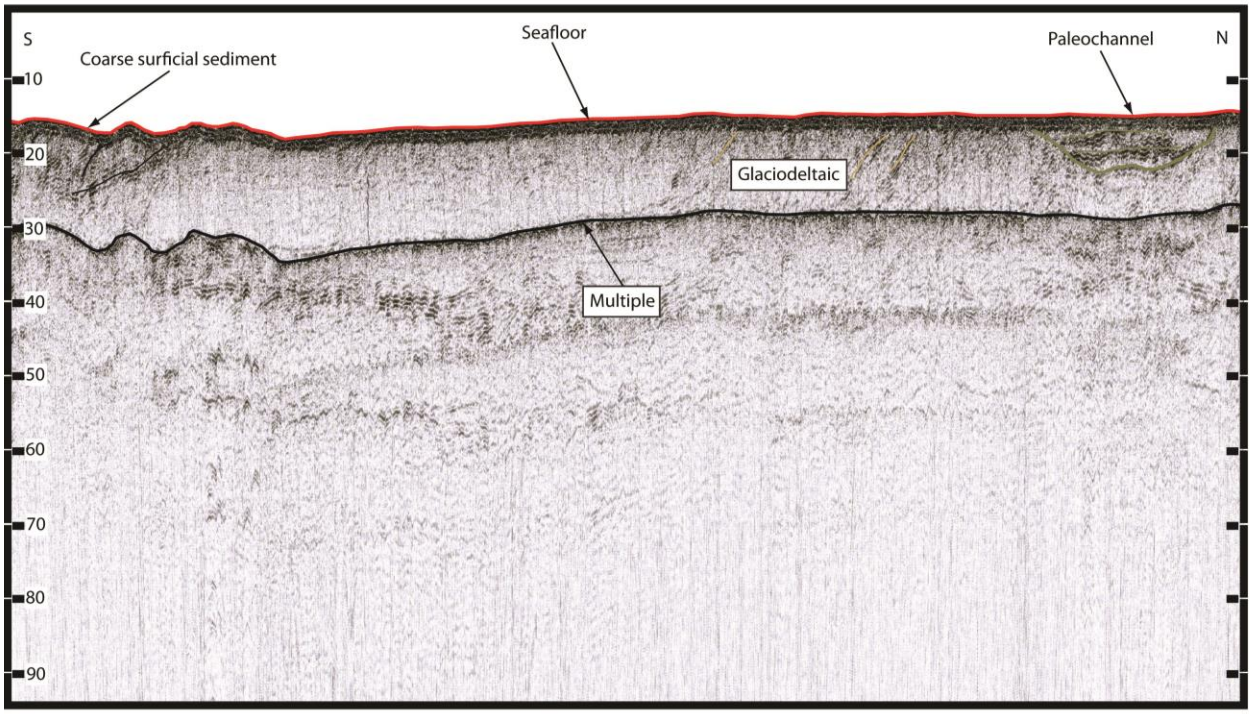

Figure 18: Interpreted section of sub-bottom profile 514, transecting Resource Area 3 (See Figure 8 for line location). The image shows the north end of the sub-bottom profile towards the right. Changes in depositional environments and unconformities are labeled and delineated. See text for detailed descriptions. Depth is reported in meters below sea surface with an assumed sound velocity of 1524 m s^{-1}.

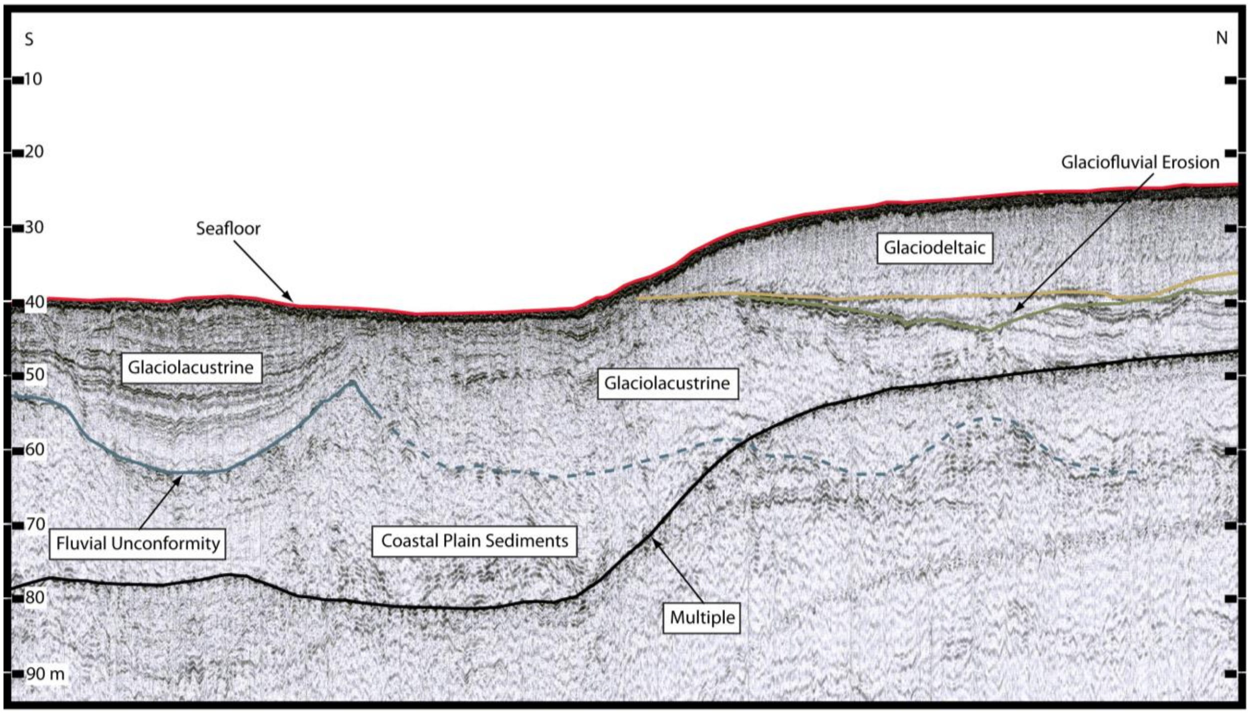

Figure 19: Interpreted section of sub-bottom profile 213, transecting Resource Area 1 (See Figure 7 for line location). The image shows the north end of the sub-bottom profile towards the right. Changes in depositional environments and unconformities are labeled and delineated. See text for detailed descriptions. Depth is reported in meters below sea surface with an assumed sound velocity of 1524 m s^{-1}

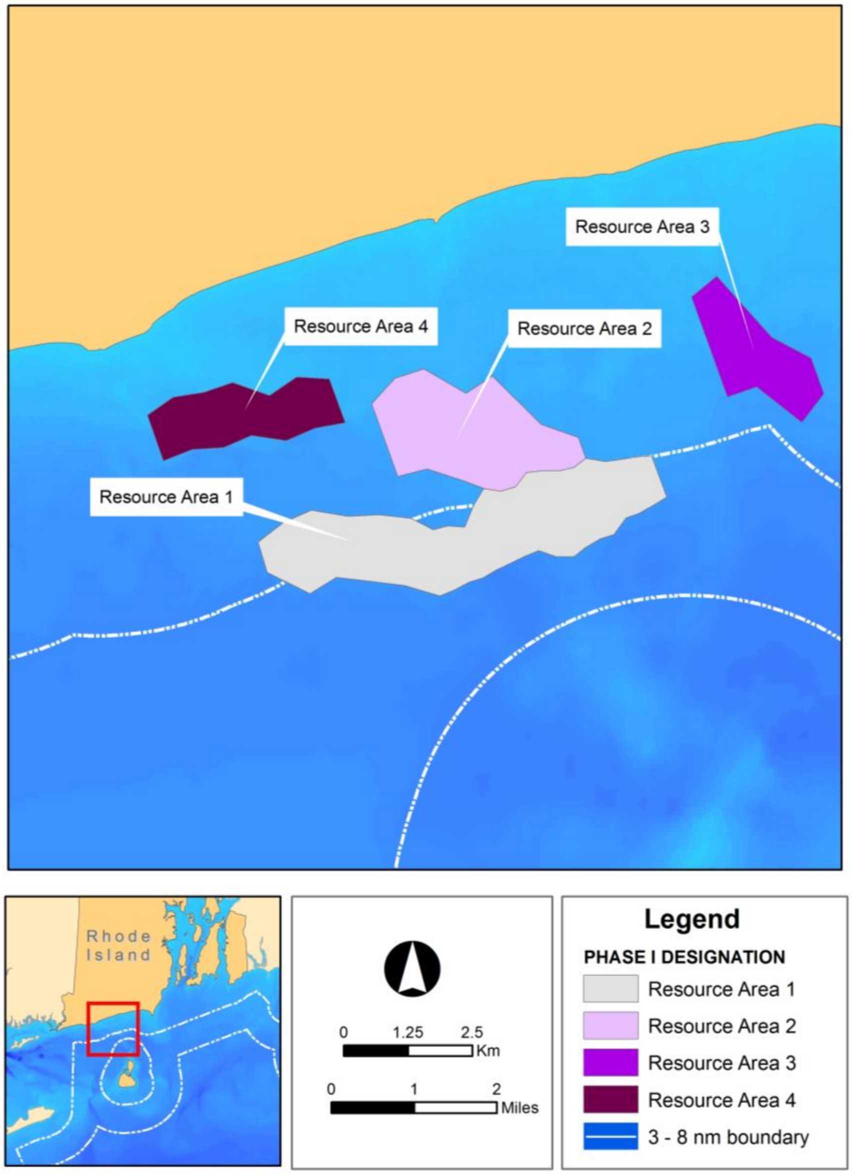

Figure 20. Map showing potential sand and gravel resource areas identified as a result of the Phase I investigation. Index map (lower left) shows the location of identified resource areas in a regional context.

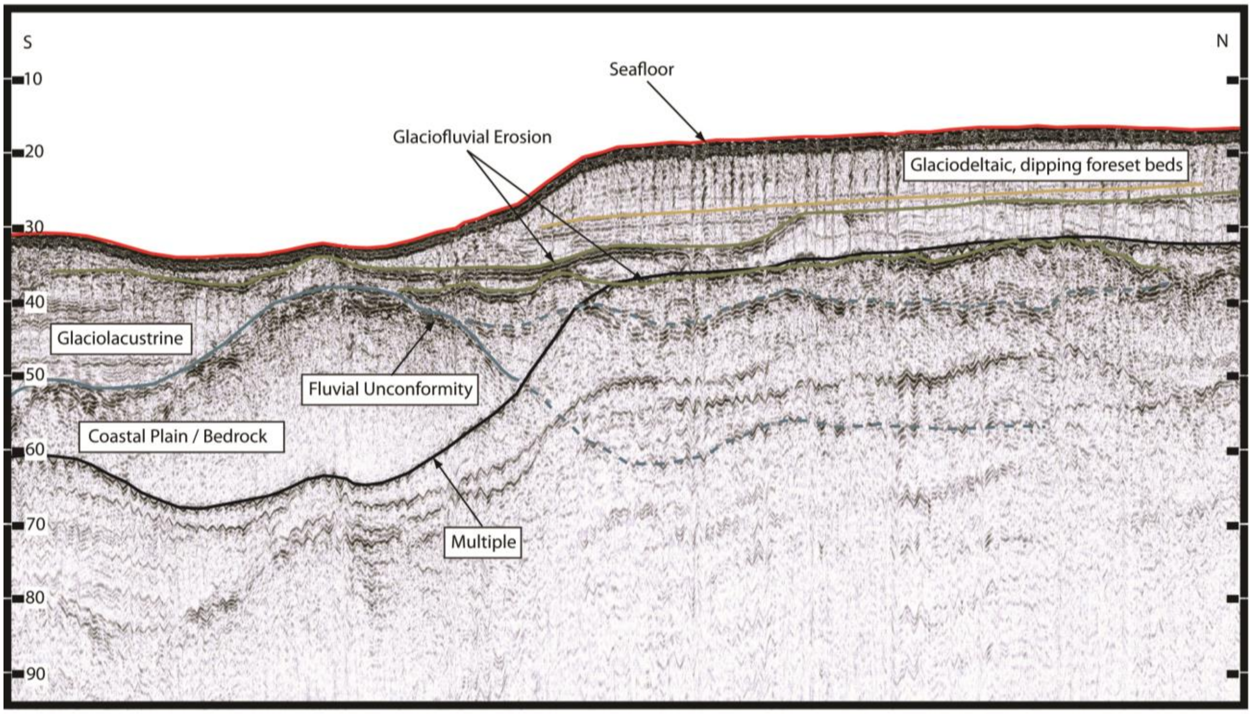

Figure 21. Interpreted section of sub-bottom profile 506, transecting Resource Area 4 (See Figure 8 for line location). The image shows the north end of the sub-bottom profile towards the right. Changes in depositional environments and unconformities are labeled and delineated. See text for detailed descriptions. Depth is reported in meters below sea surface with an assumed sound velocity of 1524 m s^{-1}.

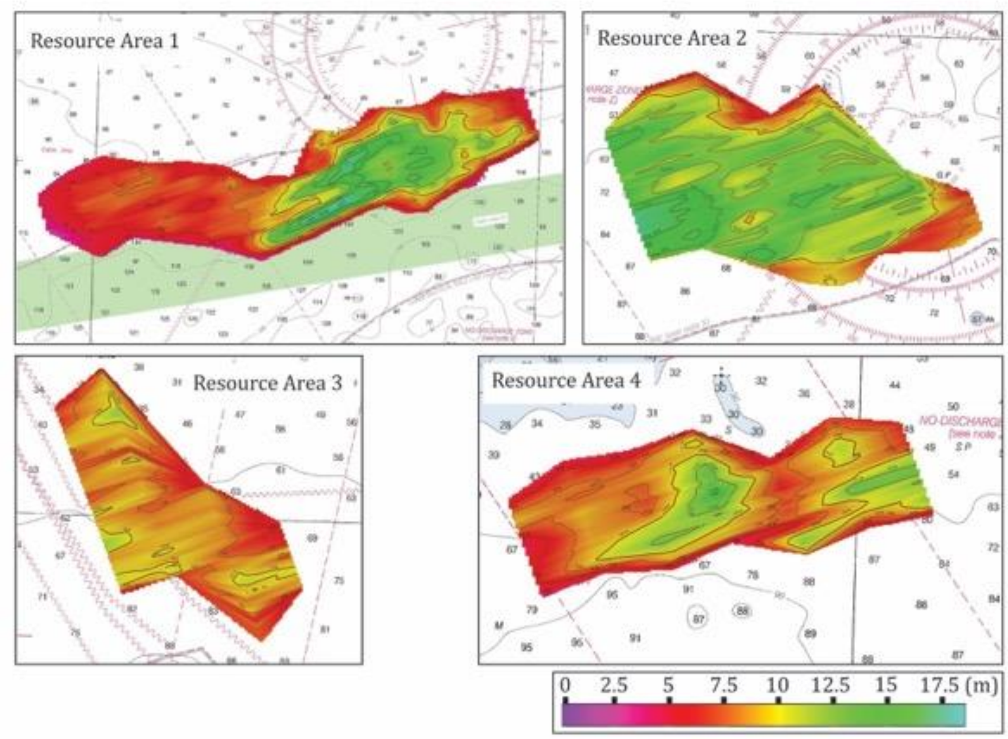

Figure 22. Isopach maps with two-meter contours showing spatial variability in sand and gravel thickness for each resource area. Cooler colers represent thicker sand and gravel resources.